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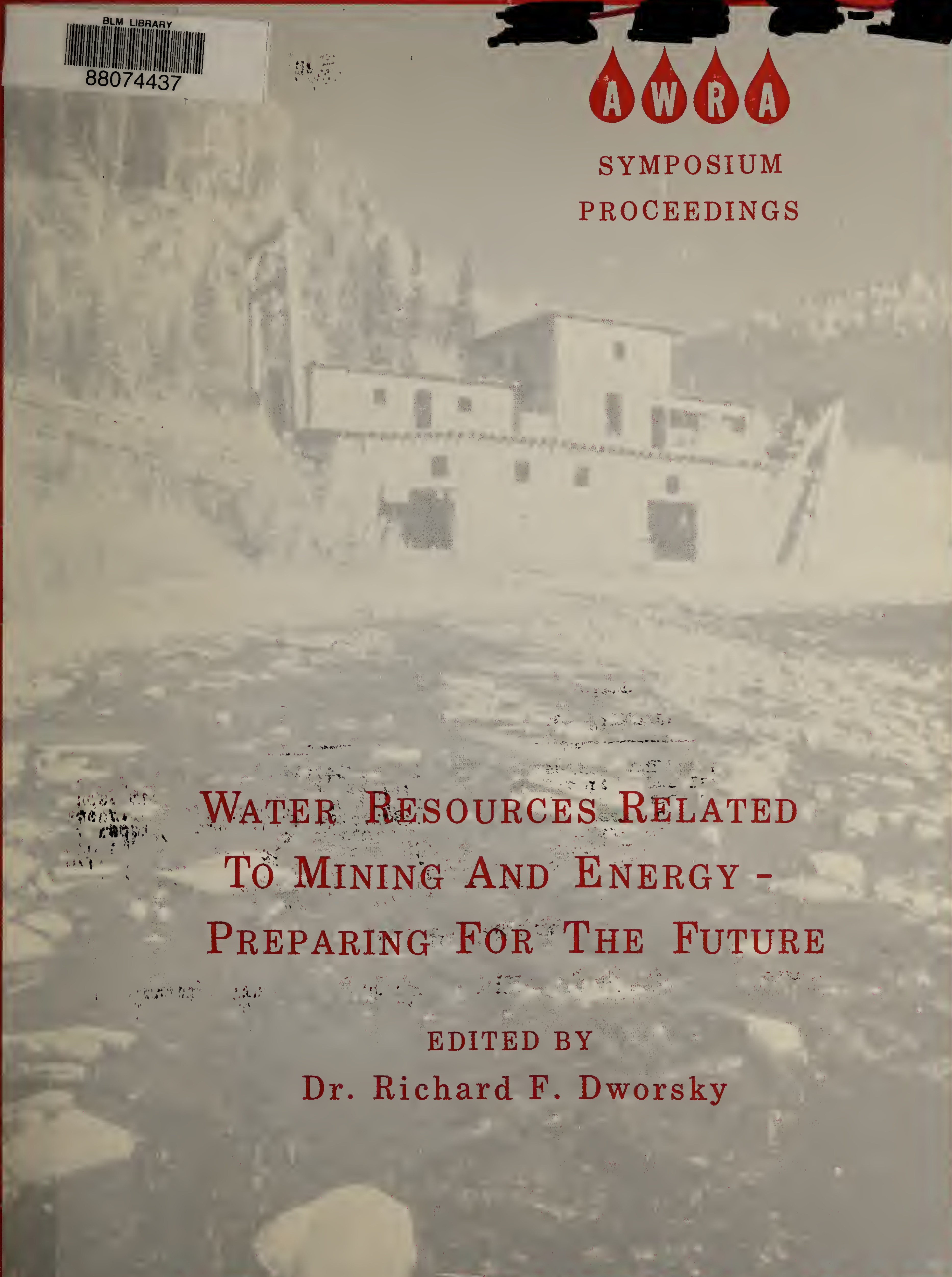

AWRA

SYMPOSIUM PROCEEDINGS

Water Resources Related To Mining And Energy - Preparing For The Future

EDITED BY
Dr. Richard F. Dworsky

Proceedings
of the
Symposium on

WATER RESOURCES RELATED TO MINING AND ENERGY — PREPARING FOR THE FUTURE

Edited by

Richard F. Dworsky, Ph.D.
Special Assistant to the State Director
U.S. Bureau of Land Management
701 "C" Street, Box 13
Anchorage, Alaska 99513

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AMERICAN WATER RESOURCES ASSOCIATION
5410 Grosvenor Lane, Suite 220
Bethesda, Maryland 20814
Phone: (301) 493-8600

Dr. Richard F. Dworsky is currently the Special Assistant to the State Director, Bureau of Land Management — Alaska. He holds a Ph.D. in forestry from the University of Massachusetts, a B.S. in Forestry from the University of Michigan, and a M.S. in Public Administration from Colorado State University. He is the author of more than 30 papers and publications.

Cover photo: Old Dredge near Jack Wade, Alaska – by Ed Bovy, BLM.

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PREFACE

We have much information and past knowledge related to water resources and mining and energy development. While there is a current slump in the United States and the world of mineral and oil prices, the future will bring increased demands. We need to focus on past and present experiences to prepare us for future development and use of water resources for mining and energy. The following papers give us an opportunity to learn from the past and build on our success and seek new solutions. These proceedings and the concomitant papers are divided into seven sections.

Section 1 focuses on data acquisition and utilization, and some information sources for identifying needs and issues in mining and energy development.

Section 2 focuses on planning and management relating to mining and energy development. These papers are oriented toward the public sector and the administration of the public lands.

Section 3 is a compilation of papers relating to mitigation actions in the boom and bust cycle, the focus is generally on the human rather than the water resources or physical elements.

Section 4 focuses on the water resource relating to technology, assessments and prediction of the impact of mining and energy.

Section 5 illustrates some of the conflict and problems relating to water rights and water supply for mining and energy.

Section 6 focuses on techniques and factors dealing with water quality and water quality research.

Section 7 focuses on the technical aspects of mitigation and reclamation in post development situations.

This symposium addresses many of the questions and problems that deal with water resources for mining and energy. It is clear that a number of lessons can be learned from the past and present. We do need, however, to continue to seek solutions, management, scientific, administrative and technical, to future development problems.

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DATA AND INFORMATION FOR MINING AND ENERGY

TECHNOLOGY TRANSFER IN NATURAL RESOURCE MANAGEMENT

Mary Cameron Gaylord[1]/

ABSTRACT: Getting scientific knowledge into use has never been easy; but with the greatly increased flow of information relating to the managing of our national natural resources, the rapidly rising need for that information, and the ever expanding audience of potential users, the task has become challenging. The author looks at the Bureau of Land Management (BLM) and its technology transfer program. Her paper contains suggestions for integrating technology transfer activities for all natural resource agencies. She further provides a selected listing of technical references produced by scientists working in the water resource discipline at the Bureau of Land Management Service Center, Denver, Colorado.
KEY TERMS: Information transfer, Technology Transfer, hydrologic studies/reports, Bureau of Land Management, natural resources.

INTRODUCTION

Two-thirds of the United States that is still forest and range has a major role in both the economic development of the country and the quality of life it enjoys. The many laws and regulations passed in recent years reflect the public's concern of how much the wildlands--their water, wildlife, minerals, forage, timber, and other products and amenities mean to all of us.

This public concern has made the task of protecting, managing and using resources far greater and more complex than before. As a consequence, there is an unprecedented demand for facts upon which to base policies, plans, and practices.

Technology[2] and management are the keys to accomplishing more with fewer resources. Only with technology is it possible to do more with less, and getting the most from today's and tomorrow's technologies requires strong management programs.

Technology transfer is a systematic and continuous effort which introduces and/or communicates a technology or process from point of discovery to practical application. BLM is expected to engage in actively promoting technology transfer because it is presumed to be in the public's interests. It is our duty to do so because the technology has been generated with public funds.

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[1]Technology Transfer Staff, Bureau of Land Management, Bldg 50, Denver Federal Center, Lakewood, CO 80225
[2]Definition: Technology is the sum of all processes and means that make it possible to transform scientific concepts into a practical application . . . the practical application then is a technique, method or process.

THE BUREAU'S PROGRAM

The Bureau of Land Management does little pure research. Rather, its research and development efforts take new technologies, mixing and adapting them to the BLM situation. The field organization is the incubator of these ideas. Through its science policy, the BLM filters these field ideas and needs and formulates a national program of research and development.[3] By necessity, our research system has multiple objectives and serves clients at many different levels. It is a decentralized system--a characteristic that has both strengths and weaknesses. Its strength lies in the fact that it is responsive to needs at all levels and can readily accommodate fresh thinking. The weaknesses seem to be the lack of a strong sense of direction and a tendency for fragmentation.

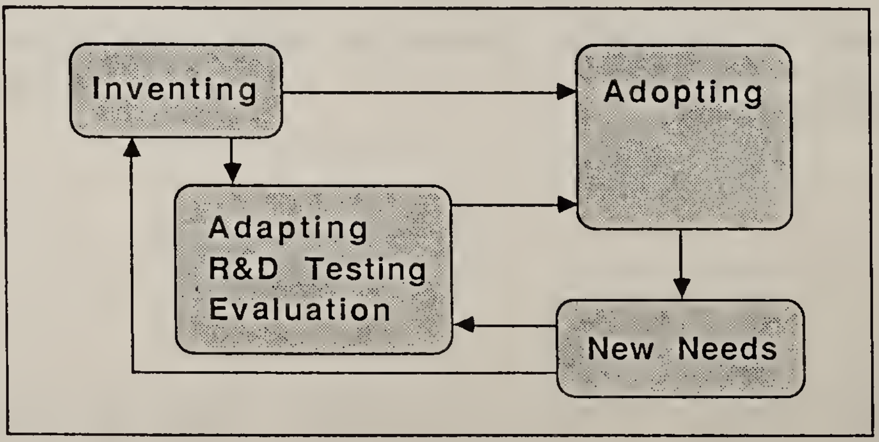
Two-thirds of the Bureau's research occurs at the Service Center at Denver. The Service Center is a mixture of resource, computer, and administrative people wrestling with the ongoing operation of existing management systems and with the purposeful search for the changes that will carry the Bureau into the year 2000.

Transfer of knowledge involves not only the delivery but also the presentation or packaging of information for those who would use or deliver it. Therefore, Service Center researchers are encouraged to become involved in the application of their findings through demonstration and consultation. This both speeds up the transmittal of knowledge and increases the applicability of the findings. The delivery of technical assistance continues up to the point that such efforts become distracting to approved applied research projects.

A scientist, innovator, or anyone with the responsibilty for getting technology applied needs to communicate the information in a systematic way to ensure its transfer. To that end, the Bureau provides a staff of media consultants and producers available to help scientists in their technical information transfer activities. Further, the BLM library provides the full range of information retrieval and distribution. Such support helps ensure the rapid adoption of new and better ways of doing the Bureau's work.

A BLM MODEL

There is no one Bureau future. There are a variety of factors changing the parameters for Research and Development (R&D) and its associated information transfer. No person working in the Technology development area lacks a model to define the process of innovation.



(Figure 1.)

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[3] BLM, Research Management and Liaison Manual 1702. 1984 Releases 1-1396 and 1-1397.

The very simple graphic demonstrates some concepts inherent in the BLM policy. Let me elaborate:

- R&D is an iterative process. We are constantly modifying our current efforts based on findings or external influences such as software breakthroughs.

- The continual influx of new information technology makes stability and orderly growth difficult at best.

- The researcher will spend most of his/her effort in product development, e.g., creating prototypes and process technology--not in the invention or innovation.

- The shifts occurring throughout this process create the need for managers and researchers willing to take risks.

- The change process takes time . . . and patience.

Persons working on R&D projects would be advised to read the book Intrapreneuring by Gilford Pinchot III. Pinchot does a remarkable job of combining both management and project management theory and applying it to innovative efforts within an organization. An intrapreneur (sic) is defined as:

> "Any of the 'dreamers who do.' Those who take hands-on responsibility for creating innovation of any kind within an organization. The intrapreneur may be the creator or inventor but it is always the dreamer who figures out how to turn an idea into a profitable reality."

These are the "inside" people that are changing the Bureau's future. Persons able to work with such an amorphous model are valuable corporate assets.

SOME CRITERIA FOR SUCCESSFUL R&D PROJECTS

When one discusses any policy and process for achieving an end result, generally speaking, one cannot describe or predict all the elements that are factors on a quality research and development project. However, one of those ingredients having the greatest impact on a successful outcome is the need for the end result of the transfer. The closer one approaches a proven need--the higher the probability of a successful transfer. The reason is simple, the more realistic the need, the more realistic will be the technical specifications. The more realistic the need, the greater the economic pull and hence probable use of the end product. Great care and objectivity are basic to establishing a real need.

When one contemplates projects that have brought about successful changes in the Bureau, it is easy to write statements of what appear to be criteria for a successful, interrelated process--from initial research to product development and continuing support. These criteria include:

- Research is issue driven by the field users.

- Research project is endorsed by a coalition of agencies/constituencies.

- There is a clear association with the historical work the Bureau has always done.

- There is an apparent pathway to the change from today to tomorrow. The user need not stretch to understand.

- The research need balances efficiency and effectiveness--i.e., doing the right research in light of scarcity of resources to do that research.

- The researcher understands the link between what he/she produces and what goes to the end user.

- Technology or work process efforts take place in several disciplines and in a multidisciplinary setting.[4]

- There is confirmed transferability of the research to field application.

- The service or product is delivered to an end user at a reasonable cost.

- The product/process is well documented and reproducible in varied field settings.

- Users are trained in the value and use of the technology/work process.

- There is adequate demonstration that the application fills a real need.

Most of these criteria are inherent in BLM's current R&D efforts. They serve the Bureau best when the "incubators of ideas" use the criteria in formulating their project proposals.

A LOOK BEYOND BLM'S CURRENT R&D

The knowledge requirements for future management and development of national resource lands are enormous. Steps should be taken to enhance research operations. Not only must the development effort be broadened, but it also needs to be better organized to produce the desired results. The acquired knowledge must be more effectively disseminated than it has been in the past, both upward to the policymakers and outward to the land managers of our sister agencies. Scientists need to achieve far more influence in resource policy than they have in the past. Also, a more effective mechanism appears necessary to communicate the needs of managers and desires of the policymakers to those developing R&D proposals.

BLM SHOULD STRENGTHEN RESEARCH PLANNING:

- Articulate long range goals and provide research strategies aimed at achieving those goals.

- Take a critical look at the usefulness of existing research results.

- Establish a power position to advocate and fine tune information system development Bureauwide especially for the most vital information programs.

- Create an intrepreneural environment to help prevent the drainage of competent employees.

- Educate employees on the utility of our existing research management and liaison policy.

- Establish mechanisms for national, not just Bureau, leadership in research planning.

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[4] Buddy McKay, U.S. House of Representatives, Chair, Task Force on Technology. Notes from Address to Technology Transfer Society Meeting June 1987, Washington, D.C.

BLM SHOULD BROADEN THE INSTITUTIONAL BASE OF OUR RESEARCH:

- Formalize networks to tap the scientific capabilities of the colleges and universities doing resource research.
- Look at the relationship and desired mix for both basic research and applied research in natural resources.
- Attend to research being done in other land managing agencies.
- Coordinate the information distributing systems of sister land managing agencies.
- Authorize greater exchange of scientists through BLM's international relations office. Increasingly, the world problem of decertification will be problems of the United States.
- Foster programs to allow for exchange of scientists with other agencies and academia.

BLM SHOULD IMPROVE THE DELIVERY OF KNOWLEDGE:

- Expand extension and technical assistance programs to better serve the needs of other users. Include those innovators within BLM's State organization.
- Undertake a joint study (USDI, USDA) with the idea of improving the packaging and delivery of information.
- Recruit and support the "super technical" persons so that BLM will be recognized as having excellence in certain disciplines.

BLM must strengthen institutional mechanisms to ensure rapid transfer and application of new knowledge. Otherwise, the void between what is known and what can reasonably be organized and applied to solving immediate problems will continue to grow. The Bureau's R&D Policy and its related technology transfer activities is one approach. An exact approach is not as important as the emphasis placed on reducing the technology transfer gap cooperatively with other natural resource managing agencies involved in generating and utilizing research knowledge.

CONCLUSION

Technology transfer does not just happen. It must be planned from the beginning. It must be continuous during the conduct of the development effort and after the project is over. The transfer effort should be devoted to the ultimate user. Although mass media is important, it is most often personal contact with the individual researcher that gets the change adopted by the Bureau work force.

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ADVANCED REMOTE SENSING APPROACHES IN GROUNDWATER EXPLORATION

Allen M. Feder, PhD [1]

ABSTRACT: Remote sensing examples and advantages in groundwater exploration are introduced. Case histories are discussed in conjunction with individual remote sensor (system) performances. These are, in turn, arbitrarily sequenced according to the electromagnetic spectrum, and then potential field, wavelength involved.

The sequence leads to a combined grouping of satellite and space shuttle sensing technology in the predominately visible spectrum region. This technology, and that of synthetic aperture radar (SAR), comprise the synoptic, areal reconnaissance foundation for follow-up, detail work using the other remote sensing techniques of gamma-ray spectrometry, far (8-14 micrometer) infrared scanning, and aeromagnetometry. The invaluable lineament analysis techniques are also discussed in conjunction.
Key Terms: Groundwater; remote sensing; lineament analysis; potential field sensors; electromagnetic sensors

INTRODUCTION

Groundwater exploration is characterized by a requirement for reconnoitering (i.e, surveying, imaging, mapping) large expanses of arid or semi-arid terrain, with a goal of minimum expenditure of time and expense. At times defying detection by surface and/or contact methods, these conditions are ideal for the employment of remote sensing technology [Reeves (1975), Feder (1984), (1985b), and Shahrokhi (1972-1979)].

Aero Service is the world's first flying company, dating from 1919, and probably the world's most comprehensive and experienced remote sensing, non-government organization. A primary plan the company uses in performing groundwater exploration data acquisition and processing is the product of nearly 30 years of development in organizations including the U.S. Geological Survey, The U.S. Army Corps of Engineers Waterways Experiment Station, The Saudi Arabia National Center for Science and Technology, Cornell University, and American industry. The plan first focusses on a regional study, employing

[1] Senior Staff Scientist, Aero Service Division, Western Atlas International, Inc., 3600 Briarpark Drive, Houston, Texas 77042

"low cost per unit area" satellite and/or space shuttle and synthetic aperture radar (SAR) imagery. The most promising prospect areas prescribed by interpretation of this synoptic imagery are then subjected to more determinitive study by some combination of gamma-ray, far infrared (8-14 micrometer) and aeromagnetic data sensing and interpretation.

Each of the foregoing remote sensing techniques, is described with their advocation as supported by successful case histories. The order selected for their description, arbitrarily, proceeds from the shortest, to the longest electromagnetic spectrum wavelengths sensed, and then deals with aeromagnetic (viz: potential field) sensing.

Visible spectrum aerial photographic imagery (i.e. standard, larger scale, aerial camera photography) generally serves as a necessary adjunct for any of the other remote sensing techniques. Satellite and/or space shuttle imagery, while possibly including band-data in addition to visible spectrum, is herein generalized as being primarily visible spectrum sensing.

Descriptions of the principles of the remote sensor hardware, software or acquisition operations involved are not included. These subjects are effectively covered in many, readily available references [Shahrokhi (1972-1979), and Feder (1985a,b)]. The reader unfamiliar with the scope and nature of remote sensing technology in its entirety will also find pertinent references available (e.g. Reeves (1975)).

GAMMA-RAY SPECTROMETER REMOTE SENSING

The remote sensor acquiring the shortest wavelength data is the gamma-ray spectrometer. This senses the radiometric environment. Figure 1 contains U.S. Army Corps of Engineers Waterways Experiment Station laboratory data from the early 1960's. The investigations in which they were collected established that the gamma-ray spectrometer can acquire data on soil composition, where conditions such as moisture content are known, and of greater importance, soil moisture content where mineral composition is known. In modern systems, digital data such as those represented in Figure 2, are collected. These data can be used to computer-map the soil and rock exposure environment of an area, through vegetation, in terms of relative percentages of uranium, potassium and thorium. Such a computer map is given as Figure 3. As the corrolary, soil moisture content can be mapped equally effectively. Specifically, where a gamma-ray spectrometer map such as that of Figure 3 was of an appropriate geologic environment, showing areas of "subdued" signal levels, compared with the surrounding signal levels, those areas of subdued signals would be the best groundwater prospects.

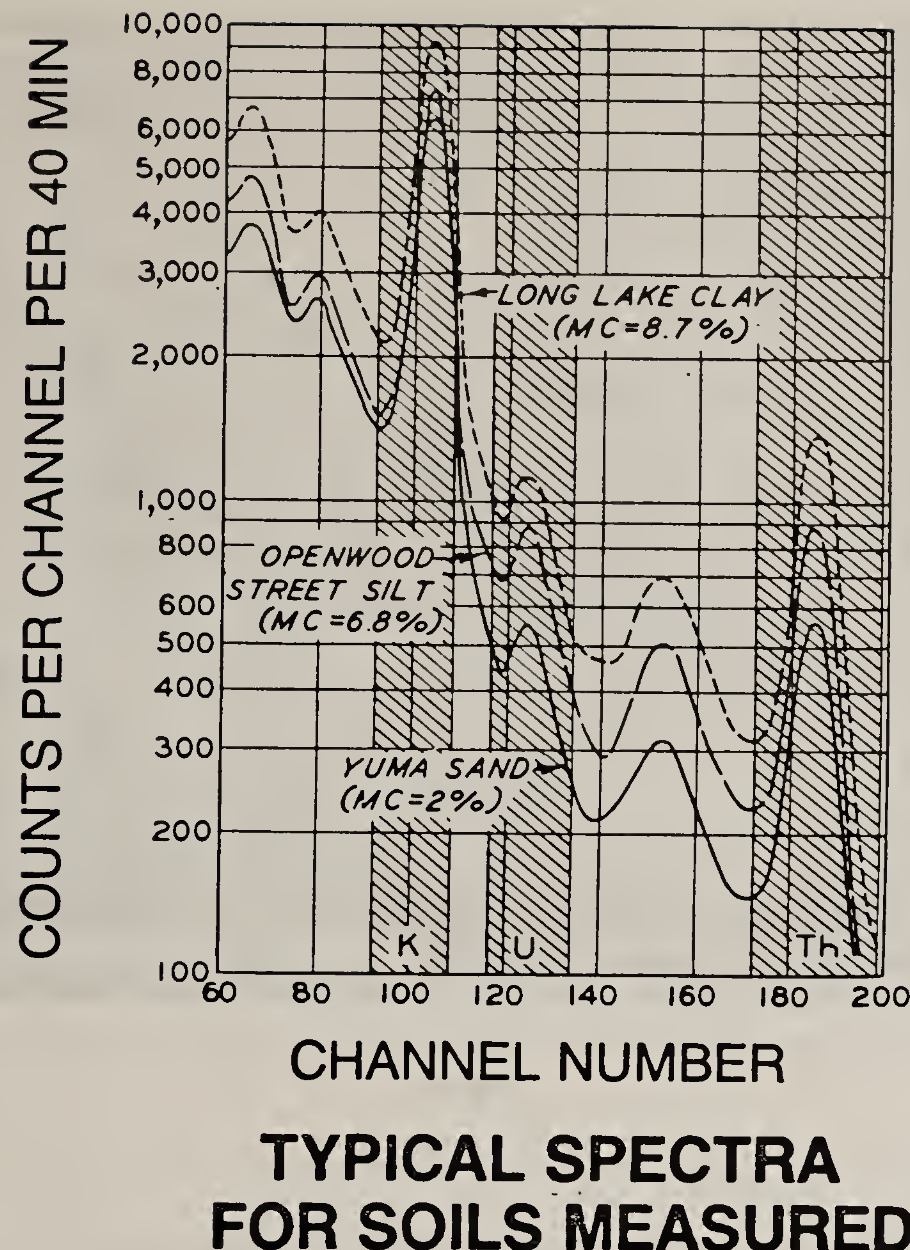

Figure 1.

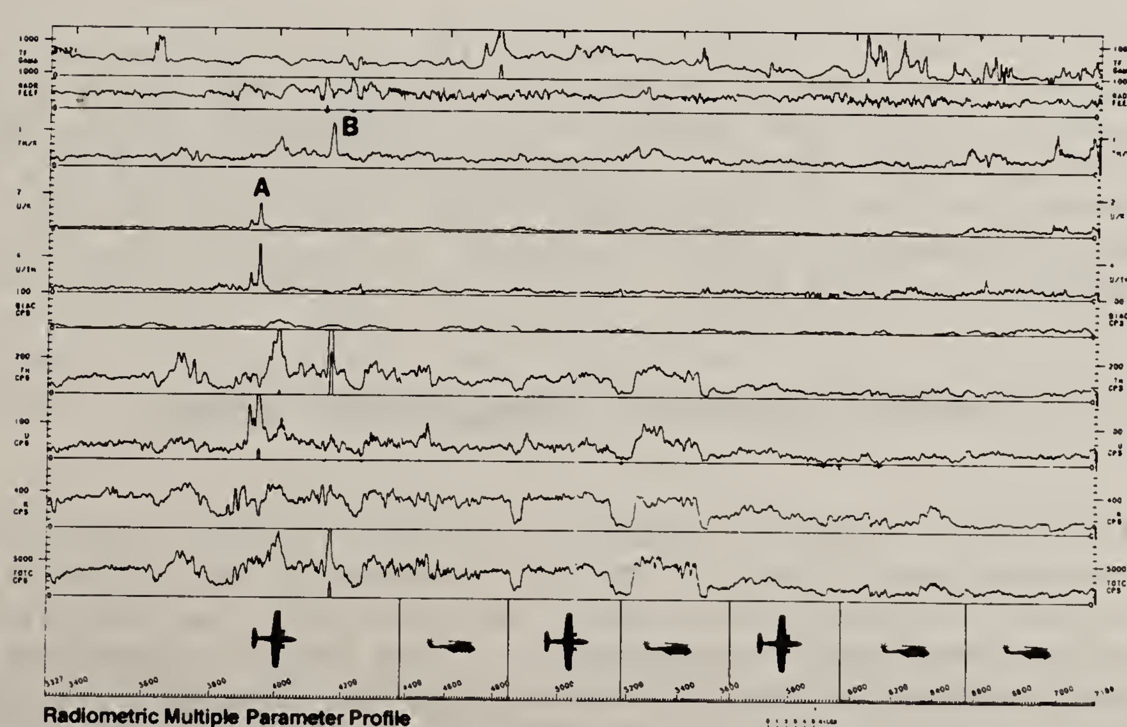

Figure 2.

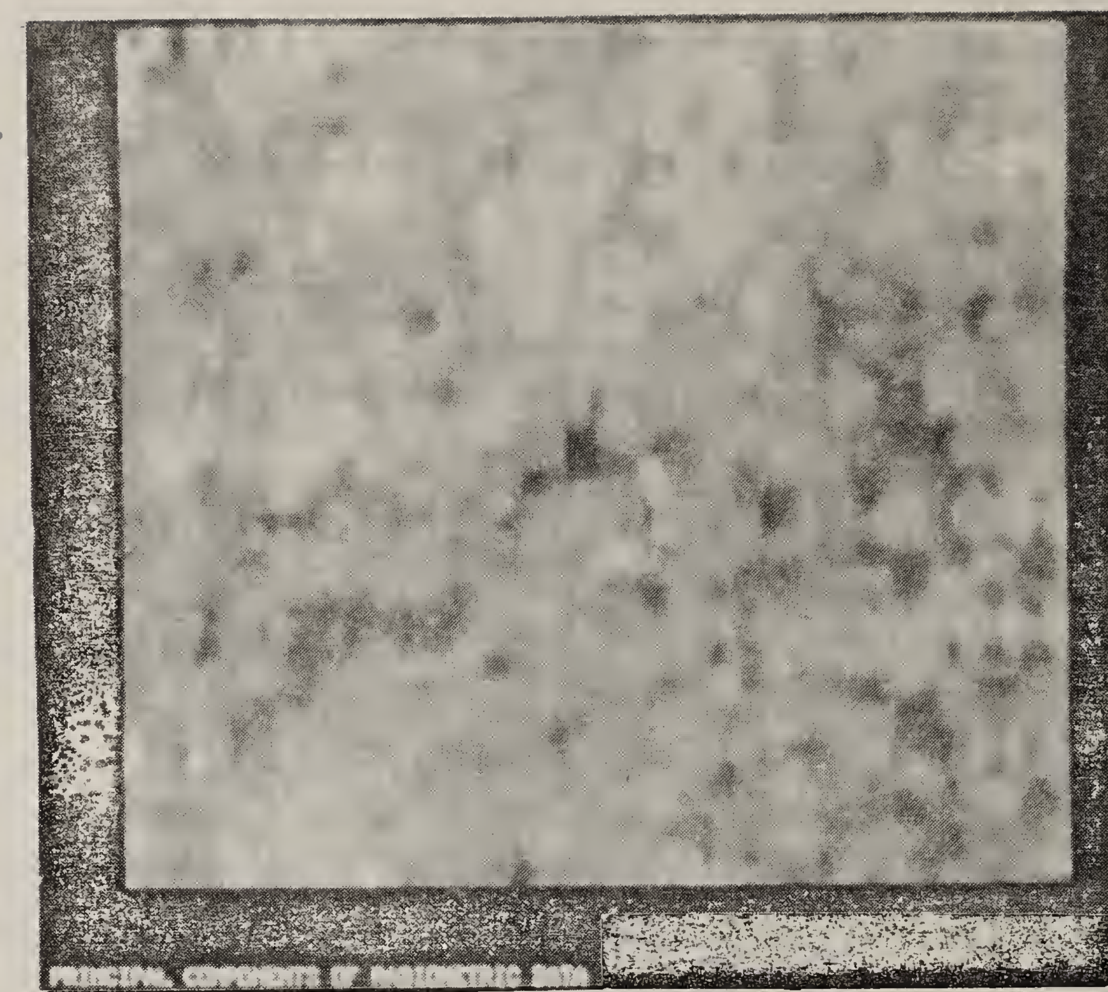

Figure 3.

Groundwater Exploration, Egypt

Aero Service recently completed one of the most extensive aeromagnetic and airborne gamma-ray spectrometer surveys in history. This was for the Egyptian General Petroleum Corporation (EGPC), with a groundwater aspect and primarily concerned east and south Egypt. Results of the survey(s) are still being studied by EGPC, and remain proprietary with that organization. Gamma-ray surveying for groundwater can be recommended, at least under conditions similar to those prevailing in south Egypt.

SATELLITE AND SPACE SHUTTLE REMOTE SENSING

Satellite and space shuttle imagery is one of the two, primary groundwater exploration reconnaissance tools. This is because of the synoptic information presented, and the inherent discrimintation permitted the familiar colors and grey scale levels of that information. (The other important groundwater exploration reconnaissance tool is SAR imagery, for reasons that will be given later).

The two following case histories deal principally with Landsat mulitspectral scanner (MSS) imagery. A typical MSS scene images a 185 km square. The applications technology discussed, however, applies equally to Landsat thematic mappper (TM) scenes, the French satellite SPOT's scenes, and likely those for satellites planned for the the foreseeable future (e.g., Japan's JERS-1). (TM "quarter" and SPOT scenes typically cover a quarter of the area of MSS scenes.)

Relative to synoptic viewing, imagery from space shuttle-borne devices, such as the Large Format Camera (LFC)*, can be employed in a manner similar to satellite imagery. This can be done with some "trade-offs" that provide varying advantages. For example, LFC imagery can have ten times better resolution than does TM, and possibly five times that of SPOT. This could be critical for lineament analysis, as will be described later. Yet, LFC's spectral data are not directly generated in a digital form, to permit manipulation, as per TM, MSS and SPOT data, and as will be shown to be so important via the case histories that follow. This point may be immaterial, however, as the "post-processed" LFC imagery can readily be digitized for effective manipulation.

Two case histories are here presented to demonstrate the synoptic, visible spectrum remote sensing required for successful groundwater exploration. The two were selected because of their diversity and their illustration of groundwater interpretation techniques. Again, satellite or space shuttle remote sensing approaches are used to select areas warranting detailed study by gamma-ray spectrometry, 8-14 micrometer scanning, and/or aeromagnetic methods.

Groundwater Exploration, Northern Arabian Shield

Much of the data of this sub-section were extracted from Tarabzouni et al (1986) and related references.

This project began in August 1978 as a suggestion of the United States-Saudi Arabian Joint Commission on Economic Cooperation. At that time a decision was made to concentrate on use of the MSS data of Landsat 1, 2 and 3. Later, the use of some data from the Landsat 3 return beam vidicon (RBV) system was made. The decision to use MSS data was greatly influenced by certain computer enhancement techniques available. Aero Service's GeoImages® package is one such technique. The enhancement techniques not only facilitated geologic interpretation but also permitted detection of phreatophytic vegetation, which, in the wild state, is an indicator of groundwater.

*The LFC is a product of Itek Optical Systems, a Litton Industries-affiliated company as is Aero Service. Itek and Aero have worked closely together toward developing LFC imagery applications, and Aero is the Licensee for future LFC missions.

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The region studied was primarily Ha'il Province, which is in the northern Arabian Shield. It is characterized by medium relief with a maximum elevation of 1,400 m above sea level in the Aja Mountains. It has cool and fairly humid winters, hot and very dry summers, and an average annual rainfall of 15 cm with two maxima: November-January and April-June. The surface drainage system is composed of ephemeral streams which drain from three primary catchment highlands.

As per GeoImages, the Landsat computer compatible tapes (CCTs) were first subjected to image corrections to remove the undesired effects of sun elevation variance, atmospheric haze, striping, noise patterns, dropped lines, and geometric distortions.

The corrected data were next subjected to several enhancement techniques. Although most enhanced images are useful, the hybrid ratio method produced those images most useful for detection of subtle physiographic features. In addition, the images produced by merger of MSS and Landsat 3 RBV data gave the added detail which the Landsat 3 RBV uniquely provided, plus the multispectral information of the lower resolution MSS. The hybrid ratio enhancement included a contrast stretch of the outputs of three ratios (each of two bands) and a final false color product. With the four MSS bands (no data from the Landsat 3 thermal band 8 were available), several ratios were available: 4/5, 4/6, 4/7, 5/7, 5/6, and 6/7. These ratios were accomplished by dividing the data number (corresponding to the magnitude of the radiance of sunlight reflected from the earth) of each pixel in one band by the data number of each corresponding pixel in another spectral band. After certain scaling steps, each of three ratios was assigned a primary color (red, green, or blue) and a color composite produced. Figure 4 is an example with the ratio of bands 5 and 4 shown in blue and the ratio of bands 7 and 5 shown in red.*

The Landsat 3 RBV provided four sub-scenes to correspond (approximately) with each MSS scene. Although these were panchromatic rather than multispectral, as were available on Landsat 1 and 2, they had greatly increased resolution and served for merging the data. Because the resolution, and indirectly the scale of the MSS and RBV are different by a factor of about 2, merging required changing one or the other, or both. False color was alternatively used to display two MSS bands and the one RBV image, or three MSS bands to each of which the data from the RBV were added. Figure 5 shows the latter with scaled up MSS Bands 4, 5, and 7 and scaled down RBV data. It covers the same area as the lower-right quadrant of Figure 4.

Thirty test sites that were predicted to have groundwater were chosen from the enhanced images. Field trips in 1980 and 1981 included data collection from existing wells (both old, hand-dug, and new machine-drilled) and from new wells drilled by the field team. The water samples were analyzed at the U.S. Geological Survey Water Resources Division Laboratory in Denver, Colorado. At all thirty sites, either water was found, or there was evidence of prior water. The depth to the aquifers varied from less than one to over 300 m.

*See Errata (closing section)

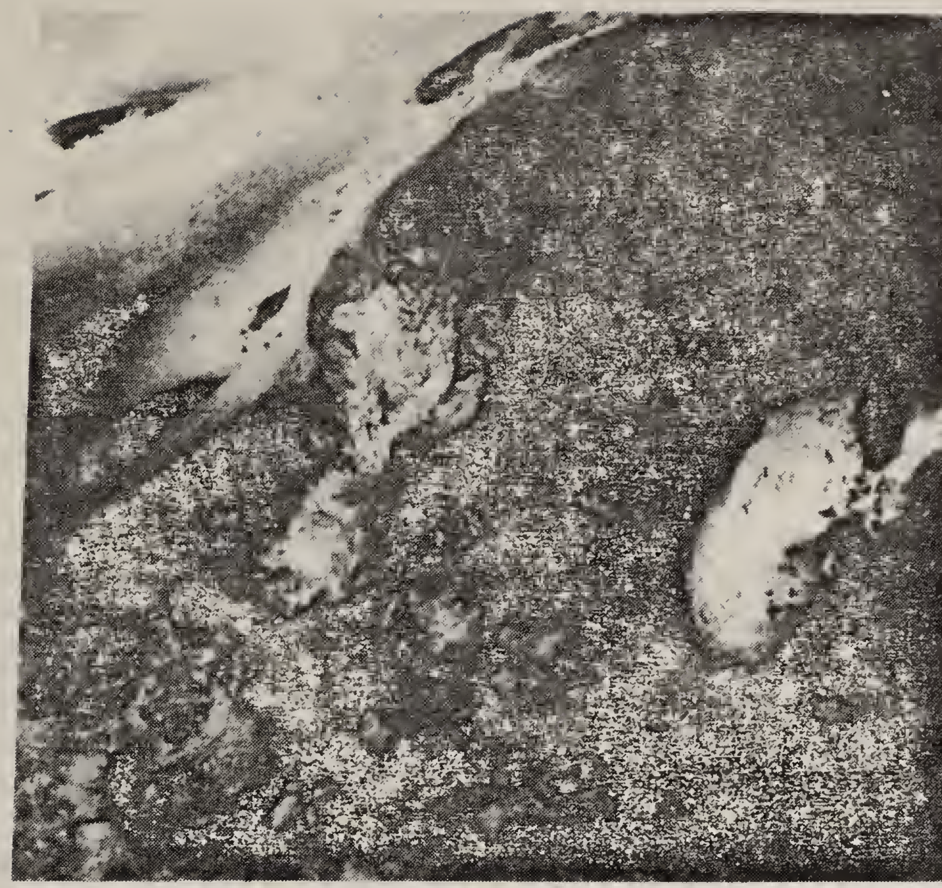


Figure 4.

Figure 5.

Much of the data of the sub-section were extracted from Akhavi (1979), (1980), (1986) and related references.

The purpose of the investigation was to obtain hydrogeologic information and delineate target areas suitable for groundwater development, including aquifer data, occurence and movement of shallow groundwater, delineation of target areas for more detailed hydrogeologic exploration, and the siting of test wells. The Daryacheh-Ye-Namak (Salt Lake) (the main playa) watershed, covers an area of 78,500 square km and encompasses heavily populated and industrial sectors in West-Central Iran, including Tehran (Figure 6).

The average amount of rainfall over the Alborz Mountains north of Tehran exceeds 900 mm a year, while in the vicinity of the main playa the average amount of rainfall is only about 100 mm a year. Large alluvial fans and bajada surfaces flank the Alborz Mountain foothills at the northern slopes of the watershed. An example of these is a large fan complex underlying the city of Tehran and extending southward to the city of Ray, for a total distance of 30 km from the apex to the margin of the fan.

Typical of most semi-arid regions, the fans contain stratified sands and gravel interbedded with finer silt-, to clay-textured layers. Materials found near the apex of the fans are very stony or rocky, while at the toe of the fans they are graded to clay-sized particles. The bajada surfaces and distributary drainage pattern characteristic of these landforms form the most important recharge zones. The margins of the fans - - zones of coalescing and interfingering of these sloping surfaces with horizontal plains consisting of continental alluvium or valley-fill deposits - - constitute the most promising sites for prospective wells and contain the most productive artesian aquifers in the region.

About one-third of the municipal water requirement of Tehran (now, possibly 10 million population) is supplied by groundwater sources encountered in alluvial fan surfaces.

Black and white transparencies of bands 4, 5, 6, and 7, and a standard false color composite (F.C.C.) were used for the study. The data were collected on 25 May 1976 and contain a variety of image recognition elements and spectral signatures indicative of various landforms examined in this research (Figure 7).

The various geomorphic/geologic landforms and hydrogeologic conditions of Figure 7 were delineated on the basis of their image recognition element (size, color, tone, texture, pattern, and association) as observed on the black and white and F.C.C. imagery, so that Figure 7 represents the results of the classification of alluvial deposits, delineation of bedrock, and detection of other landforms pertinent to a hydrogeologic interpretation. Three different categories are recognized and delineated:

Figure 6.

Hydrogeologic Map of Daryacheh-Ye-Namak Area Based on LANDSAT Imagery

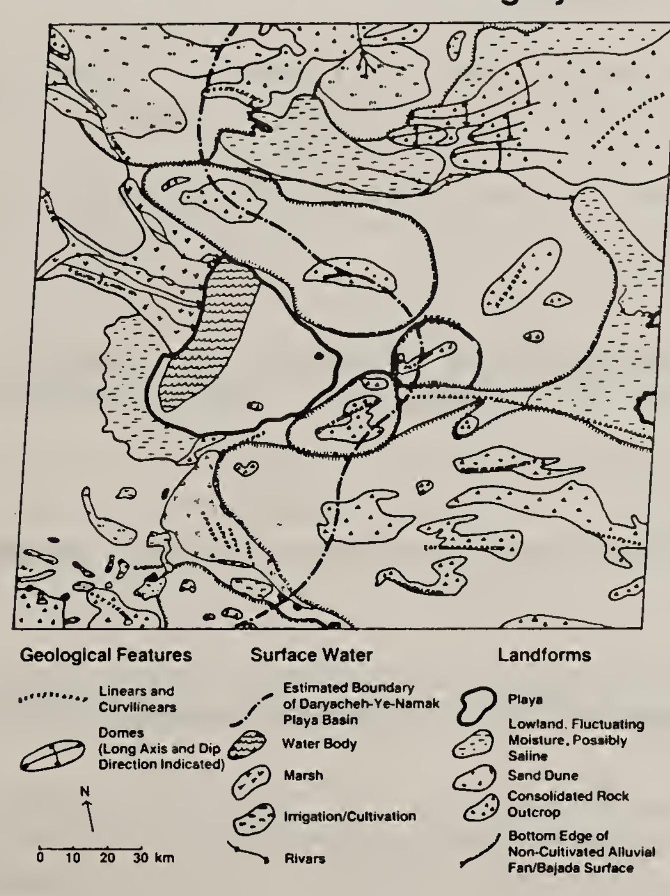


Figure 7.

1. "Geologic Features": Linear and curvilinear features are recorded as aids in the detection of groundwater discharge zones. A number of small domal uplifts were detected in Miocene marls in the northeast. Aside from their importance as petroleum traps, these sediments contain an abundance of gypsum and anhydrite and should be considered as a hazard for groundwater contamination.

2. "Surface Hydrology Features": Terrain delineated under this category contains enough moisture to support a vegetative cover, either naturally or by irrigation. Thriving vegetation is indicated by a red tone on the F.C.C. image. All vegetation in this area is due to artificial irrigation, except for the vegetation growing in the natural wetland on the west side of Daryacheh-Ye-Namak (the main playa). The wetland is dissected by a network of braided streams which, in effect, provide natural irrigation. Playas act as natural evaporation pans where groundwater and surface water terminating in these features is rapidly consumed by a high evaporation rate (exceeding 3 m per year in this area).

3. "Landforms": This category encompasses various landforms with particular relevance to groundwater potential. These include alluvial fans and bajadas (considered to contain potential aquifers), and sand dunes. Rock outcrops were mapped to indicate high recharge zones from which alluvial fans radiate. Good sites for wells potentially exist at the bottom edges of fans and bajadas where these surfaces coalesce with adjacent landforms and there is the possibility of a pressure head. Playas and lowland areas with evidence of moisture fluctuation were considered important, both as a source of groundwater discharge and, in the case of excessive dewatering of adjacent aquifers, as sources of groundwater contamination.

A groundwater potential map (Figure 8) resulted from an interpretive analysis of the hydrogeologic map (Figure 7) based on the following criteria:

1. There is potential for locating groundwater development zones near the lower edges of alluvial fans and bajadas where they coalesce with other deposits.

2. Where the lower edges of alluvial fans and bajadas are adjacent to wet landforms (playa, marsh and lowlands), the groundwater source potential, is higher.

3. There is a limited groundwater source potential near the fringe of sand dunes.

4. Existing wet landforms, though contributing to groundwater source potential, may also present salt water intrusion and contamination hazards.

5. New well sites located in the vicinity of pumping wells may result in the depletion of a dependent source.

Interpretive Groundwater Development Areas

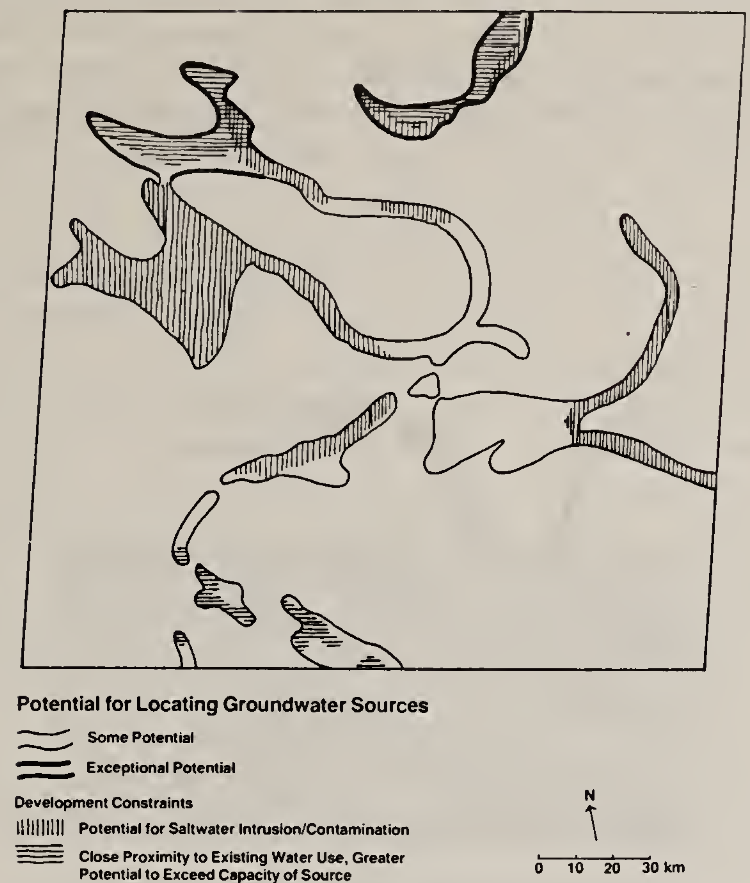


Figure 8

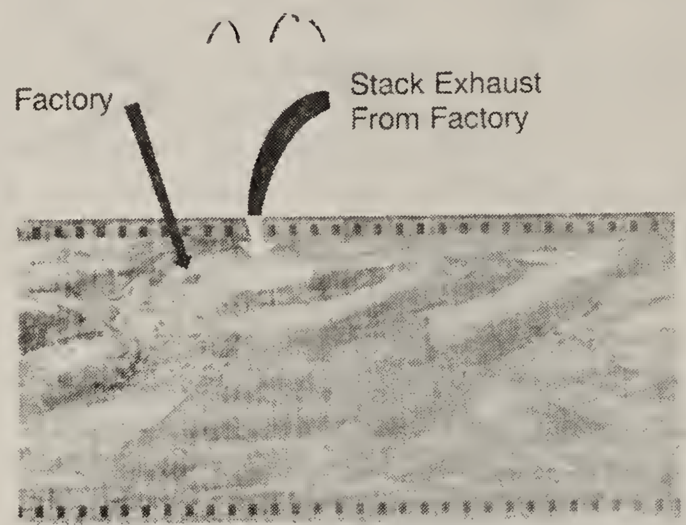
Two areas located southeast of Tehran (south of the villages of Varamin and Garmsar) were found to have prospective pumping potential, with limited to no development constraints (compare Figures 6 and 8). They have a combined areal extent in excess of 100,000 hectares and are delineated over the zone of interface between the margin of two major bajada surfaces and adjacent landforms. Groundwater development and aquifer testing in Varamin and Garmsar indicated a high transmissibility rate and piezometric condition.

Several other areas were delineated in the periphery of the main playa as possibly containing a limited groundwater supply. The rate of recharge and groundwater replenishment is low in these areas, relative to the Alborz Mountain region, due to a limited precipitation rate.

FAR INFRARED (8-14 MICROMETER) REMOTE SENSING

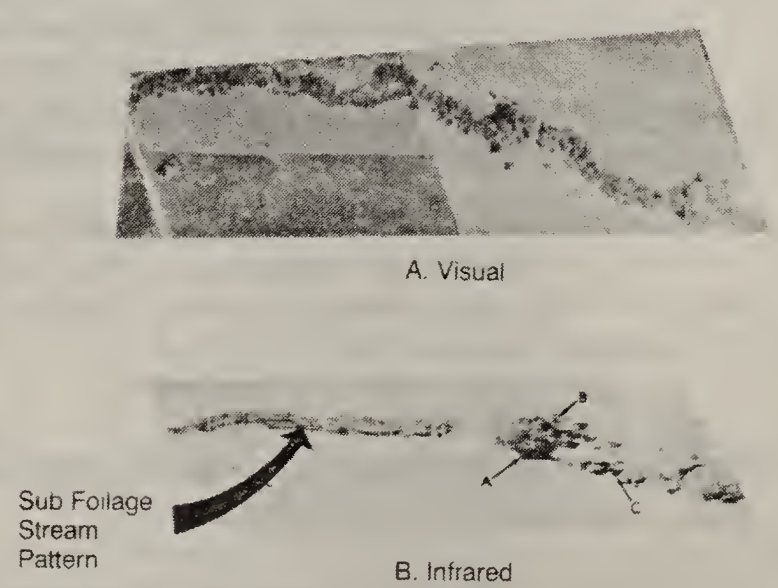
The subject type groundwater exploration experience has been extensive in e.g., Libya (for Idrotecneco S.P.A., Italy), and provides support for this section's information content.

In the 8-14 micrometer portion of the electromagnetic spectrum one detects solar energy that is absorbed by an object, and reradiated as thermal energy, and (self-) emitted thermal energy. Obviously, this thermal energy need exist in a background of contrasting temperature if detection is to be possible. Thus, in Figure 9, a factory smokestack's relatively hot exhaust is manifested as a bright signal by the temperature differential between it, and the surrounding, cooler night air. A reversal of this situation is seen in Figure 10, a day time-acquired far infrared and comparative visible spectrum pair. Here, a vegetation-canopied stream gives rise to a dark signal with the cooler air immediately over it contrasting with the solar-heated, warmer surrounding air.



3.5-5.0 μ IR Scanner Image (Night Collected) of Factory Exhaust

Figure 9.



8-14 μ IR and Corresponding Visual Spectrum Photographic Images of a Stream in Central California, Showing Sub-Vegetation Drainage on Former

Figure 10.

Figure 11 is a dramatic example of the groundwater exploration potential of far infrared imaging. It was aquired in the search for a potable water supply, and air conditioning system water, for a large building complex in western California. The visible spectrum image in the left of Figure 11 provides no indication of the buried stream channel appearing in the 8-14 micrometer image, on the right. Not only do we see the buried stream course, but, knowing the infrared image was acquired at night, can draw certain inferences. One of these is that the horizontal portion of the stream channel is probably of coarser sand and gravel than the vertical portion. This is because its bright signal suggests more readily flowing water, which is warmer than the night-air-cooled surrounding soil. The very dark signals adjoining and above the horizontal portion of the stream course, and to both sides of the vertical portion, are probably from clays. This is because they indicate a moisture content that cooled down many years ago, and because of clay's poor permeability and thermal conductivity remainded cold compared with the surrounding soil.

Drilling proved a suitable groundwater reservoir existed in the bright stream channel portion of Figure 11, at a depth of 10-12 m.

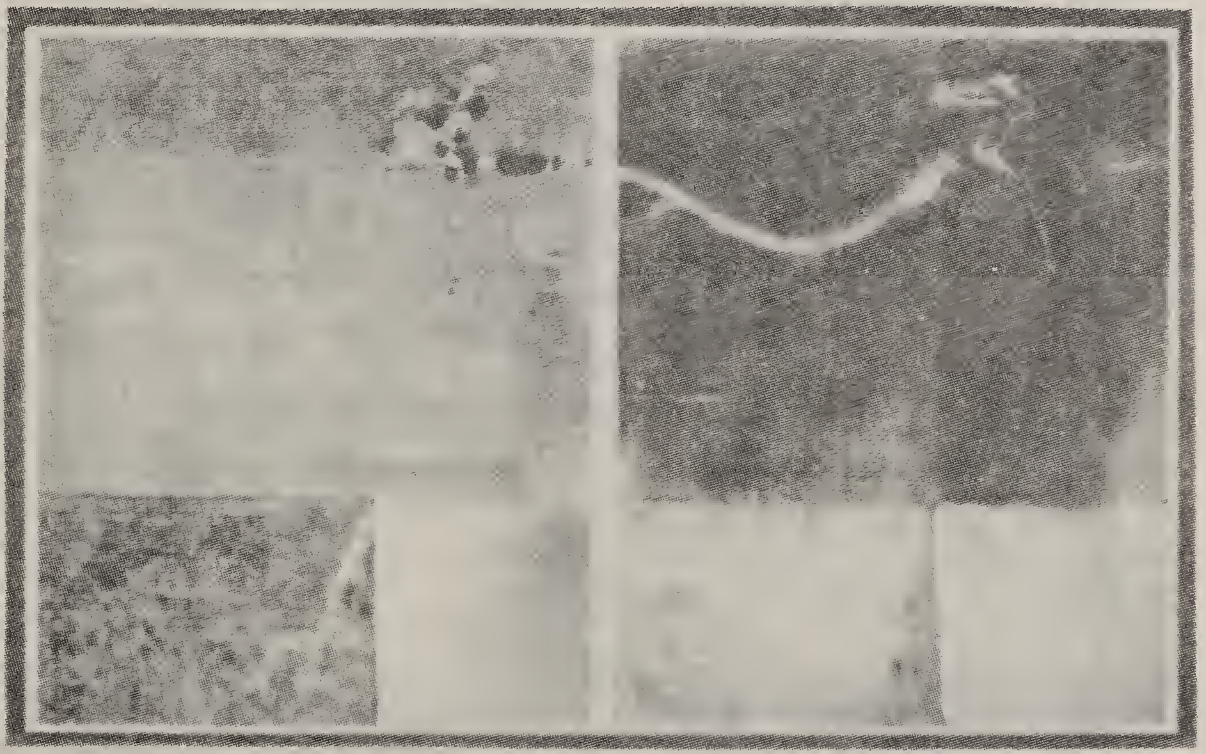


Figure 11.

A major oil company sought to develop a large oil field complex in the semi-arid, rolling topography of North-Central Texas. Initial oil drilling requirements were projected to include up to 35,000 bbl. water per day. Surface water was not (reasonably) available, and existing groundwater supplies from the Ordovician, Ellenburger formation, could not be tapped without jeopardizing the local farming and potable water supply. Accordingly, the senior author's staff made an initial survey, using MSS, for a new convenient water supply. Most promising prospects found in the MSS imagery were then investigated in detail, using 8-14 micrometer image data acquired in pre-dawn operations.

Figure 12 is from the 8-14 micrometer survey. The pre-dawn acquisition, as per Figure 11, gave rise to thermal, hence hydrogeologic data. Specifically, probable water-bearing formations interpreted as being perched water-tables, gave rise to the bright signal levels seen. Subsequent drilling established several of these perched water tables as being in Carboniferous and Permian sands and limestones (e.g. Canyon, Strawn and Wolfcamp formations), and cumulatively forming reservoirs suitable for satisfying the oil drilling requirements.

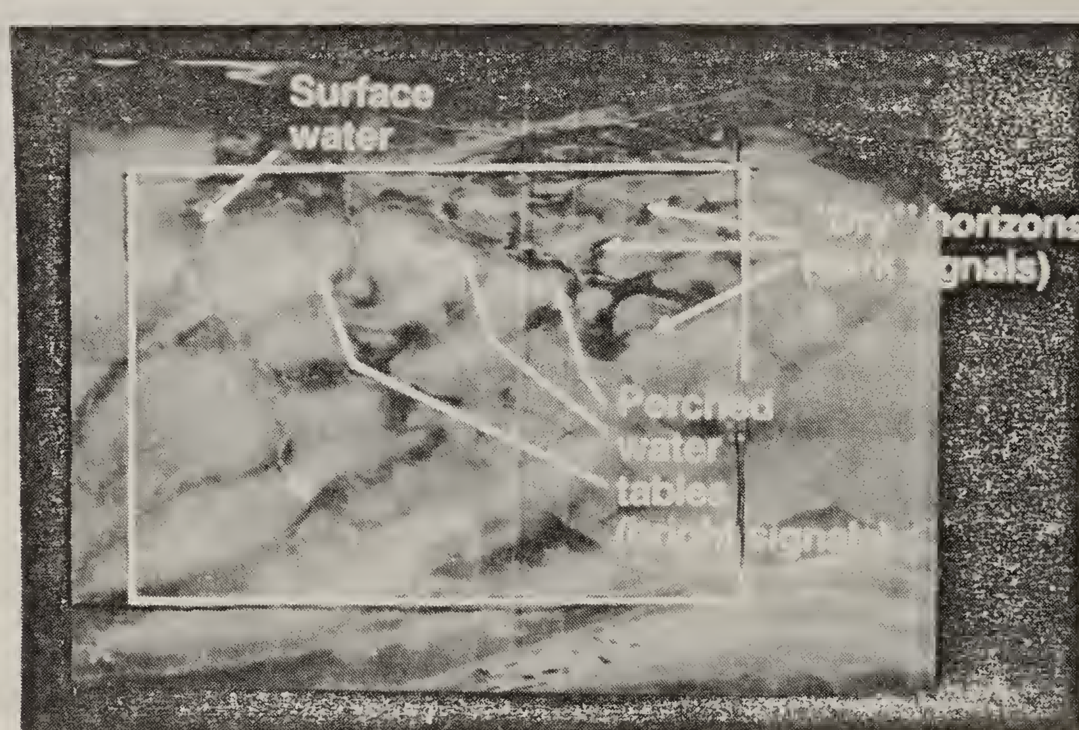


Figure 12.

Insufficient support data are available for describing Figure 13 data in a case history context. Figure 13 was acquired during daylight hours in West Texas. Consequently, the thermal imaging situation is as that described for Figure 10.

The notable feature of Figure 13 is its depiction of lineaments, as will be described in Section 5. In the figure, the lineaments are seen to be parallel and (relatively colder) water-saturated, and in one case form an obstruction causing accumulation of a groundwater reservoir.

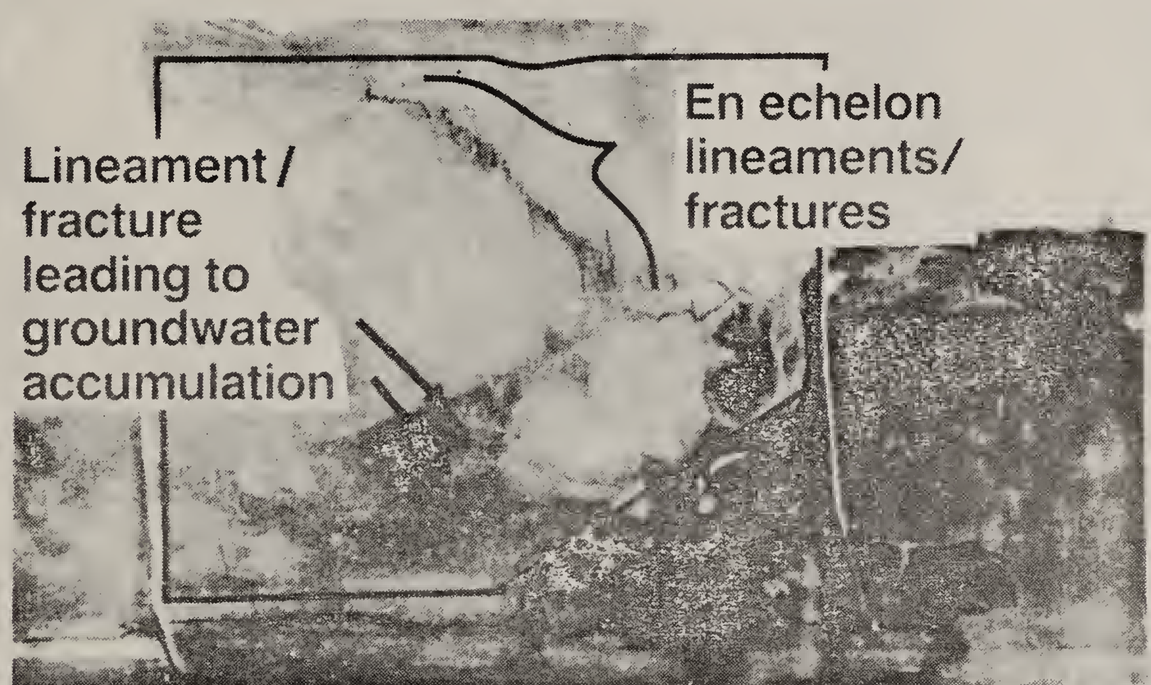


Figure 13.

Miscellany Concerning 8-14 Micrometer Groundwater Exploration

That the subject remote sensing is a valuable exploration tool is believed to be well indicated by the foregoing. Regardless, it is an exploration approach requiring an advanced level of expertise, from mission planning, through final interpretation. For example, the image acquisition time of day (and night), is critical, as has been indicated above, if depiction of the imaging objectives is to be achieved. In the image interpretation process the analyst need always be aware that he may see the manifestations of a large thermal contrast at depth, in an equal but possibly misleading manner, as he will a small and insignificant, near-surface, thermal contrast.

It is the comparison of diffuse and specular reflectors of broadcast radar energy, for given aspects, that permits us to interpret their nature. Figure 14 is an X-band (3 cm wavelength) synthetic aperture radar (SAR) image of an arid environment in Arizona. The radar, responding to surface cover texture and geometry shows brightest return signals from the bare rock mountain peaks and talus. The return signals decrease progressively downslope, through the bajada slopes, and on into the Bolson plains, with their playa features, which are totally specular. That is, they reflect the illuminating energy away from, rather than back to the receiver. The "dark" signals are from the finest materials in the area, clays and silts.

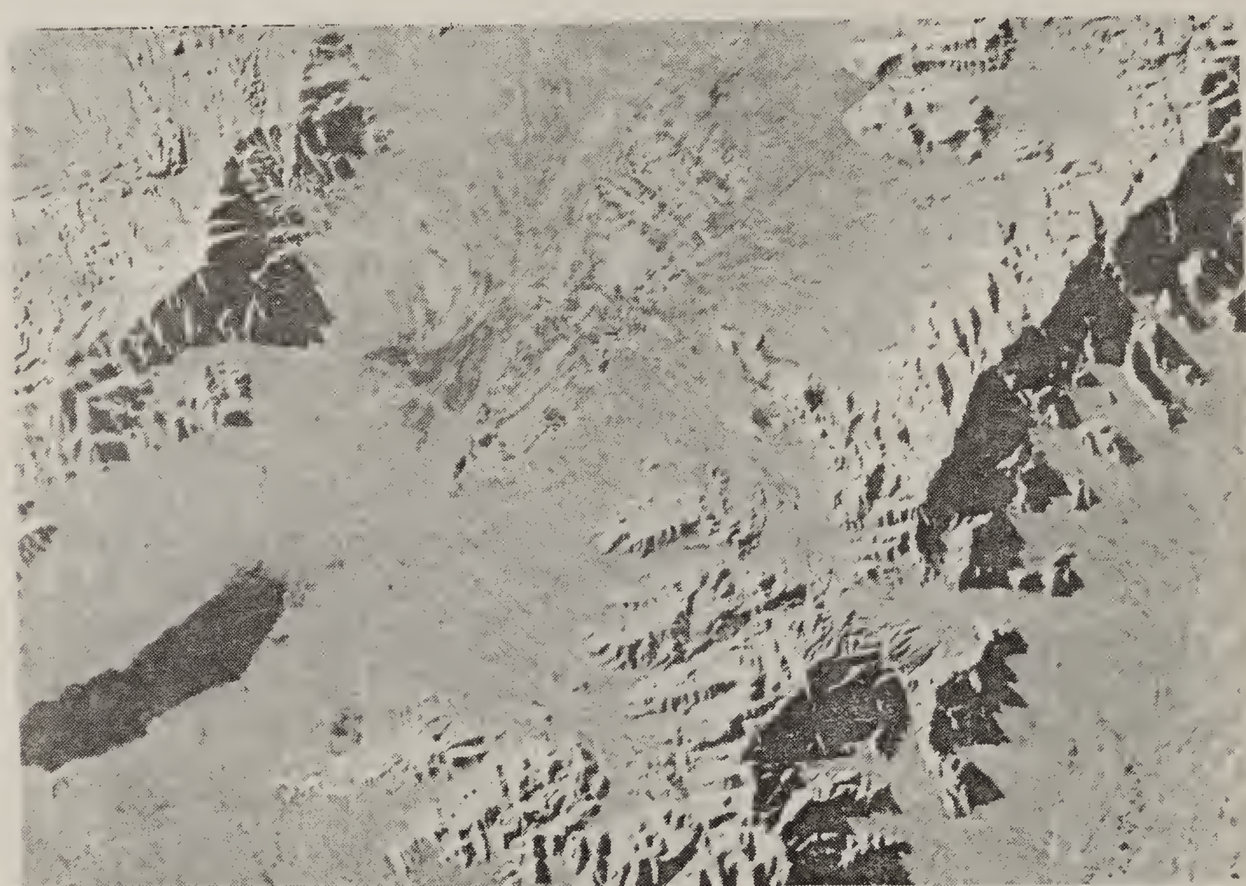


Figure 14.

In the Bolson plain are seen stringers of bright signals. These are from coarse sands and gravels and represent the braided courses of the highest velocity streams entering the area. Thus, radar in this sense, is useful in discriminating, e.g., sand and gravel deposits as could be significant in groundwater exploration, as per the case histories given in sub-sections 3.1. and 3.2.

As per Feder (1985a), SAR SYSTEM© is possibly the best radar imagery for the foregoing types of interpretations, and unquestionably has the most experience supporting such interpretations. This is particularly true for the lineament analyses, discussed below, that can be so critical in groundwater exploration.

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SAR SYSTEM imaging geometry enhances lineaments in a particularly favorable manner. Lineaments, are the terrain surface expression of fractures, jointing and other linear geologic phenomena that occur anywhere from the terrain surface, down to possibly great depths. As seen in Figure 13, lineaments can be the best conduits for transport of fluids in the terrain; in turn, they can be obstacles to such transport. Figure 15 is from a project making use of this fact (Feder et al, 1986). Specifically, the figure shows part of the results of a radar lineament analysis of the Woodbury clay of the flat New Jersey Coastal Plain. There were initial plans to locate chemical waste dumps on the Woodbury, because of its assumed imperviousness. The investigation established, however, that the Woodbury clay has many fractures through which the chemical waste could reach the area's main aquifer, the Magothy-Raritan formation, and result in its contamination (Feder et al, 1986).

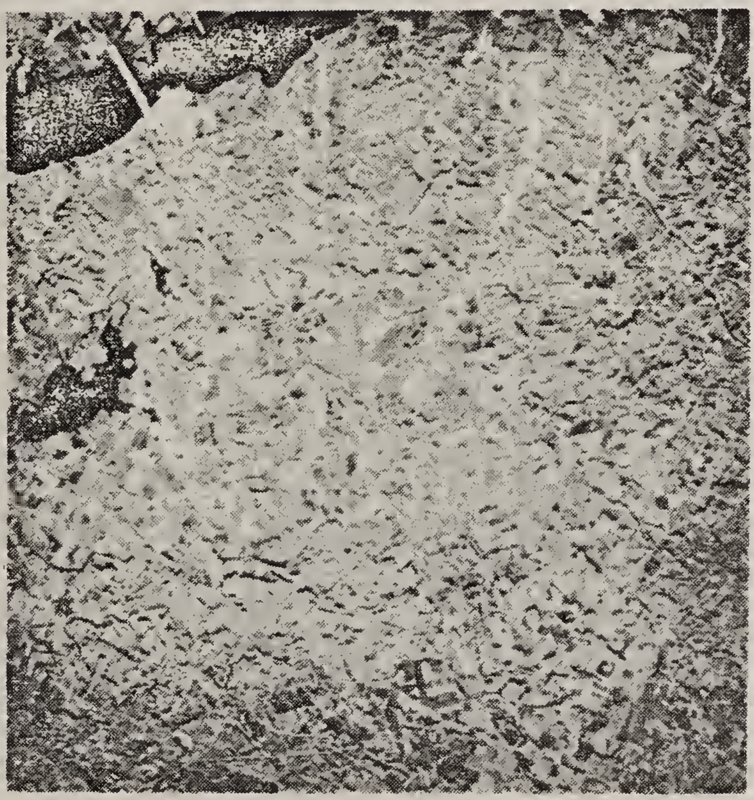

Figure 15.

Digital Lineament Analysis

Perhaps the most economical and effective means of lineament analysis is Aero Service's proprietary Digital Lineament Analysis Package (DLAP). This is a computer hardware and software system developed to assist and enhance the image interpretation process. DLAP is unusually effective in extracting the maximum amount of useful structural information from lineament overlays. Much of the information in these overlays, which typically contain 500 to 2,000 linears in an area of perhaps 100,000 square km, is never extracted because of the tedium involved in measuring lengths and orientations for all of the interpreted lineaments.

The lineament analysis begins by digitizing all of the lineaments seen by an experienced image interpreter on the image, including curvilinears. A statistical package is applied to these digital lineament data. Statistical tables and histograms, by 2°, 5°, or 10° azimuth increments, are prepared for the total lineament overlay. As many as thirty user-specifiable subsets or terrains within the total scene may be extracted for separate analysis. This separate statistical analysis may be simultaneously performed for specific geologic formations, ages, cover types, and tectonic units. The analysis might produce separate statistical analyses for: several of the more important terrains separated by age, rock type, or by suspected major faults, Paleozoic sediments, Tertiary-Quaternary sediments, rift valleys, mineral belts, or reef trends. In addition to these statistical studies, the package produces transparent overlays at the same scale as the imagery for each of the directional subsets of lineaments specified (e.g.: 18 overlays for a 10-degree azimuth increment analysis).

Overlays are prepared for the total count (all lineaments); the location of lineaments in 2°, 5°, or 10° azimuth increments, curvilinears, and the different lithologic, tectonic, or cover type boundaries used for detailed statistical breakdown. The transparent, separate overlays, superimposed in various combinations are valuable in locating the intersection of specific lineament sets and defining the location of conjugate fracture sets associated with specific geologic events, particularly uplifts. Each one of the overlays has the rose diagram summaries of the entire data set printed along the sheet margin, for convenient reference.

Groundwater Exploration, Japan

Accepting geothermal exploration as a specific kind of groundwater exploration, perhaps the largest such effort in history was sponsored by a combine of Japanese government agencies at the beginning of this decade. The SAR SYSTEM, and precision radar image mosaicking, was used to map essentially all of Japan, and specifically the northern islands in several different manners including SARSAT™. SARSAT imagery is the product of precision (digital) co-registration of satellite and SAR SYSTEM images, to provide the advantages of both, in an enhanced manner, viz: The color content information of the former and the geologic content of the latter (e.g., structure, lithology, topography).

Interpretation of the Japanese' SAR SYSTEM and SARSAT imagery is still in progress, and has not been (extensively) reported. Part of Aero Service's interpretation scheme for the project is summarized in Table I.

Groundwater Exploration, Utah

Figure 16 is a SAR SYSTEM image of the Pavant Range. The city of Richfield, Utah is at "E", in Figure 16. The unusually high resolution of the SAR SYSTEM image shows extensive agricultural development in the valley west of the Pavant Range, extending south to north and to the right of "C". This

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TABLE I

Part of The Interpretation Plan for Targeting Japanese Geothermal Resources

Features	Explanation	Documentation by SAR Imagery	Probable Example Setting in Japan
4. Structural-tectonic features	May be indicative of the existence of a mobile belt or hot spot.	Probable	Honshu Major Belt, Hidaka Belt, Shimanto Major Belt, Chishima Major Belt.
Active plate/subplate boundaries	Magmatic material in subduction zone may provide heat source for geothermal reservoirs.	Probable/ Deductible	Izu-Bonin Arc, Ryukyu Arc, Kurile Arc
Deep-crustal fractures	Fault zones and intersecting structures seem to be the most common conduites for the movement of fluids. May act as zones of weakness for magma injection.	Probable/ Deductible	Fossa Magna, Median Line of Japan
Regional fracture trends (including zones of parallel fractures)	May be indicative of deep crustal fractures and subsurface tectonic and volcanic features with no very obvious surface expressions.	Possible	Fossa Magna, Median Line of Southwest Japan
5. Phenomena which may indicate heat source	May be suggestive of hot spot	Deductible	Various phenomena identifiable in Japan
Unusually high heat flow	Generally greater than 1.5 hfu (heat flow units). Suggestive of hot spot.	Deductible	Japan blands
A dome structure	May be indicative of buried pluton	Possible	Hidaka belt, Abukuma Belt, Ryoke Belt
Circular fracture pattern	May be indicative of buried pluton or cauldron subsidence. May provide needed conduit.	Possible	Fairly abundant in Northeastarn Japan
Radial fracture pattern	May be indicative of buried pluton. May provide needed conduit for migration of fluids.	Possible	Fairly abundant in Northeastern Japan
6. Surface thermal evidence	Many thermal springs occur in volcanic districts and are related to demonstrable volcanic activity in the immediate area. Some may be surface manifestations of deeper, intrusive magmatic heat sources.	Probable	Various examples in Japan.
Vapor plume	Geothermal discharge with vapor as the continuous, pressure-controlling phase in large pores and open channels.	Probable	Senami, Niigata, Naruyo, Tamakawa, Tsuatate
Hot springs	Geothermal expressions characterized by liquid water as the continuous, pressure-controlling fluid phase	Probable/ Questionable	Toyotomi, Hokkaido, Tomine, Akita, Senami
Warm springs	Low temperature (90°C) geothermal discharge	Questionable	Joban, Fukushima Prefecture, Arima, Ikeda
Chemical springs	The amount of total dissolved solids in a spring may be indicative of the subsurface temperatures through which the spring has traversed.	Questionable	Kinshoji, Asahikawa, Akita City
Acid springs	Springs in vapor plume dominated areas are generally acid because of the H_2SO_4 produced by oxidation of H_2S in the escaping gas; pH may be as low as 2 to 3.	Deductible/ Questionable	Tamagawa hot spring
Fumaroles	A vent, usually volcanic, from which gases and vapors are emitted, generally characteristic of late stage of volcanism.	Probable/ Deductible	Tamagawa, Akita, Kusatsu, Kanagawa
Mud pots	Hot springs containing boiling mud, usually sulfurous and often multicolored; commonly associated with geysers and other hot springs in volcanic areas.	Possible/ Probable	Nagano Prefecture
Mud volcano	An accumulation usually conical of mud and rock ejected by volcanic gases.	Possible/ Probable	
Turbid pools	May be indicative of vapor dominated discharge environment with intense shallow to surface activity.	Probable/ Questionable	Northeast Japan, Nagano Prefacture
Geysers	Spouting hot springs.	Probable/ Questionable	Hakkaido, Fukushima Prefecture, Miyayi Prefecture, Oita Prefecture

development, and part of Richfield's water supply is from groundwater. The recharge area for this groundwater is the exposed rock formation faces forming the flanks of the Pavant Range. These are readily mappable in the SAR SYSTEM image. One of the discharge areas for this groundwater is interpretable in the image at "C". In this case, the discharge is a thermal spring.

As part of the U.S. Geological Survey's on-going groundwater investigations, Aero Service imaged and mosaicked the Richfield, Utah quadrangle (at 1:250,000 scale), via SAR SYSTEM. The Survey, thereupon, performed an intensive lineament analysis of the quadrangle that is available (Cooley (1984)).

Figure 16.

Groundwater Exploration, Arizona

Figure 17 is a SAR SYSTEM mosaic, with groundwater conditions interpretation providing an interesting case history. In this program it was of interest to not only "map" the groundwater reservoir area for city of Wilcox (possible) use, but to also delineate incursions of fluorine and sulfur contaminents. As Figure 17 shows the effort was quite successful, the incursions being mapped from the geologic features apparent in the imagery (i.e., lineaments). It need be recognized, however, that the SAR SYSTEM image interpretations required an incorporation of supporting data (e.g., well sample analysis) to give meaning to the groundwater incursion information.

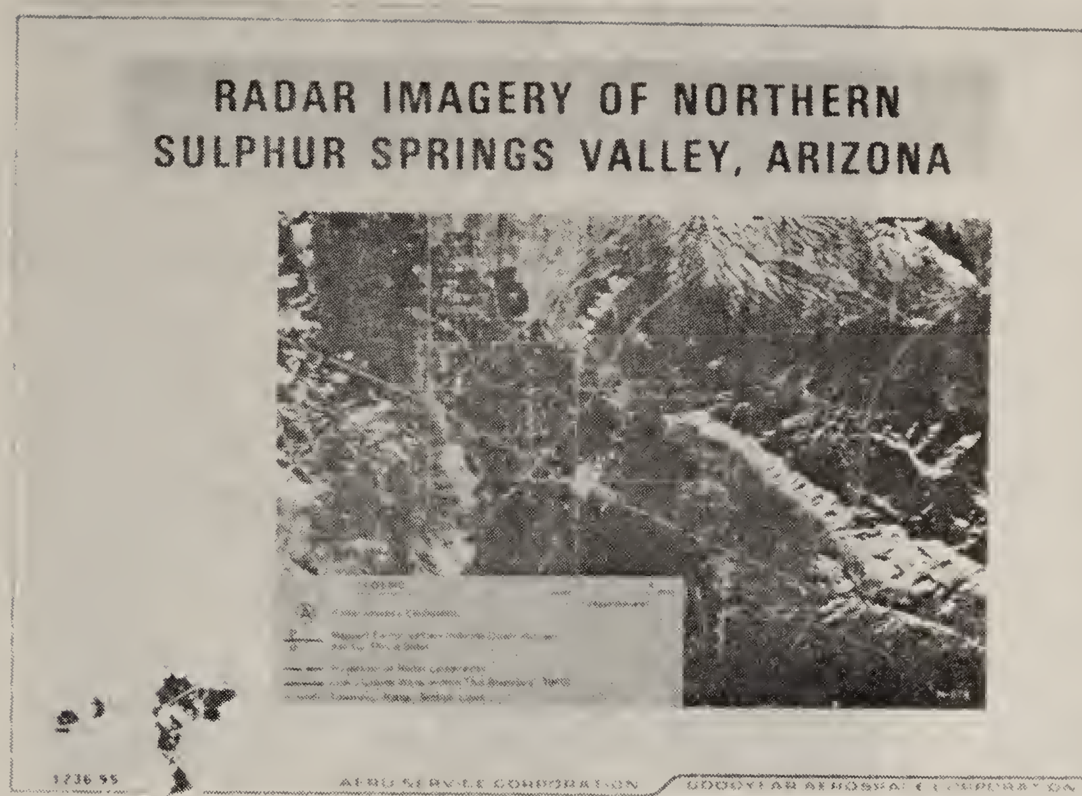

Figure 17.

Groundwater Exploration, Appalachia

The geographic area involved in this case study varies from that of the others of this paper, in that it involves a temperate climate, receiving moderate rainfall. A U.S. Geological Survey paper describes the on-going study (Lessing et al (1986)). Also it is perhaps the most comprehensive SAR SYSTEM-involved, groundwater exploration effort available for description.

The setting is the rather rugged and heavily wooded terrain of the Appalachian Mountains. As mentioned for other instances, the U.S. Geological Survey contracted the SAR SYSTEM for providing the study's imagery, and controlled mosaics (at 1:250,000 scale). Intensive investigation was made by the U.S. Geological Survey's experts, of lineaments and other factors in the "recharge-transport-discharge cycle" (Lessing et al (1986)).

More explicitly, the positive groundwater exploration results available through SAR SYSTEM imagery analysis are demonstrated in the U.S. Geological Survey example (Figure 18).

AEROMAGNETIC REMOTE SENSING

In the 125 year history of remote sensing, probably more of the Earth has been mapped with aeromagnetometers than any other airborne sensor, excepting possibly aerial cameras (Feder (1985b)). Consequently, an extensive body of literature concerning aeromagnetics exists.

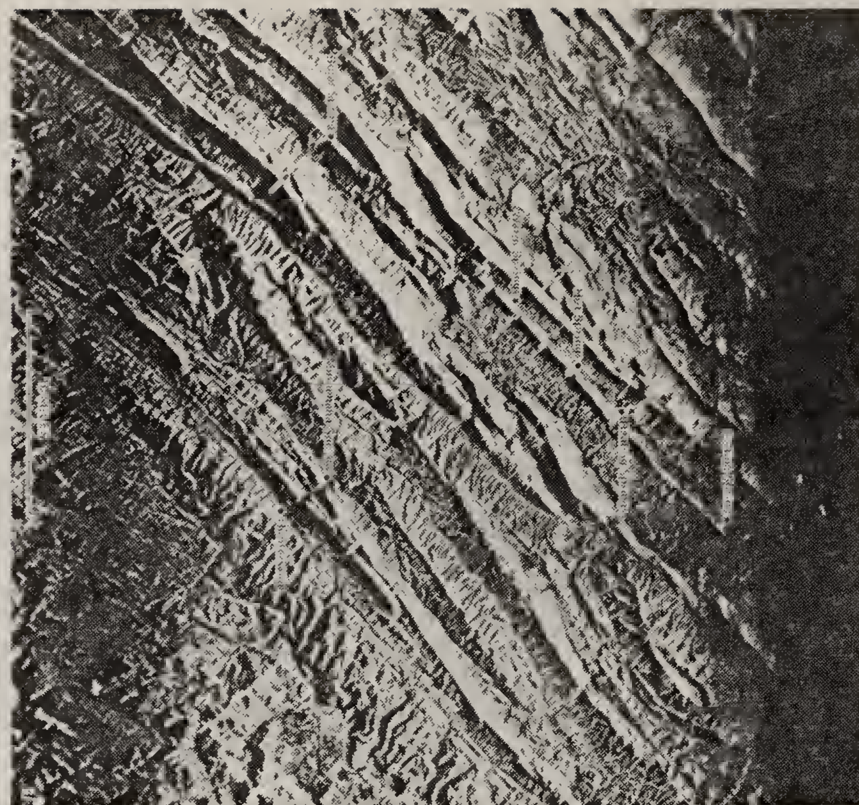

Figure 18.

Reservoir Definition

All of the remote sensing techniques described to this point provide essentially only the planimetric attributes of groundwater prospects and reservoirs, i.e, the "x" and "y" dimensional and coordinate information. Aeromagnetics is a remote sensing technique that can provide critical prospect and reservoir depth and thickness data, i.e. the "z" dimension information. This is demonstrated in Figure 19, prepared from data collected in the Yuma, Arizona basin and aquifer.

Figure 19 is of schematized data along one, central, typical cross-section line through the basin and its aquifer. It shows the granitic rock basement as profiled from drill hole, aeromagnetic and gravity data. The basement shows a block depression of perhaps 2,500 - 3,000 m. depth between points A and B.

The aeromagnetic profile, a product of data acquisition and interpretation of several flight lines, determinitively reflects the basement profile. At its simplest, the aeromagnetic profile, compared with the areas' topographic profile, could permit calculation of (the thickness of sediments available to include) reservoir conditions.

Equally, or more dramatic is the uppermost curve, of isotherms in the water table. These data were compiled from hundreds of area wells sampled by the U.S. Geological Survey. It is apparent, in Figure 19, that the water table levels replicate the basement profile, viz: sedimentary column thickness, as might be expected, as well as the basement's aeromagnetic profile (Feder and Penfield (1983)).

E-W Profile Interpretation Across Yuma Basin

Figure 19.

Drilling/Ground Exploration Optimization

The other remote sensing techniques described to this point could effectively and economically show the location of groundwater deposits, and the areal extent of those deposits. They cannot, however, tell if those deposits can be effectively tapped to serve as a reservoir, e.g., that the aquifer is appropriately fractured. This remains the role of ground geophysics and drilling, both relatively costly procedures. Aeromagnetics can be used to specify optimum sites for drilling and/or ground geophysics, thereby effecting great, total program economy. A manner in which aeromagnetics can be put to such use is shown in Figure 20.

Figure 20 was acquired by aeromagnetometry and for hydrocarbon exploration purposes. The principles for groundwater exploration are exactly the same, however, and will be equally effective whenever the potential groundwater reservoir strata have a magnetic component. Specifically, Figure 20A shows a central area of uniform signals, adjoined on its left and right, or east and west, by irregular signals. This is interpreted to be the result of a relatively thick sedimentary basin, adjoined by basement highs, and is analagous to the aquifer between A and B in the Figure 19 profile. Figure 20A alone, could show a considerable area, the central basin, requiring drilling and/or ground geophysics. Figure 20B is, however, the vertical gradient interpretation/equivalent of Figure 20A. Here at D, are shown high frequency signals, compared with the area at C. These signals are the possible result of fracture conditions prevailing. If the potential reservoir is sufficiently fractured, to support tapping, it will more likely be at D, than in and around C. Therefore, the more limited area at D should be given priority for drilling and/or ground geophysics.

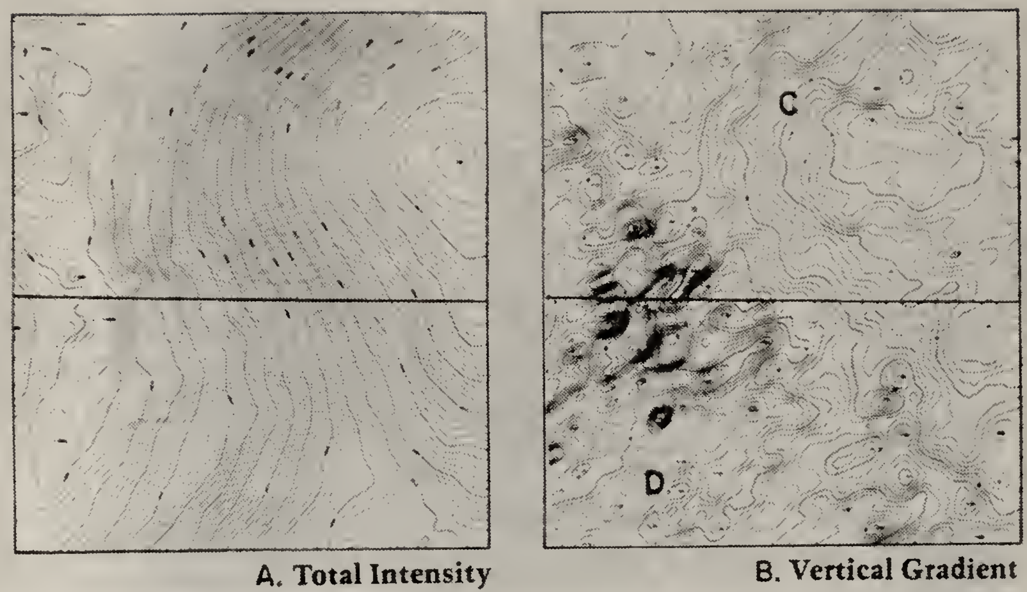

Figure 20.

SUMMARY AND CONCLUSIONS

A comprehensive overview of advanced remote sensing technology's (at times unique and usually beneficial) applications in groundwater exploration has been presented. The presented applications have been supported with case history data. The evidenced benefits, including critical economies, suggest remote sensing be considered an integral component of the groundwater explorer's "tool box". It is not unwarranted to forecast that this will increasingly be the case.

In making such a prognostication, it need be remembered that remote sensing alone is not a panacea for groundwater exploration. The professionally tailored remote sensing component of the total exploration program could well promise determinitive information. Nevertheless it will remain the role of drilling, for example, to establish the overall exploration program's final success.

ERRATA

The figures for this publication could not be printed in color and therefore lost some of their determinitive significance. A limited supply of certain of the figures are available as color prints from the author, however, and will be provided upon receipt of a letterhead request.

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WATER RESOURCES RELATED TO MINING AND ENERGY – PREPARING FOR THE FUTURE
NOVEMBER AMERICAN WATER RESOURCES ASSOCIATION 1987

IMPLEMENTING A GEOGRAPHIC INFORMATION SYSTEM FOR THE STATE OF ILLINOIS MINES AND MINERALS PERMIT REVIEW PROGRAM

Robert A. Sinclair[1]

ABSTRACT: The State of Illinois Department of Energy and Natural Resources on behalf of the State of Illinois Department of Mines and Minerals is building a Geographic Information System Mines and Minerals Permits data base, using Environmental Systems Research Institute's ARC/INFO software on a PRIME 9955. This paper states the goals and objectives of the program and describes the procedures and policies that have been developed from the experience gained, and the problems confronted, during the implementation effort. The presentation describes the manner in which building of the Mines and Minerals Permits data base was segmented among the divisions of the Department of Energy and Natural Resources to take advantage of their areas of expertise in water, geology, biology, natural resources, and economics.
KEY TERMS: Coal mining; Geographic Information System; mine permits.

INTRODUCTION

A comprehensive Geographic Information System (GIS) was developed by the Illinois Department of Energy and Natural Resources as part of its mandate under the Lands Unsuitable for Mining Program (LUMP). The GIS presently contains statewide information useful for regional planning and detailed information for coal-bearing portions of Illinois. These data span all disciplines, from archeology to zoology, with emphasis on the five areas of specialization within DENR: archaeology and paleobiology, botany and geology, hydrology and climatology, and socioeconomics and planning. The GIS software, ARC/INFO, was developed by Environmental Systems Research Institute of Redland, California (ESRI, 1986) and resides on the PRIME 9955 and 750 computer systems housed in the Natural Resources Building at the University of Illinois, Urbana-Champaign. This building is the home of the Illinois Natural History and State Geological Surveys. The GIS is networked to work stations at the Illinois State Water Survey, the State Museum, and the Department of Mines and Minerals (DMM) in Springfield.

Goals of the Project

The following objectives were established for the integration of the ARC/INFO GIS into the Mine Permit Review Program (MPRP):

1. Working closely with DMM, design a mine permit data base thatis integrated with other data sets in the GIS and that maximizes GIS applications to MPRP needs.
2. Create a mine data base in the GIS format, incorporating relevant data from all mine permit applications filed in Illinois.
3. Design and develop a set of GIS products to assist DMM in carrying out the Mine Permit Review Program (initially the GIS would expedite DMM's review of mine permit applications; eventually the GIS could support innovation in many DMM programs).

[1]Professional Scientist, Illinois Department of Energy and Natural Resources Illinois State Water Survey Division 2204 Griffith Drive Champaign, Illinois 61820

4. Establish work stations at DMM offices in Marion and Springfield, Illinois, so the DMM staff would have ready access to data available on the GIS.

5. Provide ARC/INFO software training to the DMM staff so DMM personnel could use existing GIS data sets and could create, maintain, and manipulate new data sets in response to expanding GIS applications.

BACKGROUND

To date about one-half of one percent of the entire state's land area, or 233,141 acres, has been surface-mined. A total of 103,181 acres were surface-mined in the state prior to reclamation laws. Since 1962, approximately 129,960 acres have been mined under several increasingly stringent laws including the 1980 Mine Reclamation Act (IDMM, 1986).

The DMM Land Reclamation Division reviews permit applications to assure that mine operation and reclamation proceed according to state regulations. With the start of the new program all existing mining operations proposed after February 1, 1983, had to be repermitted. To date the Division has received approximately 200 permit applications including resubmittals, revisions, and applications for new mines.

Figure 1 shows Illinois and its 102 counties along with the mine permit application sites. As can be seen, the mining effort is concentrated in southern and west-central portions of the state.

A total of 153 permits were issued to operators through 1986. Prior to obtaining a new permit, operators who filed timely applications were authorized to operate under a transition phase permit but were required to adhere to all new program standards.

Seventy-eight surface mining, 47 underground mining, and 19 carbon recovery permits have been issued. This paper deals only with MPRP and not with any carbon recovery activities.

Even though almost twice as many surface as underground mine permits have been issued, the reverse trend is true for production. In the last eight to ten years surface mine production has been on the decline and underground production has been on the rise as can be seen by figure 2. Underground production for 1986 was 40,888 thousands of tons, and surface mining producton was about half that amount, or 21,721 thousands of tons (IDCCA, June/July, 1987).

A total of 111,297 acres have been permitted over the past four years, including incidental boundary revisions, primarily for surface mines. Of this total 28,502 acres is being used for new mining, including overburden removal, support facilities, and haul roads.

Under the 1980 act surface-mined land must have all physical and chemical soil properties restored to support premining land capabilities. However, while physical capabilities must be restored, land use or vegetative cover restored is based largely on the preference of the landowner or local decision makers, with Department approval. While no reclamation has been fully completed in the new program, land use projections show trends.

In 1986 postmining land use plans showed that the change from premining to postmining land use on the 24,126 acres to be reclaimed will result in a higher percentage of pasture (IDMM, 1985), fish and wildlife habitat, and water areas and generally a lower percentage of cropland, forestry, industrial/commercial, and undeveloped acres. Figure 3 shows the premining and postmining land use distribution for 1986 under the land reclamation program.

These planned land use trends have remained constant over the first four years of the new program. In addition, the capability of the restored land to support crops has been projected for mined lands (Table 1). Since 1986 a new agricultural productivity formula to gauge the success of revegetation through yield checks has been applied to mined lands.

Therefore the ability to retrieve the premining, mining, and postmining maps and engineering data for permit approval and compliance reasons has become increasingly important.

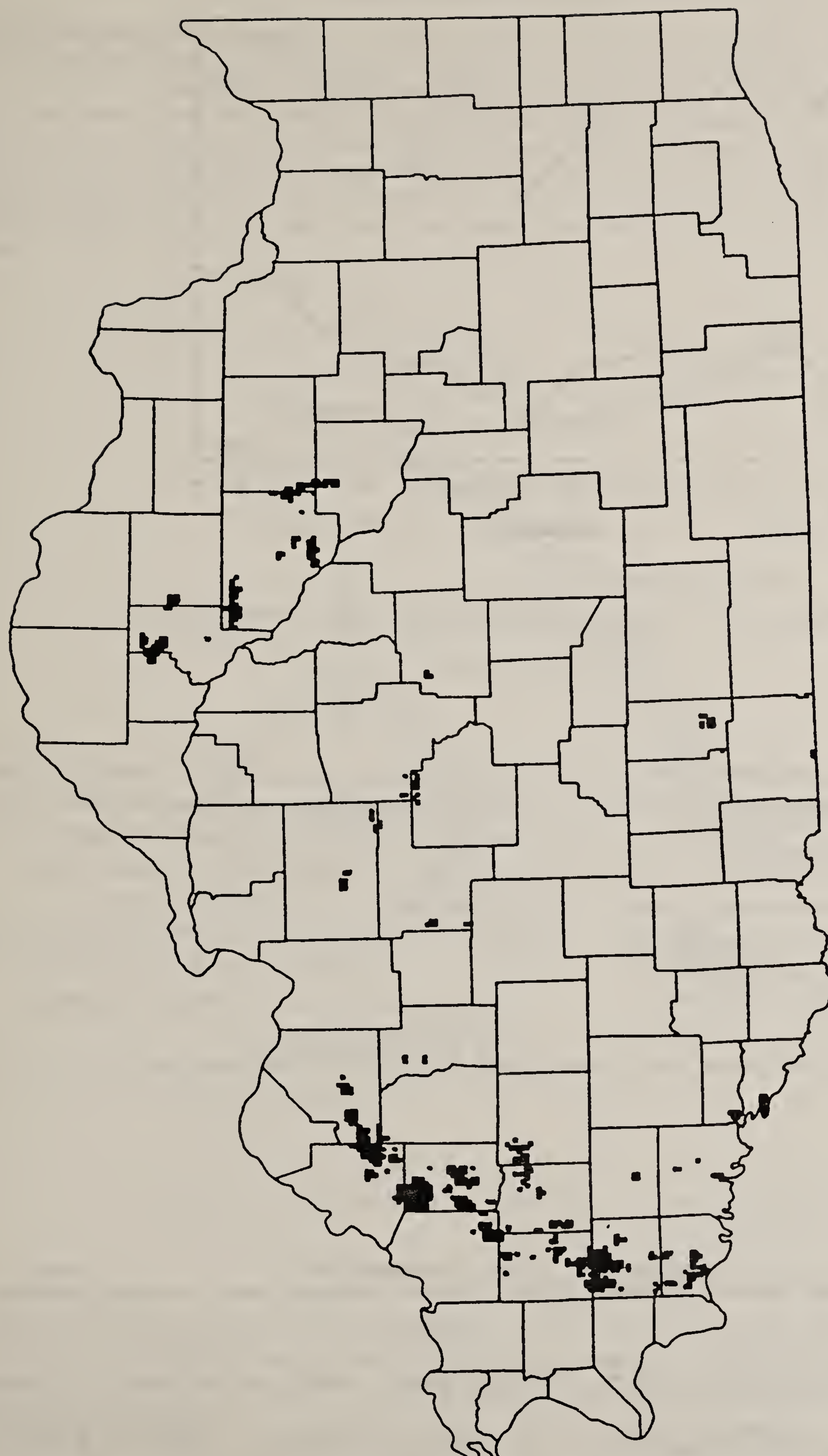

Figure 1. Mining Permit Application Sites for the State of Illinois.

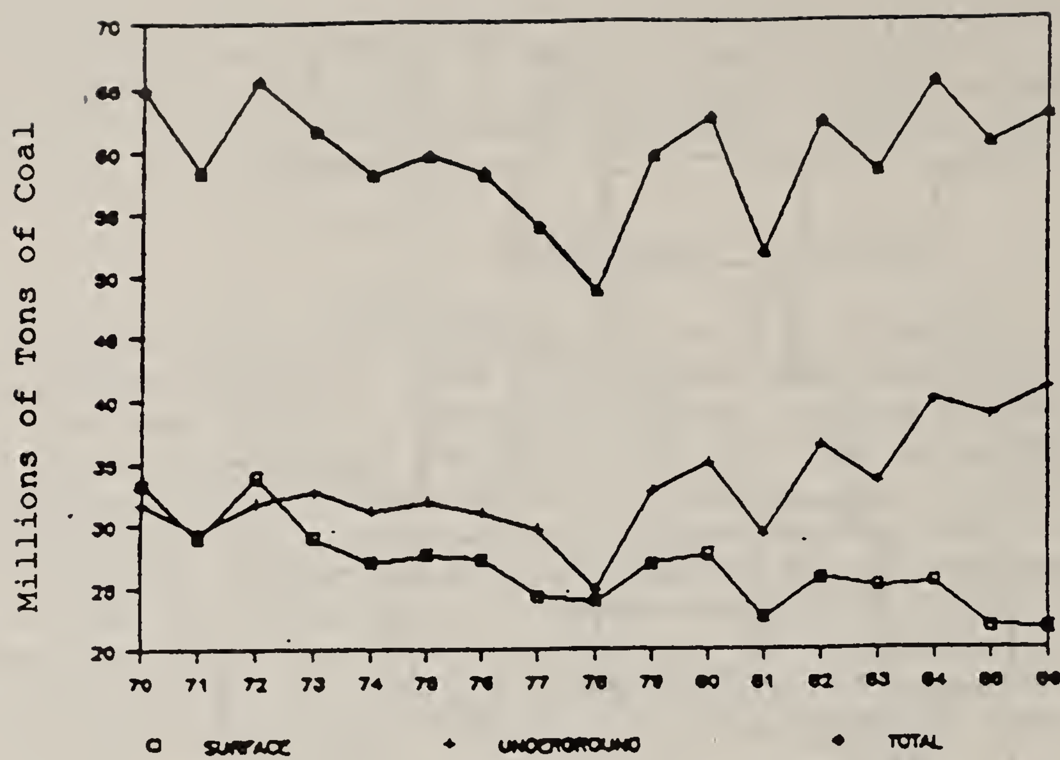

Figure 2. Illinois Bituminous Coal Production.

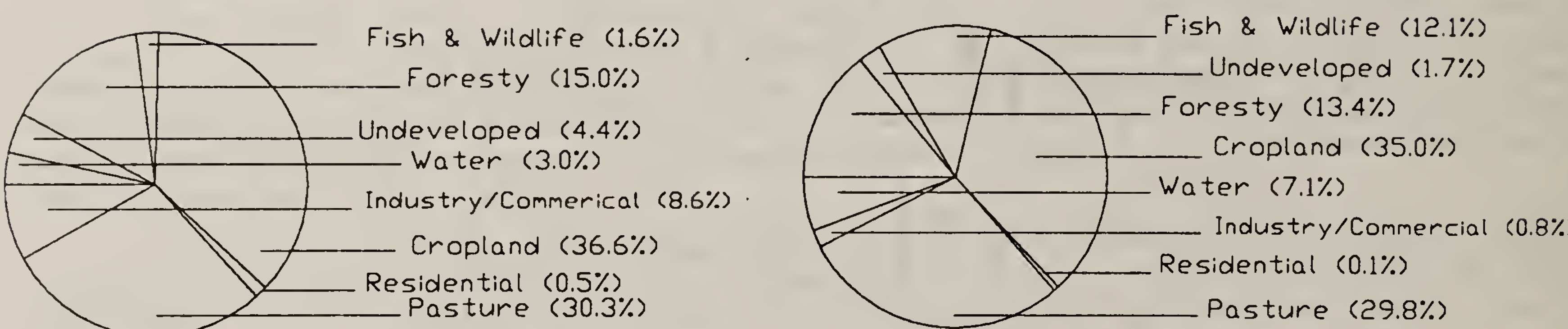

Figure 3. Premining and Postmining Land Use Distribution.

	Calendar Year 1983			Calendar Year 1984			Calendar yer 1985			Totals		
Capability	Premining	Postmining	Exempt	Premining	Postmining	Exempt	Premining	Postmining	Exempt	Premining	Postmining	Exempt
Surface Mines												
Prime Farmland	1,079.20	493.40	585.80	7,482.43	3,236.40	4,246.03	1,007.66	509.85	497.81	9,569.29	4,239.65	5,329.64
High Capability	7,383.90	7,795.10		12,811.28	17,188.61		6,649.94	6,142.15		26,805.12	31,125.86	
Noncrop Capability	7,561.70	7,696.30		18,045.89	17,914.59		9,272.45	10,278.05		34,880.04	35,888.94	
TOTALS	15,984.80	15,984.80	585.80	38,339.60	38,339.60	4,246.03	16,930.05	16,930.05	497.81	71,254.45	71,254.45	5,329.64

Table 1. Premining and Projected Postmining Land Capability for New Coal Permits (acres).

COMPUTER-BASED MAPPING SYSTEM

The projection chosen for the Lands Unsuitable for Mining GIS was the Lambert Conformal Conic Projection with two standard parallels at 33 and 45 degrees north latitude (figure 4). The computer-based mapping system was developed by the Illinois State Geological Survey, and the great advantage of using the Lambert Conformal Conic Projection is that the Illinois maps prepared with it would be compatible with the maps in the U.S. Geological Survey topographic map series for Illinois, adjacent states, and the United States (DuMontelle, 1970). To maintain uniformity throughout the mining programs, all the Mine Permit Review Program maps and the data base were done in the Lambert Conformal Conic Projection.

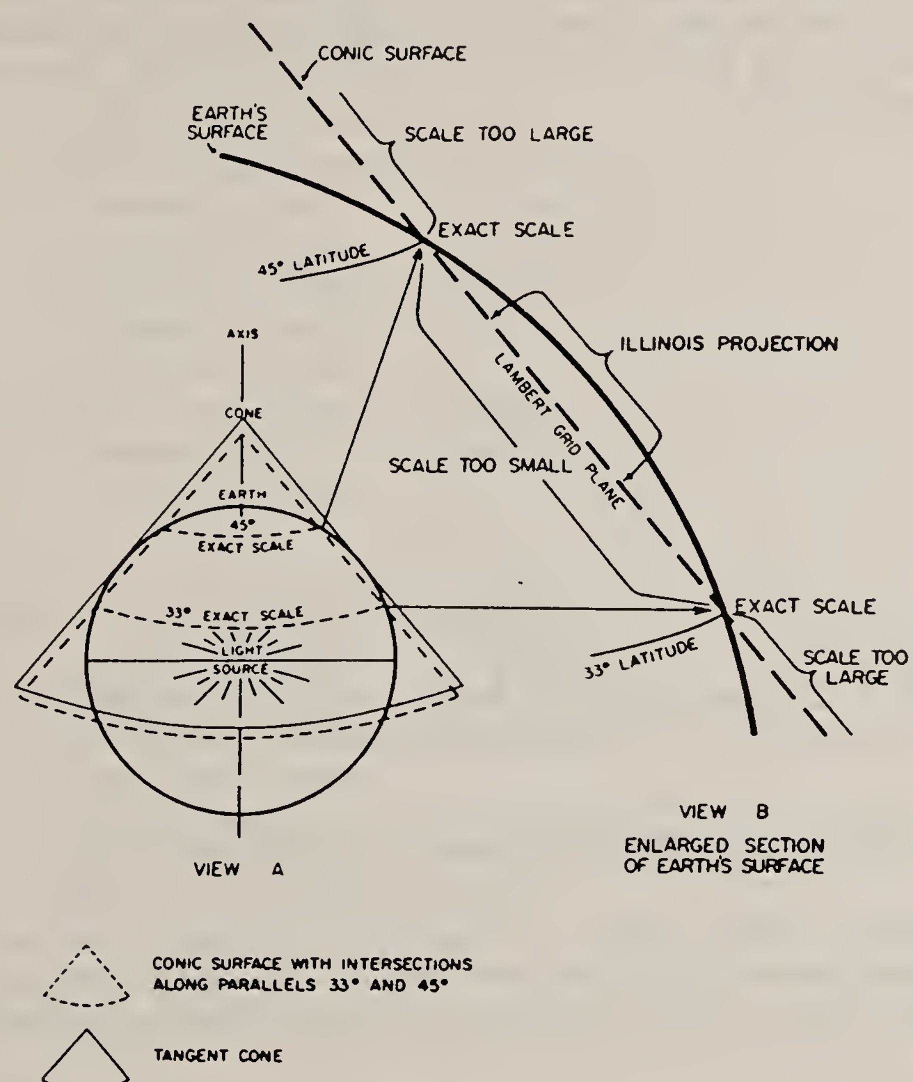

Figure 4. Lambert Conformal Conic Projection.

ORGANIZATIONAL STRUCTURE

The Divisions in the Department of Energy and Natural Resources that are participating in the MPRP are: Energy and Environmental Affairs (EEA), the Illinois State Museum (ISM), the Natural History Survey (NHS), the State Geological Survey (SGS), and the State Water Survey (SWS).

First a pilot study was completed to show the feasibility of using the GIS for the Mine Permit Review Program and to determine the strength and weaknesses of the initial effort. After successful completion of the pilot study, in which numerous policies, procedures, and methodologies were developed by trial and error, the full MPRP was implemented. Figure 5 shows the MPRP organizational structure and the flow of Mine Permit Review (MPR) material from DMM and within the DENR divisions. There is an MPRP oversight committee which gets together on an as-need-to basis to review the progress of the program and to iron out major policy and procedural difficulties.

MPRP PROCEDURES

Since an enormous amount of data and paper documents exists, extensive inventory and checkout procedures were established. The responsibility for the permit inventory rests with the Natural History Survey. Once the inventory is complete, any individual from any of the participating divisions can check out any or all of a permit.

The starting point for putting a mine permit into the GIS is the creation of the permit area boundary template (see SGS Division's component below). The State Geological Survey (SGS) has taken on the important responsibility of digitizing each mine permit's area boundary template or base map. This base map is used by all other divisions to create their coverages (a map which contains one type of attribute or datum). This is done so that good map registration can be maintained and all coverages will overlay correctly, because no two individuals digitize a map exactly the same way. Creating this template or base map of a mine permit often is most difficult because of the quality of maps which SGS has to work with.

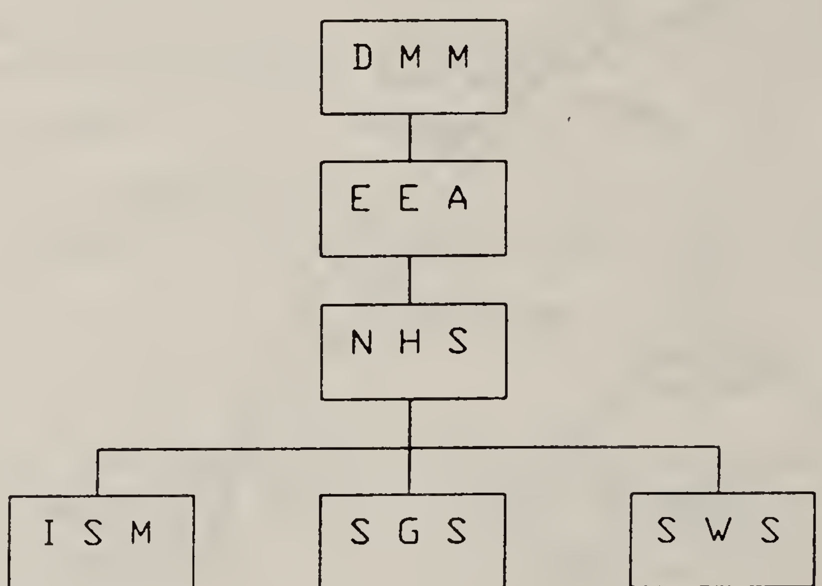

Figure 5. MPRP Organizational Structure.

Each division does certain parts of the mine permit process. Once the boundary template has been created each division can begin building the coverages within each component. The following shows the components, features, and attributes which are done by each division:

Energy and Environmental Affairs Division's Component

AFFECTED ACREAGE
- Mined Overburden
  - Permit Area
- Surface Affected Acreage
  - Permit Area
- Surface Reaffected Acreage
  - Permit Area
- Fiscal Year of Activity
  - Permit Area
* INFO Report listing acres affected by year and type of activity

ADMINISTRATIVE FEATURES

- Roads, by Surface Type
  - 9-Section Area (SGS will do roads within the permit area)
- Railroad Lines
  - Permit Area
  - 9-Section Area
- Transmission Lines
  - Permit Area
  - 9-Section Area
- Substations
  - Permit Area
  - 9-Section Area
- Public Buildings
  - Permit Area
  - 9-Section Area
- Incorporated Areas
  - Permit Area
  - 9-Section Area
- Pipelines (Oil and Gas)
  - Permit Area
  - 9-Section Area
- State and Federal Lands
  - Permit Area
  - 9-Section Area

Illinois State Museum Division's Component

ARCHAEOLOGICAL AND HISTORICAL RESOURCES

- Known Archaeological Sites
- Historical Sites
- Cemeteries
- National Register of Historic Places
- Illinois Landmark Sites

Natural History Survey Division's Component

LAND USE

- Premining Land Use
  - 9-Section Area
  - Permit Area
- Postmining Land Use (Reclamation Plan)
  - Permit Area

SOILS

- Soils
  - 9-Section Area
  - Permit Area
- Prime and Significant Farmland
  - Permit Area

SIGNIFICANT BIOLOGICAL FEATURES
- Nature Preserves
  - 9-Section Area
- Natural Areas
  - 9-Section Area
- Wetlands
  - 9-Section Area
- Endangered Species
  - 9-Section Area

State Geological Survey Division's Component

MINING OPERATIONS
- Permit Area Boundary
- Limit of Overburden Removal (Surface Mine)
- Limit of Workings/Extraction Area (Deep Mine)
- Blasting Limits
- Soil Storage Areas
- Location of Boxcuts, Haul Roads, etc.
- Limit of Coal (Coal Outcrop)
- Disposal Areas (Slurry Ponds, Gob Piles)

STRATIGRAPHIC DATA
- Well Location, Well Type
- Coal Thickness
- Coal Structure
- Coal Quality Analysis
- Overburden Thickness
- Overburden Composition
- Overburden Analysis

Any other pertinent geologic information

State Water Survey Division's Component

WELLS
- Private Wells
  - 9-Section or Larger Area
  - Permit Area
- Public Wells
  - 9-Section or Larger Area
  - Permit Area
- Well of Unknown Ownership
  - 9-Section or Larger Area
  - Permit Area

MONITORING SITES
- USGS Water Quality Stations
  - 9-Section or Larger Area
  - Permit Area
- USGS Stream Gaging Stations
  - 9-Section or Larger Area
  - Permit Area
- Surface Monitoring Points for NPDES
  - 9-Section or Larger Area
  - Permit Area

- Ground water monitoring Points for NPDES
  - 9-Section or Larger Area
  - Permit Area

SURFACE HYDROLOGY
- Lakes and Reservoirs
  - 9-Section or Larger Area
  - Permit Area
- Ponds
  - 9-Section or Larger Area
  - Permit Area
- Sediment Ponds
  - Permit Area
- Fresh Water Ponds
  - Permit Area
- Holding Ponds
  - Permit Area
- Slurry Ponds
  - Permit Area
- Watershed Boundaries
  - Permit Area
- Perennial Streams
  - 9-Section or Larger Area
  - Permit Area
- Intermittent Streams
  - 9-Section or Larger Area
  - Permit Area
- Named Diversion Ditch
  - Permit Area
- Outflow Ditch
  - Permit Area
- Levee of Dike
  - Permit Area
- Overland Flow (Natural)
  - Permit Area

PIPELINES

- Water Lines
  - Permit Area
- Slurry Discharge Lines
  - Permit Area

STATE WATER SURVEY DETAILED MPRP SPECIFICATIONS

The procedures for creating the coverages for the components by each division are quite extensive. The coding, the data entry, and the GIS manipulation to create the final products require detailed and elaborate uniform naming convention and attribute specifications. What follows are the schema and data definitions that the State Water Survey is using for the MPRP. The limited space of this paper prevents a detailed explanation of the specifications. The author felt is was better to give the complete overview of the SWS's component so as to lay out the overall concepts involved in the development of the MPRP.

A mine permit pertains to three phases: premining, mining, and postmining. The GIS work is done in a manner to fulfill the objective or scope of these three phases of a mine permit. The GIS has three types of features: polygon, line, and point data. Consequently it a maximum of nine types of coverages or map-datum features are possible.

We have attempted to use a uniform naming convention and a uniform coverage contents convention for all mine permit applications. Each mine permit has a directory (think of a directory as a filing cabinet drawer) of its own within the GIS. All directories will not contain all the coverages listed below.

Each directory (PXXX) contains only those coverages that were applicable for that mine permit application.

Naming Convention for the Coverages

```
SWSPTXXXA
111223334
                 111 Is always SWS (for State Water Survey)
                 22  Can be  PT  (Point Coverage)
                         or  LN  (Line Coverage)
                         or  PY  (Polygon Coverage)
                 333 is the permit number
                 4   can be   A   (For Premining)
                         or   B   (Mining Operation)
                         or   C   (For Postmining)
```

Coverage Names

SWSPTXXXA	All points are in this coverage; there is no B or C coverage.
SWSLNXXXA	Premining streams
SWSLNXXXB	Mining operation streams and ditches
SWSLNXXXC	Postmining streams and ditches
SWSPYXXXA	Premining water bodies
SWSPYXXXB	Mining operation water bodies and drainage boundaries
SWSPYXXXC	Postmining water bodies and drainage boundaries

INFO FILE NAMES

SWSPTXXXA.PAT	Labels the well or monitoring station
SWSPTXXXA.WELL-CONSTRUCTION	Has some well construction data
SWSPTXXXA.WELL-WQ	Water quality information from monitoring wells
SWSPTXXXA.SURFACE-WQ	Water quality data from surface water sampling
SWSLNXXXB.AAT	Has some information about ditches
SWSPYXXXB.PAT	Has some information about the ponds used during mining

Information is gathered from any map that has the information we needed.

ARC Coverages

A. Point Coverage

SWSPTXXXA (Where XXX is the mine permit number)

Additional INFO items:

POINT# - Saves the -ID number

COLOR - Used for plotting

69	Surface monitoring points including NPDES
49	Ground water monitoring points including NPDES
5	Private well
13	Public well
37	USGS water quality station
25	USGS STREAM GAGING STATION

21 Well of unknown ownership
17 Others (such as hydrologic modeling points, etc.)

CODE

1 Surface monitoring points including NPDES
2 Ground water monitoring points including NPDES
3 Private well
4 Public well
5 USGS water quality station
7 Well of unknown ownership
6 USGS stream gaging station
99 Others (such as hydrologic modeling points, etc.)

ID# - The ID# as listed in the permit documentation

B. Line Coverages:

SWSLNXXXA This coverage is based on premining water information.

Additional INFO items:

LINE# - Saves the -ID number

COLOR - Used for plotting

6 Perennial streams
26 Intermittent streams
70 Overland flow (natural)
49 Permanent diversion ditch
42 Unclassified streams
78 Others

CODE

1 Perennial streams
2 Intermittent streams
3 Overland flow (natural)
4 Permanent diversion ditch
5 Unclassified Streams
99 Others (premining)

SWSLNXXXB This coverage is based on the mine operation map.

Additional INFO items:

LINE# - Saves the -ID number

COLOR - Used for plotting

72 Water line
12 Named diversion ditch
64 Slurry discharge line
16 Levee or dyke
33 Unnamed diversion ditch
73 Outflow ditch
6 Perennial streams
26 Intermittent streams
42 Unclassified streams
60 Others

CODE

1 Water line
2 Named diversion ditch
3 Slurry discharge line
4 Levee or dyke
5 Overland flow
6 Outflow ditch
7 Perennial streams
8 Intermittent streams
9 Unclassified streams
99 Others (mine operation)

ID# - ID# or name listed in permit documentation
Drainage-area
SCS-curve#
Rainfall-25 yr-24 hr
Rainfall-2 yr-24 hr
Peak-discharge
Manning-n
Channel-slope

SWSLNXXXC This coverage is based on postmining information.

Additional INFO items:

POLYGON# Saves the -ID number

COLOR - Used for plotting

49 Ditches (permanent)
42 Unclassified streams

CODE

4 Ditches (permanent)
5 Unclassified streams

C. Polygon Coverages

SWSPYXXXA This coverage is based on premining surface and ground water information.

Additional INFO items

POLYGON# - Saves the -ID number

COLOR - USED FOR PLOTTING

22 Lakes and reservoirs
34 Ponds
0 Watershed boundaries
0 Other

CODE

1 Lakes and reservoirs
2 Ponds
3 Watershed boundaries
99 Other

SWSPYXXXB This coverage is based on the mine operation map.

Additional INFO items:

POLYGON# - Saves the -ID number

COLOR - Used for plotting

70 Sediment pond
10 Fresh water pond
23 Holding pond
36 Slurry pond
73 Levee
0 Watershed boundary
13 Subsoil storage
94 Unspecified pond
45 Others

CODE

1 Sediment pond
2 Fresh water pond
3 Holding pond
4 Slurry pond
5 Levee
6 Watershed boundary

```
  7   Subsoil storage
  8   Unclassified pond
 99   Others (gob piles, etc.)
ID# - ID# or name listed in permit documentation
Drainage-area
Runoff-10 yr-24 hr
Sediment-s-vol
Pond-design-vol
Pond-surface-area
```

```
SWSPYXXXC   This coverage is based on postmining information
   Additional INFO items
     POLYGON# - Saves the -ID number
     COLOR - Used for plotting
      22   Lakes and reservoirs
       0    Watershed boundaries
     CODE
       1   Watershed boundary
           (additonal codes may be added)
      99   Others
```

Names and Associated Legends

1. Plots used to check the accuracy of each coverage that is listed above
    A. Each coverage has an associated CPL file used to plot it and an associated legend
    B. Naming convention:
        Cover name: SWSPTXXXA (where XXX is the permit number)
        CPL file used to plot it: SWSPTXXXA.CPL
        Associated legend: SWSPTXXXA.LEGEND
        continues in the same way for the other files listed above
    C. These are generic CPL files that were run on all permits; to use them in batch, type:

```
JOB SWSPTXXXA -QUE GENERAL -ARGS 179 4800
    (Where 179 is the permit number and 4800 is desired
     map scale)
```

        To use them on your terminal, type

```
R SWSPTXXXA 179,4800
```

2. Final plots
    A. There are three final plots:
        PLOTPRE-MINING.CPL - has streams and water bodies digitized from the 24,000 scale topo maps
        PLOTMINING-OP.CPL - Has all hydrology associated with the mining operation: ditches, ponds, stream diversions, etc.
        PLOTPOST-MINING.CPL - Has final location of streams and water-bodies after the mining is finished

    The following two plots show the way this was done originally. They are kept here for documentation (P179, P163, P165).
        #PLOTXXXPERMIT is primarily concerned with the permit area;
        #PLOTXXXPERMITALL contains most of the information that was digitized. It comprises a larger area than #PLOTXXXPERMIT and contains all the streams and points that were digitized. This has the standard nine-section boundary plotted on it as a point of reference.

Both final plots use the same legends:
- LINEHYDRO.LEGEND
- POLYHYDRO.LEGEND
- WELL.LEGEND
- MONITORING.LEGEND
- PIPELINES.LEGEND

INFO Files

In addition to the .AAT AND .PAT above, which contain tabular data, the following INFO files are being created:
- SWSPTXXXA.SURFACE-WQ (WATER QUALITY)
- SWSPTXXXA.WELL-WQ (WATER QUALITY)
- SWSPTXXXA.WELL-CONSTRUCTION

The INFO description for each of the five data files is listed below:

Explanation of the comment field used in SWSPTXXXA.WELL-WQ AND SWSPTXXXA.SURFACE-WQ

- > greater than
- < less than
- A average value
- H high (of a range)
- L low (of a range)
- M missing, not in documentation
- Z zero is the data value
- 1 minimum (when summaries of data were given)
- 2 average (when summaries of data were given)
- 3 maximum (when summaries of data were given)
- 4 well just drilled - no data

Datafile name: SWSPTXXXA.SURFACE-WQ
44 items: starting in position 1

Col	Item name	WDTH	OPUT	TYP	N.DEC
1	POINT#-COMMENT	1	1	C	-
2	POINT#	8	6	I	-
10	ID#-COMMENT	1	1	C	-
11	ID#	20	20	C	-
31	DATE-C-COMMENT	1	1	C	-
32	DATE-COLLECT	6	6	C	-
38	DATE-A-COMMENT	1	1	C	-
39	DATE-ANALYZE	6	6	C	-
45	PH-COMMENT	1	1	C	-
46	PH-VALUE	10	10	N	3
56	ALK-COMMENT	1	1	C	-
57	ALKALINITY	10	10	N	3
67	ACID-COMMENT	1	1	C	-
68	ACIDITY	10	10	N	3
78	TDS-COMMENT	1	1	C	-
79	TOTAL-DIS-SOLIDS	10	10	N	3
89	HARD-COMMENT	1	1	C	-
90	HARDNESS	10	10	N	3
100	SO4-COMMENT	1	1	C	-
101	SULFATE	10	10	N	3
111	FE-COMMENT	1	1	C	-
112	IRON	10	10	N	3
122	MN-COMMENT	1	1	C	-
123	MANGANESE	10	10	N	3
133	NA-COMMENT	1	1	C	-
134	SODIUM	10	10	N	3
144	CL-COMMENT	1	1	C	-
145	CHLORIDE	10	10	N	3
155	PB-COMMENT	1	1	C	-
156	LEAD	10	10	N	3
166	TSS-COMMENT	1	1	C	-
167	SUSPENDED-SOLIDS	10	10	N	3

177	F-COMMENT	1	1	C	-
178	FLUORIDE	10	10	N	3
188	ZN-COMMENT	1	1	C	-
189	ZINC	10	10	N	3
199	SC-COMMENT	1	1	C	-
200	SPECIFIC-CONDUCT	10	10	N	3
210	NO3-COMMENT	1	1	C	-
211	NITRATE	10	10	N	3
221	MG-COMMENT	1	1	C	-
222	MAGNESIUM	10	10	N	3
232	CA-COMMENT	1	1	C	-
233	CALCIUM	10	10	N	3
	** REDEFINED ITEMS **				
32	MONTH	2	2	I	-
34	DAY	2	2	I	-
36	YEAR	2	2	I	-
1	POINT-NUMBER	9	9	C	-
10	ID-NUMBER	21	21	C	-
31	DATE-C	7	7	C	-
38	DATE-A	7	7	C	-
45	PH	11	11	C	-
56	ALK	11	11	C	-
67	ACID	11	11	C	-
78	TDS	11	11	C	-
89	HARD	11	11	C	-
100	SO4	11	11	C	-
111	FE	11	11	C	-
122	MN	11	11	C	-
133	NA	11	11	C	-
144	CL	11	11	C	-
155	PB	11	11	C	-
166	TSS	11	11	C	-
177	F	11	11	C	-
188	ZN	11	11	C	-
199	SC	11	11	C	-
210	NO3	11	11	C	-
221	MG	11	11	C	-
232	CA	11	11	C	-

Datafile name: SWSPTXXXA.WELL-WQ

48 items: starting in position 1

Col	Item name	WDTH	OPUT	TYP	N.DEC
1	POINT#-COMMENT	1	1	C	-
2	POINT#	8	6	I	-
10	ID#-COMMENT	1	1	C	-
11	ID#	20	20	C	-
31	DATE-C-COMMENT	1	1	C	-
32	DATE-COLLECT	6	6	C	-
38	DATE-A-COMMENT	1	1	C	-
39	DATE-ANALYZE	6	6	C	-
45	WL-COMMENT	1	1	C	-
46	WATER-LEVEL	10	10	N	3
56	CA-COMMENT	1	1	C	-
57	CALCIUM	10	10	N	3
67	FE-COMMENT	1	1	C	-
68	IRON	10	10	N	3
78	MG-COMMENT	1	1	C	-
79	MAGNESIUM	10	10	N	3
89	MN-COMMENT	1	1	C	-
90	MANGANESE	10	10	N	3
100	NA-COMMENT	1	1	C	-
101	SODIUM	10	10	N	3
111	ZN-COMMENT	1	1	C	-
112	ZINC	10	10	N	3
122	CL-COMMENT	1	1	C	-
123	CHLORIDE	10	10	N	3
133	F-COMMENT	1	1	C	-
134	FLUORIDE	10	10	N	3
144	NO3-COMMENT	1	1	C	-
145	NITRATE	10	10	N	3

```
  155  SO4-COMMENT          1    1  C    -
  156  SULFATE             10   10  N    3
  166  ACID-COMMENT         1    1  C    -
  167  ACIDITY             10   10  N    3
  177  ALK-COMMENT          1    1  C    -
  178  ALKALINITY          10   10  N    3
  188  TH-COMMENT           1    1  C    -
  189  TOTAL-HARDNESS      10   10  N    3
  199  TDS-COMMENT          1    1  C    -
  200  TOTAL-DIS-SOLIDS    10   10  N    3
  210  GAL-COMMENT          1    1  C    -
  211  GAL-PUMPED-BEFOR    10   10  N    3
  221  SC-COMMENT           1    1  C    -
  222  SPECIFIC-CONDUCT    10   10  N    3
  232  PH-COMMENT           1    1  C    -
  233  PH-VALUE            10   10  N    3
  243  TEMP-C-COMMENT       1    1  C    -
  244  TEMPERATURE-C       10   10  N    3
  254  TEMP-F-COMMENT       1    1  C    -
  255  TEMPERATURE-F       10   10  N    3
     **  REDEFINED ITEMS  **
   32  MONTH                2    2  I    -
   34  DAY                  2    2  I    -
   36  YEAR                 2    2  I    -
   10  ID-NUMBER           21   21  C    -
   31  DATE-C               7    7  C    -
   38  DATE-A               7    7  C    -
   45  WL                  11   11  C    -
   56  CA                  11   11  C    -
   67  FE                  11   11  C    -
   78  MG                  11   11  C    -
   89  MN                  11   11  C    -
  100  NA                  11   11  C    -
  111  ZN                  11   11  C    -
  122  CL                  11   11  C    -
  133  F                   11   11  C    -
  144  NO3                 11   11  C    -
  155  SO4                 11   11  C    -
  166  ACID                11   11  C    -
  177  ALK                 11   11  C    -
  188  TH                  11   11  C    -
  199  TDS                 11   11  C    -
  210  GAL                 11   11  C    -
  221  SC                  11   11  C    -
  232  PH                  11   11  C    -
  243  TEMP-C              11   11  C    -
  254  TEMP-F              11   11  C    -

Datafile name: SWSPTXXXA.WELL-CONSTRUCTION
    7 items: starting in position    1
  Col  Item name          WDTH OPUT TYP N.DEC
    1  POINT#               9    6  I    -
   10  ID#                 20   20  C    -
   30  ELEVATION-FT        10   10  N    3
   40  STATIC-H2O-EL-FT    10   10  N    3  # FT BELOW THE
"ELEVATION-FT"
   50  ANNULUS-DIA-INCH    10   10  N    3
   60  OPEN-INTERVAL-FT    10   10  N    3
   70  CASING-MATERIAL     80   80  C    -

Datafile name: SWSLNXXXB.AAT  (DITCHES)
   18 items: starting in position    1
  Col  Item name          WDTH OPUT TYP N.DEC
    1  FNODE#               4    5  B    -
    5  TNODE#               4    5  B    -
    9  LPOLY#               4    5  B    -
   13  RPOLY#               4    5  B    -
   17  LENGTH               4   12  F    3
   21  SWSLNXXXB#           4    5  B    -
   25  SWSLNXXXB-ID         4    6  B    -
```

29	LINE#	9	6	I	-	
38	COLOR	2	2	I	-	
40	CODE	2	2	I	-	
42	ID#	20	10	C	-	
62	DRAINAGE-AREA	10	10	N	3	(ACRES)
72	SCS-CURVE#	10	10	N	3	
82	RAIN-25YR-24HR	10	10	N	3	(INCHES)
92	RAIN-2YR-24HR	10	10	N	3	(INCHES)
102	PEAK-DISCHARGE	10	10	N	3	
112	MANNING-N	10	10	N	4	
122	CHANNEL-SLOPE	10	10	N	4	
	** REDEFINED ITEMS **					
25	X	4	5	B	-	

Datafile name: SWSPYXXXB.PAT (PONDS)
13 items: starting in position 1

Col	Item name	WDTH	OPUT	TYP	N.DEC	
1	AREA	4	12	F	3	
5	PERIMETER	4	12	F	3	
9	SWSPYXXXB#	4	5	B	-	
13	SWSPYXXXB-ID	4	5	B	-	
17	POLYGON#	9	6	I	-	
26	COLOR	2	2	I	-	
28	CODE	2	2	I	-	
30	ID#	20	10	C	-	
50	DRAINAGE-AREA	10	10	N	3	(ACRES)
60	RUNOFF-10YR-24HR	10	10	N	3	(AC-FT)
70	SEDIMENT-S-VOL	10	10	N	3	(AC-FT)
80	POND-DESIGN-VOL	10	10	N	3	(AC-FT)
90	POND-SURFACEAREA	10	10	N	3	(ACRES

CONCLUSIONS

The MPRP has been a learning experience for all those involved, especially the author. The Department of Mines and Minerals staff has been an excellent group of individuals to work with in respect to integrating the ARC/INFO Geographic Information System into the MPRP. Much time and effort was spent in developing the policies and procedure necessary to maintain good quality control within the program. This is an important issue within the contributing divisions. Serious work needs to be done within the program to improve the the efficiency of processing the permits. The non-uniformity of documentation with the mine permits causes the GIS effort to be hampered. The fact that the mine permit information is in a machine readable graphic data base is in itself very important to the future of the MPRP. The ability to retrieve, display, and analyze geographical data and information is the approach that scientists, engineers, and administrators are looking for.

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NATIONAL RESOURCES INVENTORIES FOR ECONOMIC DEVELOPMENT

Richard Dworsky[1]

ABSTRACT: Increase in the flow of natural resources information may serve as a predictor of economic growth. If this hypothesis is true then what steps need to be taken on the acquisition of knowledge and information? This paper briefly looks at the past and present efforts toward gathering data on a national scale and some effects and options toward interpreting this data.

INTRODUCTION

There have been periodic, often somewhat uncoordinated efforts to address the concept of National inventories. These efforts do point out, however, a recognized institutional demand for information and data for national and regional decision making. This paper will briefly focus on past efforts to conduct national inventories and recommend some alternative strategies for dealing with the future.

1776-1950

One of the first efforts to inventory natural resources resulted from Jefferson's purchase of the Louisiana territory (Devoto, 1953). While this purchase extended the geographic limits of the nation immensely, the technological, political and social consequences following the act of purchase were of nearly equal importance to the evolving nation. The basic premise of the Lewis and Clark Expedition, "to learn," was a reflection of Jefferson's own world outlook. Knowledge was the power he sought in order to subdue the new territory, knowing that such knowledge was necessary before the land would be opened.

Seeking such knowledge by the application of the best practical science became a forerunner of a national effort that lasted through much of the 19th century. An early benchmark was the establishment of the Topographical Engineers, an offshoot of the Corps of Engineers, who traced much of the land. The States were active in the initial establishment of Geological Surveys to catalogue all facets of state resources. By the 1830s, sixteen states established such agencies; by 1860, thirty had been established (Hynnings, 1939). Thus Jefferson's expedition defined the nation's needs to know more about itself.

During the 1800s, roads, canals, and river and harbor improvements created controversy that beset Congress, the President and the nation. Not

1 Special Assistant to the State Director, Bureau of Land Management, 701 C St., Box 13, Anchorage, Alaska 99513.

withstanding the debate over the constitutional question of Federal/State responsibility, the resolution of the internal improvements debate finally turned on the degree and extent of the problem affecting the people and the development of a wide section of the country. (Walker, 1981).

For example, in 1845 Calhoun advanced the idea that navigation and flood control on the Mississippi River were of Federal interest. By 1879 the Congress established the Mississippi River Commission to provide centralized coordination of the engineering operations to control lower valley floods. In part, the Commission was a result of the Humpheries and Abbot report of 1861 (Smith, 1971), which related to scientific principles that indicated the flood control problems in the lower Mississippi were beyond that ability of local interests. The nature of the report removed the debate from one of constitutional construction over responsibilities to a review of who could competently finance and manage the specific tasks to control the river.

The new and most important element that forced the Federal government to a stronger position in the west came about as a result of what Wallace Stegner (1954) has called "The Second Opening of the West." The key that was to ultimately define the allocation of responsibility - the sharing of authority - of the waters, lands and forests of the west was the understanding of the scientific basis in which man and domesticated animals could live. Between 1867 and 1879, four surveys of the west were conducted culminating in the report of Major John Wesley Powell. Powell divided the land and the area west of the 100th meridian or where there was approximately twenty inches of rainfall needed for successful agriculture into three classes: (1) irrigable lands; (2) forest land; and (3) pasture lands. Powell recognized that there was an important role for levels of government to assist in the management of the three classes.

The Federal government in 1897 authorized the War Department under the Rivers and Harbors Act of June 3, 1896, to survey the states of Wyoming and Colorado for reservoir sites. In 1897, Captain Hiram M. Chittenden made his report which underscored the need for a Federal role. Chittenden inquired as to the proper governmental level at which to construct reservoirs. He believed it was beyond the abilities of individuals. Corporations would make water private property and this could result in general utilization. Irrigation districts were not comprehensive and did not have the necessary resources. So, he favored the nation over the states, stating that: "Irrigation is interstate in character, and therefore a national problem. Water and forests are directly related; forest control belongs to the national government; therefore water control should also belong to it. Public opinion in the West favors government aid in the construction of reservoirs. The national government is the only agency that could construct a unified system of reservoirs for the entire region; it is the largest landholder in the West; and it alone has means sufficient to carry out the plan" (Webb, 1931).

Although Chittenden focused on the construction portion of irrigation, it appears to be implicit that knowledge of the resource base was co-equal in his ideas.

As the 20th century opened, a most noticeable change was a mounting public awareness of government's ability to aid significantly in finding solutions to social and economic problems. This awareness, made the first decade of the new century a useful point of departure for programs affecting water and related land resources, which today are still evolving.

The state was supported by the strengthening of the technical services in government such as a Geological Survey, a Biological Survey and a Forestry Branch in the Geological Survey. Information, and more importantly, a cadre of trained scientists followed in the footsteps of Powell, Chittenden, and others, by applying an understanding of the workings of nature and the environment, in the formulation of a considered policy.

Theodore Roosevelt brought this perspective into national political life in his first message to the Congress; Roosevelt stressed his conservation views, and in 1903 he appointed a commission to study the remaining public lands. In his seven years of office he added almost 150 million acres to the forest reserve and through Gifford Pinchot, the nation's chief forester, managed to reserve over twenty-five hundred power sites, in spite of Congressional opposition, by declaring them ranger stations (Dana, 1956).

The years 1907 and 1908 climaxed the efforts of the President. The winter of 1907 produced the philosophical statement of the conservation idea of wise use determined by economic, social, aesthetic and moral considerations (Dana, 1956). The goal was "the greatest good for the greatest number for the longest time." A strong statement was made to the Congress concerning the waste of natural resources. He appointed an Inland Waterways Commission. In early 1907 the idea of the Governor's Conference surfaced and the date of the Conference was set for May 1908 (USDA, 1972).

At the Conference President Roosevelt synthesized into a whole the individual tasks associated with water resources development. To navigation, he added the control of floods; for the west, he considered the problems of irrigation water in its relation to land, forests and settlers' homes. He brought the new knowledge of hydroelectric power into focus as a national resource and a national responsibility. To efforts to stem the raging water-borne epidemics of the period and early studies of the United States Public Health Service, he added his concern for water pollution and water purification. He gave new life to the nearly outmoded inland waterways by visualizing a network throughout the Mississippi heartland, along the coasts and on the Columbia (Dworsky, 1986). Taking all these into account, he charged the Inland Waterways Commission in March 1907 "to prepare a comprehensive plan for the coordinated use of the water resources of the country," which would take into consideration "the use relations of the streams to the use of all the great permanent natural resources and their conservation for the making and maintenance of prosperous homes" (Dana, 1956).

The Commission report in February of 1908 laid out the modern premise that every river system should be treated as a unit from its source to its mouth. It also laid the basis for including, in any plans established for navigation of inland waters for interstate commerce, the consideration of pollution control, floods, power, irrigation, drainage and all other uses and benefits to be derived from their control.

The Commission report renewed the Federal role in the federalist system.

Local interests, the Commission said, should be considered in relation to regional and national interests. This justified a storage facility high on the Missouri or Monogahela for benefit of flood control on the lower Mississippi. The value of this Commission lay in the identification of a political, environmental, and natural resource agenda that would be utilized for the next seventy-five years.

The Governors' Conference of 1908, called by Roosevelt to stimulate thinking as regards the nations resources, included among its recommendations: (1) that the President call future similar conferences to insure continued cooperation between the states and the Federal government; (2) that state commissions be formed to cooperate with a similar Federal commission to inventory and appraise the condition of the nation's resources, (3) that laws looking to conservation of water resources for irrigation, water supply, power and navigation be enacted.

An interesting conclusion of the congressionally created 1909 National Waterways Commission touched upon that which Chief Justice Marshall had partly settled some 86 years before: that Federal activities should be limited to the control and promotion of navigation; that the Federal government had no constitutional authority to engage in works intended primarily for flood control or power; and that any flood prevention work should only be undertaken if associated with navigation. At the same time the Commission held that the Supreme Court had clearly established Federal authority over navigable waters. "...the authority of Congress reaches to the remotest sources in the mountains of every navigable stream. There should be no misunderstanding as to the extent of the authority of Congress to exercise its full powers. With the increasing unity of our national life and the growing necessity of securing for human needs the maximum beneficial use of the waters of every stream, it will become increasingly necessary to treat every stream with all its tributaries as a unit." In the nature of the case so comprehensive a policy could be successfully administered only by the Federal government, and consequently the eventual desirability of Federal control is easy to predict (Dana 1956). The commission pointed out that by withdrawing water power sites and by rules over public lands the government had already taken steps to control the development of water power. Provisions for protection and utilization of hydropower sites were formalized in the Federal Power Act of 1920. In passing this act Congress repealed the 1917 act establishing a Waterways Commission. This Commission had been given the authority sought by conservation supporters which provided for coordination of all interests in government, investigations were to consider all water uses and the commission was to formulate a comprehensive plan for the development of waterways and water resources.

The report of the National Conservation Commission (1909) was the first inventory of natural resources and was found, "undoubtedly a beginning of a service which will be indispensable for dealing intelligently with what we have.... The progress of our knowledge of this country will continually lead to more accurate information and better use of the sources for national strength."

The Commission dealt with resources as a whole and concluded the following recommendations as a result of the inventory.

- Water can and should serve our people
- Conserve minerals, timber
- Promote land development in public land policy

- In forest policy - emphasize public good rather than temporary private gain
- Strengthen the Inland Waterways Commission
- Forest - focus on fire control and tax change
- Mineral - use increasing faster than population - need better data

In 1927 the Congress authorized the Corps of Engineers to prepare general plans for the prosecution of ...navigation improvements... power, flood control and irrigation. The plans were known as 308 reports (Agriculture, 1972).

What is clear is that the National and State governments were identifying the basic resource data to make public investment decisions and policy strategies. From the mineral side, acts like the Mining Act of 1872 and the Mineral Leasing Act of 1920 allowed private developers access to public resources for economic development and expansion.

1950-1985

Several major national inventories have taken place since 1950. In 1950, the President's Water Resources Policy Commission undertook a comprehensive study and review of federal responsibility in the: "development, utilization and conservation of water resources, including related land use and other public purposes to the extent that they are directly concerned with water resources (Cooke, 1950)."

The President's Material Policy Commission (1952) recommended: (1) speeding up of fact gathering and analysis by the Bureau of Mines, (2) acceleration of topographic and geologic mapping, (3) revamping of the entire mining claims and lease systems to eliminate opportunities for fraud.

In 1963, the organization Resources for the Future published Resources in America's Future, which asks the question: Can the United States over the balance of the twentieth century count on enough natural resource supplies to sustain a sufficient rate of economic growth?

The conclusion was - despite great and continuing gain in knowledge of how to locate and utilize natural resources, and the diminishing share of resource extraction - modern man must work within the limits of earth's natural environment. Even so, the report goes on to say natural resources are of a basic and continuing importance to natural economic growth and industrial well being. The recommendations include a few broad lines of action including (1) maintaining the flow of new and improved resource technologies in discovery and use of natural resources and (2) conservation and use of resources in accordance with sound ecological and economic principles (Lansberg, 1963).

Several other water resource studies were a result of the Water Resource Planning Act (Public Law 89-80) which directed the U.S. Water Resource Council to maintain a continuing study of the Nation's water and related land resources and to prepare periodic assessments to determine the adequacy of the resources to meet present and future water requirements. In 1968 and again in 1978, the Council published National Water Assessments.

Other studies and laws focused on reorganization of the Federal establishment to streamline public sector management in natural resources and address emergency land and water issues.

In 1960, Bain identified some effects of public resource policies that suggest national data bases are needed for national economic and political objectives. These may still be valuable today.

1. Resource policies involve interference with private enterprise competitors in extractive industries.

2. Resource policies embody subsidization of extractive enterprises or industries.

3. Resource policies impose restriction on private exploration of public resources and

4. Resource policies feature public investment in projects for natural resource development.

The ideas, then, of cooperation between and among private and public resource users have apparently been translated into the way we share information and make investment decisions. It is clear that the question of information on resources, data management strategies, and long term public commitments to data and inventories have been a focus of the historical development of the United States.

In reviewing how the various sectors have interacted in developing national natural resource inventories, major boards have been established and reorganization efforts attempted. These include:

- The National Resource Committee of 1935 and the National Resource Planning Board of 1939 with a program of collection and preparation of plans, data, and information that would be helpful to a planned development and use of national resources and land.

- The Public Land Law Review Commission (1964) focused on retention of public lands and emphasis on long range planning so that the best use of public land could be made.

- Reorganization efforts like the Hoover Commission (1955) and the Ash Commission (1977) also focused on ways to improve service and streamline government.

Clearly, the nation has focused its efforts on ways to develop better data in national inventories. What might be some of the directions available to the public to assist in natural resource data which will serve to improve information to predict national growth?

Several opportunities stand out as ways to improve our data and inventory collection to assist in informed decision making.

1. With computerized data bases, the federal and state governments should identify non-proprietary data bases for decision making.

2. Forecasting and futuring should identify possible paths for need and development of natural resources.

3. The federal establishment should reorganize into a department of natural resources to collect and manage resources, or, if the political atmosphere will not allow this option - strengthen the data collection agencies role in date coordination of all resource data.

4. The data using agencies need to clearly identify the use to which data collection efforts are directed. This includes both political and economic data needs.

5. Investigate the regional concept role of natural resources data and management to assist in interstate efforts.

6. Lastly, the Federal and State and private sector need a clearing house mechanism to improve the flow of information on natural resources, to predict the future natural resource data opportunities, and to the extent practical, share information about technology.

CONCLUSION

The purpose of national resources inventories for economic development is to provide a systematic and disciplined way to estimate the supply of and demands for land and its various uses - agriculture, timber, minerals, energy, recreation development, etc. This is one part of the equation and as history has shown has been somewhat effective or at least caught the attention of decision makers. The second part of the equation is a focusing of rapidly changing technology on the supply and demands for resources. This includes basic research in the physical, biological and social sciences as well as an understanding of international trade and raw material development in other countries. It would appear that some directed programs in resource inventories and utilization would be appropriate to continue improvement in our standard of living. This paper has briefly identified some of the historical efforts to assess - for one purpose or another - the data on natural resources. Initially the focus of inventory was to assist in the economic development of the country. As we move into a more steady state of resource use the country appears to need a greater ability to predict resource opportunities and shortfalls. The paper concludes with some modest suggestions for improving national inventories and data collection which may assist in economic development.

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WATER RESOURCES RELATED TO MINING AND ENERGY – PREPARING FOR THE FUTURE
NOVEMBER AMERICAN WATER RESOURCES ASSOCIATION 1987

IDENTIFYING EMERGING WATER ISSUES FOR ELECTRIC UTILITIES

B.F. Hobbs[1]

ABSTRACT: Water issues -- acid rain, thermal pollution, supply shortages, and instream flow requirements, among others -- have greatly affected the planning and operation of electric utilities in the past twenty years. Many of these issues went unanticipated by the industry. As a result, research and planning for efficient and effective correction of these problems was delayed, and the adaptation to new regulatory environments was unnecessarily costly and painful. Identifying emerging water issues is crucial for electric utilities, in general, and the Electric Power Research Institute, in particular. Although prediction of new issues can never be an exact science, the techniques of "issues management" can help make planners more aware of the early warning signs of issues and their possible implications. An especially important input to the issues identification process is that of water professionals who are on the "front lines."
KEY TERMS: Issues identification, issues management, electric power, water supply, water quality, hydropower

INTRODUCTION

The Electric Power Research Institute (EPRI) is a private, non-profit research organization whose activities are funded by US electric utilities. EPRI has sponsored several studies of water supply and pollution issues involving electric utilities and has been responsible for the development of many advanced effluent control and water conservation technologies.

EPRI is keenly interested in maximizing the effectiveness of its research expenditures -- which means, among other things, identifying emerging problems early enough so that the research it sponsors can have the greatest impact. To help its research planning process, EPRI has contracted with Case Western Reserve University (CWRU) to use the techniques of "issues management" to identify emerging water issues which may affect the industry.

Garnering expert opinion will be the most important part of the CWRU water issues identification project. Knowledgable people from a variety of disciplines and organizations will be asked to participate in this process via small group meetings, telephone interviews, and questionnaires. These experts will be asked to speculate on what <u>possible</u> water-related issues <u>might</u> arise which <u>could</u> affect the industry and to describe <u>possible</u> scenarios of their development. They are not be asked to predict what <u>will</u> happen; the emphasis is only on identifying the <u>possible</u>. They will also be asked to identify other sources of information which could help EPRI identify emerging issues.

The purpose of this paper is to introduce potential participants to the issues identification process that will be used in the project. The next section gives an overview of issues identification. A following section summarizes issues that have been defined in previous EPRI studies. Finally, the process that will be used in the group meetings will be explained together with possible categories of issues which might be discussed.

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[1]Assistant Professor of Systems Engineering and Civil Engineering, Case Western Reserve University, 610 Crawford Hall, Cleveland, OH 44106

ISSUES AND ISSUES MANAGEMENT

An issue has been defined as a "condition ... that, if it continues, will have a significant effect on the functioning of the organization" (Brown, 1979). As examples, the rise of environmental and water related issues over the past two decades have dramatically affected electric utility industry capital investments and operation. Examples include competition for cooling water supplies, groundwater contamination, and acid rain.

Water-related issues are of various types:

- social	- technological
- political	- economic
- international	- scientific
- ecological	- biological

Such issues interface with electric utility planning and operation in at least five ways:

- by changing the amount and quality of water available for **cooling of thermal power plants**

- by changing **demands for electric power**, for example, through increased requirements for pumping power

- via **water-related hazards**, such as flooding

- by impacting **hydropower generation**, for instance, by decreasing runoff or through instream flow regulations

- through the environmental and health impacts of **residuals** generated by the industry, such as the water quality problems resulting from gaseous, liquid, and solid wastes.

Issues are constantly changing, with new issues rapidly replacing old ones. For example, an industry-wide task force report of the mid 1960's identified the aesthetics of above-ground distribution lines as the most important environmental issue facing utilities. Since then, that issue has been nearly forgotten. Clean air, thermal pollution, nuclear safety, water supply, acid rain, PCB's, power plant siting, and many other issues have supplanted distribution lines and then, in many cases, subsided in importance themselves.

But before disappearing from public view, many issues leave a legacy of changed design and operation practices. For instance, new power plants, with few exceptions, use costly closed-cycle cooling systems as a result of past concerns over thermal pollution of surface waters.

Issues often undergo a five step development process (Chemical Week, 1981):

"The informal stage. Only a small group cares about the matter.

"The formal stage. The issue elicits broad backing, some professionals become involved, and a plan is devised to publicize and advance the cause.

"The legislative stage. One or more bills may be introduced, debated, and rejected, or enacted into law.

"The regulatory stage. Bills are passed and an official or agency draws up detailed regulations and begins to enforce them.

"The program stage. Companies implement programs with the aim of effectively responding to regulations that will be enforced."

During an issue's early stages, three items may affect its evolution: the results of scientific research which shape public perceptions; trigger events which can dramatically bring an issue to the fore and confirm public worries; and issue groups which publicize the issue and lobby for institutional response (Edison Electric Institute, no date). Figure 1 presents a summary of how issues develop and what sources of information are available at each stage.

But issues are not easily anticipated. Said Charles Luce, retired Chairman of Consolidated Edison:

> "Anyone asked to prophesy where the electric utility industry is headed in the 1980's must approach the subject with humility. To understand the perils of prediction, he need only look back to 1970, ask himself where he would have predicted the utility industry was headed in the 1970's, and then reflect upon where it actually went" (Luce, 1983).

"Issues management" was born out of the need to tackle this difficult problem. It has been estimated that at least 150 major corporations have formal issue management operations (Chemical Week, 1981).

Issues management has been defined by the Edison Electric Institute (no date) as

> "the systematic gathering of intelligence about the future and application of that information to meet organizational goals."

Issues identification is the intelligence gathering portion of the process. It is <u>not</u> the precise prediction of what lies down the road, but rather the alerting of the organization to the probability or even just possibility of what issues might arise.

The issues manager applies a variety of methods in trying to anticipate issues. Together, these methods cover the three items just mentioned which lead to issue emergence: research, trigger events, and issues groups. Issue identification methods include (Halal, 1984):

- obtaining expert opinion via interviews, Delphi-type questionnaires, or in workshops;
- surveying the scientific literature;
- scanning publications of activist groups;
- extrapolation of social and economic trends;
- modeling of social and economic phenomena;
- scenario generation;
- public opinion polls; and
- observation of trends in government regulation.

In any issues management study, several of these methods should be applied to garner the widest possible input. The result may be a list of hundreds of issues from which a few will be culled and highlighted. It is important to remain open-minded throughout this process and to "cast the net" as wide as possible, as (unfortunately) there have been more failures than successes in issues management (Chemical Week, 1981).

SUMMARY OF PAST WATER ISSUES AND RESEARCH TOPICS IDENTIFIED BY EPRI

EPRI has already used several of these approaches to examine water issues. For instance, EPRI has held two workshops on Water Supply for Electric Energy (Linsley, Kraeger Asso., 1980, 1983) and has sponsored modeling studies of future water availability for utilities (Hobbs et al., 1984; Buras, 1982).

VISIONARY UNHIBITED	-ARTISTIC, POETIC WORKS
	-SCIENCE FICTION
RENDERING IDEA TO SPECIFICS	-FRINGE MEDIA, UNDERGROUND PRESS
	-UNPUBLISHED NOTES AND SPEECHES
	-MONOGRAPHS, TREATISES
COLLABORATION OF DETAILS	-SCIENTIFIC, TECHNICAL, PROFESSIONAL JOURNALS
	-HIGHLY SPECIALIZED, NARROW-VIEWPOINT JOURNALS
	-STATISTICAL DOCUMENTS (SOCIAL INDICATORS, STATISTICAL SERVICES)
	-ABSTRACTING SERVICES, JOURNALS
DIFFUSION OF AN IDEA AMONG OPINION	-DATASEARCH COMPOSITES
	-EGGHEAD JOURNALS (e.g. SCIENCE, SCIENTIFIC AMERICAN)
	-INSIDER "DOPESHEETS" (e.g., PRODUCT SAFETY LETTER)
INSTITUTIONAL RESPONSE	-POPULAR INTELLECTUAL MAGAZINES (e.g., HARPERS)
	-NETWORK COMMUNICATIONS (BULLETINS, NEWSLETTERS)
MASS MEDIA	-JOURNALS FOR THE CAUSE (e.g., CONSUMER REPORTS)
	-GENERAL INTEREST PUBLICATIONS (e.g., TIME, NEWSWEEK)
	-CONDENSATION OF GENERAL LITERATURE (e.g., READER'S DIGEST)
POLITICIZING THE ISSUE	-POLL DATA, PUBLIC OPINION, BEHAVIORAL AND VOTER ATTITUDES
	-LEGISLATIVE/GOVERNMENTAL SERVICES, REPORTS
INSTANTANEOUS COVERAGE FOR MASS CONSUMPTION	-BOOKS
	-FICTION -- NOVELS PROVIDE SOCIAL ANALYSES OF THE TIMES
	-NON-FICTION -- PULL TOGETHER DISCORDANT PARTS INTO EASILY UNDERSTOOD WHOLE
	-NEWSPAPERS (NEW YORK TIMES & WASHINGTON POST EARLY, SOUTHERN RURAL PAPERS LATE COMMENTATORS)
	-RADIO & TELEVISION (NETWORKS COMMENT EARLIER THAN LOCAL STATIONS)
EDUCATING THE PEOPLE TO THE NEW NORM	-EDUCATION JOURNALS
HISTORICAL ANALYSIS	-HISTORICAL ANALYSES
	-TRADITIONAL DOCTORAL THESES

Figure 1. Evolution of Issues and Sources for Identifying Issues (Source: Coates et al., 1986)

In Linsley, Kraeger Associates (1980, 1983), water research priorities for EPRI were recommended by two workshops. Among the priorities and issues identified were:

- alternate sources of cooling water, including consideration of legal constraints, disposal problems, and use impacts
- improved definition of instream water requirements
- public participation
- water for slurry pipelines
- strategies for coping with drought
- socioeconomic and legal basis for resource allocation
- multiple use of power reservoirs
- environmental/hydroelectric conflicts
- water conservation methods in agriculture
- estimates of water requirements for cooling with consideration of risk
- public acceptance of utility plans and perception of catastrophic events
- water use in 'hard' and 'soft' path technologies

THE CWRU-EPRI WATER ISSUES IDENTIFICATION PROJECT

In this project, water issues which might impact the industry are being identified and reviewed using the following set of issue management methods:

- review of the scientific, professional, and interest group literature;

- questionnaires and phone interviews with planners, researchers, and activists;

- summarization of trends in social attitudes regarding water issues, as reflected in buying habits and previously conducted public opinion polls;

- summary of trends in legislation and regulations;

- scenario generation, in which plausible, although not necessarily probable descriptions of how future issues may develop and affect the electric utility industry are created; and

- workshops at conferences of water professionals. The Nominal Group Process (Voelker, 1975) will be used to structure the discussion.

Crucial to the success of the project is consultation with water professionals. Via small groups, interviews, and questionnaires, water resources experts from a variety of backgrounds will be asked to answer the following questions:

1. What are the trends in each of the following areas which might result in the development of new water issues?

2. What might those issues be?

3. How they might those issues develop and affect the operation and planning of electric power systems? (This last step is sometimes called "Scenario Building".) Participants will be asked to be specific, relating each issue to one or more of the interfaces of water and power:

   - cooling water for thermal power plants
   - demands for electric power resulting from water management
   - water-related hazards to power facilities and operations
   - hydropower
   - water quality problems posed by the residuals of power generation

Participants will be encouraged to speculate and let their imaginations "run wild"; consider, for example, how difficult it would have otherwise been to have sat in 1970 and imagined the future rise of the acid rain issue!

The small group sessions will be run as structured "nominal groups" or "round robins". Each person, in turn, is asked to respond, in writing, to the same question and to generate ideas. The ideas are then written on a flip chart. Only then are the ideas discussed and evaluated. The discussion is conducted in round-robin fashion, each person getting their turn. If appropriate, each idea is then evaluated silently and in writing by a point system, the results displayed, and another round of discussion initiated. This would be done for each of the three questions just posed.

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ARCTIC WATER AVAILABILITY: Data Bases to Meet Present and Future Needs

Jack C. Mellor[1]

ABSTRACT: Surface water appears to be abundant on the Alaskan Arctic Coastal Plain during summer months. During the winter, however, the majority of this water turns to ice in the myriad of shallow coastal plain lakes. Rivers also freeze to the bottom except in isolated deep pools. The challenge is to find sufficient late-winter water to meet development needs while assuring a minimum of environmental conflicts with overwintering fishery resources.

Environmental assessment of proposed water sources near past oil and gas exploratory wells has been expensive. Summer field examination was necessary since data was either lacking or inaccessible for arctic lakes and rivers. This paper discusses new regional data bases, such as The Beaufort Sea Fisheries Synthesis and regional inventories of river channel depths, lake depths, and subsistence uses. These data bases should enable more timely, accurate and cost-efficient environmental assessments. Lake and river depth data are helping those who need water to find adequate sources that have the least potential for conflicts with fisheries.

INTRODUCTION

The contrast between summer and winter landscapes on the Arctic Coastal Plain is dramatic. The landscape in the summer (Figure 1) is dominated by lakes, ponds and meandering rivers, suggesting that arctic water availability is of no concern. In stark contrast, during the winter the casual observer can see little difference between land and water on the flat, frozen, snow-covered landscape. This lack of visual difference in the terrain makes it difficult to locate existing water (and in large enough quantities) under frozen lake and river covers.

This paper generally covers the North Slope of Alaska (Figure 2), but provides more detail for the 10 million hectare National Petroleum Reserve in Alaska (NPR-A). The challenge is to provide adequate water sources for oil and gas exploration and potentially for development without adversely impacting aquatic resource values. Water sources need to be adequate for mid- and late-winter use. Perennially frozen ground (permafrost) to depths of approximately 300 meters usually precludes ground water availability. Therefore, surface water is the only reliable source. Most of the past oil and gas exploration in NPR-A has been during the winter. Production has been limited to a small gas field in the Barrow area.

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[1]Ecologist, Bureau of Land Management, Arctic District, 1541 Gaffney Road, Fairbanks, AK 99703

Fish are the major aquatic resource focus for potential impacts from winter withdrawal of water. There is a small commercial harvest of fish on the Colville River, but the most significant issues revolve around subsistence use of arctic fish stocks. More information about arctic fish life cycles, abundance and harvest is needed to better address the sensitivity of fish populations to large-scale development impacts.

DATA BASES

If integrated appropriately, recently developed regional data bases can improve cost efficiency for locating sites and mitigating NPR-A exploration and development. The data categories include fishery research synthesis, locations of fish harvest (subsistence use), and several different aquatic inventories.

The Beaufort Sea Fisheries Database and Synthesis

The Beaufort Sea Fisheries Database and Synthesis (1986) is an excellent example of an effort to consolidate information from both published literature and gray (unpublished) literature into a usable data base for the arctic coast (Figure 2). This data base incorporates information from Point Hope on the Chukchi Sea to the MacKenzie River drainage in Canada.

The number of anadromous fish studies in both the United States and Canada has increased rapidly during the past decade of oil and gas exploration and development along the arctic coast. Many of these study results may never become published in the scientific literature. The results from the Beaufort Sea fisheries data base synthesis are now adding to our knowledge of the fishery stock use of some marginal esturine and freshwater overwintering coastal habitats. They are also being used to postulate the origin and exchange of these fish between Canadian and Alaskan waters. Coastal development analyses involving causeways and river deltas will benefit the most from this synthesis.

Although the Colville River and its tributaries have had some fish inventories, the inventory of inland fisheries has not been extensive within NPR-A. Little fisheries data are available from many of the smaller coastal plain rivers and the vast majority of lakes.

Subsistence Use Inventories

Subsistence use, as affected by federal land use decisions, was an issue taken up in the Alaska National Interest Lands Conservation Act of 1980. Since 1980, subsistence use information has grown steadily, adding to regional fishery and other resource data.

Federal Environmental Impact Statements and Planning. Two recent planning efforts within the NPR-A have added to the regional fishery data base. The preferred alternative for "The Final Environmental Impact Statement (EIS) on Oil and Gas Leasing in NPR-A" (1983) provides stipulations to mitigate impacts from development along major subsistence-use rivers. The important geographic areas for riverine fisheries were identified from information gathered in public meetings and personal interviews with subsistence users. Approximately 1,800 kilometers of river use across the Arctic Coastal Plain were identified (Figure 3).

Figure 1. Summer photograph of Arctic Coastal Plain Lakes in NPR-A

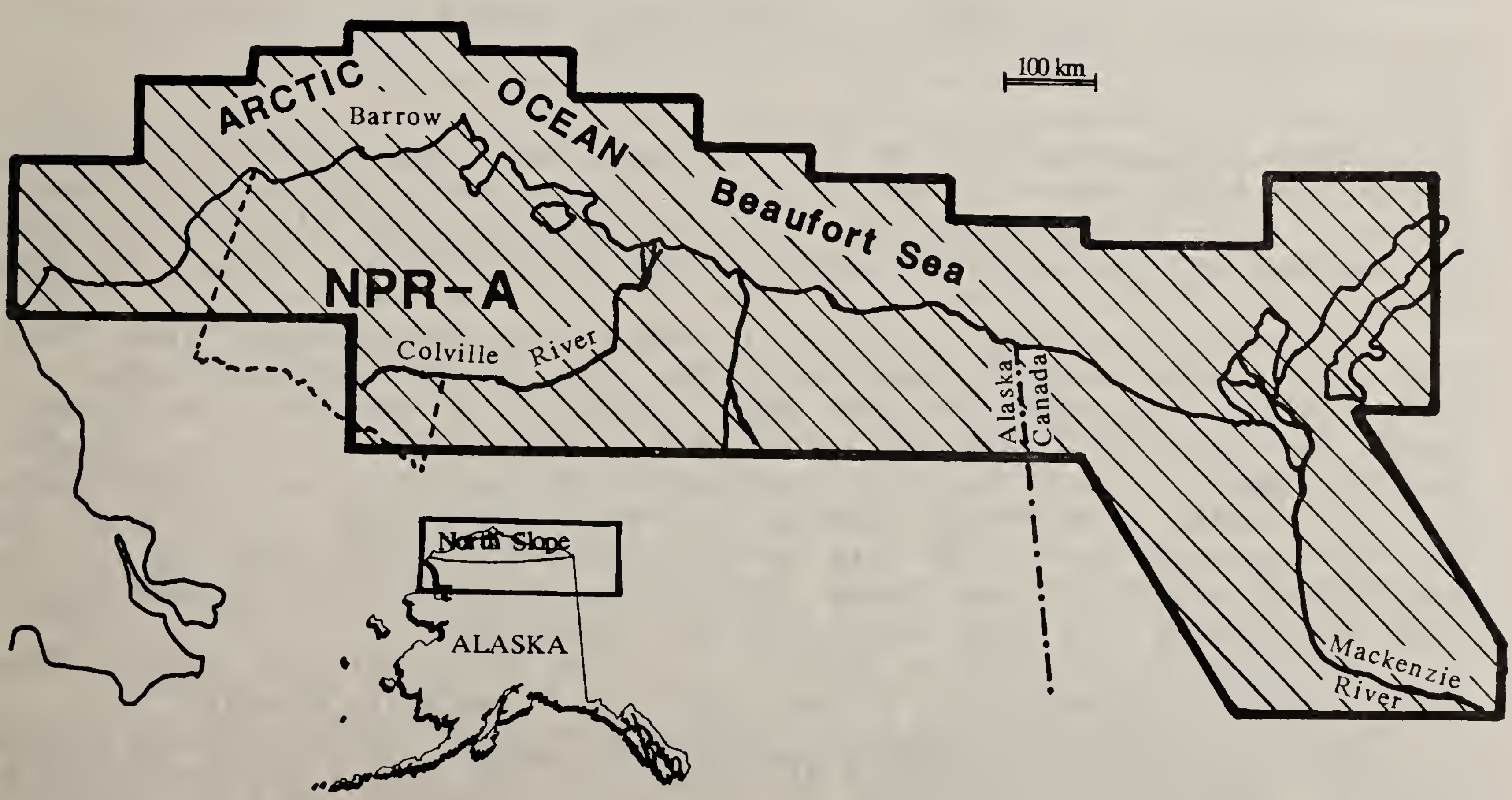

Figure 2. Beaufort Sea Fisheries Database Synthesis (from (ERA, 1986))

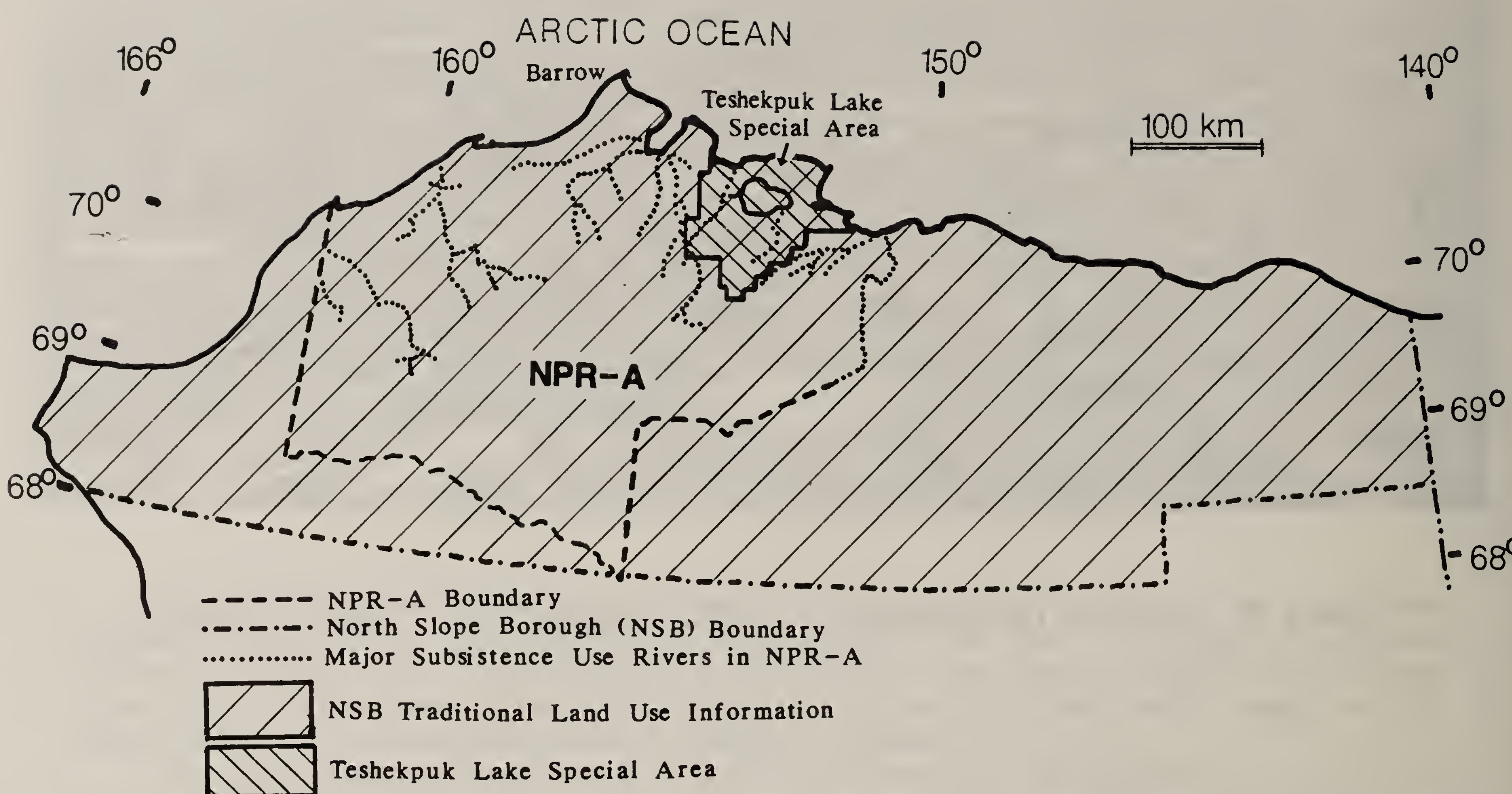

Figure 3. Subsistence use data bases with fishery information

Stipulations, developed for oil and gas exploration and development, will be applied to these river reaches to protect fishery and aquatic values. Arctic residents believe subsistence fishing is very important, but little quantitative or qualitative subsistence fishery use data are available for most of these rivers.

A habitat evaluation for the Teshekpuk Lake Special Area (BLM, 1985) resulted in more specific subsistence use data for one subregion (Figure 3) within NPR-A. Subsistence river use, identified in the 1983 Environmental Impact Statement for NPR-A, was confirmed and additional specific use of lakes, small streams and arctic coastal shoreline was documented. The highest density of deep coastal plain lakes (greater than four meters deep) to the south and west of Teshekpuk Lake could help sustain fish stocks within this region. The identification of these deep lakes and their potential for a year-round fishery will be discussed in a later section on lake inventories.

An important question to consider is, "How do we maintain many of these types of geographic data bases so that they have a cumulative benefit?"

North Slope Borough Geographic Information System. The North Slope Borough has been developing a geographic data base over the past seven years that is being managed on their geographic information system (GIS). They have entered traditional land use information for the entire NSB (Figure 3). This is being supplemented with subsistence fishery information being collected by the State of Alaska. Similarly, the two federal subsistence inventories can and should be used to update and modify the North Slope Borough GIS subsistence use data.

The Borough has offered to incorporate the Beaufort Sea Fisheries Database and Synthesis into its GIS for dissemination to interested federal, state and local agencies, as well as the oil and gas industry, on a cost-share basis. A cumulative data base, such as that being developed by the Borough, could add to the growing fishery research synthesis and subsistence use inventories previously discussed, as well as to the wetland inventories that will be discussed next.

Lake Inventories

Lake characteristics, particularly depths, have been measured or interpreted by different methods and individuals. Only a small percentage of lakes have been field-measured for depth. Remote sensing interpretation methods offer a means to determine specific lake characteristics regionally.

Field Inventories. The majority of field inventories for lake depths have been acquired by three individuals. The most easily accessible data are for approximately 40 NPR-A lakes. This was published by Holmquist in 1975. An approximation of maximum lake depth was determined with a weighted line dropped from a floatplane. A similar data set was acquired by Sloan (1977) for approximately 180 NPR-A lakes.

The Bureau of Land Management (1978, 1979 and 1980) acquired depths for approximately 80 potential water source lakes in NPR-A. These data were used for environmental assessments prior to water withdrawal near 22 proposed drill sites in NPR-A. Depth measurements were acquired on another 180 NPR-A lakes for field verification of radar-interpreted isobaths (Mellor, 1982a and 1982b). Most depth measurements for these 260 lakes were acquired by multiple fathometer transects from a floatplane to map approximate isobaths.

Since late winter ice thicknesses are approximately two meters, lakes with a maximum depth near two meters will not have much, if any, water in late winter. If maximum lake depth is not much greater than winter ice cover, there is little chance of finding large fish or a late-winter water source. A three-meter-deep lake could have a viable fish population that could be impaired by the winter withdrawal of water.

Over two decades of field measurements have provided depth measurements for almost 500 lakes, but this is still only about 3 percent of the lakes within NPR-A that are larger than 5 hectares.

Aerial Radar Images. Side Looking Airborne Radar (SLAR) images were acquired over most of NPR-A. These images were part of an investigation into the use of radar to interpret and map arctic lake depths (Mellor, 1982a). These data resulted in a series of maps (Mellor, 1985) on which three ranges of depth (0 - 1.6 m, 1.6 - 4 m and >4 m) were interpreted for approximately 21,000 NPR-A lakes (Figure 4) greater than approximately 5 hectares in size. Less than 600 (3 percent) of these lakes had interpreted depths of approximately 4 meters or greater. Lakes of this depth, concentrated to the south and west of Teshekpuk Lake (Figure 4), have a great potential to sustain a year-round fishery.

Approximately 12,300 (58 percent) of these 21,000 lakes appeared to be frozen to the bottom with no water to sustain a winter fishery. Approximately 8,200 (39 percent) were interpreted as having depths exceeding April 1980 ice thickness (1.6 m), but with depths less than approximately 4 meters. Although many of these will have some residual water even in the severest of winters, they may be marginal for sustaining a fishery. Fish existing in these marginally deep lakes could be adversely impacted by water withdrawal or accelerated ice accretion.

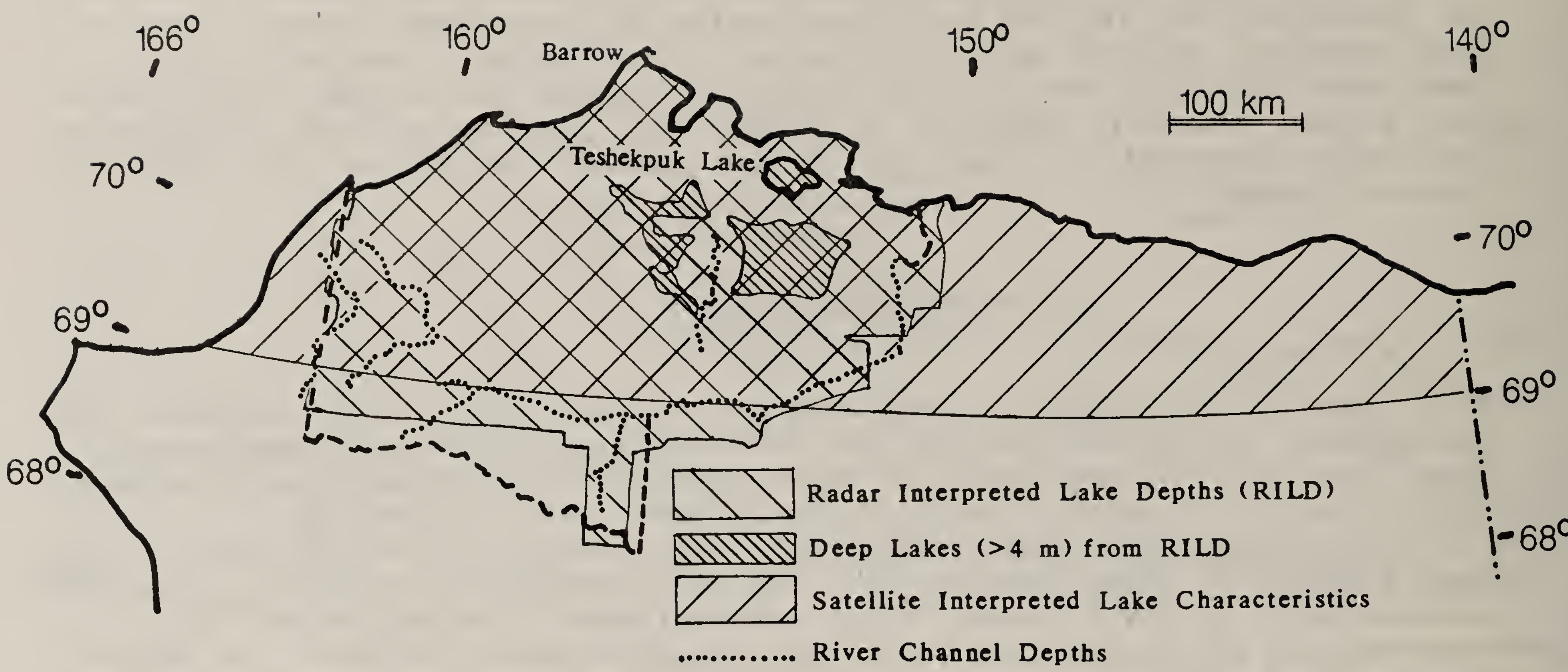

Figure 4. River channel depth and lake inventories

An oil and gas exploration well requires approximately 15,000 cubic meters of water withdrawal for construction of ice roads and ice airstrips and for domestic and drilling purposes. Roads and airstrips across lakes and rivers accelerate ice accretion where insulating snow cover has been compressed or removed. Both water removal and increased ice thicknesses could create adverse late-winter conditions for fish in marginal habitats. Natural fish kills as well as man-induced kills have been witnessed, but only infrequently, in these marginal habitats.

<u>Satellite Multispectral Scanner Image</u>. Methods have been developed to define the surface characteristics of arctic lakes using Landsat Satellite multispectral scanner images (Mellor, 1982a and 1983) (USGS, 1986). The U.S. Geological Survey has produced lake attribute files for the area shown in Figure 4. They contain acreages for lake classes (deep, shallow, turbid and ice) and a unique identifier/location from the latitude and longitude of the lake center (USGS, 1986).

This file has identified and characterized approximately the same number (23,000) of Arctic Coastal Plain Lakes in the same general area as were interpreted with the radar images discussed above. A combination of these two data sets could be more useful than the two as separate entities. This could be accomplished on either the Earth Resources Inventory System at the Office of the Geological Survey Earth Resources Observation Satellite Data Center or on a system such as the North Slope Borough's GIS.

River Channel Depths

The remote-sensing methods used for lake inventories were not appropriate for NPR-A rivers. Aerial radar and satellite multispectral images were not useful in determining unfrozen river pools with potential winter habitat for fish. Maximum channel depths, acquired by fathometer during river float trips, can be translated to maps that distinguish between shallow water habitats (riffle to less than 3 m depth) and deeper habitats (greater than 3 m). River channel depths have been measured on 1,200 kilometers of major NPR-A rivers. The methods for these fathometer depth surveys were tested on the Colville River in 1979 (Mellor, 1983). Additional fathometer records have since been acquired on the Colville, Nigu, Etivluk, Utukok, Ikpikpuk, Kokolik and Nuka rivers (Figure 4).

Once these depths are translated to maps they can be used to help select shallow-water river crossings for winter cross-country moves. Noted deep areas can be avoided. Early winter crossings could be disastrous for operators whose vehicles might break through thin ice. Once ice has thickened enough to support vehicles, river ice provides a relatively smooth transportation corridor. One side-effect of vehicle use is that snow is compressed, destroying its insulating quality, thereby increasing ice thickness and reducing under-ice fish habitat. River channel depth maps help identify and discriminate between those areas that freeze to the river bottom and those marginal and deep aquatic habitats that may sustain winter fish. Federal, state and local agencies do not generally permit winter removal of water from river reaches where fish populations would be at risk. Channel depth maps provide locations for future winter fish census in ice-covered, deep river channels.

Much like the previously mentioned lake depth data, the river depths data can be accessed much more easily when they can be retrieved from a GIS in combination with other thematic data.

SUMMARY

Recently acquired data bases can help in efficient Arctic Coastal Plain development while reducing the potential for withdrawing too much water from sensitive winter fish habitats. Although the separate data bases are useful for this purpose, future use of geographic information systems may help in: combining similar data, enhancing access to both published and unpublished data, and combining aquatic data with other resource information. The ultimate goal is to enable timely, cost-effective, yet comprehensive environmental analyses that directs efficient water usage while protecting aquatic resources.

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THE HYDROGEOLOGIC INVESTIGATIONS CONDUCTED TO ESTIMATE GROUND WATER FLOW RATES INTO A SURFACE MINING PIT USING A COMPUTER MODEL

Kim Forster[1]

ABSTRACT: During surface mining, inflow of ground water into a pit can cause operational problems and lower coal quality. The subject mining area is bounded on the west and north sides by a large creek (see Figure 1). The overburden material consists of sand, silt and clay. During mining the bottom of the mining pit will be located 150 feet from the bank of the creek and 15 to 20 feet below the water level in the creek. The mining company was concerned that water from the creek could flow through the sands above and below the coal seam into the pits. An estimate of the amount of water that would flow into the pit was needed. Data had been collected in the mining area which characterized the hydrogeology of the site. A computer model was utilized to estimate the water inflow rate and the direction of flow of ground water within the material above and below the coal seam. The calculations indicated inflow rates of 40 GPM into the test pit. A test pit was excavated to the top of the coal seam. The test pit was 100 feet long, 30 feet wide, 25 feet deep and 150 feet from the creek bank in the same area as simulated by the model. The inflow rates into the pit confirmed the rates estimated by the computer model. The results of this evaluation include estimating water inflow due to the creek, proposing a safe mining distance from the creek and obtaining data to calibrate the model from the excavation of a test pit.
KEY TERMS: Ground Water; Hydrogeology; Inflow; Computer Model.

INTRODUCTION

The purpose of this paper is to briefly describe and summarize the method and steps taken to estimate the inflow of ground water into a proposed surface mining pit.

The hydrogeologic conditions present in the mining area were identified using drill cuttings, geophysical logs (gamma, density and resistivity), observation wells installed in the sands above and below the coal seam, and aquifer tests. The overburden material consists of sand with minor amounts of clay, silt and coal. In areas where the sand is present it is poorly cemented and contains laminae of silt and clay. The general thicknesses of the lithologic sequences in the study area from the surface through the coal seam are: sand 50 feet, clay 6 feet, coal 8 feet, clay 1.5 feet and sand 12 feet (see Figure 2). Monitor (observation) wells were installed at a distance ranging from 300 feet to 100 feet from the creek as shown in Figure 1.

Static water levels from the monitored (observation) wells completed in the sand above the coal seam were approximately 14 feet above the base of the coal seam. Static water levels from wells completed in the sand below the coal seam were approximately 15 feet above the base of the coal seam. The wells are located at a distance ranging from 300 feet to 100 feet from the creek. The water level is 20 feet above the top of the coal seam in the creek. From aquifer tests the hydraulic conductivity of the sand below the coal seam

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[1] Hydrogeologist, Ken E. Davis Associates, 11805 Sun Belt Court, Baton Rouge, LA 70809

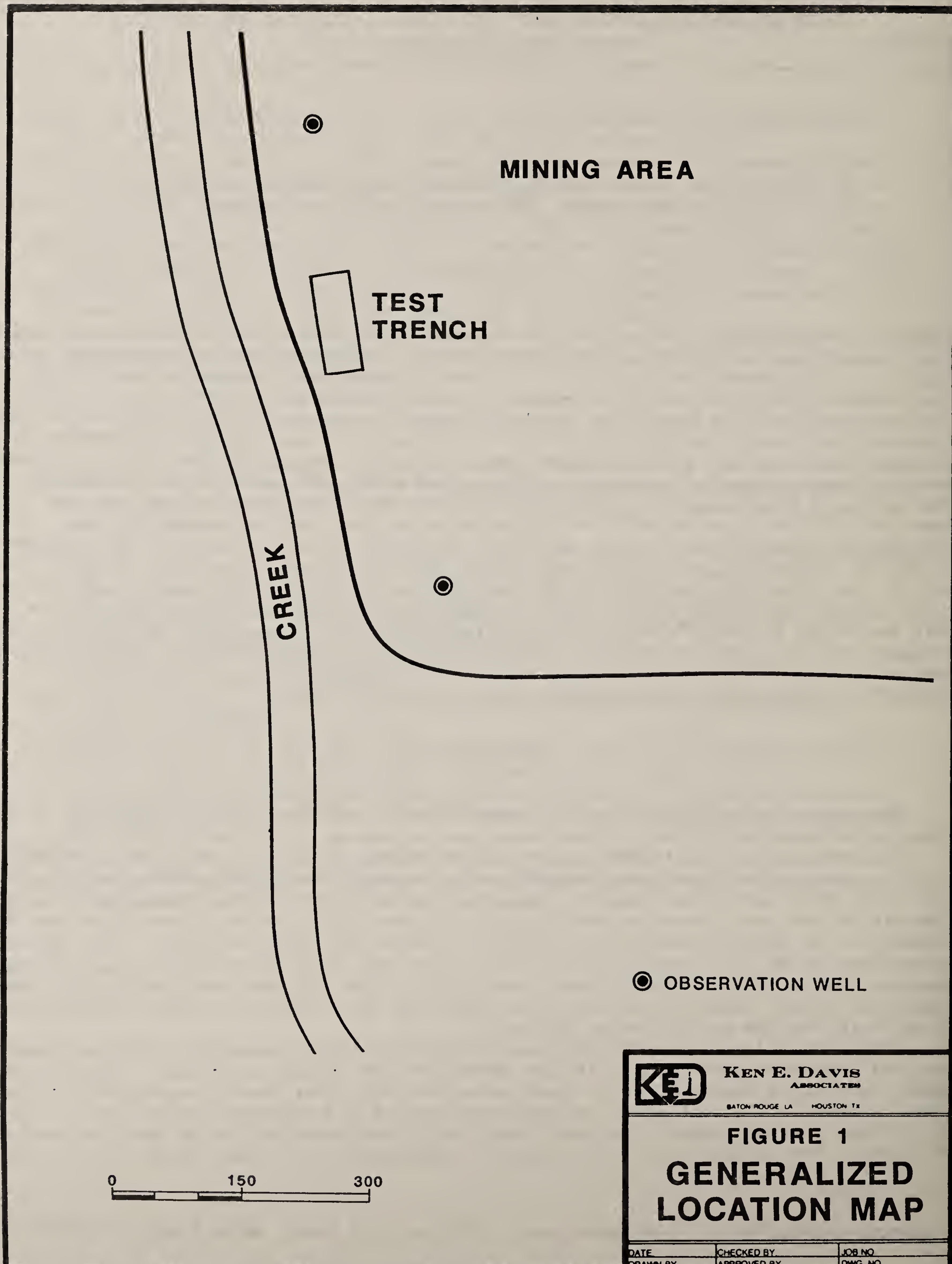

FIGURE 1
GENERALIZED LOCATION MAP

C & D REPROGRAPHICS 53555-1

was estimated to average 5 GPD/ft^2. The hydraulic conductivity of the sand above coal was estimated from aquifer tests to be 115 GPD/ft^2. Water flowing into the pit from the saturated sand above the coal seam in the overburden east and south of the creek was anticipated. The volume of water flowing into the pit from the sands above and below the coal seam bounded by the creek was not known.

DISCUSSION OF ANALYSIS

To accomplish the objective a steady state linear flow formula and a finite element computer model were utilized. The model analyzed an area 2000 feet x 2000 feet or 4,000,000 square feet with a test pit located in the center of the modeled area. The model was constructed as a series of stacked grid cells. Each grid layer represents the sand in the overburden, clay above the coal, the coal seam, the underclay and the first sand below the coal, respectively.

The computer model calculates the pressure changes that occur over the entire grid as a result of water influx into the pit. The model uses an iterative process in the calculations to arrive at steady state conditions. It also assumes that the test pit is pumped dry between iterations to simulate removal of water during mining operations.

The initial set of calculations, from the formula below, to estimate the inflow into the pit are completed and these values are used in the computer model. The equation is:

$$Q = \frac{CkA\,\Delta P}{ML}$$

Q is the flow rate where C is a constant used for linear flow, k is the permeability in millidarcy's, A is the cross-sectional area of the test trench walls, ΔP is the change in pressure, M is the fluid viscosity and L is the length of the test pit. The following aquifer parameters were derived from field tests conducted in the area.

Lithologic Unit	Permeability (md)	Thickness (feet)
Creek Sediment	10,000 md	24 feet*
Sand Above Coal	5,600 md	10 feet
Clay Above Coal	.001 md	6 feet
Coal	100 md	8 feet
Clay Below Coal	.001 md	1.5 feet
First Sand Below Coal	10 md	12 feet

*The thickness and permeability of the creek sediments were chosen to be the worst case condition. If the coal seam is present under the creek, the sediments would intersect the coal seam and provide communications from between the pit and the creek. Note: The units were converted from GPD/ft^2 for modeling purposes, 20.38 GPD/ft^2 = 1 darcy = 1000 millidarcy's (md).

The dimensions of the test pit in the model are 100 feet in length, 30 feet in width and 25.5 feet deep. The underclay was removed in the computer simulation to permit the calculation of slow rates and pressure changes that occur in the sand below the coal and underclay.

The calculations in the model are conducted as iterations. The number of iterations vary due to the number of layers of material removed. The grid cells are all at steady state pressure before the material removal is simulated in the computer model. Once the test pit has been introduced to the grid the model calculates the pressure changes that occur from the outside edge of the model toward the test pit which is located at the center of the model.

The linear flow calculation estimated that the initial flow from all sides into the test pit would be 40 GPM. The flow rate values obtained from the grid cells around the test pit indicated that most of the flow was from the overburden and not from the sand

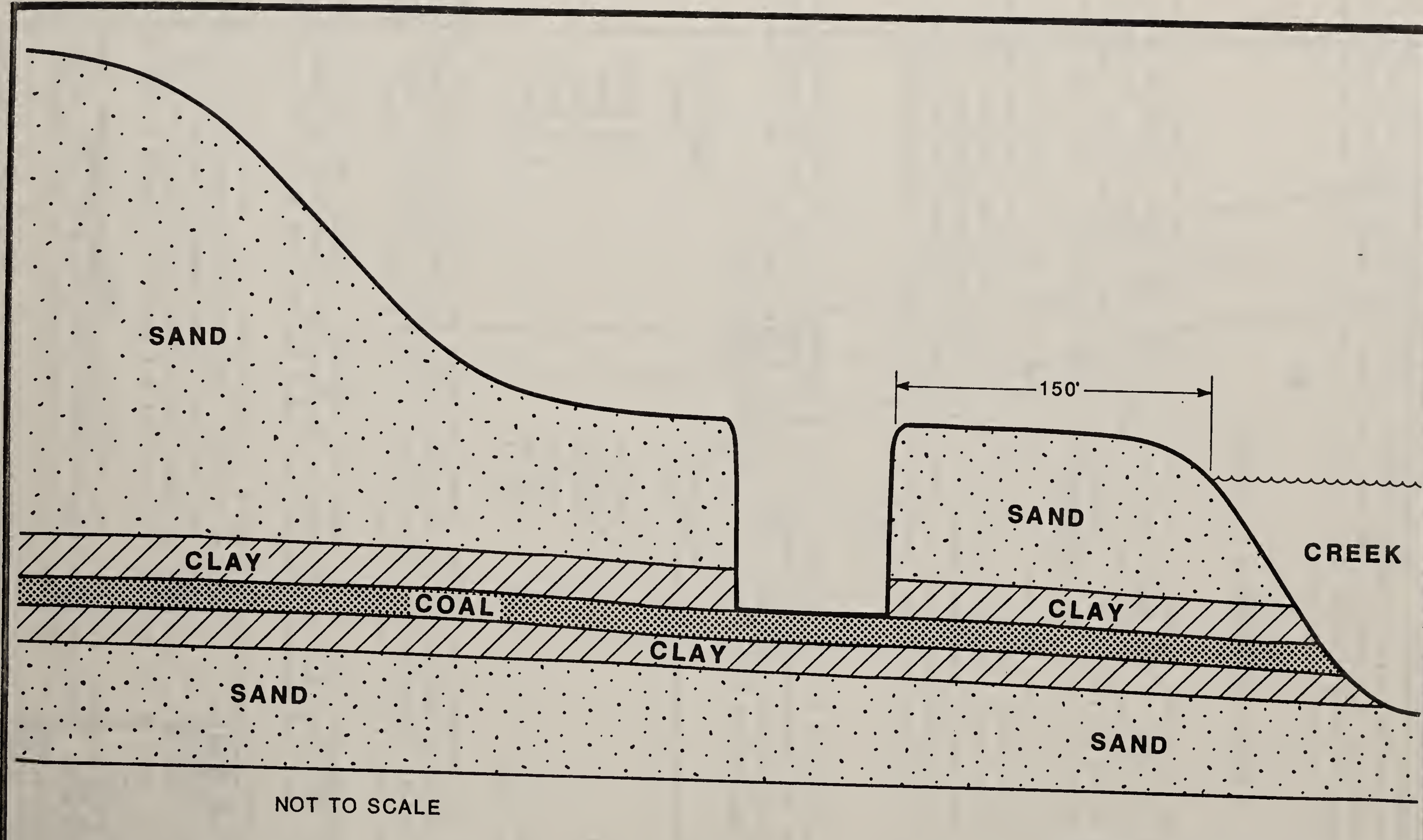

FIGURE 2

GENERALIZED CROSS-SECTION

C & D REPROGRAPHICS 53555-1

below the coal seam which extended beneath the creek. Model sensitivity was determined to be the saturated thickness of the creek sediments. If the saturated thickness of the creek sediments were doubled then the flow rates into the test pit from the floor and overburden doubled.

After predicting the water inflow with the model, a test pit was excavated at the site (Figure 2). The actual inflow into the test pit was measured by placing a pump into the excavation and pumping the water at the same rate of inflow. The measured inflow was approximately 38 GPM for the first 24 hour period, the flow then slowed to 5 GPM for the next several days. The flow was from the overburden east and south of the test pit not from the sides nearest the creek. This was determined by observing the sides of the test pit which produced the flow. The model had predicted flow from all four sides of the test pit. The reasons for the low flow rate from the sides of the test pit along the creek were determined to be: the low hydraulic conductivity of the sand below the coal seam, the clay above the sand which acts as a cap and the lack of energy in the form of head pressure to drive the fluid from the creek through the sands and clay below the coal seam into the test pit. The flow would also have been low from the sides of the test pit near the creek because of the accumulation of silts and clays in the creek channel. This would slow movement of water from the creek into the sands above and below the coal seam.

CONCLUSION

Analysis of the data from the computer model and excavation of the test pit indicate that:

1. In flow of water into the test pit would come from the sand above the overburden and not from the sand below the coal seam on the sides away from the creek.
2. Ground water flow into the test pit was dependant upon the hydraulic conductivity of the formations, available water in storage and the energy available (head pressures) to drive the fluid through the rocks.
3. Aquifer tests, core samples and geophysical data, from the material above and below the coal seam, provided an accurate estimate of the subsurface conditions.
4. The unknown quantity in the investigation was the volume of water from the creek that would flow as ground water through the material above and below the coal seam. The low flow rates from the sands above and below the coal seam nearest the creek indicate a significant accumulation of silt and clay along the sides and bottom of the creek. This layer was thick enough to slow the horizontal and downward migration of water from the creek through the sands above the coal seam and into the test pit.
5. The computer model with the aquifer test data, overburden and interburden characteristics derived from the field was able to predict the quantity of water that would flow into the test pit but not the direction of flow. The excavation of the test pit was necessary to properly calibrate the model and provide an accurate view of the hydrogeologic conditions present in the area.

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PLANNING AND MANAGEMENT FOR MINING AND ENERGY

Planning for Water Use And Development

R. Lee Barkow[1]

ABSTRACT: The Bureau of Land Management uses a nine step land use planning process to prepare resource management plans. Water resource considerations must be incorporated into the planning process from the first step in the process. Potential projects or land uses that require water as a component must be identified when planning issues are identified and analyzed throughout the process. Potential water demand dictates in part what criteria should be used to resolve conflicts, what information and data are necessary to consider and what alternatives will best accomplish the stated objectives. Involvement by water resource specialists throughout the process will ensure that appropriate and necessary consideration is given to water uses through the planning process.
KEY TERMS: Bureau of Land Management; resource management plans; public involvement; water use and development.

INTRODUCTION

The public lands administered by the Bureau of Land Management (BLM) are receiving ever increasing pressure for development. Every sector of the American public is looking at public lands to meet their respective needs. Wilderness advocates, white water rafters, timber producers, ranchers and mineral developers are all wanting to use a portion of the public lands to pursue their interests, and many of these uses depend one way or another on water.

Water use and development present unique challenges to land managers and planners because land ownership has little or nothing to do with the right to use water resources in the West. Historically, the states have individually administered the West's scarce water resources under the tenets of the Appropriation Doctrine. Fundamental to the Appropriation Doctrine is the maxim that benefiting use rather than land ownership is the foundation of the right to use water. The Bureau alone does not control water allocation and rarely manages an entire basin or groundwater aquifer. Consequently, interagency coordination and cooperation especially between federal and state entities are extremely important. Land use decisions made by the Bureau of Land Management on lands within a basin or aquifer can have a significant effect or influence decisions made on other agency lands.

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[1]Chief, Planning and Environmental Coordination Staff, USDI Bureau of Land Management, Colorado State Office, 2850 Youngfield St., Lakewood, Colorado 80215

Energy and mineral projects are often dependent to a large extent on water quality and quantity. Project proponents must be concerned with potential impacts of development to surface and groundwater resources. The water resource becomes a major factor of consideration when projects are proposed and sites selected. The consideration of water use and development in the Bureau's planning process is no different from the consideration of other resource uses and values. Unless adequate consideration has been given to the need for and impact to the water resource, potential development of the energy and mineral resource may be delayed, inhibited, or prohibited by the Bureau.

The purpose of this paper is to explore the question of when and how water resource specialists should participate in land use planning efforts, whether they are on the staff of a land managing agency or employed in the private sector by companies which will eventually be developing the energy and mineral resources.

THE PROCESS

The Bureau of Land Management uses a nine-step planning process that was developed pursuant to the requirements for land use planning in section 202 of the Federal Land Policy and Management Act of 1976 (FLPMA). This planning process is similar to that used by the U.S. Forest Service, differing only by requirements imposed by specific laws and regulations applicable only to one of the agencies. This paper is organized along the lines of the Bureau's nine planning steps.

Issues and Concerns

Technical involvement by water resource specialists must begin at the beginning. That statement seems obvious. But, unfortunately, it is not always the case. The land use planning process starts with the identification of issues and concerns. At this step, planners and managers identify agency and public issues that should be addressed in the plan. They will also identify concerns of the agency and public that do not necessarily present a resource conflict but need to be addressed in the plan to ensure orderly development of related resources.

Issues and concerns are always area or resource specific. Full consideration of an issue or concern can only be given if specific information regarding the location of or magnitude of the potential conflict is identified. This is the point in the process where potential water users should be working very closely with the land managers and planners to share information regarding possible project location and the amount and quality of water that may be needed. Possible projects which have potential impact on surface or groundwater such as coal development, placer mining, oil shale and geothermal resource development must be considered from the outset of the planning process. While the BLM does not allocate water, the responsibility to ensure development consistent with Federal and State water quality and quantity standards remains important.

Water resource needs are considered across the board. While energy and mineral development may be a direct user of water for production, other land uses will also compete for the quantity and quality of water available. For instance, timber production and livestock grazing may affect the quality of water while instream storage and irrigation may affect the quantity of available water. Certain land uses depend on water in different ways. White water rafting and scenic quality depend on water, not in a consumptive way, but in its mere presence. Obviously a dry stream is impossible to float and the scenic quality of a viewshed that is dependent on the presence of water is significantly changed when it is absent.

Issues and concerns must be reviewed by all sectors of the public to understand potential effects of management actions on the water resource. Competition for, dependence on, or impact to a particular resource creates an issue. This is why early participation in the planning process is so important. If any segment of the public is not an active participant in issue identification, inadequate or inappropriate consideration may result and the ultimate decision may be unfavorable to project proponents.

The issues and concerns identified at this point in the planning process will be the focus of the analyses and decisions that comprise the rest of the process.

Development of Planning Criteria

Once the issues and concerns have been identified, it is necessary to decide the criteria to be used to resolve these conflicts. Criteria, simply stated, identify how the issues and concerns are going to be addressed. This includes minimum standards that are prescribed in law or regulation and minimum conditions established by the land manager. Criteria are developed for each issue and concern. For the water resource, minimum standards for water quality and quantity must be identified. Consistency of criteria between various issues is paramount. For instance, if minimum standards for water quantity are established for range, mineral development and recreation, care must be taken to ensure that the sum of the minimum standards does not exceed the available water supply or an understanding reached that certain uses will be foreclosed unless additional supplies are found.

Criteria development is an important aspect in the planning process. It is at this point that the specialist recommends to the manager what minimum acceptable standards should be applied to the various resource considerations. The public plays a significant role in criteria formulation. A recommended minimum level of resource allocation should be identified to the land manager so the needs of future development or use can be considered. If a project proponent knows what resource base their project will require, if approved, that information should be disclosed at this early point in the planning process.

Information and Data Collection

Information and data must be collected and compiled to ensure that the necessary facts are available to the land manager to develop reasonable alternatives, select a reasonable preferred alternative and, ultimately, make the best resource decision possible. It is incumbent on the water resource specialist to compile and display the necessary information. The public and private sector specialists should be involved in this step to ensure that appropriate and necessary information relevant to future proposals is included in the data base. Without such input, the land manager may not give full and necessary consideration to water resource needs relating to particular types of water use and development.

The Bureau of Land Management has identified the following information to be collected for all planning efforts:

1. Water Condition Component. Soil erosion, sediment yield, water quality, run-off and stream flow;

2. Water Availability Component. Floodplains; riparian areas; municipal watersheds; State (high priority) water quality planning areas; nonpoint discharge elimination system permit sites; and polluted groundwater systems; water rights; and a baseline evaluation of supply.

Analysis of the Management Situation

The water related information and data collected is used in subsequent analyses which are important to determine capability of this resource for use and development. The factors used in the analyses are:

1. Legal requirements. The BLM has numerous statutory requirements that must be considered when establishing water resource objectives and making land use decisions. The laws include the Clean Water Act; The Public Rangelands Improvement Act; and the Safe Drinking Water Act. Executive Orders include Executive Order 11988 regarding Floodplain Management and Executive Order 11990 regarding the Protection of Wetlands. Also of consideration are those laws and regulations administered by other Federal agencies and the body of State law unique to each state and any county ordinances that may address or be affected by water use and development;

2. Watershed conditions. The BLM will study the watershed condition to determine the watershed vulnerability and responsiveness. The purpose of this analysis is to determine the susceptibility of watershed unit to degrade from its current condition and express the ability of a watershed to improve from its current condition through management or treatment measure. This analysis becomes very important because to a large extent, the results will identify opportunities to accommodate particular uses, constraints that should be imposed on all resource uses and possibly prohibition of particular uses.

The sum of the analysis of the management situation results in a description of the current situation of the resources in the planning unit and the capability of the resources to produce a product or accommodate anticipated uses.

Formulation of Alternatives

The next step in the planning process is to formulate alternatives to resolve conflicts identified in the issues and concerns. Alternatives, being different ways to accomplish the same objective or accomplish different objectives, must all meet the criteria established earlier to be considered viable. For the water resource, the criteria will ensure that all alternatives will result in a minimum acceptable water quality and quantity regardless of which alternative is selected. Water quality and quantity may vary by alternative depending on the objective of each alternative. For instance, if an alternative has as its goal to manage an area to preserve it as a wilderness area, the water quality may be very high. Another alternative may have as an objective for the same area to manage it for a multitude of uses. This alternative may have a lower but acceptable water quality. Each alternative would still ensure that the water quality would be within that established by the criteria.

The development of a range of alternatives appropriate to the planning unit becomes very important. The alternatives establish, in part, the scope of consideration for subsequent environmental analysis required pursuant to the National Environmental Policy Act of 1969 (NEPA). Agency water resource specialists, the public and private sector specialists should ensure that the scope of the alternatives is sufficient to accommodate known or anticipated proposals. If the alternatives are not sufficient to accommodate possible uses, costly and time consuming plan amendments would be required at the time of project proposal.

Estimation of Effects of Alternatives

At this point in the planning process the land manager looks at the consequences of the resource management alternatives as a whole. This analysis helps the manager and the public understand the possible trade-offs or changes associated with each alternative and displays those trade-offs or changes comparatively between alternatives. The estimation of effects is done for each alternative and for each resource or value present within the planning area.

Selection of the Preferred Alternative

The comparison of alternatives is used by the land manager to select the preferred alternative. The preferred alternative may either be one of the alternatives analyzed in the previous step or a combination of two or more alternatives. The preferred alternative will be the one that the land manager believes best resolves the conflicts. The preferred alternative may not be the most environmentally preferred alternative nor may it fully satisfy all desires. It will though, as all alternatives, meet the criteria developed in the second step of the process.

Public Review of the Draft Resource Management Plan

The draft land use plan and environmental impact statement is then distributed to the public for a review. At this point, the public has an opportunity to review all alternatives including the preferred alternative, and present comments about them. They may also propose modifications to the preferred alternative or suggest different alternatives.

It is critical at this step that the agency water resource specialist review the draft to ensure that water has been adequately addressed. The BLM in Colorado requires State Office hydrologists to review all plans thereby ensuring that adequate and full consideration has been provided to water resources.

It is equally important that the public and water resource specialists in the private sector review the draft plan to ensure that appropriate consideration has been provided that may accommodate any future proposals of which they are aware. Comments should be focused on needs, deficiencies or strengths, and recommendations for changes or additions should be made. It is virtually impossible for a land manager or planner to fully consider a comment that is not specific.

The results of the public review and comment period are considered by the land manager and necessary changes are made to the document. A final environmental impact statement and proposed resource management plan is issued. At this point, BLM regulations provide the public a 30-day administrative protest period during which any proposed decision in the plan can be brought to the attention of the BLM Director in Washington, D.C. The Director can either support the State Director's decision, modify the decision, or reject the decision in response to a protest.

Once all protests are resolved, the BLM State Director approves the final plan and issues a record of decision and approved resource management plan.

Implementation, Monitoring and Evaluation

Once the land use plan is approved, there is a common belief that the work is done. Actually, the work, and consequently the public's involvement, is just beginning. Because it is at this point in the process that the plan becomes more than just a concept. The BLM is required by FLPMA to manage public lands consistent with approved land use plans. When a project is proposed, the land manager must make a consistency determination to verify that the proposed action is compatible with the approved resource management plan. For this reason it is critical that the private sector, the project proponents, have been involved throughout the process. If inadequate consideration was given to a particular land use, or if the land manager was not aware of potential projects, the approved land use plan may not accommodate the proposal when made. Since the implementation of all actions must be consistent with the approved plan, water resource specialists should monitor the implementation of actions called for in the plan, advising the land manager of perceived inconsistencies or identifying opportunities to develop resources in favorable ways.

The BLM will initiate a monitoring and evaluation process after the plan is approved which is intended to ensure that management actions are consistent with the approved plan and evaluate the overall effectiveness of the plan to guide resource management. If the evaluation shows that the plan is deficient in certain areas or that conditions have changed which make previous decisions outdated, the land manager will initiate a plan amendment using the same process as described in this paper. If the plan is significantly outdated, the land manager may initiate a complete revision of the land use plan.

CONCLUSION

The land use planning process used by the Bureau of Land Management is an intensive effort that takes two to three years to complete. The decisions made through this process will guide management of public lands for a decade or longer. Water requirements for energy and mineral development must be considered in the planning process to ensure that timely and orderly development will occur. The water resource specialist, whether an employee of BLM or in the private sector, must be involved to ensure that proper and adequate consideration is given to water resource needs.

THE EFFECT OF WATER ISSUES ON THE SITING OF ENERGY PROJECTS, AND THE REVERSE

David C. Williams

ABSTRACT: Questions about the availability and quality of water resources can have a significant effect on the siting and approval of energy projects. Two clear examples are 1) the proposed ETSI Coal Slurry Pipeline, to run 1664 miles from Wyoming coal fields to Louisiana; and 2) the proposed All American [Crude Oil] Pipeline, 1084 miles from California to Texas. In the first, the findings of the Environmental Impact Statement demonstrated such effects from the use of water that the source had to be changed from groundwater formation to an existing reservoir. That still did not resolve the issue and the project was abandoned. The oil line was stymied for two years by concerns about potential spills in the aquifer supplying water to San Antonio, Texas, requiring substantial additional environmental analysis - but the issue is about to be resolved.

As originally proposed, each had the potential to significantly affect either the supply or the quality of water. In both cases, responsibility for the environmental analysis was that of the U. S. Bureau of Land Management (BLM), which has no responsibility for supply or quality in either project, while the primary effects were on states and localities. This type of water/energy conflict is likely to continue, but several techniques are emerging for resolving them short of extended legal battles.

KEY TERMS: Water supply; water quality; aquifers; energy project siting; environmental impacts; negotiation.

INTRODUCTION

The availability and quality of water is, and continues to be, two of the most difficult issues related to the decision to approve a major energy project. In those cases where a Federal permit is required, it is the National Environmental Policy Act (NEPA) which is the vehicle for raising - and attempting to resolve - these issues. The Bureau of Land Management gets involved because it issues rights-of-way for all Federal agencies, and thus becomes the lead on the Environmental Impact Statement (EIS). The BLM EIS required for the project has proven effective at raising significant issues about water supply and quality, even though BLM is not a "water agency." State and local governments have been able to demonstrate possible adverse effects, and get the energy project applicant to change significantly the proposed project. Such changes, of course, do not always assure approval, but the recent experience of the All American Pipeline indicates an agreement among the applicant, the State and local governments and the Federal agency responsible for environmental analysis, may lead to the successful resolution of water and energy development conflicts.

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1 Chief, Division of Planning and Environmental Coordination, Bureau of Land Management, Washington, D.C. 20240 (previously Chief of Special Projects, BLM)
NOTE: The views presented in this paper are the personal views of the author, and not necessarily the official views of the Bureau of Land Management.

WATER SUPPLY: THE ETSI COAL SLURRY PIPELINE

ETSI stands for Energy Transportation Systems, Inc., a joint venture of Bechtel, Lehman Brothers Kuhn Loeb, Kansas-Nebraska Natural Gas Company, United Energy Resources, and ARCO. Organized in 1973, the consortium proposed to construct and operate a 1664-mile long coal-slurry pipeline to transport 34.5 million tons of low-sulfur coal a year from the Powder River Basin of Wyoming to power plants in Oklahoma, Arkansas and Louisiana. (See Map 1.1 from the ETSI Draft EIS)

In 1978, ETSI submitted to the Bureau of Land Management its right-of-way application, required because 5 miles of the proposed line crossed public lands (and 26 crossed Forest Service lands). Under the EIS proposed action, the main source of water for the coal slurry mixture would be from about 40 to 45 wells drilled into the Madison Formation in Niabrara County, Wyoming. ETSI signed an agreement with the Wyoming State Engineer in 1974 which allowed the project to use 20,000 acre-feet of water per year for the export of coal slurry.

BLM selected a "third-party contractor" (so-called because the applicant pays the bill while the BLM manages the work): Woodward-Clyde Consultants (WCC) to prepare the EIS. Some 469 persons attended the nine scoping meetings held along the proposed route in August 1979. Over half - 248 - participated in work groups identifying concerns. The concern most of them identified was "subsurface water," with 142 (57%). Another 25 identified "water rights;" 23 said "alternative sources of water" was an issue. The final result of the environmental analysis and the permit effort proved this scoping to be an accurate reflection of the most serious issues.

Based on these concerns, two alternative sources of water were analyzed in the Draft EIS: a Crook County well field, also drawing from the Madison Formation; and the Oahe Reservoir, just north of Pierre, which would use water from the Missouri River under a permit from the State of South Dakota.

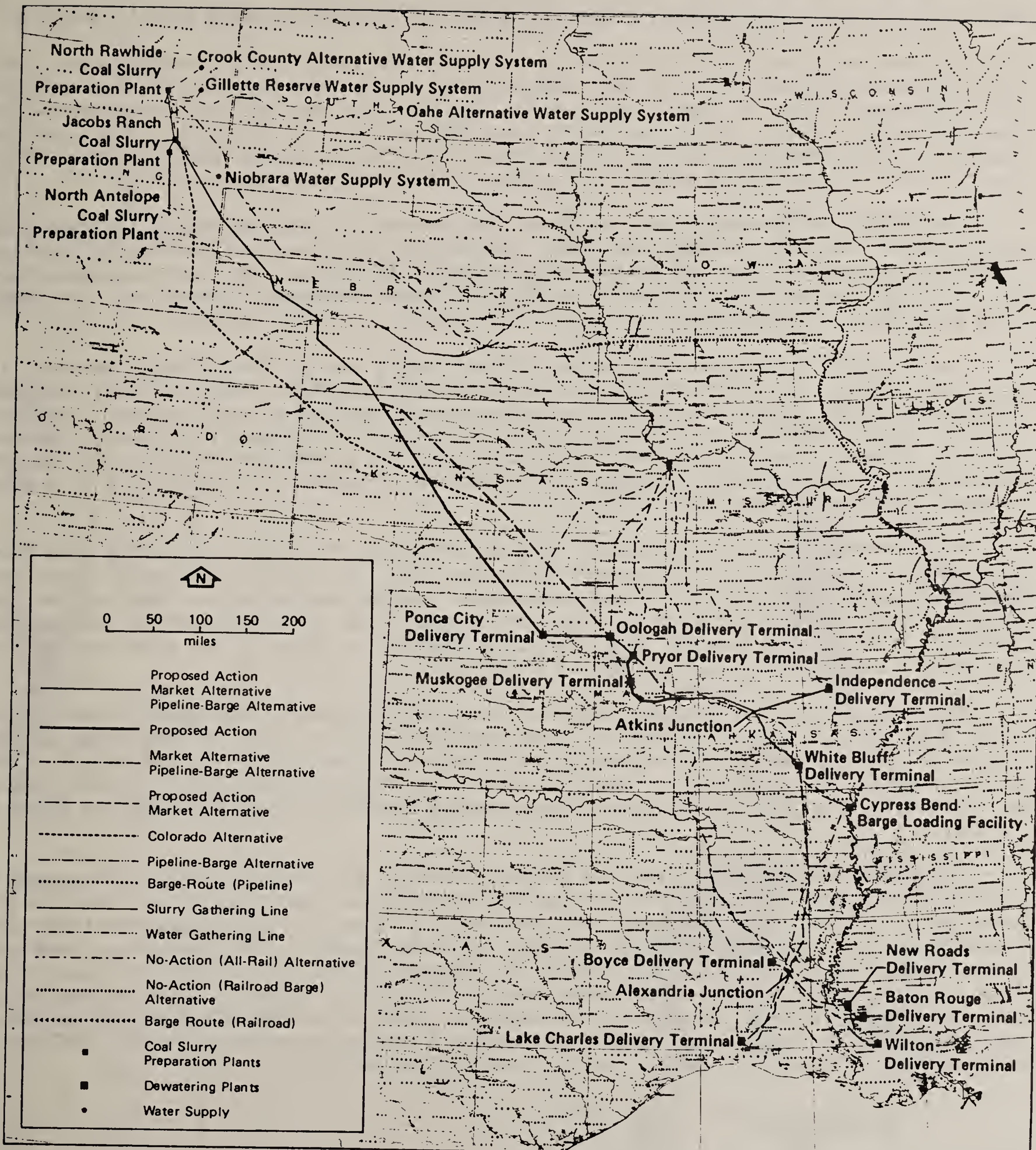
Even while the EIS was being prepared, the U.S. Geological Survey was preparing a five-year "Madison Formation Study." Unfortunately, the USGS conclusions were not available for WCC to use in the EIS, so the ETSI contractor had to prepare another model to estimate declines in water levels that would result from the project. The Draft EIS presented the agency-preferred alternative as:

> Water source. The Niabrara well field was selected, because determination of water rights is a state responsibility. The State of Wyoming has already issued well-field permits for the Niabrara well field.
>
> ETSI DEIS, November 1980, p. 9.

The estimated effect of this alternative on water levels was substantial:

> Pumping approximately 1 million acre-feet of water from the Madison aquifer at the Niabrara well field over the ETSI project's 50-year design life (1985-2035) would result in large declines in the potentiometric surface of the Madison aquifer system...
>
> ETSI DEIS, November 1980, p. 4-4

These drawdowns would be greater than 25 feet for about 5300 square miles, greater than 200 feet for 3800 square miles, and greater than 400 feet for the 500 square miles within 15 miles of the well field. (See Map 4-1 from the ETSI DEIS)



Map 1-1. LOCATION AND GENERAL ARRANGEMENT OF PROPOSED COAL SLURRY TRANSPORTATION PROJECT AND ALTERNATIVES

An estimated effect given little highlight in the DEIS was that the water level at the seven municipal water supply wells of Edgemont, South Dakota would drop by 303 feet.

In contrast to using the Niabrara well field, the Oahe Reservoir alternative, with no pumping and the use of a 275 mile long pipeline to get the water to the Powder River Coal Field would have no impact on ground water, in particular to the Madison Formation and its users. With a total inflow to the Oahe Resrvoir of 21 million acre-feet per year, the ETSI withdrawals would be less than 0.15 percent of that annual inflow. This was expected to have little effect, obviously, on the Oahe water supply.

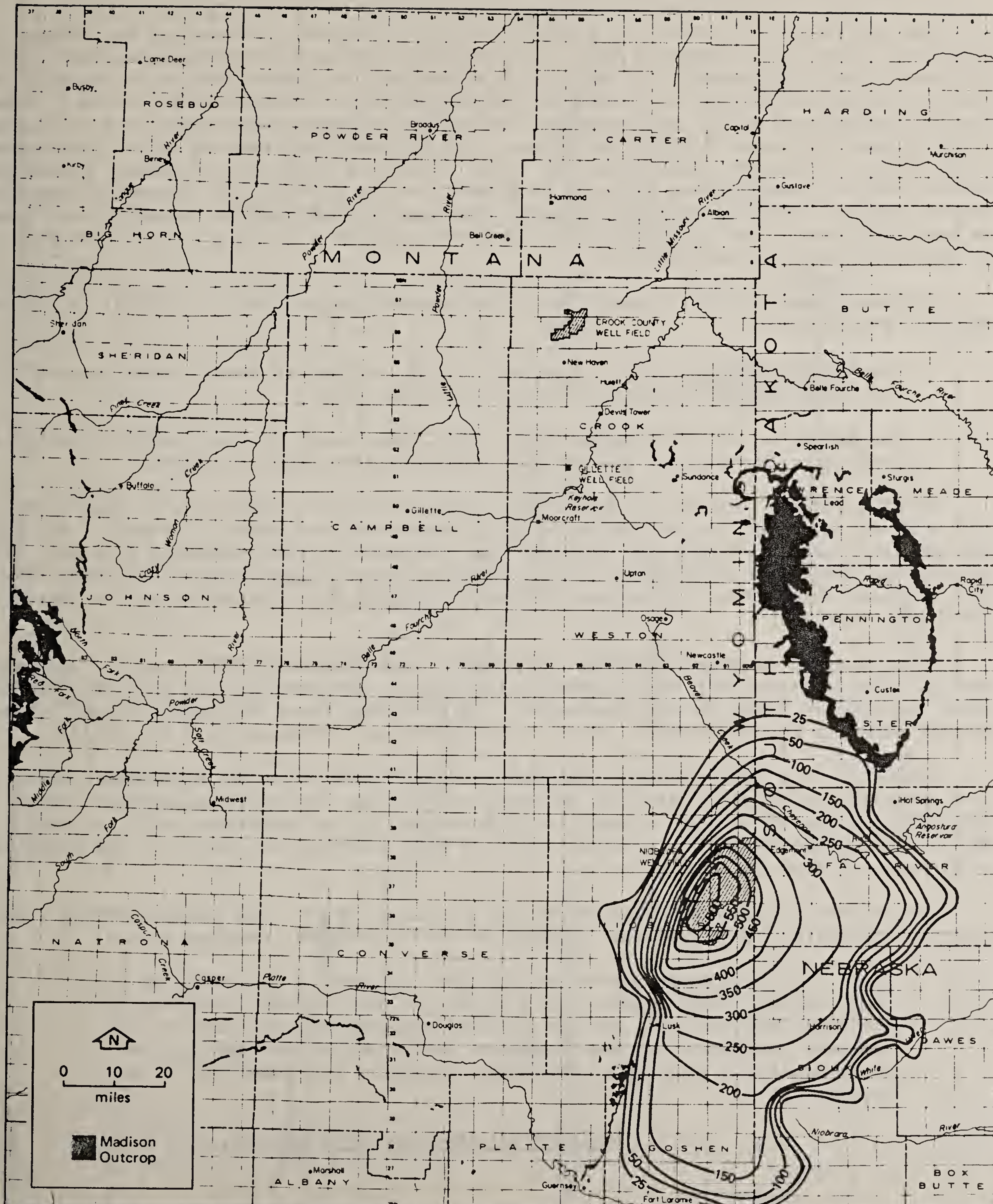
The 60-day review period for the Draft Environmental Impact Statement included time for 9 public hearings attended by about 900 people; 161 presented testimony. Comment letters were received from 235 individuals, agencies and groups. By far the largest number (BLM did not publish the count) related to "water resources" (especially the model used by Woodard-Clyde Consultants), to aquifer recharge, and to drawdown.

South Dakota's Governor, William J. Janklow, wrote one of the strongest letters, in which he said: "...I take this opportunity to personally state that the draft document is inadequate and almost cavalier in its treatment of impacts on South Dakota." (Janklow to BLM, 1/6/81) This letter was supported by a 59-page set of negative comments, starting with flaws in the EIS process, inadequacies of the hydrological model, and failure to address alternative water supplies. It took BLM 77 pages in the Final EIS to answer comments on water supply alone.

Two new water source alternatives were added to the Final EIS: purchasing Oahe Reservoir water directly from the Bureau of Reclamation (then called the Water Power and Resources Service), and using treated wastewater. Reprinting the entire draft EIS as the Final EIS took an additional two months, but it was worth it: there were no lawsuits on the quality of the EIS itself. BLM, therefore, issued its right-of-way grant on January 23, 1982, only 7 months after filing the Final EIS.

BLM had (and has) no jurisdiction over the source of water. As demonstrated in the Draft EIS, impacts of the project on local water led the ETSI group to modify its application in 1983 to make the Oahe Reservoir its primary water source (it had been a major alternative in the Draft EIS). ETSI buying up to 50,000 acre-feet of Missouri River water from the State of South Dakota eased Wyoming's concern about depleting the Madison Formation.

The States of Missouri, Iowa and Kansas, however, did not have their minds eased - and they filed suit against the Department of the Interior, and others, over the sale of water upstream from them. In response, South Dakota filed a strong counter-suit defending its sale of the water. Partly because of these lawsuits, the controversy and the delay, ARCO sold its 25 percent share of the project to the Internorth Group, and then invested its money in oil and gas development. The entire question of water ownership and authority to sell it became moot on August 1, 1984, when ETSI cancelled the project. ETSI President Paul G. Doran blamed the cancellation on opposition by the railroads which currently transport coal out of the Powder River Basin.



Map 4-1. DRAWDOWNS (in feet) IN THE MADISON AQUIFER POTENTIOMETRIC SURFACE AFTER 50 YEARS (1985-2035) OF PUMPING FROM NIOBRARA COUNTY WELL FIELD ONLY (PLAN 1)

WATER QUALITY: THE ALL-AMERICAN PIPELINE

The Celeron and All American Pipeline Companies propose to construct two connecting pipelines (Celeron/All American) that would transport heated Outer Continental Shelf (OCS) and other locally produced crude oils 1,206 miles from the Santa Barbara and Santa Maria Basins through Emilio station (southwest of Bakersfield), California to McCamey, Texas. The Celeron segment would go 122 miles from Exxon's proposed Santa Ynez Unit processing facility west of Santa Barbara to Emilio. The All American segment would then extend 1,084 miles, ending at connections to other crude oil pipelines spreading throughout Texas. (See All American Map 1-1) As considered in the EIR/EIS, the McCamey to Freeport Alternative is a 460 mile extension from the terminal in West Texas to existing refineries on the Gulf Coast. The All American Pipeline would be 24" to 30", and could transport up to 300,000 barrels per day (BPD).

The Environmental Impact Report (EIR)/Environmental Impact Statement (EIS) is a joint document prepared for:

-- the California State Lands Commission (SLC), acting as lead agency pursuant to the California Environmental Quality Act (CEQA); and

-- the Bureau of Land Management (BLM), U. S. Department of the Interior, acting as lead agency pursuant to the National Environmental Policy Act (NEPA).

The SLC and BLM joined with the County of Santa Barbara, California to form a Joint Review Panel to direct the completion of this joint State and Federal document. SLC and BLM managed, under a third-party contract, the work done by the consulting firm ERT (Environmental Research & Technology, Inc.). [Note the EIR/EIS also covered the Getty Pipeline proposal which, like the Celeron proposal, extended from the Santa Barbara coast to the Emidio station.]

Seven scoping meetings were held in November and December, 1983 along the proposed routes. The furthest East meeting was in Las Cruces, New Mexico (this fact will become quite significant later in the discussion). Of the six issues of "high concern," three related directly or indirectly to water: river crossings, hydrology, and oil spills.

Basically, the Draft EIR/EIS published in August 1984 found no significant effects from construction of this pipeline on groundwater along the Emilio to McCamey segment. The effect of an oil spill on sensitive groundwater during operation could be significant. The probabilities of a rupture are very low, however, so impacts of the pipeline on groundwater were not considered high.

The McCamey to Freeport Alternative had a sleeper in it. The Draft EIR/ EIS found the most notable of the groundwater aquifers to be the Edwards limestone aquifer

> which has the largest perennial yield of any aquifer in Texas and is the principal water supply for the City of San Antonio. Because of the high degree of use, shallow depth to groundwater, and ease of contaminant transport in open fractures and solution cavities in limestone aquifers, this entire 135-mile segment of the pipeline is sensitive.
>
> Celeron/All American Draft EIR/EIS, p. 3-130

MAP 1-1 REGIONAL SETTING

The first key point here is that contaminants can move much faster and for greater distances in limestone aquifers than in porous aquifers. A second key point is that the Edwards aquifer is the primary water source for a city - San Antonio - now quite aware of the environmental sensitivity of its water supply.

The possible impacts of the routine construction and operation of a crude oil pipeline, common throughout the entire country (and especially in Texas), were heavily overshadowed in this case by concerns over the transport of OCS oil in coastal Santa Barbara County, which has long been the subject of environmentally concern. The blowout of an offshore well in the Santa Barbara Channel in 1969 is a classic "environmental disaster," which led to much stricter Federal controls on OCS oil and gas development.

During the 90-day comment period (ending November 1, 1984), 8 formal public hearings were held, including one at Las Cruces, New Mexico (none in Texas). Even in the written comments, little concern was raised in Texas by the Draft EIR/EIS. Only the Sierra Club Lone Star Chapter commented on possible effects on groundwater. Its 49th comment was: "How will you reduce the risk of contamination of the Edwards Aquifer recharge area?" The Final EIR/EIS said that four required mitigation measures would reduce the risk of rupture and thus oil spills, but that "these measures cannot completely eliminate the potential for aquifer contamination." (Celeron/All American Final EIR/EIS, January 1985, pp. 2-56 to 2-59).

After publication of the Final EIR/EIS, and BLM's decision to approve the right-of-way across public lands in California, Arizona and New Mexico, the applicant changed the route of the pipeline east of McCamey. The new destination was Houston. This route had not been considered in the original EIR/EIS (in fact, there were no alternatives to the McCamey to Freeport Alternative), so BLM prepared a Supplemental EIS (the California State Lands Commission was not interested, obviously, in this proposal).

BLM recognized by now the need for public involvement in Texas, and scheduled 11 scoping meetings along the proposed route. About 300 people attended, more than all the scoping meetings and public hearings for the entire previous EIR/EIS. In the Supplemental EIS, published in January 1987, BLM gave extensive treatment to the hot issue of groundwater contamination of the Edwards Aquifer .

During the 60-day comment period, a lot of concerns were raised. Now riled-up citizens noted that the aquifer was the recharge zone for Austin as well as San Antonio. At only 6 miles wide but 250 miles long, the Edwards Aquifer would be difficult for the oil pipeline to avoid . Major concerns raised, though, were those presented, but little noted, in the Draft EIR/EIS: this is the most sensitive aquifer in Texas, and it is a limestone karst, not a sandstone aquifer. That means contaminants go faster and farther.

BLM has, as noted, no public land - and thus no authority - in Texas. And there is no state agency to issue rights-of-way. But given the high citizen interest, the Texas State Attorney General became involved, and launched a lawsuit. After extensive negotiations among the Attorney General's office, the Bureau of Land Management, and the All American Pipeline applicant, an out-of-court settlement was reached.

The applicant agrees to all of BLM's route selection and mitigation proposals: the pipeline route would go far north around the end of the aquifer recharge zone. This may resolve the issue. The Final Supplemental EIS is scheduled for filing with EPA in September 1987, and BLM intends to issue its Record of Decision immediately. The actual permission for building the pipe-line will be given by private landowners and county governments, probably over-seen by the State Attorney General.

LESSONS TO BE LEARNED

Before considering future issues, let's look at what can be learned just from these two cases:

1. Even though proposed energy projects may have little presence on Federal lands, they will often end up having to comply with Federal law. The ETSI project had only 31 miles on Federal land of a 1664-mile total. But the project required an Environmental Impact Statement prepared under the rules of the National Environmental Policy Act (NEPA).

   LESSON: Get very knowledgable about NEPA and the decision-making processes of Federal agencies.

2. The Bureau of Land Management issues all rights-of-way for the use of all Federal land, including Forest Service, National Park Service, Fish & Wildlife Service lands, and all others, including Defense lands.

   LESSON: Go to BLM first, and get very knowledgable about BLM procedures.

3. Most major energy states have sophisticated processes for evaluating and approving large energy projects, such as pipelines and power plants. Both focus states in these cases do: Wyoming and California. The result was little difficulty in either of these states. The problems came from adjacent states which did not: South Dakota and Texas.

   LESSON: All states could benefit from the creation of energy siting processes which could address the impacts of energy projects on water supply and quality, and of water resources on energy projects.

4. For big projects, BLM will often use third-parties to prepare the EIS. The applicant may nominate the contractor, but BLM will make the selection and manage the work. The applicant just gets to pay! In both cases, however, the project moved forward quickly, on schedule, and the information was developed with which to resolve the issues.

   LESSON: Third-party contracts are the way to go in preparing EISs (or EIRs). The critical factor is creating credibility through selection of a competant and neutral party.

5. The issues and problems which turn out to be most troublesome are often not perceived as such at first. Partly that's because problems known early in the project are given a lot more attention during the entire process. The attention in the Celeron/All American Pipeline to the Santa Barbara coast diverted attention from the groundwater in Texas.

   LESSON: Be open to new issues, and carefully consider the findings of the environmental analysis even before the public comments.

6. Not everyone who will be involved in the decision at the end is involved at the beginning. The scoping requirement of NEPA (and similar state laws) are designed to get all affected parties involved early, but this requires some knowledge of who they are. In both these cases, these "end" parties were in states that were not the major focus of the project: South Dakota vs. Wyoming for ETSI, and Texas vs. California for All American.

   LESSON: Scope equally in every state involved in a project, regardless of the intensity of the issue. Get everyone involved at the beginning. Don't let anyone feel later that they were left out. ETSI should have held scoping workshops in South Dakota; All American should have in San Antonio.

7. Resolution of the groundwater issue raised by the All American Pipeline was seriously delayed by the lack of information on a different route or different methods of mitigation to the proposed action.

   LESSON: Never put in an alternative to a project which is an "add-on," such as the McCamey to Freeport Alternative was, without having an alternative (or two) to it.

LOOKING TO THE FUTURE

Water and Energy -- Energy and Water. The two will continue to be linked. Much of the energy development of the Nation will continue to be in areas of limited water supply especially the Southwest. An Environmental Agenda for the Future has sections for both because of their critical importance. The energy chapter stresses the need to shift to renewable and less damaging sources of energy. That means less reliance on coal and oil, the two sources discussed in this paper. What this could mean is that the surge of proposals for large energy projects in the 1970's and early 1980's is essentially over. The fight over whether or not to approve a gigantic nuclear plant may never be seen again. A 3 to 5 megawatt coal fired power plant has gone the way of the dinosaur. Natural gas is the only traditional, non-renewable fuel that should given emphasis. The Agenda also strongly opposes efforts to commerialize synthetic fuels, such as oil shale.

Given that future, to which economics as well as environmental concerns are leading us, there will still be energy proposals. But these will be for for much smaller units, and for other types of energy source: e.g., small-scale hydro, wind, geothermal. A major concern will be with the cumulative impacts of projects, an area in which our current analytical methods are still evolving.

The environmental issue of the 1990's will be groundwater, according to a number of thoughtful analysts. Much of the issue will concern the "mining" of aquifers which do not replenish themselves as fast as they are drawn down - an issue especially in the ETSI case, and the contamination of groundwater supplies - the critical issue for the All American case.

A good example of the kind of energy/water issue which we need to address is a current case in Alaska. There the Bureau of Land Management has approved plans of operation for about 60 mining claims in a watershed which flows into the Birch Creek Wild and Scenic River. Each plan was approved separately, and each meets the water quality standards set by the State of Alaska. However, the Sierra Club sued the Bureau for not considering the cumulative impacts of these operations on the Wild and Scenic River which BLM manages. Sierra Club won, as it perhaps should have, for cumulative impacts had not been considered as NEPA requires. BLM is now preparing an EIS to analyze these cumulative impacts. The results may affect the number, location or level of activity of each claim, as well as the enforcement of existing State and Federal laws on water quality.

What I see, then, is a shift to assessing the effects of a large number of smaller energy projects on water supply and quality. This will require a new emphasis on techniques for estimating cumulative impacts. More than that, it will require a new look at institutions and procedures. These many smaller projects will lie on the lands of many jurisdictions: Federal lands and private, State and local - and be regulated by a miriad of uncoordinated rules and procedures. The potential is there - in fact, it's here now - for many of these cases to end up in court.

There must be a better way to resolve environmental disputes. There is:

> Negotiation, mediation, consensus building, policy dialogue - these and related approaches through which parties can resolve their differences voluntarily are becoming increasingly important in settling environmental disputes.

So begins the exciting report: Resolving Environmental Disputes: A Decade of Experience, sponsored by The Conservation Foundation just last year. In it, Gail Bingham presents the results of several years of experience in resolving disputes out-of-court at local, state and Federal levels. The results are impressive, and the potential is high for using these techniques in resolving conflicts between energy use and water quality.

ACKNOWLEDGEMENTS

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Bill Haigh, Federal Project Manager, Caleron/All American and Getty Pipeline Projects, Environmental Impact Report/Environmental Impact Statement
Chief of Planning and Environmental Coordination, California Desert District, BLM

Dick Traylor, Project Manager, ETSI Environmental Impact Statement now in the Headquarters staff of BLM, Washington, D.C.

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AREAS OF CRITICAL ENVIRONMENTAL CONCERN: A MANAGEMENT OPTION FOR SENSITIVE GROUNDWATER RECHARGE ZONES

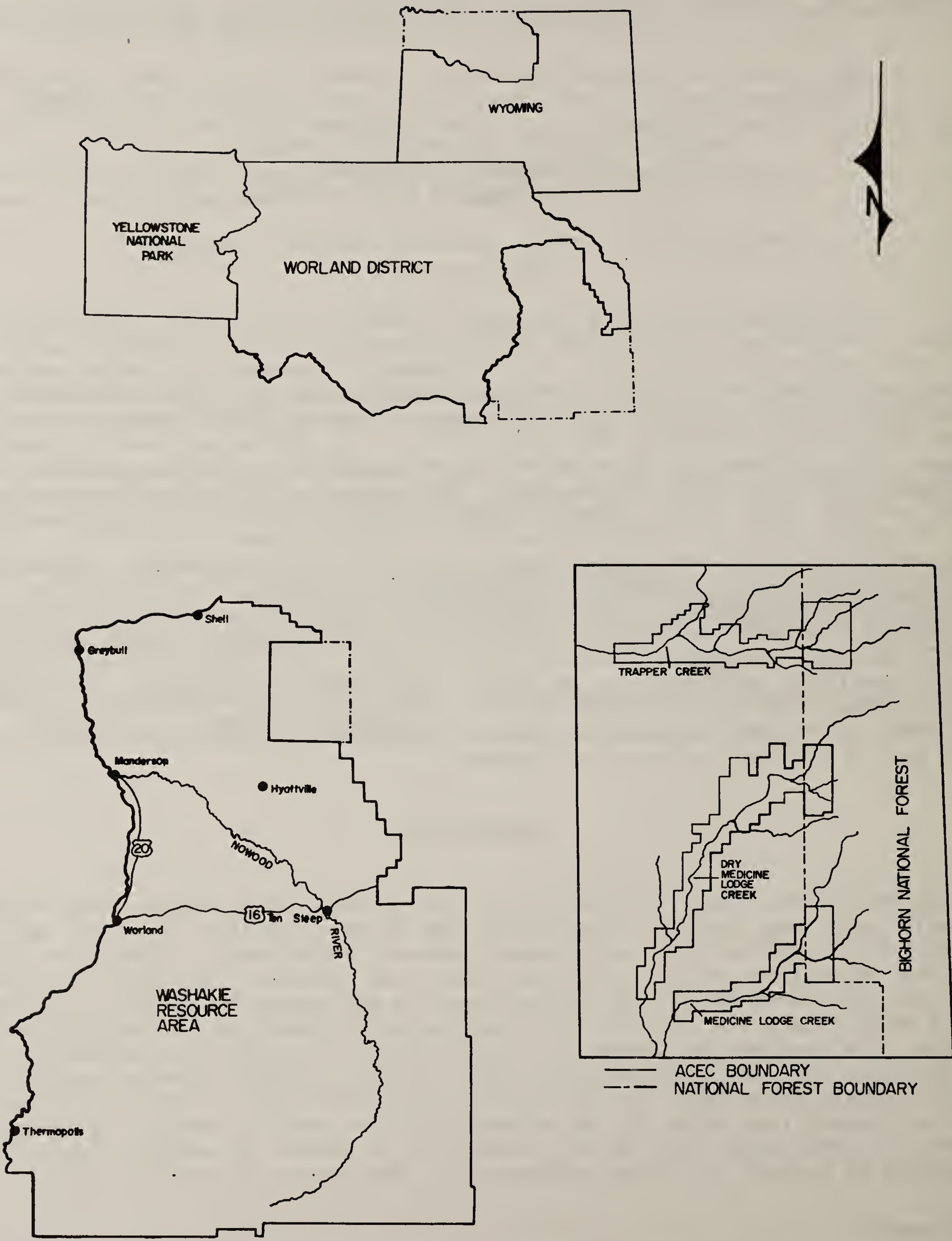
David L. Stout, Gary W. Rosenlieb, Steven S. Barrell[1]

ABSTRACT: The management of aquifer recharge areas is often delayed until long after water well fields are developed. The management of extensive geologic outcrops may involve restricting conflicting land uses and require extensive coordination with several jurisdictions. The Area of Critical Environmental Concern (ACEC) designation authorized by the Federal Land Management and Policy Act of 1976 (FLPMA) was used to identify and emphasize the management of the proposed Spanish Point Karst ACEC in the Bureau of Land Management's (BLM) Washakie Resource Area. The proposed ACEC is in an area of sensitive karstic recharge areas to the artesian Paleozoic Madison aquifer of the Bighorn Basin in north central Wyoming. An ACEC management plan would guide existing and future land uses in a way that would protect the quality of water entering karstic waterways, thus reducing the potential for groundwater contamination. Potential future land uses include mining of tar sand deposits, logging and exploratory oil and gas drilling. The process of identifying an ACEC, as well as alternatives for ACEC management developed through the Bureau's Resource Management Planning (RMP) process, is presented as one option for managing sensitive recharge areas on public lands where other economic enterprises and land uses exist or are contemplated.
(KEY TERMS: groundwater management; resource management planning; groundwater recharge zones; Area of Critical Environmental Concern.)

INTRODUCTION

The Spanish Point area, located in the Bighorn Mountains of north central Wyoming is a classic karst area (Map 1). Underlain by the Paleozoic Madison Limestone and Bighorn Dolomite, it is typified by sinking stream segments, underground drainage, and cavernous formations which have created nationally known cave systems. The Paleozoic formations dip to the west, from the initial outcrop areas in the Bighorn Mountains, to underlie the Bighorn Basin, where the aquifers have been tapped for municipal and agricultural water supplies. The confined and secondary permeability characteristics of the Madison aquifer make it ideal for the development of large yielding, surface flowing artesian wells. Municipal supply wells which flow 14,000 gallons per minute with shut-in pressures of 210 pounds per square inch attest to the capability of the Madison Limestone to produce large volumes of fresh water. The Madison aquifer is a source of municipal water for the communities of Worland, Ten Sleep and Hyattville, and provides irrigation water for

[1]Respectively, Community Planner, Bureau of Land Management, P.O. Box 119, Worland, Wyoming 82401; Hydrologist, National Park Service, 301 South Howes Street, Room 335, Fort Collins, Colorado 80521; Geologist, Bureau of Land Management, Denver Federal Center, Building 40, P.O. Box 25047, Denver, Colorado 80225-0047.



Map I
GENERAL LOCATION MAP

thousands of acres in the Bighorn Basin. The estimated water withdrawals from the Madison aquifer are displayed in Table 1.

Table 1

ESTIMATED ANNUAL MADISON MUNICIPAL AND AGRICULTURAL WATER WITHDRAWALS

	Daily		Annual	
	Million Gallons/Day	Cubic Feet Per Second	Million Gallons	Acre-Feet
Worland[1]	1.60	2.50	590.0	1,810
Ten Sleep[2]	.07	.11	30.0	92
Hyattville[3]	.01	.02	3.6	11
Subtotal	**1.68**	**2.63**		**1,913**
Irrigated Agriculture[4]				7,000
TOTAL				**8,913**

[1] Actual 1984 Pumpage

[2] Estimated with 1980 Census Data and Assuming Consumption of 200 gpcd

[3] Estimated by Assuming Population of 50 and Consumption of 200 gpcd

[4] 1976 Estimate by USGS, 1985

Karst areas such as those found in the Spanish Point area can serve as conduit recharge areas for water well fields miles away from the initial outcrop areas. Karst areas may also serve as initial rapid entrance pathways for groundwater pollutants and contaminants from land uses upstream of karstic sinkholes. The direct contamination of confined aquifers is usually limited by the presence of layers which exhibit low permeability. However, these aquifers may become contaminated by indirect recharge via their outcrop and/or recharge areas.

A potential major land use in the Spanish Point area is mineral exploration and development. In past years, a tar sand deposit about two miles south of Trapper Creek has been the focal point of interest in the area for at least one oil company. Interest in tar sand has waned with the economic recession in the oil industry, but the potential still exists development. There reportedly are several other deposits of tar sand in the Spanish Point area that could be developed if economic conditions improve. Impacts associated with tar sand development include the possibilities of increased sedimentation, introduction of chemical or hydrocarbon pollutants into surface waters, and changes in water flow regimes because of surface disturbance and removal of vegetation. Additionally, the somewhat remote possibility exists for damage to cave passages or karstic waterways because of strip mining operations. Oil and gas exploration and development, and activities associated with hard rock mining would produce similar impacts. The probability is quite high that cave passages or karstic waterways would be penetrated by drilling during oil and gas exploration.

Sound groundwater management strategies have recognized the need to establish protected zones or areas where there are activities that would conflict with the quality of recharge water (Jackson 1982). In the Spanish Point area, establishing protected zones could conflict with existing rights, such as mineral leases, and other existing land uses. This paper will present the case history of using the Bureau of Land Management's current land use planning process and the Area of Critical Environmental Concern designation, authorized by the FLPMA, to establish a protected groundwater recharge zone.

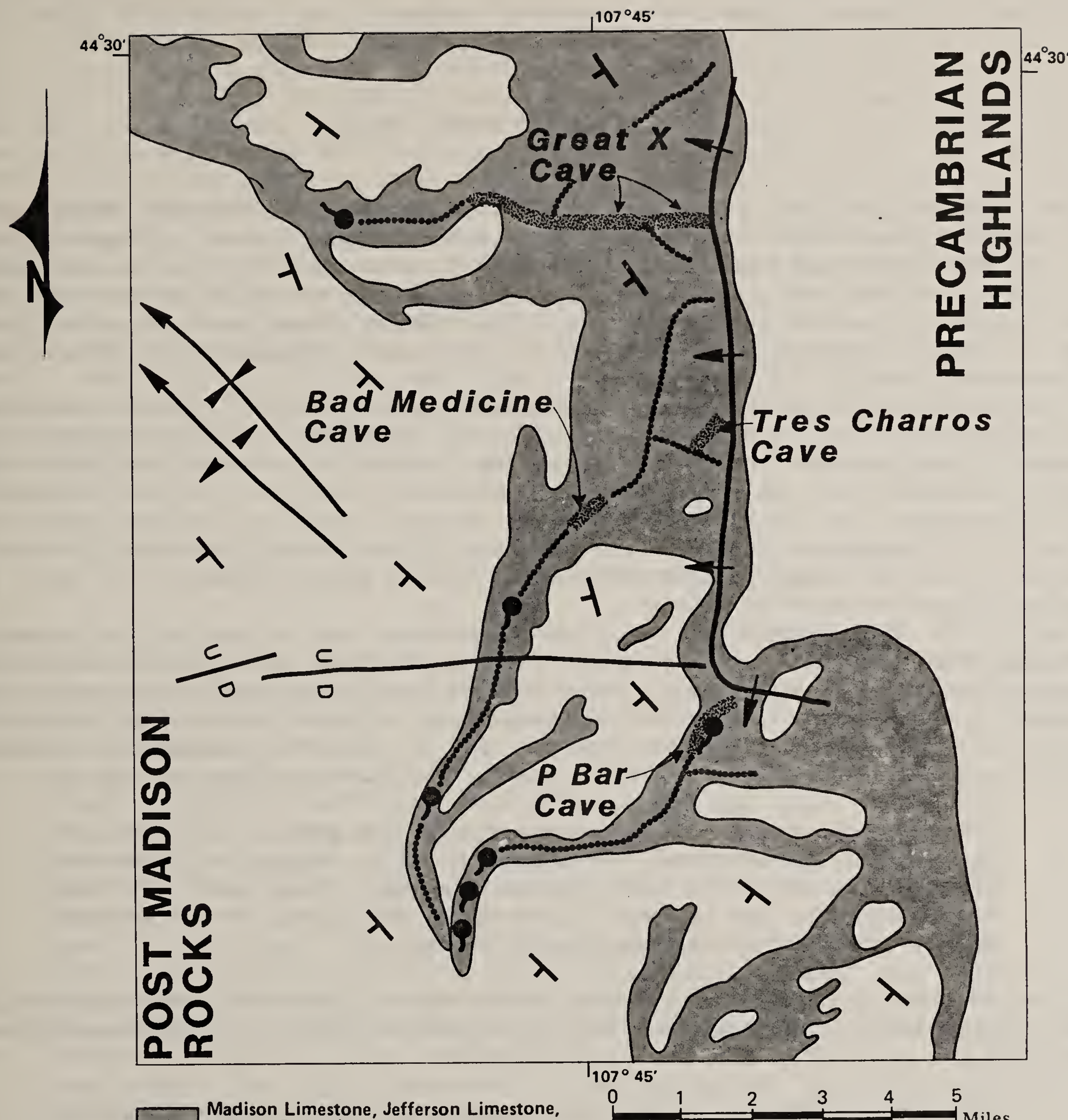
DESCRIPTION OF THE SPANISH POINT KARST AREA

The proposed Spanish Point Karst ACEC includes stream channels and canyon rims of Trapper, Dry Medicine Lodge and Medicine Lodge creeks (Map 1). Geographically, the area is located along the eastern border of the BLM's Washakie Resource Area on the west slope of the Bighorn Mountains (Map 2). Huntoon (1985b) has described the regional hydrogeology in the following way:

> "The Trapper-Medicine Lodge area serves as a recharge area for aquifers interbedded within the Paleozoic and Mesozoic section. The sediments dip gently westward at about six degrees in a homocline that is being stripped of its younger sediment by erosion. The resulting configuration is one of broad dipslopes composed of successively older units as one proceeds upstream in various drainages in the area.
>
> The 1,150 ft. section of carbonate rocks comprising the Madison aquifer crops out between younger rocks to the west, and Cambrian and Precambrian rocks to the east. Units within the carbonate sequence include from bottom to top: Ordovician Bighorn Dolomite, Devonian Jefferson Limestone and Mississippian Madison Limestone. Overlying and underlying shales in the section serve as regional confining layers both westward in the basin and within the Trapper-Medicine Lodge area in locations where they are preserved.
>
> All surface streams which originate on the Precambrian highlands to the east [the Bighorn National Forest] sink into the first downstream carbonate outcrops they encounter. In most cases, sinkholes are developed in the basal Bighorn Dolomite, where extensive caves dissolved from the carbonate sequence conduct water downgradient but up section to resurgences in the floors near the westernmost exposures of the Madison Limestone."

Entrances, passageways and karstic waterways associated with four major caves are included within the boundaries of the proposed Spanish Point Karst ACEC. The four are Great Expectations Cave (Great X) in Trapper Creek (presently the second deepest cave in the United States), La Caverna de los Tres Charros (Tres Charros) and Bad Medicine Cave in Dry Medicine Lodge Creek, and P-Bar Cave in Medicine Lodge Creek. Two lesser caves, Dry Medicine Lodge Creek Cave and the Sinks of Johnny Creek Cave also are included in the ACEC. The complete, known cave system of Tres Charros, Bad Medicine, and Dry Medicine Lodge Creek caves is within the ACEC boundaries. The complete systems associated with Great-X, Johnny Creek and P-Bar caves are not contained completely within the ACEC.

Both Aley (1983) and Huntoon (1985a) have investigated the fate of water initially entering the karst system. Caves within the Trapper-Medicine Lodge area have the capacity to initially receive large quantities of flowing water. For example, BLM personnel have measured flows of 50 cubic feet per second (cfs) entering the entrance of Dry Medicine Lodge and Tres Charros Caves. However, not all of this water is lost to the interior basin as groundwater. Dye tracings conducted by Aley in Dry Medicine Lodge Creek confirm that significant quantities of water exit the system as surface waters via



Madison Limestone, Jefferson Limestone, Bighorn Dolomite

Explored Cave

Subsurface Karstic Waterway

Fault

Anticline

Syncline

Monocline

Strike and Dip of Rocks

Resurgence

Modified from Huntoon: Gradient Controlled Caves, Trapper-Medicine Lodge Area, Bighorn Basin, Wyoming, 1985.

Map 2

CAVES, SINKING STREAM SEGMENTS
and SUB—KARSTIC WATERWAYS

resurgences. Huntoon (1985a) has calculated a theoretical annual recharge rate to the Madison aquifer of about 5 cfs.

IDENTIFICATION OF THE ACEC

The current land use plans in the BLM are known as resource management plans (RMPs). The Bureau's planning process consists of three tiers: a legislative/policy level; the RMP level; and the activity plan level. The product of each succeeding level is more specific than the last. The general, resource area-wide guidance developed at the RMP level is translated into site specific activity plans, such as a cave management plan or an ACEC management plan, to guide the continuing management of the areas covered by the activity plans.

Scoping for the Washakie Resource Management Plan, and the attendant environmental impact statement (EIS), identified several complex considerations that directly affected the caves in the Spanish Point area, including concerns with maintaining water quality, management emphasis for cave systems, and recreation use. As the development of the RMP/EIS progressed, it became apparent that several sensitive issues were developing relative to the management of the area. Because of the natural resources present and the legislative, political, and administrative constraints that applied to the area, a number of complex interrelationships existed.

Out of the early stages of the planning process came a preliminary recommendation for dealing with those interrelationships: the designation of the Spanish Point area as an Area of Critical Environmental Concern (ACEC) to highlight the need for special management consideration. The ACEC designation, created within the FLPMA, is an all-encompassing classification that can be used to tailor management prescriptions to sensitive resources located on the public lands. The FLPMA defines an ACEC as:

> "An area of public lands where special management attention is required to protect and prevent irreparable damage to important historical, cultural, or scenic values, fish and wildlife resources, or other natural systems or processes, or to protect life or provide safety from natural hazards."

Before designation, a potential ACEC must meet both relevance and importance criteria to become eligible for further consideration. The Code of Federal Regulations defines these criteria as:

> "Relevance. There shall be present a significant historic, cultural, or scenic value; a fish or wildlife resource or other natural system or process; or natural hazard.
>
> Importance. The above described value, resource, system, process, or hazard shall have substantial significance and values. This generally requires qualities of more than local significance and special worth, consequence, meaning, distinctiveness, or cause for concern. A natural hazard can be important if it is a significant threat to human life or property."

A review by the planning team of the resources in the Spanish Point area identified characteristics that met the relevance and importance criteria, as required by the regulations. The relevant resource within the proposed Spanish Point Karst ACEC is karst topography. These karst formations are a manifestation of natural hydrogeologic processes and consist of areas of limestone and/or dolomite which are typified by sinking stream segments, cave and cavern formation, and rapid subterranean movement of water.

The karst formations are important because they contain caves of national and statewide importance and also provide an important recharge area for the Madison aquifer. Caves within the ACEC boundaries offer opportunities for recreation and scientific study. Within the ACEC boundaries are about 45,000 feet of explored cave passages and an estimated 100,000 feet of karstic waterways. The cave entrances, passages and waterways serve as a receptacle and circulation system for very fresh water (total dissolved solids equal to about 75 mg/l) originating in the Precambrian highlands to the east on the Bighorn National Forest. A portion of the water that circulates through the karstic system is entrapped in the carbonate rocks and recharges in the widely used and economically important Madison aquifer of the interior Bighorn Basin.

From the review of the relevance and importance criteria evolved the premise that an ACEC designation was appropriate under any of the RMP's alternatives. Thus, the Spanish Point Karst ACEC was identified and carried forward through the land use plan. The ACEC designation does not imply that any special management restrictions are in force. Management of the ACEC must be determined through an analysis of alternatives in the resource management plan. Each of the Washakie RMP's four alternatives proposed a different level of management for the ACEC and those levels were analyzed in the Draft RMP/EIS.

DEVELOPMENT OF ACEC MANAGEMENT ALTERNATIVES

Work conducted by Aley concluded that karstic waterways within the Spanish Point area have been historically impacted by sediment from grazing, timber harvesting and off-road vehicle use. Aley (1983) summarized the impacts from sediment to the karstic system in the following manner:

> "Under natural conditions the streams of the area transport substantial quantities of sediment and organic material. These materials in turn enter the cave systems. Without doubt, grazing, road building and logging have all tended to accelerate the transport of these materials into the streams and ultimately the caves of the area. The question of concern is, has this change been detrimental to cave or water resources? Based upon our examination of the area and underlying cave systems, our understanding of groundwater transport in karst systems and [interpretation of data collected from dye studies], it is our conclusion that the increased contributions of sediment and organic material into groundwater systems of the area has been harmful to both water and cave resources. Damage has occurred to groundwater systems through the plugging or partial plugging of solutionally enlarged conduits through which water naturally travels through the groundwater system. Cave resources have been damaged by deposition of sediment and debris in cave passages, and particularly in some of the lower gradient passages such as ponds and lakes in Tres Charros."

It also was intuitively obvious that sinking stream segments within the Spanish Point area would serve as a direct conduit to the groundwater system for any pollutant that was capable of being transported by water. With the potential for tar sand extraction, or oil and gas exploration, and associated surface disturbing impacts in the Spanish Point area, the BLM planning team formulated and analyzed alternatives for leasable minerals management. The alternatives considered, briefly stated, are:

1. Continue to lease and allow the development of leasable mineral resources without special consideration for the karst resource.

2. Allow the exploration and development of oil, gas and tar sand with no surface occupancy stipulations attached to the lease.

3. Allow the exploration and development of leasable minerals with a combination of "no surface occupancy" and special subsurface stipulations that would require mineral development activities to be conducted in a manner which would avoid caves and karstic waterways.

4. Designate the proposed Spanish Point Karst ACEC as a "no lease" area.

The analysis of alternatives 1 and 2 quickly revealed that the resource protection needed within the karst area would not be accommodated by these options. Although alternative 2 would alleviate most concerns about surface disturbance, subsurface values would be unprotected. Thus, only alternatives 3 and 4 remained as potential management options.

The use of the "no surface occupancy" (NSO) stipulation is intended for use only when other stipulations are determined insufficient to adequately protect the public interest and/or as an alternative to "no leasing." As stated above, the NSO stipulation by itself does not adequately protect the karst and groundwater resource.

When considering the "no lease" option, a rigorous test must be met and fully documented in the land use planning record. Since the rejection of a lease offer is more severe than the most restrictive stipulation, the record must show that consideration was given to leasing subject to reasonable stipulations, including a NSO stipulation. The record must also show that stipulations were determined to be insufficient to adequately protect the public interest. A "no lease" decision should not be made solely because it appears that directional drilling would be unfeasible, especially where a NSO lease may be acceptable to a potential lessee.

When comparing and contrasting the ultimate resource protection afforded the karst areas by alternatives 3 and 4, alternative 3 initially appeared to provide adequate protection for the proposed Spanish Point Karst ACEC. However, when further consideration was given to the nature of the karst resource in relation to potential mineral development activities, the planning team opted to propose alternative 4 to BLM managers. The overriding factor in proposing the option of closing the area to leasing was the limited extent of knowledge regarding the exact location of caves, caverns, passageways, and karstic waterways within the proposed ACEC. Although many passages have been explored, extensive mapping of the area has not been completed. Therefore, the BLM could not provide a lessee with adequate stipulations containing precise information relating to the location of underground caverns so that avoidance of these areas could be successfully accomplished, even with the use of directional drilling technologies. There is also a high probability that undiscovered passageways and caverns exist within the boundaries of the proposed ACEC.

After thorough consideration and much debate, BLM managers ultimately selected the "no lease" option as the preferred management alternative. Management of the proposed ACEC, according to the preferred alternative, would emphasize watershed protection and in conjunction with the "no lease" prescription would include:

A withdrawal from the nondiscretionary land laws, including the location of mining claims under the 1872 Mining Law, would be pursued.

Off-road vehicle use restrictions would be applied to the entire area. All roads and trails in Dry Medicine Lodge Canyon would be closed and rehabilitated where accelerated erosion is occurring.

Logging restrictions would be applied on steep slopes, in stream buffer zones, and to equipment use.

The use of insecticides, herbicides and silvicultural chemicals would be considered on a case-by-case basis. If approved, the use would be conducted under stringent guidelines. Alternative forms of control, such as physical or biological controls, would be preferred.

Vegetation would be managed to maximize or maintain ground cover.

Cooperative agreements would be sought, where possible, for the management of surface activities in nearby watersheds on the Bighorn National Forest and on private lands, to complement the management proposed for public lands.

Full implementation of these planning recommendations would create a protected zone around critical karstic groundwater recharge areas. However, there are still several important, time consuming processes, which must be completed before the planning decisions are fully implemented. After the Final RMP/EIS is published and an approved management plan for the Washakie Resource Area is developed, an ACEC management plan would be written to specifically address the future management of the area. The prescriptions provided in the approved management plan would be used as guidance in the development of the ACEC management plan. The management of surface disturbing activities in the watersheds of the ACEC would emphasize the protection of known caves and related sinking stream segments from unnecessary sedimentation and chemical pollution. Subsurface management would ensure that caves and karstic waterways would not be penetrated by exploratory drilling or other mining activities. A complementary cave management plan would identify the management needed to protect caves and water resources from impacts associated with cave recreation.

SUMMARY AND CONCLUSIONS

The management of the recharge areas within the proposed Spanish Point Karst ACEC has been, and will continue to be, a complex effort. Ownership of the surface above the caves in the ACEC is split among private individuals, the United States (managed by the BLM), and the State of Wyoming. Immediately upstream from the caves are federal lands managed by the U.S. Forest Service. That portion of the mineral estate owned by the federal government is leased with existing rights of development. Not all landowners agree as to what the best management alternatives are for particular lands. Changes in vegetative cover from mineral development, logging, livestock grazing, road building, and recreation, can affect the quantity and quality of water flowing directly into the caves or percolating through the karstic areas within the recharge zone.

The use of protected zones for management of critical municipal and agricultural aquifers is a concept that should be increasingly used as additional groundwater supplies are developed throughout the United States. In the western United States, where vast acreages are still in public ownership and are managed by the Bureau of Land Management, Areas of Critical Environmental Concern offer an administrative opportunity for the identification and management of vital groundwater recharge areas. The ACEC designation allows for ultimate management flexibility, because management can be tailored to the resources to be protected.

In the proposed Spanish Point Karst ACEC, stringent protective management was proposed and ultimately accepted because of the importance of the direct surface water-groundwater relationship created by the karstic topography. It should be noted however, that uses of natural resources, including extractive uses, need not be excluded from an ACEC, so long as the critical environmental concerns are protected.

The Bureau of Land Management is committed to the management of critical watersheds, such as those found in the proposed Spanish Point Karst Area of Critical Environmental Concern, as part of its multiple-use mandate. Guidance developed through resource management planning and environmental analysis will continue to be an important tool for water resources management.

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THE INFLUENCE OF ENDANGERED FISH PROTECTION ON WATER DEVELOPMENT PROJECTS IN THE UPPER COLORADO RIVER SYSTEM.

Dr. Gregory F. Thayn[1], Jerald E. Farringer[2], and Robert Ruesink[3]

ABSTRACT: The presence of Federally listed endangered fish species in the Upper Colorado River Basin has the potential of preventing any further development of water projects on the upper Colorado River and its tributaries. Federal and state agencies and special interest groups are cooperating to achieve both protection of endangered species and development of water resources. Two projects involving BLM rights-of-way and the need for Colorado River system water illustrate how both objectives are being met.
KEY TERMS: Endangered species; Upper Colorado River; water development; Section 7 Consultation.

INTRODUCTION

The Congressional Policy statement in the Endangered Species Act as amended is that all Federal departments and agencies shall seek to conserve endangered species and threatened species while cooperating with State and local agencies to resolve water resource issues in concert with conservation of the endangered species. In keeping with this policy the Bureau of Land Management (BLM) reviews applications for rights-of-way (ROWs) and other land use authorizations for potential effects on endangered species.

Two proposed projects in the Uintah Basin of Utah provide examples of efforts by the BLM and other Federal agencies to conserve endangered species in the Upper Colorado River system, while providing for development and use of water resource projects. They are the Bonanza Power Plant and the White River Dam Projects.

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[1]EIS Coordinator, Bureau of Land Management, Utah State Office, 324 South State, Salt Lake City, Utah 84111-2303

[2]Wildlife Biologist, Bureau of Land Management, Utah State Office, 324 South State, Salt Lake City, Utah 84111-2303

[3]State Supervisor, Fish and Wildlife Enhancement, U.S. Fish and Wildlife Service, 1745 West 1700 South, Salt Lake City, Utah 84104-5110

BACKGROUND

In 1979 Deseret Generation and Transmission Cooperative (Deseret) filed application with BLM for ROWs required for construction of the 800 megawatt Moon Lake Power Plant Project in Uintah County Utah (See Figure 1). Following construction the Moon Lake Power Plant was renamed as the Bonanza Plant. Deseret's proposed course of action was to pipe water approximately 19 miles from a collector-well system located beside the Green River to the power plant near Bonanza, Utah (See Figure 2). The water was to be taken from a 30-cubic-feet-per-second (cfs) (21,720 acre-feet per year) Green River water right owned by Deseret (BLM, 1981).

As proposed, a maximum of 21,720 acre-feet of water was to be withdrawn annually (30 cfs) from the Green River during the project's planned 30 year life. The Green River is considered a firm water supply even in time of extreme drought because of the large upstream storage capacity of Flaming Gorge Reservoir.

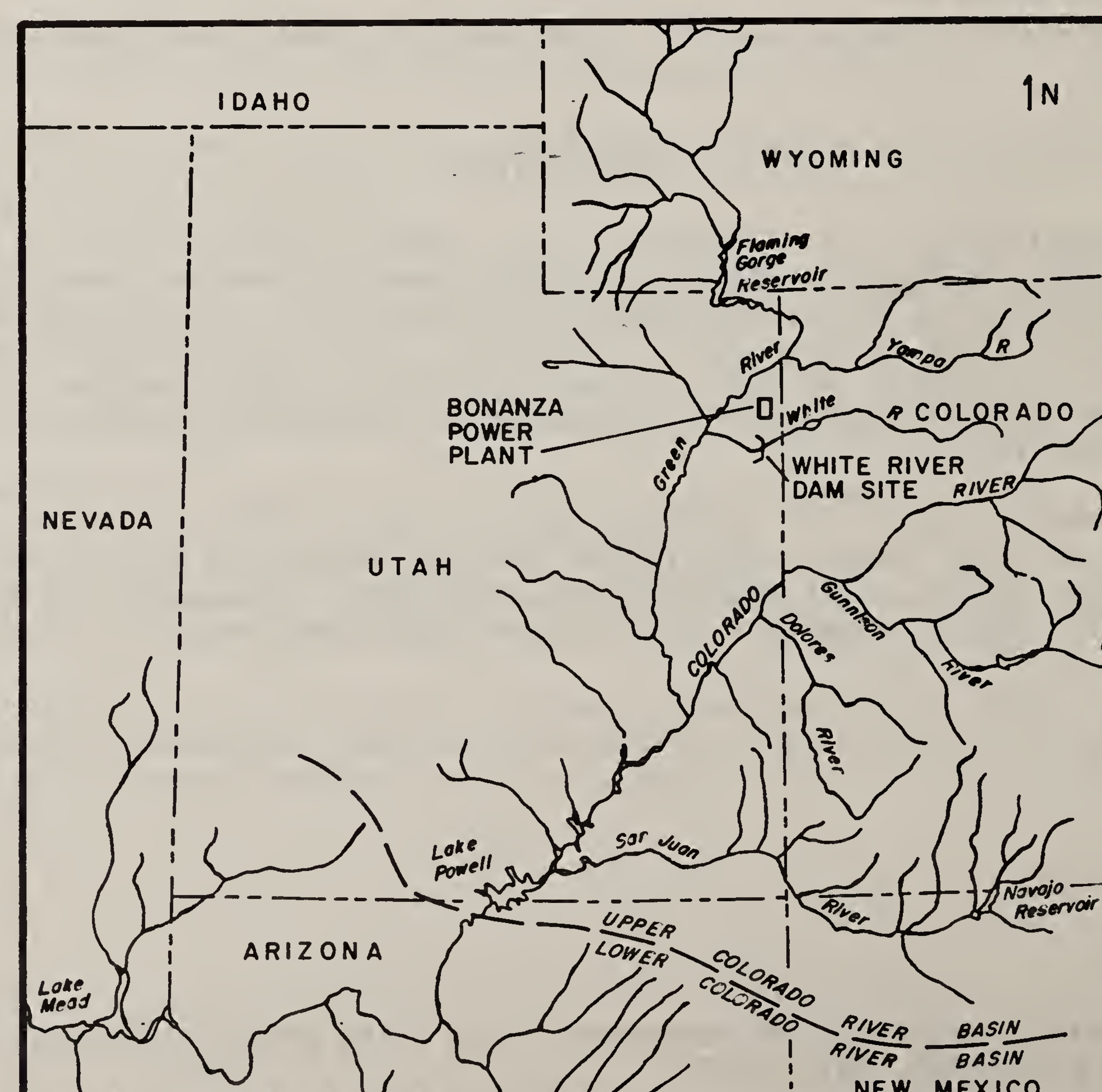

FIGURE 1

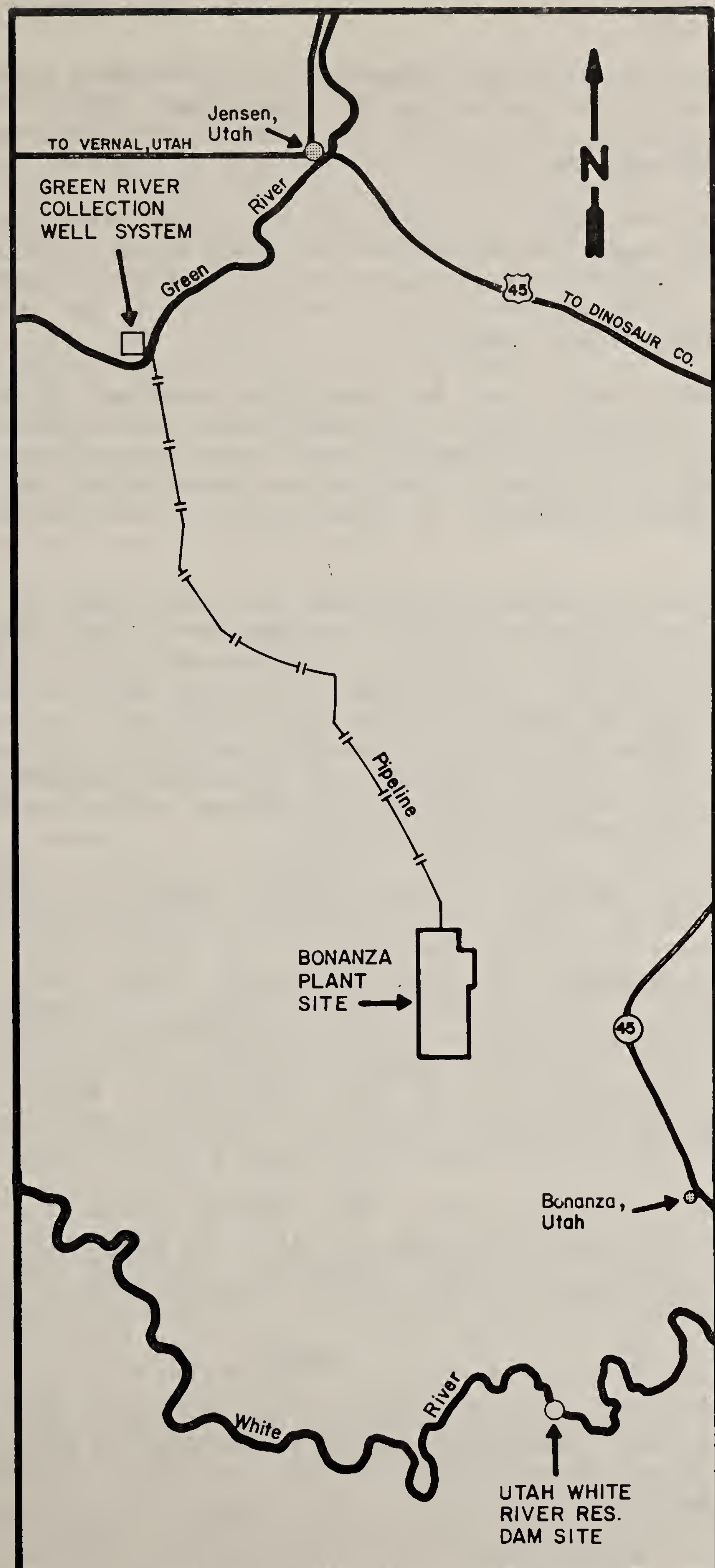
TO VERNAL, UTAH
Jensen, Utah
N
GREEN RIVER COLLECTION WELL SYSTEM
Green River
45
TO DINOSAUR CO.
Pipeline
BONANZA PLANT SITE
45
Bonanza, Utah
White River
UTAH WHITE RIVER RES. DAM SITE

FIGURE 2

The proposed water supply system was a cluster of 9 wells placed 45 feet deep in permeable materials adjacent to the Green River. Each well unit was to include a reinforced concrete caisson with a series of 200 foot long screen pipes projecting underneath the river.

Similarly, in 1975 the Utah Division of Water Resources had filed a right-of-way application with the BLM for 3,402 acres of public land to facilitate construction of an earthen dam across the White River to create an 11.7 mile long reservoir with 1,980 surface acres. The purpose of the reservoir was to provide water for industrial development.

The reservoir design was to have 70,700 acre-feet of active storage capacity and a sediment reserve capacity of 38,550 acre feet. Also proposed were a 15-megawatt (MW) hydroelectric power plant, power transmission system, recreational facilities, and access roads. The proposed location of the project is 40 miles southeast of Vernal, Utah and 12 miles south of the Bonanza Power Plant Project (See Figure 2).

In response to these applications the BLM prepared the Draft and Final Environmental Impact Statements for the Moon Lake Power Plant Units 1 and 2 and White River Dam Projects in 1981 and 1982 respectively (BLM, 1981 and 1982). As required by the National Environmental Policy Act (NEPA) and the Endangered Species Act, the BLM initiated Endangered Species Act Section 7 consultation with the Fish and Wildlife Service (FWS) concerning potential impacts on endangered fish species in the Green, White, and Colorado Rivers as a result of the water withdrawals for the Bonanza Plant and the blockage and change of flow regime and water quality associated with the White River Dam Project.

The species involved are the Colorado squawfish, (Ptychocheilus lucius), humpback chub (Gila cypha), and the bonytail chub (Gila elegans). These species were once abundant throughout the Colorado River system from the Gulf of California to southwestern Wyoming. The squawfish now is limited to the upper mainstem and major tributaries of the Colorado River system. The humpback and the bonytail chubs are found only in limited areas within the Colorado River Basin in Colorado, Utah, and Arizona. The primary causes of decline for these fish species is human alteration and degradation of the river environment. Major impoundments and water diversions have depleted water supplies and altered the temperatures, turbidity, salinity, and flows of the stream, thus reducing habitat for endemic fishes.

The major interacting factors that largely explain the present status of the endemic species of the Colorado River Basin are reservoirs, diversions from the basin for agricultural, municipal, industrial, etc. use, and environmental changes in the river brought about by the reservoirs and withdrawals (FWS, 1981).

FINDINGS

The FWS formal biological opinions (FWS, 1981 and 1982) stated that operation of the projects with conservation measures designed to aid in the recovery of the endangered Colorado River fishes, would not likely jeopardize the continued existence of the fish.

The biological opinion on the Bonanza Power Plant recognizes that flow depletion in the Green River has the potential for immediate and long-term effects. The immediate effect would be to reduce the required habitat. The depletion of water during the peak runoff periods may lower overall reproductive success of the fishes. Reduction of flows to an unknown critical level could result in the loss of habitat restricting the endangered fish population, and increasing the danger of disease and predation by other fish. Consequently, conservation measures would need to be included in the project.

The White River Dam Project, without the conservation measures, would adversely alter habitat characteristics in the White River. It would reduce peak spring flows, reduce turbidity and silt load, and reduce annual flows. The Dam would isolate squawfish above the dam site, and prevent fish migration. The reservoir would create habitat for nonnative fish species and reduce the amount of habitat available to native species. The project design included a multiple level outlet works so that water releases would not significantly alter the temperature regime of the river below the proposed dam.

The biological opinions on these and other projects involving the Upper Colorado River System define the phrase "jeopardize the continued existence of" to mean that a project would "reasonably be expected to reduce reproduction, numbers, or distribution of a listed species to such an extent as to appreciably reduce the likelihood of the survival and recovery of that species in the wild." The Bonanza Power Plant Project was determined not to appreciably reduce the likelihood of survival of the Colorado River endangered fishes. However, it was determined that since the "precarious status of the fish can be related to decreased flows in the basin, additional water use is likely to make recovery of the species more difficult." Without conservation measures the Bonanza Power Plant Project would jeopardize all three of species endangered fish, and the White River Dam would jeopardize the Colorado squawfish.

Deseret was given two options for conservation measures to ensure that the endangered fish were not jeopardized. Option A was to negotiate a contract for purchase of up to 30 cfs (22,089 acre feet) of Flaming Gorge water, contingent upon the approval of the Utah State Engineer of an application for change of point of diversion and nature of use; and Option B was for Deseret to fund their fair share of activities developed for the purpose of financing studies and/or programs designed by the FWS to conserve the endangered fish species in the Colorado River system in an amount not to exceed $500,000.

Deseret selected Option B and on November 4, 1985 submitted a check in the amount of $81,567 to Region 6 of the FWS for conservation of endangered fish. Deseret's contribution was based on a depletion charge of $14.92 per acre-foot of water. The FWS calculated this figure on the basis of the remaining unallocated water in the Upper Colorado River Basin (approximately 1,675,000 acre-feet) and an estimated 25 million dollar cost for recovering the endangered fish populations (FWS, 1987a). The $81,567 charge was based on the operation of only one of the two proposed 400 MW units.

To date, 3 wells are inplace and operational, delivering approximately 4,200 acre-feet of water per year to the power plant (Deseret,1987).

This approach to endangered fish conservation is referred to by the FWS as the "Windy Gap Process", named for the concept applied originally for the Windy Gap Reservoir Project in Wyoming in 1980. The Bonanza Power Plant Project was the second to which the FWS applied the Windy Gap concept (FWS,1987a). The initial thrust of the process was to provide money for studies as a data base for use in protection and recovery projects for the endangered fish while providing a way for water development projects to proceed. Since 1981, the FWS has refined the Windy Gap process and incorporated it into the context of a cooperative Federal, State and interest group program outlined in the draft "Recovery Implementation Program For Rare and Endangered Fish Species In The Upper Colorado River Basin" (Colorado River Coordinating Committee, 1986). This document was prepared at the request of the Upper Colorado River Coordinating Committee which was organized in 1984 through a Memorandum of Understanding (MOU) between the FWS, Bureau of Reclamation, and the states of Colorado, Wyoming, and Utah. The main objective of the Coordinating Committee is to provide for recovery of the Endangered fish populations while accommodating resource development. The MOU also established a technical steering committee and subcommittees responsible for compiling and assessing data and making recommendations to the Coordinating Committee. These committees are comprised of representatives of groups such as water users, water development proponents, and conservation organizations.

Under the draft plan, new water project proponents involved in Section 7 consultation may compensate for the effects of water withdrawal by making a one-time contribution of $10 per acre-foot based on the estimated average annual depletion of the project. The $10 per acre-foot charge is based on the amount of undeveloped water that is expected to be used over the life of the recovery program and is comparable to the amount previously collected, using the windy gap approach. The figure is adjusted annually for inflation. Bureau of Reclamation projects are exempt from the depletion charge, since they can refine operations to provide water for rare species and they regularly contribute financially to the recovery program on an annual basis. One of the major uses of the collected funds is to purchase water rights to ensure instream flows. Because the program is intended to provide water rights, the FWS considers this as offsetting depletion impacts that otherwise would occur, making non-jeopardy opinions possible in Section 7 consultation.

Nondepletion impacts of water projects such as those that would be caused by construction of the White River Dam (eg. inundation, habitat modification, migration barriers etc.) still are subject to implementation of design, location, or operational alternatives to offset impacts. The conservation measures required by the FWS for the White River dam are examples of such alternatives which can lead to a nonjeopardy opinion. As outlined in the biological opinion the State of Utah was to provide funding and/or equivalent resources to insure that the conservation measures were implemented. Design measures included outlets from four levels in the reservoir to ensure mixing of water to maintain normal water temperatures, and studies to determine the feasibility of squawfish passage around or through the dam to avoid a migration barrier. Required operational measures included minimum daily flow requirements for normal, wet and dry years and limitations on the fluctuation of flows. Problems with nonnative species were to be offset by developing the reservoir as a native species fishery. This would require downlisting of the squawfish to threatened status in the reservoir only.

In addition, the State was to support studies of spawning areas and the potential enhancement of habitat above the reservoir. Contribution to a hatchery program also was anticipated. Specific details on responsibilities, time frames and funding were to be developed in a Memorandum of Agreement between the State of Utah and Department of the Interior prior to any physical construction activities.

The Draft Recovery Implementation Program requires that funds collected from project proponents are placed in interest-bearing accounts until they are utilized. Funds are to be applied equally to acquisition of water rights for instream flows and to other recovery activities. Other areas suitable for expenditure of funds include 1) program management, 2) habitat management (eg. defining flow needs), 3) habitat development (eg. structures), 4) stocking of native fishes (eg. hatchery work and reintroductions), 5) control of nonnative species and sportfishing, and 6) research, monitoring, and data management. Participants and proponents may provide in-kind services in lieu of financial contribution to support the recovery program if these services are determined to meet the objectives of the recovery program. Deseret's contribution has not been spent, and will likely be utilized as outlined in the implementation plan (FWS, 1987a). The BLM rights-of-way for the White River Dam Project were issued by BLM but the project has not been constructed by the State due to reduction in demand for the water.

According to Larry Shanks, Chief of Endangered Species and Environmental Contaminants, FWS, Denver, Colorado (FWS,1987b), the future emphasis of the FWS in providing for recovery of endangered fish populations is to become involved early in project planning to ensure that project design and operation are compatible with endangered species recovery before formal Section 7 consultation is initiated.

Proponents of water projects in the Upper Colorado River Basin are encouraged to work with both the BLM (where Federal lands are involved) and the FWS for protection of the endangered Colorado River Fishes.

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PROTECTION OF WATER RESOURCES FROM OIL AND GAS PRODUCED WATER DISPOSAL

Steve Vandas[1], Paul Summers[2]

ABSTRACT: The Bureau of Land Management (BLM) is responsible for the administration and leasing of all federally owned oil and gas resources. BLM is also required to protect and maintain the quality of the water resources on public lands. Through the BLM planning process lands are identified as having potential for oil and gas leasing. Some of these areas require special stipulations to protect various resource values; oil and gas leasing may be precluded in environmentally sensitive areas. The protection of water resources is a primary consideration of the Bureau's oil and gas leasing program.

The disposal of produced water from developed leases has a great potential for impacting the existing water resources. Produced water can be disposed of by underground injection, discharged into surface impoundments, or other acceptable methods. Several Federal laws and regulations dictate methods for the disposal of produced water.

Within a broad regulatory framework, BLM must make numerous decisions concerning not only where to lease, but how to dispose of produced waters. This paper describes BLM's planning system as it relates to oil and gas leasing, discusses regulations concerning the disposal of produced waters, and provides several analytical techniques which can be utilized to make predictions about the potential movement of contaminants. These methods provide land managers with the information necessary to ensure proper disposal of oil/gas field drilling wastes.

INTRODUCTION

The Bureau of Land Management (BLM) is responsible for the administration and leasing of all federally owned oil and gas resources. BLM is also required to protect and maintain the quality of the water resources on public lands.

Both of these objectives are initially addressed through BLM's planning process. BLM has developed a resource management planning process to assist managers in making land-use decisions. BLM's planning process is used to develop resource management plans that examine management alternatives for all resources and land uses on BLM public lands. All resource management programs must utilize the planning system to identify management options.

[1] Hydrologist, U.S. Bureau of Land Management, Colorado State Office, Denver, Colorado
[2] Hydrogeologist, U. S. Bureau of Land Management, Service Center, Denver, Colorado

The decision concerning which areas are available for oil and gas leasing is made in the resource management plan. The plan also includes special stipulations and conditions necessary for the protection of the water resources. As an example, an area may be leased with a no surface occupancy stipulation, such as leasing in floodplains, or in areas with steep highly erosive soils. Lease development would have to be done outside these critical areas through slant drilling.

The resource management plans take into consideration the specific problems facing each individual BLM resource area. An environmental impact statement is written in association with the resource management plan, in which impacts to the water resources are identified and mitigated. State and federal laws require the protection of existing uses of the water resource. Federal Regulation 43 CFR 3162.5-2(d), Oil and Gas Leasing, requires that the lessee isolate and protect from contamination freshwater and other viable water zones containing less than 5,000 ppm it dissolved solids. Additionally, 43 CFR 3162.1(a), 43 CFR 3162.5-2(d), and 43 CFR 3152.5-1(a) identify the lessee/operator's responsibility to protect and maintain the quality of the environment including water and soil resources, site productivity, and watershed values on public lands. The BLM must assure that the lessee complies with the protection of water resources.

After an area has been leased and developed, the Bureau of Land Management must ensure proper disposal methods of the produced water. This paper will only address the disposal of produced waters on lease. Off lease disposal has numerous lands and rights-of-way implications, and will not be addressed here. Produced water can be disposed of by underground injection, discharged into surface impoundments, or other acceptable methods. The approval authority for produced water disposal varies from state to state between the BLM, Environmental Protection Agency (EPA), and a state agency.

The greatest volume of produced water is disposed of through underground injection. The underground injection of produced waters is usually regulated by either the EPA, or the state if granted primacy. The injection of produced water is dictated through the

Underground Injection Control (UIC) program. The UIC program was established under the authority of Part C. of the Safe Drinking Water Act with the objective of protecting underground sources of drinking water (USDW). It applies to all classes of injection wells. The injection of produced waters has been classified as Class II. By definition, a USDW is an aquifer or its portion which supplies any public water system; or which contains a sufficient quantity of ground water to supply a public water system; and

a. Currently, supplies drinking water for human consumption; or

b. Contains fewer than 10,000 mg/l total dissolved solids; and

c. Which is not an exempted aquifer.

In the course of permitting wells, the regulating entity is often requested to exempt certain aquifers or portions of aquifers which qualify as USDWs. After an aquifer has been exempted from USDW status, the regulating entity will allow injections to take place that normally would be prohibited. For the regulating entity to designate a USDW as an exempted aquifer, the aquifer must meet the following criteria:

It does not currently serve as a source of drinking water; and

It cannot now and will not in the future serve as a source of drinking water because:

a. It is mineral, hydrocarbon or geothermal energy producing or can be demonstrated by a permit application for a Class II or III operation to contain minerals or hydrocarbons that, considering their quantity and location, are expected to be commercially producible; or

b. It is situated at a depth or location which makes recovery of water for drinking water purposes economically or technologically impractical; or

c. It is so contaminated that it would be economically or technologically impractical to render that water fit for human consumption; or

d. It is located over a Class III well mining area subject to subsidence or catastrophic collapse; or

e. The total dissolved solids (TDS) content of the ground water is more than 3,000 and less than 10,000 mg/l, and it is not reasonably expected to supply a public water system.

The public is encouraged to comment on all proposed aquifer exemptions. Public notice will be published in local and regional newspapers for all aquifer exemption and permit actions. Public hearings will be held if sufficient interest is shown.

The UIC program for Class II wells is only for the protection of drinking water aquifers from the injection of production waters. Protection from degradation of both drinking and non-drinking water aquifers from the disposal of oil and gas produced waters by pits or other methods is the responsibility of the BLM or the State Oil and Gas Commission; usually not EPA.

When the BLM has the approval authority for determining the appropriate disposal method for produced waters, it is guided by requirements and standards established in Notice to Lessee (NTL) 2B. These regulations establish criteria necessary for the determination of surface disposal methods. NTL-2B specifically addresses data requirements for assessing the necessity to line a disposal pit.

For disposal of water in lined pits, the following information is requested prior to approval by BLM.

1.
Map showing size and location of pit.

2.
The daily quantity, sources of the produced water, and a water analysis which includes the concentrations of chlorides, sulfates, and other constituents which are toxic to animal, plant, or aquatic life.

3.
The evaporation rate for the area compensated for annual rainfall.

4.
The method for periodic disposal of precipitated solids.

5.
The type of material to be used for lining the pit and the method of installation.

6.
The method to be employed for the detection of leaks and plans for corrective action should a leak occur in the liner.

For the disposal in unlined pits, the lessee or operator must show, by application that the disposal meets any one or more of the following:

1.
The water to be disposed of has an annual weighted average concentration of not more than 5,000 ppm of total dissolved solids, provided that such water does not contain objectionable levels of any constituent toxic to animal, plant, or aquatic life.

2.
That all, or a substantial part, of the produced water is being used for beneficial purposes. For example, produced water used for purposes such as irrigation and livestock or wildlife watering shall be considered as being beneficially used.

3.
The water to be disposed of is not of poorer quality than the surface or subsurface waters in the area which reasonably might be affected by such disposal or the surface and subsurface waters are of such poor quality as to eliminate any practical use thereof.

4.
The volume of water to be disposed of per facility does not exceed five barrels per day on a monthly basis.

Applications for approval of unlined surface pits pursuant to exception numbers 1, 2, 3, or 4, above, must include:

1.
The daily quantity and sources of the produced water and for exception Nos. 1 through 3, a water analysis which includes total dissolved solids, pH, and the concentrations of chlorides and sulfates.

2.
A topographic map of suitable scale which shows the size and location of the pit.

3.
The evaporation rate for the area compensated for annual rainfall.

4.
The estimated percolation rate based on the soil characteristics under and adjacent to the pit.

5.
The depth and areal extent of all usable water (i.e., less than 10,000 ppm total dissolved solids) aquifers in the area.

Utilizing the above requirements, the BLM must decide which method to approve, balancing water resource protection, with least cost to the lessee/operator.

The protection of the water resources is primarily an antidegradation issue. Antidegradation implies that existing uses shall be maintained as required by state and federal law. No further water quality degradation is allowable which would interfere with or become injurious to existing uses.

Many of the oil and gas leases on BLM lands are located in remote, sparsely populated areas. As a result, very little information is usually available concerning the ground water resources. In order to protect the existing uses of water and make a determination as to the type of disposal method, information is required to rate the ground water contamination potential, and rate the magnitude of potential endangerment to current users of the area's water resources.

The parameters needed in order to rate the water resource contamination potential are:

1.
The thickness of the unsaturated zone (re depth to ground water) and the type of earth material of that zone (permeability of the zone, geologic dip, and presence of any continuing layers).

2. Distance to surface water supplies

3.Water quality of the produced waters.

4. The quality of the surface and ground water resources of the area.

The parameters needed in order to determine the magnitude of potential endangerment to current uses of the area's water resources are:

1. Type of water source (surface or ground water).

2. Anticipated flow direction of the produced waters.

3. Existing water uses.

4. Quality of the area's waters.

The EPA has established numeric criteria for certain constituents based upon designated use, (i.e., human health standards, agricultural standards). Each state must adopt water quality standards for the water of the state, that are at least as stringent as those developed by EPA. The states can be more stringent if they choose. It is these state standards that provide the basis for determining degradations to the receiving waters from oil and gas produced waters.

Utilizing the above information in many instances, BLM can make a determination as to the recommended disposal method.

Depending upon the quality of the produced waters, distances to potential receiving waters (both surface and ground waters), and the existing uses in quality of that water, further analysis may be required.

The potential risk to ground water resources from produced water disposal in surface impoundments is rated using hydrogeologic factors for the specific site. This ranking method provides an assessment of potential contamination at a minimum cost, by utilizing existing information and applying professional judgment to the factors. If, after the screening process identifies serious contamination potential, specific detailed investigation or computer modeling of the site can then be conducted. Methods of evaluating hydrogeologic factors for ground water contamination studies and monitoring is discussed in Summers, Griffith and White (1985).

Ranking schemes for evaluating ground water pollution potential have been developed by several investigators (LeGrand, 1980; LeGrand, 1964; and Aller, 1985). Most of these systems are concerned with evaluating hazardous waste sites. However, the factors that need to be considered for oil/gas produced water impoundments are similar to the factors for hazardous waste sites.

A rating scheme developed for surface impoundments (Silka and Swearingen, 1978) can be used for screening potential ground water contamination at specific impoundment sites. This method was used by EPA in the National Surface Impoundment Assessment (EPA, 1983). The SIA method identifies two phases of the investigation: 1) the rating of the ground water contamination potential, and 2) the rating of the relative magnitude of potential endangerment to current users of underground drinking water sources. The method presented here is similar to EPA's Drastic Methodology (Aller, 1985), except that the drastic ranking procedure does not consider the pollutant which is entering the ground water system. When considering the pollution potential of ground water, the following factors should be included: 1) the thickness of the unsaturated zone, and the type of earth material in that zone, 2) the relative hazard of the waste, and 3) the quantity and quality of the underground drinking water source beneath the site (Silka and Swearingen, 1978). Of these, the primary factor to consider is the potential endangerment to public health. Thus, all water wells or water supply systems being used for drinking water supply in the vicinity (1 mile) of the impoundment must be inventoried.

SITE EVALUATION METHODOLOGY

When evaluating a surface impoundment site (or a potential future site), a complete assessment must be made of the hydrogeologic factors that controls potential aquifer pollution. The evaluation process described here is a procedure which rates the site's hydrogeology, the character of the waste in the impoundment, and finally, the potential endangerment to existing water uses. This process evaluates the following factors: (1) the unsaturated zone, (2) the availability of ground-water, (3) the waste hazard potential, (4) the existing ground water quality, and (5) the overall ground-water contamination potential (combination of factors 1 + 2+ 3 + 4). Using this information, the site is then rated as to the potential endangerment to water uses in the vicinity of the impoundment. The final step is to assign the level of confidence about each of the scoring factors. This step is used to determine the reliability of the information to help assess whether further studies are needed.

EVALUATING THE UNSATURATED ZONE

The character and thickness of the unsaturated zone is a crucial factor in the potential for contamination of a site. A thin unsaturated zone will not provide for the attenuation of pollutants; in addition, ground-water mounding underneath the impoundment is more likely to occur. Ground-water mounding can provide a direct conduit for pollutants to enter the ground-water system, without undergoing any attenuation of pollutants. A method of calculating the build-up of the ground-water mound can be found in Hantush (1967).

The depth of the unsaturated zone is the depth from the base of the surface impoundment to the water table (in unconfined aquifers). For confined aquifers, this depth is measured from the base of the impoundment to the top of the confining bed (see figure 1). Where a perched water table is known to occur, the depth may be measured to the perched layer, rather than to the regional water table. The decision to measure the unsaturated zone to the perched water table or to the regional water table should be based on the extent and thickness of the perched aquifer, and its use as a source of

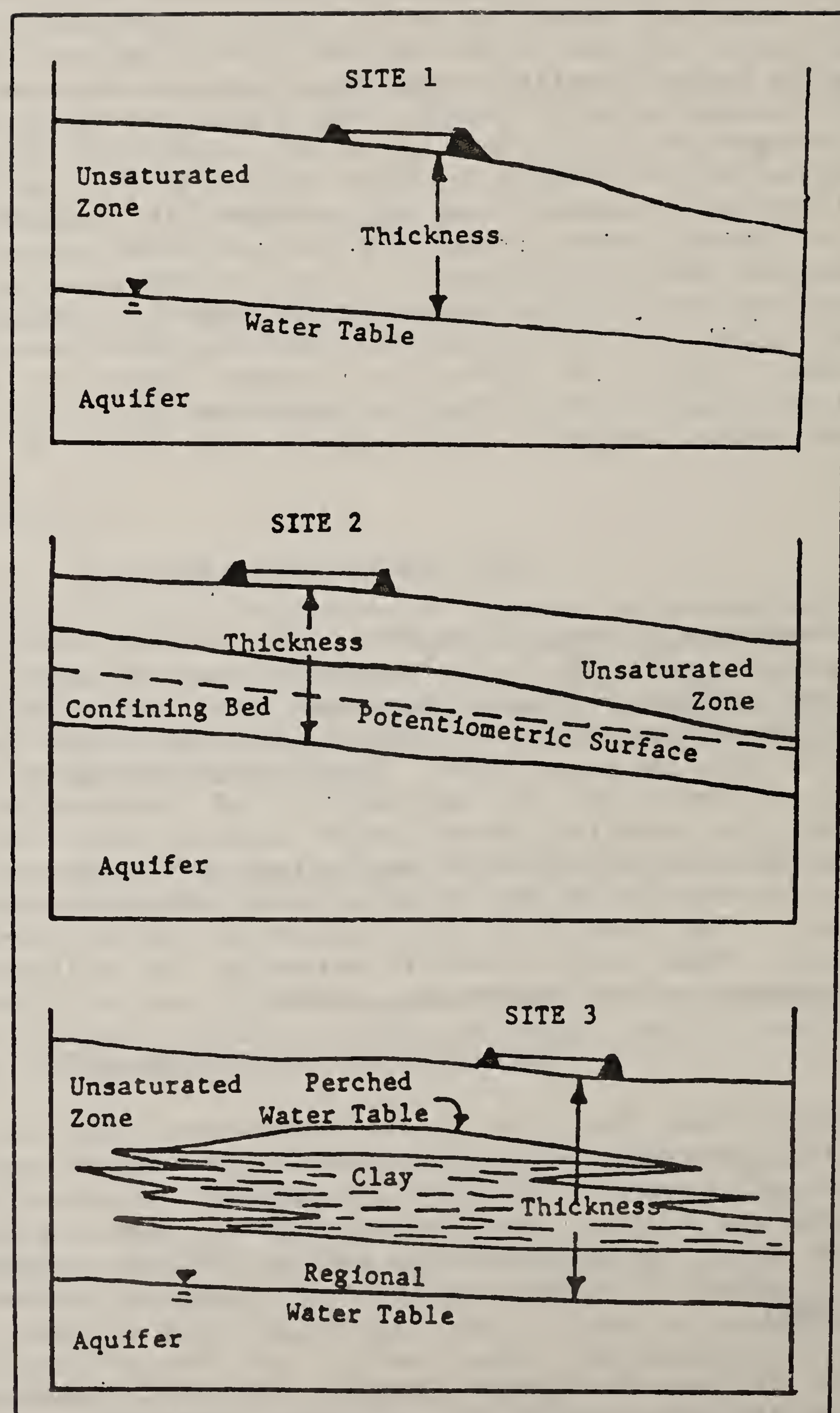

Figure 1. Guide for the determination to the saturated zone (water table for the unconfined case; top of confining bed for confined aquifer) for evaluation of unsaturated zone. (from Silka and Swearingen, 1978)

drinking water. If the perched aquifer is currently being used as a drinking water source, the depth of the unsaturated zone is the depth to the uppermost perched aquifer that is being used for a water source.

If the the depth to the water table, is less than 100 ft., consideration must be given to possible diurnal, seasonal or annual variations in the water table, as well as variations due to local pumping effects. A complete analyses of the water use of surrounding wells should be made, and an estimate made of the static, non-pumping water level for the area under study.

For confined aquifers, although the depth to the top of the confining bed may be great, the effective depth to water under the impoundment may be much less than suspected due to leakage of the confining bed. Most confining layers leak to some degree. This vertical leakage can sometimes supply large amounts of water to the overlying beds, creating in effect a water table aquifer above the artesian aquifer. Thus, complete understanding of the hydrogeologic system underlying the impoundment is essential, especially in situations where impoundments contain liquids other than produced water from oil/gas operations.

Evaluating of the unsaturated zone must include identification of the type of earth material which makes up the unsaturated zone. Materials must be ranked according to their permeability and their sorption capability. In general, grain size (or pore size) is proportional to permeability and inversely proportional to surface area which is an important factor in sorption mechanisms. As grain size is inversely proportional to sorption capacity, sorption capacity is inversely proportional to permeablility. Thus, while permeability decreases, sorption generally tends to increase.

The use of the Unified Soil Classification System may assist the investigator in making determinations about the permeablility and potential sorptive capacity of materials found at the site. Soil surveys done by the SCS should be consulted.

The geology of a potential impoundment site may be a very complex layering of unconsolidated clays, sands and gravels or consolidated sedimentary rocks. Contaminants can move readily through many of these sediments in a rather predictable way. However, secondary permeability (i.e. fractures, joints, and faults) may provide pathways for contaminants which may not be readily obvious.

EVALUATING THE AVAILABILITY OF GROUND WATER

An estimate of the ability of the aquifer to transmit water must be made. Because this methodology is to be used as a screening tool only, the ground water availability is estimated using approximations of permeability of various aquifer materials. Values of permeablility of rock units have been published by several investigators (Cherry, 1980; Fetter, 1980; and Mercer, et al., 1982).

To understand where and how ground-water pollution occurs and moves within areas of surface impoundments, the hydrogeologic framework must be understood. This information will aid in the evaluation of pollutant movement as well as in the design of efficient ground-water quality monitoring systems if the situation warrants monitoring.

Because some subsurface data are available in most areas of ground-water development, initial hydrogeologic work will consist of gathering, organizing, and analyzing existing information. For this screening procedure, collection of geologic or hydrologic information requiring field work will not be required. Specific materials needed for the evaluation, as well as how they are obtained, include the following:

1. Aquifer locations, depth, and areal extents - from geologic data.
2. Transmissivities of aquifers - from well pumping tests and geologic data.
3. Map of depths to ground water - from water levels and topographic data.
4. Areas and magnitudes of natural ground-water recharge - from precipitation, evapotranspiration, soils, land use, and water level data.
5. Areas and magnitudes of natural ground-water discharge - from spring locations, wetlands, streamflow, and water level data from wells..
6. Directions and velocities of ground-water flows - from water level and transmissivity data.

In preparing the above materials, it should be kept in mind that these pieces of information serve as tools for the evaluation. Consequently, the collection of hydrogeologic data should not become an obstacle to the completion of the overall analysis. All hydrogeologic data are incomplete in a relative sense. What is needed is an overall picture of the hydrogeologic situation in the monitoring area. Initially, refinement is less important than comprehensive coverage, no matter how preliminary or approximate. Categories indicating ranges rather than specific values, such as for transmissivity or dissolved solids, are often sufficient. Also, it should be recognized that, with time and with increasing amounts of ground-water and geologic data, knowledge of the hydrogeologic situation will gradually improve, and refinements can be made to the concept of how the system operates

EVALUATING THE EXISTING GROUND WATER QUALITY

Ground-water quality determines the use of water from a particular aquifer. Surface impoundments located in an area where the aquifer contains poor quality water will be ranked much lower in vulnerability to pollution than for an area where good quality water exists. Table 1 shows the rating system suggested by Silka and Swearingen (1978) where a score of 5 indicates that maximum protection is required. This ranking system is based on the criteria set forth in the Underground Injection Control Regulations (43 CFR Part 146) of the Safe Drinking Water Act of 1974. Consideration of only the background water quality of the aquifer is intended.

EVALUATING THE WASTE HAZARD POTENTIAL

The contaminants leaking from a surface impoundment must be evaluated for their potential impacts to existing or potential water uses. In the case of oil/gas produced water impoundments, these contaminants are primarily Sodium and Chloride, although concentrations of heavy metals are also found such as As, Ba, Cd, hexavalent Cr, total Cr, Pb, Hg, and Zn. Various organics and other toxic constituents are sometimes found.

Evaluating the Waste Hazard Potential

The quality of waters found in oil and gas reservoirs varies widely, reflecting characteristics of the deposition environment of the oil/gas field. Some oil field-produced waters are extremely saline, and certain disposal waters may contain toxic elements. For example, one study (Fryberger, 1972) of oil field brines in Arkansas found 5.8 ppm lead and 87 ppm of Barium. The drinking water limits for these two constituents are .05 ppm and 1.0 ppm, respectively. A recent study of oil field

Table 1

Rating the Ground Water Quality

Rating	Quality
5 (most protection required)	500 mg/1 TDS or a current drinking water source
4	500 - 1000 mg/1 TDS
3	1000 - 3000 mg/1 TDS
2	3000 - 10,000 mg/1 TDS
1	10,000 mg/1 TDS
0	No ground water present

brines in Kansas (Whittemore et al, 1985) indicates that the major source of ground water contamination near Burrton, Kansas, is oil field brine that seeped from surface disposal pits prior to 1950. After 1950, underground injection became the predominant brine disposal method, and the severity of contamination has slowly decreased.

A well is often treated with acid to increase permeability of the reservoir rocks in order to increase oil recovery or to improve injection efficiency. Acids often used are hydrochloric, nitric, sulphuric, hydroflouric, formic, and acetic.

Various chemicals are often added to drilling fluids to facilitate difficult drilling situations; these additives can contaminate ground water supplies.

Ground water contamination from oil/gas brine disposal is substantial in certain parts of the country. In Texas, 23,000 cases of ground water contamination have been documented, primarily from brine pits (Office of Technology Assessment, 1985).

Evaluating the hazard potential of a particular waste is difficult because of the complex interactions which can occur between substances and the many variables of the ground-water environment. Individual constituents from a particular source should be identified and evalulated based upon their solubility/toxicity.

EVALUATING THE POTENTIAL ENDANGERMENT TO HUMAN HEALTH

The endangerment to human heath is largely a function of the distance of the drinking water source from the impoundment. Thus the distance from the impoundment as well as the direction of ground-water flow is used to rate the endangerment to current water supplies. The direction of ground-water flow within 1 mile of the impoundment should be determined. In addition, the gradient of the flow must be estimated. This will give an indication of the rate at which ground water will be moving in the aquifer system. However, this is not necessarily the rate at which pollutants may be moving in the system, because some constituents move faster or slower than the ground-water flow. Each known potential contaminant should be evaluated for its behavior within the ground-water environment. Table 2 shows a rating scheme for the endangerment to human health.

DETERMINING THE INVESTIGATOR'S DEGREE OF CONFIDENCE

In many situations, the investigator will not have available all the needed information required to make the desired level of analysis. Many of the parameters are estimates based on the literature and on professional judgement. For this reason, a rating of the investigator's level of confidence about the scoring for each factor needs to be made. The following factors are used to evaluate the level of confidence for the various evalution criteria (Swearingen and Silka, 1978):

<u>Confidence rating for determining the earth material of the unsaturated zone(step 1):</u>

Rating	Basis for Determination of Rating
A (highest)	Driller's logs containing reliable geological descriptions and water level data; U.S. Department of Agriculture soil survey used in conjunction with large scale, modern geologic maps. Published ground-water reports on the site.
B	Soil surveys or geologic maps used alone.

Table 2

Potential Endangerment to a Water Supply

<u>Highest Priority</u>: Rate the closest water well within 1 mile of the site that is in the anticipated direction of waste plume movement. <u>Second Priority</u>: If there is no well satisfying Case A, rate the closest surface water within 1 mile of the site that is in the anticipated direction of the waste plume movement. <u>Third Priority</u>: If no surface water or water well satisfying Case A or B exists, rate the closest water supply well or surface water supply within 1 mile of the site that is not in the anticipated direction of waste plume movement. <u>Lowest Priority</u>: There are no surface waters or water wells within 1 mile of the site in any direction.

	General ground-water reports. Driller's logs with generalized descriptions. Driller's logs or exposures such as deep road cuts near the site of contamination allowing interpolation within the same general geologic unit.
C	On-site examination with no subsurface data and no exposures of subsurface conditions nearby. Estimation of water levels or geology based on topography and climate. Extrapolations of well logs, road cuts, etc., where local geology is not well know. Estimation based on generalized geologic maps. Estimation based on topographic analysis.

Confidence rating for determing the ground-water availability ranking(step 2):

This step involves the earth material categorization and thickness of the aquifer's saturated zone. The confidence rating for this Step follows the same basis as Step 1, Part B, above.

Confidence rating for determining background ground-water quality(step 3):

Rating	Basis for Determination of Rating
A (highest)	Water quality analyses indicative of background ground-water quality for wells at the site of nearby wells or springs or known drinking water supply wells in vicinity.
B	Local, county, regional and other general hydrogeology reports published by State or Federal agencies on background water quality. Interpolation of background ground-water quality from base flow water quality analyses of nearby surface streams. Estimates of background ground-water quality from mineral composition of aquifer earth material.

Confidence rating for waste character(step 4):

Rating	Basis for Determination of Rating
A (highest)	Waste character rating based on specific waste type.
B	Waste character rating based on industry category or on general character of waste.

Confidence rating for determination of the anticipated direction of waste plume movement:

Rating	Basis for Determination of Rating
A (highest)	Accurate measurements of elevations of static water levels in well, springs, swamps, and permanent streams in the area immediately surrounding the site in question. Ground-water table maps from published State and Federal reports.

B Estimate of flow direction from topographic maps in noncavernous area having permanent streams and humid climate.
Estimate of flow direction from topographic maps in arid regions of low relief containing some permanent streams.

C Estimate of flow direction from topographic maps in cavernous, predominantly limestone areas (karst terrain).
Estimate of flow direction from topographic maps in arid regions of highly irregular topography having no permanent surface streams.

ANALYTICAL METHODS TO ASSIST IN THE ANALYSIS

Microcomputers provide a fast, relatively easy way to model contaminant movement in a ground water flow system. Software is available for making predictions of interest in protecting ground water supplies from contamination.

Two situations require predictive modeling: (1) the buildup of a ground water mound beneath a surface impoundment; and (2) movements of pollutants down-gradient from the site once contaminants enter the saturated zone and are under influence of the flow system.

Software for predicting the buildup of a ground-water mound commonly utilizes the method given by Hantush (1967). The analytical method of Wilson and Miller (1970) to predict transport of pollutants down-gradient is used in software packages from several vendors.

SUMMARY

All ground-water investigations are not conducted in the same manner. The level of investigation and the methodology employed to solve the particular situation will vary over a wide range of costs and time. The prevention of contamination from oil/gas produced water impoundments requires that the hydrogeologic system in the vicinity of the impoundment be understood to the greatest degree possible. Screening methods as outlined in this paper will provide the regulatory agency with a basis for making produced water disposal decisions. Where more detailed sit specific evaluations are required, more extensive studies which include the design of a monitoring methodology must be developed.

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ROLE OF UPFRONT COORDINATION IN MAJOR PROJECT PERMITTING; THE TRANS-ALASKA GAS SYSTEM --- A PRELIMINARY REVIEW

Jules V. Tileston[1]

ABSTRACT: Coordination during the formative stages of developing information for use in Federal permit processing plays a significant role in the final decision process. Early identification of potential issues and solutions prior to the time project planning, economic considerations and alternative approaches are formally submitted for evaluation can expedite the decision time frame. Upfront coordination is especially important for large, complex or controversial projects such as the Trans-Alaska Gas System. At least 16 Federal entities have direct interest or jurisdiction in this pipeline proposal. In addition Congress will have an opportunity to specifically review the proposed final decision. Some 12 State entities will be involved; two Boroughs; several local communities and cities; four Alaskan Native Regional and Village Corporations, and; two major pipeline companies. The proposed pipeline plans to use engineering concepts similar to those used in the construction and 10 year operation of the Trans-Alaska Pipeline System that currently delivers 20 percent of the U.S. oil supply. It also will be similar to the authorized but unconstructed Alaska Natural Gas Transportation System. Although engineering, social and environmental aspects of the proposed gas pipeline are no longer new, the decision process to handle approval of an energy export project has no prior precedent. Early coordination with untested decision frameworks at the Federal and State levels are successful only to the extent there are comparable data evaluation and permit processing requirements. Upfront coordination is also dependent upon timely filing for approvals with all appropriate entities.

KEY TERMS: Gas pipeline, coordination, Alaska, Bureau of Land Management.

INTRODUCTION

"Upfront" as used in this paper, means coordination, consultation and/or cooperation taking place before an applicant formally files for a go, no-go decision from a authorizing entity.

In 1984 the Yukon Pacific Corporation (YPC) filed applications with the U.S. Army Corps of Engineers (USACE) and the Department of the Interior, Bureau of Land Management (BLM) to construct and operate a large diameter natural gas pipeline system within the State of Alaska. The Trans-Alaska Gas System (TAGS) would, if approved, provide a means to export Alaskan North Slope natural gas to foreign markets; principally Japan, Korea and Taiwan.

The TAGS proposal of 1984 contemplated a buried, chilled large diameter gas pipeline from the Prudhoe Bay oil fields to a tidewater Liquid Natural Gas (LNG) plant and marine terminal for ocean tanker shipment to Pacific Rim Nations.

[1] TAGS Project Officer, Bureau of Land Management, 701 C Street, Box 30, Anchorage, AK 99513

The TAGS route proposed in 1984 passed through a portion of Denali National Park (formerly McKinley National Park) within the cleared right-of-way for the Parks Highway. Hence all permits for the TAGS project were required to be filed simultaneously with all Federal permitting agencies under a new Federal law, the Alaska Natural Interest Lands Conservation Act (ANILCA), that also established stringent times for the complete Federal decision process-including subsequent actions by the President and the Congress. ANILCA further directed that no permits be granted until all permits were ready for approval. ANILCA finally requires that there be a rigorous evaluation of alternative routings to determine if there are any viable and more environmentally acceptable ways to avoid a National Park. Federal regulations implementing this portion of ANILCA (42 CFR 36) did not become final until 1986.

Shortly after filing applications, YPC asked that Federal permitting be temporarily suspended. Work was not resumed until January of 1986. In December, 1986 YPC amended its 1984 application to shift the proposed site of the LNG plant and marine terminal from Cook Inlet to Anderson Bay near the oil terminal for the Trans-Alaska Pipeline System (TAPS). This shift in the siting of the LNG plant also placed the entire project proposal within an already developed transportation and utility corridor recognized in Federal, State and local land use planning efforts. The 1986 amendment by YPC avoided the crossing of Denali National Park and was sufficiently close to the well understood TAPS oil pipeline to give high probability that geotechnical and technical and environmental solutions to pipelining in Arctic and Subarctic environments of Alaska could be adapted from a hot oil line to a cold gas pipeline system. This is especially significant where both pipeline systems cross major rivers, mountain ranges and fault zones in the same general area.

YUKON PACIFIC CORPORATION

YPC initially was a wholly Alaskan owned entity. Its principal leader was Walter J. Hickle, former Governor of Alaska and Secretary of the Interior. Its corporate membership subsequently has been expanded to include CSX Corporation (railroad and gas transportation interests in the conterminous States). The YPC Board of Directors include Robert O. Anderson, Past Chairman of ARCO, Hays Watkins, Chairman CSX and Walter J. Hickle.

Upon resumption of active Federal permit acquisition in 1986, YPC sought a lead permit officer to work with State and Federal entities. The person selected had a wide range of successful Federal and State permit acquisitions for controversial, complex development projects in Alaska. Several included multi-agency permits in Congressionally designated conservation units such as Misty Fjords and Admiralty Island and Cape Krusenstern National Monuments. The first two involved areas under National Forest Service Administration; the last is a unit of the National Park System System.

One of the first actions after permit processing was reinitiated by YPC in 1986 with the Federal and State permitting agencies was to say the TAGS project was still in the formative stages and that YPC sought identification of areas where there were substantive concerns needing attention. This "open door" approach set an overall atmosphere of cooperation that has expedited the Federal decision process. The "open door" philosophy by YPC made it possible for State and Federal agencies to set out concerns and for YPC to respond in a non-threatning environment. During this time Federal and State permitting agencies and industry were able to raise significant concerns about caribou, salmon streams, levels or engineering and environmental information available for the TAGS right-of-way and wetland/navigable waters permit process as compared to information for the TAPS and ANGTS projects. This process resulted in shifts in alignments and facility locations to avoid sensitive habitats and reduce industry concerns prior to public polarization on avoidance of the very same areas. During this period a tiered decision process was developed to handle the go, no-go decisions on the principal concepts of the proposed TAGS project. This spirit of mutual respect and frank discussion established during the upfront coordination period by YPC continues to permeate the Federal and State decision processes.

FEDERAL ROLES

As might be expected Federal involvement in a proposal to export energy receives more than passing interest. In addition to the normal Federal role the Congress reserves to itself the opportunity to review the proposed final decision on petroleum pipeline systems requiring a pipeline larger than 24 inches in outer diameter. This mandatory review period of up to 60 working days happens at the conclusion of the National Environmental Policy Act (NEPA) process. Congress has further directed that special decision processes be used when there is a proposal to export natural gas to foreign markets from existing or prospective natural gas supplies located on the Alaskan North Slope.

Initial review by BLM of Federal agency interest in the TAGS project identified at least 17 entities. A summary of these Federal interests is shown in TABLE 1. These range from the BLM authorizations to use Federal lands for pipilining in Alaska to the USACE wetlands and navigable waters permits. In between are agencies such as the Fish and Wildlife Service (Threatened and Endangered Species), National Park Service (Denali National Park on the Cook Inlet alternative), Forest Service (buffer lands on the highlands above the LNG plant and marine terminal), Environmental Protection Administration (air quality), to Minerals Management Service (off-shore leasing for oil and gas development).

Of course the major Federal interest in the TAGS project focuses upon the decision on whether Alaskan North Slope natural gas should be exclusively reserved for domestic markets in the United States. This Federal role requires two actions: a finding by the President that export of Alaskan North Slope natural gas will not diminish the supply or quality, or increase the cost of energy available to the United States; the second on issuance of an export license and place of export involve the Energy Regulatory Administration (Department of Energy) and the Federal Energy Regulatory Commission (FERC).

BLM ROLE

The primary role of BLM is to establish acceptable communication links within both Federal and State permitting agencies. Within the Federal establishment it was quickly determined that BLM and USACE would share a co-lead role under the Council of Environmental Quality regulations for evaluations made to meet the requirements of the NEPA. Accordingly, the BLM and USACE agreed that each actively participate with the BLM being the primary Federal contact point. This Agreement supplemented an earlier agreement between BLM and YPC. The BLM on behalf of itself and the USACE then asked the State and other Federal agencies to be "cooperators" in the NEPA process. BLM contact with the FERC was deferred until a formal response to YPC was made to a December 1986 request to FERC for clarification of the FERC responsibilities in the TAGS project.

The Department of the Interior regulations at 43 CFR 2800 covering pipeline right-of-ways for projects such as proposed by YPC require reimbursement to the BLM for processing the application and the preparation of the draft and final environmental impact statements. These regulations also encourage preapplication, or upfront coordination. Accordingly, one of the first areas of upfront coordination focused upon firming up the working relationships between YPC and BLM and upon clarifying estimates of BLM reimbursable costs. At this time several significant procedural decisions were

TABLE 1

ENTITIES HAVING SUBSTANTIAL INTEREST IN THE TRANS-ALASKAGAS SYSTEM PROJECT

ENTITY*	SUMMARY ROLE
STATE	
Division of Governmental Coordination	AK Coastal Management Program, development of coordinated State position, consistency with land use plans.
Public Utilities Commission	Certificate of Public Convience and Necessity
Division of Measurement Standards	Oversize and overweight vehicles
Department of Environmental Conservation	Air quality, open burning, permit to operate, PSD, water quality, pesticides, oil discharge contingency plans, food service permit, sewage systems and water and wastewater treatment works, soild waste disposal, wastewater disposal and operation.
Department of Fish and Game	Scientific and educational collecting permits (fish, game and acquatic plants) anadromous fish protection, critical habitat areas, use of State game units, subsistence data and game-fish population statistics.
Department of Health and Social Services	Health facility operation.
Department of Labor	Boiler operators, electrical and plumbing, explosive handling, pressure vessels, prevention of accident and health hazards, workers compensation, unemployment compensation.
Department of Natural Resources	Burning permit, land use permit, pipeline right-of-way essment, water rights, gas sales, historic/cultural protection, special park use sale of mineral materials, sale of timber, forest fire prevention.
Department of Public Safety	Facility fire prevention, life and fire safety plan for facilities, law enforcement including fish and game.
Department of Transportation & Public Facilities	Airport landlease/right-of-way permit, encroachment permit along State highways, highway maintenance, Dalton Highway access permits.
Alaska Rialroad Commission	Use of Alaska Railroad system.
FEDERAL AGENCIES	
Forest Service	Special use permit, land uses in Chugach National Forest.
National Oceanic and Atmospheric Administration	Endangered species.
Corps of Engineers	Discharge of dredged or fill matetials into U.S. waters, structures in or affecting navigable waters, use of military reservations, use of Federal flood control structures.
Economic Regulatory Administration	Export permit.
Federal Energy Regulatory Commission	Place of export.
Bureau of Indian Affairs	Use of Alaskan Native lands, rights-of-way, mineral material sales, archaeological values.
Bureau of Land Management	Land transfers to State, airport leases, archaeological permits, sale of mineral materials, rights-of-way on Federal lands, temporary use of Federal land, other leases and temporary use authorizations, sale of timber, forest fire protection, determination of compatibility of TAGS with existing Federal rights-of-ways, enforcement of right-of-way provisions.
Office of the Federal Inspector	Enforcement of ANGTS Federal right-of-way provisions.
Federal Highway Administration	Compliance with Federal aid to highway standards.
Fish and Wildlife Service	Endangered species.
U.S. Army/Air Force	Use of military reservations.
U.S. Coast Guard	Vessel traffic control, marine sanitation, bridges over navigable waters, permits for facilities or vessels to handle hazardous materials.
Federal Aviation Administration	Airport safety, air traffic control.
Office of Pipeline Safety	Pipeline integrity and LNG terminal standards.
Environmental Protection Agency	Air quality, oil spill prevention-containment-contermeasure plans, water quality.
Department of State	International treaties/agreements.

LOCAL GOVERNMENT	ALASKA NATIVE LAND OWNERS	INDUSTRY	LEGISLATIVE
North Slope Borough	Arctic Slope Regional corporation	Alyeska Pipeline Service Company	Alaska Legislature
Fairbanks North Star Borough - Fairbanks, Valdez, Big Delta, Glennallen and several smaller communities	Doyon Regional Corporation	Northwest Alaskan Pipeline Company	U.S. Congress
	Ahtna Regional Corporation	Yukon Pacific Corporation	
	Chugach Regional Corporation		
	Several Alaska Native Village Corporations		

* Several entities have subdivisions such as the Department of Natural Resources, which contains specific units for minerals, forests, parks, land and water and historic preservation.

developed by BLM and discussed with YPC. The first decision was that an Environmental Impact Statement would be prepared and that this work could be best handled through a third party contract. Another decision was that there was sufficient non-confidential and/or non-proprietary information from prior gas and oil pipeline proposals in Alaska during the 1970's and early 1980's that conceptual evaluations of the proposed TAGS project could proceed on the basis of "incorporation by reference" under the CEQ regulations. During this early period considerable effort was used to identify major decision points and time frames. In retrospect these milestones or go, no-go decision points should more properly be interpreted as "MAYBE YES" and "MAYBE NO." In substance, no single Federal agency has unabridged, unilateral, unchallengable decision authority for the export of Alaskan North Slope natural gas.

The ability to reexamine and, as appropriate, adjust permit processing details in an important positive attitude in Federal-State-Applicant relationship. Permitting agencies must be willing to objectively explore "why" questions raised by the Applicant or others. The easiest response to "why" is; "we always did it that way" or "we never did it that way". In an era of rapidly advancing technology and enhanced environmental awarness, it is very desirable to allow time to examine the permit process to see if it actually fits current conditions. New laws, regulations or policies can make past practices inappropriate or very cost ineffective. In the case of TAGS, State permitting needed modification and for the USACE a tiered decision process was developed to fulfill wetland and navigable water authorizations. BLM adjusted its billing procedures and determined available information substantially reduced the extent of detailed data compared to that previously required for both TAPS and ANGTS at the conceptual approval stage.

As indicated earlier, one of the initial tasks by BLM was to determine how to best coordinate with the State of Alaska. Except for the Gubernatorial election campaign, (where the TAGS proposal became a focus of attention) the established BLM-State upfront coordination process has worked smoothly. A slight hitch happened when uncertainties resulted during the period when a new State Administration and State Legislature assumed leadership. Although there has been a shift in the BLM contact point from Juneau to Fairbanks, the overall result is positive from the BLM perspective as it appears to place Federal communication and coordination within the State Government at a point where the most long-term experience on pipelining decisions now resides. A second element of uncertainty focused on the inability of the State to conditionally approve construction of major projects on State ownerships. This aspect was corrected by the last session of the Alaska Legislature when State approval procedures were modified to closely resemble the Federal process. In addition, the State was invited to join with the USACE in the evaluation process leading to selection of a third party contractor to prepare the Federal NEPA documents.

Until the FERC role was determined in the early summer of 1987, the BLM worked exclusively with the Energy Regulatory Administration (ERA). The ERA was invited by BLM and USACE to actively participate in the NEPA scoping hearings in Alaska. ERA not only took an active part, but in advance of a formal application by YPC to export natural gas, arranged to have an analysis completed of the overall residual environmental effects (air quality and solid waste disposal) in the conterminous States. This analysis for ERA has been included in the BLM-USACE draft environmental impact statement. The ERA contribution to the BLM-USACE evaluations were initially unanticipated as it was originally thought there would be tiered NEPA decisions as contemplated in the CEQ regulations. Any right-of-way approvals by BLM would be contingent upon subsequent successful "go's" for export and for detailed pipeline system design where engineering details involved new, unproven technologies or where sensitive environments appeared to be effected. A similar tiered decision process has been developed by the USACE for its wetlands/navigable waters authorizations.

Thus the overall role of BLM was to act as the Federal focal point for decisions needed to authorize the TAGS project. This included recovery of costs for the TAGS project and facilitated development of a coordinated time line between numerous Federal interests and an equally diverse set of State interests. Special attention has been given to providing a single set of public involvements where all concerned Federal and State decision agencies will be represented at the same place and time.

STATE OF ALASKA ROLES

The State of Alaska has several important roles in the decisions on whether the TAGS project would be approved. First and foremost the State owns 12 percent of the natural gas in the Prudhoe Bay complex. Second it is a principal land owner; approximately 45 percent of the TAGS pipeline route crosses State ownerships or State owned navigable waters including all of the primary LNG plant and marine terminal. Third is its lead role in permitting for water quality matters, salmon stream crossings, state highway and airport uses, taxation, solid and hazardous wastes, local hire, social-economic effects, coastal zone uses, and unorganized Boroughs (Borough = County).

At first blush there are at least 13 State agencies having more than a passing interest in the TAGS project. Table 1 summarizes these State interests. Principal focus on upfront coordination between the YPC and the State has been with the Cabinet level agencies, the Governor and the Legislature. The initial focus of upfront coordination between BLM and the State was with the Division of Governmental Coordination (DGC) in the Governor's Office.

From the Federal perspective initial efforts with the State had the primary objective of reducing opportunities for nasty surprises. DGC was invited to participate in the development of a coordinated Federal-State public involvement process that resulted in a single decision process for the pipeline route, compressor stations, gravel sources, construction camps, construction schedules and the LNG plant and marine terminal.

From the perspective of BLM there was a major effort by YPC to get a single focal point for information flow to and from the State. This effort paid off in that the State permitting process now resembles the Federal one. The Federal process allowed the use of informed judgment as to whether the applicant was capable of doing what it said it would. The State process required stringent proof that applicants were "fit, willing, and able". YPC worked closely with both cabinet and legislative bodies to get an amendment of State Law that now parallels Federal processes.

Upfront coordination between BLM and DGC involved an intensive review of the existing coordination mechanisms between BLM and the State for review of proposed Federal decisions under the National Environmental Policy Act and for right-of-way authorizations. The State and BLM concluded existing processes were adequate. There is need, however, for several cooperative agreements between the State and BLM. These areas for additional coordination and cooperation involve details on how to best handle Federal decisions on lands pending transfer from Federal to State ownership, development of common terms and conditions in any authorizations for TAGS where the same issue will be addressed irrespective of land or resource ownerships, and most importantly, what type of combined Federal-State technical and policy decisions for the design criteria approval, design approval for construction and for operational monitoring would best fit in the light of today's standards and techniques. Lead responsibility for overall State coordination has shifted from the Governor's Office to the Alaska Department of Natural Resources (DNR). With the shift in leads, the location for State coordination was moved from the State Capital to Fairbanks. In addition to DNR and DGC offices, the Alaska Department of Fish and Game (DFG), the Alaska Department of Environmental Conservation (DEC), and the Alaska Department of Transportation and Public Facilities (DOT-PF) also are located in Fairbanks, where office heads played significant roles in the approval, construction and operation of TAPS and/or Federal approval of ANGTS. Therefore, they bring an excellent background of technical and Alaskan political understanding to major project construction in Alaska.

LOCAL GOVERNMENTAL ROLES

Local governments have a major role in project approval. The approval process in Alaska ranges from concern over how to cover increased costs to local infrastructures such as schools and streets to use of municipal lands. Most of these matters are issues between the applicant and local community. The Federal process however, must be sensitive to pending local decisions to the extent locations of facilities on Federal lands are influenced and vice versa. A major element of Federal evaluation for the TAGS project deals with effects upon local entities. The primary issue identified during the scoping process was concern about how TAGS might change existing local social, environmental and economic conditions. Upfront coordination hopefully permitted early evaluation and resolution of the bad side of major project construction and enhancement of the good effects to the local communities along the TAGS route.

The TAGS project has one major advantage in that the affected local communities dealt with the construction of TAPS more than ten years ago and have first hand experience on what happens after construction booms made the transition to standard operation. During the scoping process it became very apparent that most communities had strong feelings on what went well and what did not during TAPS construction. The major concerns of local communities dealt with local hire (when can I start work) to what will happen to tourist traffic (will highway or air accesses be restricted). Generally, the concerns about "what if" were answered satisfactorily during TAPS construction and operation. Local infrastructures are in place and at present underutilized.

ALASKAN NATIVE ROLES

Federal laws and regulations create a special decisions role for Alaskan Natives. Alaskan Native Corporations established under Federal Law directly own or are owners of lands and waters affected by the TAGS project. These Alaskan Native (Indian, Eskimo or Aleut) ownerships are private ownerships in the same context as any other corporate or private holdings in the United States. There are two special conditions in Alaska: ANILCA requires Federal decisions to carefully evaluate the expected results upon "subsistence" and upon American Indian religious factors. The first requires a series of findings; principally whether there would be a "significant restriction" to existing subsistence uses bu "rural Alaskan residents" and if so whether there were any ways to reduce the adverse effects. The second deals primarily with ancestral use areas. Upfront coordination about these Alaskan Native values as with State interests reduces the chance for surprises when the Federal decision process is well underway.

INDUSTRY ROLES

BLM has a special obligation to protect prior Federal authorizations on Federal lands. In Alaska the TAGS project involves two Federally authorized pipelines: TAGS and ANGTS. Both pipelines had special enabling legislation that predated enactment of ANILCA. Both were also approved under regulations that are different from those now contained in 43 CFR 2800. Other Federal and State statutes and regulations covering such diverse issues as protection of threatened and endangered species, hazardous wastes and American Indian cultural values.

Federal authorizations to construct and operate TAPS requires consultation with Alyeska Pipeline Service Company before approval of any project that might effect TAPS.

Federal Regulations (43 CFR 2800) now contain a provision that a determination be made that subsequent uses of Federal lands are compatible with prior authorizations. BLM met early with YPC, Alyeska Pipeline Service Company for TAPS and with Alaskan Northwest Pipeline Company for ANGTS. The substance of the BLM discussions was to identify how BLM would treat confidential and proprietary information belonging to the respective companies and to encourage industry to solve its own problems. BLM stressed that final decision authority rested with the Federal government and that it preferred to not step into industry matters. This recommended industry to industry coordination process has worked very well for issues concerning TAPS. Alyeska Pipeline Service Company has clearly stated that it is reserving its final judgment on the effects of the proposed TAGS project on the existing TAPS oil delivery capabilities until such time as detailed engineering information is available. Both companies have participated in on-the-ground evaluations to determine specific areas of concern and potential satisfactory solution. Unfortunately a similar spirit of mutual industry problem identification and solution has not been established between the TAGS and ANGTS projects.

TIMING

Timing of applicant initiated actions has a direct bearing on the subsequent time frame for Federal and State decision processes. In the case of TAGS, initial action was started at the Federal level in 1984. Shortly thereafter, YPC requested BLM to suspend action. In early 1986 YPC asked BLM to restart. After BLM and YPC developed an understanding of who does what and when, YPC asked USACE to resume permit processing. A Supplemental agreement between the BLM, USACE and YPC was implemented with BLM and USACE being co-leads in the NEPA process and BLM the Federal focal point.

Initial time frames prepared by YPC suggested the public scoping process would be in the early spring of 1986 and a final Environmental Impact Statement completed during late winter 1987. This schedule was prepared on the assumption, by YPC, that answers to a series of questions raised in 1984 over the adequacy of the initial TAGS proposal to build a pipeline system between Prudhoe Bay and Cook Inlet. It subsequently became apparent that satisfactory answers were not readily available. During the early spring and summer several interagency-YPC meetings were held to discuss decision processes, costs, timing and areas of special concern. The end result was a draft amended application being sent to BLM and USACE for informal review and comment. This review draft was distributed to all Federal and State permitting agencies with a request for 30 day turnaround. In December, 1986 YPC formally amended its Federal applications to the BLM and USACE.

Notice that no reference has been made to any applications with the State of Alaska or for export licenses. Application for use of State ownerships were not filed with the State by YPC until March, 1987. The primary discrepancy in the timing between the filing for Federal pipelining authorizations appears to be directly related to the inability of the State permit process to reach fruition without Alaska Legislative action. Another issue influencing the timing for State approvals was the ongoing reorganization of State governmental agencies under a new administration.

As of August, 1987 YPC has chosen to not apply for a Federal export license.

The disparity between requests for Federal and State authorizations leads to considerable difficulties in the area of schedule development and necessary upfront coordination. After a time BLM is hesitant to indicate when information from the company would be available for interagency action. In turn cooperating agencies are uncertain as to when key technical or policy staffs need to respond to BLM's request. In spite of these uncertainties, the initial efforts to establish good faith, professional working relationships between all interested parties help keep things from going off the deep end too often. Overall Federal and State agencies have taken special care to be responsive and timely to requests from BLM during the NEPA process and preliminary development of authorization documents.

SUMMARY

Upfront coordination is a vital element in major project Federal decision processes. It involves honest exchange of ideas and a mutual willingness to listen to the others' concerns. A significant element in upfront coordination/cooperation is mutual trust of each others' professional integrity.

Upfront coordination in the proposed TAGS project lead to a conceptual design and location of major facilities that maximized prior Federal and State and local decisions land uses in Alaska and thereby reduced levels of real and perceived controversy and unnecessary polarization between industry, State and Federal permitting agencies, Alaskan Native Corporations and the public.

Upfront coordination requires the applicant to be willing to expose conceptual plans at an early stage of development. It places a dual obligation on those consulted to be forthright in their opinions and to be consistent with their early comments; it places a strong obligation on the applicant to seriously consider and to respond to identified areas of concern. In both cases there must be a committment to follow through as the project elements are subsequently developed.

Upfront coordination requires a very flexible approach to time schedules by the applicant and all permitting entities. The overall advantage appears to be one where the final proposal addressed concerns in sufficient detail to avoid delays that frequently bog down projects when the applicant comes in and says "Here it is; I need my approval in __ days. Oh by the way I've got my construction crew on site now."

Upfront coordination may involve entities which have no overriding interest; or conversely may not involve entities having substantial interests until the permit evaluation process is well underway. When in doubt, invite participation.

Upfront coordination really works; in the long run it is a useful tool to reduce posturing and solve problems that can cause serious project delay if left unaddressed until well into the decision process. Try it and you will like it!!!

PERMITTING A GOLD PLACER MINE WITHIN THE CAPITAL CITY OF MONTANA, PROCESSES AND PROBLEMS

Kevin R. Jones[1]

ABSTRACT: The permitting of a placer gold mine inside of the city limits of the capital of Montana presented unusual problems in the presentation of technical information to the general public and city officials. Although placer mining and processing is not generally considered to be a ground water pollution threat, major concerns arose during the review process, over the potential for ground water contamination and depletion. The water resources concerns were generally based on locally visible problems caused by historic mining activities. Local historic problems have included acid mine drainage, unreclaimed, metal laden tailings and unreclaimed placer mines. Several public meetings were held in which the mine company attempted to explain the nature of the mine and its water supply system. During these meetings it was necessary to educate the public about placer mining and processing before the concerns could be addressed. In order to obtain approval from the city staff, which was unfamiliar with mining systems, an education process was needed. This education process was aided by the use of computer modeling to project the impacts to the regional water supply in terms of both quality and quantity.

INTRODUCTION

The city of Helena began as a placer mining camp in the 1800's. However, placer mining has not been an active part of the local economy for thirty years. In 1985 the Special Lady Mining Corporation proposed to mine and process placer gravel on a forty acre parcel (Figures 1 and 2) located within the city limits, in an area adjacent to historic placer tailings, a shopping center and residential housing. The rebirth of mining in the capital city raised concerns which included the potential impacts to the ground water quality and quantity in the area. Although placer mining is generally not considered to be a threat to ground water quality, a majority of the objections centered on this concern and concerns for ground water quantity. These concerns were largely based upon the highly visible historic problems related to mining in the Helena area. The permitting of the operation was complicated by its location in the city limits and involved eight separate agencies and boards. This paper reviews the permitting process and how the mining company approached the resolution of those concerns.

[1] Hydrologist, Jones & Associates, 314 N. Last Chance Gulch, Helena Mt.

FIGURE I

SPECIAL LADY MINING CORP.

PROJECT AREA
MAP

Lewis & Clark Co. Montana

Scale

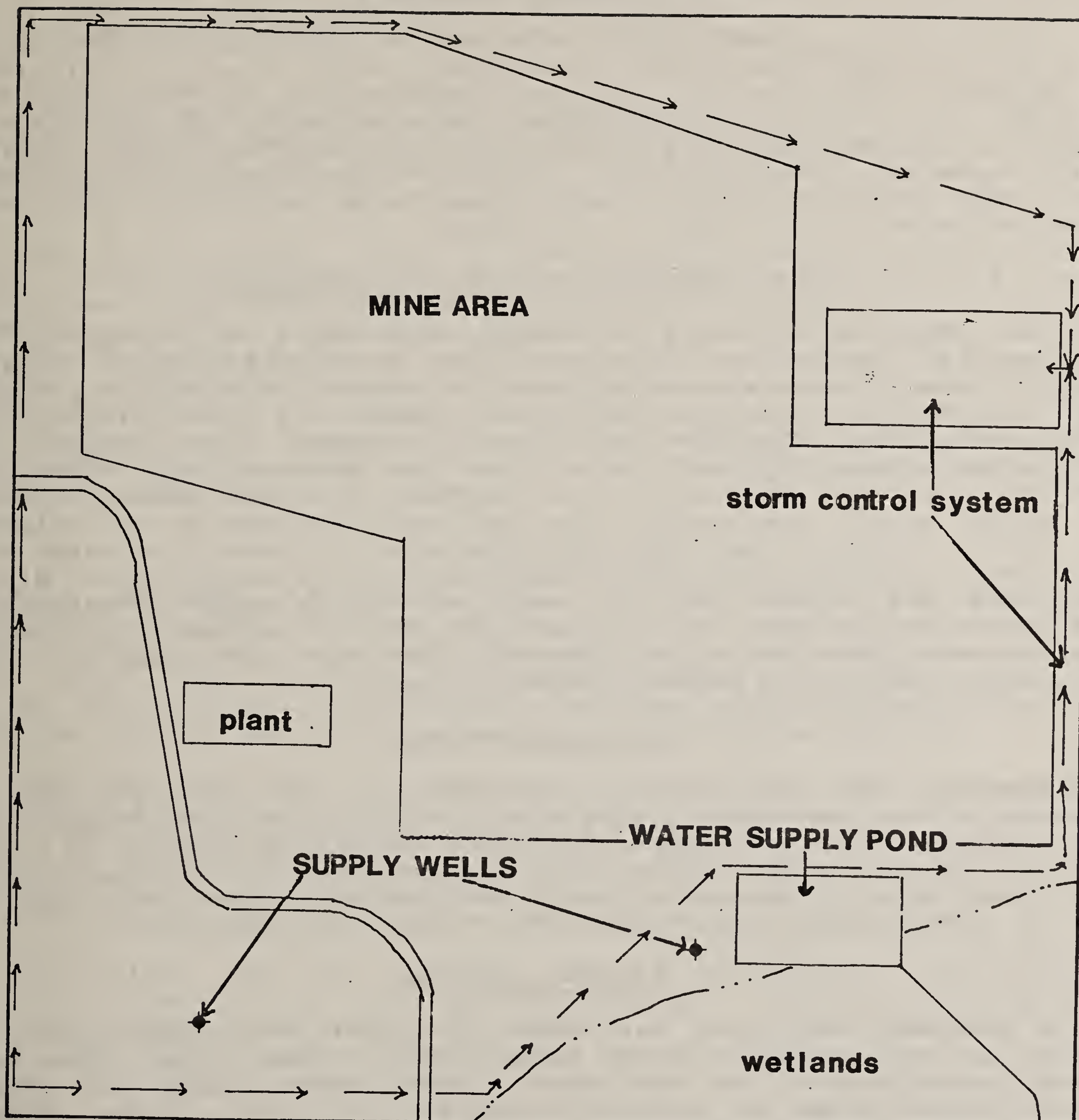
0 2000 4000 Ft

Map by	Drft M.M.	Date

To Accompany

Author Date

FIGURE 2 GENERAL SITE MAP



HISTORIC PROBLEMS

Large scale placer mining in the Helena area began in 1864 with the discovery of the Last Chance Gulch placer, which is now the main street of Helena. Placer mining expanded through the mid 1870's until the majority of the high grade deposits were depleted. In 1904 the first connected bucket line dredges began producing gold from deeper and lower grade deposits. From 1934 to 1957 the Porter Brothers Dredge Company mined the outwash deposits of Last Chance Gulch immediately to the north of Helena using a large bucket line dredge.

Dredge tailings and physical disruption

The early miners were generally unconcerned or unaware of the environmental damage that their activities could cause. While the early miners disrupted stream beds and caused extensive sedimentation problems, the large scale, long term disruption is generally related to the later period of mining when the dry land and bucket line dredges were introduced. These dredges could mine and process many times more material than the early miners, and, perhaps more importantly, deposited the waste gravel separately from the finer fractions of the sediments. The coarse fraction was stacked in large piles behind the dredge while the finer grained material was discharged into the dredge pond. Without the fines the coarse material would not readily support vegetation so that waste piles over fifty years old are still essentially bare. In addition the disrupted stream channels could not reestablish as quickly because the large piles blocked the stream paths.

Acid mine drainage

Although not related to placer mining, acid mine drainage is a problem in the hard rock mining districts to the south of Helena. Acid mine drainage has caused substantial long term metals problems in a creek that was also dredged. While the metals contamination is related to the hard rock mines, the general public see that the stream, which they are told is contaminated, flows through the dredge tailings piles.

Nitrate pollution

A problem unique to the historic placer mine areas adjacent to Helena is the presence of a large nitrate plume in the ground water system down gradient of the mine. This nitrate plume has affected several domestic wells and has precluded the drilling of other wells in the influenced area. The nitrate plume was caused by using sewage water in the mid 1900's to float a dredge. It was necessary to bring in additional water to float the dredge, since sufficient water was not available. The owners of the dredge reached an agreement with the city of Helena to purchase effluent from the sewage system for the dredge pond. The mining company would then bury the final dredge pond and complete the disposal of the effluent.

PERMITTING PROCESS

Largely because of the historic problems with unreclaimed mining disturbances and increased environmental awareness, a series of mine reclamation, water quality protection, air quality protection and land use planning laws were passed on the state and federal level. In order for a mine to be permitted under these laws it is necessary for the mining company to present the following information:

* how the mine will be operated,
* how the mine will be closed and reclaimed,
* how the air quality impacts of the mine will be mitigated,
* how the mine will meet the water quality standards, and,
* how the mine will fit into the existing land use of the area.

Due to the high level of public concern and its location in the capital city of Montana, the detail required in the permitting process was greater than would have been expected for a placer mine in a similar geomorphic setting. The mine is basically a shallow surface mine with ore material taken from a series of 25 to 50 foot deep pits. The material is washed to remove the gold, and the waste material (silts, sands and gravels) is returned to the pit. When the pit is backfilled and compacted, the salvaged topsoil is replaced and seeded with an appropriate mix of native species. The mine does not utilize any milling or recovery reagents in the process.

Agencies involved

With the City of Helena, the State of Montana and the Federal governments involved in the environmental permitting of the site, the mining company had to comply with eight different agencies and boards. While overall the process went smoothly, there were times in which the various requirements conflicted and there were several delays. Table One lists the agencies and boards and their areas of responsibility.

The operator initially proposed to approach the permitting agencies together in order to expedite the process. However, the city agencies (APO, PAB, CC) required that a full description of the mining activity be presented before exploration activities could begin on the site. A conceptual mine plan was developed for the city agencies which met their requirements but would not meet the needs of the state agencies.

Permitting for the operation began in March of 1986 with a conceptual plan filed with the APO (Figure 3, Permitting Flow Chart). Following thirty days of staff review a report was presented to the PAB. The first public hearing and review of the plan by the PAB was delayed for thirty days because a quorum was not present for the meeting. When the PAB held its hearing it placed a number of requirements on the mine operation, including several that were in conflict with state law. These included using salvaged topsoil from the operation to construct a berm around the property and then placing a fence on top of this berm, and stockpiling material in the wetlands area. Following the PAB review, the CC held further public hearings and issued a conditional use permit (CUP) in May of 1986. Final approval was withheld until certain conditions were met, including the approval of the state permit.

With the issuance of the CUP work began on developing both the economic reserves of the property and the collection of the environmental baseline data for the state permits. The application for an operating permit was filed with DSL, WQB, AQB, and the APO in January of 1987. Following public hearings, and several deficiency responses DSL prepared

TABLE ONE
PERMITTING AGENCIES INVOLVED IN THE
ST. JOSEPH MINE

Agency	Responsibility
Area Wide Planning Organization(APO)	*Insure compliance with the City and County Comprehensive Land Use Plan
Planning Advisory Board(PAB)	*Provide citizens input to the planning process
City Council(CC)	*Issues conditional use permit, may add conditions and stipulations to the recommendations of the APO and PAB
Department of State Lands(DSL)	*Primary mine permitting agency in Montana, covers operation, and reclamation of the mine, environmental and social impacts caused by the mine
Water Rights Bureau(WRB)	*Issues water rights for the operation, reviews application to insure it does not affect existing beneficial uses of the water
Water Quality Bureau(AQB)	*Insures compliance with the Montana Clean Water Act, coordinates closely with DSL
Air Quality Bureau(WQB)	*Insures compliance with the Montana Clean Air Act, cooperates closely with DSL
Army Corps of Engineers(ACE)	*Responsible for wetlands protection

a Preliminary Environmental Review for public comment. After the response to the public's comments were made, the Operating Permit was approved with the concurrence of the WQB and AQB in July, 1987.

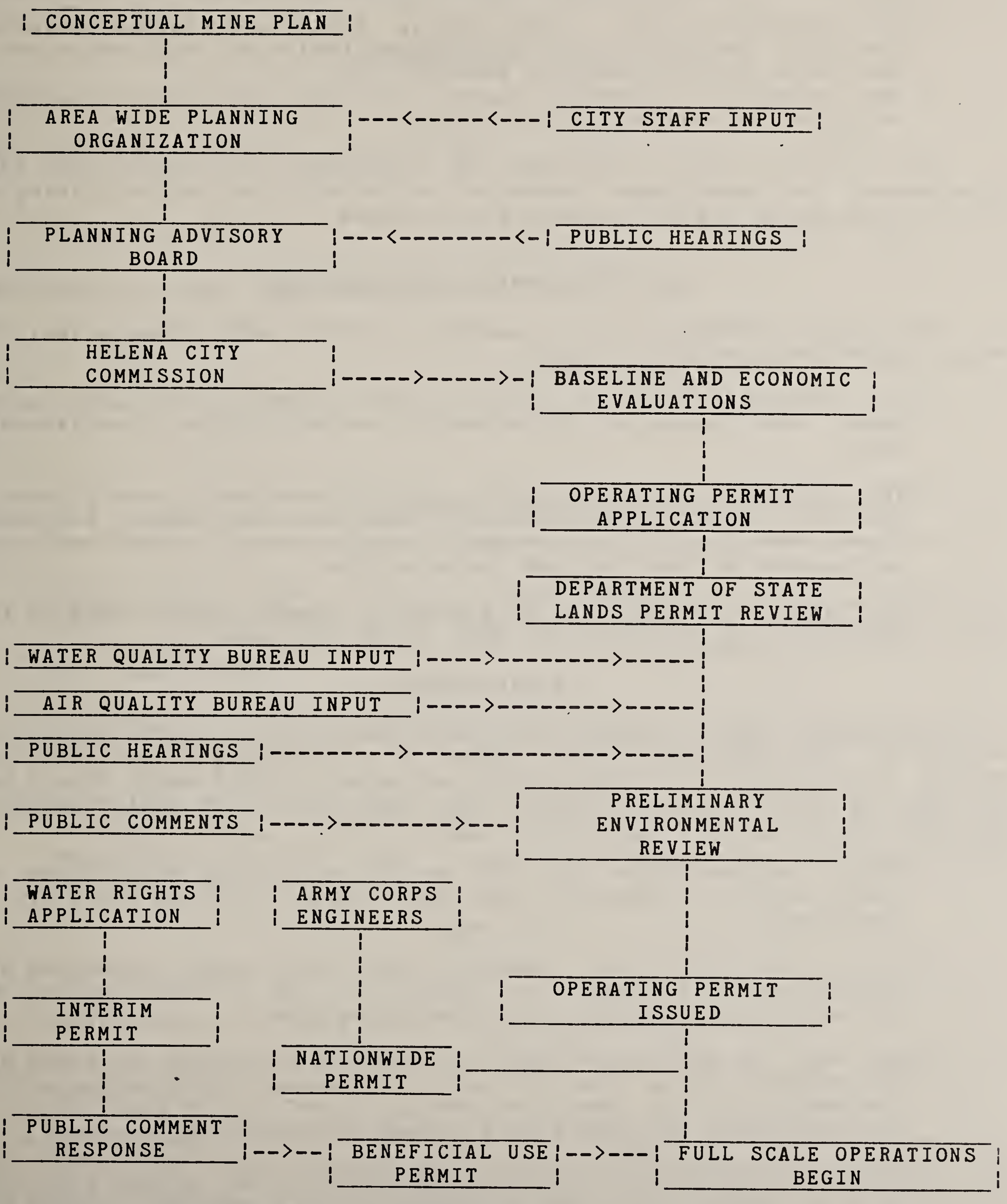
While the state process was underway, the Army Corps of Engineers notified the mining company that a permit for the activities in the wetland was required. The application was filed and after negotiations the activity was allowed under a Nationwide Permit if all fill material placed in this area (as required by the city CUP) was removed. Based upon the position of the ACE, the city permit was modified and accepted by the city council.

Concurrently with the Operating Permit process, an application for a Beneficial Water Use Permit was made with the Water Rights Bureau. An interim permit was issued to allow for aquifer testing with the full permit still pending (July 1987).

In July, 1987 the city notified the mining company that they had completed their review of the Operating Permit application, and that they needed further commitments as to dust control and the landscaping of the site. These concerns were met and the final city approval was given in 1987.

Throughout the permitting process the same concerns were raised about the water resources at the site. These concerns were:

Figure 3
Permitting flow chart



* The water development at the site would cause area wells to go dry.
* The operation would cause metals pollution, nitrate pollution, bacterial pollution and the sedimentation of local wells due to the use of unlined settling ponds.
* The control of surface runoff at the site would decrease the recharge to the ground water system.

The concerns were addressed by attempting to explain the water development and management measures at the site, and by explaining the characteristics of the area ground water system.

WATER DEVELOPMENT AND MANAGEMENT

The water development plan consists of three parts (Figure Two, Site Map). These parts are:

1)The development of a shallow (0-15') swampy area located on the south east corner of the property through the use of an excavated pond.

2)The diversion into the supply pond of storm water runoff from the city of Helena which currently feeds into the swamp. Any excess storm water will be directed to a storm water control pond which is required by the city and state permits.

3)The use of two 100 to 150 gallon per minute supply wells to feed directly into the plant and into the supply pond.

Water demands

Originally SLMC projected a process water need of 3,000 gallons per minute to operate the plant. Based upon a revised design this water demand was decreased to 1,500 gallons per minute. This water demand will be met in the start-up phase of the operation in the following manner (Figure 4):

1)Prior to the start of the ore processing the supply pond, the storm water diversions, and the initial settling ponds will be completed.

2)After the ponds are completed the wells will be pumped at a maximum of 150 gallons per minute for 8 to 10 hours per day into the supply pond and the initial settling ponds.

3)As soon as sufficient water is stored in the ponds the plant will be started on a limited basis. Pumping of the wells will be continued in the same fashion until sufficient water is in the settling ponds to allow for recycling operations to commence.

During the operational phase, the majority of the process water will be provided by recycling as much of the water as is possible. Water that does not come from the recycling operation is called makeup water. It is anticipated that upwards of 25 percent, or 375 gallons per minute of the water will be lost through pond seepage, water contained in the silts and sands in the wastes, and evaporation. This makeup water will be obtained in the following manner (Figure 5):

<u>Figure 4</u>
<u>Start up water circuit</u>

```
SLMC Production well #1------->---->--¦
                                      ¦
                                      ¦
                                      ¦-->--¦->---Water Supply Pond
                                      ¦     ¦                    ¦
                                      ¦     ¦                    ¦
SLMC Production well #4------->---->--¦     ¦                    ¦
                                            ¦                    ¦
                                            ¦                    ¦
                                       Settling Pond-->------->-¦
                                         ¦                       ¦
                                         ¦                       ¦
                                         ¦                       ¦
                                         ¦                       ¦
                                         ¦                       ¦
                            Processing Plant------<----------<-----¦
```

---

1)Supply well SLMC 4 will be pumped at 100-150 gpm directly to the plant during the times that the plant is operating (12-14 hours/day). Supply well SLMC 1 will be pumped at 100-150 gpm to the supply pond.

2)During the time that the plant is not operating (11-12 hours/day) SLMC 4 will be pumped at 25-50 gpm into the supply pond and SLMC 1 will be shut down.

3)At least 1,125 gallons per minute will be recycled from the settling ponds to the plant. This water will be pumped from the secondary settling pond to the water supply pond and then to the plant for use.

<u>Water use</u>

The water at the site is used for:

1)Dust control on roads and ore hauling operations, and,

2)the processing of ore to remove the heavy mineral sands which contain gold.

As the dust control activities will be minor in terms of water use this discussion will concentrate on the ore processing activities. As previously stated the processing of the ore will use approximately 1,500 gallons per minute at optimum capacity.

The process separates the gold and other heavy minerals from the gravels at the site by gravity. The process washes the material down through a series of sloping ridges (riffles) in a sluice box which causes a series of eddies in the water. When the material is washed into the eddies behind the riffles the gold and other heavy minerals will be trapped behind the riffle, because they have a higher specific gravity than the majority of the sands and gravels found at the site. The process does not use chemicals to concentrate the gold, therefore the waste water contains only clay, sand, and gravel. As the process relies on the washing action of the water to break up the clays and to separate the material from the coarse gravels, contamination of the water by organics such as oil and grease must be avoided.

Figure 5
Make-up water circuit

```
SLMC Production well #1------->----->--|
                                       |
                                       |
                                       |-->---->---Water Supply Pond
                                                     |             |
                                                     |             |
SLMC Production well #4------->--|                   |             |
                                 |                   |             |
                                 |                   |             |
                                 |       Settling Pond             |
                                 |       |                         |
                                 |       |                         |
                                 |       |                         |
                                 |       |                         |
                                 |       |                         |
                           Processing Plant------<----------<-----|

                      Water Circuit During Plant Operation
```

```
SLMC Production well #1 (turned off)


                                           |-->---Water Supply Pond
                                           |
                                           |
SLMC Production well #4------->-------->---|
(25-50 gpm)

                                         Settling Pond




                           Processing Plant
                      Water Circuit During Plant Shut-Down
```

Hydrogeology of the Helena Valley

The Helena Valley is a basin filled with a thick accumulation of unconsolidated material overlying faulted sedimentary, metamorphic and igneous rocks. Ground water in the basin is derived from three separate aquifer units (Noble and others, 1982). These units are:

1) A bedrock aquifer consisting of sedimentary rocks ranging from from Precambrian to Cretaceous age, and later Cretaceous and early Tertiary igneous rocks.

2) Tertiary age sediments composed primarily of clays of volcanic origin interbedded with thin layers of sand, gravel, and lignite.

3) Quaternary age sediments composed of a moderately sorted heterogeneous mixture of gravels, sands, silts and clays.

The bedrock aquifer is relatively unimportant in the Helena Valley. Wells drilled along the edges of the valley rely upon fracture permeability to obtain sufficient yields. Well yields in the bedrock aquifer average 5 to 10 gallons per minute and are of good quality for domestic and stock use.

The Tertiary aquifer unit yields only a small quantity of water to wells due to the fine grained nature of these sediments. Well yields range from 15 to 30 gallons per minute with deeper wells that penetrate multiple sandy layers, producing in excess of 200 gallons per minute. The overall ground water availability and quality is highly dependent on location and the composition of the deposit.

The most important aquifer unit in the Helena Valley is the sand and gravel layers of the Quaternary aquifer unit. Because of the heterogeneous nature of the deposits, the sand and gravel layers form a complex, but generally interconnected, system of aquifer zones that are considered as one multiple-aquifer system (Moreland and Leonard, 1980). Water quality in the Quaternary unit is generally good with the exception of the nitrate plume related to the past dredging activities. It is in this aquifer unit that the majority of the wells in the area occur.

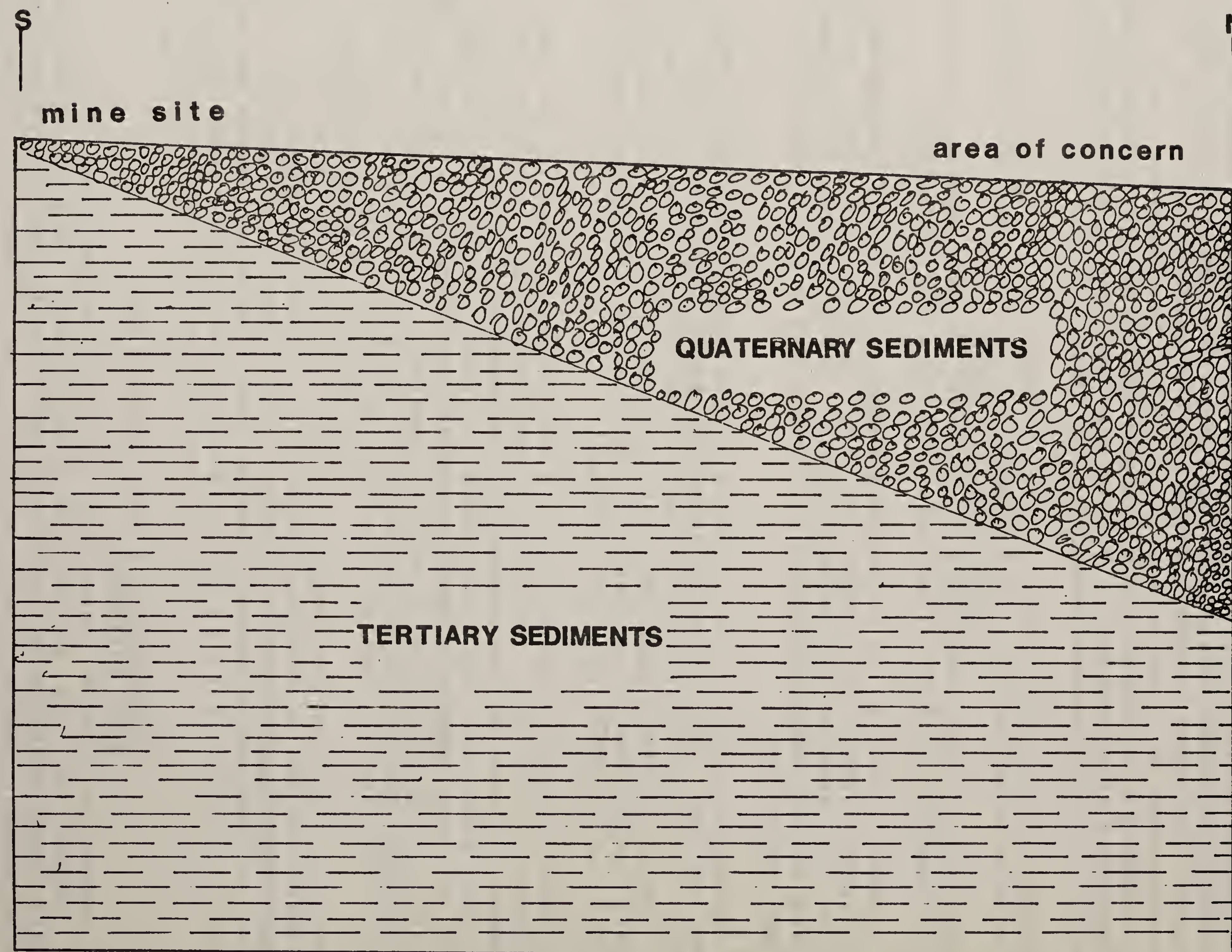
Recharge to the unconsolidated deposits is from precipitation on the valley floor and the surrounding mountains. Streams crossing the valley lose significant quantities of water to the underlying material. Deep percolation of irrigation water, leakage from irrigation canals and storm water runoff from the City of Helena provide significant recharge to the system.

Hydrogeology in the project area

The depth to ground water at the site ranges from 0 feet in the southeast corner of the property to greater than 155 feet on the north edge. Based upon drilling and test pits at the mine site there are three major stratigraphic units found at the site (Figure 6, Site Cross-Sections). These units are:

1) A small clay unit which forms a perched aquifer system in the southeast corner of the property. This unit consists primarily of volcanic clay and interbedded sand layers. The unit is

Figure 6 Site cross-section



approximately 15 feet thick along the south edge of the property and rapidly thins to the north. This unit is probably an upper portion of the Tertiary unit.

2)Interbedded clays, sands and gravels of Tertiary age. This unit, which is found at the surface along the edges of the perched aquifer system, dips steeply to a depth of 55 feet at the north edge of the property. It is in this unit that the production wells for the operation are located. As noted in the discussion of the Helena Valley, the yields from this unit are highly variable. Of the four drill holes completed in the unit, two produced less than ten gallons per minute and two are capable of producing in excess of one hundred gallons per minute.

3)Moderate to well sorted sand and gravels of Quaternary age which first occur approximately midway across the property and increase in depth to 55 feet at the north edge of the property. These deposits are formed by the fringe of the Prickly Pear Creek alluvial fan sediments and are covered by alluvial fan deposits from Last Chance Gulch and other small drainages. These alluvial fan deposits consist of a heterogeneous mixture of clay, silt, and gravel with depths of 0 to 55 feet. Throughout the project area the Quaternary deposits have been dry.

There are several large capacity wells located in the vicinity of the project area as well as many domestic and stockwater wells. Major sources of recharge specific to the vicinity of the project are infiltration from Last Chance Gulch, the municipal stormwater and water distribution system, and other tributary drainages south of Helena. Irrigation in the north portion of the area also is a source of ground water recharge.

RESOLUTION OF THE WATER RESOURCES CONCERNS

Throughout the permitting process the same concerns were raised about the water resources at the site. These concerns were:

* The water development at the site would cause area wells to go dry.
* The operation would cause metals pollution, nitrate pollution, bacterial pollution and the sedimentation of local wells due to the use of unlined settling ponds.
* The control of surface runoff at the site would decrease the recharge to the ground water system.

Resolution of these concerns took two concurrent approaches. Initially the primary effort was placed upon meeting the concerns through discussions and the presentation of information to the regulatory groups. While at all levels the agencies were represented by trained and dedicated personnel, at the city level the planning groups were not familiar with mining activities. The first step in the process was an explanation of how the mining would take place, the cause of the past impacts related to mining and how those impacts were to be avoided. This step was accomplished through a series of meetings in which examples of current mines were examined, the potential impacts of placer mining operations were outlined, and an explanation of how a placer mine could recover the gold without the addition of reagents was given. These discussions gave the city personnel a basic understanding of the mining and processing activities as they reviewed the actual proposal. In addition, the company worked to bring the state personnel responsible for mine regulation together with the city personnel early in the process to allow for a better exchange of ideas and questions.

The second step in the process with the regulatory groups was to present the actual proposal, which outlined the steps that would be taken to mitigate or eliminate potential impacts to the water resources. An integral part of the analysis was the use of analytical computer modeling based on the techniques found in Walton (1985) to project ground water drawdown effects, and the effect of seepage from the settling ponds. This analysis took the data from published studies, which included aquifer tests and well logs from sites in the immediate area, and data developed on the site to develop a simple model of the system. When it was projected that there was a potential drawdown impact to a well in the area, a monitoring program was established to cover that well.

The contamination risk was largely addressed using published information to demonstrate the low potential for metals contamination from placer mines. Studies were referenced which indicated that while in some cases settling ponds will show high metals levels, those metals are tied to sediments in the ponds. The ground water immediately adjacent to the ponds and clear seepage from the ponds did not show metals contamination. The source of the past nitrate pollution from an adjacent historic mine was researched and demonstrated. The regulatory agencies did not view the mine as a bacterial pollution or a ground water sedimentation threat.

The second approach was to attempt to meet the public's concerns relative to the operation. The same basic techniques were used in a series of public meetings held by the regulatory agencies and in private meetings with the concerned citizens. In addition to the concerns with ground water depletion and metals contamination, these groups raised the issue that the settling ponds would cause bacterial contamination and sedimentation of the ground water.

One of the major problems in the resolution of the water concerns was the conceptualization of the ground water systems involved. Although the mine water supply was completed in a separate ground water aquifer unit (Tertiary age sediments) than the wells in the area of concern (Quaternary age sediments), it was hard to imagine that wells completed as close as a mile of apart could be separated. The public's concerns with water depletion issues were addressed with two premises:

1)We believe, based upon the data we have collected that the supply wells and the wells of concern are in two separate aquifer units and therefore the effects of pumping are isolated to the particular unit.

2)If the wells are in fact connected, based upon computer modeling, the impact of the supply wells on the wells of concern would be minimal.

Again analytical computer models were used to make the projections for the presentation.

The concerns relative to the bacterial contamination of wells were addressed by describing the attenuation capabilities of the unsaturated zone. The closest well is approximately 3/4 of a mile away from the settling pond, with an unsaturated zone between the pond bottom and the regional ground water table of 82 feet. People with concerns began comparing the ponds favorably with the septic systems in the area, which seemed to convince the remaining objectors.

The sedimentation concern represented an unusual problem. Many people could not visualize the difference between water moving in a surface water system and water moving through the sediments at the site. The concern was approached by projecting the velocity of the water movement in the aquifer and comparing that velocity to the velocity necessary to move the various particles in a stream setting. Slides were shown of a physical sand model with a colored tracer injected into the flow stream to demonstrate how ground water moved.

CONCLUSION

The mine company dealing with water resources impacts has two major tasks. The first task is to adequately plan and design the operation with the minimization of impacts to the water resources. The second task is to present that information to the regulatory agencies and the general public. The regulatory agencies are staffed by people who are trained in their areas of responsibility but not necessarily in water resources and mining issues. This makes it especially important to present the information in a clear, concise, complete manner. Presenting the information to a public audience that is not familiar with mining presents problems with the conceptualization of both the mining and water systems involved. In this example it was necessary to rely on comparisons with familiar situations which were only approximations of the ground water systems in the area. A very useful technique involved the use of physical models and analytical computer models to aid in the explanation of the ground water system. In addition, the monitoring of wells, even though not required by regulatory agencies, and a willingness to meet with any concerned individual or group went far to alleviate concerns.

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"Surface and Ground Water Protection as Related to Public Minerals"

Author: Lee C. Koss, Hydrologist
Division of Geology and Mineral Assessment
Bureau of Land Management
Washington Office

Abstract:

BLM´s involvement with surface and ground water concerns both protection and supply (development). Hydrologic activities in the Bureau are divided among lands and renewable resources programs and energy and mineral resources programs. While water is an element in most Bureau programs (and interrelated between programs), activity in hydrology during the period between 1975 and 1984 has been greatest in the Solid Minerals Leasing Division. This paper briefly discusses the historical development of BLM´s recent experience with the need by the Department of Interior to collect hydrologic information (known as the Energy Minerals Rehabilitation Information Analysis Program (EMRIA) and later as Technical Investigations for coal leasing) and the development of a Precipitation/Runoff Modeling System for use in the Federal Coal Management Program. At the time this Program was being developed, the Surface Mine Reclamation and Enforcement Act (SMCRA) was approved by Congress.. This resulted in the formation of OSMRE, a new set of regulations and a new level of cooperation between Federal and State agencies concerning Federal coal ownership and protection of water resources. This discussion includes the seperation of SMCRA´s hydrologic responsibilities (on Federal coal lands) between three Department of Interior agencies (BLM, USGS amd OSMRE) and recent moves by these agencies and the State agencies designated primacy to enforce SMCRA, to undertake cooperative investigations (designed to satisfy both Federal leasing and mine permiting/reclamation responsibilities).

The remainder of this paper concentrates on a topic of high interest: Access to past and continuing coal hydrology information collected through cooperative USGS/BLM EMRIA and Technical Investigations, the scope of the studies, their intent and changes over the years 75-82, the 1984 evaluation of these studies and recommendations to improve them, the current groundwater emphasis, data adequacy standards and efforts to automate study locater and discriptive information.

INTRODUCTION

BLM's involvement with surface and groundwater concerns both protection and supply (development). The land-use objectives, legal standards and requirements which form the basis for carrying out programs such as Wildlife, Forestry or Coal Management also enable the BLM to play a major role in protecting water quality and quantity. This paper mainly concerns the cooperative effort to study and protect water resources during the Federal Coal Management Program.

In most states where BLM has considerable surface as well as subsurface coal ownership, the effort to obtain ground and surface water information relative to coal mining has been a combined State and Federal effort. In the mid-seventies, the US Geological Survey (USGS) played the pivotal role in this process by operating an extensive hydrologic data gathering network of their own which complemented and often was inseparable from the Coop- (50/50 cost sharing) programs they had on one hand with the States to collect and interpret coal hydrology data and on the other hand, the sizable BLM Energy Minerals Rehabilitation Inventory and Analysis Program (EMRIA) to do complementary monitoring and interpretation.

As we entered the end of the 70's and beginning of the Eighties, the Surface Mining Control and Reclamation Act (SMCRA) brought another Federal component, the Office of Surface Mining (OSM) into this effort and with it, another framework for State and Federal cooperative management and studies aimed at protecting groundwater as well as surface water, and combined the resources of the State Governments, the USGS and the BLM.

This paper briefly covers: 1. the level of effort which has been expended over the past decade to protect water during the process termed the Federal Coal Management Program and 2. how Federal and State agencies have cooperated in the effort to gather surface and groundwater data in areas where little monitoring had been done before, analyze this information and provide interpretations and often predictions which could feed back into both Federal and State decision-making processes to insure that water resource values were protected. In doing so, this paper covers changes in this cooperative effort during the past ten years and what is happening at the present time.

WATER RESOURCE PROTECTION IN THE FEDERAL COAL MANAGEMENT PROGRAM

In 1974 the Bureau initiated the EMRIA program to provide information on water as well as other resource information which would be needed in areas with potential to be leased for Federal coal development. The Bureau in 1974 was beginning a major emphasis in mineral management as the Interior Secretary's new Federal Coal Management Program was starting to take form. Although 1974 preceded the actual initiation of the Secretary's Program by seven years, it was apparent to Bureau personnel on the scene that a coal leasing program (of the size invisioned) would require a level of information, especially for surface and groundwater, which simply did not exist in many areas where the Federal Government had coal ownership. These persons also realized that collection and analysis of this information had to be phased parallel to the development of the Coal Leasing Program and development of the Programmatic EIS because:

1.
Knowledge of the scope and magnitude of the data gathering and analysis effort which would be needed to support a major coal leasing action on the part of the Federal Government was necessary feedback for program development and the Programmatic EIS.
2.
The lead time inherent, especially in the conduct of groundwater investigations, required studies to be initiated years prior to the time the final data interpretations would be used by BLM in the planning process.

Originally the EMRIA program attempted to gather a wide range of aspects relating to the "reclaimability" of areas shown on figure 1 as "Federal Coal Production Regions in the U.S." These reclaimability aspects included

hydrology, overburden geochemistry, soils, vegetation, revegetation, and at times, even development of equipment needed to correct a troublesome problem involving a particular aspect of reclaimability.

Before surface and groundwater protection can be explained in relation to the Federal Coal Program, the role BLM has had in this program must briefly be discussed. Before leasing could occur, a detailed planning analysis had to be accomplished.

In the land-use plan for an area in question, Surface and ground water resource values and development/protection opportunities were identified by the BLM hydrologist and then weighed against those of other resources. The BLM hydrologist's responsibility in this planning exercise was to optimize both surface and groundwater resource values. Legislation and agency directives dictated that several water resources variables be carefully considered and accounted for before leasing was allowed to progress. Water resources management objectives included such considerations as: protection of hydrologically sensitive areas, water-quality management, floodplain and water yield management, and water rights assertion.

In coal activity planning an environmental impact statement was then written for the entire coal region. Both tract-specific and cumulative impacts were analyzed. From a hydrologic standpoint the cumulative impact analysis was important because more than one tract could be leased and developed within the same drainage basin.

Once a decision was made to lease a tract to industry, the BLM could attach stipulations to the lease agreement to ensure compliance with all applicable resource management and environmental regulations such as a stipulation pertaining to the protection of a groundwater source.

Just prior to the period when the first regional lease sales were held and leases issued (1980-81), OSM was created as the agency to carry out the responsibilities legislated to the Secretary of Interior for administration of the Surface Mining Control and Reclamation Act (i.e. approving the mining and reclamation portion of the permit application package (PAP), monitoring mining operation, and ensuring performance standards/bond formulation and compliance). While OSM responsibilities under the Act involved both Federal and non-Federal coal areas, the Mineral Leasing Act as amended gives them specific responsibilities to protect the surface and groundwater as well as other resources on Federal coal lands.

BLM has had one additional responsibility to ensure that the land is returned to the desired post-mining land use, which included the surface and groundwater resource recommendations in the original land-use decision.

The surface and groundwater information for this Federal Coal Management Program resulted from the combined efforts of the BLM and USGS in Montana, North Dakota, Wyoming, Colorado, Utah, New Mexico, Oklahoma, Alabama plus some other Appalachian states. The basins within these states were chosen on the basis of their high concentration Federal minerals and the possibility of being mined in the future. The level of State involvement in the coop-program with USGS to obtain coal hydrology information varied from state to state, reaching its highest level in Montana where monitoring stations supported by all agencies contributed to each others interpretative studies.

Starting in 1976, reconnaissance studies were performed in large areas (over 50 square miles) containing Federal coal. They were designed to provide baseline surface and groundwater data where no such data existed previously. Area hydrologic investigations were conducted on smaller areas (10 to 50 square miles) where the BLM felt that some coal leasing could likely occur. Site-specific hydrological surveys were performed on delineated coal lease tracts or on specific reclamation study areas and might also have been conducted in connection with a site-specific study of unsuitability criteria (e.g. concerning sole source aquifers shallow underground flow in alluvial valley floors). Topical hydrologic studies were initiated in some areas to answer specific questions about hydrologic process-response functions and to improve general knowledge of the surface and groundwater of the coal regions.

Small watershed models were developed as tools to assist hydrologists in the transfer of data from gaged basins to ungaged basins and in the prediction of hydrologic impacts of surface mining. The modeling effort was not as successful in the West and the East because of the availability of data necessary to drive the model as well as the technical capabilities of available personnel to use the model.

This description of the coal hydrology studies and their relationship to the Bureau's planning system and the Coal Leasing Program brings us through the 1979 to 1981 period when EMRIA studies ceased to be interdisciplinary in scope, (i.e. aimed at determining the reclaimability of lands disturbed by surface coal mining). The focus of the studies now shifted to only hydrologic concerns under the title of Technical Investigations (TI) involved with coal leasing and operations. The overall level of baseline data and interpretive work likewise decreased in 1982 by 50% from the peaks year of 1981. 1983 again saw another 50% decrease in the amount of coal hydrology information USGS compiled for BLM and the total reduction of their own larger and often interrelated data collection and analysis network. However, throughout this period the percentage of groundwater data being collected and interpreted began to rise.

Three efforts which are now being conducted by BLM's Division of Geology and Mineral Resources will provide help to potential users of the surface and groundwater information generated as part of the EMIRA and TI efforts:

1. The RDTS tracking information for pre-1984 EMRIA and TI studies is being compiled and added to the existing RDTS computerized information

2. Standards of what constitutes adequate hydrologic data for use in the Federal Coal Leasing and Management Program (termed Data Adequacy Standards) have been drafted and are now in the process of Agency Review.

3. A pilot effort has begun to organize descriptor and locator information of all coal hydrology studies one Federal Coal Region and

physically plot them according to township. Using this framework, quick reference to a series of maps provides information on:

a. study boundaries (mapped on a 1:100,000 scale).

b. whether the study involved surface water or groundwater.

c. whether the study was evaluated to be of "good" "moderate" or "of little" use to BLM (from a coal hydrology viewpoint) and a discussion on why.

d. whether the study was a baseline or interpretive report (from a coal mining hydrology viewpoint).

e. Whether the study was regional (county or multiple county level) or site specific (watershed, 100 sq. mi. or less level).

f. The number of studies of a particular category either entirely within or partially within an individual township.

g. Their spatial relationship to selected lease tracts.

Additional hardcopy information being compiled with the above are: report cover pages, library locations, abstracts, summaries and study area maps.

This detailed mapping of studies is in progress for the Powder River Federal Coal Region (where a majority of studies have been conducted) and is being tracked with an effort to computerize other related information. In all, the 1:100,000 scale Power River Region pilot mapping effort, the updating of the RDTS and computerizing of the information accompanying the DSC 1:5,000,000 scale map will help information users both within and outside the Bureau access the wealth of information generated by coal hydrology studies conducted by a wide variety of sources in areas of Federal Coal.

<u>Summary</u>

In summarizing the situation surrounding coal hydrology studies in, the USGS is still the predominately the major agency conducting the data collection, analysis and interpretation under a cooperative agreement allowing the direct transfer of funds. By far the majority of study effort is now being centered in the Colorado/Wyoming/Montana parts of the Green River-Hams Fork and Powder River Federal Coal Regions.

Another recent development in the past several years has been the shift from predominately surface water studies to groundwater studies, including geochemistry of spoil areas and groundwater/surface water interactions and expansion interagency coordination and cosponsoring of these studies.

Overall, BLM's involvement with surface and groundwater in the coal management program can be summarized by the management objectives:

1. To protect water resources from undue and unnecessary degradation consistent with existing laws and criteria for current and anticipated uses.
2. To provide for the availability of surface and groundwater to carry out authorized uses of the public lands in accordance with Federal and State water laws.

Future Direction

Future directions are always difficult to predict, however two general directions can be identified at this time:

1. Increased management awareness at all levels of the Bureau of groundwater as a potential issue, including an assessment of specific problems and issues in BLM State Offices.

2. Guidance in developing and using groundwater information for land management activities, for example:

   a. Develop Bureau-wide Handbooks or guidance on groundwater information sources and uses within the Bureau, maximizing use of existing groundwater analysis models.

   b. Develop program specific technical guidance (e.g., data adequacy for coal management activities).

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MITIGATION FOR MINING AND ENERGY

MITIGATING THE BOOM AND BUST CYCLE

J. M. Robson

ABSTRACT:
The effects of the boom and bust cycle in mining development can be mitigated in two ways. One is the use of an effective business plan and the other is the creation of a mining plan or resource data base. This paper describes the use of a business plan, like the U.S. Bureau of Mines MINSIM program applied to a drill defined database. Aspects of data base analysis, design and physical testing are described.

INTRODUCTION

Features of a good business plan are planned use of a single commodity ore deposit. This type of deposit reduces the necessity common at many mines that prices of more than one commodity must be favorable to sustain production. For example many Arizona mines have a copper-molybdenum product which must meet an open pit mining grade. Commonly this grade is .5% copper/ton or, with molybdenum, .5% copper "equivalent". Mines with the .5% "equivalent" are dependent on weak molybdenum requirements of the steel industry and depressed prices caused by expanded foreign copper production. It seems unlikely that both market conditions will change favorably at the same time.

Another feature is that the mine should have a low holding cost during periods of adverse commodity prices. A key element is that modern sucessful mines have far lower capitalization costs than the underground mines of the 40's or the porphyry copper mines of the 60's. The effect of non-production on invested capital is the major concern for any realistic planner. Mines that require extensive preliminary stripping or shaft sinking are dangerous to start. Later, developed mines have expenses during periods of non-production. Underground mines like Noranda's at Cobalt Idaho need to be maintained; e.g. shafts pumped and all discharged water neutralized. These are added expenses to a balance sheet which is at the time lacking the mine as a source of revenue. This leads to the realization that today's mine must be easily moth-balled. New mines in Nevada like Battle Mountain are open pit in design and feature low cost, generic trucking and quarrying equipment all of which can be leased and possesses a more or less redeemable blue book value. Sucessful Alaskan mines like Sharon Steel's which controls the Alaska Gold Operation at Nome and the Ranchers Exploration and Development operation at Slate Creek are monominerallic, are cheaply started and deactivated, and possess excellently designed mining plans. (Although placer mines, these Alaskan operations produce from 16000 to 7000 ounces respectively per year. To impact the balance sheet of a New York Exchange sized company requires about 10000 ounces of gold production annually).

The mining plans developed by these companies indicates to mine management what can be done with these properties under the current mix of business conditions. This paper describes the key parts of these mining plans especially of interest to the BLM. Useing Alaskan examples, suggestions are made where the BLM might help improve the quality of use by mining enterprises on public lands. The design of a generic geographic and econometric data base is proposed which must guide the physical work of development drilling and sampling from the start.
KEY TERMS: MINE-PLANNING, MINE-DEVELOPMENT, ALASKA-GOLD-DEVELOPMENT

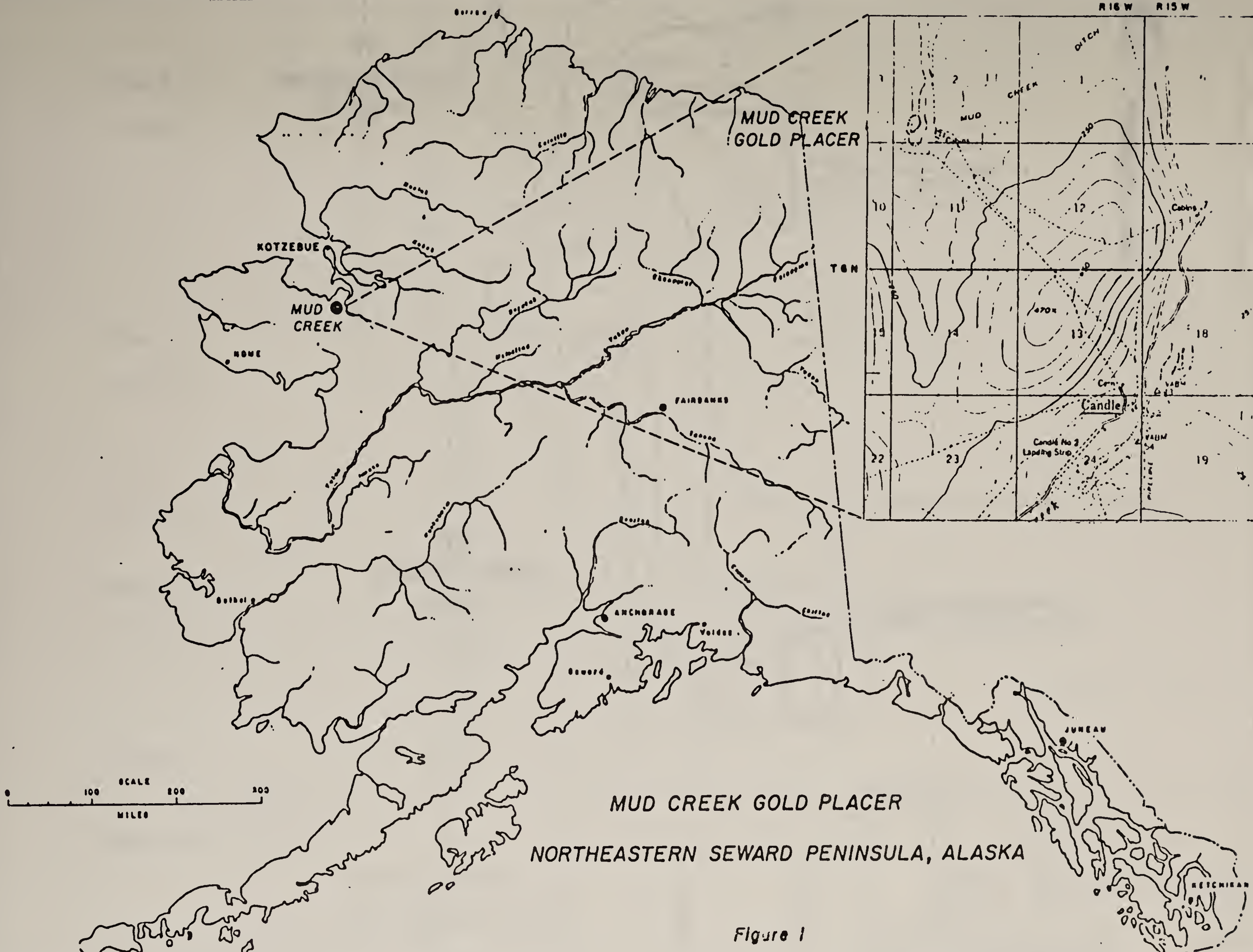
O U T L I N E

The basic tools for mine planning are a discounted cash flow rate of return computation which can be used for various sets of business data and a metal inventory system relateing to the developed property. A good example of the first is the U.S. Bureau of Mine's Minesym program. This type of program can determine the commodity price necessary to insure a stated return on investment given certain development costs, production costs, a percentage of resource recovery and the grade of the resource.

This business planning is based on a geographically based metal inventory system. This type of system consists of a database of sample data derived by drilling and a collection of spatial analysis tools. Many software packages in the public domain contain useful tools and logic for mine inventorys. For example the Fortran5 version of MOSS as supported currently by the BLM's Denver Service Center allows cellular analysis of study areas described by randomly located sample points. Similar capabilities are available in code created by the Kansas State Geologic Survey. "OUNCES", a program written by the author, uses spatial tools to perform a precious metal inventory of a placer deposit useing Kansas State models.

The Minesym program's main benefit for the planner is the availability of sensitivity calculations. These calculations show the impact on mine performance of changes in operating parameters. The sensitivity calculations should be done after the geometry and grade of ore deposit has been determined by development drilling and the recovery has been estimated by a specific effort of bulk (metallurgical) sampling sufficient to characterize the gross mineralogy of the ore deposit. In other words, the reserve computations have already been completed and an inventory exists.

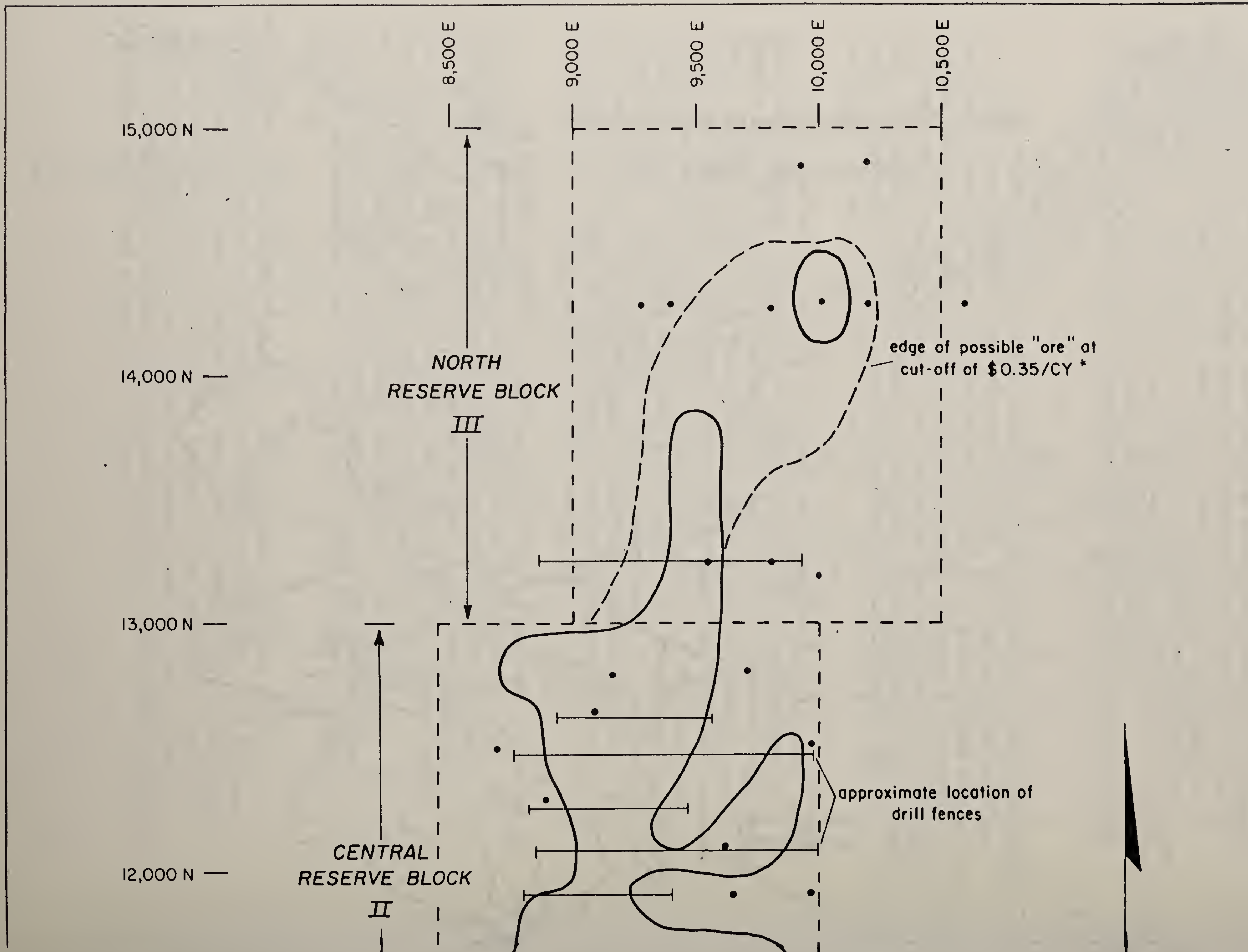
The following data is from the Mud Creek Prospect located near Candle Alaska and is given by the courtesy of Mr. Bud Meyers of Fairbanks, Alaska. The author was the property project geologist for Noranda Exploration, Inc. and designed the physical testing, geologic modelling and ore reserve calculations; Mr. Bill Cobb of Denver served as a project evaluation engineer, researched costs and developed cash flow models. See figure 1.

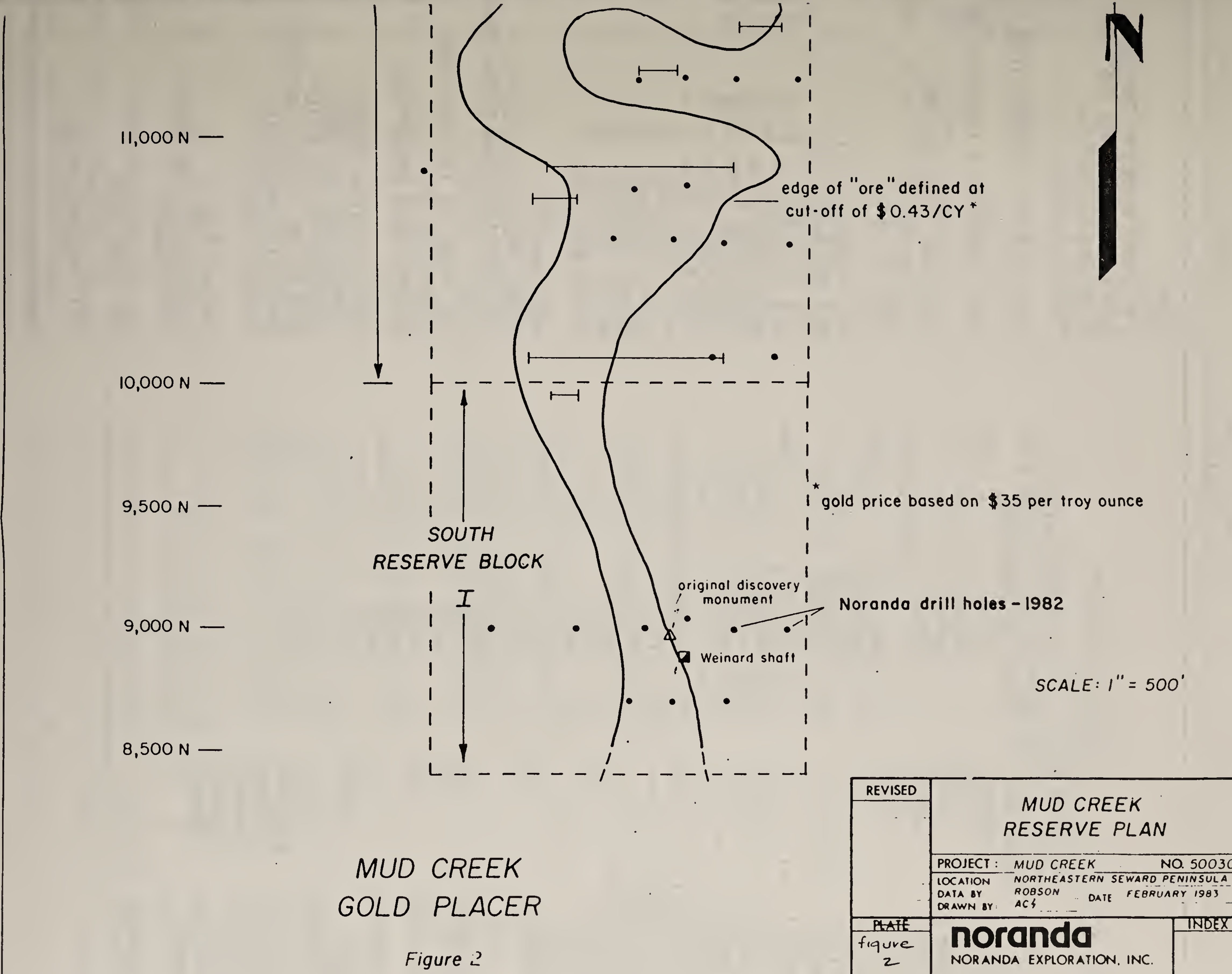


MUD CREEK GOLD PLACER

NORTHEASTERN SEWARD PENINSULA, ALASKA

Figure 1


8,500 E
9,000 E
9,500 E
10,000 E
10,500 E
15,000 N
14,000 N
13,000 N
12,000 N
NORTH
RESERVE BLOCK
III
edge of possible "ore" at
cut-off of $0.35/CY *
approximate location of
drill fences
CENTRAL
RESERVE BLOCK
II



MUD CREEK
GOLD PLACER

Figure 2

TABLE 1.

```
MUD CREEK          CASHFLOW PROGRAM
         ENTER ACTUAL DATA
         PROJECT BASIS - ACRS DEPRECIATION
         DEVEL PERIOD DEPR ADDED TO DEVEL EXP
         CASH FLOW REPORTED IN THOUSANDS
ORESV      2800000          GSFAC1          .05
GRADE1        .026          GSFAC2     .........
GRADE2     1.E-20           GSFAC3     .........
GRADE3     1.E-20           GSFAC4     .........
GRADE4     1.E-20
PRICE1        525           NSRUNT1         525
PRICE2     .........        NSRUNT2    .........
PRICE3     .........        NSRUNT3    .........
PRICE4     .........        NSRUNT4    .........
HGRESV     .........        MRECY1           90
HGRADE1    .........        MRECY2     .........
HGRADE2    .........        MRECY3     .........
HGRADE3    .........        MRECY4     .........
HGRADE4    .........
DEPLRATE1      15          PREPRODUCTION CAPITAL
DEPLRATE2.........          YR1        .........
DEPLRATE3.........          YR2        .........
DEPLRATE4.........          YR3        .........
NSRRATE        10           YR4        .........
NPIBPB     .........        YR5        .........
NPIAPB     .........        YR6        .........
PPRRATE        12           YR7        .........
                            YR8        .........
                            YR9        .........
TAXRATE        58           YR10       .........
ITCRATE        10           YR11       .........
HROLRATE       15           YR12       .........
                            YR13       .........
MLIFE           5           YR14       .........
TMILL        1543           YR15       .........
DILTM      .........
OPCOST/T     5.81           CHKTOT            0
TOTPPCAP  6940000
M&ECAP    3585000
BLDGCAP    560000
DEVCAP    2795000
WKNGCAP    860000
#PPYRS          3

ONGOCAP    .........
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YEAR

M & E AND ONGOING CAPITAL
BLDGS & STRUCTURES CAPITAL
DEVELOPMENT CAPITAL
WORKING CAPITAL

TOTAL CAPITAL EXPENDITURE

UNREC PREPROD & ONGOING CAP

OPER COST PER TON ORE

TONS MILLED

NET RECOVERY - 1
NET RECOVERY - 2
NET RECOVERY - 3
NET RECOVERY - 4
RECOVERED METAL - 1
RECOVERED METAL - 2
RECOVERED METAL - 3
RECOVERED METAL - 4
METAL REVENUE - 1
METAL REVENUE - 2
METAL REVENUE - 3
METAL REVENUE - 4
TOTAL REVENUE

NSR PAYMENT
TOTAL OPERATING COST
NET PROFITS FROM OPERATIONS

NET PROFITS INTEREST PAID
EFFECTIVE NPI - %
INCOME FROM OPERATIONS

DEPRECIATION (ACRS)
DEVELOPMENT WRITEOFF
PERCENTAGE DEPLETION
DEPLETION LIMIT (MAXIMUM)
DEPLETION DEDUCTION
TAXABLE INCOME

INCOME TAX
INVESTMENT TAX CREDIT
TAX PAYABLE

NET CASH FLOW

NET PRESENT VALUE

UNRCVRD PP EXP & CURR CAP
=========================
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TABLE 1. (continued).

1	2	3	4	5	6	7	8	TOTALS
0	3585	0	[illegible]	0	0	0	[illegible]	3585
0	560	0	0	0	0	0	0	560
650	2795	0	[illegible]	0	0	0	0	3445
0	0	860	0	0	0	0	-860	0
650	6940	860	0	0	0	0	-860	7590
689	8128.08	10015.05	9155.032	6479.763	3483.393	127.4598	0	
0	0	5.81	5.81	5.81	5.81	5.81	0	
0	0	324	596	596	596	596	0	2708
0.00	0.00	0.01	0.02	0.02	0.02	0.02	0.00	
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
0	0	7.88	14.46	14.46	14.46	14.46	0	65.72
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	4137	7591.5	7591.5	7591.5	7591.5	0	34503
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	4137	7591.5	7591.5	7591.5	7591.5	0	34503
0	0	413.7	759.15	759.15	759.15	759.15	0	3450.3
0	0	1882.44	3462.76	3462.76	3462.76	3462.76	0	15733.48
0	0	1840.86	3369.59	3369.59	3369.59	3369.59	0	15319.22
0	0	0	0	0	0	0	0	0
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
0	0	1840.86	3369.59	3369.59	3369.59	3369.59	0	15319.22
0	722.6	1214.4	916.[illegible]	624	331.6	39.2	33.[illegible]	4145
0	0	482.2509	887.1034	887.1034	887.1034	887.1034	0	4030.665
0	0	558.495	1024.853	1024.853	1024.853	1024.853	0	
0	0	72.10457	783.0433	929.2433	1075.443	1221.643	0	
0	0	72.10457	783.0433	929.2433	1024.853	1024.853	0	3834.036
0	0	1286.505	783.0433	929.2433	1126.034	1418.434	-33.[illegible]	-031.255
0	0	746.1727	454.1651	538.9611	653.0998	822.6918	0	3215.090
0	0	358.5	0	0	0	0	0	358.5
0	0	387.6727	454.1651	538.9611	653.0998	822.6918	0	2856.590
-650	-6940	593.1873	2915.42[illegible]	2830.629	2716.490	2546.898	860	4872.630
[illegible].217	-5247.64	390.0303	1666.904	1407.323	1174.414	957.4734	281.1355	54.42495
689	8128.08	8174.190	5785.5[illegible]	3110.173	113.8034	0	0	

Table 1 shows capital and operating costs for this Alaskan prospect distributed over 8 years. The costs are in terms of thousands of 1983 dollars. This property is consists of a dredgeable reserve of 72,000 ounces of fine gold or four years of mine life assumeing a dredge capable of processing 6000 CY of gravel daily. The total amount of gravel at a grade of .026 ounces per cubic yard is 2.8 million cubic yards. This grade has been determined by 244 drill holes and reflects fine gold content. Since the percentage of recovery is to be an evaluation variable, the goal of recovery during prior sampling was to achieve an estimate of the property's maximum metal content.

The basic mining plan is dependent on the costs of two tasks. One task requires stripping of 20 feet of ice and loess which overlys a dredgeing section. The stripping is to be done by dozers equipped with hydrallic rippers. Second, the underlying dredge section must be thawed by useing Nome style techniques consisting of cold water injection of holes drilled on 20 foot triangular apices. The dredge section is 30 feet thick; 700,000 cubic yards of this section must be stripped and thawed annually one year before actual dredgeing.

Separate capital costs include a refurbished bucket ladder dredge, a townsite, and exploration/developments.

TABLE 2

SENSITIVITY CALCULATIONS

		Required Gold Price
1. Base case	- 15% discount factor - 10% in kind royalty - 90% recovery - current exploration costs sunk - three years until production	$525.
2. 10% decrease in recovery to 81.82%:		$585.
3. 10% increase in operating costs 6.39/cy:		$550.
4. 10% increase in capital costs: $7,635,000:		$545.
5. Doubling of known reserves due to successful exploration or acquisition:		$450.
6. Project costs distributed to currently profitable other corporate efforts:		$415.

Table 2 shows a series of gold prices necessary to support this prospect for a given decrease in gold recovery, an increase in operating cost, an increase in capital cost, acquisition of more reserves to amortize capital costs and writing off startup costs against other currently profitable corporate enterprises.

These cases are compared with a base case useing the data of figure 1. for development, capital and operating costs at a 15% discount cash flow. In case 1 is a 10% in kind royalty to lessors, a 90% recovery rate, a 6.94 million dollar capitilization.

Case 2 is a 10% decrease in overall recovery. This case requires a $60 increase in the gold price compared with the base case and and suggests that the most important factor in cash flow is recovery. In this operating environment, recovery risks might include passage of unthawed gravel through the processing system or inability to dig to the bottom of the deposit.

Case 3 and 4 are moderately higher than the base case suggesting that the prospect is relatively insensitive to capital and operating costs.

Case 5 shows the dramatic effect of doubling reserves on the start up gold price. If a reasonable exploration target can be successfully pursued, like development of a parallel fluvial system similar to the main reserve, the viability of the prospect is greatly enhanced.

Case 6 shows the benefit of treating the prospect in concert with other corporate ventures.

These cases suggest that added capital costs should be incurred if significant risks to recovery exist. These costs might take the form of additional metallurigical testing with a view of avoiding miscalculations concerning the baseline recovery factor.

These analyses reflect how one mining concept might perform as an investment. Other concepts involving different projected recoveries, capital costs and operating costs can easily be tested. A difficult goal is to find at least one operational plan that will provide a minimum specified financial return. At this point the Mud Creek project had modest property acquisition costs and about $800,000 in drilling costs.

After a successful project plan is identified, the exploration and development phase of the project terminates. The project is considered a successful research and development effort by the resource corporation.

This phase often marks a change of management of the property from company's exploration/development staff to its production staff. It is worthwhile for public land managers to recognize this handoff period. It is a period in which business and environmental risk is at largest. These risks arise from arrangeing, often with venture partners, for large capital investments and in communicating resouce information from one management team to another.

MINE PLANNING SYSTEM

The metal inventory system is a geographic information system which estimates prospect characteristics based on samples. This system can inventory any geologically measured attribute like the ice content of the overburden, the total ounces in the deposit etc. provided the sampling work addressed the attribute during physical exploration.

The requirements of this system are to be able to determine the number and location of fine gold ounces that are mineable given a unit cost of production. The source information for this system is a table of drill holes which contain a geographic reference, a mining thickness or "dredge section", and a diluted grade.

The study variables required are cell size dimensions, a window or study limits expressed in coordinates, a break even production cost in dollars per cubic yard and a specified, reasonableness distance from a cell center to its set of neighboring drill holes . This last measure is used to determine whether a cell's computed grade is based on remote drilling information and hence contains speculative gold reserves or should be considered to rather contain proven gold reserves. This distinction is preserved by totals of proven or speculative reserves.

For the Mud Creek deposit, areas of contrasted geology with ore reserves received separate inventory calculations. For example one area consisted of deeply incised, very high grade coarse gold accumulations and another was the site of a vertical stacking of arcuate meander deposits.

These areas were windowed separately so that separate totals were derived for each area. Gold bearing areas not bounded by barren drill holes were closed by projections of local barren depositional features. These features were marked in the drill hole data base by dummy barren holes. The reason for this approach was to characterize areas as possessing varied operational ease or risk.

Different types of cell estimation were used. The nearest neighbor sample selection method for four drill holes resulted in property totals almost identical to results achieved in the late 1940's useing the BLM's triangular reserve modelling scheme. (The old computation was done by Douglas Colp ,M.E., of Fairbanks.) Useing a sector search for selecting holes along the axis of gold deposition for each cell resulted a property total which was 2% higher than provided by the simple nearest neighbor search. Since particulate gold is deposited in a linear fashion by fluvial systems, the sector search method of cell estimation seems to best reflect the actual distribution of gold in the deposit.

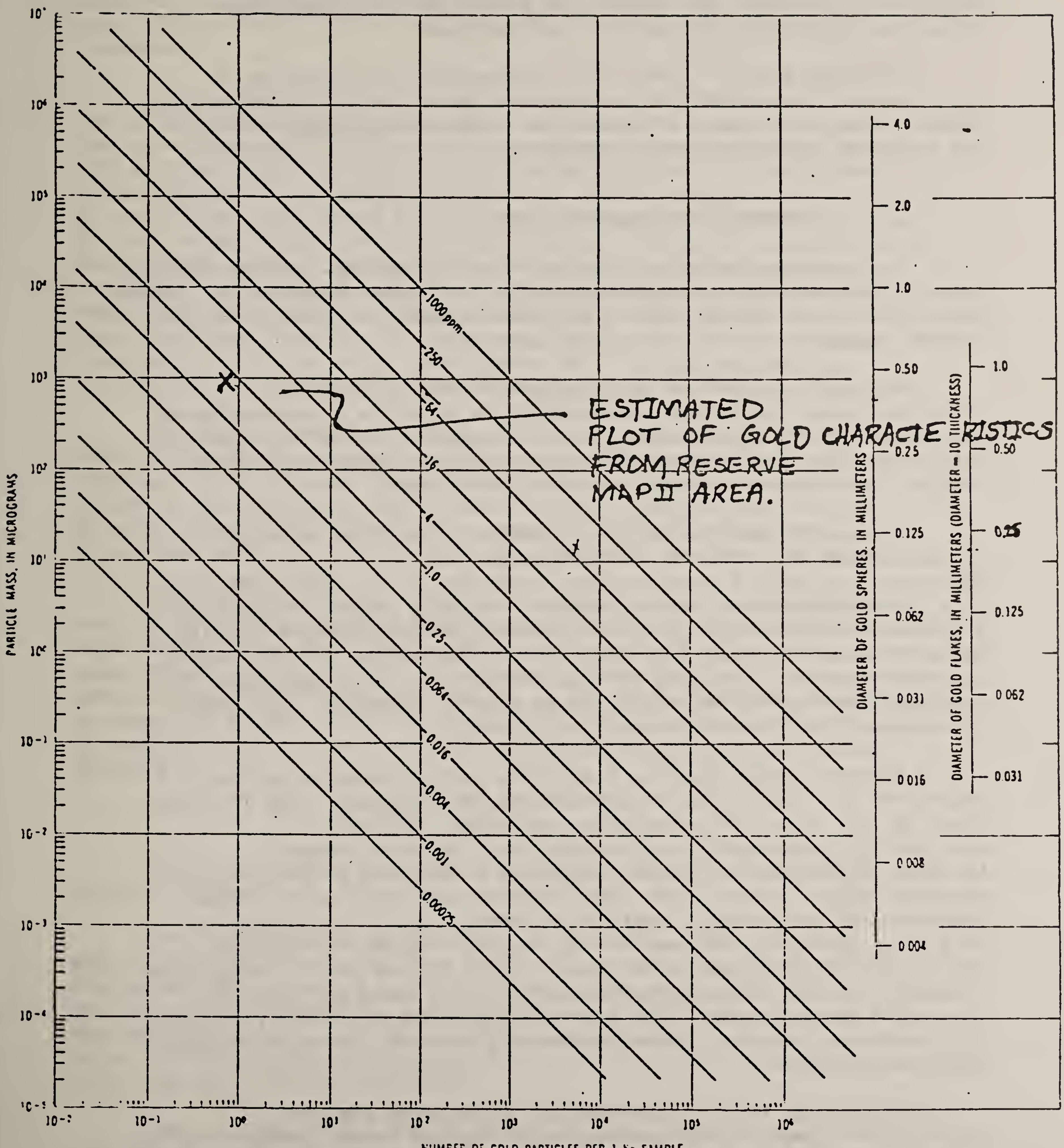

FIGURE 2.—Relationship between number of particles per 1-kg sample, particle mass (assuming all particles to be of uniform mass), and grade or tenor of the sample in parts per million. Scales to right relate grain size of gold spheres and flakes to particle mass. GEOLOGICAL SURVEY PROFESSIONAL PAPER 625-C.

Figure 3.

This calculation method was used iteratively for 600 blocks to create a reserve block data base giving for any block presence of ore at a given cut off grade, its overburden thickness, its contained fine ounces and volume, and location.

This data base was useful for determining the location of aggregates of reserve blocks available at given levels of production costs. Also, the amount of overburden removal associated with any proposed production was determined.

INTEGRITY OF RESOURCE DATA

Any resource model must be accurate; sampleing a placer deposit deposit has been described by John Wells in "Placer Examination", Technical Bulletin 4, USBLM, 1969. Both BLM workers and those form the private sector are involved in this sampling.

The sampling practice is important to the BLM because it is the basis for patent recommendations which is a very profound transaction for a land manager, sets an example for correct testing methodology for the mining community, and gives involved personnel insight into Alaska's mineral resource endowment.

The application of Well's concepts is obscured because of descriptons in terms of old technology.
The thrusts of Well's work includes selection of a correct sample size, encapsulation of samples within a caseing or with the walls of a frozen hole, location of the mineralized zone within the drilled section, measurement of the metal content and volume of the sampled geologic section. The goal of these efforts is the computation of a diluted grade for the section to be mined. Commonly, this grade is expressed in fine ounces per cubic yard.

A correct sample size in a drilling project relates to the selection of a drill with an appropriate bit diameter. Two foot sections of the column of material extracted by the drill are commonly processed for a running count of gold content. At issue is whether this gold represents a mineable grade over a mineable width. Figure 3, of USGS Professional Paper 625-C, shows the relationship between sample size, sample grade, the number of gold particles per 1-kg sample. In Alaska, evaluating engineers try to use drills larger in diameter than 6 inches and to reduce consolidated section samples represented by 30 or more gold particles to a total gold content. The goal of 30 or more particles per sample is directed at avoiding particle scarcity effects. These effects are discussed in 625-c.

According to Paul S. Glavinovich, consulting engineer, actual grades requried for production by bucket ladder dredges in Alaska are .001 ounces per cubic yard in frozen material (Nome) and .0005 ounces per cubic yard in thawed material (Nyak).

Today, the largest threat to accurate sampling of unconsolidated material is the lack of appropriate drilling equipment. Equipment in use is often that leased from commercial drilling contractors. Historically, water well drillers have provided much of this equipment.

In the 1940's, the churn drill provided the capability of measureing all of these parameters well. Today churn drills are somewhat rare because of the introduction of reverse circullation drilling systems which drill water wells more efficiently. The reverse circulation drill fails as a sampling device because the sample is is continuously evacuated from the area of the drill bit by air flow. (In the churn drill, the drill pipe encloses a stick of cored material which can be sampled incrementally from above within the caseing.) Correlation of material with actual depths within the hole is not possible and material in excess of what is cut is evacuated. Because of this inability to determine section volume, the reverse circulation drill is not a quantitative drill for mine planning or patenting proceedures. Unfortunately, it is commonly used.

In frozen ground, in Alaska generally north of the Alaska range, a fix to the results of the reverse circulation drill is possible. Hole volumes can be measured by lowering known quantities of water down the drill hole and after determining the rise in water level, the volume can be measured. This proceedure is not currently used by the BLM, e.g. Gaines Creek, but should be.

For work in unfrozen materials, the following technologies tend to meet the requirements for sample accuracy: traditional cased churn drills , resonant drills or piledrivers, and hollow stem auger auger drills with split spoon samplers. These drilling devices are commonly available in various caseing sizes to fit with geostatistic sampling needs. (The resonant drill offers logistical challenges; it and its carrier are a marginal weight load for a C130 Hercules aircraft.)

PHYSICAL TESTING PLAN

Physical testing consists of tasks of sample evaluation and sample creation.

Sample evaluation is described by Wells, op.cit. To the goal of 100% gold recovery from the sample processing effort, should be added a second goal of timely sample evaluation. Drill hole results must be available to allow informed placement of the next drill site. Patent examiners should be able to allow alibi holes for holes that penetrated barren portions of a mineralized units while the drill is still on site.

Some evaluators try for a sample recovery of say 90% with a view that production recovery will duplicate this percentage. Most of the lost gold is assumed to be a component of a fine gold fraction difficult to extract with the equipment at hand. This proceedure will confound later efforts to consider enhanced recovery if the value of fine gold fractions is not known. A better approach is to acquire some metallurgical samples early in exploration and to measure gold size abundances and physical settling characteristics of the sized fractions. This allows a comparison of the benefits of enhanced recovery against increased capital costs. The Mineral Research Laboratory in Fairbanks is equipped to evaluate alternative sample recovery systems. At Mud Creek gold had good settling characteristics. A three man sampling team used a sucessful combination of equipment to reduce 2040 pounds of sample daily to say 40 milligrams of gold amalgam sponge. This equipment consisted of tubs with propane heaters (crab pot heaters) to thaw and disaggregate clays, an E-Z Panner consisting of a vibrating screen and oscillating sluice box, a patient professional panner for the concentrate, a longtom tailing sluice for scavageing fine gold and an amalgamation laboratory with gold scales. These components worked as a recovery circuit providing next day sample results.

SAMPLE CREATION

The activities of sample creation are customized to the drill employed because each drill has a different sample recovery system. A check is made that each of Well's concerns for sampling is addressed by the capabilities of the selected drilling system.

Testing should be limited to a single depositional basin. The basin sets the limits to geologic variability needed by planning and by operational copeing. Within the basin, one should try establish that fineness, gold size distribution, permeability of the auriferous unit and depositional style are constant.

For placer deposits, three logs help guide data capture. The logs are important to because they represent the data which becomes somewhat interpreted in data bases and models.

The most important log is the lithologic log which should show a visual graph of all geologic units encountered by the drill hole and should contain a discription of the material. The overburden should also be characterized because of its significance in reclamation concerns. High ice contents like 50% are common in areas dominated by buried frozen lakes. The overburden composition will vary regionally being in some places loess dominated or containing rather, rock slide material. Commonly, the distribution of these units is unrelated to modern topography; Mud Creek is so deeply buried by loess that it's geometry was determined by blind drilling.

The ore bearing unit must be described well because of the need for high recovery of this unit minimizing dilution from units above and below.

A percentage of settleable solids, slime fraction and screen oversize can be made from samples from resonant drills and hollow stem auger drills. This may be done with each drill hole and variations noted across the deposit. The benefit of capturing this information is to get a property wide insight into water requirements for processing the entire orebody. Later, this effort be duplicated by a few 7 to 15 cubic yard metallurgical samples from a few selected sites.

The second log is the operations log. It shows the quality and uniformity of the sampling operation. Actions which reduce sample quality like a reducton in drill diameter size ought to be noted. This happens when penetration is difficult.

The third log is the computation sheet. It should show the standard grade computation given by Wells, the application of a dilution factor for the mining section and notes from any coroboration of the pay zone volume. This coroboration might take the form of the water measurement described earlier. The fineness factor should be referenced to a smelter receipt.

SUMMARY

In conclusion, performing appropriate business calculations and creating a geologic data base will provide a basis to estimate future business performance. In time, operating experience can be used to improve cost estimates. Land use planners might note that the Minsym program has an option to view such business and geologic data as more than an instance of site specific information; it may view such a data collection as itself representing a sample of regional resouce information to be evaluated with other prospect or mine data.

I would like to thank Bob Caughey of the BLM's Graphic Develop- Section, Information Services, Anchorage, AK. for interest in this paper and Earl Boone of the Division of Minerals for some support.

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REFLECTIONS UPON ADVICE GIVEN A UTAH BOOMTOWN

Robert P. Huefner and Donald Zillman*

ABSTRACT: Reflecting upon advice which they and others gave a Utah boomtown, the authors suggest that too much lipservice and too little genuine recognition is given to the fact that in a boomtown uncertainty is enormous, flexibility is essential, and managerial resources are dear. Three guides are offered to better recognize these circumstances. The first is that communities should get to work using the tools they have, rather than waiting to make major investments in new tools such as a new master plan or a new form of government. Use of available tools allows skills to develop and action to proceed. The second is to not make unnecessary commitments early in the development and to not presume that all programs must be in place when a project begins. Waiting, for example, before designing and staffing new social services buys time to build resources and skills and keeps open options until conditions and desires are better understood. The third is to reduce the dangers of community financial risks, not by expecting to eliminate them but by understanding, reducing, and then managing them through (a) structuring common interests between the community and the developers and (b) building reasonable fall back positions in case expectations misfire.

INTRODUCTION

This is a confession by two professors whose advice was sought by Millard County officials at the beginning of the growth associated with the Intermountain Power Project's power plant near Delta, in Millard County, Utah. It reports some advice we and others gave, and it shares our second thoughts, based upon what happened in Millard County and other parts of Utah during the energy boom of the Seventies and early Eighties (England and Albrecht, 1984; Hachman, 1979; Zillman and Solomon, 1983; and Zillman, 1986).

The Intermountain Power Project touts its power plant as the "largest new construction effort in the Intermountain West" (S.L. Tribune, 1987, pp. 2 & 11). Built at a cost of $5.5 billion, it uses coal to generate 1,600 MW of electricity -- 25% going to 29 municipalities and cooperatives in Utah and 75% going to Los Angeles and 5 other municipalities in Southern California. "Completed ahead of schedule and under budget," it was dedicated and fully operating on June 13, 1987. The peak workforce of 4,500 was more than half the 1980 pre-boom population of all Millard county, a rural county in central Utah, 75 miles from a metropolitan area, whose land area of nearly 7,000 square miles is somewhat larger than Connecticut and Rhode Island together.

The power plant's development was relatively quick, considering the difficult public policy questions it raised. The dedication came less than six years after the groundbreaking in October of 1981. The groundbreaking had come a little more than a decade after planning started.

The plant's history (Zillman, 1986) began in 1970 when the U. S. Bureau of Reclamation informed Utah municipal and cooperative utilities that it could not provide additional power from the Colorado River Storage Project for their future growth. The Intermountain Power Project (the Project) was established less than four years later, in January, 1974, as a non-profit corporation to generate power for these Utah utilities and large

*Co-authors: Huefner is Professor of Political Science and Zillman is Professor of Law, both at the University of Utah, Salt Lake City Utah, 84112.

Southern California municipal utilities. It offered the Utah utilities the efficiency of a large generation facility, one larger than what they, themselves, needed and could support. It offered the California utilities a site outside of Southern California and its environmental problems.

Three years later, in 1977, the Project was prepared to ask the Utah Legislature for facilitating amendments to the state's Interlocal Cooperation Act. The amendments passed by large majorities, in spite of "impassioned debate" arguing that the amendments encouraged public power and tax avoidance (Zillman, 1986). That year the Project also proposed a site, but it encountered serious environmental concerns that made the necessary state and federal approvals doubtful. Then federal and state agencies, rather than considering alternative sites as they might be proposed by the Project, formed a joint task force to identify an appropriate location. In 1978 they found consensus on a Millard County tract. In December of 1979 the Project gained the key formal site approval from the U.S. Secretary of the Interior.

In the fall of 1979, shortly before the site approval, the Millard County Attorney visited the University of Utah to request help from its president. The attorney described himself as a retired country lawyer who had been asked to return, part-time, to public life to help the County deal with the developing prospect of the power plant. He found that the county faced many unfamiliar questions of public policy. He and other local officials were entering complicated negotiations regarding these policies, and dealing with "sophisticated lawyers from the big cities:" first Salt Lake City, and then Los Angeles. Now, he said, to prepare for issuance of billions of dollars of municipal bonds, the Project had employed New York City lawyers. The communities were uncertain about what their interests were, and about how to protect those interests. They were neither organized nor staffed for the development. To further compound their difficulties, they were threatened with local dissention: the Project's purchase of water rights had made millionaires of some residents while neighbors and relatives had only the promise that they would live in boom towns.

A few University faculty, staff, and students became involved. They helped estimate financial prospects and options for the County, helped outline alternative governmental structures, helped update master plans and land use controls, helped draft and even negotiate the formal agreements, helped coordinate intergovernmental efforts, helped monitor the changes taking place, helped develop procedures to hire professional personnel, and helped train teachers and other school staff.

While they played roles of some significance in these activities, in no case did they play a dominant role. They provided ideas, background information, and reactions; sometimes they provided prestige that prompted or allowed second thoughts to be given to plans that were being pressed hard. But the amount and influence of their help was limited, in part because of limits upon the University's resources and in part because all parties thought it essential that the communities control their own policy.

It is from this experience and perspective that we offer second thoughts about some of the advice we and others gave the local governments. Three points of advice will be considered. The first, advice given by the first author, was that the communities quickly push their attention beyond the questions of finance that they already were addressing, to questions of land use planning and, even more importantly, to problems of social interaction. The second, strong advice urged upon the County by both the State and the Project, was that the local governments establish a formal cooperative effort to manage the boom. The third, advice given by numerous sources, was that the local governments take care that the Project not shift its risks to the communities. All three suggestions seemed prudent. But none was followed, except in quite incomplete ways. At the time the reason did not appear to be disagreement with the suggestions but rather lack of experience and lack of time. Looking back, the incomplete adoption of these suggestions may reflect something else: that they were not the most appropriate moves. If so, we now can improve the advice.

1. REFLECT THE LEAD TIMES

How the Advice Was Delivered

One of the authors (Huefner) gave this advice, stressing the need to know how long it would take for various preparations for the power plant, and then to use such knowledge to set priorities. The advice was delivered, extemporaneously, when the County Attorney assembled at the County Courthouse in Fillmore a meeting of Project representatives, most public leaders in the county, and observers such as Huefner -- and then at the meeting asked Huefner to make suggestions. It was the University's first public response to the County Attorney's request for assistance.

The officials were at that moment focused upon establishing an "impact alleviation" agreement with the Project for the purpose of gaining financial assistance for public expenditures. The County and School District already faced new expenditures: employing engineers to assess needs for County public works and employing architects to design a new school. These and other jurisdictions could see many similar and immediate needs. The local officials also saw two other reasons to press for a quick agreement: (1) the tax base would be slow to respond to the new developments and (2) the officials presumed their bargaining position with the Project would never be stronger. The Project had indicated its willingness, and eagerness, to provide financial assistance, which some understood to mean even secondary costs such as the municipal costs in servicing a new McDonalds or whatever else should develop because of the power plant. But now agreement could not be easily found regarding the amount of assistance and the requirements and control which might be attached to it.

Huefner's suggestion attempted to broaden the focus. The financial arrangements, he said, were critical: they deserved immediate and serious attention. The rapidly developing events had made their importance clear to all those at the meeting. But another problem would surface as soon as actual development began, and probably sooner. That was how to manage land use regulations. These regulations and the forgotten master plans deserved a thorough overhauling, a task requiring more lead time than the impact alleviation agreement. He suggested that problems of social adjustments to the population's growth, to the changes in roles, and to the mixing of cultures would surface still later and yet require even longer lead times to manage. These problems of social adjustment would not become real until the new populations arrived in large numbers. In summary, three major efforts would be required, and the order in which their need would surface was the opposite of the order in which these efforts should begin, given their respective lead times.

How the Advice Was Used

The advice was thoughtfully received. Local leaders were aware of all three needs, had given them at least some thought, and subsequently gave some continuing and serious effort to each. But the pressures of the moment kept nearly all attention focused upon the alleviation agreement. The same persons were responsible for much of what would be done in each of the three efforts, and they were too few to feel they could gain reasonable command of even one effort. For example the County Attorney would play a major role in updating the land use ordinances, but even when a part-time deputy was added to his staff of one secretary the three of them could hardly keep up with the growing load of traditional legal matters plus the alleviation agreement negotiations.

Significant efforts to advance land use planning and community development waited until crisis forced action. The land use crisis began when the Project required revisions of the master plan and zoning ordinance in order to allow construction of the plant. It continued when New York bond attorneys required additional and even more careful revisions to assure that the plan and ordinance met all legal planning and procedural standards. As it worked out, these revisions gave the County added leverage to gain an early financial contribution (as a conditional use permit fee) and to conclude formal alleviation agreements. A conditional use permit was used to protect the County's interest in not granting irrevocable permission for construction. It reserved some authority over development in case of changes in conditions or problems with the Project. Ironically the state zoning legislation was more dated than the County's ordinance; it did not specifically authorize conditional use zoning.

Community development problems commanded public attention after development began and the new population arrived. Some advance planning, which did work well, resulted in the Project building a self-contained "man camp" at the plant site for single workers who did not expect to stay in the county for a long period. On the other hand, provisions for more permanent workers and their families, those most likely to have a continuing interest and commitment to the communities, were not so successful. These people were to reside in existing communities, particularly the major nearby community of Delta. Tensions developed over the extent to which the Project would leave housing to the market or provide it directly. These tensions were exacerbated when the Project unilaterally decided to promote development of permanent and temporary housing on a 288 acre tract adjacent to Delta, an action that resulted in geographic segregation of new and old residents and which, at least for some, promoted an "us against them" mentality between the two groups.

Once the new population arrived, a range of needs appeared. The schools played particularly important roles in diagnosing and dealing with problems. Then programs were established or expanded. The County developed its first substantial programs in mental health and drug and alcohol treatment. The Utah Department of Social Services was the one state-level agency to enter into an impact alleviation contract with the Project to finance expanded state services.

Huefner's initial advice may have reduced the surprise when the other crises appeared, perhaps it generated some individual thinking which helped speed action once a crisis did arise, and possibly it increased guilt and pressure felt by the already stretched public leaders. But events moved so fast, and all the local participants were so busy, that the advice probably did little of any of these. Nonetheless, it was given and received with a respect which helped build a trusting relationship. That may have been its primary accomplishment.

How the Advice Looks in Retrospect

Looking back, developments confirmed the predicted evolution of needs. But Huefner's suggestions deserved adjustment to reflect the realities of the community's capacities. Even a community strong in resources, stability, and sophistication has difficulty meeting expectations in land use planning and community development (Levin, 1987). Observers generally conclude that boomtowns face tougher circumstances in all three of these respects, although there is not always consensus about what strategies best meet these conditions (Brower et al, 1984; Decker, 1987; Hawley and Mazie, 1981; and Honadle, 1983). In addition, much of the population whose interests presumably are being pursued are not yet represented, are not yet in the boomtown, or are not yet even known. Thus, both for reasons of limited resources and for reasons of democratic representation, much action will or should be postponed. In any event it will be postponed, given the pressures of time and the limited resources, until a crisis is upon the community.

Huefner's suggestion would have been more helpful if better and more narrowly targeted: the community should polish the usual and basic activities in planning and community development, with which the community already is familiar, and not move immediately for new land use master plans or for new organizations initiating comprehensive community development programs. In other words the focus should be upon the development of local understanding and skills, rather than on broad new plans and programs.

In land use planning the community will be far ahead if it (1) has officials and citizens who, as soon as the boom becomes a prospect, gain experience and sophistication with planning tools by using them more deliberately in the routine issues, that now are likely to increase and (2) has a trusted and skilled planning staff that can form the core of the support eventually needed to deal with the new development. Millard County and its communities, as may be typical for boomtowns, had no professional planning staff and had not had the occasion, nor probably the interest, to carefully use its planning tools. At this point ambitious and comprehensive revisions of master plans and ordinances proved unreasonable. There was too much uncertainty and there were too many major policies needing negotiation between the Project, the local governments, and state and federal governments to enable preparation of a reasonably stable master plan, and to wait for a plan before applying the ordinances or making commitments to some developments. For example, while the power plant is enormous by any measure, its planned size -- the size anticipated by the conditional use permit -- was twice that of the now-operating plant. The energy picture reversed itself after construction began, and the Project and the community were fortunate to have the flexibility to halve, and save, the plant. Early commitments were needed in order to make project financing possible, and yet flexibility proved essential for both the Project and the communities.

With hindsight, advice should be more specific and limited. The communities should employ, as quickly as possible, an experienced professional planner, as Millard County did by using state funds granted in 1979 for a professional planner to assist the several cities and the County. This planner's immediate task should not be to embark upon a major new planning program, one moving first to a comprehensive plan, then the development of new ordinances, and finally to implementation of the plan. Instead it should be to improve the application of existing procedures and programs, adjusting them on an incremental basis as the needs and opportunities develop. The most important purpose would be to give guidance and support to officials and the public: to enhance their skills and understanding. The planner also would act as a prod and source of information to attract appropriate attention to the planning process and speed up the eventual recognition of the need for more thorough adjustment. But in the meantime the planning process would involve frequent adjustments -- adjustments that minimize the arbitrary and avoid the capricious. Planning would focus upon careful and fair use of procedures. It would focus less upon predicting and controlling the detail of the future community. To do this requires an immediate financial commitment for a professional planning staff; thus provisions for employing the community's own planner deserve to be a part of the initial financial arrangements. However this approach allows the heaviest financial burden to be postponed until the needs are more apparent, resources more plentiful, and desires more certain.

In building social services and community culture, the community will especially benefit from abilities to diagnose and treat problems as they arise. The original suggestion implied that there was an early need to establish and staff programs for a comprehensive range of social services. But pressures of time and of financing will severely restrict these actions. Action also will be restricted by community indecision: the community is inexperienced with such problems and in a poor position to design effective and appropriate approaches. Expansion of existing staffs, such as schools and police, offer good opportunities to broaden skills and increase capacity. But expense and uncertainty discourage the staffing of new programs necessary to meet the range of needs that may develop.

The community's instinctive inaction may be the best action. Uncertainty is a major characteristic of boomtowns, and flexibility a primary advantage in dealing with the booms and busts. The local governments can preserve financial options by holding back on the staff of social services, where the primary costs are staff which can be hired quickly, and concentrating the limited administrative and financial resources on essential public works. Public works do require long lead times -- and are the efforts which local officials best understand. This is a surprising priority considering the early assessments of boomtown social crises. But it is not so surprising considering later and more careful assessments that the social problems were exagerated by the early studies (Burch and Deluca, 1984; England and Albrecht, 1984; Krannich and Greider, 1984; McKell et al, 1984; and Weber and Howell, 1982). What is lost by postponing new social service programs and staffs is the development of staffs experienced with the particular community. But there is likely to be uncertainty about what problems are most likely to surface: outsiders tend to emphasize the need for counseling services while residents give more emphasis to police protection. What is gained by postponing new programs is the opportunity to preserve options about program design and staff selection until there is a more precise indication and local understanding of the problems faced and the skills required, and until the staffs and programs will be better appreciated because they are dealing with evident problems.

Looking back, a better focused suggestion would emphasize immediate responsibility by existing entities. The suggestion has two parts. The first is that schools, law enforcement agencies, service clubs, churches, and social service agencies not wait for a comprehensive community structure and effort. Instead they should immediately concentrate upon developing skills to diagnose problems and to identify ways to deal with these problems. It still means developing linkages between agencies but linkages which are initiated as each agency seeks needed connections, rather than linkages developed in a more formal and comprehensive planning effort and depending upon newly staffed programs. The second is that state and other outside organizations concentrate on how they can support local agencies, rather than urging broad expansions upon them. Such backup might involve direct provision of services, e.g. enlargement of state social services offices. It also could involve short-term loans of specialized staff to enable the community to match problems with specialized staff, while avoiding advance staffing for the whole range of skills. Then the community can establish permanent staffs after needs and approaches are more certain.

2. GET THE ACTS TOGETHER

How the Advice Was Delivered

The State had a major stake in the success of the power plant because of its impact upon the local communities and upon the reputation and standard it would establish for development in Utah. The State immediately offered technical and financial assistance, coordinated through the State Department of Community Affairs. The Department believed that the communities could better manage the development and better bargain with the Project, if they were united. The State therefore made a major effort to establish an association of governments responsible for comprehensive planning, which the State would help fund until financing arrangements could be worked out with the Project. It seemed a reasonable approach. It was one the Project supported, even demanded, as part of the alleviation negotiations in order to simplify negotiations; one the State began demanding as a condition of financial support; and one the authors encouraged and attempted to help achieve through mediation between the local jurisdictions and between these jurisdictions and the State.

How the Advice Was Used

It never happened, not as a formal and comprehensive organization or process. Although it was the major effort of the local governments over a period of several months, agreement could not be reached on a structure to which the various jurisdiction were willing to delegate significant responsibility or resources. The Project's hope for only one contract for all impacts in the county depended upon a remarkable delegation of authority, even if there had been a long history of cooperative organization and if the jurisdictions had the advantage of reasonable certainty about the futures they faced. It not only proved impossible to pull together such an agreement, but also impossible to establish even a purely advisory joint planning process. Eventually the major jurisdictions, first the school district and then Delta City, began developing independent alleviation agreements and succeeded in opening negotiations with the Project. Still, meetings were held to organize a cooperative effort, and these meetings continued to constitute a major effort, and burden, for more than a year. Eventually other forms of coordination evolved: much informal coordination, a sharing of a planner between Delta City and Millard County, and the County's use of its conditional use permit as leverage for finalizing the alleviation agreements with the County and with some other jurisdictions as well.

How the Advice Looks in Retrospect

A cooperative effort is worth encouraging, as it improves coordination, pools resources, and offers a united and stronger bargaining position. But effective cooperation builds upon a sensitive development of relationships and trust -- a network which can hardly be expected to be formed quickly or imposed from the outside.

The local entities should be encouraged to pursue the opportunities they see for cooperation: those made feasible by past relationships and trusts and by present willingness to negotiate. But planning for water and other public facilities, negotiations over finances, and preparation of land use controls should not be held up by efforts to achieve a new organization.

3. DON'T LET THEM GIVE YOU THE RISK

How the Advice Was Delivered

This advice too was ubiquitous. Everyone realized that some compromise would be necessary. But most advisors, including the authors, worked hard to reduce the risks borne by the local community. After all, the local community had limited resources while the Project was assembling massive resources, both managerial and financial. The Project presumably was in a better position to know where it was going and to control that direction. Thus, with its own relative certainty and far greater resources, the Project ought to be able to keep from unloading upon the local governments uncertainties about financial support for facilities and services.

How the Advice Was Used

The jurisdictions and their negotiators took this goal seriously and, at least initially, felt they had basic support from the Project. But as time progressed, conflicts developed about what was uncertain and about what was fair and responsible (Zillman, 1986). It also became clear that while the Project could pass on its costs, through charges made for its electrical power, there were political and legal limits as to how generously the Project could treat the local governments (Watson). The Utah municipal agencies would be accountable to their citizens, and both the citizens and the agencies themselves believed they were doing Millard County a great favor by providing the employment and tax base that would be coveted by nearly any local government. For the Califonia agencies there were possible suits from their ratepayers if the support was too generous.

A major issue arose over a concern of the authors and others about the costs local governments would face if the Project folded. Shouldn't there be a provision in the initial agreement to cover these costs through an escrow account or bond? The Project seemed taken aback by this proposal and resisted it throughout the negotiations. The final agreement provided escrow accounts but primarily for other purposes and giving very limited protection against this contingency.

For its part, the Project began seeking substantial audit control, including prior approval of even detailed expenditures, of the use of funds the Project provided. The local governments became concerned about the delays involved and about their loss of control of public operations. The controversy created hard feelings and delays for a year. The eventual compromise provided negotiation of budgets in advance of each fiscal year, with the local government providing "reasonably necessary" information. It removed the Project from a detailed pre-audit role.

Another issue arose over what costs should reasonably be attributed to, and paid by, the Project. Early statements by a Project representative that it would cover both direct and indirect costs comforted the local governments but may have caused some concern for Project participants. As negotiations proceeded the Project's concept of the indirect costs for which it would be responsible was substantially different than what some had initially interpreted it to be. The Project felt it should not, for example, cover the costs of supporting community services to secondary activities such as new commercial business, because these activities would be providing their own tax base for such services.

The issue became crucial in preparing additional amendments (1980) to the Interlocal Cooperation Act, which gave legal definition to the financial responsibilities to be carried by the Project. Two of the several important questions were: (1) which purposes (police, roads, education, general administration, etc.) should be covered and (2) what part of each of these costs, as primary or secondary impacts, should be covered? The authors feared that the local governments were given too much risk in the way these questions were handled. The law was vague on the second point; it limited the Project's responsibility to "direct" impacts but provided almost no help in deciding what portions of the governments' costs that included. Thus the local governments were given the burden to force a payment to which it thought itself entitled. On the other hand the law provided a specific definition of the purposes (roads, etc.) covered, thus limiting the Project's responsibilities to just those activities that could be anticipated and for which advance agreement had been reached in writing the amendments.

But the most difficult problem was in deciding how and when to decide the amount of the direct costs of the specified purposes. Should fixed sums be set in advance or should this be left to continuing negotiation based upon experience with the services needed and their costs? To wait for experience meant that the question was open for repeated negotiation, and that this negotiation would come after the local governments had lost their bargaining positions in issuing the zoning permit and in working with the Utah legislature for the facilitating amendments to the Interlocal Cooperation Act. But to make decisions in advance created a different uncertainty for both parties about how well they could anticipate the future. In the end the local governments, possibly more than the Project, wanted flexibility rather than firm commitment.

The final compromise, adopted as state law in the 1980 amendments and as a provision of the conditional use permit, provided that the Project and the governments should negotiate agreements each year. If this consensual approach failed, the dispute would be arbitrated by the Utah Community Impact Board composed of local officials from throughout the state and thus presumably able to see and balance the perspectives of both parties. The compromise left much imprecision regarding the resolution of the issues mentioned here and of a number of other crucial questions. In spite of the time and effort applied to these questions, and the tensions created by the uncertainties and negotiations, the contract built upon faith at least as much as it did upon dependable law.

In large measure, the approach worked. Tensions were frequently high and negotiations tough in the early years, but eased with time. Eventually seventeen state and local entities entered into nearly 50 impact alleviation contracts. The most common purpose, involved in about one quarter of the contracts, was for water and sewer projects. This reflected the poor state of these facilities before the boom began, and the high priority new residents and the Project placed upon adequate water and sanitation (Zillman, 1986).

How the Advice Looks in Retrospect

In the end, the development worked out well because the parties worked together well. They were reasonably faithful in carrying out their respective responsibilities in ways which statisfied the other and which reasonably reflected the intentions of the early agreements. They developed a trust in each other that allowed flexibility when it was needed. The laws and contracts that established formal obligations were called into play a few times, but not often. They were more important in setting expectations and incentives for meeting these expectations. Perhaps they were most important in providing the mechanism by which expectations were forced to be explored and by which communications and understanding were made more real. But they certainly were not clear enough nor strong enough to have avoided catastrophic problems if the parties had not been operating in reasonably good faith.

In the end it was trust that allowed progress. The local governments took substantial risks. The efforts to reduce these risks sometimes took so long that they created new risks, e.g. that tentative understandings would fall apart or that relationships would deteriorate into mistrust and demands that would hobble both sides in their action and progress. Progress would have been quicker, and might have produced even more trusting and effective relationships, if there had been an earlier recognition by both parties of the necessity of sharing risk. After all, there are some risks which are necessarily tradeoffs, such as the risk of not knowing how much money will be available against the risk of not having enough to cover the uncertain demands of the future. It would have been especially helpful if the Project had more quickly provided operating funds to Delta and Millard County, to help them beef up their core staffs.

This argues for trust -- prudent trust building upon or structuring common interests, not naive trust allowing exploitation. For example, the Project eventually trusted the usual audit procedures rather than fully depending upon its own audits and attempting to second guess the management of local government. The local governments were bound to make mistakes, but so was the Project if it took over their functions. The trust was reciprocated by the local governments which, knowing that they were not skilled in safety inspections for such plants, provided the building permits on the basis of assurances of plant safety by the usual industry inspections rather than the County's own building inspection. The authors still would argue for stronger protection of community interests in case of project closure and in defining costs to be born by the Project. But the compromise has seemed increasingly reasonable as it has worked out with time. It represents a considerable dependence upon trust, but with a prudent fall back upon arbitration that encourages both parties to keep the trust and gives both parties at least some assurance that they have minimum levels of protection.

CONCLUSION

Leadership always falls short of our hopes, at the local, state, national, and international levels and in the public and private sectors. The limitations of time, understanding, and other resources are simply a part of the human condition. Yet still we tend to push for perfection, or to push for achievements and to outline strategies which at heart presume such perfection. It is important to realize that a boomtown can be successful without perfection. In Delta and Millard County, many problems were solved, and many were not, but the general consensus in the community is that the boom's benefits easily outweighed its costs. More important than understanding that success can come without perfection is to understand that to press for perfection can so delay and overload the community's efforts that the community losses the less perfect but more realizable benefits.

A boomtown faces severe contraints, especially in communities that have a long history of stability and are small. Past problems were solved over generations; now they must be solved in months. The issues are unfamiliar and threaten the very fabric of the community's culture. Professional skills are few and do not match the new conditions. Communications with outside and large organizations are limited. And institutional and financial resources within the community are limited and little exercised. There may be opportunities for bold visionary plans for land use or community relations and culture. If so, they can be taken. But such opportunities are rare. They should neither be expected nor forced. The needs of a boomtown especially deserve to be approached as situations full of uncertainty and requiring realistic expectations.

There is a tendency for planning to become too focused upon the long term and to thereby postpone actions needed immediately while at the same time promoting early commitments which would be better postponed. For example, there is a tendency to hold back on making zoning adjustments to accomodate new housing while committing planning resources to long-term master plans and research to predict ultimate city size. Good planning works to enhance future options, such as the size of the water system, the support facilities to be provided for the power plant, and the types of social services to be delivered. And at the same time it makes some early commitments: those necessary for at least minimally adequate water supplies, for enough certainty in the permits for the power plant to acquire private financial commitments, and for the development of sensitivity and skills to better react to social problems as they develop. Three guides can help combine action and flexibility:

- "Work with what you've got." In other words use the tools available, such as the existing plan, the existing planning ordinances, and the existing units of government, if they are at all reasonable. Adjust them incrementally rather than investing time, money, and leadership in comprehensive revisions. Using available tools to immediately engage the emerging needs will both develop community skills and allow quicker action.

- "Keep options open." Postpone commitments where reasonable, in order to buy time to build resources and skills and in order to keep options open until conditions and desires are better understood. When immediate decisions are appropriate, seek choices which enhance future flexibility. Options also are protected when financial risks are shared by developers or other levels of government and when other levels of government assist by temporarily sharing professional staffs.

- "Build prudent trust." This means accepting the necessity of risks, and then reducing their dangers by understanding and managing them through (a) structuring common interests between the community and the developers and (b) building reasonable fall back positions in case expectations misfire. Hard bargaining has value not so much in eliminating risk as in building mutual understanding and trust; thus the bargaining should not neglect these latter purposes.

In sum, these suggestions mean some plans and changes will be postponed until the picture and the interests are clearer. They also mean that some action will be taken even though the results are neither fully understood nor the risks entirely removed. They look to both reduce and work with uncertainty, by developing appropriate timing of action, by protecting and enhancing flexibility, and by establishing prudent trust with others.

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EVALUATION OF PRE- AND POST-PROJECT MITIGATION EFFORTS OF THE INTERMOUNTAIN POWER PROJECT

Panel Presentation by Reed T. Searle

I. Description of Intermountain Power Project (IPP)

IPP was planned as a four unit 3000 megawatt power plant to be constructed between 1981 and 1986 north of Delta City and 130 miles southwest of Salt Lake City. The project was scaled back to a two unit 1500 megawatt plant currently in full commercial production.

Twenty-three municipalities in Utah formed the Intermountain Power Agency (IPA), (an interlocal cooperation entity,) to own the power plant. Project entitlement shares were sold to one private utility, Utah Power & Light, six rural electric cooperative utilities and six California municipal utilities.

The governing board, the IPA board, is comprised of seven elected members from the 23 Utah municipalities. The contract participants share in management decisions through a coordinating committee which is comprised of one person from each participant entity. The IPA Board's authority is limited to approving or disapproving recommendations from the coordinating committee.

II. Potential Socio-Economic Impact on Local Region

In 1980 Millard county had a population of approximately 7000 with over half the population living in Delta ten miles south of the construction site.

IPP was estimated to employ a peak work force of over 3000 and eventually experienced a peak work force of almost 4500.

Schools, housing with the full range of ancillary facilities, health and public safety services were recognized as being necessary prior to the in-migration of the new population.

The primary obstacle to the provision of these services and facilities was the delay in the receipt of property and sales and use taxes by the local officials.

Special legislation was enacted to help correlate the receipt of funds by the local government agencies with the time frame in which new roads, schools, health and recreation facilities and personnel were required.

III. Legislative Efforts to Avoid "Boomtown" Consequences

Although IPA was a tax exempt entity under the Constitution of the State of Utah, IPA requested the legislature impose upon it an obligation to pay fees in-lieu of ad valorem taxes. The legislature enacted such a law.

One of the most ingenious provisions of the law was one allowing IPA to forego the payment of these fees in-lieu of property taxes until the power station was operable. In-lieu thereof IPA was required to pay impact mitigation payments for which a partial credit would have to be given after fees in-lieu of property taxes were owed. The law, therefore, required that a part of the impact mitigation costs had to be born by the taxing jurisdiction via a future credit against property taxes. IPA believes that such a requirement caused the local governmental entities to be frugal in their requests for impact assistance and helped make sure that the local governments could continue to afford to operate and maintain the facilities built with impact funds.

IV. Keys to Impact Mitigation Success

IPA believes is was successful in working with primarily Delta City and Millard County to avoid the classical consequences of rapid large scale population growth.

Probably the most effective activity was the very early granting of funds to the city and county to hire staff to develop and implement a planning process to accommodate the population boom. By utilizing these funds wisely the local government were ready with master plans, zoning requirements and fairly good impact mitigation applications before construction commenced. The result was the provision of government services and facilities ahead of the demand.

A second key component of the impact mitigation success was a willingness of the project to participate in the provision of housing under the direction of Delta City and Millard County. The following housing was provided by the project:

- One hundred trailer homes were purchased and sited in a new mobile home park financially supported by IPA.

- An on site construction worker housing complex for over 1000 workers to encourage workers to commute from the Wasatch Front on a weekly basis. This complex had its own eating and recreation facilities.

- A planned community with developed lots, a mobile home subdivision, an apartment complex and recreation facilities available to the entire community. To prevent this community from becoming a company town all lots, mobile home pads and apartments were available to anyone, not just IPP construction employees.

IPA believes this housing program accomplished two other very important objectives for both the project and the community. The first was that the provision of housing by the project in a planned manner resulted in less expense rather than more. Fewer roads, sidewalks, sewer lines, etc. were eventually required because the housing developed in a tight area rather than in a spread-out haphazard manner which is expensive to serve. Thus the project's impact mitigation payments to finance infrastructure was reduced by millions as were future maintenance expenses by the city and county.

The second objective IPA's housing program achieved was to stop speculation and housing price inflation. Land and rental prices began early to shoot sky high. IPP's housing program re-established prices at their old levels and maintained them there during construction.

This helped Delta attract people to their community and helped IPP keep its construction work force who otherwise may have been driven away from the area by unreasonable housing costs and an unsightly community.

V. Program Problems

As the first several million dollars of impact aid reached the towns and counties new schools, roads, parks and city halls commenced. Upon witnessing this infrastructure boom the IPA Board members compared this with what was happening in their own towns and recognized that their own streets, sewers, schools and city parks were old, inadequate, and in some cases, totally absent. A sense of jealousy began to be felt among the IPA board members and impact assistance became a little tighter.

The lesson here is that having a statutory obligation to provide impact mitigation counteracts the tendency IPA and most industry will have to be frugal and without financial aid. An industry may have good intentions and plans but actual expenditure of the dollars is something different.

Another serious problem was the discord which erupted all too frequently between project and local government officials. This was primarily due to differing points of view regarding impact mitigation payments. The project believed it was granting the government funds and believed it appropriate to closely monitor the use of those funds. The local officials, on the other hand felt IPP should be treated like any other taxpayer and stay completely out of the affairs of the local officials.

This is a difficult issue to address but one which is sure to rise in any process where special or unique financial arrangements are made between industry and local governments. It merits much advance discussion and efforts to find solutions. Unfortunately, this problem was not foreseen by either party and left unresolved interfered dramatically with what was otherwise an excellent joint public/private effort to accommodate a burgeoning population.

VI. Water Rights

The project as originally planned required water rights for 45,000 acre feet of water to assure adequate water during even the most severe drought periods as recorded for the past 100 years.

The Sevier River Basin from which the water was derived for IPP is a closed water basin with no surface outlet. As a result it is one of the most fully appropriated and utilized water systems in the country. Utah state water laws award water to the first user to make beneficial use of the water. Later, appropriators can only use what water is left after earlier appropriators have received their full appropriation. Consequently, IPP was required to purchase water rights from their existing owners which were primarily agricultural owners.

VII. Objectives of Water Acquisition Program

The Intermountain Power Agency developed several water acquisition objectives designed to reduce detrimental affects of acquiring those water rights.

These objectives included:

Minimizing the amount of farm acreage which would be taken out of production.

Negotiate water rights according to a comprehensive plan and unfirm price.

Offer a water price which would help obtain local support for the project to assist in obtaining local government permits and licenses.

Acquire water rights in a manner which would help improve the efficiency of the various water delivery systems in the water basin.

VIII. Comprehensive Plan for Water Acquisition

The water negotiations resulted in satisfactory achievement of all these objectives. Local water owners consented to pool their negotiating efforts with IPP. They hired several attorneys, one of which was a prominent local water attorney who understood the complicated system by which the five local irrigation companies managed and delivered the Sevier River water to the area's water users. The project in turn worked with these attorneys to have a study performed by the lower Sevier River water master to identify a procedure for acquiring water rights which would take water primarily from marginal irrigation lands and minimize the acquisition of water utilized for irrigating prime farm land. The study also identified inefficient delivery systems which could be eliminated or altered to minimize the impact of the water purchases on agriculture.

IPP eventually agreed to pay $1,750 per acre foot of water, an amount significantly higher than the agricultural value of the water. At this price there were more rights offered for sale than needed. The project was, therefore, able to purchase rights which were used to irrigate the more marginal farming land which had been identified in the acquisition study.

The project also purchased water in a way which allowed the discontinuation along open canal conveyance systems which delivered only 20 percent of the water put into the canal. The purchase of 100 percent of the water rights in that canal reduced irrigation on only 20 percent of the land that amount of water could typically irrigate. The project purchased a significant portion of the area's total agricultural water. However, only a very small reduction in crop production resulted.

Only days after the initial water checks were in the mail the project opened an office to offer water for rent back to farmers who had sold their water rights to the project. The offered price was very reasonable as the objective of the program was more to minimize the agricultural impact of the project than to recover water acquisition expenses for the project.

IX. Ancillary Benefits of Water Acquisition Program

Because the water contracts were negotiated prior to approval by Millard County of the construction permit the water sales agreements provided significant help to the project in its negotiations with the county concerning terms of the construction permit. During the permitting process, local officials were under constant pressure by water seller to reach agreement with the project on plant approval.

In all $83 million were paid local citizens for water rights. This went far to establishing an extremely favorable local attitude for the project which helped the project in its licensing process and subsequent dealings with the county. But even more helpful in fostering a positive local atmosphere toward the project was having the community aware of the project's attempts to minimize the impact of the project. IPA believes the funds spent to develop a good water acquisition program was one of the project's most prudent expenditures.

X. Summary

In conclusion, IPA believes that by working early with local officials it avoided most of the typical "boomtown" consequences. We feel the expense incurred to accomplish this were offset to a significant degree by having a pleasant community available for the work force to live in. Contentment among the workers and their families lowered employee turnover and assisted in constructing the project ahead of schedule and under budget.

IPA believes its water acquisition program also demonstrates that industry is wise to take care to concern itself with community concerns. A simple, less expensive approach to water acquisition would have obtained our water but much of what we are proud of in term of what was accomplished by mutual industry/community effort would have been foregone.

ROUGH RIDERS OF THE UINTAH BASIN'S ENERGY CYCLES

Robert P. Huefner, Janice L. Miller, and Carl M. Mott*

ABSTRACT: This paper reviews how local governments in Utah's Uintah Basin rode the energy cycles between 1970 and 1986. The paper looks at the governments' financial data to see how revenues and spending changed and looks at employment statistics to see how governmental changes reflected the economic cycles. Then the paper summarizes interviews of local officials to identify and evaluate techniques these officials used to tame the cycles, as they tried to assure that the energy developments served their communities. If there is a theme in their techniques it is to recognize and to reduce uncertainty. The employment data show the irregularity of development, the lag in reactions which smooth and yet aggravate the cycles, and the opportunity to use these data to anticipate change. The financial data reveal problems of timing and demands for police and other services, as well as the benefits of increased financial capacity. Together, these three views of the Basin find value and practicality in a basic strategy aimed at flexibility in decisions and dependable knowledge of developments.

INTRODUCTION

Managing energy boom towns is like bronc busting. It's associated with the West. It takes daring and persistence. It involves mostly the young, but experienced hands can save pains and breaks. It's up and down, with the up being the time to prepare for the down and the down the time to prepare for the up. Actually, today's booms and busts are the unexpected happening of the expected. They occur in regions which have long been known to contain resources. In fact the warnings of potential development are part of the problems; they've come so many times that they also have come to be ignored. The problem isn't in realizing that development will take place, the problem is in knowing when. Everyone also expects the booms to bust; in resource development, what goes up must come down. But even hard facts are hard remembering, and foresight is lost, because a community becomes buried over its eyes in the problems and opportunities of growth.

The Uintah Basin is in northeastern Utah, bordering Wyoming and Colorado. It felt the energy boom of the Seventies more than any other part of Utah, being a major center of activity in oil, oil shale, and coal-fired electrical generation, as well as being the primary location within the U. S. for consideration of tar sands development. Still the Basin's changes were not as abrupt nor as great as those in Wyoming and Colorado boom towns, and the development came to communities (Vernal in Uintah County and Roosevelt and Duchesne in Duchesne County) which already had some size and capacity because of other economic activity and past experience with boom and bust cycles.

There were three booms in the Uintah Basin during this period, as revealed in the data which follow. Two were in Duchesne County. The first came in the early 1970's as a combination of construction for the Central Utah Project and an oil boom associated with the first oil crisis. The second developed in the late Seventies as a larger oil boom following the second oil crisis. The third, and largest, boom was in Uintah County. It too was driven by the second oil crisis, but involved coal, oil shale, and tar sands as well as oil.

*Co-authors: Huefner is Professor of Political Science, Miller is Director of Technical Assistance and Training, Center for Public Affairs and Administration, and Mott is a PhD candidate in Political Science, all at the University of Utah, Salt Lake City Utah, 84112.

Population

County	Municipality	1970	1980
Duchesne		7,299	12,565
	Duchesne City	1,094	1,677
	Roosevelt	2,005	3,842
Uintah		12,684	20,506
	Vernal	3,908	6,600

Source: U.S. Bureau of the Census

The booms, in spite of the problems they brought and the busts which followed, are credited by local officials with bringing more benefits than costs. They brought new economic activity for the people and economic resources for public facilities and services, they brought new (and valued) life in a younger and more culturally diversified population, and they gave the communities the financial and human resources and the opportunities for greater self direction and renewal. Yet the problems were enormous when measured against the size and capacity of the communities. The booms gave a rough ride: painful though rewarding.

IMPACTS: LOOKING AT PUBLIC FINANCES

Much has been written about the high cost of providing adequate services in boom and bust situations. This analysis examines actual revenues and expenditures of the two counties and three cities in the Uintah Basin, from 1970 through 1985. The sources are audit reports (through 1981) and US Bureau of the Census financial reports (1982-85). The following charts adjust these figures for inflation and population by **showing dollars as constant (1972) dollars per dwelling unit.**

Revenues and expenses show substantial variation for all jurisdictions, but several conclusions can be drawn. First, the expenditures per dwelling unit, when adjusted for inflation, show substantial growth in the cities but not much change in the counties. Second, among the three cities the high spender stayed high and the low tended to stay low, while in the two counties relative spending was less stable. Third, federal and state revenues made significant but late contributions to total revenue. Fourth, the counties benefited from additional property tax generated by industrial development, while cities generated new sales tax revenue from the increased retail sales. Next, the change in debt burden over the period was significant, with the counties' debt burdens increasing while those of the cities decreased. Finally, there were wide fluctuations in spending for each service but one clear result was increased emphasis on law enforcement.

Total Operating Expenditures

Chart 1, of general operating expenses (excluding water and sewer, capital improvements, and debt service), shows that all three cities more than doubled operating expenditures, with Roosevelt having the highest percentage increase of 144%. But relative relationships remained rather stable as Duchesne City spent 50% as much as Roosevelt in 1971 and 48% as much in 1985, with Vernal being between them in both years.

Chart 2 shows total spending for the two counties, as well as operating expenses where those data are available. (Capital spending information was not differentiated in Duchesne County until 1979.) Total spending increased slightly for the period as a whole, with wide fluctuations (e.g. a Uintah County highway in '82) along the way.

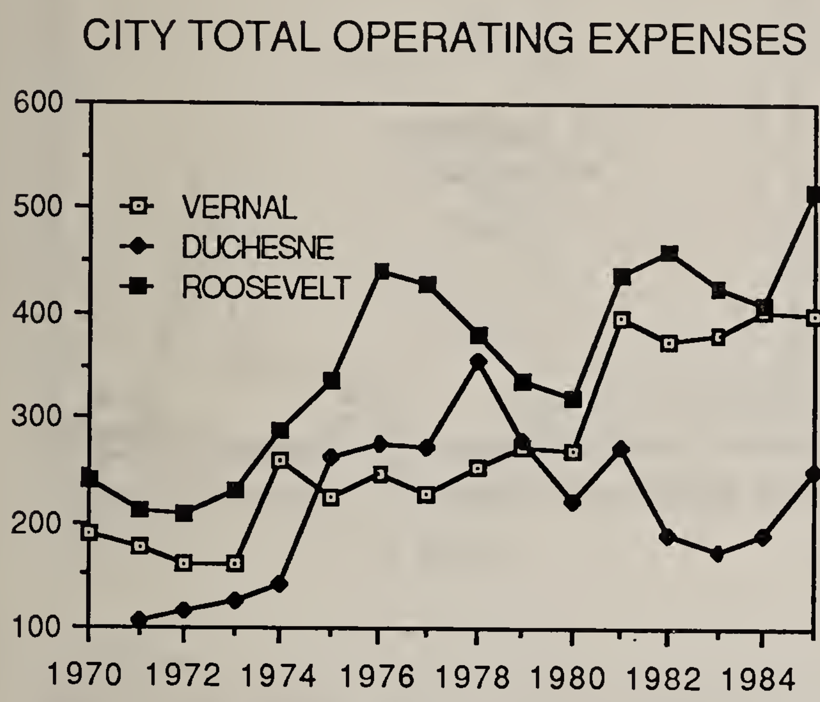

Chart 1

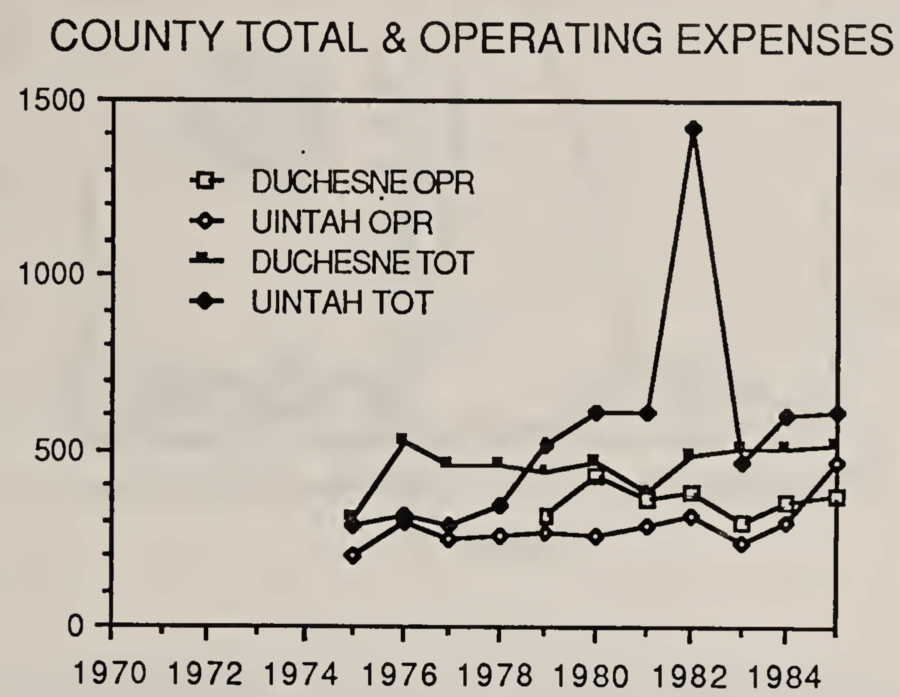

Chart 2

Federal and State Revenues

Charts 3 and 4 show revenues from federal and state governments and from major developers, primarily the electric power and oil shale plants in Uintah County. Such revenues fluctuated widely and usually were tied to capital improvements, the expenditures for which can be seen in Charts 5 and 6. Most arrived late in the boom, primarily after 1977. Roosevelt's major water and sewer expansion occurred in 1975-77, but it did not receive large intergovernmental contributions until 1978-79; the early work was financed by bonds (Miller, 1985).

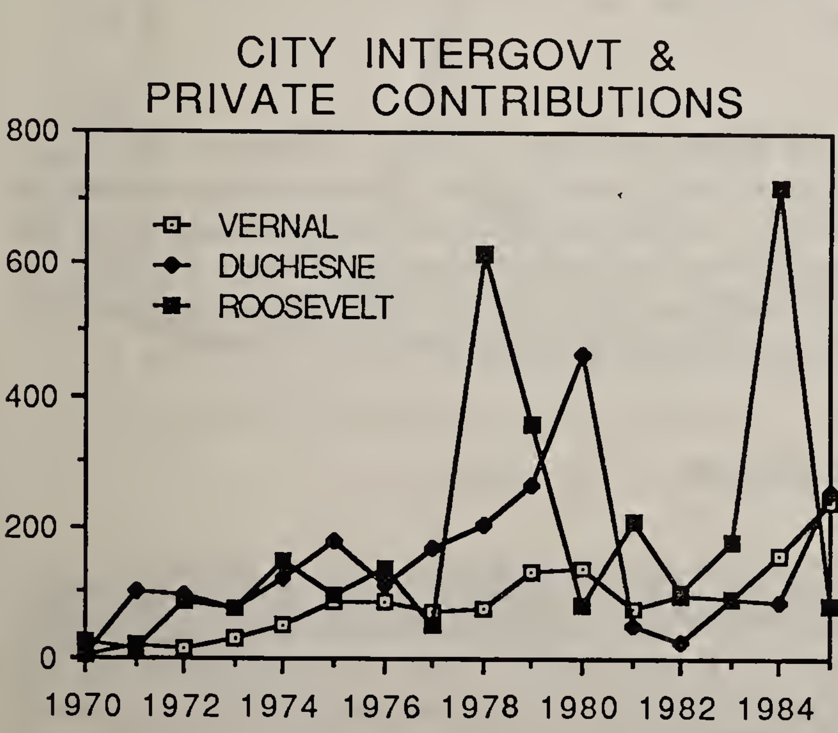

Chart 3

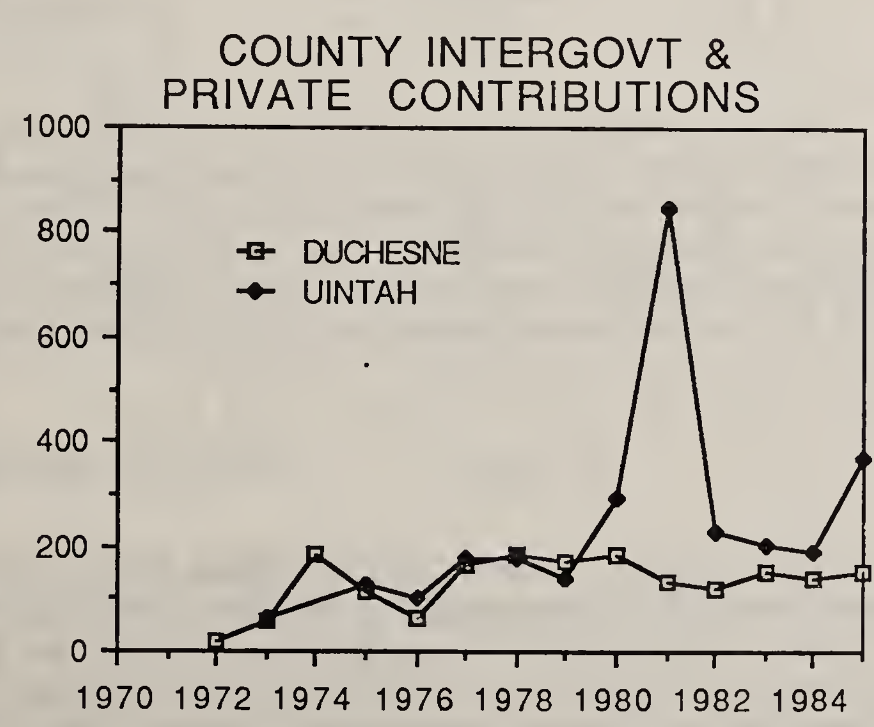

Chart 4

CITY CAPITAL IMPROVEMENTS

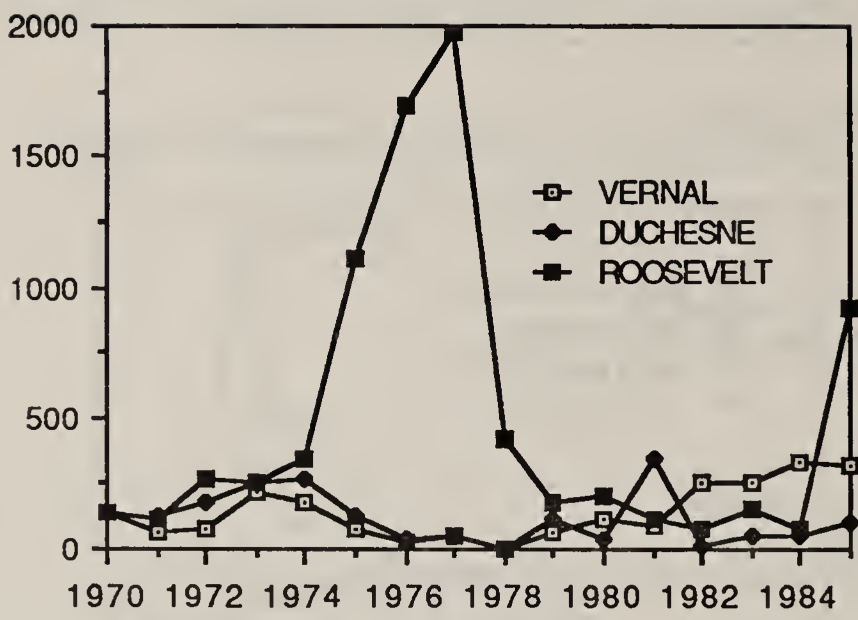

Chart 5

COUNTY CAPITAL IMPROVEMENTS

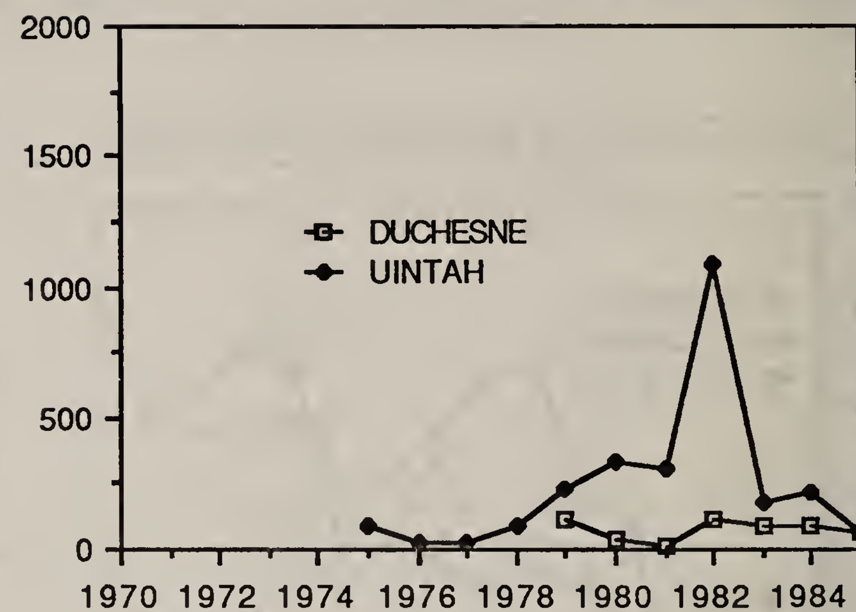

Chart 6

Effects on the Tax Base

The data, not shown here, reveal that property tax collections for the counties increased markedly (216 and 235%, after adjusting for inflation and dwelling units) even though mill levies were increased only 24 and 7% for the same 1973-1985 period. In the cities, property tax collections held nearly constant (from -5 to 29%) but this was in spite of reductions in mill levies of from 12 to 60%. The cities realized their large increases in revenue from the sales tax, where collections for the same period increased from 5 to 123% after the same adjustments for inflation and dwelling units. The largest city did the best overall, and the smallest city did the worst.

Debt Service

The cities carried substantial debt burdens at the start of the boom, while the counties had none. The early development spread the city debt over a larger population and tax base, reducing the relative burden except in Roosevelt where new debt increased the burden. Then in the early 1980's the debt burden increased in all the counties and the cities, though in Vernal and Duchesne City it still remained half of what it had been in 1970. In 1985 the total debt per dwelling unit, in current dollars, was $21 for Duchesne City, $109 for Roosevelt, $46 for Vernal, $72 for Duchesne County, and $79 for Uintah County.

Emphasis on Various Services

Comparison of Charts 7 and 5 shows the cities' heavy and early emphasis upon water and sewer construction. This is especially pronounced for Roosevelt. The capital expenditures for improvements in Duchesne's water supply are understated because the Bureau of Reclamation made major portions of the investment. The figues also are understated for the Vernal area because much of the expansion of water and sewer facilities there was done by a competing district outside the city's limits.

WATER, SEWER, SOLID WASTE EXPENSES

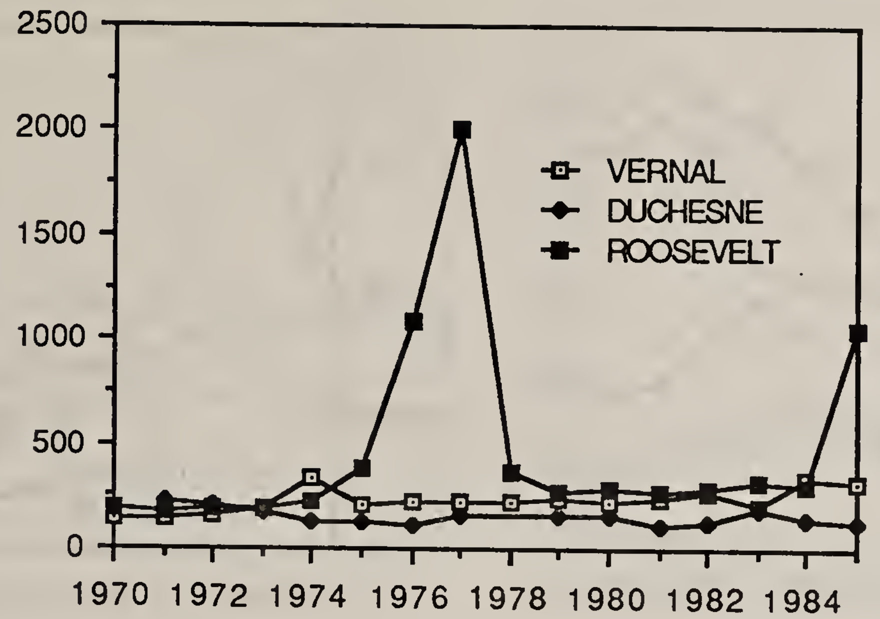

Chart 7

Charts 8 and 9 show highway expenses were a high priority throughout this period. Highway spending made up more than half the annual spending in the two counties for several years. It is worth noting that the two counties spent nearly the same total amount for highways in constant dollars per dwelling unit over this period: $2338 in Duchesne County and $2475 in Uintah County. Uintah spent almost half of that in one year for a road to the oil shale and power plant sites, that was financed largely by developers and intergovernmental revenue.

CITY STREETS

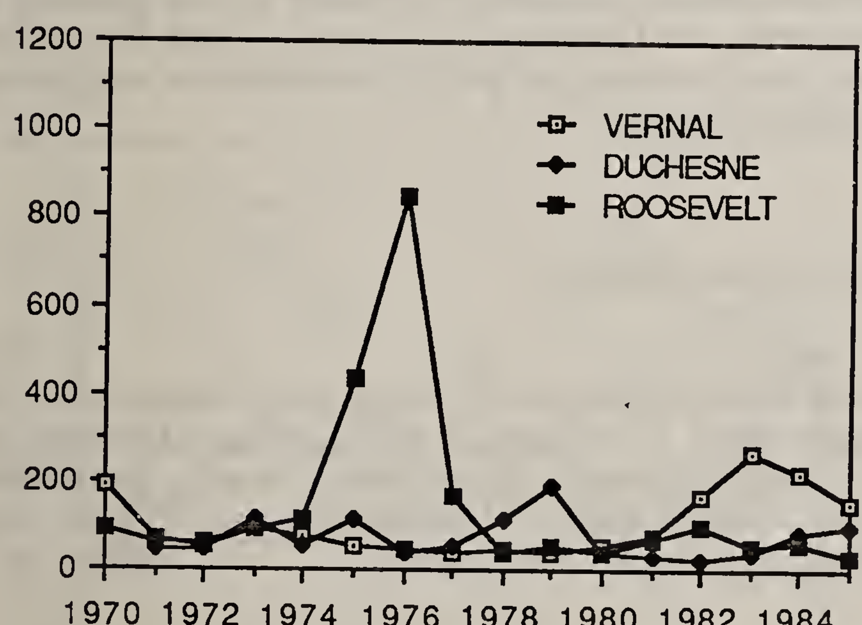

Chart 8

COUNTY ROADS

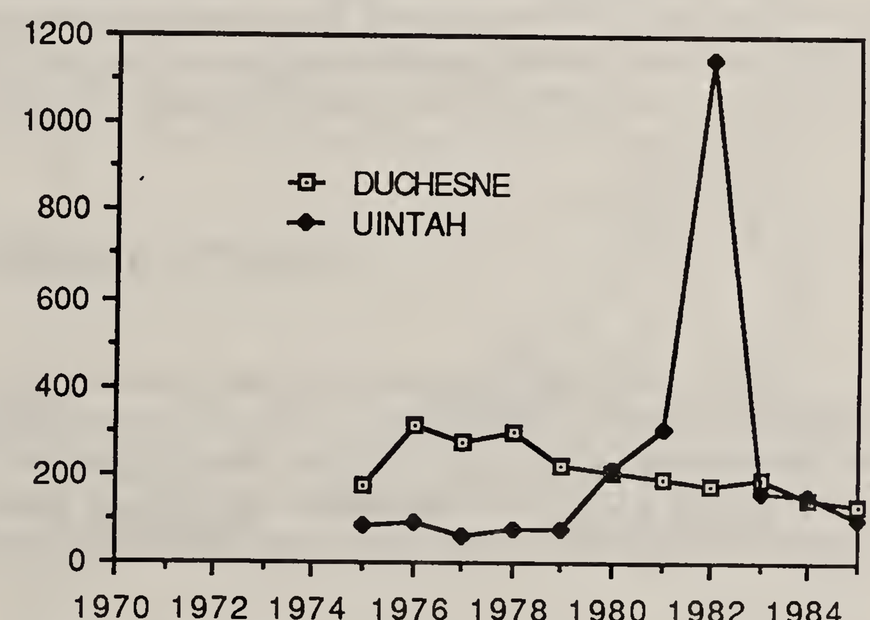

Chart 9

Not shown on these charts is the fact that both counties made sizable investments in health care facilities; the long-term debt incurred in both counties was for hospitals. Other health and welfare spending fluctuated widely over the period.

The most striking increase in spending by the cities was for law enforcement, shown in Chart 10. Duchesne's spending per dwelling unit doubled, Vernal's tripled, and Roosevelt's nearly quadrupled. Chart 11 reveals that marked increases also occurred in the spending for the sheriffs' offices and corrections in both of the counties.

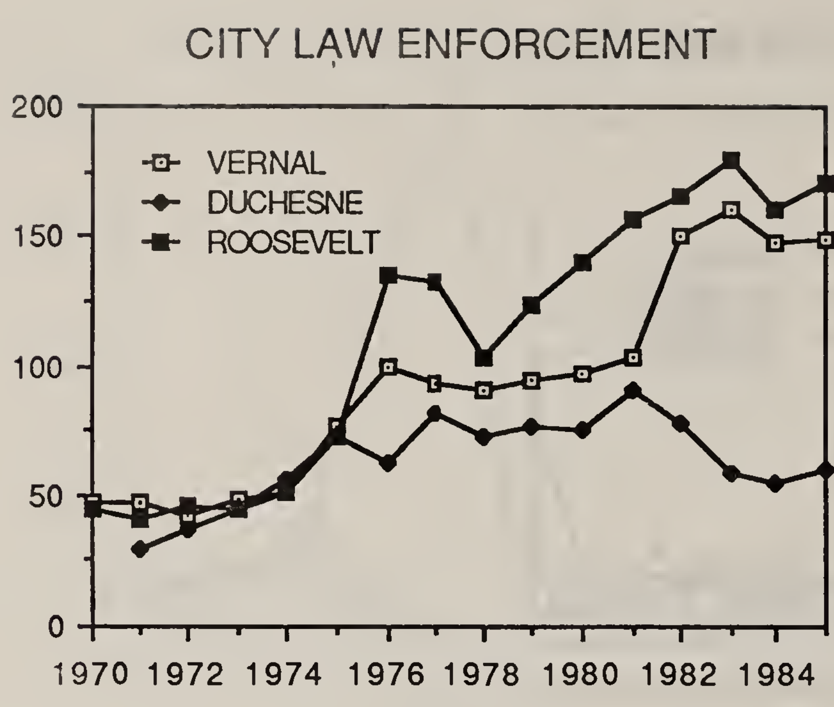

Chart 10

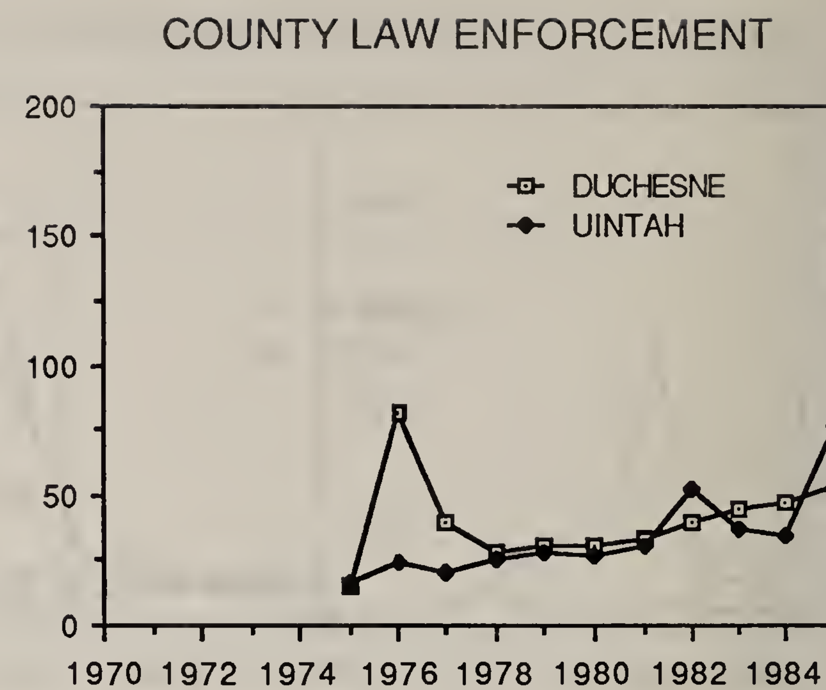

Chart 11

General administrative operating expenses (not shown) by the counties was $49-60 per unit in 1975. By 1985 both counties were spending about $75, though they each reached peaks as high as $110. The most significant difference in level of spending between the counties is in operating expenditures for parks and recreation. Although the two counties were spending nearly the same amount in 1975, Uintah spent an average of $30 (1972 dollars) per year per dwelling unit during 1975-85 while Duchesne spent only $10.

In the cities, general administrative expense is notable because the cities varied so widely in their spending at the beginning of the period and also because spending by each city fluctuated so widely through the period. Vernal was more stable than the other two cities, and Uintah was the more stable of the two counties, suggesting that larger jurisdictions can better stabilize and control administrative costs.

IMPACTS: LOOKING AT EMPLOYMENT

While county employment data are available and have been studied on a monthly basis, annual averages reasonably represent these data. Of the following ten charts, charts 12 through 19 **use an index of percent of the base year (1970) to reflect the magnitude of fluctuations in employment and population.** Charts 20 and 21 show actual annual averages of employees in each category. Note that the vertical ("Y" axis) scales are not identical on all charts, an important point when comparing the two counties.

Basic Industry and Total Employment

Charts 12 and 13 show automatic stabilizers at work. While Mining and Construction, the basic industries driving the boom, had substantial fluctuations, total Nonagriculture employment shows more stable trends, and population has an even smoother curve. (At least part of the smoothness of the Population curve is because there are not annual counts of the population: the Population figures are estimates, influenced in part by prior year estimates.)

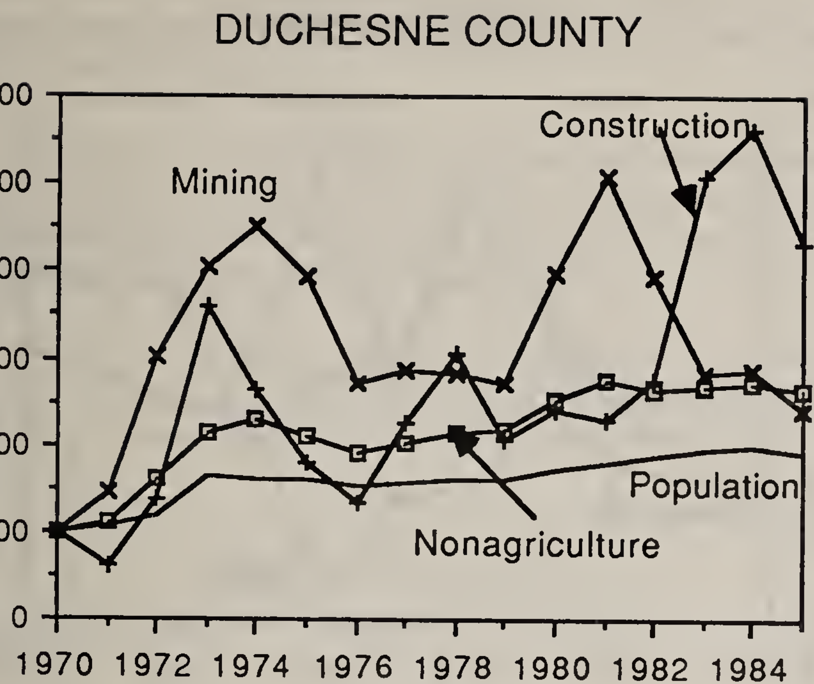

Chart 12

Indexes of Employment and Population

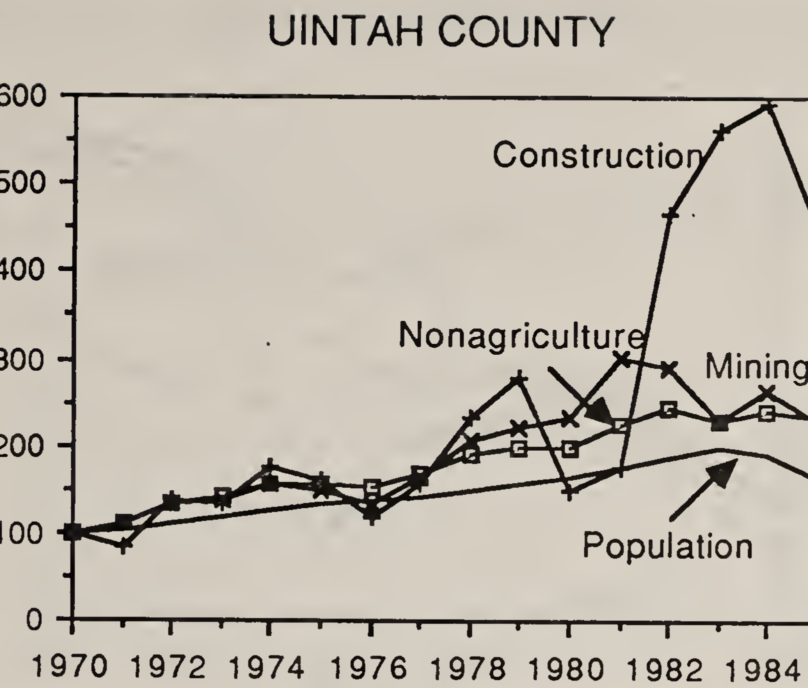

Chart 13

Indexes of Employment and Population

Government Employment

Total Nonagricultural employment and Government employment reflected, and were roughly proportional to, employment in the basic industries of Mining and Construction. But during the cycles the total did not change as dramatically as mining or construction, in either the boom or the bust. Fluctuations in total Government employment were smoother and ultimate change was less, at least through 1985.

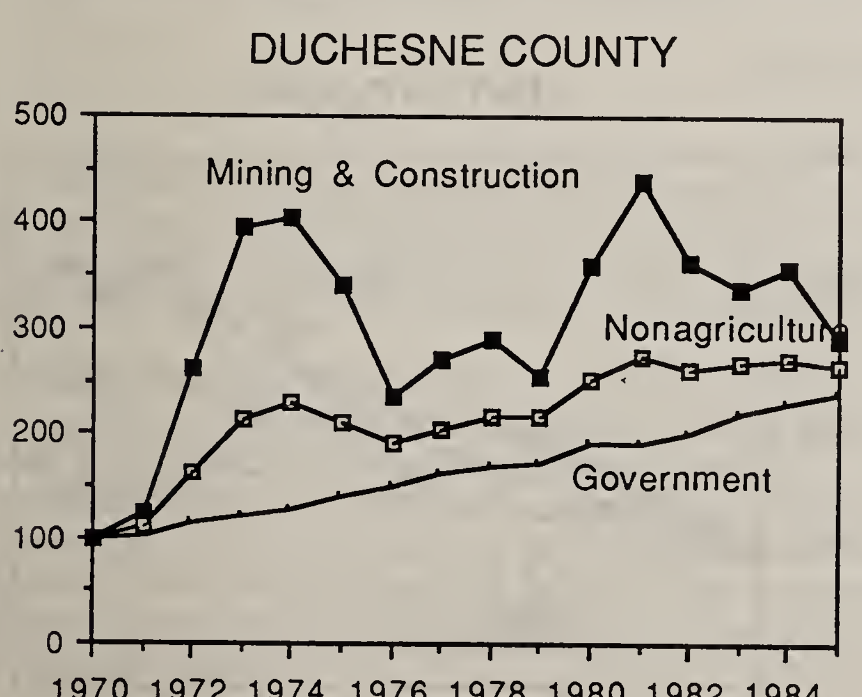

Chart 14

Indexes of Employment

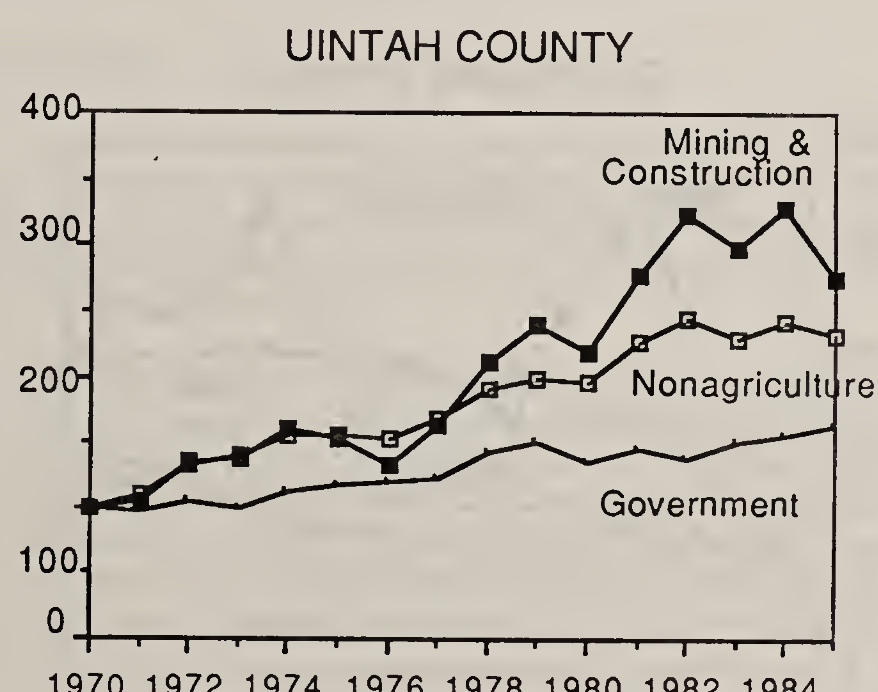

Chart 15

Indexes of Employment

The Government employment sector can be separated by level of government after1974. The change in local government is a response to the boom: providing municipal services to an expanding population. The change in the federal government may be driving the boom rather than responding to it, as it includes the Central Utah Project in Duchesne County and land management programs in Uintah County. State employment, in terms of that located in the Basin, changed the least.

DUCHESNE COUNTY

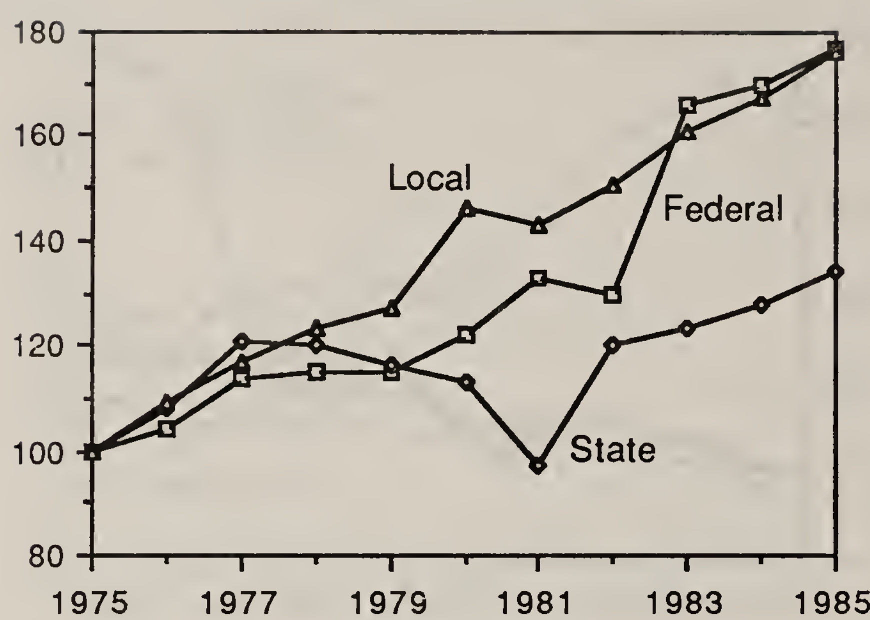

Chart 16
Indexes of Government Employment

UINTAH COUNTY

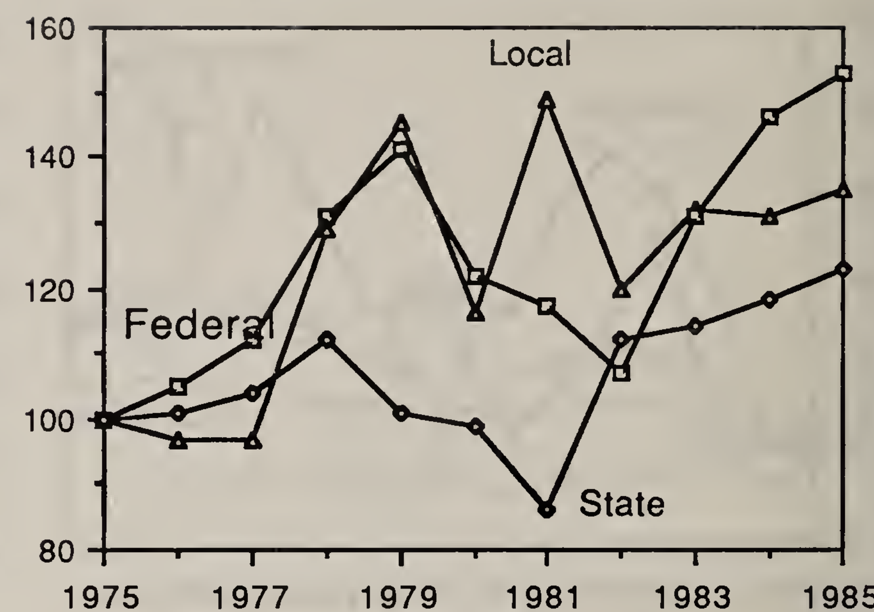

Chart 17
Indexes of Government Employment

Trade and Service Employment

Most of the private secondary employment, in other words private sector employment stimulated by and serving the boom, was in Trade (wholesale and retail) and Services. But the rates of change differ significantly between the two counties. The Service sector employment shows more dramatic increase (Chart 19) in Uintah,

DUCHESNE COUNTY

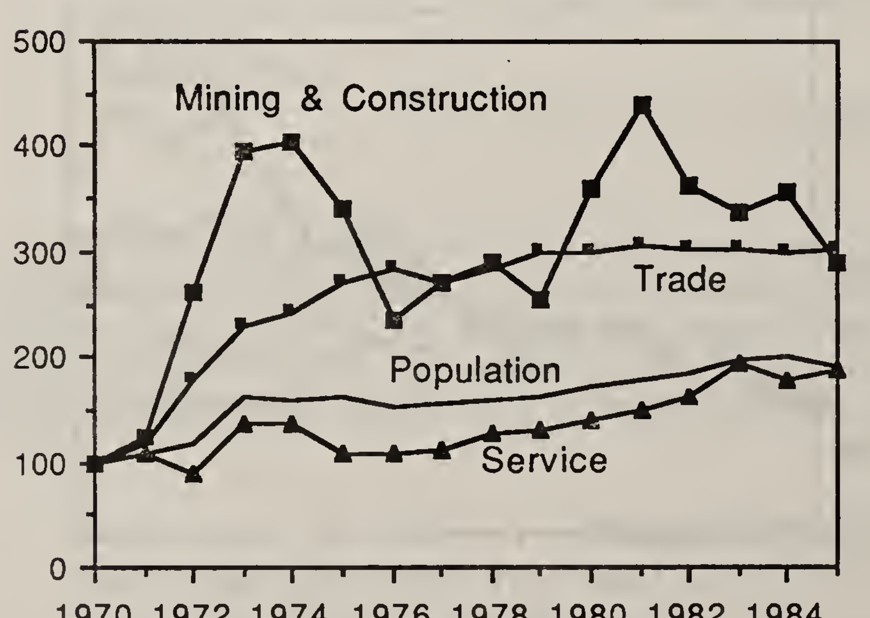

Chart 18
Indexes of Employment and Population

UINTAH COUNTY

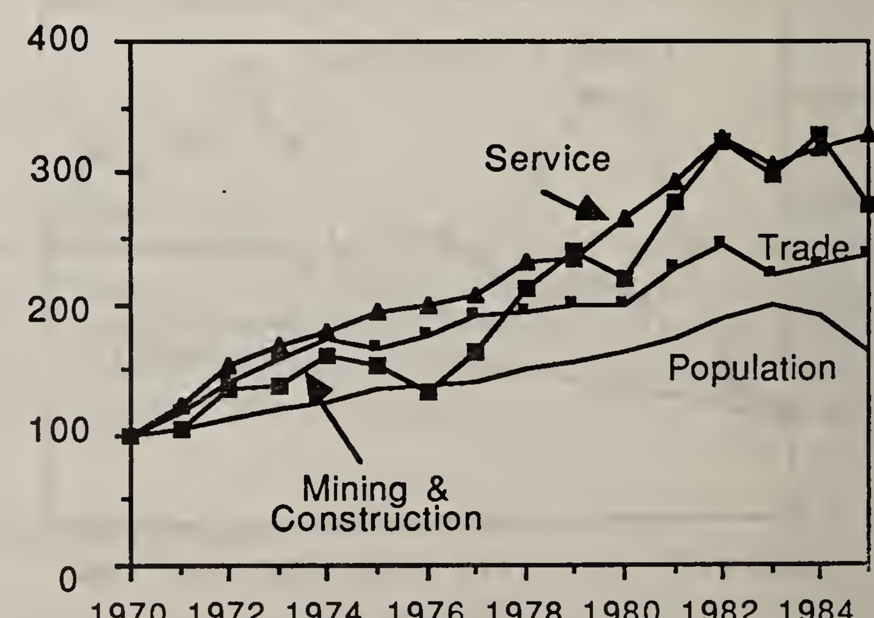

Chart 19
Indexes of Employment and Population

the larger county. Employment in the Trade and Service sectors did not emulate the wild fluctuations seen in Mining and Construction, especially in Duchesne County. Part of this was due to the fact that some businesses opened during a bust period although they were planned during a boom period. This resulted in the economy as a whole, based on employment data alone, continuing to show some strength even after the basic driving forces reversed direction. This in turn hid the change, and when not understood led to regretted investments in the public and the private sectors.

Charts 20 and 21 are not indexes, but **actual employment averages** for each year. Service and Trade have been combined, but the difference between the two counties still is evident. The more detailed data, not included in the charts, show that in Uintah County, the Service sector's employment exceeds that in Retail Trade. In Duchesne County, the opposite is true.

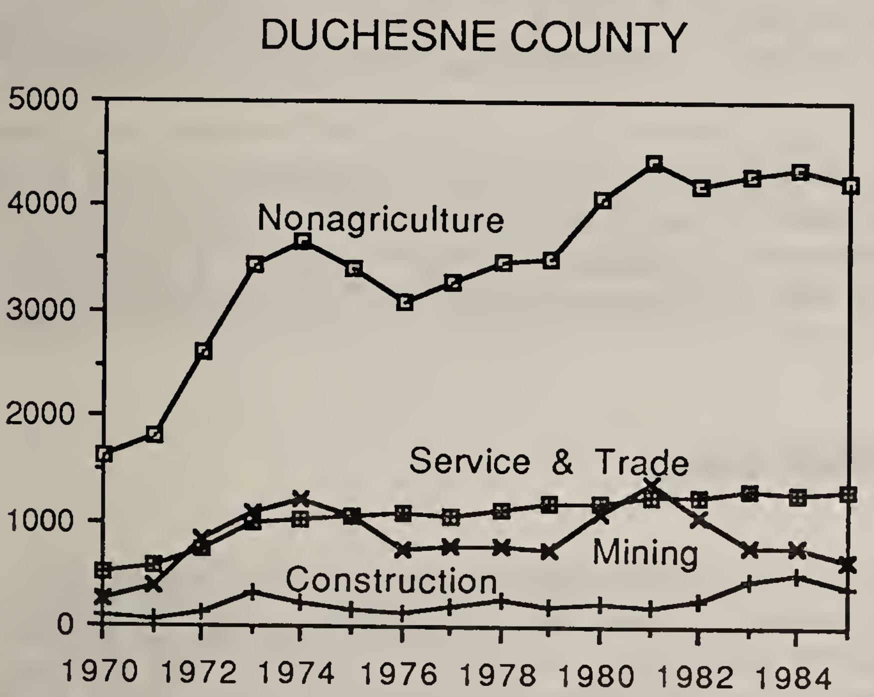

Chart 20
Employment Averages

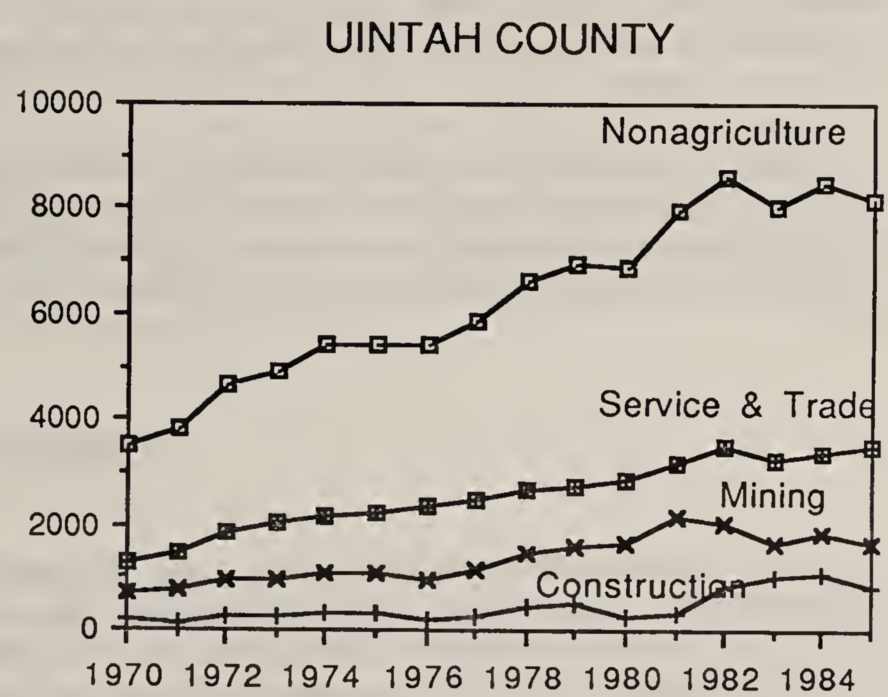

Chart 21
Employment Averages

<u>Anticipating Change</u>

A particularly important need in a boom town is to predict economic growth and decline. Employment in the basic industries does appear to be a good indicator, and probably is better than the charts suggest because some of these changes can be predicted well ahead. For example, the decrease in Construction employment could be projected long before the completion of the Deseret Power Plant in Uintah County.

This indicator's value can be further enhanced if employment in Construction is seen to have two components, one being the construction of power plants, access roads, and other facilities intrinsic to the basic boom itself, and the other component being residential, commercial, and municipal construction stimulated by the basic boom. There is evidence that changes in the secondary component of Construction employment lagged the basic shifts in the economy, just as did employment in Trade and Services. Thus Construction employment, which includes both components, will not show as certain or strong a shift in direction as would just the "basic" component of Construction employment. So focusing on the "basic" Construction should provide an earlier and more certain signal.

The county employment figures do not distinguish between these two types of construction. But fortunately the "basic" Construction employment is the employment which can be most easily estimated, and predicted, from information collected through contacts with developers and other informal means. This employment tends to be concentrated in a few large and relatively well planned projects, controlled by large industries and agencies. These organizations should be interested in providing good information, to help local officials insure that there are adequate and efficient support services for their employees.

TECHNIQUES

The local officials, looking back on how cycles in the Basin were managed, credit several decisions and approaches as being particularly useful, although they would adjust some of them on the basis of the experience (Uintah Basin Interviews). The techniques, as a group, appear to take a central theme of point-counterpoint: **recognize** that there is great **uncertainty,** work to **reduce** the **uncertainty, recognize** that great **uncertainty** remains, etc. Recognizing the uncertainty means making decisions which can be later adjusted to changes in the timing, duration, and size of resource development. Fighting to reduce the uncertainty means increasing the understanding of the intentions and actions of others and helping to insure that the stated intentions do become actions.

Here are some of the techniques, identified by local officials but selected and summarized by the authors. Water and wastewater needs were among the primary motivators of nearly all these techniques. And because of the importance of water and wastewater programs, any narrowness, inflexibility, "turf" contests, or pettiness of persons involved in them will be (and in the Basin too often were) primary problems in managing the booms and busts.

Larger, Not More, Towns

"One important thing that happened here with the Deseret Power Plant was that they came with the intent of building their own community at the plant site. We could see a real problem: to provide services in both the present communities and in the new community. We refused to give a permit for a city at the site. But we chose to work with them, and said: if you work with us we will do everything in our power to see that you have a good transportation system to the plant. They went along, and we've worked well together. But I'm sure that we would have had a construction camp and community at the site if we hadn't taken a firm stand. The financing for the highway network included $4 million from the White River oil shale project, the same from Deseret, one and a quarter million from the state for a bridge, and the rest from county funds" (edited quote, Uintah Basin Interviews).

Community facilities and services for a thousand new residents can be better and more quickly provided if the newcomers settle in an existing community having utilities, streets, public services, and retail businesses. The larger the community the easier the absorption. This strategy reduces the costs of services and also allows more tolerance in the timing of new facilities and services: a new fire department or water system is not needed at the very moment activity starts. Delays are less costly, and may even be planned as a way to postpone commitments until needs are more certain, a flexibility especially valuable for public works which require long lead times. This strategy also reduces the impact of the subsequent decline in population, as the decline is related to a much larger continuing base than that of the permanent employees of the new facility. Finally, it is politically popular because it is perceived as offering opportunities for local businesses and property owners to benefit from the development. (In fact, the new development resulted in the construction of outlets of retail chains which proved tough competition for the older businesses.

The approach worked in the Uintah Basin, as well as for the Intermountain Power Project in western Utah (Zillman, 1986). In both cases, however, it was found useful to treat housing for single construction workers differently, by constructing separate "man camps" with temporary but well equiped dormitories and recreational facilities suited for temporary workers.

Connections: Outside and Inside

A particularly effective team in negotiating policy and financial support for developments in Uintah County was formed by one of the three county commissioners and a long-time resident who had been chair of the state's land board and then of its oil and gas commission. The county commissioner credited their success to his recognizing and following the expertise and wisdom of the former state official: "He made the bullets and I shot them" (Uintah Basin Interviews). But there appears to have been more to it. The commissioner knew the county and its population well, maintained a wide range of contacts with its people, and enjoyed the confidence of other local officials and the general public. The former state official knew state and federal programs and personalities and enjoyed high respect outside the county. Although they had not met until the boom began, they quickly gained a mutual trust which enabled them to marry their connections, and thereby effectively link, and lead, interests inside and outside the county.

The inside connections are more difficult than might be expected, because the community is changing so much and so fast. The leaders repeatedly emphasized the importance of building contact with new arrivals, both the businesses and the people, and to help link them with the existing community. The chambers of commerce were valuable communications links, being in frequent touch with developers and businesses. The schools also proved to be on the front line: the first to see and face poverty of transient families unable to find work, drug usage by new and old residents, family tensions and child abuse, and other such problems associated with the turmoil and uncertainty of a boom town. In addition, the schools provided a primary point for new and old residents to interact, which eventually promoted mutual respect and interests. The leaders felt they gained remarkable returns from recreation programs (Roosevelt had 80 softball teams at the peak of its boom) and from support for new religious and social organizations (public and private officials cooperated to make board rooms and other facilities available for their use in the evenings and on weekends).

A Combined Effort

The state and the resource development companies had means and responsibility to provide assistance to the local governments. But they also had reason to preserve funds, for other purposes and for profit, and to keep from being overwhelmed by the many wants of the many governments in the Basin. The governments of Uintah County found they could present a more coherent package of requests, and more forcefully support those requests, by agreeing among themselves upon a development plan and a ranking of priorities. They credit this packaged approach as the principal reason that all their first priority requests were met.

On the other hand, progress in both counties was frustrated by bickering and mistrust, especially among the water agencies. In Duchesne County the issues revolved around which areas would be served culinary water by the Central Utah Project and what would be the capacity of the water systems. It proved impossible to develop a county-wide system, although some leaders remain convinced it would have been more efficient to do so. The size and cost of the major systems have proven to be greater than many leaders now consider appropriate. A difficult and expensive conflict developed in Uintah County between competing systems inside and outside of Vernal. The competition caused delays in development of facilities, resulted in what many believe are inefficient systems, and appears to have weakened the direction and follow-through of land use planning.

There also was difficulty in coordination between counties: the Uintah Basin Association of Governments was disabled without the participation of Uintah County during most of the period. In addition the counties and the cities also were slow in coordinating zoning, tax base, and expenditure programs.

These problems add reasons to avoid the proliferation of independent jurisdictions, such as the several and independent water authorities, and to build, in advance, effective communication between the jurisdictions, particularly on matters of revenue distribution, land use planning and street and utility planning.

Go for What Is Already Needed

There is much uncertainty about which facilities and how much service will be needed during the growth period. But the capacity, both financial and political/administrative, will be too limited to provide all the facilities and services desired. A criterion which some Uintah Basin officials used, they believe successfully, was to begin with those things already needed. These would be useful even if the development failed to materialize. They also would place the community in better shape to handle the growth if it did come.

This criterion should not eliminate other considerations, such as the lead time necessary to develop facilities and services. School buildings require a couple of years to finance and construct, but temporary classrooms require only a few months to make operational and so can help deal with uncertainty and soften the impact of delays in permanent construction. Water and sewer lines and treatment plants required the longest lead times, for project planning, approval, and construction.

Water and sewer treatment facilities were at the top of the priority lists because serious existing deficiencies meant they already were needed and because of their long lead times. But the difficulties of projecting ultimate needs and of designing systems of economical flexibility resulted in financial disaster for the small community of Myton, and expensive services for the larger municipalities discussed in this paper.

There tends to be a bias in going for what is (thought) to be already needed. It favors physical projects and favors the projects and programs which the communities already understand. Still, the Basin's priorities included a heavy emphasis upon health related facilities and services, not just new hospitals but a nursing home in Vernal and a health clinic in Duchesne. The bias has the advantage of tending to postpone those new services which can be most quickly expanded because they primarily depend upon staffing. These services also tend to be the services which the community least understands and is most likely to misdirect until it has first hand experience with the problems such services attack. But the bias also has costs of delaying local understanding of the problems and the capacity to deal with them. The bias ought to be understood and steps should be taken to balance it by developing an understanding of probable social needs and ways to detect and address them.

Share the Risk

The resource developers ought to be in the best position to judge the probabililties of the development, and to time the commitments to new public facilities and services to match the pace of the development. They also have an interest and responsibility regarding these facilities and services. It thus is both appropriate and useful to require major financial participation from the developers, and to particularly tie these contributions to those projects whose value most depends upon the development actually occuring. This reduces the financial risk carried by the community and also helps assure that decisions are based upon the best information available to the highest levels of the participating companies.

Share the Resources of State Government

The state's help was substantial. It reduced the risks to the local government by reducing their shares of the financing for water and highway projects and by providing a probable fallback if development should move more rapidly than expected, or than local governments could manage. The most serious problems were that the help was slow in coming and, in the view of most local officials, should have been greater.

Suffer the Changes in Officials

A most difficult adjustment, and one painful to participants and observers, is the nearly inevitable turnover in public officials. Even the most successful leaders have relatively short political lives during the boom cycles, being replaced both during the upswings and the downturns. In part this comes because communities in such rapid transitions collectively change faster than do the attitudes and visions of not only most individual members of the communities but even those of the political leaders who by nature may be relatively flexible. But in part this comes because expectations generated by the boom become impossible to meet, given the rapid change, the uncertainties, the dreams of the times, and the problems that arise. So it is important to the health of the community and to the health of its leaders to accept and suffer without rancor or depression the changes which inevitably occur. The best contributions will still only be one act in a rapidly developing drama. Satisfaction must be found in that.

Build and Preserve Capacity

The quality of leadership and services within the boomtowns and the quality of professional and political support from the state and others outside the boomtowns proved crucial to the ability of the communities to effectively respond to the cycles of resource development. It is in the state's interest, as well as the interest of the communities, to build experience and capacity to deal with these changes, and to preserve that capacity and those skills for future booms after the immediate boom ends. Thus it is in the state's interest to give extra value to job development in nonurban areas, where job development usually is more difficult and expensive, if there is the potential for the areas to rebound in future periods of resource development.

CONCLUSION

Knowledge and communication can solve most problems, but both are scarce resources. Experience and professional skill can increase these resources and improve their allocation. These are not necessarily new experiences and skills. In the Uintah Basin the governments still provided the same services. What was needed was experience and skill able to quickly and efficiently expand services in both size and sophistication. It also was important to have governmental structures, agency attitudes, and program plans which kept options open and were capable of timely decisions that also remained open to subsequent adjustments. What may have changed the most was the need to build connections: with outside governments, with the resource industries, with the people moving into the community, and with data which helped reveal what was happening to the community.

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IPP NOTES

Robyn R. Pearson[1]

In the beginning the Intermountain Power Project (IPP) was created only in the minds of some visionary dreamers. And IPP was without form, and void; and darkness, on occasion, was upon the face of Southern California. And the Spirit of IPP moved upon the minds of many people. And the Intermountain Power Association (IPA) said let there be a firmament in the midst of Millard County and let us divide our land from the other B.L.M. land. And IPA separated the firmament from the B.L.M., and it was so. And IPA called the firmament IPP. And the evening and the morning were the first year.

And IPA said, Let the waters be gathered together from out of the hands of the farmers into our hands, and let the dry farm land appear: and IPA saw that it was good. And the evening and the morning were the second year. And IPA said, Let us create engineers, planners, and statisticians to bring forth ideas, numbers, and statistics to confuse and bewilder man. And IPA saw that it was good. And the evening and the morning were the third year.

And IPA said, Let us create construction workers both male and female and let them have dominion over the plant site, but they were not made in the image of your average construction worker becasue they had right to work laws and a site stabilization agreement. IPA blessed them, and they were fruitful and multiplied far beyond IPA's original projections. IPA built trailer parks and mancamps to handle the surplus population. And the people lived in peace and harmony. And the evening and the morning were the fifth year.

And finally IPA said, Let there be light, and there was light. And IPA saw everything that it had made, and behold it was very good. And the evening and the morning were the sixth year.

Thus units I and II of the Intermountain Power Project plant were created. And in the seventh year IPA ended its work to rest for a season possibly in anticipation of building units III and IV.

[1]Millard County Administrator

To be able to adequately understand the significance of the impacts which have been placed upon Millard County by the Intermountain Power Project, it is essential to have an historical back drop from which one might adequately evaluate.

The Sevier Desert is an immense tract of rather level land situated in what was once a part of the lake bed of ancient Lake Bonneville. The Sevier Desert proper consists of 16,000 square miles, mostly of broad level desert areas. Its extreme length is 178 miles from south to north and its extreme width from east to west is 123 miles. It comprises by far the largest single unit of arable land in the State of Utah.

Picture in your minds eye a country of magnificent distance - a vastness of land covered with greasewood, rabbit brush, sagebrush and marshland - the Sevier River, winding like a silver ribbon through the desert; its banks lined with willows, tamarisks, and wild rose bushes.

The early history of the water istuation in West MMllard County is important. The first settlers tell the story of how they came because there was so much water. After ten years of trying to control it, and get it out of the river onto the land, they left - there was too much water. The history of the people and the history of the water has been completely interwoven. Time was measured by the highs and lows of the river. If there were ever to be meaningful settlements, the river would have to be tamed.

As early as 1860, the first attempts were made to build a damn to divert water onto the land. The damn was made of cottonwood trees, willows, greasewood brush and rock hauled from a quarry 20 miles away. After hard, back breaking work, the damn was finally completed. Each family was allotted so many acres according to the work they had done. Crops were planted and the virgin soil yielded abundantly, and the settlers were encouraged. By the spring of 1861 there were 142 families established in the new country. In the summer of that year, the damn broke and most of the crops were lost. They immediately began to replace the damn and by the fall of that year had the damn restored.

In 1862, the damn broke again and the crops were ruined. A similar disaster was reported each year there after until most of the settlers became discouraged and moved away by 1868. For many years the area was entirely vacated. Every foot of progress, every inch of advancement made in this desert country was stubbornly resisted by nature, and was overcome only by dogged persistence and repeated efforts. Not ghost towns, but ghost projects in this valley testify that subduing this great Pahvant Valley was no easy accomplishment.

In 1874 a company of non-Mormons made preparations to build a new damn across the Sevier River. They hauled considerable timber onto the ground and made improvements, which they subsequently sold to the Mormons. This damn subsequently failed. In the spring of 1875 another effort was made to erect a damn. This damn was built mostly of rocks and willows, the latter being bound in bundles and sunk with large rocks until it was raised to the surface of the water. This latest damn cost approximately $4,000.00 and lasted only 2 years. After the damn failed, a noted member of the community, Joseph S. Black, gathered the people together at the damn site and said "never let it be recorded that we have tried and failed." A vote was taken to commence work on the damn the next morning and to keep working until the water was raised. The people accomplished what they had set out to do and saved their crops that year.

In 1879, the first irrigation company was organized. The new company was stocked for $6,000.00. It was figured that an acre share of water would water one acre of land. They paid $1.00 a share for the water. Trouble persisted with the damn until 1909 when it broke again and Desert was totally flooded. After this flood, there was a terrible epidemic of typhoid fever, caused by so much water under the floors of the homes, and many people died.

Death and plague were constant companions to those early settlers. If they were not being attacked by indians, then they were fighting black diphtheria. Typical of the death and sorrow the plagues brought was the case of the George Croft family. Ten year old Thomas Croft was the first victim. He was taken to Fillmore, 50 miles away for burial and his funeral was held outside. That same night the mother Letitia, became ill and two days later she died. On the same day her Father, Thomas Davies died with the dreaded disease.

After the mother's funeral, the children returned to Deseret. On August 11th, 1909, Florence the youngest daughter became ill and died on the 13th. Mary Evelyn, the oldest daughter, became ill that day and died on the 15th. Both girls were buried at night in a heavy rain storm by their elder brother George and Jacob.

The Sevier River, of course, was the principal motivation behind any settlement. It is the only major river within the state of Utah that rises and ends within the State. It drains an area in southwestern Utah comprising more than one-fourth of the whole area of the state. Its waters are completely consumed for agricultural and industrial purposes. The towns of Panguitch near the head of the river, Richfield near its center and Deseret near its terminus were each colonized under the direction of Brigham Young during the early 1860s. Along the upper and central portions of the river, the matter of diverting its waters was a simple affair. The banks of the river were low and the water could be diverted by anchoring a few cottonwood trees across the channel and then piling juniper boughs and rocks on the up-stream side of the obstruction. On the lower end of the river, the stiutation was entirely different. When the Sevier River left Leamington Canyon and finally established its course on the flat plain of ancient Lake Bonneville, it cut a very deep course. At the point where highway 6 crosses the river, about two miles north of Delta, the bed of the river is approximately 120 feet below the surface land.

Early records show that during the years 1890 to 1893, the average flow of the river at Leamington Canyon was more than 350,000 acre feet per year. At the time there was no state-wide regulations of the use of the water of the river, and those on the lower end received only such water as those above could not use. This presented no great difficulty to the lower users until the late 1890s. At that time there began a series of dry years which reached its climax in the year 1900. During this year, the average flow of the river at Leamington Canyon from the first day of June until the first day of November was only 17 cubic second feet. Not a drop of that water reached Deseret during that period. No crops could be grown and there was not sufficient water for range cattle on the lower end of the river. In desperation, the people of Deseret, Oasis, and Hinckley sent a group of men up the river to tear out the damns of the later appropriators. This accomplished little, since the dams could each be replaced in half a day's time.

In 1902 a decision was made to build a major damn upstream which would give the people of the lower Sevier control over the river. The purpose of construction of the Sevier Reservoir was to store and use the waters of the Sevier River that no other had ever been able to use. It constituted the most ambitious undertaking by such a small group in the economic development of the West. It was constructed entirely by men and teams of horses. There has been no other period in modern history when it could have been so constructed. The construction required the excavation of three trenches across the bed of the river to a depth of 30 feet and the building of a coffer damn to impound the water until trenches were dug and filled and the foundation of the damn constructed. This was possible only because during the fall of 1903 the river was practically dry. For example, during the month of October of that year the total flow of water at that point averaged only 7 acre feet.

It took 8 long years to build the damn and practically every able bodied boy and man from Millard County worked on the project. The official name of the new reservior was Sevier Bridge Reservior but the common name was U.B. Damn. As they progressed with the work, it became evident why this name was chosen. They were damed by the upper water users for building the reservoir and their future was damned if they didn't. All the men working on the U.B. Damn were paid in stock by the Deseret Irrigation Company at $5.00 per share. The Damn was completed at a cost of $125,000.00. Today, the reservoir covers an area of 3,670 acres and has a storage capacity of 289,962 acre feet of water.

The U.B. Damn finally allowed for the stable and steady settlement of the lower Sevier Basin. Canals and laterals were constructed to allow for the irrigation of up to 103,000 acres of land. Approximately 87,000 acres are serviced by tile drains. The cost of constructing the drains was far in excess of the construction of all of our Reservoirs and the water distribution systems. Agricultural crops cannot be grown in the area without drainage.

After the new irrigation and drainage systems had been installed, West Millard County began to reap the benefits from those who had toiled so long and hard to tame the river. The principal crop has always been alfalfa. For many years the area produced more than one third of all the alfalfa seed produced in the United States. In addition to alfalfa, corn and grains were prominent. During World War I, the largest sugar factory in the world was built in Delta to handle the thriving sugar beet crops. Since 1952 both insects and weeds have been increasingly difficult and expensive to control so that the present trend is towards more general farming. The area has seen periods of highs and lows for many decades, but two things have always remained constant: 1. The ever dependance on agriculture through the life giving water of the Sevier River, 2. The sturdy- never say die attitude of the inhabitants most of whom can tie their lineage back to those early pioneers who settled the land.

INTERMOUNTAIN POWER PROJECT

My first contact with Millard County came as a graduate student at Brigham Young University. The State of Utah had commissioned BYU through its Graduate School of Management to assit with a demographic analysis of various Utah communities which were being considered as major growth areas. Our task was to develop a computer model which could analyze the raw data and help provide answers to the decision makers about how major growth factors would affect a given area. Although I never got to go to Millard County first hand, I felt that I had a good knowledge of the area. My initial impressions were, at that time, that if a major industry, such as a power plant, were to move into Millard County, the results would be disastrous. The communities were too static, totally dependant upon agriculture, with inadequate infastructure to meet the high growth demands that would be placed upon them.

My biggest fear was that emotionally, and mentally, the people could not handle the upheaval and the life style changes which would be brought about. Millard County has been quite isolated from the rest of Utah, with the closest significant population area being almost 100 miles away. A good many of the residents live in the same house that their father, grandfathers, and greatgrandfathers were raised in. The family farms and water-rights have been passed on from generation to generation. The communities are basically conservative and Mormon. Because almost all of the people were employed in agriculture in one way or another, the median family income was almost 30% below the State average. I've often heard many old timers say that they just didn't know that they were poor until everyone came in and told them.

In my minds eye, I could see a disastrous disruption of this fragile lifestyle.

The formal decision to bring the Intermountain Power Project to Millard County was made in 1980. In early 1981, I accepted the position as the Millard County Administrator and I continued to retain the same perception of Delta and West Millard County---that it was an area destined for change without the ability to cope. I was not the only one who had that perception. I can still remember one T.V. news reporter's prophesy of the impending disaster which was about to decend upon the poor unsuspecting people. The news team placed their T.V. cameras on the West end of what was then an almost empty main street, and as a tumble weed blew by, the reporter described how this helpless sleepy little ghost town was about to be transformed into "sin city". He talked about the problems which have existed in typical boomtowns--high crime rates with large jumps in violent crime, wall to wall people, inadequate housing, inadequate sewer and water facilities, and overcrowded schools and recreation facilities. He also described the unsavory nature of the newcomers who would not be tolerant of the communities customs and standards.

This type of media hype created panic in the minds of some of the longtime County residents, who began to second guess the decision to locate the IPP within their borders. These were people who never had to lock their doors at night or wait in line at the grocery store. The majority of the people, on the other hand, remained calm and collected. On top of the IPP pending impact, there was the even greater threat from the MX. Even though the MX never did materialize, its presence was anticipated and discussed by community leaders and citizens alike. Many meetings were held to assess community opinions and to generate awareness. Never did these meetings divide the Community, or cause panic, which was puzzeling to me as a newcomer.

The one event that did create some difference of opinion amoung the people was the sale of water to the power plant. A coal-fired plant like IPP, consumes a tremendous amount of water. To sell the water for some was like selling ones birth right or heritage. Without the water, the land would return to a desolate wasteland again. Many farmers agonized long and hard over this decision. There were strong differences of opinion even amoung family members. IPP eventually offered $1,750.00 per share and paid 83 million dollars for 45,000 acre feet of water. This was almost 20% of the water right owned by the four irrigation companies. I'm sure that many of the Pioneers turned over in their graves when these dealings were finalized. Yet the benefits which have resulted from the water sale have been substantial. Many farmers were able to get out of debt and purchase modernized equipment. Most of the ground in West Millard County has recently been lazer leveled which makes for more efficient use of the water, saving anywhere from 20-30%. Many irrigation ditches have been lined this also saving large amounts of water.

To summarize, the impacts of the Intermountain Power Project have come and gone. A tremendous amount of time, money and effort have been put forth by the communities, the County, the State and the Project to make the experience a positive one. Much has been written and will be written about the procedures, the formats, and the formulas which were used. Discussions will center around the Impact Alleviation Contracts, the Site Stabilization Agreement, the Conditional Use Permit, the Interlocal Cooperation Act, and the payments in lieu of tax, all of which have contributed greatly to the success of the project.

As this project is dicussed debated and written about, I doubt that little if anything will be said about the people past and present who have made this area their home. The building of the U.B. Damn by the early pioneers was every bit as monumental and significant a task as was the building of the IPP. The impacts placed upon them were even more threatening in their scope and magnitude.

The current generations have exhibited many of the same qualities which the early pioneers possessed. They were determined that the construction of the Intermountain Power Project not change the nature and quality of life as they had come to know it. As the saying goes, people make the difference and I personally believe that a significant portion of the success of this project can be attributed directly to the qualities possessed by the people of Millard County. As Joseph S. Black recorded over 100 years ago "Never let it be recorded that we have tried and failed".

THE IMPACT OF WATER AND MINERAL DEVELOPMENT PROJECTS ON A RURAL COMMUNITY AND ITS EDUCATION PROGRAMS

Thomas J. Abplanalp

ABSTRACT: This paper is a report on the impacts of a Federal Water Conservation project and the development of an oil field drilling development in a rural city and county in north-eastern Utah. During the time period covered by the report, a long planned for water conservation program known as the Central Utah Project came into being followed by and overlapping with a very successful oil drilling project. The focus of the report is to take a close look at what happens when large numbers of people move into a sparcely populated area that has a low economic base and the actions taken to meet the oncoming "Boom" situation. Data for the report was drawn from county, city, and school records, with a great deal of experience by the writer included. The multiplicity of problems and challenges created situations never before encountered by the local entities and provided a great challenge to all concerned. As the projects are finished and the economy subsides, we can but ask what next.

INTRODUCTION

The Central Utah Water Conservation project and the unexpected development of an oil producing field in the Uintah Basin area of Utah with a central focus on the City of Duchesne, Utah brought into being an impact that shook a complacent community of approximately 1200 population to its proverbial roots. The impact is great when one hundred fifty Bureau of Reclamation families become a part of a growing population and this is followed by a sudden development of oil drilling activities that bring into an area many oil field workers and their families.

The two developments were long talked about possibilities in the Uintah Basin area that suddenly became realities. Problems came with the population growth such as housing, planning and zoning laws, provisions for adequate water and sewer facilities, fire protection, police protection, shopping centers, recreational facilities and above all educational facilities and staff to meet the needs placed on the school system by the influx of families. With adequate finances, local government agencies could build, buy, expand, but local money was not available to meet the needs placed on Duchesne City and Duchesne County as a whole by the population growth.

In the 1960's, Duchesne County was one of the poorest counties in the State of Utah with a total assessed value in 1966 of

$12,141,412.00. This along with a complacent citizen attitude created by years of waiting for something to really happen and seeing nothing done compounded the problem. The challenge was there, it would be for a long time, how was it to be met?

As the population increased so did the problems. Trailer homes began arriving, parking in any available space. The Bureau of Reclamation began constructing its own community on land it had purchased. The area was plotted for double-wide mobile homes, water and sewer hookups had to be provided, power lines erected, etc., and a new community began to emerge. As the freshly graded dirt fields became roads traveled by a great number of Government vehicles, a dismal cloud of dust hung over the city bringing with it a negative local attitude toward "new-comers".

To solve some of the growing challenges, the city fathers called a series of public meetings to jointly look at the situation as it existed with all people involved. Zoning and community planning was a first and major topic. It appears that the local community had done very little with this area in the past and suddenly trailer houses were present wherever a parking place could be found. This item created a critical schism that split the community and created a scar that was slow in healing. As one meeting progressed, an "old-timer", labeled the "new-comers" "trailer trash", and an organized approach to meeting the coming challenges of a community to change an obstacle to growth, improved economic conditions, and good will was established.

No community can ignore its own future, especially when that future has been on a drawing board for many years. The Central Utah Project had been planned and re-planned for years before it became a reality. Because of the delays of the past, the local citizens of Duchesne and its community leaders did not accept the fact that finally maybe something would happen with Central Utah and that maybe drilling for oil was not just another passing rumor. When little action is taken to become informed and stay informed, little planning will take place for activities that may descend on your old hometown. So, it was in Duchesne City, Central Utah and oil drilling were not realities until they were there in full bloom.

In meeting the challenge of going from "Bust to Boom", the gathering of facts, knowing what is coming next, and being prepared to achieve the most of an opportunity is an absolute necessity.

As planning takes place, facts are collected, and a plan of action is formulated, the total local community must be kept informed and oriented to what is taking place and be prepared to become a part of it.

As the Bureau of Reclamation and later as oil field personnel moved into the community several actions were taken. Immediately trailer courts were licensed, facilities were provided for rental, businesses expanded as best they could and prices of about everything soared. Employment opportunities greatly increased, money began to flow freely as payrolls increased. The period of Boom was on.

As the "Boom" progressed, a critical situation was faced by one county agency, the Duchesne County School District was faced with a no-choice problem. School pupils were coming to the county with their families. A static school population began rapidly increasing. The average daily membership of 2481.8 pupils in 1970 jumped to 3532.9 by 1975. This growth of 1051 pupils may seem insignificant, but in a poor rural district with inadequate and outdated buildings, a poor transportation system, an extremely low teacher salary schedule, and very little money, created a near crisis situation. A new district school administrator came into the county in 1963, faced with a gigantic task of pulling the past educational system into focus and projecting it into a meaningful and challenging future. There was no lead time for pre-planning, the key was action and fast.

A public relations program was organized and implemented. People of the school community must realize that the Central Utah Project was indeed a reality and that the oil industry was developing rapidly, both bringing a rapid increase in school population and a demand on the educational systems to gear up to meet whatever needs would arise. Several actions were taken. These included:

1. A total county wide evaluation covering such items as:
   a. The physical condition of all school buildings and the maximum pupil capacity of each plant.
   b. Establishing how existing building space could be re-organized to house more pupils.
   c. Determining how many pupils would actually arrive for a given school year and when they would arrive.
   d. Locating growth patterns in different areas of the school district. Duchesne County School District covers an area of 3,266 square miles and covers an area of approximately 2,090,240 acres. Within the school district there were ten schools.
   e. Bus transportation routes were mapped and the total program evaluated.
   f. Teacher staffing was closely evaluated for each school with an attempt to organize for maximum efficiency. The addition of staff was a critical financial challenge.

Data gathering is time consuming, and costly. Physical plant evaluation required on the spot visits. A cost analysis must be established for doing the necessary remodeling. Because of the poor economic condition of the county school district in the 1970's, an engineer or architect could not be hired to the job needed.

A reliable count of school children had to be obtained. Several techniques were used. These included:

1. Working with the local U. S. Post Offices. The number of new mail boxes rented each week was obtained giving a lead to new families arriving in the community.

2. All religious denominations were contacted and new membership counts obtained.

3. Government agencies involved in the Central Utah Project were contacted, getting all information available on their projected plans.

4. Oil companies were contacted as their drilling projects materialized. Number of wells to be drilled, numbers of people to be involved, where they would be located, and how long they would be in a given area were requested. Because of the uncertainty of the drilling projects, information was hard to acquire. The oil companies and drilling companies seemed very reluctant to "give out" any concrete figures. Estimates were gathered, but little in concrete numbers.

5. Pre-school registrations were held during summer months. These were extremely helpful in getting reliable numbers on given grade levels.

6. Close contact was kept with city and county officials getting all information possible on water and meter hookups, building permits issued, sale and purchase of property for home construction, permits for trailer parks, electric power hookups, etc., etc.

As information was collected, the emergency situation emerging in the county school system was evident. School buildings were old and inadequate, the bus transportation system was in a deplorable shape, salary schedules were extremely low, money was not available for the needed upgrading required to meet the identified needs. During the first seven years of the growth period, the Bureau of Reclamation was the chief source of pupil increase. Being a U. S. Government tax free entitiy, they added little to the local tax economy except personal property tax payments. After this period when drilling and oil production entered in the picture, the assessed valuation of the county improved greatly.

In meeting the challenge of the Bureau growth period, a crash program was put in action. Classrooms were partitioned, large hallways were converted to class use, portable class rooms were purhcased, an old vacated building was re-activated creating three classrooms. These were temporary measures to meet immediate needs. Immediately Government funds were solicited to meet both community and school needs, public law 874 funds were obtained to build at Duchesne, the area where the Bureau offices and community was centered. These were temporary measures, but as time passed and more people arrived on the scene, the problems of growth did not diminish.

Faced with its many problems, the Duchesne County Board of Education decided it must take the problems it faced to the public so it geared up for a school bond election to raise two million dollars for building construction. After five previous attempts and five failures this event was a great challenge. Cooperation and public involvement was a key. All agencies concerned were involved. The population growth pattern was expanding, county wide.

It was no longer a matter of the Bureau of Reclamation moving into a given area to do a specific job. The oil boom was on its way. The population of Duchesne County had been chiefly farming and stock raising until this time. They were generally a conservative group, but in showing them the school needs of the county, and an increasing tax base that would prevent a raise in taxes, the bond issue was passed and the school officials were given some leeway to meet the needs in school construction.

As the population growth pattern continued, other educational problems arose. The Bureau of Reclamation members were generally well educated, trained in professional fields, with high expectations for good schools with good educational programs. Recreation and athletic offerings, good shopping centers, good police protections, etc., etc., were part of their expectations. On the other hand the oil drilling crews who followed the drilling rigs from job to job were a more unstable population, their children attending several schools in some years. These pupils came from a widely diversified field of experience. Many came from states whose school laws were much different than those found in Utah. Some had left school when they were fourteen or fifteen years of age. When they arrived in Utah and were faced with Utah's eighteen years of age compulsory attendance law, more problems arose. Special programs had to be provided for those who returned to the classroom. Because of conflict with some parents and pupils, legal permission had to be obtained to drop them out of attending school. Attitudes had to be dealt with, these ranged from positive to very negative.

In a "Boom" growth period, problems and their solutions cannot be procrastinated. They must be dealt with and solved on a day by day basis if possible. Getting involvement of concerned people was a vital key to finding solutions to problems. When faced by a disgruntled patron, get him on a committee or involved in a paren-teacher organization or visiting school to actually see what is going on. When one problem appeared to be subsiding, another arose. From a no job to a few job opportunity area, Duchesne County became a high employment area. Many local citizens including some secondary school pupils went to work in the oil fields on high-paying jobs. Low incomes became high incomes. Many farmers became oil field or Bureau employees, their farms became a side-line or hobby. Money rolled in, not only in wages but in taxes. From a very financially poor situation Duchesne County was fast becoming a wealthy area. The big boom was arriving.

As the school system expanded, so did the local towns and cities. The Duchesne City administration obtained federal funding to build a lagoon system for sewage disposal. Water systems were upgraded and as the Starvation Dam was completed, a contract was entered with the Water Conservancy District for construction of a water purification plant to serve Duchesne City and surrounding areas. New businesses related to drilling activies arose supplying more jobs and bringing in new people.

With the rapid increase in the assessed valuation of Duchesne County, additional funds became available to Duchesne County School District for construction of school buildings and upgrading the total education process. Several old buildings were replaced, new schools for special education classes were established, a fine vocational center was built, auditoriums and lunch room facilities were added to schools, along with bigger and better gymnasiums and athletic fields.

Needs were being met, and wants began to appear. The securing of federal funds, the pasing of a bond issue and an increase in tax revenues opened another door. The old Ford wasn't satisfactory anymore, we wanted a Caddy, but we had to ask how long will our prosperity last and can we continue to make the payments. Overspending and overbuilding challenges must be met. A strict pay as you go plan was organized and put into action by the school administration and Board of Education.

What a remarkable change had taken place since 1966 when the assessed value of the county had been $12,141,412.00, and began a growth pattern that carried it to $33,195,478.00 in 1972, and up to $252,870,655.00 in 1986. The age of prosperity had surely arrived, but something different was coming into focus again. In 1987 the assessed value had decreased by an amount of $81,878,451.00. Cities, towns, county and school district felt the first pinch of a declining revenue.

The Bureau of Reclamation had finished its work in the area, employees were being transferred to other jobs, plans were underway to close the main Bureau Camp. The oil industry came slowly to a standstill, drilling almost totally ceased, jobs were no longer available, unemployment skyrocketed, hard times appeared to be just around the corner. As the "pinch" increases, school budgets are being cut, as are city and county revenues. As families leave the area, homes are left empty, the real estate business appears to be dead. Business, especially those related to the oil industry are folding, unemployment is high, being one of the highest in the State of Utah. The boom is apparently over, the bust is back. The cycle has been completed. What next for this rural community, and its future?

WATER POLLUTION MITIGATION IN TWO NATIONAL PARK SERVICE UNITS AFFECTED BY ENERGY AND MINING ACTIVITIES

Mark Flora[1], Sam Kunkle[2], and Dan Kimball[1]

ABSTRACT: The importance of regulating mining and energy development as a resource management function in the National Park Service (NPS) has increased dramatically over the past decade. Presently, the water resources of a number of NPS units are affected by mineral and energy development activities. Frequently occurring problems include water quality degradation resulting from oil and gas development, acid mine drainage arising from abandoned coal mines, and riparian zone disturbance, sediment loading and water quality degradation associated with mining operations. In order to address these issues, the NPS has utilized a variety of assessment, monitoring, research and mitigation techniques. This paper will present two case studies in which mitigative measures are being applied to improve water quality degraded by energy and mining activities. The first study reviews promising efforts of the U.S. Bureau of Mines and National Park Service in testing the suitability of an artificial bog to mitigate acid mine drainage impacts from an abandoned coal mine which flows into Friendship Hill National Historic Site (PA). A second study documents a cooperative research effort by Exxon, U.S.A.; the Florida Department of Environmental Regulation; and the National Park Service in mitigating ground-water contamination resulting from the use of shallow surface impoundments that store drill cuttings and produced water generated during oil well drilling in Big Cypress National Preserve (FL).

KEY WORDS: water quality, national parks, mining, acid mine drainage, oil and gas, ground-water contamination

INTRODUCTION

A review of minerals ownership and development activity in and around units of the National Park System (Temple, Barker and Sloane Inc., 1985) indicated that more than two-thirds of the 337 units of the National Park Service could potentially be affected by either internal or external mining or energy development activity. In 1985, mining or energy development was occurring within 33 NPS units and in the vicinity of an additional 151 areas. The mining and energy development activities are diverse, and include oil and gas extraction, hardrock mining, coal mining, the recovery of mineral materials (e.g., sand & gravel operations, placer mining, etc.), and potential geothermal development. A summary of these activities is presented in Figure 1.

[1]Hydrologists, National Park Service, Water Resources Division, 301 S. Howes St., Fort Collins, CO 80521
[2]presently with the USDA, Forest Service, Washington, D.C.

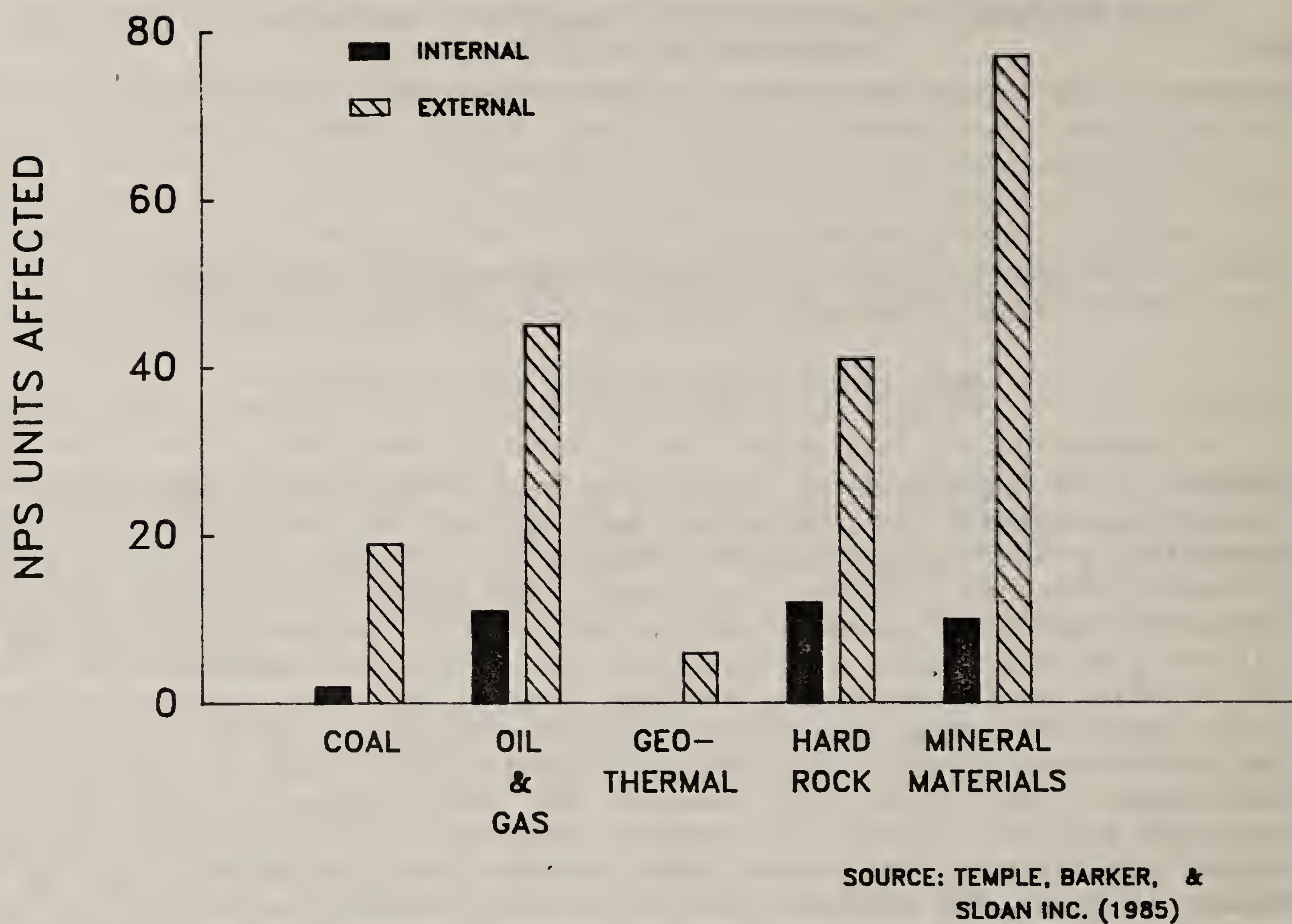

Figure 1. Mineral development activity occurring in the vicinity of the National Park System.

Water resource impacts resulting from mining and energy development activities are also diverse and may include:

- the disruption of natural surface-water and ground-water flow patterns
- increased watershed erosion and sediment loading to receiving waters
- degradation of surface-water and ground-water quality
- the disturbance or destruction of stream and riparian zone habitat

In response to mining and energy development threats the National Park Service has implemented water resource assessment, monitoring, research, and mitigation activities in a number of NPS units (Flora and Kunkle, 1986; Rikard et al., 1986; Deschu, 1987). This paper will discuss two case studies in which a variety of monitoring, research, and assessment techniques have been applied to mitigate water resource problems resulting from mining and energy development activities.

The Mitigation of Acid Mine Drainage at Friendship Hill National Historic Site, Pennsylvania

Experiments are underway on a polluted creek at Friendship Hill National Historic Site, in the Monongahela River Basin of Pennsylvania, to test the effectiveness of using an artificially constructed wetland as a living filter for removing the pollution caused by coal mining. This research is being carried out in conjunction with the U.S. Bureau of Mines (Kleinmann, 1985; 1986). The small creek winds about one mile (1.6 km) through the 661 acre (268 ha) historic site, falling 200 feet (61 m) enroute, and receives much of its flow from the constant drainage of an abandoned coal mine shaft upstream. Because of the acidity and metals in the water, riparian vegetation has been killed, nearly all aquatic life is gone, and the stream's natural appearance has given way to the coffee and orange colors indicative of severe chemical impacts.

Experts felt that the costs of treating the stream by engineering measures, such as liming or settling ponds, would be prohibitive; therefore, the creek was deemed a good area for cooperative research on the recent concept of artificial wetlands as a means of countering pollution. A created wetland would aesthetically be preferable to the present scene; the acid and metal pollution could possibly be reduced; and scientific and educational benefits would evolve. The wetland would establish an ecologically interesting environment for visitors and provide wildlife habitat.

The concept of wetlands as a pollution clean-up tool has been observed in nature. For example, at a natural bog in West Virginia, mine-polluted water with a pH of 3.4 and conductivity of 222 uS/cm entered a bog (Tub Run Bog) and improved to pH 4.5 and 38 uS/cm on passing through the bog, making the outflow comparable to unpolluted bog waters in the area (Wieder and Lang, 1982).

The Friendship Hill creek is exceptionally polluted, even by Appalachian standards, with acidity, sulfate, and metals far above any acceptable criteria level, as summarized in Table 1. The creek's discharge varies seasonally from about 6 to 25 liters per second (100 to 400 gallons per minute); however, water quality is relatively consistent at all flow levels. The quantity and quality of the water pose problems for the wetland treatment which thus far has only been tested on smaller flows and at sites where iron concentrations are below 100 mg/L and pH levels are at least 3.0. Because the study is breaking new ground scientifically, a conservative approach, using test plots and pilot studies, is underway. These tests were considered essential prior to any wetland construction on a larger scale.

Small plot studies were carried out during 1985-86 on a variety of plant species, planted in the water, to determine which ones could 1) survive in pH 2.6 water and 2) reduce the acidity, metals, and sulfate concentrations. Successful plants in the 1985-86 plot included peat moss (*Sphagnum recurvum*), cattail (*Typha latifolia*), and hardstem bullrush (*Scirpus acutus*). The larger-scale field testing of the wetlands plants began in the fall of 1986, with completion of a prototype 0.15 hectare (0.4 acre) wetland. Some low-water control barriers were constructed to impound water and maintain the desired level, bales of hay were placed as an organic substrate in the wetland's flow, and the vegetation was planted. As of late spring, 1987, the cattails and bullrushes appeared to be the two species tolerant of the

Table 1. Data from monitoring the creek at Friendship Hill, 14 times during 1983-1985.

Parameter	90 Percentile Range	Comments[1]
pH	2.5 - 2.9 pH units	4.5 in a natural bog; >6.5 in many other streams
acidity	1100 - 1400 mg/L	>134 mg/L considered harmful to fish
sulfate	2100 - 2600 mg/L	250 mg/L upper limit drinking water
iron	230 - 340 mg/L	>1.0 mg/L not acceptable for most uses
aluminum	57 - 75 mg/L	>0.25 mg/L generally harmful to fish
manganese	7 - 11 mg/L	>0.1 mg/L generally harmful to fish

[1]mainly drawn from Flora et al., 1984

severe conditions (Kleinmann, U.S. Bureau of Mines, personal communication, 1987).

Testing of the plant growth and survival will continue during 1987. Among other tests, water quality monitoring conducted above, within, and below the prototype wetland will evaluate pH, acidity, conductivity, calcium, sulfate, and a suite of metals to observe changes in water quality. If the wetland vegetation is successful in improving water quality in the stream, a larger, full-scale wetland of approximately two hectares (5 acres) will be established.

Ground-water Contamination Mitigation from Produced Water Impoundments in Big Cypress National Preserve, Florida

Oil field development in Big Cypress National Preserve generates large amounts of "produced water" during the drilling process. The produced waters may be contaminated both with high concentrations of dissolved salts (found naturally in the deeper aquifers underlying the preserve) and contaminants associated with drilling fluids and muds (e.g., heavy metals, hydrocarbons, etc.).

A suspected loss of produced-water brines from a temporary surface storage impoundment at the Raccoon Point oil field in 1984 both degraded water quality and resulted in damage to vegetation located downgradient from the impoundment. To assess the problem of this loss and the potential for groundwater contamination from the routine use of produced-water impoundments, a cooperative effort was undertaken jointly by Exxon, U.S.A., the Florida Department of Environmental Regulation and the National Park Service. A study design was adopted, and Exxon, U.S.A. contracted with the consulting firm of Environmental Science and Engineering (Gainesville, Florida) to carry out the field research (ESE, 1986).

Prior to this incident, produced water, drill cuttings, and drilling-fluid residuals were temporarily stored in clay-lined, surface-water impoundments known as mud retention pits. When sufficient drill-hole depth was reached, the liquid portion of these residues was reinjected into the drill hole to a depth far below the usable ground-water aquifer. The residual solids, consisting primarily of drill cuttings, were then trucked to a landfill outside the preserve. Eventually, the area disturbed by the impoundment (approximately 0.8 acres) was restored.

A loss of produced water probably occurred from the mud retention pit at an Exxon location (Site 2) during the winter of 1983-84. When cypress leaf-out occurred in March, 1984, a "dead zone" of pond cypress was reported over an area of three acres downgradient of the pit. A more extensive survey in July, 1984 confirmed this report and further indicated that abnormal basal sprouting was occurring in the surviving cypress over an area of approximately seven acres downgradient from the pit (Snider, Big Cypress National Preserve, personal communication, 1986).

In order to monitor the fate of the contaminants, six monitoring wells were installed at the Site 2 location in October, 1984. Four of these wells were located between 15 m and 225 m downgradient from the mud retention pit, while two other wells upgradient of the site served as controls. "Shallow" wells of 0.4 m depth were used to monitor conductivity, chloride, sodium, pH, and oil and grease in the root zone of the cypress, while "deep" wells (2.7 m) documented these water quality parameters in the upper zone of the ground-water aquifer. Chloride concentrations at shallow well 2 B, located in the root zone approximately 90 m downgradient of the pit, peaked at 1380 mg/L approximately 18 months after the probable loss incident (Figure 2). This peak value is significantly higher than chloride concentrations found in the shallow upgradient well (13-42 mg/L) and is within the range of chloride concentrations reported as damaging to cypress trees (500-2000 mg/L). Chloride concentrations decreased dramatically during the following wet season, and by March, 1986, were down to 148 mg/L. Since chloride concentrations in the root zone tend to increase during the dry season and decrease during the wet season, projections made by Environmental Science and Engineering suggest that peak chloride concentrations at this well will exceed 500 mg/L for at least three years following the spill (ESE, 1986).

A second study was designed to assess the integrity of the routine use of mud retention pits with respect to ground-water contamination. In this study 4 "shallow" and 5 "deep" wells were established both upgradient and from 10-30 m downgradient of a new mud retention pit (Site 28) prior to oil well drilling. No contamination was noted for the first three months following the onset of drilling in December, 1984. However, by March, 1985, conductivity and both sodium and chloride concentrations began to increase in the "deep" wells 10 m (well 28 B) and 30 m (well 28 D) downgradient from the pit (Figure 3). Chloride concentrations peaked (1190 mg/L) at well 28 B in July, 1985, and at well 28 D (690 mg/L) in September, 1985, indicating that the bentonite-lined mud retention pits are not impermeable and serve as a probable source of ground-water contamination.

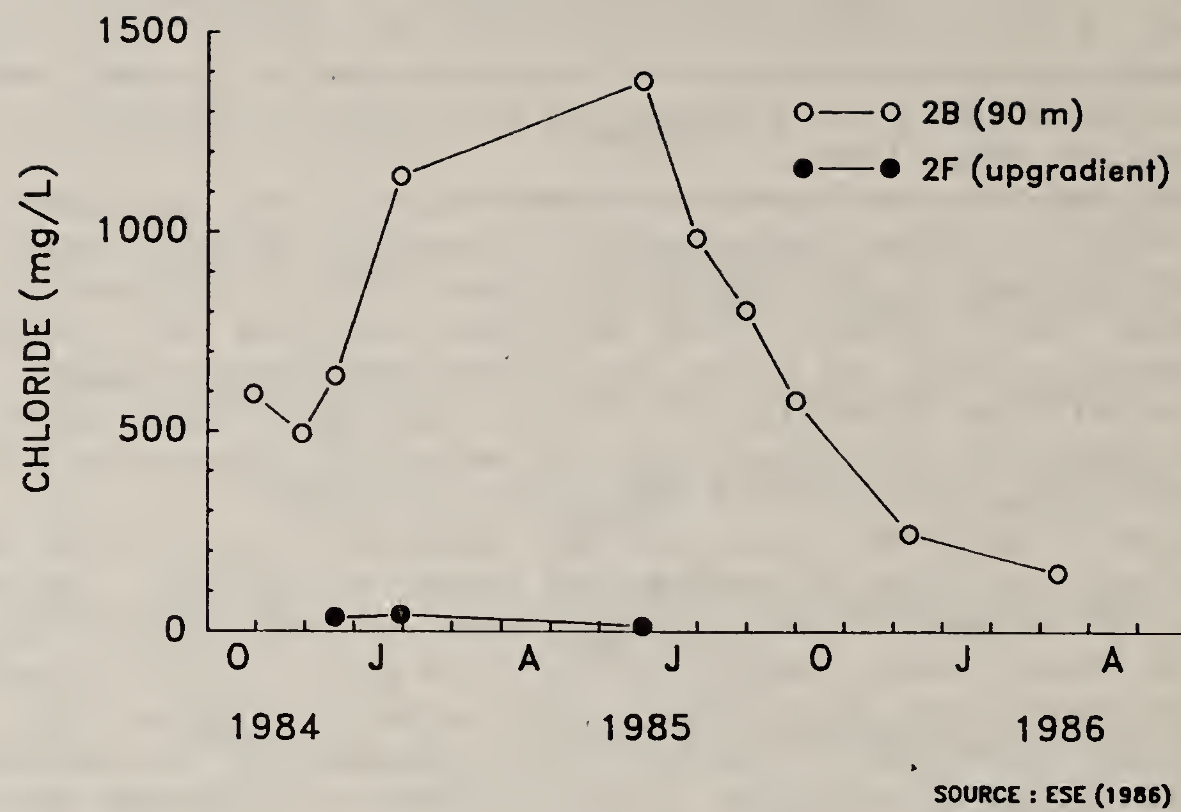

Figure 2. Chloride concentration in "shallow" (0.4 m) downgradient well 2 B (90 m) and "shallow" (0.4 m) upgradient well 2 F following a suspected brine loss at Site 2.

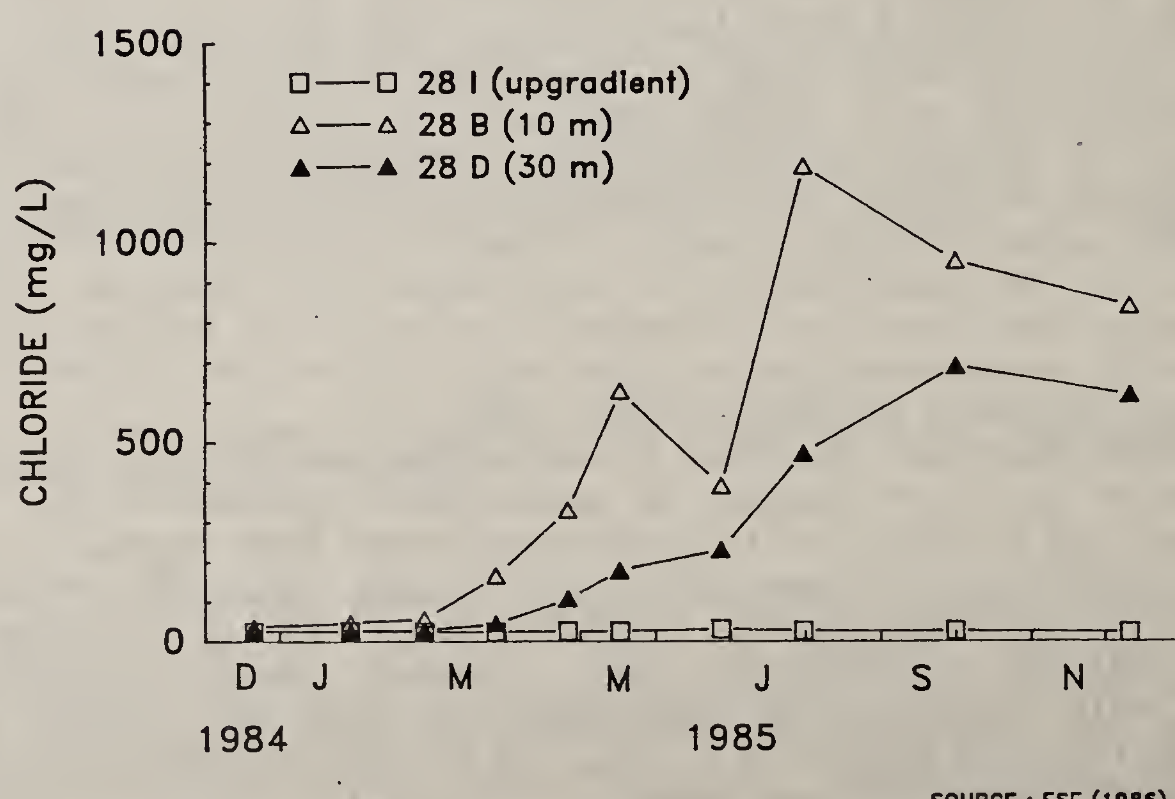

Figure 3. Chloride concentration in "deep" (2.7 m) upgradient (28 I) and downgradient (28 B and 28 D) wells at the site 28 drilling location.

Based on these results, Big Cypress National Preserve and Exxon, U.S.A. agreed that changes in well drilling procedures were warranted. Numerous technical alternatives were considered, and agreement was made that future plans of operation would stipulate that drill cuttings be separated from produced water and drilling fluids, and that the liquids be stored in closed, containerized systems prior to reinjection, thereby reducing one probable source of ground-water contamination. Though more expensive, this procedure will better protect water quality and disturb a smaller area of land.

CONCLUSIONS

As approximately two-thirds of the units administered by the National Park Service may eventually be affected by mining or energy development activities outside or within park boundaries, a coordinated program of water resource management relating to these issues is clearly warranted. Unfortunately, resources have not always been available to conduct the comprehensive hydrological assessments that might be desirable. However, in several instances, natural resource management specialists in the parks, working in cooperation with NPS technical specialists attached to regional or Washington offices, have been effective in implementing cooperative studies to address specific issues. Often, these efforts have resulted in applied research on mitigation to improve already damaged resources (Friendship Hill National Historic Site) or in monitoring that influenced operational modifications to better protect existing high quality resources (Big Cypress National Preserve).

ACKNOWLEDGMENTS

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WATER RESOURCES FOR MINING AND ENERGY

WATER RESOURCES RELATED TO MINING AND ENERGY – PREPARING FOR THE FUTURE
NOVEMBER AMERICAN WATER RESOURCES ASSOCIATION 1987

TECHNOLOGICAL PROGRESS IN ALASKA PLACER MINING OPERATIONS

Leslie F. Simmons

ABSTRACT: Steeped in history and tradition, the Alaska placer mining industry is under pressure to become cleaner, more efficient, and more economical. Because this grassroots industry is important for Alaska, much time and money has been spent in trying to resolve the conflicts. The ultimate goal is to have gold mining and clean water. During the last decade, technological advances have been made in the industry that bring us closer to this goal. These advances include water reduction methods, both in the washing processes and in the effluent volumes, and improved wastewater treatment designs. Most operations now have some combination of settling ponds, stream water bypasses, and water use reduction machinery. Several miners are also trying such advanced wastewater treatment techniques as chemical coagulants and flocculants, hydrocyclones, and overland and subsurface filtration.
KEY TERMS: placer mining, sediment control, settling ponds, hydrocyclones, coagulants & flocculants, filtration.

INTRODUCTION

With the deregulation of the price of gold, its subsequent climb to $852 in 1980, and its stabilization between $300 and $500 during the 1980s, there has been a corresponding renewed interest in gold placer mining in Alaska in the last decade. An industry steeped in tradition, history, and lore, flourished as in the days of the first Alaskan gold rush. With improvements in technology and the widespread availability and use of efficient earthmoving equipment, the miners of the 1970s and 80s enjoyed widespread success. Unfortuneately this increase in activity created many problems for those who wished to use the same precious resource that the miners needed - the water. Once pristine waters capable of supporting fish and human activities became slurries of mud. The sediments would be washed downstream for hundreds of miles creating a biotic void. From the recreational miner, the "mom and pop" family operations, to the large scale mining corporation, mining represents a way of life that is uniquely American and is fiercely guarded as a basic right. Just as fiercely sought is the right to clean, safe water, free from industrial pollution. Finding a way to have both mining and clean water is a high priority for the people of Alaska. Millions of dollars have been spent in finding a solution to these highly charged, emotional issues. The most notable program in the last few years was the $2.7 million Placer Mining Demostration Grant Project which awarded money to placer miners to test new methods of pollution control, waste disposal, water use reduction, and fine gold recovery. Through the use of exploration, efficient wash plants, process water recycle, stream diversions, settling ponds and other wastewater treatment techniques, water quality has improved in many streams as a result of the reduced sediment loads in mining effluents. The Alaska Departments of Environmental Conservation, Natural Resources, and Fish and Game have established technical assistance programs to help the miner incorporate these techniques into the mining plan. This paper discusses the changes in mining practices seen during the last decade and some of the findings of the more successful efforts in water pollution control technologies research.

TECHNOLOGICAL RESEARCH

As mandated by the Federal Water Pollution Contol Act, later known as the Clean Water Act, the United States Environmental Protection Agency (EPA) has funded several studies in its efforts to develop effluent guidelines limitations for the gold placer mining industry. While the effluent limitations guidelines have not yet been finalized, much information has come from the studies conducted in the data gathering stages. The Alaskan legislature appropriated monies to study the problems and provide assistance to the mining community. The most notable project was Senate Bill 461, the Innovative Mining Grants Program. The bill made available to placer miners, money to research new approaches to gold recovery, water use reduction, pollution control, and waste disposal. The legislature felt that the practical experience of the miners would result in more useful research than if the funds were given to professional researchers who might have a more theoretical, less pragmatic approach.

The studies, conducted for the most part since 1981, address the feasibility of using ponds for collecting the water-borne sediments, of using recycled process water, of using chemical coagulants and flocculants to aid in sediment removal, of using overland or subsurface filtration techniques, and of using various mechanisms within the processing plant to reduce the amount of throughput water and to increase the overall efficiency of the washing process. While the economics of several of these techniques are disputed, the technological applicability is certain.

EFFLUENT VOLUME REDUCTION

A reduction in the amount of water discharged from the mine reduces the amount of water requiring treatment. Effluent volume reduction techniques include a number of items now commonly found in some combination among most mining operations. These include the use of classification (sizing) and washing equipment, channels to pass streams around the operation, process water recycle, and water infiltration and exfiltration control techniques.

Even just a few years ago, it was not an uncommon practice for miners to use stream water via hydraulic monitors, or giant nozzles, to wash away the overburden, that mass of accumulated soil covering the gold-bearing gravels. The stream would then serve to carry downstream the less dense sediment and gravels of the pay, leaving the gold particles behind in the miner's sluicebox. These days, the use of hydraulic monitors for stripping overburden requires circumstances which allow the water to be contained on site, or requires the treatment of the large volume of water, a costly proposition. Alaska Placer Development, Inc. presently incorporates three monitors and two sprinklers to erode away the 70+ vertical feet of overburden at their site (Berglan, 1987). Because of their lake-sized ponds and recycle system, the water is retained on site. At sites where hydraulicking is not practical by virtue of the lack of room or water availability, the overburden is stripped and stockpiled with the aid of heavy machinery.

The incorporation of feed classification or sluice classification equipment into the mining operation has allowed the miner to reduce the amount of water used. Feed classification equipment includes such items as grizzlies, trommels, screens, wobblers, vibrating tables, washing plants, and conveyors. They serve to eliminate the oversized material prior to the sluice box or other gold recovery stage, thus reducing the amount of water needed to push the material. The jig, a gravity concentrator which uses a pulsating flow of water to separate heavy minerals from the lighter materials, in addition to being an effective gold recovery mechanism, greatly reduces the amount of water needed in the washing process. Jigs have been shown to produce improved gold recovery using as little as 50 percent of the water needed for the sluice (L.A. Peterson & Assoc., 1987).

Another method of reducing the amount of treatment required is to reduce the amount of water gained and therefore discharged. This is accomplished with the use of stream channels which divert the excess water around the active operation. Unheard of a decade ago, stream bypasses are now a requirement of most operations. Several demonstration grant projects successfully controlled groundwater infiltration and surface runoff to allow them to keep the volume of water to be treated to a minimum. Additionally, that water which is retained within the system requires less treatment than that discharged, hence, the miner realizes a savings in final effluent treatment costs. The McIntosh grant project and other large mines in the Faith Creek drainage have successfully controlled their effluents through a combination of process water recycle, and stream and groundwater diversion channels (L.A. Peterson & Assoc., Inc., 1987; Townsend, 1987). In areas without the plentiful water available in other regions, process water recycle is common, or the miner finds himself unable to mine in an otherwise already short mining season. One hundred percent of the miners in the Tolovana River drainage recycle their process water this 1987 mining season; several of them have no discernible discharge to the receiving stream.

In evaluating the applicability of recycle to enhance effluent quality, the question of the effect on fine gold recovery has been considered. Several studies have concluded that recycling does not significantly increase viscosity and hence gold migration or loss (Johnson, et.al., 1987; L.A. Peterson & Assoc., et.al., 1986). It does seem, however, that riffle packing and decreased washing effectiveness, as associated with increased water duty, may cause gold migration or loss. Alaska Placer Development found that the post-sluice fine gold recovery equipment was unnecessary when they throroughly washed the pay with a hydraulic lift prior to the sluice. Fine gold loss and migration may be a function of influent total suspended sediment concentrations and time between sluice cleanups (L.A. Peterson & Assoc., et.al., 1986). This suggests that cleaning the sluice more frequently has more of an effect on fine gold recovery than merely having clean water.

The EPA, in developing the effluent limitations guidelines for the gold placer mining industry, is considering adopting 100% process water recycle as part of the standard for the Best Practicable Technology (BPT), Best Conventional Technology (BCT), Best Available Technology Economically Achievable (BAT), and New Source Performance Standards (NSPS) for some categories of mines (EPA, 1987).

SETTLING PONDS

Of the wastewater treatment techniques used at placer mines, settling ponds have gained the most widespread acceptance. They can be constructed using equipment already in use at the mine and they can be more economical than alternatives. If designed, constructed, and maintained properly, they are effective at removing the majority of the water-borne sediments. They are, however, not efficient at removing the finest particles, those smaller than 0.002 mm (R & M Consultants, Inc., 1982). For the quantities of water used at some mines, they also require a considerable surface area if they are to be the sole treatment mechanism. If used in conjunction with water reduction techniques, their size and frequency of cleanings can be reduced. With the addition of stream channel bypasses, the ponds do not have to provide treatment for more than the process water and the water gained from surface runoff or subsurface infiltration. With a small "presettling" pond or long tailrace to catch the coarser material near the end of the sluice, the longevity of the main ponds is increased.

The Placer Mining Wastewater Settling Pond Demonstration Project, completed in

1982, and the Placer Mining Demonstration Grant Project, completed for the most part in 1987, each resulted in the production of a handbook to assist the miners in designing their operations. Each provides design criteria for sizing the pond to meet at least 0.2 ml/L settleable solids at the effluent. Two-tenths of a milliliter per liter settleable solids is currently the National Pollutant Discharge Elimination System (NPDES) permit limit for an Alaska placer mine effluent.

COAGULATION AND FLOCCULATION

Currently under investigation in Alaska are four different types of chemical treatment techniques with applicability to placer mine operations.

The U.S. Department of the Interior, Bureau of Mines (BOM) is investigating the feasibility of using polyethylene oxide (PEO) at Alaska mines. The process involves using a unit in which the waste slurry is pumped to the conditioner mixer where PEO is added. The water and resulting floc flow out of the tank and are distributed onto a static screen. The flocculated solids move down the screen, while released water goes through the screen and flows to a pond for either recycling or for discharge to the stream. The solids roll off the screen into a mine cut or pit where they continue to dewater. The solids eventually reach a solids content high enough to allow burial or removal by mechanical equipment. Although the final results of the 1987 field season tests are not in, PEO appears to be a process feasible for those mines which have very little room for settling ponds. The dewatering process is conducted on static screens, alone or in combination with a trommel. The effectiveness of PEO at attaining water of a sufficiently high quality to meet the Alaska Water Quality Standards in the receiving stream seems to be site specific (Smelley and Scheiner, 1986).

A second PEO project, related to the BOM project was tried during the 1986 mining season. Using less expensive, more commonly found materials instead of the first-class materials used by BOM, the EPA attempted to show that PEO would work at Alaska mines as well as its high-tech counterpart. Dubbed the "Alaska model", the setup showed considerable promise and the results have been incorporated into the effluent guidelines development.

Another design which holds promise for the average mine is a flocculant in the form of a gelatin log. Manufactured in the gel form as a result of a process to increase the molecular weight, this log has potential application at mines in Alaska. The advantage of using a flocculant in a gelatin form is that the logs are easy to handle: there are no piping, mixers, or pumps; there are no electrical or water connections; the system responds - to some degree - automatically to changes in flow rate; and the system can function unattended for days at a time. These advantages can result in a savings in initial cost and in operational expense (Arctic Hydrologic Consultants, 1986). Applications in industries with similar sediment removal needs as Alaska mining have proven floc logs a successful alternative to conventional chemical applications (Aldrich, 1987). Six mines in interior Alaska have incorporated the floc logs into their mining plans. In its desire to see these flocculant projects succeed or fail based on the merits of the product and not improper installation, the Alaska Department of Environmental Conservation has hired a consultant to assist these miners in proper system design and to evaluate the effectiveness of the logs. The problem the researchers are presently trying to overcome is one of getting the gelatin to dissolve adequately. A full-scale study is planned for the 1988 field season.

A third type of chemical treatment design is also being studied. Originally one of the Demonstration Grant projects, the system is similar to conventional wastewater treatment coagulation and flocculation configurations. The coagulant solution, after being dissolved, is injected into the main effluent stream. Further mixing is accomplished in an in-line, static mixer followed by a 100-foot long, corrugated pipe mixing loop. Flocculant is then injected and mixed in a second 100-foot long, corrugated pipe. The treated effluent then flows into a settling pond where it is dewatered (Phillips and Pollen, 1987). The system has been modified for the 1987 mining season to eliminate one of the mixing coils, improve the water feed system, adust the chemical dosage, reduce settling pond size, and reduce labor requirements to less than one hour per day (Pollen, 1987).

A fourth application incorporates the flocculant into the system by spraying the dissolved chemical onto the pond in which the water to be treated sits. Two projects employed this technique during the 1986 mining season. The first project employed Naturaid and successfully reduced the settleable solids levels in the effluent to meet the miner's NPDES permit (Masterman, 1985 (sic)). The project report does not specify the product's effectiveness at removing the suspended sediments or at reducing turbidity levels. The second project, conducted by the EPA, used Cat-Floc T and employed a similar method of application. After being diluted to a stock solution, the chemical was fed into a barrel submerged in the miner's wastewater pond. The intake hose to the pump was also placed in the barrel. The 20-foot pump suction line took the polymer and wastewater through 100 feet of additional hose to the test settling pond where the flocculant settled quickly and the effluent discharged. The turbidity and settleable solids tests showed the chemical effective at reducing the turbidity levels to less than 25 ntu (Umholz and Davis, 1986).

HIGH RATE GRAVITY SEPARATORS

Although used in other industries to separate solids from liquids, only a limited amount of work has been done with hydrocyclones in placer mining applications to date. What has been done, however, shows that hydrocyclones may have a place in the mining operation. In the pilot-scale model, Chapman (1986) showed hydrocyclones to be an effective means of removing the larger particle fractions of mining wastewater. It did not efficiently remove the clay particles. He concluded that his 10 mm cyclone could not, however, economically replace a well designed final settling pond. Richard Loud, a placer miner with little room for settling ponds in 1986 found the hydrocyclone effective at removing all but the smallest fraction of the suspended sediments. Like the Demonstration Grant hydrocyclone project (L.A. Peterson & Assoc., 1987), Loud found the cyclone to be somewhat labor intensive while they worked out the glitches. Although the information about Mr. Loud's use of the hydrocyclone is yet anecdotal, the process seems to have the most promise in applications where there is little room for building ponds.

Undiscussed in the current literature since 1981, and untested in Alaskan placer mining applications to the best of the author's knowledge, tube settlers and Lamella settlers may have their place in placer mining wastewater treatment. The flow velocity at which a horizontal settling chamber is operated is directly proportional to the length of the device and inversely proportional to its depth. The shallow settling device becomes self-flushing if it is inclined at an angle which exceeds the angle of repose of the settled material. In the tube settler system, wastewater is clarified by particle sedimentation as it moves from the influent well or distribution chamber, upward through small tubes and into a collection gallery, clearwell or launder. Because the tubes are installed at a steeply-inclined angle of 45-60 degrees, continuous gravity drainage of the settleable solids in the tubes is achieved. The incoming solids settle to the tube bottom then exit by sliding downward and are trapped in a downward flowing stream of previously settled and concentrated solids (Burns and Roe, Inc., 1971).

The Lamella settler, a nest of parallel inclined plates through which the suspended sediments are passed, can obtain a high settling capacity in a very small volume. The basic difference between the Lamella separator and tube settling units is that the Lamella separator is fed from the top, whereas the tubes are fed from the bottom.

Through the use of flow stabilizing devices in the inlet and by dividing the unit into many compartments, the possibility of secondary flows is reduced. The clarified effluent exits without recontamination through the use of a tube network which collects the liquid uniformly across the width of the plate with return to a center plate (Burns and Roe, Inc., 1971). While it seems the Lamella separator is commonly used in such industries as municipal wastewater treatment plants, steel pickling rinse waters, and pulp and paper mills, it was (is?) used at a large placer operation in the Caribou mining district of British Columbia (Sigma Resources Consultants, Ltd., 1981).

FILTRATION TECHNIQUES

Two types of filtration devices have found successful application in improving placer mine wastewater: tundra (overland) filters and tailings (subsurface) filters. A third type of filter, the geotextile or filter fabric, has not yet been applied to the mining industry, but, it too has application.

While the Demonstration Grant tundra filtration project did not accomplish its goal, it is expected that when the filter is used as a secondary treatment device in conjunction with recycle and primary settling of coarse sediments it will prove more useful. Vegetative filters are commonly used in other industrial applications to remove sediment. The effectiveness of vegetation strips is related to incoming sediment load, flow rate per unit width, vegetal height and density, and filter slope and length. Barfield, Warner, and Haan (1981) find grass filters ideally suited for sediment control at the toe of spoil banks, topsoil stockpiles, and downslope of areas that have been reclaimed but not yet sufficiently stabilized.

Tailings have also proved useful in filtering placer mine wastewater. Two Demonstration Grant projects, similar in design, operated with mobile wash plants from which the wasterock and wastewater were discharged together into the previous cut. The water pooled upstream of the tailings, settling out the coarser sediments, and filtered through the continually renewed filter. With a final pond to provide final quiescent settling and water for recycling, the two projects were able to successfully remove most of the sediment. In review, the projects were claimed as successfully able to meet the Alaska Water Quality Standards because of site specific conditions. It is the author's belief that the principles applied should prove successful at any site able to employ water quantity control through diversion ditches and recycle and through the use of continually renewed filter mediums such as tailings and other filters.

A third type of filter medium which is successfully employed in other practices is the geotextile, or filter fabric. Synthetic or biodegradable, filter fabrics are used in many types of applications as soil retention barriers. Commonly used in road construction to restrict the movement of gravels and sediments from incorporation into the underlying soils, yet still allowing the passage of water, the geotextile may be used in settling ponds or diversion ditches to impede erosion. As a filter fence with a countercurrent gradient, the fabrics may function alone or enhance the effectiveness of settling ponds and other wastewater treatment devices.

CONCLUSIONS

During the last decade or so, Alaska has seen a considerable increase, a reawakening, in placer mining activity. In an attempt to solve the environmental problems associated with gold mining, state, federal, and private energies and monies have been expended to find solutions. While we still don't have all the answers, we are well on our way to having both mining and clean water. The evidence of this can be seen in the incorporation of technologies which reduce water volumes and which provide primary and secondary wastewater treatment. With the the completion of the current research projects, it is hoped that Alaska can come another step closer to achieving its goal of gold placer mining and clearwater streams.

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WATER RESOURCES RELATED TO MINING AND ENERGY – PREPARING FOR THE FUTURE
NOVEMBER AMERICAN WATER RESOURCES ASSOCIATION 1987

A SEMI-EMPIRICAL METHOD FOR PREDICTING HYDROLOGIC IMPACTS OF UNDERGROUND MINING IN FRACTURE-CONTROLLED GROUNDWATER FLOW SYSTEMS

Arthur P. O'Hayre[1], Michael J. Day[1], and Dennis Conn[2]

ABSTRACT: The Surface Mining Control and Reclamation Act (SMCRA) requires evaluation of probable hydrologic consequences (PHC) of coal mining and reclamation activities. A PHC determination includes predictions of seasonal changes in groundwater storage and flows, mine inflows, mine discharges, potential changes in spring flows and stream baseflows. The choice of appropriate predictive methods is usually determined by the significance of groundwater issues, the complexity of site hydrogeology, and preferences of the regulatory agency. Typically, PHC analyses are prepared using numerical groundwater models.

Monitored inflows during the first five years of operation at the Mt. Gunnison underground mine near Somerset, Colorado indicates that the major controls on groundwater occurrence and flow are discrete fracture zones and overburden cover. Numerical techniques have limited application in these hydrogeological conditions. A simple vertical flow model was developed and calibrated based upon observed seasonal inflows. This simple modeling approach was very effective in developing estimates of mine inflows and potential stream depletions for the life of mine operation. The approach also provided a basis for identifying springs that could possibly be affected by underground mining activities.
KEY TERMS: Mine water inflow; Probable Hydrologic Consequences; underground mining; groundwater modeling

INTRODUCTION

The West Elk Coal Company is currently operating an underground coal mine, the Mount Gunnison No. 1 Mine at a location approximately seventy miles east-southeast of Grand Junction, Colorado within the Somerset Coal Field as shown on Figure 1. Mining is conducted in the F Coal seam of the Mesa Verde Formation as shown on the generalized strategraphic column provided in Figure 2. The F-seam is the uppermost minable coal seam and is overlain by the Barren Member of the Mesa Verde Formation.

Prior to start of mining, an assessment of the probable hydrologic consequences (PHC) of mining was performed as part of the permit application. Estimates of groundwater inflows and drawdowns were calculated by idealizing the mine workings as a large diameter flowing well, with the water level being maintained at the bottom of the F-seam. Inflow to the mine was estimated by applying the theory of non-steady flow to a well of constant drawdown in and extensive aquifer (Jacob and Lohman, 1952). It was assumed that significant hydrologic connection occurred between the coal and the Barren Member up to 100 ft. above the top of the F-seam. Unconfined conditions were assumed for estimating

[1] Applied Hydrology Associates, Inc, 2140 S. Ivanhoe, Denver, Co 80222
[2] West Elk Coal Company, PO Box 591, Somerset, CO 81434

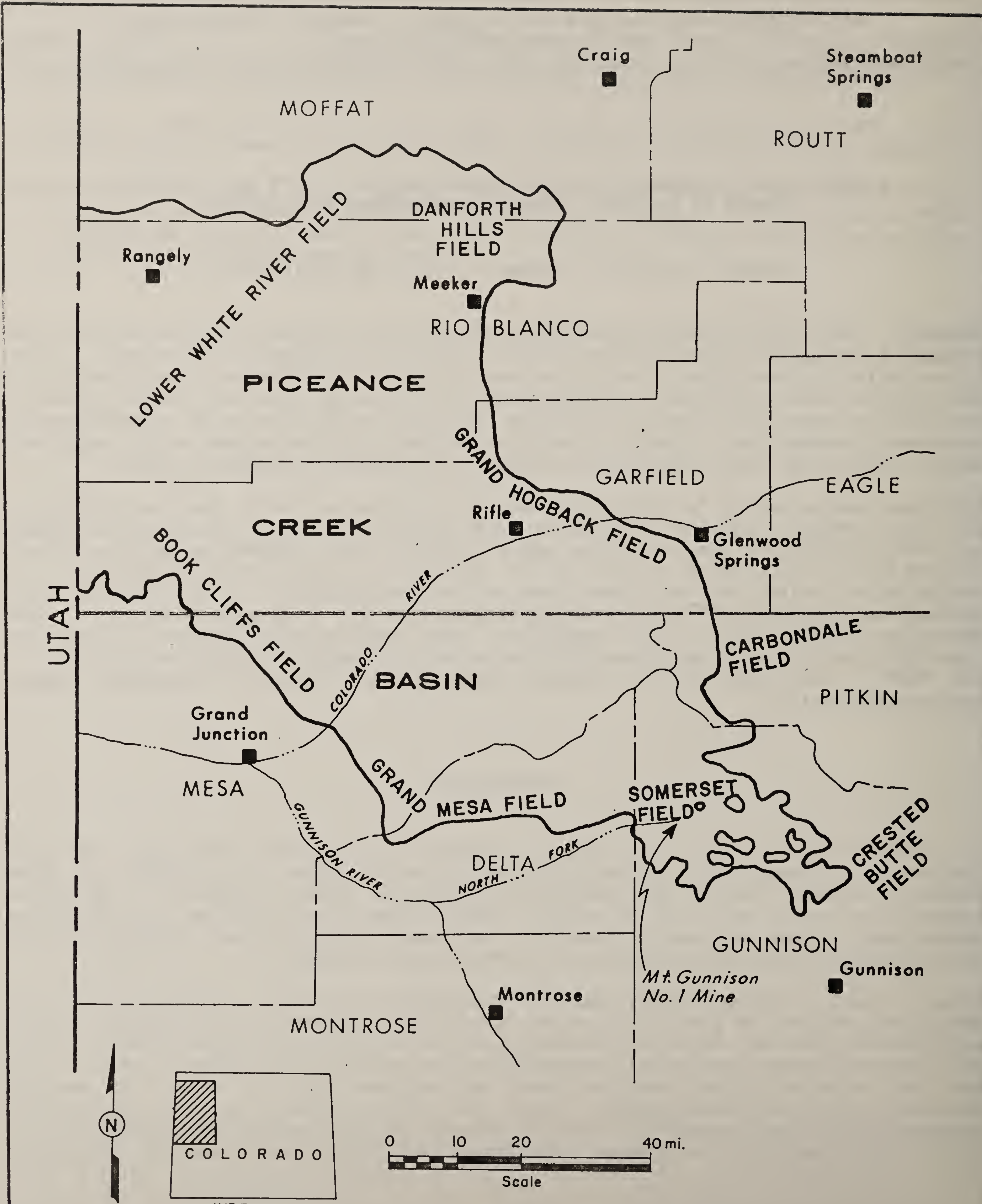

Figure 1. General Location Map

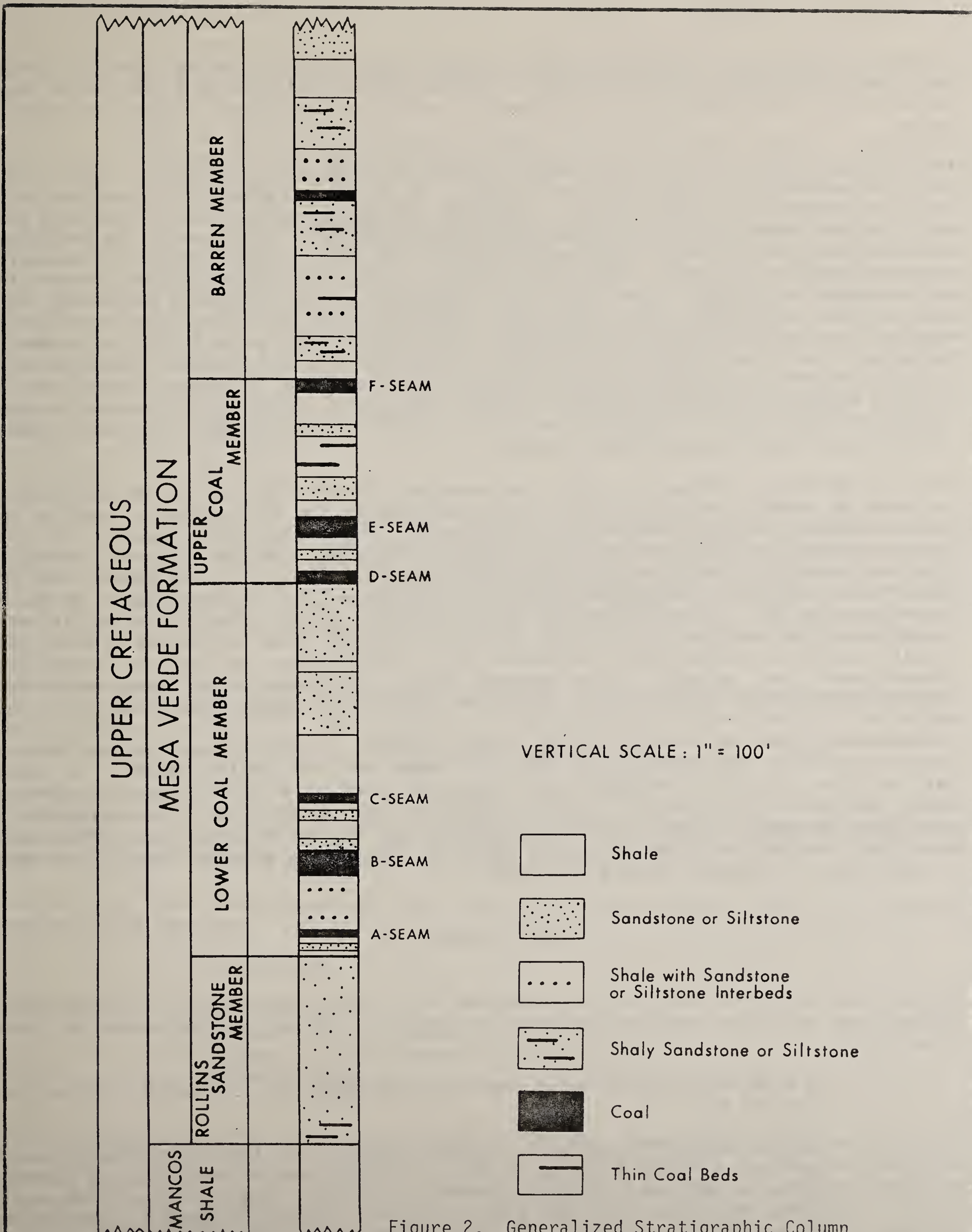

Figure 2. Generalized Stratigraphic Column

inflow and confined conditions were assumed for estimating drawdown in order to provide upper bound estimates. For the analysis, both the F-seam coal and the Barren Member above the coal were considered to be a continuous, isotropic, homogeneous aquifer of infinite extent.

The hydraulic properties of the F-seam coal are actually quite variable. Many of the drill holes showed the coal seam to be dry. Water was encountered in fracture zones usually located along stream valleys. Of course, aquifer parameters used to estimate mine water inflows and drawdown were determined from response tests performed in the drill hole locations where water was encountered. Likewise, the Barren Member cannot be considered to be a continuous aquifer. Most drill holes at the Mt Gunnison property showed the Barren Member to be dry. When water was encountered during drilling, monitoring wells were completed in the water-bearing units. Water levels in wells vary significantly with depth of completion within the Barren Member. Furthermore, the water levels in the Barren Member wells are typically within or slightly above the screened interval within the wells indicating very little pressure head. At these locations, the low pressure heads and the vertical hydraulic gradient close to or greater than unity, indicate very limited vertical hydrologic communication. This is consistent with the interpretation of isolated perched aquifer conditions within the Barren Member.

Actual mine inflows during the first five years of operation were monitored and found to be about an order of magnitude lower than predicted by the PHC analysis. Most of the inflow occurred along the subcrop and was seasonal. Continuous inflow occurred only in a fracture zone associated with the Sylvester Gulch drainage. Well water level monitoring also confirmed the interpretation of isolated discontinuous aquifer conditions. West Elk Coal Company monitores 5 wells completed in the F-seam and 9 wells completed in the Barren Member between the F seam and the 300 foot overburden contour. The monitoring of water levels showed no response that could be related to mining. The monitoring of well water levels and mine inflows both confirmed the interpretation of fracture controlled, discontinuous and pearched water bearing units and demonstrate that conventional representations of groundwater flow are not very reliable in these situations.

The PHC analysis was revised during permit renewal to more accurately reflect the interpretation of the hydrogeology of the F-seam Coal and Barren Member. A simple vertical flow model was developed and calibrated based on monitoring results from the first four years of operation. This simple modeling approach was very effective in developing estimates of mine inflows and potential stream depletions for the life of mine operation. The approach also provided a basis for identifying springs that could possibly be affected by underground mining activities.

MODEL FORMULATION

Observations in the Mt Gunnison mine during the first four years indicate that groundwater inflows are very low and are seasonal in nature. Inflows mainly occur in three situations:

1) In areas not close to major fracture zones where the overburden cover is less than 300 feet.

   This situation is typified by inflows observed near the main portal entrance. Inflows are highly seasonal in nature and only tend to occur for a few months following the onset of Spring snowmelt. Maximum flows of 20-25 gpm may occur during the Spring but these reduce to almost zero by the Summer. The inflows are believed to represent the interception of groundwater in shallow bedrock and colluvial zones that are only saturated during the Spring runoff period.

2) In the vicinity of major fracture zones where the overburden cover is less than 500 feet.

This situation is typified by inflows observed at the Sylvester Gulch area. Inflows are seasonal, reaching maximum rates of about 30 gpm during the Spring and reducing to about 13 gpm during the rest of the year. The more consistent nature of the inflows are believed to be related to the proximity of more active bedrock groundwater flow within major fracture zones. The fracture zones appear to control the alignment of the major creeks in the area and consequently are thought to be coincident with these creeks. The width of the fracture zones is unknown but is estimated to be a maximum of 1000 feet based on the inflows in the Sylvester Gulch area. Fractures within these zones are expected to become closed under sufficient overburden cover. It is estimated that below a depth of about 500 feet fracture permeability within these zones is low enough that vertical flow would be minimal. This assumption is supported by no significant observed flows in the mine workings under the fracture controlled segment of Lone Pine Gulch where the overburden cover is about 500 feet.

3) From the F seam

Small amounts of groundwater inflow are observed issuing from the F seam in various parts of the mine. These inflows are probably related to zones of higher fracturing within the seam itself but are not thought to represent major fracture zones that could provide significant vertical communication with the overlying Barren Member and surface drainages. Inflows are primarily derived from storage within the seam and reduce to minimal rates within a few weeks.

A revised model for projecting groundwater inflows to the mine was developed on the basis of actual observed inflows. This model is more representative than previous projections. In a "worst case" scenario, all groundwater inflow into the mine may be considered to result in effective depletion of the same magnitude to surface water systems.

The model assumes that inflows to the mine will occur in areas that have similar characteristics to situations 1 and 2 described above. Situation 3 was not included in the analysis as inflows from this source constitute a relatively insignificant fraction of the total inflow and probably does not influence surface flows.

Inflow rates under both situations 1 and 2 are calculated using the simple one dimensional vertical flow equation:

$$Q = Kv.I.A/1440$$

where: Q = Flow rate (gpm)
Kv = Average vertical permeability (gpd/sq.ft.)
I = Average vertical hydraulic gradient (dimensionless)
A = Area undermined (sq.ft)

For situation 1, the calculation is based on the area undermined having an overburden cover less than 300 feet. For situation 2 the calculation is based on the area undermined falling within the 1000 ft fracture zone width defined by the major creeks and having an overburden cover of less than 500 feet. The vertical hydraulic gradients for both conditions are assumed to be unity This value was used to be conservative and conform to "worst case" projections. Values for vertical permeability for the two cases were back calculated from observed inflow rates in the portal area and the Sylvester Gulch area respectively as described in the next section on model calibration.

MODEL CALIBRATION

The estimates of vertical permeability under creek fracture zones were based on the observed inflows in the Sylvester Gulch return area. The estimated value of 0.1 gpd/sq.ft. was calculated by solving for K in the one dimensional vertical flow equation for the known inflow rate, fracture flow area and a unit hydraulic gradient. The estimated value is about an order of magnitude lower than the highest values calculated from well tests in the creek areas. In stratified bedrock formations the vertical movement of groundwater is primarily controlled by the units having the lowest vertical permeability. Even when permeability is fracture-controlled there is usually some lithologic influence on fracture propagation and continuity. Consequently, the vertical permeability values that would be most appropriate for the estimation of vertical groundwater flow are typically one or two orders of magnitude lower than the average horizontal permeability. Permeability values calculated from well testing should therefore be used with caution. Observation and documentation of actual mine inflows is the best way of projecting future mine inflows. Additional well data will not yield good estimates of vertical permeability.

For situation 1 associated with subcrop areas a vertical permeability of 0.02 gpd/sq.ft. was also calculated using the vertical flow equation and the measured inflow rate in the portals area, the area above the portals where cover was less than 300 feet and a unit hydraulic gradient. Since inflow in the portal area are seasonal, the highest inflow rates were used to estimate vertical permeability for situation 1. Inflows under situation 1 are projected to occur only during the three month period following the start of Spring snowmelt.

RESULTS

The projected mine inflows and resulting surface and shallow ground water depletions are determined for Situation 1 and Situation 2 using the vertical flow equation and estimated values of vertical permeability. Figure 3 "Geologic Features used in the Projection of Mine Inflows and Spring Depletions" shows the major fracture zones was used in conjunction with the mine plan to breakdown the inflows based on 5-year mining increments and the possible affected watershed area. The results are summarized in Table 1 "Projected Mine Inflows and Stream Depletions Mt. Gunnison Mine #1," and are separated into seasonal inflows (Situation 1) and perennial inflows (Situation 2).

A worst case spring impact analysis was developed by assuming that all springs issuing from the F-seam or from locations that are undermined where the overburden cover is less than 300 feet would be potentially impacted. Also all springs in the vicinity of major fracture zones that are undermined where overburden cover is less than 500 feet were assumed to be potentially impacted. Furthermore, if the surface drainage area upgradient of a spring located in a major fracture zone is undermined where the overburden cover is less than 500 feet, then the spring was assumed to be potentially impacted regardless of its location with respect to the F-seam. Likewise, if the surface drainage area upgradient of a spring not located within a major fracture zone is undermined where the overburden cover is less than 300 feet, then the spring was assumed to be potentially impacted only if it is located within or above F-seam. Springs located below the F-seam outside major fracture zones are not expected to be affected by mining because the fire

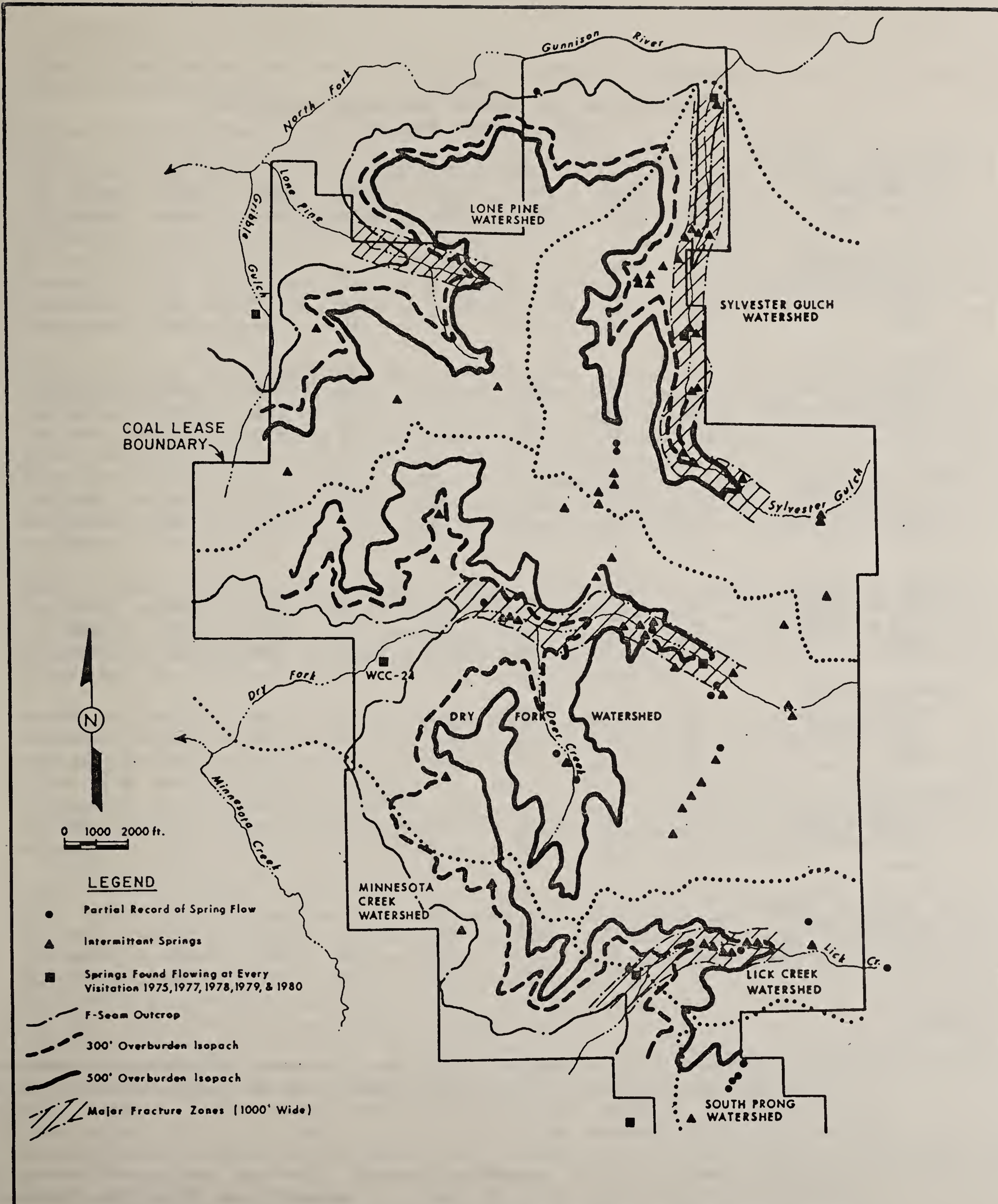

Figure 3. Geologic Features Used in the Projection of Mine Inflows and Stream Depletions, Mt. Gunnison No. 1 Mine

TABLE 1.
PROJECTED MINE INFLOWS AND STREAMFLOW DEPLETIONS
MT. GUNNISON MINE #1

CUMULATIVE INFLOWS BY DRAINAGE BASIN (GPM)	MINING PERIODS 1982-1985	1986-1991	1992-1996	1997-2001	2002-2006	2007-2011	2012-2016	2017-2022
N. FK. GUNNISON								
Fracture Zone (1)	0	0	0	0	0	0	0	0
Thin Overburden (2)	14	14	14	14	14	14	14	14
Total	14	14	14	14	14	14	14	14
SYLVESTER GULCH								
Fracture Zone	14	94	180	180	180	180	180	180
Thin Overburden	2	5	5	5	5	5	5	5
Total	16	99	185	185	185	185	185	185
LONE PINE GULCH								
Fracture Zone	0	57	57	57	57	57	57	57
Thin Overburden	0	14	14	14	14	14	14	14
Total	0	71	71	71	71	71	71	71
DRY FK. MINNESOTA CK.								
Fracture Zone	0	0	54	54	78	78	110	110
Thin Overburden	0	0	0	101	130	130	130	130
Total	0	0	54	155	208	208	240	240
MINNESOTA CREEK								
Fracture Zone	0	0	0	0	0	0	0	0
Thin Overburden	0	0	0	0	0	50	81	81
Total	0	0	0	0	0	50	81	81
LICK CREEK								
Fracture Zone	0	0	0	0	0	0	5	78
Thin Overburden	0	0	0	0	0	0	0	50
Total	0	0	0	0	0	0	5	128
ALL DRAINAGE BASINS								
Fracture Zone	14	151	291	291	315	315	352	425
Thin Overburden	16	33	33	134	163	213	244	294
Total	30	184	324	425	478	528	596	719

NOTES:

(1) Calculated based on area undermined within fracture zones and having an overburden cover of less than 500 feet as indicated in Figure 3, "Geologic Features used in the Projection of Mine Inflows and Spring Depletions. Assumed vertical permeability of 0.1 gpd/sq. ft.

(2) Calculated based on area undermined outside fracture zones and having an overburden cover of less than 300 feet as indicated in Figure 3, "Geologic Features used in the Projection of Mine Inflows and Spring Depletions. Assumed vertical permeability of 0.02 gpd/sq. ft.

clay at the base of the F-seam would severely restrict hydrologic communication with the units below the F-seam.

The only spring below the F-seam that could be affected is WCC-24 located in the Dry Fork Valley about 280 feet below the F-seam. Since this spring is perennial and exhibits a relatively high rate of discharge on the order of 25 to 100 gpm, it is conceivable that the spring is controlled by fracture flow. The ionic composition and TDS levels are unlike the water quality measured in groundwater wells on the property with the exception of SOM-80, a Barren Member well in Sylvester Gulch. Since Sylvester Gulch is also thought to be fracture controlled. It may be that the higher calcium, magnesium and sulfate composition of these waters may be a feature of fracture flow. All other springs below the F-seam are outside the area of potential influence usually across surface drainages from mining activity.

Table 2 "Worst Case Hydrologic Impact Evaluation," presents the worst case analysis of spring depletions broken down by watershed and by 5-yr mining period. In compiling this table the highest flows recorded for each potentially impacted spring during the Spring and Fall were taken as being representative of a wet year. Similarly, the lowest recorded flows during these periods were assumed to be representative of a dry year. Under worst case conditions all potentially affected springs will be totally depleted. Table 2 includes the calculated peak seasonal and expected perennial mine inflows by year and watershed from the analysis described in the section on model calibration and summarized in Table 1.

Table 2 shows that the predicted mine inflows are generally within or slightly higher than the range of the predicted total peak spring depletions from each watershed. This lends credibility to the mine inflow analysis calculations which were based on observed mine inflows and assumptions concerning potential interconnection with shallow ground water flows that are believed to be the major source of spring flows.

From examination of measured flows of springs located near the initial mining area, it is difficult to assess whether any changes in flow has occurred as a result of mining which was projected to have first had an impact on these springs near the end of 83. It is clear from these data that the degree of impact, if any, is much less than the worst case assumption of total depletion that was used in developing the estimates for Table 2. Even if the flow in a spring were depleted as a result of mining, the depleted flow would be expected to either re-issue at another location or become mine inflow.

Table 2 also contains a comparison of the worst case projections of spring depletions and mine inflows with streamflow data representative of wet year and dry year snowmelt flows and wet year and dry year baseflows for the corresponding basins. All streamflow estimates in Table 2 with the exception of Dry Fork Minnesota Creek were derived from gaging stations located on the streams below the coal outcrop. Since flows in the lower Dry Fork gaging station are controlled by release from Minnesota Reservoir, the estimates for Dry Fork were obtained from the gaging station located upstream of the coal lease. The major component of the flow at this location is the diversion from Deep Creek Ditch. Flow estimates from potentially affected springs in the Dry Fork Basin would be additive to the Dry Fork flow below the mine along with other basin contributions.

Even though one of the springs in the Lone Pine drainage produces perennial flow, the drainage rarely yields surface water flow. Spring flows in this drainage infiltrate into the colluvium and alluvium. This water would be expected to flow to the North Fork Gunnison River or its alluvium.

The revised projections of mine inflows and resulting surface water depletion for the life of mine were based on actual observations and data collected from the mining operation and are therefore thought to be more reliable than previous projections. The results of these

TABLE 2. WORST CASE HYDROLOGIC IMPACT EVALUATION
(all flow estimates are given in gallons per minute)

		WORST CASE SPRING DEPLETIONS				WORST CASE MINE INFLOWS		SEASONAL STREAMFLOW ESTIMATES			
		SPRING SEASON		FALL SEASON		PEAK SEASONAL	PERENNIAL	SNOWMELT AVE		OCTOBER AVERAGE	
BASIN	YEAR	WET YR	DRY YR	WET YR	DRY YR	INFLOWS	INFLOWS	WET YR	DRY YR	WET YR	DRY YR
North Fk Gunnison	1981	1	0	0	0	14	0				
Sylvester Gulch	1983	35	0.7	12.5	0.0	16	14	4086	366	90	5.2
	1986	161	15.7	31	2	99	94				
	1992	161	15.7	31	2	185	180				
Lone Pine	1986	90	90	12	12	71	57	?	0	0	0
Dry Fk. Minnesota Creek	1992	30	10	10	0	54	54	2982	413	115	0
	1997	132	36	71	25	155	54				
	2002	170	56	89	26	208	78				
	2012	246	61	97	27	240	110				
Minnesota Creek	2007	2	0	0	0	50	0	15000	?	4535	0
	2012	2	0	0	0	81	0				
Lick Creek	2007	0	0	0	0	5	5	2690	1936	45	6.5
	2017	59	2	1	0	128	88				

revised calculations indicate a life of mine operations may result in maximum projected depletion from the Dry Fork of Minnesota Creek Basin of about 130 gpm from interception of snowmelt runoff during the spring period and about 110 gpm from interception of shallow groundwater, springs and streamflow associated with the fracture zone of the creek valley. The latter depletion would be applicable throughout the year and thus could be considered a perennial inflow or depletion. The projections are based on conservative assumptions and represent maximum anticipated depletions. Actual depletions are expected to be considerably less than these projections.

CONCLUSIONS

The estimates of mine water inflows and potential impact on springs and stream depletions were developed based on conservative assumptions and represent worst case projections. The projected impacts were developed for the proposed life of mine plan. The impacts were determined using a simple but realistic model of the hydrogeology of the mine site. The model was developed and calibrated using observed inflows in the fracture zone associated with the Sylvester Gulch return area and inflows in the subcrop area associated with the mine portals. The model and estimated vertical permeabilities and anticipated inflows under creek areas may be further refined when Sylvester Gulch and Lone Pine Gulch are undermined between 1986 and 1991 under the proposed mine plan . If mine inflows under these gulches indicate that the projections are not valid then a revised mining strategy under Dry Fork of Minnesota Creek and Lick Creek would be considered. The current plan calls for minimal extraction through a protective corridor under both creeks, until subsidence data is obtained. At that time, the mining plan will be updated or revised utilizing the subsidence data. Observation and documentation of actual mine inflows is probably the best way of projecting future mine inflows in this area. Additional well data will not yield good estimates of vertical permeability.

ACKNOWLEDGMENTS

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PREDICTING THE IMPACTS OF A LOGICAL MINING UNIT SYSTEM ON THE WATER RESOURCES OF AN AREA

Angelus S. C. Owili-Eger[1]

ABSTRACT: Since the extraction of coal is one of the major activities which may affect the natural or existing hydrological equilibrium, the mining industry is committed to the conservation and protection of the water resources within and around mining environments. This commitment embodies thorough and systematic consideration of the quantitative and qualitative variations and, in general terms, the environmental consequences of the mining activity on the natural water systems. In the case of the study coal basin, concern had been expressed about the short-term and long-range hydrological impacts of maximum and possibly multiple seam extraction as it pertains to recoverable coal reserves. Consequently, a concerted comprehensive research program was initiated and conducted with these fundamental objectives: establish base flow parameters and inorganic quality of the waters in surface streams and aquifers; determine the rate and ascertain the direction of leakage, if any, between aquifers and confining strata; establish recharge-discharge relationships within the area of interest; monitor and document quantity and quality variations of mine discharges and the effects of increased mining activity on such factors as base flow and sediment load; and determine aquifer characteristics and develop models of identifiable and quantifiable hydrological subsystems, as well as for the overall hydrological environment, for utilization as practical predictive tools.
KEY TERMS: aquifers, impacts, water resources, mining environments, watershed, models.

INTRODUCTION

Mining within the study coal basin is expected to increase dramatically during the next decade. All the recoverable coal reserves in this area are located within a sandstone bed which, incidentally, is the primary aquifer system in the region. Coal production at the present time is from underground room-and-pillar operations, but there are plans to install longwalls in the future.

STRATIGRAPHY AND GEOMORPHOLOGY

The rocks outcropping locally are either Quaternary or upper Cretaceous in age. The Quaternary rocks are comprised of alluvium and terrace deposits and are sandy loam and sandy clay. The upper Cretaceous rock units are of marine depositional origin. The illustration in Figure 1 shows a generalized stratigraphic column of the local geologic and geohydrological environments.

The shale stratum above the sandstone formation consists of blue-gray mudstone and siltstone with thin layers of sandstone. This unit is saline and has been eroded away in places, thereby exposing the sandstone formation. The exposed areas of this shale bed can be recognized by the lack of vegetative cover and existence of low rolling hills.

[1]Research Group Leader, Consolidation Coal Company, Research & Development, 4000 Brownsville Road, Library, Pennsylvania 15129

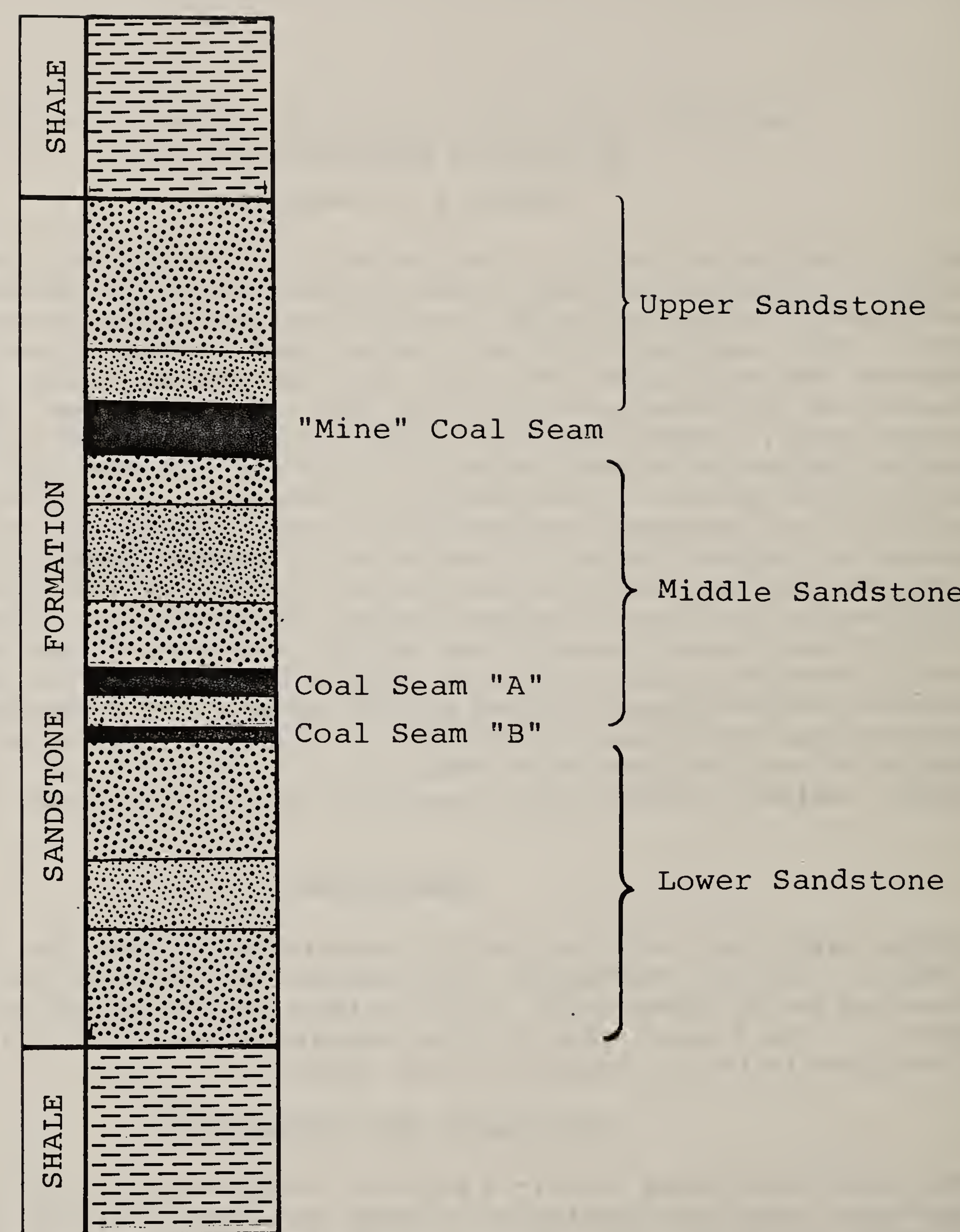


FIGURE 1: A generalized stratigraphic sequence depicting the local hydrogeological environments

The sandstone member consists of two units which can be distinguished on the basis of depositional history and lithology. The upper portion is a yellow-gray and brown, medium-grained sandstone with shale and carbonaceous interbeds. When exposed at the surface, this sandstone system weathers to a rust color. The upper and lower segments are separated by the "mine" seam and some carbonaceous shale and mudstone.

Underlying the sandstone formation is another shale bed. This shale unit is a marine mudstone blue-gray to black in color. It offers little resistance to erosion and forms the lower confining layer for the sandstone groundwater system.

The Quaternary deposits and the upper Cretaceous beds are separated by an angular unconformity. The upper Cretaceous beds dip approximately 5 degrees to the west and northwest because of the marginal influence of a swell. The major structural feature in the area is a fault zone about 3.2 km in width and extending approximately 120 km in length. This graben is located between the mine area and the plateau front and trends northeast to southwest.

HYDROGEOLOGICAL ENVIRONMENT

There are basically two subsurface water systems that were identified within the sub-watershed of interest. These aquifers are located in the Quaternary alluvium or the upper shale stratum and the sandstone formation. Geological units below the lower shale member (refer to Figure 1) are not considered here, since they are not affected by the mining activity. The groundwater system of primary concern to the mine and the local residents is the confined sandstone reservoir.

The alluvial or the upper shale groundwater system is under water table conditions. The location and the overall saturated thickness of this aquifer vary considerably. Consequently, perched water tables which give rise to numerous springs are very common during wet seasons. The recharge to this aquifer system is sustained in large part by the intensive irrigation practiced locally and snowmelt runoff during early spring. The thundershowers which occur mainly in the summer probably contribute very little to the overall recharge quantities. This is due to the low rainfall amounts coupled with a high evapotranspiration rate. Figure 2 shows the approximate initial water level contour map for this reservoir. This aquifer is in hydraulic communication with surface streams, and its seasonal contribution to the streamflows within the watershed was evaluated.

The upper sandstone formation aquifer is artesian, being confined above by a shale bed and below by the "mine" coal seam. As illustrated in Figure 1 there is a thin layer of shale immediately above this coal seam. This portion of the confined aquifer is hydraulically connected to the surface water system at a number of points along the streamflow channels. Over the mined-out area, however, this groundwater body is unconfined. The contour map in Figure 3 depicts the initial piezometric water level in this aquifer. The main recharge areas for this system are believed to be a plateau region to the north and northwest, which receives about 76 cm of precipitation annually, and the fault graben. The sectional schematic in Figure 4 indicates that some recharge to this aquifer may be coming from the middle sandstone portion and precipitation on the outcrops. These contributions are believed to be minor compared to the recharge from the plateau and the fault zone. The net recharge to this system is estimated to range from 0.030 to 0.075 m^3/s.

The mine and the surrounding areas are drained by two streams as shown in Figure 5. Creek "A" is a perennial stream that emerges from the plateau to the north, flows southeastward, and joins the main trunk just below the mine portal. The channel flow of this stream is maintained by runoff from local irrigation as well as rainfall, snowmelt, and groundwater seepage from the sandstone aquifer. Creek "B" also emerges

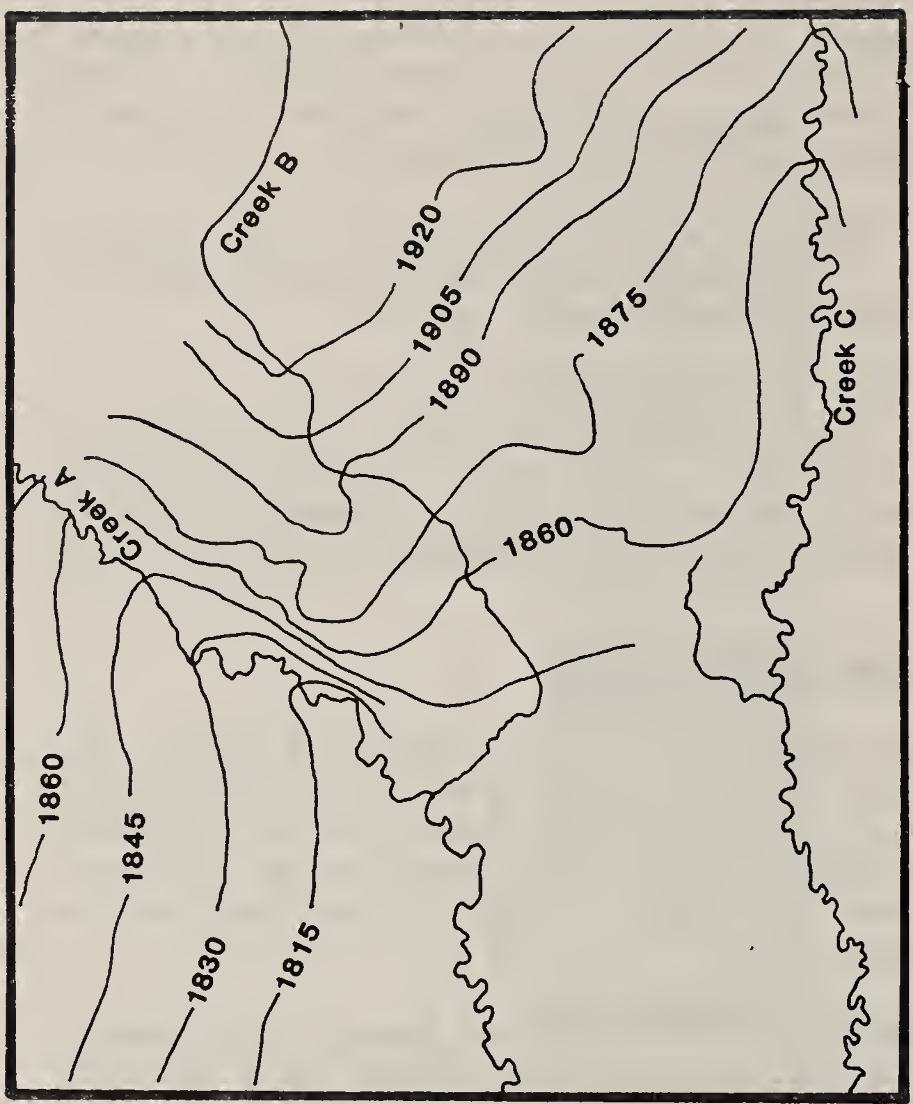
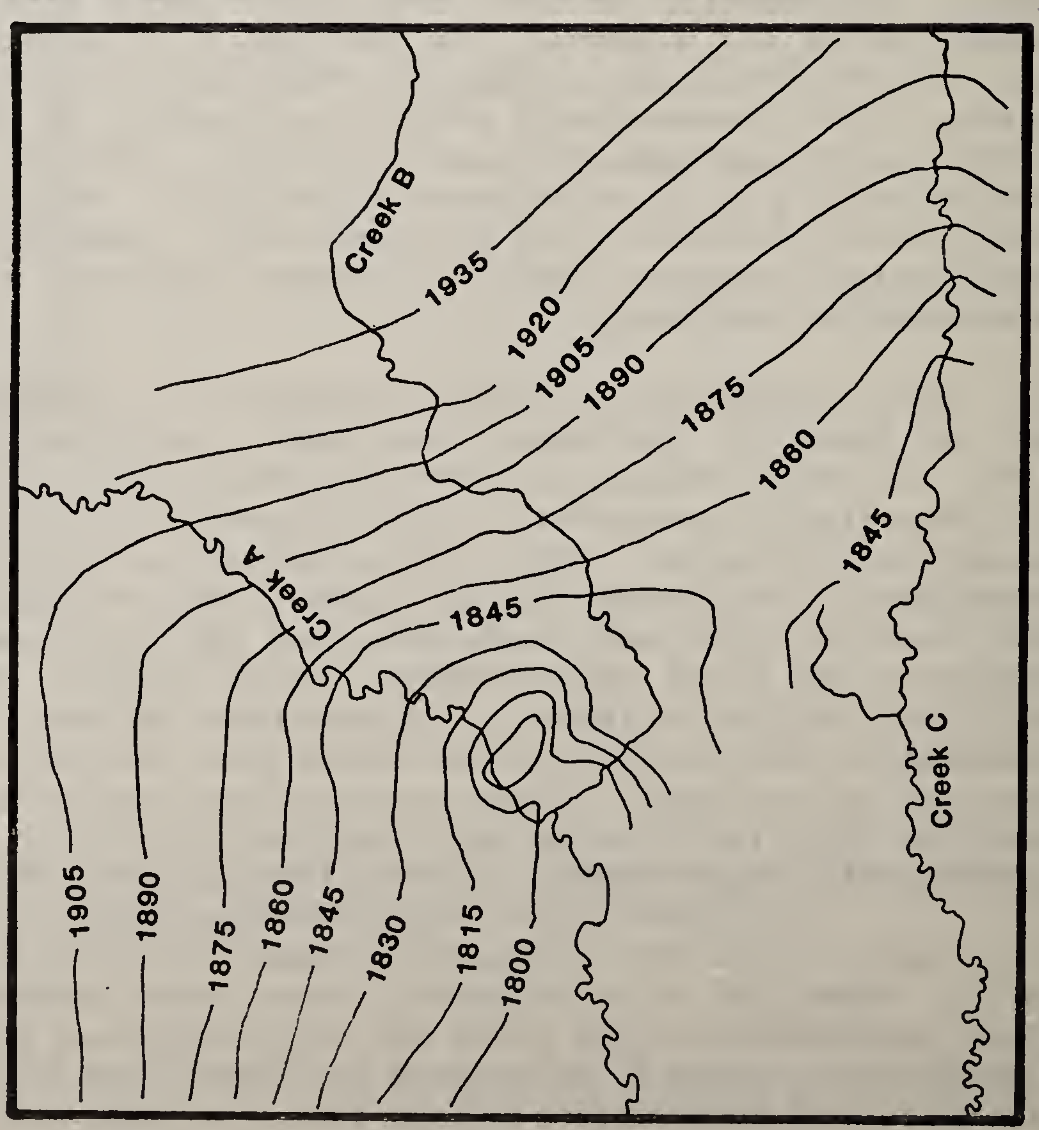
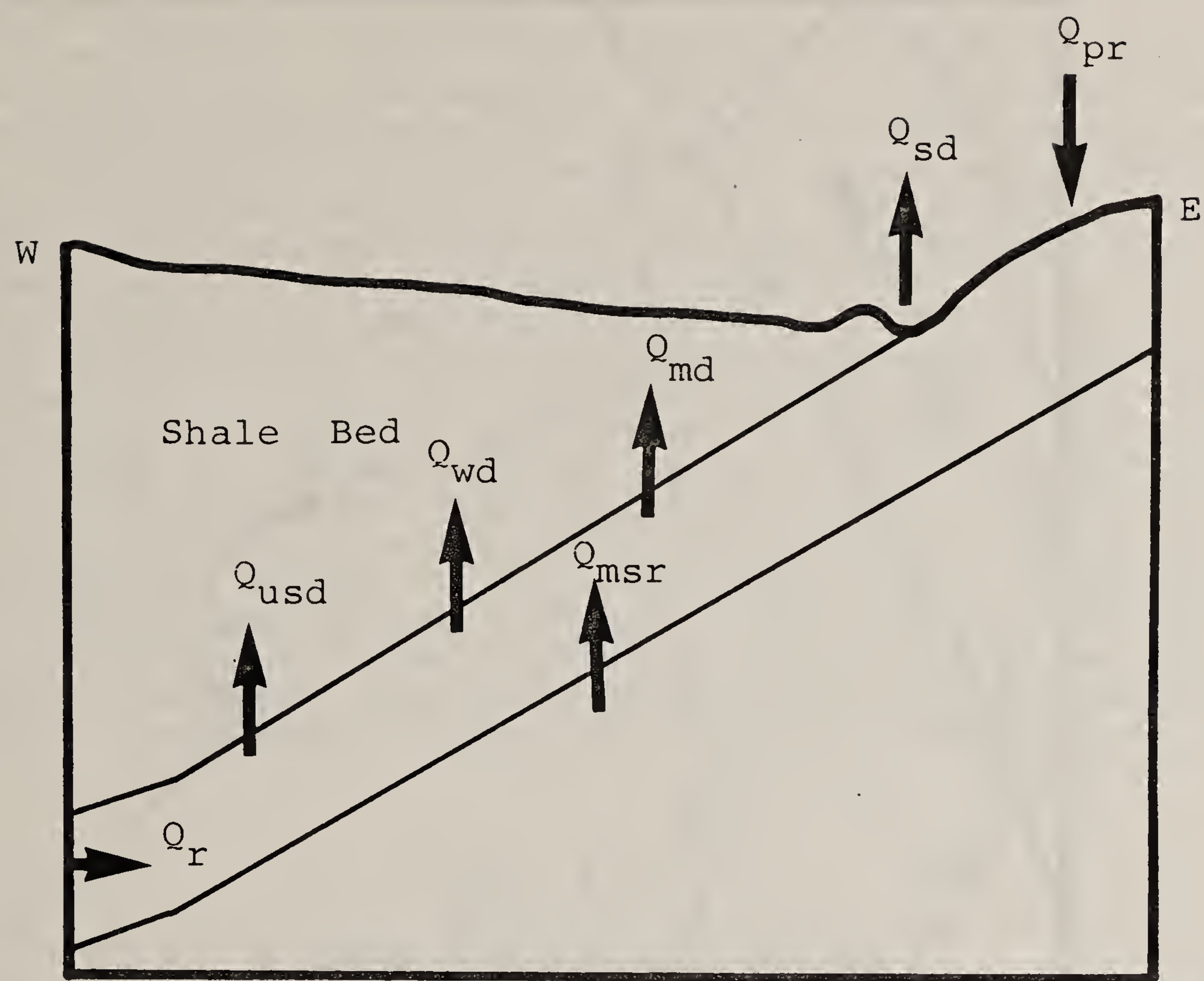


FIGURE 2: Water level contour map of the water table aquifer

FIGURE 3: Piezometric level of the water in the upper sandstone aquifer





Q_{md} = mine drainage
Q_{wd} = well discharge
Q_{sd} = leakage along streams
Q_{usd} = leakage into the upper shale bed
Q_{msr} = seepage from the middle to the upper sandstone
Q_{pr} = recharge from precipitation on the outcrops
Q_r = recharge from the plateau region

FIGURE 4: Sources of recharge to and discharge from the upper sandstone formation aquifer

● Stream sampling and gaging point

FIGURE 5: A major portion of the local watershed showing streams, springs, settling pond, and the fault zone

from the plateau and is perennial. The streamflow in this creek is fed by rainfall and snowmelt in the spring months. Near the mine, abundant runoff from irrigation, spring discharges, and water from the mine settling pond flow into Creek "A".

The surface streams of this watershed were strategically sampled on a quarterly basis for a period of five years. The sampling stations (as shown in Figure 5) were located so as to pinpoint the significance of the surface activity and the soil materials to the surface water quality. There is considerable variance in the chemistry of the water during the various seasons because of runoff and irrigation practices. The average annual water quality parameters have been summarized in Table 1. The average pH of the watershed is an alkaline 8.05, though the range is from 7.91 to 8.14. The amount of dissolved solids in the water averages about 2,106 milligrams per liter (mg/L). In spite of the relatively low-average dissolved solids content stated above, some minor tributaries may at times contain total dissolved solids in excess of 10,000 mg/L. The predominant chemical constituents in the surface waters are sulfate, bicarbonate, magnesium, sodium, and calcium. The iron content is low, generally below one milligram per liter. The average salt load transported out of the watershed through natural drainage is 47.3 metric tons per day in an average channel flow of 0.47 m^3/s. The primary contribution of the mine to the surface water system is via the mine settling pond. The average pond discharge into a tributary stream is 0.009 m^3/s, but the flow can vary from a trickle to over 0.023 m^3/s. The pH value of the pond discharge is alkaline 8.3. The dissolved solids contents average 4,145 mg/L, and the pond discharge contributes approximately 6 percent to the overall sediment load of the watershed.

TABLE 1

THE 5-YEAR AVERAGE WATERSHED WATER QUALITY

	SAMPLING STATION								
PARAMETER	1	2	3	4	5	6	7	8	9
pH (units)	7.91	8.01	8.04	8.1	8.14	8.05	7.94	8.09	8.02
Conductivity*	2,349	3,030	2,197	2,500	957	2,197	2,464	1,502	1,599
TDS	2,753	3,644	2,653	2,573	1,106	1,421	1,355	2,057	1,485
Hardness	1,166	1,314	1,088	1,093	374	598	481	578	582
Sodium	328	447	365	359	190	271	253	441	269
Potassium	7	8	7	7	5	5	6	5	5
Calcium	291	313	231	217	110	184	164	175	179
Magnesium	338	536	264	254	89	118	116	165	134
Total Iron	0.26	0.50	0.45	0.42	0.27	0.34	0.29	0.49	0.53
Sulfate	1,904	1,997	1,571	1,470	984	834	717	1,182	794
Chloride	45	49	81	48	38	53	65	68	43
Bicarbonate	291	344	302	272	253	333	256	272	250

*Conductivity is expressed in micromhos per centimeter

TDS = Total dissolved solids

Table 2 presents a comparison of the water quality parameters from all the sources within the study basin.

TABLE 2

COMPARISON OF WATER QUALITY FROM VARIOUS SOURCES

PARAMETER	SOURCE 1	SOURCE 2	SOURCE 3	SOURCE 4
Bicarbonate	303	273	363	439
Calcium	263	163	146	138
Chloride	56	53	193	144
Conductivity (μmhos/cm)	2519	1744	4672	4013
Dissolved Solids	2906	1485	4145	3700
Magnesium	348	125	199	172
pH (units)	8.0	8.1	8.3	8.1
Potassium	7	5	8	29
Sodium	375	285	1028	838
Sulfate	1736	902	2414	2382

1 - Creek B
2 - Creek A
3 - Settling pond effluent
4 - Mine inflow

GROUNDWATER SYSTEMS AND CHARACTERISTICS

The hydraulic parameters of the upper sandstone aquifer were determined by a pump test. The field test results established the hydraulic conductivity of the upper sandstone at 0.02 m/d with a storage coefficient of 0.0004. The approximated value of the vertical permeability of the same zone is 0.002 m/d.

Based upon the operating characteristics of the pump installed at the main mine sump and the results of gaging the settling pond discharges, the average amount of groundwater entering the active mine openings is about 0.02 m^3/s. However, the range of influx varies from a low of 0.005 m^3/s to a maximum rate of 0.03 m^3/s. Most of this water enters the mine voids through cleats and joints in the roof and at major roof falls.

Generally, there is a thin layer (about 1.5 m in overall thickness) of very low-permeability clay and shale located immediately below the coal seam, which apparently retards any significant vertical seepage of groundwater through the mine floor. The resultant mine inflow, consequently, is predominantly from vertical leakages through cracks and fractures in the roof and roof falls. This pattern of flow is expected to persist as the mine expands.

From the established hydraulic characteristics, the discharge stress exerted on the sandstone aquifer was determined. Based upon this information, the long-term quantity of water entering the underground mine is expected to climb to 0.025 m^3/s. The erratic peak influx that can be expected is 0.03 m^3/s of water.

EMPIRICAL BASIN MODELS

The equation stated below can be utilized in the estimation of the quantity of dissolved solids and the concentrations of sodium and sulfate constituents of water whose conductivity is known.

$$(TDS, Na, SO_4) = C_s + C_o C_w \quad (1)$$

where C_s is a constant; C_o is the slope of curve fit; C_w is the conductivity of the water, in micromhos per centimeter; TDS is the amount of total dissolved solids in water, in mg/L; Na is the concentration of sodium ions in the sample, in mg/L; and SO_4 is the sulfate concentration, in mg/L. The seasonal and average numerical values of the parameters in the above equation are presented in Tables 3 and 4.

TABLE 3

CONSTANTS FOR THE WATERSHED, SANDSTONE AQUIFER, AND MINE DRAINAGE

	MINE DRAINAGE		SANDSTONE AQUIFER		WATERSHED	
Period	C_o	C_s	C_o	C_s	C_o	C_s
Fall					1.14	-155
Spring					0.91	-161
Summer					1.05	-409
Winter					0.94	543
Average	0.88	485	0.85	-136	1.04	-53

TABLE 4

SODIUM AND SULFATE IONIC CONSTANTS

	SODIUM ION		SULFATE ION	
System	C_o	C_s	C_o	C_s
Sandstone aquifer	0.15	129	0.62	-552
Mine drainage	0.20	148	0.75	-760
Watershed	0.18	-51	0.70	267

An empirical quantitative basin model developed from the results of this research effort is expressed as:

$$Q = C_v A \quad (2)$$

where Q is the water influx into the active mine, in m^3/s; C_v is a constant of vertical leakage of water from a confined aquifer, in m/s; and A is the area of the roof fall zone or the exposed portion of the aquifer, in square meters. The numerical value of C_v ranges from 2.21 to 4.86. This leakage parameter, which henceforth is referred to as the "basin leakage factor," has been used only at this particular mine. Nevertheless, the above model can be used to provide initial rough estimates if required for planning purposes.

MINE INFLOW PROJECTIONS

The area modeled by a numerical simulation model and shown in Figure 3 had a width of 1800 m and extended for about 5300 m. The simulations made earlier indicated that the peak mine inflow was 0.04 m^3/s. During this period, the actual measured mine inflow based on sump and pump capacities averaged 0.03 m^3/s.

Since then the mine has expanded and, as expected, the total mine inflow has increased correspondingly. The last simulation exercises were performed in 1984 partly to satisfy regulatory requirements and to project mine inflows over the life of the mine. The same model region was used but the mined-out area was much larger than in the earlier study. In the simulation runs made during this time period, the following assumptions were used:

- Most of the water entering the mine voids is from the upper sandstone formation aquifer. Minor quantities may come from leakage from the upper confining shale bed, but these are considered insignificant. Seepages from the lower aquifers are negligible since some coal is left in the floor and there are thin layers of shale material in the immediate floor strata.

- The mining method of room-and-pillar does not cause massive caving of the roof until after the retreat mining of the coal pillars. The extent of the mine void is considered dynamic from one simulation time period to the next one (if desired). However, during any one time step, the void is assumed static. If massive caving occurs, the model can be instructed to evaluate and update nodal or block characteristics.

- Recharge to the aquifer occurs along the fault graben and possibly from precipitation at the outcrops as well as downward leakage from the upper shale bed.

- The aquifer is treated as a confined groundwater system with the upper shale stratum and the thin shale layer in the floor of the "mine seam" acting as the confining layers. Both fractured and unfractured flow characteristics are considered.

The generated flow volumes based on five-year mining plan cycles are summarized in Table 5.

TABLE 5

PROJECTED PEAK INFLOWS OVER THE LIFE OF THE MINE

Mining Plan Period	Peak Inflow (m^3/s)
1984-1988	0.07
1989-1993	0.12
1994-1998	0.11
1999-2003	0.13
2004-2008	0.14

CONCLUSIONS

Analysis and evaluation of the assembled information and the results of various hydrological field tests conducted within the region provided the basis for several critical conclusions.

- The water exiting the watershed is relatively soft and has moderate total dissolved solids. The minor intermittent tributaries, however, contain extremely large quantities of dissolved solids and convey tremendous amounts of sediment loads.

- The mine discharge water will not significantly impact the quality of the waters within the watershed. Nevertheless, the mine drainage water quality deterioration can be minimized if contact time with the underground mine environment is reduced or controlled.

- The upper sandstone formation above the "mine" seam is an artesian aquifer isolated from the middle and lower portions of the formation in most places. Consequently, it can be treated as a unit of relatively low permeability and as the primary source of water leaking into the underground mine.

- The empirical models developed here can be utilized at this mine with a fairly high degree of accuracy and consistency. Caution must be exercised in applying them in other coal basins even though the intent is to document and expand such applications.

- The volume of water that will flow into the proposed longwall sections is not expected to be excessive. However, a pumping system is needed to convey this water away from the working faces. The impact of the longwall operation on the water resources of the region will be localized and minimal. The lower aquifers will not be affected by the longwall mining operation, and these aquifers have higher yields than the upper zone.

RECOMMENDATION OF FLUSHING FLOWs FOR MAINTENANCE OF SALMONID SPAWNING GRAVELS IN A STEEP, REGULATED STREAM

D.W. Reiser[1], M.P. Ramey[2], and T.R. Lambert[3]

ABSTRACT: This paper presents the results of a study focused on developing flushing flow recommendations for maintaining the quality of salmonid spawning gravels in a regulated stream in California. The paper discusses problems associated with development of a method for prescribing such flows, and presents the method ultimately used. Results of the study indicated a flushing flow of 2,000 cfs occurring for from 1-3 days would be sufficient to transport sediments from spawning gravels. This flow was intermediate to levels which maximize surficial gravel flushing and levels which maximize surficial cobble flushing.

INTRODUCTION

Flow regulation in streams can result in long-term problems of sediment deposition and accumulation. This can occur as a slow, insidious process when small quantities of sediment are deposited with no subsequent transport, or be triggered as a rapid, almost catastrophic event resulting from a slump or landslide. The movement of sediments in a stream is dependent on two factors: (1) the availability of sediment in the drainage, and (2) the sediment transporting ability ("competency") of the stream. Either factor may limit sediment transport rates, and changes in both can occur in conjunction with water development projects and flow regulation. In general, most water developments tend to reduce or eliminate the natural peak flows of the stream thereby reducing its competency. The net effect is that sediment in the system tends to accumulate rather than being periodically removed. With time, such sediment deposition and aggradation can adversely affect important fish spawning and rearing habitats (Chevalier et al. 1984; Cordone and Kelley 1961; Everest et al. 1986).

In regulated stream systems an important solution to this problem exists via the programmed release of a predetermined discharge for a given duration. Such flows, often termed "channel maintenance" or more commonly "flushing flows" can be applied to meet a variety of interrelated management goals. To date, the methods which have been used to prescribe flushing flows typically fall into one of three categories; (1) methods based on regime theory such as bankfull flow; (2) methods based on discharge records which generally state flushing flows as some percentage of the average annual flow: and (3) methods based on empirical observations and/or theoretical determinations using sediment transport formulae. Reiser et al. (1985) reviewed thirteen such methods which have been used for making flushing flow prescriptions.

[1]Senior Fisheries Scientist, EA Engineering, Science, and Technology, Inc. 41A Lafayette Circle, Lafayette, CA 94549
[2]Hydraulic Engineer, Bechtel Civil Inc., San Francisco, CA 94119
[3]Senior Fisheries Scientist, Pacific Gas and Electric Company, 3400 Crow Canyon Rd., San Ramon, CA 94583

Not surprisingly, the application of two or more methods to the same stream system will often result in a wide range of flow recommendations. Wesche et al. (1983) noted an average difference of 60 percent in the flushing flows recommended on two independent studies for the same stream system in Wyoming. The approach used by Estes (1985) and Orsborn (1982) may result in as much as a 600-900 percent difference in flows compared with recommendations using the Tennant method (Tennant 1975). Milhous and Bradley (1986) compared flushing flow prescriptions for a Colorado stream resulting from five methods. The recommendations ranged from 142 cfs based on the Hoppe (1976) method to 800 cfs based on the methods of O'Brien (1984). Interestingly, Milhous and Bradley (1986) did not consider any of the methods satisfactory since they were not based on physical process logic.

Such disparity in recommendations amplifies the importance of the development of sound, reliable methods for determining the magnitude, duration and timing of flushing flows. However, it is highly unlikely that a single standard method for this purpose will ever be developed. There are simply too many variables and interactive parameters to allow the formulation of a single method applicable to all stream systems and for all purposes. Stream systems will vary in both hydrological and morphological characteristics as well as the biological reasons for requiring a flushing flow (e.g., cleansing of spawning gravels, improve rearing habitat, channel maintenance etc.). As a consequence, most methods used to prescribe flushing flows will evolve from and be specific to a given set of stream conditions and management objectives. This paper presents one such methodology which exemplifies this situation.

PROBLEM DEFINITION

In many gravel bed streams typical of systems in the Rocky Mountains and Pacific Northwest, sediment deposition is likely to occur in well-defined pool and riffle areas. Such areas are noted for their importance to salmon and trout for rearing, spawning, and food production, and excessive sediment deposition in these areas can prove detrimental. In these systems, the objective of a flushing flow would be to remove the sediments from the habitat component considered most important to the existing populations. Intuitively, one would expect that higher flows are needed to remove sediments from pool versus riffle areas and indeed this is the case. However, as discussed by Bjornn et al. 1977) even higher flows are needed to flush fines from below an armored layer within a riffle. An armor layer generally forms whereby finer material is held in place by coarse material.

In steep, regulated streams of the Sierra Nevada in California, a situation often develops in which pool-riffle areas are largely undefined. In these systems, the available rearing and spawning habitats are widely, almost randomly scattered throughout the stream. Such areas are typically located in proximity to large boulders or bedrock outcroppings which have, depending on orientation and the hydraulics imposed, scoured-out pool areas, or allowed deposition of spawnable size gravels. Although excessive sediment deposition is less likely to occur in these systems (owing to steep gradients and blockage upstream of sediment/gravel sources by the dams), it can and does occur. Thus, suitable flushing flows are also needed for these systems. This is especially important in these systems since the amount spawning gravels etc. are relatively small, and the existing fish populations will be sensitive to any degradation. Such is the case for the North Fork of the Feather River (NFFR), a regulated system located in north central California near Oroville. In this system, an important agency concern is for the continued maintenance of clean spawning gravels via periodic flushing flow releases from two dams. However, a paradox exists in that the recommended flows need to be sufficiently large to clean and remove fine sediments from the gravels, without mobilizing and removing the gravels themselves, which are a finite and important element to the continued propagation of the fishery resource.

METHODS

As a consequence, the derivation of a suitable flushing flow recommendation for the NFFR required development of a method sensitive to management objectives and physical characteristics of the system. The objective of developing flow recommendations for cleansing existing spawning gravels was made difficult since the majority of such gravels were in small, scattered pockets.

Field Techniques

Use of traditional cross-channel transects for field data collection proved to be unsatisfactory since data collected in that manner would be limited to areas directly under a straight-line, bank to bank demarcation. As a result, we developed and employed a two-point-arc procedure for data collection. As illustrated in Figure 1, the procedure

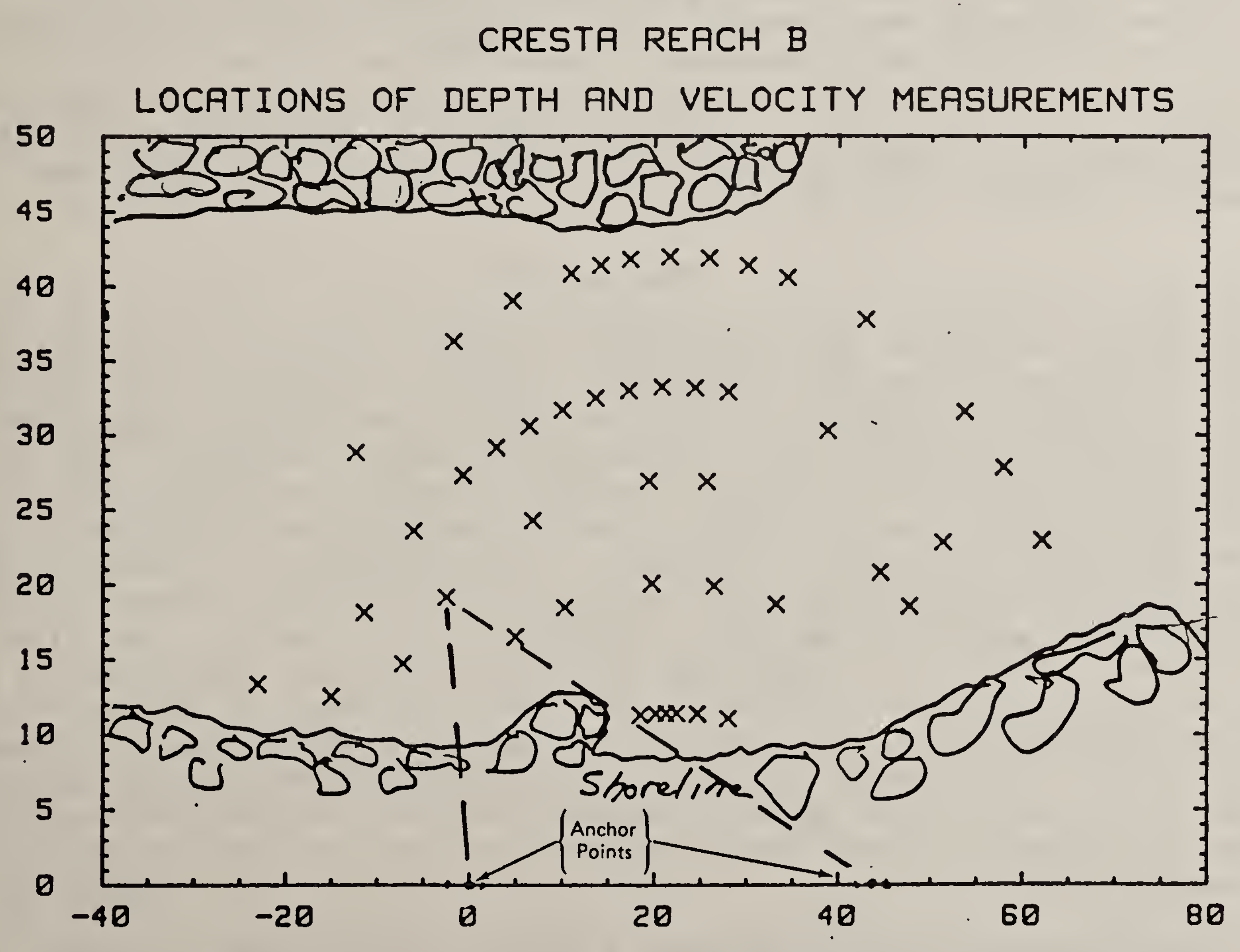


Figure 1. Example of the two-point arc procedure used for collecting physical and hydraulic data.

entailed establishing two separate anchor points for the attachment of a standard, plastic measuring tape. The end (0 ft) of the tape was fixed to one anchor pin: the tape extended-out into the desired area of measurement and returned to the second pin for attachment. By positioning a top-setting rod under the tape and moving away from shore, the tape was drawn taut. Discrete measurements (depth, velocity) were then made by positioning the rod at various lengths on the tape, all the while keeping the tape tight. Measurements made at different tape lengths defined a given arc as determined by the total tape length between the two anchor pints. Several sets of measurements (i.e., additional arcs) were made by adjusting the length of tape at the second anchor point. By noting the length of the tape at the second anchor point and the tape lengths at each discrete measuring point, it was possible to relocate and re-measure each point at two or more flows. This method provided a means to concentrate measurements over spawning gravels, which were often widely scattered throughout the study stations.

Measurements were made using the above procedure at each of five stations. The number of measurements taken depended on the length of tape and variability in substrates and hydraulic conditions as defined by a given arc. The number of measurements for a given arc ranged from as few as 4-5 to as many as 15. At each vertical, water depths were measured using a top setting rod; water velocities were measured using a Marsh-McBirney Model 201 current meter. Both point velocities (taken on the stream bottom) and mean column velocities (taken at 0.6 depth for depths less than 2.5 ft; and at 0.2 and 0.8 depths for depths greater than 2.5 ft) were measured at each vertical. In conjunction with the hydraulic measurements, the substrate characteristics within a 0.5 ft radius of each vertical were assessed. Substrate was classified into the two most dominant size categories using the substrate size classification developed by the AEIDC (1981). Three separate sets of measurements were taken corresponding to three different flows ranging from 60 to 400 cfs. The collection of data at several flows provided for development of a predictive model for deriving recommended flushing flows.

Data Analysis

Analytical techniques for determining flushing flows are generally derived from work done in the area of sediment transport mechanics. Although most transport theories are based on physical processes, there are many uncertainties associated with their application under field conditions. Consequently, both experimental and field data are typically used to develop acceptable sediment-discharge relationships. The extreme scatter in data evidenced by the typical log-log presentation of sediment results is an indication of the present state-of-the-art. In addition, the transport theories that have been developed are applicable to steady, uniform flow and are useful for evaluating sediment transport using average flow conditions in a channel. The flushing of fine sediments from gravels in the NFFR does not conform to these techniques. The areas of interest are generally in back-eddies behind large boulders, or in protected areas outside the main-channel flows. In these areas, even the prediction of a velocity field is a difficult task. As a result, the field techniques previously described were developed to define the velocity field in the immediate vicinity of the spawning gravels. This information, combined with mean channel flow properties, was used to formulate a flushing flow recommendation.

The determination of a recommended flushing flow was based on data collected at three field measured flows. These data were then extrapolated to estimate conditions at higher flows. Four critical levels of bed mobilization were considered for the evaluation of the flushing flow. These were:

- Surficial flushing of gravels
- Mobilization of gravels (d_{50} = 1 inch)
- Surficial flushing of cobbles
- Mobilization of cobbles (d_{50} = 8 inches)

As previously noted, the river bed in the NFFR is dominated by cobbles and small boulders, with spawning gravels occurring in scattered pockets. The larger substrates can thus shelter the gravels and inhibit adequate flushing. As a result, the analysis was focused on recommending flushing flows which would surficially clean cobbles without removing important spawning gravels. Field measurements were made at three relatively low-flow conditions. Higher flow conditions were then extrapolated using Manning's equation. Manning's "n" was assumed to be 0.06, a typical value for mountain streams composed primarily of cobbles and boulders. Average bed slopes were taken from U.S.

Geological Survey (USGS) topographic maps. A depth-discharge curve and a velocity-discharge curve were subsequently determined using the following relationships:

$$Q = a_1(Y - Yo)^{5/3} \quad (1)$$
$$Q = a_2(V - Vo)^{5/2} \quad (2)$$

where: Q is the discharge
Y is the flow depth
V is the depth-averaged flow velocity
Yo, Vo, A_1, a_2 are constants

These relationships were based on Manning's equation as applied to a wide rectangular channel. A least-squares method was used to determine the unknown constants a_1, Yo, a_2 and Vo using the measured low flow data and the high flow data predicted from Manning's equation.

The conditions for incipient particle motion were determined for exposed cobble material and for exposed gravel material. The local channel bed in the NFFR is composed primarily of cobble-sized material with a median grain size of about 8 inches. There are also isolated deposits of gravel-sized material with an approximate median grain size of 1 inch. In a turbulent flow field, it is difficult to precisely define a condition of incipient particle motion. This difficulty arises from the probabilistic nature of particle movement. Sediment transportation near the bed may be described as a stochastic response to the random, fluctuating turbulent forces exerted by the flow field. There is thus, no general accord concerning what constitutes a "threshold" condition. What may appear to be a condition of "incipient" particle movement is often a condition of infrequent particle movement. However, practical recommendations have been developed for determining a condition of "incipient" particle movement.

In this study, the Shields' parameter, $_*$, was used to determine this condition for the cobble-sized material. This parameter is defined as follows:

$$_* = \frac{\tau}{(\gamma_s - \gamma)d_{50}} \quad (3)$$

where: τ is the shear stress at the bed surface; γ is the specific weight of water: $_s$ is the specific weight of the sediment: and d_{50} is the median particle size. Neill (1968) recommended a Shields' parameter value of 0.03 for design o a stable bed. The shear stress at the bed surface was determined as follows:

$$= \left(\frac{0.4\ d_{50}^{1/6}}{n} \right)^{3/2} \gamma Y S \qquad (4)$$

where: d_{50} is expressed in terms of feet; Y is the flow depth; and S is the energy slope.

A mean-velocity threshold criterion was used in the analysis for the spawning gravels. Neill (1967, 1968) performed laboratory experiments to determine the critical depth-averaged velocity at which particle motion begins. The size of the spawning gravels is within the range of sizes used in the experiments of Neill (1967, 1968). The results of Neill's experiments may be described by the following equation:

$$\frac{\gamma V c^2}{(\gamma s - \gamma) g d_{50}} = 2.93 \left(\frac{d_{50}}{Y} \right)^{-0.2} \qquad (5)$$

where: Vc is the critical depth-averaged velocity for incipient motion and g is the acceleration due to gravity.

It is also possible to surficially flush fine material from the coarser pavement material without disturbing the pavement. To estimate the critical conditions at which this may occur, Milhous and Bradley (1986) recommended the following relation:

$$\tau_{*f} = \frac{2\tau_{*c}}{3} \qquad (6)$$

where τ_{*f} is the Shields' parameter required to initiate surface flushing and $_{*c}$ is the Shields parameter required to mobilize the armor layer. This criterion was directly applied to the cobble-sized material. An equivalent relation was determined for the gravel-sized material. The above criteria and relationships were used to determine: (1) the discharge required for surface flushing, (Q_f), and (2) the discharge required to mobilize the pavement, (Q_c). From this, a "window of acceptability" was subsequently defined as follows: $Q_f < Q < Q_c$. Flows within this window are higher than required to provide surficial flushing, but lower than levels at which bed mobilization occurs. Such flows were thus the recommended flushing flows since they met the original objective.

RESULTS

As previously discussed, the local velocity and depth measurements at each study site were used to evaluate hydraulic conditions representative of areas of gravel deposition within the NFFR. In addition, four separate flow levels were identified based on the level of anticipated sediment and flushing. These levels were surficial flushing of gravels, mobilization of gravels, surficial flushing of cobbles, and mobilization of cobbles. Figures 2 and 3 depict each level along with the average flow conditions of one of the stations. As shown, surficial flushing of a coarse gravel pavement would likely occur at a discharge of about 1,200 cfs. Incipient motion of a gravel pavement would occur at about 3,200 cfs. Surficial flushing of a cobble pavement and incipient motion of the cobble pavement would occur at 6,800 cfs and 13,800 cfs, respectively.

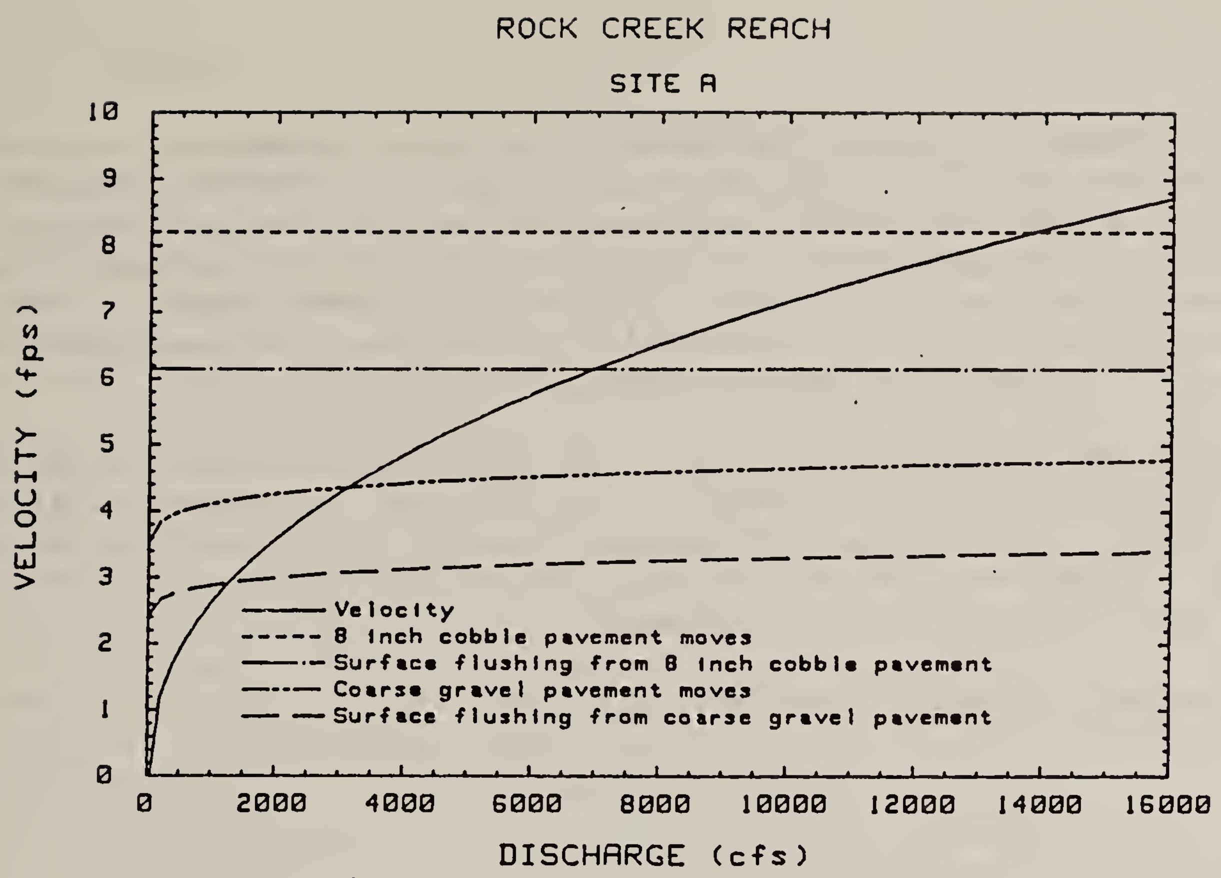


Figure 2. Velocity - discharge relationships for one of the North Fork Feather River study station. Points of intersection on the velocity curve indicate flows at which substrate materials begin to move.

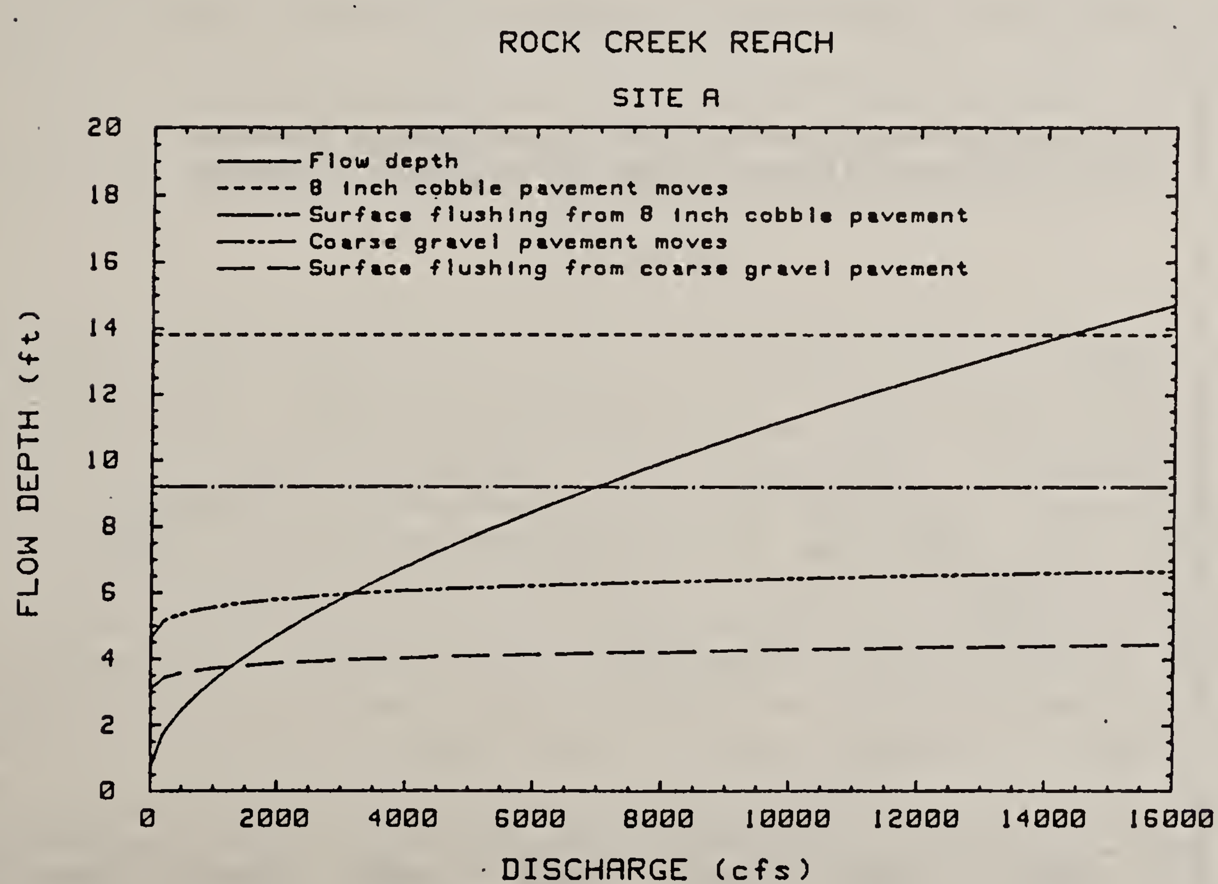


Figure 3. Depth - Discharge relationships for one of North Fork of the North Fork of the Feather River study stations. Points of intersection on the depth curve indicate flows at which substrate materials begin to move.

From field observations it was noted that gravel deposits were often intermixed with coarser cobble material. At these locations, the coarser cobbles would tend to shelter the gravels and surficial fines deposited within the interstitial spaces. As a consequence, it would be impossible to effectively flush the protected gravels without causing substantial movement of gravels in less protected areas. Thus, the flows at which cobbles are mobilized and surficially flushed must be considered when evaluating the adequacy of a flushing flow for the gravel materials.

The results shown in Figures 2 and 3 are for average conditions at one of the five study sites. In order to fully evaluate the flushing performance, the data from all sites were combined. From this, the four previously discussed flow levels were determined for each of the study sites, and the "window of acceptability" defined. This was done for both the gravel and cobble pavement.

The percentage of sample locations which met this criteria were then plotted as a function of discharge (Figure 4). The resulting relationships indicated that surface

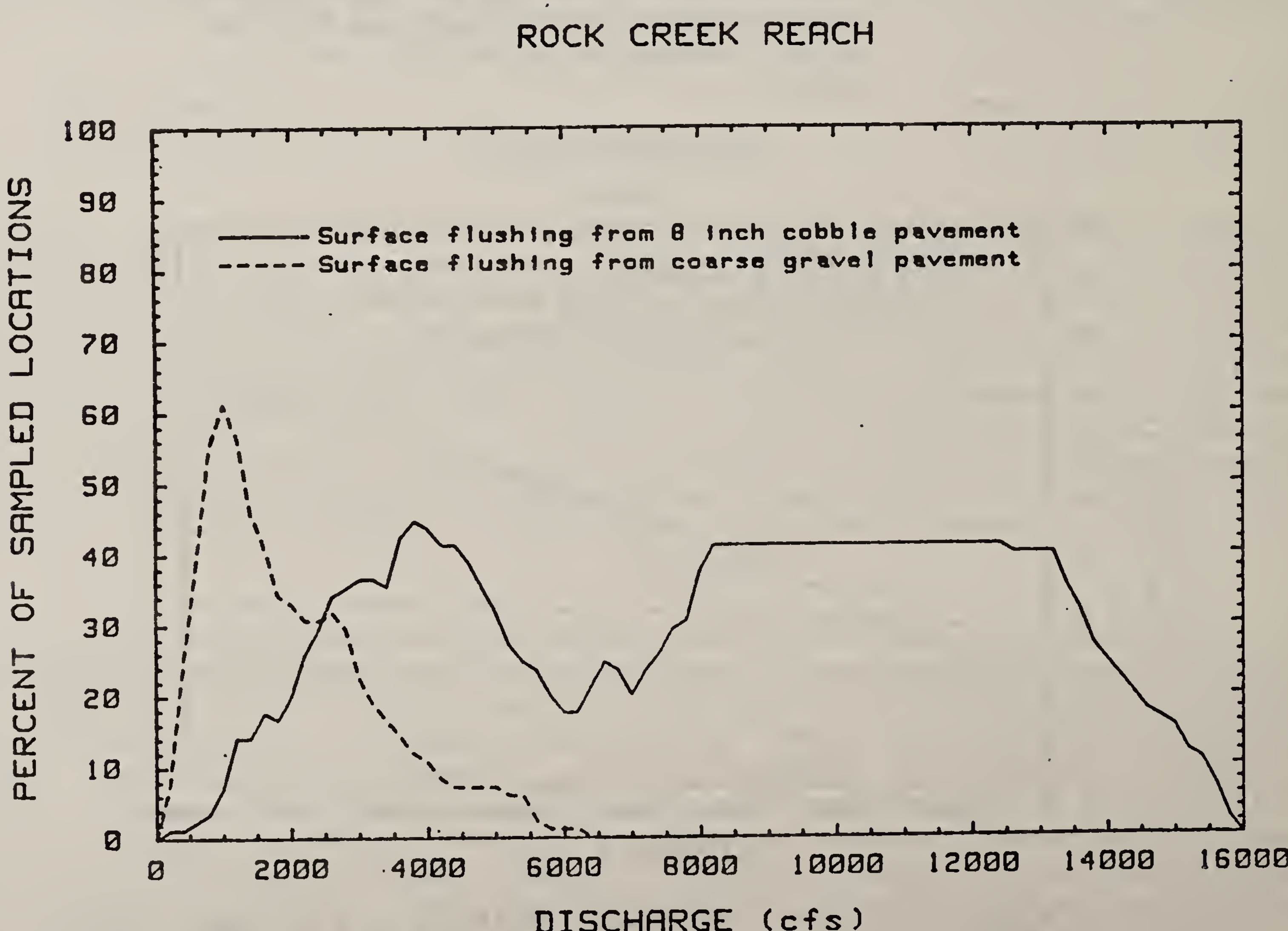


Figure 4. Percentage of combined sample locations meeting two flushing criteria, as a function of discharge.

flushing of exposed gravels would be maximized when flows are about 1,000 cfs, and surface flushing of exposed cobbles would be maximized when flows are about 4,300 cfs. As flows increase above 1,00 cfs in the study reach, additional flushing of gravels would occur. However, there would also be an increased mobilization of exposed gravels. For gravels protected by large cobbles and boulders, flows which provide surficial flushing of cobbles should also effectively clean the gravels. However, such flows would be too high for the NFFR reaches since they could completely "flush-out" important spawning gravel materials. As a result, a flow level between the flow which maximizes surficial gravel flushing, and the one which maximizes surficial cobble flushing was selected as the recommended flushing flow. This flow was 2,000 cfs. The magnitude of the flow was purposely selected closer to the gravel flushing flow for the above stated reasons. At this flow, the majority of sediments should be effectively flushed from the gravel deposits. Although some movement of the gravels will also likely occur, the 2,000 cfs recommended flow is not expected to cause an excessive depletion of this limited resource.

The required duration of the recommended flushing flow was difficult to accurately assess and is influenced by such factors as reach length, channel gradient and morphology, and pool-riffle ratio. For this study, we assessed the question of flow duration using the sediment transport relationship developed by Meyer-Peter and Muller (1948). Using this relationship and a d_{50} gravel size of 1 inch, transport rates of 6.4 lbs/sec/ft were estimated for the NFFR reach. Assuming that a 1 inch-thick layer of fine sediments cover the channel bed, and that the reach was about 8 miles long, the calculated time to flush fine materials was 0.8 days. However, based on the physical characteristics of the NFFR it was felt this type of direct approach would probably underestimate required flushing times. As a result, we increased the duration times and classified them into two categories; minimum duration and recommended duration. The minimum duration was set at 1 day and should be sufficient to remove most sediments from important gravels. A more thorough and effective cleaning would occur with a flow extending for 3 days, the recommended duration. However, both times were not firmly established and would require refinement through direct field observation.

DISCUSSION

From the results of this study, a flow of 2,000 cfs was recommended as the flushing flow for the NFFR. This flow, maintained for a duration of 1-3 days was considered necessary for effectively removing surficial fines from important spawning gravels. However. as in all flushing flow studies, it is recommended that such flows be confirmed with direct field observations to evaluate their effectiveness and sufficiency for sediment removal. Regardless of the absolute amount of the flow, it is important to stress that "manufactured" flushing flows should only occur if a definite need for them has been established. As noted by Reiser et al. (1985) an unsubstantiated blind recommendation and release of a flushing flow may actually be more detrimental than beneficial to the aquatic resource. This is especially true for the NFFR where spawning gravels are already at a premium. and where normal "spill" events already provide some cleansing of the substrates.

This study illustrates the complexity of problems and variables which must be considered in developing sound flushing flow recommendations. Such complexity makes the development of a single method for recommending flushing flows unlikely. Indeed, we believe as previously stated that methods for prescribing flushing flows will vary on a case by case basis and must be tailored to the specific physical characteristics of the stream and the resource management objectives.

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WATER RESOURCES RELATED TO MINING AND ENERGY – PREPARING FOR THE FUTURE
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RECOMMENDATION AND EVALUATION OF A MITIGATIVE FLUSHING FLOW REGIME BELOW A HIGH MOUNTAIN DIVERSION

T.A. Wesche[1]
V.R. Hasfurther[2]
Q.D. Skinner[3]

ABSTRACT: The recommendation of flushing flows as part of an overall instream flow regime is becoming more common below water development projects in the western United States. Typically, objectives of these high magnitude, short duration releases are to maintain channel capacity and fish habitat quality by preventing riparian encroachment and flushing accumulated fine sediments from the streambed. While several methods have been developed for estimating flushing requirements, little evaluation has taken place regarding the effectiveness of implemented releases. Water development-related construction activity in the headwaters of south-central Wyoming's Little Snake River during mid-1984 resulted in substantial deposition of fine and coarse sediment in the stream channel. Given the potential for severe embeddedness of Colorado cutthroat trout habitat, our study was conducted to 1) quantify the amount and composition of deposition; 2) monitor quantitative and qualitative changes in the deposition in response to varying hydrologic, hydraulic and sediment transport characteristics; 3) recommend a flushing flow regime to mitigate the sediment spill; and 4) evaluate the effectiveness of the recommended regime. Flushing flow releases were somewhat successful in meeting management objectives. Preliminary discussion of a new method for flushing flow analysis, termed "sediment transport input-output modelling", is also presented.
KEY TERMS: Flushing flow, sediment transport, instream flow, fish habitat.

INTRODUCTION

Alteration of stream flow regime and sediment loading from water development activities can result in both short- and long-term changes in channel morphology and conveyance capacity. Subsequently, the condition of the aquatic habitat can be affected. In recent years, much research and development effort has been directed toward the determination of suitable instream flows to maintain fisheries habitat in regulated streams (Stalnaker and Arnette, 1976; Wesche and Rechard, 1980). However, there are several facets of the instream flow problem which have not been adequately investigated, one involving the recommendation of flushing flows to simulate the peak runoff hydrograph characteristics of most unregulated streams (Reiser et al., 1985).

Limited research has been conducted to develop methodology for determining the magnitude, timing, and duration of flushing flows needed to maintain channel integrity

[1]Research Biologist and Hydrologist, Wyoming Water Research Center, University of Wyoming, Laramie, WY 82071

[2]Professor, Department of Civil Engineering, University of Wyoming, Laramie, WY 82071

[3]Professor, Department of Range Management, University of Wyoming, Laramie, WY 82071

and associated habitat characteristics through the movement of sediment deposits. Of the 15 methodologies identified by Reiser et al. (1985), a majority were not designed specifically to assess flushing flows, but rather were approaches for studying sediment transport problems. The several formal methodologies currently available (Wesche et al., 1977; Environmental Research and Technology, Inc., 1980; Rosgen, 1982) were developed in response to immediate management needs and are relatively untested in terms of accuracy and reliability.

During 1984, the Wyoming Water Research Center initiated a research project entitled, "Development of methodology to determine flushing flow requirements for channel maintenance purposes." Objectives of this project are to 1) document the rate of change of various channel characteristics resulting from aggradation/degradation processes under altered flow regimes; 2) quantify the physical and hydraulic properties needed to transport deposited sediment through natural channels; 3) test the predictive capabilities of existing sediment transport models against field data; and 4) develop methodology to predict conditions of flow needed to flush sediments to maintain given streams in prescribed hydraulic, physical and biologic conditions.

One stream selected for study in response to these objectives was the North Fork of the Little Snake River (North Fork), a steep, rough, regulated, headwater stream. Wesche et al. (1977) recommended both maintenance and flushing flow regimes for the North Fork in light of the proposed expansion of water diversion facilities in the drainage by the City of Cheyenne, Wyoming, as part of their Stage II water development program. Construction of Stage II began in 1983. During the late summer of 1984, intense rainfall in the construction area resulted in the deposition of a broad size range of sediments in that section of the North Fork where flushing recommendations had been made. At the request of the Wyoming Game and Fish Department and in cooperation with the United States Department of Agriculture Forest Service, the authors initiated a study of the North Fork. The objectives of this paper are to describe 1) the methods used to assess the extent of the 1984 sediment deposits; 2) the response of the deposited sediment to the 1985 spring runoff flow regime; 3) the mitigative flushing flow regime recommended for 1986; and 4) the effectiveness of the 1986 flushing flow recommendation.

DESCRIPTION OF STUDY AREA

The North Fork of the Little Snake River is a steep, rough, regulated tributary of the Little Snake River located in the Green River sub-basin of the Colorado River basin in southwest and southcentral Wyoming (Figure 1). The headwaters of the North Fork rise on the west slope of the Continental Divide at an elevation of 10,000 feet (ft) above mean sea level (msl) and flow southwesterly 12 miles to the confluence with the Little Snake River at an elevation of 7,000 ft. Average gradient is 4.6 percent. A United States Geological Survey (U.S.G.S.) streamflow gaging station (#09251800) located 1.5 miles below the study area was in operation from 1957 to 1965 and recorded a maximum discharge of 515 cubic feet per second (cfs) on June 7, 1957. Average discharge over the period of record was 26 cfs. Prior to initial water diversion in the mid-1960's, the North Fork hydrograph was typical of unregulated mountain streams in the central Rocky Mountain Region, with the majority of runoff occurring in the May to late-June period, as a result of the melting snowpack.

The North Fork and its tributaries support the largest known, essentially-pure, naturally-reproducing endemic population of Colorado River cutthroat trout (Salmo clarki pleuriticus Cope) (Binns, 1977). For this reason, management of the population is a high priority for the Wyoming Game and Fish Department.

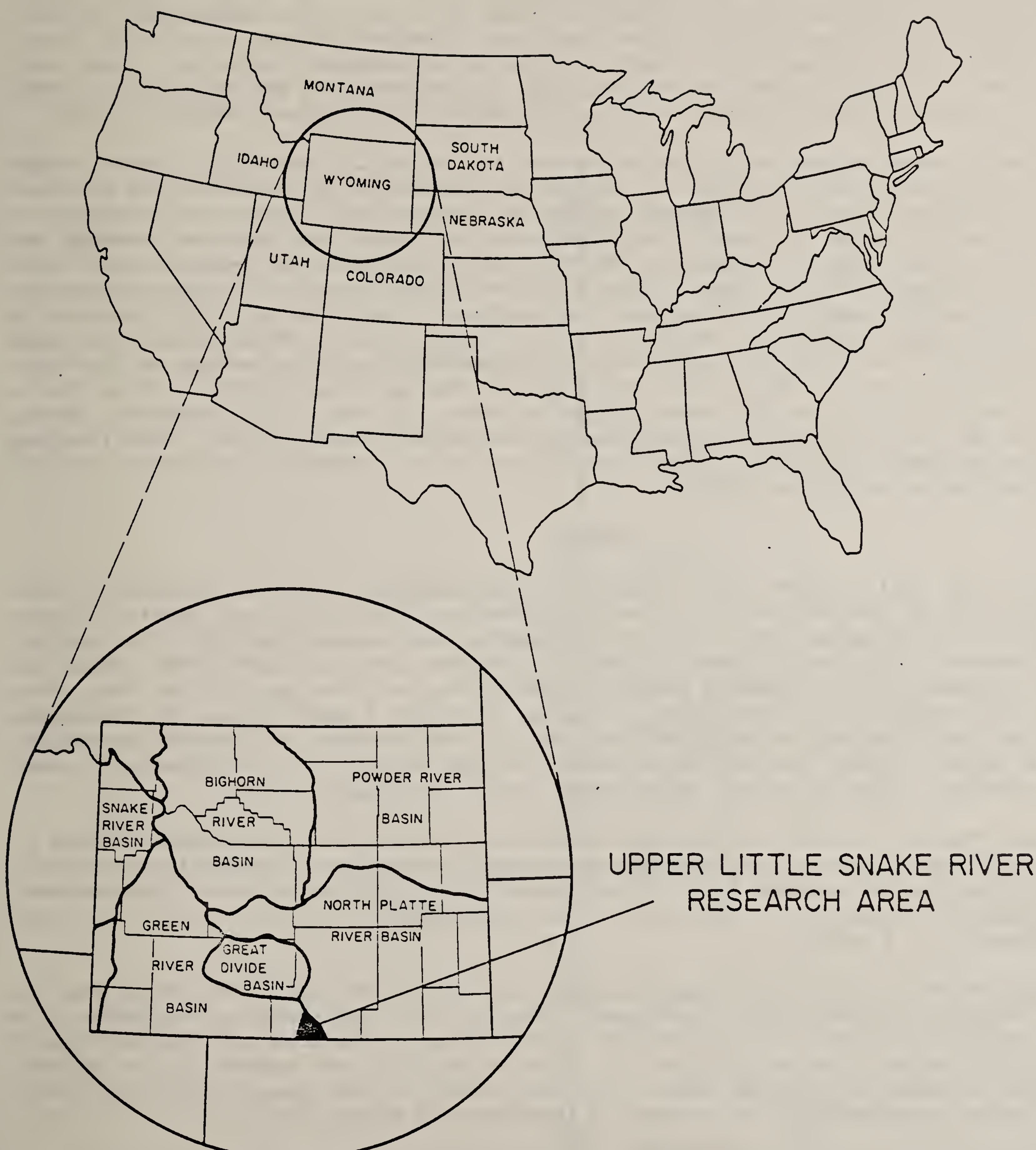


Figure 1. Location of the Upper Little Snake River Research Area.

Transbasin diversion of water from the North Fork drainage has occurred since 1964 when the City of Cheyenne, Wyoming completed Stage I of its water development program. Approximately 8,000 acre-feet per year have been diverted (Banner Associates, Inc., 1976). During 1983, construction began on Stage II collection facilities. When completed, a total of 23,000 acre-feet per year will be conveyed from the upper Little Snake drainage to the east slope of the Continental Divide (U.S.D.A., Forest Service, 1981).

The study area on the North Fork is located in Section 27, Township 13 North, Range 85 West at an elevation of 8,580 ft, within the boundaries of Medicine Bow National Forest, 1.5 miles below the diversion structure. Within the study area boundary, a stream section 0.3 miles in length, construction of a bridge and pipeline crossing was underway in the late summer of 1984 when heavy rains precipitated the sediment spill that led to the initiation of this study. Gradient through this area is 4.4 percent while the predominant natural substrate is boulders and cobbles. Wesche et al. (1977) reported a mid-July 1976 water temperature range of 55 to 63° Fahrenheit, a total alkalinity range of 25 to 32 mg l^{-1}, a pH of 7.1, and clear water conditions for this section of the North Fork. Instream flow recommendations developed by Wesche et al. (1977) called for a minimum flow of 3.0 cfs or the natural flow, whichever is less, and a three-day annual release of 60 cfs for flushing purposes during the spring runoff period. This flushing recommendation was based upon field measurement of low bankfull discharge and the findings of Eustis and Hillen (1954).

METHODS

During the Fall of 1984, four reaches were selected for study in cooperation with personnel from the Wyoming Game and Fish Department and the U.S. Forest Service (Figure 2). Reach 1, the uppermost site below the diversion, was located just above the confluence of Second Creek, approximately 1,200 ft upstream from the North Fork bridge and pipeline crossing. Reach 1 served as the control above the construction area from which much of the sediment spill originated. Reaches 2, 3 and 4 were located in descending order below the North Fork crossing area and were within the zone of immediate deposition from the spill. Given the intensive nature of the sampling to be conducted, study reaches were kept short in length, with Reach 2 being the longest, 50 ft.

During the Fall of 1985, three additional study reaches were established. Reach 0, located above the diversion, was selected to represent unregulated hydrologic and hydraulic conditions, while Reaches 5 and 6 were added to monitor migration of the sediment spill downstream (Figure 2). This paper will focus on the analysis of data collected from Reaches 2, 4, 5 and 6.

Three recording streamflow gage stations were installed within the study area in 1985 to monitor the North Fork hydrograph (Figure 2). Each station consisted of a stilling well constructed from perforated plastic pipe, a Leopold and Stevens Type F water stage recorder, a steel platform on which the recorder was seated, and an outside staff gage for measuring stream stage. A rating curve for each gage station was developed following standard U.S.G.S. procedures (Buchanan and Somers, 1969).

Four equally spaced cross-channel transects were established within each study reach. Field data collected along these transects were used to quantify changes in response to the runoff hydrograph of 1) hydraulic characteristics, including discharge, channel width, top width, water depth, cross-sectional area, wetted perimeter, hydraulic radius, and mean water velocity; 2) bedload transport; 3) suspended sediment transport; 4) quantity and distribution of deposited sediments; and 5) quality of the deposited sediments.

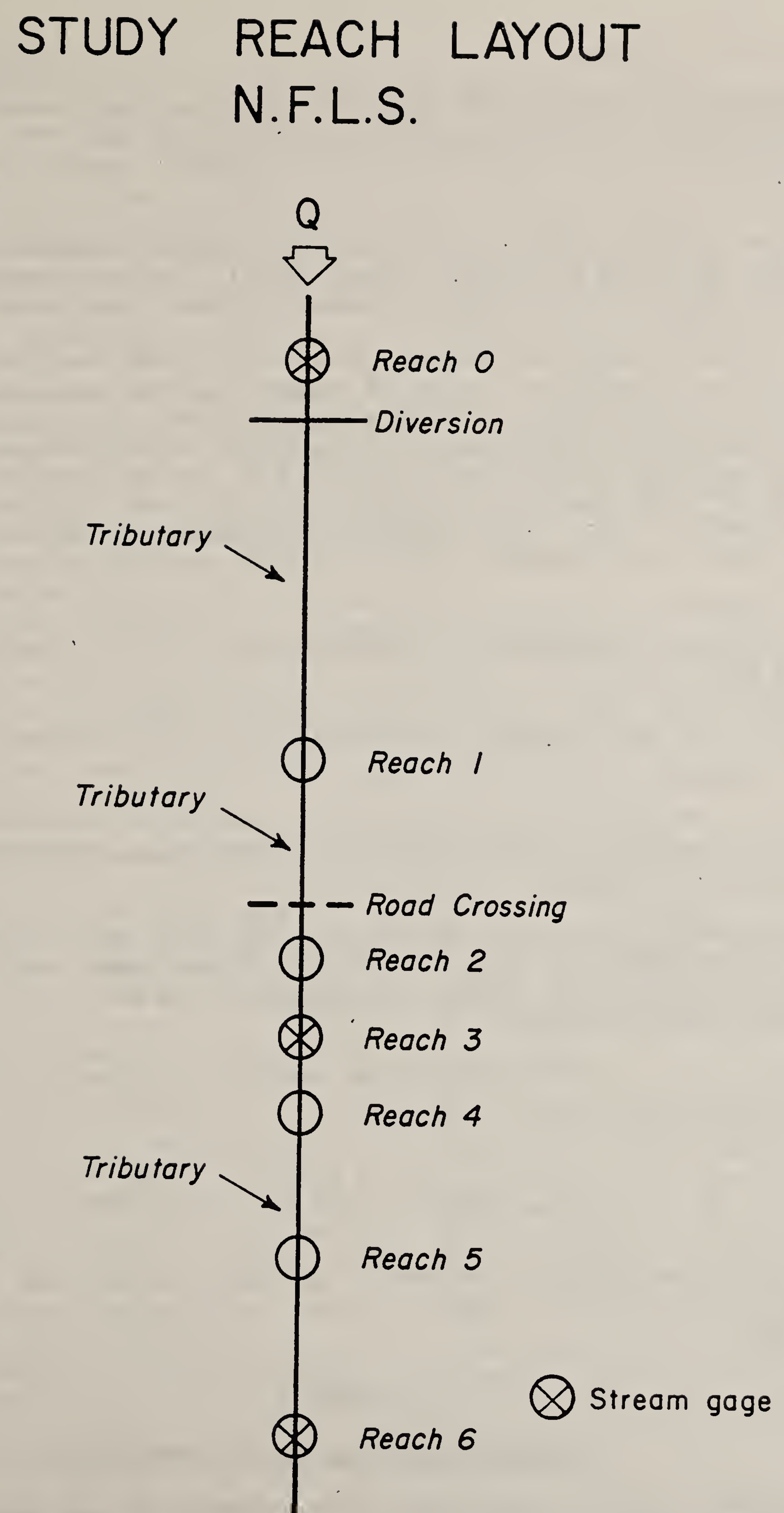


Figure 2. Study Reach Layout on the North Fork of the Little Snake River.

Field sampling began in late October, 1984, was then discontinued over the winter months, and was reinitiated in early May, 1985 as spring runoff began. Sampling continued throughout the open water period. This sampling pattern was repeated during 1986 and 1987.

Suspended sediment samples were taken with a USDH-48 sampler using the Equal Transit Rate technique described by Guy and Norman (1970). Bedload transport was measured using a Helley-Smith sampler as described by Emmett (1980).

The quantity of deposited sediment within each study reach at each sampling time was determined by multiplying the volume of material by its mean density and dividing this product by the surface area. Volume was calculated as the product of mean depth of deposition (measured at approximately 80 locations within the reach using a round steel depth rod), reach length, and reach width. Mean density determinations were based upon the analysis of core samples collected from each reach using a McNeil-Ahnell sampler (McNeil and Ahnell, 1964). All cores were oven dried for at least 24 hours at 140°F to standardize weight measurements. Volume of each core was determined by water displacement.

The composition and quality of the deposited material within each reach over time was assessed by:

Collecting 12 core samples periodically at each study reach over the period of study.

Particle size distribution by weight within each core sample was determined by dry-sieve analysis at the University of Wyoming's Department of Range Management Watershed Laboratory.

The mean particle size distribution for each reach at each sampling time was determined by averaging the results from the 12 individual core samples. Distribution plots of particle size versus percentage (by weight) finer than the given sieve sizes were then developed.

Deposition quality by reach over time was then assessed by calculating the geometric mean particle size (d_g), as follows:

$$d_g = (d_1^{w_1} \times d_2^{w_2} \times \ldots d_n^{w_n}), \qquad (1)$$

where d_n is the midpoint diameter of particles retained by the nth sieve and w_n is the decimal fraction by weight of particles retained on the nth sieve (Platts et al., 1983).

RESULTS

Development of Flushing Recommendation

The sediment spill on the North Fork occurred in the late summer of 1984. As streamflow during this season was near baseflow and water storage capabilities did not exist to allow trial flushing flow releases, study of the response of the deposited material to the runoff hydrograph could not begin until the spring of 1985. Based upon the 1985 investigation, the recommended mitigative flushing flow regime would then be implemented in 1986.

A summary of selected hydraulic characteristics by study reach is presented in Figure 3. Reach 2, representative of the steep gradient, boulder strewn, riffle-cascade habitat common on the North Fork, had water surface slopes exceeding 4.0 percent. Water velocities were higher and depths shallower at Reach 2 than at other study reaches. Reach 4 was characterized by lower gradient (less than 1.0 percent), deeper water and slower velocities, and typified the pool habitat, formed by woody debris, that serves as important rearing areas for Colorado River cutthroat trout. Reaches 5 and 6 were similar in character to Reach 4. Reaches 1 and 3, not shown in Figure 3, were similar in hydraulic characteristic and represented more moderate conditions. For the purpose of mitigative flushing flow regime development, analysis has focused on Reaches 2 and 4.

Spring runoff hydrographs for 1985, 1986 and 1987 at the Reach 3 streamgage are presented in Figure 4. Also shown is the magnitude of the maintenance flushing flow recommended by Wesche et al. (1977) for the North Fork in the vicinity of Reaches 2, 3 and 4. This recommendation, 60 cfs for a duration of three days, was not intended for mitigative purposes in response to a sizeable sediment spill, but rather for routine channel flushing and maintenance under normal operating conditions.

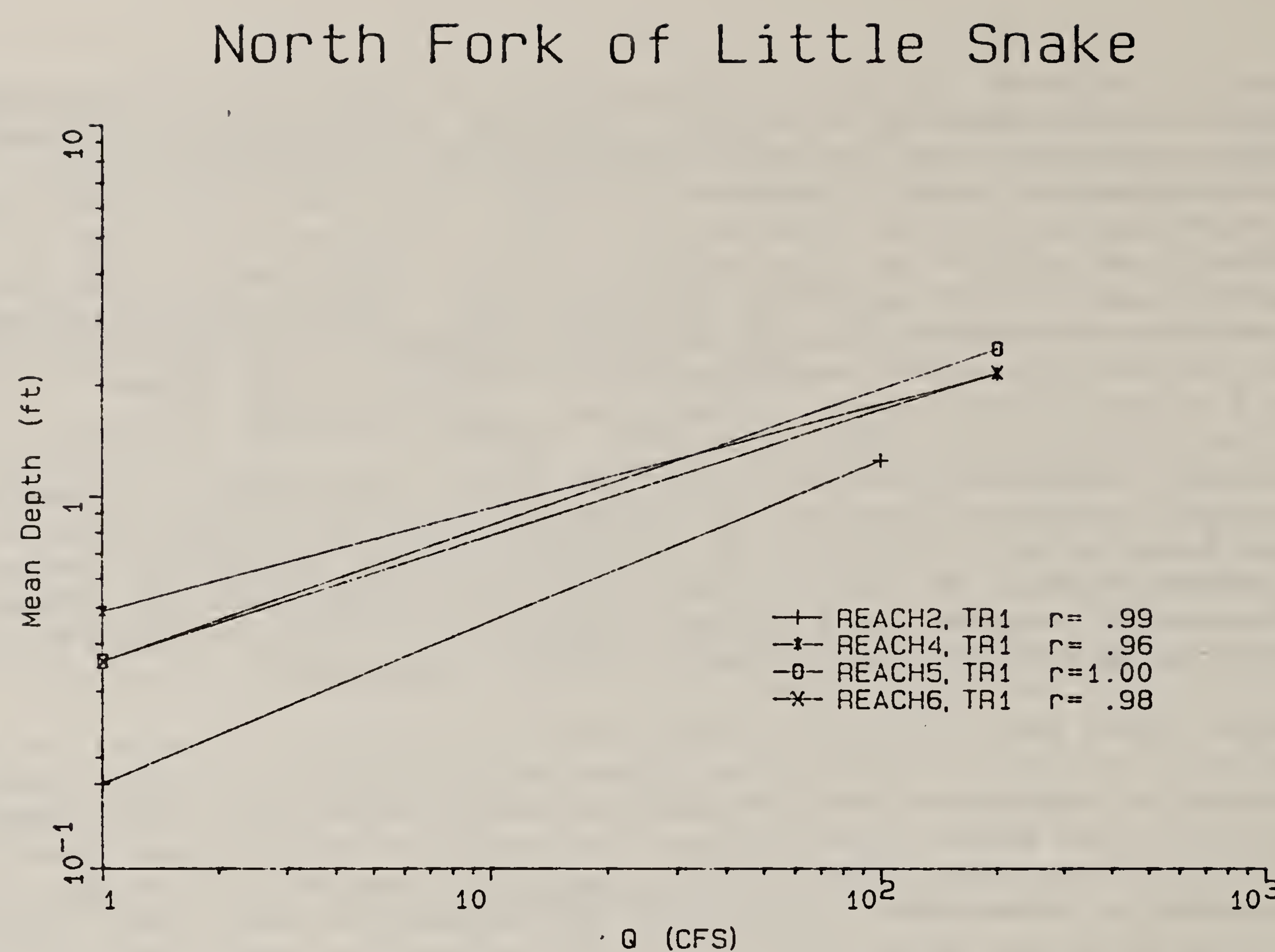
Three major runoff peaks occurred during 1985 which equalled or exceeded the magnitude and duration of the 1977 flushing flow recommendation (Figure 4). Each peak had a maximum instantaneous discharge of 105 cfs while the maximum mean daily peaks ranged from 73 to 80 cfs. Based upon maximum instantaneous discharge, the earliest peak lasted three days (May 10 to 12), the second peak extended over eight days (May 23 to 30), and the third peak exceeded the recommended discharge on five consecutive days (June 6 to 10). A fourth peak occurred in late June during which the maximum flow approached the 60 cfs level, but only for a portion of one day.

A time series plot of the quantity of deposited material within the study reaches is presented in Figure 5, while the quality of the deposition, expressed as geometric mean particle size, is plotted over time in Figure 6. Reach 4, the low gradient pool section, was found to have the greatest magnitude and variation in terms of deposition quantity as well as the lowest deposition quality throughout 1985. Based upon these results and the assumption that the maintenance of pool quantity and quality is essential to the well-being of the Colorado River cutthroat trout population in the North Fork, Reach 4 became the focus of our mitigative flushing flow regime development study.

Five factors needed to be considered in the development of the mitigative flushing flow regime for the North Fork. These included 1) the number of flushing events needed; 2) the magnitude of each event; 3) the duration of each event; 4) the desired rate of hydrograph rise; and 5) the timing of the releases. Figure 7 presents the relationship of the 1985 instantaneous hydrographs for the four runoff events to the quantity of deposited sediments in Reach 4. These results formed the basis for our 1986 recommendation.

Number of Flushing Events.--Analysis of Figure 7 indicates that the latter three flushing events were successful in reducing sediment deposition from 82 to 51 lbs per ft^2 over the period from May 21 to July 1. The first flushing event, May 10-12, resulted in the import of 50 lbs/ft^2 into Reach 4 (32 lbs/ft^2 in October, 1984; 82 lbs/ft^2 on May 15, 1985), 60 percent of which was removed by the latter three flushes.

The 1985 data indicated that three flushing events would be necessary in 1986. The first event would concentrate any additional surplus sediments from the upstream steep and moderate gradient reaches in the pools, while the second and third events would reduce the aggraded material. On the average, the latter three 1985 flushes each



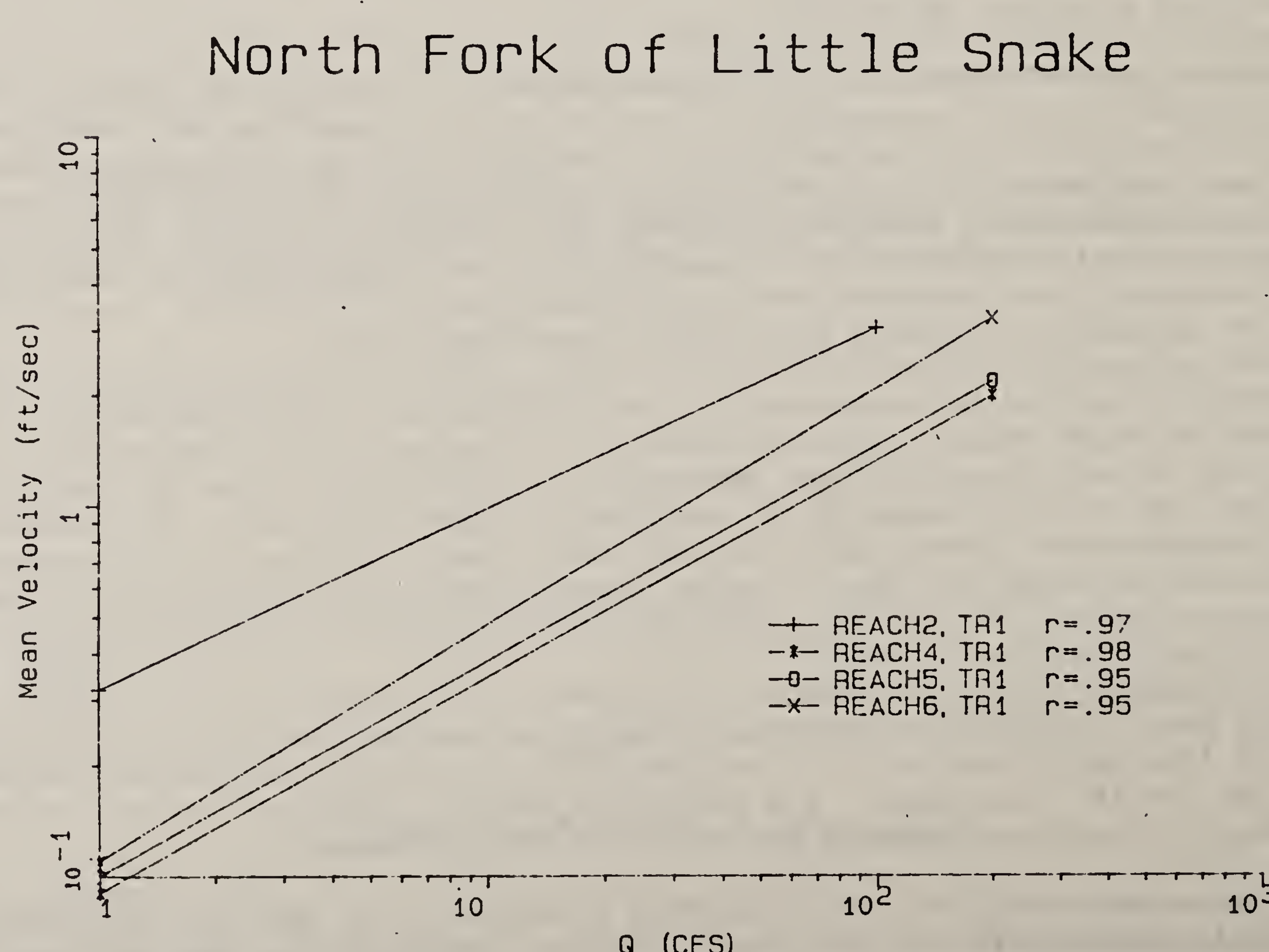


Figure 3. Relationship of Water Depth and Velocity with Discharge at Four North Fork of Little Snake Study Reaches.

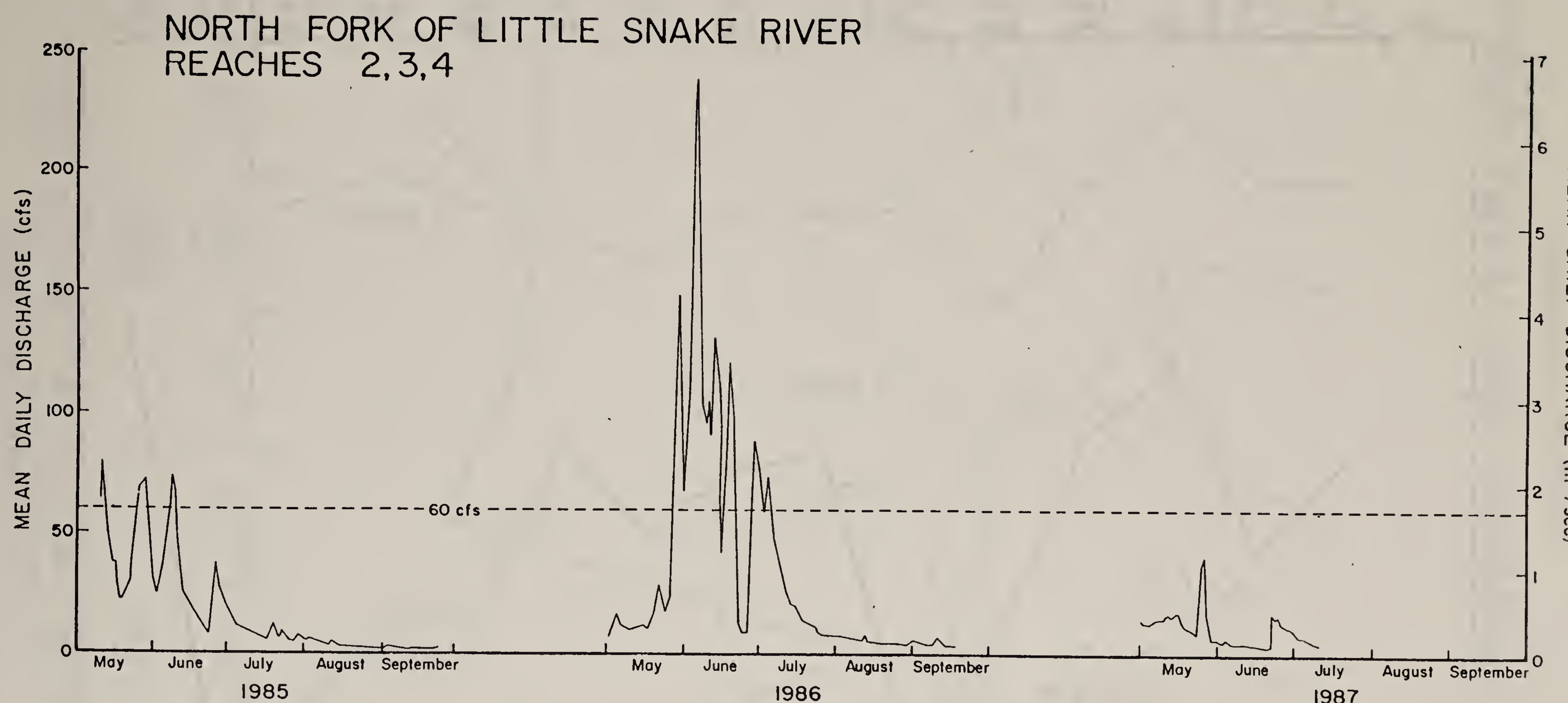


Figure 4. Hydrographs for 1985, 1986 and 1987 at Reach 3, North Fork of Little Snake River.

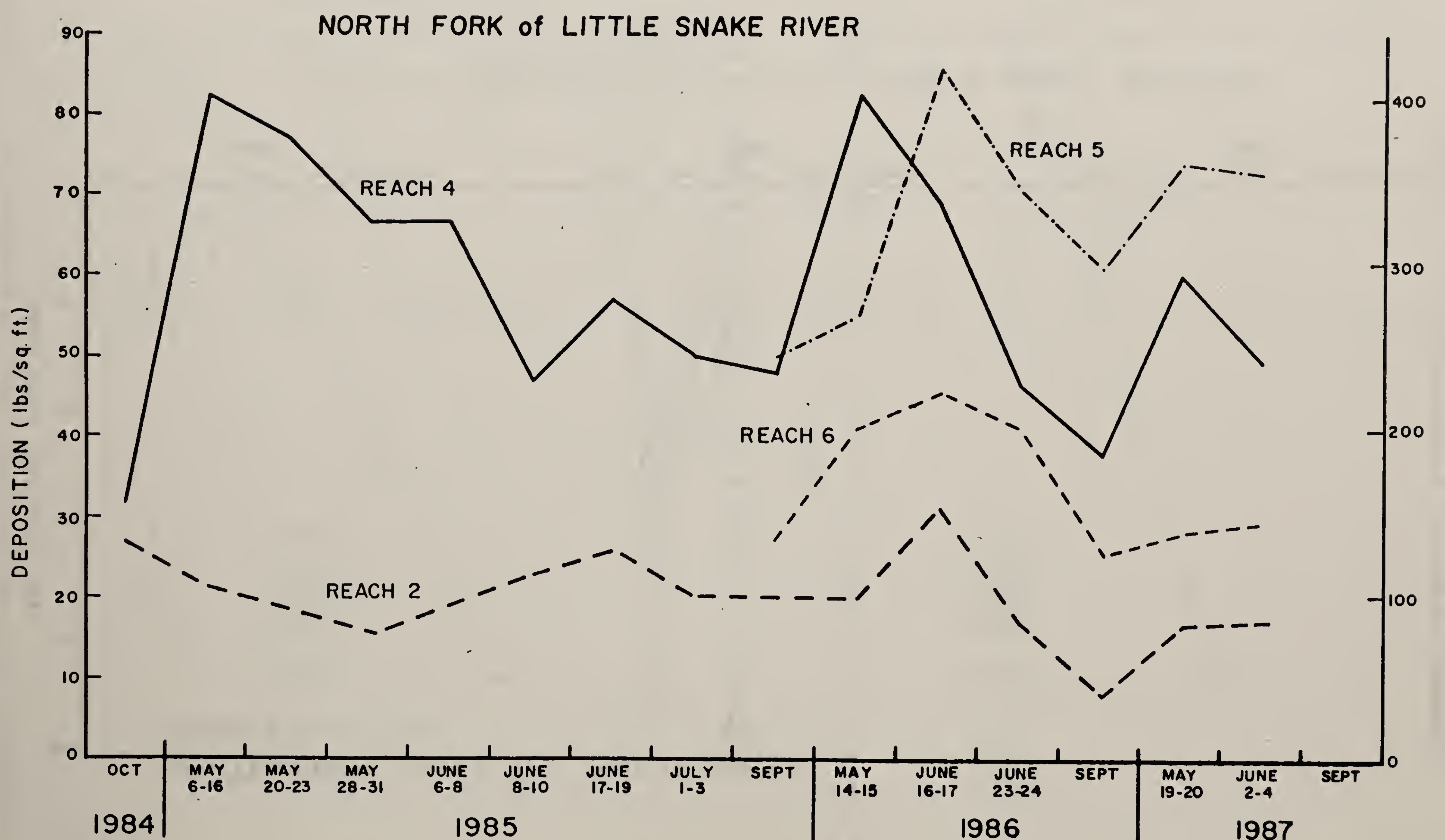


Figure 5. Quantity of Sediment Deposition Over Time at the North Fork of Little Snake River Study Reaches.

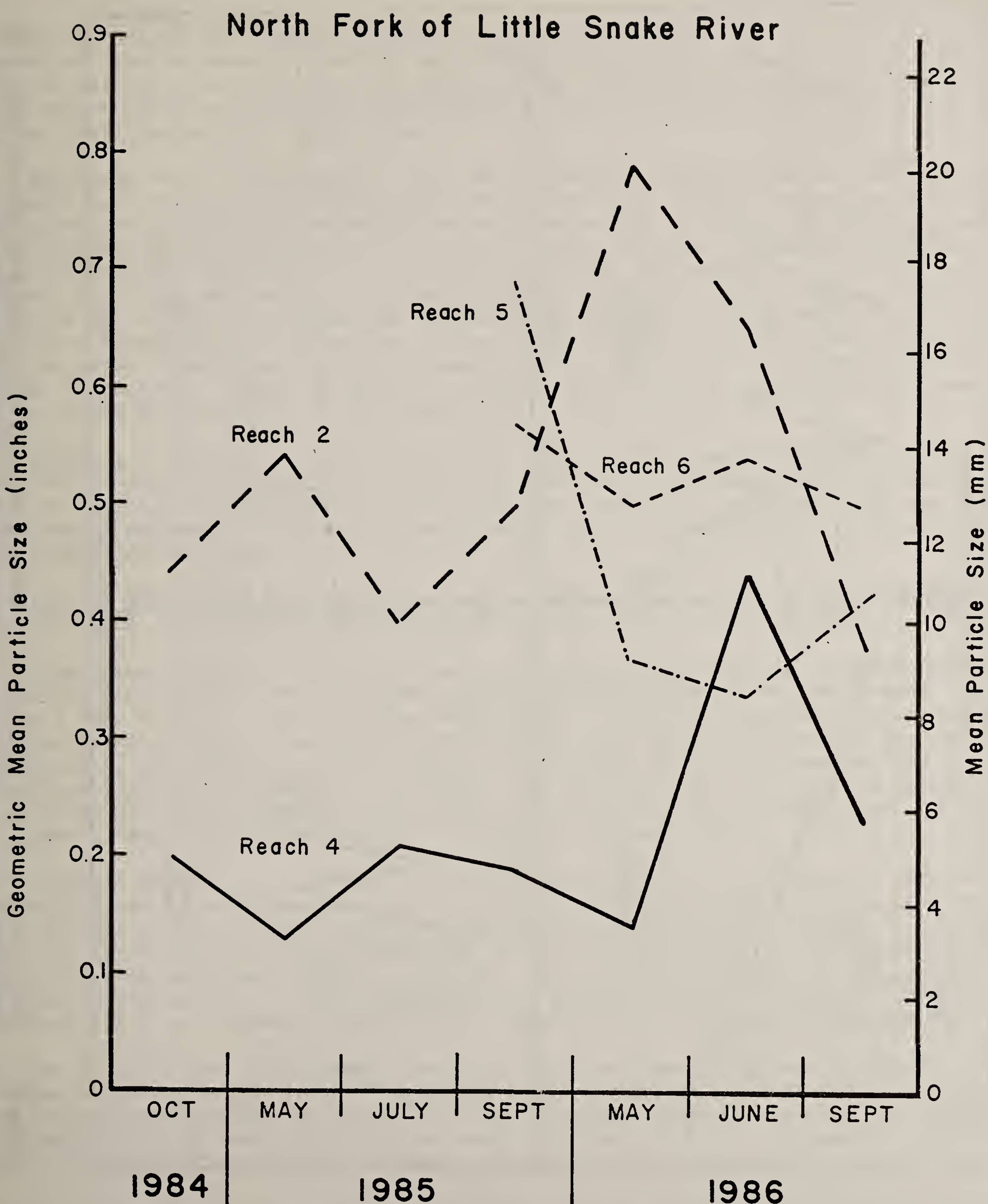


Figure 6. Quality of Deposited Sediments Over Time at the North Fork of Little Snake River Study Reaches.

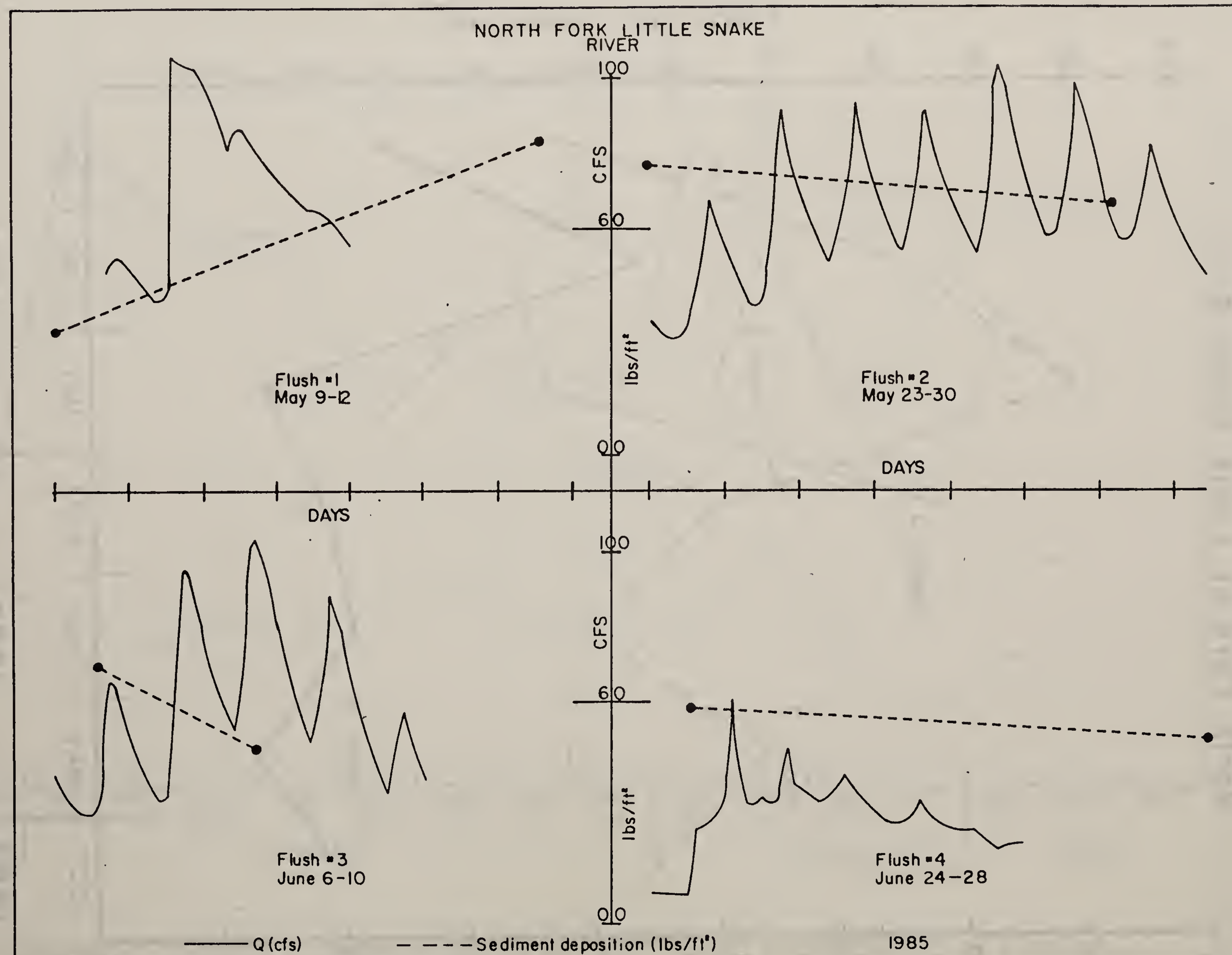


Figure 7. Relationship of the 1985 Instantaneous Hydrographs for the Four Runoff Events to Deposition Quantity at Reach 4, North Fork of Little Snake River.

removed 10 lbs/ft^2 of aggraded material. If the assumption was made that the target deposition level in Reach 4 would be approximately 30 lbs/ft^2 (the October 1984 level), and that material from the 1984 sediment spill had not reached this study section to any great extent prior to our October 1984 sampling, then the result of the latter two 1986 flushes would approach our target level.

Magnitude.--The 1985 flushing events were somewhat successful in removing deposited sediments and increasing mean grain size of bed material. The peak instantaneous flow during each of the four flushes equaled or exceeded 60 cfs, while for Flushes 1, 2 and 3, 60 cfs approximated the median flow, based upon flow duration analysis. Inspection of cross-section plots indicated that a discharge of 60 cfs covered the active low flow channel in both steep and low gradient sections, paralleling the results reported by Wesche et al. (1977), who recommended 60 cfs as the flushing flow for this portion of the North Fork. Analysis of 1985 bedload composition data indicated that the majority of the material being transported at flows greater than or equal to 60 cfs was less than 0.5 inches in diameter. Thus, we would not expect severe disruption of quality spawning gravels given flushing flows of this magnitude.

Duration.--Analysis of Figure 7 indicated that Flush #1 (three-day duration) and the first three days of Flush #3 were the most successful for moving bed material. In contrast, deposition measurements taken after six consecutive days on which peak daily flows had exceeded 60 cfs indicated that Flush #2 was not as effective. Thus, each flush was recommended for three days.

Rate of Hydrograph Rise.--Clearly, magnitude and duration of events were not the only variables determining flushing success.

Inspection of Figure 7 indicated that the flushes which moved the most bed material, #1 and #3, also had the steepest slopes on the ascending limbs of the hydrographs. Flush #1 had a rate of rise of 16.4 cfs/hour while Flush #3 rose 10.2 cfs/hour. Flush #4, the smallest event in terms of magnitude and duration, resulted in a net export of 7 lbs/ft^2 from Reach 4, only 30 percent less than that exported by Flush #2. However, the rate of hydrograph rise for #4 exceeded 13 cfs/hour for the main portion of the ascending limb compared to less than 7 cfs/hour for the steepest portions of the hydrograph for Flush #2. Thus a rate of rise of at least 10 cfs/hour was recommended.

Timing.--As water storage was not possible on the North Fork, flushing flow events had to be timed in accordance with the spring snowmelt runoff period. Inspection of the 1985 hydrograph and the discharge records from USGS gage station No. 09251800 indicated that the probability of having sufficient streamflow available for the three flushing events was greatest from mid-May to mid-June. As cutthroat spawning activity begins on the North Fork during the latter part of June (Quinlan, 1980), all flushing should be completed prior to that time to prevent egg deposition in areas soon to be dewatered.

The trend of the 1985 sediment deposition data indicated that moderate pool filling occurred between flushing events, but that the peak amount of deposition between successive non-flushing periods decreased over time. Because of this and also to attempt to coordinate flushing events with normal work week patterns, we recommended a ten-day non-flushing period between each successive flush.

To achieve the recommended rate of hydrograph rise, flushing events were to be initiated during mid-afternoon. Inspection of the 1985 instantaneous hydrographs indicated the most rapid rise in the hydrograph occurred at that time due to snowmelt runoff.

Evaluation of Flushing Recommendation

During the winter of 1985-86, negotiations were conducted between the involved parties and the mitigative flushing flow recommendations presented above were approved for implementation during the spring of 1986. Thus, we were provided the rather unique opportunity to evaluate the success (or failure) of our recommendation.

Snowpack in the North Fork watershed was well above normal during the winter of 1985-86. This, coupled with the agreement to pass all flow during the required three flushing periods, resulted in flushing releases well in excess of the required 60 cfs. As shown in Figure 4, peak mean daily discharges approached 250 cfs. Due to needed maintenance on the diversion system, additional flushes were also released in late June and early July.

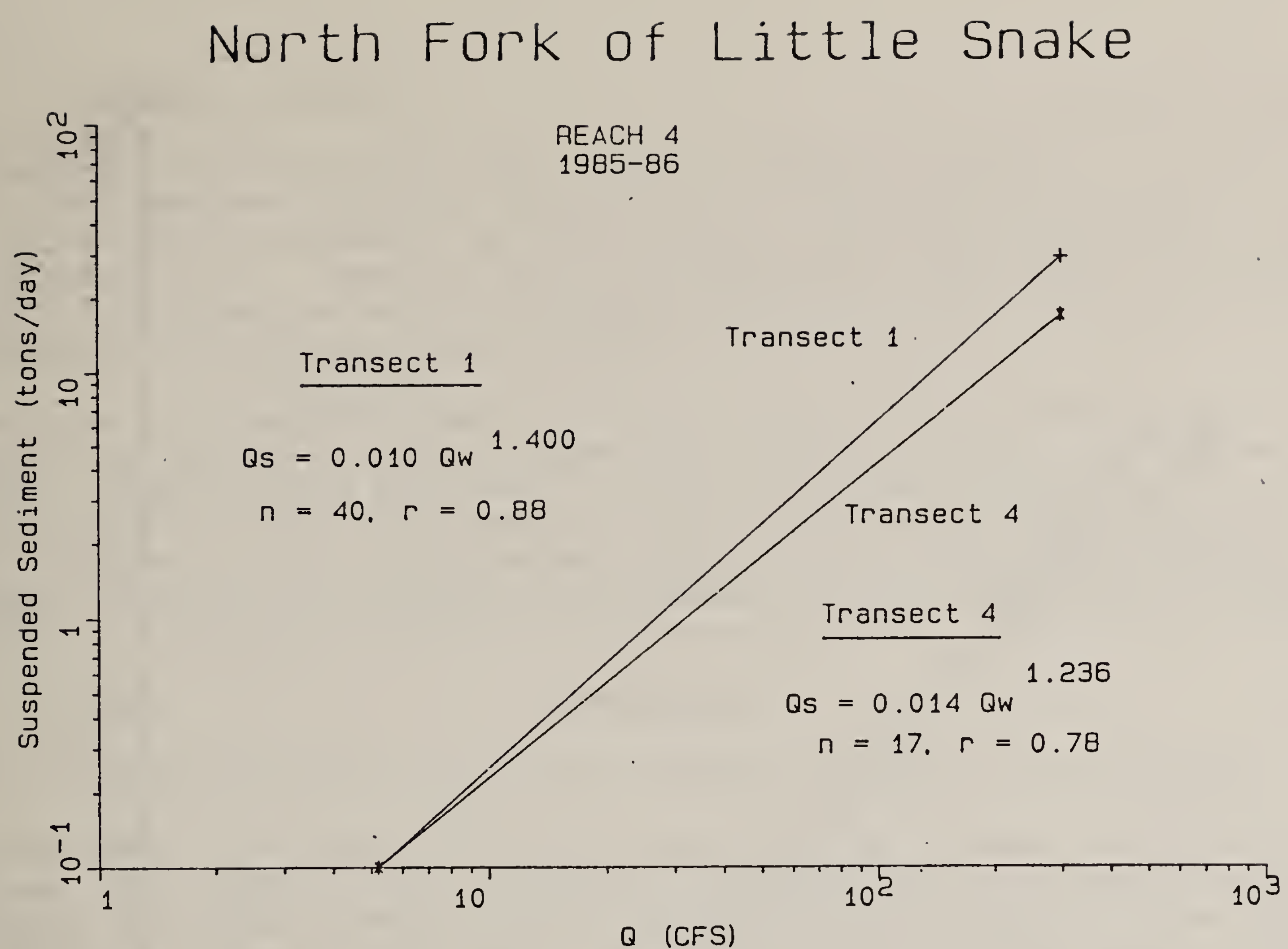
While excess water was available for release in 1986, additional sediment deposition had occurred in Reach 4 between September, 1985 and mid-May 1986 (Figure 5). Stored material increased from 48 to 82 pounds per square foot over the winter, approximately the same quantity of deposition measured in May, 1985. Also, deposition quality had declined, just as it had the previous year (Figure 6).

Overall, the flushing regime released on the North Fork during 1986 was quite successful at Reach 4 (Figures 5 and 6). Deposition quantity was reduced from 82 to 46 pounds per square foot by June 23 and to 38 pounds per square foot by September. Geometric mean particle size increased to 0.44 in. by late June, but declined by September to 0.23 in. These trends, evident at Reach 2 as well, would indicate that deposition quantity had been even further reduced by mid-July immediately following flushing releases and that fine sediments transported by lower flows had begun to redeposit. Unfortunately, no sampling was conducted between late June and September to verify this.

The migration of sediment downstream from the zone of greatest impact from the spill can be charted by comparing Reaches 4, 5 and 6 on Figures 5 and 6. The first several flushing cycles of 1986 moved material from Reach 4 and transported much of it 900 feet downstream to Reach 5. Reach 6, located approximately 3,000 feet below Reach 5, also showed increasing sediment storage through the first three flushes, but not of the magnitude observed at Reach 5. Deposition quality remained stable at Reach 6, indicating little deposition of the finer fractions being transported.

Therefore our analysis of the North Fork database has been limited primarily to gross comparisons of deposition quantity and quality both spatially and temporally. Over the next 12 to 24 months, analysis will increasingly focus on the processes of sediment transport in steep, rough tributary channels such as the North Fork, the role of woody debris in controlling such processes, the testing of the several flushing flow and sediment transport models currently available, and the development of new models.

One flushing flow method we currently have begun testing can be termed a "sediment transport input-output" model. For streams such as the North Fork, where discrete critical habitat types such as debris jam pools can be readily identified, measured, and managed in terms of flushing flow requirements, such a model would require development of sediment transport-discharge relations immediately above and below the critical habitat type. The minimum flushing flow requirement would be that discharge at which sediment output from a pool exceeded sediment input. For example, suspended load and bedload transport curves for Transects 1 and 4 at Reach 4 are presented in Figure 8. Transect 4 is located at the pool entrance while Transect 1 is at the pool exit. Combining bedload and suspended load transport curves for each transect gives an estimation of total transport into and out of the pool, as shown on Figure 9. Below approximately 110 cfs,



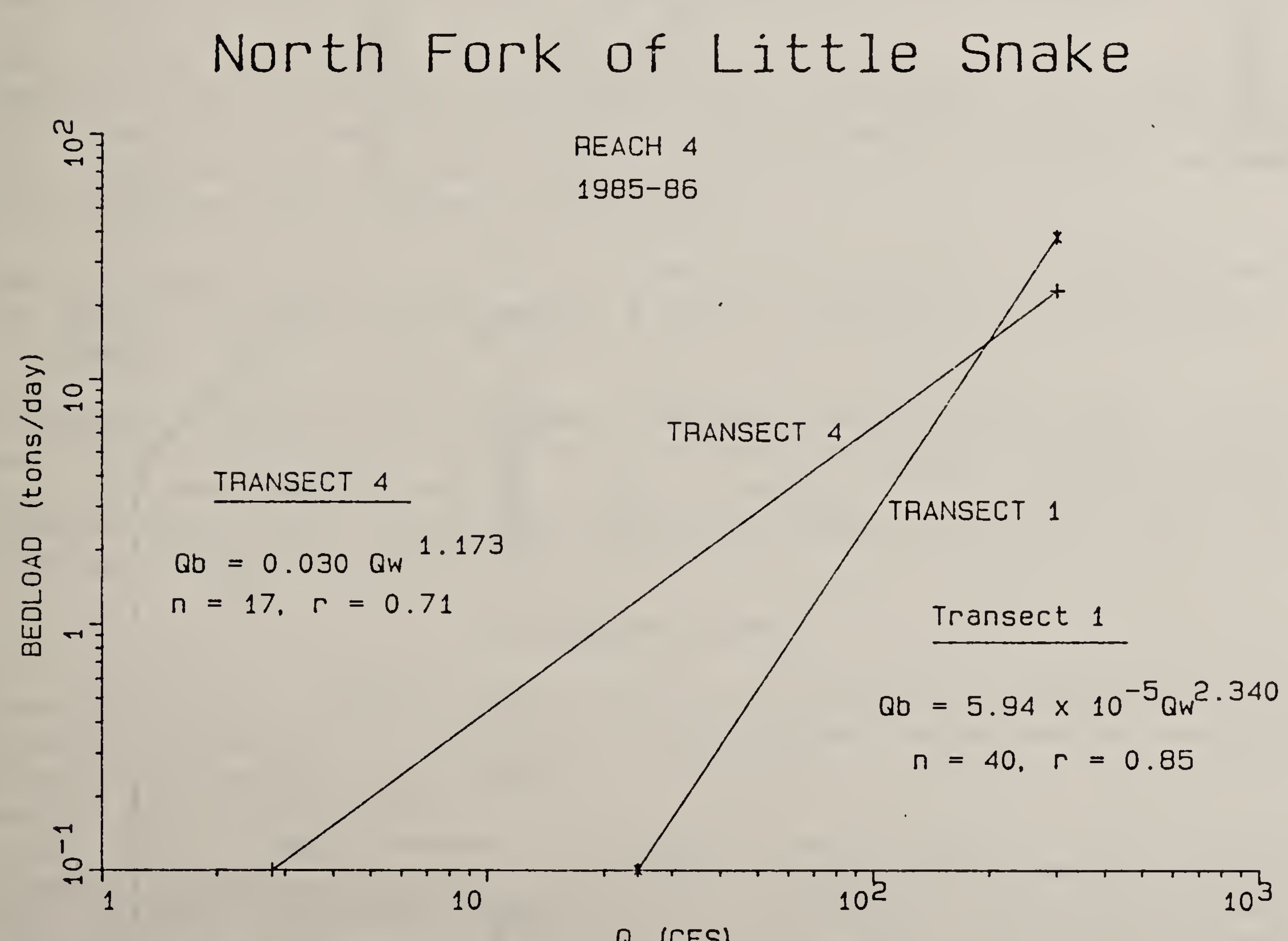


Figure 8. Suspended and Bedload Transport Relations at Transects 1 and 4, Reach 4, North Fork of Little Snake River.

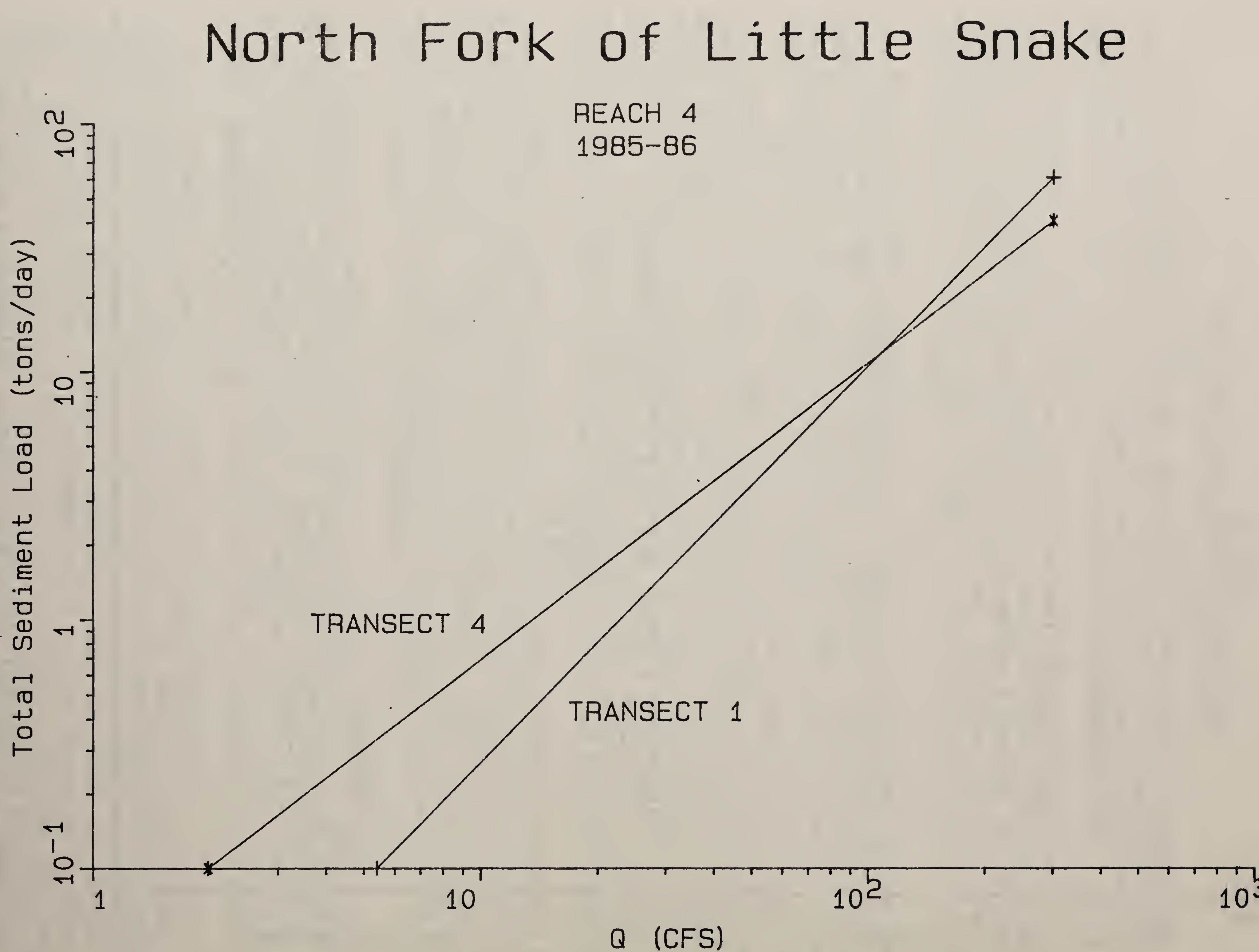


Figure 9. Total Sediment Load Transport at Transects 1 and 4, Reach 4, North Fork of Little Snake River.

the sediment load entering the pool exceeds sediment exiting and deposition occurs. Above 110 cfs, sediment transport exiting exceeds that entering and scour or flushing occurs. Knowing the "crossover" discharge defines the minimum boundary for the magnitude of the flushing flow. Combining this information with knowledge of the quantity of material to be flushed and water availability facilitates the hydrologist in the design of a flushing flow regime to achieve specific management goals.

Comparing the results of the "input-output" model to the 1986 flushing hydrograph and time-series deposition quantity plots for Reach 4 shows a remarkable degree of similarity. Between May 15 and June 22, 1986, the flushing regime removed 35,500 pounds of material from the pool, based upon deposition depth measurements. Applying the total sediment transport curves for Transects 1 and 4 to the mean daily discharges for that same period results in an estimate of approximately 34,500 pounds being transported out of the pool, a discrepancy of approximately three percent.

CONCLUSIONS

Based upon our analysis to date, the following conclusions can be drawn:

1. In the North Fork of the Little Snake River, a steep, rough, well armored tributary stream, the magnitude and variability of stored sediment is much greater in low gradient pool habitats than in high gradient riffle-cascades. This, coupled with the apparent value of such deep, slow habitats for Colorado River cutthroat trout, established such pools as critical areas for flushing flow analysis.

2. Flushing flow releases on the North Fork have been successful in reducing stored sediment in the stream reaches most directly influenced by the late 1984 sediment spill. Below this zone of greatest impact, deposition quantity decreases and quality increases in a downstream direction, indicating the effects of the spill are being moderated both temporally and spatially.

3. Given the above normal runoff of 1986 and the continued pool aggradation during the late fall, winter and early spring, a direct evaluation of the mitigative flushing flow regime recommended for the North Fork was not possible.

4. Preliminary evaluation of a sediment transport "input-output" model to determine the magnitude and duration of required flushing flow releases to meet specific management objectives was encouraging. This, as well as other flushing flow and sediment transport models, will be more thoroughly evaluated against the North Fork database in the next 12 to 24 months.

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TAR CREEK: DIVERSION EFFORTS TOWARD AN UNPOLLUTED FUTURE

David S. Malone [1], Janet S. Walstrom [2], and Ron Jarman [3]

ABSTRACT: As lead and zinc mining activities ceased in the tri-state area of Kansas, Oklahoma, and Missouri in the early 1970's, dewatering pumps were shut off and mine cavities became flooded. By 1979, acid mine water from the mines began to surface through abandoned mine shafts and boreholes.

The Oklahoma Water Resources Board (OWRB), in conjunction with the Tar Creek Task Force (TCTF), began investigations into the pollution problem in 1980. In October 1981, Tar Creek was included among the sites on the National Priorities List under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA).

Remedial investigations and feasibility studies were conducted in 1982 and 1983. These studies produced the following seven alternatives to mitigate the threat to public health:

1. No action
2. Plug abandoned deep water wells
3. Surface water diversion
4. Alternative drinking water supplies
5. Discharge treatment of surface waters
6. In-situ treatment of mine water
7. Collection and treatment of mine water

Deep water wells were plugged, diversion dikes were constructed around subsidence features, and streams were rerouted to combat the pollution problem.

Health hazards remain, but a major step has been taken to reduce the adverse impacts imposed by the mining activities of yesteryear.

KEY TERMS: Boone & Roubidoux Aquifers; acid mine water, CERCLA, Remedial actions; lead/zinc mining.

HOW THE PROBLEM CAME INTO BEING

Picher Mine Field - Location

The Picher Mining Field, located in Ottawa County, Oklahoma, and Cherokee County, Kansas, is one of the lead and zinc subregions which make up the tri-state mining region of Oklahoma, Kansas, and Missouri (Figure 1). Encompassing thirty square miles, the Picher Field was one of the most productive lead and zinc mining areas in the United States (Playton et al, 1980).

The Picher Field is situated on the west ridge of the Ozark Plateau province. The Ozark Plateau is a broad, low structured dome laying mainly in southern Missouri and northern Arkansas. However, the main part of the Picher Field is within the Central Lowland Province.

1 Project Manager, Black & Veatch, Engineers-Architects, Kansas City, Missouri
2 Environmental Scientist, Black & Veatch, Engineers-Architects, Kansas City, Missouri
3 Division Chief, Water Quality Division, Oklahoma Water Resources Board, Oklahoma City, Oklahoma

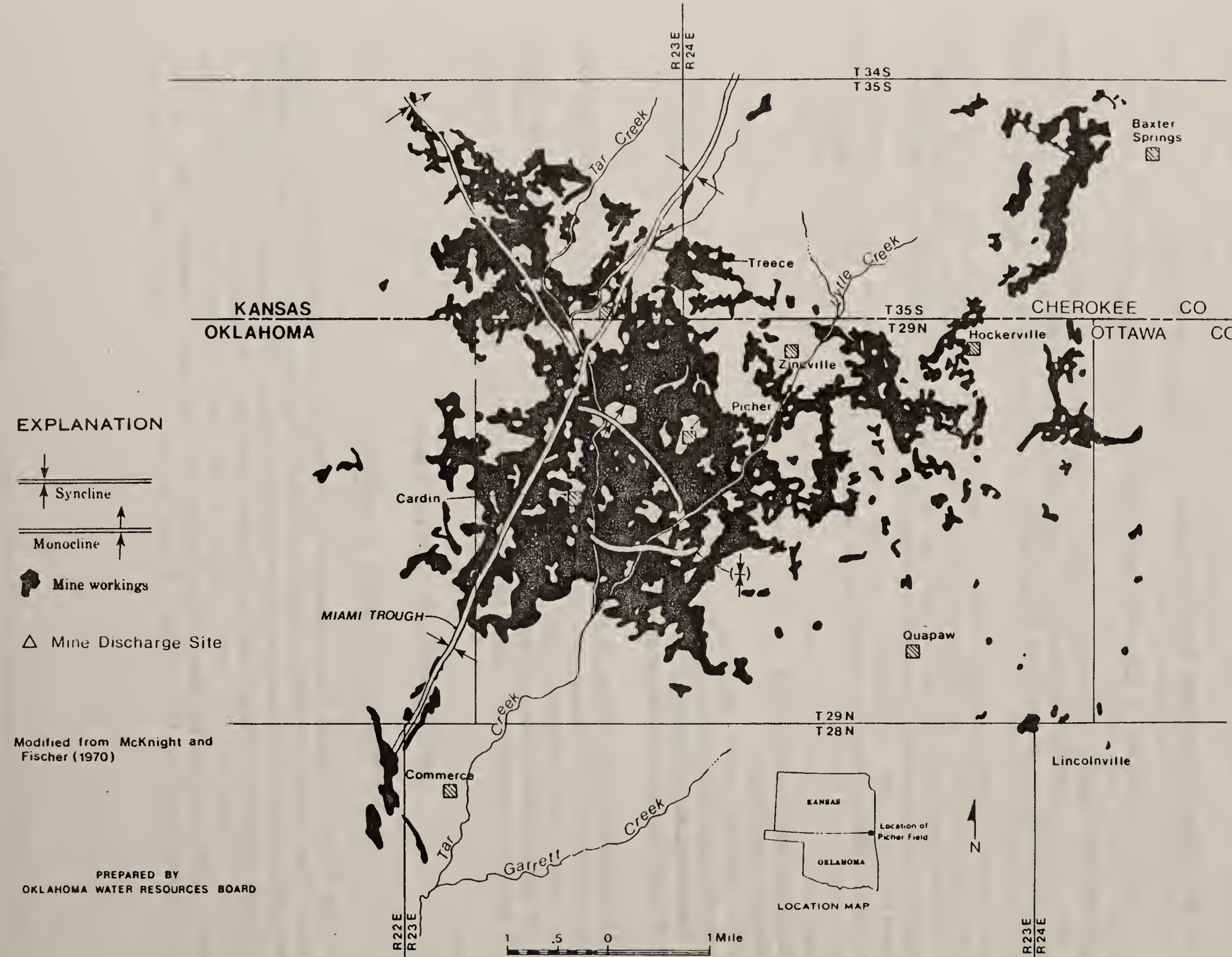

T 34S
T 35S
R 23E
R 24E
Baxter Springs
Tar Creek
Treece
Lytle Creek
KANSAS
OKLAHOMA
T 35S
T 29N
CHEROKEE CO
OTTAWA CO
Hockerville
Zincville
Picher
EXPLANATION
Syncline
Monocline
Mine workings
Mine Discharge Site
Cardin
MIAMI TROUGH
Quapaw
T 29N
T 28N
Lincolnville
Modified from McKnight and Fischer (1970)
Commerce
Tar Creek
Garrett Creek
KANSAS
OKLAHOMA
Location of Picher Field
LOCATION MAP
N
PREPARED BY
OKLAHOMA WATER RESOURCES BOARD
R22E
R23E
1 .5 0 1 Mile
R23E
R24E

Figure 1

This province is characterized by a nearly flat, treeless prairie underlain by Pennsylvanian shales.

The streams that traverse the mining field flow southward to the Neosho River. Elm Creek, on the western edge of the field, and Tar Creek and its main tributary, Lytle Creek, are the principal streams. A short distance east of the mining field is the Spring River, which is the major south-flowing tributary of the Neosho River.

The principal communities within the Picher Field are Miami, North Miami, Picher, Cardin, Quapaw, and Commerce. All these communities receive their drinking water from the Roubidoux aquifer, which is approximately 1,100 feet from the surface.

Picher Mining Field - Site History

The principal ores found in the Picher Mining Field are Sphalerite/Zinc Sulfide, Galena/Lead Sulfide, and Iron Pyrite. Lead-zinc ores were first discovered in the Picher Field in 1901, with output of concentrates beginning in 1904. The main portion of the ore body was discovered in 1914, leading to a vast increase in ore production. Early mining was characterized by a multitude of small operators on 40 acre tracts, with each operator conducting mining, drilling and milling operations. In 1927, centralized milling began, leading to the consolidation of mining and milling operations.

Large scale mining activities began their decline in the late 1950s, but production continued through most of the 1960s. Peak production occurred in the 1920s when the Picher field yielded approximately 55% of the total zinc produced in the U.S. Total production of concentrates from the Picher mining field were approximately 7.3 tons zinc and 1.8 tons lead, yielding miners approximately $1.4 billion.

Acid Mine Water - Formation

During the mining activities, pyrite rich wastes in the Boone formation were oxidized when exposed to atmospheric oxygen. When the mines flooded, these oxidized sulfides dissolved into the surrounding groundwater and this produced acid mine water. The acid water then reacted with the surrounding rock which caused many of the metals present to dissolve. The resulting mine water possessed high concentrations of zinc, lead, and cadmium.

Acid Mine Water - Surface Water Impacts

Tar Creek is the principal drainage system in the Picher Field (Fig. 2). With its headwaters in Cherokee County, Kansas, Tar Creek flows southerly through the field between Picher and Cardin, passing Commerce and Miami on the east, to its confluence with the Neosho River, one of two major rivers in northeastern Oklahoma. Tar Creek is a small ephemeral stream characterized by standing pools. Along with its major tributary Lytle Creek, Tar Creek drains approximately 53 square miles of area.

Because of the low flow during most of the year, and the low buffering capacity of Tar Creek, the impact from acid mine water artesian flows is severe. The acid mine drainage has had a severe impact on Tar Creek, causing numerous water quality violations. As a result, the beneficial uses assigned to Tar Creek, including aesthetics and secondary warm water fishery, cannot be realized. Most of the biota in the creek have disappeared, and red stains caused by precipitation of ferric hydroxide dot the banks and bridge abutments. The sediments in Tar Creek are contaminated by lead, zinc, cadmium, and iron from the mines. However, concentrations of these metals in both water and sediment near the mouth of Tar Creek are much less than further upstream.

The impact of Tar Creek on the Neosho River is evident from the red stains observed on cliffs and bridge abutments. On two occasions, the water quality standard for zinc was exceeded. No other water quality standards violations have been detected. The sediments of the

Neosho River appear to be relatively free of acid mine contamination. Furthermore, it does not appear that any beneficial uses assigned to the river are presently being impaired by the Tar Creek discharge.

Acid Mine Water - Ground Water Impacts

The Oklahoma Water Resources Board collected water samples from six Roubidoux wells in the Picher area. Samples were collected on three occasions, during the period from November 1982 to January 1983. Additional historical and background water quality data from Boone and Roubidoux wells (USGS files) was available, determined adequate and used in the analysis.

The Roudiboux aquifer generally produces a good quality calcium-bicarbonate type water. Five of the six municipal wells sampled by the OWRB showed no current pollution problem due to the inflow of acid mine waters. However, the City of Picher's wells have shown some degradation. Lead and cadmium concentrations in all wells sampled were below detection limits and no samples indicated a threat to human health. The pH for the Roubidoux wells sampled is generally between 6.5 and 7.0 standard units, compared to expected pH levels of 7.7 to 8.4, typical of dolomite aquifers. In addition, there were scattered instances of elevated concentrations of dissolved iron. This data suggests that water from mines in the Boone Formation is reaching parts of the Roubidoux Formation. As a result, some degradation of this important water source would occur. The City of Quapaw, for example, has abandoned a total of three Roubidoux wells due to poor water quailty.

Mining operations intersected many deep wells which were apparently improperly or never plugged. In addition, acid mine waters are probably reaching the Roubidoux Formation via holes in corroded casings of active wells. In the recent past, Commerce, Cardin, and Picher have replaced corroded well casings after experiencing a large increase in iron concentration in their drinking water supplies. Replacing the well casing alleviated the problem, but the corrosive water in the Boone and Roubidoux aquifers will probably cause the problem to recur in the future. The City of Picher experienced a complete well failure in 1984 due to collapse of the well casing.

Discovery of the Problem

In 1978, the U.S. Geological Survey completed a groundwater study concerning the chemical quality of water contained in the abandoned lead and zinc mines of the Picher field (Playton, et al 1980). The study concluded that, due to the rising water table of the Boone aquifer, discharge of highly mineralized water from the abandoned mines in the district was imminent.

Continuous discharge of acid mine waters from the abandoned mines of the Picher Field began near Commerce, Oklahoma, in late November 1979. Reports of the discharge were brought to the attention of the Oklahoma Water Resources Board by State Senator William Schuelein. The OWRB initiated a preliminary assessment of the pollution problem caused by the discharging mine waters and made recommendations concerning a further course of action in a report released in March 1980 (Adams 1980).

ADMINISTRATION OF THE TAR CREEK SUPERFUND SITE

Formation of the Tar Creek Task Force

Acting on recommendations made by the OWRB, Oklahoma Governor George Nigh formed the Tar Creek Task Force in June 1980. The TCTF was comprised of representatives from 24 local, state, and federal agencies who were charged with the responsibility of implementing field studies in the Tar Creek area, determining the most practical and cost effective solutions to the pollution problem, and overseeing remedial actions. The Task Force was co-chaired by Ed Pugh, Special Assistant to the Governor, Ron Jarman, Chief of the OWRB's Water Quality Division, and Ron

Coker, a member of a Miami Citizen's group. The OWRB was designated lead agency of the Task Force.

Over the course of the next two years, 3 TCTF subcommittees conducted extensive field investigations to determine the extent and impact of the pollution problem. These studies were funded partially by the EPA under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA = Superfund). The major findings of the subcommittees were as follows:

* The Health Effects Subcommittee concluded that:

  - there were no adverse health effects as long as mine water was NOT consumed;
  - properly treated waters of the Neosho River, Spring River, and Grand Lake were safe to drink;
  - water supplies provided to citizens by wells in the Roubidoux aquifer were safe to drink;
  - air in the mining region was safe to breathe;
  - fish in the mouth of Tar Creek, Neosho River, Spring River, and Grand Lake were safe to eat.

* The Environmental Effects Subcommittee concluded that:

  - the aquatic life of Tar Creek was severely stressed, if not destroyed, by discharges of mine waters into the system;
  - the effects on the fish community diminished rapidly once waters entered the Neosho River;
  - the fish community of Grand Lake showed no effects of heavy metal toxicity and no significant accumulation of metals in their tissues;
  - the sediments and plankton community were believed to be the major pathways of metals cycling; further, the sediments were thought to provide an effective long-term sink for the heavy metals thereby removing them from most bilogical processes.

* The Technical Subcommittee, through several remedial investigation reports, concluded that:

  - Tar Creek was heavily impacted by heavy metals whose origin was from mine water discharges and stormwater runoff from area tailings piles;
  - levels of contamination contributed via runoff from tailings piles were insignificant when compared to contamination via mine discharges;
  - the quantity of water in the flooded underground mines was estimated to be greater than 76,000 acre feet;
  - based on inflow/outflow rates it was estimated that the mines would flush themselves in 60 - 100 years;
  - groundwater investigations indicated that contaminated waters of the Boone formation could migrate downward through fractures or abandoned wells and boreholes to contaminate waters of the underlying Roubidoux aquifer.

Based on findings of the 3 subcommittees, the TCTF recommended that studies be conducted to determine the feasibility of plugging deep wells in the mining area, directing surface and stormwater flows away from inflow points to the mines, and treating reduced mine water discharges. Further, a sampling program would be implemented to monitor area municipal wells for heavy metal contamination. Finally, the Task Force developed a contingency plan of alternative drinking water supplies for users of Roubidoux wells in the event that wells showed signs of contamination in the future.

Record of Decision

Following completion of the remedial investigation and feasibility studies in January 1984, the TCTF submitted to the Governor and the EPA its alternatives evaluation and recommendations for remediation of the Tar Creek Site. The following 7 alternatives were presented to the EPA:

- No action
- Plug abandoned Roubidoux water wells
- Surface water diversion
- Alternative drinking water supplies
- Surface discharge treatment
- In situ treatment of mine water
- Collection and treatment of mine water

Items 6 and 7, initially selected for evaluation, were eliminated from detailed analysis due to excessive expense. Of the remaining 5 alternatives presented in the Task Force's alternatives evaluation, the following strategies were approved for implementation in the EPA's Record of Decision:

- Divert surface water flows around 2 major inflow areas in Kansas and 1 potential inflow site in Oklahoma;
- Plug 66, later increased to 83, abandoned Roubidoux wells and exploration holes which might serve as conduits through which contaminated mine waters could migrate into the Roubidoux aquifer;
- Implement a monitoring plan to assess the effectiveness of (a) the diversion in mitigating discharge of acid mine waters onto the surface and (b) the well plugging in preventing contamination of the Roubidoux aquifer;
- Develop alternative water supplies for area residents should contamination occur despite remedial action; and
- Evaluate the need for treatment of surface flows should discharge occur despite remedial actions.

Unique Aspects of the Tar Creek Superfund Site

Tar Creek is quite different from the "typical" Superfund site now familiar to both the public and government. Due to its unique nature, administration of the study and cleanup efforts of the site required some very unique solutions to some very unusual problems. Problems such as:

- Type of Hazardous Waste: Tar Creek is not a toxic waste dump. Therefore, there was great uncertainty as to whether the site qualified for funding under CERCLA.

- State Lead Responsibility: In the state of Oklahoma, the Oklahoma State Department of Health typically administers state-lead CERCLA investigations. Here, the TCTF with the OWRB as lead agency was charged with that responsibility by Governor Nigh.

- Site Location: The Tar Creek Superfund Site is located in 2 states which are administered by 2 different EPA regions (6&7) and 2 different Corps of Engineers Districts. It was extremely important to determine as early as possible which state, region, and district would assume administrative control over the site. Once that could be determined, the major obstacles were coordinating efforts and insuring flow of information.

- Contribution of State Funds: Under CERCLA, a state must incur a 10% cost match of funds used to construct remedial measures at a site. At the Tar Creek site construction activities were to occur in both the state of Oklahoma and the state of Kansas to remediate discharge of waters onto the surface in Oklahoma and prevent contamination of Roubidoux wells in both states. A major problem to be dealt with was the legality of the state of Oklahoma expending funds in both Oklahoma and Kansas to remediate the pollution problem at Tar Creek. This issue required a written opinion by the State of Oklahoma's Attorney General concerning expenditure of state funds for site remediation.

SURFACE WATER DIVERSION

Tar Creek Watershed

As stated previously, Tar Creek is the principal drainage system in the Picher Field. With its headwaters in Cherokee County, Kansas, Tar Creek flows southerly through the field between Picher and Cardin, passing Commerce and Miami to the east, to its confluence with the Neosho River (Figure 2).

The mechanics of the pollution problem created by the abandoned mines is a simple one. Mining in the Picher Field was by the room and pillar method. As the ore bodies were depleted, gougers (illegal miners) would enter the abandoned mines and mine as much ore as possible from the pillars. Removing the mine roof support pillars from the mines eventually resulted in many cave-ins and subsidence features in the mining area. One subsidence, for example, occurred under the existing Tar Creek channel. This site was later identified as the number one priority for remedial action. As the mining activity was discontinued and the dewatering pumps shut down in the mines, subsurface water began flooding the mines. Surface water from precipitation runoff began entering the mine cavities through mine shafts, open boreholes, and subsidence features. Once the mines were completely flooded, water flowing into the mines in Kansas then began to push waters onto the surface at many sites in Oklahoma because of the hydraulic gradient (Figure 3).

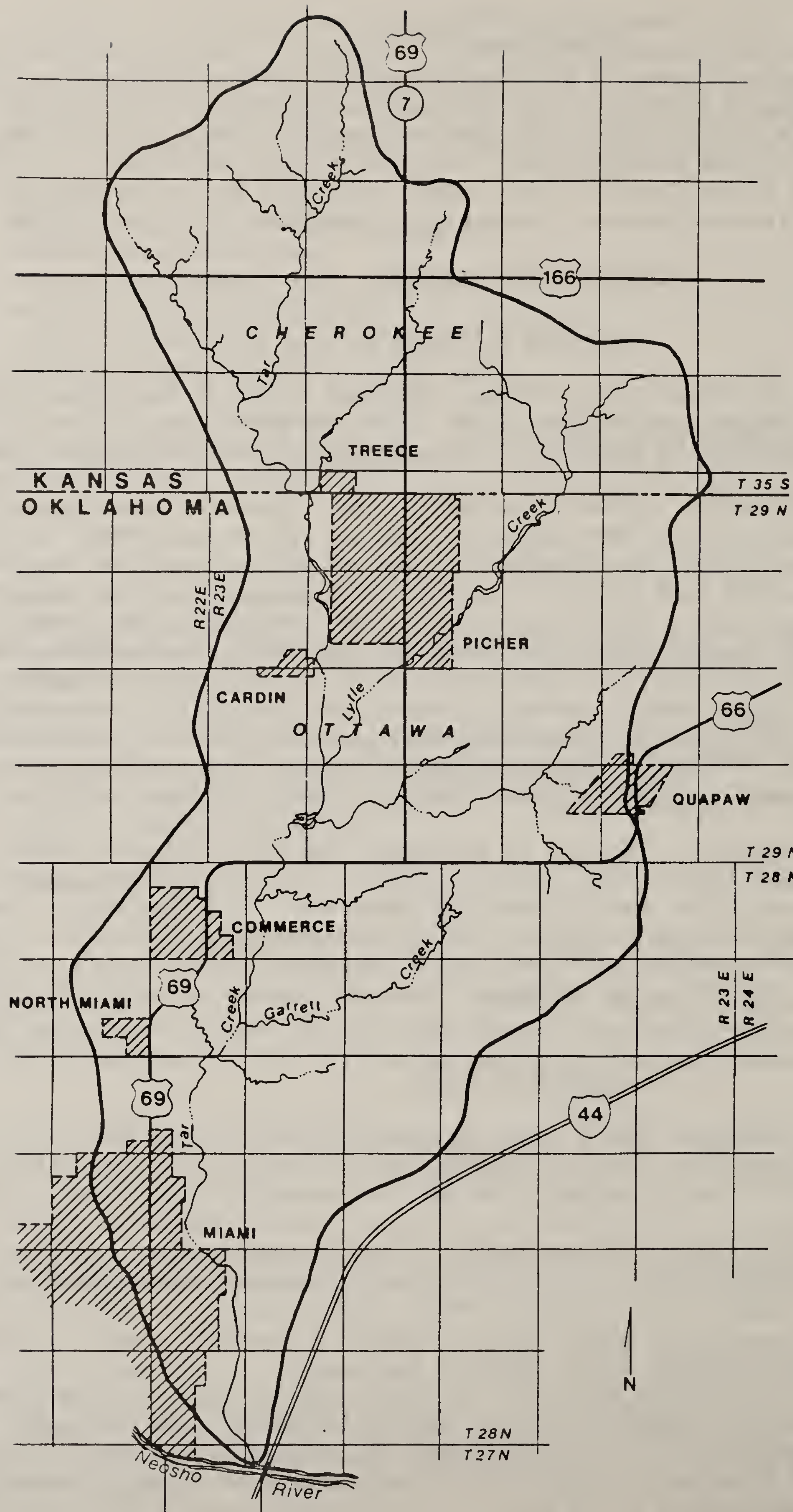
Feasibility studies, previously referred to, identified how the mines functioned in the Tar Creek drainage system, located inflow and outflow points, estimated surface runoff into each inflow point, and ranked each inflow point in order of importance. The feasibility studies were conducted by the Soil Conservation Service (SCS), the Oklahoma and Kansas Geological Surveys and numerous other individuals involved with the TCTF. Extensive hydrological studies were performed by the SCS. Dr. John Vitek of Oklahoma State University in conjunctin with the SCS prioritized inflow points.

Diversion Design

The Oklahoma Water Resources Board began a selection process in 1984 to employ an engineering firm to provide services for the diking and diversion remedial action. Work on plugging of abandoned water wells was conducted under a separate contract and was already underway.

In late 1984, the OWRB retained Black & Veatch to provide engineering services for the design and construction-related services for the diking and diversion work at the 3 sites having highest priority. After conducting a literature review, field surveys, an extensive subsurface exploration program, and numerous site visits, it was concluded that only minor revisions to the preliminary diversion plan recommended by the SCS were necessary.

The 3 sites slated for diversion work were the Muncie and Big John mines in Kansas which accounted for >75% of the total estimated inflow, and the Admiralty mine in Oklahoma. Work at the Muncie included construction of a ring dike around the subsidence feature to prevent Tar Creek from flowing into the mines and realignment of a new channel to convey stormwaters around the subsidence. Design improvements at the Big John included the plugging and backfill of the



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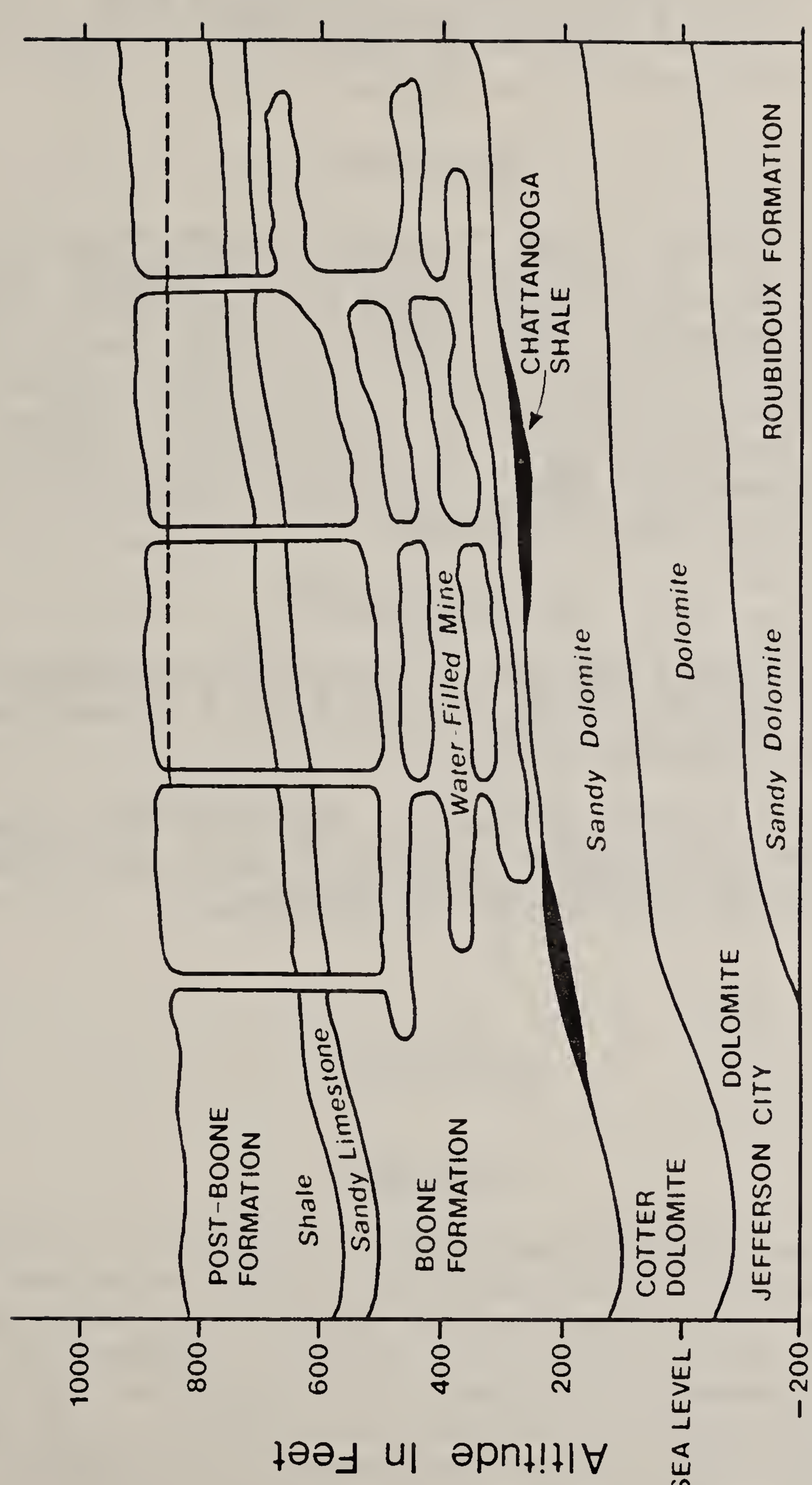
Creek
166
CHEROKEE
Tar
TREECE
KANSAS
OKLAHOMA
T 35 S
T 29 N
Creek
R22E
R23E
PICHER
CARDIN
Lytle
OTTAWA
66
QUAPAW
T 29 N
T 28 N
COMMERCE
Creek
NORTH MIAMI
69
Creek
Garrett
R 23 E
R 24 E
69
44
Tar
MIAMI
N
T 28 N
T 27 N
Neosho
River

Figure 2



Altitude In Feet
1000
800
600
400
200
SEA LEVEL
-200
POST-BOONE FORMATION
Shale
Sandy Limestone
BOONE FORMATION
Water-Filled Mine
CHATTANOOGA SHALE
COTTER DOLOMITE
Sandy Dolomite
JEFFERSON CITY DOLOMITE
Dolomite
Sandy Dolomite
ROUBIDOUX FORMATION

Figure 3

Big John shaft and channel design to convey flows back into Tar Creek. The improvements at the Admiralty site in Oklahoma consisted of a new channel and containment dike to route Lytle Creek around a major subsidence feature and into Tar Creek at a new point of confluence, approximately 1,500 feet upstream of the existing confluence.

Black & Veatch prepared plans and specifications for the improvements, advertised for bids and later recommended to the OWRB that Harry Keith and Sons, the low bidder, from Coffeyville, Kansas, be awarded the construction contract. Construction began in April 1986 and was completed in December 1986. The original bid amount was approximately $850,000 for construction services at all 3 sites. The total cost reached approximately $990,000 due to change orders for additional excavation and fill quantities and weather-related overruns.

Monitoring

As required by EPA's Record of Decision, a comprehensive after action monitoring plan to assess the effectiveness of the remedial action in mitigating surface and groundwater contamination in the Tar Creek area was submitted to the Agency in March 1986. EPA reviewed and approved the 4 point plan designed to assess Roubidoux aquifer quality, fluctuations in Boone mine water levels, discharges from mines and stream systems and watershed stream water quality.

Preliminary data on mine discharges and stream water quality gathered prior to and during diversion construction activities indicated that the diversion structures have had a favorable impact in reducing mine water discharges. The long-term impacts of the diversion remedial action, however, may take several years to evaluate.

LITERATURE CITED

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A STREAMFLOW WATER-QUALITY NODE-STREAMREACH MODEL FOR ASSESSING MINING-RELATED IMPACTS

by

Timothy D. Steele[1], Geoffrey P. Saunders[2], and Richard A. Mills[3]

ABSTRACT: A comprehensive node-streamreach, quantity-quality model (called WATBAL an acronym for water balance) has been developed for evaluating ambient conditions as well as hydrologic impacts in streams draining areas undergoing mine-related development. The node configuration of the model was dictated by monitoring sites (streamflow and/or water quality) or other points of interest in a given stream system. Several alternative data-input options were used in a case-study application for a small watershed in northwestern Colorado affected by coal-mining development. Streamflow-estimation or water-quality data fill-in procedures were devised to provide a monthly-incremental data base for a 8-year historical period of record used for model calibration. Model output by node provides a detailed summary by month (with annual totals) for streamflow and each water-quality constituent concentration and load of interest for each year of data. For assessing mine-related impacts, projected mine discharges at designated locations in the stream network were evaluated in the predictive mode of the model, assuming that ambient conditions observed during the historical period at sites upstream from the mining development would be representative of future conditions. The results were a quantitative comparison of ambient water quantity and quality to regulatory standards, and prediction of probable hydrologic consequences of mining.
KEY TERMS: Water quality; simulation model; data analysis; regression analysis.

INTRODUCTION

Background

A study was conducted to analyze and evaluate water-quality and quantity conditions in streams in the Twentymile Park area of Routt County, northwestern Colorado. The study consisted of formulation, design and implementation of an empirical computer model for evaluating ambient seasonal and annual variations in streamflow and selected water-quality variables. In addition, the model was applied to assess anticipated changes due to impacts of coal mining in areas underlying Foidel Creek and Fish Creek, tributaries of Trout Creek, which flows northward into the Yampa River near the town of Milner, Routt County, Colorado (Figure 1).

[1] Water Resources Manager, In-Situ, Inc., 7401 W. Mansfield Ave., Suite 114, Lakewood, Colorado 80235.
[2] Hydrogeologist, Morrison-Knudsen Company, Inc., P.O. Box 17217, San Antonio, Texas 78217.
[3] Senior Environmental Engineer, Cyprus Yampa Valley Coal Corporation, 29588 Routt County Road #27, Oak Creek, Colorado 80467.

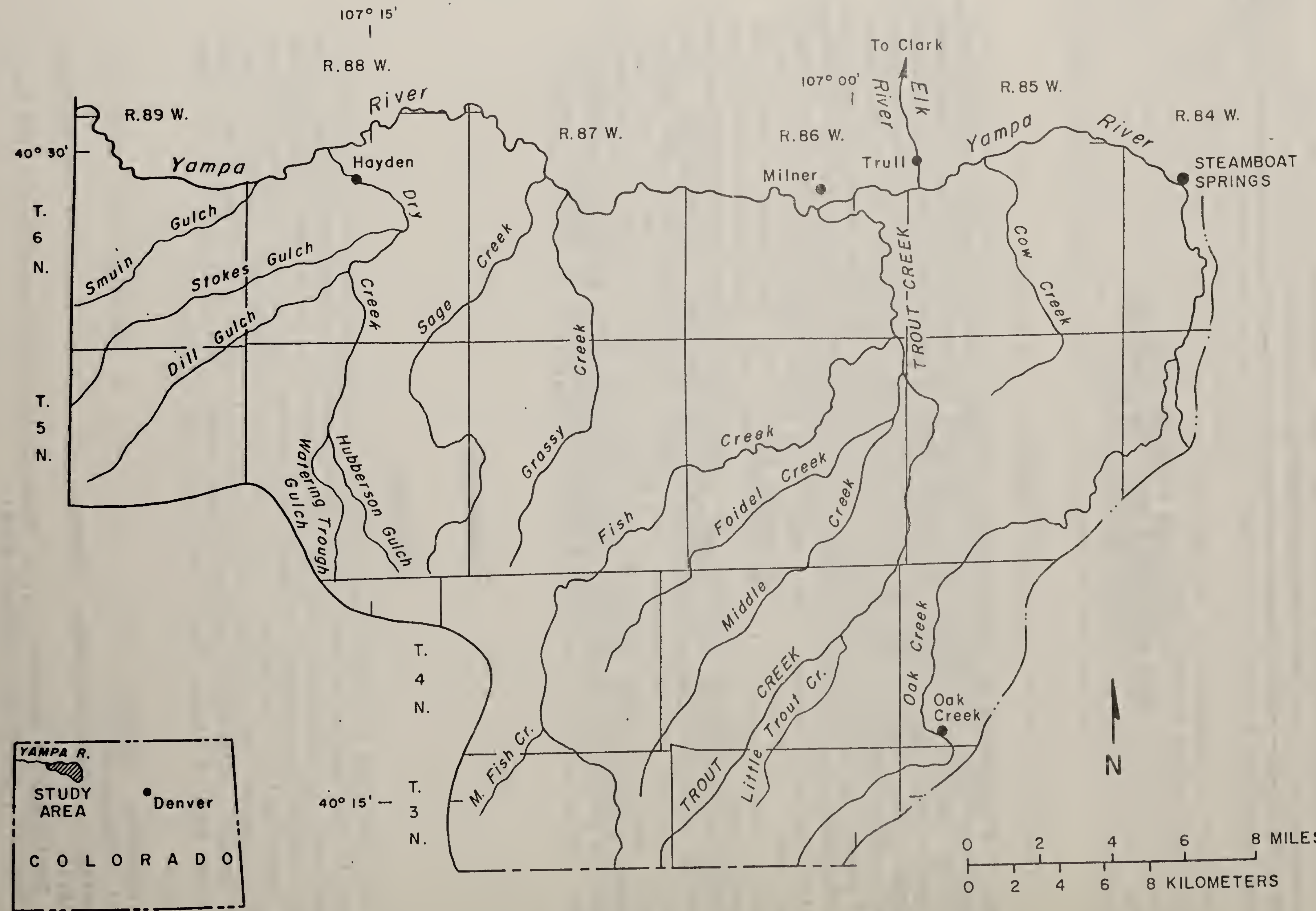

FIGURE I -- GENERAL LOCATION MAP OF THE TROUT CREEK BASIN

Much of the historical streamflow and water-quality data for the Trout Creek basin had been compiled and analyzed by the USGS (Parker and Norris, 1983). Extensive published hydrologic data exist for the study area (Giles and Brogden, 1978; Wentz and Steele, 1980; Maura, 1982; Turk and Parker, 1982; Saunders, 1982, 1983, 1984a, 1984b; USDA SEA, 1980, 1981; and USGS, 1984 and preceding annual basic-data volumes). In addition, considerable data were available from Twentymile Coal Company (TCC) monitoring programs.

Scope and Purpose

This study was initiated to provide an analytical tool for comparing existing water quantity and quality to regulatory stream standards and threshold concentrations. The primary study objective was to develop and apply a computer-based model to evaluate ground-water, surface-water interactions and selected water-quality characteristics under ambient-baseline (calibration) and mine-impacted (prediction) conditions in the Twentymile Park area of Routt County, Colorado. As part of this study, data and reports available in the public domain and as provided by Twentymile Coal Company (TCC) have been incorporated. These have included a review of existing published and unpublished reports, data and information available from the U.S. Geological Survey (USGS), Colorado Mined Land Reclamation Division (CMLRD), TCC and corporate affiliates, and other state and federal agencies. Due to the quite extensive data base made available for this study, the resultant model development and analyses represent a considerable degree of refinement over previous modeling efforts in the Trout Creek basin. Probable hydrologic impacts of mining on water quantity and quality were to be predicted, based on the quantitative results from the WATBAL model.

APPROACH

Data Sources and Period of Record

In general, data inputs to this modeling-analysis study were obtained from the following sources: (1) Twentymile Coal Company (TCC), (2) U.S. Geological Survey (USGS), (3) U.S. Department of Agriculture, Science and Education Administration (USDA, SEA), (4) Colorado Department of Health (CDH), and (5) Colorado Mined Land Reclamation Division (CMLRD). The specific data components by source are outlined in In-Situ, Inc. (1985).

For calibration purposes, the 8-year period of record from the 1976 through 1983 water years was designated for assessing the historical variability of ambient conditions of streamflow and water quality. This is in contrast to the 6-year period of record included in the earlier Parker and Norris (1983) model study. Parts of this historical period or average conditions then could be selected, as desired, for evaluating mine-related impacts, based upon data and information provided by TCC on their proposed mine plan. For this historical period, gaps occurred in many of the available streamflow records; also, streamflows for the entire study period had to be estimated at selected model nodes.

Water-quality data for designated nodes frequently were sparse and at best were collected intermittently over parts of the historical period of record. Through use of regression functions related to streamflow or indicator water-quality variables, a more detailed and comprehensive water-quality characterization was obtained for purposes of the modeling analyses. Streamflow data fill-in procedures and use of regression functions relating water-quality characteristics to streamflow or indicator water-quality variables are described in detail in In-Situ, Inc. (1985).

Streamflow. Streamflow data for the study area were available at 13 nodes in the Trout Creek hydrologic system and at one node on the Yampa River (Figure 2 and Table 1). Due to the data-record gaps and/or lack of data at some of the upstream node points, several forms of data-fill-in procedures were considered and three upstream flow records in the Yampa River basin were used. Available streamflow data and the methods of streamflow data fill-in are given in In-Situ, Inc. (1985).

Commonly, streamflow records were missing in early years of the historical (1976 through 1983 water years) period before gaging stations were operational and in winter months when gaging stations would freeze up and/or recorders were not in operation. As an extreme, as little as 7 percent of the 8-year (96-month) record was available at one station. One record out of 14 nodes was complete, and, on the average, records were slightly more than half (53 percent) complete. However, at other stream nodes other than the 14 gaging stations, entire monthly streamflow data sets had to be estimated, for purposes of upstream node controls or sites where water-quality data but no streamflow records were available. In all, calibration data on streamflows and water-quality were considered at 21 nodes in the Trout Creek system and at 1 node on the Yampa River upstream and 2 nodes on the Yampa River downstream of its confluence with Trout Creek (Figure 2).

Water Quality. Historical water-quality data for the period of the 1976 through 1983 water years were considered for the modeling-calibration analysis. All model nodes except nodes 20 and 23 had some water-quality data available (Figure 2). The types of available water-quality data are summarized in Table 1 and are categorized by source as follows: (1) Twentymile Coal Company (TCC), (2) U.S. Geological Survey (USGS), (3) Colorado Department of Health (CDH) and (4) Colorado Mined Land Reclamation Division (CMLRD). Details of data components are given in In-Situ, Inc. (1985). Certain inherent characteristics of these individual water-quality monitoring programs tended to discourage total integration of the available data. Several problems encountered in this report were described in In-Situ, Inc. (1985).

Water-Quality Regression Functions

The most effective method to relate the selected water-quality characteristics of interest in this modeling analysis was through use of regression functions. The regression functions used in this analysis were derived from historical site-specific data or from data extrapolated from nearby monitoring sites. Moreover, a 2-step procedure was applied to the available data to provide some degree of flexibility in this method. Namely, selected indicator water-quality variables were related to streamflow using logarithmic-regression functions. Also, a wider suite of chemical constituents was related to these indicator variables by means of arithmetic regression functions. This tiered method has been described by Steele (1972; 1973) for water-quality applications.

Station-by-station regression coefficients based upon this method are described in In-Situ, Inc. (1985). The regression coefficients were based upon analysis of historical water-quality data from the information sources described previously (see Table 1 and In-Situ, Inc. (1985)). Where data for certain water-quality variables were not available at selected nodes in the Trout Creek-Yampa River system, they were inferred from nearby nodes having the needed coefficients. Data on major ions and selected trace metals available at (TCC mine) sites were inventoried.

Using this method of model analysis, certain inconsistencies were noted for regression results for differing data sources. Specific concerns focused upon two alternative indicator variables--specific conductance and dissolved solids. In this

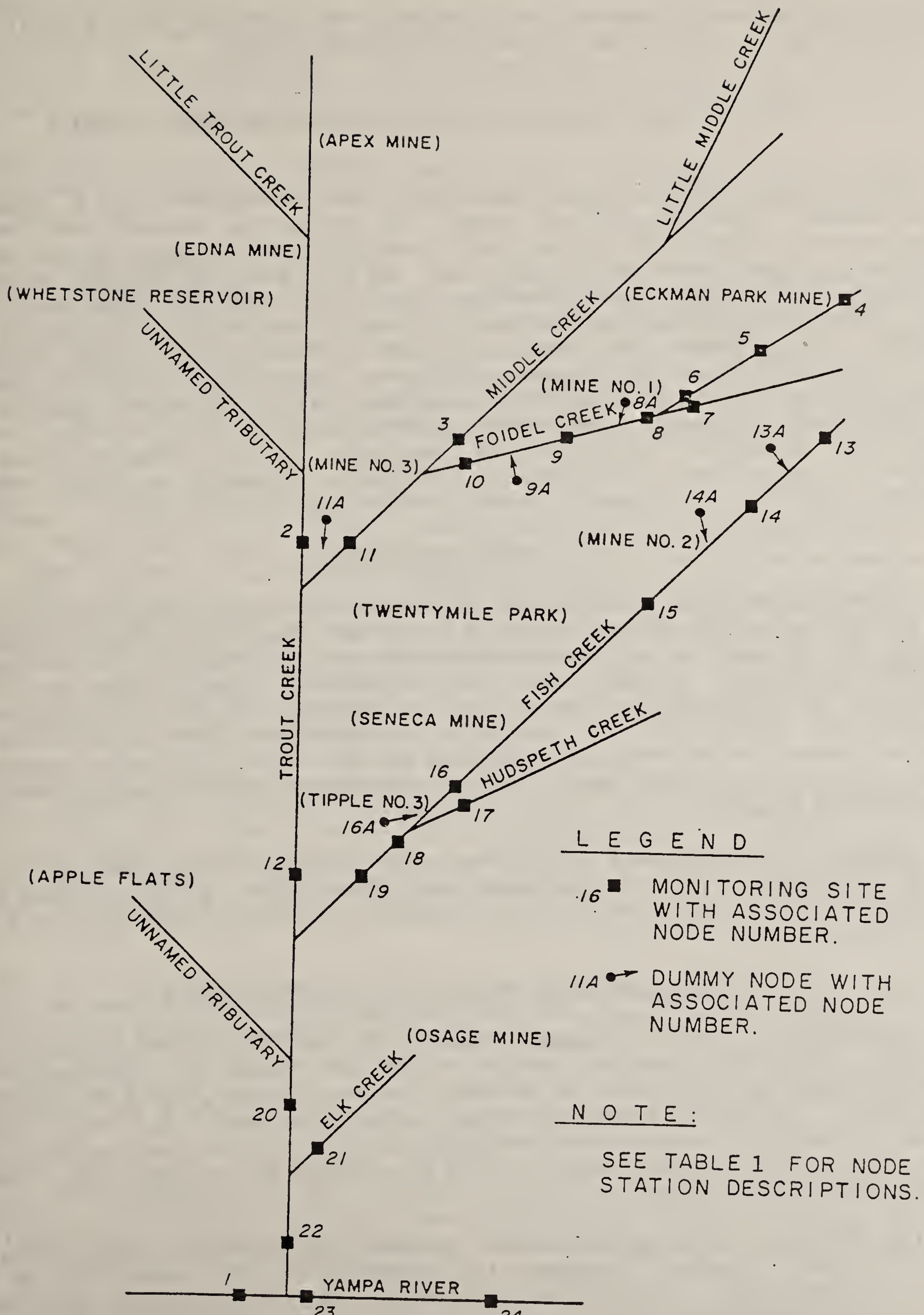

Figure 2 Note System Used for Water-Balance (Quantity-Quality) Model Analysis

study, professional judgment was necessary in deciding how to fill in needed regression coefficients when data were limited or lacking.

WATER-BALANCE (QUANTITY-QUALITY) ACCOUNTING MODEL (WATBAL)

An integral part of this study was the development of a comprehensive water-balance (quantity-quality) model for evaluating ambient and anticipated mine-impacted conditions in the Trout Creek basin and a segment of the Yampa River affected by Trout Creek flows (Figure 1). In this modeling analysis, consideration was given to earlier related modeling efforts, particularly those carried out for this same area by Parker and Norris (1983) and a detailed dissolved-solids modeling analysis of the Tongue River basin in Montana by Woods (1981). Also, study results of a cumulative hydrologic impact analysis of the Yampa River basin by Kaman Tempo (1982) and Ferraro and Nazaryk (1983) were considered. The WATBAL modeling analysis for this study represents a refinement of these previous study efforts. Moreover, a much more extensive data base was available for this WATBAL modeling analysis applied to the Trout Creek basin. Information regarding the WATBAL model may be obtained from TCC or its parent company, Cyprus Coal Company.

Node Configuration

A model accounting of water-quantity and water-quality conditions in streamflow was applied at individual points called nodes depicting either sampling locations or points of interest in a given hydrologic system. A stream reach is defined as the segment of stream between nodes. In the modeling analysis, data can be entered, modified, or outputted at each node. Although the data were adjusted and/or compared at these nodes, the changes of quantity and chemical composition of water are attributed to the reach upstream from any particular node and/or any additional inputs in the upstream area, such as ground-water/surface-water interactions or mine-related inflows.

Internal nodes are used to input proposed changes in water-quantity and quality of individual coal mines or intervening significant stream gains or losses either on a quantity or quality basis to the stream reach from ground water or other flow sources or sinks.

Accounting Procedures - Calibration Module

Conceptually, the calibration module of the WATBAL model routes streamflow, specific conductance, and/or concentrations and loads of dissolved solids and selected chemical constituents through a stream network, based on information at individual node points in the hydrologic system. The basic algorithm of this model is an accounting procedure which aggregates water quantity and quality at monthly time intervals from one or more upstream points to a downstream point. These model results then were used to:

(1) Estimate flow rates between upstream and downstream node points at fixed time intervals (assumed for purposes of this model to be monthly increments), taking into consideration intervening spatial gains or losses to streamflow,

(2) Compute monthly and annual runoff volumes at each node point (and compare them with known values, if available),

(3) Take into account accretions or depletions of streamflow and associated quality due to mining, irrigation, and other forms of economic development affecting water resources. This accommodated in large part to the insertion of additional node points, based in part on the results of the comparisons in item (2) above, and

(4) Take into account selected water-quality variables to estimate concentrations and loads for specified nodes in the network system in space and over time.

For the water-quality constituents included in this modeling analysis, conservation is assumed for each constituent, even though in actuality this may not be the case, depending on the water-quality constituents considered. The WATBAL model takes into account indicator variables such as specific conductance, dissolved solids, total suspended solids and suspended sediment, as well as options to consider individual major ions (calcium, magnesium, sodium and potassium as cations; bicarbonate, sulfate, and chloride as anions); and selected trace metals (iron and manganese).

Streamflow. The calibration of streamflows for the Trout Creek nodal system was enhanced through addition of 6 "dummy" nodes--two in the Foidel Creek subbasin, three in the Fish Creek subbasin, and one on Trout Creek between those subbasins (Table 1). Mean, dry-year, and wet-year annual streamflows for nodes in the Trout Creek-upper Yampa River system were evaluated and summarized in In-Situ, Inc. (1985). Several dummy nodes to provide streamflow increments were included to obtain a better water-quality balance. Estimated streamflows for dummy nodes were not adjusted to year-to-year variations, and the seasonal distribution of streamflows at a given dummy node was applied for each year of the 8-year period of analysis for purposes of nodal calibration.

Unaccountable flows occurred in upper Trout Creek between upstream site 09243603 (node 2) and downstream site 09243993 (node 12). Addition of a dummy node (site 09243950) (at node 11A, Table 1 and Figure 2) averaging about 5.5 cfs of annual incremental flow improved streamflow comparisons at the downstream site 09243993 (node 12) on Trout Creek. The flows at this node took into account inflows of Middle Creek, with major contributions during the snowmelt-runoff months of April, May, and June.

Streamflows in downstream reaches of Trout Creek below the confluence with Fish Creek and in the Yampa River both upstream and just downstream from the confluence with Trout Creek were estimated using professional judgment. Such estimates may be subject to considerable errors. Using the flow-estimation procedures described in In-Situ, Inc. (1985), the resultant streamflows derived in the calibration procedure were judged adequate for a predictive assessment of mine-related impacts.

For purposes of stream calibration, actual or estimated streamflows from upstream nodes were compared with any recorded or filled-in streamflows at a given downstream node. Any differences in downstream node streamflows were evaluated to see if an upstream dummy node was warranted or if differences were quite random over time during the 96-month (8-year) study period.

Water-Quality Concentrations. At a given node, the accounting comparisons for all chemical constituents followed the same method as described for streamflow. Upstream-node chemical-load contributions were converted to concentrations and compared to concentrations at a given downstream node point. Downstream-node

TABLE 1
TROUT CREEK MODEL, NODE SYSTEM SUMMARY

Node No. (Fig. 2)[7]	Site Designation	Stream	Q Data[1]	WQ Data[2]	Indicator Variable Data Availability[8] SC	DS	TSS	SS
1	09242501	Yampa River	S[3]	CDH	X	X	X	
2	09243603	Trout Creek	A	P&M	X	X	X	
3	09243701	Middle Creek	A	USGS	X	X		X
4	09243720	Foidel Creek Trib.	S[4]	TCC	X	X	X	
5	09243730	Foidel Creek Trib.	N	TCC	X	X	X	
6	09243741	Foidel Creek Trib.	A	TCC	X	X	X	
7	09243751	Foidel Creek Trib.	A	TCC	X	X	X	
8	09243801	Foidel Creek Trib.	A	USGS	X	X		X
8A	09243810	Surface Mine #1	S[5]	(Dummy)				
MI-X	09243825	Mine Portal	M	(TCC)				
9	09243853	Foidel Creek	A	TCC	X	X	X	
9A	09243890	Agri. Land Use	S[5]	(Dummy)				
10	09243901	Foidel Creek	A	USGS	X	X		X
11	09243920	Middle Creek	S[6]	TCC	X	X	X	
11A	09243950	Snowmelt Runoff (Trout Creek)	S[6]	(Dummy)				
12	09243993	Trout Creek	A	TCC	X	X	X	
13	09244100	Fish Creek	A	TCC	X	X	X	
13A	09244105	Recharge/Impound	S[5]	(Dummy)				
14	09244110	Fish Creek	N	TCC	X	X	X	
MI-Y	09244125	Fish Creek Shaft	M	(TCC)				
14A	09244129	Surface Mine #2	S[5]	(Dummy)				
15	09244131	Fish Creek	A	TCC	X	X	X	
MI-Z	09244135	Tow Creek Shaft	M	(TCC)				
16	09244140	Fish Creek	N	TCC	X	X	X	
16A	09244145	Recharge/Land Use	S[5]	(Dummy)				
17	09244151	Hudspeth Creek	A	TCC	X	X	X	
18	09244170	Fish Creek	N	TCC	X	X	X	
19	09244181	Fish Creek	A	TCC	X	X	X	
20	09244186	Trout Creek	S[6]	--				
21	09244191	Elk Creek	A	TCC	X	X	X	
22	09244196	Trout Creek	S[6]	(TCC) Data since 10/83 only				
23	09244203	Yampa River	S[6]	--				
24	09244410	Yampa River	A	USGS	X	X		X

Notes:

1 A = actual, S = synthetic (see footnotes), N = no Q, M = mine plan.
2 CHD = Colorado Department of Health; P&M - Pittsburg & Midway; USGS = U.S. Geological Survey; TCC = Twentymile Coal Company.
3 Added upstream data (see text).
4 Extropolated upstream (see text).
5 Inferred from upstream and downstream data.
6 Inferred from upstream data.
7 MI-Series: three inflow sites for mine related impacts; dummy nodes are indicated by an "A" after closed upstream number.
8 SC = specific conductance; DS = dissolved solids; TSS = total suspended solids; SS = suspended sediment.

concentrations generally were derived through regression functions. In cases of large concentration discrepancies, insertion of dummy nodes with associated chemical load contributions were introduced. To a limited extent, concentrations associated with a given dummy node were adjusted upward or downward, depending on whether the concentrations at the downstream node were too low or too high. However, examples were noted where concentration discrepancies occurred associated with minimal incremental flows. In such cases, benefits of including a dummy node for adjusting observed downstream concentrations for the 8-year calibration period were questionable. Also, cases were noted where loads and related concentrations computed from upstream nodes exceeded those provided by site-specific data for a given downstream node. In such cases, no method was provided in the model to reduce these loads and associated concentrations. For purposes of calibration data used in the model-prediction module, the site-specific regression function results were used.

Water-Quality Loads. Within the WATBAL model-calibration module, constituent loads are computed in deriving downstream concentrations. Moreover, chemical loads may be included as model outputs either with or without associated concentration results. For purposes of downstream water-quality accounting, loads are additive from single or multiple upstream sources, as appropriate, and then are reconverted back to concentrations. Given the monthly and annual time increments, load values are maintained in units of tons/day and represent averages for any indicated longer time period.

Accounting Procedures - Prediction (Mine-Impact) Module

The WATBAL model-prediction module operates quite similar to the calibration module with notable exceptions. The year-by-year, node-by-node ambient (baseline) information in general is provided directly to the prediction module from the calibration module (see User's Model Description available from TCC). This procedure thus limits the additional data (water quantity and quality) inputs to those mine-inflow related nodes. For purposes of this study, mine-inflow related nodes. For purposes of this study, mine-inflow data were supplied by TCC for an anticipated 32-year life-of-mine period, on an annual-increment basis. Data included both mine-related flows and anticipated water-quality characteristics. Only annual variability in the mine-related inputs was available for inclusion in the study-modeling analysis. Over the long-term, such variability would be expected to be minimal.

Flow and water-quality characteristics for a total of three mine-inflow node points were considered in the model-prediction analysis (Table 1): (1) the Mine Portal flowing into Foidel Creek, (2) the proposed Fish Creek Shaft, and (3) the proposed Tow Creek Shaft, both flowing into Fish Creek. The model-prediction analysis then compared at down-stream node points the ambient concentrations for individual years or average conditions during the 8-year baseline period (1976 through 1983 water years) with the mine-impacted concentrations for specified years or periods for the life-of-mine (1984 through 2015 water years). Selected specific mine-inflow impact-analysis results are summarized below.

Output Options

Alternative output formats are provided in both the calibration module (WATBALC) and the prediction (mine-impact) module (WATBALP) for optional tabular and graphic displays of data. Procedural details are given in the User's Model Description, which may be obtained upon request from TCC. Brief descriptions and examples of the output alternatives are given in In-Situ, Inc. (1985).

RESULTS

Selected model results for the calibration model WATBALC and for the predictive module WATBALP are given to demonstrate the capabilities as well as flexibilities in optional model outputs. More extensive model results have been summarized in In-Situ, Inc. (1985). Calibration results are discussed for ambient conditions prior to the proposed mine development. Next, prediction results are discussed, based upon mine discharges and associated water-quality characteristics.

Calibration Comparisons for Selected Node Points

A regional characterization is given in terms of selected water-quality variables for the Trout Creek basin and a reach of the Yampa River upstream and downstream from the confluence with Trout Creek. For purposes of contrasting the range of hydrologic conditions, this regional water-quality characterization is given for mean annual (that is 8-year average) conditions as well as for a dry year (1977 water year) and a wet year (1983 water year) within this eight-year period. These designated years represent, in general, the driest year (1977) and wettest year (1983), respectively, for the 8-year calibration period. Dissolved-solids concentrations in the Middle Creek subbasin range from about 380 to 390 mg/L in upper Middle Creek and the headwaters of the Foidel Creek tributary to nearly 890 mg/L in lower Middle Creek near its confluence with Trout Creek (Figure 3). In comparison, dissolved-solids concentrations are lower in Fish Creek than in Middle Creek and Foidel Creek, ranging from an average of 280 to 285 mg/L at the upstream sampling sites to 440 to 460 mg/L in the Lower Fish Creek reaches. Trout Creek upstream from Middle Creek has an estimated average dissolved-solids concentration of nearly 220 mg/L. Due to the relatively higher dissolved-solids concentrations contributed by downstream tributaries, the average dissolved-solids concentrations of Trout Creek are estimated to increase to 380 mg/L below Middle Creek and increase to nearly 400 mg/L below Fish Creek and near its confluence with the Yampa River between Milner and Hayden increases in downstream direction, from about 140 mg/L above Trout Creek to between 155 and 170 mg/L below Trout Creek (Figure 3). Similar spatial variability is apparent for dissolved-solids concentrations in the study area for dry-year and wet-year conditions (In-Situ, Inc., 1985).

As would be expected, regional patterns in sulfate concentrations at node points in the study stream system mirror those observed and described previously for dissolved solids (In-Situ, Inc., 1985). However, somewhat different patterns in spatial variability are observed in the case of iron concentrations. In general, iron concentrations are relatively greater in Fish Creek than in Foidel Creek and Middle Creek, in contrast to the patterns described previously for dissolved-solids and sulfate concentrations. Iron concentrations generally increase in a downstream direction in cases of Foidel Creek, Fish Creek, and Trout Creek. However, the variability is quite low and the impact of Trout Creek inflows on iron concentrations in the Yampa River is negligible. In face, a substantial loss of iron loads may occur upstream from the Yampa River site near Hayden. Iron concentrations do not show much variability with streamflows; hence, no comparisons are reported for wet- or dry-year conditions.

In summary, using the WATBAL model calibration module, comparisons with node-specific data were made for all water-quality variables considered in this study. Only selected calibration results have been described for purposes of this paper.

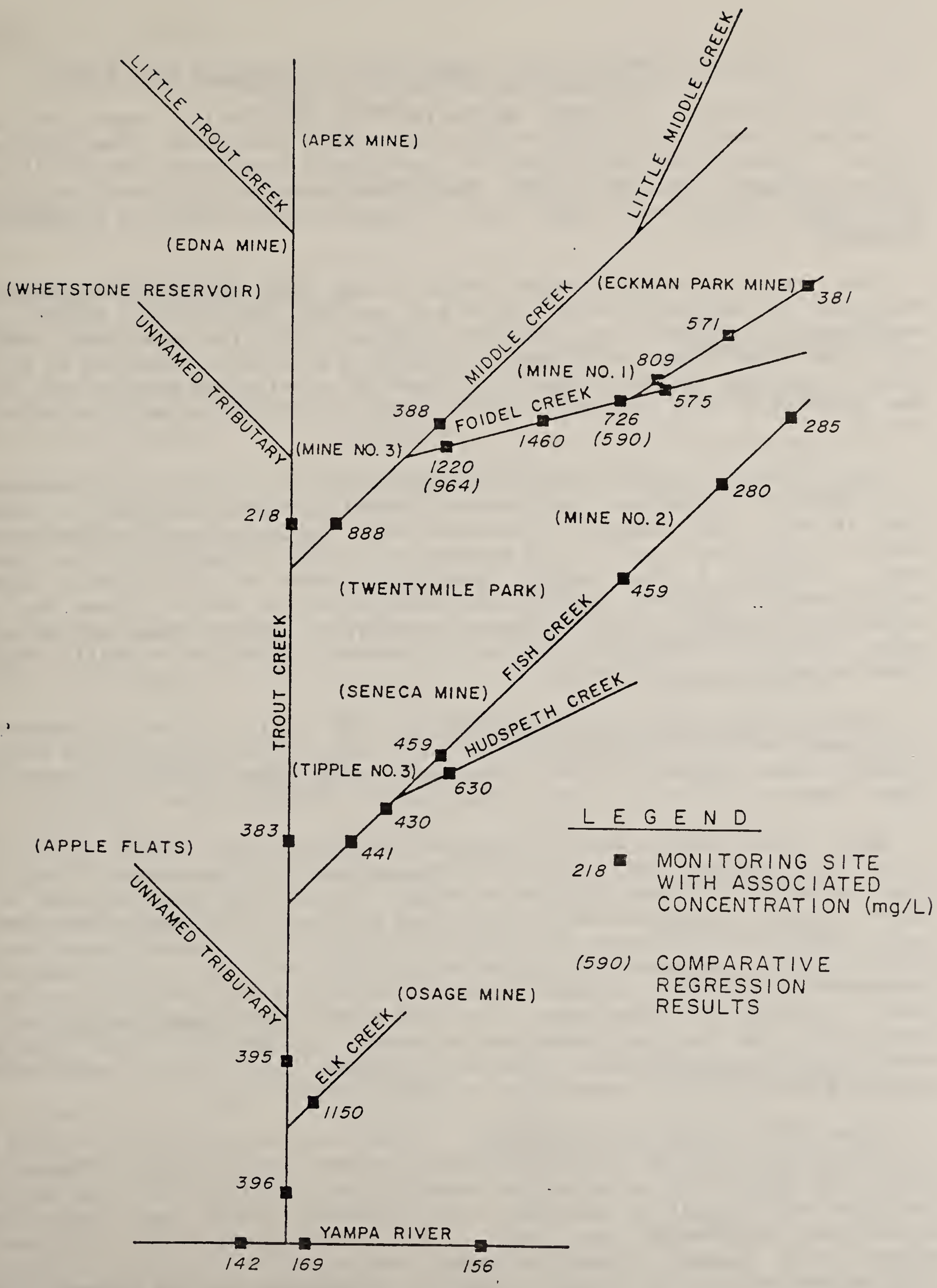

Figure 3 Mean Annual Dissolved-Solids Concentration, Trout Creek and Upper Yampa River

Prediction (Mine-Impact) Comparisons for Selected Node Points

From the WATBALC calibration module run, the site-specific regressions were used to estimate ambient streamflow and water-quality conditions. The projected mine-related inflows summarized in In-Situ, Inc. (1985) were based upon the life-of-mine inflow analysis conducted by TCC. The assumed water-quality characteristics of the mine-related flows were based upon a single sample collected in the mine after treatment.

The prediction-module results (Table 2) were given by four 8-year modeling runs depicting the 32-year planned life of mine and were contrasted to ambient (pre-mine development) conditions as depicted by the calibration model runs. These mine-prediction results were based upon a mining plan previously submitted by TCC (1983). Actual near-term impacts have varied from those estimated by this mine plan. For the discussion that follows, results will be highlighted only for selected node points.

Based upon the WATBALC calibration module results, site-specific streamflow and water-quality information for pre-mining conditions were available to compare with mine impacts. For purposes of this discussion, comparisons with average historical baseline conditions (that is, the average of the 1976 through 1983 water years) were used. Options in the WATBALP prediction module are available to compare mine impacts with individual years of the baseline period; however, these have not been included for purposes of this comparative analysis. Results have been summarized on Table 2 for the selected variables of interest: streamflow, specific conductance, dissolved solids, and sulfate.

Lower Middle Creek (Site 09243920). By virtue of being relatively close downstream to the discharge of one of the mine-flow points (mine Portal, Site 09243825) and because of the relatively small flows of Foidel Creek and Middle Creek, impacts of mine flows were pronounced at this node point (Table 2).

Also, mine impacts were most apparent during the first period (that is, mining years 1 through 8), when compared to average conditions during the 8-year calibration period (1976 through 1982 water years). Despite the small increase in streamflows (about 6 percent) due to flows from the Mine Portal during the first mining period, specific conductance and dissolved solids, at this nearby downstream site on Middle Creek, increased by approximately 20 percent, and sulfate concentrations increased by over 50 percent. During the later 3 mine periods (that is, mining years 9 through 32), these impacts on lower Middle Creek became negligible. During this latter time, average streamflows increased by slightly more than 1 percent, but water-quality characteristics were near to or even below ambient conditions for the average baseline period, based upon the WATBALP module runs.

Lower Fish Creek (Site 09244181). At this site on Fish Creek, average streamflows were about 5 times those encountered for lower Middle Creek. Because of these relatively greater flows, mine-flow contributions from the Fish Creek Shaft and the Tow Creek shaft result in relatively little increase in Fish Creek Flows. Resultant streamflows represented less than a 3 percent increase during the second mining period, when maximum streamflow impacts were noted for this point (Table 2). For this maximum-impact time, specific conductance increased about 6 percent, dissolved-solids concentrations increased nearly 10 percent, and sulfate concentrations increased by over 11 percent. Smaller concentration increases for dissolved solids and sulfate were noted carrying over into the third mining period (that is, mining years 17 through 24). For the last mining period (mining years 25 through 32),

TABLE 2
COMPARISON OF CALIBRATED AND PREDICTED
VALUES AT SELECTED NODE POINTS

Site & Variable[3]	Site-Specific I/B[1]	Calibration (C)	Prediction (P) (8-yr. Averages)[2]
09243920 Lower Middle Creek (node 11)			
Streamflow (cfs)	5.16/5.16	5.16	5.48/5.23/5.23/5.23
Specific Cond. (μmhos/cm)	760/771	1048	1220/950/948/934
Dissolved Solids (mg/L)	888/898	864	1056/812/810/797
Sulfate (mg/L)	406/388	372	570/377/375/366
09244181 Lower Fish Creek (node 19)			
Streamflow (cfs)	26.0/26.0	26.0	26.6/26.7/26.5/26.3
Specific Cond. (μmhos/cm)	491/491	460	456/488/457/409
Dissolved Solids (mg/L)	441/441	430	443/471/444/402
Sulfate (mg/L)	172/172	150	176/196/177/148
09244196 Lower Trout Creek (node 22)			
Streamflow (cfs)	72.6/72.6	72.6	73.3/73.2/73.1/72.9
Specific Cond. (μmhos/cm)	381/381	n.a.	367/359/348/322
Dissolved Solids (mg/L)	396/397	n.a.	345/338/328/314
Sulfate (mg/L)	159/159	n.a.	144/139/133/123
09244410 Yampa River (node 24)			
Streamflow (cfs)	997/996	991	992/992/991/991
Specific Cond. (μmhos/cm)	265/265	240	241/240/238/236
Dissolved Solids (mg/L)	156/156	169	166/166/164/162
Sulfate (mg/L)	34/34	38	39/38/37/36

1 I = Site-specific results from WATBALC.
B = Site-specific results from WATBALP.
These differ slightly due to variable upstream nodes in the flow system in the calibration and prediction model runs, respectively.
2 For mining-year periods: 1-8/9-16/17-24/25-32 after initiation of mining.
3 See Table 1 and Figure 2.

constituent levels were below those noted for the baseline calibration, despite a slight (1 percent) increase in Fish Creek streamflows due to the mine inflows.

Lower Trout Creek (Site 09244196). At a node point on Trout Creek where effects of all 3 mine flows can be assessed, streamflows would not be expected to increase by more than 1 percent for an average mine period (Table 2). Unfortunately, no site-specific data are available at site 09244186 or 09244196 to truly evaluate the calibration values based upon upstream loads. As such, all prediction constituent levels were less than ambient levels, based upon the upstream constituent loads passing downstream in the mass-balance computations (Table 2).

Yampa River (Below Diversion near Hayden) (Site 09244410). As would be expected at this downstream site, streamflow increases only nominally (less than 0.1 percent) and concentrations for all mine periods were not affecting constituent levels, except for specific conductance and sulfate concentration during the initial mine period (that is, 1984 through 1991 water years). These increases were approximately 1 micromho/cm for specific conductance and 1 mg/L for sulfate concentration. Model prediction results for streamflow, dissolved-solids concentration and sulfate concentration for each of the 4 mining periods are given in In-Situ, Inc. (1985).

SUMMARY AND CONCLUSIONS

A generalized computer-based water-quality and -quantity balance (WATBAL) model was developed to characterize streamflow and water-quality conditions at a set of node points in a given stream system. This model was applied to extensive hydrologic and water-quality data available in the Trout Creek basin and the reach of the Yampa River affected by Trout Creek basin and the reach of the Yampa River affected by Trout Creek inflows. The data considered in this modeling-analysis study were obtained from several sources. Site-specific streamflow and water-quality data were used to compare results of the WATBAL's calibration module (WATBALC). In this calibration process, a total of six "dummy" nodes were inserted in the stream system to better depict streamflow and water-quality changes observed between node points. The site-specific data calibration results then were retained in a computer file for comparison with the results of the WATBAL's prediction module (WATBALP).

The maximum dissolved-solids loads to the Trout creek system due to the proposed mining are anticipated during the 1987 water year, when maximum mine flows would occur, according to the TCC mine-impact analysis. During this maximum mine-inflow year, dissolved-solids loads contributed by these inflows would average nearly 13 tons/day. This maximum-year load increment should be contrasted against the average load increment for the proposed 32-year mine life, which would be slightly over 4 tons/day. The major anion associated with the mine inflow is sulfate. The major cations associated with groundwater discharges and mine inflow are calcium and magnesium. These dissolved ions mix with sodium-bicarbonate type surface waters to form the chemistry of downstream waters. The dissolved-solids and other solute loads are treated conservatively in the WATBAL analysis, in that no physical, chemical, or biological processes were considered that would reduce or attenuate these incremental loads. Those anticipated dissolved-solids loads are barely discernible relative to average ambient conditions in Trout Creek (about 70 tons/day) or the Yampa River (approximately 250 tons/day).

Since the completion of this study, the number of monitoring sites in the Trout Creek basin has been reduced substantially (Colorado Yampa Coal company, 1987a, 1987b; Twentymile Coal Company 1987). However, the hydrologic database continues to be reviewed and the network evaluated so that the resultant data-collection program can be efficient in terms of information provided and can be cost-effective to operate.

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WATER SUPPLY FOR MINING AND ENERGY

FEDERAL RESERVED WATER RIGHTS FOR DESIGNATED WILDERNESS AREAS AND OTHER SPECIFIC MANAGEMENT AREAS

Boyd Christensen[1] and Thomas F. Slater[2]

ABSTRACT: A 1985 Colorado Court decision has resulted in recent concern that water rights and water resource development programs in the west may be significantly limited as a result of certain designated Federal management areas, such as units of the National Wilderness Preservation System, national parks, and wildlife refuges. The court reinforced the idea that a Federal water right exists as of the date of the designation and for the purposes of the designation. It is left to the land managing agency to define the precise need and extent of that right. The court case is under question. Also, it has prompted possible Congressional action. Many allegations, both substantive and perceived, have been raised during the wilderness study for Bureau of Land Management (BLM) lands in Utah. This paper reviews the current situation, examines several river basins in Utah, and provides insight as to the possible outcome.
KEY TERMS: Federal reserved rights, instream flows, water rights, wilderness, Utah.

CONGRESSIONAL DESIGNATION

Certain Federal lands are set aside by Congress for designated special management and uses. These differ from other Federal lands in that specific purposes are mandated which guide, and in some ways limit, the management options.

Many designated special management areas, such as wilderness areas, national parks, and wildlife refuges are created to protect and conserve the natural, ecological, and scenic resources. Since water is an inherent need for survival of plant and animal life, it usually is essential to the mandated purposes of these specially designated areas. Likewise, water is a focal point of visual interest and, in some cases, for visitor survival in western desert regions.

Although a few of the national parks were created many years ago, most of the specially designated areas in the west have been established within the past 23 years, subsequent to the Wilderness Act of 1964. Included are about 800,000 acres of wilderness in Utah set aside within the National Forests and 23,000 acres of wilderness in Utah currently set aside on BLM-administered Federal land. Additionally, about 4.5 million acres of Federal land in Utah will be under

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[1]Hydrologist, Bureau of Land Management, Utah State Office, 324 South State Street, Salt Lake City, Utah 84111

[2]Chief, Branch of Planning and Environmental Coordination, Lands and Recreation, Bureau of Land Management, Utah State Office, 324 South State Street, Salt Lake City, Utah 84111

consideration for wilderness designation by the Congress in the next few years.[3]

THE COLORADO COURT DECISION

Water rights matters have a long history of concern and legal debate, including a number of Supreme Court rulings.[4] On November 25, 1985 the Federal District Court in Colorado ruled that Federal reserved water rights exist in the National Forest wilderness areas in Colorado (Civil Action No. 84-k-2). The court did not determine that a Federal reserved right must be claimed in every instance, but it did determine that the Forest Service (and presumably each of the other Federal agencies that manage wilderness areas) has the responsibility to protect the wilderness water resource. The court directed the Forest Service to prepare a plan to show how protection would be afforded, including, if necessary, the claim for a Federal reserved right. The Federal defendents have taken the position that the District Court has no jurisdiction to decide the case and the appeal process could take several years.

The Colorado court decision has been viewed by many people as renewing historical arguments and setting the trend for current water-related policy for special management areas of all Federal agencies. It has become one of the major issues in the Utah BLM wilderness study process, and has affected wilderness proposals now before the Congress for other states.

Generally, the water necessary to fulfill the purposes of Congressionally designated management areas would be nonconsumptive and would be utilized as natural instream flows, rather than diversions or reservoirs.

THE REAL AND PERCEIVED CONSEQUENCES

If a Federal reserved water right is claimed for a particular designated area, the date of that right would be coincident with the date of the Congressional designation of the special management area (i.e., the date the wilderness area, national park, or national wildlife refuge was created). Private and public water rights existing prior to that date would remain in effect, and would be senior to the Federal reserved right. Any perception that existing rights would be reduced or eliminated is not correct.

Unappropriated water could be affected. Public or private water rights, or changes in point of diversion, which post-date the Congressional designation could be affected.

For example, in Utah it has been estimated that about 85 to 90 percent of the water (statewide) already is appropriated (UDWR 1985); therefore, up to 15 percent of existing waters may be influenced by the creation of new wilderness areas. It is important to note that, in large part, the most readily developed, economical, and accessible water sources already are claimed with existing rights and have been utilized for community supplies, agriculture, industrial supplies, and other consumptive uses. Also, it is important to note that reliable water is crucial for

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[3]This total is comprised of 3.2 million acres with BLM administration and 1.3 million within National Parks.

[4]See Appendix List of Supreme Court Decisions.

these activities in the arid west. State water law gives precedent and priority standing to the diversion and consumptive use of water.

On the other hand, current Utah law regarding instream flows generally is not compatible with uses that do not involve a physical diversion (Bangerter 1986). Only recently has the state legislature recognized a legally beneficial instream value, and only the Utah Division of Wildlife Resources is entitled to obtain an instream right. An existing perfected right may be transferred to the wildlife agency, but only with case-by-case legislative approval (Utah Code Annotated).

In light of traditional state law and practices, the extension of the long-recognized concept of a Federal reserved water right to wilderness areas, primarily for instream flows (and which would preempt state water law), runs counter to the expectations familiar to water developers and users.

The subject is complex. It involves water tradition, several laws, philosophy, and emotion. It also involves a wide variety of natural environments and ecological relationships in the broader context of land and related resource management for a wide range of public values. Local interests and national interests may not coincide.

SPECIFIC EXAMPLES

The following case studies are illustrative of typical situations that could occur with the application of Federal reserved water rights. The Virgin River study is an example of the many complex variables that may be involved. The Green River case typifies the "upstream," "downstream," and regional implications of Federal reserved water rights associated with designated lands. Birch Creek and Cottonwood Creek are two examples of headwater streams with somewhat different use considerations.

Virgin River

The Virgin River is an interstate stream. It headwaters in southwestern Utah, flows through northeastern Arizona, and enters the Colorado River (Lake Mead) in Nevada. It is part of the lower Colorado Basin under the Colorado River Compact, but there is no interstate compact specific to the Virgin River itself. It is a contributor to the Colorado River salinity problem as a result of the inflow of salts from LaVerkin Springs.

Portions of the Virgin River and/or its tributaries occur in Zion National Park established in 1919, the BLM Beaver Dam Wilderness Area designated by Congress in 1984, and the Forest Service Pine Valley Mountains Wilderness designated in 1984. See Figure 1.

Zion National Park and the Pine Valley Mountains Wilderness Area are entirely within Utah. About 19 percent of the Beaver Dam Wilderness Area is in Utah and 81 percent is in Arizona. The Virgin River enters the northeast corner of the Beaver Dam wilderness and runs through the wilderness for about two miles in Utah. The river continues in the wilderness in Arizona. Water laws and uses of the river in the two states are not the same.

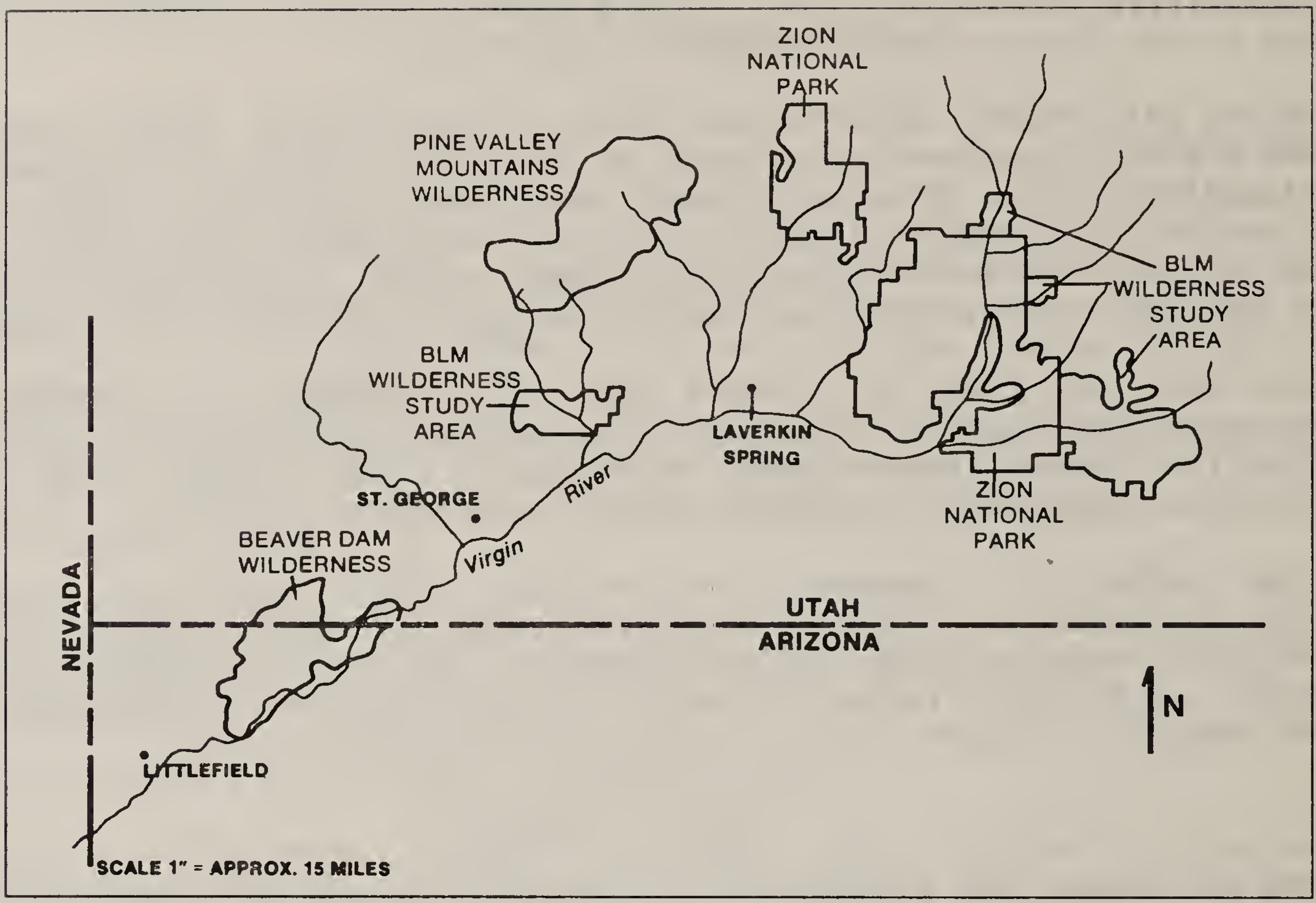


FIGURE 1

Congress could designate additional wilderness in the Virgin River Basin within Zion National Park and with 15 wilderness study areas included in the BLM study (BLM, 1986). Four of the most significant wilderness study areas are shown on Figure 1.

The Virgin River supports one species of endangered fish (woundfin minnow) and one proposed endangered fish with critical habitat (Virgin River roundtail chub) which are officially protected under the Federal Endangered Species Act. Many studies have been conducted relative to these fish, and minimum instream flow recommendations of 80 cubic feet per second (cfs) or more for various reaches of the river have been identified by the Fish and Wildlife Service (FWS, 1980).

Traditionally, the Virgin River in Utah has been over-allocated, with more demands (in actual use and/or applications) than the normal flow of the river would support. Many existing rights are based only on the spring flood flows. Some other rights are based on return flows. River flows are highly variable, and are further affected by irrigation diversions. Historical average annual flow is about 223,900 acre-feet at the Bloomington gaging station, and 150,000 acre-feet upstream at the Virgin gage. The Virgin River periodically goes dry (or only has underground flow at less than 50 cfs) in the Utah portion of the Beaver Dam Wilderness Area and in the Virgin River Gorge in Arizona: and then it reappears near Littlefield, Arizona in springs at the west end of the gorge. Average annual flow is 176,000 acre-feet at the Littlefield gage (USGS, 1987).

The Washington County Water Conservancy District claims rights to 276,000 acre-feet of water from the Virgin River (UDWR, 1986). The river has been identified as the main source of future water for the expanding urban growth in the county. Additional water resource projects (two dams and reservoirs) have been identified by the water conservancy district for future design and construction. They would require Federal rights-of-way from the BLM since both sites are on the public land. Also, both sites currently are in potential BLM wilderness areas and are upstream from Zion National Park and the Beaver Dam wilderness area.

The State of Utah currently is adjudicating the waters of the Virgin River Basin in Utah.

Federal reserved water rights in this basin could have three differing results: (1) specified minimum flow through Zion National Park, (2) natural outflow from tributary headwaters in Pine Valley Mountain wilderness area (both Zion National Park and the Pine Valley wilderness are upstream from most existing rights and comsumptive use), and (3) no minimum flow at the Beaver Dam wilderness (due to full prior appropriation upstream, if determined by the current adjudication proceedings). Most BLM wilderness study areas are in headwater areas of the basin and would be upstream from most existing rights and uses.

Green River

The Green River is a major tributary to the Colorado River. It is part of the upper basin under the Colorado River Compact, and it originates in Wyoming and flows south into Colorado and through Utah to its confluence with the Colorado River in southeastern Utah. The river flows in Utah have been highly regulated since the late 1960's by storage and releases from Flaming Gorge Dam (a Bureau of Reclamation hydroelectric project).

The BLM Desolation Canyon wilderness study area borders or includes more than 60 miles of the Green River. See Figure 2.

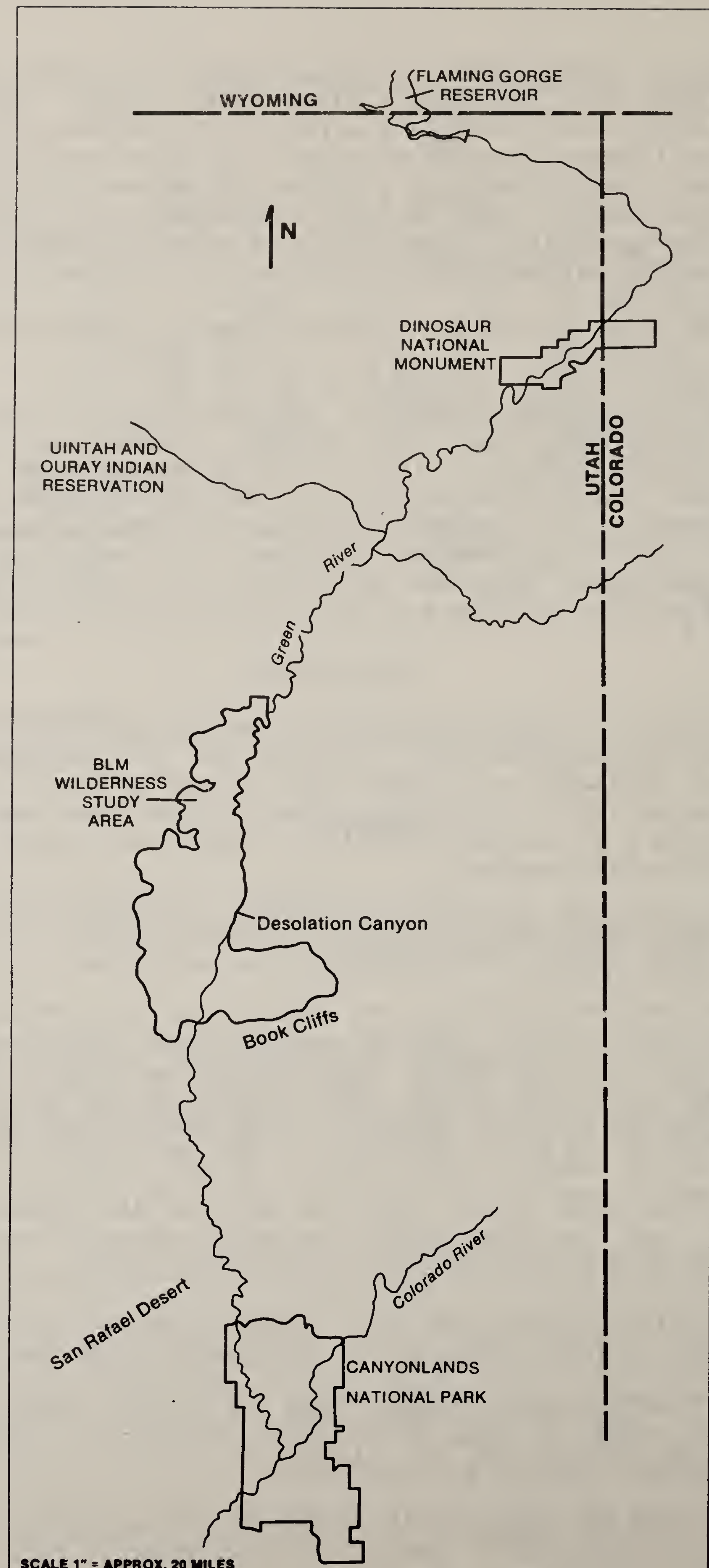
Upstream of Desolation Canyon, the uses of the river include many diversions for consumptive uses, storage, instream use for power production, sport fishing, and recreation (including individual and commercial rafting). Also upstream, the Uinta and Ouray Indian Reservation (Ute Tribe) has decreed water rights and currently undefined water rights granted by the Winters Doctrine. Quantification of these tribal rights has been in process for many years and still is unresolved.

A portion of the Green River, along with parts of its tributaries, Price River and Range Creek, are identified in the Nationwide Rivers Inventory as potential candidates for the Wild and Scenic Rivers System (NPS, 1982).

Within Desolation Canyon, the river primarily supports recreation use, with about 60,000 annual visitors participating in individual and commercial rafting.

Downstream from Desolation Canyon, there are limited diversions and additional recreation uses. Currently, the Green River contributes substantial flows to subsequent downstream uses of the Colorado River.

In efforts for the upper basin states to utilize their water entitlements specified in the Colorado River Compact, various projects have been and in the


FLAMING GORGE
RESERVOIR
WYOMING
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OURAY INDIAN
RESERVATION
UTAH
COLORADO
River
Green
BLM
WILDERNESS
STUDY
AREA
Desolation Canyon
Book Cliffs
Colorado River
San Rafael Desert
CANYONLANDS
NATIONAL PARK
SCALE 1" = APPROX. 20 MILES

FIGURE 2

future will be proposed to divert flows from the Green River and its tributaries upstream from Desolation Canyon. This is a significant activity based on long-standing compact provisions; and in Utah, for example, it includes major Federal funding of "out-of-basin water transfers" as part of the Central Utah Project. With this effort, future flows in the Desolation Canyon portion of the Green River may be reduced (at least on a seasonal basis).

If the Desolation Canyon area is designated wilderness, part of the purpose for the designation would be to maintain the riverine values, including the river-oriented recreation, the riparian conditions, and the several threatened and endangered fishes (Colorado squawfish, razorback sucker, and humpback chub). A Federal reserved water right would focus on the flow requirements to meet these needs. Due to the Endangered Species Act, limitations or special conservation measures for water projects already are required where Federal lands or permits are necessary.

Average annual flow of the Green River in Desolation Canyon is about 3.9 million acre-feet. Utah's annual allotment for diversion under the Colorado River Compact is about 1.7 million acre-feet (UDNR, 1980). Current annual water use in Utah is less than one million acre-feet, although many additional water filings exist. Entitlements of the Ute Indians, Colorado, and Wyoming would add to this use.

The extent to which certain required instream flows at Desolation Canyon would limit upstream use and foster additional downstream use is unknown. Defining a Federal reserved water right in this situation would be a challenge. Undoubtedly many studies, legal reviews, and negotiations would be needed.

Birch Creek

Birch Creek is about 10 miles long at the south end of the Deep Creek Mountains. It headwaters on the Goshute Indian Reservation and on state-owned "school trust" land, flows for 1.5 miles through the BLM Deep Creek Mountains wilderness study area, and eventually is used on public and private land in the Snake Valley of western Utah. See Figure 3.

No water flow records or data exist for Birch Creek. It is estimated that flows are similar to those in nearby Trout Creek which vary from about 1/4 cfs to 177 cfs, with an average discharge of about 6 cfs, for 4,300 acre-feet/year (USGS, 1987).

Water rights, if any, associated with the Goshute Indian Reservation and the state land in the upper part of the drainage are undetermined. Private water rights exist downstream in the Snake Valley. There are 4 water right holders with a total of 18 cfs in the valley. Consequently, the existing water rights allow for use of about 3 times the average flow of the stream (UDWR, 1987a).

Birch Creek (and the related Trout Creek) from their source to their junction are listed as Nationwide River Inventory segments (NPS, 1982). Thus, they are eligible for study for possible addition to the National Wild and Scenic Rivers System. The inventory found that Birch Creek has excellent primitive recreation opportunities, unique geological features relating to ancient Lake Bonneville, a vertical granite canyon, Utah cutthroat trout (a protected, sensitive species), and

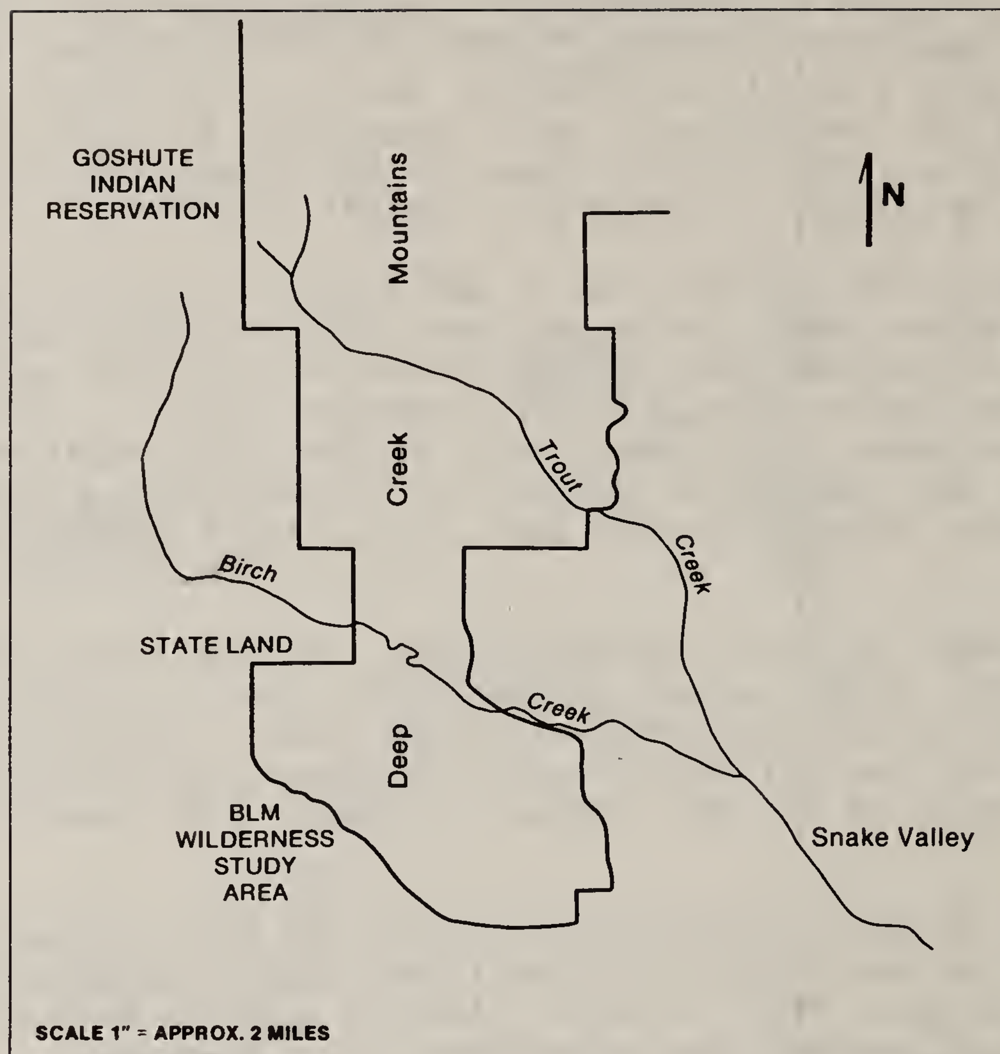

FIGURE 3

bristlecone pine. Consultation with the National Park Service is required for any Federal action that could contribute to foreclosing wild, scenic, or recreational river status for inventory segments (CEQ, 1980).

Two private, small hydroelectric generating projects have been proposed, involving the lower parts of Birch and Trout Creeks. Most features of these projects would be adjacent to and outside (downstream from) the wilderness study area. Federal rights-of-way and permits would be required.

If the Deep Creek Mountains are designated wilderness, a Federal reserved water right would be oriented to the same values as listed above for the wild river inventory. This water right may (or may not) affect upstream future uses on the Goshute Reservation and on State land. Use of waters for hydropower production downstream from the wilderness area would not be affected by a Federal reserved right since the wilderness use would be non-consumptive. Similarily, downstream use of the creek for agriculture or other purposes in the Snake Valley would be unaffected.

Cottonwood Creek

Cottonwood Creek extends for a distance of about 12 miles in the Bookcliffs, crosses the Cisco Desert, and eventually enters the Colorado River in eastern Utah. It headwaters primarily on public land, but crosses several state "school trust" sections. About 40 percent of the Bookcliffs part of the Cottonwood drainage basin is within the BLM Spruce Canyon wilderness study area. See Figure 4.

The Bookcliffs segment of the stream is used as a source of water for livestock on the open range. Downstream the creek is exposed to highly saline mancos shale that degrades water quality conditions to the extent that uses are prohibited. The creek has potential for watershed treatments to reduce downstream sediment and salinity problems. Although Cottonwood Creek is considered to be a minor tributary, during flood flows these problems are contributed to the Colorado River.

A gaging station was operated by USGS on Cottonwood Creek from May 1983 to September 1986 for a total of 3 years of record. The minimal flows varied from 0.6 cfs to 110 cfs with an average of 6.45 cfs, for 4670 acre-feet/year (USGS, 1987).

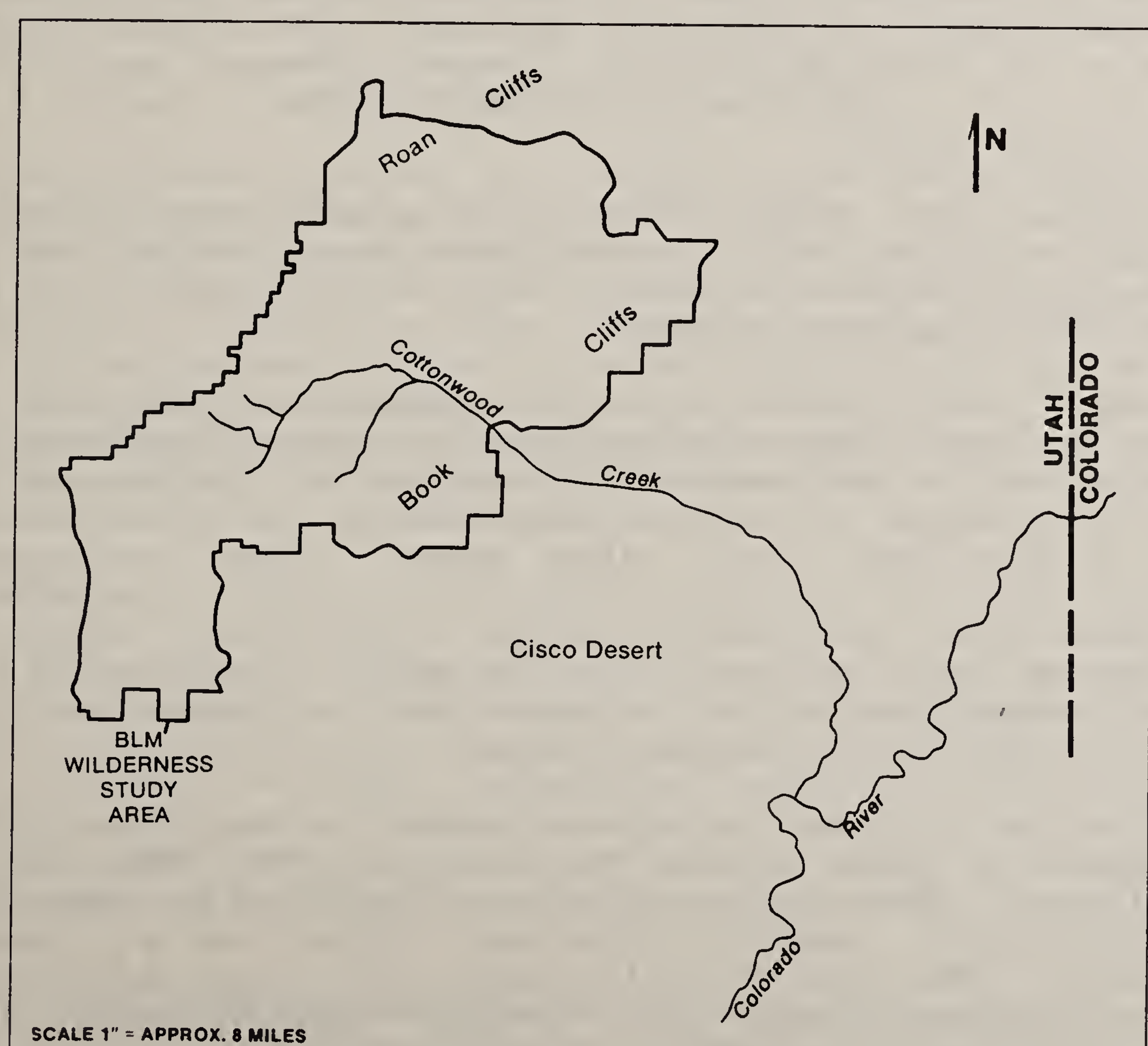

FIGURE 4

There are two water rights on Cottonwood Creek claiming a total of 3.68 cfs. (UDWR, 1987) There is an adjudication scheduled for 1988. Since Cottonwood Creek is a direct tributary to the Colorado River, the State of Utah policy is to allocate the stream flows toward the State contribution to the Colorado River Compact. Although the State would allow appropriation of small amounts of water for households.

If the Spruce Canyon area were designated as wilderness, a Federal reserved water right would have no effect on the current water rights and uses of Cottonwood Creek. Livestock watering could continue. Wilderness management would limit increased sedimentation from future soil disturbance but also would limit options for watershed treatments, but neither of these would be a result of a Federal reserved water right. As in the case of Birch Creek, noted above, the nonconsumptive uses of water for wilderness values would not affect opportunities for downstream uses, although such uses now are limited due to the poor water quality in the Cisco Desert.

CURRENT ADMINSTRATIVE AND CONGRESSIONAL ACTIONS

The Colorado court decision brought new attention to the matter of Federal reserved water rights and has resulted in mixed reaction from Federal agencies. The Forest Service in Colorado has filed the wilderness water protection plan specific to the National Forest areas in question. Broader implications have been reviewed and many Federal officials have accepted that a Federal reserve water right does exist and should be exercised if needed. However, some officials have asked for legal review to see if an opinion can be issued to support a conclusion opposite of the court ruling.

State agencies, local elected officials, and water conservancy districts have expressed opposition to the court ruling, and have voiced the view that wilderness recommmendations be postponed until the water rights situation can be further defined (UBWR, 1986; Orangeville, 1986).

Environmental group representatives have stated that wilderness areas need reserved rights as water is the lifeblood of the arid west (Sierra Club, 1987). It would be inconsistent to designate an area as part of the National Wilderness Preservation System because of important natural values and then allow for removal of the water on which those natural values depend. Further, representatives of these groups note that the principle of Federal reserved water rights for specially designated Federal areas was upheld in earlier Supreme Court rulings. In this sense, the Colorado Court case did not state new or unique concepts. The main thrust of the Colorado Court suit was to assure that the agencies exercise, rather than ignore, reserved rights for wilderness areas.

A group of western senators and representatives have vowed to block any wilderness legislation that includes the automatic (but imprecisely defined) reservation of water. Most previous wilderness legislation has been rather vague on this important point. Several Congressional actions now are underway (PLN, 1987a; PLN, 1987b). One is an effort to resolve water rights matters specific to Colorado in order to move ahead with a Colorado wilderness bill. If this is successful, it may serve as a procedural precedent for others.

Another group in Congress is trying to establish a procedure relative to a New Mexico wilderness bill which clarifies that wilderness designation creates no inherent new Federal water rights. This approach would allow varied language specific to the bill, to create reserved rights only if expressly specified by Congress with wilderness designation on a case-by-case basis. The language concerning water rights could vary with each new wilderness bill.

PREDICTIONS

Maintaining Natural Values

Often it may be difficult to document the precise amounts and seasonal variations of water necessary to support the natural values (i.e., to fulfil the purposes of the reservation). Some streams, such as Birch Creek, have no historic flow records. Other streams have partial data. Even in situations with considerable flow data, such as the Virgin River and the Green River, the number of variables (ecologic, hydrologic, compacts, Indian entitlements, and existing use patterns) give rise to complex predictive situations.

Previous efforts to define instream flow needs have used these four approaches: fishery habitat, riparian vegetation survival needs, visual effect ratings, and canoe or recreation needs. In general, fishery habitat considerations comprise the most commonly used determinant in traditional minimum flow studies. All of these approaches require the application of field data and a high degree of individual, professional judgement. This latter aspect may be subject to considerable differences of opinion, and consquently will be controversial.

Meeting Water Management Goals

Looking at Federal reserved water rights in the context of basin-wide water management goals, two differing situations may occur: (1) Federal water rights associated with headwater areas would have little or no effect on downstream flows and future water diversions,[5] and (2) Federal water rights on streams that flow through designated wilderness or other special management areas could have limiting effects on future upstream uses of any waters unappropriated at the time of the Federal designation. In both cases, although Federal reserved rights add another element for consideration, the opportunities for comprehensive river basin planning will continue--in fact, such planning will become increasingly important to the coordination of the various involved interests.

CONCLUSION

It has become apparent that water associated with designation of Federal lands for special uses must be an integral part of the decision process. Department of the Interior Assistant Secretary Horn has been quoted as stating that "rather than relying on the courts to discern congressional intent, we strongly urge Congress to specify what water rights will be set aside" (PLN, 1987a). This will increase the complexity and completeness of wilderness studies prior to legislative action. Given the already complex situation with streams such as the Green River, there is

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[5] Wilderness management may preclude headwater storage projects but this would not be the result of Federal reserved water rights.

question, as a practical matter, on how much instream quantification the Congress may be able to assign. If Congress can quantify reserved water rights, it would clarify matters for new wilderness areas; however, unless retroactive review legislation is undertaken, the lack of clear, quantified intent for existing wilderness areas and other existing Federally designated special management areas will remain.

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APPENDIX

Pertinent Water Rights Decisions

1908 Winters v. United States, 207 US 564, 28 S. CT. 207, 52 L. Ed. 340 (1908)
The Supreme Court held that the creation of the Fort Belknap Indian Reservation not only set aside land, but also implicitly reserved a sufficient quantity of water to fulfill the purposes of the reservation.

1939 United States v. Powers, 305 US 527, 59 S. CT. 344, 83 L. Ed. 330 (1939)

1955 Federal Power Commission v. State of Oregon, 349 US 435, 75 S. CT. 832, 99 L. Ed. 1215 (1955)

1963 Arizona v. California, 373 US 546, 83 S. CT. 1468, 10 L. Ed. 542 (1963)
The Supreme Court held that the implied reservation of water doctrine was equally applicable to other Federal establishments such as National Recreation Areas and National Forests.

1971 United States v. District Court in and for the County of Eagle, 401 US 520, 91 S. CT. 998, 28 L. Ed. 2d 278 (1971)

1976 Cuppaert v. United States, 426 US 128, 96 S. CT. 2062, 48 L. Ed. 2d 529 (1976)
The court found that reserved rights exist for National Forest wilderness purposes.

1978 United States v. New Mexico, 438 US 696, 98 S. CT. 3012, 57 L. Ed. 2d 1052 (1978)
The court determined that reserved rights exist for the primary national purposes of securing favorable conditions of waterflows and provision of a continuous supply of timber. Also denied additional reserved water rights for recreation, aesthetics, wildlife preservation, and cattle forage.

1985 Sierra Club v. John Block, et. al. (The Colorado decision discussed above in the text of the paper.)

Water Marketing and Rate Setting for Water for Energy in the Upper Colorado River Basin

by
Deborah Martens Linke
Chief, Repayment Staff, Upper Colorado Region
Bureau of Reclamation

ABSTRACT

The Upper Colorado River Basin is home for a vast array of energy and mineral resources, including oil, gas, coal, oil shale and tar sands. The Basin is also the major source of water in the Colorado River System. This paper examines the inter-relationship between water and resource development. The Bureau of Reclamation's Upper Colorado Regional Office has developed much of the available water in the Basin through the Colorado River Storage Project and has implemented several major transfers of water for energy projects. The paper uses these case studies to focus on alternative marketing and pricing strategies used to facilitate water transfers in the Basin.

Several rate setting procedures such as the debt service methods, comparable market values, power foregone, willingness to pay, and sliding-scale standby rates are described in detail, using case studies.

The paper concludes with a discussion of trends in water marketing in the Colorado River Basin. Implications of Indian water rights settlements, the growing demand for water in the Lower Basin, the decline in local energy production and agricultural economies, and the legal and institutional constraints are translated into a long-term outlook.

KEY TERMS: Water for energy; water marketing; rate setting; Upper Colorado River Basin.

UPPER COLORADO RIVER BASIN

The Upper Colorado River Basin encompasses the drainage basin of the Colorado River above Lee Ferry, Arizona, which is the dividing point between the Upper and Lower Colorado River Basins, and the Great Divide Basin in southern Wyoming. The Upper Colorado River Basin, which covers nearly 114,000 square miles, includes parts of the States of Arizona, Colorado, New Mexico, Utah and Wyoming.

An average of about 95 million acre-feet (MAF) of water a year is generated by precipitation each year. About 85 percent returns to the atmosphere through evapotranspiration. The 15 MAF remaining represents the average annual available water resources in the Basin. The use of this resource has been greatly enhanced by the presence of several large Bureau of Reclamation reservoirs which are discussed later in the paper. Most of the runoff in the Basin is generated in the mountains of Colorado.

LAWS OF THE RIVER

Each State in the Upper Colorado River Basin has a series of State laws which provides for control of the water within each state. These laws are generally based on a system of prior appropriation. This means that ownership of the water resources is determined according to the date that the filing for the right and by definition of a beneficial use. The states control the appropriation system for their water.

There are three additional documents which play a major role in governing the interstate control of water--the Colorado River Compact of 1922, the Mexican Water Treaty of 1944, and the Upper Colorado River Basin Compact of 1948.

The Colorado River Compact divides the Colorado River Basin into the Upper Basin and the Lower Basin, separated at a point on the river near the Utah/Arizona border known as Lee Ferry. Article III(a) splits the water of the Colorado River between the Upper and Lower Basins. Each Basin is given the right to consumptively use 7.5 MAF of water each year. In addition the Lower Basin may increase its beneficial consumptive use by 1 MAF. The Compact also obligates the Upper Basin States to not cause the flow of the river at Lee Ferry to be depleted below an aggregate of 75 MAF in any 10 year period.

The Mexican Water Treaty defines the right of Mexico to the use of Colorado River water. It guarantees delivery of 1.5 MAF of water from any and all sources to Mexico from the United States. Reclamation has interpreted the law of the river to mean that each Basin provides one-half of that amount.

The Upper Colorado River Basin Compact divides the Upper Basin allotment among the States. Under this compact, Colorado receives 51.75 percent, New Mexico 11.25 percent, Utah 23 percent, Wyoming 14 percent and Arizona 50,000 acre feet (AF).

Each state has the duty and responsibility of determining under its state statutes how its remaining amount of Colorado River Basin water is to be used. The Secretary of the Interior cannot interfere with these State responsibilities.

Another major law which impacts the use of water for energy in the Upper Colorado River Basin is the Endangered Species Act (Public Law 93-2050). Under this Act, the Secretary is required to provide for conservation of endangered species and to utilize existing authorities to conserve endangered and threatened species and to take no actions to jeopardize existence of such species. Several endangered native fish species, notably the Colorado squawfish and the humpback chub are present in the Basin. The preservation of these species through adequate stream regimes continues to be a major consideration in use of water in the Basin.

In addition the Secretary of the Interior has trusteeship responsibility for the Indian tribes in the Upper Basin. There are five major Indian reservations in the Basin. In recent years, Indian tribes have made numerous claims to water in the Basin. These claims include both appropriated state water rights and Winters Doctrine rights called "reserved rights". The Upper Colorado River Basin Compact allows for "borrowing" of water among the Upper Basin States so long as it does not impair the ability of any State to use its Compact entitlement. At least one of the Upper Basin States, Colorado, has passed State legislation prohibiting interstate export of water.

Water can be made available for use by energy projects in one of several ways. The first is to seek a new appropriation. Any new appropriation must demonstrate that it does not affect senior water rights holders and must be in the public interest in the eyes of the state involved. It should be noted however, that many of the streams in the Upper Basin are over-appropriated. The second is to buy or lease senior water rights outright and demonstrate that the new use will not impair more senior rights. The third option, which is the focus of this paper, is to purchase water for up to forty years through a federal water service contract.

ENERGY RESOURCES IN BASIN

The Upper Colorado River Basin is home to a vast array of energy resources including petroleum, uranium, coal, molybdenum, trona, oil shale and tar sands. Total crude oil resources are 6.7 million barrels; natural gas resources are estimate at 103 trillion cubic feet. About 70 billion tons of coal are considered recoverable. Oil shale deposits in the region constitute the largest undeveloped energy source of the United States and are estimated to have a potential of yielding of 2 trillion barrels of shale oil. Eighty percent of the land in the Basin is under governmental or Indian ownership.

STATUS OF ENERGY DEVELOPMENT IN BASIN

During the 1970s the Upper Colorado Region saw tremendous growth in the production of energy, particularly coal, oil and gas. In the Upper Basin States coal production tripled over the decade. In addition the OPEC's oil embargo triggered Project Independence, a national program aimed at eliminating the United States' dependence on foreign energy sources. One facet of Project Independence which greatly influenced the Upper Colorado Basin was a thrust to develop the oil shale resources in the Uintah and Piceance Basins of Utah and Colorado.

The 1974 report, "Water for Energy in the Upper Colorado River Basin", predicted that 18 additional coal-fired electric generating plants, 4 coal gasification plants, and 11 oil shale plants would be constructed in the Basin by the year 2000. Ten of the generating stations were constructed in whole or part and several oil shale facilities were started.

However, as world oil prices dropped during the early 1980s the Basin saw a corresponding slump in energy production and exploration. Oil shale research and development virtually halted and oil and gas exploration decreased dramatically. Coal production also plummeted and the development of any new coal resources ground to a stop.

The general consensus is that the energy resources of the Basin will ultimately be needed. The timing of the demand is far from certain.

COLORADO RIVER STORAGE PROJECT

The Colorado River Storage Project (CRSP) Provides for the comprehensive development of the Upper Colorado River Basin, The CRSP furnishes the long term regulatory storage needed to permit the Upper Basin States to meet their flow obligations at Lee Ferry and still use the water apportioned to the States by the Upper Basin Compact. The CRSP includes four mainstem storage units; Glen Canyon, Flaming Gorge, Aspinall, and Navajo. Much of the water for use in each of the Upper Basin States is developed by twenty smaller participating projects located in the various states. Construction was initiated in 1956 on the mainstem Colorado River reservoirs all of which are now complete. Construction is complete or underway on fourteen of the participating projects and one is awaiting construction funding.

The mainstem storage reservoirs have a total capacity of nearly 34 MAF. During periods of low stream flow, the stored water in the Upper Basin is released to meet the Lee Ferry obligation. The CRSP mainstem and participating projects are multi-purpose developments serving irrigation and municipal water, flood control, fish and wildlife, power and recreation purposes.

CRSP REPAYMENT

The authorizing legislation for the CRSP, Public Law 94-485, passed in April, 1956, envisioned a unique repayment scheme. Power customers, municipal and industrial users all repay a proportionate share of the operation and maintenance costs and the costs allocated to their use, with interest. Agricultural users pay operation and maintenance costs plus capital costs up to their ability to repay, without interest. The CRSP mainstem powerplants, plus water service sales contracts from the mainstem storage reservoirs serve as the primary "cash registers" to repay the costs associated with irrigation which are above the irrigators' repayment capability. Some costs, such as flood control, fish, wildlife and recreation are considered to have national benefits and are non-reimbursable costs which are borne by the federal government. Once the entire CRSP complex's costs are repaid, excess revenues are apportioned back to the Upper Basin States to use for participating project repayment.

Total investment costs for the entire CRSP are projected to be nearly $6.3 billion. Over 75 percent of these costs are reimbursable by project beneficiaries. Through 1985, about 26 percent of the $1.12 billion in plant in service had been repaid. Power sales produced nearly 98 percent of the net revenues during 1985. Repayment to date is in addition to payment of all operating, replacement and current reimbursable interest costs. Virtually all of the participating projects constructed to date have been turned over to local water districts for local operation, and became the financial responsibility of the local entity. Recent projections indicate that repayment of all the reimbursable costs of the mainstem power features can be achieved by the year 1995 and repayment of nearly all of the authorized CRSP participating projects can be accomplished by the year 2090.

WATER AVAILABILITY

The average annual undepleted discharge of the Colorado River in the Upper Basin is about 15.1 MAF. Of this amount, 8.25 MAF must be delivered to Lee Ferry to meet Lower Basin and Mexican Treat obligations. This leaves an average of 6.85 MAF available for use in the Upper Basin. The current depletion level of the Upper Basin is about 3.65 MAF, which leaves about 3.2 MAF yet to be developed.

The CRSP mainstem storage reservoirs have a total of about 34 MAF of water stored, of which about 26 MAF is in active storage. This storage assures delivery of 8.25 MAF to the Lower Basin and provides a total yield of at least 5.5 MAF to the Upper Basin.

As development occurs in the Upper Basin, the amount of water available for marketing from the mainstem reservoirs through water service contracts for energy and other uses on a relatively short-term basis (no more than 40 years) decreases over time. Current estimates indicate that about 1.1 MAF are available for marketing through the year 1990, and about 0.5 MAF are available through the year 2010 from the CRSP mainstem reservoirs. In addition there are several smaller amounts available for the same time period from smaller participating projects which could bring the total to over 0.6 MAF.

FEDERAL CONTRACTING PROCEDURES

Water service contracting for irrigation, municipal and industrial water from the CRSP is authorized by the Reclamation Project Act of 1939 (Public Law 76-260). The broad authority of this Act, when taken in concert with the CRSP authorizing legislation, permits the Secretary of the Interior to market water through water service contracts for up to 40 years for "...such rates as in the Secretary's judgment will produce revenues at least sufficient to cover an appropriate share of the annual operation and maintenance cost and an appropriate share of such fixed charges as the Secretary deems proper.."

FEDERAL RATE-SETTING METHODS

Traditional Cost Allocation Method

Traditionally, on a Bureau of Reclamation water project, costs are normally allocated, or assigned, over the various project purposes and beneficiaries using the "separable cost remaining benefit method" of cost allocation. The benefits for each purpose are determined by defining the costs of a single purpose project which would produce the same result. On a multi-purpose project costs can either be separable or joint. Separable costs are those costs which are directly and singly attributable to one specific purpose. For example, an aqueduct which serves only municipal and industrial users would be a single purpose M&I feature. A joint cost facility is one in which a project feature serves more than one purpose. A dam which stores water for both irrigation and industrial use would be a joint cost facility.

The separable costs of a project are separable by project purpose. When the separable costs for each purpose are subtracted from the benefits for each purpose the net is the remaining benefit. The costs for the joint facilities are then allocated in proportion to the remaining benefits for each project purpose.

Once the cost allocation procedure is completed, there is a cost allocation for municipal and industrial water which is then translated into an annual cost for water. The annual cost for water is derived by dividing the capital cost for the water by the number of acre-feet, then amortizing the capital cost over the life of the project, typically 40 to 50 years, at the legislatively determined interest rate for the project. Historically, the interest rate for the CRSP has lagged behind market value. CRSP also provides for fixing the interest rate at the time project construction is initiated. This has resulted in artificially low prices for water at a subsidized interest rate (sometimes two or three percent).

In addition to the amortized capital cost, each acre-foot of water bears a proportionate share of the operation, maintenance and replacement costs. Because of the large sizes of the CRSP mainstem reservoirs, the OM&R figure for CRSP has also been low (about $1.00 per acre-foot annually) due in large part to OM&R being assigned to the entire yield of the mainstem reservoirs, resulting in an economy of scale and power revenues paying for OM&R for unmarketed yield.

The traditional method set a price for CRSP water at $7.00 per acre-foot per year plus O&M. Several contracts were negotiated for water for energy in the Four Corners area of New Mexico at this rate during the mid-1970s. This rate setting method was used in the transfer of water on the Emery County Project from agriculture use to use by a coal-fired electric generation station in the late 1970s.

Debt Service Rate Setting

In the early 1980s Reclamation's Upper Colorado Region recognized that the water rates for CRSP mainstem water service contracts were artificially low when established under the traditional rate setting methodology. The debt service rate setting for the CRSP was devised to remedy that problem.

Debt service rate setting recovers the true cost to the Federal treasury of developing the water, storing it in Federal reservoirs unmarketed, and recovering the interest subsidy. Using 10-year Treasury interest rates, which are representative of the actual financing costs to the Treasury, this method computes the present worth of the CRSP investment. At the beginning of each year, the total unpaid investment for consumptive uses is indexed to account for the interest on the unpaid investment and amortized at an appropriate interest rate to derive a rate for each use. Recognizing interest charges for a year vary with the date of execution, two rates for each type of use (one for the first half and one for the second half of the year) are set to reflect interest costs.

Ten-year Treasury interest rates are used to set the industrial rate, which is $38 per acre-foot for the second half of 1987. The CRSP interest rate is used for municipal water use since historically, it has lagged behind market rates and is more representative of the long-term financing afforded municipalities. The second-half 1987 rate for municipal water from CRSP is $54 per acre-foot. Annual irrigation water rates, consistent with Reclamation law, are calculated on an interest-free basis. This rate is $12.40 for 1987. All current CRSP water marketing uses the debt service rate setting method.

Option Contract with Sliding Scale

A variation of the debt service method involves an option-type contract. During the time period leading up to actual use of contract water the entity pays a standby charge for reservation of water service. The standby charge is a negotiated figure and is typically not less than the interest charge for that year, plus operation and maintenance. Coupled with the standby charge concept is that of a sliding scale for the charge. The standby charge increases over time with the net effect of either moving the water costs toward the actual debt service cost or making the standby price prohibitive for holding for speculation. This rate setting method has been used by Reclamation on the Utah International Inc. water service contract for 35,300 acre-feet of Navajo Reservoir water.

Opportunity Cost

On some Reclamation projects, particularly in the Missouri Basin, the opportunity costs of the value of the federal power foregone is used as the cost of water. When water service is provided by Federal contract to an industrial user, the water depleted from the river system is typically no longer available for Federal hydropower generation. Generation losses may have to be replaced by purchasing energy from other available sources at market rates to meet Federal power customer commitments. If this method were used on the CRSP, the rate for water would be in the $25-30 per acre-foot range.

Cost of Most Likely Alternative

This rate-setting method is premised on an entity being willing to pay a cost comparable to its next best alternative. The cost of a single purpose facility necessary to serve the industrial water supply is estimated. Market rates for financing are assumed and an acre-foot cost of water is derived. This method has some inherent weaknesses in light of institutional uncertainties such as the entity's ability to obtain a state water right, costs for compliance with the Endangered Species Act, and the ability to accurately identify the real costs of the next best alternative.

Market Value

This rate setting option has direct applicability where there is already a clearly established market for the water. Mutually acceptable rates have been established between willing buyers and sellers which are tied to then-existing economic conditions in the area. Probably the best known example of market value rates in the Upper Colorado Basin is the water acquisition for the Intermountain Power Project (IPP). The negotiators for IPP issued a set of principles to follow in negotiations. The primary points in these principles included: Negotiating only with established water entities; equal opportunity for all water users to sell water to IPP, minimizing impacts to those who chose not to sell. A negotiated rate of $1750 per acre-foot resulted. This rate has served as the benchmark for subsequent non-federal industrial water sales.

Willingness to Pay

The willingness to pay rate setting method applies only where there is more demand than water supply. The concept is premised upon the concept that in situations where the water resource is scarce or limited, the buyer will be willing to pay more than market value. Willingness to pay would be determined by a closed bid by the potential purchaser, with a set minimum acceptable bid.

Trends in Water Marketing in the Basin

Water resources projects planning, development and marketing are changing. These changes are being forced by a far-reaching range of federal and non-federal policy shifts. Some of the more significant trends which will affect water marketing for energy in the Upper Colorado Region are:

- The increasing emphasis on maximizing and rehabilitating existing water projects and the possible marketing opportunities, as well as assurance that beneficiaries pay for the benefits received.

- The shift to smaller, locally oriented projects and the accompanying shift to local values.

- The impact of federal budget cuts and the shift to non-federal financing.

- The potential role Indian water rights settlement agreements and the Endangered Species Act could have on both water availability and marketing opportunities.

- The increasing likelihood of non-traditional coalitions emerging to support water marketing.

- The effects of full water use within basins and the pressure for increased interbasin water transfers.

- The conversion of agricultural water to industrial and municipal use in rapidly growing areas.

Budget Trends

The state of the federal budget, the Gramm-Rudman deficit reduction and balanced budget initiatives are all affecting water resource development. These budgetary and financial constraints are also going to be significant factors affecting water marketing for energy from federal water projects.

Water projects have long been some of Congress's pet projects, particularly in the arid western states. And until now Bureau of Reclamation projects, for the most part, have enjoyed funding levels which assured the continuation of construction. There can be no doubt, if one believes the current mood in Congress and this Administration, that spending for domestic programs, including water projects will be constrained in the coming decade or two.

With the decline in the energy market and resulting decrease in state tax revenues, the Upper Basin States are also facing significant budget shortfalls. These lead rapidly to the conclusion that the States are going to be acutely interested in any new potential for sources of revenue such as water sales.

Shift Toward Non-Federal Sector

There is likely to be a shift in funding sources from the federal sector to the state and local sectors. This means that instead of receiving federal dollars to develop water projects, any new water projects will be looking for alternate funding sources which will demand assurance that revenue streams are secure for repayment of the costs.

Hand in hand with non-federal financing, is the trend toward smaller, more locally-oriented projects. These smaller projects tend to be responsive to local needs, policies and politics. As we all know these local priorities may or may not match with either state or national priorities.

With the shift to local projects which are locally financed, I think we are going to see an expectation from the local entities that at a minimum, there will be no "freebies" and that at a maximum, any water sales should benefit state and local coffers. Any water sale for energy should carry its own economic weight, and that any proponent for the water sale should be prepared to pay for (read that finance) those benefits. This may seem a bit harsh, but with the move by Congress to severely limit the financing vehicles available to local and state government, not to mention Gramm-Rudman, those local entities faced with increasing populations and water demands are, at the same time, being faced with decreasing financial resources at their disposal.

Although there would be some who would argue that "federal red tape" is terrible, the same "red tape" and the attendant "attached strings" have resulted in significant national and regional economic benefits. A federal agency is mandated by law to adhere to any number of laws, such as the Freedom of Information Act, State water law, specific project authorizations for benefits, the Davis-Bacon Act and the National Environmental Policy Act. By virtue of the requirements of these and other laws, a federal agency must visibly comply with rather stringent disclosure criteria and compliance requirements. These requirements become part of a federal agency's written policy on how to do business and thus are difficult to eliminate or sidestep between federal agencies and changes in management. These requirements also assure that the assets of the American taxpayer are protected in any sale of water.

As funding shifts to state and local government, these requirements may or may not apply. Not every state has its own version of the NEPA, an ethic to develop resources in the most prudent manner, or a commitment to public disclosure. Thus, it will become increasingly difficult to properly track project benefits and true beneficiaries through the planning and development of projects.

State and local governments faced with decreased federal funding must look either to their constituents (and taxes) or to the private sector for water project funds. The current administration has a commitment toward seeking non-federal funding of water projects and forming private/governmental partnerships for development. With the decreased federal dollars, the trend will accelerate toward private/state/local financings.

This trend could also have some rather interesting financial implications. A recent experience in seeking non-federal funding for a hydropower project in Utah is illustrative. The project started out quite large and expensive and has continually dwindled in size--not because the project wasn't a good one from an engineering perspective (it was), and not because there weren't significant economic benefits (there were). The large project was discarded because the financial market could not absorb the costs and the power market could not absorb the energy generated. The conclusion reached must be that private financing of water and power projects will have an intense focus on the "bottom line" and decisions will be made primarily, if not entirely, based on existing market conditions.

More Emphasis on Maximizing Use of Existing Facilities

This brings me to the next trend I'd like to discuss. I see increasing emphasis on prioritization of projects. At the federal level decreased funding means that only those projects which are either crises or at the very top of the list will be built. This ties in very neatly to private financing and I believe, will accelerate the focus on cost-effectiveness and marketable products. I believe we will see most of our new water dollars spent on those projects dealing with innovative technology maximizing the benefits for the dollars spent or those featuring minimal construction of new civil works.

I'd like to dwell a moment on my last statement about minimal construction of new civil works. Most of the really large feasible water projects are constructed, and many of these projects are forty to fifty years old. Early western water projects had irrigation as their primary purpose, with little or no water for municipal and industrial purposes. These older, single-purpose projects are faced with fluctuating energy markets, urban encroachment and changing demands for water.

This trend will cause those projects to maximize the use of the available resources for the most public uses. The maximization of the resources will lead to rehabilitation of the existing structures so as to be water efficient and so that they can serve more than one purpose. There are some real opportunities for moving toward multi-purpose projects in these rehabilitation and betterment projects--opportunities such as providing water for energy, power or recreation through meaningful water conservations programs. As water professionals, we need to be looking for those opportunities and making them work for us.

Hand in hand with the improvement-type of projects comes the conversion of water from agricultural to municipal and industrial purposes. Conversion can be either a negative or a positive from a water availability perspective. Water use, rather than being primarily warm weather use, becomes year-round use. This seasonal shift has the potential to cause concurrent changes in seasonal stream flows and water quantity.

Increasing Emphasis on Water Marketing

We are seeing more water marketing from existing federal projects at the federal level and a move to pricing policies which more nearly approximate the market value of the water. A good example of this trend is the Colorado River Storage Project water marketing policy discussed earlier.

In addition, consideration is being given to alternative policies which would let marketplace economics determine the value of the water on existing projects where conversion is occurring and to allow market transfers of water to occur. This is a relatively new concept, and it is not clear what the ramifications or final direction may be over the long term.

Market pricing trends have some interesting implications in the Colorado River Basin. The water of the Colorado River is over-appropriated. In addition, due to population increases in the southwest and a declining energy economy in the Upper Basin, the limited water supply lies in a different basin from the interim market. Market economics coupled with water shortage is causing some interesting things to happen, primarily on the non-federal side.

Strange Bedfellows

One of the resulting trends is what is called the "strange bedfellows" trend. During the three previous decades, it would have been largely inconceivable that major water user groups would even think of aligning themselves with endangered species proponents, or Indian tribes, or salinity interests. Yet I am convinced that we are going to see just that happen as water becomes increasingly scarce in he Colorado River Basin. The latter three interest groups are committed, respectively, to adequate flow regimes for endangered fish species, settlement of Indian water rights claims for marketable water supplies outside the basin, and maintaining existing water quality/salinity levels for use in the Lower Colorado River Basin. I believe that the Lower Basin water users and the three "special interest" groups could form a very powerful, and effective, coalition which would have been unheard of ten years ago. I think we will see more networking and coalition-building on water-related issues.

It is also likely that we are going to see an increasing number of locally-sponsored or privately-sponsored proposals for interbasin transfers of water. A good example was last year's private sector proposal to build a reservoir in western Colorado in the Upper Colorado River Basin to make releases to meet San Diego's water demands in the Lower Colorado River Basin. The shock waves that met that proposal still haven't died down, but these types of interbasin transfers, out of necessity, could become commonplace by the turn of the century.

These transfers may have some help from ongoing Indian water rights settlements. Several settlement talks are ongoing which feature transfer of storage rights to Indian tribes. These storage rights and water are proposed to be marketable by the involved tribes as a source of funding for on-reservation tribal economic programs. Granted, there are a number of legal impediments to be overcome prior to these schemes becoming reality, but they could receive serious consideration in the coming five years by all parties concerned.

The localized water shortages and potential demands for water for energy mentioned earlier call for innovative solutions which will be predicated on such "environmental" tenets as water conservation programs with real economic teeth and secondary water systems for outdoor use.

OPPORTUNITIES

There are some very real opportunities for providing water for energy. CRSP water is competitively priced and comes with full compliance with environmental laws. Leasing water makes sense as a hedge against boom and bust energy cycles which are legend in the Upper Colorado River Basin. Reserving water for energy now in the Upper Basin for use in the Basin keeps it in the Basin. The water is immediately available; there is nothing to build, permit or finance. In addition, an energy company deals with an experienced, well-backed partner interested in the long-term return and ultimately, the future of the region.

SUMMARY

Even with the new debt service rate setting, water from the CRSP is a bargain compared to the other available resources. This is due in large part to the large sizes of the mainstem reservoirs and the inherent economies of scale.

State and local governments are financially strapped and are not likely to build many new projects developing any significant amounts of water. Private projects for the most part are much smaller, more expensive and highly speculative since they face enormous institutional uncertainties.

Water from the CRSP is available and priced below market price. Although the use of water from the CRSP must comply with NEPA and the ESA, the federal government has the experience and capability to move these compliance procedures through expeditiously.

There can be no doubt that the energy resource base in the Upper Colorado Basin exists and will eventually require water to develop. In the interim, water resources are going unused in the face of a existing market outside the Basin.

The resulting short-term marketing trends point toward CRSP water serving as an integral resource in meeting both short-term water needs and long-term energy water demands. In order to respond to these trends, water resource professionals working in the Basin must place greater emphasis on flexibility, fiscal realities, and interim marketing opportunities.

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ACQUISITION AND MANAGEMENT OF INDUSTRIAL WATER RIGHTS IN THE ARID WEST

David B. Bush[1]

ABSTRACT: Strong pressure for water transfers exists in many regions of the West as water resoures are fully developed and new demands can only be accomodated through transfer from established uses. Heavy water-using industries, particularly in the mining and energy development sectors, are hard pressed to find secure water supplies in sufficient quantities and at reasonable costs. Case studies of past and ongoing transfers of water rights for mineral and energy development in three states--Arizona, New Mexico, and Utah are presented. Several different types of market transactions are described and evaluated, including the transfer of water company stock, transfers of individually appropriated rights, acquisition of water rights through the purchase and retirement of irrigated farmland, water rentals, and negotiated options to buy land and water rights.
KEY TERMS: Water marketing; water rights; water transfers.

INTRODUCTION

Strong pressure for water transfers exists in many regions of the western United States as water resoures are fully developed and new uses can be accomodated only through transfer from established uses. In many cases these transfers are being accomplished through privately negotiated, market or market-like transactions (Saliba and Bush, 1987).

Market reallocations of water resources have not been trouble-free. Few water markets are unified; transactions are often scattered, disconnected, highly localized, and informal. Water transfers typically are subject to numerous legal, hydrological, and economic limitations. Information vital to establishing water values and market prices--how much water would be available for use by the buyer, conditions under which the water might be used, the "going" price paid by others in similar transfers, and the costs associated with carrying out the transaction--can be difficult to determine. Yet market activity is becoming increasingly widespread and the frequency and volume of market transactions in water is expanding rapidly (Saliba and Bush, 1987).

Heavy water-using industries, particularly in the mining and energy development sectors, have been hard pressed to find reliable water supplies in sufficient quantities and at reasonable costs. During the boom years of the 1960's and 1970's, rapidly increasing demand and high prices for food and primary materials led to intensified efforts in the agricultural, energy and mining industries to secure adequate supplies of water to support continued growth. Industrial and agricultural water users often competed among themselves for scarce water supplies. Where water rights have been available in open market settings, industrial water users, able to pay high prices for land and water resources, tend to outbid irrigators. The process of reallocating water from out of agriculture to mining and energy production has raised concerns over the potential impact of large-scale water transfers on the viability of irrigated agriculture in the West (Whittlesey, 1986; Young, 1982; Gisser, et al., 1979).

[1] Research Associate, Department of Agricultural Economics, University of Arizona, Tucson, Arizona 85721.

In the 1980s, depressed prices and slack demand for food, raw materials, and energy have reduced pressures to develop or transfer additional supplies of water to primary production and extraction industries. Foreign competition has eroded the market for many domestically produced agricultural and mineral commodities. Meanwhile, costs of domestic production have not fallen and in many cases they have risen significantly.

Caught in a squeeze between high production costs and low demand, producers have had to make numerous adjustments in order to remain competitive. These adjustments include the adoption of improved production technologies, reducing output, eliminating unprofitable products, and diversifying into other more profitable enterprises. Many producers, unable or unwilling to adapt to the changing economic environment, have gone out of business. As a result, demand for water in a number of primary production and extractive industries in recent years in the West has either declined or increased only slowly.

Slow or negative growth in some traditional industries, however, does not necessarily signal a general economic decline in the West. It is more likely an indication of a trend towards less natural resource-intensive, more water-efficient economic activities (Randall, 1982). Transportation, tourism, service industries, and high technology are examples of rapidly growing economic sectors in the West. These sectors typically use far less water to produce a unit of value than is required in industries such as agriculture, mining, and energy (Kelso, Martin, and Mack, 1973).

In the past, the major challenge facing the mining and energy industries with respect to water was finding enough resources to satisfy current and future demands. When existing water supplies in a region became fully claimed and developed, they sought to acquire additional water rights through transfers from existing users. Their quest for water often led them into direct competion with irrigated agriculture. While the majority of water reallocations still occur from out of agriculture, and many of these transfers continue to be for mining and energy uses, this process represents only one set of events in an increasingly complex and fast-changing western water economy. Competition for scarce water supplies between agriculture and the mining and energy industries is less important than it was only a short number of years ago, while the thirst of urban developments and nontraditional industries in the West continues to grow. Agricultural, mineral, and energy producers alike are finding themselves in possession of significant quantities of scarce and valuable water resources which may be more valuable to them as saleable market commodities than as productive inputs for their own operations.

This paper reviews some of the fundamental structural aspects of western water markets. Case studies of past and ongoing transfers of water occuring both to and from the mining and energy industries are then presented.

WATER MARKETS: STRUCTURE AND FUNCTION

Definitions

A water resource is a source of water supply, such as a lake, reservoir, river, stream, or aquifer. A water right is a legally recognized privilege of access to a water resource under specific conditions defined in the right, such as point of diversion, season of use, location and purpose of use, volume or rate of withdrawals, and priority of use relative to other rights holders. While water resources typically are regarded as the inalienable endowment of the whole community ("the people of New Mexico", for instance), water rights are often considered private property rights and may be bought, sold, traded or leased among private individuals, commercial enterprises, and political entities.

A market consists of the interactions of actual and potential buyers and sellers of one or more related commodities. Negotiated transactions generate prices and conditions of sale and use for each commodity. A market is usually characterized by a series of transactions taking place over an extended period of time. When relatively few transactions occur within a given period of time, the market is considered "thin" and one of the key functions of a market, the establishment of a market price, may be lacking.

Types of Water Rights

Markets for water are difficult to characterize because water rights take many forms, and the ways water markets function are integrally related to the type of rights being traded. Water rights are distinguished by how they may be used, the means by which they may be transferred, and the terms under which they may be applied to new uses. Differences among various water rights determine their relative values to buyers and sellers.

There are five basic types of water rights--riparian rights, appropriated rights, use permits, entitlements (or allotments), and mutual stock. Although general distinguishing characteristics may be associated with each of the five types listed, water rights are difficult to classify unambiguously. The administration, and consequently the characteristics, of the same general types of water rights may vary significantly from one jurisdiction to another. Classification of water rights given in the following discussion therefore is somewhat arbitrary.

Riparian Rights.--Under the riparian system, rights to use water reside with the owners of land adjacent to a watercourse. The water is available for use only on those lands and may not be transferred to any other lands. As riparian water rights are virtually inseparable from the lands to which they are attached, or appurtenant, generally they cannot be transferred independently from the land. Riparian water rights originated in humid areas of western Europe and its application is uncommon in the West.

Appropriated Rights.--The appropriation doctrine was developed to serve the unique demands for water in arid and semi-arid environments, where water often had to be captured, stored, and transported considerable distances from the source to the place of use. Appropriated water rights are by far the most common type of water right in the West. Under the appropriation system, water rights usually are assigned for use on specific lands but the assignment is not necessarily permanent. In many cases appropriated water rights may be reassigned to another location or the purpose of use changed with the approval of the appropriate state agency. However, in order to avoid adverse impacts on other water rights holders, the state may limit the transfer to a quantity equal to the consumptive use historically associated with the exercise of the right or place other restrictions on the manner of use of the right.

Most appropriated water rights are subject to two major constraints on their ownership and use. The first is that appropriated rights must be put to "beneficial use." Water rights holders who do not use their rights fully or else use water "wastefully" may lose their rights. The second restriction is that appropriated rights typically are managed under a priority system, whereby certain holders of rights have preferred access to water over other holders. Priority of use is established by the date when the state water authority recognized the user's right to appropriate water--the earlier the date, the higher the priority of the water right.

Use Permits.--Use permits may be considered as a catch-all term for water rights that are similar to appropriated rights, but distinct from them in several important ways. The principle differences between water use permits and appropriated water rights is that permits are not necessarily granted in perpetuity, they are not always subject to beneficial use limitations, and they generally are not ranked by priority. Sometimes water use permits are issued for specific purposes and are not transferable to other uses. In most western states, use permits exist in only highly specialized circumstances. Arizona is unique in that all groundwater rights are managed under a use permit system.

Allotments.--Water available from a water resource or under an appropriated right may be divided among the various users according to a formula, established through interstate compact, interagency negotiations, or by the governing board of a water service organization. The essense of a water allotment is a contractual agreement to deliver (or, to limit one's own diversion and use of) a certain quantity of water per unit of time. Entitlements are difficult to market because transferring them could violate the terms of the original agreement. Amending the agreement to permit a transfer of water usually requires the consent of many separate parties and frequently involves multiple jurisdictions with conflicting objectives. The legal complexities and delicate political balances characteristic of most water compacts have precluded the successful transfer of water between two different states. Intrastate reallocations of water project entitlements have occured, but they remain uncommon.

Mutual Stock.--When water rights are held by water service organizations, water service to its users (or members) generally is provided under either an allotment system or through the distribution of mutual stock. Under the mutual stock system, the water service organization, usually established as a private water company, controls a certain quantity of water rights which it has the authority to distribute to users anywhere within the service area of the company. The organization issues paper shares of stock, each share representing a fixed proportion of the total water service obligation of the company. The more stock a water user holds, the more water the user can get. Unlike water allotments, which are granted only to users and which may be reassigned only by the granting authority, mutual stock certificates usually are freely transferable among stockholders. So long as the stock certificates are traded within the service area of the water service organization, and so long as no specific legal restrictions on the type or manner of use of the water are violated, this type of water right is readily marketable.

Types of Water Market Transactions

Different types of water market transactions are possible, depending primarily upon two variables: first, the degree of control over the water right which the seller will give up and the buyer will assume, and second, the length of time over which the transfer will remain in effect. There are four basic types of market transfers of water--perpetual transfers (sales), temporary or seasonal transfers (leases), deferred transfers (options), and various types of negotiated adjustments in the relative priority, timing, or consumptive use of water rights.

Sales.--Sales are distinguished by the purchaser's assumption of all privileges and obligations associated with the water right, in perpetuity. Sales may be accomplished in a variety of different ways, including transferring the title to the water right itself, signing over a stock certificate, or reassigning contractual obligations, tax liability, or bonded indebtedness to a water project or water district.

Leases.--A lease of a water right entitles the lessee to enjoy all or most of the same benefits, endure the same risks, and undertake the same obligations in holding a water right as if a transfer of ownership had taken place, but only for a limited period of time. Leases most typically last for no longer than a single season or a year, although leases for 5, 10, and even 99 years have occured.

Options.--Water users may sometimes want to acquire control over more water rights than they want to use immediately. Extra water rights may be desired if a user intends to expand water use in the future. Even if there is no intention of using more water in the future, a user may wish to hold extra water rights simply as a measure of security against possible supply fluctuations, as may be caused by a drought or a disruption in water service.

The most direct way of holding additional water rights is simply to buy extra water rights. However, purchasing more water rights than can be used may be both expensive and risky. It may be expensive in that money is invested in a resource which will remain idle for an extended period of time. It may be risky in that unused water rights could be forfeited if the user fails to demonstrate to the state water authority that the rights have or will be put to beneficial use in a timely manner.

Options may provide a means for a water user to control a given quantity of water rights without having to bother with the risk and the expense of owning them outright. An option is a contractual agreement which gives one party the perogative, usually over a specific period of time, to purchase or lease water rights from another party.

Negotiated Adjustments.--Sometimes the quantity, quality, or reliability of a water supply for one user may be improved when one or more water users adopt a given change in their use patterns, without actually effecting a transfer in water rights. For example, an irrigation district may agree to line its canals and thereby significantly reduce its seepage losses. Some or all of the conserved water could then be released for use by another water user downstream. In another example, one user holding a senior water right may agree to allow another user with a junior water right to take water "out of priority", thereby increasing the quantity of water available under the junior appropriator's right. Negotiated adjustments may be temporary or perpetual.

Southern Arizona

The case studies in Southern Arizona both lie within the Tucson Active Management Area (AMA), created under the Arizona Groundwater Management Act of 1980. Pursuant to this Act, the Tucson AMA created and distributed over 500,000 acre feet of groundwater use permits to the water-using entities within its jurisdiction, based upon their recent history of use. The Tucson AMA includes the Tucson metropolitan area, with a rapidly growing population in excess of 600,000, and portions of rural Pima, Pinal, and Santa Cruz counties. The area is within the basin and range province of the Sonoran Desert and the population is almost entirely dependent upon groundwater. An appropriation held by one irrigation district of approximately 29,000 acre feet of underground channel flow in the Santa Cruz River constitutes the only other significant source of water currently available in the area. Beginning in the early 1990s, up to 200,000 acre feet per year of Colorado River allotments will be delivered via the Central Arizona Project (CAP), mostly for use in the City of Tucson.

Copper Mines in the Upper Santa Cruz Valley--The Santa Cruz Valley begins in northern Mexico and runs through Pima and Pinal counties in central and southern Arizona. Most of the major mining activity in this valley began in the 1950s, reaching its peak during the Vietnam War years. More than a decade of low copper prices have caused most of the mines to either shut down or sharply curtail production.

Most of the land and water resources acquired by the mines came originally from ranches built on old Spanish land grants or from irrigated farms in the bottomlands of the Santa Cruz River. Until passage of the Groundwater Management Act of 1980, groundwater rights in Arizona were neither clearly defined nor quantified. Beyond certain constraints imposed on groundwater pumping under a series of court decrees promulgated in the 1970s, the right to withdraw groundwater was mainly the perogative of the landowner. There were no established groundwater rights, only the right to own land and to pump as much water underlying that land as could be put to beneficial use.

With passage of the Groundwater Management Act, water rights throughout the Santa Cruz basin were precisely quantified. Almost all water rights for mining fell into either one of two categories, Type I and Type II nonirrigation groundwater rights. The 27,000 acre feet of Type I rights assigned to the mines were freely transferable to other, nonmining uses, but could not be severed from the land to which they were appurtenant. The 48,000 acre feet of Type II rights assigned to the mines were freely transferable to alternative locations, but were restricted to mineral extraction use only.

The extensive land and water right holdings of the mines have proved a boon for real estate developers and for those mines with enough financial backing to remain in business. Within a short period of time after the rights were established, water and land began changing hands in rapid succession. One mining operation shut down completely, and only one other mine remains in full operation. The other mines are operating at significantly reduced capacity. Nearly half the Type I water rights have been acquired by real estate developers, and only a fraction of the remaining Type I rights and the Type II rights held by the mines currently are being used.

An irrigation water right owned by one of the mines on land it held in reserve for possible future expansion of operations was sold recently to the City of Tucson. Under state water law, the City may petition to convert the irrigation water right to a Type I nonirrigation right and transport the water to the city for municipal consumption.

The Desertron--The proposed $2 billion Superconducting Super Collider (SSC), the largest and most advanced cyclotron in the world, promises to bring a cornucopia of jobs, federal dollars, and scientific prestige to the state chosen as the site for the project. One of the prime locations for the SSC is found at the base of the Sierrita Mountains in the Santa Cruz Valley. Up to 4,000 acre feet of water would be required per year to operate the facility. In making its bid to host the SSC, Arizona must, among other things, demonstrate to the federal government that adequate water supplies would be available.

Promoters of the SSC in Arizona, popularly dubbed the "Desertron", have pursued numerous options for securing adequate water supplies. Alternatives that have been considered include reallocating an allotment of Central Arizona Project water to the SSC, hooking up to the City of Tucson water service system, using reclaimed effluent from the nearby town of Green Valley, applying to the state Department of Water Resources for a special groundwater extraction permit, and transferring old mining water rights (Brooks, 1987).

Transfer of a Type I water right from an old mine to the SSC would be a relatively simple matter legally. Given the speculative real estate market in the Upper Santa Cruz Valley, however, the expense of obtaining the necessary quantity of land and water rights would be prohibitive. While Type I water rights in the Santa Cruz Valley are scarce and expensive, Type II water rights remain largely unused. These rights have been of no value to alternative uses, however, because of the legal prohibition against their application outside of mining. Recently a real estate developer acquired an 11,500 acre foot Type II mineral extraction right when it acquired the assets of a defunct mine. Interested in promoting the SSC, the developer agreed to donate the water right to the SSC if the right were needed and if state water law were amended to permit the use of a mineral extraction water right for the SSC. In July, 1987, during a special session of the Arizona state legislature, an amendment to the groundwater code was passed specifically granting an exemption to the SSC for the use of Type II mineral extraction groundwater rights (Arizona State Senate, 1987).

Gila San Francisco Basin, New Mexico

All three case studies in New Mexico lie within the drainage basins of the Gila and San Francisco rivers, located in the southwestern portion of the state. The area is bordered to the east by the Continental Divide and to the west by the state of Arizona. Most of the land in the basin is part of the Gila National Forest, a vast expanse of sparsely populated forest and chaparral environments at elevations ranging from 6,000 to 10,000 feet. The only urban settlement in the area is the town of Silver City, located just outside of the basin and across the Continental Divide, with a population of approximately 20,000.

Both groundwater and surface water rights in the Gila-San Francisco Basin are administered by the State Engineer under the appropriation doctrine. Approximately 31,000 acre feet of appropriated rights are held in the basin, about 23,500 in the

Gila drainage and about 6,500 in the San Francisco drainage. The Basin has been closed to additional appropriations of water since the late 1960s, so that any new user of water must transfer water rights from an existing use.

Phelps Dodge Copper Mine.--Phelps Dodge began purchasing land and water rights in the Gila drainage of the basin in about 1956, through its secretly owned subsidiary, the Pacific Western Land Company. Pacific Western acquired nearly 150,000 acres of irrigated river bottom land and open range land in the Basin over the next 10 years. Pacific Western developed its holdings into one of the largest ranches in New Mexico and, when the Gila-San Francisco was adjudicated in the mid-1960s, was able to demonstrate beneficial use on thousands of acre feet of appropriated water rights. In 1966, Phelps Dodge announced its plans to open a copper mine in the area, and in 1968, nearly all of Pacific Western's water rights were transferred to the mining company. Phelps Dodge requested and was granted a decree from the State Engineer permitting the water rights to be used for either mining or irrigation purposes. In this manner, Phelps Dodge enabled itself to bank a large reserve of water rights until the mine expanded to a size where the rights would be needed, by continuing to use them in irrigation (Tyseling, 1985).

Phelps Dodge currently holds nearly 12,000 acre feet of water rights, roughly a third of all the water rights in the Gila-San Francisco Basin, for operating its mine near the settlement of Tyrone. The mine is surrounded by the lands retained by Pacific Western, which is still a working ranch. In the early years of the mining operation, Pacific Western used a substantial quantity of water rights for irrigating pasture and some field crops. Since that late 1970s, however, the ranch has reconveyed its irrigation rights back to Phelps Dodge, relying on dryland pasture to feed its cattle. Pacific Western retains only small quantities of rights for livestock watering and household use (Allen, 1987).

Phelps Dodge has bought, sold, and leased water rights in a number of transactions since the late 1960s. Numerous small parcels of land with household water rights that were not considered necessary for the company's operations have been sold. Other small water rights have been purchased. In at least one case in the late 1970s, Phelps Dodge leased several hundred acre feet of rights. This happened when it was discovered that the combined withdrawals of water by the ranch and the mine exceeded the maximum quantity they were legally permitted to use. In an agreement with the State Engineer, Phelps Dodge leased irrigation water rights from over a dozen different individuals and temporarily retired the rights--that is, left them inactive for periods of time ranging from 1 to 5 years--as a credit against their own excessive water use (Tyseling, 1985).

The life of the Tyrone mine site is limited. It has been estimated that the ore body will be depleted within 5 to 10 years. Phelps Dodge will continue to process low-grade ore with the use of a recently installed electrowinning plant, but its use of water is expected to decline significantly. Whether Phelps Dodge will simply reconvey the surplus water rights back to Pacific Western or find another use for them is a matter of much speculation. Recently the company contracted with Estes Homes to plan real estate developments on its extensive landholdings in Arizona and New Mexico (Smith, 1987). It would not be surprising if at least a portion of the land and water rights held in the Gila-San Francisco Basin, conveniently located close to recreation areas in the Gila National Forest, were developed for residential purposes.

Boliden Copper Mine.--Exxon Minerals Company conducted explorations for opening a new copper mine in the Gila-San Francisco Basin in the late 1970s. In order to secure for itself an adequate quantity of water rights for the proposed mine while it was still determining the feasibility of the project, Exxon negotiated option contracts with individual water rights holders to purchase water rights at an unspecified future date. Approximately two dozen separate options contracts were negotiated, some for water rights only, some for land and water rights combined. The typical contract had a five year term. Some provided for a down payment equal to an average of 20 percent of the contracted purchase price, others had no such provision.

Each contract provided for an annual option payment equal to about 5 to 10 percent of the unpaid balance. Purchase prices ranged between $1,000 and $2,000 per acre foot, a significant increase over previous water rights prices in the Basin (Saliba, Bush, and Martin, 1987).

By 1982, Exxon had decided that the mine would not be economically feasible, and sold its assets, including all purchase options on land, mineral rights, and water rights, to the Boliden Minerals Company. Two years later, Boliden reconveyed five of the water rights purchase options back to Exxon, who in turn exercised the options, won approval from the State Engineer to change their use from irrigation to municipal purposes, and sold the water rights to Silver City. The 130.8 acre feet of consumptive use water rights were sold for about $359,700, or $2,750 per acre foot (Johnson, 1985). At about the same time, Boliden began exercising its options to purchase water rights, and by 1985 had acquired a total of 912.3 acre feet of water rights and 309.2 acres of land, at a total cost of $1,146,640 (Bernard, 1985). An unspecified, but small number of the purchase options were permitted to expire.

The water rights acquired by Boliden have been approved by the State Engineer for a change of use from irrigation to mining purposes. The company has no plans to use any of the rights for any other type of use. The Boliden mine has not yet opened, and there are indications that the company is undergoing a reorganization which may delay the opening of the mine further.

In addition to the acquisition of water rights through purchase options in the Gila-San Francisco basin, Exxon developed a major new groundwater right in the neighboring Mimbres Basin. The well was drilled virtually on the eve of the closing of the Mimbres basin to additional appropriations in the mid 1970s, and several years of litigation followed to determine the validity of Exxon's water right. After having successfully secured a right to 1,433 acre feet per year in the well, Exxon began seeking a buyer for it. In the fall of 1985, Silver City agreed to purchase the right for $1.2 million, or about $837 per acre foot. Proceeds from the sale were distributed 80 percent to Exxon and 20 percent to Boliden (Shoemaker, 1985).

<u>Challenge Mine</u>.--Challenge Mining Company produces gold and silver from its location in the northern portion of the Gila-San Francisco Basin, within the drainage of San Francisco River. It is a small operation compared to the large copper mines to the south. With an average daily production of gold and silver ore of 150 tons per day, Challenge has roughly one tenth the projected capacity of the Boliden mine and probably only one hundredth the capacity of the Phelps Dodge mine. Unlike Boliden and Phelps Dodge, however, Challenge Mine has modest plans to expand its operations and continues to acquire water rights for that purpose. The smelter at the Challenge minesite currently has a capacity of about 150 tons of ore per day and requires between 21 and 22 acre feet of water per year to operate. Challenge uses some of its other water rights for exploratory drilling, and is holding the balance of the rights in reserve for developing additional capacity in the future (Manning, 1987).

Challenge Mine opened in 1978, at a time when both mineral prices and water rights prices were at an all-time high. At first, the mine was unable to find any water rights to purchase at all. For the first year of operations, the mine leased approximately 20 acre feet from a nearby farmer. One year later, in 1979, Challenge purchased its first water rights. It has continued to acquire additional water rights gradually ever since. Two major floods, one in 1978 and another in 1983, washed out significant numbers of irrigated farms and prompted many holders of irrigation water rights to sell out, and prices for water rights have fallen by as much as half since Challenge first entered the market. Initial acquisitions of water rights were arranged directly with the sellers, but in more recent years Challenge has allowed a local real estate broker to handle the transactions on their behalf (Manning, 1987).

As of 1987, the mine has acquired approximately 55 acre feet of irrigation rights, which have all been changed to mining use by the State Engineer. Challenge continues to lease on an annual basis approximately 10 acre feet of irrigation water rights per year. These rights have been temporarily reassigned for mining use, but will automatically revert to irrigation use when the lease expires.

Central Utah

The two case studies in Utah are in the central portion of the state, an area dominated by high arid desert and rugged mountains. Utah recognizes the appropiation doctrine in administering its water rights. However, a substantial portion of the water used in the state is controlled not by private individuals but by mutual stock companies. The Bureau of Reclamation also provides some water in Utah under an allotment system, and this quantity will increase with the completion of the Central Utah Project.

Intermountain Power Project.--In 1978, the Intermountain Power Association, a consortium of western utility companies, decided to locate a new coal-fired generating plant in the Lower Sevier River Basin of central Utah, about 150 southwest of Salt Lake City. The Intermountain Power Project (IPP) was designed to produce 3,000 megawatts of power--the largest facility of its kind in the world.

Construction of IPP was contingent upon finding sufficient water rights to serve the plant. A firm supply of 45,000 acre feet of water per year would be needed, all of which would have to be transferred from existing uses. Several alternatives were considered, including purchasing water rights out of Utah Lake, some 100 miles to the north. Few alternatives appeared to offer a reliable yield in sufficient quantities. The best possibility appeared to be the purchase of irrigation rights from local irrigation companies along the Lower Sevier River.

When local farmers heard about IPP's prefered site and their need for water, they took the initiative of forming a sellers' cooperative, called the Joint Venture, to handle negotiations. All individuals who either owned water shares in any of the irrigation companies or who owned groundwater rights were given an equal chance to signify their interests in bargaining with IPP for the sale of their water and the quantity of water each would like to sell. Altogether, some 373 individuals associated themselves with the Joint Venture (Little and Greider, 1983).

In response to the establishment of the Joint Venture, IPP promulgated a set of general guidelines it would follow in purchasing water rights (Clark, 1980):

1. IPP will negotiate only with established water entities or their representatives; we will not go behind anyone's back.
2. The existing water users will all have equal opportunities to sell their water rights to IPP.
3. Impacts on nonsellers will be minimized. If you don't want to sell, you don't have to and we will see that you are protected.
4. Acquisition will be conducted so as to minimize the effect on agricultural production.
5. IPP will endeavor not to become a water broker because of excess water accumulated in high years.

Irrigation water rights in the Lower Sevier Basin had been selling for an average price of approximately $250 per acre foot prior to the entry of IPP and formation of the Joint Venture (Austin and Helquist, 1978). The intitial sale offer of the irrigation companies to IPP was $3,400 per acre foot of firm yield; IPP responded with an offer of $550 per acre foot. The final price agreed upon in 1980 was $1,750 per acre foot (Wahl and Osterhoudt, 1986).

A total of 45,011 acre feet of water rights--39,600 acre feet of groundwater and 5,400 acre feet of surface water--were transferred to IPP. A total of 687 individual purchase contracts were signed, 656 contracts for mutual stock in 5 different irrigation companies and 31 contracts for privately held groundwater rights (Novak, 1985).

Even though the total quantity of water rights purchased was considerable, the large number of sellers involved in the transaction spread out the effect of the transfers. Some individuals sold as few as 3 acre feet while others sold as much as 1,100 acre feet to IPP. The majority of those involved in the transaction, however, sold fewer than 54 acre feet each. The average transfer per contract was only about 65 acre feet, and the average quantity transfered per individual was slightly more than 118 acre feet. Only 4 individuals sold all their water rights to IPP. Most retained at least a nominal quantity of water, the average being around 310 acre feet per person (Little and Greider, 1983). Interviews with local individuals indicated that most of those who sold water rights to IPP intended to remain in farming. Most individuals felt that, by removing marginal lands from production and investing some of the proceeds from the sale on improving irrigation technology, the net effect of the water sale on agricultural production in the area would be moderate (Saliba and Bush, 1987).

Since the transfer of irrigation water to IPP involved both a change in type of use, from irrigation to electric power generation, and a change in place of use, from the service areas of the irrigation companies to several miles outside these areas, it was necessary to apply for approval of the transfer before the state water authorities. IPP and the Joint Venture requested and were granted an order expanding the place and purpose of use of the water to include power generation at the IPP facility, but which also permitted continued use of the water in agriculture. In this manner, water unused by IPP could be leased back to farmers for irrigation.

Shortly after conclusion of the water rights purchase, reduced projections of growth in energy demand led IPP to announce plans to reduce the size of the facility from four generators to only two. Average use of water by IPP would be only about 18,500 acre feet per year, making an average of over 25,000 acre feet of water available for lease to farmers. Although an active rental market for irrigation company stock water has existed in the Lower Sevier River Basin for decades, no single holder of water rights had ever been in a position to dominate the market as was IPP.

The full effect of IPP on the water rental market in the Lower Sevier River Basin may not be known for several years. In 1981 and 1982, the first two years that IPP owned its water rights, it leased most, but not all, of its water rights. An unusual wet cycle in the river system followed in the years 1983 through 1986. Even after the reservoirs filled, water continued to flow down the Sevier River, filling the normally dry Sevier Lake. With so much water available in the the system, virtually nobody demanded supplemental water and there was no active rental market. The surplus began to dry up in late 1986. In the summer of 1987, IPP's second generator came on line, bringing the facility up to full production capacity. Rentals resumed in 1987, but demand for water has been moderate and IPP has not leased out all its available surface water supplies. IPP has no plans to lease its groundwater rights, because, unlike the mutual water company stock, any lease of groundwater would require a new change application, a costly and complicated procedure (Staker, 1987).

With only three years of active experience in renting water, IPP has yet to establish a definitive rental policy. It is aware that its actions can have a heavy influence on the market, and has elected to procede cautiously. Past studies of the water rental market in the Lower Sevier River Basin indicate that rental prices are extremely sensitive to the available supply of rental water (Stewart, 1965). If IPP chose to dump large quantities of surplus irrigation water onto the market at once, it could depress rental prices considerably. As there are still numerous farmers with excess water rights in the Basin who earn income from leasing out water, such a measure could generate a great deal of animosity in the local community. At the same time, withholding too much water from the market or charging too high a price could also create ill will, this time among those farmers who depend on rental water to supplement their supplies.

Under its current system, IPP meets with the Lower Sevier River commissioner each spring to predetermine a "fair" price for rental water. The price is based on what the commissioner suggests appears to be the direction of the market in the coming year. IPP then mails letters to farmers in the area announcing its price. Other renters in the market typically enter the market shortly thereafter, offering their own rental water at slightly lower prices than those offered by IPP. In this manner all other sources of rental water are disposed of first, and IPP serves as the marginal supplier during each irrigation season (Perez, 1987).

Future plans for the management of IPP's surplus water are uncertain. Construction of the third of the four generating units in the original project design may begin within next the five years. So long as plant expansion remains a real possibility, IPP will retain all the water rights it purchased. Proposals have been explored for leasing surplus water for terms longer than a single year, but no action will be taken until future construction schedules for additional power generating facilities are firmly established.

Kennecott Utah Copper Mine.--Kennecott's copper mine is located 30 miles from Salt Lake City, in the southwest corner of Salt Lake County. The mine has been in existence since the early 1900s. Prior to its closing in 1983, the mine processed over 100,000 tons of copper ore per day. Since reopening in 1985, the mine has gradually returned to a scaled-down production capacity of approximately 80,000 tons of processed ore per day. Kennecott is in the midst of a $400 million modernization which, when completed in late 1988 or 1989, will further improve upon efficiency gains which have been realized in the production process in recent years. One of the results of the modernization will be a significantly reduced water requirement, freeing up a large portion of Kennecott's water rights for alternative use or transfer (Hansen, 1987).

The first water rights acquired by the mine in the early part of this century were a modest quantity of water rights purchased from irrigators. About a decade later, the mine developed an appropriated right to approximately 70,000 acre feet of water in the Jordan River. Several years later, an additional appropriation for another 35,000 acre feet was developed. In later years, rights to over 35,000 acre feet of groundwater were appropriated, as were a number of miscellaneous direct streamflow and reservoir rights. Finally, approximately 8,500 acre feet of water rights in Utah Lake were purchased from two mutual stock irrigation companies. These irrigation rights are senior to (and therefore more secure than) any other rights held by Kennecott. Under a decree issued by the Utah State Engineer, Kennecott's beneficial use of its surface water rights is limited to about 108,000 acre feet per year. While there is no similar restriction on the exercise of its 35,000 acre feet of groundwater rights, groundwater is pumped mainly to supplement Kennecott's withdrawals from Utah Lake and the rights have not been used to their fullest extent.

Prior to 1983, Kennecott used an average of 108,000 acre feet of water per year. By 1987, the mine was approaching capacity with a use level of 80,000 to 90,000 acre feet per year. It has not yet been disclosed how much water will be needed by the mine once modernization of the facilities has been completed. At the present time, the only water rights owned by Kennecott that are not being used for mining are the 8,500 acre feet of irrigation water rights purchased from the two mutual stock water companies. These rights are leased back for irrigation on an annual basis. Most of the individuals who lease the rights are company employees, who pay only a nominal fee for the rental. Kennecott rents the water at the price of the annual assessment on the water stock, which in recent years has been about $10 per share. At an average of 5 acre feet of water delivered per share of stock, the lease rate has been about $2 per acre foot (Hansen, 1987).

In early 1987, the Bureau of Reclamation approached Kennecott with a proposal to purchase surplus water rights from the mine. The Bureau intends to purchase 70,000 to 100,000 acre feet of water rights in lieu of constructing the Utah Lake component of the Central Utah Project (Water Market Update, 1987). Kennecott is negotiating the sale of all 108,000 acre feet of its old appropriated surface water rights. The company believes that its groundwater rights, miscellaneous stream and reservoir rights, and its irrigation company stock will provide enough water to serve the modernized facility (Hansen, 1987).

CONCLUSION

Historically, the overriding concern of water users in the West has been security--the protection of water rights against impairment caused by the arbitrary actions of others. Western laws and institutions continue to work to maintain a secure system of water rights, but their purpose has expanded and diversified. Economic efficiency, water quality, protection of riparian habitat, and community values are all issues being addressed by western water policymakers (Saliba, 1987). Increasing demands for scarce water resources have led to the realization that western economic prosperity is tied to water rights that must not only provide security, but enough flexibility to allow shifts to new uses as the need arises. Pressures to develop more flexible systems of distributing water rights have led to an interest in water markets as a mechanism for reallocation.

This review of some of the water market commodities and transactions in the West provides insight into the structure and function of western water markets and their role in reallocating water resources to and from the mining and energy industries. Numerous opportunities exist for marketing water rights, and more are emerging. These opportunities help provide the flexibility in water allocation systems necessary to increase the economic efficiency of water use in the rapidly growing and changing economy of the western United States.

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WATER FOR MINERAL DEVELOPMENT: ACQUISITION AND DEVELOPMENT OF THE RIGHT

George Vranesh[1]

ABSTRACT: This paper analyzes the legal issues affecting the mineral developer's acquisition and development of water rights. The thesis of the paper is that a mineral developer must not limit his analysis to the acquisition of water rights pursuant to state water rights law but that he also must be prepared for important constraints on water rights development, both within and independent of the State water rights acquisition process. Acquisition of water rights under the western states' system of prior appropriation is first examined, including a look at some obstacles to water rights acquisition and development within this system. The paper then discusses various impediments to the development of acquired water rights independent of the State water rights system. These include Indian and Federal reserved water rights, Federal environmental laws, the "law of the river," equitable apportionment, and the public trust doctrine.

KEY TERMS: Mineral Development; Water Rights

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[1] Partner, Vranesh and Raisch, Boulder, Colorado. The assistance of James Ellman, Esq., Boulder, Colorado, in the preparation of this paper is gratefully acknowledged.

INTRODUCTION

Water is essential to mineral development.[2] Quite simply, mineral development will not occur without a sufficient supply of water for extraction, transportation, and milling. The western United States, although blessed with an abundance of mineral resources,[3] is faced with a scarcity of water. The mineral developer is thus faced with the crucial task of securing enough water to fulfill the needs of his project. This paper will examine the methods by which a mineral developer in the West acquires water rights, as well as the constraints placed on their development.[4] The western states' water rights system of prior appropriation will be discussed. The paper will then analyze problems independent of State water right law that may present obstacles to the development of acquired water rights.

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[2] See 4 American Law of Mining §113.01 (Rocky Mt. Min. L. Fdn. 2d ed. 1986).

[3] For example, the West contains over half of the nation's coal and virtually of its oil share reserves. See EPA, Environmental Perspective on the Emerging Oil Shale Industry 2-11 (1980).

[4] This subject has been addressed in numerous articles. See, e.g., Clyde, "Coal Mining, Development and Processing - The Associated Water Problems," 21 Rocky Mt. Min. L. Inst. 163 (1975); Holland, "Mixing Oil and Water," 52 Den. L.J. 657 (1979); Kneese & Brown, "Water Demands for Energy Development," 8 Nat. Resources Law. 309 (1975); Muys, "Legal Problems Involved in Developing Water Supplies for Energy Development," 8 Nat. Resources Law. 335 (1975); Vranesh & Riordan, "Water for Synfuels Development: Problems in Acquisition and Development," 16 Nat. Resources Law. 439 (1983). See also Water Acquisition for Mineral Development Inst. (rocky Mt. Min. L. Fdn. 1978). And finally, 4 American Law of Mining Chapter 113, "Acquisition of Water Rights" (Rocky Mt. Min. L. Fdn. 2d ed. 1986) provides an excellent treatment of the subject.

Surface Water

The western states have evolved a body of water rights law based upon the concept of "First in time, First in right." This is known as the prior appropriation doctrine. The different states have adopted different versions of this doctrine running the gamut from California's heavy regulated hybrid riparian/appropriation system to Colorado's relatively unregulated strict appropriation system. While a description of the many nuances in each state's prior appropriation system is well beyond the scope of this paper,[5] it will be useful to examine the doctrine's basic tenets.

The prior appropriation doctrine stands in marked contrast to the riparian water law of the eastern United States. Under the riparian doctrine,[6] a landowner is entitled to that quantity of water abutting his land as is reasonably necessary for his needs. Landowners not contiguous to a body of water have no right to the water.

It was recognized almost from the beginning of the settlement of the semiarid West that the riparian system would not work. The shortage of water demanded the development of a different system to allocate the scare resource. The early-day miners of California are credited with beginning the prior appropriation system.[7] Some of the basic principles of the doctrine have been described as follows:

> [W]ater is a publicly owned resource subject to state (not Federal) laws of distribution and use. A vested property right to the use of that water may be acquired by appropriation for a beneficial use. The date of acquiring a water right determines its priority which will govern the distribution among the several water users competing for water from the same source. The basis, the measure, and the limit of the vested water right is defined by the beneficial use of that water.

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[5] There are a number of excellent treatises covering western water law. See, e.g., G. Vranesh, Colorado Water Law (1987); 5 T. R. Clark, Water and Water Rights (1972); R. Dewsnup, V. Jensen & R. Swenson, National Water Commission, A summary Digest of State Water Laws (1973); W. Hutchins, Water Rights Laws in the Nineteen Western States (1971).

[6] See generally T. R. Clark, Water and Water Rights (1976).

[7] See Vranesh & Riordan, 16 Nat. Resources Law. at 441.

> A water right ... may not be appropriated for speculative purposes. A water right ... may be transferred from one use to another, from one owner to another, and from one location to another, so long as the transfer does not cause injury to any other water user.... [A] water right may be lost through abandonment or adverse use. Finally, a water right may be condemned for a preferred use .... Generally, the first step of an appropriation is some action directed toward the ultimate diversion of water coupled with the intent to apply such water to beneficial use.... In addition the appropriator must protect his appropriation by confirming the priority of the water right through an "adjudication" process in front of the state engineer or in a special water court.[8]

There are some possible obstacles to acquiring or using water rights that exist in state water rights systems. They re based in the "strong tendency to treat water as an asset of society, with private rights being obtainable under regulations that protect the general social interest."[9]

Most of the western states have instituted permit systems for appropriative water rights.[10] An application for a permit must be filed with the state engineer or other appropriate official before an appropriation can be initiated.[11] Most of the permit system states have statutory provisions requiring the appropriate official to consider the "public interest" or "public welfare" before approving, conditioning, or rejecting a permit

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[8] Id. at 441-42.

[9] Clyde, "Current Problems - Legal Overview," Water Acquisition for Mineral Development Inst. 2-1, 2-8 (Rocky Mt. Min. L. Fdn. 1978). For some recent thoughtful articles on this aspect of western water rights law see O'Brien, "New Conditions for Old Water Rights: An Examination of the Sources and Limits of State Authority." 33 Rocky Mt. Min. L. Inst. 24-1 (1987) (to be published in 1988); Dunning, "State Equitable Apportionment of Western Water Resources," 66 Neb. L. Rev. 76 (1987); Wilkinson, "Western Water Law in Transition," 56 U. Colo. L. Rev. 317 (1985).

[10] See 4 American Law of Mining § 113.07 [1] [c] [iii].

[11] But see Colorado's system where the right to beneficially appropriate unappropriated water "shall never be denied." Colo. Const. art. XVI, § 6. No permits are required to initiate an appropriation.

application.[12] These provisions can definitely pose problems for those seeking water rights.[13]

Three additional tenets of western water rights law can impede water rights development. First, appropriators are not entitled to waste water; they must make their diversions in reasonably efficient manners or they can lose part of their alloted water.[14] Second, some western states expressly reserve the power to modify water rights.[15] The third potential problem is the "reasonable use" doctrine.

"Today the notion that appropriators . . . are limited to reasonable beneficial use of water is well entrenched in western water law."[16] This doctrine was approved in an early United States Supreme Court decision.[17] A recent California case[18] used the theory as an independent basis to modify appropriative rights. "Independent of its reserved powers, we think the Board was authorized to modify the permit terms under its power to prevent waste or unreasonable use or methods of diversion of

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12 See e.g., Alaska Stat. § 46.15.080 (1982); Ariz. Rev. Stat. Ann. § 45-143(A) (Supp. 1987); Cal. Water Code § 1253 (1971); Idaho Code § 42-203A(5) (Supp. 1987); S.D. Codified Laws Ann. § 46-2A-9 (1983).

13 See e.g., Shokal v. Dunn, 707 P.2d 441, 447-50 (Idaho 1985); Tanner v. Bacon, 136 P.2d 957, 962-64 (Utah 1943); In re Application for Water Permit No. 4580A-3, S.D. Water Management Board (Oct. 9, 1986) (reported at XIX Water Law Newsletter No. 3 at 6 (Rocky Mt. Min. L. Fdn. 1988).

14 See Wilkinson, 56 U. Colo. L. Rev. at 332-33 nn. 63-69 and accompanying text.

15 See e.g., Cal. Water Code § 1394 (Supp. 1986); United States v. State Water Resources Control Board, 182 Cal. Appl 3d 82, 227 Cal. Rptr. 161, 185-87 (Cal. App. 1986); East Bay Municipal Utility District v. Department of Public Works, 1 Cal. 2d 476, 35 P.2d 1027 (Cal. 1934).

16 Dunning, 66 Neb. L. Rev. at 110 (emphasis added). See also Dunning, "The Physical Solution in Western Water Law," 57 U. Colo. L. Rev. 445, 448-58 (1986).

17 Schodde v. Twin Falls Land & Water Co., 224 U.S. 107, 121 (1912) (appropriative water rights are enforced when "exercised within reasonable limits . . .").

18 United States v. State Water Resources Control Board, 182 Cal. App.3d 82, 227 Ca. Rptr. 161, 187-88 (Cal. App. 1986).

water."[19] The future scope and use of the reasonable use doctrine to modify water rights is unclear[20], but at least one commentator predicts its spread throughout the West.[21]

Groundwater

It is important to note that there are different state laws applicable to the appropriation of groundwater than for surface water.[22] For example, Colorado has statutorily created three categories of groundwater--tributary, nontributary, and designated--with different provisions for each.[23] Arizona's Groundwater Management Act of 1980[24] is perhaps the best example of a comprehensive state groundwater management system. Groundwater law is an immense and complicated area of law, but for our purposes it is sufficient to warn potential appropriators of groundwater's different statutory treatment.

Water Rights Acquisition[25]

A mineral developer must of course secure the actual water needed for his project. Because most western waters are generally overappropriated, it usually is necessary to find water rights that already have been initiated and attempt to acquire an interest in those rights. Some possible methods include purchasing water directly from completed projects with a senior water right, purchasing land with senior water rights, purchasing water rights severed from the appurtenant land, purchasing and developing conditional water rights, joint venturing with

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19 227 Ca. Rptr. at 187.

20 The reasonable use doctrine is constitutionally and statutorily recognized in California. Cal. Const. art. X, § 2 (amended 1974); Cal. Water Code §§ 275, 1050 (Supp. 1986).

21 "It can be expected that, in the coming years, courts and agencies in the western states will increasingly rely on the reasonable use requirement as a jurisdictional basis for the regulation of water rights." O'Brien, 33 Rocky Mt. Min. L. Inst. at § 24.02[3].

22 See generally 5 R. Clark, Water and Water Rights §§ 440 et seq. (1972).

23 See Colo. Rev. Stat. §§ 37-90-101 et seq. (1973 & Supp. 1986).

24 Ariz. Rev. Stat. Ann. §§ 45-401 et seq. (Supp. 1986).

25 See generally 4 American Law of Mining, §§ 113.02[5], 113.03; Vranesh & Riordan, 16 Nat. Resources Law at 444-45.

conditional water rights holders, and joint venturing with or purchasing water from Indian tribes with reserved water rights. What is essential is that the water rights have sufficient quantity and seniority to provide a dependable supply and the necessary amount of water, and that the infrastructure required to develop the water rights (including necessary water storage capacity) can be constructed.

CONSTRAINTS ON WATER RIGHTS DEVELOPMENT INDEPENDENT OF STATE WATER RIGHTS LAW.

Indian and Federal Reserved Water Rights[26]

Indian and federal implies reserved water rights claims have a significant impact on state water rights. The doctrine was first expressed in the 1908 Supreme Court decision of Winters v. United States[27], a case dealing with an Indian reservation. It was extended to non-Indian federal lands in 1963 in Arizona v. California[28] and extended to groundwater in the 1976 decision of Cappaert v. United States[29]. The reserved rights doctrine has been summarized as follows:

> When the Federal Government withdraws its land from the public domain and reserves it for a federal purpose, the Government, by implication, reserves appurtenant water then unappropriated to the extent needed to accomplish the purpose of the reservation. In doing so the United States acquires a reserved right in unappropriated water which vests on the date of the reservation and is superior to the rights of future appropriators . . . [Government intent to reserve water] is inferred if the previously unappropriated

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26 See generally 4 American Law of Mining §§ 113.04, 113.05. See id. § 113.04[1]n.1 for a list of publications that thoroughly analyze Indian reserved water rights. For articles on non-Indian federal reserved rights see e.g., Little, "Administration of Federal Non-Indian Water Rights," 27 Rocky Mt. Min. L. Inst. 1709 (1981); Waring & Samelson, "Non-Indian Federal Reserved Water Rights," 58 Den. L. J. 783 (1981); Trelease, "Federal Reserved Water Rights Since PLLRL," 54 Den. L. J. 473 (1977).

27 207 U.S. 564 (1908).

28 373 U.S. 546 (1963).

29 426 U.S. 128 (1976).

waters are necessary to accomplish the purposes for which the reservation was created.[30]

Indian and federal reserved water are exempt from state appropriation laws but are subject to valid appropriations made prior to the federal withdrawal. The adjudication and quantification of reserved rights may proceed in state courts.[31] The potential impact of these adjudications and quantifications should not be underestimated. An example of the magnitude of the claims is that Indians in Arizona claim an entitlement to 27 million acre feet of water in Arizona to irrigate their 20 million acres of land. This is more than five times the amount of water that is available to the state of Arizona under the compacts, statutes, and treaties that divide up the waters of the Colorado River System.

There are numerous federal enclaves in the West including Indian reservations, national forests, national parks and monuments, wilderness areas, wildlife refuges, etc. Many were created in the late 1800s and early 1900s and thus enjoy a relatively senior priority date. The lesson for state water right holders is that their rights may be limited by federal and Indian reserved rights.[32]

Federal Environmental Laws

Additional significant impediments to water rights development are presented by various federal environmental laws.[33] Some of the more important statutes that may impact water rights include: the Clean Water Act's National Pollutant Discharge Elimination System[34], water quality standards provision[35], and dredge and fill permit system[36]; the National

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[30] Id. at 138-39.

[31] See 43 U.S.C. § 666 (1982).

[32] For two interesting recent cases on reserved water rights see United States v. Bell, 724 P.2d 631 (Colo. 1986) (denying the United States' 1983 attempt to amend a still-pending 1971 adjudication application which would have given the 1983 claims priority dates of 1969 and 1924 rather than 1983); Sierra Club v. Block, 622 F.Supp. 842 (O. Colo. 1985) (holding that federal reserved rights exist in wilderness areas).

[33] For a more detailed overview of this subject see Vranesh & Riordan, 16 Nat. Resources Law at 457-67.

[34] 33 U.S.C. § 1342 (1982).

[35] Id. §§ 1312, 1313.

Environmental Policy Act's environmental impact statement requirement[37]; the Federal Land Policy and Management Act's land management[38], rights-of-way[39], and wilderness study[40] provisions; the Endangered Species Act's protection of endangered species[41]; the Wilderness Act's protection of wilderness[42]; and the Wild and Scenic Rivers Act's protection of rivers[43]. Environmental statutes can and often do present major constraints on every type of development including water projects.

Law of the River

A set of compacts, treaties, and statutes affecting the Colorado River Basin known as the "law of the river" may present another obstacle to the exercise of western water rights[44]. Beginning with the Colorado River Compact of 1922[45], the law of the river divides the waters of the Colorado River System between Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming, as well as guaranteeing water to Mexico. The problem stems from the fact that in 1922 the virgin annual runoff from the upper basin states (Colorado,f New Mexico, Utah, Wyoming, and a small part of Northern Arizona) was overestimated by over 4 million acre feet (MAF) per year.[46]

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36 Id. § 1344.

37 42 U.S.C. § 4332 (1982).

38 43 U.S.C. §§ 1712, 1732 (1982).

39 Id. §§ 1761-1771 (1982 & Supp. III 1985).

40 Id. § 1782 (1982).

41 16 U.S.C. §§ 1531 et seq. (1982 & Supp. III 1985).

42 Id. §§ 1131 et seq.

43 Id. §§ 1271 et seq.

44 For a recent comprehensive examination of this subject see Carlson & Boles, "Contrary Views of the Law of the River: An Examination of Rivalries Between the Upper and Lower Basins," 32 Rocky Mt. Min. L. Inst. 21-1 (1986). See also Vranesh & Riordan, 16 Nat. Resources Law at 445-49.

45 42 Stat. 171. The Compact also is set forth at Colo. Rev. Stat. § 37-61-101 (1973 & Supp. 1985).

46 See Vranesh & Riordan, 16 Nat. Resources Law. at 446-47 nn. 43-45 and accompanying text.

The net result of a serious of law of the river water allocations between the upper basin states and lower basin states[47] (Arizona, California, and Nevada) is that the upper basin states may well face law of the river - imposed water shortages by the year 2010.[48] While this is not a certainty,[49] and it is unknown how a compact call would be administered, the law of the river poses a definite threat to the development of upper basin water rights that may become a reality within 25 years.

Equitable Apportionment

The doctrine of equitable apportionment[50] also can affect water rights development. It is used by the Supreme court to settle interstate water conflicts in the absence of interstate water compacts. Even though the doctrine is only used when states are the parties to the case, the apportionment is binding on the individual water users within each state.[51] The doctrine is designed to balance the equities of each state in order to properly divide their interstate waters. In an equitable apportionment:

> Priority of appropriation is the guiding principle. But physical and climatic conditions, the consumptive use of water in the ... river, the character and rate of return flows, the extent of established uses, the availability of storage water, the practical affect of wasteful uses on downstream areas, the damage to upstream areas as compared to the benefits to downstream areas if a limitation is imposed on the former - these are all relevant factors ... not an exhaustive catalogue. They indicate ... the delicate adjustment of interest which must be made.[52]

In a potentially far-reaching development, a recent Supreme Court equitable apportionment decision imposed a conservation duty on water users, stating that under some circumstances "an

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47 Id. at 446-48.

48 Carlson & Boles, 32 Rocky Mt. Min. L. Inst. at §21.03[2].

49 See id. §§21.04-21.05.

50 For a recent thorough analysis of this subject see Tarock, "The Law of Equitable Apportionment Revisited, Updated, and Restated," 56 U. Colo. L. Rev. 381 (1985).

51 See Wyoming v. Colorado, 286 U.S. 494 (1932).

52 Nebraska v. Wyoming, 325 U.S. 589, 618 (1945).

important consideration is whether the existing users could offset the [junior proposed] diversion by reasonable conversation measures to prevent waste."[53] Although it is too early to tell if this holding will have a major effect in equitable apportionment cases in the future, it is clear that equitable apportionments may pose additional hindrances to using water rights that were thought to be secure.

Public Trust Doctrine

The final constraint on water rights development to be considered could turn out to be one of the most important. The California Supreme Court's 1983 application of the public trust doctrine to water rights[54] in National Audubon Society v. Superior Court of Alpine County[55] (the Mono Lake case) has been greeted with almost apocalyptic fervor. It has been described as being "potentially as important as any development in western resources law during the last several decades."[56]

The Mono Lake court ruled that the public trust doctrine, which recognizes "the duty of the state to protect the people's common heritage of streams, lakes, marshlands and tidelands"[57] based on the sovereign's ownership of all navigable waterways and the lands underneath them, "imposes a duty of continuing supervision over the taking and use of appropriated water"[58] after the appropriation has been approved. Thus, the public trust doctrine can be used by the state to change previously perfected water rights taking into account environmental factors.

The extent to which the public trust doctrine's application to water rights will spread to other western states is unclear. North Dakota seems to be the only other western state that has

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53 Colorado v. New Mexico, 459 U.S. 176, 188 (1982).

54 For a recent comprehensive analysis of this subject see Dunning, "The Public Trust Doctrine and Western Water Law: Discord or Harmony?" 30 Rocky Mt. Min. L. Inst. 17-1 (1984).

55 33 Cal. 3d 419, 658 P.2d 709 (Cal.), cert. denied, 104 S. Ct. 413 (1983).

56 Wilkinson, 56 U. Colo. L. Rev. at 335.

57 658 P.2d at 724.

58 Id. at 728.

explicitly applied the doctrine to water rights,[59] although the Idaho Supreme Court arguably came close.[60] A number of other western states have applied the doctrine in water cases not involving water rights.[61] Only the future will tell if the public trust doctrine turns out to be a severe impediment to the exercise of water rights in the West.

CONCLUSION

Hopefully this paper has served as a useful guide for the mineral developers through the minefield of acquiring and developing water rights. In the good old days, a water right was much more of an absolute thing. If you appropriated your water, put it to a beneficial use, and had a senior priority, it was virtually certain that you possessed a secure water right that would enable you to develop your water. But that was before the advent of permit systems, Federal environmental laws, reserved water rights, the "law of the river," equitable apportionment, more aggressive use of the "public interest" test and "reasonable use" doctrine, and the public trust doctrine's application to water rights. If these anti-water rights trends continue, the traditional water right may be well on the way to becoming an endangered species.

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[59] United Plainsmen Ass'n v. North Dakota State Water Conservation Comm'n, 247 N.W. 2d 457 (N.D. 1976) (in fact, the North Dakota decision predated Mono Lake).

[60] See Shokal v. Dunn, 707 P.2d 441, 447 n.7 (Idaho 1985).

[61] See, e.g., Kootenai Envt'l Alliance v. Panhandle Yacht Club, 671 P.2d 1085 (Idaho 1983); Montana Coalition for Stream Access v. Curran, 682 P.2d. P.2d 163 (Mont. 1984).

A CHALLENGE IN WATER SUPPLY PLANNING: ACHIEVING A BALANCE BETWEEN INDUSTRY NEEDS AND AGRICULTURE IN EMERY COUNTY, UTAH

C. B. Burton[1]

ABSTRACT: During the 1970s and 1980s, Utah Power and Light Company constructed two steam-electric generating stations with a combined installed capacity of 2,000 megawatts in Emery County, Utah. Prior to construction, Utah Power and Light was faced with the dilemma of acquiring a firm water supply even during the driest years while minimizing the impact on the agricultural economy of the area. Three basic problems became evident early in the preliminary investigations: (1) the runoff from Huntington, Cottonwood, and Ferron Creeks fluctuates greatly from month to month depending upon the pattern of snowmelt; (2) the annual water supply varies greatly from year to year depending on the snowpack accumulation during the winter; and (3) irrigation interests hold long-standing decreed and certificated water rights to the flows in Huntington, Cottonwood, and Ferron Creeks. Monthly flow data were analyzed for the historical period of record dating back to the 1920s. The driest cycle of record (1958-1961) followed by the driest year of record (1977) was used as the drought cycle for determining water supply availability. A combination of irrigation direct flow water purchases from the three creeks, a new reservoir, purchase of existing irrigation reservoir storage rights, a firm annual water supply contract, new water applications for storage and natural flow, and water exchanges were undertaken to meet power plant water requirements during the simulated extended drought cycle. This paper documents the methodologies and presents the legal, political, and physical problems which were encountered during the water acquisition period of 1968 to 1984. It also serves as a guide for acquisition of water for industrial use from western river basins that are fully appropriated.

INTRODUCTION

During the late 1960s and 1970s, the western states experienced a dramatic increase in population. This population increase was especially evident in Utah Power and Light Company's (UP&L) service area which encompasses most of Utah, southeastern Idaho, and southwestern Wyoming. During the period 1960 to 1969

[1]Hydrological Supervisor, Utah Power & Light Co., Salt Lake City, Utah 84110

UP&L's electric customers increased by 22% (UP&L, 1969). For the period 1970 to 1979, UP&L's customers increased by 46% (UP&L, 1970).

In response to the accelerated increase in energy demands, projected industrial demands for oil development in western Wyoming, and projected future residential demands, UP&L embarked on a program in the mid 1960s to identify potential sites for construction of new power plants. While dozens of potential sites were identified, the most feasible sites available were in Emery County located in southeastern Utah. Emery County was chosen for power plant construction because: (1) the environmental constraints could be met; (2) the area held vast reserves of high quality, high BTU coal in close proximity to the power plant sites and; (3) the nearby water supply appeared to be adequate to meet power plant needs. Two power plants were subsequently constructed in Emery County during the period 1970 to 1983. The Huntington Power Plant, consisting of two 400 megawatt units, was completed in 1977 while the Hunter Power Plant, consisting of three 400 megawatt units, was completed in 1983.

GEOGRAPHICAL SETTING AND WATER RESOURCES

Emery County is situated in southeastern Utah and lies about 100 air miles from Salt Lake City (Figure 1). The geography is varied, ranging from high mountain terrain in the western portion to arid desert and desert plateaus in the central and eastern portions. Virtually the entire water supply originates from streams flowing out of the mountains in the western part of Emery County. The major streams include Huntington Creek, Cottonwood Creek, and Ferron Creek (Figure 2). All three streams flow out of the mountains in a southeasterly direction. The three steams merge to form the San Rafael River at a point six miles southeast of Castle Dale, Utah. The San Rafael River flows easterly for about 50 miles through the desert and empties into the Green River near Green River, Utah.

Average annual runoff is equal to 65,000 acre feet per year on Huntington and Cottonwood Creeks, and 45,000 acre feet per year on Ferron Creek. The annual runoff from these streams is highly variable each year depending on the winter snowpack and spring snow melt conditions. For example, the historical annual discharge from Huntington Creek varies from 24,000 acre feet to 150,000 acre feet. In addition, the monthly discharges are highly variable as a function of snowpack and snow melt conditions or local climatic events. Local irrigation companies divert most of the river flows on about 32,000 acres of cultivated farm ground (Utah Water Resources, 1979). In wet runoff years, a portion of the undiverted flows pass downstream into the San Rafael River and subsequently into the Green River. During the winter period, some of the flows are stored in local reservoirs for use the next irrigation season.

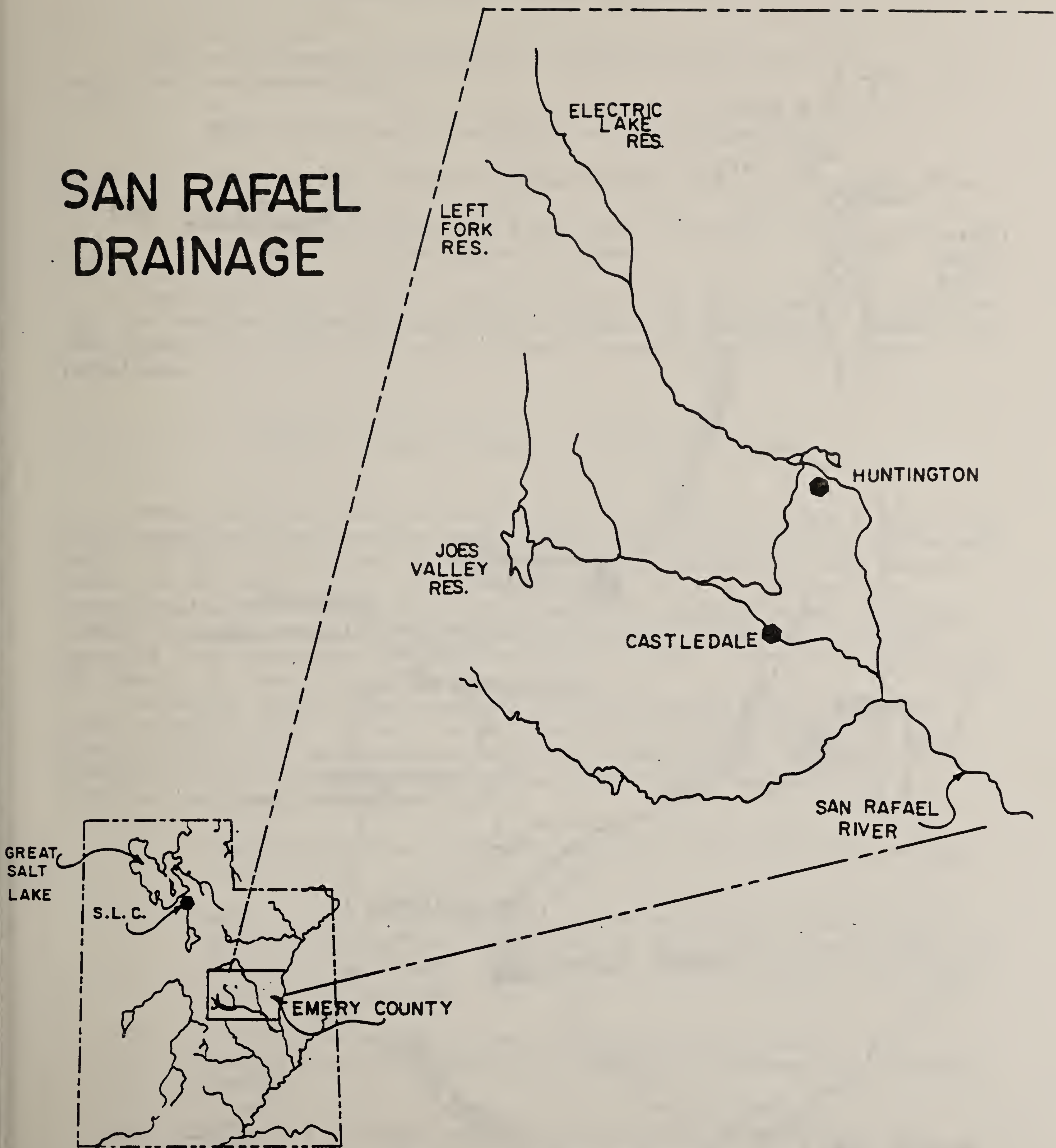

FIGURE 1. EMERY COUNTY.

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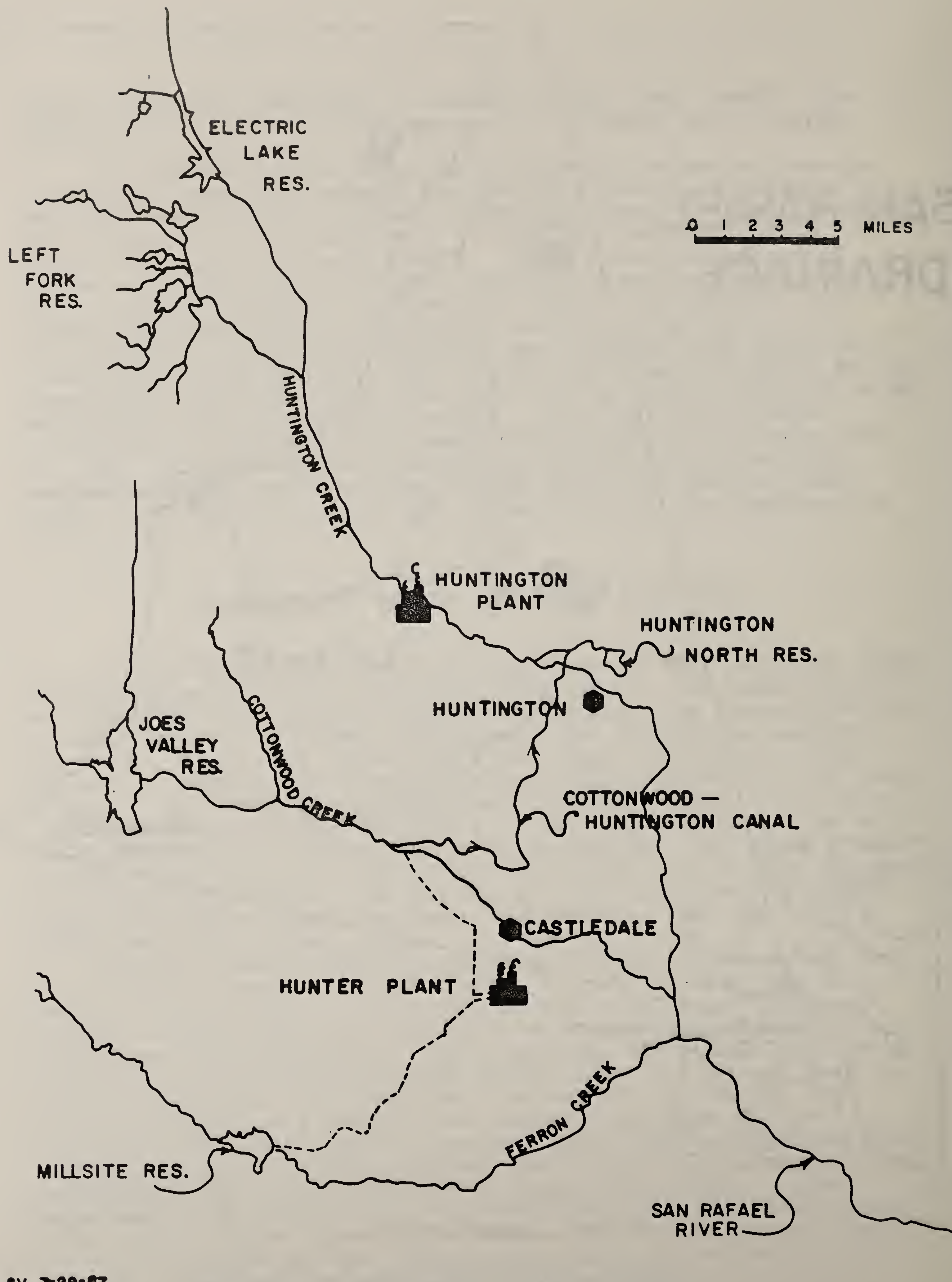

FIGURE 2. WATER SYSTEM IN EMERY COUNTY.

WATER ACQUISITION PROBLEMS

UP&L's dilemma in acquiring adequate steam plant water supplies was three-fold:

1) The annual water supplies were highly variable.

2) The monthly water supplies were highly variable.

3) Irrigation interests held long standing water rights to the water in the three streams.

The challenge was to acquire firm steam plant water supplies for the entire range of historical runoff events while minimizing the impact on the local agricultural community to the extent possible.

PHASE I ACQUISITIONS - HUNTINGTON PLANT

Water acquisitions occurred in two phases. Phase I involved water acquisitions for the Huntington Plant in the late 1960s and early 1970s while Phase II involved acquisitions for the Hunter Plant in the mid 1970s and early 1980s. In the preliminary investigation of the water supply for Huntington Plant, a water supply and demand model was developed using historical runoff records from Huntington and Cottonwood Creeks which were supplied by the U. S. Geological Survey.

Prior to model development, the historical water records, water rights, and storage facilities in the Huntington and Cottonwood Creek drainage basins were analyzed in detail. The results of the initial investigation provided the following information:

1) Historical flow records were available for the period 1923 to 1967 in both basins.

2) Water rights for irrigation amounted to a maximum of 392 cfs of the natural flow of Huntington Creek and 300 cfs on Cottonwood Creek during the irrigation season (April 1 - October 31).

3) During the spring runoff period, flows were periodically in excess of irrigation demands and water rights.

4) Existing storage reservoirs on Huntington Creek amounted to about 9,00 acre feet.

5) On Cottonwood Creek, the Bureau of Reclamation constructed the Joe's Valley Irrigation Project, a 62,000 acre foot reservoir plus the 4,000 acre foot

Huntington North reservoir in the lower Huntington Creek drainage including diversion dams and a trans-basin canal (Cottonwood-Huntington Canal) from the Cottonwood to the Huntington drainage.

6) During the winter period, the first 4,000 acre feet of Huntington Creek flow was reserved for storage in the Huntington North Reservoir. Most of the remaining winter flows were committed to provide stock water to the canals in the Huntington Irrigation system.

The model was developed based on the following criteria:

1) Plant demands of 28,000 acre feet per year for four 400 megawatt units.

2) Monthly historical water supply for each basin.

3) Irrigation demand of a maximum of 392 cfs on Huntington Creek and 300 cfs on Cottonwood Creek for the period April 1 through October 31.

4) Annual irrigation allocation of a maximum of 28,000 acre feet per year from Joe's Valley Reservoir.

5) Simulated acquisition of water for power plant use from Joe's Valley Reservoir on Cottonwood Creek (to be acquired from the 28,000 acre foot irrigation supply).

6) Estimated flow of North Fork of Huntington Creek (for future reservoir operation).

7) Reservoir evaporation losses and canal conveyance losses.

8) Simulated acquired irrigation flows for plant use.

9) Simulated acquired surplus irrigation flow for storage in Electric Lake.

10) Storage and release of new reservoir volumes (Electric Lake) on North Fork of Huntington Creek for supplemental plant use.

11) Use the driest year of record (1934) after the longest drought cycles of record including the 1930s (use two consecutive 1934 years) and the 1959-61 period.

Computer runs were made to determine the best combination of acquired irrigation flows and new reservoir volumes which would provide a firm annual power plant water supply of 28,000 acre feet per year even during the driest periods experienced in the past. The emphasis was to minimize the impact on the irrigation needs to the extent possible. The final determination of water supply for the Huntington Power Plant included:

1) Acquisition of 23% of the Huntington Creek irrigation supply through stock purchases from individual farmers owning stock in the Huntington-Cleveland Irrigation Company.

2) Acquisition of 20% of the Cottonwood Creek supply through stock purchases from individual farmers owning stock in the Cottonwood Creek Consolidated Irrigation Company. This supply, which is delivered to the lower Huntington Creek drainage via the C-H Canal, would only be available for use during the irrigation season. The Cottonwood water is delivered to the Huntington system at a point downstream from the Huntington Plant diversion. An exchange was devised whereby Huntington Creek irrigation water was diverted to the power plant in exchange for UP&L's Cottonwood water delivered to the Huntington irrigators.

3) Change applications filed in the name of each irrigation company to change the point of diversion, place and nature of use of water by UP&L at the power plant sites.

4) Construction of a 30,000 acre foot reservoir on the North Fork of Huntington Creek including a new water rights application by UP&L for the storage.

5) Water application by UP&L for 20 cfs of direct flow to provide for a winter water supply and a supplemental supply during high spring runoff.

6) Acquisition of 6,000 acre feet from the Joe's Valley Project supply on Cottonwood Creek. The Joe's Valley supply was critical to the Huntington Plant operation because the water could be used on a year-around basis and unused allocations could be held over for use the next year. This supply would only be available on an exchange basis since the water could not be physically delivered upstream to the Huntington Plant. (Similar to the Cottonwood Creek acquired irrigation water.)

The next step in the acquisition process was to meet with local directors of the two irrigation companies plus the Bureau of Reclamation and the Emery Water Conservancy District for acquisition of the Joe's Valley "Project Water". Concurrently, feasibility studies and obtaining permits for construction of Electric Lake dam was underway.

The irrigators were skeptical of a large industry disrupting the long standing operation of their irrigation systems. It became obvious during initial negotiations that UP&L would have to concede to all the irrigators demands to secure an industrial water supply. From UP&L's perspective, the benefits to the local economy included hundreds of new jobs, a higher tax base, and a shift from an agricultural to an industrial economic community. Negotiations were lengthy and it took 16 years to develop a set of operating criteria which completely protected, and in some instances enhanced the irrigators position, and which met the operating needs of UP&L at both the Huntington and Hunter plants.

First and foremost to the irrigators was the protection of the remaining irrigation interests in the canals after a portion of the water was taken out for use in the power plants. The immediate concerns of the irrigators in early negotiations included:

1) Protection of the remaining irrigation water supply in the canals.

2) Protection of existing administrative, operation and maintenance costs to deliver water to the remaining irrigators in the canals.

3) Assurances that the voting for board members would not be altered from past methods. (The irrigators were concerned that UP&L would eventually acquire enough stock to take control of their companies.)

UP&L's strategy in early negotiations was simple, but effective. Although it would become the largest stockholder in the two irrigation companies, UP&L's approach was to be treated no differently than any other stockholder in the irrigation companies. UP&L agreed to be charged the same canal conveyance losses, the same assessments, and UP&L agreed not to participate in the voting for directors in individual canals or in the general company. UP&L did, however, reserve the right to vote on general company issues in annual or general stockholders' meetings. UP&L also agreed to a special industrial assessment to cover administrative costs incurred through stock acquisitions and changes in the irrigation company's operation. UP&L's strongest selling point in the negotiations was to lease back a portion of the unused acquired water to irrigators who sold their irrigation stock for power plant use. UP&L has leased back a portion of the acquired supplies every year except for 1977, which was the driest year in history.

The acquisition of the Huntington and Cottonwood irrigation supplies for the Huntington Plant was essentially complete by 1971. In 1972, negotiations were completed for acquisition of 6,000 acre feet of water from the Joe's Valley Project. UP&L entered into a 40 year water delivery and repayment contract with the United States and The Emery Water Conservancy District.

The repayment contract required an annual payment of $20 per acre foot plus annual operation and maintenance costs of $1 per acre foot. The price included the actual costs of dam construction plus interest without the benefit of the federal subsidy for irrigation. In contrast, the irrigation repayment contracts amounted to about $4 per acre foot annually.

Construction of the 30,000 acre foot Electric Lake Dam was completed late in 1973. Water storage commenced shortly thereafter; however, due to a combination of below normal runoff and leakage problems which restricted storage, the dam was not filled until 1980. A Forest Service Special Use Permit was required prior to initial dam construction. The permit was later modified to provide long-term operating guidelines including water quality protection and minimum flow requirements. The minimum flows mutually agreed upon were 12 cubic per second (cfs) during the period October 1 to April 30 and 15 CFS from May 1 to September 30. During the early filling period, however, the minimum flow requirement was 6 cfs.

The first Huntington unit came on line in 1974 and the second unit began operation in 1977. Problems with the Huntington irrigators started upon initial operation of the power plant. The water diversion and intake system for the plant was designed to be fully automatic. A float level sensor in the 250 acre foot primary settling basin would sense a low pond elevation thereby activating the intake gates to full open until the pond was full. While this system worked well for the power plant operation, the frequent fluctuation in river flows totally disrupted the downstream irrigation system operation. The problem was remedied by rendering the float sensor system inoperable and setting a constant flow on a weekly basis to coincide with the irrigation company's weekly call system.

UP&L had to coordinate storage and release of water from Electric Lake in a manner which would not disrupt the downstream irrigation demands. During the spring runoff period, UP&L would store all available water in Electric Lake except for minimum flows required under the Forest Service Special Use Permit. This would result in inadvertent storage of water which the Huntington irrigators were entitled to use for irrigation. An arrangement was adopted where the irrigation water stored in Electric Lake was exchanged for UP&L acquired irrigation water stored in the irrigator's Huntington Left Fork Reservoirs. This exchange agreement minimized the interference in reservoir operation for both parties.

On occasion, UP&L changed the outflow from Electric Lake without notifying the irrigators of the change. This, of course, disrupted the irrigation system operation. The notification process was soon implemented in the guidelines established for operation of the dam.

PHASE II ACQUISITIONS - HUNTER PLANT

In the early 1970s, the new Federal and State air quality standards required UP&L to reevaluate its power plant construction program in Emery county. The new air quality standards, in effect, disqualified the Huntington site for a 4 unit, 1600 megawatt operation. Plans were changed to limit the

Huntington site to a 2 unit, 800 megawatt operation and to construct a 4 unit, 1,600 megawatt facility at the Hunter site located about 12 miles south of the Huntington site near the town of Castle Dale, Utah (see Figure 2).

The water supply analysis was reevaluated and expanded to include the Ferron Creek drainage located south of Cottonwood Creek (see Figure 2). Results of the preliminary investigation are shown below:

1) The Huntington Plant demands were reduced from 28,000 acre feet to 14,000 acre feet per year since the installed plant capacity was reduced from 1,600 megawatts to 800 megawatts. The Hunter Plant demands were set at 28,000 acre feet per year for four 400 megawatt units.

2) The acquired Huntington Creek irrigation supply and the 30,000 acre foot Electric Lake supply appeared to be more than adequate to meet Huntington Plant's demand of 14,000 acre feet per year. This reduced demand at Huntington Plant also freed the acquired Cottonwood irrigation supply and the Joe's Valley supply to provide a portion of the 28,000 acre foot annual demand at the Hunter plant.

3) The presence of the Cottonwood-Huntington Canal (C-H Canal) made it possible to pool the acquired water supplies from Cottonwood and Huntington Creeks. The C-H Canal and Electric Lake provided the capability to deliver Cottonwood Creek water to the Huntington Plant by exchange or to deliver Electric Lake water by exchange to the Hunter Plant. Electric Lake water could be delivered to the Huntington irrigators entitled to use Joe's Valley water with a UP&L credit accruing in Joe's Valley Reservoir for use at the Hunter Plant.

4) On Ferron Creek, the Soil Conservation Service sponsored the construction of the 18,000 acre foot Millsite Reservoir for irrigation purposes.

5) The waters of Ferron Creek were fully appropriated based on irrigation direct flow rights and storage rights in Millsite Reservoir; hence UP&L could not justify new water filings for industrial water on Ferron Creek.

In 1974 UP&L entered into a 40 year lease contract with the Ferron Reservoir and Canal Company and the Utah Water Resource Board to provide a water supply for the first Hunter unit which was scheduled to begin operation in 1978. The canal company agreed to guarantee the delivery of 7,000 acre feet annually to UP&L's point of diversion at Millsite Dam. In return, UP&L agreed to construct 1,500 acre feet of additional storage capacity at Millsite Dam and to retire the Rock Creek Canal through a total buy-out of 1,611 shares of canal stock. This stock would then be committed to the 7,000 acre foot annual industrial allocation. UP&L was unable to construct 1,500 acre feet of additional storage capacity at Millsite Dam due to existing structural problems on the dam's left abutment. The additional capacity (2,000 acre feet) was constructed at the Hunter Plant. This new reservoir at the plant proved to be better suited to the plant operation because it functions as a regulating reservoir as well as a storage reservoir when periodic pipeline maintenance required curtailment of pipeline flows from either the Ferron or Cottonwood systems.

UP&L agreed to pay an annual charge of $30 per acre foot per year or $210,000 for the 7,000 acre foot supply over the 40 year contract period. Built into the annual charge is an annual adjustment based on the wholesale price index for each year after 1974.

UP&L was also required to pay off a portion of the Millsite Dam construction costs to the Soil Conservation Service. The payment to the Soil Conservation Service was based on the proportionate share of Millsite Dam construction costs without the benefit of the federal subsidy extended to the Ferron irrigators. In 1984, UP&L paid $513,000 or $60 per share ($30 per acre foot) to the Soil Conservation Service based on the shares acquired in the Ferron irrigation system.

The complexity of the water supplies, the occurrence of the 1977 drought, water demands by both irrigation and power, exchanges, and other elated factors, prompted UP&L to hire a private consulting firm to prepare an independent analysis of the water supplies needed to meet plant demands. The firm of Vaughn Hansen Associates was selected because of their past experience in irrigation and water supply analysis. The consultant and UP&L analyzed the historical flow records for Huntington, Cottonwood and Ferron Creeks for the period 1923 through 1978. The new criteria used in the final analysis are listed below (Hansen, 1977):

1) The most critical period of record in history was the drought cycle of 1959 through 1961. In addition, the 1977 runoff was the lowest on record, even lower than 1934. The consultant and UP&L concluded that the water supply for the period from July through September 1958, 1959, 1961, 1977 and October to May 1962 would be the period used in the analysis. This period represents a 5 year drought cycle. It was determined that if plant water requirements could be met during this five year period, the water needs could also be met during any other period in history.

2) Plant demands were 13,000 acre feet per year at Huntington and 26,000 acre feet per year at Hunter. (Note - plant demands were reduced to 6,500 acre feet per unit per year based on actual plant usage at

Huntington and Hunter from 1974 to 1979. Actual plant use varied from 5,500 to 6,000 acre feet per year.)

3) The assumptions used in the 1968 model analysis of Huntington and Cottonwood Creek flows were also applied to the Ferron Creek flows.

UP&L and the consultant conducted the model analyses independently but the conclusions reached were about the same. The recommended water acquisitions program to secure a firm water supply for the two plants during the specified drought cycle is shown in Table 1. The acquired irrigation water was increased from 23% to 33% on Huntington Creek and was increased from 20% to 35% on Cottonwood Creek. The Joe's Valley acquired water was increased from 21% to 43%, or from 6,000 to 12,000 acre feet. The Ferron Creek acquired irrigation water was set at 27% which was in addition to the 7,000 acre foot supply acquired in 1974.

The total acquired water supply needed for the 39,000 acre foot annual demand amounted to 87,000 acre feet. On the surface it appeared that the supply was more than adequate to meet plant demands; however, the full capacity of Electric Lake storage, all of the Joe's Valley annual allocations, and the full 7,000 acre foot per year firm supply from Ferron Creek was required to augment the 1/3 of normal acquired irrigation yields during the drought scenario.

UP&L also investigated other sources of water including groundwater, a reservoir on lower Cottonwood Creek, a reservoir on the Upper San Rafael River and a diversion dam pumping system and pipeline from the Green River. These alternatives were not pursued due to high cost, poor water quality, or insufficient water supply to meet plant demands.

UP&L commenced with the acquisition of the additional water late in 1978. By 1980, it had secured the recommended irrigation primary supplies from the three irrigation companies, however, only 2,576 acre feet of Joe's Valley water could be acquired from the qualifying farmers in the Cottonwood and Huntington drainages. Since the recommended amount of additional Joe's Valley water was 6,000 acre feet additional, the acquired amount was 3,424 acre feet short. UP&L decided to postpone acquisition of the 3,424 acre feet until the fourth Hunter unit commenced operation. However, due to reduced load growth during the early 1980s the construction of the fourth unit was cancelled in 1984.

UP&L faced the problem of transferring the acquired 2,576 acre feet of Joe's Valley water from agricultural to industrial use. This process was necessary because the Joe's Valley Project was authorized only for irrigation use by the Bureau of Reclamation and the entire allocated irrigation water supply was federally subsidized. The procedure for transfer of the water was accomplished as follows:

1) Individual farmers who sold their Joe's Valley shares to UP&L signed a relinquishment agreement which was conveyed to the Huntington Cleveland or Cottonwood Irrigation companies. They also assigned their stock

TABLE 1

SUMMARY OF WATER ACQUISITIONS

FOR THE HUNTINGTON AND HUNTER PLANTS

Plant	Source	Amount Needed (AF)*	% Irrig. Supply Needed	Period of use
Huntington	Huntington Creek			
	1) irrigation acquisitions	17,000	33	Apr 1-Oct 31
	2) Electric Lake	27,000	-	year around
	3) Private water rights	20 CFS	-	year around
Hunter	Huntington Creek			
	1) Electric Lake	3,000	-	year around (exchange)
	Cottonwood Creek			
	1) irrigation acquisitions	9,000	35	Apr 1-Oct 31
	2) Joe's Valley Storage	12,000	43	year around
	Ferron Creek			
	1) Firm Contract from Irrigators	7,000	16	year around
	2) irrigation shares acquired	12,000	27	Apr 1-Oct 31
TOTAL SUPPLY		87,000		
TOTAL IRRIGATION ACQUIRED		**57,000**	33	

*Amounts listed represent yield during average runoff conditions.

certificate to UP&L. UP&L paid $603 per acre foot for the water and project lands.

2) UP&L then petitioned the Huntington-Cleveland and Cottonwood Irrigation Company board of directors to pass a resolution relinquishing the purchased water back to the Emery Water Conservancy District.

3) The District, in turn, relinquished the shares back to the United States for reissue to UP&L as industrial water under a separate repayment contract, leaving the irrigation companies responsible only for their irrigation repayment.

This transfer also required amended repayment contracts to the United States. These amended contracts reduced the irrigation obligation and provided for full cost pricing to UP&L without the irrigation subsidy in effect. As of July 1987, UP&L is still negotiating the pricing formula and resulting costs pursuant to signing the contracts. Negotiations are expected to be complete by the end of 1987.

Although the water studies and acquisitions were given careful consideration, events occurred which UP&L could not foresee nor could it control. The 1977 drought, for example, was the lowest runoff event in history. UP&L had to modify its water supply criteria as a result of the 1977 runoff. This change occurred at the time when UP&L was evaluating the water supply for the Hunter third and fourth units. In fact, UP&L leased 10,000 acre feet from the Huntington and Cottonwood irrigators in 1977. This lease was necessary because of a combination of extremely low runoff and a low storage volume in Electric Lake. The water was actually reserved for use in 1978; however, adequate 1978 runoff eliminated the need for the leased water. UP&L considered the lease as a type of insurance policy which guaranteed a one year reserve to meet power plant demands. UP&L believes that water leasing would be a viable option in the future if unforeseen events such as reservoir failure, pipeline failure, or other problems warranted the acquisition of an emergency water supply.

1977 also produced the threat of a lawsuit from irrigators on the lower San Rafael, some 50 miles downstream of the Hunter Plant. The lower irrigators claimed that upstream storage and diversion of water for use in the Hunter and Huntington plants had reduced the available supply to the lower farms. Rather than face the prospects of releasing water to meet the needs of these downstream users, UP&L negotiated the purchase of these farms to eliminate future problems.

On occasion, UP&L has experienced substantial discrepancies between water consumed and water orders which are charged against its share account by the irrigation companies. In addition, UP&L has had to order a greater flow than the amount actually diverted for plant use. This "cushion" requirement is due to the daily fluctuation in river flows and inadvertent diversion of water upstream. Inadvertent operator error has, on occasion, resulted in loss of entitled water. These events demonstrate the unforseen problems which are not planned for but actually occur as part of the day-to-day and year-to-year operation.

CONCLUSIONS

The diversity of the water supply acquired for power plant use is UP&L's best safeguard for its power plants in Emery County. The ability to utilize reservoir storage during the winter, irrigation natural flows during the summer, and to exchange water between basins provides flexibility in meeting power plant needs even during dry years. Agriculture continues to be the lifeblood of Emery County even though industry has achieved at least an equal importance in the economy. The irrigators have indicated that farm practices have become more efficient as a result of one third of their water supply being transferred to industrial use. A balance has been reached between two competing uses of the precious water supply. That is the goal envisioned in the beginning of industrial development in Emery County.

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3) Utah Power and Light Company, Annual Report, 1979, page 34.

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WATER QUALITY FOR MINING AND ENERGY

GROUND WATER QUALITY PROTECTION, MINING AND MINING FACILITIES IN UTAH

Robert P. Barnes [1]

ABSTRACT: Utah's ground water resources are extremely important to the health and economic well-being of the state's citizens. As a state second only to Nevada in aridity it depends heavily on ground water sources for water for the public, industry, and agriculture. Ground water furnishes about 20% of the state's total water needs and 66% of the public supplies.

To protect this water source for current and future users, Utah has developed a Ground Water Policy and initiated the development of a ground water quality protection strategy. Included in the strategy development process was an assessment of the effects that mining and associated activities can have on ground water quality.

The effect mining has on ground water quality depends on the ore and gangue minerals, the mining method, the ore processing, and the method of disposal for waste rock, tailings, and excess mine and mill waters. Sulfide minerals will oxidize to form soluble sulfates and sulfuric acid when exposed to air. Underground, open pit, and solution mines differ in their impact on ground water quality as do the different ore processing methods - conventional, heap leach, solar evaporation, etc. Finally, the methods selected for waste disposal are a major determinant of the impact on ground water quality by mining operations.

In the future mining companies will need to give increased consideration to protecting ground water and other resources by designing in features to protect these resources from degradation.

INTRODUCTION

Ground water is one of Utah's most valuable natural resources. It furnishes a clean, readily available supply of water that is a necessary supplement to surface water supplies for the urban areas of Utah, and it is indispensable in many rural areas where other sources are not available. Two-thirds of the state's population depend on ground water sources for their drinking water. In Utah's rural areas, residents depend almost completely on ground water for their water needs. Ground water supplies 90% of the rural domestic water needs and 80% of the water for livestock comes from ground water sources.

[1] Ground Water Geologist, Bureau of Water Pollution Control, Division of Environmental Health, Utah Department of Health, Box 16690, Salt Lake City, Utah 84116-0690

Today this resource of high quality water is threatened. First by the careless use, handling, and disposal of many of the products we use in our society and second, by the undesirable side effects that often accompany the production of the products our society uses. Small but significant amounts of organic and inorganic chemicals are being found as contaminants in our ground water. This contamination is extremely difficult and expensive to clean up. Surface waters are cleansed by the beneficial effects of sunlight, aeration, and biologic activity. However these beneficial agents are largely absent in the ground water system. As a result ground water, once contaminated is for all practical purposes permanently degraded. Thus the only effective way to protect the ground water quality is to prevent its contamination.

Recognition of Utah's dependance on its ground water resources has resulted in the development and issuance of a Utah Ground Water Policy as an Executive Order by the Governor. The policy states: "The quality of ground water will be protected to a degree commensurate with current and probable future uses. Preventive measures will be taken to minimize contamination of the resource so that current and future public and private uses will not be impaired."

To reach this goal the Department of Health was authorized to initiate the development of a ground water quality protection strategy to protect Utah's ground water resources. People from state and local government, industry, and the academic community contributed to the preparation of a report that describes ground water concepts, influences, uses, sources of contamination, and current protective regulations. The report, entitled Ground Water Quality Protection Strategy for the State of Utah, presents a series of proposals for public consideration that would form the basis for a more effective program of ground water quality protection.

The proposals include the following:

1. Develop better ground water resource management tools.
   Good technical information is necessary for sound management of the state's ground water resources. Better data needs to be produced, utilized, and shared to enhance our ability to provide effective protection for the quality of our ground water.

2. Control sources of pollution.
   Facilities and practices of government, industry, and agriculture should be accessed for their potential for contaminating ground water. Landfills and waste treatment facilities should be located in areas and operated so as to minimize the potential or adverse impact of ground water contamination. Industry must practice good housekeeping in generating, handling, and storing hazardous chemicals. Crop lands, that by virtue of their soils, geologic and hydrologic setting, or use, are particularly susceptible to contamination of the ground water by agricultural chemicals must be identified so that best management practices can be implemented.

3. Protect recharge areas.
   Locally-controlled programs for protection of aquifer recharge areas need to be developed.

4. Provide technical assistance.
   Elected officials and the public need access to technical information and advice on ground water contamination.

5. Develop emergency spill response capability.
   A better capability for quickly responding to spills of hazardous chemicals needs to be developed to prevent contamination of surface and ground waters.

Fifteen hundred copies of the Strategy were printed and distributed to private and public organizations and interested individuals. This supply has been exhausted and it is therefore no longer available.

MINING AND GROUND WATER QUALITY

The mining industry generally includes those activities associated with the exploration, development, production, and processing of mineral deposits into saleable products. The effect that mining-related activities have on ground water quality in the vicinity of a mining facility is dependent on the composition of the mineral deposit, the mining method, the process used to extract the valuable minerals, and the method of disposal for waste rock, tailings, and excess mine and mill waters. In the following sections each of these is considered in more detail.

Composition of Mineral Deposits

The mining and processing of mineral deposits that contain metallic sulfides (Ex: pyrite, FeS_2; chalcopyrite, $CuFeS_2$), radioactive elements (Ex: uraninite, UO_2), and toxic elements (Ex: realgar, AsS) or of minerals that may require leaching for their recovery (Ex: gold) can pose a threat to ground water quality. Ground water contamination is not usually a problem with the production of sand and gravel, clay, stone, limestone, dolomite, and solar evaporate minerals.

Sulfide minerals are a common constituent of mineral and coal deposits. They may be present both as ore minerals such as chalcopyrite and as gangue minerals such as pyrite and realgar. Sulfide minerals are major ore minerals for copper, silver, lead, and zinc. Pyrite is a frequently occurring accessory mineral in both metallic and coal deposits. It often occurs as vast disseminated halos of low-grade or barren rock surrounding porphyry copper deposits such as the Bingham Canyon deposit.

Mining and processing of sulfide-bearing mineral deposits exposes the sulfides to air and moisture. In the removal of the mined materials the gangue sulfide minerals are separated as waste rock and discarded. Small amounts of ore sulfide minerals may also end up as wastes because of the inability to obtain 100% recovery in the concentrating process.

Upon exposure the sulfide minerals oxidize to form sulfuric acid. The resulting acidic solution can dissolve toxic metal compounds and carry them into the ground water system. When carbonates such as limestone are present, the sulfuric acid is neutralized producing soluble sulfates and an increase in the total dissolved solids in the surface and ground waters.

Deposits of uranium also contain uranium daughter products that are the result of the radioactive decay of uranium. These uranium daughters account for much of the radioactivity associated with natural occurrences of uranium. When the uranium ore is processed the uranium, which has relatively little radioactvity, is separated from the radioactive daughter products. The daughters are relegated to the tailings and the uranium recovered. Oxidation of pyrite in the tailings can solublize the daughter products and carry them into the ground water system.

In the processing of certain low-grade ores of gold, copper, uranium, and other metals, dilute solutions of cyanide or sulfuric acid are applied to mine waste dumps or low-grade ore piles and allowed to seep through the material. The pregnant solution is then collected and the metal values recovered. Failure to recover all the leach solution is an economic loss to the company and may pollute the ground water system.

Mining Methods

The mining method used to remove the mineral deposit directly affects the potential and magnitude of ground water contamination from the mining facility. Mining methods are determined by the size, grade, mineral commodity, economics, and geometry of the ore deposit. Often the mining method can change as changing economics dictate new approaches. Examples in Utah include the conversion from underground to open pit mining at Bingham Canyon and Mercur and the conversion from underground to solution mining at Texasgulf Chemicals' Cane Creek Mine near Moab.

Mining methods are usually categorized as underground, surface, or solution with many different variations of each. Following is a more detailed discussion of each category and the potential for degradation of ground water they may produce.

Underground Mining.--Underground mining methods have been developed to handle a variety of mineral deposits. If the host rock is strong and competent, various self-supporting mining methods such as open stoping or room and pillar can be used. If the rock is not strong enough for self-supported openings, various means of support are used. The support can result from back-filling, timbering or the use of mechanical support such as long-wall mining systems. When the mineral deposit is large and usually low grade, various caving techniques can be used that utilize breakage and collection of the broken ore from beneath the ore zone. At present no mining operation in Utah uses block caving although it has been proposed for some undeveloped ore deposits.

The adverse effects on ground water from underground mining result from the exposure of sulfide minerals to moisture and air. Oxidation of these sulfides produces sulfuric acid, the major constituent of acid mine drainage (AMD). AMD typically produces increased levels of metals and total dissolved solids in surface and ground waters.

In Utah AMD is a problem at some abandoned metal mines. Our alkali soils and carbonate rocks act to neutralize the acidity. However an increase in total dissolved solids in surface and ground water does result.

Surface Mining. Open pit, strip, and placer mines, and solar evaporation ponds are usually classed as surface mining operations. Open pit mines are used to extract ore deposits that are close to the land surface and frequently are very large and low-grade. Strip mines are used to mine bedded mineral deposits such as coal or phosphate rock. Overburden is removed, the mineral commodity removed, and the overburden replaced in the mined area. Placer mines are used to mine modern or ancient stream beds for gold, diamonds, tin, and other minerals. Solar evaporation ponds are used to recover salt, and other minerals from saline lake waters or solutions created by injecting water into bedded salt and potash deposits.

Open pit mines have the potential for creating major ground water contamination problems because of the extremely large volumes of ore and waste rock that are handled in the mining operation. Leaching of low-grade ore dumps and the percolation of water from rain and snow-melt through the waste dump creates sulfuric acid through the oxidation of sulfides. The end result is creation of sulfates that are carried into the ground water and elevate the total dissolved solids. The ground water contaminate plume that parallels that Bingham Creek drainage in Salt Lake County is a product of this process.

Strip mining can expose sulfide bearing material to air and moisture particularly in coal strip mining in a manner similar to open pit mines. The result can be the creation of acid mine waters and elevated levels of sulfates and metals in surface and ground waters. The Alton coal mining project envisions the use of strip mining to mine their coal deposits. Careful reclamation following mining can mitigate or eliminate these problems.

Placer mining utilizes differences in specific gravity to separate heavy mineral grains such as gold, platinum, and tin from lighter constituents. It does not have a substantial effect on deeper aquifers although it can have a substantial effect on the water-table aquifer. Placer mines in Utah are small scale operations with no significant ground water effects.

Solar evaporation ponds have been developed on the periphery of the Great Salt Lake to recover lithium, magnesium and salt. Minor seepage of saline lake water has had little effect on the natural saline ground water present in these areas.

Solution Mining.--Solution mines utilize water or dilute chemical solutions to recover mineral commodities. Water is used to solution mine salt and potash near Moab and weak acidic or basic solutions have been used in Texas and Wyoming for in-situ mining of uranium deposits. The impervious cap rock present over the salt and potash deposits limits the potential for ground water contamination in the solution mining. However if leaks occur in the injection or recovery wells, evaporation ponds, or through earlier mine workings, ground water contamination could result. Both the injection and recovery wells are regulated under Utah's Underground Injection Control program.

Mineral Processing

Following excavation, the ore is processed to concentrate and clean the mineral commodity of impurities and produce a saleable product. This processing generally includes both physical and chemical treatment. Wastes from this processing includes tailings of finely divided rock saturated with water from the ore milling and slags from smelting.

Typically ore is transported to a mill at the mine facility to produce a mineral concentrate for further processing. Usually this includes both physical treatment to reduce the size of the fragments and treatment with chemical agents to concentrate the mineral commodity. Wastes from the milling can include both the original rock material and various organic and inorganic chemicals that are added during the milling. These wastes are usually disposed in a tailings pond in the vicinity of the mill facility.

Mill tailings present many of the same ground water contamination problems as other mine wastes. Tailings are typically finely divided, contain gangue mineral sulfides, and are saturated with water. Thus they have a high potential for developing ground water contamination problems. Uranium mill tails frequently are sources of arsenic, cadmium, molybdenium, vanadium, lead, and other toxic metals in ground water in addition to uranium daughter products such as radium 226. Metal mine tailings have been sources of elevated levels of lead, arsenic, and cadmium in ground water. Lining of tailings disposal ponds with clay or synthetic liners may be a deterrent. Careful site selection should also be strongly emphasized together with good facility design.

Coal cleaning plants utilize water for cleaning and sizing mine coal. Sludges from these coal preparation plants usually contain pyrite and shale particles. These can produce ground water acidification or increases in the total dissolves solids. Fortunately, most of Utah's coal is a low-sulfur coal, and although problems exist, they are not of the same magnitude as many of the coal producing area of the eastern U.S.

Smelter wastes include the slag, dust, sludges, and waste water that result from the smelting of ore concentrates and the production of ferrous and nonferrous metals. Substantial accumulations of these wastes are present at operating and abandoned smelting facilities in Utah. They are recognized sources of surface and ground water contamination. Utah's Bureau of Solid and Hazardous Wastes is currently studying several of these sites to develop programs for ground water remediation.

Mine and Mill Water Disposal

Mine waters result from the dewatering of the mine operations area prior to the excavation of the ore material. The volume of water pumped from a mine depends on the climate, geology, and the size of the mine. It can range from as little as 10 gallons per minute to as much as 10,000 gallons per minute. Mine waters are often saline and may also contain high levels of toxic metals. Ground water problems can result both from the mine area dewatering and the disposal of the mine waters.

At the mine site, the dewatering may produce major readjustments in the ground water regime affecting springs, stream flow, and water wells. In addition it can degrade ground water quality by causing increases in the toxic metals, total dissolved solids, and other undesirable constituents.

Disposal of large volumes of mine waters can pose major problems for mine operators. Evaporation ponds often leak to the ground water system, reinjection is difficult and expensive as is treatment of the water. Satisfactory answers still elude both operators and regulators.

Mills often use mine waters for processing ore materials. Generally the waters are stored in holding ponds and used repeatedly. These holding ponds should be lined with impervious clay or synthetic liners to prevent leakage. Older mine facilities often have unlined ponds that are contributing to degradation of ground water quality.

CONCLUSIONS

Today we can look with smug hindsight at the mistakes that were made in the past by Utah's mining industry. We tend to focus on these mistakes and forget the products, employment, and prosperity that this industry brought to remote area of the west.

However, we can also benefit from these mistakes if we learn from them. In the future mining operations will be larger, the ore grades lower, and the mined volumes greater. With careful planning and operation we can enjoy the benefits the mining industry brings without degrading our air, water or environment.

ACKNOWLEDGMENTS

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FACTORS CONTRIBUTING TO DIFFERENCES IN ACID NEUTRALIZING CAPACITY AMONG LAKES IN THE WESTERN UNITED STATES

J.M Eilers[1], D.H. Landers[2], D.F. Brakke[3], and R.A. Linthurst[4]

ABSTRACT: A survey of lakes in mountainous areas of the Western United States was conducted in fall 1985 by the U.S. Environmental Protection Agency (EPA) in cooperation with the USDA - Forest Service. Of the 719 probability sample lakes, only one was acidic; 99% of the lakes were estimated to have pH > 6.0. However, acid neutralizing capacity (ANC) was $\leq$ 50 ueq L^{-1} for an estimated 16.8% of the lakes in the study area. Of the five subregions in the West, California had the highest proportion of lakes with ANC $\leq$ 50 ueq L^{-1} (36.7%) and the Southern Rocky Mountains had the lowest proportion (4.6%). The lakes in the West were post-stratified into geomorphic units corresponding to major mountain ranges. Watershed factors, including watershed area, lake area, watershed area:lake area ratio, lake depth, watershed slope, percent exposed bedrock, elevation, and hydraulic residence time, were examined within six geomorphic units in order to evaluate their relationship to lake ANC. These watershed variables had poor predictive capability with respect to ANC. The results suggest that higher-resolution information for factors such as mineralogy and hydrology are required for prediction of lake ANC within a given geomorphic unit.
KEY TERMS: Lakes, acid neutralizing capacity, watersheds, western United States, geomorphic units.

INTRODUCTION

Acid neutralizing capacity (ANC), or total alkalinity, is a key variable for assessing the current acid-base status of a lake. If a lake has already lost ANC as a result of acidic deposition, the utility of ANC as a measure of sensitivity is reduced. Although the sum of [Ca + Mg] and the sum of base cations may be more universally applicable as measures of lake sensitivity to acidification by acid deposition (Wright, 1987), ANC provides equivalent information for lakes that have not been acidified. Much of the research regarding the impact of acidic deposition on aquatic resources in the United States during the past decade has focused on the eastern United States, with particular emphasis on the Northeast (Altshuller and Linthurst, 1984). Only recently has substantial effort been directed toward assessing the possible impacts of atmospheric deposition in the western United States, with respect to current or future acidic

[1]Senior Scientist, Northrop Services, Inc., 200 SW 35 St., Corvallis OR 97333.

[2]Research Environmental Scientist, US EPA, Environmental Research Laboratory, 200 SW 35th St., Corvallis, OR 97333.

[3]Professor, Western Washington University, Institute for Environmental Studies, Environmental Sciences Bldg, Room 600, Bellingham, WA 98225.

[4]Program Director, US EPA, Environmental Monitoring Systems Laboratory, Mail-Drop 39, Research Triangle Park, North Carolina 27711.

deposition effects (Roth et al. 1985). One of the most comprehensive evaluations of the current status of western lakes is the recently completed Western Lake Survey (Landers et al. 1987a), a companion survey to the Eastern Lake Survey (Linthurst et al. 1986). One area of research in assessing lake and stream response to acidic deposition involves determining the factors that control present surface water chemistry. By understanding the factors that explain present conditions, we hope to better predict future responses of lakes and streams to changing amounts of acidic deposition. Investigations of lakes in other regions have shown that lake chemistry is strongly associated with physical and hydrologic factors (Hunsaker et al. 1986; Eilers et al. 1983). Other analyses have indicated the importance of geology (Landers et al. 1987a) and precipitation amount (Eilers et al. 1987) in explaining differences in lake chemistry among major areas in the West. The purpose of this manuscript is to present selected results from the survey and to examine factors that may contribute to differences in lake chemistry in the West, especially factors that affect lake ANC.

METHODS

The methods for the Western Lake Survey (WLS), with the exception of site access, were the same as those used in the Eastern Lake Survey (ELS). These are described in Landers et al. (1987a) and Linthurst et al. (1986), respectively. Lakes selected for sampling were limited to areas in the western United States believed to contain the vast majority of lakes with ANC < 400 ueq L^{-1} (Figure 1) as described in Omernik and Griffith (1986). Within the study area, sites were excluded from consideration (i.e., termed non-target lakes) if they were too shallow to collect an undisturbed sample (< 0.75 m), were considered impacted by activities near the lakeshore, had high conductivity (> 1500 uS cm^{-1}), or were non-lakes. In the WLS, approximately 50 lakes were systematically sampled from each of three alkalinity strata (alkalinity believed to be < 100, 100-199, ≥ 200 ueq L^{-1}) within each of the five subregions (4A-4E). The design ensured that each lake within a stratum had a known probability of being selected, and thus, the physical and chemical characteristics of the population of lakes could be estimated from sample

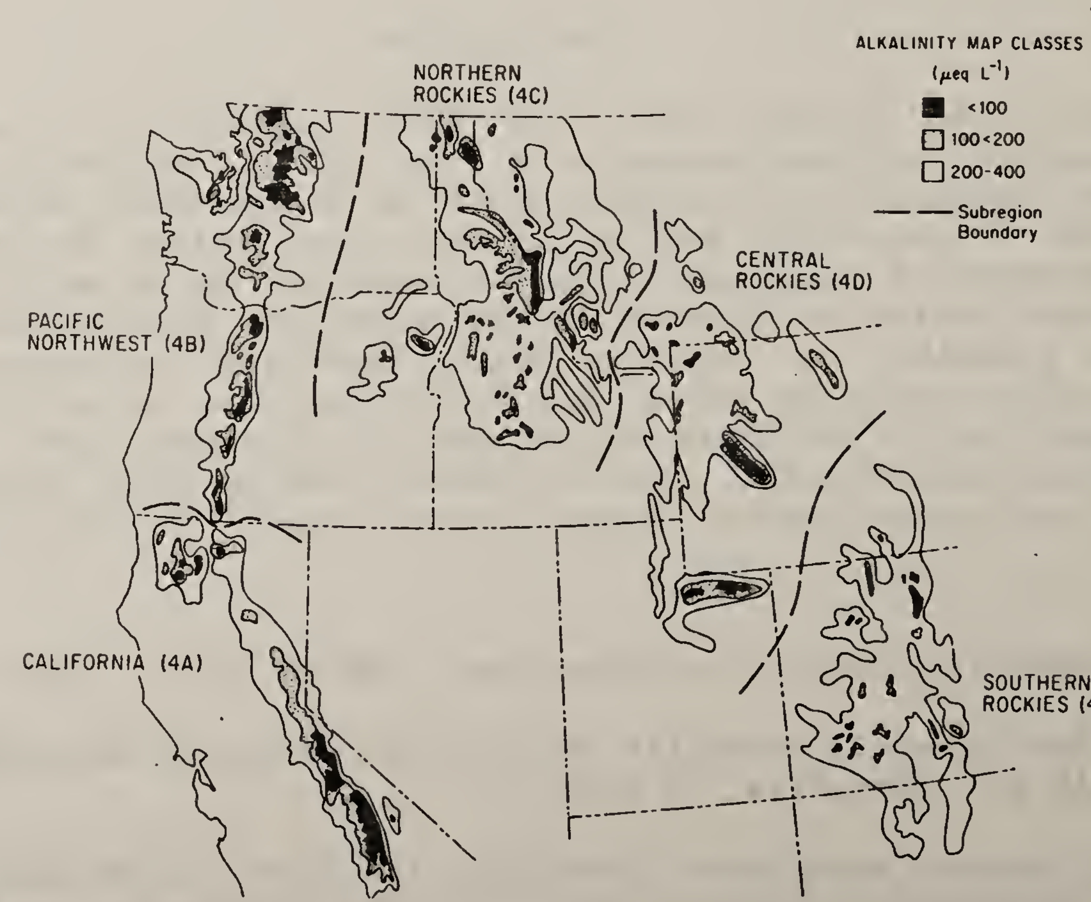


Figure 1. Subregions and alkalinity map classes in study areas of the Western Lake Survey - Phase I.

results with a known degree of confidence. The sample is based on 719 lakes, representing an estimated 10,393 lakes in the target population. This target population consists of lakes > 1 ha in area that are present on 1:100,000-scale USGS topographic maps (less those lakes estimated to be in the non-target category).

Lakes were visited by ground teams or by helicopter during fall 1985, when the lakes were usually homothermic. Each lake was sampled near the deepest portion of the lake using a 6.2 L acrylic Van Dorn sampler. Samples were transported to field laboratories for analysis of unstable parameters (pH, DIC, color, and turbidity); they were subsequently preserved and shipped to analytical laboratories for analysis of anions, cations, ANC, DOC, Al, Fe, Mn, SiO_2, total P, and conductivity. ANC was measured using a modified Gran titration. Major anions were measured using ion chromatography, and cations were measured using atomic absorption spectroscopy or inductively coupled plasma emission spectroscopy (Kerfoot and Faber 1987). Physical characteristics such as lake area, watershed area, lake elevation, watershed relief, and land cover types were derived from USGS topographic maps at scales of 1:24,000, 1:25,000, or 1:62,500. Statistical analyses were performed using the Statistical Analysis System (SAS) (SAS User's Guide 1985).

RESULTS AND DISCUSSION

The results from the Western Lake Survey are presented in this paper not as sample data, but rather as population estimates for target lakes within the study area. The tabular results are presented as percentages of lakes less than or equal to, or greater than reference values, and as medians and quartile descriptive statistics. The overall results for the WLS are presented first and compared to results for the ELS. These are followed by results for groups of lakes identified from a post-stratification based on delineations of mountain ranges. Implicit in the design is the concept that a single surface water sample is adequate for characterizing the chemistry of the lake at any given time and that a fall sample provides a realistic representation of the lake's chemical status. It is recognized that a single fall sample alone is insufficient for assessing short-term or long-term changes resulting from snow melt and thunderstorm episodic events.

Overview

The WLS results for selected chemical variables are provided in Tables 1 and 2. Only 1% of the lakes had pH $\leq$ 6.0, and of the 719 sample lakes, only one, representing 0.14% of the target population, had ANC $\leq$ 0. If acidification has occurred in the West, it has not been great enough to cause a complete loss of ANC. The one lake with negative ANC, Fern Lake located in Yellowstone National Park, was associated with influent geothermal springs, which was evident in the highly mineralized lake water. Two other variables of considerable importance in evaluating lake response to acidic deposition are sulfate, which is recognized as the dominant strong acid anion in acidic lakes (Landers et al. 1987b), and aluminum, which is often mobilized under acidic conditions (Driscoll et al. 1980). The median sulfate concentration in the western lakes was 19 ueq L^{-1}, compared to 115 ueq L^{-1} for lakes in the Northeast (Linthurst et al. 1986), and only 13.5% of the lakes in the West had SO_4^{-2} > 50 ueq L^{-1}, compared to 97.3% in the Northeast. Similarly, extractable aluminum concentrations in the West exceeded 50 ug L^{-1} in only 0.3% of the lakes, compared to 5.2% for lakes in the Northeast and 14.4% for lakes in the Adirondacks (Linthurst et al. 1986).

Watershed sources have the potential to contribute organic acidity to lakes as strong and weak acid anions. These organic acids are usually estimated based on a measure of organic carbon, either in dissolved or total (unfiltered) forms. Dissolved organic carbon (DOC) concentrations in the West were low, with concentrations generally < 2 mg L^{-1}. However, because the western lakes are so dilute, even a small amount of organic anion has the potential to represent a substantial percentage of the total anions. Using the model by Oliver et al. (1983), the median organic anion concentration in the West is estimated to be 12 ueq L^{-1}. However, this model is based largely on

Table 1. Descriptive statistics (Q_1 = first quartile; M = median; Q_3 = 3rd quartile) of selected chemical variables for lakes in the Western Lake Survey

Subregion[a]	Lakes Sampled	Estimated Number of Lakes[b]	pH[c]			ANC[d]			SO_4^{-2}[d]			$[C_B]$[e]			DOC[f]		
			Q_1	M	Q_3	Q_1	M	Q_3	Q_1	M	Q_3	Q_1	M	Q_3	Q_1	M	Q_3
California (4A)	149	2401	6.67	6.94	7.29	37	63	108	4	7	11	35	52	98	0.6	1.0	1.8
Pacific Northwest(4B)	159	1706	6.73	7.00	7.27	61	140	236	4	15	38	64	133	231	0.6	1.3	2.2
Northern Rockies (4C)	143	2379	6.92	7.35	7.89	80	195	789	8	16	29	76	185	784	0.8	1.2	2.2
Central Rockies (4D)	129	2299	6.99	7.18	7.41	74	105	173	20	24	32	95	123	194	0.8	1.3	2.7
Southern Rockies (4E)	139	1609	7.19	7.60	8.15	119	317	951	19	35	77	144	336	940	0.9	1.5	3.4
West	719	10,393	6.87	7.6	7.55	63	119	305	8	19	33	66	124	323	0.7	1.2	2.3

a See Figure 1.
b The standard error of the number of lakes estimated for each subregion is 74.5, 61.7, 143.3, 83.0, and 106.6, respectively.
c pH (closed system) in standard units.
d ueq L^{-1}.
e Sum of base cations $[Ca^{+2} + Mg^{+2} + Na^{+} + K^{+}]$ in ueq L^{-1}.
f Dissolved organic carbon in mg L^{-1}.

Table 2. Population estimates for the number of lakes (95% upper confidence limit), and percentage of lakes greater than or less than a given reference value, Western Lake Survey. Units are the same as those in Table 1.

Subregion		pH ≤ 6.0		ANC ≤ 50		SO_4^{-2} > 50		$[C_B]$ ≤ 50		DOC ≤ 2	
		Number	%	Number	%	Number	%	Number	%	Number	%
California	(4A)	32 (84)	1.3	880 (1081)	36.7	187 (300)	7.8	553 (728)	23.0	1937 (2105)	80.7
Pacific Northwest	(4B)	41 (73)	2.4	332 (415)	19.5	292 (374)	17.1	183 (246)	10.7	1161 (1277)	68.1
Northern Rockies	(4C)	0	0	301 (413)	12.7	256 (399)	10.7	121 (193)	5.1	1685 (1929)	70.8
Central Rockies	(4D)	30 (63)	1.3	158 (240)	6.9	128 (198)	5.6	0	0	1548 (1717)	67.3
Southern Rockies	(4E)	0	0	74 (96)	4.6	543 (711)	33.7	3 (8)	0.2	908 (1088)	56.5
West		103 (172)	1.0	1745 (2004)	16.8	1405 (1676)	13.5	861 (1060)	8.3	7239 (7642)	69.7

aquatic systems in eastern North America with high DOC and may not be appropriate for application to lakes in the West. Because of the dilute nature of western lakes, lakes in Scandinavia may be more suitable analogs for lakes in the West. Analysis of strong and weak acid contributions in Norwegian lakes by Brakke et al. (1987a), suggests that dilute lakes with total organic carbon < 2 mg L^{-1} contribute virtually no anions to the ion balance. Other studies of high-altitude lakes in the West (Baron 1983, Nelson and Delwiche 1983, Duncan 1985, Meglen et al. 1985, Melack et al. 1985, Brakke and Loranger 1986) also indicate that cation/anion balance can be achieved within five percent without invoking a contribution by organic anions.

Despite the absence of acidic lakes in the West, a large number of these lakes may be sensitive to changes in atmospheric deposition. The percentage of lakes in the West with ANC $\leq$ 50 ueq L^{-1} is 16.8% (36.7% for lakes in California), compared to 19.2% for lakes in the Northeast (Linthurst et al. 1986). Total ionic strength, as represented by conductivity, was extremely low in the West; 26.6% of the lakes had values < 10 uS cm^{-1}, and the median value was 16.5 uS cm^{-1}. In contrast, the minimum conductivity observed in the Northeast was 11.0 uS cm^{-1}, with a median value of 43.3 uS cm^{-1} (Overton et al. 1986). The sum of base cations (C_B) is also low in the West, where 8.3% of the lakes have values $\leq$ 50 ueq L^{-1}, compared to a minimum value of 61 ueq L^{-1} observed in the Northeast (Kanciruk et al. 1986).

Geomorphic Units

One of the purposes of the stratified survey design was to provide population estimates for relatively homogeneous physiographic areas, represented by the regions and subregions. It is apparent from the results that lakes in the West are very different from those in the East, and it is also evident that lakes in subregions of the West exhibit distinct chemical characteristics that justify treatment of western lakes on a scale finer than that of the regional level. For descriptive purposes, the current subregional stratification factors appear satisfactory. However, for detailed evaluation of the relationship between lake chemistry and watershed characteristics, the use of subregion as a unit of analysis may not be appropriate. Each subregion within the West is composed of several mountain ranges, each of which may have different geologic origins. These mountain ranges contribute to differences in lake chemistry within subregions that could mask important relationships not evident in the presentations by subregions. To avoid confounding analyses of factors that could provide spurious associations, we have post-stratified the western lakes by recognized geomorphic units (Hunt 1974). The boundaries for these units are generally coincident with mountain ranges in the West. From the geomorphic units identified in Figure 2, we selected those units with a sample size sufficient to provide us with confidence in characterizing the physical and chemical aspects of the target lakes represented. The sample sizes of the six geomorphic units used for this analysis ranged from 37 in the Bitterroot Mountains to 114 for the Sierra Nevada. These six geomorphic units represent 46% of the target population size, yet represent 70% of the target population with ANC $\leq$ 50 ueq L^{-1}.

The Sierra Nevada is dominated by a massive batholith composed of granite and granodiorite, although metavolcanics and metasedimentary rocks extend along the northern and eastern portions of the range (Chronic 1986). Other differences in bedrock type within the batholith are attributed to locally occurring plutons and dikes. The Oregon Cascades (also called the Middle Cascade Mountains; Hunt 1974) are composed of uplifted tertiary lavas with volcanic peaks extending high above the range. The Northern Washington Cascades geomorphic unit is defined here as the area comprising the Wenatchee Mountains and the Middle and North Washington Cascades (Landers et al. 1987a). The Southern Washington Cascades have been omitted from this geomorphic unit because the bedrock is largely volcanic and is more similar to that of the Oregon Cascades. The Northern Washington Cascades are comprised largely of Paleozoic sedimentary rocks which have been folded and metamorphosed. Intrusions of granitic rocks and the presence of a variety of other rock types make this among the most geologically diverse geomorphic units. The Bitterroot Mountains are on the northeastern edge of the Idaho Batholith, a geologic formation with composition similar to that of the Sierra Nevada. The Wind River

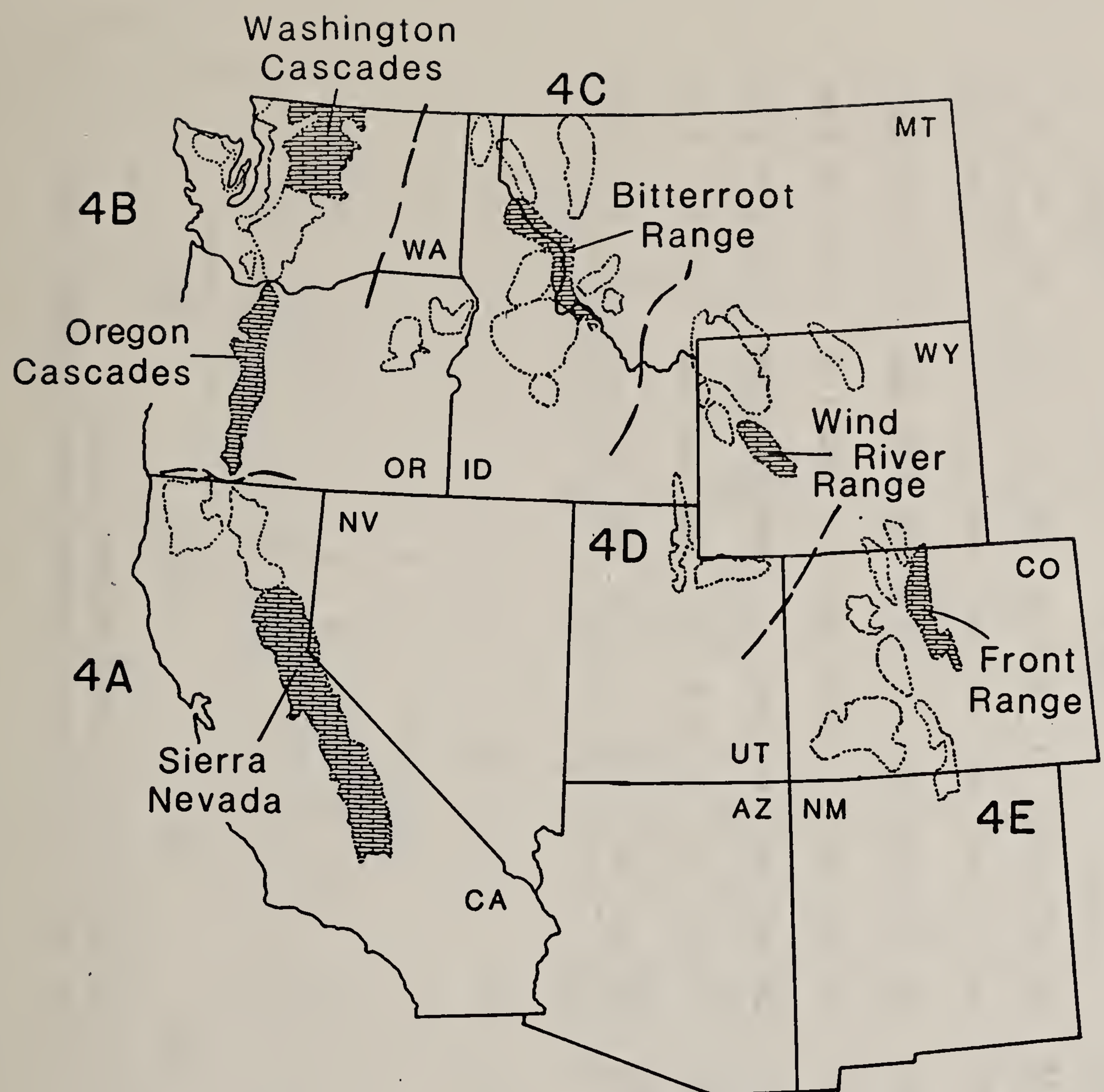


Figure 2. Locations of geomorphic units for specific subpopulations of lakes, Western Lake Survey. These units represent physiographic areas of common geologic origin and generally coincide with major mountain ranges. Highlighted areas represent the six units used in this analysis.

Range, which includes the Bridger-Fitzpatrick Wilderness Area, is an uplift of Precambrian granites and gneisses. The Front Range, which includes Rocky Mountain National Park, is primarily composed of granite, gneiss, and schist (Hunt 1974).

Population estimates for physical and chemical characteristics of lakes in the selected geomorphic units are presented in Tables 3 and 4, respectively. Lakes in these western areas are generally smaller than those in the East (Linthurst et al. 1986), but have relatively large watersheds evident in the watershed area to lake area ratios. Lakes in the Oregon Cascades are relatively shallow, especially when compared to those in the Bitterroot Mountains and the Wind River Range. Lakes in the Sierra Nevada, Wind River, and the Front Range were generally located above 3000 m, and consequently many are located above treeline (Arno and Hammerly 1984); in contrast, few lakes in the Oregon Cascades are located above treeline. The combination of high precipitation and lake/watershed morphometrics caused lakes in the Oregon and Washington Cascades to have estimated hydraulic residence times two to four times less than those of lakes in the other mountain ranges. Although there are notable differences in physical characteristics of the lakes in the various mountain ranges, the chemical differences among geomorphic units are much greater, with median concentrations for ANC, [Ca + Mg], and SO_4^{-2} differing by up to a factor of six.

The chemical heterogeneity of lakes, as measured by interquartile ranges ($Q_d = Q_3 - Q_1$), was lower in geomorphic units than in the respective subregions. ANC interquartile

Table 3. Descriptive statistics (Q_1 = lst quartile; M = median; Q_3 = 3rd quartile) for selected physical characteristics of lakes in major mountain ranges of the western United States

Geomorphic Unit	Lakes Sampled	Estimated Number of Lakes	Lake Area (ha)			Watershed Area (ha)			$A_w:A_l$			Lake Depth (m)			Elevation (m)			Hydraulic Residence Time (yr)		
			Q_1	M	Q_3	Q_1	M	Q_3	Q_1	M	Q_3	Q_1	M	Q_3	Q_1	M	Q_3	Q_1	M	Q_3
Sierra Nevada, CA	114	2119	2.5	4.6	9.5	55	149	387	13.6	22.8	50.3	5.5	8.9	15.1	2634	3103	3311	0.11	0.29	0.73
Oregon Cascades	42	443	2.5	3.4	7.2	32	74	270	6.8	21.4	42.2	2.9	4.8	8.1	1257	1488	1684	0.05	0.10	0.25
Washington Cascades	68	710	2.1	4.2	11.0	50	110	250	11.3	19.5	36.3	4.3	10.6	25.0	1223	1552	1745	0.04	0.16	0.41
Bitterroots, ID/MT	37	283	2.8	4.8	7.4	48	95	164	11.0	16.0	29.3	6.3	11.8	17.3	1809	2043	2210	0.13	0.57	1.10
Wind River, WY	47	884	4.2	6.4	14.3	77	187	507	15.7	22.5	48.5	6.9	10.9	20.7	2992	3108	3214	0.16	0.41	1.17
Front Range, CO	51	311	1.8	3.7	18.6	50	150	394	12.1	23.8	56.3	3.1	6.7	15.6	2669	3234	3445	0.07	0.41	1.03

* Watershed area:Lake area.

Table 4. Descriptive statistics (Q_1 = lst quartile; M = median; Q_3 = 3rd quartile) for selected chemical variables of lakes in the major mountain ranges of the western United States. Units are same as those in Table 1.

	pH			ANC			$[C_B]$			SO_4^{-2}			DOC		
Geomorphic Unit	Q_1	M	Q_3	Q_1	M	Q_3	Q_1	M	Q_3	Q_1	M	Q_3	Q_1	M	Q_3
Sierra Nevada, CA	6.69	6.94	7.29	36	60	105	50	77	116	4	7	11	0.6	0.8	1.6
Oregon Cascades	6.61	6.94	7.16	45	92	176	54	113	189	1	2	3	1.2	1.7	2.1
Washington Cascades	6.81	7.05	7.32	59	113	189	88	151	207	9	17	33	0.3	0.7	1.4
Bitterroots, ID/MT	6.67	6.79	7.14	45	70	135	57	98	164	6	9	16	0.8	1.2	1.8
Wind River, WY	6.96	7.15	7.33	88	109	155	123	151	220	22	24	30	0.8	1.2	2.7
Front Range, CO	6.91	7.44	7.79	81	338	442	131	392	551	23	35	64	1.0	1.5	3.1

ranges were only 3% smaller by geomorphic unit in the Sierra Nevada (which contained most of the lakes in Subregion 4A), but 57% smaller in the Front Range (Subregion 4E). Interquartile ranges for sulfate showed no change in the Sierra Nevada, but sulfate interquartile ranges were 94% smaller in the Oregon Cascades geomorphic unit than in Subregion 4B as a whole. By focusing on geomorphic units, we are restricting the analysis to discrete physiographic units that generally exhibit greater chemical homogeneity compared to the subregions used in the sampling stratification. More importantly, use of geomorphic units increases the likelihood that association between watershed factors and lake chemistry can be interpreted in the appropriate context.

PHYSICAL FACTORS

As noted in the introduction, the purpose of exploring the relationships between ANC and lake and watershed physical attributes is to develop an understanding of the processes that regulate lake chemistry. Identification of associations, even though they may not be causal, still has the benefit of providing a classification tool for subsequent analyses. Exploration of the relationship between watershed characteristics and lake chemistry can be better focused if we approach the problem with a conceptual model of the lake/watershed system. Our conceptual model of a western lake system resembles that of Turk and Adams (1983) where lake ANC is presumed to be a function of bedrock composition, contact time of water from precipitation and the watershed, length of flow path in the watershed, soil coverage and depth, temperature, and vegetation composition and density. Although it is not possible to quantitatively measure the influence of all factors on lake chemistry, we have assumed that the lake represents the integration of these watershed factors.

We evaluated relationships between lake chemistry and the following physical variables: watershed area, lake area, lake depth, watershed slope, lake elevation, landcover type, and hydraulic residence time (Landers et al. 1987a). Watershed slope is defined as the median percent slope measured along 10 transects on the topographic maps. Eleven classes of landcover type were measured based on the USGS topographic maps and definitions (Anderson et al. 1976). Tundra, barren, and permanent snow field cover types were combined to estimate total percent of watershed without vegetation or soil (referred to here as percent exposed bedrock). Hydraulic residence time, the time required to replace the volume of a lake, was estimated from interpolated values of precipitation and runoff.

Plots of ANC versus watershed factors were examined for each of the six geomorphic units. Population weighted linear regression models using raw and transformed data as independent variables and ANC as the dependent variable were also developed. Finally, weighted stepwise multiple linear regression models using all watershed factors were prepared.

The results shown in Table 5 indicate surprisingly poor predictive capability of these variables in explaining lake ANC. Although some of these watershed variables no doubt influence the lake ANC, their overall utility for either classifying or predicting lake ANC is limited. Only in the Oregon Cascades, Wind River Range, and Front Range did any of these variables individually or collectively explain greater than 20% of the variance in ANC. The low variance from the regression of lake elevation on ANC observed here contrasts sharply with the results of Turk and Adams (1983) who found that lake elevation explained 76% of the variance in lake ANC for 27 lakes ranging in elevation from 2837 to 3418 m in the Flat Tops Wilderness Area, Colorado. The increased predictive capability of elevation in the Flat Tops cannot be attributed to a greater range in elevation gradient among the geomorphic units. However, the range of ANC values in the Flat Tops (70-1400 ueq L^{-1}) is somewhat greater than measured in these geomorphic units. Partitioning the WLS lakes into high and low elevation classes (@ 3000 m) revealed substantial differences in ANC for the Central and Southern Rocky Mountains, but provided little discriminatory power for lakes in California (Landers et al. 1987a).

The results in Table 5 also contrast with observations in the eastern United States where physical factors have been useful in classifying or predicting lake ANC. Landers

Table 5. Percent variance* in lake ANC (r^2) explained by watershed and lake factors in selected geomorphic units of the western United States. The top row within each unit represents the results for the single-variable model; the bottom row represents the partial r^2 for significant variables at 0.15 based on the stepwise multiple regression

Geomorphic Unit	Lake Area (A_l)	Watershed Area (A_w)	A_w:A_l	Lake Depth	Watershed Slope	Percent Bedrock	Hydraulic Residence Time	Elevation	Precipitation
Sierra Nevada	0.033	0.045	0.109	-	-	0.038	-	-	-
	-	-	-	-	0.104	-	-	0.041	-
Oregon Cascades	0.176	0.385	0.053	-	-	0.285	-	-	-
	0.257	0.314	-	-	0.115	-	-	-	-
Washington Cascades	-	0	0.182	0.075	-	0.061	-	-	-
	-	0.037	0.186	-	0.061	-	-	-	-
Bitterroot Mtns.	-	-	-	-	-	0.114	-	-	-
	-	0.086	-	0.075	-	-	-	0.140	-
Wind River Range	-	-	-	-	0.144	0.387	-	-	
	-	-	0.041	-	-	-	-	0.449	-
Front Range	0.117	-	-	0.108	0.272	0.187	0.241	-	0.185
	-	0.093	-	0.054	0.279	-	0.138	-	-

* Values not significant at 0.15 are excluded.

et al. (1987b) observed that acidic lakes in the ELS were generally smaller than non-acidic lakes with respect to lake area, watershed area, and watershed area:lake area ratio. Acidic lakes in the Northeast were also generally found at higher elevations than non-acidic lakes. Acid neutralizing capacity in ELS lakes was also highly related to hydrologic factors, as represented by lake type and residence time (Brakke et al. 1987b). Hunsaker et al. (1986) also observed that headwater lakes in the Adirondacks, which were typically at higher elevation, had lower ANC than non-headwater lakes. Elevation, lake size and hydrologic type were observed to have a strong influence on lakes in Maine (Kahl 1987).

In light of these and other studies in the East showing strong relationship between ANC and watershed factors, it is surprising to observe such poor agreement in the West. These findings suggest that the chemical composition of a watershed (e.g., bedrock, till, or soils) is more important in influencing lake chemistry in the West than physical attributes of a watershed. Gibson et al. (1983) observed a weak inverse relationship between ANC and elevation for streams in the Rocky Mountain National Park, but concluded that the primary factor controlling stream chemistry in their study area was watershed mineralogy.

Other Potential Sources of ANC

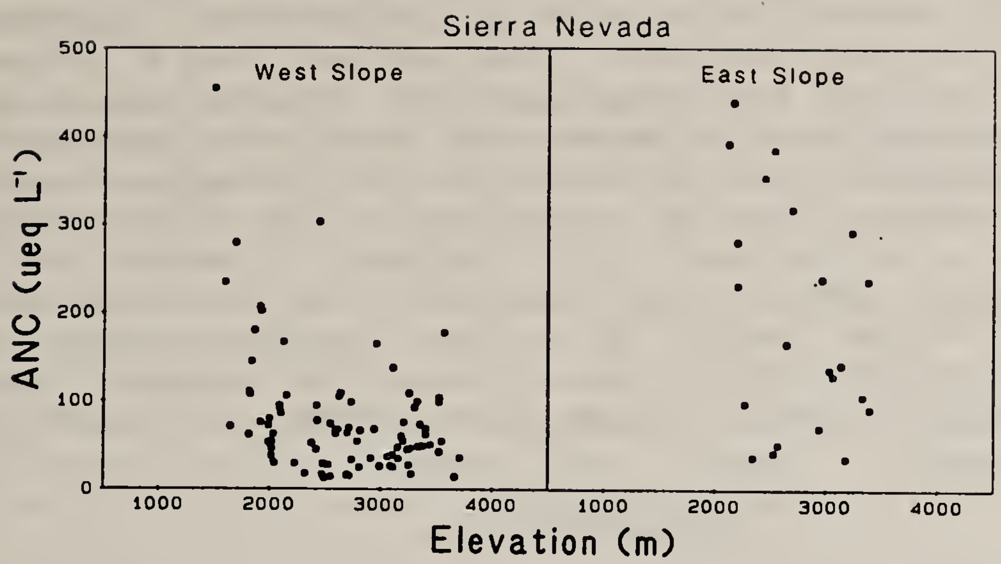
This presentation has focused on watershed sources of ANC to lakes in the West. Two additional sources of ANC that may be important are atmospherically-derived ANC, and ANC generated internally within lakes. Messer (1983) notes that the chemistry of snow in the Wasatch Mountains of Utah was alkaline with a mean bicarbonate concentration of 26 ueq L^{-1}. Results from principal component analysis and linear stepwise regression of the snow chemistry were consistent with a major source derived from wind borne particulates of gypsum (Messer et al. 1982), although scavenging of acid sulfates onto carbonates could not be excluded. The paucity of deposition data from high elevation sites in the West makes it difficult to evaluate the importance of deposition as a factor in contributing or depleting ANC in lakes represented in the WLS survey.

Orographic effects may modify the chemistry of lakes in the Sierra Nevada where a substantial "rain-shadow" effect is exerted by the 3500 m crest. Figure 3 shows ANC versus elevation for lakes in the Sierra Nevada and Oregon Cascades. Lakes on the eastern side of the Sierra Nevada have higher ANC concentrations; median ANC concentrations for the western and eastern slopes are 52 and 138 ueq L^{-1}, respectively. In contrast, the lakes in the Oregon Cascades, which has a crest of approximately 1800 m, show no evidence of orographic effect.

Within-lake alkalinity generation has been suggested as a major source of ANC (Schindler et al. 1986). However, given the large watershed area:lake area ratio values and short hydraulic residence times for most lakes in the West, we would expect that within-lake sources would be small relative to watershed sources for most western lakes. Exceptions to this would be deep lakes subject to infrequent or incomplete mixing. Although estimated hydraulic residence time did not show a relationship with ANC, lake position with respect to local surface water and groundwater flow paths may exert considerable influence on the chemistry of western lakes. Lake position within the watershed was examined for 18 lakes with conductivity < 10 uS cm^{-1} in the Oregon Cascades. Only two of these lakes had inflowing streams shown on 15' and 7.5' USGS topographic maps. The remaining 16 lakes were located on or adjacent to topographic divides from which the flow paths would be away from the lakes. Although this observation is qualitative, it is consistent with the conceptual model in which length of flowpath and contact time with the watershed are two important factors.

SUMMARY AND CONCLUSIONS

The results of the survey show that lakes in the West have positive ANC, with the exception of a small number of naturally acidic systems. However, many western lakes may be sensitive to changes in atmospheric deposition given their low levels of ANC and base



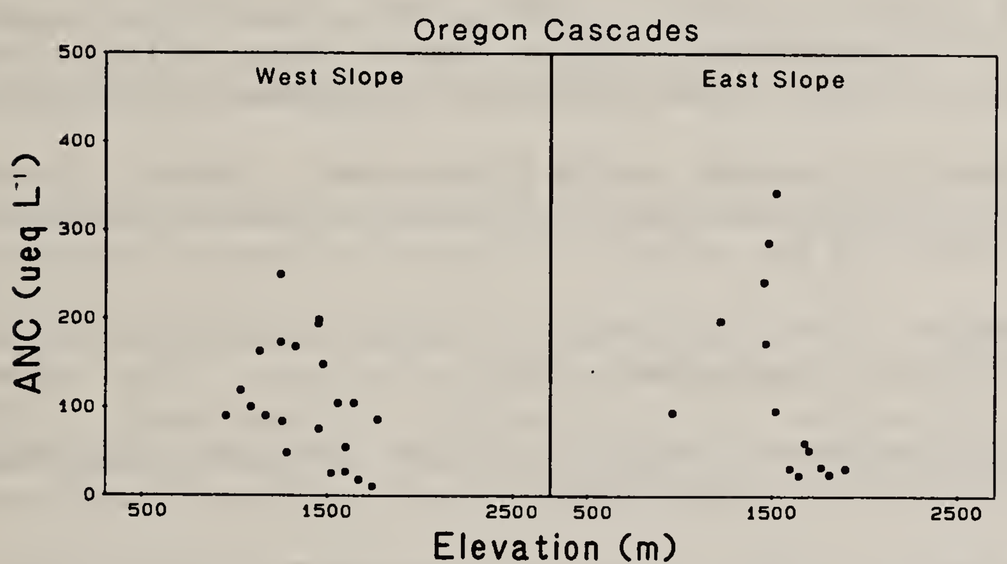


Figure 3. Relationship between ANC ($\leq$ 500 ueq L^{-1}) and elevation (m) for lakes on the western and eastern slopes of the Sierra Nevada and Oregon Cascades.

cations. Comparison of western lakes with those in the Northeast shows western lakes have far lower concentrations of sulfate, aluminum, and base cations, but the Northeast and the West have comparable proportions of lakes with low ANC ($\leq$ 50 ueq L^{-1}). Considerable variation in lake chemistry is evident in the West where the proportion and number of low ANC lakes is greatest in California and generally decreases clockwise from the Pacific Northwest to the Southern Rocky Mountains. A post-stratification of lakes into geomorphic units provides a suitable framework for evaluating the influence of watershed factors in contributing to differences in ANC. Examination of bivariate plots of watershed factors versus ANC revealed little pattern in the data. Single and multiple regression models, using these watershed factors as input variables, were generally unsuccessful in predicting lake ANC. The results suggest that identification of factors contributing to heterogeneity in lake chemistry within geomorphic units requires higher resolution data than is currently available on a survey basis.

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A BIOHYDROMETALLURGICAL APPROACH TO SELENIUM REMOVAL

By D. M. Larsen,[1] K. R. Gardner,[2] and P. B. Altringer[3]

The Bureau of Mines, U.S. Department of the Interior, is conducting research on the removal of heavy metal ions from residual waters. This research has included exploratory batch and small-scale continuous laboratory studies on the biohydrometallurgical removal of selenium from agricultural drainage waters. Tests were conducted on alkaline drainage waters obtained from the Kesterson National Wildlife Refuge, San Joaquin Valley, CA. The waters contained 280 to 3,800 ppb selenium present as SeO_4^{2-}. Using indigenous bacteria, the selenium was reduced from selenate, Se(VI), to selenite, Se(IV), and then precipitated in elemental form from solution. Selenium removal ranged from 87 to 96 pct, regardless of the initial selenium concentration; in one system, the selenium level was reduced from 3,800 ppb to less than 150 ppb in about 1 h. The technique was effective when the bacteria were added directly to the water, or when the water was pumped through a substrate that had been previously innoculated with bacteria.
KEY TERMS: Selenium, waste water, decontamination, reduction, bacterial precipitation.

INTRODUCTION

The Fish and Wildlife Service, in 1982, determined that fish and waterfowl inhabiting the Bureau of Reclamation's Kesterson National Wildlife Refuge in the San Joaquin Valley, CA were being adversely affected by ingested selenium. Selenium is a naturally occurring element in the rock and soils of the district. As a trace element, selenium is a necessary nutrient, but in concentrations found at Kesterson, it causes malformation and death to wildlife. The Kesterson Wildlife Refuge received agricultural drainage water from farms in the San Joaquin Valley; the water was pumped from the subsoil into the San Luis Drain and ran into the Kesterson Reservoir. The release of selenium into the groundwater was a natural reaction due to weathering, irrigation, and cropping practices. Since this discovery, selenium contamination has been found in six Western States.

Bureau of Mines interest in this problem stems from two factors. First, a number of the waterfowl species being affected by the selenium are migratory and thus are protected by treaty (with Canada) and by Federal law. The Bureau, therefore, initiated research to solve this problem and to assist the Secretary of the Interior in meeting these treaty and statutory obligations. Second, liquid wastes and runoff with similar compositions result from a number of mineral-processing operations (Hoffmann, 1984). Therefore, experience gained from this research would be readily applicable to a variety of mineral processing waste waters.

[1]Metallurgist.
[2]Physical science technician.
[3]Group supervisor.
Salt Lake City Research Center, Bureau of Mines, U.S. Department of the Interior, 729 Arapeen Drive, Salt Lake City, UT 84108.

A novel approach to this complex problem is the biologically assisted control of the selenium. Microorganisms capable of reducing selenium salts to elemental selenium have been used for diagnostic tests since the 1920's (Levine, 1925; Leifson, 1936). More recently, it has been found that selenium can be altered by bacteria through three mechanisms: (1) extracellular reduction and precipitation by various bacteria such as Salmonella, and Citrobacter (Smith, 1959), (2) intracellular accumulation by incorporation into proteins of the cell wall of E. Coli (Gerrard, 1974; Tuve, 1961), and (3) volatilization of selenium by a strain of Pseudomonas, where the selenium forms methyl- or dimethyl-selenide compounds (Chan, 1976). Alexander (1961), Summers (1978), and Brierley (1982) have also observed bacteria-induced selenium reactions.

Research at the Bureau's Salt Lake City Research Center has focused on the biologically assisted control of selenium using indigenous bacteria cultured from the Kesterson area. A natural biological system, which immobilizes and concentrates selenium, exists within the Kesterson Reservoir. Research is being conducted to emulate these natural processes and reduce the selenium to non-toxic levels before it enters the Wildlife Refuge.

RESOURCE DESCRIPTION

The Bureau of Reclamation constructed the 1,280-acre Kesterson Reservoir and the 85-mile San Luis Drain through the San Joaquin Valley between 1968 and 1975. Most of the selenium in the Kesterson Reservoir came from subsurface, agricultural drainage water carried via the Drain. The drainage water in the Five Points area in Fresno County, CA, is collected by subsurface drainage tiles; sump pumps convey the water into the Drain where it runs into the Kesterson Reservoir in Merced County, CA.

The Bureau, with assistance from the Bureau of Reclamation, obtained water samples from the entire Kesterson area; this included selected farm sumps, points along the Drain, and the Kesterson Reservoir. The selenium content of the samples ranged from 280 to 3,800 ppb Se as selenate, Se(VI), with a pH range of 7.0 to 9.0. A large water sample was obtained from the Drain in April 1986, just before officials plugged the Drain inlets. The sample analyzed 525 ppb Se as the selenate ion with a pH of 8.1.

Bacteria cultures for laboratory experimentation were isolated from the Drain by the Idaho National Engineering Laboratory. These bacteria are believed to be responsible for the natural precipitation of selenium in the Kesterson Reservoir. The cultures are maintained at the Bureau in a nutrient broth containing 100 ppm Se. Smith-tube tests demonstrated that the bacteria are aerobic in nature; however, further tests in agar tubes have shown these bacteria to be microaerophilic (require only limited amounts of air). Common bacterial identification procedures conducted at the Bureau, such as gram stains, flagellar stains, and growth on various agars, indicate these bacteria belong to the family Enterobacteriaceae; genera Salmonella and Citrobacter and the family Pseudomonadaceae.

Selenium Analysis

A round-robin analysis system was established to find the best method for total selenium determination and to establish whether sample aging changed the selenium concentration. Samples were analyzed periodically over a 3-month period by (1) the Bureau's Salt Lake City Research Center using electrothermal atomic absorption (AA), (2) the Bureau's Twin Cities Research Center using a modified hydride generation AA procedure, (3) the U.S. Geological Survey in Denver, CO, using hydride generation AA, and (4) the University of Missouri using neutron activation analysis (NAA). Since neutron activation is regarded as the most accurate method, it was used as a standard of comparison for all results. Results from the electrothermal AA method agreed within

6 pct of the NAA results, whereas the results of other methods differed by as much as 48 pct. Consequently, the Salt Lake City Research Center used electrothermal AA for total selenium analysis in this research. No change in selenium concentration was observed over the 3-month period, therefore, aging was determined not to be a problem. A further question arose concerning selenium adhesion to storage containers and the effect of sunlight. This hypothesis was tested by storing one-half of a sample containing 3,800 ppb Se in glass containers and the other one-half in linear polyethylene containers. After 2.5 months of storage under an ultra-violet lamp, no change in the selenium concentration in either sample could be detected. Results indicated that samples are not affected by sunlight nor by container material during storage.

Rapid, convenient, and accurate selenium assays were obtained from bacteriological studies by radioactive tracer analysis. Low levels of a radioactive isotope of selenate (Se_{75}) were mixed into the Kesterson water. The amount of selenium removed from the water was determined by filtering and counting the difference in radioactivity between fixed volumes of feed and treated solutions. These results were later confirmed using electrothermal AA analyses.

LABORATORY EXPERIMENTATION

Batch Testing

Shake Flasks.--Initial research on selenium removal from Kesterson water was conducted in batch shake-flask tests. Kesterson water, selenate tracer, and nutrients were mixed in a flask and sterilized. The nutrient solution contained 5 g/L peptone, 2.5 g/L glycerol, and 0.5 g/L yeast extract (PGY). Flasks were inoculated in duplicate with six different bacteria cultures. After 20 days, they were filtered and analyzed radiometrically to determine the amount of selenium precipitated. The two most active cultures, Se-34 and Se-180, were used in further research; each of these cultures precipitated 80 pct of the selenium from the water.

Static-Bed Columns.--Two packed-bed columns were assembled and operated in a recirculating, downflow mode (fig. 1). The columns had internal diameters of 1.7 cm and the beds were 28.5 cm deep. Each contained 120 g minus 10-mesh alundum boiling stone (fused alumina - Al_2O_3) in a 65-cm^3 bed with 27 cm^3 void volume. A PGY nutrient solution was recirculated at 8.5 mL/min by a peristaltic pump through the column from a 200-mL reservoir. The solution was maintained at a level above that of the packed bed. One column was inoculated with culture Se-34 and the other column with culture Se-180. After 14 days, the solution was replaced by Kesterson water containing 280 ppb Se, selenate tracer, and PGY nutrients. After 3 days, culture Se-34 removed 86 pct of the selenium (39 ppb residual selenium), and culture Se-180 removed 88 pct (34 ppb residual selenium); no further selenium was removed after 7 days. In each case, the viable cell count doubled from about 7 X 10^7 initially to 1.4 X 10^8 cells per milliliter after 7 days. Bacterial content was determined by a direct microscopic count of live cells with a Helber counting chamber (Simmons, 1944). Similar results were obtained in this manner with Kesterson water containing 3,800 ppb Se. The Se-180 bacteria removed 84 pct of the selenium (608 ppb residual selenium) in 40 h. A sterile control column under identical conditions removed about 5 pct of the selenium. Bacteriological treatment of the Kesterson waters in the recirculating system approached roughly 85 pct Se removal independent of the initial selenium concentration. As opposed to a purely biosorption process, where a greater extraction should be obtained with less concentrated solutions, the independence of extraction on initial selenium concentration suggests that the mechanism of selenium removal involves a chemical reaction process.

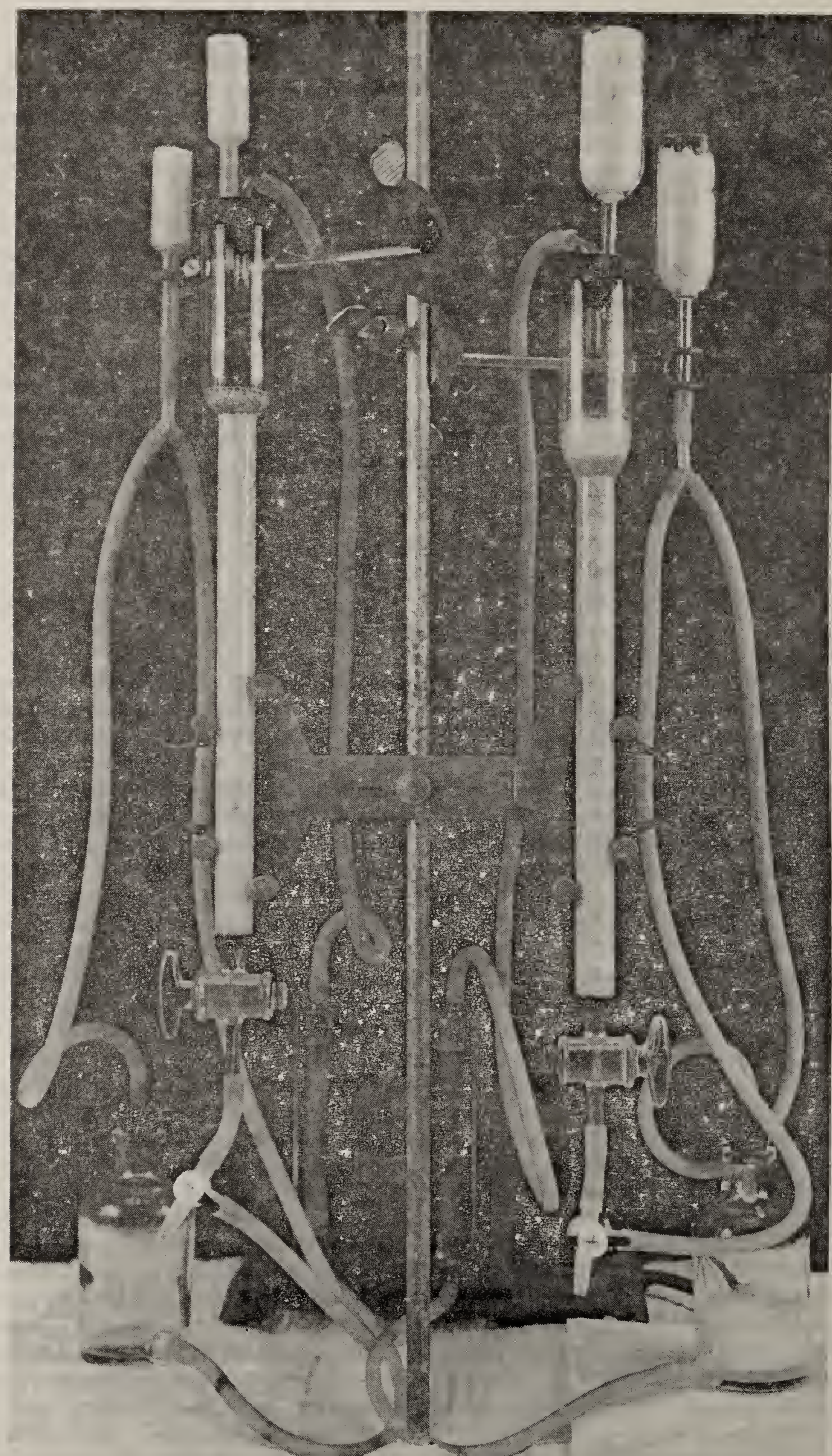

FIGURE 1. - Static bed columns

The mechanism of selenium removal was elucidated in the same test apparatus using Se-34 and Se-180 bacteria, individually in Kesterson water containing 525 ppb Se as Se(VI). In addition to total selenium, the concentration of Se(IV) was determined as a function of time. The Se(IV) was extracted into toluene, then analyzed by gas chromatography. The formation of Se(IV) was detected 18 h following inoculation. The concentration continued to increase and then peaked at 300 ppb after 40 h using culture Se-34 and at 170 ppb after 110 h using culture Se-180. In each case, about 85 pct of the selenium was removed (79 ppb residual selenium) in 140 to 160 h; the remaining selenium analyzed Se(VI). This result demonstrates that Se(IV) was formed as an intermediate reaction product in a reductive precipitation process.

CONTINUOUS TESTING

Static-Bed Columns

The retention time necessary for continuous processing of the Kesterson water in a static bacterial bed was established by operating the same column in a downflow mode with recycle. A peristaltic pump was used to recirculate the column effluent at 11 mL/min. This differs from the previously described batch tests in that untreated water was fed to the top of the column, while a fraction of the effluent was bled from the system. The column had previously been inoculated with Se-180 bacteria. The best extraction achieved when treating water containing 525 ppb Se was 89 pct (57 ppb residual selenium) with a retention time of 73 min (0.37 mL/min). Furthermore, as shown in table 1, when the feed water contained 3,800 ppb Se, a maximum selenium removal of 96 pct (150 ppb residual selenium) was achieved with a retention time of 64 min (0.42 mL/min). The retention time in the column was initially 257 min (0.105 mL/min); the extraction increased with each successive doubling of the flow rate. After approximately 175 h of operation, a red-brown selenium precipitate could be easily observed accumulating throughout the bed; it eventually blocked the flow. It was hypothesized that a greater extraction with a higher flow rate was due to (1) an increase in biological activity resulting from a system variable such as aeration or (2) an increase in populations of microorganisms resulting from longer operating periods. The retention time of the continuous flow test, significantly lower than in batch operation, can be attributed to elimination of the lag time between inoculation and exponential bacterial growth associated with biological systems. However, this was the first test apparatus that extracted greater than 85 pct of the selenium from solution. This indicated that 85 pct removal was not an equilibrium phenomenon, and that a greater extraction at a reasonable retention time can be achieved by appropriate system design.

TABLE 1. - Selenium removal from Kesterson water containing 3,800 ppb Se

Operating time, h	Flow rate, mL/min	Retention time, min	Extraction, pct
0-72	0.105	257	86
72-205	0.21	128	95
205-220	0.42	64	96

Laboratory-Scale Rotating Biological Contactor

A rotating biological contactor (RBC) offers the advantages of continuous operation, aeration, a large surface area for immobilization, and sloughing of the expired bacteria. One such commercial system is the Homestake Mine water treatment plant in Lead, SD (Whitlock, 1986).

A laboratory-scale RBC was constructed with four disks, each 165 mm in diameter, fabricated from polystyrene foam (fig. 2). The tank was acrylic plastic and held a total volume of 541 mL with disks in place. The disks, mounted on a horizontal rotating shaft, were half submerged in media within the tank. Each disk was separated by a baffle, thus, in continuous operation, media passed through each disk compartment in a staged flow pattern. At startup, the tank was filled with simulated Kesterson water containing 620 ppb Se and PGY nutrients. Fourteen days after inoculation with Se-180 bacteria, the disks were coated with a thin bacterial film, and the viable cell count in the media was 1.7 x 10^9 cells per milliliter. Continuous flow was then initiated with the same simulated waste water, nutrients, and Se(VI) tracer.

The RBC was operated continuously for 78 days. During that time, results from varying the following operating parameters were observed, and trends were established. Varied parameters include (1) retention time (feed rate), (2) effluent recycle, (3) disk rotation rate, (4) nutrient addition, and (5) air intake. Selenium volatilization was also investigated.

The initial retention time in the RBC was 30 h, corresponding to a flow rate of 0.3 mL/min. Within 1 week, the contactor attained steady-state operation, and the selenium extraction leveled off at 85 pct (93 ppb residual selenium). Next, by increasing the feed rate, the retention time was reduced to 15 h (0.6 mL/min), 7.5 h (1.2 mL/min), and 3.0 h (3.0 mL/min), consecutively. Sufficient time was allowed for the system to attain equilibrium following each step change. The extraction of selenium decreased with the retention time from 85 pct at 30 h to 44 pct at 3 h.

Variations of the physical parameters affecting the operation of the RBC were investigated in an effort to increase reactor performance. The flow of media through the RBC was altered by installing a recycle loop to feed the effluent back into the inlet port. A peristaltic pump circulated the solution at a recycle-to-new feed ratio of 36. The extraction, 85 pct before recycle was installed, dropped to 55 pct. The recycle was consequently removed. The rotational speed of the disks was varied from 3 to 27 rpm. A maximum extraction of 85 pct was obtained at 11 rpm, which is equivalent to a peripheral speed of 5.7 m/min; at both extremes, 3 rpm and 27 rpm, the extraction dropped to 55 and 65 pct, respectively.

The bacteria are aerobic heterotrophs; that is, they obtain their energy only from organic compounds. However, excessive aeration impedes the selenium reduction. Therefore, the oxygen and nutrient supplies were investigated in the RBC system. An enclosure covering the exposed portion of the disks was constructed with six 19-mm holes for gas exchange. When the air supply was reduced by placing rubber stoppers in all holes, the selenium extraction increased by 5 pct. It was deduced that better performance could be obtained by submersing the disks to a greater depth; however, this hypothesis was not tested. The PGY nutrient addition was reduced by one-half with no effect on the extraction.

The hypothesis that certain organisms can volatilize selenium directly into a gaseous state, possibly methyl selenate, was investigated. A gas scrubber was installed on the RBC to determine if selenium was being volatilized. Three separate tests confirmed that approximately 15 pct of the available selenium ends up in the gas phase. The scrubber was made from a graduated cylinder filled with 100 mL of solution containing 20 mL of 30 pct hydrogen peroxide (H_2O_2), 5 mL 1N NaOH, and 70 mL of water. A glass frit was immersed in the scrub solution, and a tube led from the glass frit to the top of the RBC. All holes in the RBC lid were sealed except for one small opening for air to enter and another on the opposite side where the scrubber was connected. Air was drawn through the RBC enclosure and into the solution through the frit. The process and scrub solutions were analyzed by radiotracer and electrothermal AA. During

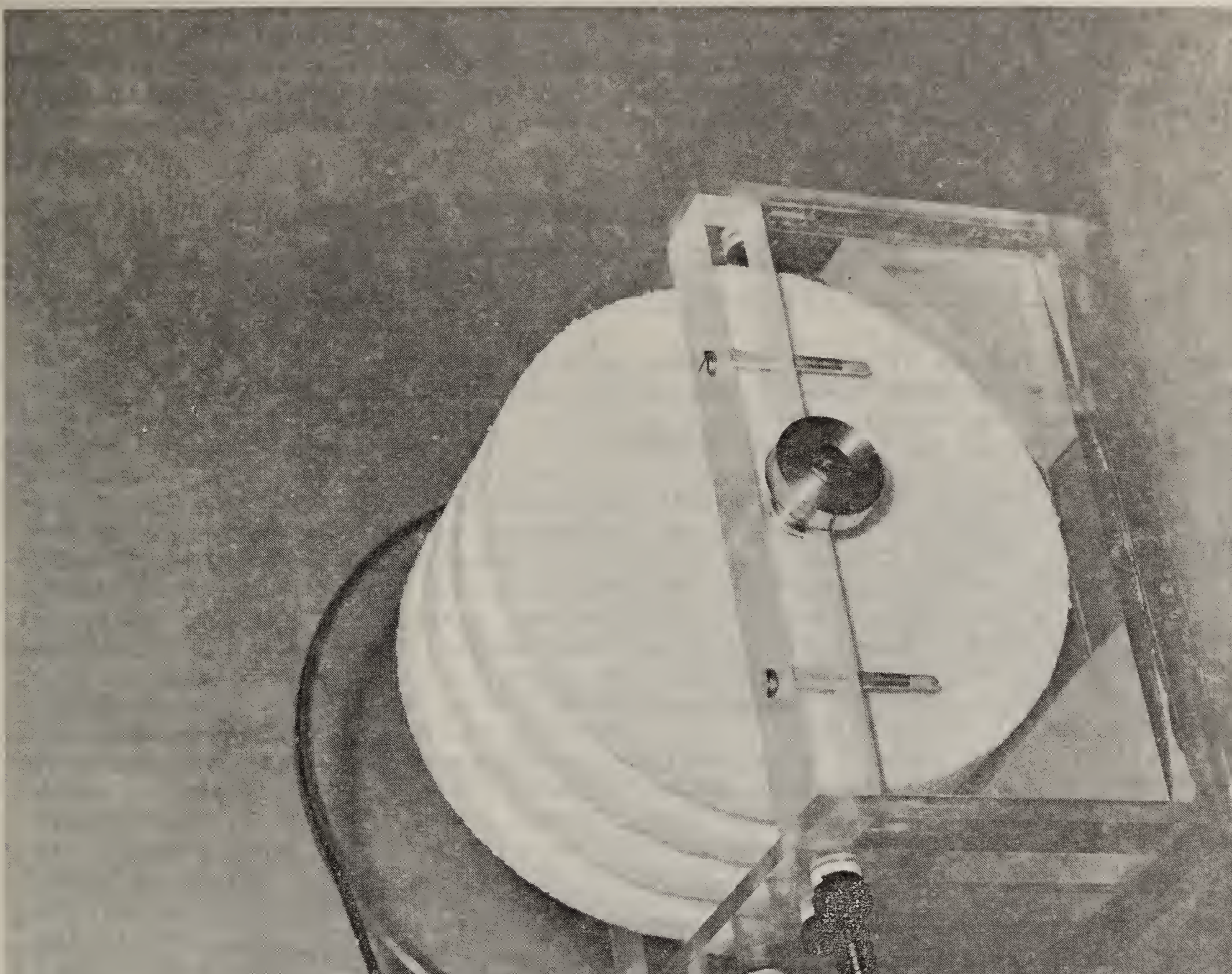

FIGURE 2. - Rotating biological contactor

this time period, the RBC was operating at steady state with approximately 65 pct extraction. The data presented in table 2 demonstrate overall that approximately 15 pct of the available selenium enters the gas phase in the RBC system.

TABLE 2. Selenium volatilization

Scrub time, h	Se extraction, pct radioassay	Se as gas, pct	
		AA	radioassay
4	64	13	NA
4	61	15	18
6	64	11	18

SUMMARY

The bacteria used in this experimentation respond positively to tests indicating the presence of *Pseudomonas*, *Salmonella*, and *Citrobacter*. Growth in these cultures was predominant under aerobic conditions; however, the reduction and precipitation of Se(VI) was enhanced when the air supply was restricted. It appears that in an excess of air, the bacteria reduce oxygen in preference to the Se(VI) ion. Selenium reductions approaching 100 pct should be possible under optimal conditions with a reactor of appropriate design. The desired characteristics of such a reactor are (1) high internal surface area for maximum retention of bacteria in the system, (2) a provision for renewal of the biomass, i.e., sloughing and removal of the dead biomass, and (3) the ability to control oxygen availability in the system. The cultures used consisted of a consortium of bacteria acting to remove selenium from the aqueous phase by the mechanisms of reductive precipitation, volatilization, and possibly biosorptive processes. The selenium product is precipitated as a red amorphous mass. Research is continuing at the Salt Lake City Research Center to improve reactor design, implement optimal growth conditions, and elucidate the complex mechanisms involved in the selenium extraction process. It is envisioned that this research will lead to the development of a cost-effective process that will help alleviate the wide-spread selenium contamination being encountered in mineral processing and other industries throughout the Nation.

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THE REACTION OF CALCITE WITH DILUTE FLUORIDE SOLUTIONS

Z. Yang[1] and R. W. Smith[2]

ABSTRACT: Fluorides are sometimes used as modifying agents in mineral flotation concentrators. Thus, there is potential for substantial aqueous waste discharge of fluorides from the plants, albeit in dilute form. This paper investigates the interaction of calcite, a common carbonate rock mineral, with dilute HF and NaF solutions. When dilute HF solutions were reacted with calcite at different temperatures and the reaction studied as a function of time, under unstirred conditions, it was determined that the reaction followed an apparent second order rate law. From Arrhenius and Eyring plots of the data it was found that the activation energies and enthalpies were intermediate in magnitude between solution diffusion control and solution reaction control of the reaction. When dilute NaF solutions were interacted with calcite the reaction was much slower and appeared to be independent of temperature and obey an apparent first order rate law. There was indication that an insoluble layer was forming on the calcite. From the kinetic data an attempt is made to elucidate the mechanisms of the dilute fluoride solutions - calcite interactions.
KEY TERMS: Fluoride wastes; calcite; reaction kinetics

INTRODUCTION

Fluorides and fluorosilicates have been widely used as modifying agents in various mineral flotation plants (Sutherland and Wark, 1955; Pryor, 1965; Dean and Ambrose, 1944; Smith, 1965; Warren and Kitchener, 1972; Smith and Steiner, 1980). The use of such fluorine containing compounds greatly enhances the selectivity of many of these operations. In such plants the quantity used is usually of the order of 0.4 to 4 kg/tonne of ore processed. There is, therefore, potential for substantial waste discharge of fluorides or other fluorine containing compounds. Although this use of fluorine compounds is obviously desirable from a technical processing point of view, their use is not an unmixed blessing since fluorides and fluorosilicates are known to be extremely toxic substances. Also it should be noted that fluorides somtimes occur in mineral processing or hydrometallurgy effluent streams due to dissolution of fluoride from some mineral constituent present such as in the processing of fluorite.

When fluoride containing effluent streams are placed in settling or tailings ponds the solutions can flow into surface streams, go into the ground water or the water can evaporate leaving the fluorine containing salts as solids (or any combination of these items). In the case of evaporation only the fluorine containing solids remain in place unless dispersed by wind action or resolubilized by rain or snow water. Otherwise the salts will travel wherever the water is naturally transported as long as they remain in solution. Individual ions can change form based on many factors such as other ions present, total ionic strength, pH, temperature, oxidizing or reducing conditions, etc. The fluorine can exist in such environments as F^-, HF_2^-, HF(aq), SiF_6^{2-}, $HSiF_6^-$, as any number of complex metal fluorides, or as organic-fluoride complexes (Smith, 1965; Hem, 1968, 1970). The F^-, HF_2^-, and HF species have the potential for reacting with minerals

1 Research Fellow, Department of Chemical & Metallurgical Engineering, University of Nevada-Reno, Reno, NV 89557.

2 Professor, Department of Chemical & Metallurgical Engineering, University of Nevada-Reno, Reno, NV 89557.

or metal ions to form various complex fluorides, some soluble and some insoluble. Also the uncomplexed and complexed species have the potential for adsorbing onto any number of surfaces such as many naturally occurring mineral surfaces. The mechanisms of interactions of fluoride with most minerals is still uncertain.

The primary objective of this study is to investigate the kinetics and mechanisms of interaction of dilute fluoride streams with the naturally occurring mineral calcite.

MATERIALS AND METHODS

The calcite used in the present study was obtained from Ward's Natural Science Establishment, Inc., Rochester, New York. An X-ray diffraction study of the calcite indicated that it was nearly pure calcite. A chemical analysis of the material is listed in Table 1.

Table 1. Composition of the Calcite Studied (%)

CaO	$\geq$ 52
MgO	$\leq$ 3.5
SiO_2	< 1.7
P_2O_5	$\leq$ 0.02
SO_4	$\leq$ 0.25
Other impurities	< 2.15

The reagent grade HF used was purchased from Fisher Scientific Co., Chemical Manufacturing Division and the reagent grade NaF was purchased from J.T. Baker Chemical Company.

The calcite was prepared for experimentation by crushing and grinding to minus 600 μm (28 mesh) and separated into various size fractions. Table 2 lists the size fraction plus the specific surface areas of the fractions as determined by the BET method using a Quantisorb surface area analyzer.

Table 2. Surface Areas of Calcite Size Fractions

Particle Size (microns)	Particle Size (mesh)	Specific Surface Area m^2/g
-600, +425	-28, +35	0.058
-425, +300	-35, +48	0.082
-300, +212	-48, +65	0.115
-212, +150	-65, +100	0.159
-150, +106	-100, +150	0.255
-106	-150	0.352

In the experimentation fluoride ion concentration (activity) was measured by use of a specific fluoride ion electrode and an ALTEX Select Ion 5000 Ion Analyzer. This ion analyzer was also used for pH measurement. All containers, pipets, beakers, graduated cylinders, volumetric flasks, etc. used were made of teflon.

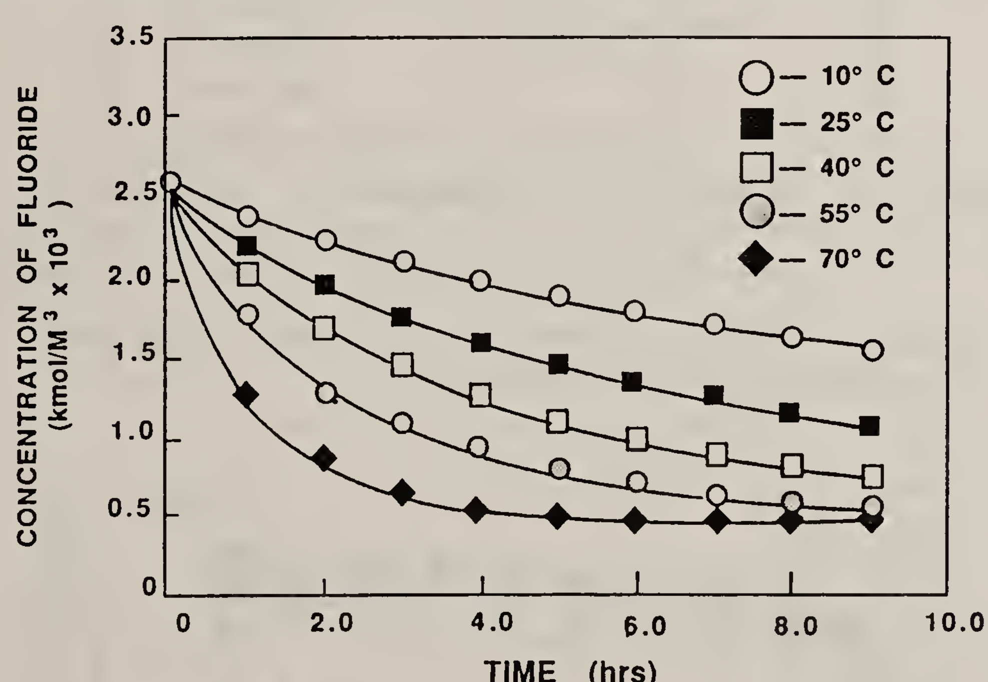
Fluoride solutions used in the experimentation contained initially 2.65×10^{-3} $kmol/m^3$ of either HF or NaF.

The interactions between the dilute fluoride solutions and calcite were determined by placing 1.0 g samples of calcite in 20 ml of fluoride solutions contained in teflon reaction vessels (either HF or NaF solutions). Temperatures were varied by placing the vessels in and equilibrating with a constant temperature water bath. The fluoride ion concentrations were then determined as a function of time after introduction of the calcite. The pH was also monitored and when necessary the concentrations of HF calculated using our measured value of the pk_a of HF (2.97) (Yang and Smith, 1987). Total "fluoride" present was, thus, the concentration of HF(aq) + the concentration of F^-. Although the experimentation reported on here is for unstirred interactions so as to simulate more closely natural solution-mineral interactions, additional experiments were also performed with stirred calcite-fluoride solution suspensions. In the stirred experiments the reactions in all cases were more rapid.

EXPERIMENTAL

Figure 1 shows the concentration of fluoride in solution as a function of time and temperature after having added a 1 g sample of -212, +150 μm calcite to 20 ml of 2.65×10^{-3} $kmol/m^3$ HF solution. Note that temperature greatly accelerates the reaction and that in 9 hours 80% of the fluoride is removed from solution at 70°C. Figure 2 shows

Figure 1. Concentration of Fluoride in Solution as a Function of Time and Temperature; 1g of -212, +150μm (-65, +100 mesh) Calcite in 2.65×10^{-3} $kmol/m^3$ HF solution.



a plot of the reciprocal of the fluoride concentration as a function of time and temperature. The straight line plots for each constant temperature indicate that the reactions involving dilute HF solutions obey an apparent second order rate law (see King, 1964; Frost and Pearson, 1961). Figure 3 indicates the change in pH of the HF solutions as a function of time after having added -212,+150 μm calcite to them. Note the initial rapid rise in pH followed by a slower decreasing rise in ph. figure 4 shows the effect of particle size on the rate of interaction HF solution-calcite. in general the rate was little affected by change in particle size except for the case of the fine -106 μm fraction.

Figure 5 shows similar data to that of figure 1 except that a 2.65×10^{-3} $kmol/m^3$ NaF solution was substituted for the HF solution. It is immediately evident that the reaction between calcite and dilute NaF solution is much slower than between the mineral and HF solution and is sensibly independent of temperature. An attempt to plot the data of this figure in the manner of figure 2 (reciprocal concentration versus time) failed to yield a straight line. However, when the $\log_{10}$ of fluoride concentration was plotted as a function of time the straight line curve of figure 6 after 30 minutes reaction time was

Figure 2. Second Order Rate Plot (reciprocal of Fluoride Concentration versus Time) for the Data of Figure 1.

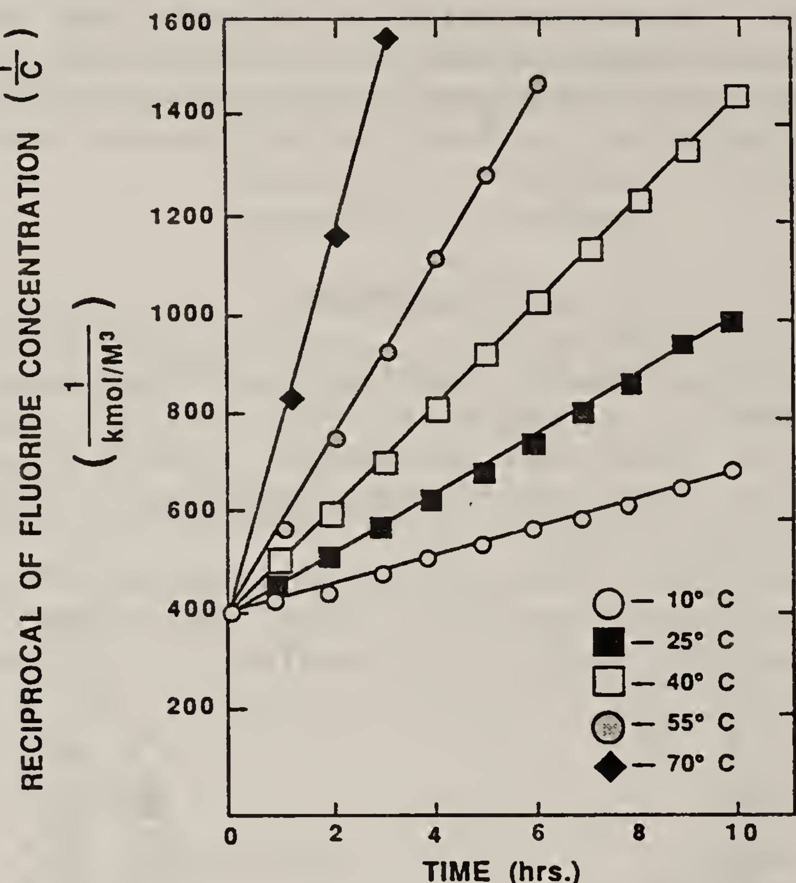


Figure 3. Change in pH as a Function of Time During the Experimentation of Figure 1.

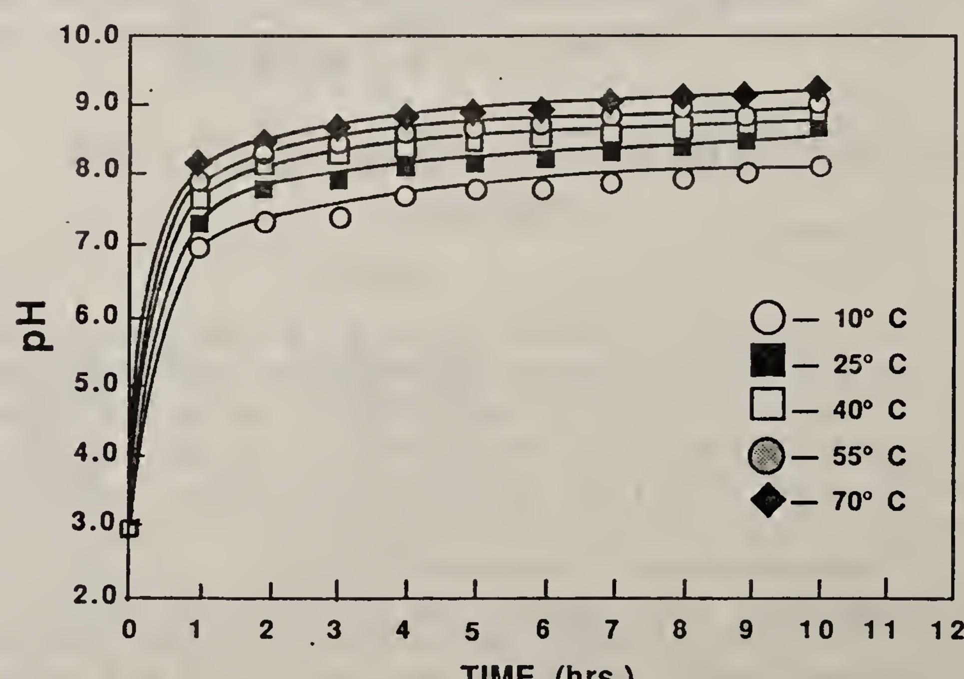


Figure 4. Effect of Particle Size on the Reaction Rate Calcite-HF Solution; 25°C; 1g Calcite in 20 ml 2.65×10^{-3} $kmol/m^3$ HF Solution.

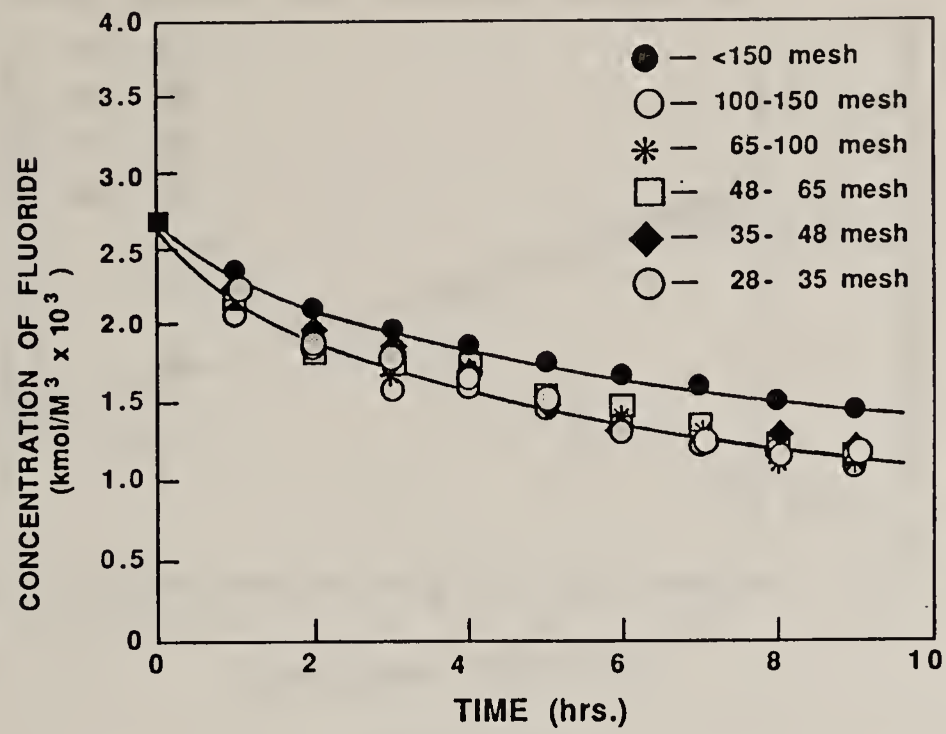


Figure 5. Concentration of Fluoride in Solution as a Function of Time and Temperature; 1 g of -212, +150 μm (-65, 100 mesh) Calcite in 2.65×10^{-3} NaF Solution.

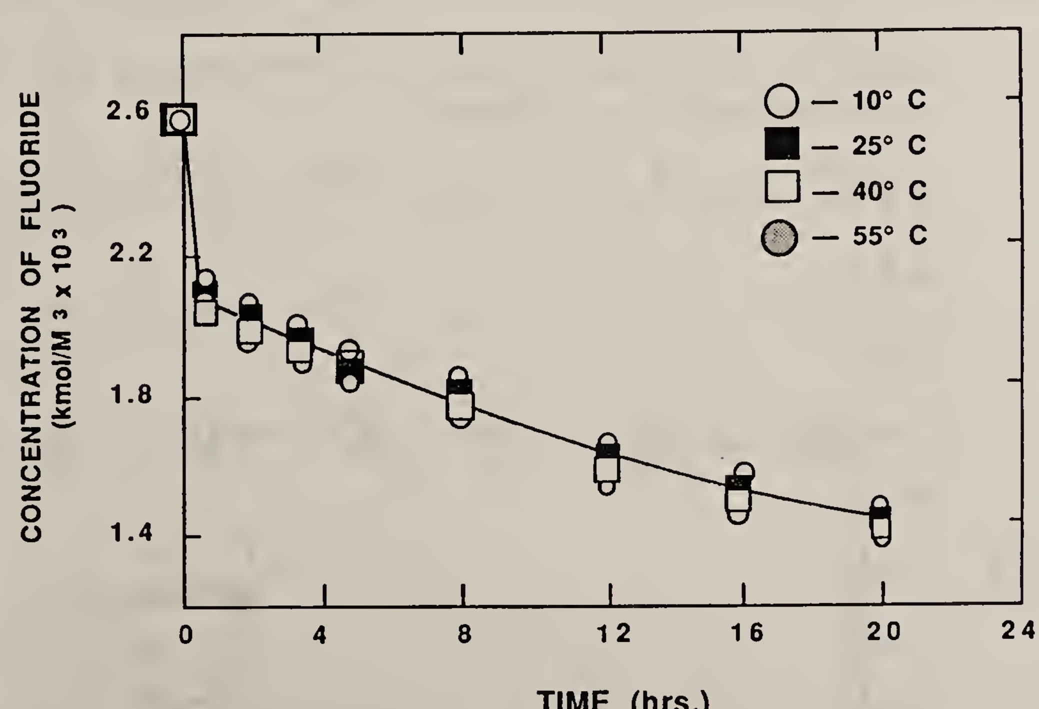
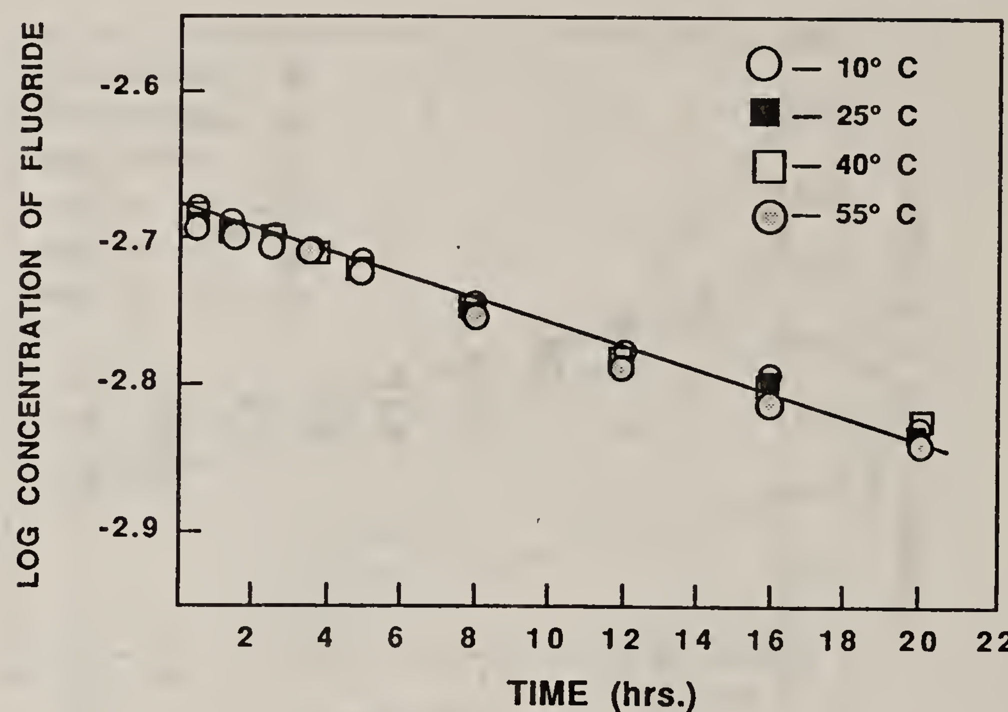


Figure 6. First Order Rate Plot (Log Concentration Fluoride Versus Time) for the Data of Figure 5.



generated. The straight line curve indicates that the calcite-dilute NaF solution reaction obeyed an apparent first order rate law (see King, 1964; Frost and Pearson, 1961) after the initial 30 minutes.

Figure 7 illustrates the change in pH as a function of time after having added calcite to dilute NaF solutions. The initial rapid increase in pH was followed by a constant pH of the solutions with further elapsed time. Figure 8 shows the negligible effect of particle size on the rate of dilute fluoride solution interaction with calcite.

Figure 7. Change in pH as a Function of Time During the Experimentation of Figure 5.

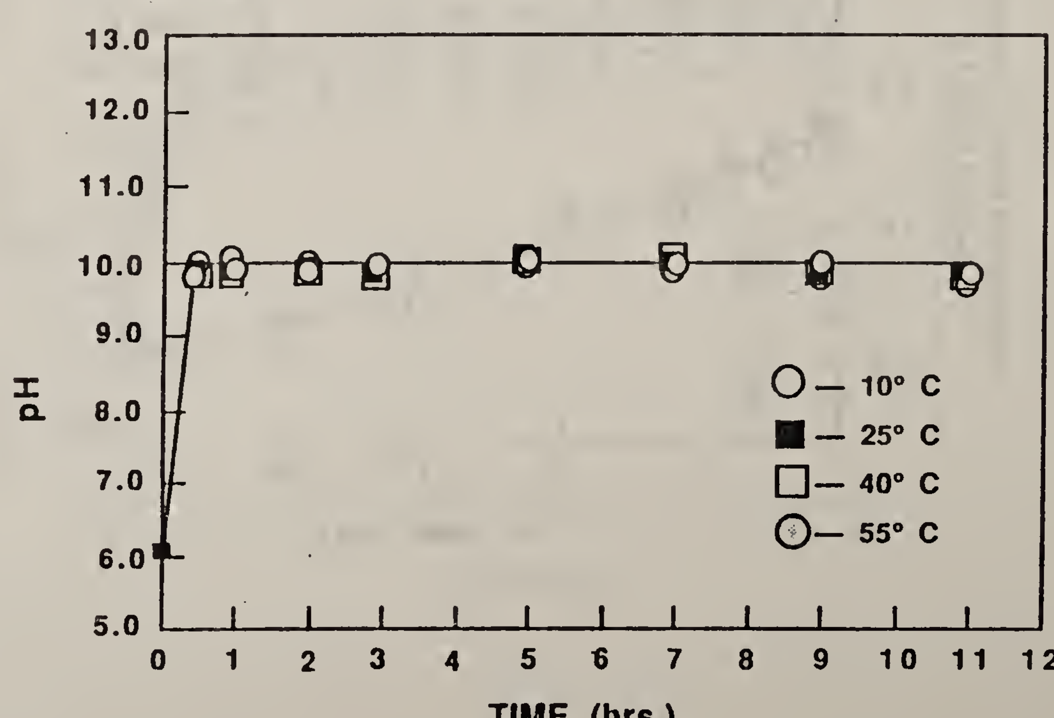
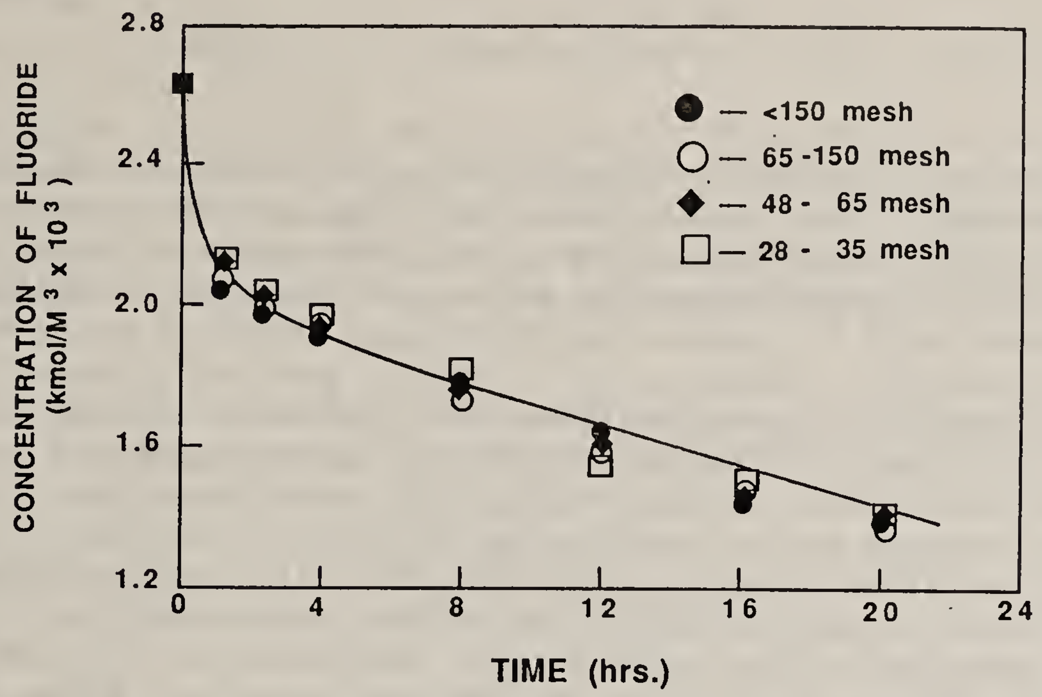


Figure 8. Effect of Particle Size on the Reaction Rate Calcite-NaF Solution; 25°C; 1 g Calcite in 20 ml 2.65×10^{-3} $kmol/m^3$ NaF Solution.



DISCUSSION

When calcite is placed in water in the absence of fluoride the following reactions take place (Somasundaran and Agar, 1967; Hanna and Somasundaran, 1976):

$$CaCO_3(s) \rightleftharpoons CaCO_3(aq) \quad , \quad K_1 = 10^{-5.09} \tag{1}$$

$$CaCO_3(aq) \rightleftharpoons Ca^{++} + CO_3^{--} \quad , \quad K_2 = 10^{-3.25} \tag{2}$$

$$CO_3^{--} + H_2O \rightleftharpoons HCO_3^{-} + OH^{-} \quad , \quad K_3 = 10^{-3.67} \tag{3}$$

$$HCO_3^{-} + H_2O \rightleftharpoons H_2CO_3 + OH^{-} \quad , \quad K_4 = 10^{-7.65} \tag{4}$$

$$H_2CO_3 \rightleftharpoons CO_2(g) + H_2O \quad , \quad K_5 = 10^{1.47} \tag{5}$$

$$Ca^{++} + HCO_3^{-} \rightleftharpoons CaHCO_3^{+} \quad , \quad K_6 = 10^{0.82} \tag{6}$$

$$CaHCO_3^{+} \rightleftharpoons H^{+} + CaCO_3(aq) \quad , \quad K_7 = 10^{-7.90} \tag{7}$$

$$Ca^{++} + OH^{-} \rightleftharpoons CaOH^{+} \quad , \quad K_8 = 10^{1.40} \tag{8}$$

$$CaOH^+ + OH^- \rightleftharpoons CaOH_2(aq) \quad , \quad K_9 = 10^{1.37} \qquad (9)$$

$$Ca(OH)_2(aq) \rightleftharpoons Ca(OH)_2(s) \quad , \quad K_{10} = 10^{2.45} \qquad (10)$$

Thus, depending on pH the various calcium and carbonate species can assume greater or lesser importance. When fluorides are also present the various fluoride species can either react directly with the calcite or they can react with the various calcium species present in solution. Considering the above equilibria it is unlikely that calcium hydroxide species could be present in significant quantity under the conditions of the present experimentation. However, Ca^{2+}, $CaHCO_3^+$ and $CaCO_3(aq)$ will be present.

In the present experimentation since the reactions involve calcite, a solid, and an aqueous phase containing a fluoride (HF or NaF) a heterogeneous reaction is involved. In a heterogeneous reaction a certain sequence of events must take place: 1) transport of reactant(s) in solution to the reactive solid-liquid interface (this will involve diffusion through the liquid layer surrounding the solid and, sometimes, diffusion through an unreactive solid layer), 2) adsorption of the reactant(s) at the solid-liquid interface, 3) reaction at the interface, 4) desorption of reaction products, 5) diffusion transport of the products away from the reactive interface (this will involve, sometimes, diffusion through an unreactive solid layer and, certainly, diffusion through the surface liquid layer into the bulk of the liquid and 6) finally, sometimes, reaction of the products with components of the solution. Any one of these steps or substeps can control the actual rate of the reaction or in some cases several of the steps can be partly rate determining.

It is apparent from figures 1 and 2 for the reaction of calcite with dilute HF solutions and from figures 5 and 6 for the reaction of calcite with dilute NaF solutions, that the reaction rates for the two systems are controlled by different mechanisms. In either case it is likely that the end product of the reaction will be CaF_2 as indicated by the following reaction and its solsubility product (Butler, 1964):

$$CaF_2 \rightleftharpoons Ca^{2+} + 2F^- \quad , \quad k_{SO} = 10^{-10.4}, \; 25°C \qquad (11)$$

For the case of the dilute HF system figure 2 indicates that some apparent second order rate phenomenon controls the reaction rate. Figure 3 shows that there is an initial rapid consumption of protons (H^+) in the system indicating there is a rapid reaction between this ion and calcite and/or rapid dissolution of $CaCO_3$ followed by reaction of Ca^{2+} produced with water yielding OH^- (see chemical equations 1-4). One consequence of the pH rise is the thereby altering of the form of fluoride in solution considering the following relation (Perrin, 1982; Yang and Smith, 1987):

$$HF \rightleftharpoons H^+ + F^-, \; k_a = 10^{-2.96} \text{ to } 10^{-3.23}, \; 25°C \qquad (12)$$

Thus, at the initial pH of the experiments near pH 3 the fluoride should be present about equally in HF and F^- form, but that in less than one hour's time the remaining uncomplexed or unreacted fluoride should be almost entirely in F^- form.

Several items fall directly from the data of figures 1 and 2. Firstly, the slopes of the straight line curves of figure 2 should be second order rate constants for the reactions (King, 1964; Frost and Pearson, 1961). Further, it should be also possible to obtain from the data both activation energy and activation enthalpy for the reaction. Table 3 lists the calculated second order rate constants plus additional manipulated data necessary for the computation of the activation energy and enthalpy.

The Arrhenius equation (Frost and Pearson, 1961; King, 1964; Wadsworth, 1972, 1979) is simply stated as follows:

$$k = Ae^{-\Delta E_a/RT}$$

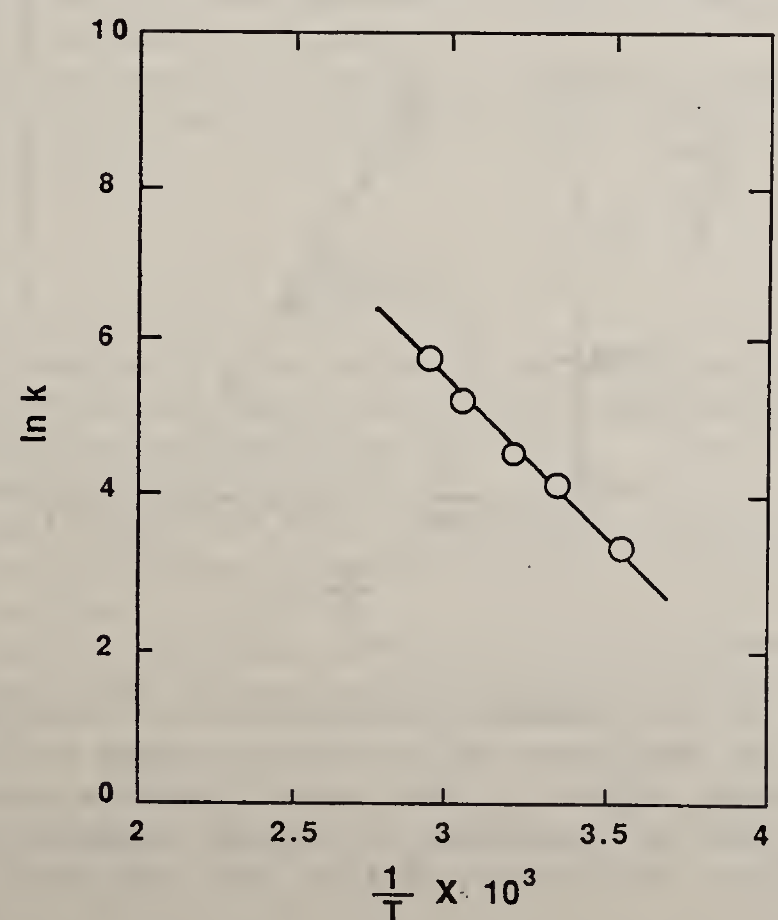
where k = equilibrium rate constant, A = frequency factor, ΔE_a = activation energy, R = gas constant, T = absolute temperature.

This equation suggests that if the natural logarithm of the rate constant for a reaction is plotted against the reciprocal of absolute temperature a straight line should be obtained whose slope will equal $-\Delta E_a/R$ from which the activation energy can be calculated. Figure 9 shows an Arrhenius plot constructed from the data of Table 3. Note that in this treatment of the Arrhenius equation it was assumed that both A and ΔE_a are independent of temperature.

Table 3. Second Order Rate Constants and Related Values for the Reaction of Calcite with Dilute HF Solutions.

Temperature, T (°K)	$\frac{1}{\text{Temperature}}$ ($\frac{1}{°K}$ x 10^3)	Rate Constant, k (liter mol^{-1} hr^{-1})	ln k	ln($\frac{k}{T}$)
283	3.53	30.3	3.41	-2.23
298	3.36	60.8	4.11	-1.59
313	3.20	106	4.66	-1.09
328	3.05	180	5.19	-0.60
343	2.92	388	5.96	0.12

Figure 9. Arrhenius Plot of the Data of Figure 2 (ln Rate Constant, k, Versus Reciprocal Temperature).



A related type of plot derived from absolute reaction rate theory also can be constructed, the Eyring plot (figure 10). In absolute reaction rate theory the temperature dependence is somewhat different from that expressed by the Arrhenius equation since in the former case the frequency factor also contains temperature (Wadsworth, 1972, 1979). The absolute reaction rate relation similar to the Arrhenius equation is:

$$\frac{k}{T} = \frac{\kappa}{h} \exp\left(-\frac{H^{\ddagger}}{RT}\right) \exp\left(\frac{S^{\ddagger}}{R}\right)$$

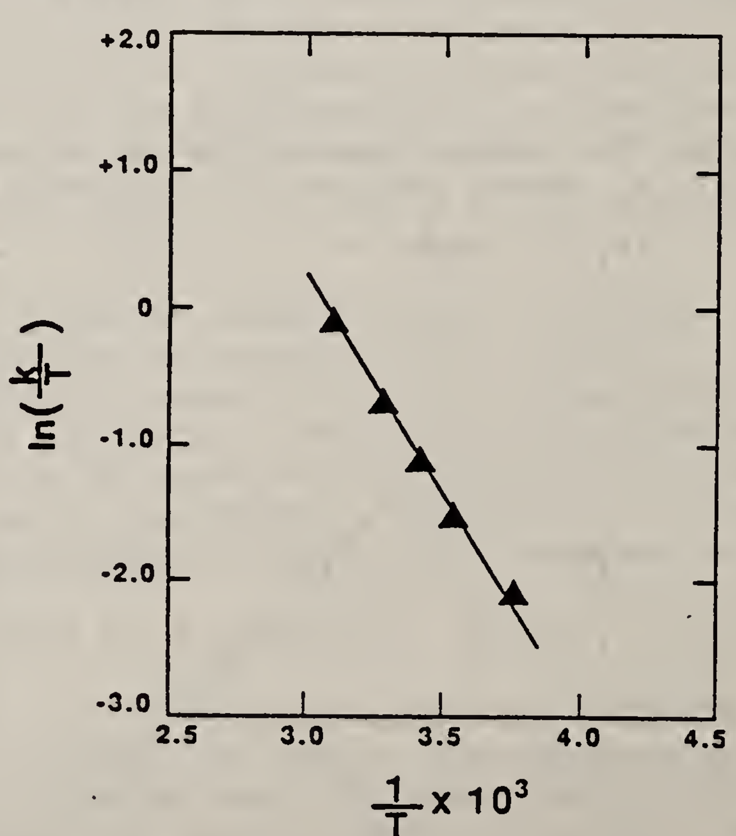
where k = equilibrium specific rate constant, T = absolute temperature, κ = Boltzmann constant, h = Planck constant, R = gas constant, $H^{\ddagger}$ = Eyring activation enthalpy, $S^{\ddagger}$ = activation entropy.

Thus, the slope of a plot of $\ln \frac{k}{T}$ versus reciprocal of temperature is proportional to $H^{\ddagger}$, the Eyring activtion enthalpy, which is then readily calculated. For the present experimentation with dilute HF solution the calculated values are:

Arrhenius activation energy = 7729 cal mol^{-1}
Eyring activation enthalpy = 7145 cal mol^{-1}

These values are intermediate in value between usual values for diffusion control and chemical control of a reaction (Burkin, 1966).

Figure 10. Eyring Plot of the Data of Figure 2 ($\ln \frac{\text{Rate Constant}}{\text{Temperature}}$, $\ln \frac{k}{T}$ versus Reciprocal Temperature).



Considering the data of the present investigation it is proposed that the reaction between the dilute fluoride solutions and calcite proceeds as follows:

Initially protons rapidly travel to the calcite surface where they quickly adsorb and react with the calcite. The Ca^{2+} produced is rapidly released to the solution and reacts with either F^- or HF present in solution to form the rleatively insoluble CaF_2. Thus:

$$CaCO_3(s) + H^+ \rightleftharpoons Ca^{2+} + HCO_3^- \quad (13)$$

$$Ca^{2+} + 2F^- \rightleftharpoons CaF_2(aq) \text{ (slow)} \quad (14a)$$

or $$Ca^{2+} + 2HF \rightleftharpoons CaF_2(aq) + 2H^+ \text{ (slow)} \quad (14b)$$

$$CaF_2(aq) \rightleftharpoons CaF_2(s) \quad (15)$$

Since the reaction follows an apparent second order rate law, the homogeneous reactions between Ca^{2+} and HF or F^- must be the primary rate determining steps.

There is potential of course for the following reactions:

$$CaCO_3 + 2F^- \rightleftharpoons CaF_2 + CO_3^{2-} \quad (16a)$$

and $$CaCO_3 + 2HF^- \rightleftharpoons CaF_2 + HCO_3^- + H^+ \quad (16b)$$

However, in this case the CaF_2 has potential for forming an insoluble surface layer on the calcite surface. Evidence from the work with NaF solutions indicates that such a layer should decrease the reaction rate and change the rate controlling step. It is possible, however, that the decreased rate for the -106 μm calcite -HF solution experiments (see figure 4) may be due to an increase in importance of reactions 16a and 16b because of the greater surface area available for reaction with fluoride.

Considering the data for interaction between calcite and dilute NaF solutions, recall from figures 5 and 6 that the rates of reaction are much slower and rather independent of temperature. Also figure 6 indicates that the reaction controlling mechanism is different from that of the HF solutions. A probable shift to some manner of diffusion control is suggested. In this system some dissolution of calcite no doubt occurs through reactions 1-4. The rapid rise in pH of the system from near pH 6 to pH 10 within 30 minutes or less probably reflects such reactions (see figure 7). However, after 30 minutes no further pH change was observed. Thus, after 30 minutes or less reaction time the probable reaction of importance would be 16a. To be sure the CO_3^{2-} formed would react with H^+ and thus pH should further rise; however at pH 10, considering the amount of CO_3^{2-} produced, the actual pH change should be small.

It is suggested, then, that control (after 30 minutes reaction time) of the NaF solution-calcite reaction has shifted to diffusion control through a nearly insoluble CaF_2 layer formed on the calcite.

SUMMARY

Data obtained suggest that if the solution pH is sufficiently low (∿ pH3) the rate of the reaction is controlled by a homogeneous second order reaction in solution between Ca^{2+} and either F^- or HF to form sparingly soluble CaF_2. This effectively removes most of the fluoride in the form of a precipitate.

At a higher initial pH value (∿ pH 6) the reaction rate is much slower, first order and apparently controlled by diffusion, probably through a sparingly soluble CaF_2 layer that forms on the calcite surface.

Thus, how effective calcite (present either naturally or added to a discharge area) is in removing fluoride from a dilute aqueous effluent stream will depend on pH of the stream.

AKNOWLEDGEMENT

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WATER RESOURCES RELATED TO MINING AND ENERGY – PREPARING FOR THE FUTURE
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MONTE CARLO SIMULATIONS OF UNSATURATED FLOW THROUGH LAYERED VOLCANIC TUFFS AT YUCCA MOUNTAIN, NEVADA

S.A. Loomis and J.W. Warner[1]

ABSTRACT: A two-dimensional unsaturated flow model was developed and applied to the problem of liquid water flow in the vicinity of the potential nuclear waste repository within the central block under Yucca Mountain, Nevada. Three of the hydrogeologic units were represented as being spatially variable with respect to saturated hydraulic conductivity. A set of Monte Carlo simulations were run utilizing realizations of conductivity values derived from probability distributions assumed to be representative of the variability in space for the units of interest. No attempt was made to preserve any spatial correlation structure between conductivity values in nearby blocks. A range of travel times from the potential repository horizon to the water table was computed using a numerical particle-tracking method. The surface infiltration rate and the orientation of an assumed interface between two of the hydrogeologic units were examined as to their influence on the travel times. Travel times computed for locations not immediately adjacent to a highly-transmissive vertical fault zone were typically greater than 10,000 years for surface infiltration rates less than 1.0 mm/yr. For infiltration rates of 2.0 mm/yr and greater some computed travel times were reduced to less than 1000 years for locations within 300 meters of the fault zone. Significant lateral flow at the interface of hydrogeologic units having contrasting material properties had a strong influence on the computed travel times.
(KEY TERMS: unsaturated flow; stochastic analysis; Monte Carlo simulations; nuclear waste disposal; travel times.)

INTRODUCTION

The U.S. Department of Energy is currently evaluating the Yucca Mountain site in southern Nevada with regard to its suitability as a mined geologic repository for storage of high-level nuclear wastes. Yucca Mountain is underlain by a thick unsaturated zone above a water table which is located about 500 to 750 m below land surface. The unsaturated zone is receiving major emphasis since it has several characteristics that make it attractive as a barrier to radionuclide migration. A very low flux of water and the possible existence of natural capillary barriers are two of the important characteristics.

[1] Respectively, Graduate Student and Associate Professor, Civil Engineering Department, Colorado State University, Ft. Collins, Colorado 80523.

An important criterion in the selection of the final repository site is the travel time to the accessible environment by radioactive wastes that may eventually be released from storage packages in the repository horizon. The subsurface flow system is the primary pathway for escape of the nuclear wastes from the repository to the outside environment. Travel times cannot be exactly known, since it is impossible to collect enough data to describe geologic conditions at the repository site with complete certainty. Additionally, future climatic conditions cannot be known in advance. Thus, travel time becomes a stochastic variable which must be described by an expected range of values.

A stochastic analysis of the subsurface flow system is required in order to assess the possible range of travel times that may be expected under various conditions. The complicated stratigraphy, flow regimes, boundary conditions, and range of possible scenarios for waste storage require numerical modeling at several levels of detail. In this study the movement of water through the unsaturated zone in the central block of Yucca Mountain was simulated in order to generate a range of possible travel times that might be expected.

The results presented in this study are not intended to be definitive in terms of incorporating all available data for each hydrogeologic unit or including all possible combinations of input variability. Rather, the simulations are indicative of one possible way of incorporating spatial variability of geologic material properties into the analysis, and examining the effects on important site selection variables such as expected travel times.

HYDROGEOLOGIC SETTING

Site Description

Yucca Mountain is located within and adjacent to the southwestern part of the Nevada Test Site, approximately 105 km northwest of Las Vegas. The mountain is underlain by layers of welded and nonwelded volcanic tuff which generally tilt eastward at 5 to 10 degrees (Scott and Bonk, 1984). The part of Yucca Mountain termed the central block is the zone being investigated for location of the nuclear waste repository. A vertical cross-section of the central block is shown in figure 1.

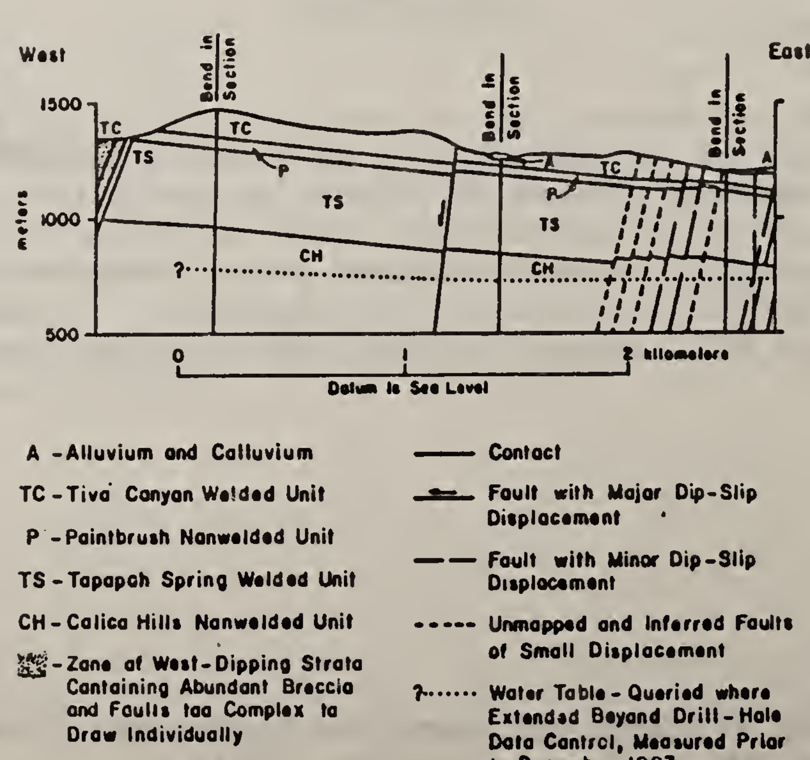

Figure 1. Vertical cross-section through the central block of Yucca Mountain (modified from Montazer and Wilson, 1984).

In the unsaturated zone three major formations have been distinguished stratigraphically. The physical properties have been found to vary widely within and between these formations. A more appropriate grouping for analysis of occurrence and movement of water is on the basis of hydrogeologic units. These groups are defined principally on the degree of welding of the tuffs comprising the units (Montazer and Wilson, 1984). The hydrogeologic units represented in this study are: Tiva Canyon welded unit, Paintbrush nonwelded unit, Topopah Spring welded unit, and the Calico Hills nonwelded unit. The generalized physical properties indicate that the welded units have much higher fracture densities, lower porosities, and lower matrix permeabilities than the nonwelded units (Montazer and Wilson, 1984).

For the purposes of this study a unit termed the Fault Zone was included to represent a major fault or fracture zone along the east edge of the central block. It was handled in the model as a highly-transmissive zone.

The Calico Hills nonwelded unit was divided into two separate units for the current study. A more highly permeable vitric facies and a less permeable devitrified facies have been identified, and are designated here as Calico Hills Vitric and Calico Hills Zeolitic.

Hydraulic Properties

The material properties for each hydrogeologic unit are given in table 1. The moisture retention and relative conductivity curves required in the numerical model are presented in figures 2 through 6. These characteristic curves and material properties are those used by Rulon, et al. (1986) in their simulations examining the relative importance of fracture versus porous matrix flow at Yucca Mountain. The relative conductivity curve representing the Tiva Canyon and Topopah Spring welded units (figure 5) incorporates the combined effects of fracture and matrix flow in these units. The saturated hydraulic conductivity value in table 1 representing these two units is also an effective value intended to account for fracture and matrix flow.

Table 1. Material properties for each hydrogeologic unit.

Hydrogeologic Unit	Porosity	Saturated Hydraulic* Conductivity (m/yr)	Anisotropy Ratio for Conductivity (horiz./vertic.)
Tiva Canyon welded unit	0.12	3.08	1
Paintbrush nonwelded unit	0.46	0.336	10
Topopah Spring welded unit	0.14	3.08	1
Calico Hills Vitric nonwelded unit	0.37	0.158	10
Calico Hills Zeolitic nonwelded unit	0.33	0.00294	1
Fault Zone	0.05	15406.0	0.02

* Effective saturated hydraulic conductivity in the vertical direction. Incorporates influence of fractures within the welded units.

In this study the Tiva Canyon, Paintbrush, and Fault Zone units were assumed to be spatially uniform with respect to porosity and saturated hydraulic conductivity. The Topopah Spring, Calico Hills Vitric, and Calico Hills Zeolitic units were assumed spatially uniform with respect to porosity, but spatially variable with respect to saturated hydraulic conductivity. The single values of conductivity in table 1 for these latter three units are presented for comparison to the mean conductivity values generated by the distribution sampling scheme described later.

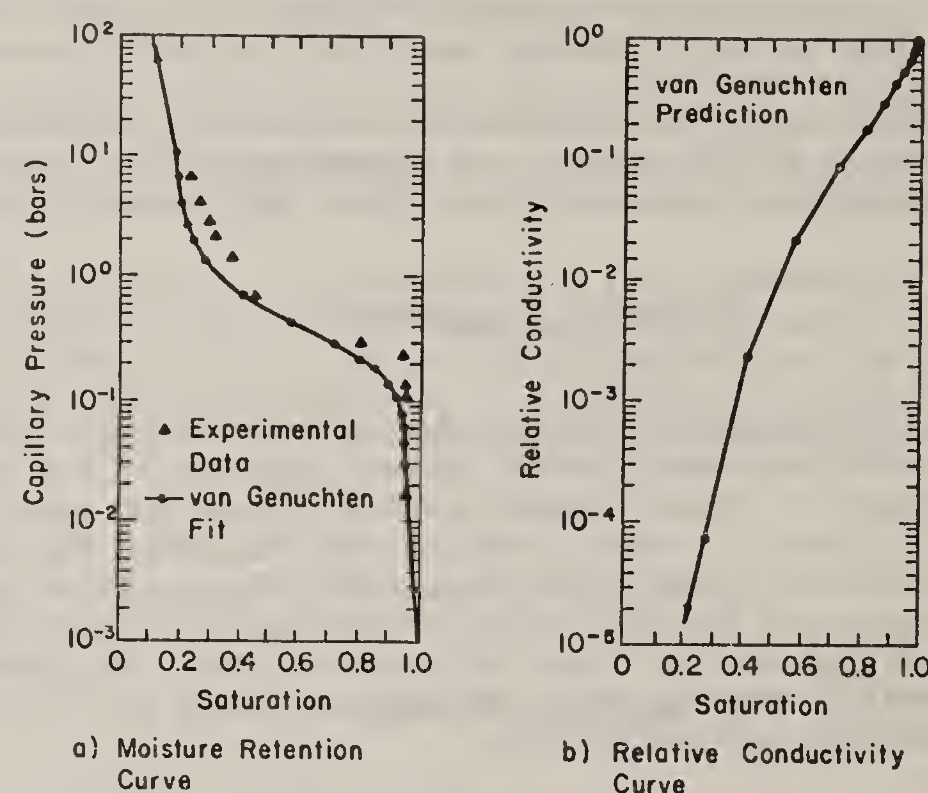

Figure 2. Characteristic curves for Paintbrush nonwelded unit (modified from Rulon, et al. 1986).

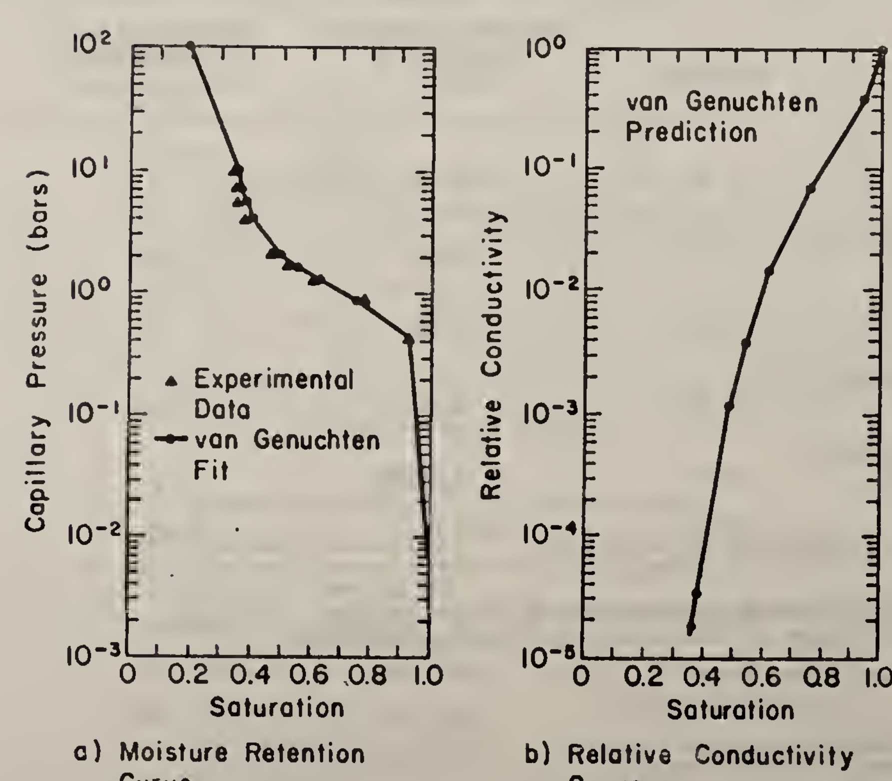

Figure 3. Characteristic curves for Calico Hills Vitric nonwelded unit (modified from Rulon, et al. 1986).

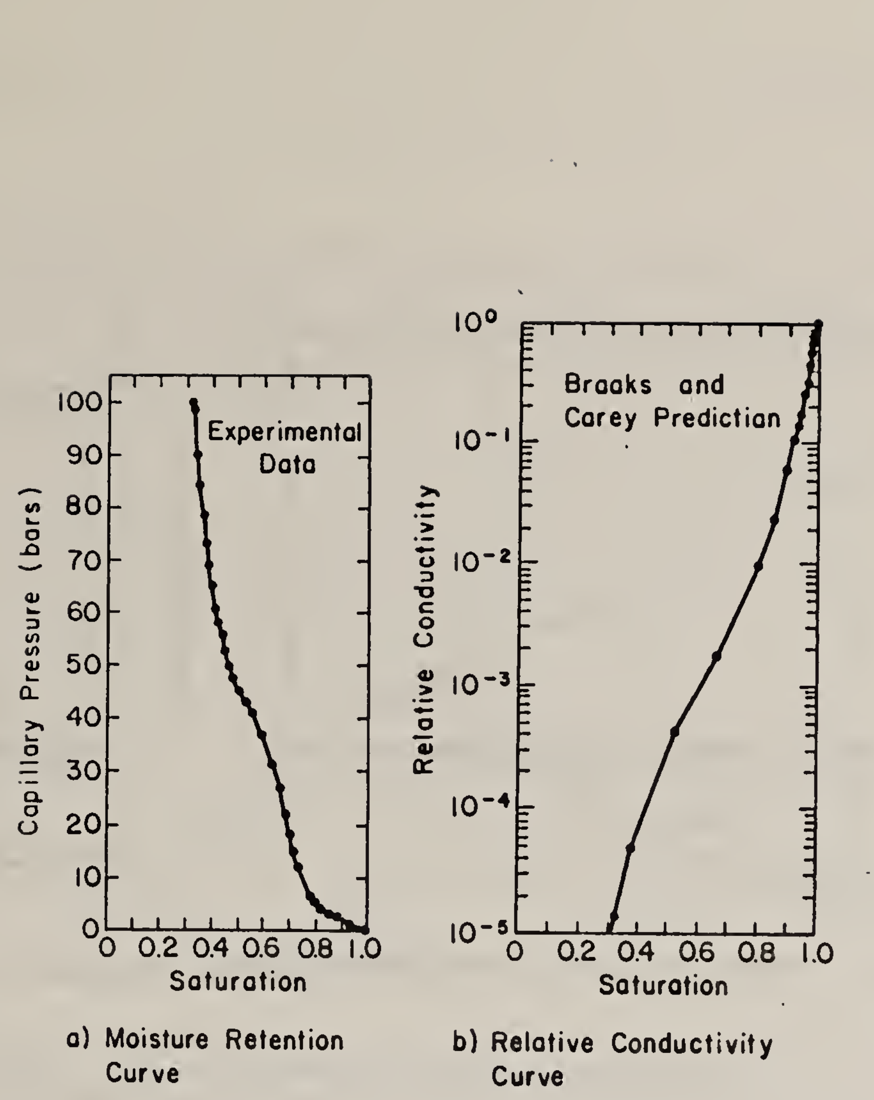

Figure 4. Characteristic curves for Calico Hills Zeolitic nonwelded unit (modified from Rulon, et al. 1986).

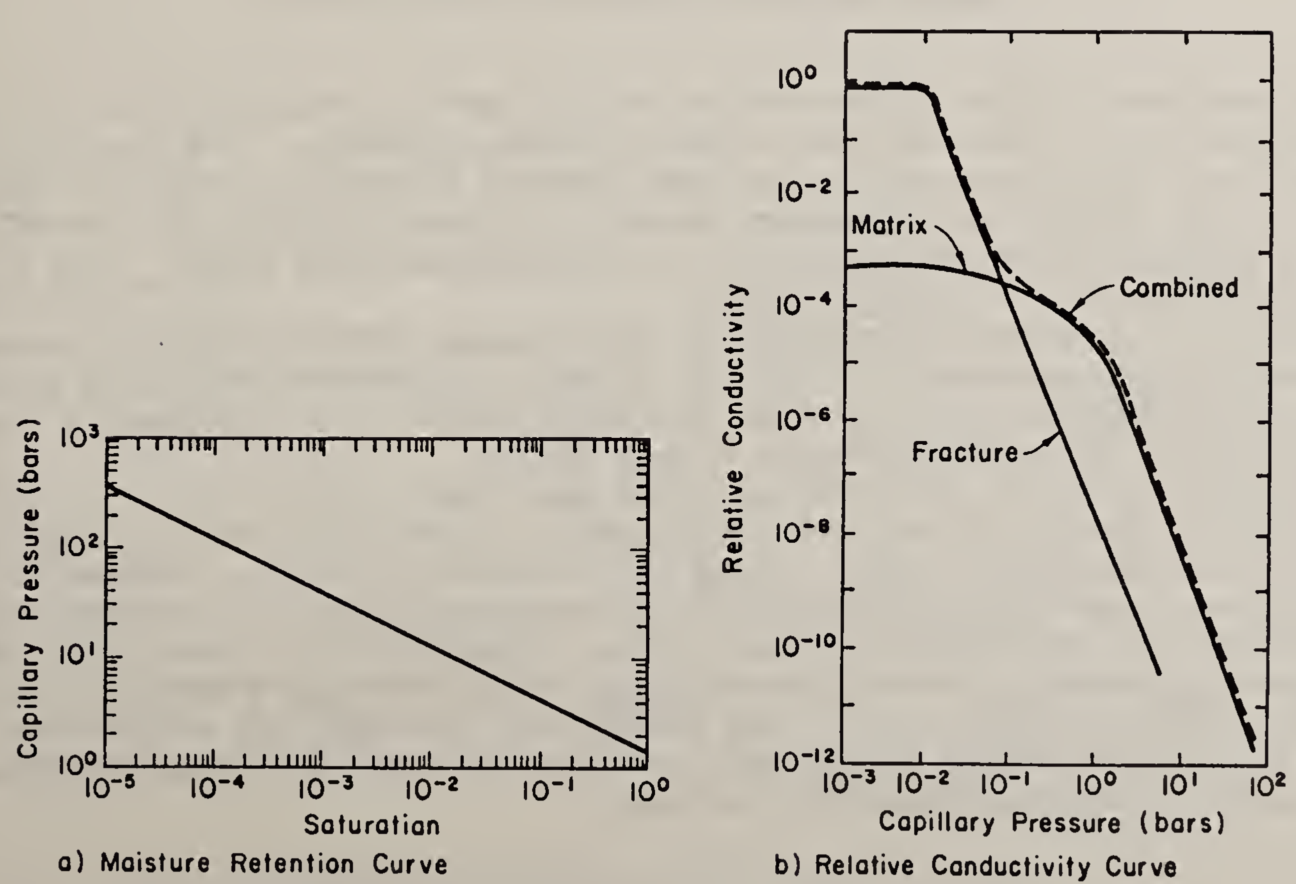

Figure 5. Characteristic curves for Tiva Canyon and Topopah Spring welded units (modified from Rulon, et al. 1986).

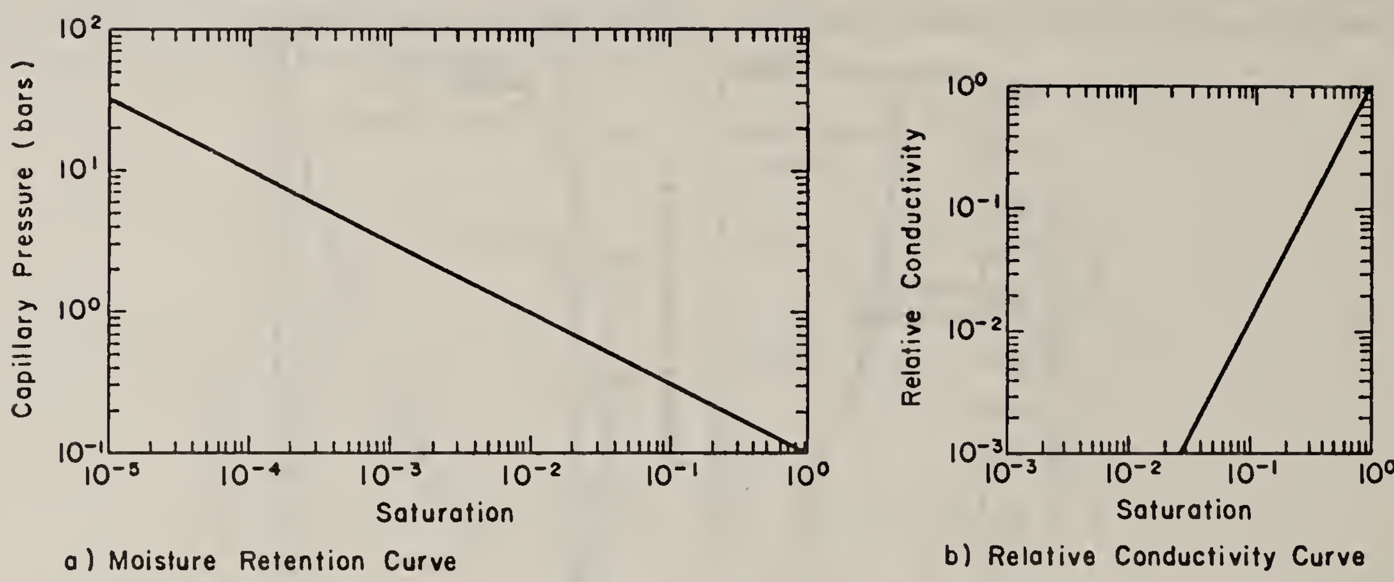

Figure 6. Characteristic curves for Fault Zone (modified from Rulon, et al. 1986).

METHODS

Model and Flow System Representation

A two-dimensional finite difference model was used to simulate the flow of water in the unsaturated zone of the central block of Yucca Mountain. The finite difference grid representing a vertical cross-section of the central block is shown in figure 7. Each finite difference block is 125 meters wide by 25 meters high. The potential repository horizon is at a depth of approximately 450 meters on this grid. The water table is located at approximately 700 meters depth.

The boundary conditions for all of the simulations consisted of a constant flux at the upper boundary representing the ground surface, a constant capillary pressure equal to zero at the bottom boundary representing the water table, and impermeable boundaries along each side. All simulations were run to steady state.

Four different surface infiltration rates were used - 0.5, 1.0, 2.0, and 4.5 mm/yr. This covered the range of current net infiltration rates that have been estimated at Yucca Mountain (Montazer and Wilson, 1984). The infiltration actually varies both temporally and spatially, but this variability was not incorporated into the current study.

Two different orientations of the Calico Hills Vitric - Zeolitic interface were simulated (see figure 8). The Calico Hills Zeolitic unit had a much smaller permeability than the Calico Hills Vitric unit, and according to Montazer and Wilson (1984), the distribution of the two facies of the Calico Hills unit may have an important influence on the flow of water below the repository horizon.

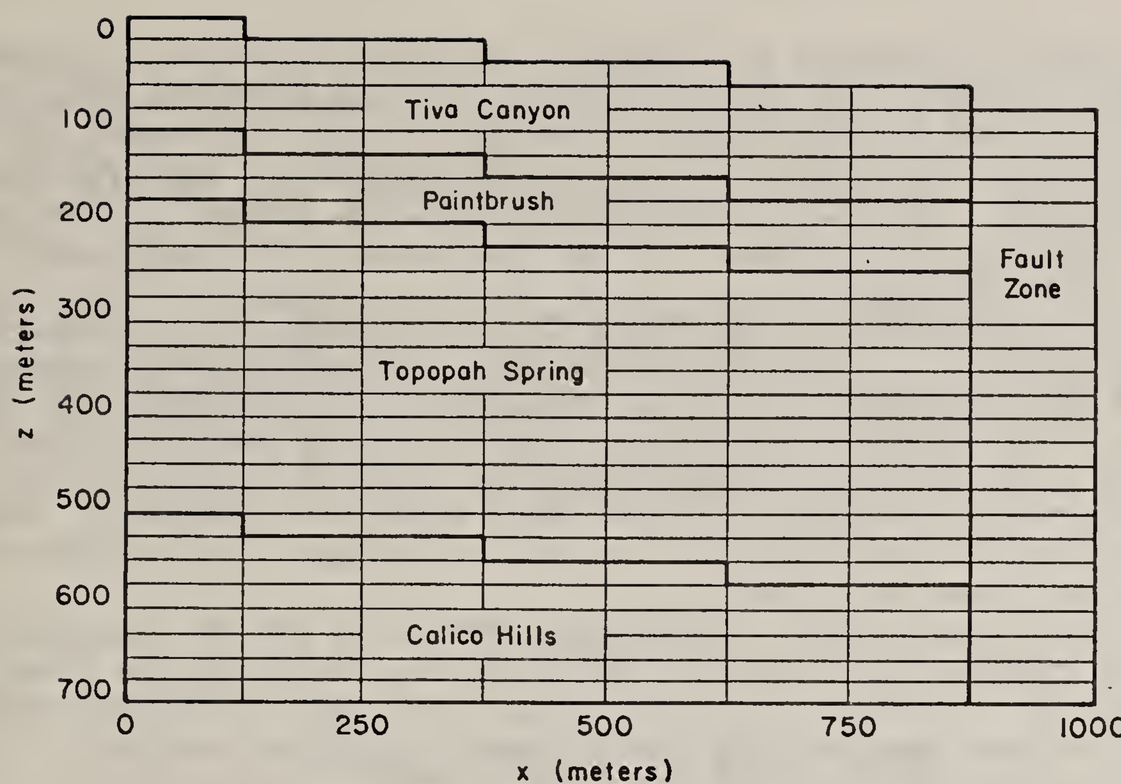

Figure 7. Finite difference grid representing a vertical cross-section through the central block of Yucca Mountain.

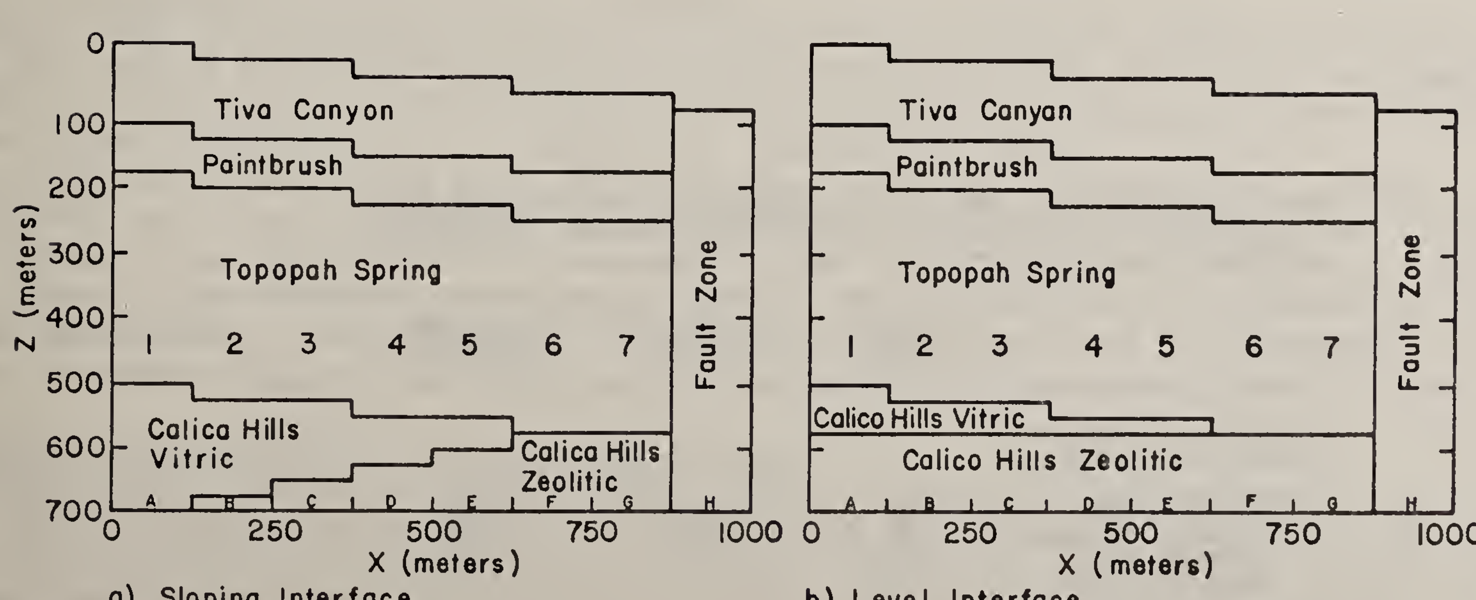

Figure 8. Sloping and level Calico Hills Vitric - Zeolitic interface configurations used in simulations. Shown are: initial particle locations (1 through 7) for travel time computations, and location of bottom blocks (A through H) for comparisons of flux to the water table.

Monte Carlo Simulations

The Monte Carlo approach using a numerical model consists of making repeated simulations in which a particular set of input data is changed from simulation to simulation. The resulting set of solutions then reflects the influence of the changing input data. In this study the Monte Carlo approach is used to examine the influence of spatially variable saturated hydraulic conductivity within three of the hydrogeologic units - the Topopah Spring welded unit, the Calico Hills Vitric nonwelded unit, and the Calico Hills Zeolitic nonwelded unit.

Values of saturated hydraulic conductivity to be used in a given simulation were sampled from log normal probability distributions for each hydrogeologic unit of interest. The distribution for each hydrogeologic unit was assumed to represent the probability of occurrence of values of saturated hydraulic conductivity within that unit. The distribution sampling and subsequent assignment of sampled values to finite difference blocks within the appropriate hydrogeologic unit were both done randomly. No attempt was made to preserve any spatial correlation structure between the conductivity values in nearby blocks within a hydrogeologic unit.

In this study the Monte Carlo approach consisted of 35 simulations for each combination of the four surface infiltration rates and two Calico Hills Vitric - Zeolitic interface configurations. Each of the 35 simulations had a different set of saturated hydraulic conductivity values sampled from the probability distributions. A complete set of conductivity values used in a simulation is termed a realization. Since all 35 realizations were generated from the same set of distributions each of the realizations has an equal probability of being representative of the true system. Therefore, the set of 35 simulations provides a range of results, with each solution having an equal probability of occurrence.

The realizations of saturated hydraulic conductivity values were generated using the random sampling routine of Iman and Shortencarrier (1984). An arithmetic mean, standard deviation, and geometric mean were calculated for each of the 35 realizations of conductivity values generated for each of the two Calico Hills Vitric - Zeolitic interface configurations. The average values of these statistics over all 35 realizations for each spatially variable hydrogeologic unit are shown in table 2. The average of the 35 geometric means for the Topopah Spring, Calico Hills Vitric, and Calico Hills Zeolitic units were very close to the single values for these units used by Rulon, et al. (1986) as shown in table 1.

Table 2. Statistics for realizations of saturated hydraulic conductivity in hydrogeologic units represented as spatially variable. Values are averages of 35 realizations.

	Topopah Spring	Calico Hills Vitric	Calico Hills Zeolitic
Level Calico Hills Vitric - Zeolitic Interface			
arithmetic mean	3.39	0.222	0.011
standard deviation	1.32	0.191	0.029
geometric mean	3.16	0.160	0.0028
number of blocks	91	9	35
Sloping Calico Hills Vitric - Zeolitic Interface			
arithmetic mean	3.39	0.239	0.012
standard deviation	1.32	0.241	0.022
geometric mean	3.16	0.163	0.0031
number of blocks	91	24	20

Particle-Tracking

The steady-state moisture fluxes and saturations from each simulation were used in a numerical particle-tracking scheme to calculate travel times from the potential repository horizon to the water table. Seepage velocities were determined in each finite difference grid block and 'particles' were moved along their respective flowpaths. The time required to move a particle a certain distance within a block is a function of the seepage velocities in the block. Accumulating the time taken to move along the entire flowpath from the initial particle location to the water table gives the computed travel time. Figure 8 shows the initial location of the seven particles that were followed.

A set of 35 travel times were computed for each initial particle location for each combination of surface infiltration rate and Calico Hills Vitric - Zeolitic interface configuration. The different travel times from an initial particle location were due to the different realization of saturated hydraulic conductivity values used in each simulation.

RESULTS

Moisture Flux to the Water Table

The calculated flux to the water table at the bottom of the finite difference grid was examined as a means of evaluating the influence of the Calico Hills Vitric - Zeolitic interface configuration and the spatial variability of saturated hydraulic conductivity. The bottom blocks in the finite difference grid are labeled A through H in figure 8. The average flux to the water table at each of the eight bottom blocks in the model grid is compared in figure 9 for the two interface configurations. The flux values shown represent an average of 35 simulations, each of which had a different realization of saturated hydraulic conductivity values. At the higher surface infiltration rates the Calico Hills Zeolitic unit generally diverted the flow moving vertically out of the Topopah Spring unit. The average vertical flux through the Topopah Spring was 80 to 85 percent of the surface infiltration rate for all cases.

Level Calico Hills Vitric - Zeolitic Interface

At the lower infiltration rates with the level interface configuration the flux to the water table from most of the Calico Hills Zeolitic unit (blocks A through G) was approximately equal to the infiltration rate. At the base of the Fault Zone (block H) the flux to the water table was 2 to 3 times the infiltration rate.

At an infiltration rate of 4.5 mm/yr the flux to the water table from the Calico Hills Zeolitic unit, as a percentage of the surface infiltration rate, was drastically reduced. There was a significant increase in the amount of flow that moved laterally to the Fault Zone at the base of the Topopah Spring unit, and then downward to the water table. A subsequent examination of computed travel times from the potential repository horizon to the water table will show the influence of this increased lateral flow.

Sloping Calico Hills Vitric - Zeolitic Interface

For the sloping interface configuration the greatest flux to the water table occurs from the Calico Hills Vitric unit (block A) and the Fault Zone (block H). The low permeability Calico Hills Zeolitic unit diverts the flow along the Vitric - Zeolitic interface. As the surface infiltration rate increases, the flux to the water table, as a percentage of the infiltration rate, increases from the Calico Hills Vitric unit (block A) and from the immediately adjacent Calico Hills Zeolitic block (block B). This percentage decreases for all other Calico Hills Zeolitic blocks and for the Fault Zone. The increase in flux through the Calico Hills Vitric unit was a result of the diversion away from the Fault Zone of the vertical flow through the Topopah Spring unit. The computed travel times are influenced by this increased flow through the Calico Hills Vitric unit.

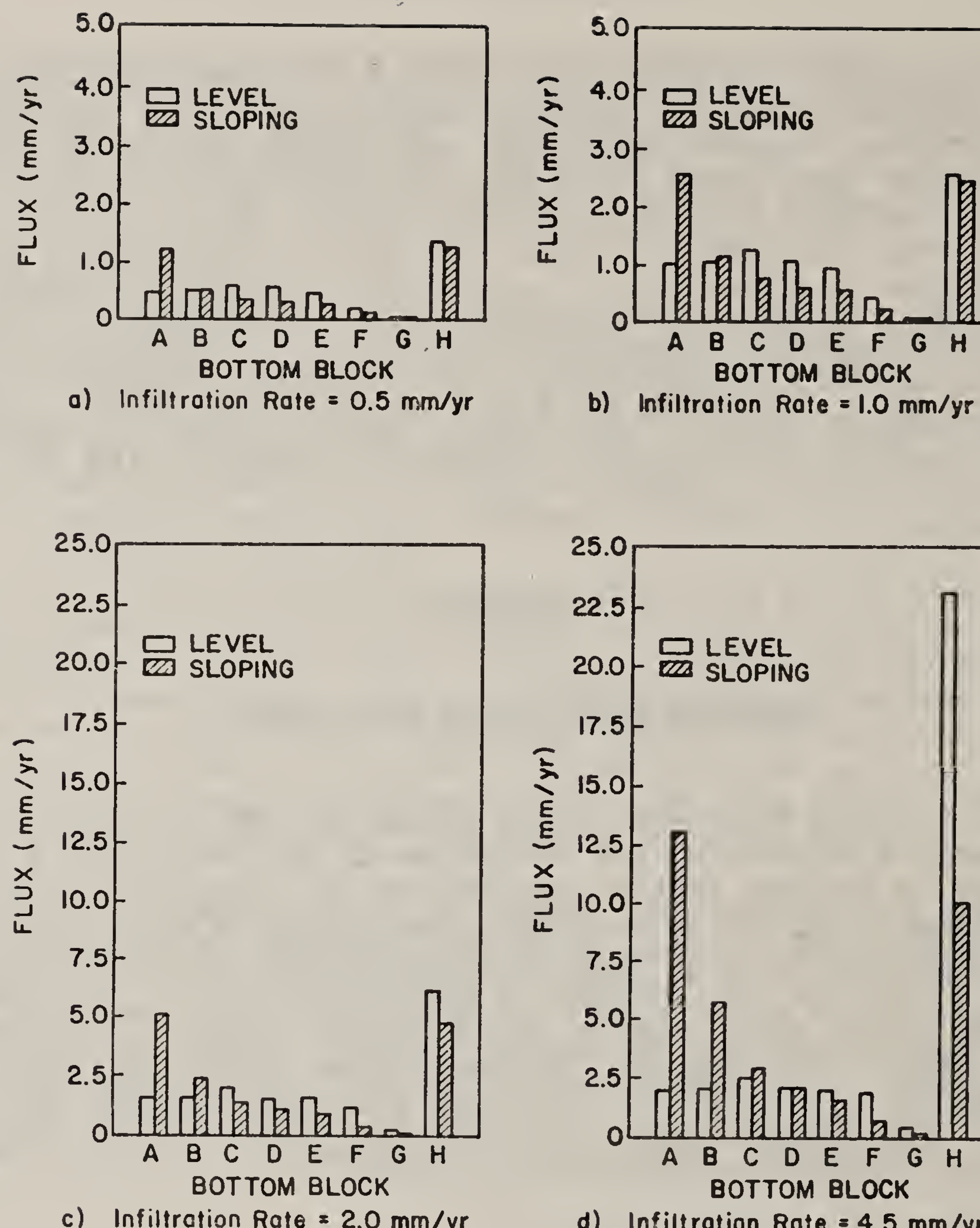

Figure 9. Comparison of moisture flux to the water table for level and sloping Calico Hills Vitric - Zeolitic interface configurations. All values are averages of 35 simulations at steady state.

Travel Times

A wide range of travel times resulted from the seven initial particle locations (labeled as 1 through 7 in figure 8) for any given simulation. The particle nearest the Fault Zone (particle 7) generally always moved to the Fault Zone, resulting in travel times to the water table of less than 600 years, even at the lowest surface infiltration rate of 0.5 mm/yr. The travel times for other initial particle locations were strongly dependent on the location of the Calico Hills Vitric - Zeolitic interface and the surface infiltration rate. Table 3 is a summary of the mean, standard deviation, and minimum travel times for particles 1 through 6, based on 35 simulations for each surface infiltration rate and Calico Hills Vitric - Zeolitic interface configuration.

Table 3. Summary of the computed travel times (years) for each Calico Hills Vitric - Zeolitic interface and surface infiltration rate combination. The mean and standard deviation are based on 35 simulations. The minimum value is the shortest of the 35 computed travel times.

Sloping Interface

	Initial Particle Location 1	2	3	4	5	6
Infiltration Rate = 0.5 mm/yr						
Mean	67200	60400	57100	59700	95900	300200
Std Dev	7400	8500	11100	19900	39800	179000
Minimum	53200	46400	40400	37800	43100	1400
Infiltration Rate = 1.0 mm/yr						
Mean	35800	32500	30300	30500	46300	126800
Std Dev	3800	4600	7000	10300	18200	74200
Minimum	28400	25000	21400	20100	21800	40100
Infiltration Rate = 2.0 mm/yr						
Mean	19200	17300	15700	15600	22400	54700
Std Dev	2000	2300	3100	6700	9700	28800
Minimum	15400	13400	11400	10300	11500	21400
Infiltration Rate = 4.5 mm/yr						
Mean	9400	8300	7200	6500	9100	29100
Std Dev	1000	1100	1100	1500	4000	15500
Minimum	7600	6600	5700	4600	5800	10200

Level Interface

	Initial Particle Location 1	2	3	4	5	6
Infiltration Rate = 0.5 mm/yr						
Mean	103800	88500	79400	78000	80000	265400
Std Dev	30800	28800	28200	39300	24100	170600
Minimum	59500	55000	41500	32400	50000	105300
Infiltration Rate = 1.0 mm/yr						
Mean	57400	42200	39300	40200	46800	109700
Std Dev	25100	9300	13200	21400	20300	55300
Minimum	30800	27700	15500	8300	14600	45000
Infiltration Rate = 2.0 mm/yr						
Mean	35400	26300	28700	30100	38900	21700
Std Dev	16800	11800	18400	16000	50900	51200
Minimum	17900	13800	12800	7900	1300	200
Infiltration Rate = 4.5 mm/yr						
Mean	20800	22800	16800	5600	1600	700
Std Dev	8300	12800	15600	8100	3900	2800
Minimum	11200	8500	3400	900	200	100

Level Calico Hills Vitric - Zeolitic Interface

In the level interface configuration the flow through the Calico Hills Vitric and Zeolitic units was predominantly vertical at the lower surface infiltration rates. This resulted in long travel times to the water table since most of the flow passed through the very low permeability Calico Hills Zeolitic unit. At a surface infiltration rate of 0.5 mm/yr the average travel times were greater than 75,000 years for initial particle locations farther than 125 meters from the Fault Zone (particles 1 through 6). Doubling the infiltration rate to 1.0 mm/yr resulted in average travel times to the water table that were generally greater than 40,000 years. The very large travel times associated with particle 6 were due to the vertical path through the Calico Hills Zeolitic unit in a zone having extremely small seepage velocities. At these lower infiltration rates there was insufficient lateral flow at the interface of the Topopah Spring with the Calico Hills units to force the particles to deviate from a generally vertical path.

At a surface infiltration rate of 2.0 mm/yr the influence of lateral flow at the Topopah Spring - Calico Hills interface became apparent. There was sufficient lateral flow to divert particle 6 to the Fault Zone without any movement through the Calico Hills Zeolitic unit. The relative reduction in travel time for particle 6 was much more significant than for the other particles. Average travel times at this infiltration rate were all greater than 20,000 years, but several of the minimum travel times fell below 10,000 years.

The influence of lateral flow at the base of the Topopah Spring became very dominant at a surface infiltration rate of 4.5 mm/yr. Every particle was diverted more drastically by the increased lateral flow, with at least half of the particles moving to the Fault Zone. This can be seen in the set of typical particle flowpaths shown in figure 10b. The resulting average travel times for several of the particles near the Fault Zone fell below 10,000 years. The minimum travel times out of 35 simulations at this infiltration rate were nearly all less than 10,000 years, and several were less than 1000 years.

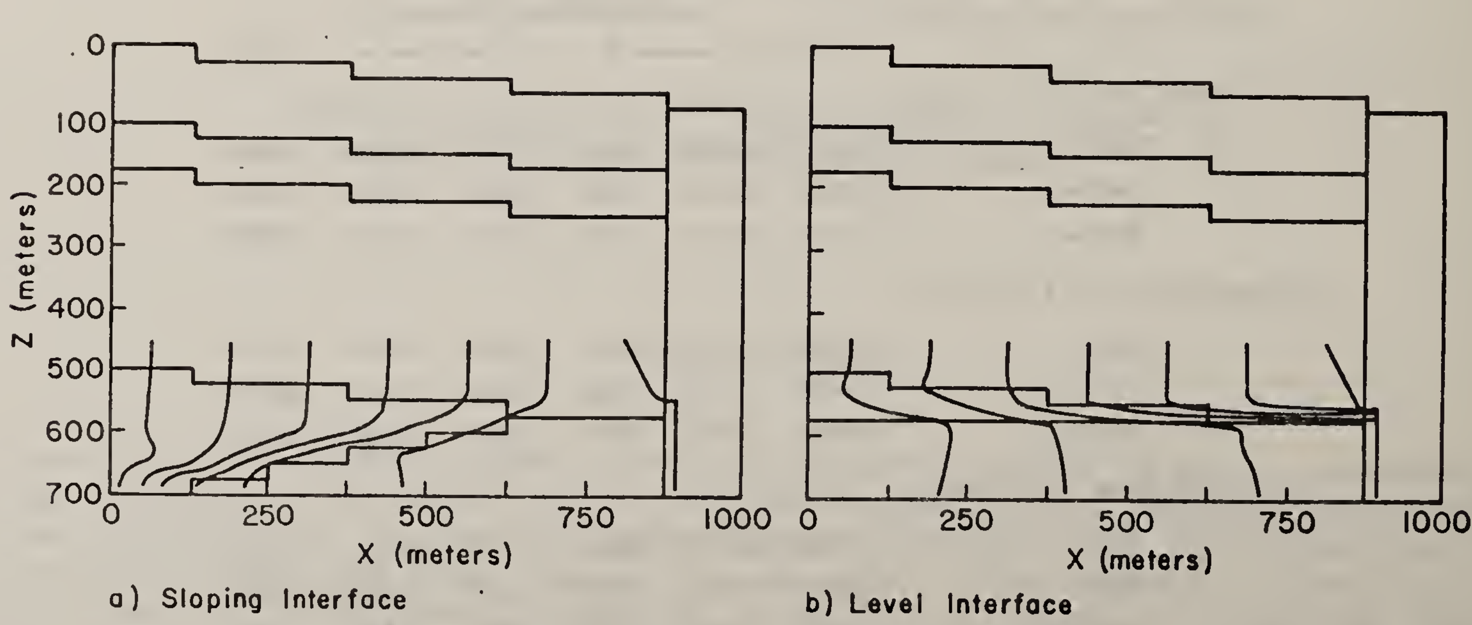

Figure 10. Typical particle flowpaths for simulations at a surface infiltration rate of 4.5 mm/yr.

Sloping Calico Hills Vitric - Zeolitic Interface

The sloping interface configuration resulted in a diversion away from the Fault Zone of much of the flow at the base of the Topopah Spring unit. This was particularly evident at the higher surface infiltration rates.

At infiltration rates of 0.5 and 1.0 mm/yr the flowpaths and travel times for particles near the Fault Zone were similar for both of the Calico Hills Vitric - Zeolitic interface configurations. The travel times for particles more distant from the Fault Zone (particles 1 through 4) were approximately 25 to 30 percent smaller for the sloping interface configuration. The average travel times were longer than 50,000 years and 30,000 years for surface infiltration rates of 0.5 and 1.0 mm/yr, respectively.

At the higher infiltration rates, most of the flow from the Topopah Spring unit was diverted down the sloping Calico Hills Vitric - Zeolitic interface. At an infiltration rate of 2.0 mm/yr travel times for particles which initially started above the Calico Hills Vitric unit (particles 1 through 5) were reduced 30 to 50 percent below those in the level interface simulations. The average travel times were longer than 15,000 years. Particle 6 showed a much longer travel time for the sloping interface configuration since it was not diverted to the Fault Zone as it was in the level interface simulations.

At a surface infiltration rate of 4.5 mm/yr the influence of the sloping Calico Hills Vitric - Zeolitic interface was very pronounced (see figure 10a). Travel times for particles farthest from the Fault Zone (particles 1 through 3) were less than 50 percent of those computed for the level interface simulations. Again, particles near the Fault Zone had much longer travel times under the influence of the sloping interface configuration since they were diverted away from the Fault Zone. The average travel times for particles farther than 125 meters from the Fault Zone were all greater than 6500 years, and the minimum travel times for the same particles were at least 4500 years.

SUMMARY AND CONCLUSIONS

A stochastic analysis is required in order to estimate the travel times of water and associated radionuclides to the accessible environment. The complex flow system and range of possible waste storage scenarios prohibits accurate measurements of individual travel times. A plausible range of travel times and associated confidence limits are needed.

The Monte Carlo approach applied to numerical simulations of flow through the unsaturated zone at Yucca Mountain provided a range of possible travel times from the repository horizon to the water table. Many assumptions were made about the behavior of the flow system and the material properties of the hydrogeologic units that were incorporated in the analysis. The ranges of computed travel times are influenced by many factors, including the boundary conditions, the input distributions of saturated hydraulic conductivity, and the size of the finite difference blocks used in the numerical model. Another factor currently being examined is the influence of spatial correlation structure in material properties between blocks.

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RECLAMATION FOR MINING AND ENERGY

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PLACER MINING AND SURFACE DISTURBANCE ON PUBLIC LANDS IN ALASKA: TECHNICAL ASPECTS OF MITIGATION AND RECLAMATION

Thomas C. Mowatt[1]

ABSTRACT: The Bureau of Land Management (BLM) has the dual role of encouraging use, as well as the protection of the public lands of the U.S.A. Of particular concern to BLM in Alaska are the effects of placer mining activities, in various areas throughout the State. Under 43 CFR 3809, BLM has been directed to prevent "unnecessary or undue degradation" of federal lands which may result from operations authorized by the mining laws, while providing for mineral entry, exploration, location, operations, and reclamation of disturbed areas. In addition, the procedures used are to be coordinated, to the greatest extent possible, with appropriate State of Alaska and other Federal laws and regulations.

BLM neither recommends nor provides design criteria or standards, but, rather, manages surface-disturbing activities via use of performance standards. The principal considerations entail:

1. Saving and ultimate re-spreading of topsoil materials.

2. Control of toxic substances.

3. Control of sediment discharge.

4. Continuing stabilization, reshaping, sloping, grading and contouring, to blend with surrounding landscapes and minimize ponding and/or erosion.

5. Provision for fish, wildlife and human passage during and after operations, and rehabilitation of habitat.

6. Stabilization of all slopes or river banks cut or filled during operations.

7. Revegetation (natural, if at all feasible) of all disturbed lands.

Fundamental goals of reclamation are to facilitate reestablishment and/or recovery of natural vegetation, and to control erosion. With the short Alaska growing season some sort of effective mechanical stabilization of disturbed lands often is required to allow vegetation time to recover.
KEY TERMS: Alaska, placer mining, reclamation, surface-disturbance, public lands, mitigation.

1/ Geologist, U.S. Bureau of Land Management, Alaska State Office, 701 C Street, Anchorage, Alaska 99513

INTRODUCTION

Of all the various types of surface disturbing activities on public lands in Alaska, those associated with placer mining are presently of greatest concern. This is due both to the heightened numbers and levels of such activities in recent years, due to economic considerations, and to the intrinsic nature of such activities. Placer deposits are generally found in association with present stream drainages, large and small.

The Bureau of Land Management (BLM) has the dual role of both encouraging the use of and protecting the public domain in Alaska. For example, in some areas of sensitive fish and wildlife habitats, a professional land manager might feel that there is no acceptable level of surface disturbance and recommend closure of the area to all surface disturbing activities. In other areas, such as long-established mining areas, surface disturbance may be so extensive that a professional land manager may recommend allowing significant surface disturbances as the priority land use as long as new disturbed areas are reclaimed and effluent from the activity meets State and Federal standards.

These two examples are basically two opposite extremes of surface protection. However, most BLM management concerns deal with surface disturbing activities between these two extremes. In general, no BLM area is ever totally closed to all disturbance, nor is any area ever written off as unreclaimable no matter what the cost of reclamation might be.

Basically, BLM personnel in the field determine when surface disturbance has occurred, and when reclamation has been achieved. It is the field specialist who best can determine when "casual use" has been exceeded and when a user of the public domain has restored a "project area" to an acceptable condition. BLM field judgments are balanced by an appeal process to protect the rights of the user.

During the course of the construction of the Trans-Alaska Pipeline System (TAPS), a wealth of information was developed related to surface-disturbance and attendant reclamation. Much of this is quite relevant to other types of surface-disturbing activities in Alaska, including placer mining. Major considerations include the following.

Minimizing Surface Disturbance

Emphasis should be placed on minimizing clearing of vegetation and disturbance of surface materials. Unless a permanent access road is to be built, all access should be conducted on frozen or snow-covered surfaces. The use of vehicles that exert low ground bearing pressures should be required for any ground access not using permanent roads. Excavated materials should be placed where they will not adversely disturb vegetation, the thermal regime or surface drainage.

Fish and Wildlife

Free passage and movement of terrestrial and aquatic organisms should be maintained. Permanent alteration of stream hydraulics or disturbing significant areas of river or stream beds or vegetated banks should be avoided. Erosion and sediment control structures should be used to the maximum extent possible during the thaw season to minimize impact on water quality. All activities should be restricted in key fish and wildlife areas during periods of fish and wildlife breeding, nesting, spawning, lambing, calving activity, overwintering, and during major migrations of fish and wildlife. Such key areas should be clearly and throughly substantiated with regard to the spectrum of considerations inherent to multiple-resource management.

Drainage and Erosion Control

Temporary erosion control was a recurring problem during pipeline and related construction, and remains a minor problem. Access over stream banks should be made by filling rather than cutting whenever possible, to lessen erosional problems. Riprap and armour stone should be of sufficient size to remain in place and be effective at peak discharges.

Cuts in Ice Rich Materials

Cuts should be made with nearly vertical backslopes. A wide ditch should be provided at the toe of the cut. Trees and shrubs should be hand cleared from the top of the cut for a distance from the top edge of the cut back to approximately one and one-half times the height of the cut. Stumps should be cut as close to the organic mat as possible but should be left no taller than one foot in height. As thawing and subsidence occur during the stabilization process, it might be necessary to hand clear additional trees.

Reclamation

Initial revegetation along TAPS was based primarily upon the accepted practices of mulching, fertilizing and seeding with adapted agronomic grass species. Attempts to use native grass species in the seed mix were limited. Native grasses are only slowly reinvading some artificially revegetated areas. The long-term persistence of exotic species from initial revegetation efforts and the effect upon reestablishment of native vegetation is still being studied. Native tree and shrub transplants and cuttings had limited success in relationship to cost.

Current practice stresses establishment of erosion stability, elimination of any ponding and encouraging native vegetation as quickly as possible.

Some pipeline restoration problems were irremediable, such as those involving the loss of topsoil and organics which were buried or otherwise lost during operations.

Current practice calls for segregation of slash, organics/topsoil and overburden into separate stockpiles at any excavation.

GENERAL CONCERNS

Based on the TAPS experience, in addition to appreciable other knowledge acquired over the course of many years, as presently viewed, the principal considerations regarding management of surface disturbing activities on public lands in Alaska can be summarized, in a rather general fashion, somewhat as follows:

1. Saving of all available topsoil (including the organic mat) for final respreading after reshaping the disturbed areas.

2. Stabilization of the saved topsoil, overburden and disturbed areas to prevent erosion, slides or degradation of adjacent waters.

3. Isolation, removal or control of toxic materials.

4. Provision for fish, wildlife, and human passage during and after operations; rehabilitation of habitat.

5. Revegetation of all disturbed lands to prevent erosion prior to final reclamation, and as an essential part of such final reclamation.

6. All slopes or river banks cut or filled during access or operations must be stabilized to prevent thermal, water and/or wind erosion.

7. A. As each part of an operation is completed, erosion control devices should be installed as required, and the area should be reshaped, sloped, and graded to blend with surrounding landscapes and to minimize ponding and/or erosion.

   B. Economic material handling generally entails minimizing the equipment and number of steps utilized in achieving the desired result. Ideally, removal, processing and placement of materials into the final reclaimed configuration and condition should be essentially one continuous function within the same operating season. One important advantage of this in Alaska is that the final emplacement of the materials is effected before freeze-up. During the winter piles of topsoil, overburden and tailings will freeze from the surface down; if placed over existing permafrost soils, the permafrost will facilitate freezing of the piles from below as well. This of course will present problems when these frozen stockpiles of materials subsequently need to be moved for reclamation. The water-saturated fine-grain size (silt/clay) materials in settling ponds are highly susceptible to freezing - in some cases may permanently refreeze. Subsequent movement/modification of such materials would be difficult and expensive. It might be noted that there is a positive aspect to this latter situation, in that the fine-grained materials thus frozen are essentially "fixed" into a relatively much less erodable state, which feature might used to advantage in some situations.

ACCESS TO THE MINING OPERATION: MINIMIZING IMPACTS

The access route is an integral part of an operation, and the operator is responsible for any unnecessary or undue degradation resulting from the construction, use or improper restoration of any access route. In Alaska, on public lands such access should:

a. Be constructed to the minimum BLM standards listed in BLM Manual Section 9113, or be designed by a licensed professional engineer.

b. Incorporate a design commensurate with use, and consistent with the need to maintain environmental integrity.

c. Avoid crossing active river and/or stream channels. If necessary, however, crossings should be made via temporary bridges, properly installed culverts or correctly constructed low-water crossings.

d. Use gravel fill ramps at stream bank crossings to minimize siltation, rather than cutting through the bank, if feasible.

e. Avoid high erosion hazard areas; in some cases a slight location change may eliminate a major erosion problem.

f. Avoid access through vegetated areas but, if necessary:

1. Access across vegetation in the snow-free season should not be made with any vehicle that would remove or damage the organic layer, without a properly constructed permanent gravel road.

2. Winter access across vegetation should not be made until the organic layer is protected by an adequate layer of snow and ice or the organic layer has been protected by the construction of snow and/or ice roads capable of supporting vehicular traffic with minimal effect on the organic layer.

g. Be planned for the minimum width needed for operations and should follow natural contours, where practicable, to minimize cut and fill.

h. Have turnouts on single-lane roads that take advantage of natural existing sight distance and topography.

i. Culvert gradient should be kept as close to the natural gradient as possible so that no upstream or downstream velocity barriers are created.

j. Culverts should have sufficient capacity to pass the design flood with no backwatering or ponding at the upstream end.

k. Culverts should not be placed where a channel cutoff or diversion would result.

l. Culverts should not be placed where the discharge is directed at an unstable bank.

Everything feasible must be done to prevent unnecessary melting of ground ice when constructing roads. Ground ice is associated with permafrost, and its abundance and distribution are significant considerations in route selection, road design, construction practices, maintenance requirements and operating methods. The majority of ground ice occurs in fine-grained, unconsolidated sediments. Ground ice can also occur as pore ice, ice films, lenses, layers, sheets, wedges and possibly buried glacial ice. If the access route or operation thaws ground ice, costly remedial measures may be required to restabilize the area.

The proper way to achieve access across an ice rich slope is to fill rather than cut. If access routes or operations involve cuts in ice rich materials, the slopes may take years to stabilize, even if the following recommendations are followed:

a) Cut nearly vertical backslopes on the cuts (if a cut is to be pushed no farther into the permafrost slope, it may be possible to grade spoil up against the vertical cut face as soon as possible following work at that location, and modify items b, c, and d).

b) Provide a wide ditch at the base of the cut to allow removal of even more material as well as to allow deposition of melting ice rich material during the stabilization process. The ditch will also permit a porous revetment to be made to enhance drainage and stabilization of the slope.

c) Hand clear trees and standing brush from the top of the slope for a distance about equal to one and one-half times the height of the cut. Stumps should be cut as close to the surface as possible and left no taller than one foot. All efforts should be made to keep from damaging or tearing the vegetative mat. As melting and subsidence occur during the stabilization process, it might be necessary to remove additional trees from the top of the slope.

d) Seeding, if required, should be attempted only on relatively stable portions of the slopes. Near the end of the first thaw season, the lower portion of the slope should be heavily seeded with grasses and fertilized to try to establish a relatively firm and stable toe down into the drainage ditch before thawing occurs the following season. If this procedure is followed for two or three successive seasons, grasses may slowly establish themselves from the toe of the slope up to the natural vegetative mat edge as subsidence progresses. If the slope is not seeded, natural invasion by seed or resprouting of root material is likely to occur within several summers as subsidence slows.

BLM RESPONSIBILITIES DURING OPERATIONS ON PUBLIC LANDS

Under surface protection regulations, BLM has responsibilities during the approval and operational phases of an activity on the public lands, as well as for insuring adequate reclamation. As indicated in the preceding section on accessing the site, proper planning can eliminate or minimize impacts upon the surface resources.

Planning for Surface Protection

Planning for surface protection need not be elaborate, but it does need to be done carefully.

It should be stressed that BLM neither recommends nor provides design criteria or standards, but, rather, manages surface-disturbing activities via use of performance standards. In other words, BLM will attempt to define acceptable levels of performance, in terms of existing legal requirements together with site-specific judgments, but is not in a position to direct the operator in the specifics of attaining such acceptable performance. BLM has prepared publications featuring bibliographies of various publications which address the technical aspects of relevant topics in detail, however. An example is BLM-Alaska Technical Bulletin AK-BLM-PT-87-008-1610-933 (1987).

Several factors should be considered by the operator and BLM when planning the surface disturbing operation:

a. Technical aspects, such as the:

    1. Extent of the proposed disturbance.

    2. Extent of processing, mobile and stationary equipment, and operating skills required.

b. Economics, such as:

    1. How far and how easy is it to reach the site with the proper equipment?

    2. How much site preparation, including overburden removal and construction of ancillary structures (cabins, access roads, airstrips, etc.) is required?

3. What type of stream diversion or training structures are required?

4. What is the cost of rehabilitation?

c. Environmental characteristics, such as:

1. Can effluent and other environmental requirements be met?

The BLM must be especially concerned with gathering enough baseline data on each operation to meet NEPA documentation requirements and to determine the appropriate course of action . In support of this data collection, the field BLM personnel will call upon other expertise, i.e. sociologist, archaeologist, engineer, geologist, hydrologist, soil scientist, vegetation specialist and fish and wildlife biologist for timely input and advice.

A thorough plan should:

a. Locate all streams and ponds, existing settling ponds, existing tailing piles and aufeis fields.

b. Identify the operational location or locations with respect to floodplain location type, such as active channel, active floodplain, highwater channel, inactive floodplain, abandoned channel, terrace or valley wall.

c. Have a map showing the size and relative location of all work areas on the site.

d. Describe the season, duration and frequency of all site work by individual work area, that is - approximate dates the entire and portions of the operation will begin and end.

e. Describe and locate all buffer (undisturbed land) strips and give dimensions and vegetation type.

f. Describe the methods, schedules and locations for vegetation and overburden clearing as well as handling and storage of topsoil.

g. Describe the operational methods. Include descriptions of the type of equipment to be used and descriptions of the intended processing steps such as lifting, sorting, sluicing, placing tailings, spreading tailings and topsoil, etc.

h. Give an estimated cross-sectional configuration of the mine site, at various working portions of the site.

i. Give specific locations, specification, material composition and construction method for access roads, river diversion and/or training structures and sediment control ponds.

j. Describe all logistical support and material transportation methods, general routes to be followed and season/frequency of movement of equipment and supplies to and from the site.

The plan should adequately discuss the intended methods and procedures for reclaiming the disturbed area, removal or leaving of permanent structures such as camps or river training dikes, and whether access is to be kept open after the site is reclaimed - which influences the required design life of the access road.

Both the operator and the BLM will be trying to ascertain in some detail what "unnecessary or undue" degradation means at each site. This determination requires the following baseline information to be developed, at least generally, for each site:

a. Known biological resources of the general vicinity, including fishery resources of the subject river system.

b. Timing of major fish and wildlife life-cycle events and presence of limiting habitat occurring in the vicinity of the site.

c. Hydraulic characteristics (such as channel configuration and discharges) in the vicinity of the mine.

d. Cultural resources.

The maps of an operation should include, whenever possible, detailed sketches, ground photographs, topographic maps and, if available, aerial photography showing, as appropriate:

a. Accurate claim boundaries;

b. Past, present and future work areas;

c. Any buffer areas to be left undisturbed, in order to minimize impacts on active channels;

d. Locations of all site-related temporary and permanent structures planned, such as access roads, airstrips, camps, river diversion and/or training structures, bank protection devices, stockpiles, tailings pile, processing area, overburden piles, etc.

It is very helpful to:

a. Flag the boundaries of present disturbed areas and proposed future expansion areas, so that the operator and BLM can agree and document the areas where operations and reclamation are to occur;

b. Establish and mark (flag) reference points on the site to record/estimate the height of aufeis buildup, spring breakup runoff or other flood events in the vicinity so that operations can be optimized, while minimizing environmental impacts.

Prior to opening a new site or expanding an existing site, the operator and BLM should give some thought to minimizing surface disturbance, and to needed reclamation. The following are relevant considerations:

a. If possible, place all test pits to avoid crossing or working in an active channel.

b. Schedule activities to avoid conflict with predictable flood periods and major fish and wildlife use of an area.

c. Avoid disturbing vegetated areas if test pits can be made in unvegetated areas. By using unvegetated areas, additional sediment runoff should be minimized, along with helping reclamation / revegetation requirements.

d. If vegetated areas cannot be avoided, favor small disturbances within large stands of homogeneous, mature vegetation where habitat diversity will be increased by the disturbance, rather than disturbing riparian or other edge habitats of limited availability where reclamation and revegetation will be more difficult.

e. With regard to the exploration for/development of mineral deposits, such activities are inherently likely to require significant disturbance in areas where this may be less-than desirable from an environmental degradation standpoint. Careful planning, mitigation and reclamation will be essential in such situations.

If at all feasible, operations and all ancillary activity should be conducted so as to:

a. Avoid any activity in an active channel.

b. Maintain a buffer of undisturbed land between active channels and the operation.

c. Avoid excavating to depths or in locations that will induce permanent channel alteration or ponding of water.

d. Avoid constructing any river training or bank protection devices since they may disrupt natural stream processes/balances and may result in scour and erosion elsewhere in the stream system.

e. Avoid disturbance of natural banks.

f. Avoid clearing of riparian vegetation.

Where a choice exists, operations in the following areas should be done very carefully or not at all, in order to minimize or eliminate disturbances:

a. Critical habitat of threatened or endangered species, as designated by State and/or Federal agencies.

b. Fish and wildlife habitats limiting local populations, such as fish and wildlife breeding, nesting, spawning, lambing or calving areas and along major migration routes.

c. Active river channels. Oftentimes, as in many mining operations, avoidance is not possible.

d. Springs.

e. Wetlands.

Buffers are areas of undisturbed ground surface designed to maintain the integrity of adjacent active river or stream channels and minimize change, including siltation, to the aquatic habitat. There is no set width for a buffer, but important variables to consider in the selection of buffer location, width and elevation include:

a. Configuration of the adjacent channel.

b. Channel size.

c. Local hydrologic characteristics.

d. Channel aufeis.

e. Permafrost or ice-rich stream banks.

f. Type of local vegetation.

g. Soil composition.

Topsoil

Topsoil (such as may be present) must be saved for final application after reshaping of disturbed areas has been completed. This means that the operator and BLM will have to determine both what constitutes "topsoil", and how to best store it, at each site. At a minimum, topsoil in Alaska should be thought of as all of the active organic layer, plus as much of the subsoil (even where not really "topsoil", in the usual sense) as appears capable of supporting plant growth. In actual practice, the operator should save all of the top organic layer, if present, and the subsoil as feasible. If less than six inches thick, it may be difficult to salvage with mechanical methods. One anonymous knowledgeable specialist offers the following comments:

"In Alaska, topsoil is a loosely defined term alluding to litter, organic mat and the A and B horizons. A term such as "original surface material to a depth of _?_ inches" may be more appropriate. Very few trained people will argue against the fact that this surface material is probably a better growing medium as well as a source of seed and other propagules.

The fact remains that stockpiling and redistributing this material is a technical and costly operation. This material, if not handled properly, may cause more serious problems than the stripped area.

> For example: a stable, gravelly area may be classified as having a low potential for erosion. When the organics and silts are reapplied to the gravelly area, the erosion potential may be classified as significant. This increase may cause the miner to respond with additional work (I believe these situations are called a "catch 22" or a "no win" situation). Not only may the veneer of "topsoil" cause an erosion problem, but the stockpile prior to redistribution could become a source of sediment."

In general, the best approach would seem to require that, in order to save and protect the fertility of the topsoil for use in reclamation, the operator should:

a. Separate and properly dispose of all large woody material from the topsoil to be saved.

b. Store the topsoil in piles away from the active channel, in locations where the topsoil will not have to be rehandled or disturbed in any way prior to respreading.

c. Construct the piles to prevent slope failures and minimize erosion.

d. Make the piles long and narrow and oriented parallel to the flow of the active channel, if in the floodplain.

e. Make sure the piles are of sufficient height and have sufficient armouring at the toe to withstand spring breakup flows and at least the two-year flood event. Use moderate slope gradients in order to minimize erosion.

There are two major purposes for saving and respreading topsoil during reclamation:

a. In most cases, topsoil will provide the best growth medium for plants.

b. Topsoil will provide better infiltration and less surface runoff of water and, hence, less erosion, in general.

Toxic Materials

Each operation generally will produce toxic substances, such as crankcase oil, sewage, etc. and some may also uncover potentially toxic natural substances (e.g. sulfide minerals subject to degradation upon exposure). All use of the public lands must be conducted in an environmentally acceptable manner, which means:

a. All fuels and other toxic materials should be stored out of the floodplain.

b. Fueling and servicing of equipment within the floodplain should be avoided to reduce spills of fuel, lubricants and waste oil such as spent crankcase oil.

c. The effluents from all activities including support activities occurring on or near the operation - such as gray water, domestic sewage and solid waste - should be disposed of as required under applicable State and Federal Regulations, and should not be disposed of within the floodplain without proper treatment and approvals.

Erosion

For a given climate setting, erosion rate is influenced by:

a. Types of materials on the site.

b. Steepness and length of slopes.

c. Drainage and water control structures provided.

d. Amount of vegetation or surface roughness on slopes.

High erosion rates may be ameliorated by:

a. Surface manipulation.

b. Mulching.

c. Proper timing of topsoil replacement and revegetation.

Controlling Drainage on the Site

Rundquist, et al (1986) have discussed this in some detail. Proper drainage control requires identification of all sources of water on a site, as well as the sources of erosion, so that the operation can be planned and carried out from beginning to end so as to minimize erosion and pollution of receiving waters. A properly functioning drainage system acts to divert clean water around an operation, as well as retaining and treating any operations-related sediment-laden water within the site.

In general, proper drainage control measures include:

a. Proper diversion of stream channels and off site overland flow around operations -- There is no reason operators should try to remove sediment from any water not muddied directly or indirectly by their operations. One of the first steps in opening a new site should be to divert any active stream channels and off site overland flow around the operation, and to protect the area with berms, in order to lessen the amount of water intercepted and requiring treatment. The diversion should be planned, constructed and operated to avoid excessive erosion or deposition of sediment, to contain floods within the range of acceptable risks, and to allow for fish passage in a fish stream. The diversion channel should be inspected frequently, and maintained as necessary.

b. Interception and diversion of ground water around the operation -- The amount of water passing through a settling pond may be substantially increased by groundwater seeping into the operations area and through the settling pond, if located in a low-lying area. However, just as surface streams may be diverted around an operation, it is also permissible to cut-off trench and intercept any groundwater (which might otherwise surface in the operation, where it would have to be routed through the settling pond) and lead it to surface waters bypassing the site. As with surface diversions, the interception and diversion must not adversely impact upon water quality.

c. Proper overburden removal, placement and protection of storage stockpiles -- Proper removal, segregation and stockpiling of overburden - including vegetation, organic and inorganic components - should be performed just prior to processing the underlying materials/deposits, in order to limit the time period during which erodable slopes are exposed. It may be necessary to encircle the operations with containment berms/dikes to collect runoff from stripped slopes and route it through the settling pond. Storage stockpiles sometimes may need to be armored. As feasible, they should be placed in areas where they will not need to be rehandled, and where they can be protected from erosion. Vegetative materials may be considered for use as armor, and in dikes. Stockpile slopes should be minimized, as feasible, to minimize erosion. Storage stockpiles of highly erodable material should be stabilized, - by seeding and fertilizing if necessary, to prevent erosional losses.

d. Proper grading and shaping of spoil -- Grading and shaping of spoil, and reduction of tailings piles concurrently with operations will not only reduce erosion but also ease overall site reclamation. If tailings are properly placed and graded during operations, additional grading may not be necessary upon site closure. Constructing floodplain terraces and furrows parallel to the contours of steep side slopes will reduce the effective length of erodable slopes, thereby limiting erosion and slope failure.

e. Adequate settling pond systems -- Settling ponds are used to clarify water draining from mining and other types of surface disturbing operations. Location of the settling pond(s) should be one of the most important physical parameters considered during planning for the operations. In general, settling ponds should be:

1. Located above the groundwater table to prevent seepage into the pond.

2. Designed to obtain enough water residence time to allow fine sediment to deposit.

3. Designed to allow for easy removal of accumulated sediment, or construction of a new settling pond to replace one nearing 60% of capacity.

4. Designed for easy reclamation by dewatering/removal of sediment, filling, or leaving as fishery habitat, as applicable and approved.

Settling Ponds

Whether they are called settling ponds, sediment ponds, stilling basins, filter ponds, siltation control ponds or some other name, the use of settling ponds has been the principle technique used to attempt to prevent degradation of water quality for many mining and other types of operations in Alaska. Alternative techniques are presently being evaluated, including a variety of "total recycling" methods, and various lines of research are being pursued by various groups on other innovative schemes (e.g. mobile washing plants and gravel filters; tank flocculation; etc.) as well. For the time-being, however, the settling pond approach remains an essential ingredient in many, if not most operations in Alaska. Settling ponds may or may not in fact represent "best available technology"; this issue is somewhat controversial, and such generalizations are difficult to sustain in any event. Economic considerations will be a major factor as well, in any situation, together with new technology. If a settling pond system is properly planned, constructed and operated, it should be capable of removing at least the coarser fraction of soil particles in the effluent stream and should also reduce wastewater turbidity. BLM does not recommend specific design criteria; as long as unnecessary or undue degradation is prevented, an operator may construct essentially any type of structure desired. The Alaska Dept. of Environmental Conservation's (1987) Placer Mining Demonstration Grant Project Design Handbook presents materials which may be useful in certain situations.

In addition, some basic concepts include:

a. Before anything else, make sure that the operation has diverted as much water as possible around the active area, and that operations will be done using the least amount of water possible, in order to limit the amount of water needing treatment.

b. Make a field reconnaissance of the general site area to :

1. Determine how much surface runoff, groundwater and stream flow above the site could be diverted around the activity area. Review the operating and processing methodology to insure that operations will be carried out using the least amount of water possible, to limit the amount of water needing treatment. Recycling of process water through a small sump to remove coarse sediments may be sufficient to supply all the water needed at the processing plant, with minimal effluent.

2. Determine internal site drainage patterns, and estimate high flow.

3. Make preliminary layout sketches, and compute the volume and economics of all alternatives capable of handling the expected site drainage.

4. Select the most favorable alternative. Analyze the on-site building materials.

5. Analyze the settling pond's embankment geometry.

6. Prepare construction sketches and estimate all specifications.

c. During the planning process, remember that several small ponds are usually better at removing sediment than one huge pond.

d. A long tailrace from processing equipment to the first settling pond will help settle out coarser tailings and other particles before they are deposited in a pond, where removal is more difficult.

e. All sediment ponds must avoid fish entrapment.

f. If ponds are to be placed in the floodplain, they should be protected with dikes designed for at least the 10-year flood.

There are several types of ponds used in water treatment strategies. These include:

a. Settling Ponds -- Pond With Outlet. These ponds require:

1. A large cross-sectional area so that the horizontal velocity of water is very low.

2. Water to enter the pond over most of the width to make the entire pond effective, and to avoid "short-circuiting" and channel formation.

3. The settling pond outlet to be wide to skim off the top clear water while maintaining a low horizontal velocity.

b. Filter Ponds -- Pond Without Outlets. If the surface material on a mine is suitable, it may be possible to build a pond with no outlet that will allow outflow by filtration through the substrate. Some parameters include:

1. The water table below a filter pond must be low enough that water will filter out of, not into, the pond.

2. The walls and bottom of a filter pond must be porous enough to allow outflow. The pond should be kept full so that the entire pond, walls and bottom, are working, to prevent premature sealing.

3. Filter ponds must be large enough to prevent premature clogging with fines.

4. Coagulants should not be used in filter ponds as they will shorten pond life.

5. It is best to use a filter pond in series with a preceding settling pond to remove heavy particles.

c. Coagulation Pond -- Artificially Speeding Settlement. A coagulation pond is any type of pond to which coagulants/flocculants are added to speed up settling of sediment.

1. Coagulants should be used when there is a high concentration of solids that will not settle out and/or where there is a limited area for settling ponds.

2. Coagulants must be thoroughly mixed into the inlet water to be most efficient. Experience has shown that this is very important.

3. Many coagulants work best in warm water, with the basic settlement rate increasing substantially with increase in temperature. Others are equally effective over a broad range of temperature.

4. Coagulants are most effective when used in a series of ponds.

5. Coagulants should be added at the inlet of each pond to maximize exposure to the sediment, although if the initial mixing is done properly, the coagulants should only need to be added at the one point in the system.

6. Commonly used coagulants include: Aluminum sulphate (alum), ferrous sulphate, calcium hydroxide (hydrated lime), calcium oxide (quick lime), sodium aluminate, sodium carbonate (soda ash), ferric chloride and sodium silicate.

Various agencies (U.S. Bureau of Mines, Environmental Protection Agency) are presently investigating aspects of the use of coagulants/flocculants (particularly "PEO" - polyethylene oxide). Alternate technologies are being developed which may eliminate the need for settling ponds in treating waste water.

RECLAMATION

All plans should be prepared, and all operations carried out with final reclamation in mind. They must adequately consider the intended methods and procedures for reclaiming the disturbed area, removal or leaving of permanent structures such as camps or river training dikes, and whether access is to be kept open after the site is reclaimed since this influences the required design life of the access road. Final reclamation requirements, as well as the required interim stabilization of areas during the operation, may affect how the operator strips overburden, locates settling ponds, diverts streams, locates roads, constructs buildings, stores fuel, selects operating and rehabilitation equipment and, in general, plans all phases of the operation. Reclamation of areas disturbed by casual use, notice or plan operations will occur annually or on completion of operations, as determined by the BLM Authorized Officer, in conjunction with the operator. A schedule for reclamation will be a required part of all plans. It should be stressed, again, that BLM standards for reclamation are performance rather than design standards.

Goals of Reclamation

Fundamental goals of reclamation are to facilitate reestablishment and/or recovery of natural vegetation, to control thermal and water/wind erosion, and to provide for passage of fish and wildlife. In most cases, surface erosion on disturbed sites will be greatest in the period between grading/shaping and establishment of a protective vegetative cover. This means it is imperative that slope stabilization measures such as grading, contouring, terracing, etc. be applied as soon as possible after disturbing an area, so that reclamation is essentially concurrent with disturbance. These stabilization measures must be capable of providing rapid and effective erosion control benefits until a nurse or protective crop of fast-growing exotics or final native vegetation can be established. While having an operator do minimal grading, contouring and shaping and then applying large amounts of seed and fertilizer may be a common, effective practice elsewhere, in itself this is not generally acceptable reclamation in Alaska. With the short Alaskan growing season some sort of effective mechanical stabilization of disturbed lands is required to allow vegetation the time to recover.

During the course of many surface disturbing activities involving the processing of earth materials, inevitably some segregation by particle-size occurs - in fact many such activities, including placer mining, are predicated on effecting some sort of separation such as this. To varying degrees, this will be manifest in the resultant processed materials which are ultimately to be redistributed during reclamation of the disturbed area. This may or may not be a serious concern, in any given situation. An interesting, if perhaps somewhat extreme effect of this may occur in areas underlain by permafrost. In the Fairbanks, Alaska area, some early placer mining operations on which little or no reclamation was attempted resulted in situations where coarser gravels remained segregated from silt/clay size materials, or were left under a capping of silt/clay/"soil" materials. This resulted in enhanced local drainage situations, with the further result that the previously underlying permafrost was thawed as well, to varying extents. This in turn resulted in the development of local ecosystems somewhat different from those originally present at these sites, prior to the mining activity. The desirability/acceptability of such a result might well be rather controversial, in any case. The chain of cause and effect relationships involved is illustrative, at least, of the complexities involved in attempting to manage surface disturbing activities and their attendant effects.

Because operations in Alaska are subject to many economic vicissitudes which may lead to abandonment, it is very important to protect the environment during prolonged periods of inactivity. Specific measures to be taken during any "temporary" work suspension should include, but should not be limited to:

Removal of all equipment, materials and stockpiles from the portion of the floodplain active during spring breakup or other predictable flood events.

Interim Stabilization

The operator must prevent and control on-site damage to surface resources during all operations. This should normally include the following, unless otherwise approved by the BLM Authorized Officer:

a. Saving of all available topsoil (including the organic mat) for final respreading after reshaping the disturbed areas.

b. Stabilization of the saved topsoil, overburden and disturbed areas to prevent erosion, landslides or degradation of adjacent waters.

c. Isolation, removal or control of toxic materials.

d. As each part of an operation is completed, erosion control devices should be installed and the area should be reshaped, sloped, and graded immediately to blend with surrounding landscapes and to minimize ponding and/or erosion.

e. Provision for fish passage during and after operations.

f. Revegetation of all disturbed lands to prevent erosion prior to final reclamation.

g. All slopes or river banks cut or filled during access or other operations - related disturbance must be stabilized to prevent thermal, fluvial and/or wind erosion.

Final Reclamation

Reclamation of disturbed areas should be accomplished at the earliest feasible time, except to the extent necessary to preserve evidence of mineralization or for other acceptable compelling reasons. In addition to stabilization measures, final reclamation shall include the following, unless otherwise approved by the BLM Authorized Officer.

a. Reshaping of all disturbed areas to an appropriate slope and shape consistent with the topography of the area, as feasible. The reclaimed area must be stable and have slope and shape that will prevent excessive erosion, and allow for passage of fish and wildlife.

b. The topsoil, organic overburden and vegetative slash and/or debris removed from the site and stored prior to mining should be respread over the site where reasonably practical. Mechanical stabilization and natural revegetation should be favored over artificial seeding and fertilizing.

c. Reestablishment of streams, including their approximate natural meanders and gradients.

d. Rehabilitation of fish and wildlife habitats.

e. All manmade debris and equipment must be removed from the site unless otherwise approved.

f. All access roads, culverts, low-water crossings and/or bridges installed by the operator should be removed (unless otherwise approved) and the areas reclaimed.

g. Settling ponds should be dewatered by pumping or slowly lowering dams/dikes. Trapped silt should be either (as approved):

    1. Stabilized and left in place, with due consideration for protection from flooding.

    2. Removed and broadcast with topsoil and other organic debris.

    3. Removed and taken to an approved disposal site.

    4. Seeded, if necessary, for stabilization.

Both the operator and BLM must always keep in mind what equipment will be readily available when it is time to reclaim. Any reclamation plan which requires unavailable equipment is essentially doomed. In Alaska, a miner generally will have a bulldozer or front loader, or both. This equipment, combined with various hand tools, may represent the entire reclamation equipment inventory, and plans must be made accordingly.

Reclamation of Fish/Wildlife Habitat

If the plan calls for the disturbed site to be reclaimed as fish and wildlife habitat, the BLM and operator should develop the following types of information:

a. Site specific estimates of present and potential (after reclamation) hydraulic discharge, stages and valley cross-section.

b. Ground level sketches of the present physical and biological characteristics of the site and its environs.

c. After walking the entire site and the surrounding undisturbed area to develop an idea of the potential as fish and wildlife habitat, note the present habitat mixture, with a view towards possibly increasing habitat diversity through reclamation activities. Things to note include:

1. The type, amount and distribution of boulders, logs, and other velocity barriers and associated fishery habitat in all streams on or near site.

2. Stream bank vegetation, including whether banks are undercut or have overhanging vegetation, for all streams on or near site.

3. Submerged or emergent vegetation in waterways on or near site.

4. Water depth of all waterways on or near site.

5. Types of waterbird habitats offered by on or near site waterways.

6. Types of furbearer or game mammal habitats offered by on or near site surroundings.

7. Types of bird habitats offered by on or near site surroundings.

Stream and Floodplain Rehabilitation

As discussed by Rundquist et. al. (1986), stream rehabilitation should stabilize the active stream channel and provide it with proper configuration, size and profile to safely pass a two year flood event. If fish are present in the stream, rehabilitation should be planned to provide desirable fish habitat. The length of the stream reach being rehabilitated can be critical to overall success, and should approach as closely as possible the pre-disturbance length. If too short, the stream will tend to erode upstream and deposit downstream. If too long, it will tend to deposit upstream and erode downstream. In many cases, the bed and banks of rehabilitated streams will benefit from armouring of the bottom and banks with gravel, stones, riprap or other materials to insure bed and bank stability.

The objective is to return the floodplain to a condition that promotes rapid recovery of floodplain vegetation. Techniques to encourage this recovery include:

a. Creating a variety of plant microhabitats during the grading and shaping process, producing surface roughness to slow erosion and encourage revegetation.

b. Spreading topsoil or other suitable plant growth medium on top of coarse tailings. Sediment from settling ponds may provide an excellent growth medium in many instances.

c. Distributing woody debris over the graded floodplain to create microhabitats, and to provide seed.

As discussed in U.S. Department of Interior, Fish and Wildlife Service (1980), disturbances, including excavations, in a floodplain can be reclaimed, and, if done properly, may actually increase local fish and wildlife habitat diversity if certain concepts are followed, including the following:

a. Excavations on the inactive floodplain, separated by vegetated buffers in the range of 150 - 300 feet from an active channel, generally are not in danger of influencing active channel hydraulics.

b. All excavations must be provided with a low water outlet at the downstream end of the pit to allow escape of any fish entering the pit during high water. A pit thus connected to an active channel may provide additional fish-rearing and overwintering habitat, provided that the pit provides a diversity of depths and a suitable average depth to minimize winter mortality.

c. Pits that are not and cannot practically be connected to the active channel may provide waterfowl and shorebird habitat if a diversity of depths is provided in the reclamation process.

d. Reclaimed pits are most beneficial to local fish and wildlife when they exhibit the following characteristics:

    1. One acre or more in area.

    2. Diverse shoreline configuration.

3. Diverse water depths.

4. Contain islands.

5. Contain an outlet connected to active channel.

Some Guidelines for Revegetation in Alaska

The following comments are adopted in part from Kubanis (1982), and Alaska Rural Development Council (1983). The primary goals for revegetation should be the ultimate reestablishment of native vegetation, and prevention of thermal and water/wind erosion. Reestablishment of native vegetation will provide erosion control, regenerate natural habitats and avoid the long term maintenance problems commonly associated with exotic plant cover which, of course, is less desirable, and expensive as well.

However, it must be appreciated that in many instances it may be most effective to utilize non-native species, at least on an interim basis. The sooner a disturbed site is revegetated the better, for reclamation, in terms of physical considerations of stabilization and erosion control. The rate of revegetation by native species may be too slow, in some cases, particularly on large areas of significant surface disturbance. The use of native species entails a source of propagula, either naturally or from some other source. There are few known commercial sources of native seeds for Alaska. The seeds of many native species have relatively low viability. On the other hand, there are some exotic species which seem to be sufficiently adaptable for many cases in Alaska. These include, but are not limited to, Bluegrass (Poa sp.), Fescues, Wheatgrass, Timothy, and Meadow Fox-Tail, all of which are readily available, have excellent characteristics for use in erosion control, and are generally replaced by native species eventually.

It should be stressed that efficient and effective revegetation requires site specific study by knowledgeable specialists, and that this is essential to ultimately satisfactory reclamation.

It should be emphasized that adequate site preparation is essential for native vegetation recovery, with inherent attendant erosion control and minimal maintenance requirements. In general:

a. Areas which have little or no erosion potential need not necessarily be seeded. These areas should still receive reapplication of surface materials, seedbed preparation and, if indicated by laboratory tests, light application of appropriate fertilizer to facilitate the reestablishment of native vegetation.

b. Areas with moderate erosion potential which appear to need some vegetative cover to assist in erosion control should receive reapplication of surface materials, seedbed preparation and be seeded at recommended levels, preferably with persistent, adapted native species and, as appropriate, light amounts of fertilizer.

c. In areas which have severe erosion potential even after grading, shaping and contouring, fertilizer and non-native grasses, such as annual rye grass, should be used as a nurse crop for invading native vegetation.

Site Treatment for all Disturbed Sites.

1. Surface materials should be segregated and stockpiled for reapplication as an integral part of the mining process.

2. Final grading of both subsoil and topsoil should avoid producing a smooth surface, in order to allow the sub and topsoils to bond, and to provide enough roughness for native seed capture. Desirable surface roughness can be produced by scarifying, harrowing, chaining or other means.

3. The site should be tested for fertilizer and other needed amendments, and treated as early in the growing season as possible. Appropriate standard commercial fertilizer is generally acceptable.

4. All disturbed areas should be allowed to revegetate naturally (i.e. no seeding) except for those areas for which some type of fast-growing, exotic vegetation is necessary for erosion control.

5. Areas should be monitored to determine when additional maintenance treatments are necessary, such as fertilizer, watering, etc.

Treatment for Disturbed Sites with Significant Erosion Potential.

1. As above, except for #4, as applicable.

2. Seeding of areas with moderate erosion potential preferably should consist of native species.

3. Areas of severe erosion potential needing dense, rapid vegetative growth should be appropriately fertilized and seeded at recommended rates with strips of annual rye, or other species with similar stabilization capability. Alternatively, a native seed mix containing no more than ten percent by weight of ryegrass spread evenly across the area of concern may be effective.

4. Any seeding should be done as early as possible in the growing season, or immediately before the first permanent snow cover in the fall (assuming this can be predicted with any confidence).

5. Mulching, if necessary, should be applied separately from fertilizer and seed to insure that seed is in contact with the soil.

6. Areas should be monitored to determine when additional maintenance treatments are necessary.

Other Revegetation Treatments and Guidelines.

1. Do not try to revegetate predominantly gravel surfaces unless fines are available to blend in.

2. Sandy areas should be covered with topsoil or other growth - encouraging and anchoring medium, and seeded.

3. Whenever possible, strips or "islands" of natural vegetation should be left undisturbed within large mining areas to provide a seed source.

4. Large areas which must be planted to exotic, non-persistent grasses should be planted in narrow strips in order to leave gaps where native vegetation may invade.

5. Woody species should be investigated for planting along with other species for erosion control, wildlife habitat enhancement and provision for long-term, maintenance-free erosion control. Woody species plantings may be optimal in disturbed riparian habitats outside the annual floodplain, especially if riparian habitat is limiting to local wildlife.

6. Areas should be monitored to determine when additional maintenance treatments are necessary.

Preparing the Site for Revegetation.

As discussed in general by USDA-FS, (1979), preparation for revegetation should start with the preparation of the operations plan, or when the operator and BLM agree as to the optimal time for site rehabilitation and planting and, in general, what will be deemed as constituting success. Planting time in Alaska is usually in the spring and very early summer, but may vary depending on what time of the year surface disturbing activities conclude. The area of concern must receive any needed preliminary grading and shaping prior to topsoil placement. The following operations are important to provide an environment that will be within the tolerances of the plants:

a. Rip, harrow or scarify the subsoil to eliminate the compaction stemming from subsoil placement, grading and shaping. (During revegetation on the pipeline [TAPS], a contour harrow consisting of a large wire mesh with heavy wires protruding downward was towed over the surface both before and after seeding to increase germination success.) This step may not be essential, if good quality topsoil, or other loose material, in sufficient amount, is available for spreading.

b. Spread topsoil over subsoil.

c. Rip, harrow, or scarify topsoil to eliminate the compaction stemming from topsoil placement.

d. Stabilize area to prevent erosion and await natural revegetation.

OR

d. Spread and blend in fertilizer and/or other soil treatments if required, after laboratory testing spoil and topsoil to determine proper amounts.

e. Plant (drilling is the best method of seed planting but in most cases, some type of broadcasting will be used) if required.

f. Stabilize area to prevent erosion.

<u>Selecting Species for Revegetation</u>.

If BLM approves or requires initial revegetation other than natural revegetation, the proper species mix must be selected. Not all species are adapted to all sites or uses, and a number of factors affect adaptability. The ability of the selected species to complete its life cycle and replace itself in succeeding generations is the goal of this species selection. Here are a few things to keep in mind in making a selection:

a. "Nurse" crops or "companion" crops, which are usually unadapted annual species, may have to be planted either before or with the permanent species mix, in order to temporarily stabilize the site. However, the nurse crop must be selected carefully, as some may persist long enough to provide excessive competition with desired permanent species.

b. BLM directives and State of Alaska regulations should be consulted concerning unwanted "weed" species before formulating the species mix.

c. Each species in the permanent mix must be investigated to insure compatibility of its growth form, stress tolerance, mineral nutrition requirements and reproduction characteristics with other species in the mix.

d. Costs and availability of each species should be considered before determining the final mixture.

e. The amount of maintenance each species in a mix requires after initial establishment is extremely important.

f. Each species in the mix, and the mix as a whole, must be adaptable to:

1. Soil characteristics at the site, including pH, fertility, texture, depth, permeability, presence of toxic materials and water retention capacity.

2. Precipitation at the site, including both total amount and seasonal distribution.

3. Local temperatures, including species hardiness over the annual cycle of highs and lows.

4. Elevation of the site.

5. Slope of site, which influences soil stability and the amount of sun received.

6. Aspect or exposure of the site, which affects day length, solar radiation loads and length of growing season.

7. Wind velocities blowing across the site.

8. Other factors such as reaction to fire, browsing/grazing, pest resistance, etc.

Seeds are usually the least expensive plant materials for revegetation, if they can be properly applied when sufficient moisture for germination is expected. They can be used whenever site erosion is not a major problem, and when the proper mix for the site can be economically obtained. Seedlings should be used when site conditions are harsh and where a faster developing ground cover is important enough to offset the greater cost. Seedlings can be obtained in many different forms. Choice of the form, such as container-grown stock, bare-root stock, cuttings, rhizomes, sprigs, wildings or plugs, again depends on relative cost versus desired level of revegetation success.

Given that the goal of reclamation is to enhance the eventual recovery of natural, native, indigenous plant species and to prevent the disturbed area from eroding and polluting streams in the future, application of seed and fertilizer alone will not provide effective reclamation.

Site-specific applications of exotic nurse crop seed and fertilizer where tests and/or Alaskan experience have shown it to be needed, where it is applied during the proper season and repeated as necessary may indeed enhance native plant recovery, especially on sites where no organic materials or topsoils are available for respreading, and where a mineral soil was used as a seedbed. However, no amount of seed and fertilizer will allow establishment of permanent vegetation on bare rock or gravel without any topsoil or organic cover. It should also be emphasized that application of exotic seed and fertilizer may allow exotic species to outcompete native species, and prevent or inhibit native plant recovery. Unless there is refertilization each year, most exotic species will die after their rapid growth has used up not only the commercial fertilizer but all of the naturally available nutrients on the site normally available to native plant recovery. In some cases, it is best not to apply any exotic seed and/or commercial fertilizer. Application of exotic seed and fertilizer to improperly prepared sites or during the wrong season will do nothing to help native plant recovery. If the site has not been properly prepared the seed and fertilizer will probably be washed off with the first rains. If the seed and fertilizer is applied in fall or winter, it may often be carried away with breakup, although in some instances seed may work its way into the ground through frost cracks and become covered up during breakup.

Post-Operation Monitoring

BLM and the operator should both be concerned that site reclamation will last through the years and return the site to some useful condition. If the site was artificially revegetated, it should be refertilized and replanted as necessary until an erosion resistant, self-sustaining growth of vegetation has been established. This does not mean that every square inch of a site must support vegetation. If the site is stable (erosion resistant) with only 10% cover, the site can, in general, be considered to have been successfully reclaimed. BLM should continue to monitor the site following initial reclamation, in order to have any shortcomings corrected, until reclamation is deemed to be complete. This post-operations monitoring is essential to successful reclamation. Not all reclamation attempts will be equally "successful". There should be as clear and unambiguous an understanding as possible between the operator and BLM as to what will constitute "successful, complete" reclamation in each instance, on a case-by-case basis. This is imperative.

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PREDICTING THE INFLUENCES OF POST-MINING CONDITIONS ON SURFACE AND GROUNDWATER RESOURCES

Michael J. Day[1], Richard A. Mills[2] and James G. Nalven[3]

ABSTRACT: Backfilled areas of surface mines generally have different hydrogeological properties than undisturbed overburden material. Recharge, groundwater flows, surface discharge locations, and water quality may be significantly changed in post-mining conditions. Predicting post-mining hydrogeological conditions, and how these may vary seasonally and over time, is necessary for evaluating potential impacts on water resources. A predictive study of post-mining hydrogeologic conditions and potential hydrological influences on downstream water resources was undertaken for an active surface coal mine in NW Colorado. The study focused on existing conditions at an old backfilled area adjacent to active mining operations. A conceptual model of the backfill hydrogeology was developed based on several sources of information. These data included the hydrogeologic setting, calculated backfill recharge rates from lysimeter studies at adjacent mines, monitored flow and quality of backfill discharges, laboratory leaching studies, and water quality trends in down-gradient bedrock groundwater. Present backfill discharge varies seasonally but is in approximate balance with average annual recharge. Discharge quality is reasonably consistent and is predictable from leaching studies of overburden cores. The apparent equilibrium of the backfill hydrogeology allows a definitive assessment of seasonal hydrologic influences and extrapolation of results to future backfill areas with similar hydrogeologic settings. The study predicted no significant influence on the use of downstream water resources.

KEY TERMS: Mining; hydrologic impact; backfill; spoil; disturbed land

INTRODUCTION

The Surface Mining Control and Reclamation Act (SMCRA) of 1977 requires mining companies and regulatory agencies to perform evaluations of the probable hydrologic consequences of mining operations. In the semi-arid western United States these evaluations have particular relevance due to the importance of water resources. Surface coal mining activities involve the removal of soil and overburden materials to allow extraction of the coal resource. The topsoil and overburden materials are usually stockpiled separately prior to reclamation activities. Reclamation typically involves backfilling the mined area with overburden materials, grading to create a specifically designed post-mining topography, replacement of topsoil, and revegetation of the reclaimed surface.

[1] Applied Hydrology Associates, Inc., Denver, CO
[2] Yampa Valley Coal Company, Steamboat Springs, CO
[3] Cyprus Coal Company, Denver, CO

Significant improvements in knowledge and techniques for reclamation of surface mined lands in the west have occurred over the past 15 - 20 years. However, the nature of mining activities is such that there will always remain some difference in hydrologic characteristics between reclaimed areas and undisturbed areas. These differences will tend to influence infiltration of precipitation, surface water runoff and quality, groundwater flows and quality, and locations of groundwater discharge areas. Predicting the post-mining hydrogeological conditions, and how these may vary seasonally and over time, is necessary for evaluating potential impacts on water resources. This paper describes a predictive study of post-mining hydrogeologic conditions that was undertaken for the Eckman Park Mine in northwestern Colorado.

REGIONAL HYDROGEOLOGIC SETTING

The Eckman Park mining operations are located in Routt County in northwestern Colorado about 20 miles southwest of the town of Steamboat Springs (Figure 1). The mines are located on the southeastern rim of the Twentymile Park Basin which is part of the regional Yampa River Basin (Figure 1). The Twentymile Park Basin is drained by Trout Creek and its tributaries, Fish Creek, Middle Creek and Foidel Creek. Trout Creek is a tributary to the Yampa River.

Weather station records at Hayden, Colorado indicate that the average annual precipitation in the area is about 16.5 inches of which about 7 inches is attributable to snowfall. Streamflows in the Twentymile Park increase markedly during the spring snowmelt period (Figure 2). This period varies slightly from year to year but typically is of about two months duration and occurs within the period from mid-April to mid-July. The streamflow response during this time reflects increased surface runoff and groundwater discharge. Under natural conditions, Middle Creek and Foidel Creek are intermittent drainages that have measurable flows for 4-5 months following the spring snowmelt period (Figure 2).

The geologic formations which crop out in the area of the Eckman Park mine are primarily of Cretaceous and Tertiary age. The primarily bedrock units of interest are associated with the Mesaverde Group (Figure 3). The mineable coal deposits of the region occur in the Mesaverde group, specifically the Williams Fork and Iles Formations. The top of the Iles Formation is defined by the Trout Creek Sandstone, a persistent cliff-forming unit that underlies the Eckman Park mine area (Figure 3).

The Williams Fork Formation comprises the upper part of the Mesaverde Group. In the area of the Eckman Park mine, the Williams Fork Formation may be divided into three distinct members. The lowermost member is referred to as the coal-bearing member and is composed chiefly of siltstone and shale with thin sandstones and bituminous coal beds. Significant coal beds in this member include, in ascending order, the Wolf Creek, Wadge and Lennox seams. The Wadge Coal is mined at the Eckman Park operation. The middle member of the Williams Fork Formation is a marine shale unit composed of fissile mudstones and occasional siltstones and sandstones. The upper member of the Formation is predominantly composed of sandstones and siltstones and includes the cliff-forming Twentymile Sandstone.

The Trout Creek Sandstone and the Twentymile Sandstone have sufficiently high permeability, particularly near their outcrop areas, to allow the flow of groundwater and are considered regional aquifer units. The coal-bearing member of the Williams Fork Formation locally yields groundwater to wells but, due to the limited continuity of the sandstone units in the Member and the generally poor water quality, it is not

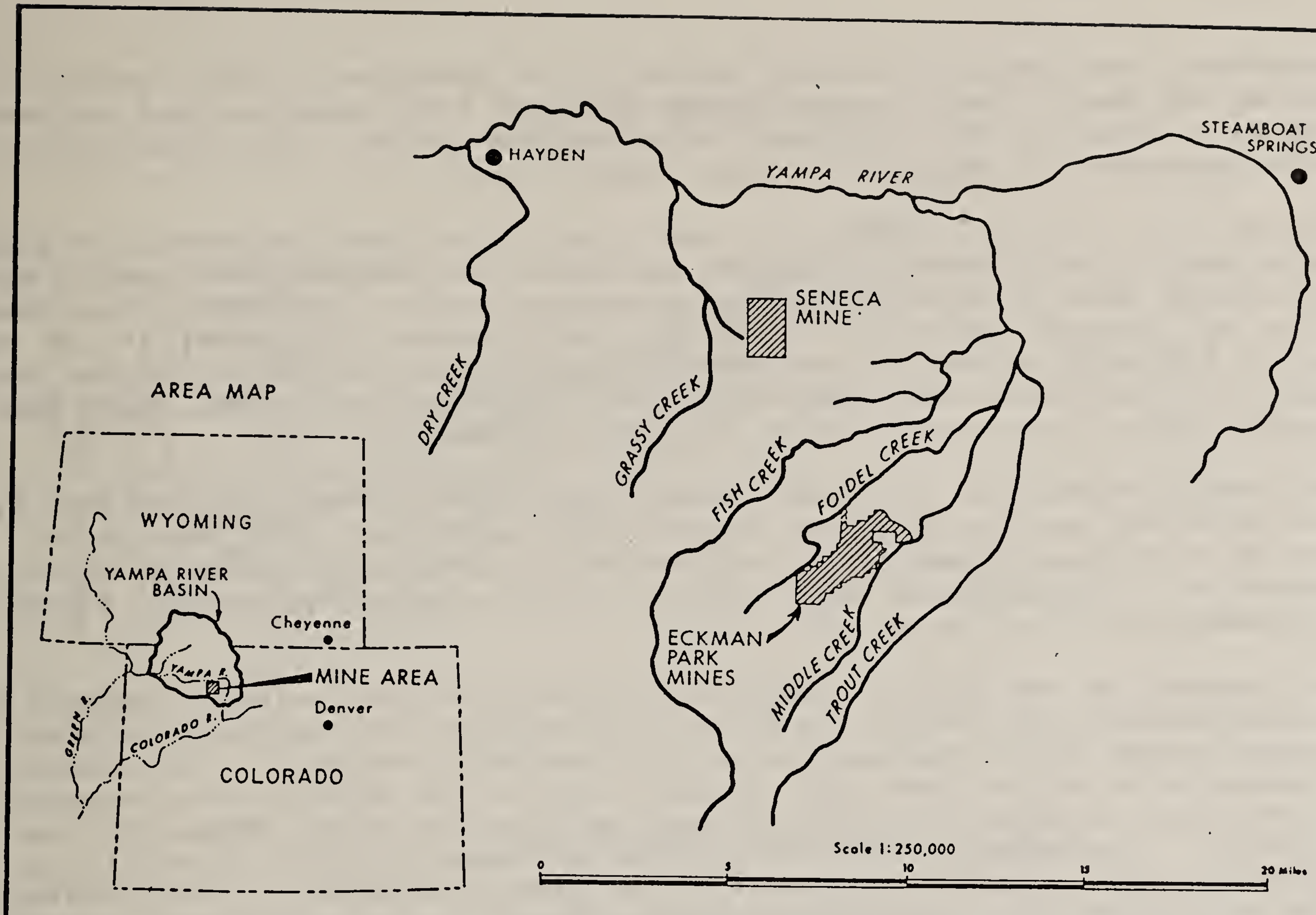

Figure 1 - Location of Eckman Park mining operations

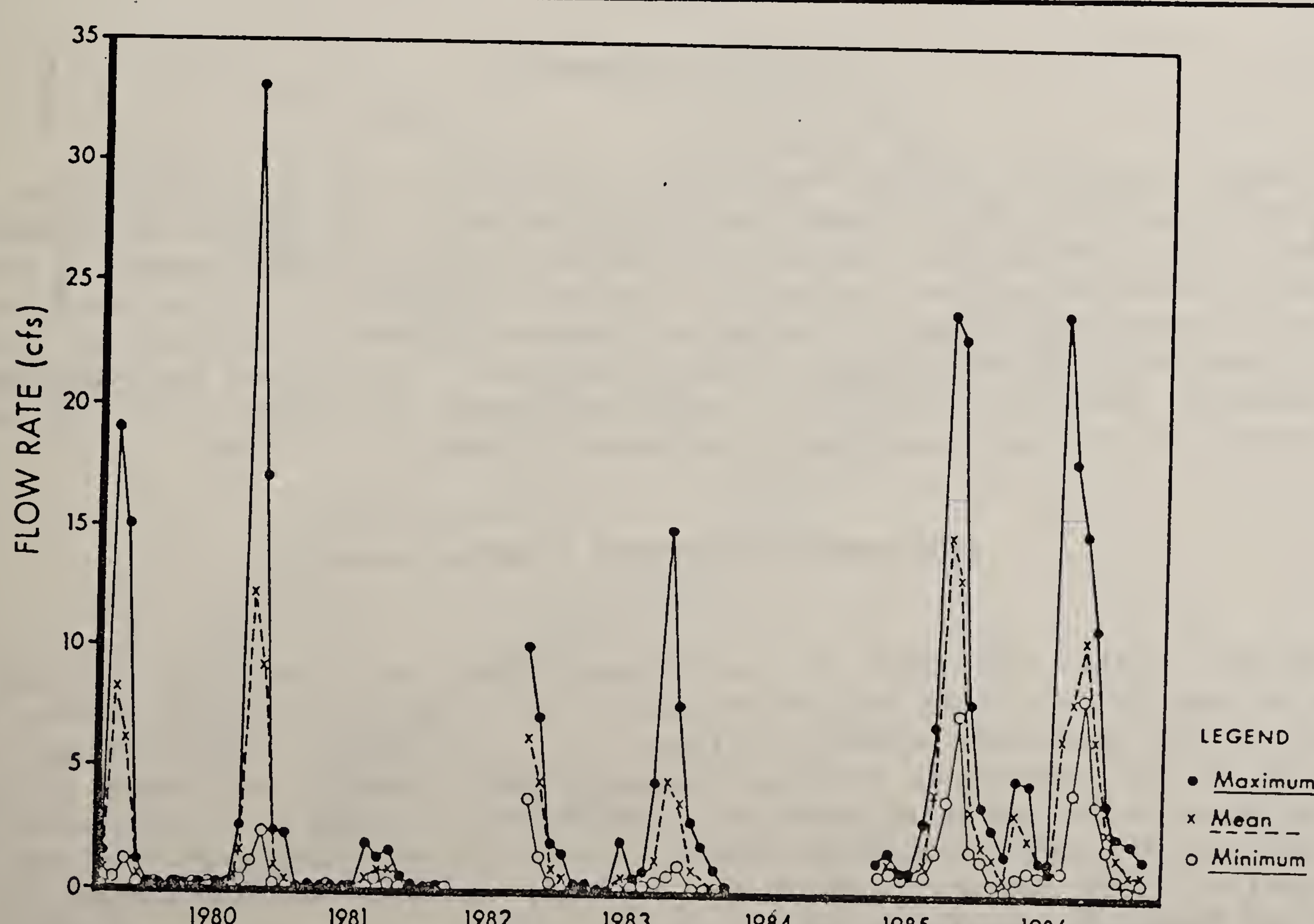

Figure 2 - Stream hydrograph for Foidel Creek (USGS Station 09243800)

considered a regionally significant aquifer. The predominantly shale geologic units such as the Marine Shale member of the Williams Fork Formation tend to restrict groundwater flow and are considered to be aquitard units. These aquitards act to confine groundwater in underlying bedrock aquifer units.

Recharge to the bedrock aquifer units most likely occurs from infiltration of snowmelt and rainfall in the southern and western margins of the Twentymile Park Basin. Most of the recharge tends to be during the spring snowmelt period. Groundwater flow tends to follow the regional dip of the lithologic units towards the center of the Basin. Natural discharge points for the bedrock aquifers are most likely in the eastern margins of the Basin where the valleys of Fish Creek and Trout Creek form the topographically lowest points across the bedrock outcrops.

The alluvial deposits of the creek valleys, particularly Trout Creek and Fish Creek, form localized aquifers that are hydraulically associated with the creeks. The alluvium is recharged primarily by infiltration of creek water during the spring high flow period. Discharge from these deposits to the creeks helps maintain baseflow in the creeks during low flow periods.

The topography of the area is strongly controlled by the more resistant geologic units of the Twentymile Park Basin. The Trout Creek Sandstone and Twentymile Sandstone form prominent cliffs in the southern part of the Twentymile Park Basin. The sandstone and siltstone units of the lower coal bearing member of the Williams Fork Formation are also resistant to erosion and form a conspicuous dip slope in the Eckman Park mine area (Figure 3). The width of the creek valleys and extent of alluvial deposits is also controlled by the erosional resistance of the underlying bedrock. Creek valleys tend to be very narrow and contain limited alluvial deposits as they cross the outcrop areas of the major sandstone units.

WATER RESOURCES

Surface water resources in the region are primarily used for irrigation. Direct diversion of water from Trout Creek and Fish Creek occurs at several locations. There are no historical or active diversions from Middle or Foidel Creeks. Groundwater resources in the area are used primarily for mining operations such as dust control and irrigation of reclaimed areas. Shallow groundwater resources and natural springs are used for stock watering and limited domestic purposes. Wells that are completed in the bedrock aquifer units tend to be at locations where the units occur at relatively shallow depth, at the Basin margins or in creek valleys.

HYDROGEOLOGIC SETTING OF MINED AREAS

Mining of the Wadge coal seam at the Eckman Park operations has occurred on the dipslope between Foidel Creek and the southern rim of the topographic divide formed by the Trout Creek Sandstone outcrop (Figure 3). Removal of the Wadge coal and replacement of the overburden material results in a backfill thickness of about 100 feet which dips to the north at about 6 to 10 degrees (Figure 3). The backfill abuts against the downdip unmined geologic units of the coal-bearing member of the Williams Fork Formation. The contact between the backfill and the unmined bedrock is just to the south of Foidel Creek (Figure 4).

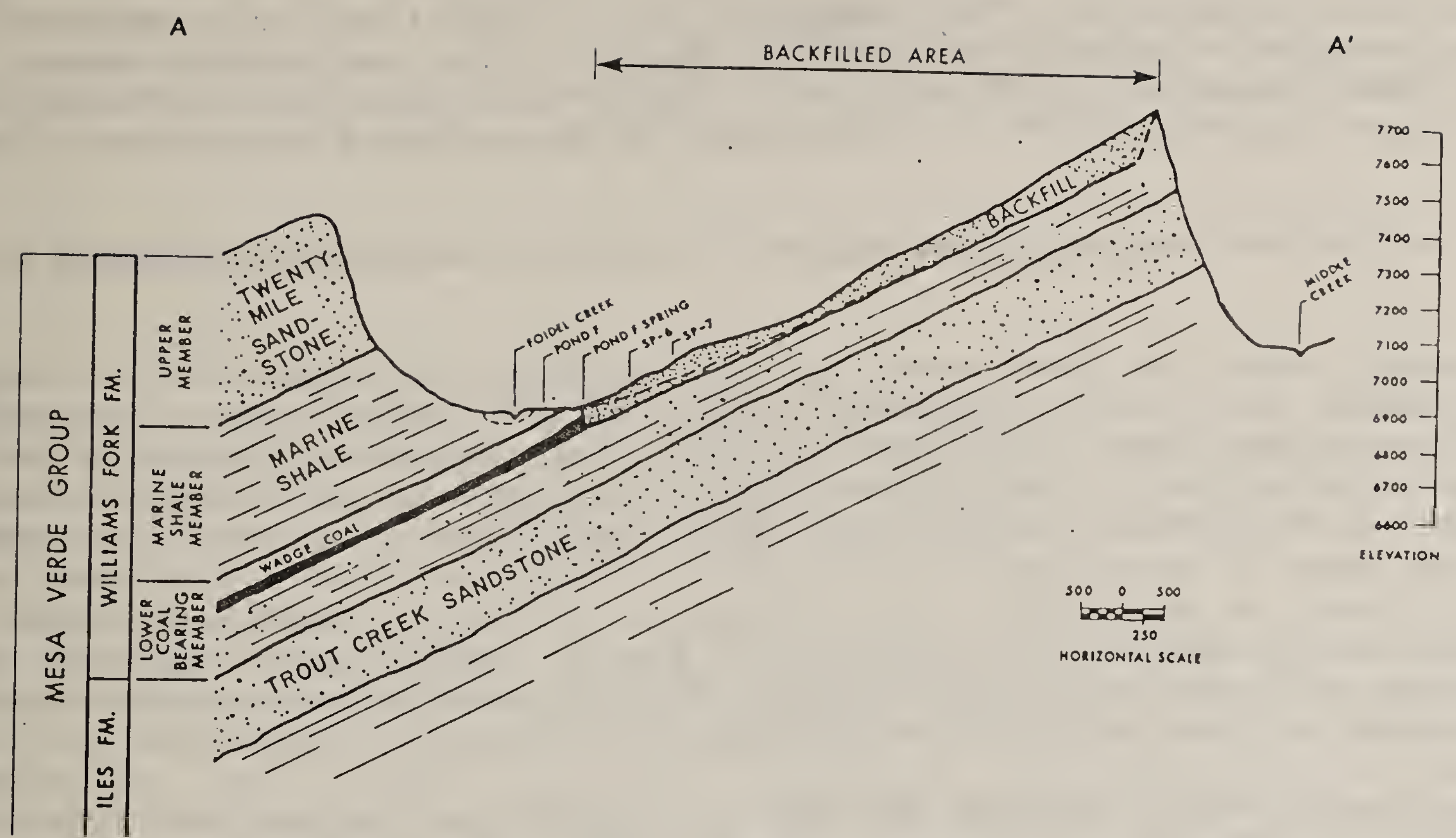

Figure 3 - Geologic setting of Eckman Park mining operations

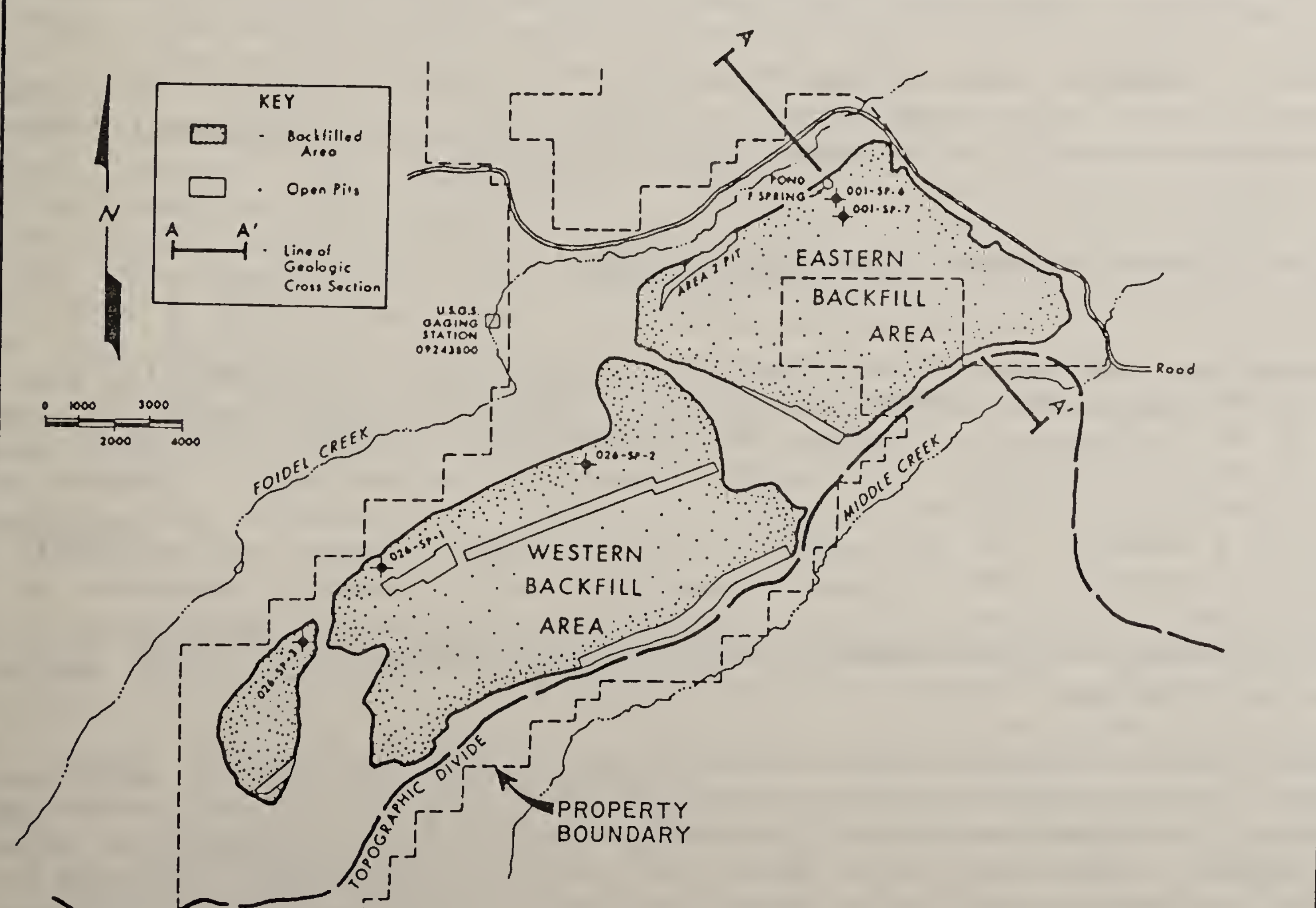

Figure 4 - Location of backfilled areas at the Eckman Park Mine

To the north of Foidel Creek, the topography rises steeply due to the presence of the resistant Twentymile Sandstone and surface mining of the coal-bearing Member of the Williams Fork Formation is not feasible. Underground mining of the Wadge coal is presently occurring downdip of a reclaimed area of the surface mining operations.

METHODOLOGY FOR EVALUATING PROBABLE HYDROLOGIC CONSEQUENCES OF MINING

The approach taken in this study was to quantify the hydrologic controls and characteristics of a fully reclaimed section of the surface mine, determine the influences of this area on adjacent surface and groundwater resources and then extrapolate the results to the projected future conditions at the mining operation. To the east of the present Eckman Park mining operations is a mined area that was backfilled about 15 years ago. This eastern backfilled area is believed to have reached a state of equilibrium with respect to hydrologic conditions. The active Eckman Park mining operation is situated in a similar geologic and topographic setting. Consequently, it seems reasonable to expect that the eastern backfilled area might be representative of final reclaimed conditions at the Eckman Park Operations.

A water and mass balance approach was used to estimate quantity and quality influences of backfill groundwater on adjacent surface water and groundwater resources. The analysis involved the use of site-specific data when available and extrapolation of data from adjacent areas or relevant studies as necessary.

QUANTIFICATION OF HYDROGEOLOGIC CONDITIONS IN EASTERN BACKFILL AREA

The eastern backfilled area extends from south of Foidel Creek to the topographic divide formed by the Trout Creek Sandstone outcrop (Figure 4). The area is trapezoidal in shape and covers some 6×10^7 square feet (1377 acres).

Hydrogeologic Characteristics of Backfill Material

The hydrogeologic characteristics of backfill material are highly variable due to the nature of the mining and reclamation process. These processes result in a backfill composed of an inhomogeneous mixture of fractured and rubblized overburden material. Groundwater movement through the backfill materials is partially dependant on the average hydraulic conductivity of these materials. The hydraulic conductivity of a material is a measure of how easily water may move through the materials under specified conditions. The overall capability of a backfill sequence to allow groundwater flow is reflected by the transmissivity of the unit. The transmissivity is given by the product of the weighted average hydraulic conductivity of the material and the saturated thickness.

The average hydraulic conductivity of the mixed backfill material is generally much higher than the original undisturbed bedrock due to the increased occurrance and continuity of fractures and voids. Continuous zones of low permeability materials, such as shales, which may have acted to restrict groundwater movement in the undisturbed overburden would not be expected to exist in the backfill. In general the backfill material will tend to allow more complete circulation of groundwater than in the undisturbed overburden.

Groundwater flow within the backfill will occur primarily within the zones of highest hydraulic conductivity. Hydrologic testing of piezometers installed in the backfill of the Eckman Park mine area indicate average hydraulic conductivities ranging from as low as 0.3 gallons per day per square foot (gpd/ft^2) to greater than 1000 gpd/ft^2. In some piezometers, the average hydraulic conductivity of the backfill was too high to obtain meaningful data from a standard response test.

Recharge to Backfill

Recharge to the backfilled area is from infiltration of precipitation, primarily during the spring snowmelt period when evapotranspiration effects are at a minimum. This is reflected in water level data from piezometers installed in the backfilled deposits. These show maximum water level elevations during the spring snowmelt period followed by a gradual decline during the remainder of the year (Figure 5).

Site-specific infiltration data in the eastern backfilled area are not available. However, data are available from a lysimeter study of reclaimed areas at the Seneca II mine, some ten miles to the northwest of the Eckman Park Operation. The geologic units involved in the Seneca II Operation are the same as those encountered at the Eckman Park Operation. The lysimeter study was performed by the US Geologic Survey between 1976 and 1981 and yielded information on rate and quality of recharge in backfill areas.

The recharge study involved five lysimeters constructed in backfilled areas which allowed the measurement of volumes and quality of water recharging the upper eight feet of backfill material. The data from this study indicated an average recharge rate of 5.93, 3.86 and 3.21 inches per year for the first three years following lysimeter installation. The recharge rates were considerably higher than originally expected and constitute 15-25 percent of the average annual precipitation of 16 inches.

The trend of decreasing recharge rates is most likely attributable to consolidation of the backfill material and establishment of vegetation. An average recharge rate of about three inches per year appears to be a reasonable estimate for the fully reclaimed eastern backfilled area at the Eckman Park Operation. If most of the recharge occurs as a result of snowmelt infiltration, this figure would constitute about 30 percent of the total snow precipitation. The total volume of recharge to the eastern backfill, based on this recharge rate and the area of potential infiltration, is estimated at about 1.5×10^7 ft^3/yr (1.1×10^8 gallons per year). Most of this recharge is assumed to occur during approximately a two-month snowmelt period.

Groundwater Flow

Snowmelt and rainfall that infiltrates into the backfill deposits will migrate under gravitational influences until a zone of saturation is reached. In the up-dip portions of the Eckman Park backfill, the first zone of saturation is encountered at the base of the backfill at the contact with the underlying shales of the Lower Williams Fork Formation. The thickness of the backfill saturated zone in these areas is typically less than a foot so that essentially the entire thickness of the backfill is unsaturated. Piezometers completed in these up-dip locations, such as SP-3 in the Western Eckman Park area, are dry.

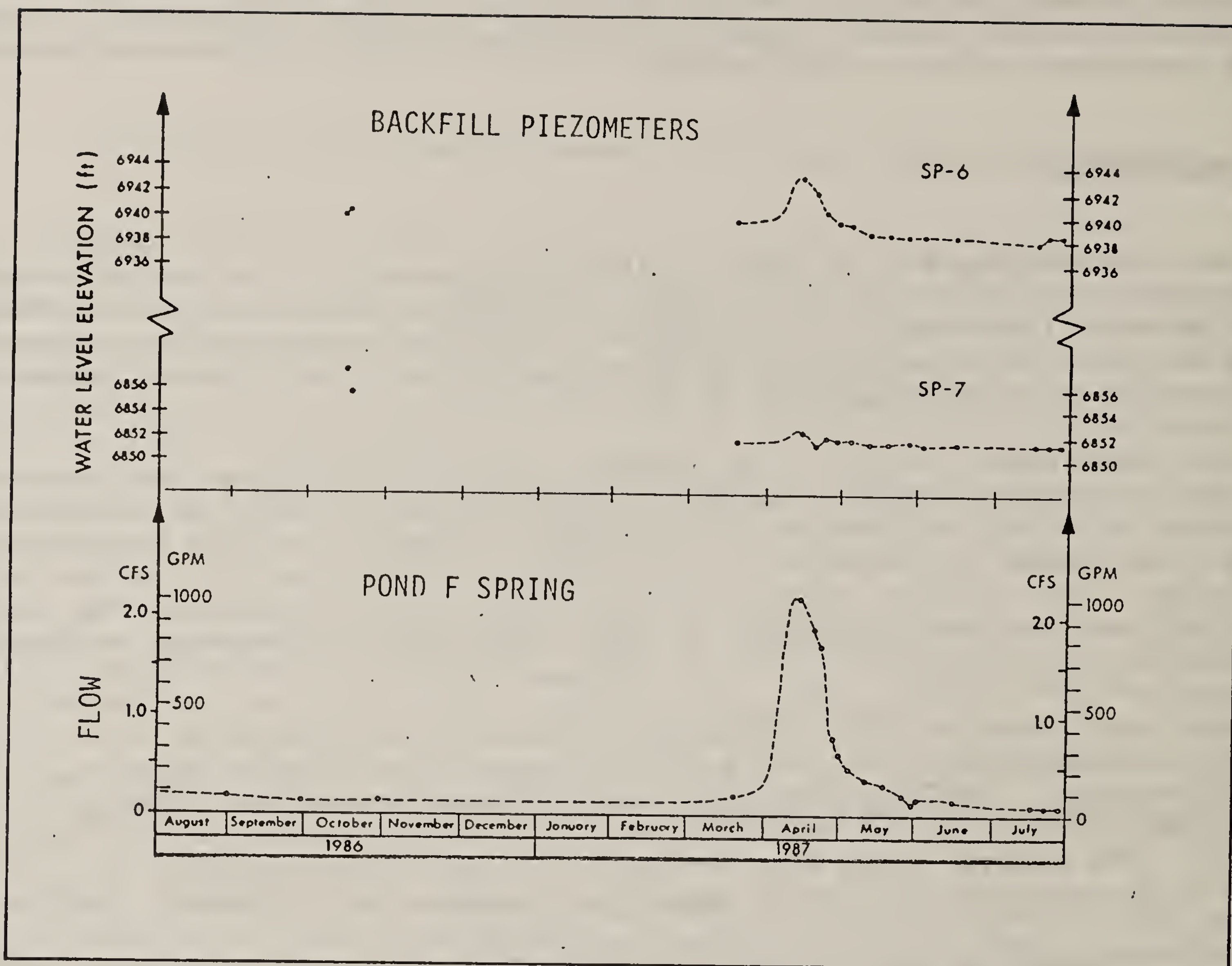

Figure 5 - Backfill piezometer and Pond F Spring discharge hydrographs

Within the saturated zone, there is a general tendency for groundwater flow in the backfill to follow the dip of the underlying low-permeability shales. This flow has lead to the build-up of a thick saturated zone in the down-dip areas of the backfill. The build-up is primarily due to restriction of backfill groundwater flow at the down-dip contact with the relatively low permeability, unmined bedrock of the lower Williams Fork Formation. Due to this restriction, only a small proportion of the backfill groundwater flows into these units. The majority of the backfill groundwater flow will discharge to ground surface at topographically low points along the backfill/bedrock contact.

Groundwater flow rates through the backfill may be estimated on the basis of standard steady-state flow equations:

$$Q = KIA \quad \text{.......................................} (1)$$

where:

Q = Flow rate (gpd)
K = Average hydraulic conductivity of backfill (gpd/ft^2)
I = Average hydraulic gradient (dimensionless)
A = Cross-sectional area of groundwater flow (ft^2)

Flow will be concentrated within the zones of highest hydraulic conductivity. As indicated above, hydraulic conductivities in excess of 1000 gpd/ft^2 exist in the backfill deposits of the Eastern backfill area. The hydraulic gradient in the backfill is a measure of the "driving force" for saturated groundwater flow. The hydraulic gradient between two points is function of the potentiometric head difference and the distance between the two points. Potentiometric head at any given location in the backfill is represented by the static water level elevation in a piezometer completed in the backfill at that location.

Piezometers SP-6 and SP-7, completed in the eastern backfill deposits up-dip of the Pond F Spring, are spaced about 400 feet apart in a north-south line parallel to the probable maximum hydraulic gradient (Figure 3). Potentiometric head elevations in both piezometers show maximum levels during the spring snowmelt period followed by a steady decline during the rest of the year (Figure 5). Potentiometric differences between the two locations range from 6.4 to 10.0 feet. This indicates a hydraulic gradient of 0.016 to 0.025 to the north in this part of the backfill.

The saturated thickness in the down-dip portions of the eastern backfill area averages about 50 feet. The east-west extent of the eastern backfill is about 7000 feet yielding a total cross-sectional area of groundwater flow in this portion of the eastern backfill of approximately 350,000 square feet. Substituting observed conditions for the eastern backfill into equation 1 yields groundwater flow rates that may be in excess of 10 million gallons per day or about 7000 gallons per minute (gpm). The point to emphesize is that high groundwater flow rates can occur in the backfill deposits so that a rapid response of groundwater levels and discharge rates to the spring snowmelt recharge period would be expected.

Discharge

Surface discharge of groundwater from the eastern backfill deposits occurs primarily at two locations along the downdip margin of the backfill. These locations are identified as the Pond F Spring and the Area 2 Pit (Figure 4). These two locations probably account for over 95% of the surface discharge of backfill groundwater. The remainder occurs as diffuse seepage that cannot be practically measured.

The Pond F Spring is a localized discharge point at a topographically low point along the backfill/bedrock contact. Discharge from the spring is measured using a cutthroat flume. At the time of the study initiation, the Area 2 Pit was an narrow unreclaimed strip bounded by the old mine pit highwall on the north and a reclaimed backfill area to the south (Figure 4). The pit was full of water and was over-topping into a sediment pond at a topographic low point along the old pit highwall. Discharge from the pit at this point could be measured using a cutthroat flume. The pit has been largely infilled since the present study was initiated and does not presently have the configuration shown in Figure 4.

Discharge data from the Pond F Spring are available from June 1985 to present. Discharge measurements are taken approximately once a week during the spring snowmelt period and monthly during the rest of the year. The seasonal variation of discharge from the Pond F Spring is illustrated in Figure 5. Discharge rates increase dramatically following the start of the snowmelt period, peak rapidly and then decrease fairly quickly to a baseflow level over approximately 2 month period. Peak discharge during 1987 was measured at 2.21 cubic feet per second (cfs) or 990 gpm and baseflow was approximately 0.12 cfs (54 gpm). In 1986, the peak discharge was measured at 3 cfs (1350 gpm). Examination of the discharge variation for the Pond F Spring over the period of record indicates a total discharge of approximately 5×10^7 gallons per year.

Discharge data from the Area 2 Pit are only available for a short period during 1985 before infilling of the pit started. The discharge from the Area 2 Pit during this period was derived from backfill groundwater inflow and appears to track the flow rates from the Pond F Spring fairly closely. This indicates that the area contributing to groundwater discharge at the Area 2 Pit has similar hydrologic characteristics and conditions to that of the Pond F Spring. This appears reasonable given the locations of these discharge points in relation to the eastern backfill area as shown in Figure 4. It is assumed that discharge rates from the Area 2 Pit are similar to discharge from the Pond F Spring for the time periods when direct measurement data is not available.

The total discharge to land surface from the eastern backfill area is thus assumed to be approximately twice the measured discharge at the Pond F Spring. The peak discharge from the eastern backfill area is thus estimated to be in the range 2000-3000 gpm. The total discharge is approximately 10^8 gallons per year.

Groundwater Storage in the Eastern Backfill

Groundwater storage refers to the volume of water that is held in the pore spaces of a geologic unit. In an unconfined water bearing unit, such as the backfill at the Eckman Park mine, the total storage is approximately equivalent to the saturated pore volume although a small proportion is also held in the unsaturated zone above the water table. Changes in groundwater storage are usually reflected in changes in potentiometric levels within the unit. An increase in potentiometric levels indicates an increase in groundwater storage and visa-versa.

Examination of the water level variation in the backfill piezometers (Figure 5) reveals a rapid increase in backfill groundwater storage following the spring recharge period. Total recharge to the backfill exceeds total discharge during this period and the excess is reflected in an increase in storage. Following the short period of active recharge, water levels in the piezometers decline, reflecting a gradual decrease in groundwater storage. The discharge from the backfill is derived almost entirely from groundwater storage during this period. The net change in storage over a complete year will be close to zero if the system has reached an equilibrium condition.

The effective porosity of fully-consolidated backfill materials at the Eckman Park mine is probably in the range of 20 to 25% which is a typical range for poorly sorted granular materials. On this basis, a uniform increase in groundwater level of 1 foot in these materials would constitute an increase in storage of 1.5 to 1.9 gallons per square foot of area over which this water level change took place.

Eastern Backfill Water Balance

The annual recharge to the eastern backfill area is estimated above to be approximately 1.1×10^8 gallons. Annual discharge from the eastern backfill area is estimated to be about 1×10^8 gallons. The overall balance of annual recharge and annual surface discharge is very close and indicates that the majority of the recharge to the eastern backfill area eventually discharges to the land surface. The estimated excess of annual recharge over annual discharge is about 1×10^7 gallons. This excess is partially attributable to margin of error in estimations and small variations in groundwater storage. A small proportion of the excess may be attributable to infiltration from the backfill to the underlying bedrock deposits. However, the majority of the estimated excess is most likely attributable to groundwater flow from the backfill into the down-dip unmined bedrock. This flow constitutes less than 10% of the total recharge to the backfill deposits.

There is independent evidence of minimal groundwater flow from the backfill into the down-dip undisturbed Wadge Overburden bedrock in the form of groundwater quality changes in the bedrock units. Electrical conductivity of groundwater in the Wadge Overburden units (a measure of total dissolved solids) has been measured in the Foidel Creek underground mine located immediately down-dip from the eastern backfill area of the Eckman Park surface mine. Measurements from a 1986 survey indicates a limited zone of bedrock groundwater where electrical conductivity measurements indicate influence from mixing with backfill groundwater. This very localized mixing zone has taken over 15 years to develop.

Average hydraulic conductivity of the undisturbed overburden deposits, based on numerous pumping tests at the Eckman Park mine, is about 3 gpd/ft^2. The hydraulic gradient in the overburden deposits down-dip from the eastern backfill area is about 0.1. Using these hydrogeologic parameters and a cross-sectional recharge area of 700,000 square feet, the groundwater flow from the backfill to the bedrock may be calculated from equation 1 at about 28,000 gpd or 10^7 gallons per year. This value is consistent with the value estimated from water balance considerations and constitutes about 10% of the total annual recharge to the backfill deposits. The extent of the localized bedrock groundwater mixing zone that has developed down-dip from the backfill over the past 15 years is consistant with the measured hydrogeologic conditions within the bedrock.

The conceptual model of groundwater flow within the eastern backfill deposits of the Eckman Park mine area appears to be supported by several independent sources of information. A summary diagram illustrating the conceptual model and the calculated annual flow volumes is shown in Figure 6. Typical annual variation in total recharge, discharge and storage within the eastern backfill deposits is illustrated in Figure 7.

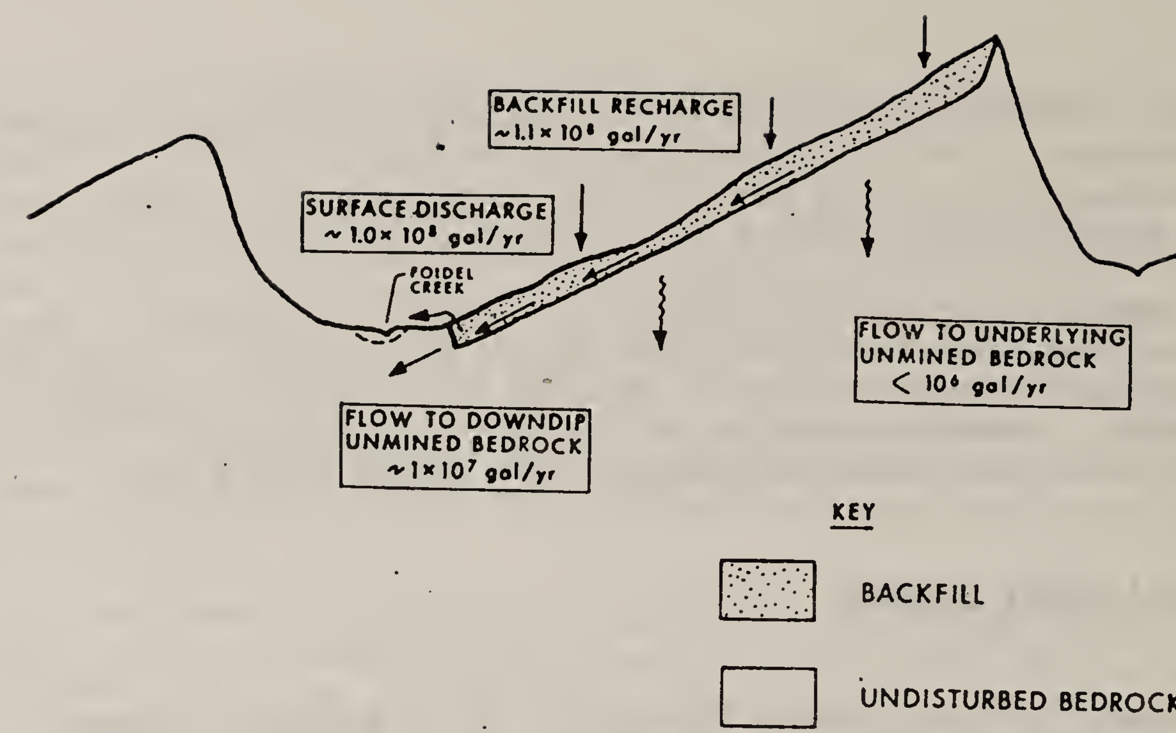

Figure 6 - Conceptual model of backfill water balance

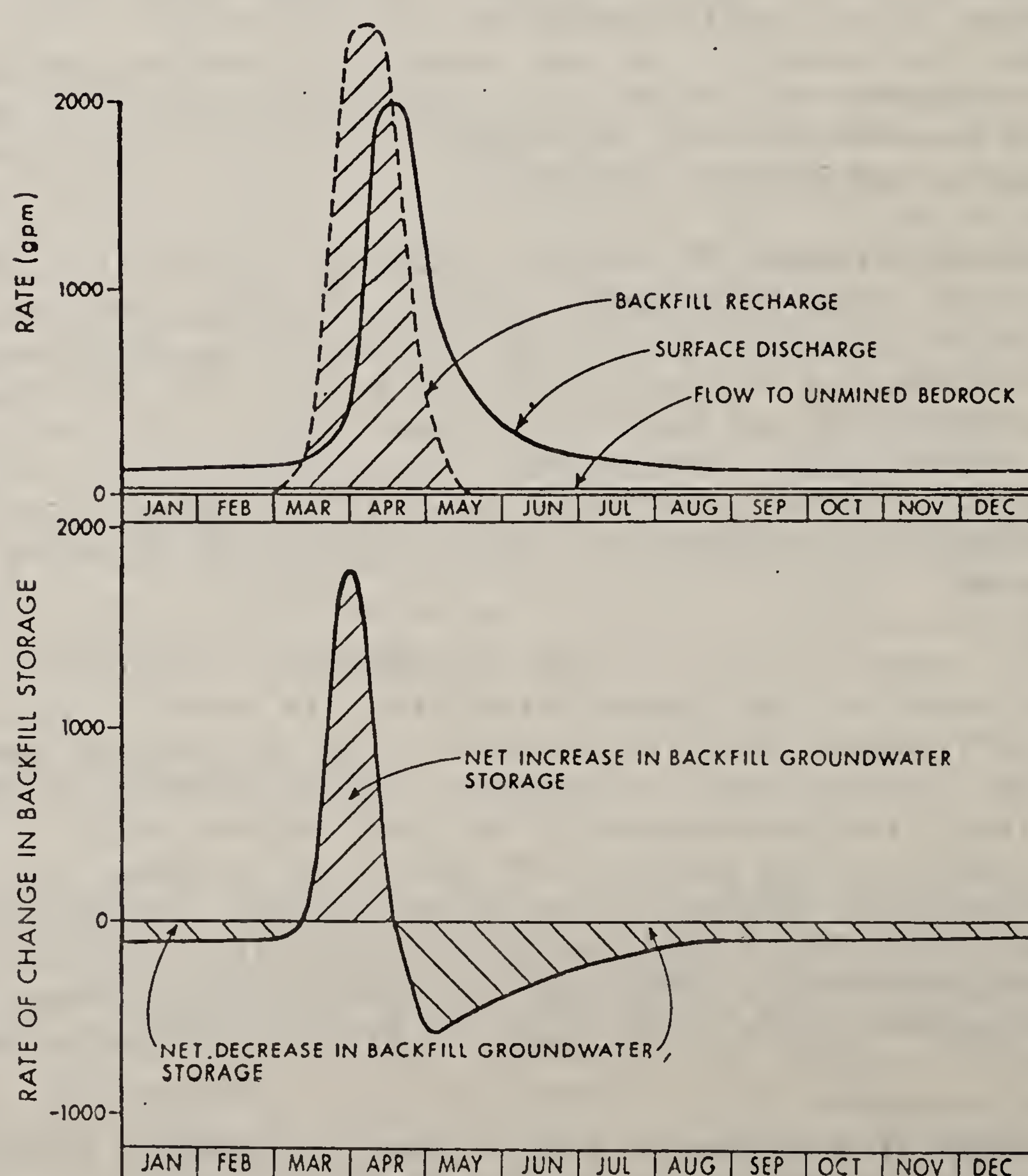

Figure 7 - Annual variation of backfill recharge, discharge and storage

Water Quality

The fracturing and mixing of overburden materials in the backfill exposes new rock surfaces to circulating groundwater. The absence of continuous low permeability layers also enhances the rate of vertical groundwater circulation. Due to these changes in physical conditions, the solution of minerals from newly exposed surfaces may occur at an enhanced rate compared with pre-mining flow paths. The chemistry of backfill groundwater is therefore likely to be different from that of undisturbed overburden.

Water quality characteristics of the Pond F Spring discharge are thought to be typical of a fully stabilized reclaimed backfill area. Water quality from the Pond F Spring is remarkably consistent and shows very little evidence of seasonal trends. The lack of correlation of water quality to discharge variations indicates that backfill groundwater solute concentrations probably attain chemical saturation conditions fairly rapidly. The Pond F Spring discharge typically has a total dissolved solids (TDS) content of about 4000 milligrams per liter (mg/l) dominated by calcium, magnesium and sulfate (Figure 8). This water quality is consistant with other studies of backfill water quality in the Twentymile Park area (McWhorter et al, 1979)

This water quality characteristics of the backfill discharge are very different from the unaffected overburden bedrock groundwater which typically has a TDS of about 900 mg/l and is dominated by sodium and bicarbonate (Figure 8). The chemical characteristics of bedrock groundwater, immediately downgradient from the backfill areas, is intermediate between backfill and baseline bedrock characteristics suggesting a mixing of these two water types (Figure 8).

Laboratory leaching studies of backfill material have demonstrated that over 90% of the dissolved solute constituents are attributable to the particle size fraction that is less than 0.5 millimeters. The water quality characteristics of leachate from these laboratory tests was very consistent with that observed from actual backfill groundwater. This indicated that laboratory leachate tests were a reasonable method of predicting backfill groundwater quality.

Numerous laboratory batch leaching and column leaching studies of the fine grained fraction (<0.5mm) of crushed overburden materials have been performed as part of overall mining impact evaluations at the Eckman Park mining area. Data from these studies have been used to estimate time-dependant water quality changes in the groundwater of backfill materials at the Eckman Park mine. The studies indicate that solute concentrations of leachate from crushed overburden materials begin to decline rapidly after an infiltration equivalent to about 0.9 liters per kilogram (l/kg) of overburden material. Leachate concentrations typical of undisturbed bedrock groundwater occur after infiltration of about 1.5 l/kg (Figure 9).

PROBABLE HYDROLOGIC CONSEQUENCES OF ECKMAN PARK MINING OPERATION

Projected Backfill Discharge Characteristics for Entire Mine Area

The quantification of flow and water quality characteristics of groundwater in a stabilized reclaimed backfill area may be used to evaluate overall impacts of the Eckman Park mining operation. The similarity of hydrogeologic setting of the mining area suggests that data from the eastern backfill area may be extrapolated to the

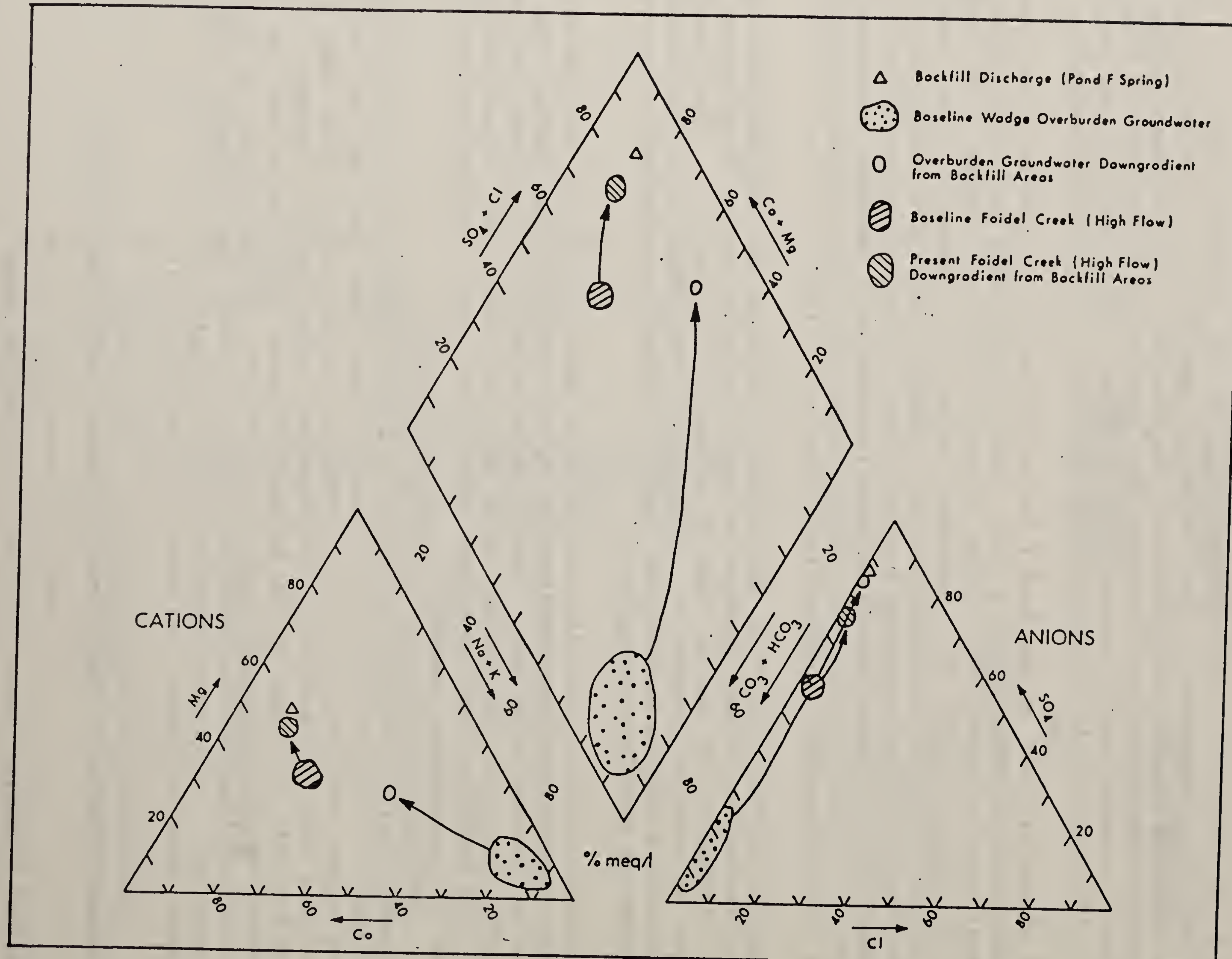

Figure 8 - Surface and groundwater quality characteristics

remainder of the area. Furthermore, the similarity of results of laboratory leaching studies and actual present backfill groundwater quality suggests that the time-dependant water quality changes indicated from the leaching studies may be extrapolated to the backfill deposits.

The water balance studies on the eastern backfill area indicates a total annual recharge of about 1.1 x 10^8 gallons, equivalent to about 3 inches of recharge over the area. Most of the recharge occurs during a two month period coincident with spring snowmelt. Extrapolating this recharge estimate to the total Eckman Park mining area, encompassing 1.5 x 10^8 square feet (3444 acres), would indicate a total annual recharge of 2.8 x 10^8 gallons.

Discharge to land surface from the eastern backfill occurs at the contact with lower permeability undisturbed bedrock at the northern edge of the mine property. Annual discharge is about 10^8 gallons which constitutes about 90% of the estimated annual recharge. Discharge from the backfill peaks following the spring snowmelt period at a rate ranging from 2000 to 3000 gpm. The western portion of the mine area, after final reclamation, will have a very similar hydrogeologic setting so it would seem reasonable to extrapolate the discharge characteristics of the eastern area to the total mine area. On this basis, the projected annual discharge from the total mine area after complete reclamation will be approximately 2.5 x 10^8 gallons, with peak discharge rates ranging between 5000 and 7500 gpm.

The quality of the backfill groundwater discharge is expected to be initially similar to that observed at the Pond F Spring. Laboratory leaching studies indicate that backfill water solute concentrations may decrease after leaching of about 0.9 l/kg of backfill material. Extrapolation of these studies to the backfill deposits at the Eckman Park mining area indicates that, with the estimated rate of recharge, it may take several tens of years before water quality will return to approximate undisturbed overburden groundwater conditions.

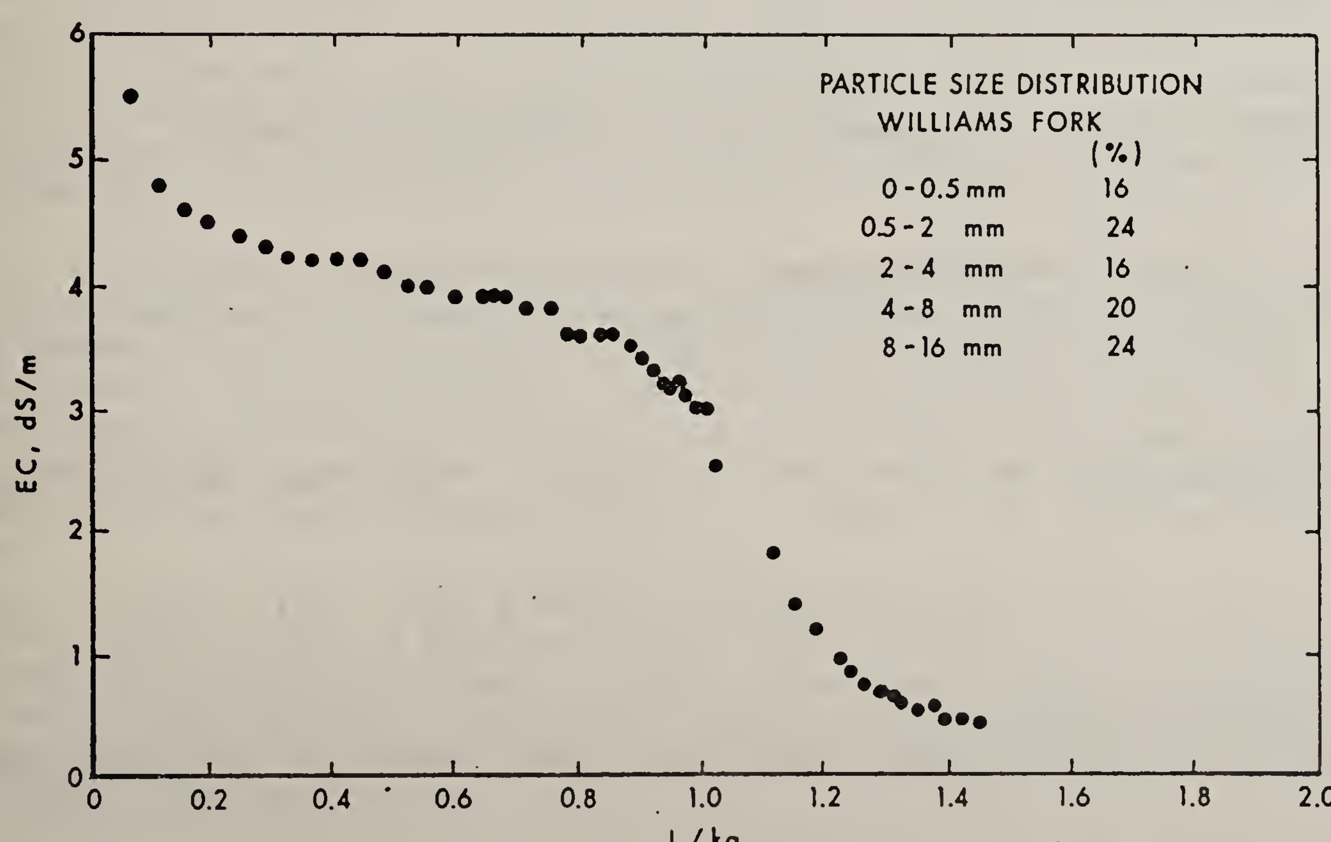

Figure 9 - Backfill leaching study results

Influences of Backfill Discharge on Surface Water Resources

The major potential influence of backfill discharge to surface water resources is to cause an increase in dissolved solids and modification of chemical characteristics. The water quality of surface streams is of concern primarily from the standpoint of irrigation use. Consequently, the potential influences of backfill discharge on the use of surface water resources for irrigation are examined in this paper.

Irrigation in this region is typically from direct diversion via ditches during the period July to October. The most critical period is usually towards the end of the irrigation season when stream flows are at a minimum and total dissolved solids concentrations tend to be at their highest seasonal levels. Two water quality criteria are usually examined for suitability for irrigation - total dissolved solids content and sodium adsorption ratio (SAR). The allowable values for these parameters are dependant on the type of crop to be irrigated. The types of crops most commonly grown in this region would be classified as moderately sensitive to moderately tolerant with respect to soil salinity. Other water quality criteria that are also important to crop health such as boron concentration are not considered here as the backfill discharge water quality does not contain elevated concentration of these elements.

Foidel Creek is the receiving stream for backfill discharge from the Eckman Park Operation. Foidel Creek is not utilized for irrigation purposes due to its naturally intermittent flow characteristics. The first use of surface waters for irrigation

Table 1 - Flow and Water Quality data from Trout Creek

(Flow in Cubic Feet Per Second; Total Dissolved Solids (TDS) in Milligrams Per Liter)

Trout Creek above Fish Creek (Site 69)	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mean Flow	7.5	7.5	20.6	85.4	142.8	217.1	106.0	17.4	12.1	8.6	9.5	13.8
TDS @ Mean Flow	368	393	511	571	369	208	376	496	551	372	363	360

downstream of the Eckman Park mine is from Trout Creek, just north of its confluence with Middle Creek. During the critical irrigation months of August, September and October, flow in Foidel Creek may be sustained primarily from mine discharges and would eventually contribute to Trout Creek flow.

The simplest method of evaluating the potential influence of backfill discharge to Foidel Creek on the water quality of surface waters at points of irrigation diversion on Trout Creek is to perform a mass balance calculation. For this particular evaluation, the form of this calculation is as follows:

$$C_{tcd} = \frac{(C_{tcu} * Q_{tcu}) + (C_{fc} * Q_{fc}) + (C_{mc} * Q_{mc})}{(Q_{tcu} + Q_{fc} + Q_{mc})} \quad \ldots\ldots\ldots\ldots(2)$$

where:

C = Concentration of chemical constituent
Q = Flow rate

with subscripts referring to the various stream segments as follows:

tcd = Trout Creek downstream from Middle Creek confluence
tcu = Trout Creek upstream from Middle Creek confluence
fc = Foidel Creek
mc = Middle Creek

This type of calculation assumes conservative behavior of solutes. A "worst-case" scenario would assume all flow in Foidel Creek to be attributable to backfill discharge, no flow in Middle Creek and low flow conditions in Trout Creek. Flow and water quality data from Trout Creek are available from a site downstream from the confluence with Middle Creek. Data prior to 1980 is believed to be representative of conditions prior to significant backfill discharges from the Eckman Park area. Mean flows and TDS values on a monthly basis for the Trout Creek station are given in Table 1 taken from a report by Kaman Tempo (1982). The discharge of water from the Foidel Creek Underground mine also contributes solutes to Foidel Creek flow. The influence of this contribution was included in the flow and mass balance calculation.

The results of the mass balance calculations are presented in Table 2. It can be seen that the contribution of solutes from the backfilled areas at the Eckman Park mine presently accounts for an increase of about 57 mg/l in Trout Creek under worst case low flow conditions. This contribution constitutes about 9% of the total salt load in Trout Creek downstream from Middle Creek and represents an increase of about 10.3% over baseline Trout Creek conditions. Present Trout Creek TDS concentrations during low flow conditions are well below levels that might cause concern with respect to irrigation.

Backfill contributions for a fully reclaimed Eckman Park mine are projected to account for an increase of about 122 mg/l in Trout Creek under worst case conditions. The backfill solute contribution constitutes about 16% of the total projected salt load in Trout Creek downstream of Middle Creek. This represents an increase of about 22% over baseline Trout Creek conditions.

The calcium-magnesium dominance of the backfill water serves to reduce SAR values in Trout Creek flows. Therefore, the influence of backfill groundwater on Trout Creek water is actually beneficial with respect to this characteristic. As indicated above,

Table 2 - Salt Load Analysis for Trout Creek

Present Conditions	Flow (cfs)	TDS (mg/l)	Flow-weighted TDS Contribution mg/l	(%)
Trout Creek Upstream	12.1	551	533	83.8
Foidel Creek Mine Discharge	0.23	2500	46	7.2
Backfill Discharge	0.18	4000	57	9.0
Trout Creek Downstream (from equation)	12.51	636		
Projected Future Conditions				
Trout Creek Upstream	12.1	551	506	67.0
Foidel Creek Mine Dischrg.	0.67	2500	127	16.8
Backfill Discharge	0.40	4000	122	16.2
Trout Creek Downstream (from equation)	13.17	755		

there are no elevated concentrations of trace elements, such as boron, in the backfill discharge that have potentially detrimental influences on the quality of irrigation water derived from Trout Creek.

CONCLUSIONS

The study of backfilled areas at the Eckman Park Mine indicates that present and projected influences on surface and groundwater resources of the area are quantifiable using fairly simple mass balance techniques. Slight increases in the salinity of downstream surface waters will result from the discharge of groundwater from backfilled areas. However, the use of downstream water resources for irrigation should not be affected.

ACKNOWLEDGMENTS

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WATER RESOURCES RELATED TO MINING AND ENERGY – PREPARING FOR THE FUTURE
NOVEMBER AMERICAN WATER RESOURCES ASSOCIATION 1987

MANAGING DRILLING WASTES IN A NORTHERN ENVIRONMENT

Daniel L. Wilkerson[1]

Bradley Fristoe[2]

The management of waste disposal in the northern environonment presents a challenge to industry and resource managers to minimize environmental risk. Until recently, waste disposal as generally practiced by the oil and gas industry in the two major production areas in Alaska (Cook Inlet and North Slope), often amounted to leaching or directly disposing drilling wastes into the environment. There are several major reasons such practices are no longer acceptable. The decay curve for wastes is considerably increased in northern latitudes; drilling depths are generally much greater, increasing the waste volume; and the use of potentially toxic additives is frequently involved to enhance drilling at increased depths. Beginning in 1982 a study was conducted of oil and gas waste disposal practices in Alaska, and in other areas. It was determined that in other regions, eg. Canada, Gulf Coast, Rocky Mountain Overthrust Belt, West Coast, industry and resource managers have been applying a variety of improved techniques to control waste disposal. Improvements have been applied such as reduced water use, treatment of fluid wastes, reinjection to formation, controlling additives, lining of waste pits, and containment and reclamation or removal of wastes. With a mandate to minimize potential for surface and ground waster contamination, a process was initiated to develop new management controls. That effort led to the development, in consultation with industry and other interest groups, of a new regulatory approach to managing oil and gas waste disposal practices. The design of that program has had to be reconciled with available agency resources and the logistics of resource exploration and development across a land mass of some 586,000 sq. mi..
KEY TERMS: Waste management regulations; toxic additives; drilling waste disposal practices; containment.

INTRODUCTION

The use and disposal of oil and gas drilling wastes in Alaska's environment has been a growing management problem related to activities in both the Cook Inlet and North slope oil and gas fields. Various incidents

1 Resource Planner, AK. Dept. of Environmental Conservation, 3601 "C" St., Suite 1350, Anchorage, AK., 99503
2 North Slope District Manager, AK. Dept. of Environmental Conservation, P.O. Box 1601, Fairbanks, AK., 99707

have occurred associated with improper disposal and the migration of wastes into sensitive environments.[1] As a consequence of ongoing field problems, in 1983 the department initiated various investigations, including a survey of drilling mud use and disposal practices.[2] The survey report was based on information provided by the oil and gas industry in Alaska, as well as on a review of field practices in Canada, in the Rocky Mountain Overthrust Belt and on both the Pacific and Gulf Coasts. The purpose of the survey was to familiarize State agency staff with industry practices and problems, to identify new technologies which were already operational in other oil and gas regions and suggest future management directions for the State regulatory agency.

OVERVIEW OF INDUSTRY PRACTICES[3]

The oil and gas industry has been active in Alaska for some 20 years, with the oldest field, Cook Inlet, predating Prudhoe Bay and other North Slope fields. While exploration drilling continues in and around these areas, much of the ongoing drilling activity has been production drilling into known reservoirs. Drilling activity in Cook Inlet has often been to shallower depths, around 5,000 to 8,000 feet, while much of the North Slope drilling activity has been at depths of approximately 10,000 feet or more. However, with directional drilling, the total diagonal and vertical depth or penetration, has in some instances exceeded 20,000 feet. During exploration drilling, the industry in Alaska has frequently constructed a single reserve pit, into which all wastes have been discharged. On the North Slope, a single production pad which may have one or more reserve pits, might serve from 10 to 60 wells, and in addition receive wastes from other sites including offshore operations. The reserve pit has generally been developed by excavating a pit and/or constructing dikes out of native materials. Also, in wetland and permafrost situations, the rig and reserve pit have been operated in conjunction with a built-up gravel pad, or with piling. While exploration drilling has often been limited to winter conditions, production drilling may occur year around. The reserve pit has usually been unlined, with wastes frequently leaching into the environment. Even so, the reserve pit has been a final repository for a variety of wastes which are associated with the mud system and the operating machinery of the drill rig and related equipment. Some of those wastes may be considered noxious. In recent practice, the reserve pit was often left open at abandonment and in many instances, the retaining berms were intentionally breached.[4] With seasonal precipitation, the hydraulic head would be increased, facilitating continued leaching of remaining wastes from the unlined pits.

INDUSTRY WASTE STREAM[5]

The waste stream generated by the oil and gas industry in relation to the recovery of oil and gas, is often quite complex, consisting of a variety of wastes associated with drilling. While fresh water drilling muds and the cuttings may represent the largest volume of wastes, there are an array of wastes contained in or associated with the mud system which are perhaps more noxious. The ancillary wastes may include contaminants such as antifreeze, (arctic pack), acid, rinsates, condensates, solvents, diesel, spent oils and lubricants, pipe dope, and oil and fuel spills. The drilling mud system may also contain numerous noxious additives or other components. These include additives to the system such as lubricants, corrosion inhibitors, and bactericides, along with contaminants contained in products used in the mud system or encountered in drilling sub-surface formations. In practice, the waste stream may vary at each well or field, based on sub-surface geology, drilling depth or penetration, or difficulties encountered in drilling and operator practices.

BASIC DRILLING TECHNOLOGY AND INTRODUCTION OF CONTAMINANTS[6]

The drilling of oil and gas wells involves a somewhat complicated technology designed to accomplish the drilling of the well and to enable recovery of oil and gas. A mud system, usually consisting of water, clay, weighting materials and chemicals, is utilized to lubricate the bit, raise cuttings, and control formation pressures. Drilling is generally conducted in two phases, the first being the spud phase, when the near surface formations are drilled (3,000 to 5,000 ft.). In the 1st. phase, the mud system is kept rather simple, consisting of clay and water, to protect natural water bearing formations. During the secondary phase, from below the surface formations to bottom hole, the mud system can become increasingly complex. A variety of materials including barite (for weighting), various chemicals and diesel may be added to not only lubricate or free-up the bit, but control mud system performance relative to high pressure and temperature and the stability of formations being drilled.

In the 1st. phase, or spud phase of drilling, the mud system is often considered rather benign, and provides a more limited potential for contaminants being present. However, during the secondary phase, when drilling becomes more diffiicult due to depth, high pressure and temperature, a variety of additives may be incorporated in the mud system to control down-hole conditions. Due to the inherent toxicity of many of these additives, eg. bactericides, the mud system may be contaminated. Additionally, the mud system may assimilate contaminants from the formations being drilled, such as salts and heavy metals.

During the drilling, work-over, site clean-up or shut-in of the well, a variety of other materials may be introduced to the waste stream from the rig deck, the well cellar, or from the rat or mouse holes where the drill pipe is stacked. Wastes such as machine oils and lubricants, pipe dope (lead), acid, and solvents can become part of the waste stream. All of these contaminants or conditions may be found or affect the waste stream in the reserve pit. A number of these substances and the additives or components in use, which may be technically defined as hazardous, have customarily been disposed in the reserve pit as non-hazardous wastes. Currently such wastes are exempted from management under the Resource Conservation and Recovery Act. Additionally, substances in the waste stream which may be considered somewhat toxic, under the high temperature and pressure encountered at depth, may become highly toxic compounds.[7] Also, such parent compounds or substances may interact synergistically in the reserve pit, resulting in highly toxic components.[8]

REGULATORY REQUIREMENTS - INDUSTRY PRACTICES IN OTHER REGIONS

In examining the administrative/regulatory requirements of a number of other oil and gas producing regions in North America, there are a variety of measures and practices applied to reduce the risk of environmental contamination. In some instances deleterious fluids are stored in a lined pit, apart from the reserve pit, and an emergency pit (not to be used for storage) is constructed separately to contain emergency overflow.[9] In many oil and gas regions, provision has been made for lining reserve pits to prevent seepage and environmental contamination. In Michigan, in addition to the reserve pit, both "rat and mouse holes", where drill pipe is stacked, may be required to be lined.[10] In Canada's Northwest Territories, drill fluids, muds, cuttings and rigwash must be totally contained, to prevent leaching into the environment.[11] In a number of locales, the wastes remaining in the reserve pit must be stabilized, prior to burial in place.[12] In Wyoming the Oil and Gas Commission prohibits the use of surfactants, disbursants, wetting agents, surface reduction agents and other chemicals which could destroy or reduce the fluid seal of a reserve pit.[13] In Texas, if certain reserve pit fluids are to be disposed at an offsite facility, a manifest system must be utilized to track the nature, quantity and location of such waste disposal activities.[14] In California, the majority of drilling wastes are classified into two classes, according to toxicity, both requiring disposal in consolidated, specially designed commercial disposal sites.[15] California also requires that waste sites be located in areas where subsurface geologic formations would prevent escape of wastes into ground water aquifers.[16]

In response to growing concern over the disposal of oil and gas wastes, the oil and gas support service industry has evolved an array of technologies to neutralize, reduce or eliminate the waste stream. Pit wastes can be treated in place with the fluids being rendered inert.[17] The wastes can be "squeezed" and returned to the pit, with the remaining solids becoming environmentally stable.[18] The entire pit contents can be turned into a concrete mass with an admixture of portland cement or fly ash. The wastes can also be processed into a concrete brick for burial at landfills.[19] The pit wastes can be heat treated and pelletized for landfill or road application or the entire mud stream can be sprayed through a flame, burning-off the wastes and leaving only an ash residue.[20] The waste stream volume and level of contamination can also be dramatically reduced by using a closed system, limiting water usage and disposing the wastes from the spud phase prior to placing well completion wastes in the pit.[21]

METHODOLOGY FOR MANAGING DRILLING WASTES

In investigating oil and gas industry practices, and issuing and monitoring permits over the past five or six years, it was determined that although drilling mud systems could be innocuous, there were numerous opportunities for contaminating the waste stream. In addition to all the other contaminate sources associated with well drilling, the reserve pit has traditionally been the respository for any and all waste materials. This is especially true in Alaska, where back hauling has been avoided as a matter of routine practice. As the development of administrative regulations was in progress, it was argued that in the arctic, tundra disposal was an acceptable technique and in fact that leaving the pit and wastes unreclaimed (open, uncovered pits) at abandonment was the best methodology.[22] It was also argued that the mud systems were normally benign and toxic additives were so dilute in the mud return system as to not pose any environmental risk.[23] However, as noted previously, it was learned from a variety of sources that the parent compounds could react synergistically, with new compounds appearing in the mud return system which could be much more toxic.[24] Also, it was recognized that the decay curve for biodegradation could take decades in Alaska's arctic and semi-arctic environment.[25] However, it was argued that nothing of any significance was turning up in the environment as a result of drilling waste disposal practices. Again, numerous instances were discovered of contaminants in the environment associated with the disposal of drilling wastes, eg. arsenic, aromatic hydrocarbons, chromium, and salinity.[26]

Considering that the waste stream from oil and gas drilling activities in Alaska can easily amount to a million barrels being disposed annually in the environment, it would be very difficult to know how much of the waste stream is contaminated or where to look. To sample a single reserve pit and determine with some accuracy what is in the pit would require a vertically and horizontally integrated sampling routine.[27] Applying such a sampling methodology would be logistically difficult in Alaska as many North Slope operations are helicopter supported sites and climate could be an obstacle. With a small regulatory agency, fiscal reality dictated that any management concept be within agency personnel capabilities. Therefore, any regulatory scheme to be applied relies to a large extent on self monitoring by the industry to assure that oil and gas wastes do not escape into the environment.

From the mounting array of information and data collected, it became apparent that a new management solution was needed. However, if new management procedures became so complex that regulations were unenforceable, the program would be of little value. With a limited staff available in each of the oil and gas fields, and the logistics and expense of surveying remote sites, the agency would not have sufficient resources to administer complex regulations. Thus, while a RCRA (Resource Conservation and Recovery Act) type of approach, eg. California, appealed to some interest groups, such a program was not within available resources.[28] For similiar reasons, it was not feasible to utilize a generic approach allowing some wastes to be disposed in the environment, assuming that they would be benign. The potential to contaminate "generic wastes", from a variety of sources and by way of routine practices utilized by the industry, was simply too great. The only practical solution, given the field conditions in Alaska, was to seek total containment of the wastes. It was determined that if the wastes were properly sealed-off from the environment, including being frozen in-place and the hydraulic head removed, there would be very little concern about the migration of wastes into the environment.

As a consequence, for the past three years, the State regulatory agency has been working on a set of administrative regulations which are a combination of design and performance standards. The management of drilling wastes has now been incorporated within the revised solid waste management regulations.[29] The intent of the revisions has been to insure that all waste disposal practices are conducted in a manner which limits the potential for migration into the environment. The resulting regulations provide considerable flexibility in selecting and designing waste containment facilities. The higher the potential for waste migration, the more restrictive the standards. Where waste control practices are effectively applied to minimize potential waste migration, the standards applied aren't as restrictive. The application of the standards are also governed by the proximity of waste disposal activities to population and drinking water sources, or biologically sensitive environments. All new containment structures need to be lined or sealed in a manner which will generally prevent waste migration during the active life of the reserve pit. Monitoring and reporting must be conducted and if a violation occurs, the operator has to notify the State regulatory agency and take corrective action. Considering the variability of the arctic environment, specific provision has been made for waste containment in permafrost regions, eg. the North Slope, allowing for freezeback. Perhaps the most significant change occurring in industry operations has been reinjection of fluids. With the hydraulic head removed, and the site closed-out on abandonment, the potential for waste migration is dramatically reduced.

In the regulatory process, key concerns debated included fluid management and the use of liners, site monitoring, pit closure and use of pre-existing pits. The industry argued that the clays used in the mud system sealed the reserve pit and prevented seepage. However, it was known that reserve pits leak and hydrocarbons would pass through any clay or most native materials.[31] The resolution was to reduce fluids, allowing the use of natural or synthetic liner materials which must be compatible with pit fluids. Also, during the operating life, fluids should not penetrate more than 25% of the pit wall/containment liner. Site monitoring was also debated, particularly concerning the location and frequency of monitoring relative to the operating pit. The industry argued that in operation accidental spills would occur, which should not be considered pit failure. The solution called for pit monitoring within 50 feet of the operating pit, with the industry responsible for clean-up immediately on discovery of a spill or failure. If in fact problems became apparent outside the pit, permanent or temporary cessation of operations would be necessary, with repair, reconstruction or closure required.

As noted, previously reserve pits were often abandoned without being closed-out, or were actually breached. While some argued that this was an acceptable mode of operation, it was determined that wastes should not be left to seep into the environment.[32] The final resolution established closure requirements, with all pumpable fluids removed and the remaining wastes sufficiently stabilized to support a cap. Also, the cap would be constructed to provide a seal against infiltration/percolation and withstand the extremes of the arctic environment. One of the greatest concerns was the operation of pre-existing pits on the North Slope. To resolve this particularly difficult issue, it was agreed that after placement of monitoring wells, if no contaminants were identified as escaping the pit, operations could continue. However, at pits where problems were apparent or occurred after monitoring, a liner would be constructed in the existing pit walls by trenching a key-way down to permafrost and lining the trench with a barrier. If problems persisted, the pit would have to be closed-out or reconstructed.

While the industry and other interest groups may not have been universally enthused with all aspects of the administrative program as devised, to their credit they have cooperated in the regulatory process. In particular, the Alaska Oil and Gas Association, the Center for the Environment and the Trustees for Alaska have made a concerted effort to work with the Alaska Department of Environmental Conservation in arriving at regulations that they believed were workable and that were also enforceable relative to the agency's statutory responsibilities[30].

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WATER RESOURCES RELATED TO MINING AND ENERGY – PREPARING FOR THE FUTURE
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GROUND WATER MONITORING AND REMEDIATION AT A TAILINGS IMPOUNDMENT IN NORTHWEST MONTANA

Kevin R. Jones[1]

Abstract: The disposal of process fluids from an antimony refinery into a fifteen acre tailings impoundment was investigated to determine the effect on local ground and surface water. Batch leach testing indicated a leachate containing 997 mg/l antimony and 34.5 mg/l arsenic would be produced by the tailings. Although high amounts of dissolved antimony and arsenic are currently available in the pond fluids through ground water intrusion and precipitation, the foundation of the impoundment and the unsaturated zone provide major attenuation for the contaminants of concern. Due to concerns relative to the finite capabilities of the attenuation zone, several remedial measures were investigated. These measures included the removal of the tailings from the alluvial valley floor, capping the material in place, ground water control, and in-situ treatment. Based upon review of the alternatives an in-situ treatment pilot program is being initiated. The treatment consists of using sulfide solutions to cause the antimony and arsenic found in solution to precipitate to less soluble forms. Monitoring wells, suction lysimeters located in the tailings, and solids sampling of the treated tailings are being used to determine the effectiveness of the treatment.

INTRODUCTION

Since the initiation of mining and milling by the United States Antimony Corporation (USAC) in western Montana in 1971, there has been environmental concerns expressed by the regulatory agencies. This concern is due to high concentrations of antimony and arsenic found in the mine tailings and pond fluids. Because of the potential for ground and surface water contamination, monitoring and research programs have been required at the site.

The U.S. Forest Service required USAC to construct a bentonite enriched, compacted soil liner for the tailings impoundment and install four monitoring wells. A surface and ground water monitoring program was implemented and continued for a year without detecting contamination. Monitoring was discontinued at that time, as no contamination had been detected, and funding for the study was limited (Frye, 1983). In 1975, USAC received permission to expand the tailings impoundment to its current configuration. Concerns about the potential impacts related to the waste disposal continued, and in 1975, the U. S. EPA sampled pond fluids and found substantial concentrations of antimony, arsenic, and

[1] Hydrologist, Jones & Associates, 314 N. Last Chance Gulch, Helena Mt.

zinc (USEPA 1975). Follow-up work by the EPA relative to the potential treatment of waste fluid from antimony production was conducted in 1979 (Parker, 1979).

In 1983, the Montana Water Resources Research Center, in cooperation with USAC, sponsored a ground and surface water investigation at the site. The purpose of the study was to determine the impact of the impoundment on local water resources. The investigation found antimony concentrations in ground water near the impoundment up to 1.9 mg/l. The study concluded that sulfate, sodium, and antimony degraded surface water and ground water for a least three and one half miles downgradient of the site (Woessner and Shapley, 1984).

In response to the findings of the study, USAC discontinued refinery operation, and disposal of refinery effluents into the impoundment. An investigation to determine the cause of the release and the extent of contamination began. The investigation determined that contamination was caused by disposal of process solutions into the inactive impoundment. The process solutions contained high concentrations of antimony and sodium hydrosulfate, an antimony leaching agent (Jones, 1986).

In conjunction with its on-going water quality assessment activities, USAC conducted a study to determine the effect disposing barren refinery effluent into the impoundment (Jones, 1987). Its purpose was to determine the potential for future releases of contamination, and to determine effective remedial alternatives. The paper reports on the results of that investigation.

LOCATION AND GENERAL DESCRIPTION

The project site is located at the confluence of Cox Gulch and Prospect Creek in Sanders County, Montana near Thompson Falls, Montana (Figure 1). The project area is in the Burns Mining District, which is generally considered to be an extension of the Couer D` Alene Mining District.

Prospect Creek in the project area is a third order intermittent stream with 23 square miles of drainage above the project area. Downstream of the project area Prospect Creek develops into a perennial stream. Cox Gulch is a first order intermittent stream with 2.6 square miles of drainage. Spring runoff from Cox Gulch enters the Prospect Creek valley in the vicinity of the tailings impoundment, and flows parallel to Prospect Creek for approximately 2,000 feet before seeping into the valley floor. The baseline water quality in both streams is generally good.

The ground water system at the site is a complex alluvial valley fill type aquifer. Because of the heterogeneous nature of the sediments, the layers of sand, gravel, silts, and clays form a complex but generally interconnected system of aquifer zones that are considered as one multiple-aquifer system. In the project area the alluvium has a depth of approximately 100 feet. The complexity of aquifer zones has a marked effect on possible contaminant plumes originating from the tailings impoundment. Flow in the system is generally down valley with areas of surface expression throughout the drainage. The bedrock in the area

FIGURE 1

LOCATION MAP

Scale: 1"= 250,000

consists of Precambrian argillites of the Prichard Formation. The baseline water quality is generally good.

HYDROGEOLOGIC CONTAMINANT TRANSPORT

The ground water at the project site is found in a complex but generally interconnected system of aquifer zones that are considered as a multiple-aquifer system. However, these systems overlap and form, for water development considerations, a single aquifer system. Based upon data collected at the site it is believed that for contaminant hydrogeologic analysis purposes, the aquifer can be divided into the Cox Gulch unit and the Prospect Creek unit (Figure 2). Although these units are connected, channel deposits and sorting within and along the boundaries of the units would affect the projected patterns of contaminant plumes from the impoundment. The origin of the units can be related to the different depositional processes active at the site. These processes consist of an alluvial fan system originating from the side valleys and the Prospect Creek alluvial system.

Information collected to date indicates that arsenic and antimony were released from the site resulting in a contaminant plume, due to the disposal of leaching fluids into the impoundment during 1983-84 (Woessner and Shapely, 1984, Jones, 1986). Monitoring subsequent to the cessation of the leach fluid disposal indicates that the plume has decayed rapidly.

Analytical and numeric modeling techniques found in Walton (1985) were used to project the probable characteristics of future contaminant releases. Modeling indicated that contaminant plumes would have the following characteristics:

1)Plumes would be longitudinally large with little transverse dispersion, due to high transmissivity of the aquifer units.

2)Significant ground water mounding will not occur.

3)Contamination will be rapidly manifested in downgradient wells.

4)The impoundment foundation and the unsaturated zone substantially attenuate contaminant transport.

CURRENT MONITORING EFFORT AND RESULTS

The objectives, design criteria, and reporting procedures are described in detail in a water monitoring network design report (Jones, 1985) developed by USAC for the Montana regulatory agencies. Based upon the results of the on-going sampling this basic plan has been modified several times. In accordance with that plan samples have been collected for the required parameters on a monthly basis. Statistical analysis of the data is performed on a regular basis with reports filed with the Montana Water Quality Bureau and the Montana Department of State Lands.

Ground and Surface water sampling locations are shown on Figures 2 and 3. All samples are collected and analyzed in accordance with EPA approved techniques.

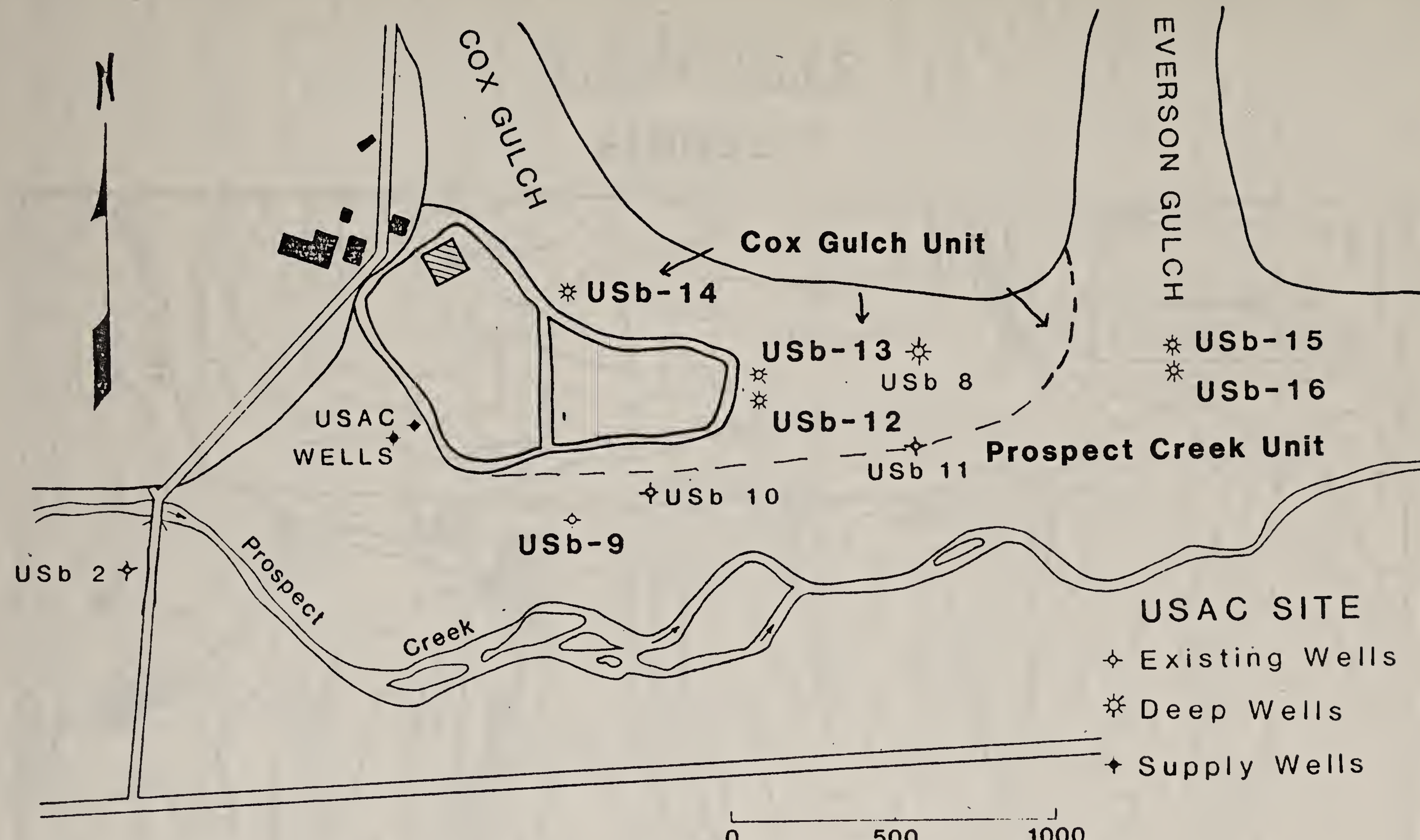

FIGURE 2

GROUNDWATER SITES

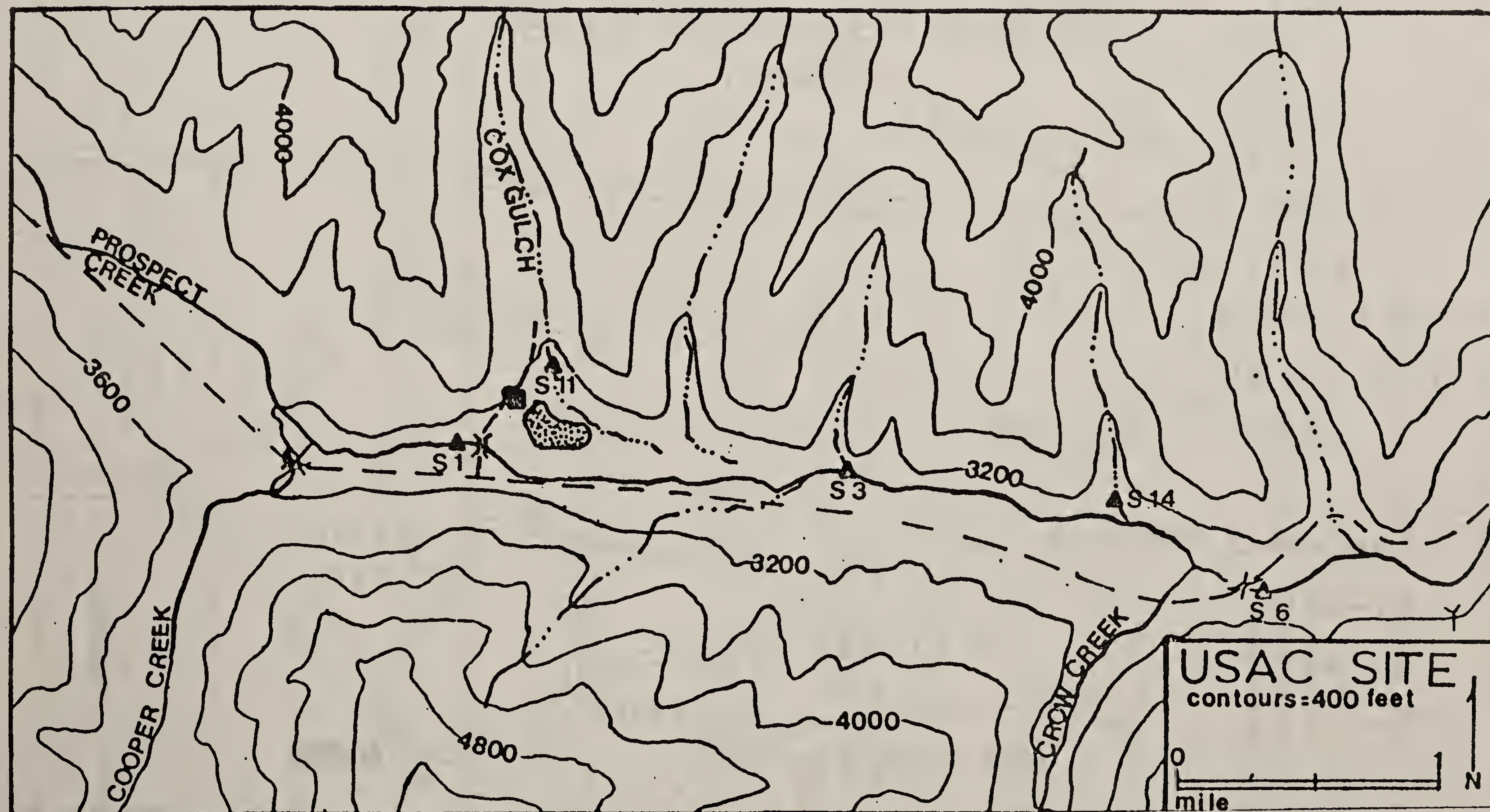

FIGURE 3

USAC SITE

Under the current network design samples have been collected from the site since January of 1985. These samples have ranged in concentration from less than 0.005 mg/l to a high of 0.019 mg/l dissolved antimony in the ground water system downgradient of the impoundment. Antimony values in the surface water system have ranged from less than 0.005 mg/l to 0.011 mg/l dissolved antimony. Arsenic values in both the surface and ground water have ranged from less that 0.005 mg/l to 0.007 mg/l. In comparison during the period of the Woessner/Shapely study (1983-84), dissolved antimony values in the ground water system ranged from 0.010 mg/l to a high of 1.9 mg/l. Arsenic values for the same period ranged from less than 0.005 mg/l to a high of 0.033 mg/l.

In order to determine if a significant increase in the antimony levels downgradient of the site has occurred, the data has been analyzed using a Student`s "t" test. This analysis has shown that at a .95 confidence level three wells (USb 7, 8, 11) have continued to show significantly higher antimony levels than the upgradient stations. Two of the surface water stations also show significantly higher levels of antimony as compared to the upstream stations. For trend detection a linear regression method has been used. These regressions indicate a downward trend in antimony values at all downgradient and downstream stations over the study period.

POSSIBLE REMEDIATION MEASURES

Introduction

As the tailings represent a potential source of contamination to the aquifer, five remedial actions, capping the tailings in place, removing the tailings to a secure site, pump-back wells/hydraulic control, containment barriers, and combined refinery effluent disposal/in-situ treatment, were considered.

The capping and the removal options were rejected as it is the intention of USAC to maintain operations at the facility. However, these options are still being considered for the future closure of the facility. At this time the preferred option is for the capping of the material on-site due to the difficulty of finding a secure site for a large quantity of material, the hazard of transport, and the capital costs involved.

Based upon this evaluation the preferred option is to combine the disposal of the refinery bleed stream with the in-situ treatment of the tailings. This option is preferred for the following reasons.

1)The option provides for a positive decrease in the potential contaminant inputs prior to an actual contaminant release.

2)The option can be instituted immediately at a low additional cost to USAC while the operation is in production.

3)The other considered options have significant technical problems that could restrict the effectiveness of the remedial action.

Pump back wells-hydraulic containment

A pump-back well/hydraulic containment type remedial action (Figure 4) was considered. The scenario used for the evaluation was based upon a possible response to a detected contaminant plume that approached or exceeded the EPA water quality criterion of 0.146 mg/l (EPA, 1980). The initial system would consist of converting USb-8 and 11 into production wells. The discharge from these wells would be treated to remove metals, and reinjected into the aquifer upgradient of the facility. Additional wells would be constructed between the initial wells to complete the capture of the contaminant plume. In order to improve the efficiency of pump-back type systems, it is possible to use fresh water injection wells to create pressure barriers to aquifer flow into the contaminant zone. In addition, these wells will tend to "push" the contaminant plume towards the discharge wells, and would dilute the plume. Canter and Knox (1985) have outlined basic constraints that must be met in order for the system to function properly. The constraints include proper location of the recovery system, producing a large enough discharge so that limiting flow lines bound the plume, and seeing that drawdowns do not exceed the limits specific to the aquifer system.

There are several drawbacks to the use of a pump back-hydraulic containment system at the USAC site. These drawdowns include:

1)Ground water elevations in the area vary up to 65 feet seasonally. Therefore it would be difficult to design a system that would work well under high and low ground water conditions.

2)The high transmissivity of the aquifer would make it difficult to contain the contaminant plume.

3)The remedial action would be a response to an actual contaminant release rather than a reduction in the potential for releases.

4)A treatment facility for water removed from the aquifer would have to be constructed. The efficiency of the treatment of the water removed from the aquifer would be low due to the dilute nature of the contamination. Extremely large volumes of water would require treatment.

5)The removal of the required volumes of water from the aquifer would affect the in-stream flow requirements of Prospect Creek and the water rights of downstream water users.

6)The action is cost and time intensive as a treatment facility would have to be constructed, and additional injection and discharge wells would be needed.

Physical barriers

In order to contain potential contaminant plumes from the tailings impoundment, a series of slurry cutoff walls could be constructed (Figure 5). As part of the wall system a series of pressure relief wells would be constructed up gradient of the walls. In addition a major diversion

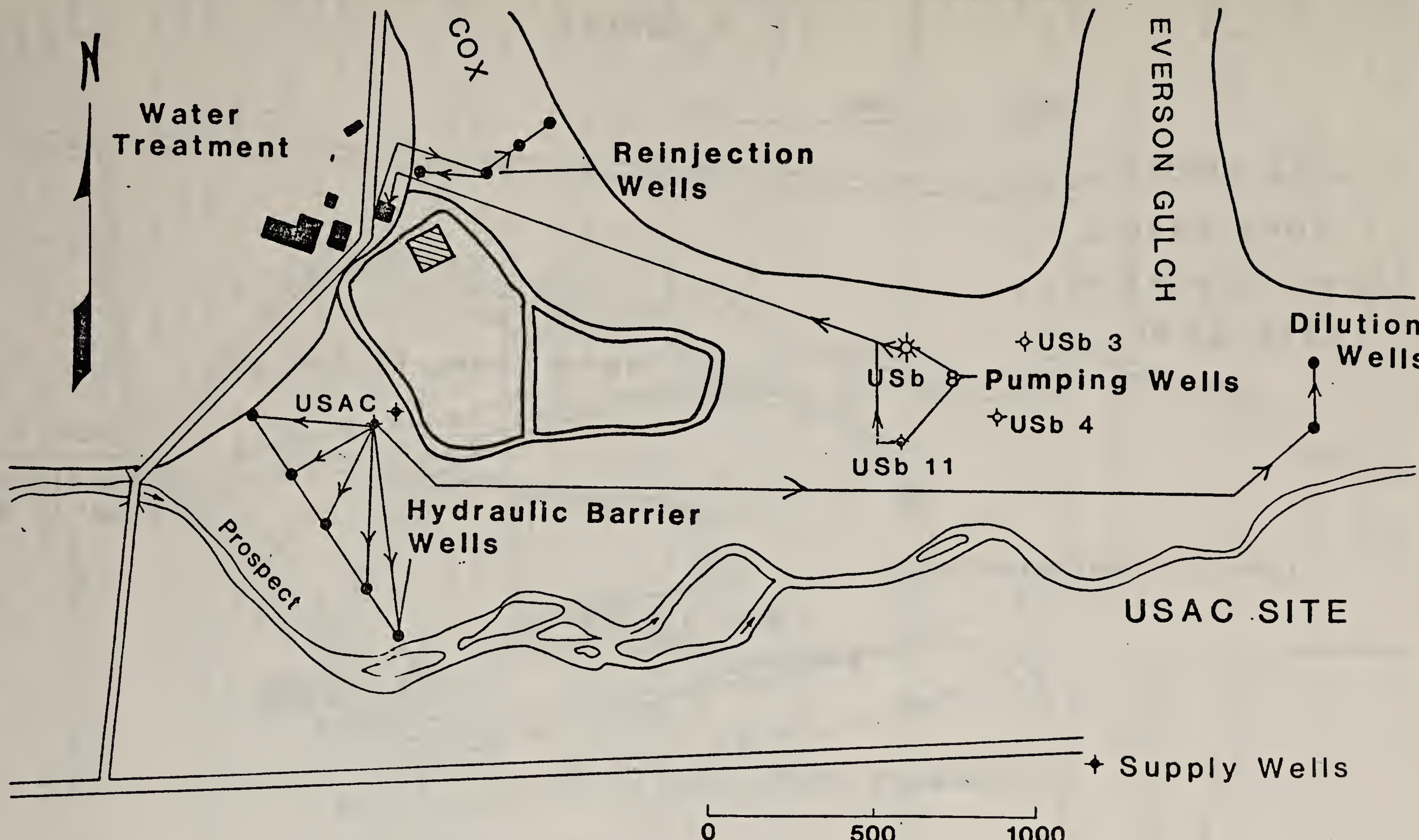

FIGURE 4

PUMP BACK WELL – HYDRAULIC CONTAINMENT SYSTEM

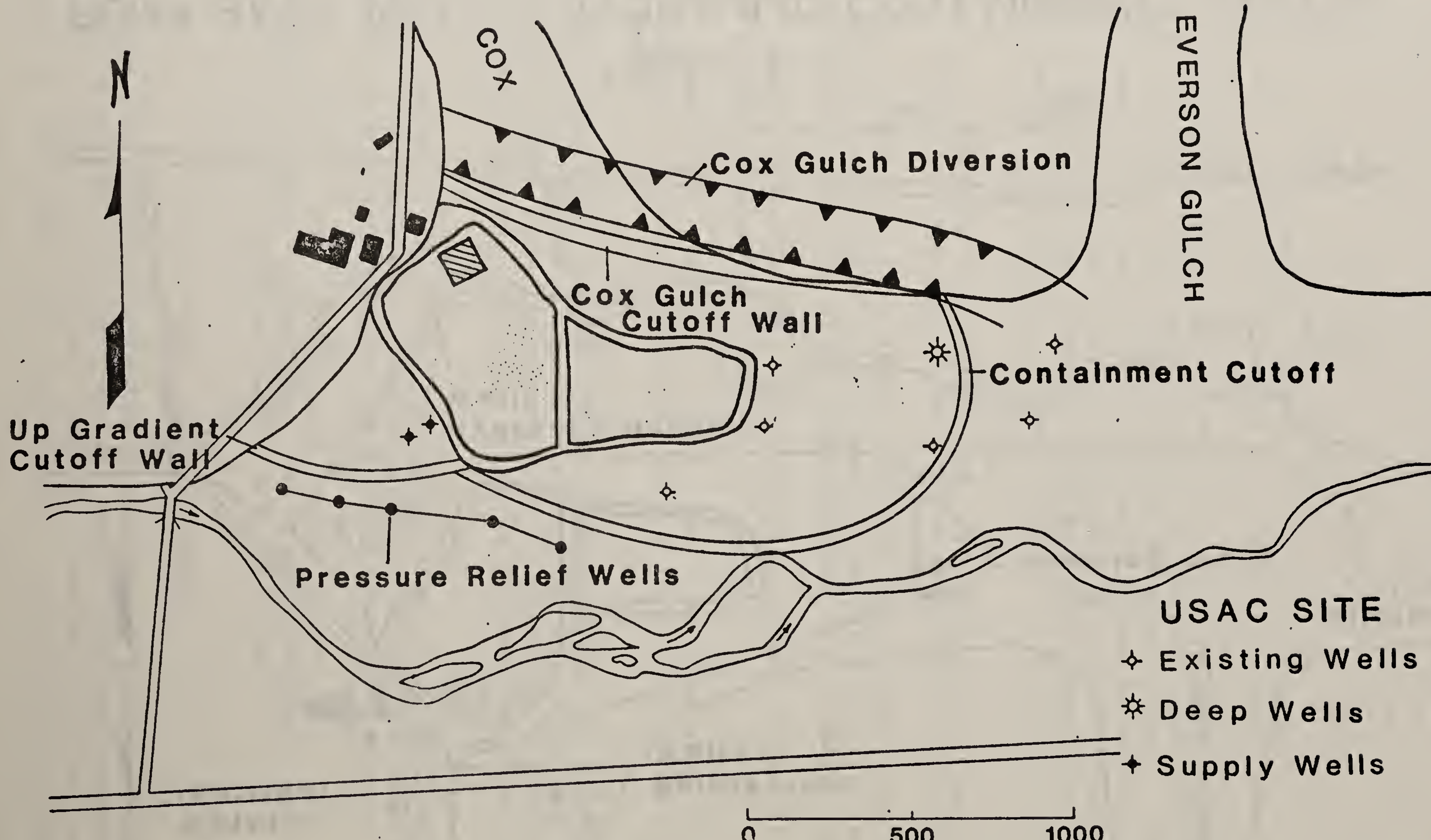

FIGURE 5
SLURRY WALL CONTAINMENT SYSTEM

would be needed in the Cox Gulch drainage to avoid damage to the walls. However, the following factors would preclude its use in this setting.

1) Even with the pressure relief wells the slurry walls would be subjected to tremendous flow pressures.

2) It is likely that the bedrock under the alluvial system is highly fractured and jointed.

3) The slurry wall would tend to flow into the coarse alluvium both during the construction and life of the wall.

Refinery effluent disposal/in-situ treatment

Effluent disposal combined with treatment to make the metals in the tailings less soluble was evaluated, and found to be the best alternative. This option is discussed in further detail in the following sections.

PROPOSED REFINERY EFFLUENT DISPOSAL AND TAILINGS TREATMENT

Introduction

In order to evaluate the feasibility of combinded effluent disposal and treatment, a literature review and an evaluation of the USAC tailings impoundment were conducted. A series of tailings samples were analyzed to determine the soluble antimony and arsenic. Because of the high levels of the metals identified by this evaluation (Taylor, 1987) and through past sampling (Jones, 1986, 1987; Woessner and Shapely, 1984), a process was developed to precipitate the soluble antimony and arsenic from the tailings. The basic process consists of a pH adjustment to less than six and adding sodium sulfide in slight excess to the refinery bleed stream prior to disposal in the tailings.

While we do not believe that the sulfide precipitation process has been used directly in this manner, the process itself has been documented for antimony reduction in waste water, and in the reduction of metals from flue dust. Parker and others (1979) discuss the use of sulfide precipitation, along with other methods for the treatment of mine and mill waste waters containing antimony. This study found that reports on the technology for the removal of antimony were scattered and contradictory. The study concluded that the technologies for the removal of antimony beyond settling, recycling, and evaporation, were essentially unproven. It did find that a high percentage of antimony is adsorbed onto the settleable solids and co-precipitates with those solids. The study further found that other metals will precipitate as sulfides before the antimony. This characteristic allows the process to also be used for the removal of arsenic contained in the bleed stream.

Bloom and others (1982) proposed a process to remove arsenic, zinc, cadmium, and indium from smelter flue dust. The process used an acid leach to remove these metals from the flue dust. Sulfide precipitation was then used to precipitate the arsenic from the solution for disposal. The study concluded that sulfide precipitation is one of the most effective and economical methods for the removal of arsenic from solution although the process is not fully understood. Further references to the sulfide precipitation process can be found in Larson and Ross, 1982; Bhattacharyya and Ku, 1984; and Kondo, 1980.

Tailings and impoundment fluid chemistry

Since the initiation of operations at USAC, several sampling episodes of tailings and pond fluids have been conducted (USEPA, 1975; Frye, 1983; Woessner and Shapley, 1984; Jones, 1986). The studies indicated varying, but significant concentrations of antimony and arsenic in the fluids and tailings.

The recent sampling efforts consisted of collecting a set of eighteen samples from six sites within the upper tailings impoundment for analysis. Samples were collected from 3', 6' and 9' depth intervals (Taylor, 1987). Depth composite samples from two sites were selected for batch leach testing. Distilled water was the leach fluid. After agitating the mixture for 24 hours and filtering the fluid, the solution was analyzed for antimony and arsenic. Results indicated up to 1.944 lbs of soluble antimony/ton of tailings (997 ppm) and 0.069 lbs. of soluble arsenic/ton of tailings (34.5 ppm).

Impoundment hydrology

The impoundment hydrology under current conditions is a complex unsaturated flow system. Gross saturated hydraulic conductivity is approximately 1 X 10-5 cm/s with an estimated foundation conductivity of 1 X 10-7 cm/s. However, due to the depositional environment of the tailings there will be radical variations in the characteristics of the tailings within short vertical and horizontal distances.

REFINERY EFFLUENT DISPOSAL/IN-SITU TREATMENT

Proposed treatment

The treatment of the refinery effluent prior to disposal in the tailings impoundment would consist of adjusting the pH of the bleed stream to less than 6 and adding sodium sulfide in excess. The resulting bleed stream would cause the precipitation of the soluble arsenic and antimony contained in the tailings. The reactions of interest in the treatment are:

$$2Sb^{-3} + 3S^{-} = Sb_2S_3$$

$$2As^{-3} + 3S^{-} = As_2S_3$$

The experimental results of this treatment were:

	Before treatment	After treatment
test 1	1.994 lbs/ton soluble Sb	0.01 lbs/ton soluble Sb
test 2	3.025 lbs/ton soluble Sb	0.01 lbs/ton soluble Sb
test 1	0.069 lbs/ton soluble As	below detection
test 2	below detection As	

Based upon the laboratory results it was recommended that the treatment of the tailings be initiated. However, due to the variability in the tailings under environmental conditions and possible variations in the plant bleed stream, pilot scale testing was recommended as a first step. Pilot testing would allow for corrections in the treatment, and would aid in determining the effectiveness of in-situ treatment.

The proposed treatment would allow for the disposal of the refinery bleed stream while initiating the in-situ reduction in the levels of soluble metals. The major advantages are:

1)it can be implemented prior to an actual release of contaminant fluids,

2)reductions in soluble metals are anticipated, and,

3)the scale of the action allows for a detailed evaluation of the action without contamination of the aquifer.

The concern over the ability to transfer bench scale technology to the actual treatment of tailings will be met by initiating pilot testing prior to attempting full scale treatment. In order to determine the effectiveness of the treatment an expanded monitoring program is being initiated.

PROPOSED MONITORING EXPANSION

Introduction

In order to determine the effectiveness of the in-situ treatment of the tailings an expanded monitoring effort is proposed. The treatment monitoring includes continued solids sampling and impoundment fluid sampling. The objectives of the monitoring effort are to:

1)obtain a representative sample of the tailings solids and fluids, and,

2)determine the effectiveness of the treatment.

Random solids sampling

In order to meet the objectives of the sampling, a three dimensional simple random sampling methodology, and a stratified random sampling methodology have been reviewed. Based on the known physical and chemical characteristics of the tailings, it has been determined that a layered simple random sampling strategy will be satisfactory. In this method the impoundment is divided into a three dimensional grid with the samples distributed among that grid through the use of a random number generator.

Samples will be collected from the grid on a quarterly basis. These samples will be analyzed for soluble arsenic and antimony following a batch leach test as previously described in the tailings analysis section (Taylor, 1987).

Lysimeter installations

In order to sample the impoundment fluids eight lysimeter stations will be located in the upper tailings impoundment. Each station will consist of two lysimeters, one located at approximately a 5 foot depth and a second at a 15 foot depth. The lysimeters will be sampled for arsenic and antimony as part of the routine monthly sampling episodes.

CONCLUSIONS AND RECOMMENDATIONS

Based upon the tailings evaluation the following conclusions and recommendations were made and implemented:

1) A pilot scale treatment of the tailings impoundment is being initiated. This pilot scale treatment consists of adjusting the pH of the bleed stream and adding sodium sulfide in slight excess prior to disposal in the tailings impoundment.

2) The expanded monitoring network has been established in the tailings impoundment as part of the pilot study.

3) If the pilot study is successful in the treatment of the tailings, an investigation should be made into the feasibility of establishing a flow system in the tailings impoundment to insure full treatment of the material. Options include injecting the treatment solution in the upgradient end of the impoundment with a collector system in the impoundment toe, or the flooding of the impoundment with the treatment solution. These and other possible methods should be evaluated for the effectiveness and potential environmental impacts.

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WATER RESOURCES RELATED TO MINING AND ENERGY – PREPARING FOR THE FUTURE
NOVEMBER AMERICAN WATER RESOURCES ASSOCIATION 1987

RECLAMATION OF ABANDONED MINED LANDS ON THE WAYNE NATIONAL FOREST

Robert G. Moss[1]

ABSTRACT: The Wayne National Forest contains several thousand acres of abandoned surface mined lands, many that are derelict and in need of reclamation. Recent reclamation efforts on the Forest have been multi-faceted and have involved a number of innovative techniques. Early reclamation designs frequently consisted of attempts to regrade back to original contour, while saving the best available spoil encountered during regrading with which to restore the surface for revegetation.

Experience has demonstrated that this approach has many disadvantages. High costs result from excessive quantities of spoil being regraded, and the site is adversely affected by destruction of pockets of successful revegetation, creation of long, erosion-prone slopes, and excessive compaction. We have found that minimal grading, consistent with restoring the mined area to pre-mining resource values, has substantially diminished these problems.

Several unusual reclamation problems have been undertaken in the past six years. A surface mining related landslide that threatened a county road was stabilized, a burning pile of waste coal was extinguished and the area restored, an area-type ridgetop mine was reclaimed, and two contour-type abandoned mines, one with multiple seams, were regraded and surface amendments applied. Topsoil, lime, and paper mill sludge were used in various combinations as surface amendments to enhance revegetation.

KEY TERMS: Mine land reclamation, revegetation, minesoil amendments.

INTRODUCTION

The Wayne National Forest, which lies within the coal-producing area of Southeastern Ohio, contains several thousand acres of abandoned surface mined lands. These lands are in various stages of revegetation, some of which has occurred naturally, and others which have required assistance. Surface mining for coal within the boundaries of the Forest first took place during the 1930's while the Forest itself was in the early stages of acquisition. The acreage affected by strip-mining remained small, however, until the early 1950's when more efficient equipment and an increasing demand for coal provided the impetus for expanded mining operations.

State reclamation regulations were minimal at that time, requiring little more than tree planting. Later, grading was required to level the peaks of the spoil banks, which was then followed by the planting of trees. Many of the spoils in this area, Athens, Hocking, and Perry Counties, were toxic, and vegetation, natural or planted, either

[1]Forest Hydrologist, Wayne-Hoosier National Forest, 811 Constitution Avenue, Bedford, IN 47421

perished or was difficult to reestablish. Plantings made on less toxic spoils usually survived, but if not, volunteer natural vegetation soon invaded and further reclamation efforts were usually unnecessary. As surface mining expanded in the 1960's and early 1970's more acres were added to the backlog of abandoned, barren lands in need of additional restoration measures. In 1972, the State of Ohio enacted a reclamation law that virtually ensured that every acre of land strip-mined for coal would be adequately reclaimed. Federal legislation, PL 95-87, enacted in 1977, has of course, superseded State regulations and also virtually ensures successful reclamation of the surface.

Past Reclamation Efforts

During the 1960's and 1970's the approach to surface mine reclamation was to grade spoils back to approximate original contour. OSMRE regulations have reflected that approach in the case of active surface mining for coal since 1977. This thinking tended to influence our abandoned mined land restoration as well. In 1980, the Wayne-Hoosier National Forest decided that another, less costly, approach was needed. Reclamation costs are heavily influenced by the cubic yards of spoil moved.

A partial regrading procedure, coined the "Green Island" technique, was developed. Most abandoned mined lands on the Forest have scattered pockets of vegetation. Much of this vegetation is effective in preventing erosion and stabilizing the site. In most instances, it is not necessary to perform a total regrade back to original contour, and these green islands of established vegetation can be left essentially undisturbed. Selective placement and burial of toxic spoils, acid pond elimination, and slope reduction typically require the sacrifice of 20%-25% of these vegetated areas.

Minimum grading has resulted in other benefits. The reclamation areas are much more aesthetically appealing and beneficial for wildlife because of the diversity of vegetation. Long, erosion-prone slopes are broken, lessening the need for construction of diversions. Less grading, and fewer passes per unit of area with heavy equipment, helps reduce compaction. Excessive compaction on surface mines is one of the greatest deterrents to successful reforestation (Davidson et. al., 1984, Ashby et. al., 1982, Parr, 1982).

Dense herbaceous vegetation is a further deterrent to successful forest plantation establishment. While reforestation and wildlife habitat management are primary land management objectives on the Wayne National Forest, it has been demonstrated that the use of grasses and legumes for erosion control is somewhat in conflict with these objectives (Smith, 1980). Erosion control specialists have long recognized the value of quickly-established herbaceous cover for the protection of soils from erosion. Without it, even fast-growing tree species cannot provide adequate cover until crown closure occurs several years after planting. Current surface mine reclamation regulations require the rapid establishment of a complete herbaceous cover. Traditionally this usually involved the use of time-tested species that quickly formed a permanent cover that required little or no future maintenance. A dense erosion-prevention cover is usually guaranteed in Southeastern Ohio when such species as Ky-31 fescue, sericea lespedeza, and crownvetch are used. Many wildlife species find these grasses and legumes unpalatable, and it is extremely difficult to establish a forest without supplemental effort, and, additional expense. The dense cover provides more competition to planted and volunteer tree seedlings than is desireable (Vogel, 1980). To alleviate the problem, the Forest is experimenting with the seeding of grasses and legumes that are relatively short-lived perennials, are low-growing, and that do not form a dense sod cover. This method requires waiting three to five years until the herbaceous cover declines to the point where competition is greatly reduced. Thus, the additional cost of mechanical or chemical site preparation for tree planting is eliminated. Many herbaceous species are available that offer possibilities (Vogel, 1981)

CASE HISTORIES

Four reclamation projects have been selected from those completed between 1981 and 1984 to illustrate the kinds of reclamation problems encountered, and the approaches taken to solve them.

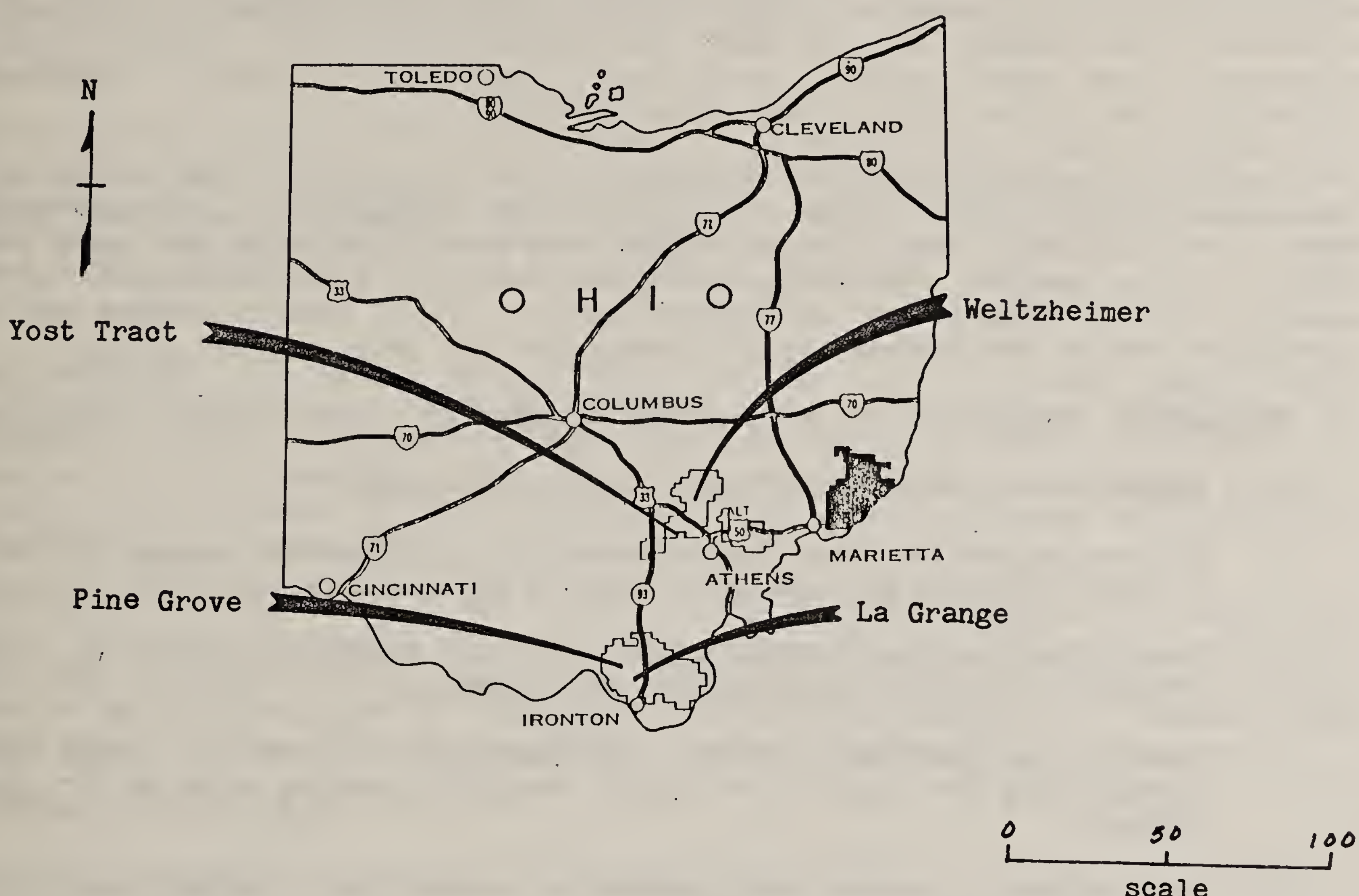

Figure 1
Reclamation Project Areas

Yost II

The Yost Tract was purchased by the Forest Service in 1970 for multiple-use purposes as a part of the Wayne National Forest. Surface mining had already taken place before acquisition. The tract contained approximately 157 acres of abandoned mined land in need of reclamation. The lack of more restrictive reclamation standards had resulted in a legacy of acid ponds, toxic spoils, steep slopes, landslides, and off-site sedimentation.

Mining History The Yost II reclamation project area has a lengthy history involving disturbance on two different occations. The Middle Kittanning (No. 6) coal was the seam which was mined, with the initial mining operation taking place in 1952. Although records are unavailable, actual disturbance was probably not great because of equipment limitations. However, it is also apparent that the most toxic spoils within the mined area were generated at that time. A carbonaceous and highly pyritic layer of shale averaging 8 to 10 feet in thickness overlies the Middle Kittanning coal in this particular area. At the time of first entry into the seam where it cropped out on the hillside, only a small amount of overburden was removed. A large percentage of this overburden was, therefore, toxic shale.

The area was again contour mined in 1965-1966. This operation extended further into the hillside creating highwalls up to 40 feet in height above the floor of the pits. This operation created somewhat more benign spoil because overburden in the geologic cross-section above the carbonaceous shale is much more calcareous. A much wider area was affected by this operation. The peaks were leveled and planted with various mixtures of trees. Reclamation laws at that time required only that trees be planted, not necessarily that they survive. As a result, survival was patchy, depending on the toxicity of the surface spoil at any given location.

Mined Area Configuration The configuration of the project area before reclamation can be characterized as a series of nearly-vertical highwalls, long linear ponds at the base of the highwalls, leveled spoil benches, and short steep outslopes which dropped off into the older spoils. The mining operation had left a variable width of irregular mounds, pits and outslopes of carbonaceous shale. All of these outslopes were devoid of vegetation, and at the maximum angle of repose for the spoil (65-70% slopes).

Reclamation Objectives The project was designed to alleviate these conditions by:

1. Elimination of acidic and highly mineralized ponds.

2. Elimination of acid and highly mineralized groundwater seepage by draining and filling the ponds and realigning surface and subsurface drainage patterns.

3. Backfilling the ponds and pits with the toxic spoils and resoiling all disturbed areas that had a pH less than 4.2 after grading.

4. Reducing erosion and off-site sedimentation by reducing steep slopes and revegetating the graded areas with specified seeding mixtures of grasses and legumes.

5. Reestablishing buried drainageways by excavation, grading, and lining with limestone rip-rap.

Reclamation Design Concept A partial regrading procedure, in keeping with efforts to reduce costs and potential adverse impacts, was used. The "Green Island" technique was employed because numerous large islands of well-revegetated spoil were scattered throughout the reclamation area. This created an aesthetically appealing construction project, retained a more diverse wildlife habitat, and resulted in somewhat lower construction costs.

With this technique, as much of the well-revegetated area as possible was retained. Removal and selective placement of toxic spoils, pond drainage, and slope reduction required the sacrifice of approximately 24 acres of already well-vegetated spoils. It was anticipated that this would help improve water quality, reduce off-site sedimentation, and enhance future management of the lands. Two typical spoil grading and placement situations were present in the project area:

1. Random mounds, ridges, and valleys in the older outermost surface mined area. These sections were basically regraded in place, with the maximum distance for spoil grading set at 200 feet. Very gentle slopes of 10% or less resulted after grading in these sections.

2. Steep outslopes, and a few inslopes along obliterated ponds. An attempt was made to remove, with earthmovers, all the toxic material on the steep outslopes. This spoil

was buried in the drained pits. During the design phase it was not possible to estimate how much of this spoil would remain on the surface after a desirable slope was created. Every effort was made to create a final slope of 4:1 (25%) or less. This slope could not be achieved in all situations, but the criterion was attainable over most of the area.

No criterion was established for maximum highwall height to be left remaining after backfilling with the outslope material. Former highwall heights were not uniform and highwall exposures that remained after grading varied from no highwall remaining to a maximum of 20 feet.

In addition, the highwall was to be broken at approximately 500 foot intervals for more convenient access to and from the ridgetops above for wildlife, recreation, and timber management needs. This was done by locating the access points where the highwall was already low, usually where the slope was broken by a draw or ravine. A few of these points were also used for hauling the resoiling material from the borrow site to the mine.

Surface Amendment All graded areas with a resulting surface pH less than 4.2 were covered with native soil. The soil was obtained from borrow sources established on nearby ridgetops. Their configuration and exact location were laid out to cause the least amount of visual disturbance while utilizing areas of deepest soil. Where areas of suitable depth were developed (8 feet) a depression that would hold water and function as a wildlife waterhole was constructed after removal of the needed soil.

A minimum of 8 inches of soil was placed on the finished slopes where surface pH required it. This was the case on all but 4 acres of the project. In order to partially neutralize the extremely acidic shales, a different approach to the traditional application of agricultural lime was undertaken. After determining that 8 tons/acre was the required amount of lime the sequence of lime and soil placement was as follows:

1. Grade to final slope.

2. Apply 4 tons/acre of lime and incorporate into spoil.

3. Place 8 inches of soil.

4. Apply 4 tons/acre of lime and incorporate into soil.

The regraded area not requiring topsoil application was limed at a rate of 6 tons/acre, and the lime was incorporated into the spoil material to a depth of 6-10 inches.

Revegetation The primary revegetation objective was to reestablish herbaceous cover as rapidly as possible to prevent erosion. In addition, legumes for wildlife enhancement and nitrogen fixation were included with all permanent seeding mixtures. Reforestation was accomplished at a later date (approximately three to five years after projection completion).

With the exception of borrow sources, all disturbed areas that would not be reworked within 30 days were temporarily seeded (i.e., any graded area either before or after resoiling, that was not ready for permanent revegetation, was seeded with a temporary cover such as wheat, rye, or oats). This requirement involved close monitoring, control, and judgement by the project engineer. This was an erosion prevention practice employed during those periods of time when partially graded areas were idle and devoid of vegetation for extended periods of time.

The permanent revegetation of the Yost II reclamation area was designed with one of three management implications in mind. General reclamation area seed mixtures were developed for spring, summer, or fall seeding seasons so that whenever it was ready for seeding, the greatest opportunity for success was ensured, based on the seasonal suitability of various species. Mixtures were also developed for designated wildlife openings and a small (4 acre) warm season native grass area. This was the first effort made by the Forest to establish a warm season prairie-type grass community on a reclaimed abandoned surface mine.

Table 1. Plant Species Used to Revegetate the Yost II Reclamation Area

Warm-Season Native Grass Community

- Switchgrass
- Indiangrass
- Bluestem
- "Tioga" deertongue
- Sideoats grama
- Weeping lovegrass

Wildlife Openings

May 15 - July 31	August 1 - October 15
Alsike clover	Alsike clover
Medium red clover	Medium red clover
Korean lespedeza	Korean lespedeza
Sudan grass	Annual ryegrass

General Reclamation Area

March 15 - May 15	May 16 - July 31	August 1 - October 15
Orchard grass	Timothy	Redtop
Korean lespedeza	Sericea lespedeza	Birdsfoot trefoil or
Perennial ryegrass	"Tioga" deertongue	Sericea lespedeza
Birsdfoot trefoil	Weeping lovegrass	Perennial ryegrass
Spring oats	Annual ryegrass	Winter wheat

La Grange

Mining History The project area was created by a ridgetop mining operation that had occurred in 1966. Common mining practice at the time was to dump spoils over the slope in order to most expeditiously reach and remove the coal. The mining area was at the head of a very steep ravine. The elevation difference from the ridge top to the bottom was about 300 feet. There are no reliable records indicating whether any underground mining had occurred prior to the 1960's, however, a small amount of waste coal similar in appearance to that usually found at the entrance to old drift mines was discovered adjacent to the landslide.

Mined Area Configuration After minimal grading, which met standards at the time, a pit was left between the peak of the spoil bank and the 20 foot highwall at the ridge top. Sometime between 1970 and 1972 the oversteepened slope failed resulting in a rotational slump. An estimated 300,000 cubic yards of spoil moved varying distances downslope and onto county road 22 at the foot of the slope. As a stream meander encroached from the other side of the road, an immediate problem developed in maintaining an open road.

A feasibility study found that two ponds in the pit at the top probably contributed greatly to the slope failure. Also, a spring was observed shortly below the escarpment of the failure which was highly contaminated with acid mine drainage and whose flow was fairly constant. Dye testing was inconclusive in demonstrating that the spring was fed by either pond. The water in the ponds was, however, at the same elevation as the spring. The waste coal remnants were just below the elevation of the spring.

The feasibility study included making nine test borings which found that the spoil mixture of clayey sand and sandstone boulders was encountered all the way to the bedrock. It was also determined that the dip of the rock strata in the area averaged 25 feet per mile toward the east. Any soil movement would have directional slope inclination for mass failure.

Reclamation Design Concept Design work centered around the upper and lower portion of the slide. The following corrective measures were developed to treat the problem areas:

1) Limit the amount of water seeping into the slide mass.

2) Stabilize the slide material by removing part of the bulge near the toe of the landslide and shaping to flatten grade.

3) Establish vegetation on the landslide mass.

Major regrading was required to eliminate the problem at the top of the slide. The double ponds in the pit had to be eliminated, as well as removing the overload of spoil poised for another failure. This was accomplished by draining the ponds and backfilling with spoil. Immediately after drainage and before backfilling, however, a subsurface drain was installed. Since a highwall remained after the mining operation, it was decided that as much groundwater as possible, including that which infiltrated through the highwall, should be intercepted at the top of the landslide and removed. This was accomplished by installing a 6" flexible PVC drain at the level of the under clay a short distance out from the highwall. During construction, the source of the spring was discovered. An old drift mine opening was uncovered during excavation for the drain which was flowing several gallons per minute. The installation was modified to intercept this flow and within hours the spring ceased flowing.

After grading was completed at the top of the landslide, a large surface diversion was built to drain each way from the center to control surface runoff. The diversion was located to take advantage of an outcrop of bedrock, where a portion of the subsurface water moving downhill through the spoil mass could be intercepted.

The lowermost part, or leading edge, of the slide had continued to slowly move out onto the county road. Even with stabilization and water removal at the source of the slide, it was felt that the bottom would continue to move, unless something was done to alter the process. The decision was made to remove the large mass of spoil and soil that had slid downslope, and use the material to raise the road bed, with the road embankment then serving as reinforcement to the bottom of the slide. The configuration of the road was such that it ran for 600 feet, fairly level, along the face of the slide, with a positive grade on either end. Enough spoil was available to raise the entire 600 foot section 10 feet, which placed it above the flood zone of the adjacent stream. The design incorporated a 10 foot wide ditch on the upslope side of the road with the cut slope at 3:1 for added stability. Two 36 inch culverts were installed under the road for drainage. A diversion was constructed across the lower slope approximately 100 feet upslope from the road to drain off seepage water that continued to flow during the construction phase of the project.

The remaining portion of the landslide, at midslope, was not disturbed any further by reclamation. It was felt that a complete regrade would only destroy natural revegetation that had already occurred, and could create additional erosion. It was determined that some further movement of the slope would probably take place, compromising any grading efforts.

Surface Amendment La Grange was the only reclamation project undertaken in which the use of a surface amendment was not prescribed. The spoil pH ranged between 4.0 and 4.5, and averaged 4.4. Past experience had indicated that spoils of this pH are marginal for supporting revegetation, unless some sort of surface amendment is applied/incorporated in the spoil. Due to poor access (steep slopes, no road at the top) and lack of a source of topsoil, the decision was made to spread and incorporate lime only, prior to seeding and mulching. This was done at the rate of 6 tons per acre, and was incorporated into the spoil to a depth of 6-10 inches.

Revegetation Establishment of herbaceous cover as rapidly as possible for erosion control was the primary revegetaion objective. The overriding concern was to provide a semipermanent erosion control cover rather than a species mix that would eventually weaken so that reforestation could be accomplished.

Table 2. Plant Species Used to Revegetate the LaGrange Reclamation Area

Kentucky 31 fescue
Annual ryegrass
Birdsfoot trefoil
Sericea lespedeza
Orchardgrass

Weltzheimer

Mining History The Weltzheimer reclamation project area has a long and complicated mining history, involving both underground mining for removal of coal and clay and surface mining for coal. Fire clay and coal were extensively driftmined in the past, beginning as early as 1913. The fire clay immediately below the Lower Kittanning (No. 5) coal, the coal itself, and the Middle Kittanning (No. 6) coal were extensively deep mined.

Within the reclamation area, underground mines were opened for coal or clay in 1913, 1915, 1921, 1931, 1935, and 1958. None of the mines were in operation at the time of reclamation and all surface equipment and facilities had been removed. At least one early surface mining operation occurred sometime in the 1940's. The Middle Kittanning coal was partially removed along a very narrow contour at that time. Disturbance appears to have been minimal because of known equipment limitations and as evidenced by present natural revegetation where this old spoil has not been redisturbed.

The most recent mining operation intermittently contour strip mined the project area from 1965 to 1973. The operation was basically a haphazard one which consisted of salvaging the remaining Middle Kittanning coal between the highwall of the 1940's stripping and the old underground mines. Additionally, some of the Lower Kittanning coal was also salvaged between the old underground clay and coal mines and the outcrop. As a result, it is believed that very little coal remains except the pillar supports in the underground mines. More extensive surface mining was prevented by a deed restriction prohibiting strip or surface mining where the overburden exceeded thirty feet in thickness above the seam. In November 1972, because of permit violations, the operator was ordered to cease operations. Mining was stopped in 1973, and in 1974 the company went into receivership, with very little reclamation work having been done. As a result, a considerable portion of the land was left barren and numerous old underground mine openings were exposed. Acid mine drainage flowed into tributaries of nearby streams. The high acidity and heavy metals concentration resulted in the death of most aquatic life, aquatic and streamside vegetation, and a substantial lowering of water quality in tributaries of the Hocking River.

Mined Area Configuration The configuration of the project area before reclamation can be characterized as a series of near vertical, twenty to thirty foot highwalls, partially-graded spoils, abandoned pits, irregular mounds, and steep outslopes with landslides. The outslopes were devoid of vegetation, and at the maximum angle of repose for the spoil which is 65-70%.

The mined area included within the reclamation project contained 107 acres, of which 76.4 acres was barren and devoid of vegetation, 5.6 acres was water, and 25 acres was partially revegetated.

Reclamation Design Concept A partial regrading technique, in keeping with cost reduction, was used, retaining as much of the revegetated areas as possible. Removal and burial of toxic spoils, pond dewatering, and slope reduction required the sacrifice of approximately 9 acres of well-revegetated spoils. This was a trade-off that was expected to result in improved water quality, reduced off-site sedimentation, and enhanced future management of the land.

This project was designed utilizing the following corrective measures:

1. Reduction of acid mine drainage by dewatering acid mineralized ponds and burial of toxic spoils exposed to the surface.

2. Improve surface runoff patterns and groundwater quality by backfilling ponds and depressions, and creating positive drainage away from highwalls.

3. Reestablish buried drainageways by excavation, grading, and armoring with limestone riprap.

4. Reducing erosion and off-site sedimentation by reducing slope grade, installing diversions, and revegetating the disturbed area with specified mixtures of grasses and legumes.

Two typical spoil grading situations were encountered in the project area:

1. Contour strip mining operation where only one seam of coal, the Lower Kittanning or the Middle Kittanning, had been removed. In some locations partial reclamation was done during mining, in others, none was accomplished after coal removal. The highwalls were variable in height, ranging from 15 to 35 feet. In general, where the highwalls were less than 20 feet high regrading to the top was specified.

2. Double contour strip mining operation where both the Lower Kittanning coal and the Middle Kittanning coal were removed. With or without reclamation, this resulted in a stairstep configuration after mining. The two coal seams were only separated by approximately 25 feet of shale and clay in this area. The upper seam, the Middle Kittanning, had been mined first, thus both highwalls were left exposed.

No criteria was established for maximum highwall height to be left remaining after backfilling with the outslope material. Highwall exposures after grading varied from no highwall at all to a 30 foot maximum. The Lower Kittanning highwall was covered wherever it was exposed because of the very toxic carbonaceous shales that it contained. The original slope above the Middle Kittanning highwall was so steep in much of the area that it was not possible to regrade completely.

Surface Amendments All regraded areas that had a surface pH less than 4.5 needed an amendment material added to or incorporated into the surface to provide a growing medium suitable for successful revegetation. The use of topsoil is usually a first consideration. However, investigation of the surrounding area revealed that there were no suitable topsoil borrow sites within a reasonable distance of the reclamation area. Thus, the use of alternate materials had to be considered.

A considerable amount of research has been conducted recently regarding the use of municipal sewage sludge, paper mill sludge, spent mushroom compost, and other organic waste materials for mined land reclamation. There were still many questions in 1982 when this project was in the design stages regarding the suitability of different types of sludges, the appropriate use of lime, and the application of other forms of organic matter. Researchers have found that the incorporation of large amounts of organic matter is equally as important as the use of lime to counteract high acidity spoil problems. (Hoitink et. al., 1982, Sopper et. al., 1981). Due to its availability and the desire to conduct a demonstration project, paper mill sludge was selected as the surface amendment to use on the Weltzheimer project. This particular sludge was a mixture of primary and activated secondary sludge from a kraft process paper mill. The sludge is high in organic matter content, high in lime content, and has some nutrient value. The sludge is also high in wood fiber content and has excellent mulching capabilities. As a result, little or no fertilizer, no lime, or mulch needs to be applied.

All graded areas with a final surface pH <4.5 were amended with the sludge at the rate of 225 wet tons per acre (approximately 75 dry tons). It was spread uniformly with a bulldozer and incorporated with a disk to a depth of 6-10 inches. Regraded areas that were not sludge-amended (surface pH >4.5) were limed at a rate of 6-12 tons per acre, the rate depending on specific spoil sample results.

Revegetation Revegetation objectives and procedures were similar to those used with the Yost II reclamation project described earlier. The approach to seeding wildlife openings was changed to reflect spoil acidity conditions before any amendments were added. Permanent wildlife openings 0.5 - 3 acres in size were established in close proximity to undisturbed hardwood stands and water where possible.

Table 3. Plant Species Used to Revegetate the Weltzheimer Reclamation Area

Wildlife openings

Spoil pH Between 4.0-5.0*	Spoil pH Above 5.0**
Weeping lovegrass	Alsike clover
Birdsfoot trefoil	Medium red clover
Korean lespedeza	Korean lespedeza
Red clover	Annual ryegrass

*If weeping lovegrass is not available, redtop can be substituted. If redtop is substituted for weeping lovegrass, and seeding is done between May 15 and August 1, add sudangrass.
*If seeding is done after August 1, substitute redtop for weeping lovegrass and add winter wheat or annual ryegrass.

**If seeding is done between May 15 and August 1, substitute sudangrass for annual ryegrass.

General Reclamation Area

March 15 - May 15	May 16 - July 31	August 1 - October 15
Orchard grass	Timothy	Redtop or orchard grass
Korean lespedeza	Birdsfoot trefoil	Birdsfoot trefoil
Perennial ryegrass	"Tioga" deertongue	Perennial ryegrass
Birdsfoot trefoil	Weeping lovegrass	Winter wheat
Spring oats	Sorghum	
	Annual ryegrass	

Pine Grove

Mining History Underground drift mining an undetermined number of years previous, at least 25 years, based on the age of the oldest trees growing within the disturbed areas, had left behind a 0.9 acre pile of waste coal on a hillside in the forest. Sometime in the 1970's a surface mining operation removed the remaining coal along the cropline on the opposite side of the ridge, and too little coal remains for any future mining venture to economically remove. The waste coal is thought to have caught fire in 1981, and soon became a noxious, hazardous problem. While surrounded by forest land, a county road runs nearby, and two rural residences front the road on either side of the old mine and waste coal pile. Once it was on fire, the extent of burning and depth of waste coal was difficult to determine. In addition, the burning coal refuse caused three forest fires between 1981 and 1984.

Mined Area Configuration The project area lies within the upper reaches of a first order drainage between county road 25 and the ridgetop. The mine opening was located just above a gently sloping bench, so the coal waste that was generated during mining was dumped and leveled on the bench. This was a very small mine, and when it was closed, the waste covered 0.9 acres at a depth ranging from 1-7 feet.

Reclamation Design Concept The exact location of the old mine opening could not be determined during survey and design of the project. It was apparent that it had not been sealed, or had not been sealed effectively, because acid mine drainage seeped through the coal waste and then into a ravine. In actual practice, very few old drift mines were sealed when the mine was closed.

Since the regional dip in this area is toward the southeast at 25 feet per mile, most drift mines on south or east slopes will drain freely out of the old mine openings. The Pine Grove project mine was situated on an east-facing slope.

Reclamation objectives The Pine Grove project was designed to meet the following objectives:

1. Extinguish the fire and eliminate the health and safety hazard that was present.

2. Reduce acid mine drainage contamination of the entire area by installing a subsurface groundwater collection system.

3. Restore site productivity and aesthetics by grading to near original contour and revegetating the disturbed area with a grass and legume mixture.

4. The mine opening, if found, was to be sealed to the extent possible with high clay content backfill material to reduce oxygen infiltration into the mine.

Determination of the amount of waste coal that had burned and how much remained before reclamation began wasn't possible because of the hazard involved. A pit was excavated on the site, with the soil that was removed to be used for cover material later. The coal waste that was still burning was dumped into the pit and extinguished with water. During reclamation it was discovered that most of the waste coal had already burned.

After removal of the burned and unburned waste coal, the subsurface drain was installed parallel with the slope and slightly below the elevation of the original surface of the ground. A drainage tile flowing approximately 70 gallons per minute was discovered while excavating the trench for the subsurface drain. It appeared to go into the slope in the direction that an old mine opening would be expected, although it was not found. This tile was tied into the drainage system. No other seeps of significance were discovered.

The area was then covered to a depth of 3 feet with soil, and a final cover of 6-8 inches of topsoil was added to support vegetation. Two diversions were installed in order to reduce erosion on the finished slopes before vegetation became established.

Revegetation Unlike our other reclamation projects, the time frame within which the seeding would be done was predetermined, hence, only one season-specific mixture was specified (seeding was anticipated May 15-July 31).

Table 4. Plant Species Used to Revegetate the Pine Grove Reclamation Area

Orchard grass
Annual ryegrass
Korean lespedeza
Weeping lovegrass or redtop

CONCLUSION

The four abandoned mine land reclamation projects discussed afforded the opportunity to design demonstration projects to evaluate the use of various surface amendments. Considering the stated reclamation objectives of each project, all have been successfully met with the exception of water quality. Little improvement can be expected where the water quality within a project area is contaminated with discharge from abandoned underground mines. Such was the case with the Pine Grove and Weltzheimer projects. Unless an effective mine sealing program were undertaken, or a treatment facility installed, the quality of the drainage can be expected to remain relatively unchanged.

The other two projects, LaGrange and Yost II, were expected to show some improvement. Seepage of acid mine drainage from lower outslopes has continued after reclamation, usually at the same location as before. Even though seepage sources, i.e. ponds, were eliminated, the seepage has continued. One must conclude that unless the established seepage route is obliterated, a barrier placed in its path, or a subsurface drainage collection system installed, the seepage will continue.

Revegetation efforts have been very successful. Complete cover has been achieved on all the projects with the exception of a few small areas on Yost II where the topsoil application was inadvertantly thinner than specified. All of the surface amendment systems provided a suitable growing medium for the seeding mixtures that were used. The sludge-amended project appeared to produce earlier more vigrous growth and foster ground cover, but all project areas had complete cover, with the exception noted. The season-specific grass-legume mixture technique has exceeded our expectations with respect to early vigorous and lush growth. More time must elapse before long-term vegetative management objectives can be assessed, however.

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THE URANIUM MILL TAILINGS REMEDIAL ACTION PROJECT: A RETROSPECTION

John B. Price[1] (member, AWRA), James E. Brinkman[1], and Don Diego Gonzalez[2]

ABSTRACT: The Uranium Mill Tailings Remedial Action (UMTRA) Project is a program of the U.S. Department of Energy which is stabilizing inactive uranium mill tailings. The protection of water resources is a key part of stabilization. The program serves as an important precedent for other programs to control wastes including, implicitly, mixed waste. A Technology Development Program within the UMTRA Project developed site characterization data and a conceptual model for the movement of contaminants in mill tailings and their environs. The protection of water resources is constrained by other design criteria for tailings stabilization. Ongoing characterization and modeling of UMTRA Project sites represent a large database and multiple site "case study" which should be used as a source of information to develop portions of the technical approaches and generic conceptual models to be used in other waste programs. This database inludes techniques for laboratory quality assurance and infiltration modeling.
KEY TERMS: mixed waste; ground water; infiltration; mill tailings; UMTRA Project; regulatory.

INTRODUCTION

The Uranium Mill Tailings Remedial Action (UMTRA) Project is a program of the U.S. Department of Energy (DOE). Based on Federal legislation, the DOE is stabilizing uranium mill tailings at 24 inactive mill sites in 11 states (Figure 1). The program recognizes that the tailings may pose a significant radiation hazard to the public. The program focuses on reduction of radon emissions, but also has the objective of preventing or minimizing other environmental hazards from tailings. The protection of water resources is a major part of minimizing "other environmental hazards." The ultimate cost of site characterization, design and construction for the 24 sites is currently estimated at

1 Hydrogeologists and 2 Project Director, Roy F. Weston, Inc., 5301 Central Ave., NE, Suite 1000, Albuquerque, NM 87108

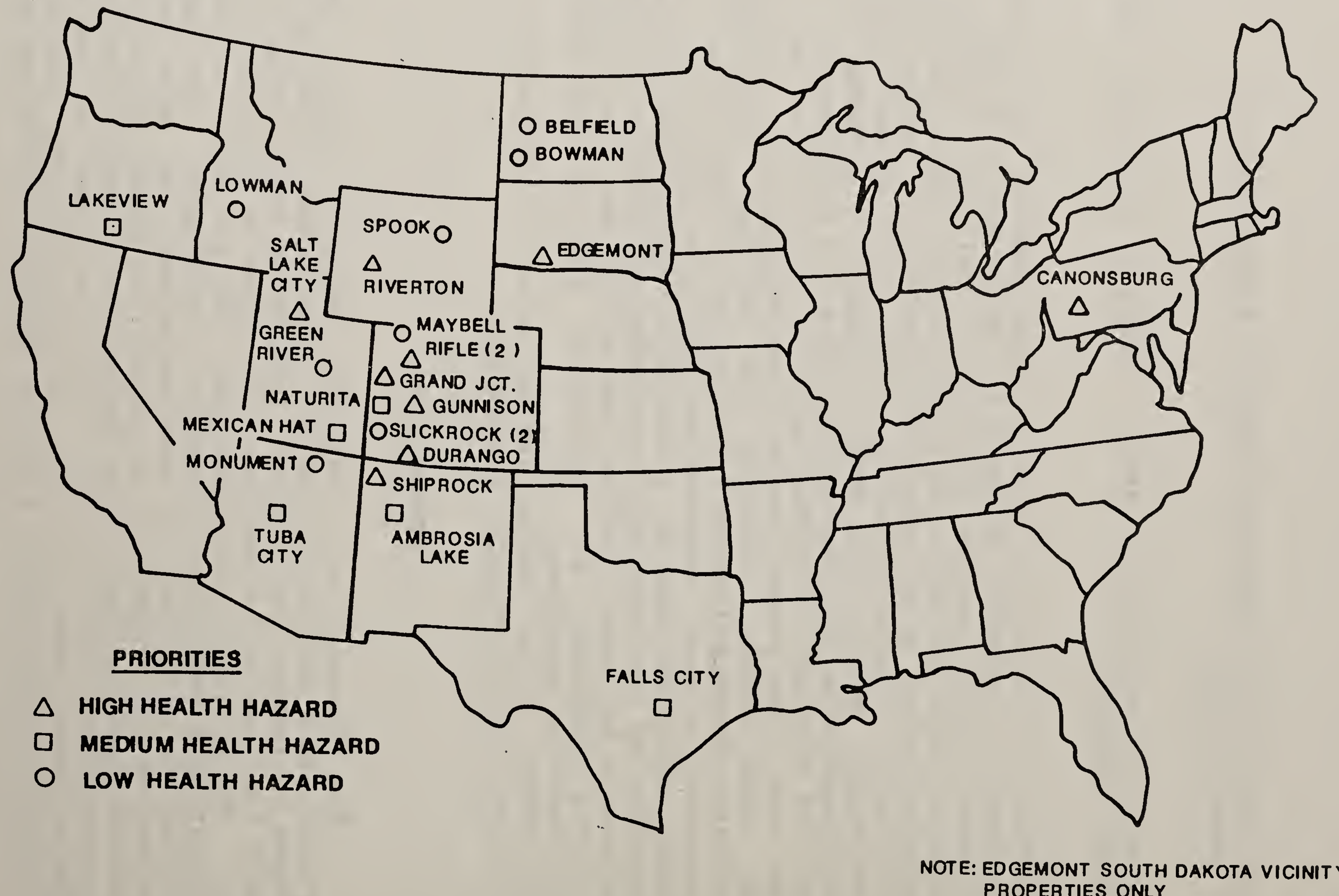

FIGURE 1: UMTRA PROJECT SITE LOCATIONS

approximately $1 billion.

The UMTRA Project is a one-time program specific to one class of waste, uranium mill tailings, and could seemingly have little importance to other waste clean-up programs. For several reasons the program has and continues to set precedents with respect to other programs. Some of this importance has to do with minor references in UMTRCA and in the EPA regulations, 40 CFR 192. The Federal legislation which initiated the UMTRA Project, the Uranium Mill tailings Radiation Control Act (UMTRCA) includes directions that the EPA regulations for the UMTRA Project shall be consistent with the standards in subtitle C of the Solid Waste Disposal Act; EPA directed in their regulations for the UMTRA Project site (40 CFR 192) that stabilization of inactive uranium mill tailings shall comply with "relevant" portions of 40 CFR 264 (hazardous waste regulations).

The references to hazardous and solid waste regulations implicitly direct that inactive mill tailings be treated as mixed wastes. The UMTRA Project sets important precedents for the characterization, remediation and post-closure surveillance and maintenance of pregnant mixed wastes in the United States. Also, the partnership of the EPA, which developed the inactive mill tailings regulations, the NRC and participating state and tribal agencies which regulate the application of the standards, and DOE which applies them, is setting important precedents for cooperation of various governmental entities in dealing with all environmental concerns. The UMTRA Project is a direct precedent for stabilization of uranium mill tailings not addressed by this DOE program.

THE RESEARCH AND TECHNOLOGY DEVELOPMENT PROGRAM

The UMTRA Project Technology Development Program was initiated in Fiscal Year 1980 to develop techniques for stabilizing mill tailings. The Technology Development Program served as an important precursor to site characterization and remedial action design in the UMTRA Project. The program addressed a number of issues including water resources protection.

In 1980 the UMTRA Project Office and Sandia National Laboratories initiated the development of a characterization program to evaluate the effects of historical operations of inactive uranium mills on water resources. The data collected during the characterization would be the basis of a conceptual model of the hydrogeochemical processes occurring in the tailings and environs. The conceptual model would be used to develop numerical hydrologic models which were intended to serve as the primary tools for the design and implementation of remedial actions relative to water resources protection. To meet the objective of developing the conceptual model, the Technology Development Program implemented investigations to (DOE, 1985):

Determine rates of rainfall infiltration through the tailings into foundation materials.

Determine the hydrogeochemistry and radiochemistry of tailings.

Determine the retardation reactions and contaminant movement across the interface between the tailings and underlying materials.

Develop models which can simulate coupling of geochemical reactions and available pore water and predict solute transport in the ground water.

Technology development related to radon emissions was adapted to complement these direct investigations of technical issues related to water resources. The investigation of moisture flux in radon barriers was used to investigate fluxes through the tailings into foundation materials.

The UMTRA Project Technology Development Program included site characterization, modeling studies, and the development of a conceptual model of contaminant migration from uranium mill tailings (Shepherd and Brown, 1982). The Program resulted in a series of reports on the various lines of investigation. The site characterization activities specific to the Technology Development Program were summarized (Shepherd and Brown, 1983) and individual reports on characterization are listed in a summary report (DOE, 1985). The entirety of the Technology Development Program, including investigations relevant to protection of water resources, is described in a summary report (DOE, 1985), which includes a listing of all of the reports of investigations sponsored by the Technology Development Program. The Technology Development Program is a database which could be used to develop portions of the generic technical approaches and conceptual models for remedial investigations at other waste sites.

Generic Stabilization Scheme

The essence of the typical stabilization scheme is to cover the tailings with a cover system which serves several purposes. The cover prevents the physical dispersal of the tailings by wind, water, animals, or humans; retains a high degree of saturation in a layer which retards radon diffusion; and minimizes the infiltration of ambient precipitation (Figure 2). Many tailings piles are relocated to another site or rehandled: an additional feature of stabilization for these sites may be an engineered sub-base with geochemical properties that retard leachate migration.

The extent to which water resources can be protected is constrained by other required aspects of remedial action. For example, in the semi-arid western United States, subgrade disposal of tailings would tend to minimize the net infiltration of precipitation into the tailings. Evapotranspiration from native vegetation and soils tends to keep percolation small, and natural soils and vegetation could be replaced over a subgrade disposal site. Subgrade disposal, however, is usually not a viable remedial action for several reasons:

1) The cost of the remedial action can usually be minimized by stabilizing the tailings in-place, i.e., above grade.

2) If tailings are relcated, the cost of remedial action can usually be minimized by a cut-and-fill design which places the tailings only partially below grade, excavating only enough material to provide a cover (radon barrier) for the tailings.

3) Protection of water resources is provided in part by placing the tailings above the water table. At most sites with a shallow water table, this precludes subgrade disposal.

Another constraint on the protection of water resources is that the typical stabilization design includes a rock cover. The remedial action is required by regulation to be effective for up to one thousand years. In order to control erosion this longevity standard has so far, in the absence of subgrade disposal, resulted in rock covers for stabilized tailings. Available research indicates that rock armoring

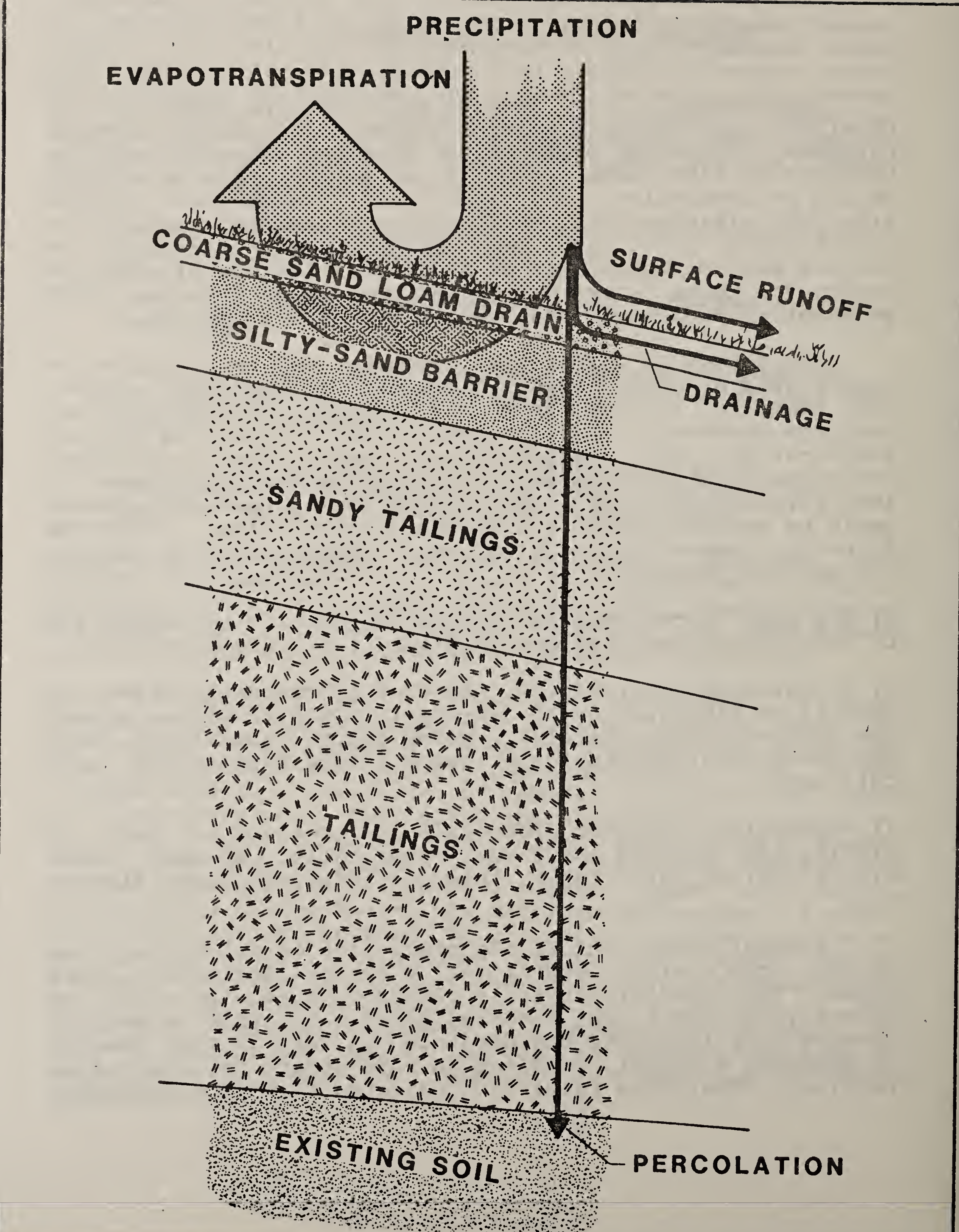

FIGURE 2: TYPICAL TAILINGS STABILIZATION SCHEME

tends to increase soil moisture retention (Beedlow, 1984). The rock cover tends to promote percolation, which is in opposition to the goal of protecting water resources.

Ultimately, the various goals of tailings stabilization are seemingly in opposition (Mayer et al., 1981). The goal of radon attenuation is achieved by maximizing moisture retention n the cover. The goal of protecting ground-water resources can be achieved by minimizing moisture flux through the cover, however, a cover which dries out can increase the emission of radon. The goal of erosion protection can be achieved by using a rock cover, which can impact ground water by increasing percolation through the cover.

Alternate Sites for Stabilization

Prior to stabilizing the tailings several design alternatives are evaluated, including relocation of tailings to alternate disposal sites. Stabilization of tailings in place is usually the least cost alternative in terms of design and construction, however, engineering and environmental considerations have lead to relocation of some tailings sites. Because of the relatively high cost of relocation, design alternatives for stabilization in place which would mediate initial environmental or engineering problems are carefully evaluated prior to relocation. Each alternate disposal site is given a complete site characterization so that stabilization alternatives can be compared in terms of costs and environmental impacts.

Site Characterization

Site characterization at UMTRA Project sites is multidisciplinary. It entails assay of tailings for residual mineral value, radiometric measurements, geotechnical characterization, and investigation of the hydrogeochemistry. The UMTRA Project has addressed a relatively large number of sites, 24 mill tailings sites and more than 50 potential disposal sites. The multidisciplinary nature and large number of sites have created an extensive database and project experience upon which to draw for site characterization for other projects.

The importance of this extensive database is demonstrated in its use to prepare a position paper relative to ground-water standards for inactive mill tailings sites. The original inactive mill regulations for water resource protection were remanded in September 1983 by the 10th circuit Court of Appeals, and the EPA is currently promulgating new standards. The Department of Energy is drawing on the extensive database generated by site characterization to develop a position paper with the objective of advising the EPA regarding the reasonableness and associated costs of various potential standards. This database could also be drawn upon to make decisions regarding other uranium mill tailings sites and other waste types which disturb relatively large areas with relatively low levels of toxicity.

Geochemistry, including sampling and chemical analysis of both water and soil or rock samples, is an element of site investigation relative to both source characterization and disposal site planning. Investigation of the geochemistry of the tailings and affected geologic environment supports the conceptual model of how contaminants have been mobilized in the past and how they will move in the future. Characterization of the geochemistry of potential disposal sites contributes to the conceptual model which is used to justify disposal plans.

Laboratory Quality Assurance

The most important aspect of the geochemical characterization is an understanding of the spatial and temporal distribution of water quality. This characterization includes definition of background conditions and the nature and extent of contaminant plumes. Quality assurance is an objective of all Department of Energy programs (DOE, 1984), and is a key facet of water quality characterization.

During initiation of ground-water programs for the UMTRA Project it was recognized that quality assurance of analytical laboratories should be a major concern (Keith et al., 1983). This quality assurance was implemented in two stages: by prequalification of laboratories (Brinkman, Rice, and Muller, 1986), and by continuing checks on the qualified laboratories (Rice and Brinkman, 1986).

The prequalification procedure consisted of the submission of samples of known concentrations to the laboratories. Based on the performance of the laboratories in analyzing the known samples, a limited number were accepted as qualified for site sample analysis. Continuing checks on the qualified laboratories are achieved by the inclusion of additional known samples in lots of field samples, to check accuracy, and the submission of replicate samples to check precision. The qualified laboratories are contractually required to achieve accuracy and precision targets for individual constituents. Also, accuracy requirements are set on cation/anion balance errors. This has required reanalysis of lots of samples which do not meet targets during initial analysis.

Regulatory Considerations

The UMTRA Project is derived from the Uranium Mill Tailings and Radiation Control Act (UMTRCA) of 1978. The Environmental Protection Agency (EPA) was given responsibility for promulgating standards for the protection of public health and the environment from uranium mill tailings. The Nuclear Regulatory Commission (NRC) was given regulatory and enforcement responsibilities for the regulations to be promulgated by the EPA. The EPA promulgated standards for inactive uranium mill tailings in 40 CFR 192, which became effective March 7, 1983.

A regulatory criterion for UMTRA Project remedial action is stabilization and elimination or limitation as is technically practicable of potential effects on public health and the environment for at least 200 years. The long term implication of "at least 200 years" adds uncertainty to prediction of design impacts. Therefore, DOE and its contractors have searched for and developed methods to bound or at least to account for the uncertainty. Several developments in the program have been:

1) creation of a numerical code to handle specifically the infiltration, percolation and soil moisture conditions expected at designed UMTRA Project repositories

2) technical approaches to provide adequate characterization and interpretation of the nature and extent of present and predicted future ground-water contamination, including analysis of the hydrodynamic and geochemical controls on the movement of the solute

3) the instigation of a project-wide plan to establish surveillance and maintenance plans for every remediated site which would include ground-water monitoring, where needed.

Infiltration

The rate of movement of moisture through and below the UMTRA repositories and the moisture content of the cover and tailings are considered in repository design. The design should ensure reasonable certainty that regulatory requirements and standard will be satisfied. A method to simulate the long-term soil moisture regimes at UMTRA Project site was developed by the Technical Assistance Contractor to the DOE. This method utilizes a computer code called Soil Moist.

Soil Moist is a one-dimensional finite difference solution to the Richards equation which can model moisture movement through multiple layers and can simulate daily precipitation, relative humidity and temperature, based on daily means and standard deviations. The code can be used to simulate vapor transport through a rock mulch and lateral movement of moisture along a sloping interface between a rock mulch and underlying soil layer. The code also accounts for runoff over the top of the rock mulch and freeze/thaw conditions. Soil data are based on field and laboratory measurements and application of empirical methods to determine the relationship of unsaturated hydraulic conductivity to soil suction. The code is an effective design tool because it is simple and numerical calculations can be performed in an acceptable timeframe. The code has been used to perform sensitivity analyses, to bound the results and parametric analyses, and to adjust the design features to meet the design standards most efficiently. Design features considered in the parametric analyses include saturated hydraulic conductivity of the rock layer, the slope of the interface between the rock layer and underlying soil layer (radon barrier) and the unsaturated hydraulic conductivity of the radon barrier as a function of soil suction.

The output from the Soil Moist code is used as input to the code used to calculate the long-term average rate of radon exhalation to the atmosphere and input to methods used to predict the long-term impact of percolation of leachate to the ground-water quality.

Protection of Water Resources

The methods used to model the long-term impact on ground-water quality vary from site to site, based on the nature and extent of the ground-water contamination and the severity of the problem relative to impacts or potential impacts to public health and the environment. Data collection programs vary from collection of several samples from several wells and soil borings to collection of several hundred samples. Modeling approaches vary from application of the simplest travel time equations to application of complex hydrodynamic, geochemical and solute transport numerical codes.

The rigor of the long term ground-water quality projections could increase once new EPA standards and regulations are in place. It is expected that these new standards will be enacted in late 1988 or early 1989. It is possible that some level of aquifer restoration will be required, i.e., that additional protection against existing contamination of ground water will be needed. The level of protection provided for water resources provided by the repositories against potential future contamination probably will not change with the new standards.

In recognition of design uncertainties and the occurrence of unpredictable natural events, a surveillance and maintenance plan will be developed for each UMTRA Project site. The purpose of the plans, in terms of water resource protection, is to verify that design predictions are satisfied and if they are not satisfied, that appropriate mitigation can be performed. When needed, a network of upgradient and downgradient monitor wells will be installed for sampling and analysis of ground water. The wells would be located and screened to determine excursions of contaminants as soon as possible. Sampling will be quarterly for the first two years following site closure.

CONCLUSIONS

The Uranium Mill Tailings Remedial Action Project is a large effort relative to the characterization and stabilization of inactive uranium mill sites. The Project serves as an important precedent for other waste programs, including mixed wastes. A Technology Development Program within the UMTRA Project developed site characterization data and a conceptual model for the movement of contaminants in mill tailings and their environs. Ongoing characterization and modeling of UMTRA Project sites represent a large database and multiple site "case study" which should be used as a source of information to develop portions of the technical approaches and generic conceptual models to be used in other waste programs.

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