Environmental Engineering Monograph

Department of Civil Engineering Colorado State University Fort Collins, Colorado

ENVIRONMENTAL ANALYSIS OF AN OIL SHALE INDUSTRY IN THE UPPER COLORADO REGION

by

D. W. Hendricks

J. C. Ward

June 1974 Number 2

The Environmental Engineering Monograph Series is a means of disseminating current research efforts of the faculty of the Environmental Engineering Program at Colorado State University as well as other works of interest. A variety of topics and disciplines in the broad area of environmental planning provide the platform for presenting original and reported works.

Topic Areas
- Water Pollution Control
- Solid Waste Management
- Water Chemistry
- Environmental Planning
- Social Forecasting
- Environmental Impact Analysis
- Technology Assessment
- Civil Engineering Projects

Discipline Areas
- Sanitary Engineering
- Microbiology
- Chemistry
- Planning

ENVIRONMENTAL ANALYSIS OF AN OIL-SHALE INDUSTRY IN THE UPPER COLORADO REGION 1/

D.W. HENDRICKS and J.C. WARD

Introduction

The oil-shale deposits found in the Green River Formation in the states of Colorado, Utah, and Wyoming are by far the largest in the U.S.A., accounting for about 80% of the known world deposits. In these states oil-shale deposits occur beneath 25,000 sq miles (16 million acres) of lands, of which about 17,000 sq miles (11 million acres) are believed to contain oil shale of commercial potential. The oil contained in these deposits in the Green River Formation amounts to about 1,800 billion barrels of recoverable oil. Figure 1-1 in Chapter 1 shows the distribution of these deposits. The area shown comprises to a large extent the Upper Colorado Region, which is the upper half of the Colorado River Basin.

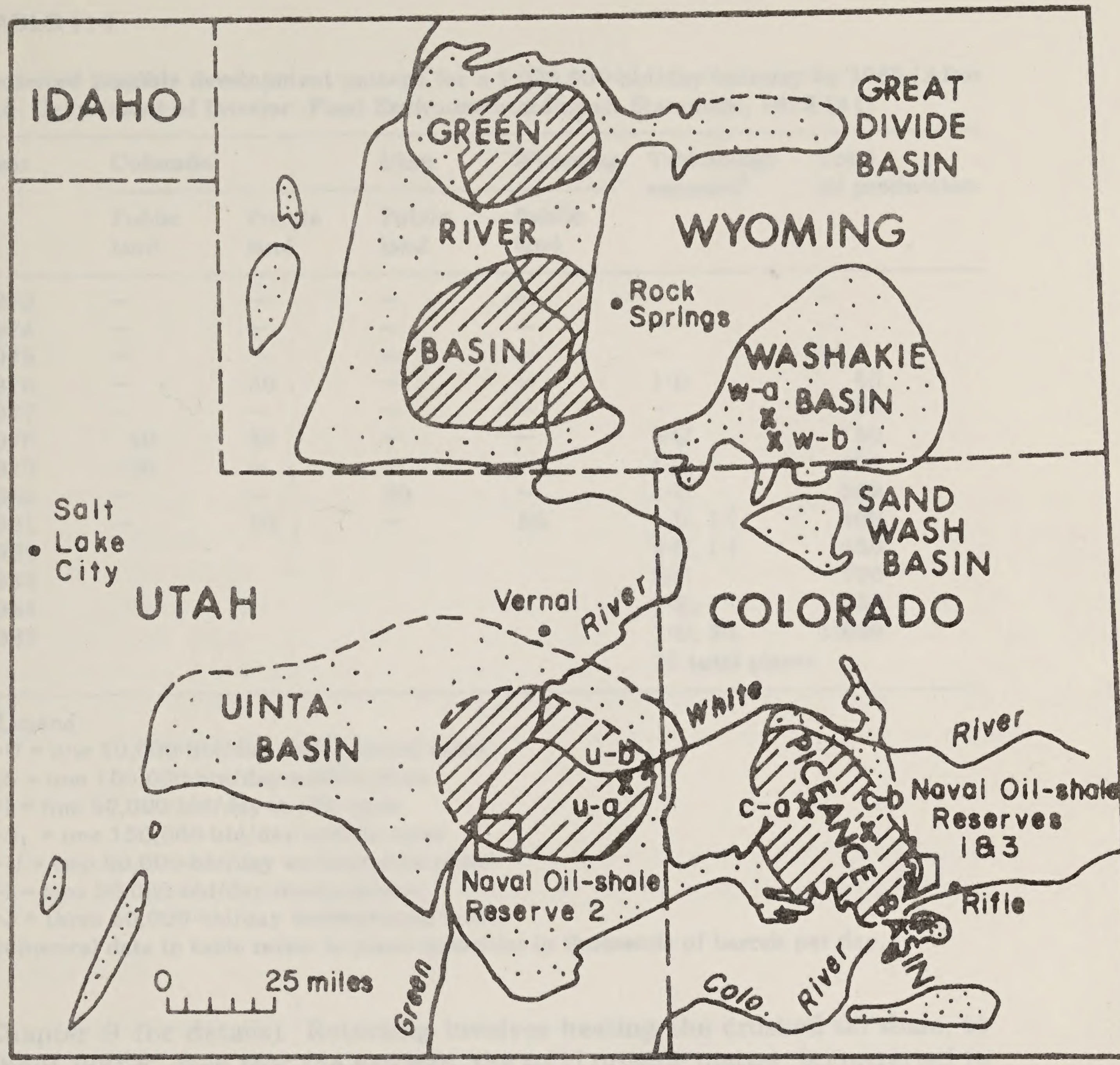
Industry development

Much of the land in the oil-shale regions is federally owned and administered by the U.S. Bureau of Land Management. The development of an oil-shale industry, therefore, is contingent upon the viability of a federal lease program. Such a program was initiated in 1973 with public bidding for six prototype leases — two each in Colorado, Wyoming, and Utah — of not more than 5,120 acres each. Figure 1-1 in Chapter 1 shows the approximate locations of the leasing sites. These sites were conceived as permitting a production level of 250,000 bbl/day by 1979. A one million barrel per day industry is anticipated by 1985 through further leasing. Table 11-I shows a possible time table for achieving the one million barrel per day production level.

The technology used in mining and processing of oil shale ore pertains strongly to questions of environmental effects. Three mining methods, i.e., surface, underground, and in-situ, are contemplated. Table 11-I also anticipates a possible technology mix for mining. Underground mining probably will predominate, because in most oil-shale areas the deposits are found at depths of 1,000 ft or greater. From Table 11-I, about 25% of the shale for a one million barrel per day industry would be mined by surface methods. According to most experts, perfection of the in-situ technology by 1985 seems questionable.

Processing technology involves crushing the ore and then retorting (see

1/ Chapter 11 in Oil Shales, edited by T.F. Yen, and G.V. Chilingarian, Elsevier Scientific Publishing Company, (to appear in 1975 or 1976).



EXPLANATION

Area Underlain by the Green River Formation in which the Oil-shale is unappraised or low grade

Area Underlain Oil-shale more than 10 feet Thick, which Yields 25 gallons or More per ton of Shale

x Designates BLM 1974 Lease Tracts of about 5000 Acres each Tract

Distribution of oil shale deposits in the states of Colorado, Wyoming, Utah (after U.S. Dept. of the Interior, 1973).

TABLE 11-I

Projected possible development pattern for a 1,000,000-bbl/day industry by 1985 (After U.S. Department of Interior: Final Environmental Impact Statement, 1973 [4])

Year	Colorado		Utah	Wyoming	Technology assumed[1]	Total oil production
	Public land	Private land	Public land	Public land		
1973	—	—	—	—	—	—
1974	—	—	—	—	—	—
1975	—	—	—	—	—	—
1976	—	50	—	—	1-U	50
1977	—	—	—	—	—	50
1978	50	50	—	—	2-U	150
1979	100	—	—	—	1-S	250
1980	—	—	50	—	1-U	300
1981	—	50	—	50	1-U, 1-I	400
1982					2-U, 1-I	550
1983					3-U	700
1984					1-S_1	850
1985					1-U, 2-I	1,000
					17 total plants	

[1] Legend:
1-U = one 50,000-bbl/day underground mine
1-S = one 100,000-bbl/day surface mine
1-I = one 50,000-bbl/day in-situ mine
1-S_1 = one 150,000-bbl/day surface mine
2-U = two 50,000-bbl/day underground mines
2-I = two 50,000-bbl/day in-situ mines
3-J = three 50,000-bbl/day underground mines
Numerical data in table refers to plant capacities in thousands of barrels per day.

Chapter 9 for details). Retorting involves heating the crushed oil shale, to about 900°F, such that the *kerogen*, the solid organic matter, is converted to gases and oil vapors. The three major retorting technologies are: (1) the Union Oil retort, (2) the TOSCO II retort, and (3) the Gas-combustion retort. These are merely different approaches to achieve the necessary heat transfer. Although the residues are different in particle size and to some extent in chemical composition, they all represent substantial disposal problems.

Characteristics of the region

General description

The upper Colorado Region is traditionally "western rural" in character; this is true in both image and fact. The landscapes are vast open spaces in all

TABLE 11-II

Land characteristics and land uses of the Upper Colorado region (From Upper Colorado Region Comprehensive Framework Study, 1971 [3])

Land Resource Groups	Area	Cropland Irrig.	Cropland Dry	Grazing	Timber Production	Urban and Industrial	Developed Recreation & Classified Watershed	Primitive Areas (Wilderness)	Developed Mineral Production	Trans. and Utilities	Developed Fish and Wildlife
					Area (Thousands of Acres						
UPPER COLORADO REGION-1930											
Alpine	1,329		-	257	-	3	22	417	-	6	-
Forest	27,152	-	-	19,926	9,351	10	155	777	-	108	-
Range	37,050	-	-	33,944	-	11	69	156	-	151	-
Cropland	1,571	1,056	515	-	-	-	-	-	-	-	-
Pasture	1,395	738	57	600	-	-	-	-	-	-	-
Urban (Priv)	392	-	-	-	-	185	-	-	-	198	-
Water & misc.	3,268	-	-	1,231	-	147	156	64	71	169	393
Total Land	72,157	1,794	572	55,958	9,351	356	402	1,414	71	632	393
Water (areas 40 ac.)	482	-	-	-	-	-	351	-	-	-	-
TOTAL	72,639	1,794	572	55,958	9,351	356	753	1,414	71	632	393

three states consisting of extensive sparsely vegetated plains with low escarpments, some forests, and several imposing mountain ranges. Elevations range from 5,000 to 10,000 feet above sea level. Precipitation varies from about 7 inches in the Wyoming plains to 24 inches in the high plateau areas of Colorado. Table 11-II gives a general statistical picture of the basic land categories and the various activities common to the region as related to land use. The "western rural" character is also evident from the numerical data given.

Population

Population density is also consistent with the "western rural" designation. Density of population is about three persons per sq mile. Table 11-III shows

TABLE 11-III

The 1970 population distribution in oil-shale areas (From 1970 Census of Population, General Social and Economic Characteristics, U.S. Department of Commerce, Washington, D.C., 1972)

State	County	Population
Colorado	Garfield	14,800
	Mesa	54,300
	Rio Blanco	4,800
Utah	Duchesne	7,300
	Uintah	12,700
Wyoming	Sweetwater	18,400
	Uintah	7,100
		119,400

the 1970 population distribution by county for the three-state region.

Towns in the region include: Grand Junction (20,000), Rifle (2,500), Meeker (1,597), Craig (4,205), Rangley (1,591), in Colorado; Vernal (4,000) in Utah; and Rock Springs (11,700) in Wyoming. Denver and Salt Lake City are the two nearest major metropolitan areas.

Water

The rate-limiting factor in further development of the region is probably the availability of water. Water is also a major factor in the development of oil-shale resources. The average annual flow in the Colorado River at Lee's Ferry, the accepted division point between the upper and lower basins, is 12,710,000 acre-ft. Of this, 5.8 million acre-ft is available for upper basin depletion. The environmental impact statement estimates 341,000 acre-ft of this water could be made available for depletion by oil shale. During the period 1949—1968, water rights applications by oil companies in the Colorado oil shale area totaled 1,103,348 acre-ft of water claimed. These applications have the status of filings and conditional decrees, which does not assure the availability of water. In some cases, irrigated land has been purchased in order to obtain water rights, but this does not assure that the water can be made available for the oil-shale development, especially if the point of diversion must be changed.

Another important factor which must be taken into consideration in any water-use plan, is the potential salt loading of the Colorado River. The average annual salinity concentration of the Colorado River at Imperial Dam during the period 1941—1970 was 757 mg/l. It is anticipated that this concentration level will increase well beyond 1,000 mg/l by 1980. The economic damages associated with these higher salinity levels are significant and have been the subject of extensive economic studies.

Mineral resources

Energy resources in addition to oil shale are extensive over the three-state oil-shale area. Recoverable natural gas is estimated at 85 trillion cu ft, whereas crude oil reserves are estimated at 680 million barrels. Coal deposits are estimated at 6—8 billion tons; two-thirds of these deposits are in Wyoming and one-third are in Colorado.

In connection with the oil-shale development, surveys have shown that about 27 billion tons of alumina are present in the central Piceance Creek Basin, along with about 30 billion tons of nahcolite. These minerals could be mined in conjunction with oil shale. This means that a single plant that produces 35,000 bbl/day of upgraded shale oil could also yield about 3% of the 1980 anticipated need for aluminum and 15% of the nation's 1980 need

for soda ash (sodium carbonate). These figures are based upon assays showing 11% by weight of dawsonite and 15% by weight of nahcolite.

Ecology

Ecologically, the Upper Colorado River Region is highly valued. Due to the limited human population and extensive areas of public lands, the region has retained its essentially natural character. Big game animals include mule deer, antelope, bighorn sheep, black bear, elk, moose, and mountain lion. Mule-deer populations in the Piceance Basin number 30,000—60,000 animals. The herd is one of the largest in the United States of America and is considered especially valuable. Herds are also large in the Uintah Basin and in Wyoming. Elk herds are also substantial. In addition, there are a number of species of small game, 27 species of migratory waterfowl and shore birds, six species of upland game birds, five species of fur bearers, 21 species of nongame animals, 200 species of nongame birds, and 24 species of raptors. Several wild-horse herds are also found in the region.

Fishery habitat in the Upper Colorado Region includes 36,000 acres in natural lakes, 275,000 acres in impoundments, and 9,000 miles of fishing streams. There is little fishery habitat in the oil-shale areas.

Plant communities depend upon the life zone represented. These are listed as follows for the oil-shale areas: sagebrush — 6,240,000 acres; salt brush—greasewood — 2,720,000 acres; juniper pinyon woodland — 2,640,000 acres; mountain mahogany—oak scrub — 1,280,000 acres; Douglas fir forest — 960,000 acres; western spruce fir forest — •••,••• acres; great basin sagebrush — 320,000 acres; and foothills prairie — 80,000 acres.

How many acres?

Much of this information is summarized in Table 11-IV, which shows the general ecological character of the overall region.

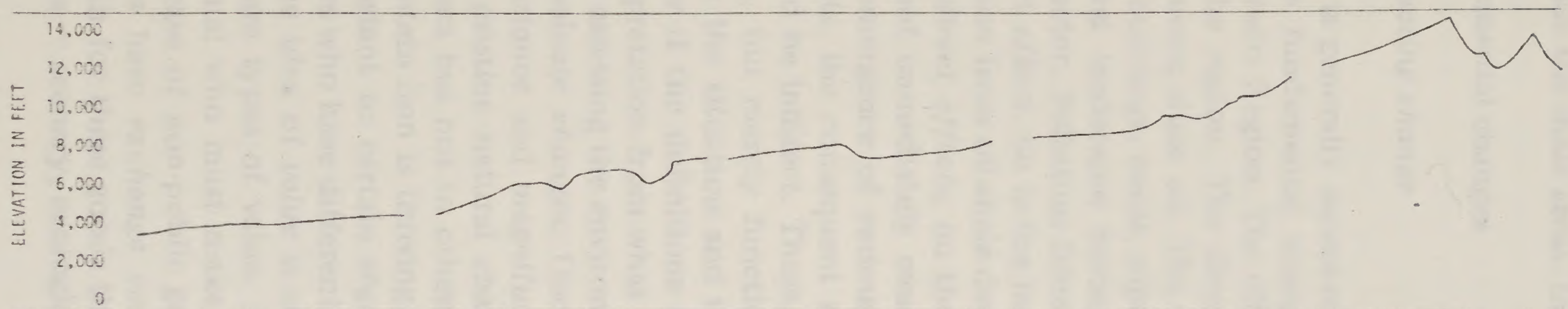
Recreation

Outdoor recreation in the region is considered of high quality due to the vastness of the essentially pristine natural environments and to the scenic and ecological richness of the area.

Hunting in October and November is one of the major recreational activities. In the Piceance Basin, mule deer hunter-days number on the order of 40,000 per year with an annual harvest of over 5,000 mule deer.

Some of the scenic areas in the region include Dinosaur, Arches, Canyonlands, and Black Canyon National Monuments, and numerous less well-known areas in the White River and Uncompahgre National Forests. Some notable areas in Rio Blanco County, Colorado, for example, include: Flat Tops Wilderness area, Douglas Creek, Moon Canyon, Cathedral Bluffs, Raven Ridge, and Piceance Creek. Ski areas in the region are numerous and include Snowmass, Aspen, and Vail.

Table 11-IV. General Ecological Characteristics of the Upper Colorado Region (4).



	LOWER SONORAN ZONE	UPPER SONORAN ZONE	TRANSITION ZONE	BOREAL ZONE	ARTIC-ALPINE ZONE
CLIMATE	SUMMER TEMPERATURES Maximum--101 Minimum--72 WINTER TEMPERATURES Maximum--67 Minimum--39 AVERAGE ANNUAL PRECIPITATION 9 inches	SUMMER TEMPERATURES Maximum--97 Minimum--70 WINTER TEMPERATURES Maximum--65 Minimum--26 AVERAGE ANNUAL PRECIPITATION 12 inches	SUMMER TEMPERATURES Maximum--94 Minimum--66 WINTER TEMPERATURES Maximum--59 Minimum--31 AVERAGE ANNUAL PRECIPITATION 20 inches	SUMMER TEMPERATURES Maximum--90 Minimum--60 WINTER TEMPERATURES Maximum--56 Minimum--28 AVERAGE ANNUAL PRECIPITATION 20 inches	SUMMER TEMPERATURES Maximum--78 Minimum--30 WINTER TEMPERATURES Maximum--45 Minimum--14 AVERAGE ANNUAL PRECIPITATION 40 inches
PLANTS (*zone indicator)	Grama grass *Mesquite *Creosotebush Cacti (Opuntia Spp.) Yucca Century plant	*Juniper *Pinon pine *Grama grass *Galleta grass *Buffalo grass *Sagebrush	*Pondersa pine Oakbrush Currant Gooseberry Buckthorn Mountain mahogany Snowberry Kinnikinnic	*Douglas fir *Blue spruce *Lodgepole pine *Aspen *Englemann spruce Bristlecone pine Limber pine	Lichens Alpine sunflowers March marigolds Dwarf primrose Dwarf genitians Dwarf forget-me-nots Grass
ANIMALS	Desert bighorn sheep Bobcat Coyote Javalina Pocket gopher Badger Red fox Goati mundis	Mule deer Antelope Mountain lion Bobcat Coyote Badger Prairie dog Rabbit, jack and cottontail	Mule deer Black bear Elk (winter range) Mountain lion Bobcat Coyote Squirrel Cottontail rabbit	Mule deer Elk Black and Grizzly bear Bighorn sheep Mountain lion Bobcat Beaver Chipmunk Squirrel	Pika Conies Marmot
BIRDS	Roadrunner Mockingbird Red-tailed hawk Horned owl Quail (3 species) Morning dove	Owls Red-tailed hawk Quail bluebird	Turkey Grouse Magpie Red-tailed hawk Eagle	Clark's nutcracker Canada jay Dusky grouse Band-tailed pigeon Raven Mallard	Ptarmigan Hawks Eagles

[1] Ranges of elevation for the various life zones decrease with increases in latitude along the Divide -- e.g., the Boreal Life Zone in Glacier National Park in Montana occurs between 5,000 and 8,500 feet opposed to a range of between 8,000 and 11,500 feet in New Mexico.

Private ranches

Some 25 private ranches in the Piceance Creek oil-shale region cater to hunting and fishing clientele. Many others catering to hunting clientele exist outside the shale areas. In Colorado, these ranches number about 78.

Incremental changes

Evaluating change

It is generally accepted that the development of an oil-shale industry will cause fundamental changes to the western rural character of the Upper Colorado Region. The effects of the industry will be both direct and indirect on the region. The *direct effects* are those resulting from the activity of producing shale oil. The visual disharmony (smoke stacks, landfills of spent ore, buildings, roads, pipelines, etc.) is an esthetic intrusion imposed on vast natural landscapes having great scenic qualities and an otherwise tranquil character. Pollution from the mining and processing of the shale is another direct effect. So is the loss of habitat for various animals due to spatial competition from oil-shale development activities.

Indirect effects, on the other hand, would be the *induced* effects, which are not immediately caused by an oil-shale development activity. Whereas the emergence of various support services and populations would be direct effects, the consequent additional *activity pressures* on ecological systems would be indirect. These, however, should not be considered precise definitions, but merely functional ones. The definitions may change depending upon the situation and interpretation. At any rate, the analysis should not suffer if the definitions are somewhat elastic, or even if there is some misinterpretation from what is intended.

In assessing the environmental effects caused by an activity, it is important to evaluate *changes*. Once identified, changes may be assessed in terms of *importance* and *magnitude* [2]. The *importance* term is a subjective one. The pristine natural character of the land would be important to some persons but not to others. For example, the fact that the bald eagle or the mountain lion is thriving in the region, constitutes an ecological value highly important to certain segments of the population, but it is unimportant to others who have different interests.

The idea of *value* is central to the question. Health, education, ecology, etc. are types of value. All have different weights depending upon the individual who must make the choices, in the event there is competition. In the case of non-public goods, such as food, housing, automobiles, etc., the goods have *exchange value*. Thus, individuals can allocate their personal wealth for these goods through the *market* mechanism. In the case of public goods — scenery, ecological systems, public lands, etc. — the values must be

weighed and allocations made through the political process. In the case of oil-shale development or any other decisions regarding public lands or public resources, such as air and water, it is the political-legal system, consisting of legislation, regulations, and court decisions, which must allocate these resources. Such resources represent essentially a *capital stock*. Thus, the value weighting, and hence the importance, must be assigned commensurately. Those animals on the rare and endangered species list would certainly figure prominently in any value weighting, because this list represents a collective judgement, through the political process, of what is important. The commitment of land for a particular use then involves a "tradeoff", which essentially uses or depletes various categories of capital stock resources (i.e., ecological habitats, open space, water quality, etc.).

The other term of change is *magnitude*, i.e., *how much* change will take place, especially in relation to the total resource. For example, how many mule deer will be affected in relation to the size of herd? How much land will be needed for the oil-shale development versus the total land in the basin? How many similar areas of pristine natural character would remain in the nation if the upper Colorado region is industrialized?

Formulating the questions, to succintly articulate the most significant issues, requires both value sensitivity, issue perception, and professional knowledge. Developing the factual data in the context of the significant questions, will then permit a systematic evaluation and good understanding of what will happen as a result of a proposed activity.

Overall changes

Table 11-V presents a summary of some of the changes which will occur or are anticipated as a result of the development of an oil-shale industry. The list is not inclusive nor is it highly selective in categories included. It is intended, however, to provide a general understanding of what will happen to the region as a result of imposing a 1,000,000-bbl/day oil-shale industry on the region.

In examining Table 11-V, it is seen that large quantities of ore and residue must be moved, i.e., about 10 billion cu ft of ore each year or 37 million cubic yards. By comparison, Fort Peck Dam on the Missouri River, the largest earth-fill dam in the world, required 125.6 million cubic yards of material. Consequently, the earth-moving task is monumental. Some of this material will be returned to the underground cavities; but it is contemplated that, in addition, some 17 canyons will be filled to depths of some 200 ft.

Land and water

Land required for oil-shale development totals about 80,000 acres. This factor is not decisive when compared with the 16 million acres of lands in weighed and alternatives made through the political process. In the case of oil-shale development or any other decisions regarding public lands or public resources, such as air and water, it is the pluralist-based system, consisting of legislation, regulations and court decisions, which must allocate these resources. Each resource requires essentially a special study. They are value weighting, and hence, like importance, must be assigned comprehensively. Those animals on the rare and endangered species list would certainly figure prominently in any value weighting, because this list represents a collective judgement, through the political process, of what is important. The commitment of land for a particular use often involves a "tradeoff", which essentially uses or destroys various categories of capital stock resources (i.e., ecological habitats, open space, water quality, etc.).

The other form of change is magnitude, i.e., how much change will take place, especially in relation to the total resource. For example, how many mule deer will be affected in relation to the size of herd? How much land will be needed for the oil-shale development versus the total land in the basin? How many similar types of unique natural phenomena would remain in the region if the upper Colorado region is industrialized?

Formulating the questions, to actually articulate the most significant issues, requires both value sensitivity, some imagination, and professional knowledge. Developing the factual data in the context of the significant questions, will then permit a systematic evaluation and good understanding of what will happen as a result of a proposed activity.

Overall changes

Table II-V presents a summary of some of the changes which will occur or are anticipated as a result of the development of an oil-shale industry. The list is not exclusive nor is it mainly selective to ecological livelihood. It is interesting, however, to provide a general ecological notion of what will happen to the region as a result of imposing a 1,000,000 bbl/day oil-shale industry on the region.

In examining Table II-V, it is seen that large quantities of rock and residue must be moved, i.e., about 20 million to 6 of ore each year or 87 million cubic yards. By comparison, Fort Peck Dam on the Missouri River, the largest earth-fill dam in the world, required 125.6 million cubic yards of material. Consequently, the earth-moving task is monumental. Some of this material will be returned to the underground cavities, but it is contemplated that, in addition, some 17 canyons will be filled to depths of some 200 ft.

Land and water

Land required for oil-shale development totals about 80,000 acres. This factor is not decisive when compared with the 16 million acres of lands in

TABLE 11-V

Baseline conditions and changes anticipated for various system categories in the Upper Colorado River region due to development of a 1,000,000-bbl/day oil-shale industry

System	System Indicator	Dimension	Pre-oil shale industry (1973 or earlier)	Post-oil shale[1] industry (1985 or later)
Industry	Oil production			
	ore mined	tons/yr	-0-	550 million
		ft^3/yr	-0-	8-9 billion
	ore residue	tons/yr	-0-	
		ft^3/yr	-0-	9-10 billion
	Land requirements			
	production processes	acres	-0-	50,000 by 1985
		acres/yr	-0-	1,200 after 1985
	urban development	acres	-0-	20,000
	utility rights of way	acres	-0-	10,000
	Water requirements			
	diversion	acre-ft	-0-	145,000
	consumption	acre-ft	-0-	90,000
	Energy requirements			
		KWH/yr	-0-	66.7 million
	Labor force			
	temporary	persons employed	-0-	29,000
	permanent	persons employed	-0-	42,400
	Taxes			
	Industry paid	dollars/yr	-0-	218 million in 1981
	taxes	dollars/yr		165 million
Community	population	persons	119,000 in 1970	234,000
	housing	dwellings	37,400	+13,000 for 42,000 new permanent employes
	water	acre-ft	35,700	17,000 additional
	energy	KWH/yr	N.A.	2,000 additional
	total employment	persons employed in 1970	44,000	86,400
	Taxes-oil shale produced			
	Federal	dollars/yr	4.9 million	541 million
	State	dollars/yr	3.5 million	86 million
	local	dollars/yr	-0-	132 million
Esthetics	None	none	natural landforms	symmetric forms i.e., buildings, stacks, roads, pipelines, power lines, etc.
Recreation	Hunting Piceance Basin	deer/yr	5,000	reduced
Colorado River at Lee's Ferry	Annual flow	acre-ft/yr	12,710,000	diminished by Upper Basin depletions
	Salt flow	tons/yr	8,642,000	Unknown
	Leachable salts from annual production of oil shale residue	tons	-0-	4,920,000
	Salt concentration average	mg/L	499	
Air	Dust	tons/day	-0-	20-100 (for 17 plants)
	Stack gases			
	SO_2 emission	tons/day	-0-	70-200
	SO_2 ambient from 900' stack @10 mi.	$\mu g/m^2$	-0-	4
	SO_2 Colorado Stack emission standard	μg/L	10	500
	NO_x	tons/day	-0-	80-150
	ambient standard	$\mu g/m^3$	none	100
Ecological	Mule deer			
	Wyoming	individuals	39,650	no estimate
	Piceance Basin	individuals	20,000-60,000	10% or more reduction
	Elk-Wyoming		3,950	
	Mountain Lions	individuals	15-20 in Colo.	fewer

[1] Numerical data taken from: Environmental Impact Statement, 1973.

the oil-shale area. The water requirement of 145,000 acre-ft does not appear excessive either, especially when compared with the 12,710,000 acre-ft average annual flow in the Colorado River at Lee's Ferry. Small increments of water, however, are significant in the Colorado River system, and incrementally this amount of water is decisive in that other water used (i.e., agricultural) must be eliminated if oil shale is to be developed. If water could be traded on the free market, oil shale uses probably would outbid agriculture. Water transfers, however, are not permitted to take place quite so freely and water availability will be a critical limiting factor. Whether the water will be made available or not will be determined by the non-market decision processes.

Salt loading

Small increments of salt loading on the Colorado system are also highly significant; the system is very much economically sensitive to salts. This has been ascertained in several years of economic studies (about 1966—1970) sponsored by the Federal Water Quality Administration (now EPA).

The potential salt loading from oil-shale residues could be appreciable. Calculations in the Final Environmental Impact Statement (U.S. Department of the Interior, 1973 [4]), based upon experiments at Colorado State University by Ward et al. [6], indicate that a 6-hour storm having intensity of 0.3—0.5 inch/hr, if assumed to completely leach a 700-acre area of spent shale residue to a depth of 12 inches, would result in 16,740 tons of salts. If there are 17 such sites and each site had one such storm each year, the additional annual salt load would be 284,580 tons. As shown in Table 11-V, this compares with a present-day figure of 8,642,000 tons/yr at Lee's Ferry on the Colorado River. This mode of leaching is merely a speculation in order to give some order of magnitude idea of what might conceivably happen.

In estimating additional salt loading it is difficult (1) to determine how much water will come into contact with the spent shale each year and (2) to predict the amount of salt which will be leached by the moisture that does make contact. The former question can be dealt with as a stochastic phenomena using records of precipitation. Ward et al. [6] have an empirical equation which can give an estimate for the latter question. Their equation was developed through snowfall and rainfall—runoff testing on field plots. It relates concentrations of salinity in the surface water runoff from rainfall as a function of spent oil-shale residue bulk density, permeability of the spent oil-shale residue, moisture content deficit of the spent oil-shale residue, slope of the spent oil-shale residue surface, length of overland flow, rainfall intensity, storm duration, and water temperature. In further work on snowfall, Ward and Reinecke [7] developed a similar empirical equation, which includes the same parameters as above but in which snowmelt runoff intensity, and cumulative volume of snowmelt runoff per unit area are subthe oil-shale area. The water requirement of 145,000 acre-ft does not appear excessive either, especially when compared with the 12,710,000 acre-ft average annual flow in the Colorado River at Lee's Ferry. Some increments of water, however, are significant in the Colorado River system, and incrementally this amount of water is needed in that other water uses (i.e., agriculture) must be curtailed if oil shale is to be developed. If water could be traded on the free market, oil shale uses probably would outbid agriculture. Water transfers, however, are not permitted to take place through a freely and water availability will be a critical limiting factor. Whether the water will be made available or not will be determined by the non-market decision processes.

Salt loading

Small increments of salt loading on the Colorado system are potentially significant; the system is very much economically sensitive to salt. This has been ascertained in several years of economic studies (report 1968–1970) sponsored by the Federal Water Quality Administration (now EPA).

The potential salt loading from spent-shale residues could be appreciable. Calculations in the Final Environmental Impact Statement (U.S. Department of the Interior, 1973 [11]), based upon experiments at Colorado State University by Ward et al. [9], indicate that a 3-inch storm having intensity of 0.3–0.5 inches, if assumed to completely wash a 250-acre area of spent shale residue to a depth of 12 inches, would result in 10,740 tons of salts. If there are 12 such sites and each site had one such storm each year, the additional annual salt load would be 284,880 tons. As shown in Table II-V, this compares with a present-day figure of 8,645,000 tons/yr at Lee's Ferry on the Colorado River. The mode of leaching is merely a calculation in order to give some idea of potential effect of what might conceivably happen.

In estimating additional salt loading it is difficult (1) to determine how much water will come into contact with the spent shale each year and (2) to predict the amount of salt which will be leached by the moisture that does make contact. The runoff question can be dealt with in a rigorous engineering sense using records of precipitation. Ward et al. [9] have an empirical equation which can be used to estimate for the latter question. Their equation was developed through rainfall and runoff-erosion testing on field plots. It relates concentration of salinity in the runoff water from of spent-shale residue as a function of spent oil-shale-residue bulk and the permeability of the spent-oil-shale residue, the surface slope, length of the slope of the plot, slope of the spent oil-shale residue surface, length of time elapsed from rainfall intensity, storm duration, and total thickness of surface area on slope fall. Ward and Reinecke [9] developed a similar empirical equation which includes the same parameters as above but in which the overall runoff or density, and subsurface variation of solution at surface and of the[illegible]

TABLE 11-VI

Hypothetical rain and snow storm

Parameter	Assumed rain	Assumed snow	dimensions
volume runoff/unit width	8.3	8.3	ft^3/ft
Porosity	0.345	0.345	dimensionless
$\frac{w}{w_s}$ where, w = soil moisture content, cm^3/g; w_s = saturation soil moisture content, cm^3/g	0.362	0.362	dimensionless
length of overland flow	226	226	feet
precipitation salinity	0	0	mg/l
rainfall intensity or rate at which snow melts to water	0.0123*	0.0235	ft/hr
surface runoff intensity	0.0123	0.00240	ft/hr
	Calculated rain	Calculated snow	
mass of salt leached per unit area of horizontal surface	45,100	171	mg/ft^2
average salinity in runoff	43,500	165	mg/l
initial value of salinity in runoff	289,000	1,100	mg/l

*Based on a 1 year frequency, 3 hour rain at Grand Junction, Colorado.

stituted for the rainfall parameters. Ward and Reinecke [7] also developed from the empirical studies a rational overland flow water quality model, which was successfully applied to their experimental results from both rainfall and snowfall experiments. This model predicts the concentration of dissolved solids in the runoff from rainfall or melting snow as a function of (1) the cumulative volume of runoff per unit width, (2) the porosity of the oil-shale retorting residue, (3) the moisture content of the spent oil-shale residue, (4) the rainfall or snowmelt rate, and (5) the fraction of the rainfall or snowmelt water that appears as runoff.

Table 11-VI outlines the necessary data and the information that can be predicted for a given rain or snow storm by the overland flow water quality model. As shown in Table 11-VI, a three-hour rain storm having intensity of 0.0123 ft/hr will result in a runoff with an average TDS (total dissolved solids) concentration of 43,500 mg/l. A storm of the intensity and duration assumed will result in 25.83 acre-ft of runoff if the site area is 700 acres. For example, for 17 such sites and 20 such storms per year (2.95 inches rain/yr), the total runoff volume of water having surface contact with oil shale is 8,782 acre-ft. Assuming the length of run is 226 ft (to conform with the test plot and to have some order of magnitude idea of salt loading), the average salt concentration of the surface runoff water is 43,500 mg/l, giving a total salt loading of 518 tons/yr. This figure is, of course, a rough lower limit calculation of what might be expected in salt loading from rainfall. The assumption that the simulated rainfall on the test plots did not penetrate the oil-

shale residue, accounts for the identical figures in Table 11-VI between rainfall intensity and surface runoff intensity. The water-pollution potential of snow is much less than that of rain. Melting snow, however, does alter the physical characteristics of the residue and will percolate into the residue at least one or two ft.

Until more time is spent on this problem, the 284,580 tons/year of salts probably is not an unreasonable figure to assume. To give some idea of an upper limit of salt leaching from spent shale residues, Ward et al. [6] also conducted leaching experiments. Their tests showed that up to 1,120 mg of salts can be leached from 100 g of spent shale by the TOSCO process. Based upon the amount of material mined and retorted annually for a 1,000,000-bbl/day industry, about 4,920,000 tons of leachable salts are contained in the spent oil shale mined over a one-year period. These salts are accessible to the Colorado River through the hydrologic processes. Whereas it is unlikely that this amount of salt will be leached annually, it will leave the spent shale eventually through leaching, over years, decades, or centuries. Another problem relating to salt is the fact that some of the oil-shale formations must be reached by mining through ground-water aquifers which are highly saline. Thus, ground water salinity, combined with the leaching of the salt residue, implies that the additional salinity which could be imposed on the Colorado River system is a potential problem of major proportions.

Urbanizing trends

Whereas an additional 115,000 population by 1985 is not significant by urban metropolitan standards, it will cause a large *incremental* effect on community systems in the region and on the natural environment. Measured against the 1970 population of 119,000, the new populations will require a doubling of existing capacity for community services. Pressures on the natural environments will also increase. But of equal concern is an overall regional *trend* toward urbanization, which the oil-shale industry could likely precipitate. In addition to the new support services, always associated with new basic industries, additional independent industries are often stimulated to move into new developing areas. Water may not be rate limiting for such new expansions, because transfers of water rights are not uncommon.

Ecology

Ecologically the region is rich, as stressed previously; Table 11-V gives some indication of this. In this sense, the region should be compared to what is available nationally. In other words, how much poorer will the nation be in pristine natural regions if the Upper Colorado Region is destined to become one of primarily industrial-urban character. To assess and even articulate this concern is a much more difficult task than comparing measureable changes

against some total measureable quantity, such as salt loadings in the Colorado River. But it should be done so that the decision to commit the region to potential industrialization can be accomplished with deliberate and full knowledge of the significant tradeoffs.

Regional system

Macroscale system

Whereas many of the specific changes, which will occur in the region, are enumerated in Table 11-V, it does not provide a sufficient grasp of the *system* nature of the changes. Any changes on any part of any of these subsystems will be felt through the entire system. Thus, not only are individual elements of the system affected, but also because of this the system must find a new equilibrium and, in doing so, becomes a different system. This is really the key concern in an environmental assessment, i.e., to describe the changes in individual elements of a system, which can be anticipated as a result of a proposed activity and then to grasp the fact that a new system may well emerge from these changes in aggregate. Whether this new system is wanted or not, is a value question to be settled politically.

The Upper Colorado Region contains both human systems and natural systems. These systems will be affected by three key characteristics of an oil-shale industry: (1) the process of creation (i.e., construction activities), (2) the existence of an industry infrastructure, and (3) the metabolism of the industry.

Figure 11-1 illustrates some of the system interactions which will be induced by introduction of an oil-shale industry. The emphasis in Fig. 11-1 is on the changes induced. As noted, some effects are direct and some are indirect. The essential message, however, is that it is a *system* that will be

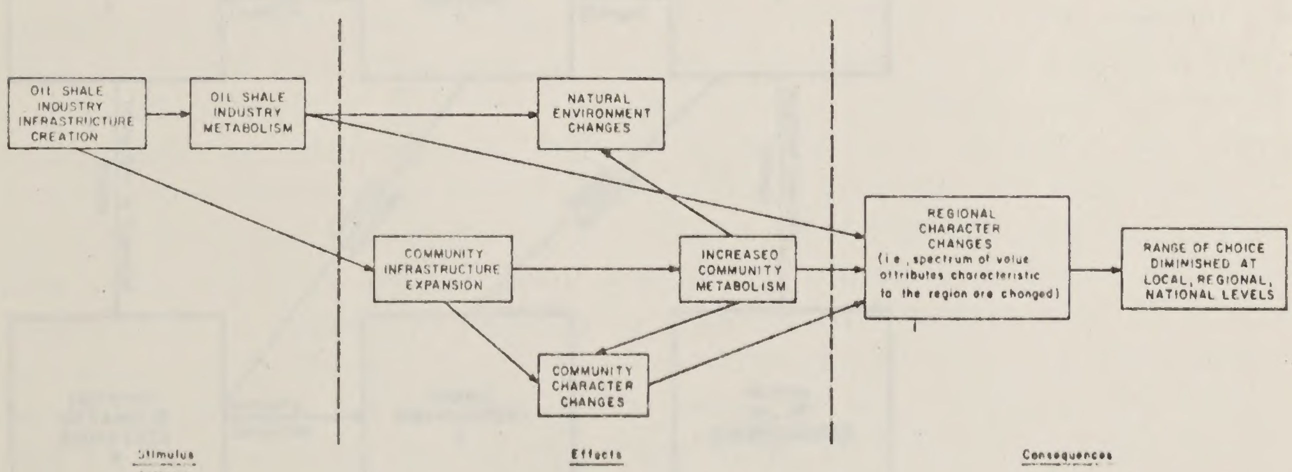


Fig. 11-1. Interactions of regional subsystems as affected by introduction of an oil-shale industry.

against some total maximum of quantity, and small loadings in the Colorado River. But it should be done so that the demand to commit the region to potential industrialization can be accomplished with deliberate and full knowledge of the significant tradeoffs.

Regional system

Economic system

Whereas many of the specific changes which will occur in the region are enumerated in Table 13.9, it does not provide a sufficient grasp of the system nature of the changes. Any change in any part of any of these subsystems will be felt through the whole system. Thus, not only are individual elements of the system affected, but also because of this the system must find a new equilibrium and, in doing so, becomes a different system. This is really the key concept in an environmental assessment, i.e., to describe the changes in individual elements of a system, which can be understood as a result of a proposed activity, and then to trace the path that a new system may well emerge from these changes. A judgment whether the new system is wanted or not, is a value question to be settled politically.

The Upper Colorado, for convenience [illegible] both human systems and natural systems. These systems will be affected by [illegible], approximately: (1) the [illegible] industry, (2) the process of [illegible], (3) the existence of an industry [illegible], and (4) the metabolism of the industry.

Figure 13.1 illustrates some of these system interrelations which will [illegible] caused by establishment of an oil-shale industry (see reference in Fig. 13.1) on the [illegible] of social [illegible], some effects are direct and some are indirect. The essential message, however, is that it is a system that will be

Fig. 13.1 Interactions of regional subsystems as affected by introduction of an oil-shale industry.

changed and will be modified in many of its basic character attributes as compared to the same system prior to the oil-shale development. New *equilibrium conditions* will be the result and the system will have different *state conditions* ecologically, socially, economically, etc.

System disaggregation

It is difficult to find a single scheme which can permit a comprehensive analysis of system interactions without going to a fairly detailed degree of resolution. When this is done, the depiction of the system becomes unwieldly and the larger picture is lost, being obscured by too much detail. Keeping in mind that the purpose of the analysis of the interactions for the system is to keep the focus on the *whole*, the disaggregation process must be sensitive to the question of aggregation. In other words, should one examine salt loading of the Colorado River in terms of average concentration over a long time period, by extremes, or by monthly averages? Whether dealing with questions of salt loading, population, economic production, *ad infinitum*, aggregation is of critical concern. The aggregation is accomplished by selecting appropriate indicators. If appropriate indicators can be chosen, a reasonable quantitative picture of the regional system might be gleaned for both before and after the introduction of an oil-shale industry. Figure 11-2 shows some of the systems which will be affected by an oil-shale industry, whereas Fig. 11-3 is a disaggregation of Fig. 11-2. In Fig. 11-2, the goal was to select appropriate aggregating indicators such that a reasonable "picture" of the before and after systems could be gleaned.

In constructing Fig. 11-3 some themes were borrowed from the physical

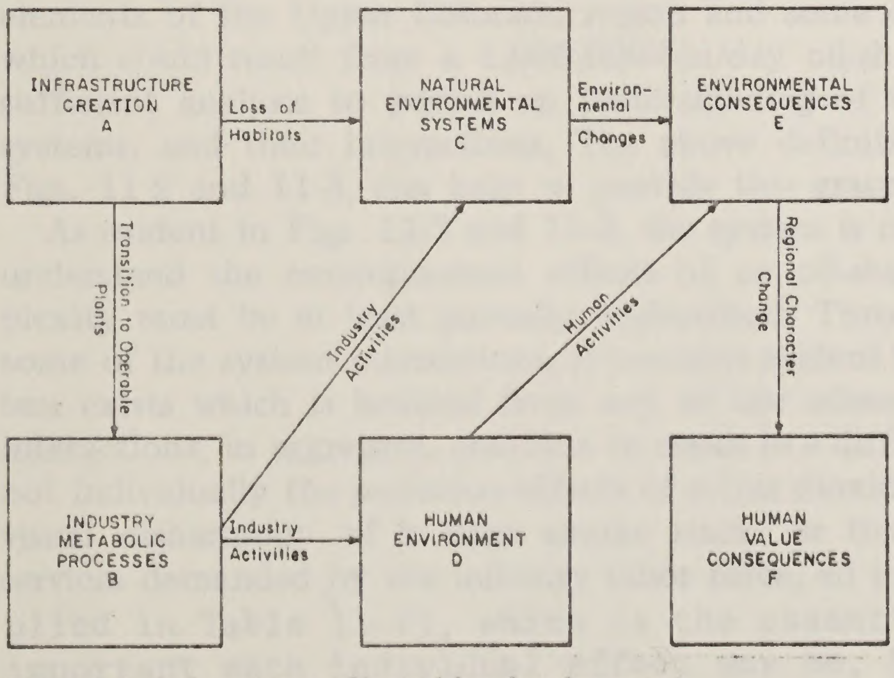


Fig. 11-2. Subsystems affected by development.

changed and will be modifying in many of its basic character attributes as compared to the same system prior to the oil-shale development. [illegible] conditions will be for the result and the system will have different main [illegible], etc.

System disaggregation

It is difficult to find a single scheme which can permit a comprehensive analysis of system interactions without going to a fairly detailed degree of resolution. When this is done, the description of the system becomes unwieldy and the larger picture is lost, being obscured by too much detail. Allowing is noted that the purposes of the analysis of the interactions for [illegible] to keep the focus on the whole, the disaggregation process must be sensitive to the question of aggregation. In other words, should one consider soil loosening of the Colorado River in terms of average concentration over a long time period, for example, or by monthly averages? Whether dealing with questions of soil loosening, [illegible] economic production, or [illegible] aggregation is of central concern. The aggregation is accomplished by selecting appropriate [illegible]. If appropriate indicators can be chosen, a reasonable quantitative picture of the regional system can be created for both before and after the introduction of an oil-shale industry. Figure 11-2 shows [illegible] of the system which will be affected by an oil-shale industry, whereas Fig. 11-3 is a disaggregation of Fig. 11-2. In Fig. 11-3, [illegible] represent aggregating indicators such that a [illegible] of the [illegible] and after systems could be gleaned.

In constructing Fig. 11-3 some liberties were borrowed from the physical

Fig. 11-3. [illegible] of [illegible] development.

and biological sciences. The analysis of the regional system can be better structured using these concepts, which are defined as follows:

(1) *Infrastructure*: the array of physical structures (power plants, transmission lines, dams, canals, pipelines, buildings, etc.) and management structures and institutions (private enterprise, laws and regulations, the judicial system, volunteer organizations, etc.), which facilitate the functioning of an organized society. The physical infrastructure both permits and directs the functioning of the management infrastructure.

(2) *Metabolism*: the relations between inputs and outputs together with internal movements, activities, and functions defines a system metabolism.

(3) *State*: the condition of a system as determined by the aggregate of indicators. For a community, this could include employment level, population, per capita income, age distribution, etc. For a terrestrial ecosystem, it might include counts of various species and trophic level distribution.

(4) *Process*: the transition relationship between states. States are changed by a process which may be the result of the creation of new infrastructures or expansion of existing ones, or by new inputs to a system. In each case, the system equilibrium is disturbed and a new equilibrium level must emerge.

(5) *Equilibrium*: a system at rest is in equilibrium with its surroundings. Human and natural systems are in *dynamic* equilibrium, that is, if the inputs, outputs, and processes are steady state, the system is in equilibrium. If a disturbing factor is imposed, the system must emerge to a new state.

System interactions

Whereas Table 11-V develops a general picture of some of the important elements of the Upper Colorado region and some of the possible changes which could result from a 1,000,000-bbl/day oil-shale industry, it is not a sufficient analysis to permit an *understanding* of the human and natural systems, and their interactions. The above definitions in the context of Figs. 11-2 and 11-3, can help to provide this grasp of the overall system.

As evident in Figs. 11-2 and 11-3, the system is complex and in order to understand the environmental effects of an oil-shale industry, this complexity must be at least partially understood. Through this delineation of some of the system interactions, it becomes evident that no one single problem exists which is isolated from any of the others, and that all of these interactions, in aggregate, combine to result in a different system. Thus, it is not individually the pollution effects of sulfur dioxide on a deer herd, or the visual disharmony of a large smoke stack, or the increased community services demanded by the industry labor force, ad infinitum (as perhaps implied in Table 11-V), which is the essential issue, however important each individual effect may be, but rather it is the fact that all of these changes in aggregate will change the essential character of the overall system. In terms and biological sciences. The aspects of the regional system can be better structured using these concepts, which are defined as follows:

(1) Infrastructure: the array of physical structures (power plants, transmission lines, dams, canals, pipelines, buildings, etc.) and management structures and institutions (private enterprise, laws and regulations, the judicial system, volunteer organizations, etc.), which facilitate the functioning of an organized society. The physical infrastructure both permits and directs the functioning of the management infrastructure.

(2) Metabolism: the relations between inputs and outputs together with internal movements, activities, and functions defines a system metabolism.

(3) State: the condition of a system as determined by the aggregate of attributes. For a community, this could include employment level, population, per capita income, age distribution, etc. For a terrestrial ecosystem, it might include counts of various species and trophic level distribution.

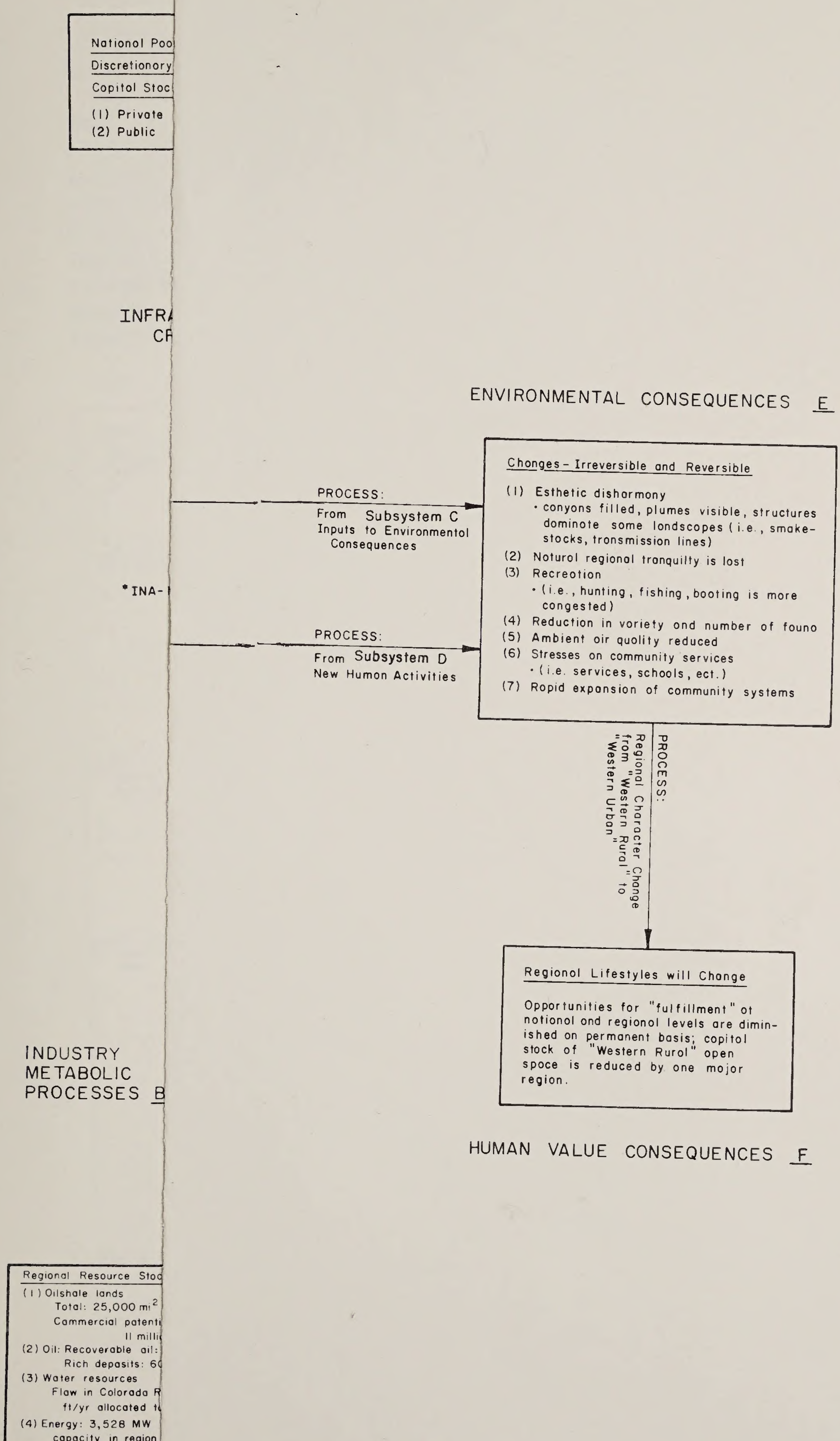
(4) Change: the transition relationship between states. States are changed by a regional withdrawal as the result of the creation of new infrastructure or expansion of existing ones, or by new inputs to a system. In any case, the system equilibrium is disturbed and a new equilibrium level must emerge.

(5) Equilibrium: a system is said to be in equilibrium with its surroundings. Human and natural systems are in dynamic equilibrium, that is, if the inputs, outputs, and processes are steady state, the system is in equilibrium. If a disturbing factor is imposed, the system must change to a new state.

System interactions

Whereas Table 11-V develops a general picture of some of the important elements of the Upper Colorado region and some of the possible changes which could result from a 1,000,000-barrel/day oil-shale industry, it is not a sufficient analysis to permit an understanding of the human and natural systems, and their interactions. The above definitions in the context of Figs. 11-2 and 11-4 can help to provide this array of the overall system.

As evident in Figs. 11-2 and 11-4, the system is complex, and in order to understand the environmental effects of an oil-shale industry, this complexity must be at least partially appreciated. Through the interaction of some of the system interactions, it becomes evident that no one single problem exists which is separate from any of the others and that all of these interactions, in aggregate, combine to result in a different system. Thus, it is not individually the pollution effects of spent shale disposal or the visual disturbance of a large mining area, or the increased community services demanded by the industry labor force, as individual (or perhaps compiled in Table 11-V), which is the essential issue, however important each individual effect may be, but rather it is the fact that all of these changes in aggregate will change the essential character of the overall system. In terms



National Poo
Discretionary
Capital Stoc
(1) Private
(2) Public
INFRA
CR
*INA-
INDUSTRY
METABOLIC
PROCESSES B
Regional Resource Stoc
(1) Oilshale lands
Total: 25,000 mi^2
Commercial potent
11 milli
(2) Oil: Recoverable oil:
Rich deposits: 6
(3) Water resources
Flow in Colorado R
ft/yr allocated t
(4) Energy: 3,528 MW
capacity in region
ENVIRONMENTAL CONSEQUENCES E
PROCESS:
From Subsystem C
Inputs to Environmental Consequences
PROCESS:
From Subsystem D
New Human Activities
Changes - Irreversible and Reversible
(1) Esthetic disharmony
• canyons filled, plumes visible, structures dominate some landscapes (i.e., smokestacks, transmission lines)
(2) Natural regional tranquility is lost
(3) Recreation
• (i.e., hunting, fishing, boating is more congested)
(4) Reduction in variety and number of fauna
(5) Ambient air quality reduced
(6) Stresses on community services
• (i.e. services, schools, ect.)
(7) Rapid expansion of community systems
PROCESS:
Regional Character Change from "Western Rural" to "Western Urban"
Regional Lifestyles will Change
Opportunities for "fulfillment" at national and regional levels are diminished on permanent basis; capital stock of "Western Rural" open space is reduced by one major region.
HUMAN VALUE CONSEQUENCES F

and biological sciences. The analysis of the regional system can be better structured using these concepts, which are defined as follows:

(1) *Infrastructure*: the array of physical structures (power plants, transmission lines, dams, canals, pipelines, buildings, etc.) and management structures and institutions (private enterprise, laws and regulations, the judicial system, voluntary organizations, etc.), which facilitate the functioning of an organized society. The physical infrastructure both permits and directs the functioning of the management infrastructure.

(2) *Metabolism*: the relations between inputs and outputs together with internal movements, activities, and functions defines a system metabolism.

(3) *State*: the condition of a system as determined by the aggregate of indicators. For a community, this could include employment level, population, per capita income, age distribution, etc. For a terrestrial ecosystem, it might include counts of various species and trophic level distribution.

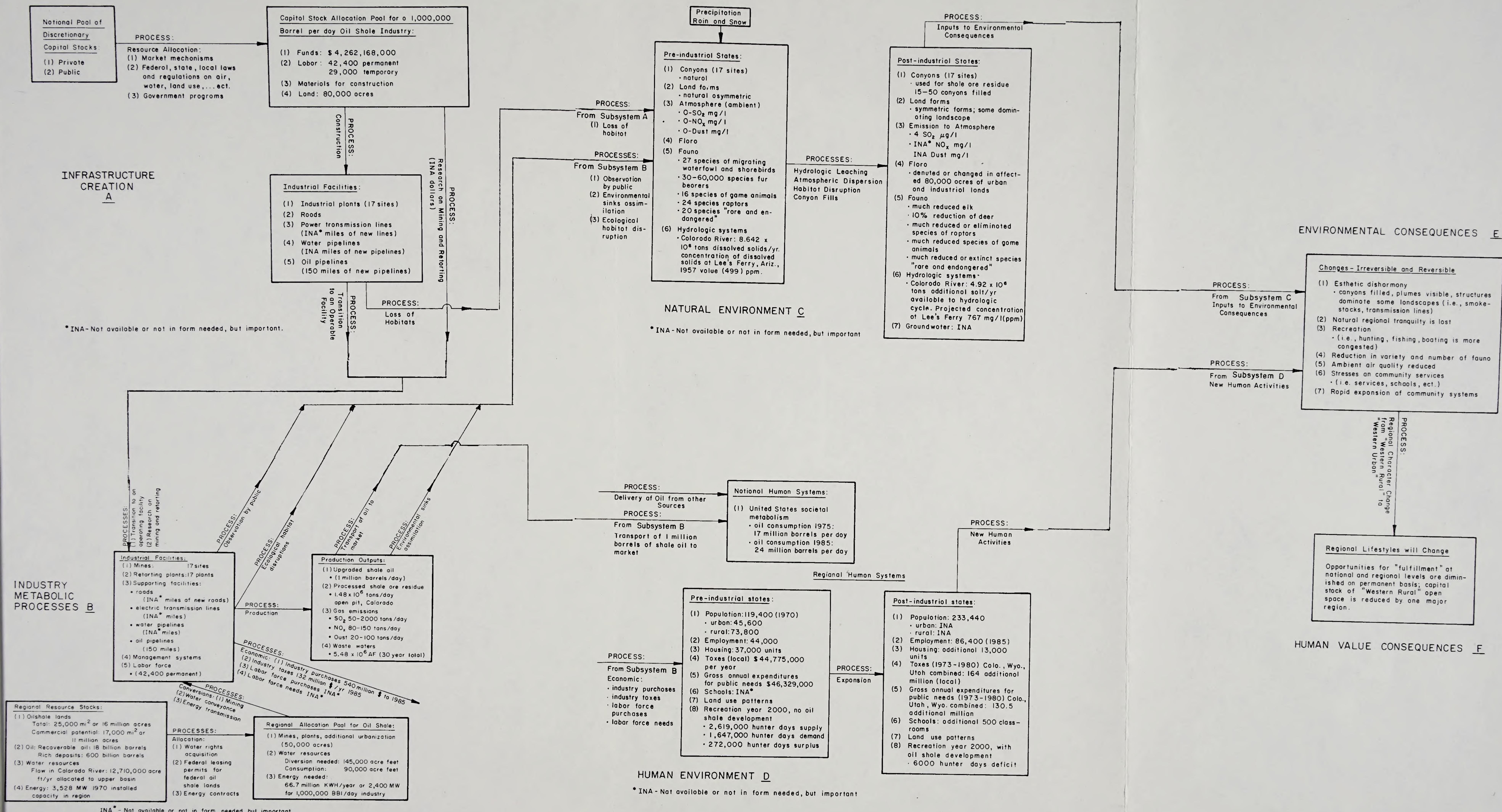
(4) *Process*: the transition relationship between states. States are changed by a process which may be the result of the creation of new infrastructures or expansion of existing ones, or by new inputs to a system. In each case, the system equilibrium is disturbed and a new equilibrium level must emerge.

(5) *Equilibrium*: a system at rest is in equilibrium with its surroundings. Human and natural systems are in dynamic equilibrium; that is, if the inputs, outputs, and processes are steady state, the system is in equilibrium. If a disturbing factor is imposed, the system must emerge to a new state.

System interactions

Whereas Table 11-V develops a general picture of some of the important elements of the Upper Colorado region and some of the possible changes which could result from a 1,000,000-bbl/day oil-shale industry, it is not a sufficient analysis to permit an understanding of the human and natural systems, and their interactions. The above definitions in the context of Figs. 11-2 and 11-3, can help to provide this grasp of the overall system.

As evident in Figs. 11-2 and 11-3, the system is complex, and in order to understand the environmental effects of an oil-shale industry, this complexity must be at least partially understood. Through the examination of some of the system interactions, it becomes evident that no one single problem exists which is isolated from any of the others; and that all of these interactions, in aggregate, combine to result in a different system. Thus, it is not individually the pollution effects of sulfur dioxide on a deer herd, or the visual disturbance of a large smoke stack, or the increased community services demanded by the industry labor force, all taken (or perhaps implied in Table 11-V), which is the essential issue, however important each individual effect may be, but rather: it is the fact that all of these changes in aggregate will change the essential character of the overall system. In terms



Notional Pool of Discretionary Capital Stocks
(1) Private
(2) Public
PROCESS:
Resource Allocation:
(1) Market mechanisms
(2) Federal, state, local laws and regulations on air, water, land use,...ect.
(3) Government programs
Capital Stock Allocation Pool for a 1,000,000 Barrel per day Oil Shale Industry:
(1) Funds: $4,262,168,000
(2) Labor: 42,400 permanent
29,000 temporary
(3) Materials for construction
(4) Land: 80,000 acres
PROCESS: Construction
PROCESS: Research on Mining and Retorting (INA dollars)
INFRASTRUCTURE CREATION A
Industrial Facilities:
(1) Industrial plants (17 sites)
(2) Roads
(3) Power transmission lines (INA* miles of new lines)
(4) Water pipelines (INA miles of new pipelines)
(5) Oil pipelines (150 miles of new pipelines)
PROCESS: Transition to an Operable Facility
PROCESS: Loss of Habitats
*INA - Not available or not in form needed, but important.
Precipitation Rain and Snow
PROCESS: From Subsystem A (1) Loss of habitat
PROCESSES: From Subsystem B
(1) Observation by public
(2) Environmental sinks assimilation
(3) Ecological habitat disruption
Pre-industrial States:
(1) Canyons (17 sites)
· natural
(2) Land forms
· natural asymmetric
(3) Atmosphere (ambient)
· 0-SO₂ mg/l
· 0-NOₓ mg/l
· 0-Dust mg/l
(4) Flora
(5) Fauna
· 27 species of migrating waterfowl and shorebirds
· 30-60,000 species fur bearers
· 16 species of game animals
· 24 species raptors
· 20 species "rare and endangered"
(6) Hydrologic systems
· Colorado River: 8.642 x 10⁶ tons dissolved solids/yr. concentration of dissolved solids at Lee's Ferry, Ariz., 1957 value (499) ppm.
PROCESSES:
Hydrologic Leaching
Atmospheric Dispersion
Habitat Disruption
Canyon Fills
NATURAL ENVIRONMENT C
*INA - Not available or not in form needed, but important
PROCESS: Inputs to Environmental Consequences
Post-industrial States:
(1) Canyons (17 sites)
· used for shale ore residue
15-50 canyons filled
(2) Land forms
· symmetric forms; some dominating landscape
(3) Emission to Atmosphere
· 4 SO₂ μg/l
· INA* NOₓ mg/l
INA Dust mg/l
(4) Flora
· denuded or changed in affected 80,000 acres of urban and industrial lands
(5) Fauna
· much reduced elk
· 10% reduction of deer
· much reduced or eliminated species of raptors
· much reduced species of game animals
· much reduced or extinct species "rare and endangered"
(6) Hydrologic systems
· Colorado River: 4.92 x 10⁶ tons additional salt/yr available to hydrologic cycle. Projected concentration at Lee's Ferry 767 mg/l(ppm)
(7) Groundwater: INA
ENVIRONMENTAL CONSEQUENCES E
PROCESS: From Subsystem C Inputs to Environmental Consequences
PROCESS: From Subsystem D New Human Activities
Changes - Irreversible and Reversible
(1) Esthetic disharmony
· canyons filled, plumes visible, structures dominate some landscapes (i.e., smoke-stocks, transmission lines)
(2) Natural regional tranquility is lost
(3) Recreation
· (i.e., hunting, fishing, boating is more congested)
(4) Reduction in variety and number of fauna
(5) Ambient air quality reduced
(6) Stresses on community services
· (i.e. services, schools, ect.)
(7) Rapid expansion of community systems
PROCESS: Regional Character Change from "Western Rural" to "Western Urban"
Regional Lifestyles will Change
Opportunities for "fulfillment" at national and regional levels are diminished on permanent basis; capital stock of "Western Rural" open space is reduced by one major region.
HUMAN VALUE CONSEQUENCES F
PROCESSES: (1) Transition to an operating facility (2) Research on mining and retorting
PROCESS: Observation by public
PROCESS: Ecological habitat disruptions
PROCESS: Transport of oil to market
PROCESS: Environmental sinks assimilation
INDUSTRY METABOLIC PROCESSES B
Industrial Facilities:
(1) Mines: 17 sites
(2) Retorting plants: 17 plants
(3) Supporting facilities:
• roads (INA* miles of new roads)
• electric transmission lines (INA* miles)
• water pipelines (INA* miles)
• oil pipelines (150 miles)
(4) Management systems
(5) Labor force
• (42,400 permanent)
PROCESS: Production
Production Outputs:
(1) Upgraded shale oil
• (1 million barrels/day)
(2) Processed shale ore residue
• 1.48 x 10⁶ tons/day open pit, Colorado
(3) Gas emissions
• SO₂ 50-2000 tons/day
• NOₓ 80-150 tons/day
• Dust 20-100 tons/day
(4) Waste waters
• 5.48 x 10⁶ AF (30 year total)
PROCESSES: Economic: (1) Industry purchases 540 million $ to 1985 (2) Industry taxes 132 million $/yr 1985 (3) Labor force purchases INA* (4) Labor force needs INA*
PROCESSES: Conversions: (1) Mining (2) Water conveyance (3) Energy transmission
Regional Resource Stocks:
(1) Oilshale lands
Total: 25,000 mi² or 16 million acres
Commercial potential: 17,000 mi² or 11 million acres
(2) Oil: Recoverable oil: 18 billion barrels
Rich deposits: 600 billion barrels
(3) Water resources
Flow in Colorado River: 12,710,000 acre ft/yr allocated to upper basin
(4) Energy: 3,528 MW 1970 installed capacity in region
PROCESSES: Allocation:
(1) Water rights acquisition
(2) Federal leasing permits for federal oil shale lands
(3) Energy contracts
Regional Allocation Pool for Oil Shale:
(1) Mines, plants, additional urbanization (50,000 acres)
(2) Water resources
Diversion needed: 145,000 acre feet
Consumption: 90,000 acre feet
(3) Energy needed:
66.7 million KWH/year or 2,400 MW for 1,000,000 BBl/day industry
INA* - Not available or not in form needed, but important
PROCESS: Delivery of Oil from other Sources
PROCESS: From Subsystem B Transport of 1 million barrels of shale oil to market
National Human Systems:
(1) United States societal metabolism
· oil consumption 1975: 17 million barrels per day
· oil consumption 1985: 24 million barrels per day
PROCESS: New Human Activities
Regional Human Systems
PROCESS: From Subsystem B Economic:
· industry purchases
· industry taxes
· labor force purchases
· labor force needs
Pre-industrial states:
(1) Population: 119,400 (1970)
· urban: 45,600
· rural: 73,800
(2) Employment: 44,000
(3) Housing: 37,000 units
(4) Taxes (local) $44,775,000 per year
(5) Gross annual expenditures for public needs $46,329,000
(6) Schools: INA*
(7) Land use patterns
(8) Recreation year 2000, no oil shale development
· 2,619,000 hunter days supply
· 1,647,000 hunter days demand
· 272,000 hunter days surplus
PROCESS: Expansion
Post-industrial states:
(1) Population: 233,440
· urban: INA
· rural: INA
(2) Employment: 86,400 (1985)
(3) Housing: additional 13,000 units
(4) Taxes (1973-1980) Colo., Wyo., Utah combined: 164 additional million (local)
(5) Gross annual expenditures for public needs (1973-1980) Colo., Utah, Wyo. combined: 130.5 additional million
(6) Schools: additional 500 class-rooms
(7) Land use patterns
(8) Recreation year 2000, with oil shale development
· 6000 hunter days deficit
HUMAN ENVIRONMENT D
*INA - Not available or not in form needed, but important

of value consequences to people in the region and in the nation as well, this is of great significance.

The 1973 Upper Colorado system existed in an *equilibrium*, that is, the subsystems were not changing with time. The *state* of the system (the aggregate of all conditions in the system, i.e., animal populations, annual rainfall, human populations, employment levels, salt loadings in the Colorado River, etc.) was designated previously as "western rural". The imposition of a 1,000,000-bbl/day oil shale industry on this system would require a new equilibrium, that is, new *states* must emerge. Whether these new states would be appreciably different from the previous ones, may be difficult to determine. To

Block	Block or Process Category	Item	
A. Infrastructure Creation	Capital Stock Allocation pool	(1)	$426,216,800 is estimated cost for a $100,000 barrel plant; figure given is multiplied by ten for a 1,000,000 barrel per day plant
	Industrial facilities	(5)	Final Environmental Statement, Vol. I, Chapter I, p. 89
B. Industry Metabolic Processes	Industrial facilities	(3)	Ibid, I, II, 89
	Production outputs	(2) (3) (4)	Ibid, I, III, 14 Ibid, I, III, 134 Ibid I, III, 60; 30 year total for surface mining
	Economic processes	indust. purch.	Ibid, I, III, 216
	Regional resource stocks	(3) (4)	Ibid, I, II, 23 (upper basin allocation) Ibid I, III, 38
	Regional allocation pool for oil shale	(3)	Ibid, I, II, 38
C. Natural Environment	Pre-industrial states	(5) (6)	Ibid, I, II, 63; I, III, 185 Ibid, I, II, 99
	Post-industrial states	(1) (3) (5) (6)	Ibid, I, III, 194 Ibid, I, III, 145 Ibid, deer-I, III, 179 rare and endangered, I, III, 171 4.92 x 10^6 tons/yr dissolved solids are leachable from shale oil residue calculated from laboratory data by Ward, et al (1971) Ibid, I, II, 34
D. Human Environment	United States Societal metabolism		1985 oil production: American Petroleum Institute, CPA, Oilmans fact finder 1973 oil production, Energy Resources Report, Business Publishers Report, Silver Springs, Md., Oct. 19, 1973, p. 316
	Pre-industrial states	(1) (2) (4) (5) (8)	Ibid, I, II, 97 Ibid, I, III, 206 Ibid, I, II, 209, 253, 307 Ibid, I, II, 209, 253, 307 Ibid, I, III, 190
	Post-industrial states	(1) (2) (3) (4) (5) (8)	Ibid, I, III, 206 Ibid, I, III, 206 Ibid, I, III, 222 Ibid, I, III, 215, 220 Ibid, I, III, 215, 216 Ibid, I, III, 191

Fig. 11-3 (continued). Documentation for portion of numerical data.

determine the effect of SO_2 emissions on ambient air quality, for example, a dispersion *model* must be used. Whereas this particular effect can be evaluated by such a determinate model, other interactions are sometimes indeterminate. In such cases, it may be sufficient to assert merely that *new states* are *accessible* and could possibly emerge. Identifying these new accessible states then becomes the task. Decisions can then be based upon knowledge on whether or not the new states are likely to emerge as a result of the change influence, but it is not known whether they *will* emerge. This type of systematic evaluation can aid in bringing planning and management into the domain of deliberate choice vis a vis random guess or avoidance of choice by lack of knowledge.

The analysis in Figs. 11-2 and 11-3 is intended to illustrate the interactions of the overall system and so it does not contain sufficient resolution for highly-detailed interpretation. Neither is the analysis comprehensive, in that some of the important elements (e.g., the overall employment sector) for the region are not included. The emphasis is on change and on understanding the system nature of the problem.

The overall aggregate changes imposed on the system will result in a new equilibrium for the regional system, which will likely result in a new character of the Upper Colorado Region. It is possible, then, to better understand the changes which will be imposed on the Upper Colorado Region and through this understanding to make more deliberate choices. In the long term, as stressed previously, this happens through the political system, because the choices are essentially non-market in nature. But an understanding of the effects which may be induced, will both aid in making informed decisions and help in determining measures which may mitigate some of the adverse effects.

Acknowledgements

Most data for this analysis were obtained from the Final Environmental Statement for the Oil Shale Leasing Program. The analysis schemes were based upon Chapter 1 in *Environmental Design for Public Projects.*

References

1. D.W. Hendricks, E. Vlachos, L.S. Tucker and J.C. Kellogg (Editors), *Environmental Design for Public Projects*, Water Resources Press, Water Resources Press, Fort Collins, Colo. (1974).
2. L.B. Leopold, F.E. Clarke, B.B. Hanshaw and J.R. Balsley, "A Procedure for Evaluating Environmental Impact", *U.S. Geol. Surv. Circ. 645*, Washington, D.C. (1971).
3. Upper Colorado Region State-Federal Inter-Agency Group, Pacific Southwest Inter-Agency Committee and Water Resources Council, *Upper Colorado Comprehensive Framework Study* (1971).
4. U.S. Department of the Interior, Final Environmental Statement for the Prototype Oil Shale Leasing Program, Vol. I, *Regional Impacts of Oil Shale Development*, U.S. Government Printing Office, Washington, D.C. (1973).
5. J.C. Ward, G.A. Margheim and G.O.G. Lof, *Water Pollution Potential of Oil Shale Residues from Above-Ground Retorting*, Presented by J.C. Ward at the symposium on Shale Oil, Tar Sands, and Related Materials, Division of Fuel Chemistry and Petroleum Chemistry, Am. Chem. Soc., Los Angeles, March 29, 1971; *15* (1) 13—20 of the preprints of papers presented.
6. J.C. Ward, G.A. Margheim and G.O.G. Lof, *Water Pollution Potential of Rainfall on Spent Oil Shale Residues*, Environmental Protection Agency, Water Pollution Control Research Series 140 30 EDB, December, 1971, 124. For sale by the Superintendent of

determine the effect of SO_2 emissions on ambient air quality, for example, a dispersion model must be used. Whereas this particular effect can be evaluated by such a determinate model, other interactions are sometimes indeterminate. In such cases, it may be sufficient to assert merely that new states are accessible and could possibly emerge. Identifying these new accessible states then becomes the task. Decisions can then be based upon knowledge on whether or not the new states are likely to emerge as a result of the change influences, but it is not known whether they *will* emerge. This type of systematic evaluation can aid in bringing planning and management into the domain of deliberate choice vis a vis random guess or avoidance of choice by lack of knowledge.

The analysis in Figs. 11-2 and 11-3 is intended to illustrate the interactions of the overall system and so it does not contain sufficient resolution for highly detailed interpretation. Neither is the analysis comprehensive, in that some of the important elements (e.g., the overall employment sector) for the region are not included. The emphasis is on change and on understanding the system nature of the problem.

The overall aggregate changes imposed on the system will result in a new equilibrium for the regional system, which will likely result in a new character of the Upper Colorado Region. It is possible, then, to better understand the changes which will be imposed on the Upper Colorado Region and through this understanding to make more deliberate choices. In the long term, as stressed previously, this happens through the political system, because the choices are essentially non-market in nature. But an understanding of the effects which may be induced, will both aid in making informed decisions and help in determining measures which may mitigate some of the adverse effects.

Acknowledgements

Most data for this analysis were obtained from the Final Environmental Statement for the Oil Shale Leasing Program. The analysis schemes were based upon Chapter 1 in *Environmental Design for Public Projects*.

References

1. D.W. Denneston, R. Vaughn, L.S. Tucker and J.C. Kellogg (editors), *Environmental Design for Public Projects*, Water Resources Press, Water Resources Pubs, Fort Collins, Colo. (1975).
2. L.B. Leopold, F.E. Clarke, B.B. Hanshaw and J.R. Balsley, "A Procedure for Evaluating Environmental Impact", U.S. Geol. Surv. Circ. 645, Washington, D.C. (1971).
3. Upper Colorado Region State-Federal Inter-Agency Group, Pacific Southwest Inter-Agency Committee, and Water Resources Council, *Upper Colorado Comprehensive Framework Study* (1971).
4. U.S. Department of the Interior, Final Environmental Statement for the Prototype Oil Shale Leasing Program, Vol. I, *Regional Impacts of Oil Shale Development*, U.S. Government Printing Office, Washington, D.C. (1973).
5. J.C. Ward, G.A. Margheim and G.O.G. Löf, Water Pollution Potential of Oil Shale Residues from Above-Ground Retorting. Presented by J.C. Ward at the symposium on Shale Oil, Tar Sands, and Related Materials, Division of Fuel Chemistry and Petroleum Chemistry, Am. Chem. Soc., Los Angeles, March 30, 1971, 15 (1): 13–20 of the preprints of papers presented.
6. J.C. Ward, G.A. Margheim and G.O.G. Löf, Water Pollution Potential of Rainfall on Spent Oil Shale Residues, Environmental Protection Agency, Water Pollution Control Research Series 14030 EDB, December, 1971, 134, Prepared by the Department of

Documents, U.S. Government Printing Office, Washington, D.C. 20402. (Catalogue No. EPI.16 4030EDB 12/71; Stock No. 5501 0197).

7. J.C. Ward and S.E. Reinecke, *Water Pollution Potential of Snowfall on Spent Oil Shale Residues*, June, 1971, 56 pp., National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22151. Accession No. PB 210 930.
8. J.C. Ward, *Water Pollution Potential of Snowfall on Spent Oil Shale Residues*, paper presented at the *Western Snow Conference*, Grand Junction, Colorado (April, 1973).

ENVIRONMENTAL ENGINEERING
MONOGRAPHS

Number		Date
1	THE WORLD OF PUBLIC PROJECTS: TRADITIONS AND TRANSITIONS, by D. W. Hendricks, E. C. Vlachos, L. S. Tucker, J. C. Kellogg	May 1974
2	ENVIRONMENTAL ANALYSIS OF AN OIL SHALE INDUSTRY IN THE UPPER COLORADO REGION by D. W. Hendricks and J. C. Ward	June 1974
3	SOCIAL ASPECTS OF SOLID WASTE DEVELOPMENT: Refuse, Recycling, Reuse by Evan Vlachos	October 1974
4	SOCIAL FORECASTING FOR WATER RESOURCES DEVELOPMENT by E. C. Vlachos and D. W. Hendricks	November 1974
5	SCENARIO WRITING FOR NATURAL RESOURCES RESEARCH Applications for Futurism by Evan Vlachos	August 1974
6	WATER QUALITY SYSTEMS: Modeling Fundamentals by D. W. Hendricks	January 1975
7	MANAGING GROWTH IN A FRAGILE ENVIRONMENT: Problems of the Rocky Mountain States by Evan Vlachos	January 1974