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Cablegation Systems for Irrigation: Description, Design, Installation, and Performance

ABSTRACT

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Decreasing energy supplies and the high and probably increasing energy costs are causing many farmers to seriously consider surface rather than sprinkler irrigation. However, surface irrigation systems must provide uniform application of the water at low labor costs if they are to improve productivity and reduce costs. This handbook reports a system which has been designed to meet these objectives. The concepts, components, installation, and operation of cablegation, an automated type of surface irrigation, are described. Cablegation is a form of gated-pipe system. The gates or outlets are near the top side and are left open. The pipe is laid on a precise grade, and a plug moves slowly through it, causing water to flow, in sequence, to furrows or bordered strips in the field. The handbook provides information that can be used by Soil Conservation Service technicians, Extension irrigation specialists, commercial installers, and farmers, who wish to understand, install, or operate one of these systems.

KEYWORDS: automated irrigation, bordered strip irrigation, cutback furrow supply, furrow irrigation, gated pipe, gravity irrigation, irrigation, irrigation system, irrigation system installation, surface irrigation.

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Cablegation Systems for Irrigation: Description, Design, Installation, and Performance

By
W. D. Kemper, D. C. Kincaid,
R. V. Worstell, W. H. Heinemann,
T. J. Trout, and J. E. Chapman,

ACKNOWLEDGMENTS

Allan Humpherys educated the authors to the cost reduction that could be achieved in piped systems if a single pipeline could serve both the transmission and distribution function. James Bondurant developed many of the concepts concerning trash screens. They are agricultural engineers with the U. S. Department of Agriculture, Agricultural Research Service, Snake River Conservation Research Center, Kimberly, Idaho. Fredrick Kemper, operator of one of the first systems, contributed many of the ideas concerning flow adjustment to handle problem furrows and designing reels.

Most of the farmers who have installed systems have contributed ideas which have found their way into this handbook. U. S. Department of Agriculture, Soil Conservation Service personnel, who have gained confidence of the farmers as a result of previous service, have introduced many farmers to this system. These men and women have spent many hours, before, during and after their regular working hours, helping the farmers to determine whether cablegation systems were suited to their needs, installing the sytems, and solving associated problems.

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NOTE: For a list of the names and addresses of manufacturers and suppliers of items described in this publication, write to the Snake River Conservation Research Center, Route 1, Box 186, Kimberly, Idaho, 83341. Please specify the item you want the list for.

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INTRODUCTION

As competition inherent in American agriculture intensified and water sources became limited, it was necessary for irrigation farmers to reduce labor input and increase the application efficiency of irrigation. Sprinkler systems, such as the center pivot, enabled farmers to do both. While energy costs were low, their economic feasibility was sound.

But energy costs have risen without comparable increases in prices of farm products. These rising energy prices drastically reduced the net returns of farmers whose systems were consuming large amounts of expensive energy. The limited supply of fossil fuels and their rate of depletion signifies eventual shortages and continuing increases in energy prices. Consequently, assessments were made of where energy was being used in irrigated farming systems. Between 30 and 50 percent of the nonsolar energy involved in raising a crop of sprinkler-irrigated corn in the Western United States is consumed in irrigation. For crops such as beans or alfalfa, which require little or no nitrogen fertilizer, the energy used in sprinkling can be as high as 60 to 80 percent of the total. The energy required for sprinkler irrigation is commonly three to five times that required for operation of trucks and tractors on the farms. Facing these facts, it became apparent that irrigation methods requiring less energy input must be developed if irrigated farms are to remain economically viable. Industry and government are making substantial headway toward decreasing the energy input to sprinkler irrigation. However, practical considerations indicate that a lower limit of energy consumption of about 40 percent of the original levels will still be necessary for sprinkler irrigation. Farmers who can achieve desired application efficiencies with improved surface irrigation systems will avoid one of the major energy costs involved in their farming operations.

This handbook provides information on a new type of system for automating surface irrigation. The system is called cablegation since a cable is used to control operation of the system. The purposes of this handbook are:

1. To provide potential users with a basis for determining whether this type of system is suited to their needs;

2. To provide designers and installers with guidelines for design and construction of cablegation systems;

3. To provide potential manufacturers and suppliers with a description of parts and equipment that are needed for installation, use, and maintenance of these systems; and

4. To provide owners with suggestions to increase the utility and efficiency of their system.

CABLEGATION CONCEPT AND BASIC COMPONENTS

General Concept

Cablegation (as described by Kemper et al. 1981) is a form of gated-pipe system. The gates or outlets are near the top side and are left open. The pipe is laid on a precise grade, and a plug moves slowly through the pipe, causing water to flow, in sequence, to furrows or bordered strips in the field.

A single pipe is used both to transmit the water along the edge of the field and to distribute equal amounts to furrows or to bordered strips. The pipe is sized large enough to carry the waterflow on the available slope without completely filling its cross section (fig. 1). Outlets are placed near the top of the pipe's circumference (offset 20 to 30 degrees toward the field from the pipe's vertical centerline) and spaced to correspond to the spacing that will be used for the furrows or corrugates during the crop rotation cycle. Water flows in the pipe below the level of the outlets until it approaches the plug. This obstruction causes the water to fill the pipe and run out of outlets near the plug. Hydraulic head pressure in the pipe increases until the sum of flow rates from the outlets is equal to the supply rate. The outlets near the plug are under the highest head and deliver water at a maximum rate, whereas those farther upstream from the plug flow at lower rates as indicated in figure 1. To automate the system, the plug is allowed to move downslope through the pipe at a controlled rate. A light cable or line from a reel at the standpipe is attached to the upstream end of the plug. The rate at which the cable is reeled out determines the rate at which the plug moves and at which irrigation progresses across the field. The water pressure provides the force to move the plug.

Pipe Size and Grade

Pipe size needed is determined by water-supply rate, slope on which the pipe will lie, roughness of the pipe walls, and temperature (viscosity) of the water. For practical purposes, irrigation water is assumed to have a temperature of about 60 degrees Fahrenheit. At this viscosity, the Hazen and Williams formula relating the remaining factors is

$$H=302(V/C)^{1.85}/D^{1.17} \qquad [1]$$

where

H is the head loss in feet per 100 ft of pipe,

V is the average velocity of the water in the pipe in feet per second,

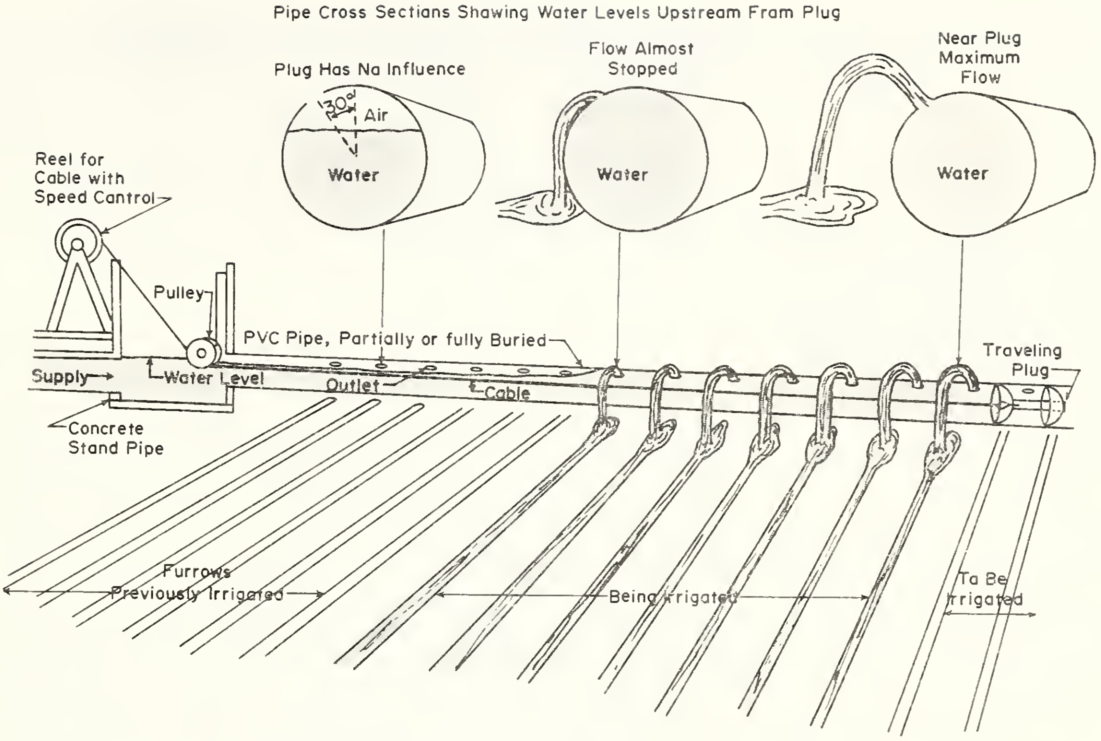


Figure 1.--General arrangement of the controls, pipes and outlets in a cablegation system.

D is the inside diameter of the pipe in feet, and

C is the roughness coefficient of the pipe.

For PVC pipe, the value of C is about 150. For aluminum pipe, a value for C of 130 is commonly used. The average velocity is the flow rate divided by the cross-sectional area of the pipe. Head losses due to friction, calculated from equation 1, are presented in appendix A for PVC pipe sizes commonly available and for aluminum pipe in gated-pipe sizes.

To avoid prolonged dribbling as flow from outlets in the cablegation pipe decreases (see fig. 6 and the related discussion for the reasons for this recommendation), we recommend that the flow rates used in the pipe be less than 85 percent of the full flow capacity rates indicated in the figures of appendix A.

The pipe must be placed and maintained on a precise grade to achieve desired uniformity of water delivery. When the grade is low (<0.5 percent), pipe elevation must be maintained within one-half inch of the designed grade. Systems placed on steep slopes can generally tolerate more variation from the designed grade than those on flat slopes and still maintain reasonably uniform delivery. If the pipe diameter is somewhat larger than that needed to carry the flow, outlets in sections of pipe which have settled slightly below designed grade levels are less likely to continue to dribble as the plug passes farther downstream. Changes in grade require changes in oulet size to achieve uniform water delivery. The minimum slope at which carefully laid and maintained cablegation pipes have worked properly is 0.1 percent.

Characteristics of Plugs, Cables, Reels, and Pipe Fittings

Plugs and Pipe Fittings

The plug must fit snugly inside the pipe to minimize leakage past the plug, but it must also slide freely as tension on the cable is released. If it moves in surges the cable might break.

A satisfactory plug was constructed from two plastic bowls. Each bowl was clamped to a metal plate welded to the end of a section of light aluminum tubing as shown in figure 2. Two bowls were used, rather than just one, to maintain alinement of the plug in the pipe and to give better sealing. The circumferences of the bowls were trimmed so they would just slip inside the pipe. Most PVC pipe has a uniform inside circumference. When pipe sections are deformed to oval shapes, the bowls deform also and maintain a reasonably good seal. Reductions in pipe circumferences are deliberately formed on the male ends by most manufacturers to facilitate easy coupling of the pipe. These manufacturers have assured us that pipe can be ordered without this reduction at the male end.

The circumference of commonly available tee couplers is commonly 5 to 10 percent less than that of the pipe size to which they couple. Plugs required to go through such constrictions must be made of material which has some ability to stretch and compress (app. J, fig. 108). The polyethylene bowls illustrated in figure 2 do not have this ability. Such constrictions were avoided when risers at right angles to the pipe were needed by cutting holes in the pipe and cementing saddles, adapted to the desired pipe size, around the holes.

From 1 to 20 gallons per minute of water leaks past the plug, but the flow is generally less than that lost over a check dam at the lower end of a set of siphon tubes. When water is in short supply, the tail end of the cablegation pipe can be plugged, allowing the operator to irrigate the bottom end row(s) with this leakage.

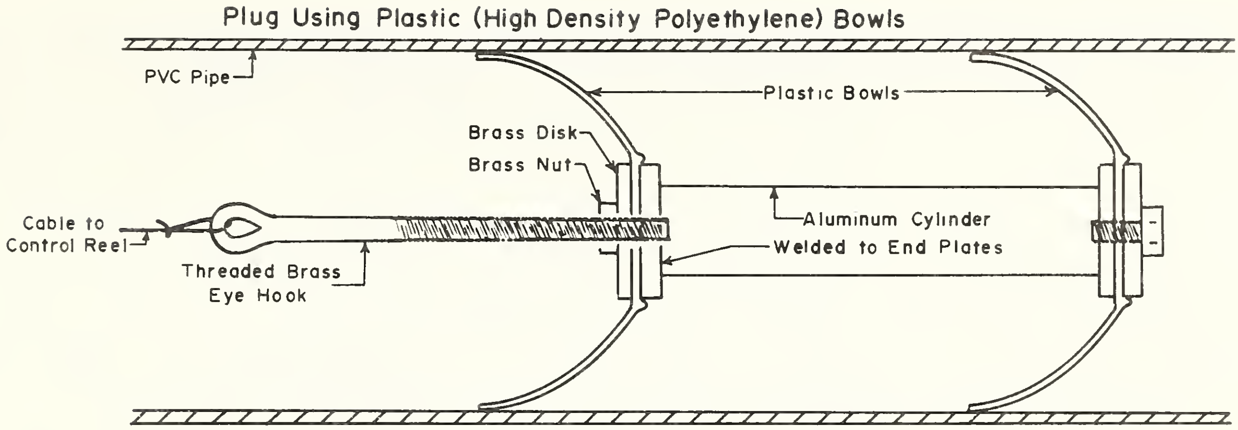


Figure 2.--Detailed construction of plugs.

Cables

The cable must withstand the force of the pressure head against the plug, the drag of the water on the cable, and surge forces resulting from sudden changes in rate of plug travel or water supply rate. This has required cables to control loads from 50 to 750 pounds, depending primarily on the slope, diameter, and depth of the pipeline. Cables used in systems have ranged from 90-pound-test braided nylon fishing line to steel and polypropylene cables with over 500-pounds-test strength. As larger diameter cables are used, the dimensions of the reels must be increased to store a greater volume of cable.

Reels

The reel is designed to store the cable between irrigations and to allow the cable to be paid out at the desired rates during irrigating. When a reasonably constant speed is desired, the diameter of the cable wound on the reel must not vary appreciably, so the width of the drum is generally increased when line lengths are greater to provide more storage for cable. The reel must also be capable of being released from the speed control mechanism (fig. 3) so that the cable can be manually rewound onto the reel at the end of an irrigation after the plug has been removed from the end of the cable.

Calculations which may be used in designing reels for various cable sizes and field layouts are outlined in appendix B.

Speed Control Mechanisms

Water pressure pushes the plug down the pipe. The rate of the plug's advance can be controlled by several types of mechanisms depending on the power available to the site. (When standard car batteries are used, they need to be changed about once a day. The power requirement for speed control can be taken from the force of the water on the plug, which is exerted on the reel via the cable, or the force of the water on a paddle wheel as discussed in appendixes J and K).

An electrically powered controller is outlined in figure 3. These have been powered by 12-volt storage batteries or power supplies providing 2.5 amps at 12 volts d.c. from a.c. lines. At the full 12 volts, the unloaded 1/35-hp d.c. motor turned at approximately 2,350 revolutions per minute to turn an internally housed gear reducer which provided a speed of about 6 r/min on an output shaft (a list of names and addresses of manufacturers and vendors of these and other components used in construction of cablegation systems is available on request from the Snake River Conservation Research Center, Kimberly, Idaho 83341). This shaft was coupled to a worm-gear drive that had a reduction ratio of 17 to 1. With a nominal reel diameter of 10 inches, this resulted in a plug speed of about 55 feet per hour. Friction in the gear train commonly slows the motor so that actual maximum speed was in the range of 40 to 50 feet per hour.

An 8-ohm, 50-watt rheostat is wired in series with the d.c. motor to achieve variable speed control. This permitted reducing the plug's rate of movement to about 7 feet per hour, or about 16 percent of the maximum rate. When lower rates were attempted, the motor tended to stall, especially after the battery was partially discharged. This stopped rotation of the worm gear and stopped the plug at the point in the line until

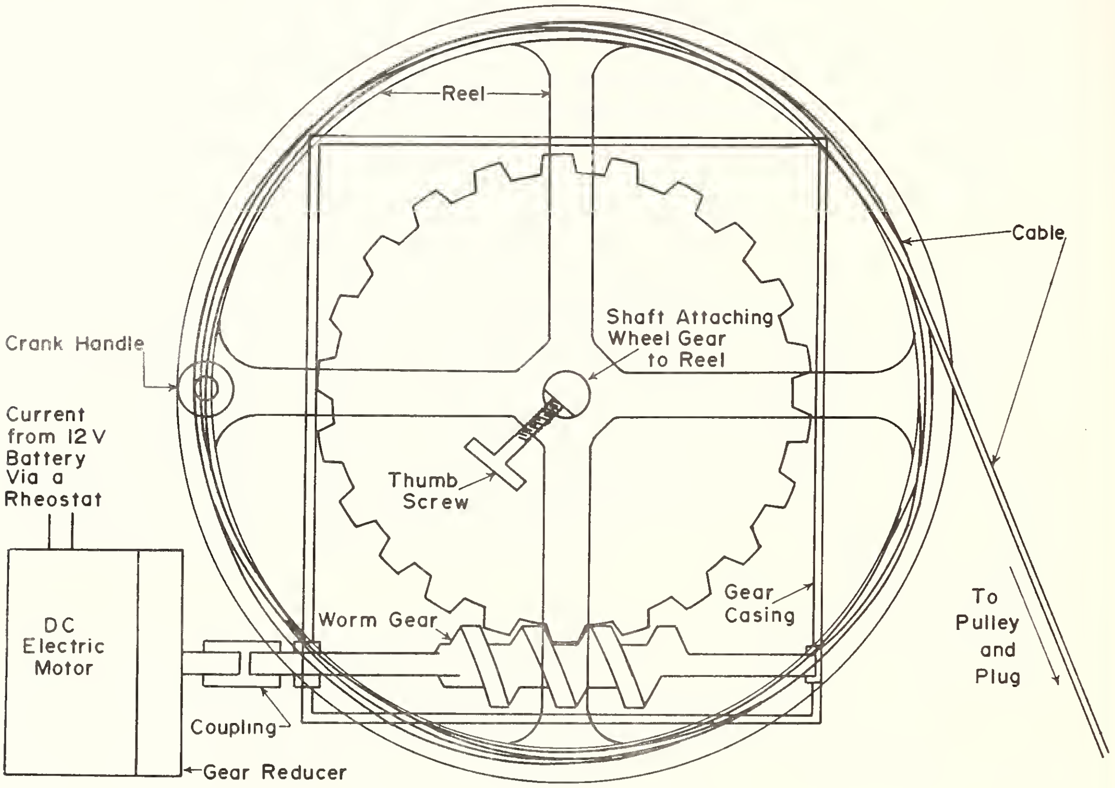


Figure 3.--Details of reel, motor and connections through which they control rate of travel.

the speed control rheostat was adjusted. Other speed control mechanisms are discussed in appendix J, Calvin LeBeau System and Roy Hood System.

Outlets

Outlets from a cablegation system can vary from a hole drilled in the pipe to an adjustable valve on a riser. The outlet or riser fitting should protrude to no more than one-half inch inside the pipe so it does not interfere with the plug movement. Adjustable outlets provide more efficient irrigation on soils with changing infiltration rates and make the system more flexible and easier to design. Risers allow the pipe to be buried so the pipe does not hinder tractor and truck traffic. Energy-dissipating outlets are required on systems with high head at the plug (more than 1.0 feet) to reduce erosion. Cutoff outlets will improve application uniformity on most soils. The number of outlets required will depend on the furrow spacing or border width. Outlets are discussed in more detail in appendix F.

Model Verification and Effects of Grade Deviations on Outlet Flow

A computer model or a simplified calculator procedure (app. C) can be used to compute furrow supply rates when the plug is in the midsection of the pipeline. Such predicted furrow supply rates are compared in figure 4 with data obtained from a cablegation system which was installed on the University of Idaho Research Farm (Kimberly), and indicate generally good agreement. This general agreement provided verification of the model and confidence in its ability to predict furrow supply rates in cablegation systems.

Measurements (Goel et al. 1982) showed that in this system about 80 percent of the deviations of furrow flow rates from the calculated flow rates were associated with the pipe being higher or lower than the designed grade at that furrow. In that system (pipe slope=0.28 percent), if the pipe was an inch above or below grade, the flow was about 12 percent less or more, respectively, than calculated. Deviation of pipe elevation from designed grade will have less effect on flow rates when grade is steeper. Specific equations from which effects of pipe elevation deviation from grade on flow from an outlet may be predicted are given in appendix C. These outlet flow equations show that the elevation deviations have relatively more effect on the flow rate from an outlet as the head and flow rate at

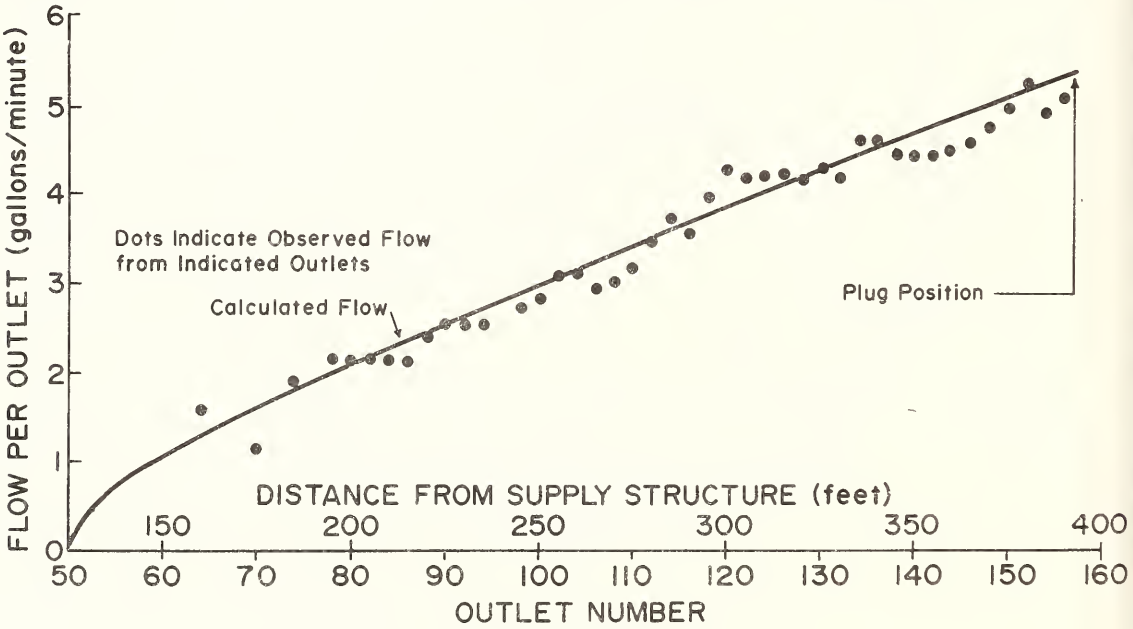


Figure 4.--Calculated and measured flow rates at outlets along the pipe.

that outlet decreases as a result of the plug moving down the pipe.

Plug Speed and Furrow Supply

Using this verified model, we demonstrated effects of plug speed and outlet size on furrow supply rates. Figure 5 shows the effect of plug travel speed on the flow rate of water to a furrow when the outlet diameter and the system pipe supply rate are constant. The total application to the furrows is proportional to the area under the curve which is inversely proportional to the plug speed. Adjustment of the plug speed is the primary means of determining the amount of water applied to the field. It determines the time during which water is supplied to the furrow.

Furrow Supply Rate Modification

High infiltration rates during the first irrigation following plowing often require higher furrow supply rates to push the water through the furrow in a reasonable length of time. One

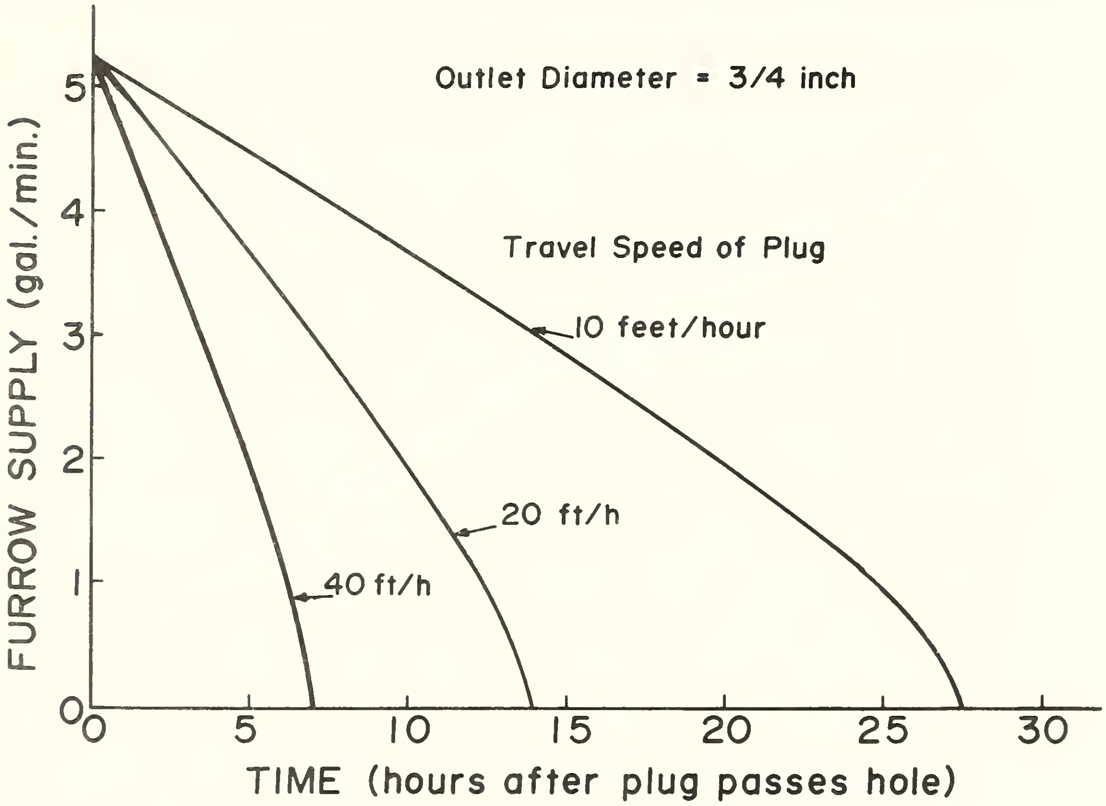


Figure 5.--Effect of time and plug speed on furrow supply rate after the plug has passed the hole supplying that furrow.

way to increase the furrow supply rate is to increase the pipe supply rate. However, as indicated in figure 6, doubling the pipe supply rate Q from 0.4 of its maximum capacity Q_c to 0.8 Q_c increases the initial furrow supply rate by only about 20 percent. Time of furrow supply is increased more than flow rate. Also note that as pipe supply rates Q approach maximum pipe-capacity flow rates (that is, $Q/Q_c \to 1$), the supply to a furrow is prolonged at low rates. This "outlet dribble" probably waters only the upper end of the field and increases the nonuniformity of irrigation. Consequently, we recommend that pipe supply rates, Q, be less than 0.85 Q_c.

The limited increase in furrow supply rate that can be achieved by increasing pipe supply rate is often not sufficient to match the high infiltration rates that occur during the first irrigation after plowing. One means of achieving this match is to decrease the furrow intake rates. In some cases, this can be achieved by compacting the furrow (Kemper, et al. 1982) or by practicing surge irrigation (Bishop et al. 1981 and appendix I). However, in some situations on some soils, it may be desirable to make major changes in the furrow supply rate. This will require a change in the outlet size.

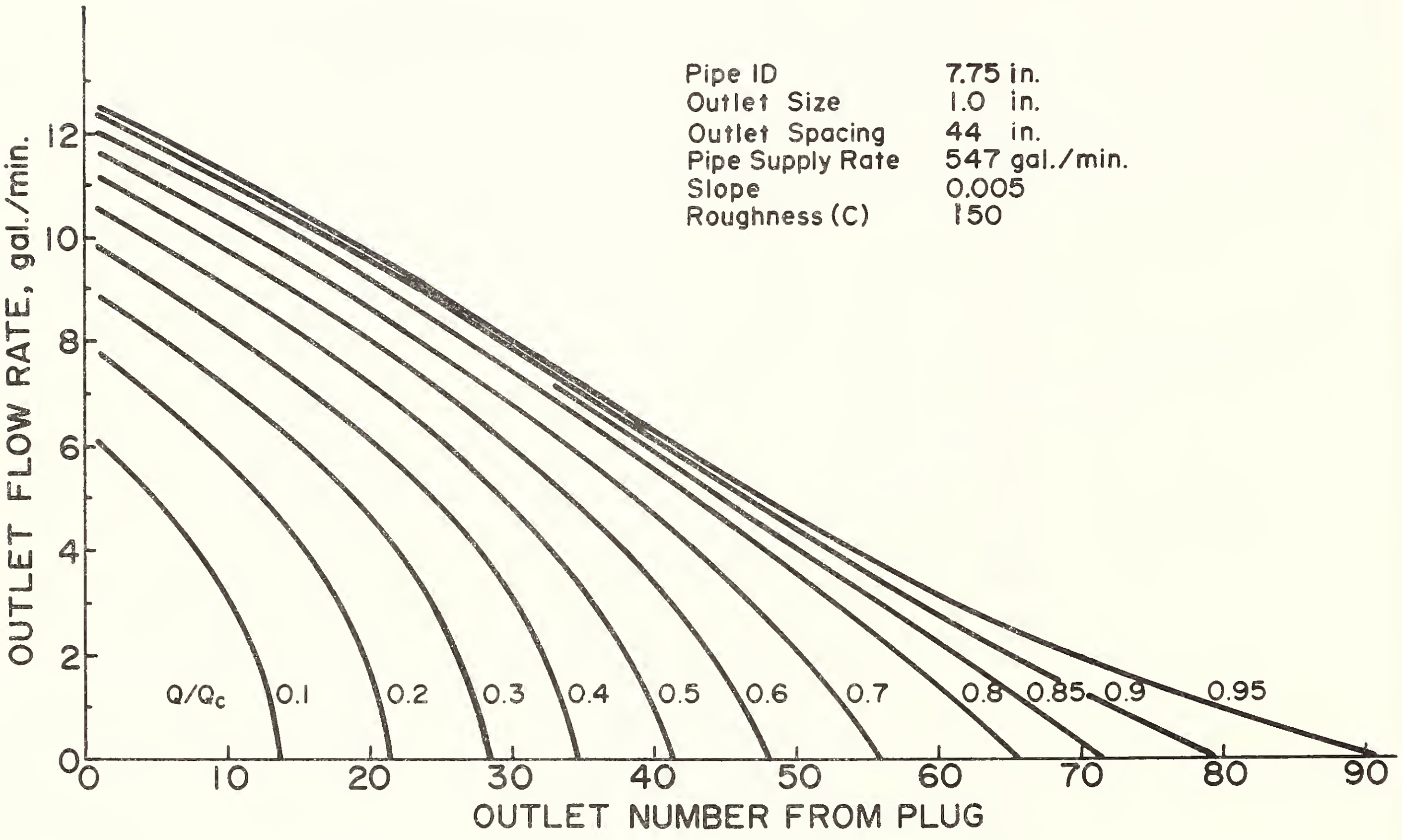


Figure 6.--Distribution of outlet flow at various fractions of pipe flow capacity.

The magnitude of change in flow rates that can be achieved with change in outlet size is indicated in figure 7. If the pressure at the outlet remained constant, flow would be proportional to the area of the outlet, or the diameter squared for round holes. However, as outlet size increases all along the line, the pressure of water in the pipe decreases and the initial flow rate is approximately proportional to the 3/2 power rather than the squared power of the round outlet diameters.

Figure 8 shows the results obtained from the model when three moving plugs were used in succession to force the water from the pipe. This capability is sometimes needed when a large flow is to be delivered from a rather steep pipeline. The two upstream plugs were designed with round outlets or holes through them to pass part of the flow to the downstream sections. The plug farthest downstream is of conventional design. This technique can be used to reduce the maximum pressure and flow rates and apply water to more furrows for a longer period of time. With smaller openings in the plugs, or longer distances between the plugs, the flow will stop in the outlets immediately downstream from the upstream plugs, providing intermittent or surge irrigation. (Surge irrigation, can in at least some cases, improve uniformity of water application along a furrow and

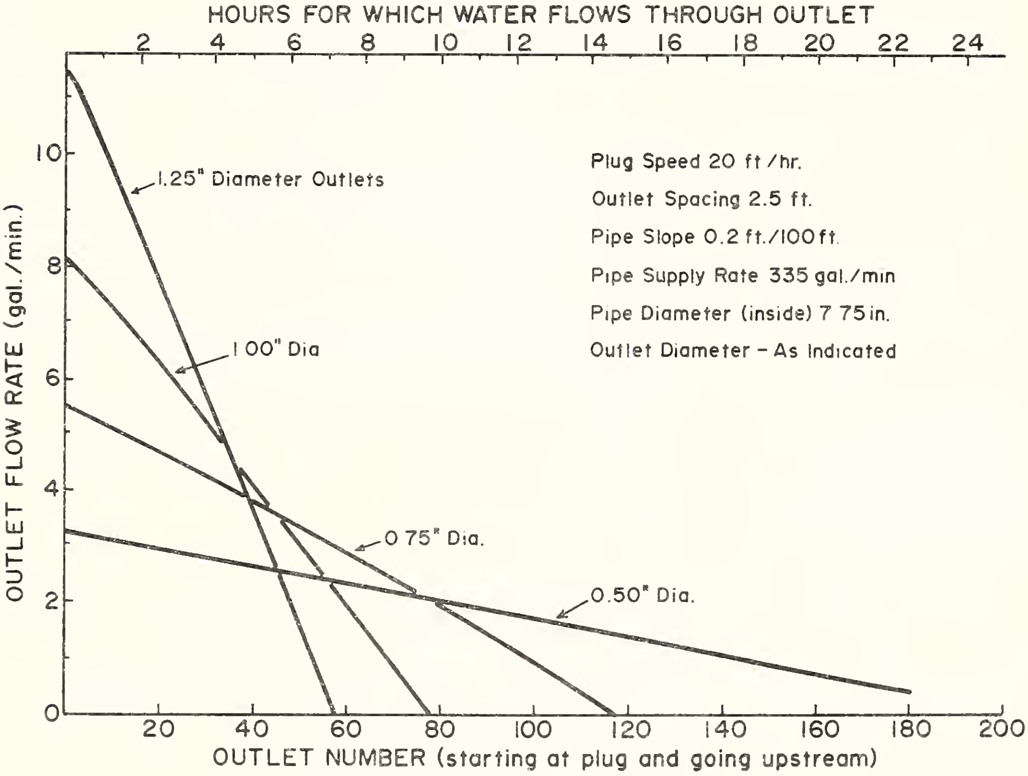


Figure 7.--Effect of outlet size on number of outlets flowing and the rate and time for which they flow.

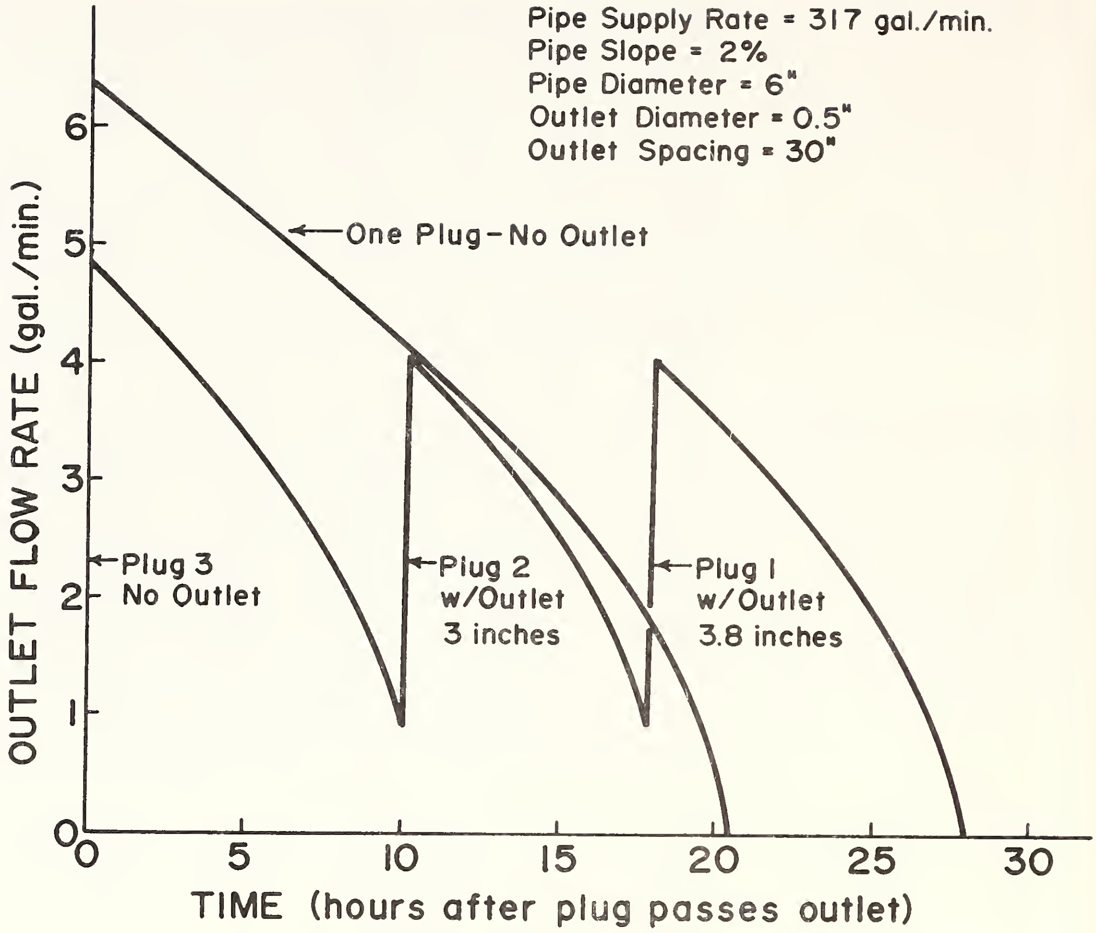


Figure 8.--Effects (on a steep slope) of multiple plugs with outlets allowing water to pass through all but the last plug.

achieve wetting of longer furrows. Some interactions of surge irrigation and cablegation systems are discussed in appendix I.)

Integrating Infiltration Characteristics in the Model

If an equation describing the rate at which a furrow absorbs water as a function of time is known, an expanded computer model (Kincaid and Kemper 1982) can estimate the amount of infiltration into the furrows across the field. This model, described in appendix C, uses the intake equation, field slope, and furrow supply rate to compute the rate of advance in the furrows which in turn yields the opportunity time for infiltration along the length of the furrows.

Predicting Runoff

Figure 9 shows a comparison between the computed furrow inflow and runoff rates and the measured values determined in a field test. The lines represent predictions by the expanded computer model. The crosses represent averages of the values found in

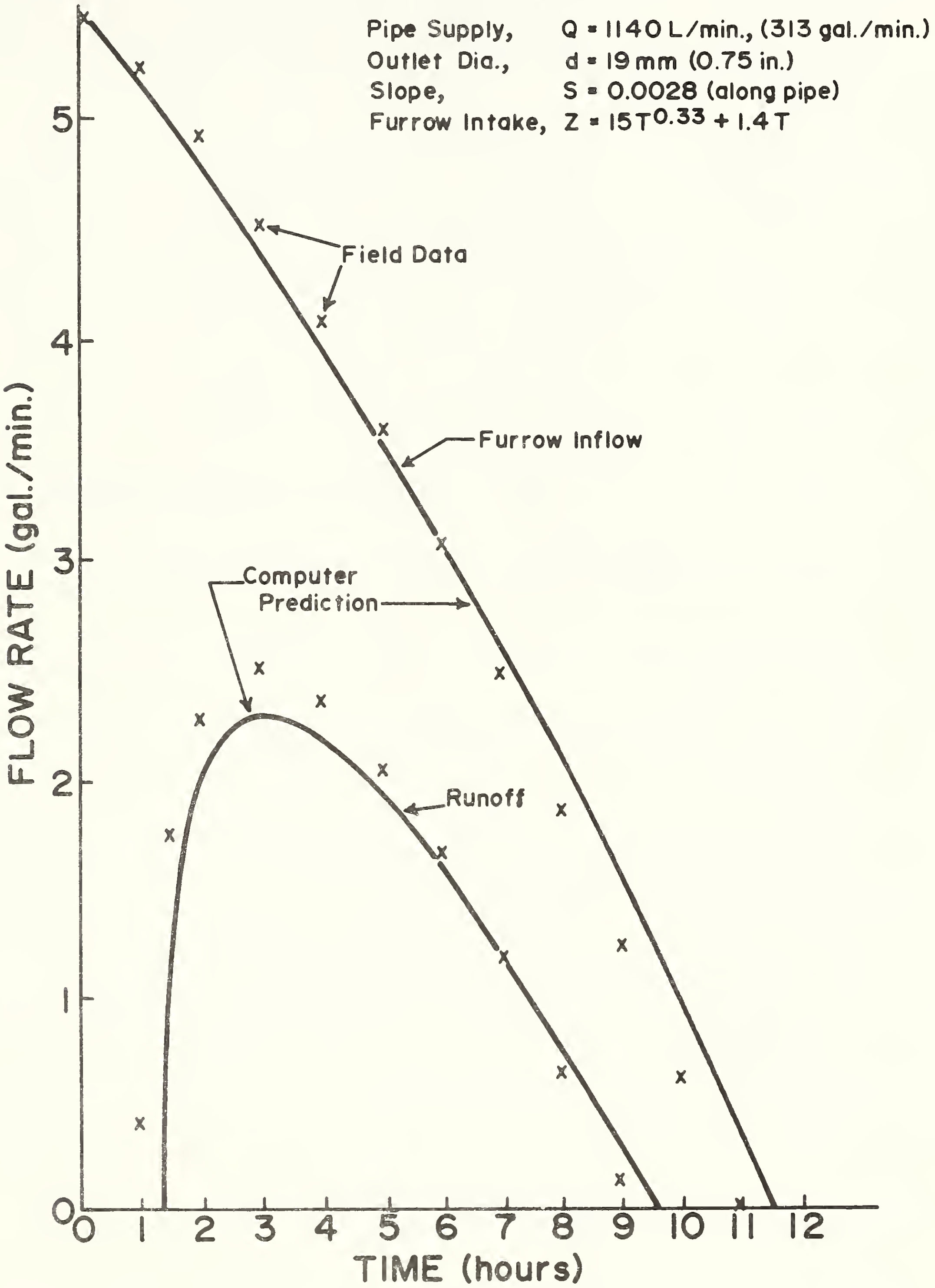


Figure 9.--Computed inflow and runoff rates of furrows compared with measured rates (average of 8 furrows).

field measurements from several rows. The computer prediction was in reasonable agreement with the averaged field data. The area between the two curves is proportional to the water infiltrated. The area below the runoff curve is proportional to the runoff. The vertical distance between the two curves represents the water intake rate of the total length of furrow at any time after runoff starts.

Predicting Infiltration Distribution

The expanded computer model, when supplied with the intake rate equation, can also estimate the distribution of the water infiltrated along the length of selected furrows as the irrigation progresses across the field. Figure 10 shows the plot of this infiltrated water along three furrows at the conclusion of an irrigation, assuming that the equation shown in figure 9 describes the intake as a function of opportunity time at all points in the field. Diameters of outlets were as shown in figure 10. This model was used to help design modifications of the system (app. I and K) to allow more uniform intakes than those shown in figure 10.

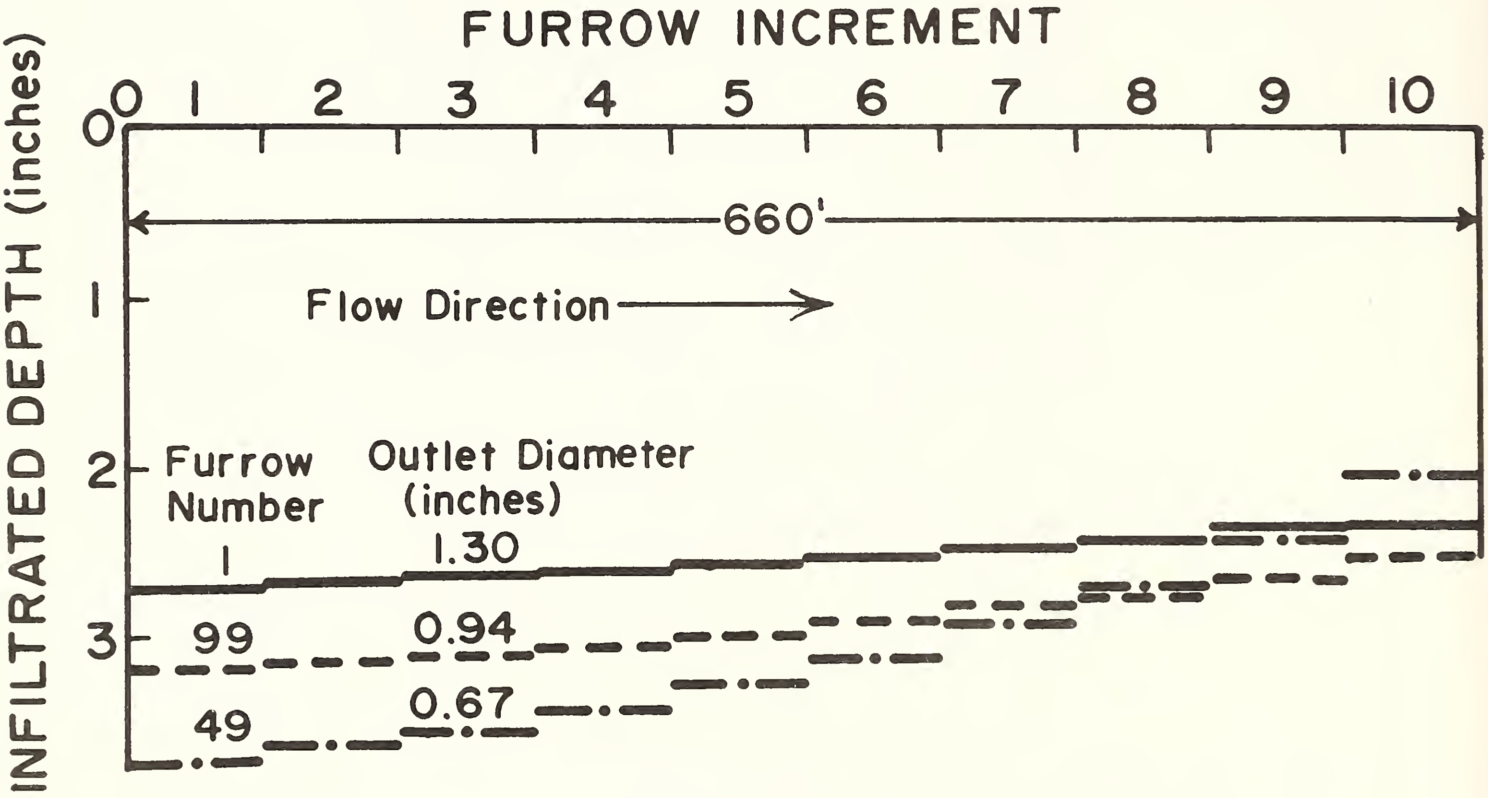


Figure 10.--Distribution of infiltrated water in selected furrows.

Preliminary Design and Cost Estimate

Most farmers, while deciding whether to install a new system, need a preliminary cost estimate. Normally, the pipe is the major portion of the cost of a cablegation system. The length of pipe required is usually the length of the previously used supply ditches or pipes at the head of the field. Specific information essential to choosing pipe size includes the maximum rate of water supply which must be carried by the system and the minimum slope that will be encountered along the line. In calculating minimum slope, it should be remembered that some head loss will occur at inlet structures, trash cleaning structures, etc., at the top end of the line (see "Final Design" page 21).

The cost of the pipe increases rapidly with size, and required pipe size decreases as minimum slope increases. Grading along the headline to make the slope more uniform can often increase the minimum slope and can occasionally reduce the pipe size and cost. Pipe is generally available in nominal 4-, 6-, 8-, 10-, 12-, and 15-inch diameters. Actual inside diameters for the different categories of pipe are given in appendix A.

Choice of pipe type may depend on specifications required by agencies who determine eligibility for cost sharing. If this is not a determining factor, a broad choice is available. Because of current price considerations and the probability that the pipes will be partially buried in the soil, PVC (polyvinyl chloride) has been used to date. PVC pipe produced for gated pipe has metal oxides in its formulation which cause it to resist deterioration from sunlight. Two of the presently installed systems have used PIP (plastic irrigation pipe) pipe because it is generally less expensive than the gated pipe. The farmers plan to keep their pipelines covered with soil. While the PIP pipe has functioned satisfactorily for 3 years, long term deterioriation and effort required to keep it covered need to be evaluated before it can be generally recommended for surface installation. Pipe size needed is selected by going to the friction-loss figure in appendix A for that type of pipe and identifying the point on the head loss ordinate equal to the minimum slope of the pipeline and a point on the flow rate ordinate equal to the maximum expected supply rate times 1/0.85 (=1.18). The first line to the right of the point corresponding to these coordinates identifies the pipe size required. For example, assume a minimum expected slope of 0.4 percent (0.40 feet per 100 feet) and the maximum expected supply rate of 700 gallons per minute, then 1.18 times maximum supply rate =826 gallons per minute. If the cablegation line is to be exposed on the surface, the sunlight-resistant gated pipe is recommended; its head losses are graphed in appendix A, figure 27. Locate the head-loss ordinate of 0.40 feet per 100 feet and the flow-rate ordinate of 826 gallons per minute; the line immediately to the right of the point specified by these coordinates is associated with the 10-inch diameter pipe.

In addition to the cost of the pipe, there will be costs for the control system, outlet gates, trash screens, engineering, grading, and installation. The control system, batteries, cable, and plug will cost between $300 and $1,000 (1982 dollars) depending on size and sophistication. Total costs may be about double the pipe costs.

In some cases, farmers may have the equipment and training and experience to design and/or install their own systems. The U.S. Department of Agriculture (USDA) Soil Conservation Service and Extension personnel may be able to help. For farmers with limited time, who do not have the equipment or surveying skills needed, commercial installers (names will be supplied on request) are available in some areas to provide these estimates and the installation. Commercial installers with laser- or wire-guided trenchers can install cablegation pipe to a precise grade.

Fitting the System to the Farm

General Information Needed

If the estimated costs and potential benefits convince the farmer to proceed, additional information about the site and past irrigation practices should be obtained. Most information needed is indicated in the questionnaire shown in figure 11. The USDA Soil Conservation Service, the State extension services, irrigation companies, etc. can often supply additional information about the field slopes, soils water-supply rate, and other special characteristics of the system. The farmer's specific needs, preferences, and planned operational procedures should also be considered.

Specific Elevations Needed

The first fieldwork normally involves determining the elevation of the water supply and running a profile of elevations along the edge of the field where the proposed pipe will be placed. Shots should be taken and elevations should be determined at about 50-foot intervals and the locations staked for future reference. (When power equipment is to be used in preparing the trench for the pipe, the elevation stakes should be offset where they will not be hit by the equipment.) Benchmarks should be established and the elevation traverse closed to identify and correct errors.

1. Owner's name ______________________________

2. Location (include directions to farm) ______________________________

3. Map (topography if available) or aerial photos of fields.

4. Crops to be grown and corrugate or furrow spacings of each ______________________________

5. Length and slope of irrigation runs ______________________________

6. Slope of proposed pipelines ______________________________

7. Estimates of intake (inches): in 1 h ___ in 6 h ____ in 12 h _____.

8. Depth and texture of soil ______________________________

9. Field slope and surface condition (level, needs touchup, needs leveling). ______________________________

10. Estimates of erosion hazard ______________________________

11. Normal water supply rate: ___cubic feet/sec, ___gallons per minute, ___miners inches.

12. Maximum water supply rate: ______________________________

13. Supply available: __constantly, __on demand, __rotation (___days out of ___days).

14. Past irrigation practice: Furrows irrigated per set:___ ___to___, time to irrigate: hours/set___to___, days per field: ___to___.

15. Water quality (trashy, silt load, moss, etc.)__________

16. Water source level_____. Elevation above highest part of field to be irrigated_____. Can this high point be cut?____. How much?____.

17. Is electricity available at the supply structure?_______

Figure 11.--Information needed for initial cablegation estimate.

This profile is plotted and studied to determine whether cut or fill will be needed along the headline to provide the desired uniformity of grade and whether the water supply elevation is high enough to serve the system. If the outlets need to be lower than the existing ground level, it is necessary to check the downfield slope to determine how far the cut must extend into the field to insure that water will flow away from the outlets pipe. Generally, the downfield slope of this cut area should be no less than 0.2 percent. Where fill is needed along the pipe, it is not generally necessary to extend the fill into the field.

While the primary factor determining the slope of the pipeline will be the slope of the land, head losses in structures and connecting pipe often use substantial portions of the elevation difference between the supply and the tail end of the system. Consequently, the structures and connecting pipes and their associated head losses must be planned before the final pipe grade is determined.

Structures, Connecting Pipes, Joints, and Associated Head Losses

In some cases, water-supply elevation will be high enough above the highest field level to accommodate all the possible head losses in the structures. However, if the supply level is no more than a foot above the highest corner of the field (1.5 feet if the water requires trash removal), there will generally be a need to design the structures, piping and joints to minimize head loss.

Head losses to be considered from the supply to the cablegation pipe include:

1. Friction loss in the pipe or ditch carrying water from the supply source to the cablegation input structure. Estimatable from equation 1 or appendix A for pipes and entrance losses to those pipes (estimatable as in No. 5 below).

2. Head loss at the screen structure which removes trash from the water (see app. H for screen types and head loss. Can be omitted if water supply is clean).

3. Head loss at a structure which allows water measurement or provides power for the cable-speed-control system.

4. Elevation head, h, required to accelerate the water to the average velocity, V, which it will have in the cablegation pipe. This can be approximated by $h=V^2/2g$; where h is in feet the gravitation constant is 32.2 feet per second^2 and V is in feet per second.

5. Entrance loss as the water enters a pipe. This entrance loss is also a squared function of the water velocity and is about half as large as the head required to accelerate the flow (No. 4) if the opening to the pipe is not streamlined.

At average flow velocities of 4 feet per second, the latter two head losses (Nos. 4 and 5) can subtract about 0.4 feet from the head. In other words, when the average velocity in the cablegation line at the first outlet is 4 feet per second, the water in the input structure will have to be more than 0.4 feet above the first outlet in the cablegation line for the water to run out of that outlet. In many cases, there is not this much head available.

Streamlining the entrance to the cablegation pipe (app. J, fig. 74), practically eliminates the entrance loss. Special bell-shaped forms were used to provide this streamlining in poured-concrete input structures. When the input structures were precast-concrete pipes (e.g. app. J, fig. 67), the joint with the PVC cablegation pipe was mortared together so the inside surfaces were as streamlined as possible. Bagged mortar mix enriched with Portland cement at a 4:1 ratio provides a strong workable mortar that was used successfully on several installations. However, it requires 12 to 24 hours to set up to where it will not be eroded by high-velocity water. Quick-setting, commercial compounds (names and suppliers of materials supplied on request) similar to mortar are easier to mold and will withstand flowing water within 1 hour of application.

A PVC collar was glued around most of the PVC pipes at this joint (app. J, fig. 101). These collars held this end of the pipes in place. Longitudinal expansion and contraction of the PVC caused by temperature changes were accommodated at the joints between the pipes (fig. 12). In a few cases, in place of the PVC collar, a rubber gasket of the type used in PVC pipe joints was placed on the pipe and mortared into the joint at the input structure. The pipes slide back and forth in these gaskets without appreciable leakage. However, if the ends of the pipes extend into the structure, they can interfere with streamlining and increase entrance loss.

Open-channel water supplies generally carry trash which can block outlets controlling the outflow of water from the cablegation pipe. When these open-channel supplies contain irrigation return-flow water, they are often a major vector bringing weed seed onto the field. Consequently, trash and weed-seed screens are recommended on most open-channel supplies that are to be used for cablegation. Types of screens and screen structures used to date, along with head losses required, are discussed in appendix H.

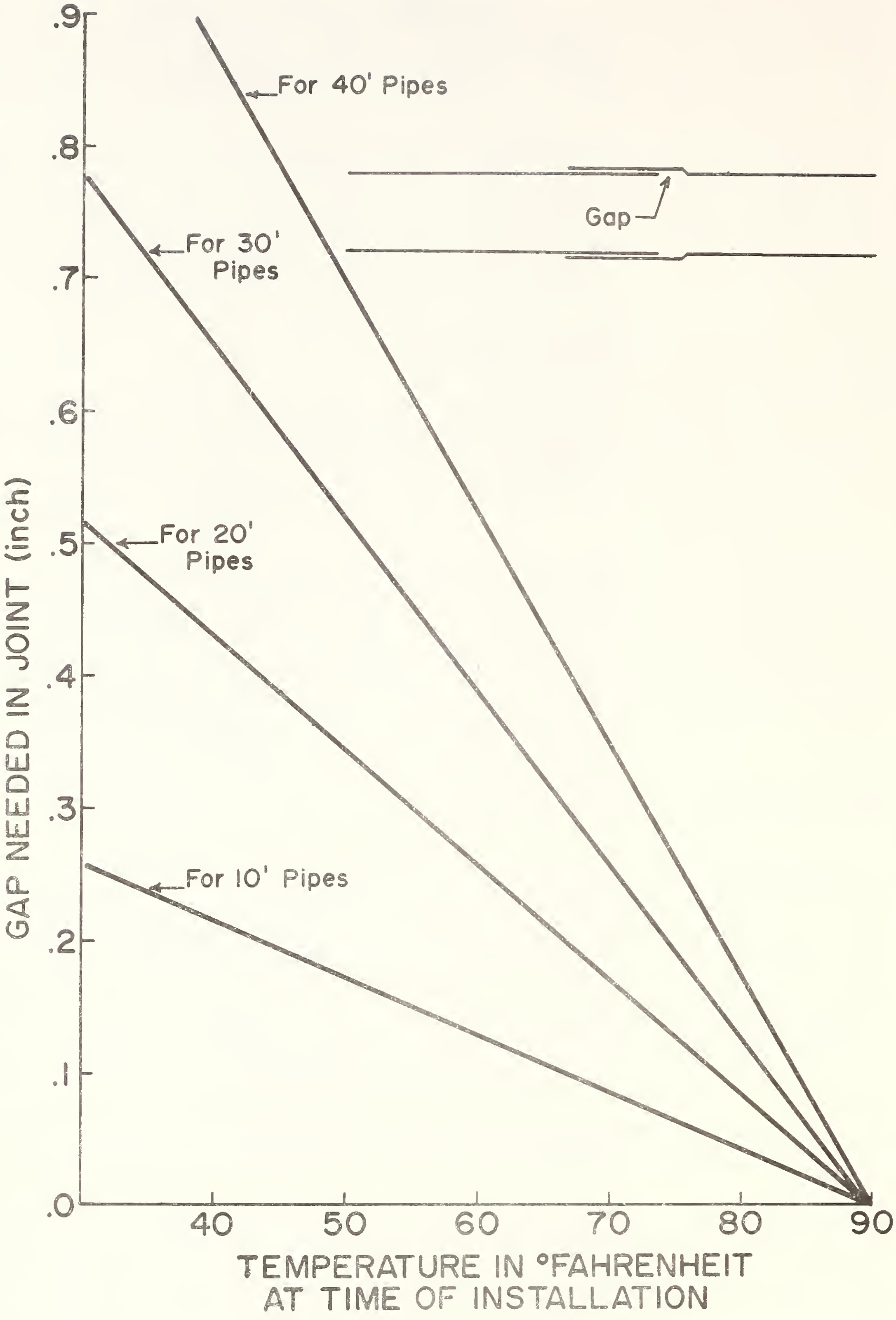


Figure 12.--Gaps needed in joints to allow for expansion of PVC pipe when its temperature increases.

In general, the 6 to 10 inches of head loss required for a self-cleaning trash screen with no moving parts is a good investment. If the necessary head is not available, it can often be developed by increasing the size of the conduit bringing water from the headgate to the screen structure, by streamlining inlets to pipes, or by lowering the soil level at the top corner of the field by a few inches.

If water power derived from water wheels similar to those used in the Hood and Lewis systems (app. J) is used to operate the cable control mechanism, 2 to 4 inches of head will be required for the controller. The lowest head loss for the combined trash-cleaning and cable controller functions in systems installed to date was in the Baker system (app. J) where 2 or 3 inches of head performs both of these functions. However, it was necessary to allow the headgate opening to submerge in the initial stages of irrigation in that system. If the amount of water which the farmer does not get during this submergence period is of no consequence to the farmer, such a system can allow the plug to be started just below the first hole.

One way of saving most of the head loss going from the inlet structure into the cablegation line is illustrated in the Roy Hood control system (app. J, fig. 101). The channel for waterflow through the structure where the cable enters the pipeline is kept narrow so the momentum of water entering the structure is not lost but carries right into the cablegation line.

Final Design

Once the head loss that will occur in the structures and connecting pipes is determined, the elevation plan should be plotted on graph paper. This should show elevation of water at the supply, head loss in connecting pipelines, head loss at the structures, cablegation pipeline grade(s) and diameters, and original soil surface along the cablegation line. Where possible, it is advantageous to lay the pipe on a constant slope. However, as illustrated in the Kemper and Meuleman systems (app. J, figs. 76 and 98), changes in slope can be accommodated. Increases in slope result in increased pressures in the line near the plug and consequently must be accompanied by decreases in outlet size to keep flow rates and times uniform. Near the transitions, the slope on one side of the transition affects pressure on the other, and intermediate outlet sizes are needed to achieve delivery rates and times reasonably similar to those above and below that transition. The best pattern for changing outlet sizes at such transitions changes if total supply rate to the pipe changes. The computer model can calculate these best patterns. However, in practice, providing adjustable outlets near these transitions allows farmers to set them where wanted and make changes when needed.

Pipe size needed in the cablegation line(s) at these slopes can be determined from app. A. Outlet sizes, possible needs for energy dissipators, and the force on the cable can be assessed using the simplified design procedures, the computer program, or the equations and figures given in appendix E.

The final design should also include plans to accommodate other factors related to specific field shape, water delivery, drainage, etc. Many such options are described in the section "Modifications and Innovations to Meet Special Requirements" and appendixes A, B, C, D, F, H, and J.

It will generally be wise to have an experienced installer check the final design. In some areas, commercial installers are available who are able to plan the whole system or check the final design. In some areas, USDA Soil Conservation Service personnel are equipped and have had the experience necessary to do this. (Names and addresses of commercial companies will be furnished on request. Snake River Conservation Research Center personnel will, on request, provide training to USDA Soil Conservation Service and State extension service personnel to help them gain the skills and experience needed to develop and check designs and advise on system installations.)

Installation

Preparing the Bed for the Pipeline

Grade stakes should be set along the proposed cablegation line but offset far enough to allow cutting and filling along this line without disturbing the grade stakes. A scraper or blade should then be used to cut or fill to the designed level, packing the soil in the fill areas to reduce the subsidence that will occur in these areas when the soil is wetted. If the fill is more than 3 or 4 inches, overfilling by about 10 percent will help keep levels sufficiently high in these reaches. A soil water content slightly below field capacity is ideal for compacting fill and digging the trench for the cablegation line. If the soil is too dry for good compaction and trenching, it can be wetted by forming a furrow where the pipeline is to go and running a small stream of water in this furrow sufficient to wet to the end of the trench. This will require a flow rate between 5 and 50 gallons of water per minute depending on the length of the line and permeability of the soil. The flow should continue until the wetted zone generally extends at least a foot from the trench and any fill material below the planned pipe location is wetted. This wetting should take place 2 or 3 days before pipe installation if the soil is fine textured and 1 or 2 days before if the soil is coarse textured.

The trench can be excavated by appropriately sized ditchers, trenchers, or plows. Prior to pipe installations, the trench bottom should be inspected and if it is not firm, it should be packed. A wheel of a tractor which has a width approximately equal to the diameter of the pipe can be an effective packer.

Following the rough trenching, the trench must be touched up to achieve the desired precision. In straight reaches where the grade is constant, the precise changes in elevation needed can be determined easily as follows: Place the level in the center of a reach directly over the trench. Place the rod directly in front of the scope with the base of the rod in the bottom of the trench, and clamp the target on the rod at the elevation of the scope. Then place the rod in the bottom of the trench at the upper end of the reach and tilt the surveyor's level until the crosshairs coincide with the target. To check this grade, take the rod to the lower end of the trench section and place it with its base in the bottom of the trench. Keeping the level on the same tilt, rotate it 180 degrees. If the crosshairs are within 0.10 feet of the target center,the sightline of the level is adequately set. An appreciable miss indicates that the trench bottom at the midpoint of the reach is appreciably lower or higher than a gradeline drawn between the trench bottom at the upper and lower end of the reach. If the crosshairs miss the target by more than 0.10 foot, the tilt of the surveyor's level should be changed so the crosshair falls halfway between the initial rod reading and the target. Then move the target to coincide with the crosshairs. The rod should then be moved to the upper end to check this again. If this has been done carefully, the crosshairs should be on target and ready for the following.

Final precise leveling of the trench can be effectively achieved with one person on the level, one on the rod, and two shoveling. The rod operator places the rod in the trench, and if the level operator sees the target appreciably above the crosshairs, more excavation is needed. If the target is below the crosshairs, the level operator signals the need for fill. Fill should be made with moist soil and packed by foot to bring the bottom of the trench to the desired levels. Sightings should be made at intervals of about 10 feet with the base of the rod set on excavations or pads built of earth to provide the proper elevation corrections. A straight edged, 10-foot-long board spanning these sightings and careful shoveling between these sightings can generally keep the trench bottom within ±0.5 inch of the designed grade. Since the radii of gasketed bell joints of PVC pipe are generally more than 0.5 inch larger than the rest of the pipe, the area under the gasketed joints needs to be excavated deeper than the rest of the trench if elevation variation is to be less than ±0.5 inch.

In straight reaches of this type, laser-plane equipment on ditchers or trenchers provide a most efficient method of obtaining a trench with the designed grade. (Names and addresses of manufacturers and operators of laser equipment will be provided upon request.) Some hand excavation under gasketed bell joints is needed if levels within ±0.5 inch are required. If the pipeline is to be curved, laser guided equipment and the simpler tilted level technique will not work and conventional grading procedures are required. The surveyor's level should be set up level, away from the pipeline trench, and trench bottom elevations adjusted as before so that rod readings increase an amount that corresponds to the designed slope of the pipe trench times the distance along that trench between shots. One person on the rod, one on the level, and two shoveling is again an efficient team for this final leveling.

Installation of Structures

Structures can be installed while the bed for the pipe is being prepared. Precise elevations should be staked for both. Examples of types of structures used to date are shown in appendix J.

Installation of Pipes

When the outlet structures are in place and the pad and trench prepared to desired slope(s), the next step is pipe installation. It is generally best to mortar or cement a short length (for example 2 feet) of pipe into the structure and to sleeve the bell joint of the next pipe over this short section. In cases where the male ends are upstream, there is more tendency for sharp-pointed debris to catch in the joints. Both rubber-gasket and glue-joint types of plastic irrigation pipe can be used in cablegation systems. Some brands of gasketed pipe have the male ends rolled inward to aid in slipping the pipe joints together. (The major PVC-pipe manufacturers have assured us they can, on short order, provide pipe without constricted male ends. Consequently, the installer can avoid this waste of pipe and labor by ordering early and telling the potential suppliers that only the nonreduced pipe will be accepted.) If the only pipe available has constricted ends, sawing off 2 inches of the male end of each pipe length generally removes the constriction.

(On one installation where the pipe was laid before its constricted ends were recognized, a plug [app. J, fig. 109] was developed which has successfully gone through these constrictions for two irrigation seasons).

This can be done quickly with a carpenter's circular saw or saber saw powered by a portable generator. During one installation, 2 hours were required to saw the ends off 44 pipe lengths (one-quarter mile of pipe). The squared ends of the remaining pipe can be lubricated with vegetable shortening, and the joints can be readily sleeved together by two people.

According to PVC manufacturers, the coefficient of thermal expansion of PVC pipe is about 0.00035 foot per foot per degree Fahrenheit. Figure 12 shows the gap length required at each joint to allow for pipe expansion as a function of the temperature at the time of installation. Calculations for figure 12 were based on this coefficient and on the assumption that the maximum temperature of the pipe will be about 90 degrees Fahrenheit. Achieving the desired gap is facilitated by measuring the length of the bell, subtracting the width of the desired gap, and then making a mark at a distance from the male ends of all the pipes equal to the remainder.

When the glue-joint type pipe was used, the pipe was assembled by lubricating the male end with vegetable shortening and slipping the joints together as described above. Because of the low pressures in the pipe, cement was not needed. This type of installation is quick and appears to be adequate. A trace of moist soil was noted initially at a few joints, but this was not a problem. Expansion couplers are not needed along the length of the pipe if the joints are not glued and the gaps of the indicated lengths are left in the bells.

As soon as is convenient after the pipe is joined, and definitely before major temperature change occurs, each length should be anchored in the trench by packing some soil around it. If the sections are not anchored as cooler temperatures shrink the pipe, several of the joints with greatest friction may stick together sliding these pipe sections sufficiently to cause disconnection of pipes sharing looser joints.

Soil used to fill around the pipe should be moist and friable so it will break down under moderate compaction to minimize large voids around the pipe. Keeping the section of the pipes around which soil is being packed partly full of water helps to weight it, minimizing lift that often occurs when compacting pressures are applied to soil on the underside of the pipe.

In some of the first installations, leveling of the trench bottom was followed by deliberate puddling of the soil around the pipe with excess water. This resulted in some flotation of the pipe, even when it was full of water, so that it no longer followed the exact designed grade. Excavation to bring these sections back to grade required considerable labor. <u>Consequently, puddling the soil around the pipes is not recommended</u>.

Outlets

Unless preslotted gated pipe is used, holes for attaching outlets must be cut in the pipe. The outlet locations along the pipe are determined by measuring along the top and marking distances to correspond to the spacing of the closest spaced corrugates to be used in the planned crop rotation. If the pipe runs at an angle different than 90 degrees from the corrugates, the spacing of the outlets should be increased accordingly. The 30 degree offset from the centerline of the top of the pipe may be quickly determined with a short carpenter's level taped to a wooden saddle. The saddle can be made of a short piece of 2 by 4 lumber by placing one side on the end of a pipe, using the outside of the pipe to draw a circle segment, and cutting along that line with a saber saw discarding the circular segment and using the remaining "saddle." The midpoint of this arch is vertical when the saddle is level. Points down the arch, one-twelfth the circumference of the pipe are at the desired 30 degree angle from vertical and can be clearly marked on both sides of the saddle. This saddle-and-level combination is then set on the pipe at the desired location and rotated until the bubble in the level is centered; a mark is placed on the pipe adjacent to the 30 degree mark on the saddle which is directed toward the furrow to be served. Locations for holes in the top of the pipe for vertical risers can be marked with the same instrument.

The outlet holes have generally been made with electric drills powered by portable gasoline generators. The holes are cut in the pipe wall with a hole saw or an adjustable-diameter hole cutter with three blades mounted on a drill bit which locates the center of the hole.

In one installation, holes were drilled on 30-inch centers along all the pipes before they were installed in the field. This allowed use of line power for the drill, avoided the cost of renting a generator, and allowed comfortable and more rapid drilling of the holes. To aline the holes, we drilled them along the printing on the pipe, assuming this was straight. When the pipe was assembled in the field, it was found that the printing actually spiraled about 7 degrees on each 40-foot length of pipe. This resulted in holes being placed from 23 to 30 degrees from vertical, rather than all at 30 degrees. They still functioned adequately in that system.

Gated pipe style of PVC pipe is available with holes that have been cut at the factory. These holes are commonly rectangular, oval or keyhole shaped, to fit standard adjustable gates. (During 1982, plugs were designed which could pass the inward protrusions that are a part of most gates used in regular PVC gated pipe.) Check that these slots are in a straight line on the pipe. When predrilled pipe is used, its proper rotation can be checked with the saddle-level instrument.

In some installations, holes cut in the pipe constitute the outlets. In others, commercially available inserts or gates have been fitted into the holes in the pipe to allow variations in the outlet size. The outlet fittings should not project more than 0.5 inch into the pipe, or they may interfere with the passage of the plug. In several of the first installations, fittings made for thin-walled polyethylene "lay flat" tubing were used which have a thin edge that only projects about one-thirty-second inch into the pipe. (Names of suppliers furnished on request to Snake River Conservation Research Center.) They are flexible so that they can be collapsed with the fingers and snapped into the holes in the PVC pipe. Two sizes are available that fit in 1.25- or 1.75-inch-diameter holes. The 1.25-inch size has been large enough to serve as the basic outlet on most of the systems installed to date. Inserts fitting 1.25-inch holes in the PVC pipe are available with outlet holes of 1.0- or 0.75-inch diameter. Reducers and caps are available to reduce the 0.75-inch-diameter model to 0.50 inch or to cap off the outlets. Since 0.75-inch holes pass more than twice as much water as 0.50-inch diameter holes, smaller increments of hole sizes are needed to attain intermediate flow rates. Caps can be purchased and punched to provide intermediate hole sizes. Table 1, column 6 gives area change of hole sizes in increments from 9 to 25 mm diameter. Flow rates are proportional to hole areas if pressure in the pipe at that point remains constant. However, smaller holes result in more pressure in cablegation pipes, and, when sizes are reduced, the flow-rate reduction is generally somewhat less than indicated in table 1.

Table 1.--Outlet size and incremental area change

Diameter		Area			Area change
mm	inch	mm^2	in^2	ft^2	(%)
9	0.354	63.6	0.099	0.000685	24.3
10	.394	78.5	.122	.000845	21.0
11	.433	95.0	.147	.001023	19.0
12	.472	113.1	.175	.001217	12.0
12.7	.500	126.6	.196	.001363	4.8
13	.512	132.7	.206	.001439	16.0
14	.551	153.9	.239	.001657	14.8
15	.591	176.7	.274	.001902	13.8
16	.630	201.1	.312	.00216	12.9
17	.669	227.0	.352	.00244	12.1
18	.709	254.5	.394	.00274	11.4
19	.748	283.5	.439	.00305	10.9
20	.787	314.2	.487	.00338	10.2
21	.827	346.4	.537	.00373	9.7
22	.866	380.1	.589	.00409	9.3
23	.906	415.5	.644	.00447	8.9
24	.945	452.4	.701	.00487	8.5
25	.984	490.9	.761	.00528	3.2
25.4	1.000	506.7	.785	.00545	

Figure 13 shows an outlet using these low-cost commercially available inserts in a round hole in the PVC pipe. In most installations of this type, a nail has been forced through the walls of the polyethylene insert, just outside the PVC pipe, to prevent the insert from slipping into the pipe when a cap or reducer is pressed on the insert. If the water is clean or screened properly, this is a satisfactory solution. If the water contains considerable trash, the nail catches trash and is a problem.

Recent development of plugs which will pass regular gates (app. J) allows cablegation users to select from the spectrum of commercially available gates designed for gated pipe. Other gates have been designed to adjust flow and dissipate energy from cablegation pipes (names of manufacturers will be furnished on request).

Installing Cable Speed Control

The control systems must be firmly anchored at the inlet structure. They can be attached to pipes driven into the ground next to the inlet structure or built on a frame which is bolted directly to the structure. In the first method, steel pipes (1.5-inch diameter) are driven 3 or 4 feet into the soil next to the input structure. The top of the pipe extends 18 to 24 inches above the top edge of the structure so the reel and speed control mechanism can be clamped securely to it above the structure with U-bolt clamps. A typical assembly is shown in figure 14.

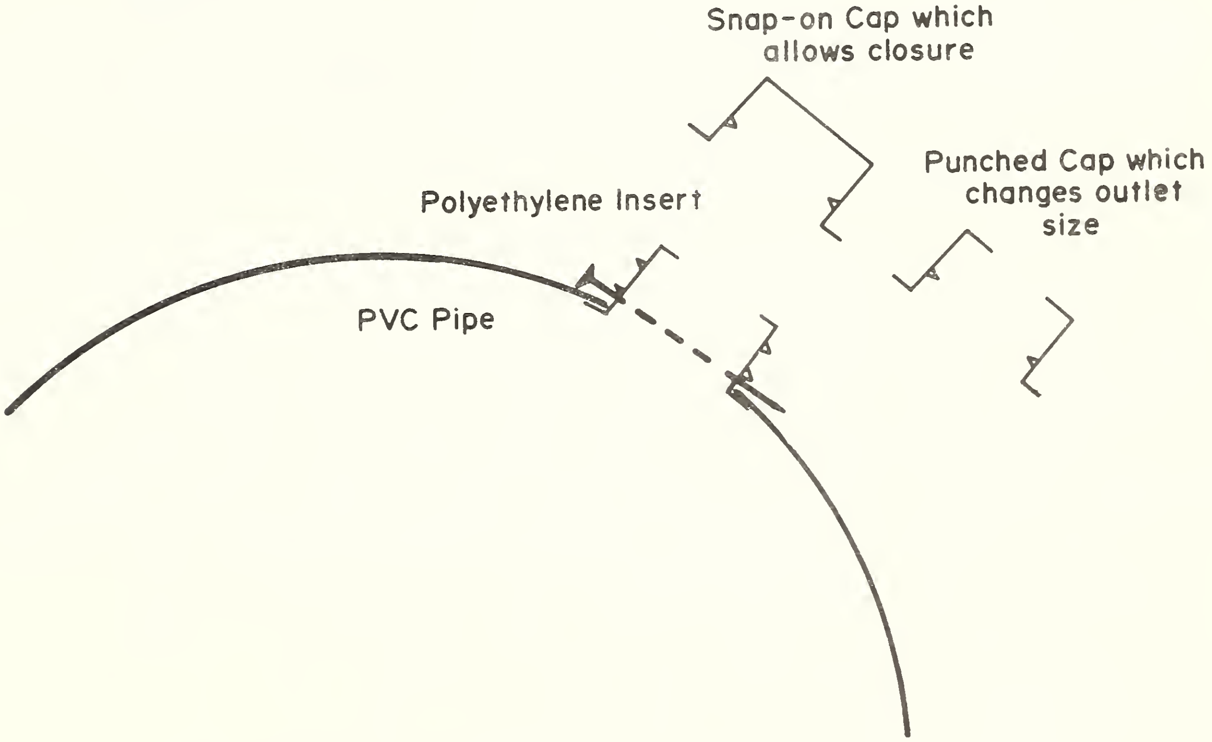


Figure 13.--Low cost polyethylene fittings.

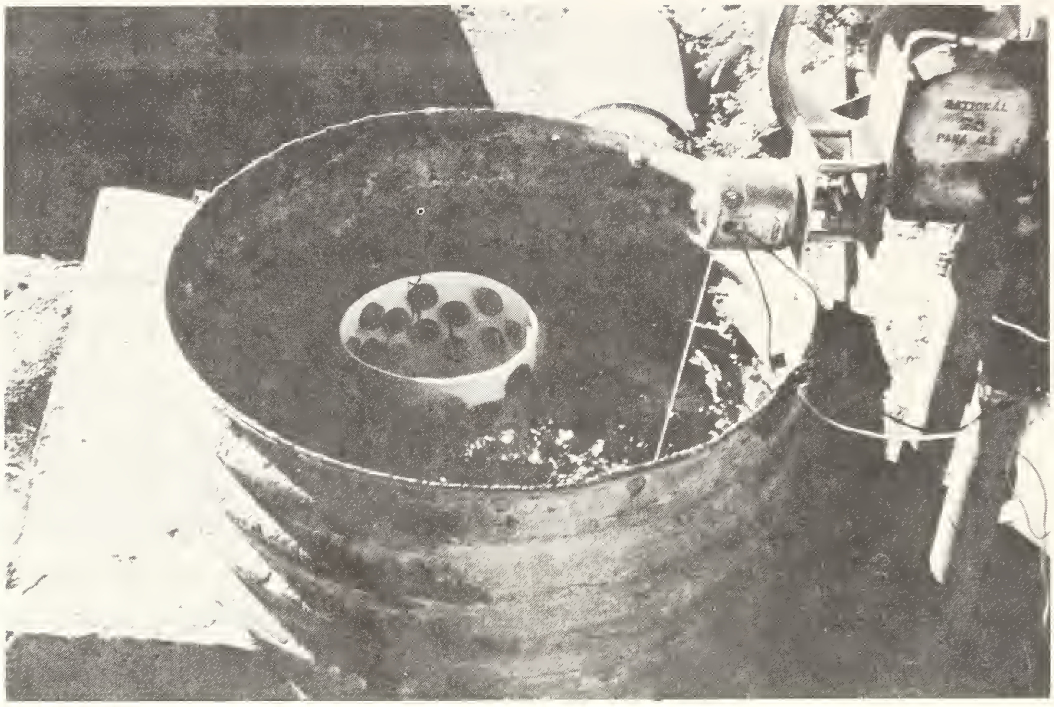


Figure 14.--Mounting of a control system on pipes driven in the ground.

A pulley or cable guide is attached to the input structure in such a position that it guides the cable coming off the reel into the approximate centerline of the pipe. The attachment of the guide to the structure should be flexible so it can be moved out of the way while the plug is inserted into the pipe. The reel's final position can be adjusted by moving the control unit up or down and rotating it on the steel pipe until the cable feeding off the reel to the pulley and thence to the pipe is in good alinement.

In most of the electric powered control systems the rheostat governing the motor was connected to a 12-volt battery with wires and battery clips when it was time for the plug to move down the pipe. (In one system, a 12-volt d.c. power supply operated from 110-volt a.c. line current. Since current usage of the motor had been measured at 2.2 amps and a power supply rated at 2.5 amps was available, it was purchased. The overload switch on the power supply turned it off several times, particularly during startup periods. A power supply with a rated capacity about 50 percent greater than motor requirement is recommended.)

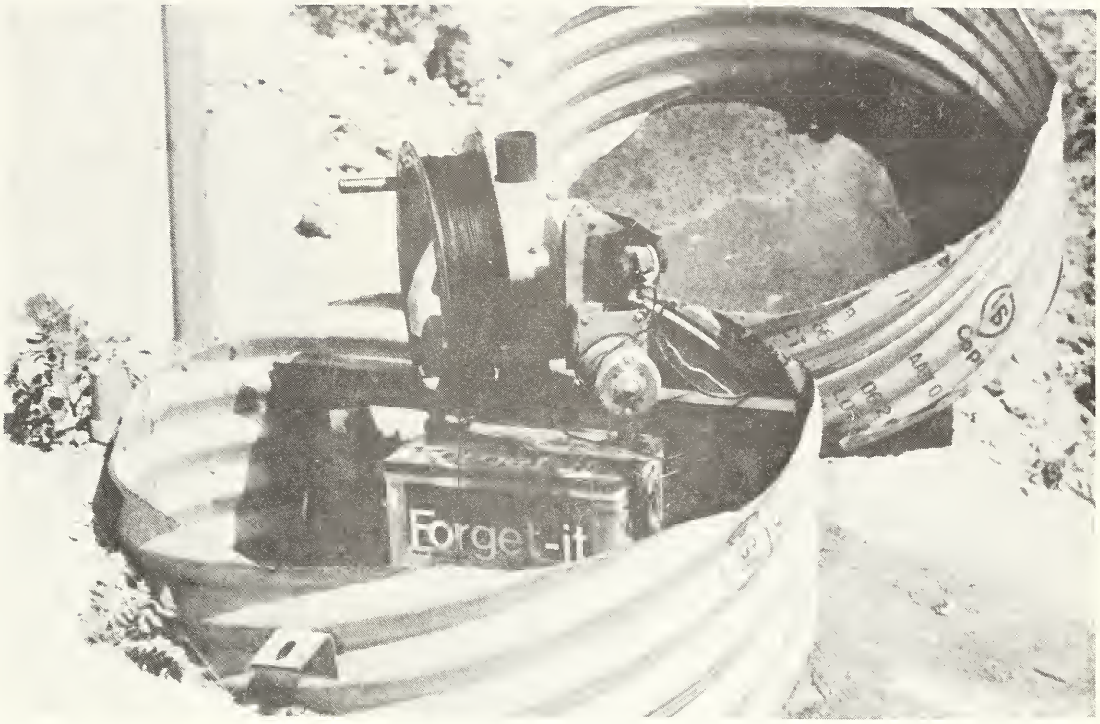


Figure 15.--Input structure which can be covered and locked.

At some locations, protection of the battery and control systems from theft and vandalism must be considered. One cooperator constructed his input structure so that the battery and controller could be mounted inside the input structure, covered, and locked as indicated in figure 15.

To function optimally, cablegation systems must be designed for specific sites and specific operating conditions. The following modifications have been used in one or more of the systems installed.

High Pressure and Energy Dissipation

Water pressure in the pipe near the plug can be high when the slope along the cablegation line is steep (>0.5 percent). Slope of 2.2 percent caused the pressure indicated in figure 16. The jet of water will cause soil erosion at the head of the furrow and can be blown into other furrows by even moderate winds.

Several energy dissipating outlets which decrease flow velocity and redirect the flow downward toward the soil surface are described in appendix F. Clip-on screens or socks can be used to dissipate energy from gated-pipe slide gates. Stiff tubing such as corrugated polyethylene hose can be attached to outlets to direct the water into the furrows. A vent hole should usually be punched in the tubing near the outlet from the pipe to prevent siphoning so that elevation of the outlet on the pipe rather than the elevation of the end of the tubing determines rate of flow. Appendix G describes ways to decrease pressure inside the pipeline.

Handling Changes in Intake Rates

During cropping seasons and crop rotations, a specific soil's water-intake rate varies. For example, intake following plowing can be two or three times the "average" rates. Grain stubble can also have high rates of intake when the soil is dry and straw and chaff on the soil surface partially block the corrugates and spread water over more of the surface. On the other hand, as furrows are used several times during hot dry summers, their infiltration rates sometimes decrease to low values.

Adjusting Outlet Size

Efficient irrigation of soil whose intake rate changes greatly with time requires adjustment of the furrow supply rates. The primary way to increase or decrease furrow supply rates is by adjusting the size of the outlet opening. This is labor intensive because it requires adjusting and resetting hundreds of outlets. Several adjustable outlets are described in appendix F.

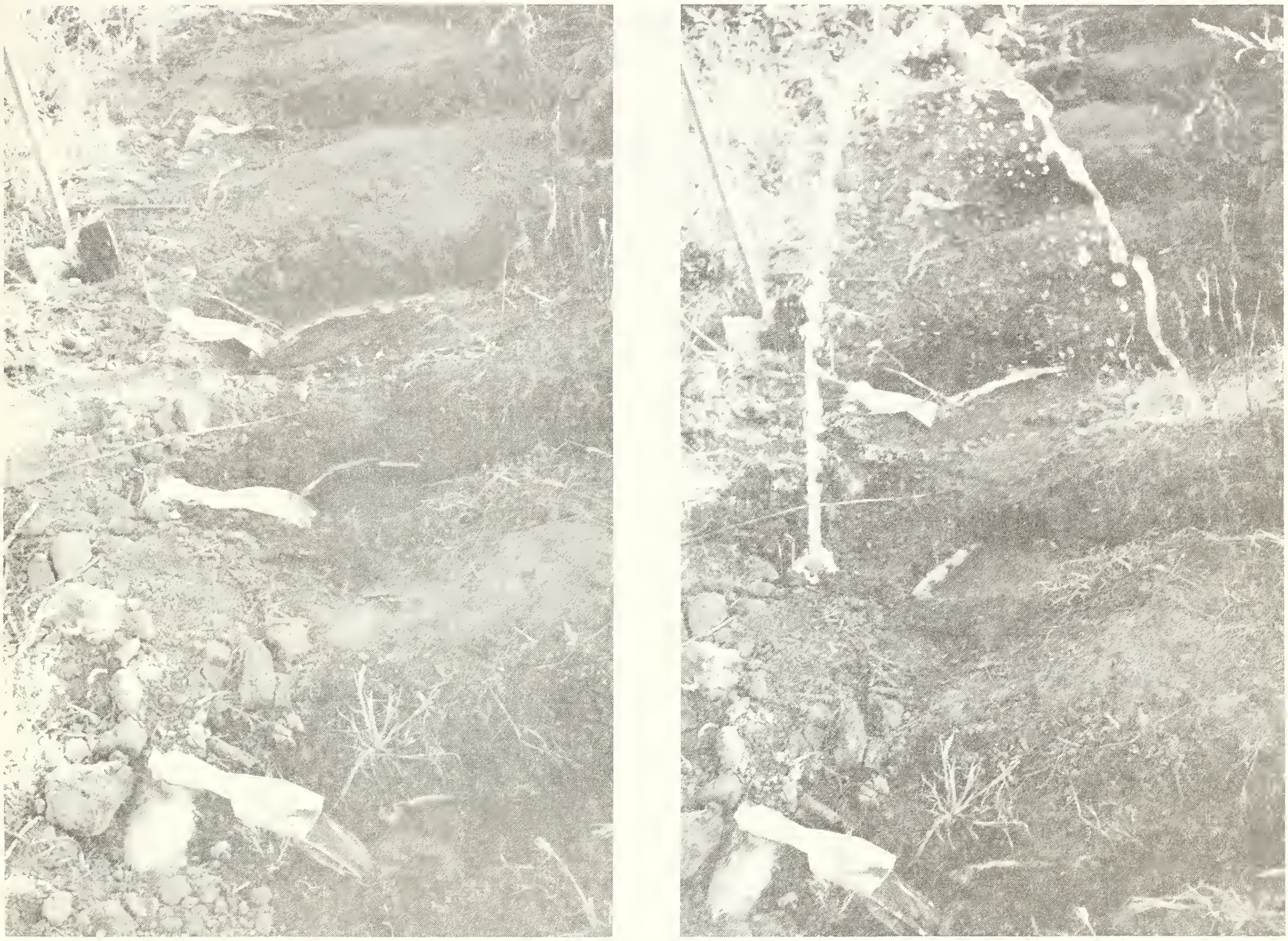


Figure 16.--Outlets in a high pressure section of the Kemper installation, with and without energy dissipators.

The furrow flow rate will normally be set to advance water across the field within a given period of time, usually no more than 30 percent of the irrigation set time to achieve acceptable application uniformities. The advance time is easy to measure with the constantly moving set of a cablegation system by counting the number of furrows behind the plug in which the water has not yet reached the tail. This number, multiplied by the time for the plug to advance one furrow, will give the advance time for the water to reach the tail. If the advance is too fast, which may result in high runoff, or too slow, which will result in poor uniformities, the remaining outlets can be adjusted accordingly. Also, since runoff from a cablegation system is constant (assuming equal row lengths), runoff can be measured anytime during an irrigation to help determine if furrow supply rates are too high or low. Whenever outlet sizes are changed, the set width will also change so the plug speed will have to be adjusted to maintain constant set times.

Varying Total Supply Rate

As more experience is gained with cablegation systems, it becomes apparent that some changes in water-intake rates can often be handled without changing outlet size. For example, in the Craig installation two adjacent 40-acre fields are served by cablegation lines as indicated in appendix J, figure 93. During his first irrigation following tillage when infiltration rates are high, Craig irrigates these fields consecutively with all the water going to one field at a time. During later irrigations when infiltration rates have decreased, he irrigates both fields concurrently by using a plug in the line servicing the first field which bypasses half the water to the second field. This decreases initial furrow supply rates to about 70 percent of their previous values and decreases the time water is in the furrows to about 70 percent of that during the first irrigation. This and other means of adjusting total supply rate, can often accommodate moderate intake-rate changes without adjustment of several hundred outlets.

Surge Irrigation

The field with increasing row length indicated in appendix J, figure 74, had been plowed out of alfalfa shortly before its first irrigation with the cablegation system. The infiltration rate was high, and by the time the plug had reached the middle of the line serving this field, water was not reaching the ends of the furrows. Having heard of the potential of surge irrigation for decreasing intake rates, the operators provided one surge by increasing the plug velocity to a maximum which left water in each furrow for about 4 hours and wetted about 70 percent of the length of the furrows. Then the plug was brought back to the inlet box, attached to the line again, hand-reeled down to the midpoint of the field, attached to the control system, and allowed to proceed slowly so water was applied to each furrow for about 16 hours. Water reached the ends of all furrows within 3 hours, and satisfactory irrigation was achieved. Intermittent supply of this type, commonly called surge irrigation (Bishop et al. 1981), can often effectively reduce high intake rates during the first irrigation following plowing and other methods of cultivation. Means for providing surge irrigation without recycling the plug are discussed in appendix I along with other possibilities for modifying infiltration rates to match outlet flow rates.

Wheel Compaction of Furrows

One installation served a field where two-thirds of the watered furrows were in wheel tracks and one-third were not. During the initial irrigation, wheel-tracked furrows required water-supply rates only 60 percent as large as the nontracked furrows to wet the whole length of the furrow. This ratio is near the average difference encountered in infiltration between wheel-tracked furrows and nontracked furrows (Kemper et al. 1982.) Considerable savings of water were achieved by adjusting outlets and by reducing supply rates to wheel-tracked furrows. However, the wheel-tracked furrows absorbed only 60 percent as much water as the others! More uniform irrigation, less deep percolation, and less labor input are achieved if equipment is used that allows all irrigation to be in either wheel-compacted furrows or in nonwheel furrows, avoiding a mixture.

Adjustment of all the outlets to provide increased flow during the first irrigation after planting can often be avoided by irrigating in the wheel-tracked furrows. The coefficient of spatial variation in the infiltration rates of wheel-tracked furrows is generally lower than that in non-wheel-tracked furrows (J.A. Bondurant, unpublished data). Consequently, irrigation in wheel-tracked furrows generally results in more uniform application of water.

The major portion of the furrow erosion which takes place in irrigated fields occurs during the first irrigation following planting when farmers increase their furrow supply rates to match infiltration rates (Berg and Carter 1980). Since erosion rates are about a second-power function of flow rate in the furrow, erosion will generally be significantly reduced if high furrow supply rates are avoided.

Sediment Flushing Outlets

The water supply for the Wilcox system (described in app. J) had an extremely high concentration of coarse sediment. This sediment tended to settle in the pipe as the water approached the plug and its velocity decreased. A sediment dune developed about 30 feet upstream from the plug and followed the plug as it moved down the pipeline. Some of the finer sediment flowed out of the outlets with the water, but a major portion of the coarse material accumulated in the dune in the pipe. The maximum height of the sediment dune in the pipe increased with time until it blocked most of the pipe cross section, forcing water out of the pipe upstream from the dune and reducing pressure and flow immediately above the plug.

This problem was solved by modifying some of the outlets as shown in figure 17. These "underslung" outlets were attached

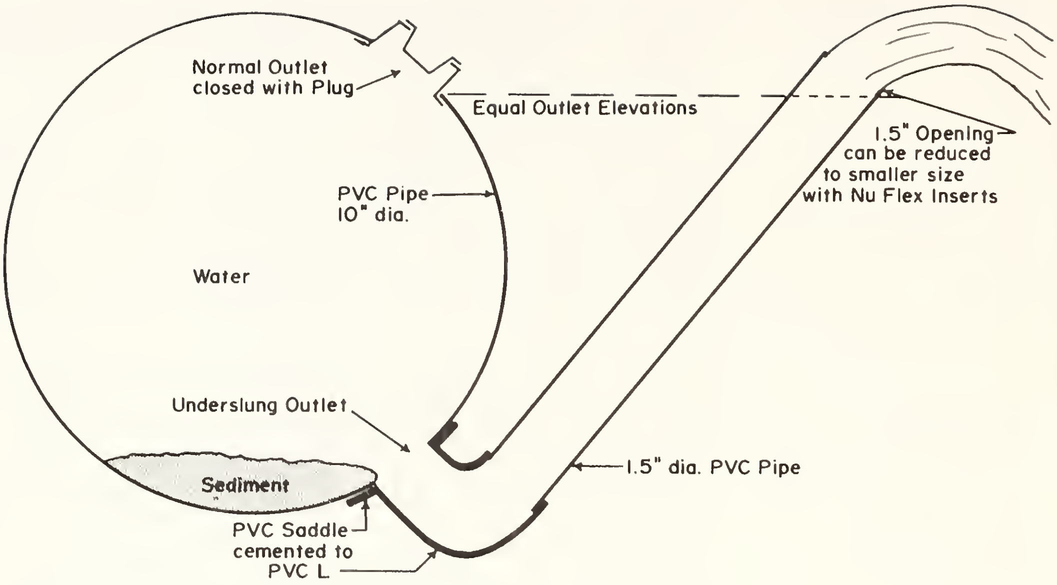


Figure 17.--Underslung outlet for removing sediment from pipe.

near the bottom of the pipe at 60-foot intervals along its length. They ejected the sediment that was collecting in the bottom of the pipe before it built up sufficiently to restrict the flow. The sediment was carried up through the riser sections and discharged into the furrow. Calculations indicated that if the sediment ejected through each of these underslung outlets was spread over 100 feet of furrow during five irrigations, the deposition would not fill them and cause the water to overflow. However, they should be checked occasionally. Construction and periodic cleanout of a sedimentation pond on the water supply of this system would also have solved this problem. In the Wilcox system, there was no satisfactory site for a sedimentation pond.

Pipe Size Transition Structure

In one system, slope of the pipeline increased from 0.004 to 0.022 at a point about halfway along the pipe. It was determined that the pipe size could be reduced from 8 to 6 inches diameter in the 0.022 slope section and still carry the design flow without being filled. This reduced the cost of the system, and the added friction loss in the smaller pipe helped reduce head in the pipe, which was more than desired near the plug. The change in pipe size was accomplished with a concrete transition structure and a special "duo-plug".

Details of the transition structure are shown in appendix J, figure 79. The top of the structure should be at an elevation that provides about 6 inches of freeboard above the level of the head expected in the pipe.

As shown in figure 18, the duo-plug is two plugs in a piggyback configuration. The plug that will move down the 6-inch-diameter pipe is attached to the cable after the cable has been passed through the 4-inch hole in a larger 8-inch-diameter plug. As this assembly moves through the 8-inch pipe, the 6-inch plug protrudes ahead of the 8-inch-diameter plug and they are held tightly together by water pressure and the cable, sealing the hole in the larger plug. As the plug assembly moves into the transition structure, the large plug stops when it reaches the 8- by 6-inch reducer, but the 6-inch plug moves into the 6-inch pipe. About 20 inches of head loss would be required to push the full water supply through the 4-inch hole in the 8-inch plug. That amount of head loss could not be tolerated. The perforations in the two pipes shown in appendix J, figure 79 allow sufficient bypass of this constriction so the head loss in the transition is only about 6 inches when the full flow rate is occurring. At the end of the irrigation, the 6-inch plug is untied, and the cable is reeled up through the 8-inch plug. An opening provided in the 8-inch diameter pipe in the transition structure permits removal of the 8-inch plug after the line has been reeled in.

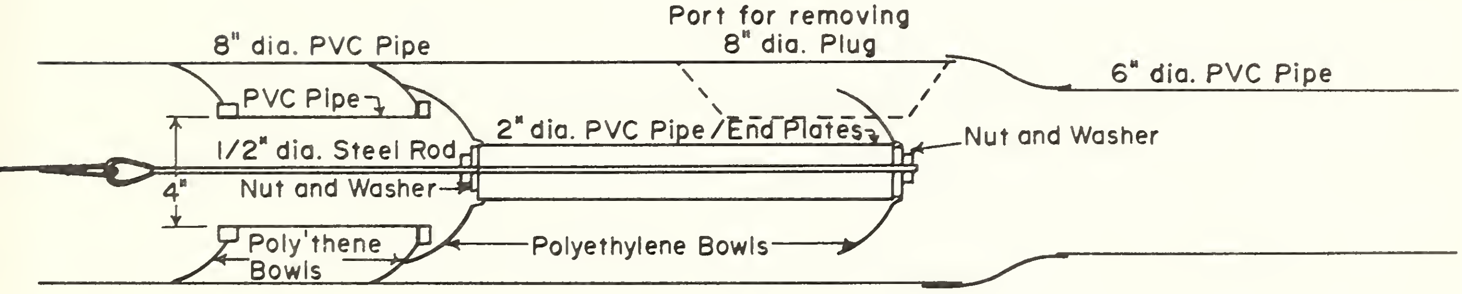


Figure 18.--Duo-plug for handling transition from 8-inch diameter to 6-inch diameter pipelines.

Flow Pattern Deviations at the Ends of the Line and Means for Minimizing Them

The Problem

Most delivery systems are designed to provide a fixed rate of water supply, with full flow beginning at a specific time. Cablegation systems are generally designed to accept this flow rate when the plug is in the central portion of the line. If the supply comes in this manner and the plug is positioned near the inlet, the few flowing outlets will not carry the whole flow and the water level will rise in the inlet structure until it overtops. Or, if the supply level is lower than the top of the inlet structure, water level in the structure will rise to the supply level and supply rate will decrease. If the plug is positioned a distance down the line equal to about two-thirds of the length of the line from which outlets are normally flowing, flow rates from holes between the plug and the inlet structure will be higher than flow rates that occur when the plug is in sections of the pipe where a normal flow pattern develops. This is shown at the left of figure 19(left top). If the plug is set in motion when the water supply starts, the flow rates will proceed in the manner shown in figure 19(left top). The amounts of water delivered through the outlets are proportional to the areas under the respective curves. The row served by the top-end outlets will be short of water.

If the normal time for which water is delivered from an outlet is T and the plug is held at the two-thirds full set position until T/2 and is then allowed to begin moving, the flow patterns of the outlet at the initial plug position and the top end are as shown in figure 19(right top). The outlet at the initial plug position provides more than adequate water for its furrow, while the furrow drawing from the top end outlet may still be slightly short.

The amounts of water delivered by the outlets can be equalized by changing the areas of the outlets as indicated in figure 19(left bottom). However, it is not possible to make the flow times equal by adjustment of outlet size. Generally, increasing outlet size and flow rates will only partially compensate for shorter flow times.

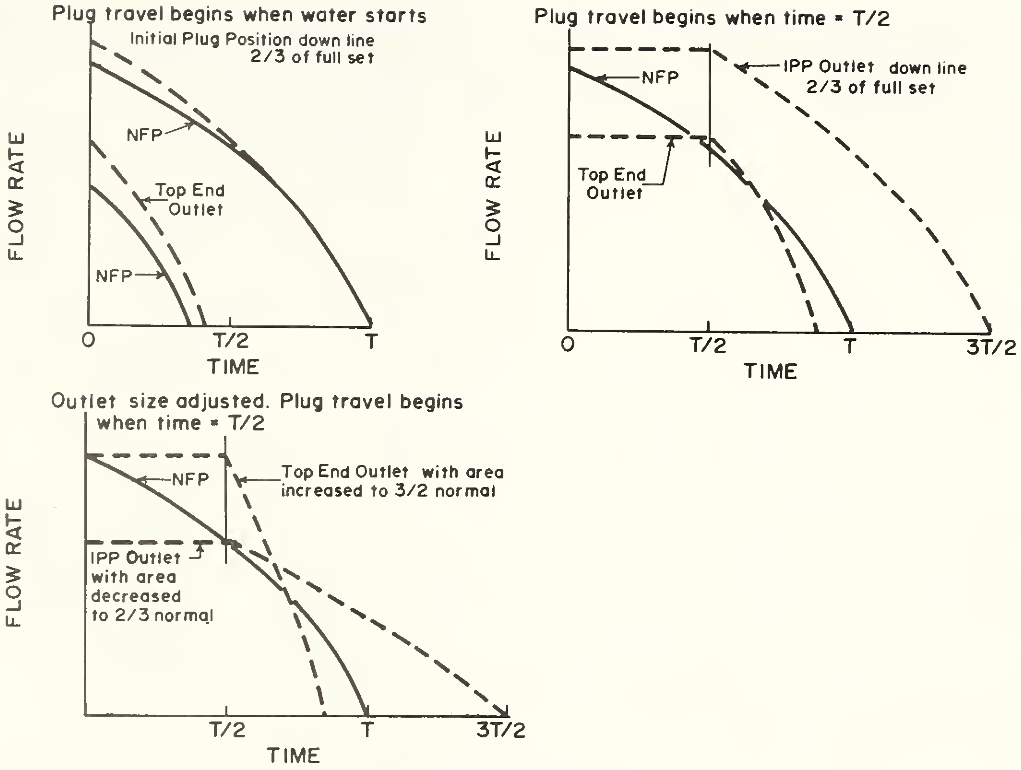


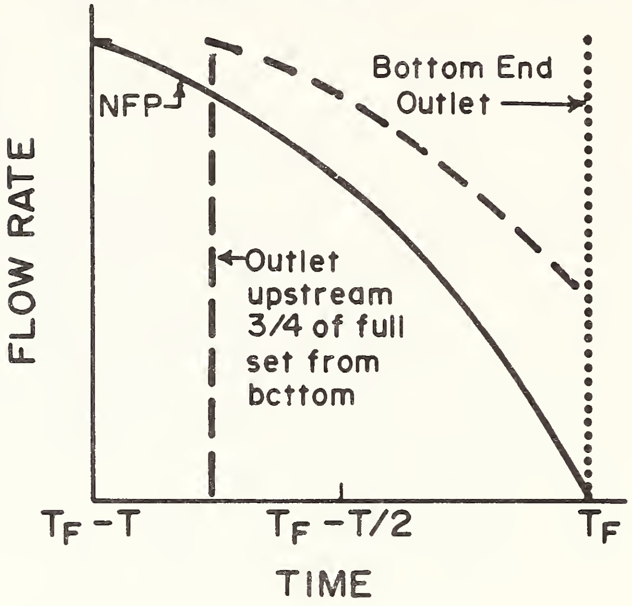
Figure 19.--Flow pattern deviations at top end.

Deviations from the normal flow pattern also occur at the lower end of a cablegation line. If the water is turned off when the plug reaches the lower end, the bottom end outlet will deliver practically no water to the last furrow, as shown in figure 20(top). Outlets three-fourths of the way up the line will deliver water for the time of 3T/4. Allowing the water to continue flowing for 3T/4 while the plug remains at the end of the line results in flow patterns shown in figure 20(bottom). Such patterns are obviously not the same as the normal flow patterns. They may be adequate for some irrigations, but if the normal flow pattern is near the ideal, these patterns of water delivery to the orifices near the ends of the pipe are less desirable. Consequently, the following means have been developed to provide more normal flow patterns to the end sections.

Transfer Systems

A transfer system is used to gradually transfer the water supply from a higher to a lower field (e.g., see app. J, fig. 98). This system provides flow patterns to furrows at the bottom end of the topline and top end of the bottom line which are equivalent in timing and flow rates to those provided to furrows served by the central sections. The system is composed of a concrete basin connected to the inlet structure for the higher field with a short section of pipe.

Flow stopped when plug reaches bottom end. Time T



Flow continued, with plug at bottom end till time = $T_F + 3T/4$

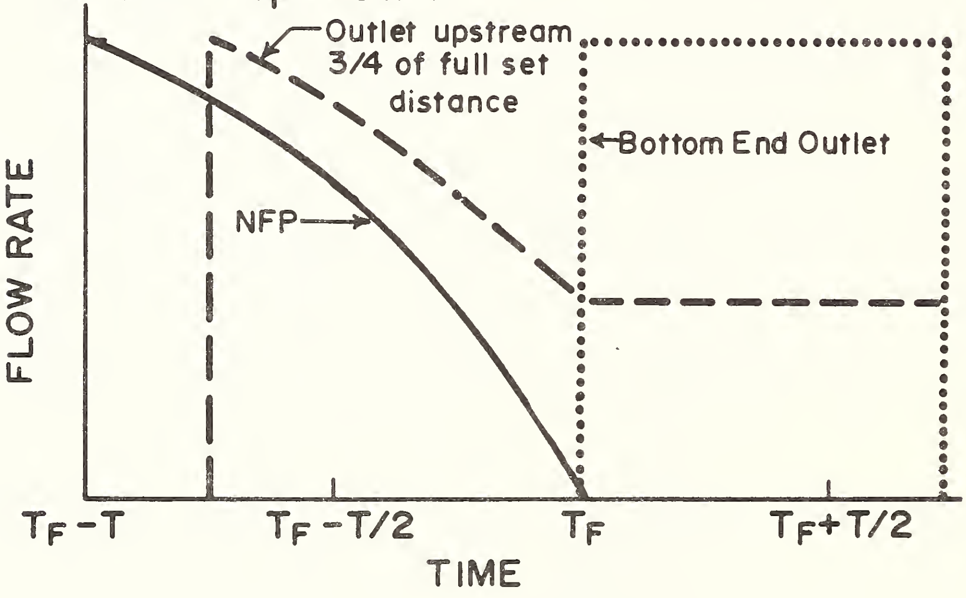


Figure 20.--Flow pattern deviations at bottom end.

Pipe connects the inlet structure to the basin and extends 3 or 4 feet into the basin. The portion of pipe which extends about 3 feet into the basin is extensively perforated. The pipe is situated in the inlet structure with its top a few inches below the bottom of the cablegation pipe serving the upper field so that when the entire flow is going to the low-elevation field, the water surface in the inlet structure will be at least 1 inch below the bottom of the cablegation pipe that serves the upper field. The inlet may have to be streamlined to achieve this.

The perforations in the transfer pipe are spaced and sized so that, as a slow-moving plug comes through this section, the flow will be released to the lower field at the desired rate. This plug remains stationary in the pipe section between the inlet structure and the transfer structure until the plug in the cablegation pipeline for the upper field nears the end of that line where it will come up against a pin which keeps it in the pipe. As the main cablegation plug nears the end of the line, the operator measures the distance the plug has left to travel, and knowing the ratio of travel and speeds of the cables controlling the cablegation plug and the transfer plug, positions the transfer plug in the pipe between the inlet and basin structures. The operator releases the brake and the reel controlling the transfer plug, reels the plug to the desired position and swivels the drive shaft on the transfer controller into a connector with the shaft on the main reel. Both reels then turn, and the transfer plug begins passing perforations and releasing water to the lower field just as the cablegation plug reaches the end of its pipe. As the reel continues to turn, it gradually transfers the water from the upper pipeline to the lower field. A pin through the cablegation pipeline stops the main plug at the end of that line, and these end rows are irrigated with a continuously decreasing supply similar to that experienced by rows fed from outlets in the midsections of the line. The lower field is also equipped with a cablegation system. As the water enters the inlet structure of this system, a float switch actuates its cable reel and the plug begins to move slowly down the line in response to the water pressure. The transfer system continues to deliver more of the flow to this lower line until it is taking all the flow. The rate of movement of the transfer plug is set so transfer of water between the upper and lower cablegation lines takes a time equal to that for which water is provided to a furrow during that irrigation. A 1.5-inch overflow pipeline connects the lower field's inlet structure to a point below the initial stationary position of the plug in the lower pipeline. This allows water to drain out of this structure if there is leakage past the transfer plug and thereby prevents premature activation of the reel via the float switch. When the plug in the lower cablegation line begins to move, it quickly passes the point where this water comes back into the cablegation line.

Bypass Systems

A cablegation system can be equipped with a bypass pipeline at the top end (fig. 21) to provide improved flow patterns at the ends of the lines. The inlet structure is made as indicated at the top of figure 21. The lower end of the main line is closed with a plug or cap. The bypass pipe runs parallel to the main pipe for a distance corresponding to the length of pipe that will be delivering water to the field when the first outlet has ceased running. The bypass pipe is connected to the main pipe with a wye fitting. The intake to the bypass line at the inlet structure is designed so the initial hydraulic head on the first outlets in the line will be about the same as on outlets in the midsection and so the main pipe can take all flow away from the bypass line when the main line is at maximum flow.

The system is started with the plug at the upper end of the main line and the total flow going into the bypass line. This flow goes to the lower end of the main line and starts irrigation at that part of the field. As the plug moves, it starts flow from the outlets at the upper end of the main line, and the flow in the bypass line decreases. As the plug progresses, more of the water flows into the main line at the top end, and the water supply through the bypass to furrows at the lower end of the main line tapers off. Finally, all the flow goes directly into the main line, and irrigation ceases at the far end of the line until the plug gets there to apply more water. When the moving

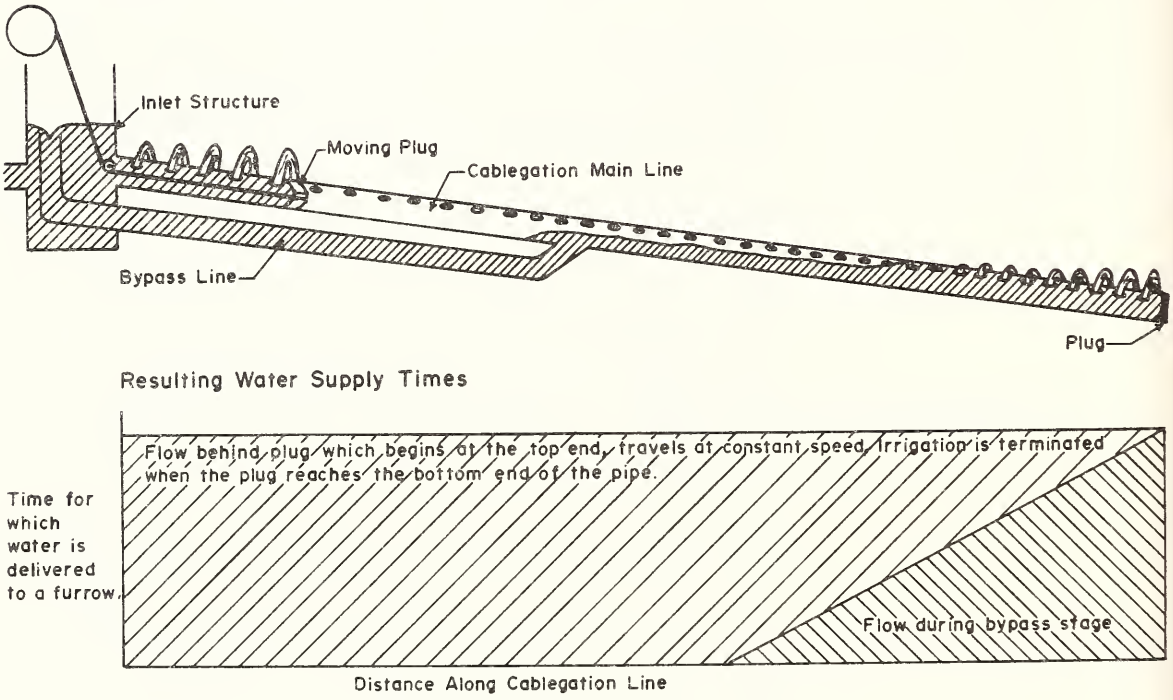


Figure 21.--Bypass pipeline to reduce flow pattern deviations at top and bottom ends of the cablegation lines.

plug reaches the end of the line, each outlet has had water supplied to it for the same length of time, and irrigation is complete. No water is lost from the end of this system, and more uniform distribution is achieved. This concept was first tested at the installation on the University of Idaho Experiment Station, Kimberly, Idaho. The water applications at the top and bottom ends were near, but not identical to that in the middle sections of the pipe. Subsequent installations involving bypass systems have utilized weirs designed by the computer program discussed in detail in appendix D (Bypass Weir and Pipe Method) and by Kincaid and Kemper (1983). These weir sizes provide practically equal flows to all outlets from the pipe.

The main cost of this bypass method is the cost of the bypass pipe, which can be appreciable. Plugs have been designed and are being tested (appendix D, Bypass Weir and Pipe Method) which allow complete initial bypass of the water and close gradually as they move down the line. Their rate of closure can be regulated. These plugs may be able to achieve the bypass function and improved application uniformity at less cost than the bypass pipeline.

Multiple Plugs for Controlling Water and Dissipating its Energy

The concept of multiple plugs attached to the cable is described under "Furrow Supply Rate Modification" (see also fig. 8). The effects of diameter of the holes through the upstream plugs and the distance between the plugs can be tested and optimized by the computer model.

One use of this multiple-plug concept is incorporated in Don Craig's system (app. J) which allows him to irrigate two equal-size fields simultaneously by using a flow-through plug. A plug controller is used for each field. All of the water is delivered to the cablegation line serving the upper field, but the plug in the upper cablegation line has a hole through it which allows half of the water to pass through to the lower field. The cablegation line on the second field is equipped with a regular plug. This allows irrigation of both fields at the same time, using initial furrow supply rates which are considerably lower than when the full supply is delivered to one field. Craig generally uses full supply to a single field for the first irrigation of the season when infiltration rates are high.

Further discussion of energy dissipation by plugs inside the pipe is included in appendix G.

Flow Adjustment to Handle Problem Furrows (for the Fastidious Irrigator)

Furrows with high infiltration rates, sediment deposits or rodent burrows below them can be difficult to wet to the end with any system. The best solution is to eliminate such problems by rodent control, uniform tillage, and compaction, and proper stream sizing to control erosion. However, when such problems exist, they can be located and remedied to get the water to the end of the row.

If the fact that water is not getting through the furrow is recognized early when most of the outlets flowing water are still above the furrow in question, widening the outlets serving it can provide a higher flow rate and get the water to the end of the furrow. Adjustable outlets which allow such flow adjustment are discussed in appendix F.

If the plug has passed downstream sufficiently far that the water is no longer running out of the outlet and the irrigator wants to get water into the furrow, there are still a couple of options. If the level of water in the pipe is higher than it is in the adjacent soil, a siphon tube inserted into the pipe through an outlet can bring a flow to the furrow needing water.

Directing the entrance end of the siphon tube in an upstream direction will also help push water through the tube. This force becomes appreciable when the velocity of water in the pipe is high. The equivalent head, H, is approximately equal to $V^2/2g$ where g, the acceleration of gravity, is equal to 32.2; V is the velocity of the water in the pipe in feet per second; and H is the elevation (in feet) to which water will rise under this pressure.

For instance, in a 6-inch pipe carrying 1 cubic foot of water per second on 1.4 percent slope, the average velocity of the water was about 5.1 feet per second and directing the opening of the siphon tube upstream provided a head of about 0.4 feet. This was somewhat dependent upon whether the open end of the siphon tube was in the middle of the pipe where the water velocity was highest or near the perimeter of the pipe where it was lowest. If supply from one tube is not sufficient, flow from two siphons inserted in adjacent outlets can be directed into the needy furrow.

If several adjacent furrows have not had sufficient water and the pipe is flowing near its full capacity, the outlets serving rows needing more water can be opened wide. Then the next lower hole can be opened, and a piece of wood lath or strip of wood or metal approximately equal to the inner diameter of the hole in the pipe can be inserted through that hole at a slight vertical angle so it will remain in position. This is often a sufficient impedence to the waterflow to raise the level in the pipe and start the water flowing from the opened holes at the desired rates. If water is not desired in some of the furrows above that point, it may be necessary to close some of them since the effects of the impedence often extends some distance along the pipe.

If the pipe is not running near capacity, more obstruction may be needed to build head at that point to where water will be forced out of the holes. Two methods have been used to do this. Three strips of wood or metal about one-eighth inch thick, with width slightly less than the outlet diameter, can be bolted together at a distance from their ends which is about 20 percent greater than the diameter of the pipe. This "fan dam" can be inserted in the pipe to where the strips are bolted together, with the tips in the pipe pointed upstream. Then the three strips can be "fanned out" inside the pipe by manipulating their ends which are outside the pipe. Additional blockage can be provided by placing a plastic bag on the fan dam before it is inserted in the pipe.

Another method which has been used to create the desired obstruction in the pipeline is to insert a deflated heavy duty rubber balloon (or light weight rubber beach ball) through the outlet below the rows to be served. Air was blown into the balloon until the desired obstruction and flow rate of water was obtained. The balloons were held in place by either closing the gate on their stems, or by tying their stems with string to a stick outside the outlet.

Cablegation Systems to Irrigated Diked Strips

Cablegation systems can be designed to automatically apply water to fields divided into strips of land between soil dikes. An example of this type of system was installed on the LeBeau farm (app. J, fig. 88). This installation involved pipes midway down fields. The pipes were buried 30 inches below the surface so farming operations could take place over them. Risers in the dikes provided outlets for the water to the adjacent strips. It is not necessary that the pipe be on grade. However, the openings at the top of the risers must be on grade so that as the plug passes each successive riser, the water in that riser begins to flow, and flow decreases from the outlet(s) immediately upstream. The pressure on plugs in buried cablegation lines is often 3 or 4 times greater than when the lines are on the surface. Consequently, stronger plugs, cables, and controllers are needed on buried lines. For details of this system see the Calvin LeBeau system, appendix J.

Irrigating land in diked strips allows water to be applied quickly so that intake opportunity times on the top and bottom ends of the strips are not too different. Diked strip irrigation can provide the most uniform surface irrigation for highly permeable soils. However, concentrating the water on one or two strips of land for relatively short periods of time requires changing sets every hour or two. Such frequent changes are labor consuming in nonautomated systems but are easily accommodated with a cablegation system.

Crops such as small grains and alfalfa are well suited to diked strip irrigation. When such crops are the only ones grown, one riser per diked strip (or one riser per two strips as planned on the LeBeau farm) can be sufficient to distribute the water from an underground cablegation line. When such crops are grown in rotation with row crops, an outlet to distribute water to each furrow will generally be needed. Surface cablegation lines at the top of the fields can provide such delivery to each furrow. They can also be modified to provide the concentrated flow to diked strips by cutting large outlets (4- by 10-inch) near the tops of the PVC pipe. Size and number per strip will depend on whether all the water is to be concentrated on one strip or whether reduced flow is to be maintained on the second and possibly the third strips behind the plug.

When furrow irrigated crops are planted again, covers made of 180 degree sections of the same diameter pipe, about three inches longer than the holes, can be placed over the large holes and clamped in position with two strands of tie wire or screw clamps. In case of lines operating at low pressure (less than eight inches), a layer of soil of thickness equal to the expected head, piled on top of the covers, will hold them on.

Modifications to Provide Surge Irrigation

Surge irrigation can be achieved with cablegation systems. In surge irrigation, water is intermittently applied to the furrows in an on/off pattern that tends to reduce the infiltration rate of upper ends of the furrows and gives a more uniform application (Bishop et al. 1981). It is generally most effective on the first irrigation after a cultivation operation.

Appendix I, figure 64 shows one method used to turn the flows on and off as the cablegation plug moved along the pipeline. Details of the construction and use of equipment which accomplished the surging are given in appendix I.

Multiple plugs spaced well apart, with outlets in all but the one farthest downstream, can also be used to achieve surge irrigation (for example, this would work for the system represented in figure 8 if plugs were spaced 20 percent farther apart).

Under some conditions (see, for example app. I and J), where a given supply rate is not sufficient to get water to the ends of furrows, one interruption of the water supply can decrease infiltration rates sufficiently in the section of furrow wetted to allow water to reach the ends of furrows when it is allowed to dry for a few hours and then wetted again. This can be achieved by running the plug through the pipe at its maximum speed and then running it through again at the normal speed.

Capping the End of the Cablegation Line to Conserve Leakage

If the water supply is minimal, or there is no provision for drainage at the end of the pipeline, the lower end of the cablegation pipe can be capped or otherwise sealed to prevent water from passing out of the end of the pipe. Water that leaks past the moving cablegation plug will then be delivered to the last furrow(s). Timing of irrigation and amount of flow per furrow can be regulated by closing outlets near the end of the line from which water is not desired.

ORIGIN AND PURPOSE OF THE APPENDIXES

Under ideal circumstances, the installation and operation of a practical and economic cablegation system is straightforward. When the complications of the real world are introduced, potential installers and users will often benefit from the specific experience and procedures outlined in the appendixes.

Appendixes A through I include procedures and information assembled by the Snake River Conservation Research Center staff, which facilitate cablegation design, installation, and use. Appendix K discusses one of the most recently developed and promising controllers. Appendix J outlines problems encountered and solutions developed in a series of installations and evaluates these. The first installation was on the University of Idaho research farm. The other installations were a series of case history studies designed in cooperation with farmers who have borne the major cost. The purpose of these case histories was to meet the real problems which the system would face and combine the ingenuity of farmers with expertise of the Research Center staff and Soil Conservation Service technicians to solve those problems. Solutions have developed quickly in the course of this cooperative case-history research and have made cablegation a low cost, efficient, practical irrigation system. However, we do not wish to obscure the potential for improving these systems by implying that the solutions obtained to date are best or final.

PLANS FOR CONTINUED COMMUNICATION AND COOPERATION

Annual meetings of users, installers, and manufacturers of cablegation systems and equipment have been scheduled at the Snake River Conservation Research Center each January, beginning in 1982, to present and discuss new findings and potentials for improvement, and how to achieve them.

Proceedings of those meetings will be printed and will constitute an effective update of this handbook, including lists of suppliers and manufacturers of equipment and installers. These proceedings will be available on request from the Snake River Conservation Research Center, Kimberly, Idaho.

APPENDIX A - HEAD LOSS DUE TO FRICTION IN PIPES

Factors Considered in the Williams-Hazen Equation

The size of pipe that will be needed to carry a given flow rate of water is dependent on the slope on which the pipeline will be laid and the friction or hydraulic drag of the water on the pipe. This hydraulic drag becomes larger when viscosity of the fluid increases or the roughness of the pipe surface is larger.

Viscosity of water is affected primarily by its temperature. Its temperature in irrigation systems varies from day to night (e.g., Goel et al. 1982) and also with the season of the year. In temperate climates, an average water temperature of about 60 degrees Fahrenheit is commonly encountered. The viscosity of water at 60 degrees Fahrenheit was used in the following calculations.

The Williams and Hazen equation at this viscosity for head loss, H (in feet of loss per 100 foot of pipe), as a function of the average velocity of water in the pipe, V (in feet per second); the diameter of the pipe, D (in feet); and the roughness coefficient, C, is

$$H=3.02.3(V/C)^{1.852}/D^{1.164}.$$

Head Loss in Pipes

The above equation was used to calculate the values indicated in Figures 22 through 29. Roughness coefficients of 150 and 130 for PVC and aluminum pipe respectively were used as recommended by ASAE Standard S-376.1 and Brater and Kings' Handbook of Hydraulics (1976), respectively.

An example of how to use these figures and information on flow rates and pipe slope to determine the proper pipe size is given on pages 2 and 3 in the section on "Pipe Size and Grade."

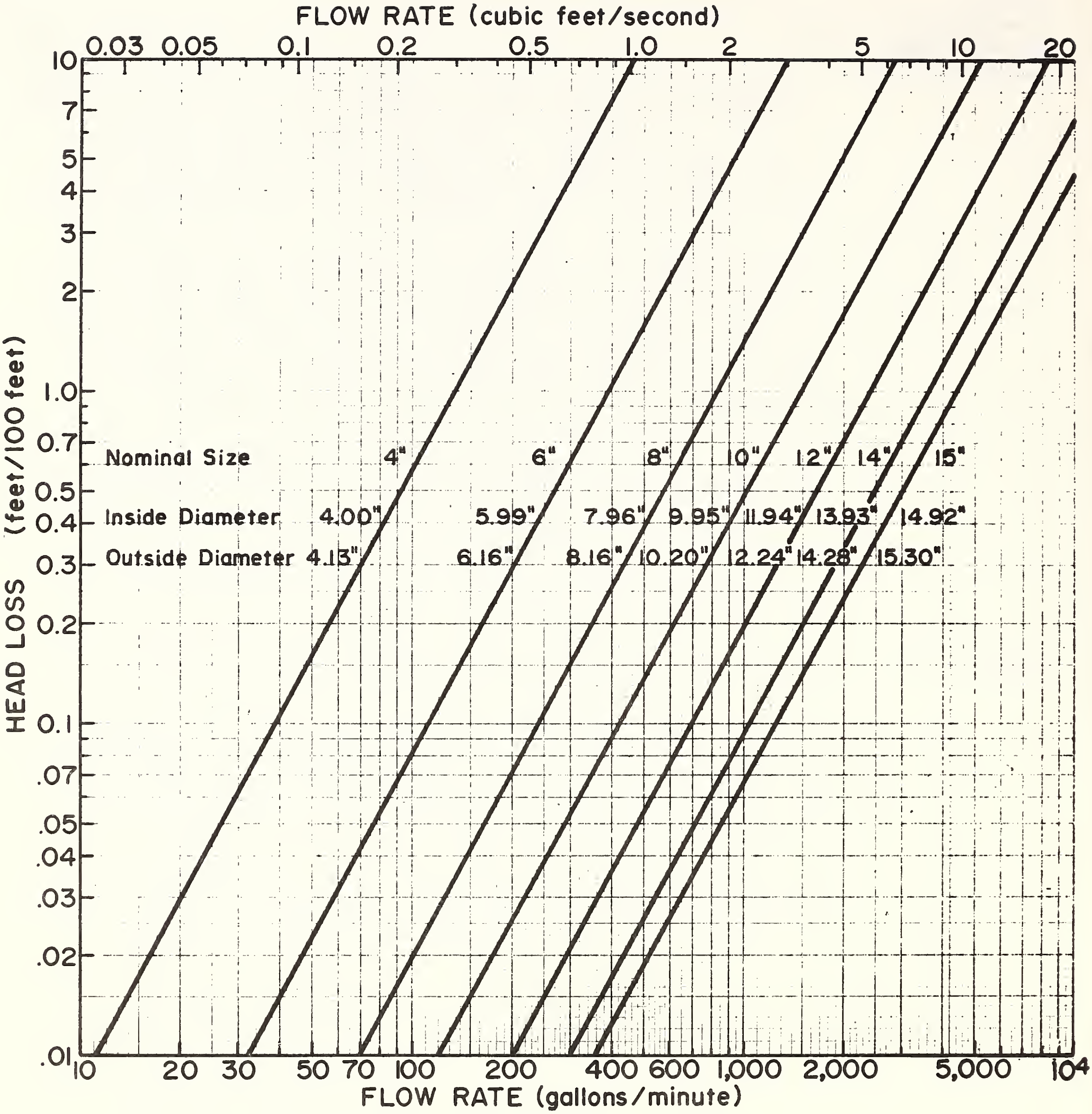


Figure 22.--Head loss due to friction in PIP (plastic irrigation pipe) sizes of PVC pipe 50 lb/in^2 rating, SDR 81, (i.e., Standard Dimension Ratio=diameter of pipe/wall thickness=81).

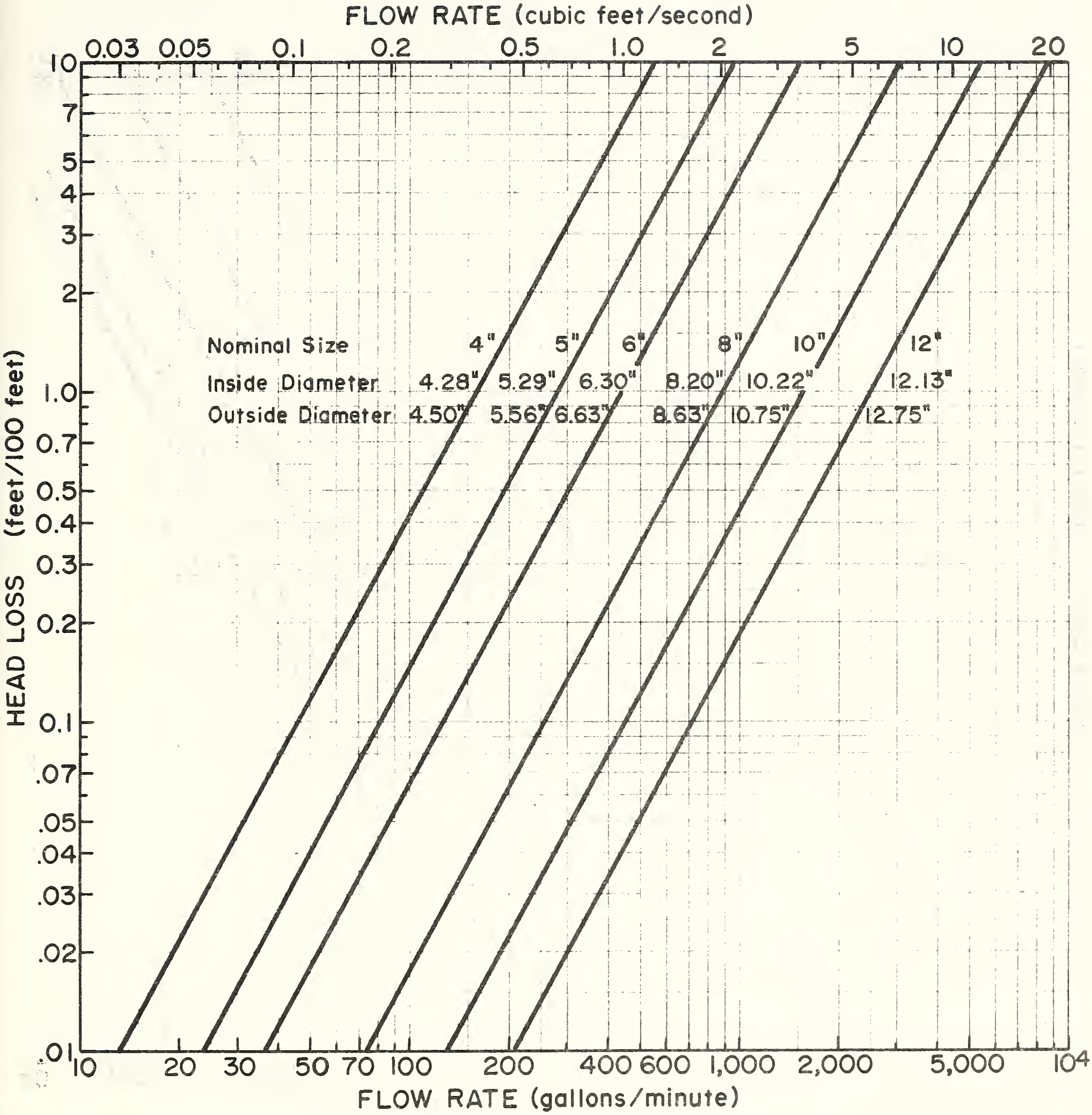


Figure 23.--Head loss due to friction in PIP sizes of PVC pipe, 100 lb/in^2 rating, SDR 41.

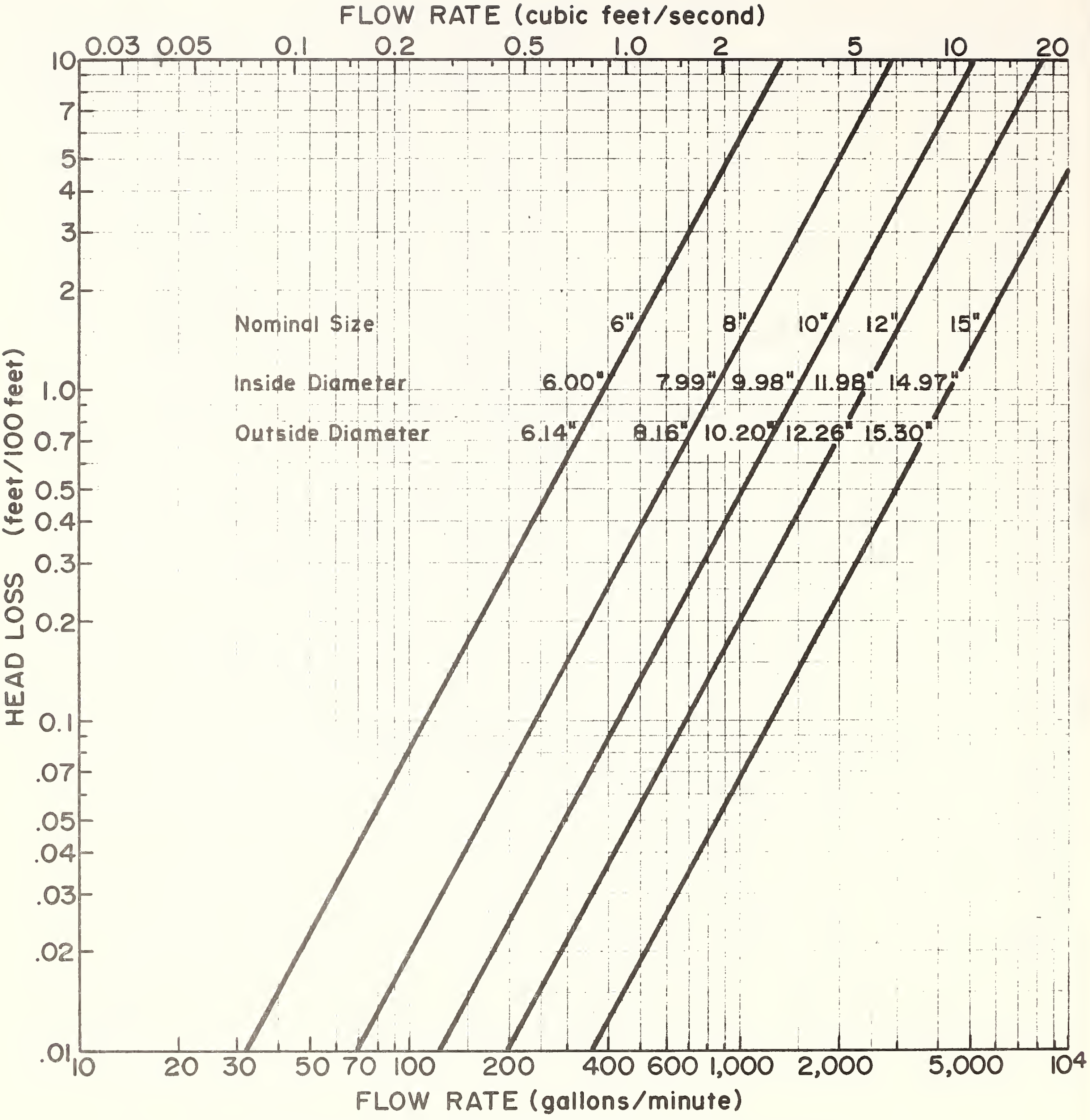


Figure 24.--Head loss due to friction in PIP sizes of PVC pipe, 100 ft head rating=43 lb/in^2 SDR 93.

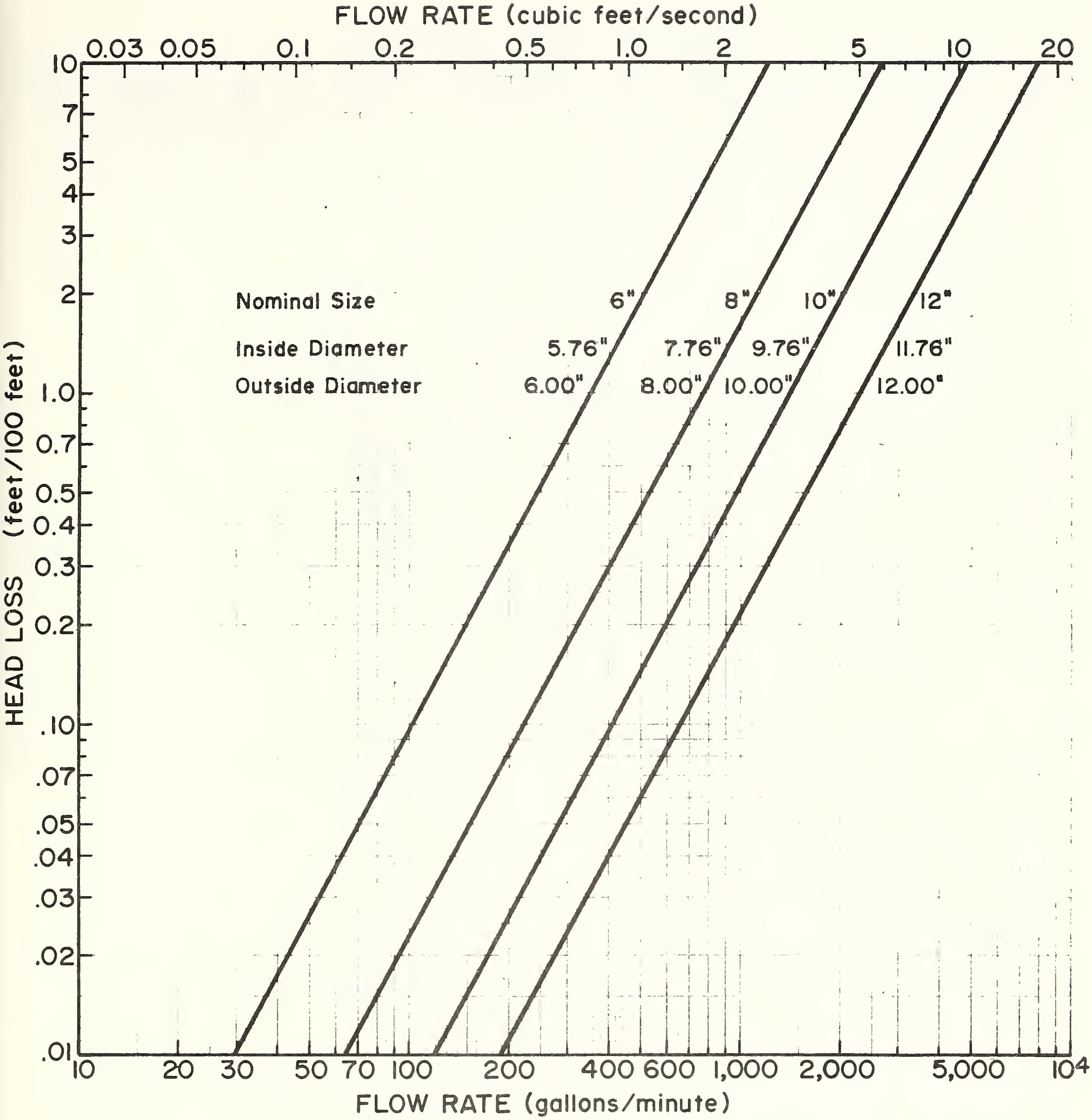


Figure 25.--Head loss due to friction in gated pipe sizes of PVC pipe. This gated pipe size is available with or without holes cut for the gates. Some manufacturers formulate the PVC for this series with metallic oxides which reduce the penetration of solar radiation and help keep exposed pipe from becoming brittle.

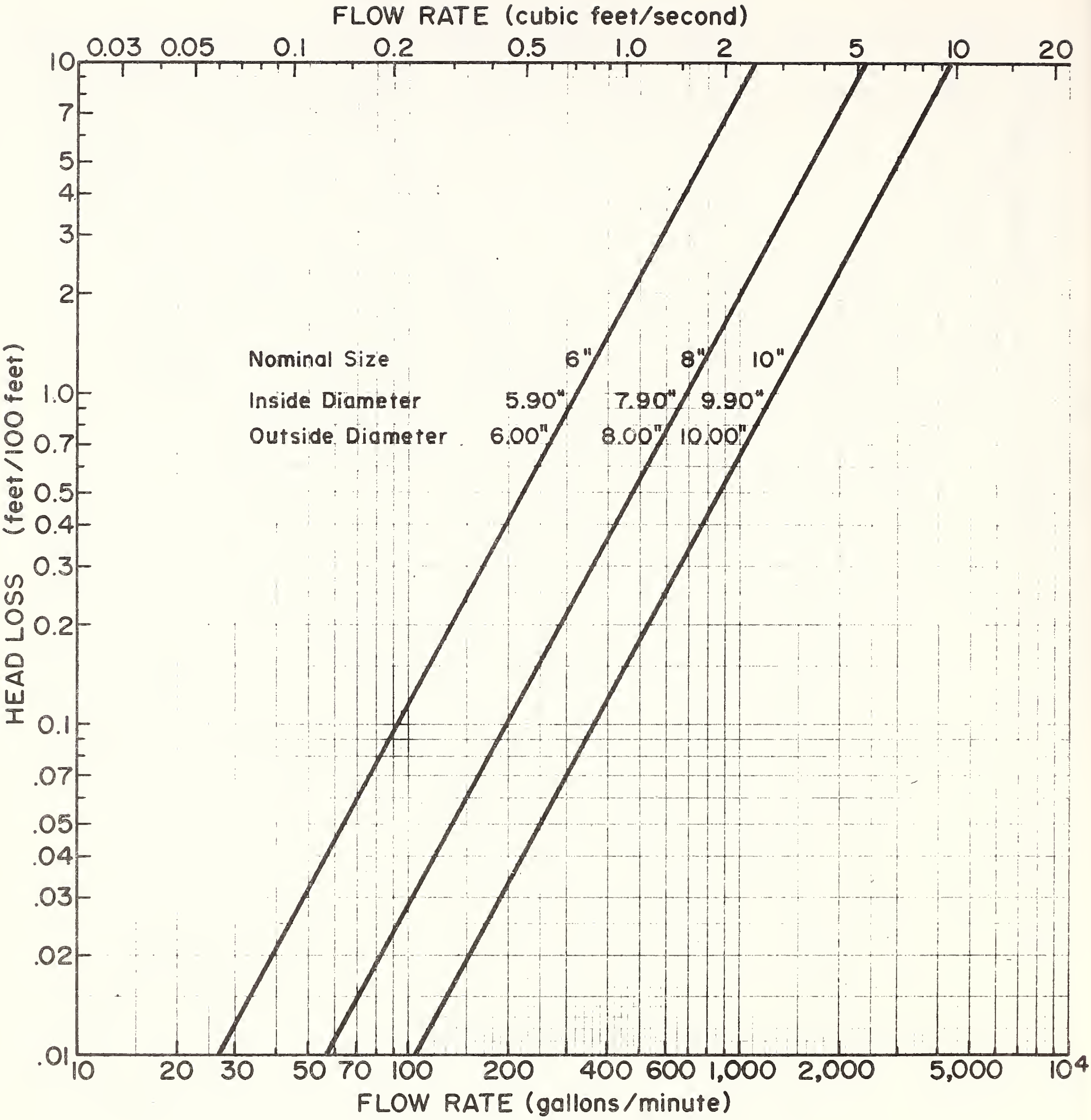


Figure 26.--Head loss due to friction in gated pipe sizes of aluminum pipe. Hazen-Williams friction coefficient, C, assumed to be 130.

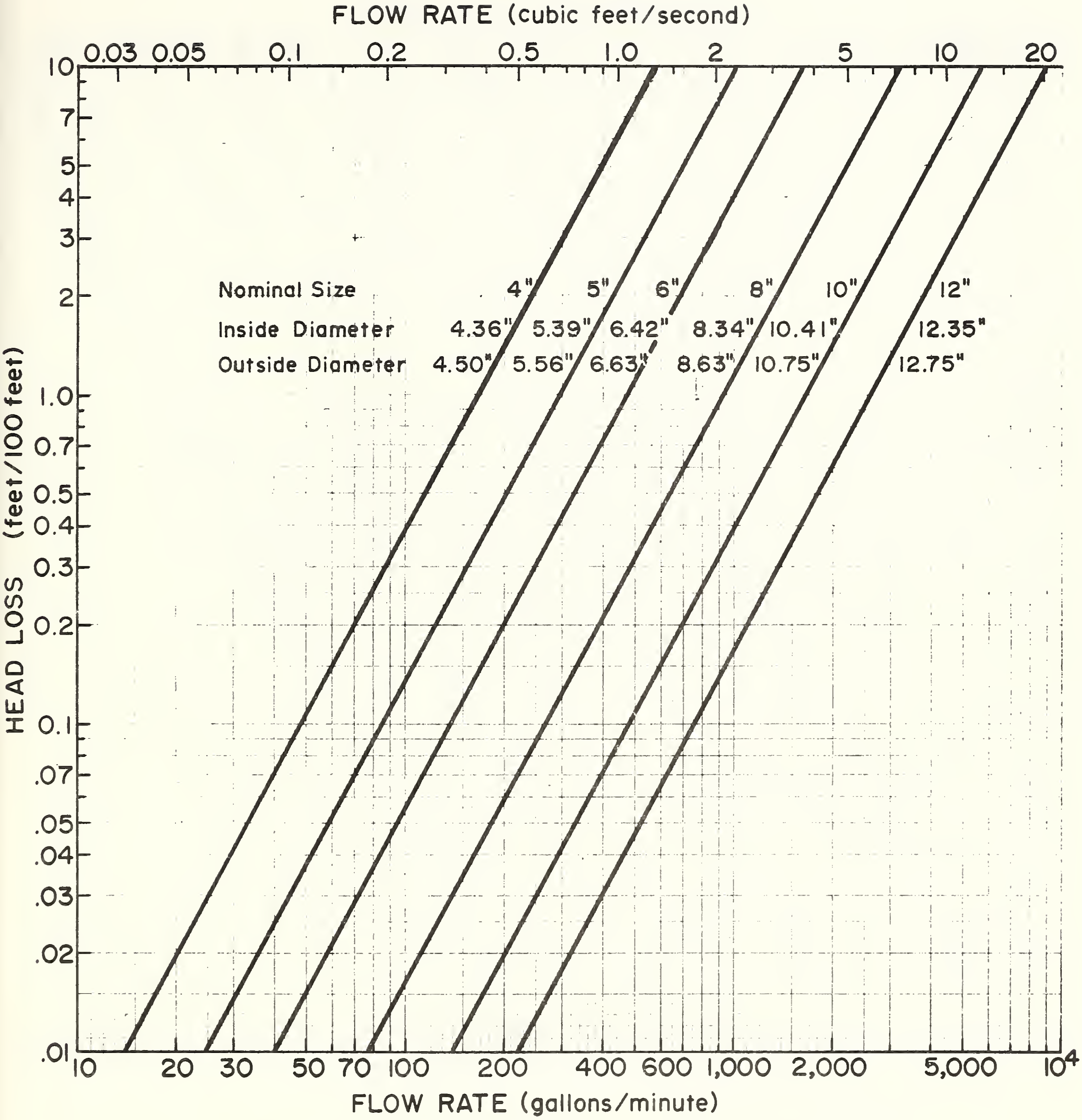


Figure 27.--Head loss due to friction in IPS (iron pipe size) sizes of PVC pipe (63 lb/in^2 rating) SDR 64.

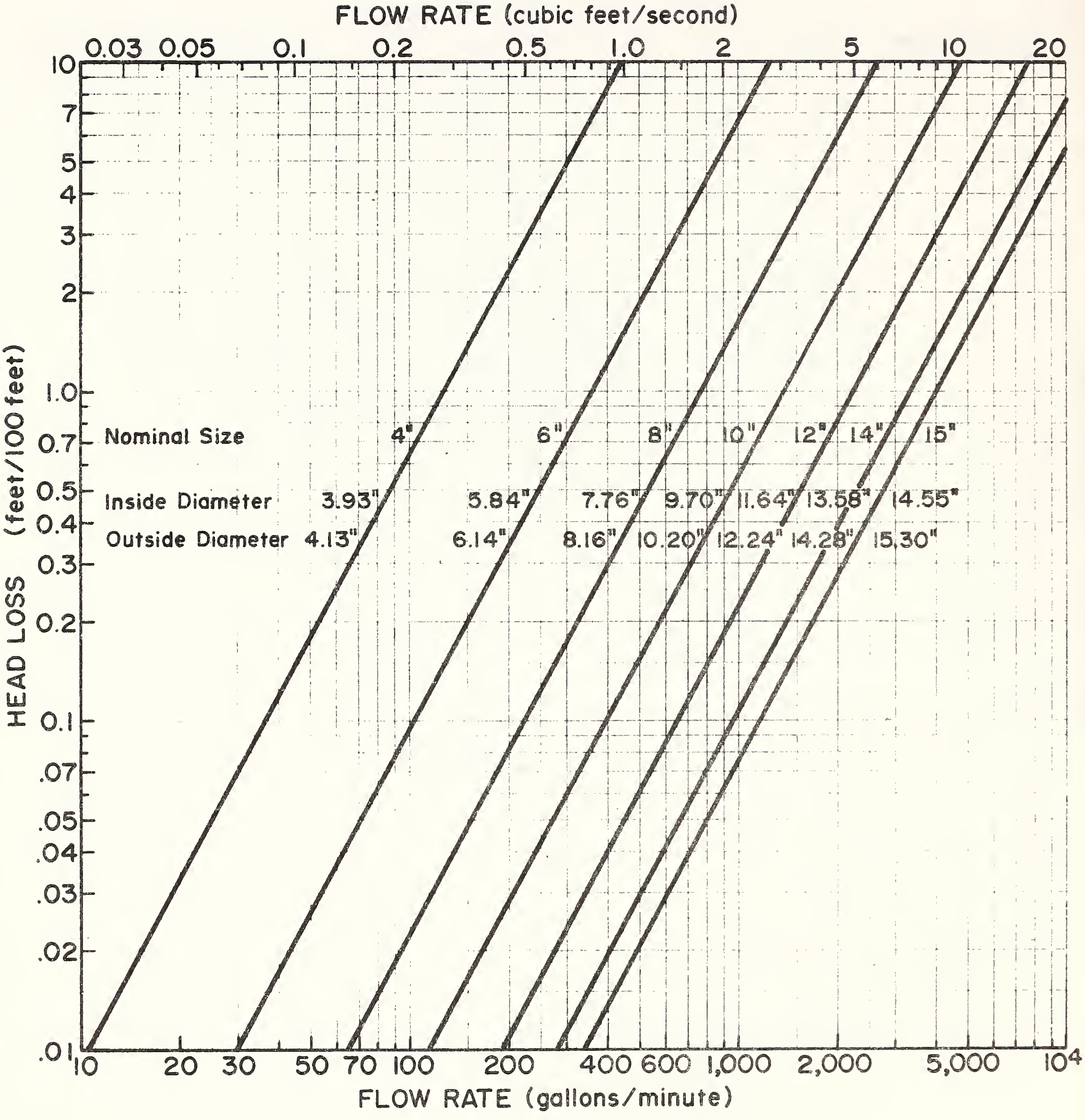


Figure 28.--Head loss due to friction in IPS (iron pipe size) for PVC pipe, 100 lb/in^2 rating, SDR 41.

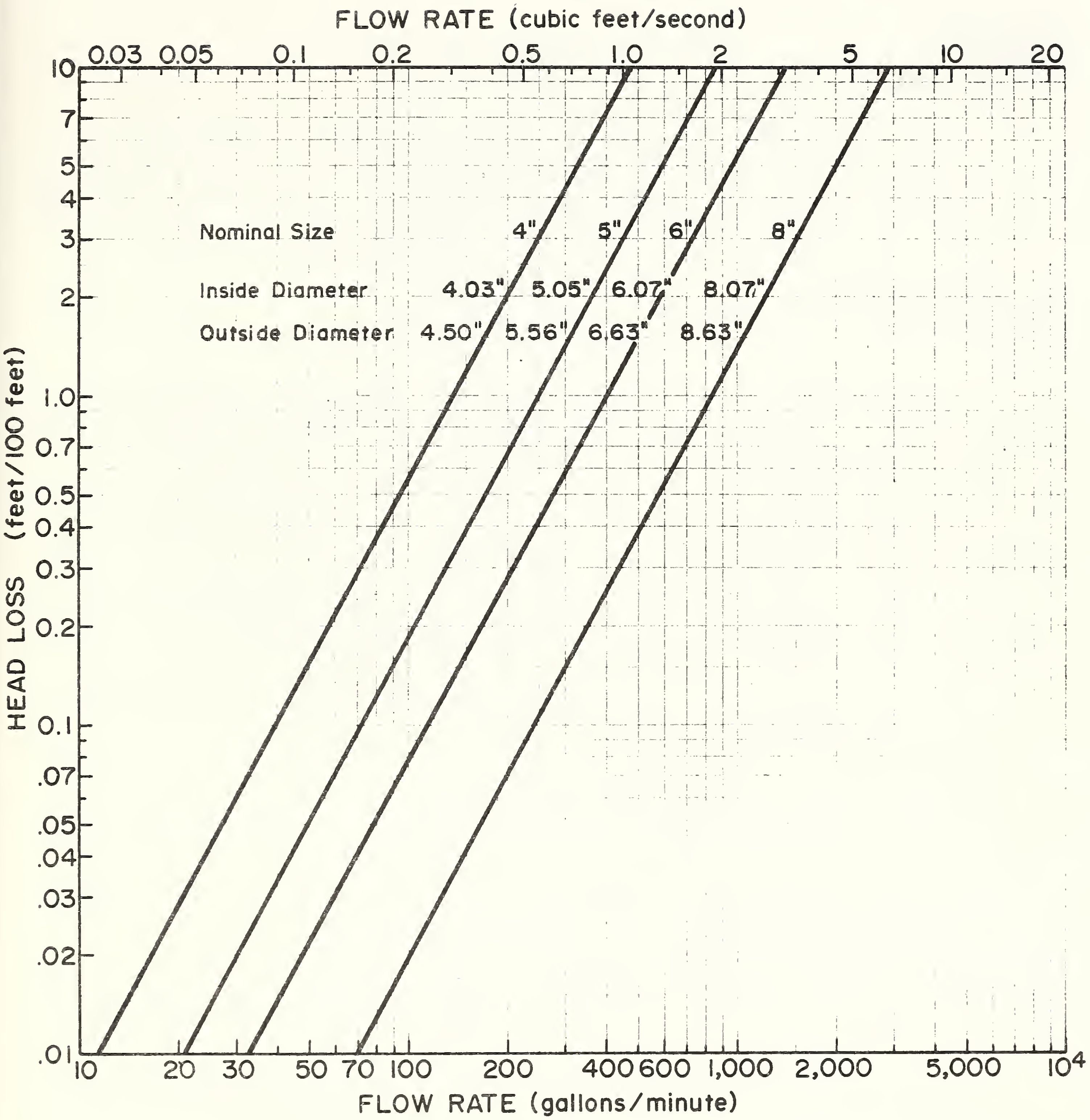


Figure 29.--Head loss due to friction in IPS (iron pipe size) schedule-40 PVC pipe. Pressure rating decreases as diameter increases. Outside diameters same as regular IPS.

Information Needed for Reel Design

The size and shape of the reel are generally determined by (1) the cross sectional area of the cable (A_c); (2) the length of the cablegation line (L_c); (3) the angular speed of the shaft on which the reel is to be mounted (W_r); (4) the desired plug speed (S_p); (5) changes in length (if any) of the rows, and (6) changes in angle (if any) of the pipeline to the furrows.

Designing Reels for Rectangular Fields

In rectangular fields, row length and angle of the pipeline are constant, so the plug speed desired is normally constant. When the angular speed of the shaft is also to be constant for an irrigation, the reel must be designed so the length of an outside wind of cable on the reel is reasonably close to that of an inside wind (the basic reel circumference is $2\pi R_r$) where R_r is the reel radius. Generally, keeping the initial plug speed to no more than 110 percent of the final plug speed is sufficient. This will be achieved with a nonstretching cable if the outside wind of cable has a length no greater than $1.1 \times 2\pi R_r$, or in other words the outside radius of the cable, $R_c=1.1R_r$.

The volume, V_{cs}, of cable supplied on a spool of the type shown in figure 30 is

$$V_{cs}=\pi L_s(R_o^2-R_i^2), \qquad [B-1]$$

and the effective cross sectional area, A_c, of the cable can be estimated as

$$A_c=V_{cs}/L_{cs}, \qquad [B-2]$$

where L_{cs} is the total length of cable on the spool.

For instance, the 36,000 inches of 200-pound test braided Dacron cable of the type used in several of the systems comes in a spool where L_s=7.9 inches, R_i=1.13 inches and R_o=2.60 inches, and consequently, from equation [B-1] the volume of the cable is 136 inches^3; from equation [B-2], its cross-sectional area is 0.00378 inches^2.

If the normal plug speed desired is 125 inches per hour and the normal angular speed of the reel shaft is to be five revolutions per hour, then the reel circumference should be 125/5=25 inches and the reel radius, R_r, is $25/2\pi$=3.98 inches.

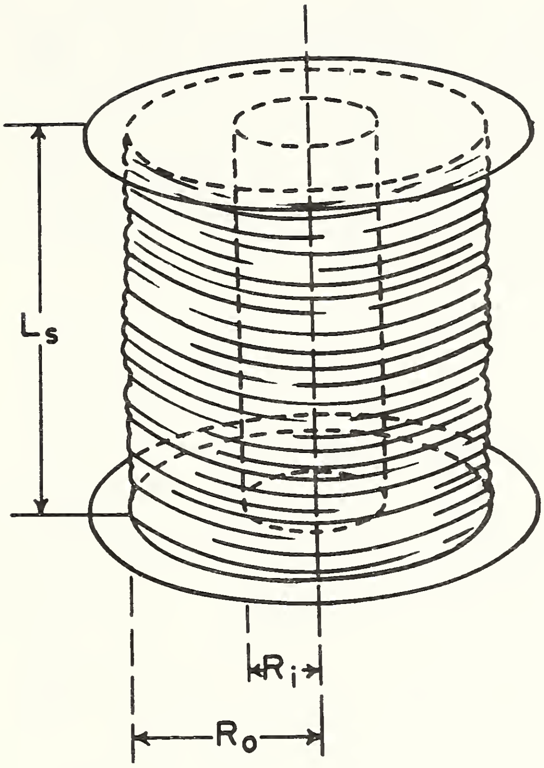


Figure 30.--Definitions of spool dimensions.

The volume of the cable on the reel is

$$V_{cr} = \pi L_r \left(R_c^2 - R_r^2\right). \qquad [B\text{-}3]$$

If the maximum radius of the cable, $R_c = 1.1\ R_r$, then,

$$V_{cr} = 0.21\pi L_r R_r^2. \qquad [B\text{-}4]$$

The volume of the cable needed is equal to the length of the cablegation line times the cross-sectional area, A_c, of the cable. So, for a cablegation line 1,160 feet (=13,920 inches) long, the volume of this cable needed is 13,920x0.00378=52.62 cubic inches.

Using equation [B-4] to determine the length of reel, L_r, needed,

$$L_r = V_{cr}/0.21\pi R_r^2 = 52.62/0.21\pi(3.98)^2 = 5.04 \text{ inches.}$$

In practice it has been found that the reduction in plug speed is considerably less than 10 percent under these conditions. Apparently, this is due to stretching of the cable, which increases when length of cable in the cablegation line is increased. As the cable is reeled out and the effective circumference is less per turn, stretching of the greater length of cable under tension in the cablegation line tends to add length to the cable and tends to compensate for the smaller circumference.

Under the stresses expected in cablegation lines, the stretch during 1 day of stress has varied from 7 to 15 percent in lines made of nylon, Dacron, and polypropylene. The stretching slows down after stretching that far but never actually stops. Considerable shrinkage occurs when the stress is removed. When the plug is removed from the cable at the bottom end of the cablegation line and the cable is rewound back on the reel, it is generally somewhat longer and thinner than it was before use. The thinner line tends to allow more wraps per unit of volume of cable. This tends to compensate for open space that occurs between cable strands on the reel when the cable is not carefully wound in tight successive layers, resulting in about the same length of line per unit of volume on reels as on the original spools. However, we recommend that sides on the reels extend at least an inch past the outer radius of the wound up cable. When the cable is being wound on the reel the plug has usually been removed and tension on the line is low resulting in a somewhat loose roll of cable. When the cable is being pulled out by the force of the water on the plug, tension on the cable is greater, compressing portions of the loose roll of cable; on other portions free strands of the cable may extend an inch or so from the ball. Extended sides on the reel keep these loops from slipping off the reel, knotting, and breaking.

For Fields with Varying Row Lengths and Cablegation Lines at Various Angles to the Rows

Data of the type in appendix J, figure 69, indicate that the delivery rate to a furrow should be proportional to the length of the furrow. Consequently, if furrow lengths are reduced by half the delivery rate to the furrow should be reduced by half by reducing the size of the outlets. However, if the supply to the pipe remained constant and the plug speed remained constant, the water would remain running in the short furrows for twice as long because it would back up farther in the pipe behind the plug. For the water to be in the short furrows for the same length of time as for the longer furrows, the plug must move past the shorter furrows twice as fast. In general, the plug speed should be inversely proportional to the furrow length; that is, the plug speed is equal to the total supply rate divided by the product of the furrow length and the gross depth of application.

In some fields, the headline may not always be at right angles to the furrows, but may be at some other angle, θ, to the rows as indicated in figure 31. Where $\theta<90$ degrees, the plug must travel the distance L to pass a furrow where distance between furrows is W. Since $W/L=\sin\theta$, $L=W/\sin\theta$. If the rows were all the same length, the plug speed should then be proportional to L or inversely proportional to $\sin\theta$. Combining both the headline angle and variable row length factors,

$$\text{plug speed}=(K/\sin\theta)/\text{row length}, \qquad [B-5]$$

where K is a coefficient dependent on furrow infiltration rate and total supply to the pipeline.

As an example of how the row length factor can be handled by reel design, consider the system shown in figure 32, where a single cablegation pipeline serves two successive fields where furrow length in the first one is a constant 1,080 feet, and, in the second field, the first furrows are 420 feet long and the last furrows are 680 feet long. All rows served are at right

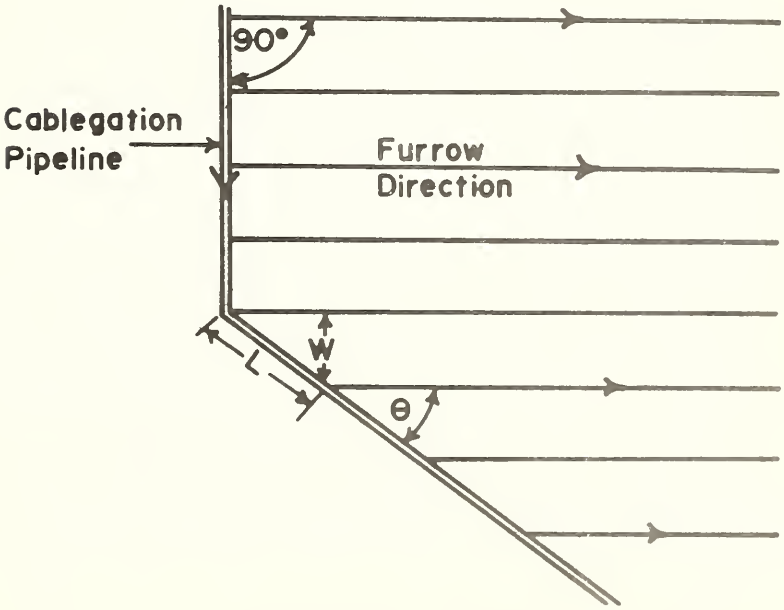


Figure 31.--Cablegation pipeline at angles $\theta \leq 90^{\circ}$ to rows.

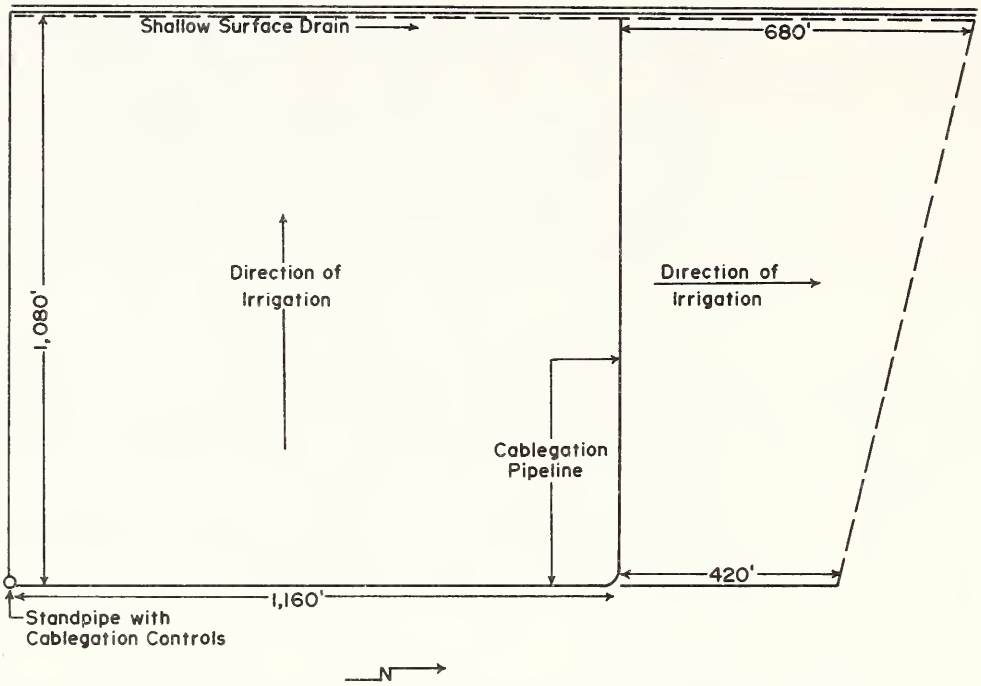


Figure 32.--Single cablegation pipeline serving rows of varying length.

angles to the pipeline, so θ =90 degrees, sinθ=1, and plug speed=K/row length. The plug starts near the standpipe and travels north 1,160 feet serving the large field, then goes round the curve in the pipeline and travels (west) another 1,080 feet serving the smaller field.

Flow rate supplied to this system is 1 foot^3/s. Irrigation applications desired are 3 inches, and expected application efficiencies are 75 percent. In other words, when 4 inches of water are delivered to the field, about 1 inch is expected to run off. On the 29-acre field, 4 inches of water will require (4/12)(29)(43,560)=421,080 cubic feet of water. At a supply rate of 1 foot^3/s, this will require 421,080 seconds=117 hours. The plug is to be positioned about 190 feet from the standpipe and held there for 14 hours, after which the plug should begin to move. After the plug passes the north edge of the first field, water continues to flow to furrows near this edge of this field for about 20 hours, during which time about half the water comes to this field. The plug should travel the 970 feet (=1,160-190) to reach the north side of the large field in about 93 hours (=117-14-20/2). Thus, normal plug speed for this section where the rows are 1,080 feet long should be about 10.4 feet per hour.

From equation [B-5] we conclude that plug speed=10.4=K/1,080, or K=11,232. This same K can then be used for the second field (assuming that infiltration rate of the soil and total supply rate to the pipeline remain constant) and divided by the length of furrows on the east side of that field to determine initial plug speed as it starts moving west. This initial speed of 11,232/420=26.7 feet per hour, should be slowed down to 11,232/680=16.5 feet per hour by the time the plug reaches the west end of this second field.

The portion of the reel from which the cable is to unwind while the plug is passing the large rectangular field is designed according to the information given on pages 60 and 61.

The portion of the reel from which the cable is to unwind as it passes the field with decreasing furrow length may be designed as follows:

As stated previously, the length of the cable serving this field is 1,080 feet=12,960 inches and the reel should be designed to give the plug a normal speed of 26.7 feet per hour (320 inches per hour) as it begins on the east end of this field, and 16.5 feet per hour (198 inches per hour) when it reaches the west end. The outside wraps of this reel should then have a radius, R_{ro}, which will provide a speed of plug travel, S_{pn}, at the east end of this field of 320 inches per hour when the rotation of the reel, W_r, is 5 revolutions per hour. Thus, $R_{ro}=320/5\text{x}2\pi$ $=10.2$ inches.

At the west end of the field

$$R_{ri}=S_{pn}/(2\pi W_r), \qquad \text{[B-6]}$$

and therefore $R_{ri}=198/2\pi\ \text{x}5=6.3$ inches.

The volume, V_c, of the cable held will be its length times its cross-sectional area=12,960x0.00378=49 cubic inches. When wound on the reel, this volume can be described by

$$V_c=L_r\ \pi(R_{ro}{}^2-R_{ri}{}^2) \qquad \text{[B-7]}$$

$$L_r=V_c/\pi(R_{ro}{}^2-R_{ri}{}^2)=49/\ (10.2^2-6.3^2) \qquad \text{[B-8]}$$

$$=49\ /[(3.14)(104-40)]=0.24 \text{ inches.}$$

The calculated dimensions of the compound reel for the consecutive 29- and 14-acre fields are shown in figures 33 and 34.

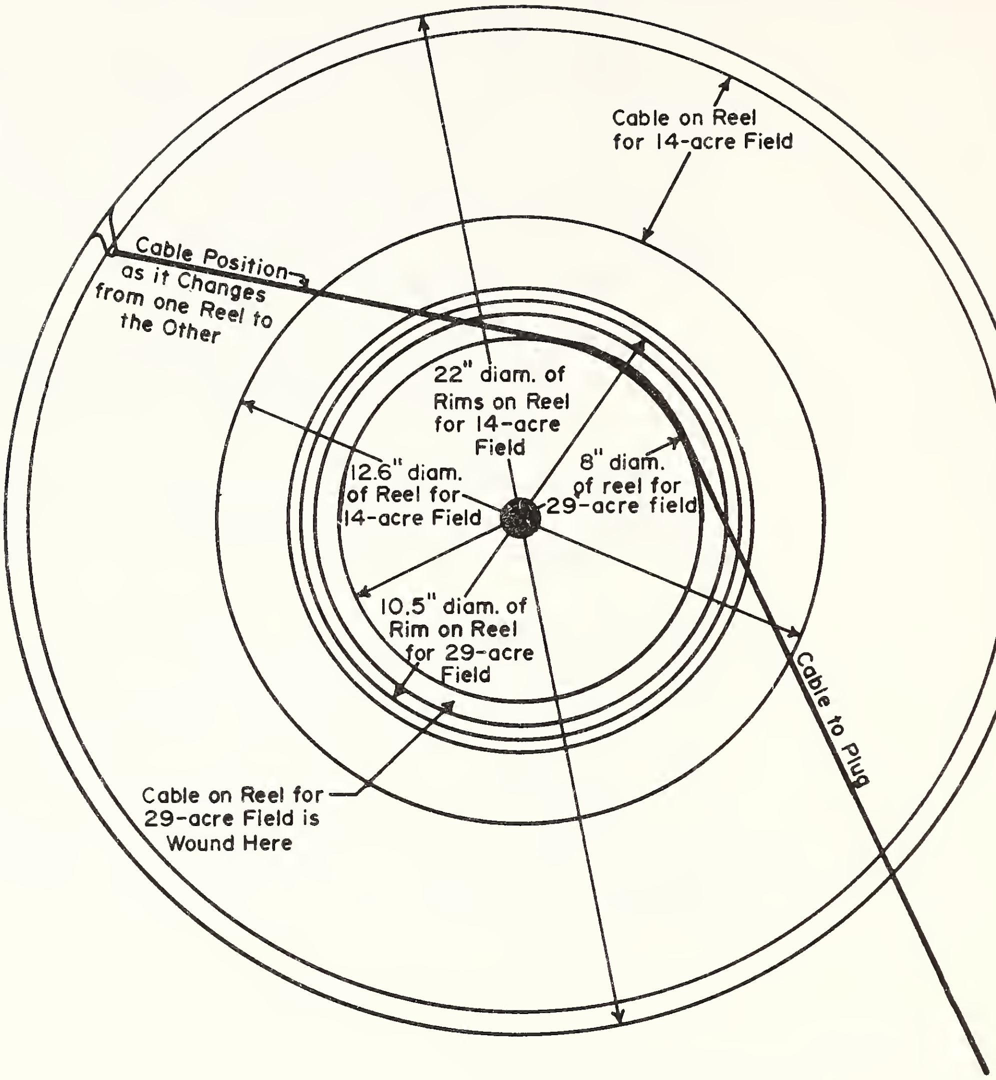


Figure 33.--Reel dimensions for consecutive 29- and 14-acre fields (side view).

To help get the proper length of cable on the respective reels, a marker can be attached to the cable about 1,080 feet from the tail end of the 2,240-foot-long line. In practice, a piece of cloth sewn to the braided line served this purpose. After an irrigation has been completed and the plug has been detached, the cable is reeled in, first on the narrow large-diameter portion of the reel. When the marker appears, that portion of the reel is practically filled, the cable is drawn through the smooth notch indicated in figure 33, and the remainder is wound on the wide 8-inch-diameter portion of the reel.

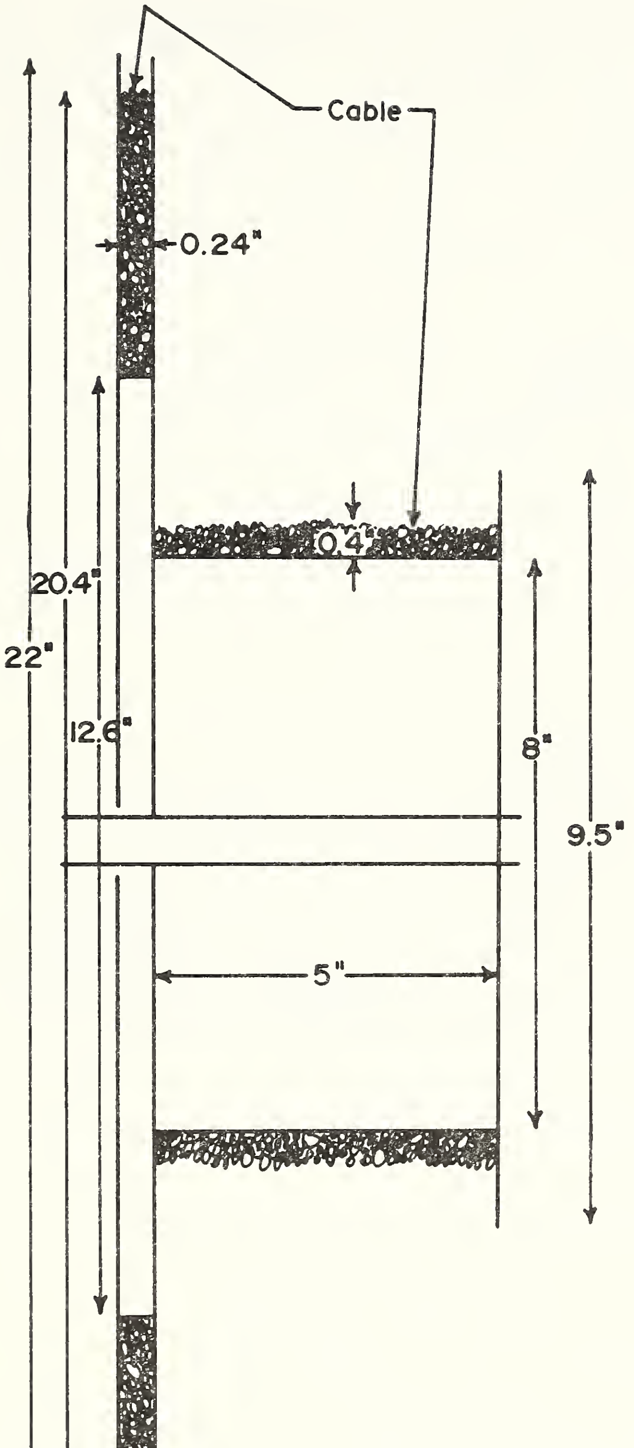


Figure 34.--Reel dimensions for consecutive 29- and 14-acre fields (end view).

The decreasing effective reel size as cable unwinds is in the wrong direction to provide proper plug speeds (equation [B-5]) for fields with furrows of decreasing length, as indicated in the top of figure 35. However, a compound reel of the type indicated in the middle of figure 35 can be used where the cable is wound with one-quarter of its length on each section, beginning with the largest reel and proceeding to the smallest. Then, when the cable unwinds (small reel first), the plug speed will be as indicated in the bottom of figure 35.

With this type of compound, or multiple-channel reel, stair-stepped approximations of desired changes in plug velocity can be achieved. It is necessary to rewind the proper amount of cable into the right channel. Small flags sewn into the braided line may be missed while the cable is wound onto these reels. In most types of braided cable, properly constructed splices do not weaken the cable. We recommend splicing cables of different colors to go into the separate channels which facilitates getting the proper amounts of cable in the proper channel.

Construction Recommendations

In constructing the narrow reel section shown in figures 33 and 34, the deep sides of the reel section must be strong enough to resist the strong outward force exerted by the cable, which is often under tension. To resist the strong outward force on narrow, deep reels, the sideplates must be strong. Steel plate, 0.25-inch thick is recommended. For other reels, most of which are designed to be shallow, there is little force on the sidewalls and much lighter material can be used for their construction.

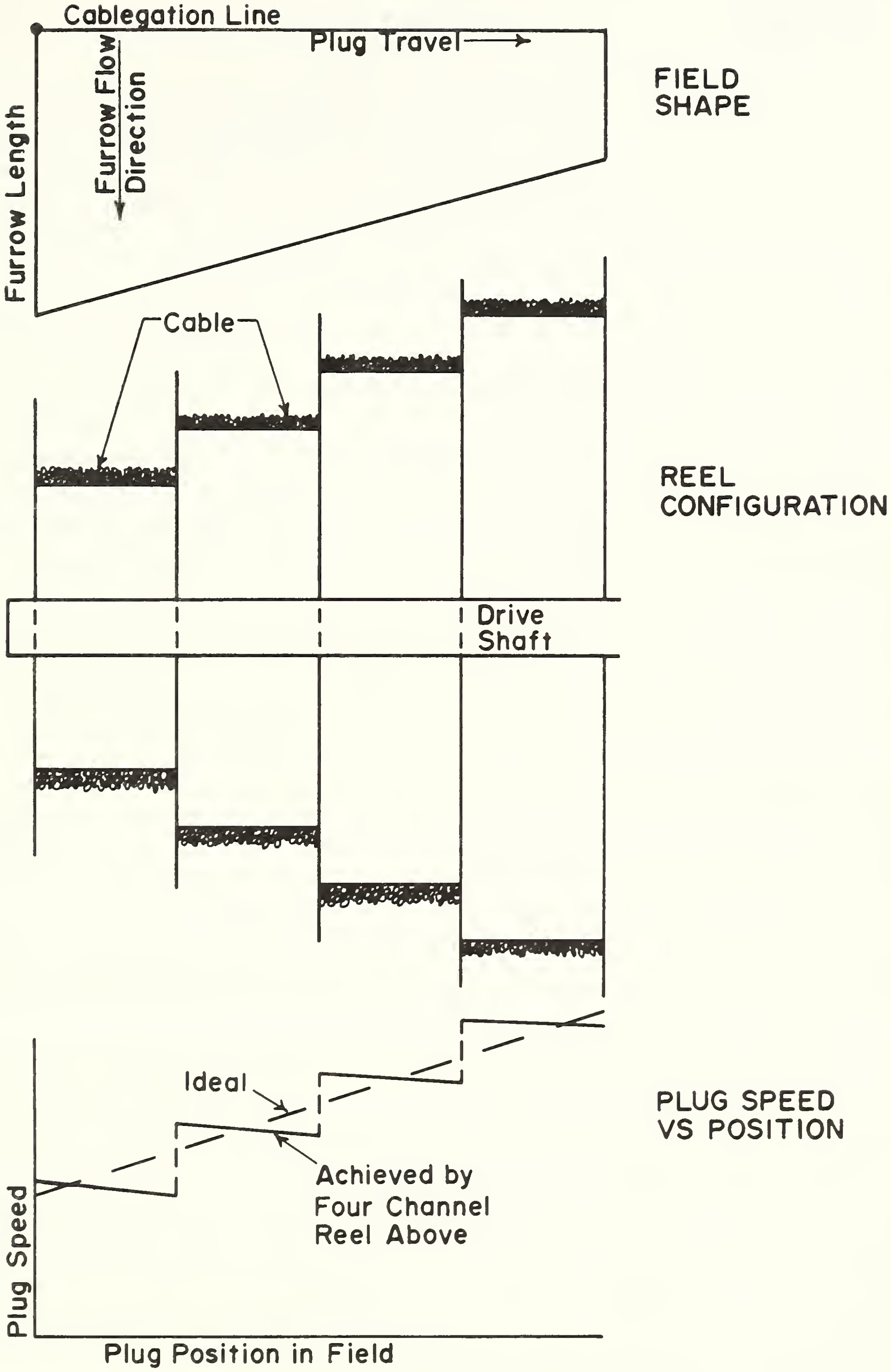


Figure 35.--Reel design for furrows of decreasing length.

APPENDIX C - CALCULATOR AND COMPUTER MODELS FOR PREDICTING FURROW SUPPLY AND RELATED VARIABLES

Purpose of the Models

Initially, the purpose of this model was to provide predictions of outlet flow rates as a function of total water supply rate, pipe size, type and slope, outlet size and spacing, plug speed, and time. After the predictions of the model had been verified experimentally, it was used to provide visual displays of the relationships such as those shown in figures 5 through 8. Inputs of field conditions such as headline slope(s), total water supply rate(s), outlet spacing, etc., into the model have given the installers of the systems described in appendix J predictions of how the system would work before major investment was required.

The model and expansions thereof have also played a major role in the development of cablegation system improvements. For instance, the bypass concept for minimizing end effects, discussed in Appendix D, was incorporated into the model and evaluated and expanded therein.

Model Development (Basic Model is Adaptable to Handheld Calculators)

The schematic diagram of a cablegation pipe with outlets placed near the top (fig. 36) shows the relationship of the energy gradeline and hydraulic gradeline to the pipeline and outlet elevations. The piezometric head is measured from the center of the outlets. Friction losses are computed based on full pipe flow.

The energy equation is used to determine the difference in piezometric head, $h_{i+1}-h_i$, between two adjacent outlets. Thus,

$$h_{i+1}-h_i=SW-h_f-h_o+(V_i^2-V_{i+1}^2)/2g, \qquad [C-1]$$

where V_i is the velocity in the pipe immediately upstream from the ith outlet in meters per second,

V_{i+1} is the velocity in the pipe upstream from the i+1 outlet in meters per second,

g is the gravitational constant, 9.81 m/sec^2,

S is the slope of the pipeline between the two outlets,

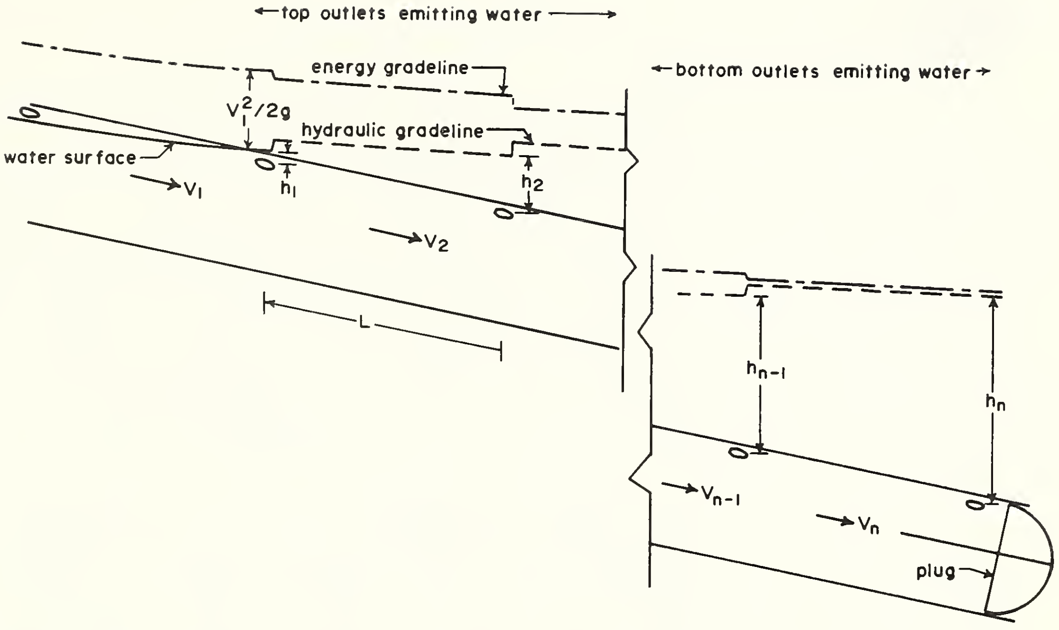


Figure 36.--Hydraulics of the cablegation system.

W is the outlet spacing in millimeters,

h_f is the loss of head due to friction between the two outlets, in millimeters,

and h_o is the loss of head due to branching flow at the ith outlet in millimeters.

The friction loss, h_f in millimeters as given by the Hazen-Williams equation is

$$h_f=6.08\times10^6 W(Q/C)^{1.85}/D^{4.865}, \qquad [C-2]$$

where Q is the total flow rate in liters per minute,

D is pipe inside diameter in millimeters,

and C is the Hazen-Williams roughness coefficient.

Outlet Discharge

The discharge, q_i, from an outlet is given by the equation

$$q_i=0.0066C_d d_i^2 h_i^{1/2}, \qquad [C-3]$$

where q_i is flow from the ith outlet in liters per minute,

d_i is the diameter of the outlet in millimeters,

h_i is piezometric head in millimeters,

and C_d is the discharge coefficient.

The discharge coefficient is usually assumed constant. A value of $C_d=0.65$ was assumed in the initial model. However, C_d is not constant but is dependent upon the velocity in the pipe and to some extent upon pressure head. In the cablegation system, the flow condition near the plug is low velocity combined with high head. Moving upstream, the velocity increases as the piezometric head approaches zero and the C value decreases appreciably.

The ratio of piezometric head to velocity head is

$$h/(V^2/2g)=r_h. \qquad [C-4]$$

The discharge coefficient begins to decrease appreciably when $r_h<10$ (Kincaid and Kemper 1982, figure 39). The following empirical relationship was derived from data collected in the hydraulics laboratory and used in the calculator model:

$$C_d/C_{do}=1-0.28/(0.40+r_h) \qquad [C-5]$$

where $C_{do}=0.65$ is the constant maximum value of C_d as the water velocity in the pipe approaches zero.

This equation fits the measured data for $r_h>0.05$. For values of $0<r_h<0.05$, the equation may not be accurate; however, this region represents such a small portion of the distribution that inaccuracies in this region do not affect the results appreciably.

Operation of the Computer Model of Pipe Flow

When water flow is from the midsection (not flowing from the first or last outlet of the pipeline), inputs to the model are the pipe inside diameter and roughness, the outlet size(s) and spacing, the pipe slope(s), and the total inflow rate(s). The inflow rate may vary with time but is limited by the flow capacity of the pipe when the friction slope is equal to the minimum pipe slope. As shown in figure 36, the hydraulic head, which is measured from the center of the outlet, becomes zero at some point upstream from the plug. Since the point of zero head is unknown, a trial and error procedure is used to determine the hydraulic gradeline. Starting at the downstream end, a value is assumed for the piezometric head, h_n, at the last flowing outlet. The outlet discharge and pipe flow are computed, and the changes in head are computed from downstream to upstream. When the piezometric head becomes zero, the total accumulated flow is compared with the known inflow rate. If the inflow rate exceeds the sum of the outlet flows, the assumed head h_n is increased; or, if the sum of the outlet flows exceeds inflow, h_n is decreased and the process repeated until the sum of the outlet flows is within one percent of the total inflow. When outlet size and spacing and pipe slope and diameter are uniform and the plug passes the outlet below the ith outlet, flow at the ith outlet decreases to what it was before at the i+1 outlet. As the plug continues down the line, flow rate at the ith outlet reduces further, taking on in sequence the values that were occurring at successive outlets upstream from the ith outlet when the plug was just below that outlet. The time increments between the flow rate changes are equal to the distance between adjacent outlets divided by the plug speed.

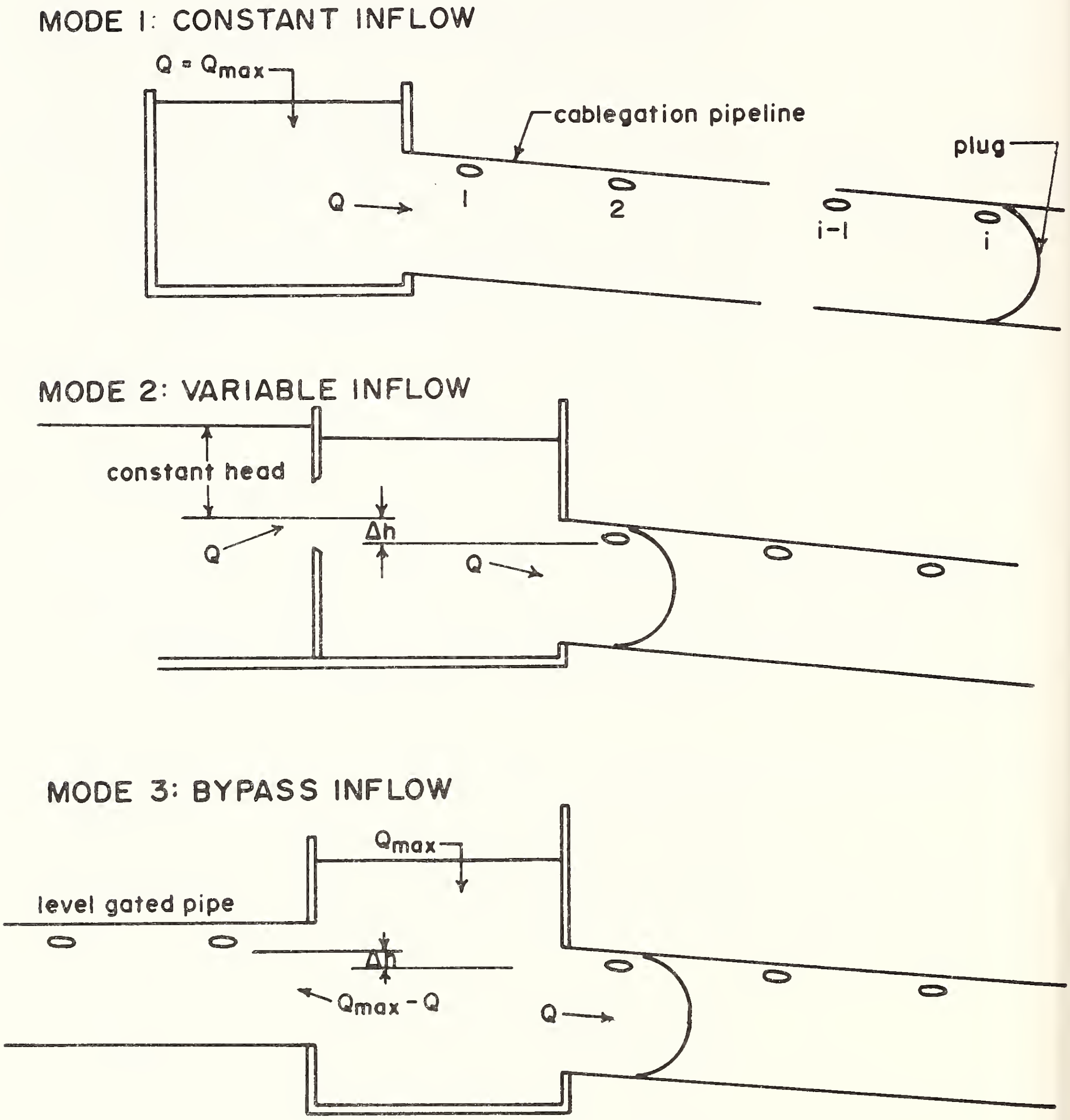
For the case of constant outlet size and spacing and uniform pipe slope, the distribution can be calculated without trial and error by starting at the upstream end where the head is known ($h=0$), and calculating downstream until the accumulated outlet flows exceed the inflow rate. This method is used in the simplified calculator program.

Predictions of outlet flows rates using this model are shown in this handbook figures 4-8 and in Kemper et al. 1981; Kincaid and Kemper 1982, and Goel et al. 1982. Figure 4 indicates the degree of agreement with flows occurring in the original cablegation system constructed on the University of Idaho research farm.

These procedures apply after the plug has moved sufficiently farther down the pipe that the first outlet has stopped flowing.

For the initial or startup period, the procedure must be modified. Three modes of operation are described for startup as shown in figure 37.

<u>Mode 1</u>: <u>Constant Inflow</u>. The plug is held stationary just beyond the ith outlet for a specified time, t_i, and then allowed to move at a constant rate. The inflow rate, Q, is constant from time zero. The initial outlet flows are constant until the plug


MODE 1: CONSTANT INFLOW

MODE 2: VARIABLE INFLOW

MODE 3: BYPASS INFLOW

Figure 37.--Modes of operation on startup.

begins to move and then decrease to zero. To obtain adequately high flows from outlets near the standpipe, they must generally be larger than those farther down the line.

Mode 2: Variable Inflow. The plug starts moving at the first outlet from time zero. The total inflow rate is initially equal to the flow rate from the first outlet and inflow rate gradually increases as the plug moves, opening up additional outlets, until a maximum specified flow is reached. The head at the first outlet gradually decreases to zero. The inflow rate is controlled by an orifice of specified area which allows water into the supply box under constant upstream head as shown. Head in the supply box decreases as additional outlets open until the water surface is lower than the first outlet.

Mode 3: Bypass Inflow. The plug moves from time zero as in mode 2. Initially, most of the flow is diverted to a level gated pipe (as in the system described in fig. 74, app. J), or an equivalent system, which comprises an initial set. As the plug moves, the flow into the cablegation pipe increases until all flow is diverted to the cablegation side. The total area and elevation, Δh, of the outlet(s) in the level pipe are specified. Figure 38 shows an example of the time distribution of inflow with modes 2 and 3.

Mode 4: Bypassing the Plug. The plug starts at the first outlet, and most of the flow is bypassed to the lower end by means of a bypass pipe and weir or through a bypass plug. This method is described in detail in appendix D.

For all startup modes, the calculation procedure is as follows. The piezometric head for the first outlet is assumed, the inflow rate is determined, and calculation proceeds downstream to the plug. If the calculated accumulated flow is larger than the inflow rate, head assumed at the first outlet is decreased or vice versa. The inflow rate is then recalculated, and the procedure is repeated until the total flows balance. As the plug moves down the pipe, the head at the first outlet decreases and finally becomes zero. At this time the calculation procedure is switched to the previously described method for the midsection.

When the plug reaches the end of the pipe, there are at least three ways of completing the irrigation:

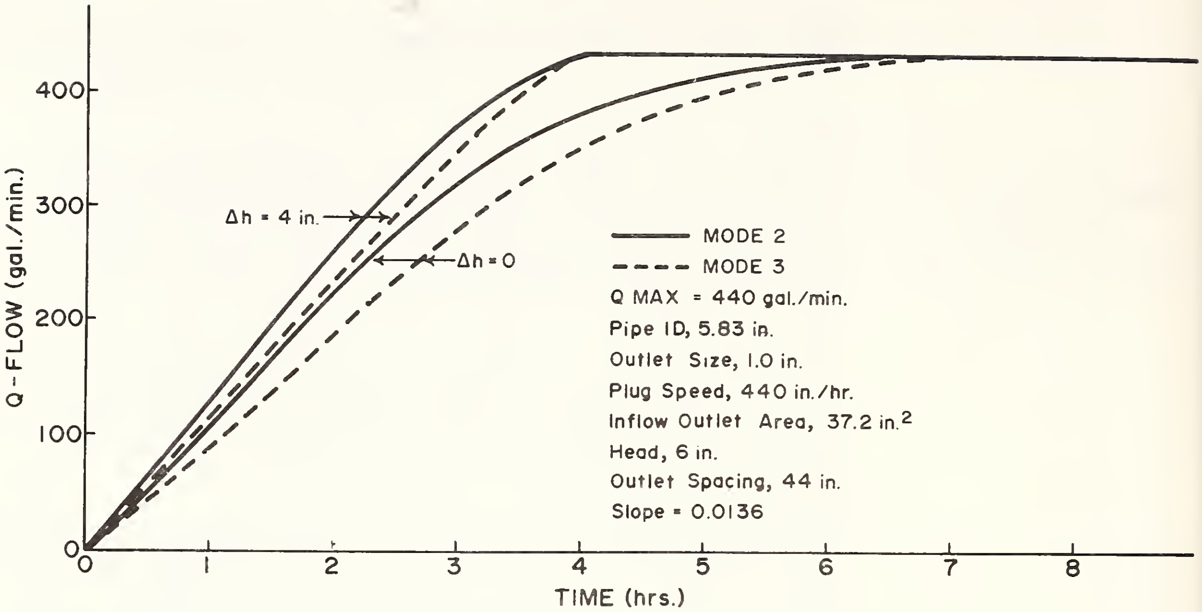


Figure 38.--Time distribution of inflow for startup modes 2 and 3.

1. Inflow continues at the same rate until a desired gross or net application has been applied at the last furrow. It is difficult to obtain uniform net application with this method because the intake opportunity time for the last furrow is less than for furrows farther upstream. Outlet sizes may be increased near the lower end to produce rapid advance and minimize the final set time required.

2. Inflow starts to decrease when the plug reaches the end. The inflow rate is decreased linearly to zero over a time period equal to the width of the flow distribution divided by the plug speed when the plug reaches the end. This method simulates the transfer of flow to a second cablegation system (operating from the same inlet box but at a lower elevation as in the Klompein system, figs. 71, 72, and 73) in which the second plug starts to move when the first plug reaches the end. This method allows more uniform outlet and stream sizes and results in a uniform net water application.

3. When the plug reaches the end, the outflow rate past the plug is allowed to increase from zero to the maximum rate, simulating the transfer of flow to a second plug system downstream. The resulting distribution is very similar to that obtained with the second method, and a uniform net application could be easily obtained. This transfer can be accomplished by letting the plug move into a standpipe which is connected to a downstream pipe system and allowing the flow to back up behind the second plug which then controls the flow.

The foregoing methods consider the startup and completion phases separately. The plug bypass methods described in appendix D effectively eliminate both top and bottom end effects.

Models Expanded to Include Infiltration in Furrows Served

An expanded model which requires a computer has been developed by Kincaid (Kincaid and Kemper 1982) which can incorporate infiltration characteristics of the soil. Given an infiltration-rate-vs-time equation for the soil, this model predicts infiltration at different locations in the furrow-irrigated field as a function of delivery system characteristics as in figure 9. This expanded model also allows prediction of runoff as a function of delivery-system characteristics. The limiting factor on the accuracy of these predictions is the accuracy and variability of the infiltration-vs-time-equation.

Not all potential designers will have access to a computer. Consequently, Kincaid has used the computer model to develop and evaluate equations involving dimensionless variables which enable individuals to develop designs for cablegation systems. These equations, their graphical form, and text describing their use, are given in appendix E.

In appendix E, Kincaid has also used the expanded computer model to develop graphical relationships between dimensionless variables which can be used to predict infiltration patterns in fields resulting from distribution-system performance. These relationships can then be used to optimize cablegation system design, taking into consideration infiltration characteristics for that field.

APPENDIX D - REFINING THE BYPASS METHOD TO ELIMINATE END EFFECTS

Reasons for a Bypass

Since furrow infiltration is basically time dependent, water must be applied to a furrow for a minimum length of time to obtain the desired average depth of intake. With a constant supply rate to the cablegation system, the plug is commonly started at some distance down the pipe, held stationary for an initial set time, and then started moving. As discussed in more detail on page 48 ("Flow Pattern Deviations at the Ends of the Line"), this results in a shorter application time for the first few furrows than for those just above the stationary plug farther downstream. Similarly, when the plug reaches the end of the pipe and stops, the flow must be left on long enough to adequately irrigate the last few furrows, and again some furrows receive more water longer than others. This nonuniformity can be reduced to levels less than those occurring in many non automated irrigation systems by using larger outlet sizes and stream sizes near the upper and lower ends. However, these complexities complicate the design and operation of cablegation systems and better intake uniformity can be achieved as follows.

As discussed in connection with figure 21, the bypass method equalizes application time and stream sizes for all furrows thus improving uniformity and simplifying system design and operation. The full supply rate is handled from the beginning of the irrigation and when the plug reaches the last furrow, the irrigation is complete. The methods described below were developed to achieve the bypass control (Kincaid and Kemper 1983).

Bypass Weir and Pipe Method

Figure 39 is a schematic of the bypass method, which passes the flow over a weir and through a parallel pipe of length equal to the flow distribution distance after the first outlet has stopped flowing. The bypass pipe is usually the same size as the main pipe but can sometimes be one size smaller. The bypass flow is controlled by an overflow weir at the inlet structure. The weir width is designed so that the head at the plug remains nearly constant as the plug migrates down the cablegation line. The weir crest is placed at an elevation above the first outlet equal to the velocity head in the main pipe when the first outlet stops flowing. Ideally, the weir should have curved sides; however, it has been determined (Kincaid and Kemper 1983) that a rectangular weir will provide flow rates close enough to those desired to practically eliminate differences in supply rates and times.

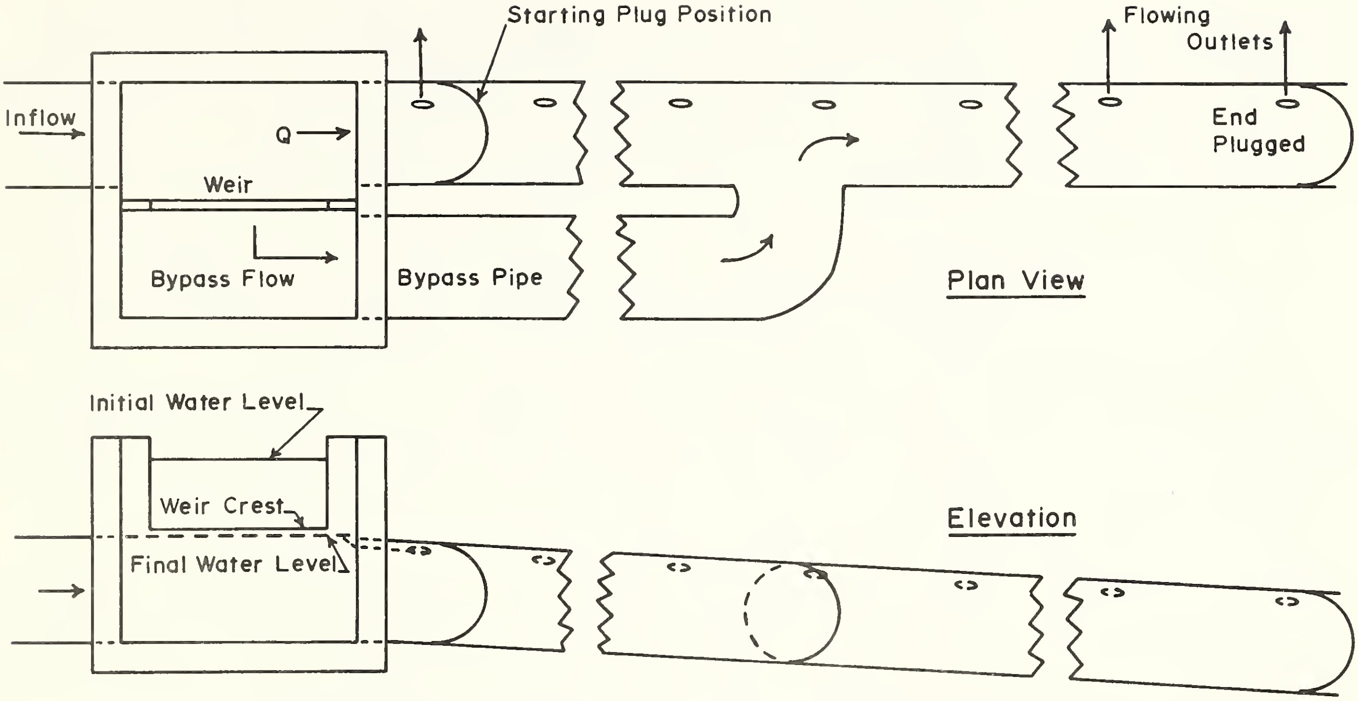


Figure 39.--Schematic layout of bypass pipe and weir.

Bypass Plug Method

Another bypass method uses a flow-through plug to bypass a decreasing portion of the total flow.

The basic form of the bypass plug used to date has been a short length of pipe, one or two sizes smaller than the cablegation pipe, with a butterfly gate at the outlet end as shown in figure 40. A flexible rubber gasket seals the annular space between the plug body and the main pipe. The mechanism indicated in that figure gradually closes the butterfly gate as the plug moves down the pipe. The mechanism shown in figures 40 and 41 proved to be practical and gives the desired control. The plug body is supported and centered in the pipe by wheels. The front wheels are small plastic support wheels. The rear friction-drive wheels are fixed to a horizontal shaft and control the gate through a gear-driven screw linkage. The plug components can be designed to close the butterfly gate from any given initial opening in the desired travel distance by adjusting the wheel size, gear ratio, screw thread pitch and the linkage distances. The linkage is adjusted so that when the gate is completely closed, the traveling nut has moved onto the reduced portion of the rotating shaft, allowing the wheels to rotate freely as the plug continues to move down the pipe.

Figure 40 shows a conical-shaped rubber gasket which was designed for use with the bypass plug. These are easily constructed from flat rubber sheets about three thirty-seconds of an inch thick and are attached to the plug body by means of a simple band clamp. The gasket angle is about 20 degrees. In field tests of the bypass plug, the gaskets proved to be flexible enough to perform well, even when the pipes were considerably out of round. The gaskets held against heads up to about 20 inches. Higher heads could be accommodated by using thicker or reinforced material. One advantage of this type of gasket is that the gasket will fold over on itself if the cable feed is reversed, allowing the plug to be pulled back out of the pipe if problems are encountered. The 7.9-inch plug was tested in 9.8-inch aluminum pipe with commercial gates. The plug and gasket performed well with two types of gates which protruded about 0.28 inch into the pipe.

The butterfly gate does not seal perfectly when closed and some leakage occurs. In laboratory tests, the combined gasket and gate leakage was about 5.3 gal/min with an upstream head of 19.7 inches. The plug is shown with a single gasket, but double gaskets could be used to reduce leakage at pipe joints or outlets.

Steel weights ($\cong$ one pound) are attached to the bottom of the plug body as shown in figure 40 to prevent the plug from rotating as it moves through the pipe and to reduce the

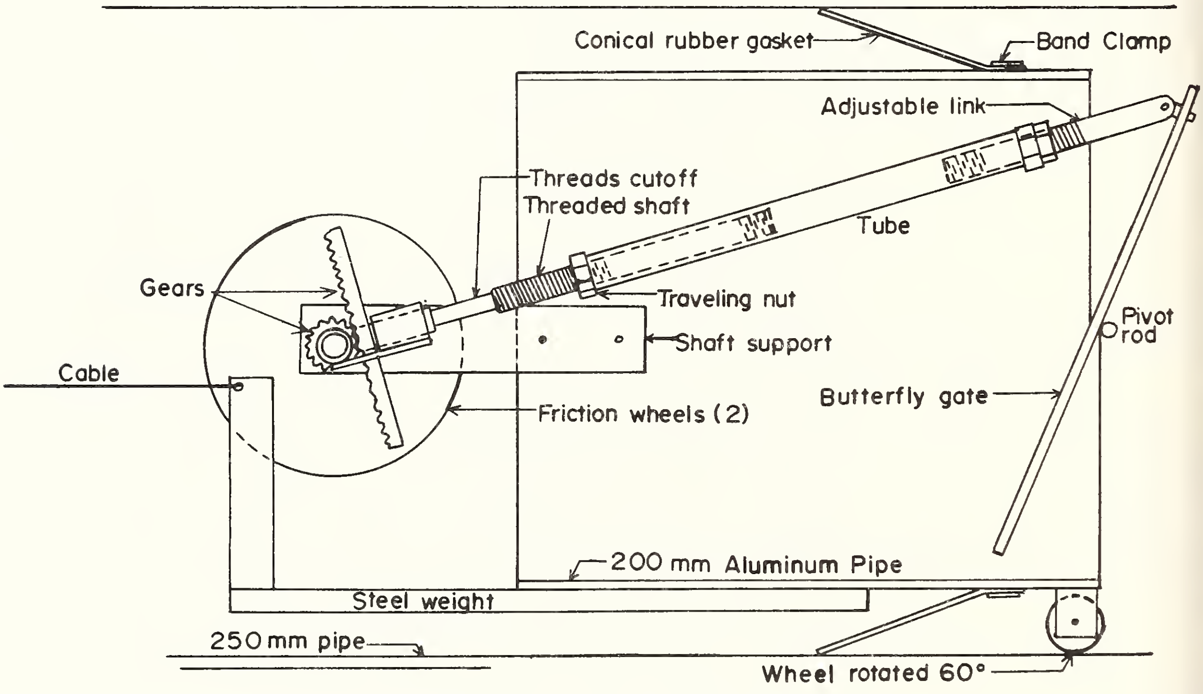


Figure 40.--Cross section of wheel driven bypass plug.

possibility of wheel slippage. The butterfly gate is inherently self-closing, and the drag on the wheels is near zero. The bypass plug closure mechanism can be jammed by trash. Therefore, we recommend a trash screen in the supply line for this system, both to protect the plug and to prevent outlets from plugging.

Details for design of the bypass plug are given in the publication "Cablegation IV: The bypass method and cutoff outlets to improve water distribution" (Kincaid and Kemper 1983).

Both the pipe and weir alternatives of the bypass method provide adequate control to practically eliminate the end effects. It appears that a bypass plug can be built at considerably less cost than the bypass pipe and weir. However, the mechanism which closes the gate may be subject to wear or seizing if the water is carrying large amounts of sediment. Field evaluations are in progress to detect wear or seizing on these mechanisms.

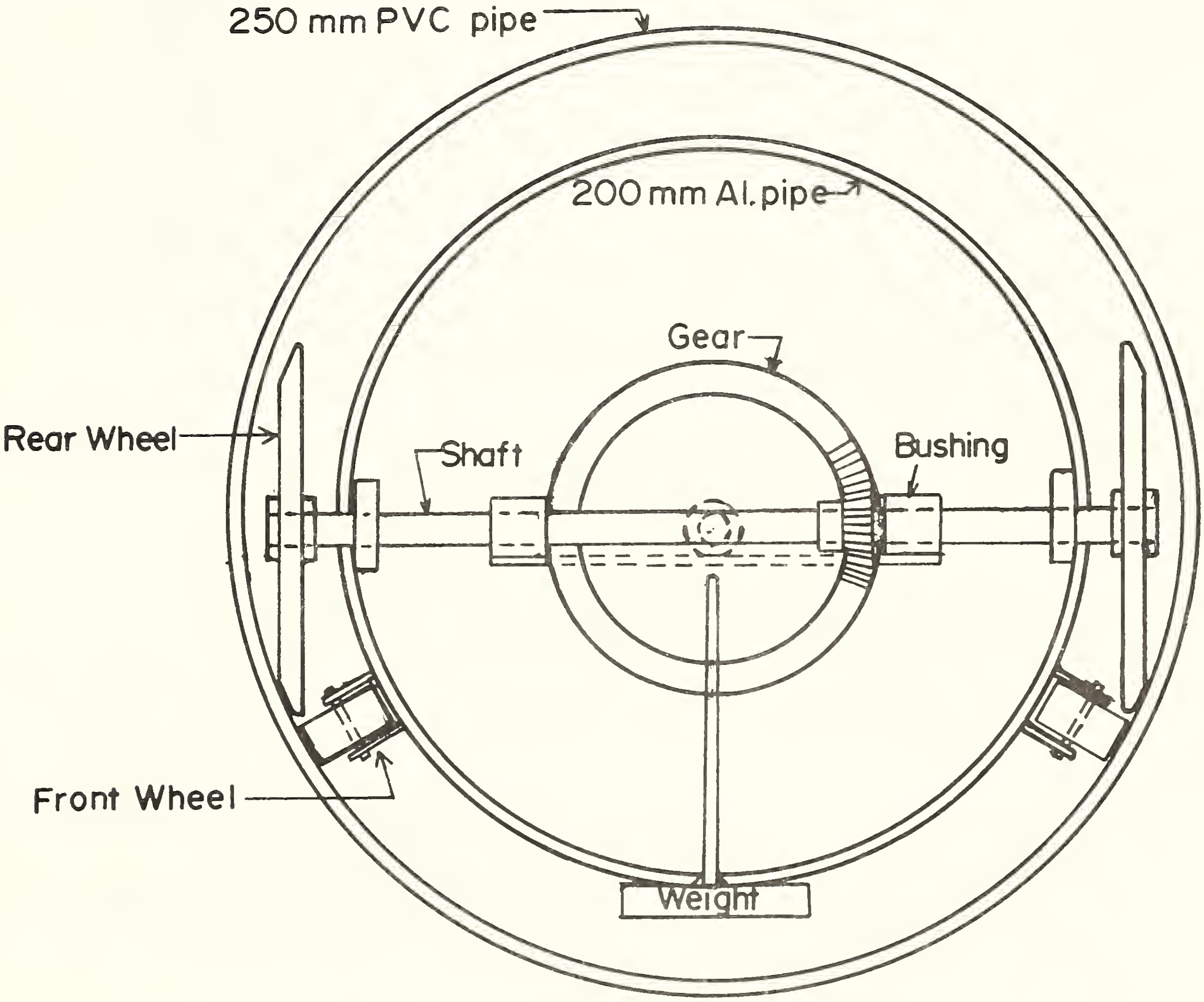


Figure 41.--Rear view of wheel-driven bypass plug.

APPENDIX E - AIDS FOR SIMPLIFIED CABLEGATION DESIGN

Reasons for Using Dimensionless Design Relationships

The design of cablegation systems using the computer model is partially a trial-and-refinement process. The pipe size is easily determined for the given pipe slope and total flow. A trial outlet size is specified. The outlet flows and heads are calculated successively from the upstream end, or first flowing outlet, until the maximum head and flow near the plug are determined. The resulting stream sizes are input to the intake-advance program, and the distribution of infiltrated water and runoff are determined. If the stream sizes and infiltration distribution are not as desired, the outlet size is changed in the direction needed and the process repeated. The computer goes through these iterations fairly quickly.

However, it would be desirable to specify the furrow length and intake characteristics, determine the stream size(s) required to obtain an acceptable intake distribution, and calculate the outlet size directly without calculating the entire distribution. The relationships presented in this appendix enable this direct determination and provide a simplified design method. The relationships are made dimensionless as far as possible to reduce problems of converting units and generalize the solutions. The relationships were derived through an empirical correlation of the dimensionless variables with output from the computer model.

The analysis is presented in two parts, the delivery system (pipe flow distribution) and the infiltration distribution.

Delivery System Design (Pipe Flow Distribution)

There are six independent variables that must be considered in designing cablegation systems: the pipe slope, S; pipe inside diameter, D; total flow rate, Q; Hazen-Williams pipe roughness parameter, C; outlet diameter, d; (or open area), and outlet spacing, F. Two dependent variables, the piezometric head at the plug, H, measured from the top of the pipe, and the distance, X, along the pipe through which outlets are flowing, are made dimensionless by dividing them by the pipe diameter, D. The outlet size and spacing are combined in one dimensionless parameter $\pi d^2/4FD$ which is equal to the ratio of the width of an equivalent continuous-slot outlet to the pipe diameter. The other dimensionless parameters are the pipe slope, S, the ratio of the total flow to the pipe flow capacity Q/Q_c, and the pipe-roughness ratio C/150, where C=150 is the value used for most PVC pipe. The flow capacity can be determined by the Hazen-Williams equation,

$$Q_c = BCS^{0.54} D^{2.63}, \tag{E-1}$$

where B=194 for D in feet and Q_c in gallons per minute, or B=0.000215 for D in millimeters and Q_c in liters per minute.

Dimensionless equations for the head, H, at the outlet nearest the plug and distance, X, were developed by inputting many combinations of the dependent variables into the computer model. Ranges of the variables used were pipe sizes from 100 mm to 400 mm (about one-third to four-thirds ft), slopes from 0.001 to 0.05, C values from 110 to 150, and flow ratios Q/Q_c from 0.5 to 0.95. Outlet diameters ranged from 5 to 100 mm (about 0.0017 to 0.33 feet); except that outlet size was limited to less than 30 percent of the pipe diameter. Outlet spacing ranged from 0.3 to 1.5 m (about 1 to 5 feet). The following dimensionless equation predicts the maximum outlet head within ±15 percent when the dependent variables are within the above specified ranges:

$$\frac{H}{D} = 13.8 \left(\frac{C}{150}\right)^{0.76} S^{1.03} \left(Q/Q_c\right)^{0.46} \left(\frac{FD}{d^2}\right)^{0.56} \tag{E-2}$$

A similar equation predicts the outlet flow distance X within ±10 percent:

$$\frac{X}{D} = 9.8 \left(\frac{C}{150}\right)^{0.44} \left(Q/Q_c\right)^{1.1} \left(\frac{FD}{d^2}\right)^{0.67} \tag{E-3}$$

For equations [E-2] and [E-3], the same units of length must be used for H, D, d, and F within any of the dimensionless factors. In the ratio Q/Q_c any flow rate units can be used as they are the same for Q and Q_c.

After the head has been determined, the maximum outlet stream size, q_m, can be determined within ±8 percent by using a standard outlet equation,

$$q_m = Jd^2\sqrt{H}, \qquad \text{[E-4]}$$

where J=1,838 for d and H in feet, and q_m in gallons per minute, or J=0.00429 for d and H in millimeters, and q_m in liters per minute.

The number of flowing outlets is N=X/F, and the average stream size is $\bar{q}=Q/N$. The ratio of the average to the maximum stream size, $\bar{q}/q_m$, gives an indication of the shape of the flow-distribution curve. A ratio of 0.5 indicates a triangular curve (similar to curves in fig. 6 where $Q/Q_c>0.8$), while higher values of $\bar{q}/q_m$ indicate that the flow decreases slowly initially and then decreases rapidly to zero.

Equations [E-2] and [E-4] can be combined and the head eliminated to yield an equation for outlet diameter, d, as a function of maximum stream size q_m as follows:

$$d = M\, q_m^{0.69} \left[\frac{(150/C)^{0.76}}{D^{1.56}\; F^{0.56}\; S^{1.03}\; (Q/Q_c)^{0.46}} \right]^{0.347} \qquad \text{[E-5]}$$

where M=17.7 for d, D, and F in millimeters and q_m in liters per minute, or M=0.00217 for d, D, and F in feet, and q_m in gallons per minute.

Equation [E-5] can be used to determine the outlet diameter required to produce a desired maximum stream size. Equation [E-3] could be rearranged to determine the outlet diameter size, d, given a desired average outlet stream size Q/N=QF/X or distance, X, throughout which outlets will be flowing. The cable tension, f, is given by

$$f = AD^2(H+D/2) \qquad \text{[E-6]}$$

where A=49 when H and D are in feet and f in pounds, or $A=7.7\times10^{-6}$ when H and D are in millimeters and f in newtons.

These equations can serve as the basis of a simplified design method for cablegation systems where the desired stream size(s) are known or have been determined by the method outlined in the following section. They can be used separately or in conjunction with the computer model to reduce the trial and refinement process in outlet-size determination.

Dimensionless Relationships to Predict Spatial Infiltration Distribution

Furrow infiltration can be modeled reasonably well by the time-based function

$$z=aT^{b}, \qquad [E-7]$$

where z=depth of intake in millimeters, T=time in hours since the beginning of wetting, and a and b are constants.

A parameter characterizing the average initial rate of application per unit area is $q_m/(EF)$, where q_m is the initial stream furrow supply rate, E is furrow length and F is furrow spacing. This is divided by the intake rate, $\partial z/\partial T$, at one hour, which is ab, to obtain the dimensionless parameter, $q_m/(EFab)$. The gross depth of water application, G, is total volume of water delivered to the furrow divided by the area, EF, served by the furrow. G is divided by the 1-hour intake depth, a, to obtain the dimensionless parameter G/a. The percentage of runoff is a third dimensionless parameter.

The shape of the curve relating furrow supply rate to time is relatively constant. The ratio $\bar{q}/q_m$ is related to the ratio Q/Q_c. Values of Q/Q_c of 0.9 and 0.5 give values of $\bar{q}/q_m$ of about 0.5 and 0.6, respectively. Thus the maximum furrow supply rate, q_m, and desired gross application, G, which determine the plug speed, completely characterize the inflow distribution. The plug speed is given by the equation

$$P=Q/(EG) \qquad [E-8]$$

where, when Q is in cubic feet per minute and E and G in feet, then P is in feet per minute, or when Q is liters per minute, E in meters, and G in millimeters, then P is in meters per minute.

The series of computer runs used to develop the following application-intake relationships used values of $\bar{q}/q_m$ of about 0.5. The relationships shown in figures 42 through 44 were developed for the intake parameter, b, having values of 0.3, 0.5, and 0.7, respectively. The solid lines were computed from cablegation simulations with decreasing furrow inflow rates. The dashed lines were computed for a constant furrow inflow rate with $q_m=\bar{q}$. These figures can be used to determine the initial (or constant) stream size required for a specified runoff percentage and gross application, given the length of furrow and

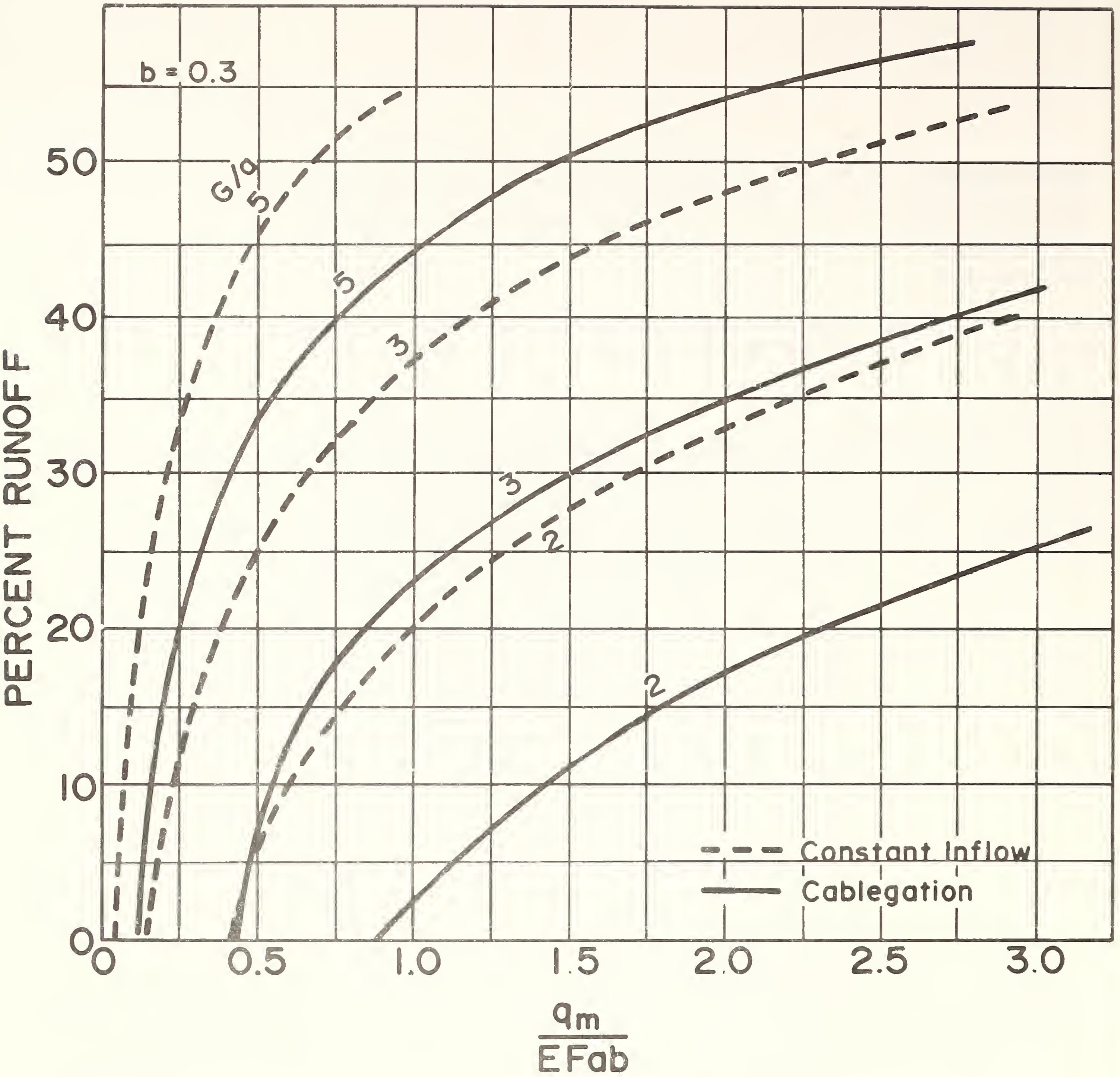


Figure 45.--Infiltrated depth ratio as affected by percentage runoff.

The distribution uniformity is characterized by the intake depth at the lower end divided by the intake depth at the upper end. This ratio is plotted in figure 45 as a function of percentage of runoff and the variables G/a and b. The distribution becomes more uniform as the percentage of runoff or gross application increases. The infiltration rate, as characterized by the value of b has a marked influence on the uniformity coefficient.

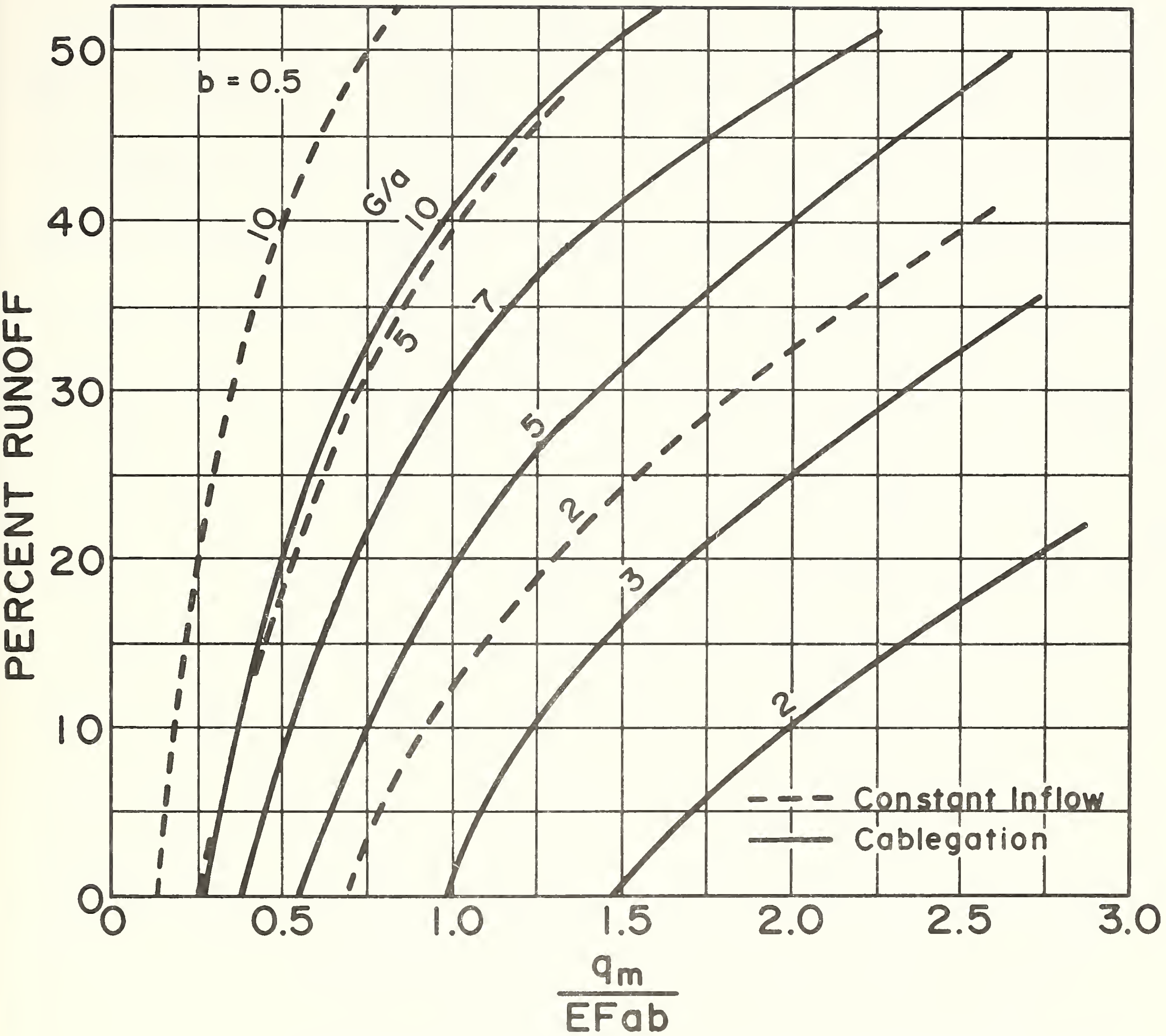


Figure 43.--Cablegation design curves for b=0.5.

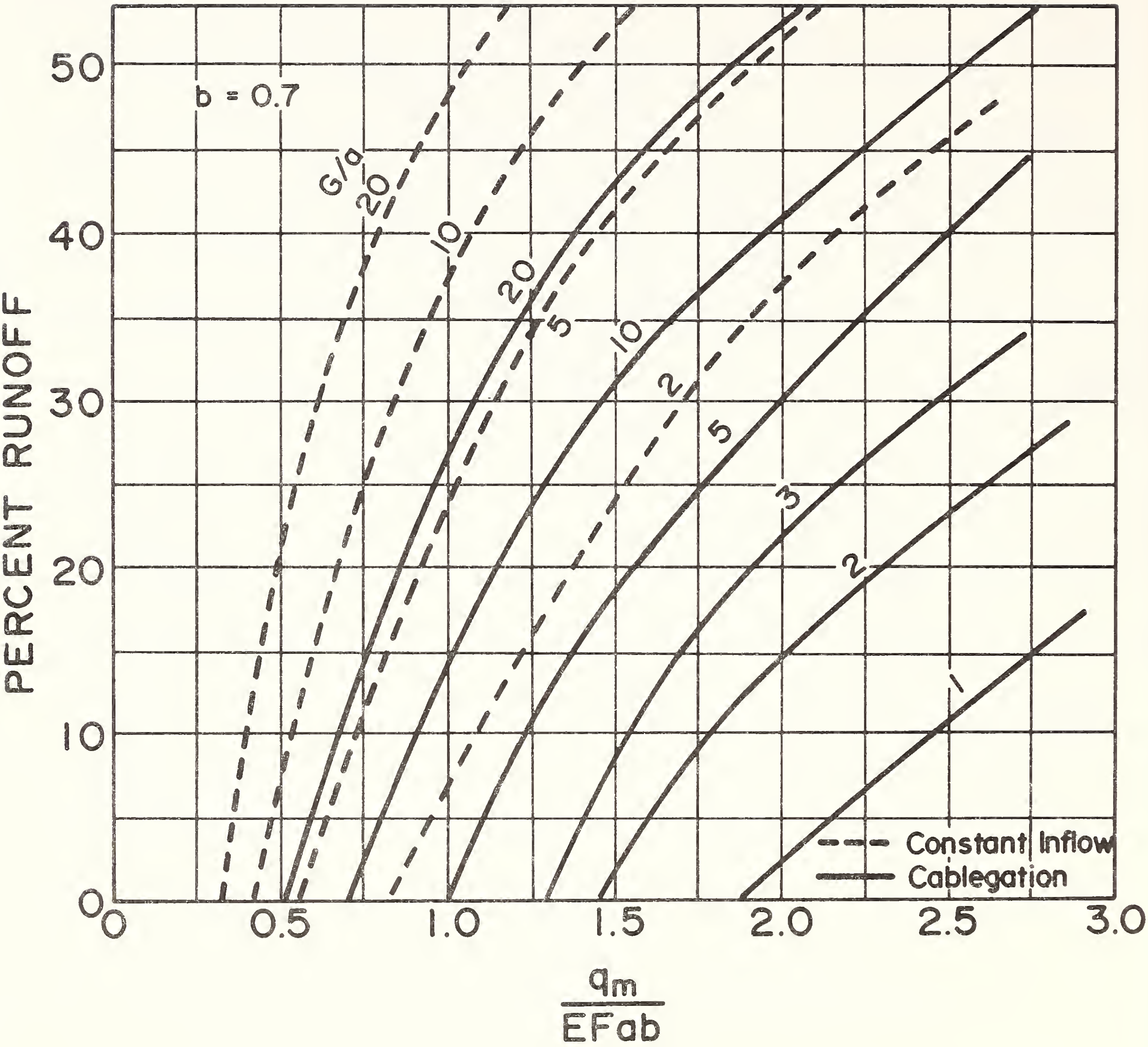


Figure 44.--Cablegation design curves for b=0.7.

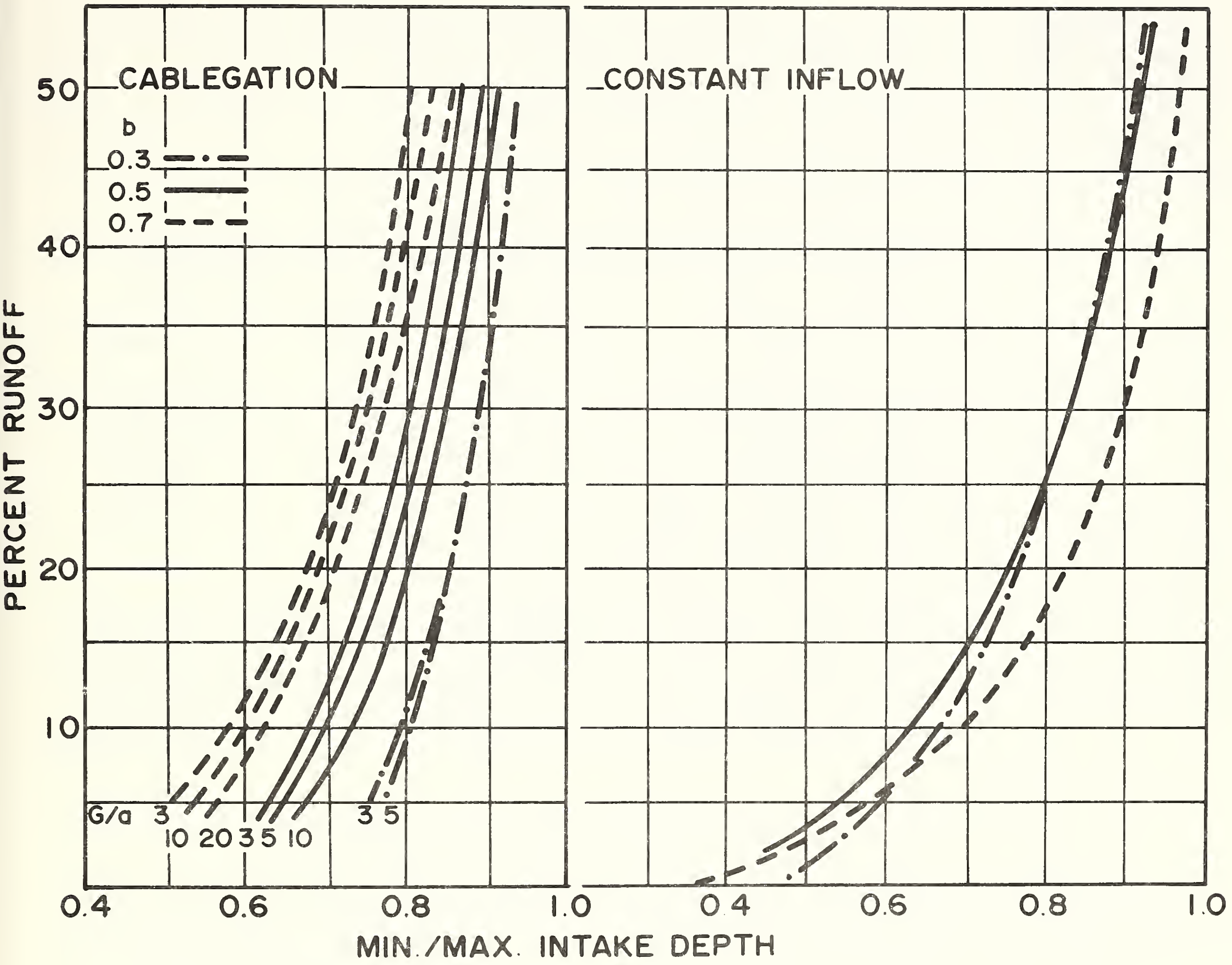


Figure 42.--Cablegation design curves for b=0.3.

intake characteristics of the soil and assuming intake uniformity across the field. A minimum stream size is needed to produce runoff for a given gross application.

Use of These Dimensionless Equations and Figures to Design Cablegation Systems

As an example of how to use these equations and figures, consider the following set of parameters which describe the features of the land for which a system is to be designed.

Parameter	English units	Metric units
Slope along headlines, S_o	0.003	0.003
Water-supply rate, Q.	581 gal/min	2,200 L/min
Distance between furrows, F . .	2.5 ft	762 mm
Length of furrows, E.	984 ft	300 m
Intake after 1.0 hour, a	0.1 ft	30 mm
Intake-time exponent, b	0.5	0.5
Gross (average) application, G .	0.5 ft	150 mm

For values of b=0.5 and G/a=5, figure 45 shows that 15-percent runoff would give a minimum/maximum intake ratio of 0.74, which is acceptable. Using figure 43 with 15-percent runoff, the value of q_m/EFab is found to be about 0.9. Thus, the maximum furrow supply rate q_m is estimated as 0.9 EFab, which in English units is

qm=0.9(984)(2.5)(0.1)(0.5)=111 ft^3/hr=1.85 ft^3/min
=13.8 gal/min. This is about 52 liters/minute.

Equation [E-1] is used to determine pipe size and flow capacity. The commercially available pipe size which is large enough to carry 581 gallons/minute on this slope is nominal 10-inch (0.82-feet) diameter. At this slope and with C=150, figure 25 shows this pipe can carry Q_c=2,840 L/minute or 750 gal/min. The flow ratio is Q/Q_c=0.77. Equation [E-5] is used to calculate the outlet size, d=0.1 feet, or 30.4 mm. The maximum outlet head is calculated by equation [E-2], H=0.5 feet or 150 mm. The flow distance, X, calculated from equation [E-3] is 215 feet or about 66 m, and the number, N, of flowing outlets is 86. In English units, the flow rate

Q=(gal/min)/(gal/ft^3)=581/7.48=77.7 ft^3/min.

From equation [E-8], the plug speed, P=Q/EG=77.7/(984x0.5)=0.16 feet/minute or about 0.05 meters/minute. According to equation [E-6], the cable tension, f, will be about 31 pounds.

APPENDIX F - OUTLETS FOR CABLEGATION SYSTEMS

Outlets distribute and direct the water to the individual furrows or borders. The outlets described here are for furrow flows. An example of an outlet for the large flows required for border irrigation is described in appendix J, figures 88, 89, and 90. An outlet is normally required for every irrigation furrow, although the number of outlets can be reduced if tubing is used to direct the flow to alternate furrows during alternate irrigations. Outlets can be installed directly on the pipe lying on the surface or can be attached to risers from buried pipe.

Outlets can fulfill requirements in addition to water distribution. Adjustable outlets allow flows to be varied with soil intake-rate changes (see "Gooseneck Outlets" page 93). They also give a system flexibility and simplify design. A disadvantage of adjustable outlets is that they allow the unconscientious irrigator to set water nonuniformly. Energy-dissipating outlets reduce the outflow jet velocity and redirect the flow toward the soil surface. This reduces erosion at the head of the furrow and prevents the jet from being blown out of the furrow by wind. Jetting and erosion can become problems when the slope on the cablegation line is greater than about 0.4 percent and pressures at the plug are greater than 1 foot. Cutoff outlets abruptly stop flowing when the flow rate decreases below a critical value. This improves uniformity by reducing or eliminating tail-end recession.

Predicting Discharge

The flow through an outlet is proportional to the flow cross-sectional area and to the square root of the head or pressure and can be calculated by the outlet-discharge equation

$$Q=C_d A\sqrt{2gh} \qquad \text{[F-1]}$$

where Q=flow rate, C_d=discharge coefficient, A=area of the outlet constriction (narrowest point), g=acceleration of gravity, and h=head (pressure) on the outlet.

When Q is in liters per minute, A is in square millimeters, and h is in millimeters

$$Q=.0084\ C_d A\sqrt{h} \qquad \text{[F-2]}$$

When Q is in gallons per minute, A is in square inches, and h is in inches, the equation becomes

$$Q=7.23\ C_d A\sqrt{h} \qquad \text{[F-3]}$$

The discharge coefficient, C_d is about 0.65 for holes drilled directly in pipe and can vary from 0.60 to 0.80 for different types of outlets. Design procedures commonly assume a discharge coefficient of 0.65 for the outlet. Outlets with other discharge coefficients can be adapted to the procedure by calculating an effective outlet area, A_e, or effective outlet hole diameter, D_e:

$$A_e=A(C_d/0.65) \qquad [F-4]$$

$$D_e=D(C_d/0.65)^{0.5} \qquad [F-5]$$

For some adjustable outlets, determining the outlet area is difficult. These can be calibrated to determine the setting to achieve an effective area or diameter for use in the design procedure.

Holes in the Pipe

The simplest and least expensive outlet is a hole drilled in the pipe. This doesn't fulfill any of the additional functions given above but can and has worked satisfactorily if pressure in the pipe is low and field infiltration rates don't vary too much over the season.

Flexible Tubing Fittings

Some adjustability can be achieved at relatively little expense by inserting the plastic outlet fittings used with thin-walled "lay-flat" irrigation tubing in the holes, as shown in figure 13. The fittings are flexible and can be collapsed with the fingers and inserted into holes in the pipe (names and addresses of manufacturers of these fittings will be furnished on request). Corsage pins or thin sharp nails inserted across the fitting can be used to hold the outlet in the hole. These fittings are available to fit 1.25- and 1.75-inch diameter holes in the pipe with 0.5-, 0.75-, and 1.0-inch outlet holes in the smaller size and 1.25- and 1.5-inch holes in the larger size. Intermediate sizes can be made by punching holes in caps made for the outlets. Outlet sizes can be reduced by snapping caps with smaller punched holes over the fitting. As equation F-1 indicates, flow will vary proportionally with the area or the square of the hole diameter. Discharge coefficients increase as the ratio of the diameter of the hole in the pipe to hole in cap. Energy dissipation can also be achieved as indicated in figure 16. However, using these fittings, changing outlet size on a 1300-foot line commonly requires several hours.

Gated-Pipe Slide Gates

Flexible plugs (e.g., app. J, fig. 109) will migrate past regular gated-pipe slide gates. These slide gates manufactured in large quantities are the least expensive adjustable gate. Use of regular PVC slotted, gated pipe also eliminates the need to drill holes to attach outlets. The flow area of a wide-open slide gate is about 2.3 in^2, or equivalent to a 43-mm (about 1.7-inch) diameter hole. Discharge coefficients decrease from about 0.8 when the gate is nearly closed to 0.65 when it is open. Some farmers depend on their visual perception to adjust gates to uniform flow. Widely varying flows are common. A small board or rod can be inserted into the slot and the gate closed against it to achieve better uniformity.

Neither the slide gates nor the inserts shown in figure 13 provide significant energy dissipation and thus they are not recommended in systems which develop heads next to the plug greater than one foot.

Gooseneck Outlets

Figure 46 shows a commercially available gooseneck outlet which provides precise adjustability, energy dissipation, and cutoff. It can be attached directly to the pipe with the rubber bushing, or to a riser with a slip coupler. A removable orifice disk, available in several sizes from 12- to 22-m (about 1/2- to 7/8-inch diameter) is inserted into the coupler or bushing. The outlet thus provides precise settings. Adjustment requires slipping out the gooseneck and replacing the disk. The 1-inch gooseneck presently available provides a maximum equivalent open area of 500 mm^2 (about 0.75 in^2) or equivalent diameter of about 25 mm (about 1-inch). Discharge coefficients average about 0.75, so equivalent diameters are about 7 percent larger than actual orifice disk diameters.

The gooseneck directs the flow to and parallel with the soil surface. Since the outflow end is larger than the constricting orifice disk at all but the maximum flow, the outlet generally provides energy dissipation.

The gooseneck outlet operates as a siphon, and the outflow end determines the reference elevation. When the flow decreases below a critical value, air will move up the tube and break the

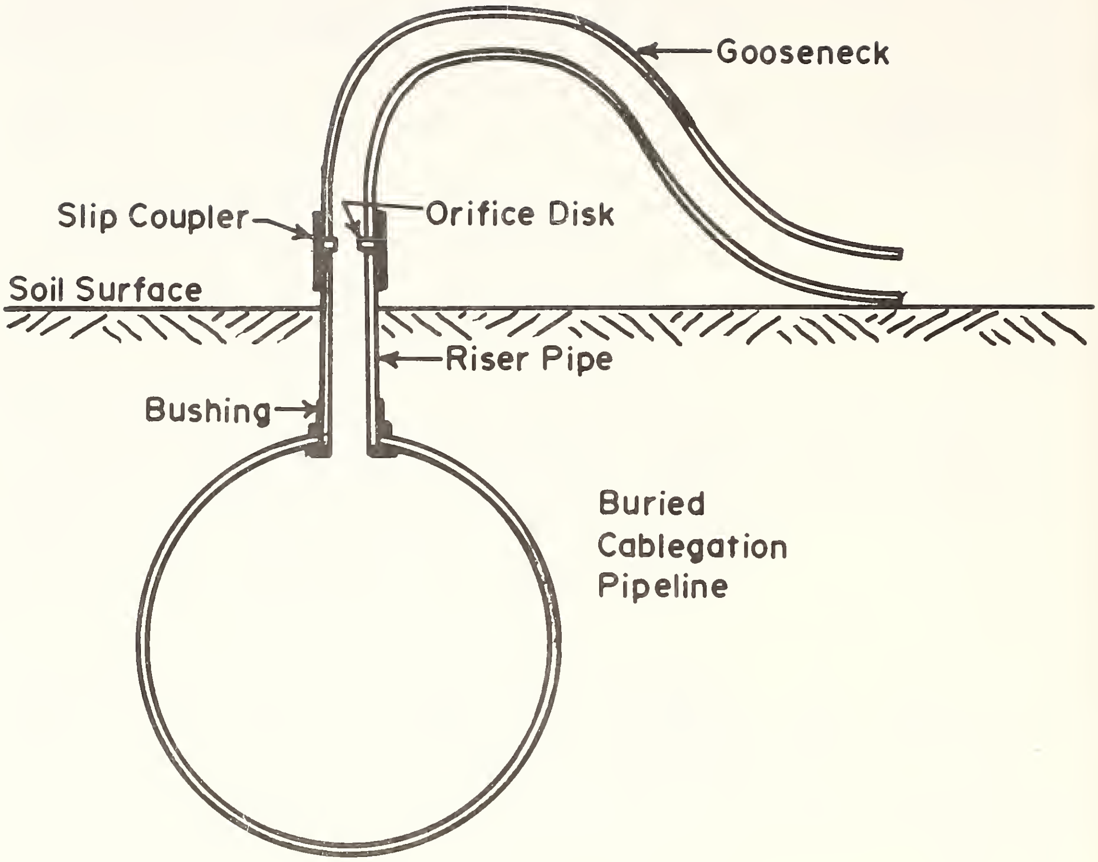


Figure 46.--Gooseneck outlet on a riser.

siphon. The cutoff flow for the 1-inch gooseneck is 8 L/min (2 gal/min). As long as the head required to provide this critical cutoff flow is less than the height of the top of the gooseneck above the outflow end, the cutoff will be complete. This cutoff head, h_c, can be calculated, based on a cutoff velocity of 230 mm/sec (9 inches/sec) as

$$h_c = K'(D/D_o)^4 \qquad [F-6]$$

where h_c=the cutoff head in millimeters, D=the outflow end diameter, D_o=the constricting orifice diameter, and K'=6.4 when the cutoff head is given in millimeters. When h_c is desired in inches, K'=0.25.

For the 1-inch goosenecks, D=26.6 mm (about 1.05 inches). The smallest orifice disk available has an inside diameter of 12 mm and has an effective diameter of 13 mm. Consequently, the maximum cutoff head required is 110 mm (about 4.3 inches), or the top of the gooseneck must extend at least 110 mm above the outflow to get a complete cutoff with the smallest orifice. With larger orifices, the cutoff head will be lower.

Because the outflow end of the gooseneck establishes the reference outlet elevation, it is important that the end be on grade. Goosenecks which tip upward or sag will discharge relatively less or more water. This can result in significant nonuniformity in systems with little slope along the pipe.

An adaptation of the gooseneck outlet made from PVC pipe and ABS plumbing fittings is shown in figure 47. When the drop tube is vented just below the orifice disk, the orifice, rather than the outflow end, becomes the reference elevation. Thus, the outlet elevation is dependent neither on the pipe outlet elevation nor on field-surface elevation. Only the riser pipes need to be cut to grade. This type of outlet was used to create an artificial grade on a cablegation line on a field with no cross slope. It could also be used to continue a cablegation line across a low area without constructing an elevated pad.

Like the gooseneck siphoning outlet, this outlet will also cut off the flow below a given rate. Due to the air vent in the drop tube, the orifice constriction forms the outflow end of the siphon. Consequently, the cutoff rate which occurs at a relatively constant flow velocity at the outflow end will vary

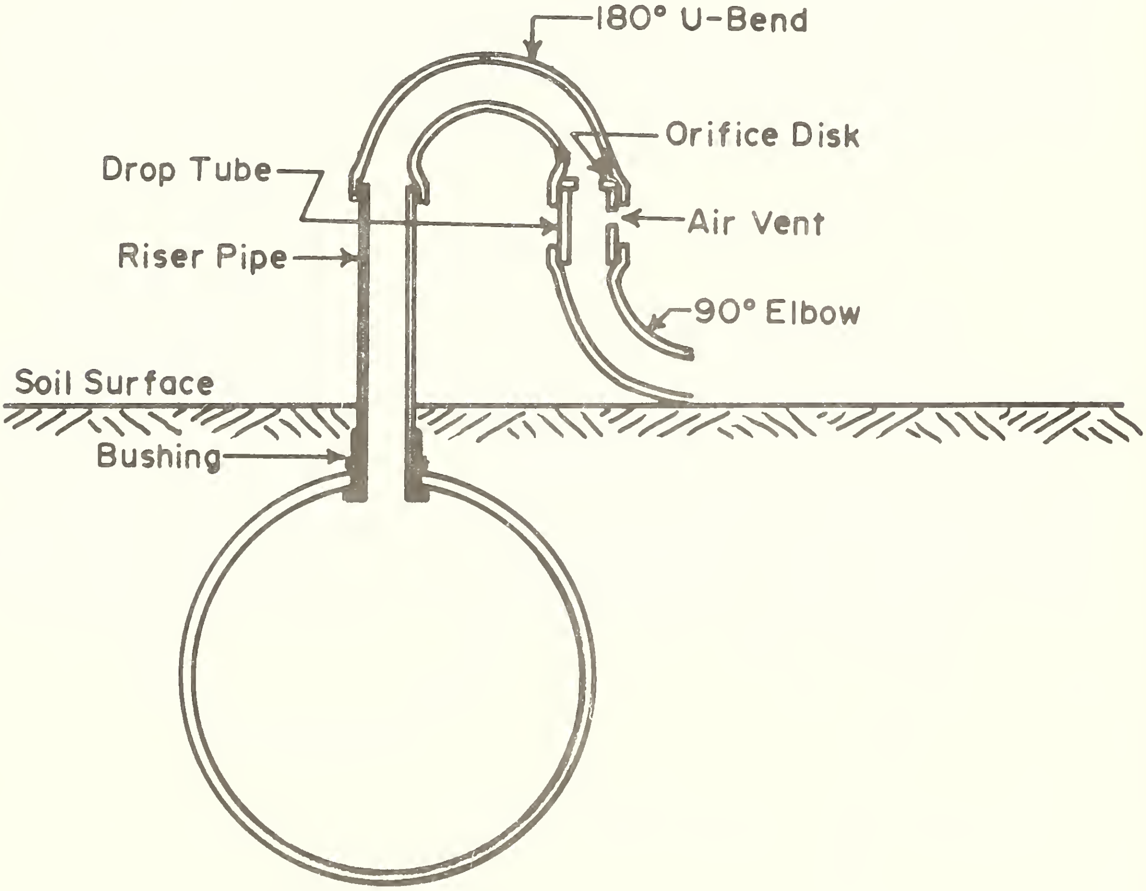


Figure 47.--Modified gooseneck outlet.

with the orifice size. The cutoff flow rate will thus be proportional to the flow rate at any given head. This allows some control in setting not only the maximum flow but also the cutoff flow for a soil's infiltration characteristics.

A 2-inch version of this outlet has a maximum effective flow diameter of 51 mm (about 2 inches). Orifice discharge coefficients average 0.70. Pipe and fittings are available in 1.0-, 1.5-, and 2.0-inch sizes, although bushings are presently available only in 1.0- and 2.0-inch diameters.

Barrel Spigot Outlets

Several adaptations of plastic barrel spigots are available for cablegation systems. Standard barrel spigots for 3/4-inch and and 2-inch taps are commercially available. Two irrigation outlets based on the spigot design, such as that shown in figure 48, are available in a 1-inch size. The 3/4-inch and 1-inch sizes can be attached directly to the pipe with threaded rubber bushings. The 1-inch and 2-inch sizes can be attached with the slip-in bushings shown in figures 46 and 47. All three sizes can be attached to risers with threaded couplers. Bushings are also available which allow the 1-inch version shown in figure 48 to snap into standard rectangular gated-pipe slots.

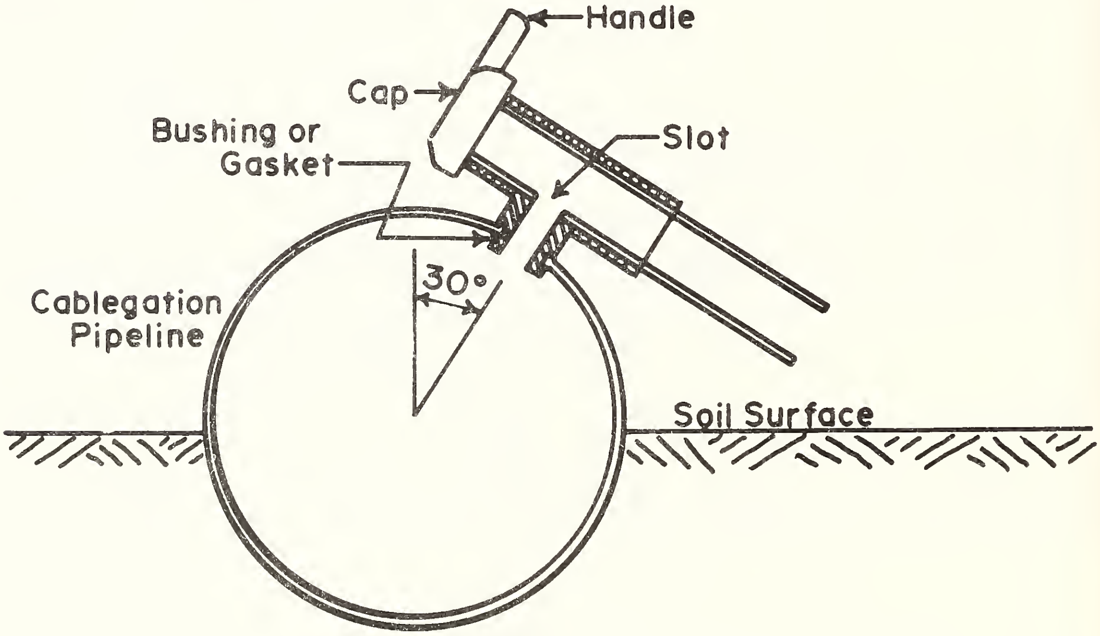


Figure 48.--Barrel spigot-type outlet.

The spigot valves are essentially plastic tees through which a capped, slotted pipe slides. When the pipe is rotated, the slot lines up to varying degrees with the leg of the tee, thus adjusting opening area and flow rate. The two 1-inch models tested had maximum effective diameters of about 25 mm (1 inch). The 2-inch version had a maximum effective diameter of 41 mm (about 1.6 inches). All can be adjusted to any setting. If the outlet has setting markings, they can be set precisely.

For all except wide-open operation, the outflow end is larger than the constriction and the outlet provides some energy dissipation. The amount of dissipation depends on the length and diameter of the outflow pipe. All spigot outlets redirect the flow 90°, a factor which can be used to direct flow down toward the ground and reduce wind effects.

When the spigots are installed at an angle and have a fairly long outflow pipe, they can act as a siphon type cutoff outlet. However, when the elevation difference between the outflow end and the outlet high point is small, the cutoff will be complete only at high settings. At lower settings, the cutoff head will be above the outlet high point, and the flows will abruptly decrease as air enters the outlet and as the reference elevation switches from the outflow end to the slot, but they will not cut off completely. Rotating the outlet downward will increase the elevation between the slot end and improve the cutoff. Rotating the outlet upward to a horizontal position eliminates the cutoff effect.

Gravity Cutoff Outlet

Figure 49 shows a mechanically activated cutoff outlet consisting of a vertical outlet and a weighted valve. The valve opens fully when the plug passes the outlet and remains fully open until the head drops below the head needed to support the weight of the valve and then closes completely. The opening distance is adjustable to control the maximum stream size. The head at which cutoff occurs is controlled by the weight of the valve assembly and the size of the outlet. This type of outlet works effectively but is not manufactured commercially.

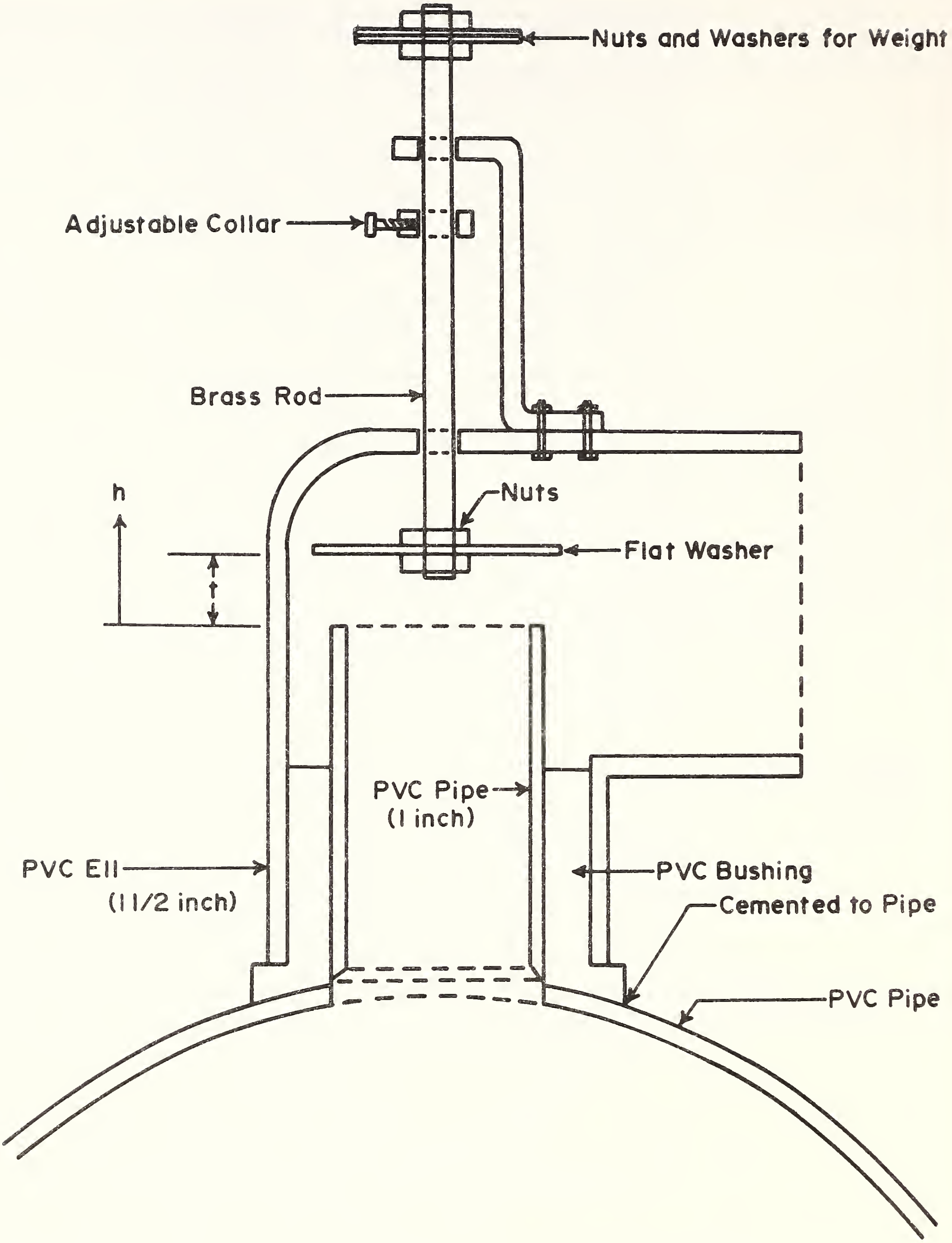


Figure 49.--Gravity-controlled cutoff outlet.

Benefits Derived From a Sharp Cutoff of the Water Supply

The inherent cutback flow of the cablegation system is generally advantageous for reducing runoff. However, the tail-end flows which are insufficient to reach the ends of the furrows can, in some cases, decrease application uniformity. For instance, in the system decribed in figure 9, water is not reaching the ends of most of the furrows after 9.5 hours, and the water added after that time is absorbed by the upper reaches of the furrow, which have already had a longer intake opportunity time than the bottom end. Ideally, uniformity of infiltrated water could be maximized if the inflow to each furrow could be cut off abruptly when the runoff from that furrow ceased. The benefit obtained from cutoff would depend on the shape of the infiltration curve. If water intake by the soil remains relatively high throughout the full period of normal cablegation delivery to the furrow, the water ceases to reach the end of the field at an earlier time and benefits of cutoff are appreciable. However, if the soil has a low sustained intake rate and high initial rate, water continues to reach the end of the furrow till near the end of the supply time, and benefits from cutoff are small.

Figure 50 shows the effect (calculated using the computer model) of cutoff outlets on intake along a furrow, when intake=0.41 $T^{0.7}$+0.21 inches and T is the hours for which water is in that

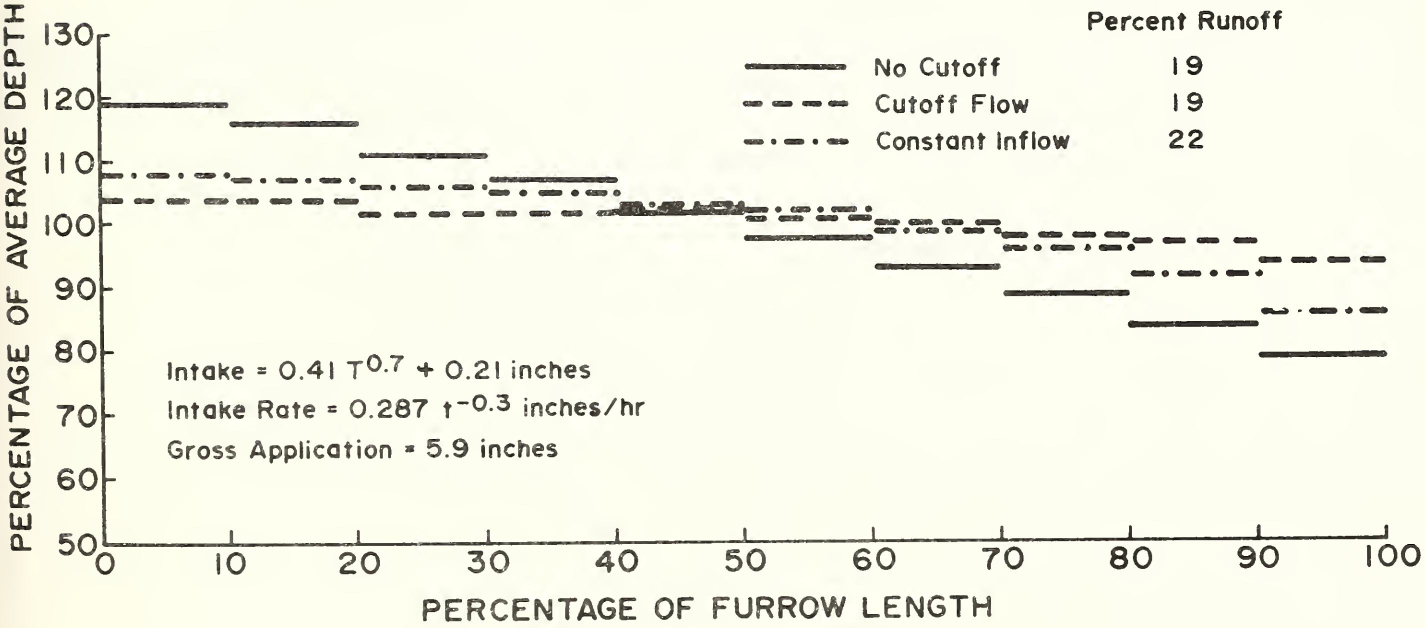


Figure 50.--Intake along a furrow.

section of the furrow. Figure 51 shows the furrow inflow and runoff rates calculated for this same soil when the supply is via normal cablegation, via cablegation with cutoff outlets, and via constant-supply gated pipe or siphon tubes. For the cutoff-flow case, the cutoff head (1.6 inches) was selected so that the cutoff occurred at about the same time that runoff ceased. The size of the cutoff outlets was reduced in order to obtain about the same percentage of runoff (19 percent on the cablegation supplied systems). Gross application was 5.9 inches in all cases. The initial stream size was slightly smaller, and the beginning of runoff was delayed, as shown, for the cutoff compared with the regular cablegation system. The selection of the optimum cutoff head is a trial-and-error process. Figure 51 also shows the runoff curve for a constant inflow rate for comparison.

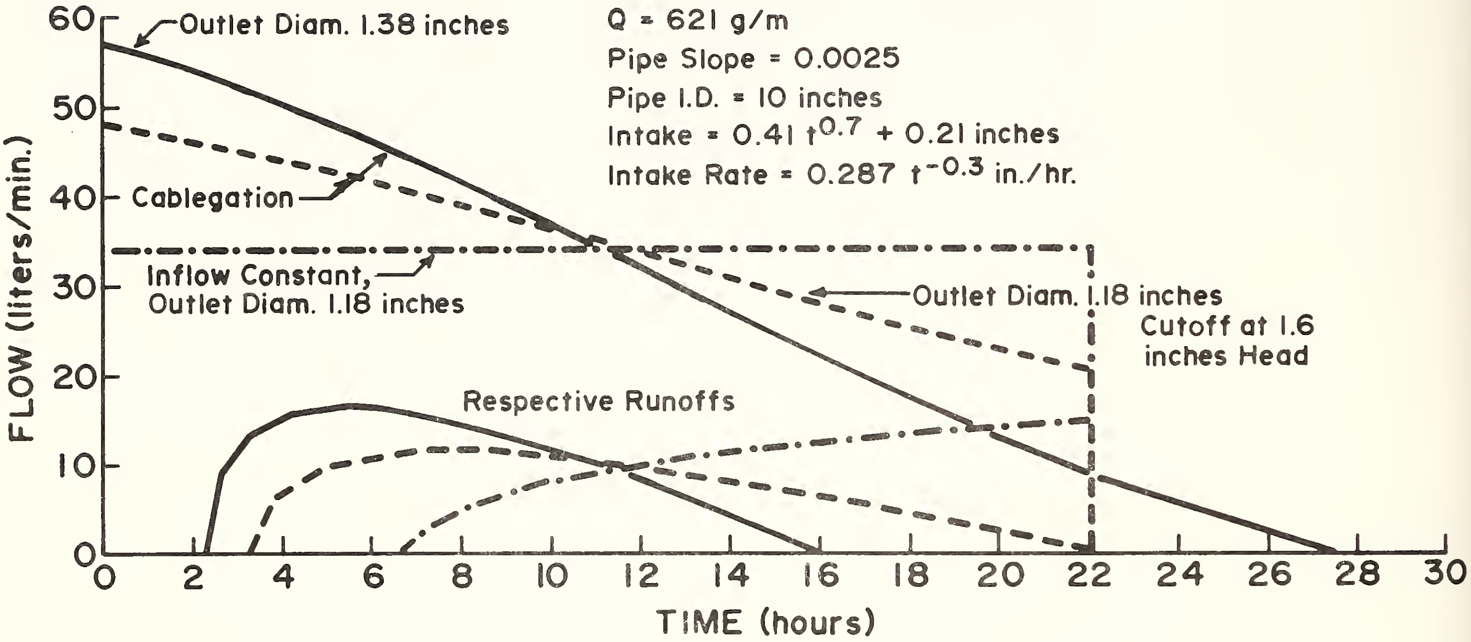


Figure 51.--Inflow and runoff rates.

Figure 52 shows the effects of cutoff outlets on intake along a furrow where intake=1.11 $T^{0.4}$ inches. The initial intake rates are higher for this intake function than for that used in figure 50, but after about 6 hours, the intake rates are lower than in the previous example. The relative improvement of the distribution because of cutoff is less than that shown in figure 50 where the infiltration rate was higher when flow ceased to reach the end of the furrow.

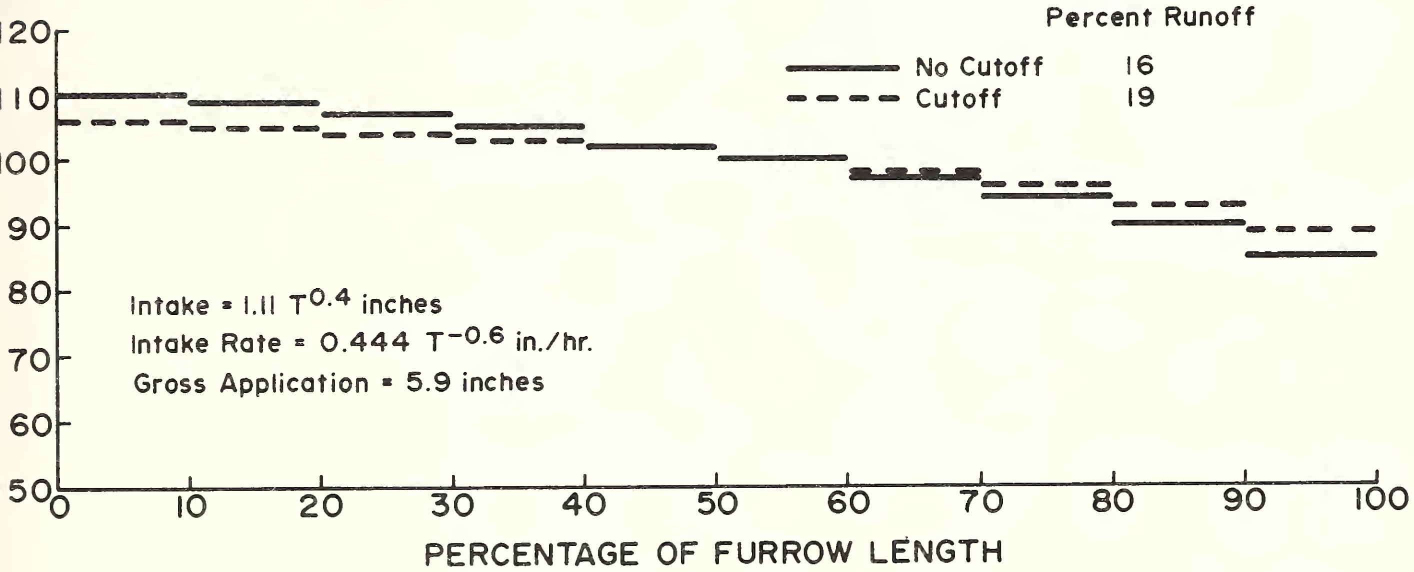


Figure 52.--Distribution of infiltrated depth.

The Need for Energy Dissipation

In cablegation pipelines, as in regular gated pipe, if the pressure or head in the pipe is high, water jets from the outlets with considerable force. If this water jet has sufficient velocity, it will cause erosion problems at the head of the furrow. In cablegation lines where outlets are turned upward, the jets shoot into the air and are difficult to direct into the furrow when there is wind.

Pressure in cablegation lines is caused by the "depth" of water backed up behind the plug, which depends upon the length of pipe full of water and the slope on the line. When this "depth," which is the product of the slope and the filled length (or number of outlets flowing times outlet spacing) minus head losses in the pipe in that section, is greater than 300 mm (about 12 inches), the head at the plug should be calculated (i.e., Eqn. E-2) to determine if a problem with jetting may occur. Since less than 250 feet of most cablegation lines flow full, high head will usually be a problem only when slopes along the lines are greater than about 0.004.

Merits of Dissipating Energy Inside vs Outside of the Pipe

Jetting can be controlled either by breaking up the jet outside the outlet with special gates, deflectors, or screens, or by reducing the pressure inside the pipeline. The special gates are often expensive and may plug with trash. Deflectors and screens interfere with adjusting the outlet gates and judging flow rate. Therefore, reducing pressure inside the pipe is often a desirable alternative.

The pressure can be reduced by dissipating the energy of the flowing water. The energy can be dissipated by partially obstructing the flow, an action which creates a head loss or pressure drop below the obstruction. When these obstructions are attached to and move with the cable, they will reduce pressures in the cablegation line.

Design of Energy Dissipators

Obstructions which cause the flow to contract and speed up then abruptly expand again generate more turbulence and consequently are more efficient at creating head loss than those where the obstruction is streamlined downstream and the expansion is gradual. These obstructions, however, must not catch at joints or gates as they move down the pipe with the cable. Figure 53 shows two types of energy dissipators which have been used successfully in the field. The first is essentially a plug with a hole in the center which acts as a circular bypass. The cable attaches to both ends of the plug. Another type (fig. 54), constructed from a section of PVC pipe and 2 end plates, resembles a boat. This boat must be heavy enough that turbulence does not cause it to bounce around in the pipe, which could cause it to catch gates protruding into the pipe or bump them to more open or closed positions. A lead weight in the bottom of these boats kept them on the bottom of the pipe. By offsetting the lead weight 30 degrees from the bottom, as shown in the bottom of fig. 53, the flat side of the dissipator can be directed toward outlet gates, minimizing the chances of bumping or catching gates which protrude from the inside of standard gated pipe. This design has been used successfully in standard PVC gated pipe. This boat type is attached to the cable as it is being fed into the pipe.

Several dissipators can be spaced behind the plug to create the desired pressure distribution in the cablegation pipe. The pressure dissipated by each device will depend upon the flow velocity in the pipe at the dissipator, the shape of the dissipator and the open area available for flow past it and can be predicted by an equation of the form,

$$H = \frac{Q^2}{C^2}\left[\frac{1 - (a/A)^2}{2g\ a^2}\right] = \frac{Q^2}{2g\ C^2}\left[\frac{1}{a^2} - \frac{1}{A^2}\right] \qquad [G\text{-}1]$$

where H is the head loss at the dissipator, Q is the flow rate in the pipe at the dissipator, C is the discharge coefficient for the dissipator shape, a is the area open for flow past the dissipator, A is the flow area of the pipe, and g is the acceleration of gravity (9.81 meters/second^2 or 32.2 feet/second^2). The coefficient, C, will depend upon the shape and abruptness of the flow obstruction, but will generally fall between 0.6 and 0.9.

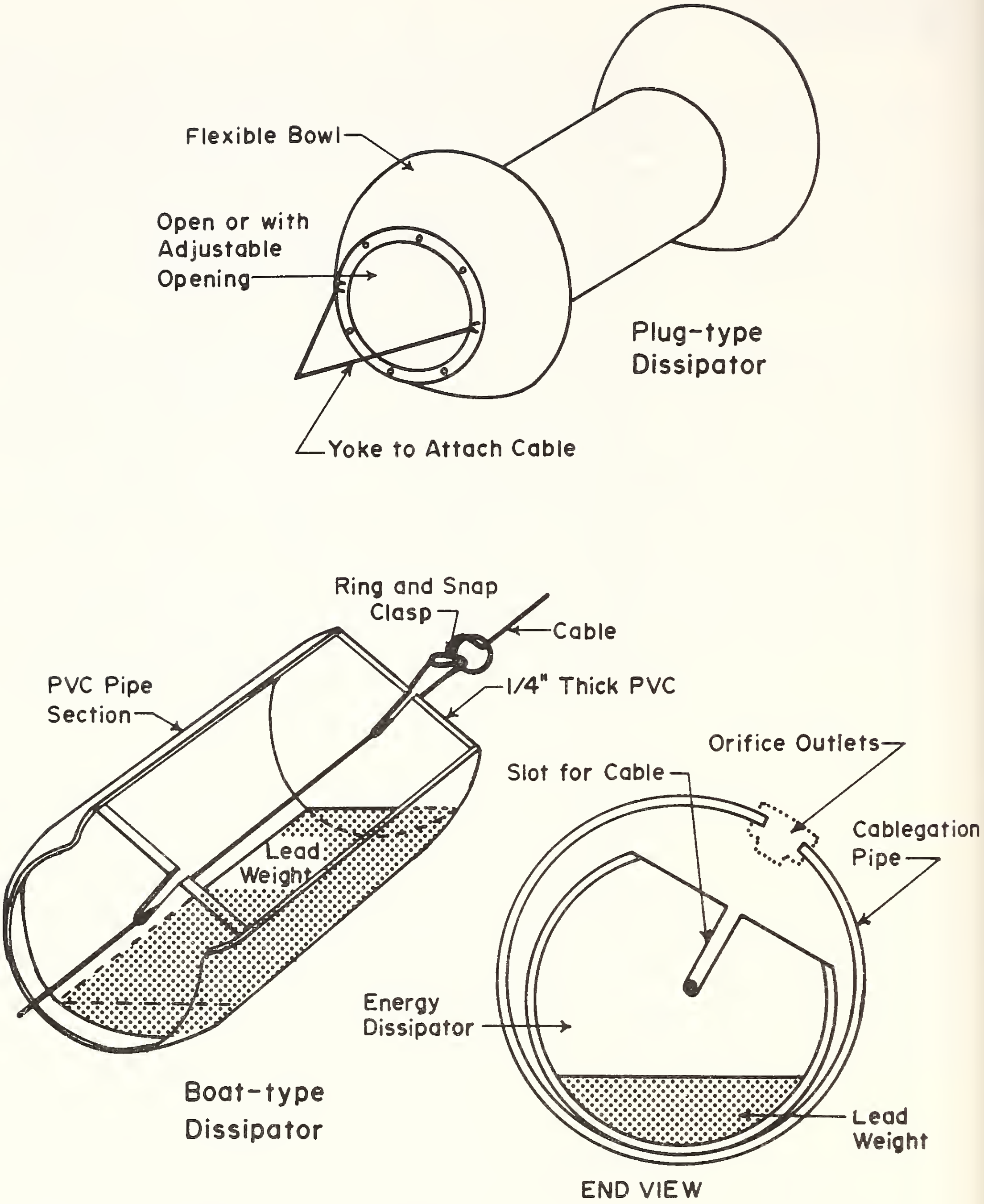


Figure 53.--Energy dissipators.

The equation shows that, as the flow rate decreases, the open flow area past the dissipator must get smaller to achieve the same amount of head loss. Thus, to reduce the pressure at the plug in equal increments, the open area must vary inversely with the flow rate at that point.

Effects on Outlet Flows

Use of dissipators to lower pressures in the pipe affects outlet flow rates. The rates no longer continually decrease with time as shown in the one-plug line in fig. 8, but decrease and then abruptly increase in cycles as indicated in the sawtooth-shaped curve in that figure. Spacing the dissipators further apart results in intermittent flow. When the pipe flow is well below capacity, outlet outflows are proportional to the square root of the pressure in the pipe. Figure 54 shows the pressures and outlet outflow rates along a cablegation line in which three of the boat type dissipators were installed. Because of the interaction between pressure and flow rate, either trial and error or incremental analysis (by computer) must be used to accurately design for the desired line-energy dissipation.

This effect on outflow distribution shows that energy dissipators could also be used to change the outlet outflow hydrograph. For example, dissipators can be used to get longer set times and lower flow rates without adjusting outlet sizes. Dissipators can also be used to reduce peak flows and flatten out hydrographs or to surge the flow by reducing heads in the line to below the outlet elevation.

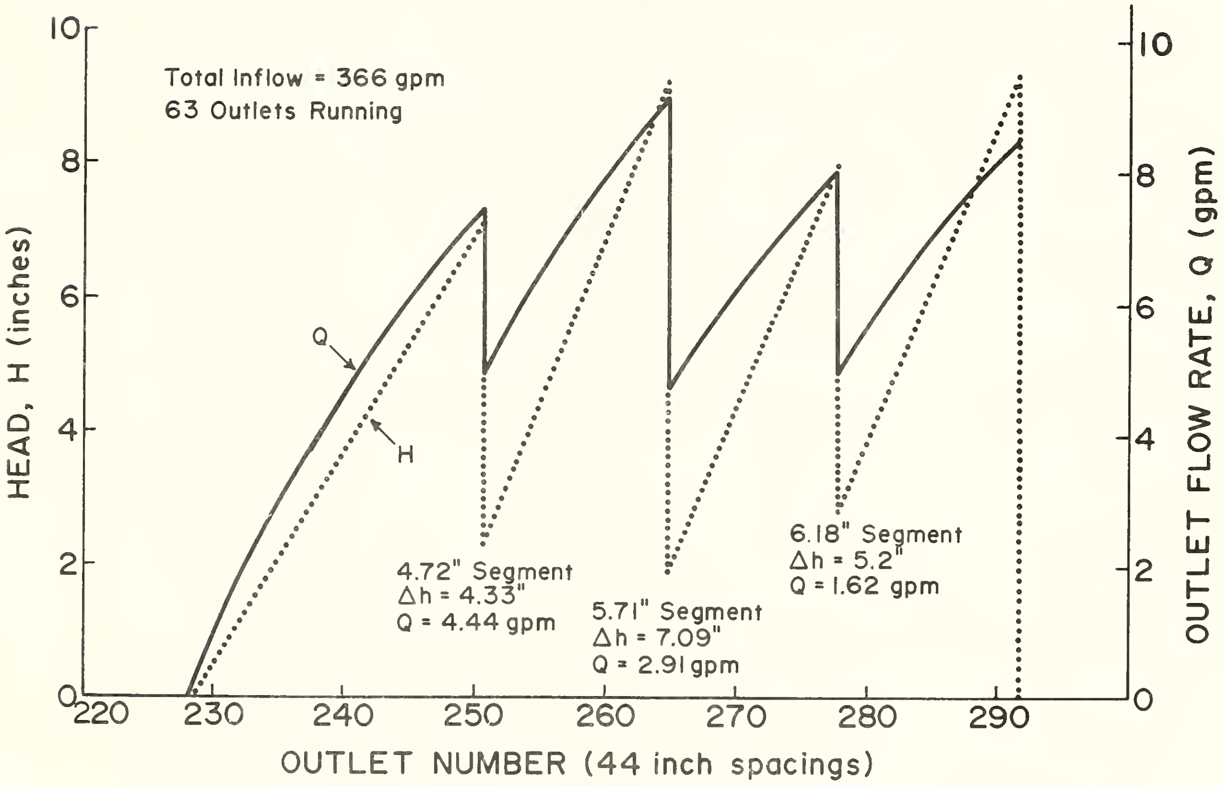


Figure 54.--Head and outlet flow distribution in an 8" cablegation line with three boat-type energy dissipators (Glenn farm).

Due to the pressure pulling on the plug, installation of the cable and attached plug and dissipators in the pipeline while the water is flowing, can be hazardous and commonly requires two persons. To avoid these problems, a lightweight line about 300 feet long was attached to the end of the cable when the plug and dissipators were removed at the end of an irrigation. When the cable was reeled in, the operator stopped reeling as soon as the end of the cable appeared, leaving the line in the pipe. When preparing for the following irrigation, a piece of bent wire was used to hook and pull the line out of the outlet just downstream from the planned starting position of the plug. The upper end of that line was detached from the cable, the plug was attached to the cable, and the line was attached to the plug. Then the line was used to pull the plug and cable into the pipe, stopping and attaching dissipators to the cable as the loops for those attachments appeared. The insertion process is easier for one person if a small reel is provided for the lightweight line next to the inlet box. Reeling in the line from that point pulls the main cable into the pipe and allows the operator to do all the operations from that position. A metal shield on the hole where the line comes out of the pipe is needed to prevent the sliding line from cutting into the PVC at the edge of the hole. The dissipators and plug can be attached to the cable and pulled into the pipe by an experienced operator in about 15 minutes.

Further work is being done to accurately predict dissipator discharge coefficients, to develop alternative dissipator shapes, to develop dissipators whose cross section can be adjusted while they are in line, and to develop design parameters for spacing and cross sections needed under various flow conditions.

APPENDIX H - SCREENING SYSTEMS FOR REMOVAL OF TRASH AND WEED SEEDS

General Objectives and Problems of Screens

Leaves, twigs, grass, straw, root fragments, moss, and other trash in the water can lodge in outlets and stop or reduce flow, resulting in inadequate irrigation of the furrows served. Constant surveillance to clean trash out of these outlets is expensive. Such surveillance is particularly incompatible with automated systems because an objective of automated systems is to reduce the labor and surveillance required.

Separation of trash from farm irrigation water is commonly accomplished by passing water through a screen which has sufficiently small openings to retain the undesirable material. The basic problem with screen removal of trash is accumulation of trash on the screen which, if not removed as fast as it accumulates, eventually blocks the flow of water through the screen.

Screens Cleaned by Brushes

Mechanical devices have been developed with moving brushes to sweep trash from an inclined screen and deposit it at the side of the irrigation channel. Many of these are reasonably effective. Some are powered by electric motors. Others, such as those shown in figure 55 are powered by paddle wheels rotated by the flowing water. This allows them to be installed at locations where electric power is not available. Moving parts and bearings on these devices require maintenance and replacement to keep the device operative. In some cases (see, for example, fig. 108) they can also furnish sufficient energy to operate the cablegation control system.

A screening system of the type shown in the top of figure 55 was tested in the Snake River Conservation Research Center hydraulics laboratory to determine the head loss which would occur when the screens were clean and the rate at which the screen would turn as a function of flow rate. (Names of manufacturers of these items will be supplied on request. Refer to this as the "paddle-wheel screen".) Data obtained on a screen system 18 inches wide with a paddle-wheel diameter of about 42 inches are shown in figure 56. The three curves were obtained for tail-water levels about 0.2, 0.5, and 0.8 feet above the screen floor. The numbers associated with each data point

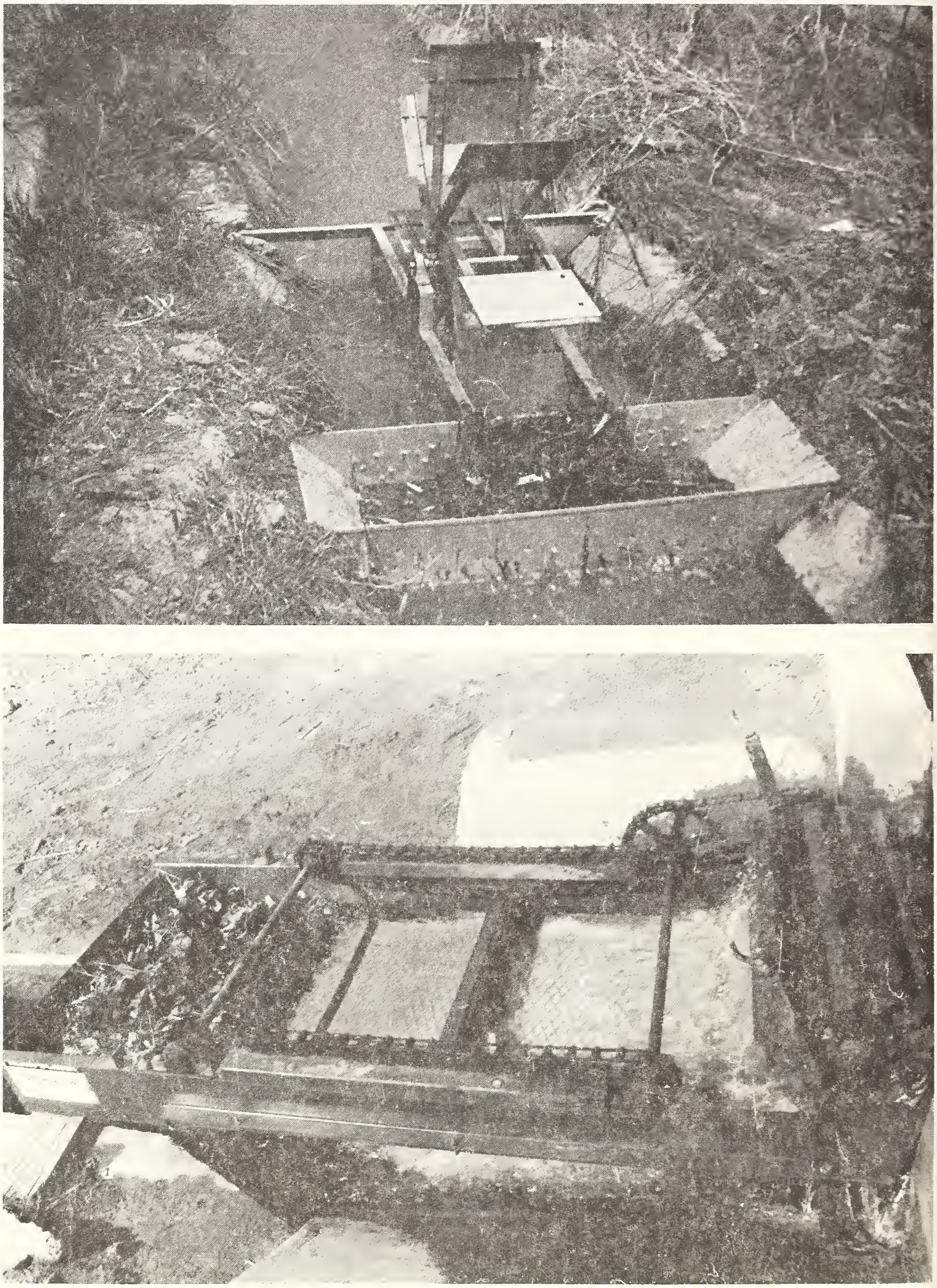


Figure 55.--Hydropowered mechanized screens.

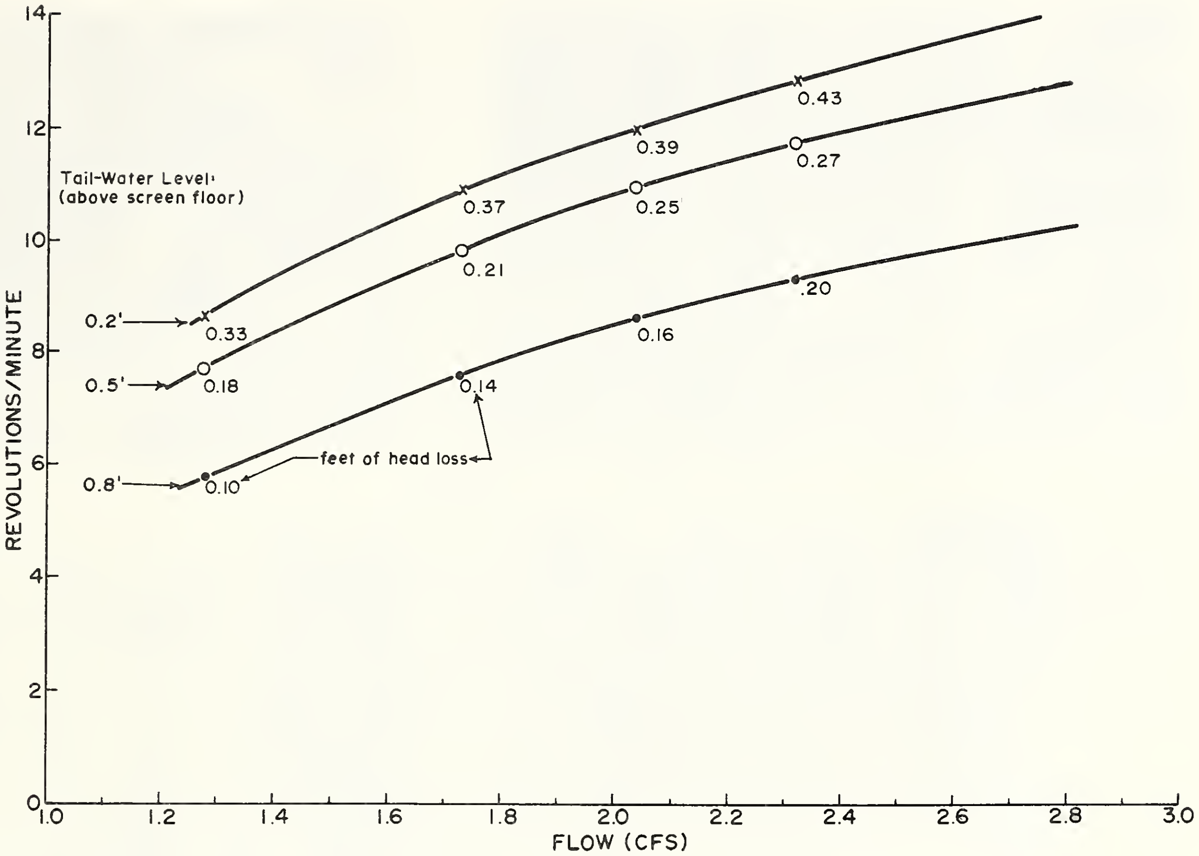


Figure 56.--Evaluation of speed and head loss of an 18-inch wide paddle wheel screen for use as a controller for the cablegation plug.

indicate the head loss, in feet, occurring at those flow rates and tail-water conditions. The force of the water on the paddle wheel was found to be approximately equal to the product of the average paddle area in the water and the pressure head drop across them. These forces ranged from about 10 to 20 pounds. The torque transmitted to the axle is equal to this force times the distance from the center of the axle to the effective midpoint of the force on the paddle wheel (which in this case was about 1.4 feet) minus losses due to friction of the rubber paddle flaps on the screen and other frictions in the system. This resulted in net torques of about 12 to 25 foot-pounds. This torque, coupled with rotational speeds indicated in figure 56, provides power that is more than sufficient to operate a control mechanism for a cablegation system.

The power from this type of screen was coupled to a cablegation control system installed on the Max Baker farm near Powell, Wyo., in the spring of 1982. Details of this installation are shown in appendix J, figure 107.

Screens Cleaned by Action of the Water

General Concepts of Falling Water Types

Dropping the water from a pipe, weir, or check structure onto a taut, horizontal screen has been found to be an effective screening technique (Bergstrom 1961). He felt that keeping the screen taut and the drop height sufficient caused the screen to vibrate and move the trash forward on the screen, tending to clear enough screen area for the water to pass through. Commercial manufacturers of these screens suggest 6 square feet of screen per cubic foot per second of flow and a minimum drop of 8 inches.

Rectangular Horizontal Screens

This type of screen has been operated with cleaning at 12-hour intervals on a stream with trash loads of 1 to 5 gallons per 12 hours. However, we had to remove trash from the end of the screen and scrub the screen to remove lodged trash after accumulation of each 5 gallons of trash. A horizontal screen is shown in operation in figure 57. (Names and addresses of manufacturers of this and other screens described in this section will be furnished on request.) The material shown on the screen in the subfigures on the left side of figure 57 was screened from a flow rate of about 1 cfs during an 8-hour period. Some material had lodged on the area where the flow impacts on the screen. The continued pressure of the steady concentrated stream at the point of impact held leaves and other flat organic matter tight against the screen. A major portion of the water was then deflected by this stationary organic matter and moved over the screen in a manner shown by the froth at the edge of the organic matter. Over longer periods of time with higher concentrations of trash in the water, this screen clogged so that most of the water ran off instead of passing through the screen.

The operation of this screen was improved by using a deflector, as shown in the top right of figure 57, to distribute the water more widely across the screen. Another and probably more important effect of this frame was to create more turbulence in the water. The relative amounts of organic matter that lodged in the impact area of the screen without and with the deflector are shown in the lower left and right portions of figure 57, respectively. In preparation for each photograph, the impact area of the screen was scrubbed clean of trash and about 2 pounds of previously accumulated trash was sprinkled into

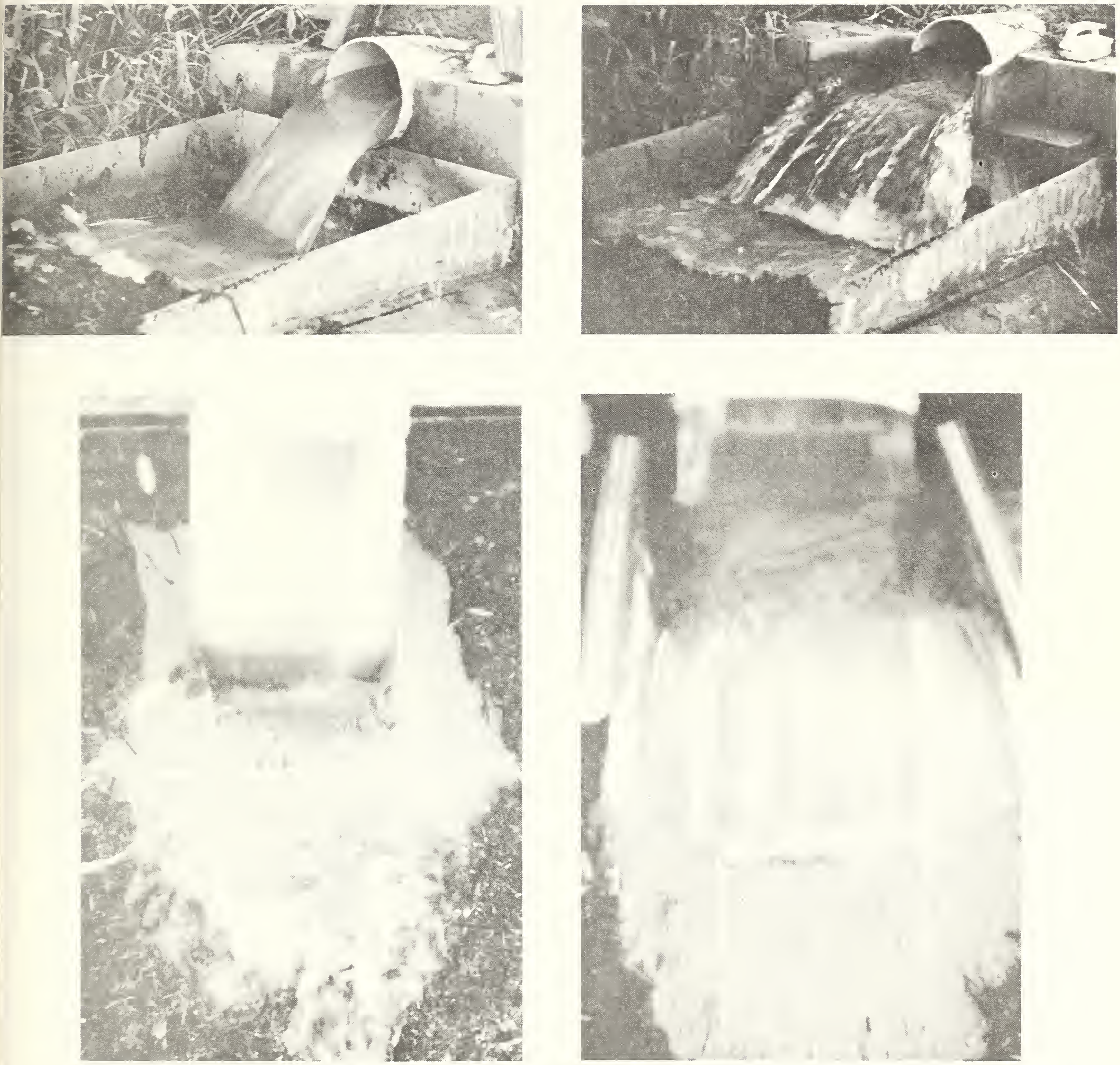


Figure 57.--Rectangular horizontal screens. Upper left--screen with 8 hours collection of trash; upper right--with deflector to broaden impact area and increase turbulence; lower left--trash on impact area with little turbulence; lower right--less trash on impact area with more turbulence.

the supply ditch above the screen. The photographs were taken about 10 minutes after the trash application. When the deflecting frame was used, the increased turbulence dislodged more of the organic matter, and more of the water passed through the screen. Momentary lodging of leaves occurred even when the deflecting frame was used. This caused occasional horizontal jetting of water at the surface of the screen and subsequently pushed loosened trash away from the impact area. From observations of this type we concluded that turbulence of flow, rather than vibratory motion of the screen was the primary factor moving trash off the impact area.

A 24-inch wide by 36-inch long, 20-mesh horizontal trash screen was installed on the Klompien farm to screen water which was flowing at a rate of 1.4 cfs to a cablegation system. The screen, placed with a 4-inch drop, received water from a free discharge, bottom-opening gate as indicated in appendix J, figure 73. Because of considerable pressure in the lateral, the jet of water issuing from this gate impacted on the screen more than halfway down the length of the screen. Because there was considerable horizontal momentum even after impacting the screen, a large portion of the trash and a substantial part of the water moved past the end of the screen. To correct this, a 6-inch diameter, 4-spoke paddle wheel was installed in the effluent jet of the turnout (appendix J, figure 72) as suggested by Bergstrom (1961) for cases of insufficient drop. This paddle wheel was mounted in free-running, oiled wood bearings with a bottom clearance of approximately one-eighth of an inch. The paddle wheel turned at approximately 50 rpm causing about three oscillations per second in the flow. The screen operated satisfactorily thereafter in a water supply with a trash supply rate of 0.5 to 3 gallons per 12 hours.

Turbulent Fountain Type Horizontal Screens

Observations on the effect of turbulence on the efficiency of trash-screen operation (Kemper and Bondurant 1982) led to the design of a circular, center-fed, horizontal trash screen (fig. 58). Water supply is brought up through a vertical pipe extending through the center of the horizontal circular screen and spills on to the surrounding screen. Trash caught on the screen is moved to the outside edge of the screen by the turbulent action of the water. The screen frame was supported on the outside edge by a section of 30-inch-inside-diameter, concrete pipe which is set vertically in the ground. The water passing through the screen is collected in the large pipe section and flows to the cablegation system via the pipe shown at the right of the figure.

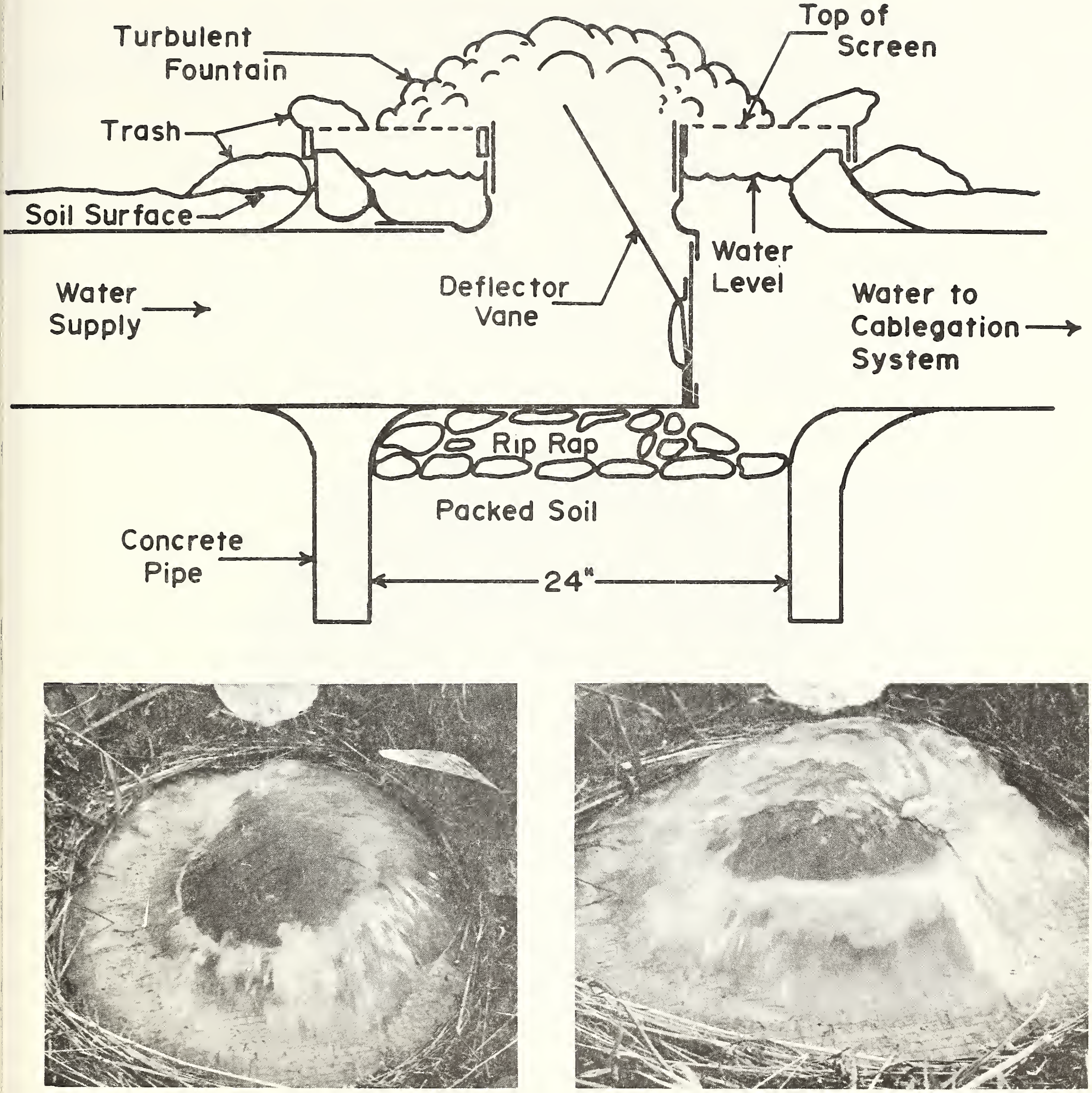


Figure 58.--Turbulent-fountain type of trash screen. Top--side view of a circular, center-fed, horizontal turbulent-fountain type of trash screen; lower left--moderately turbulent unsymmetric flow with vane out of fountain; lower right--violently turbulent symmetric flow with vane in fountain.

The lower portion of figure 58 (taken at 1/60 second), shows a flow of 1.2 cfs using an 8-inch-diameter inlet pipe and a 30-inch-diameter screen where the underground components are arranged as shown at the top of figure 58. The screen details are shown in figure 59. The vertical section of the 8-inch-diameter inlet pipe was deliberately kept short to help induce turbulence. However, it also caused the flow velocity to be greater on the outside of the pipe bend, and most of the flow spilled over that side of the screen. To obtain a more symmetrical discharge from the outlet pipe and cause more turbulence, the deflector vane indicated in the top of figure 58 was installed. (The discharge symmetry can be achieved more completely by increasing the length of the vertical section of pipe. However, when this is done, the action of the square elbow which helps to create the turbulence is also lost. Additional head must then be used to create the turbulence

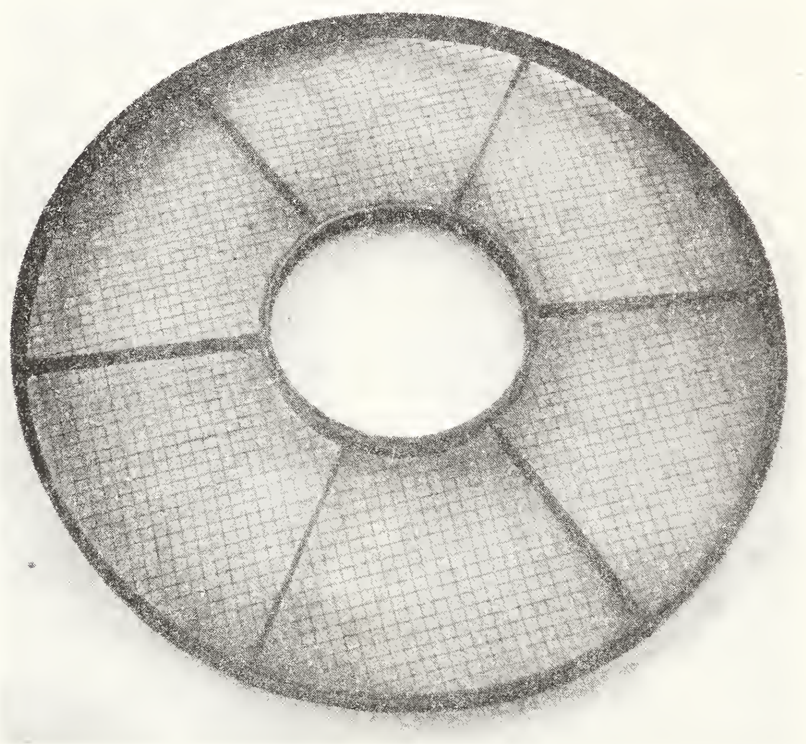


Figure 59.--Metal-framed screen lying in snow after use for one season.

[that is, the pipe outlet must be narrowed].) This vane (also shown out of the fountain in the lower left of figure 58) resulted in the flow indicated in the lower right of figure 58 (photo taken at 1/125 second). The turbulence is more obvious in the photo (figure 60) taken at 1/500 second with the vane in the pipe. Several photographs similar to figure 60, taken at high shutter speed, show a large portion of the water breaking into discrete splashes which hit the screen at continuously varying angles. This action of the water results in migration of organic matter off the screen.

Several of these turbulent-fountain type screens have been field-tested. Under many conditions they do not require cleaning for the whole season if flow is maintained. However, when the flow through screen is reduced 50 percent, the turbulent action of the water decreases and these screens can clog within a few hours.

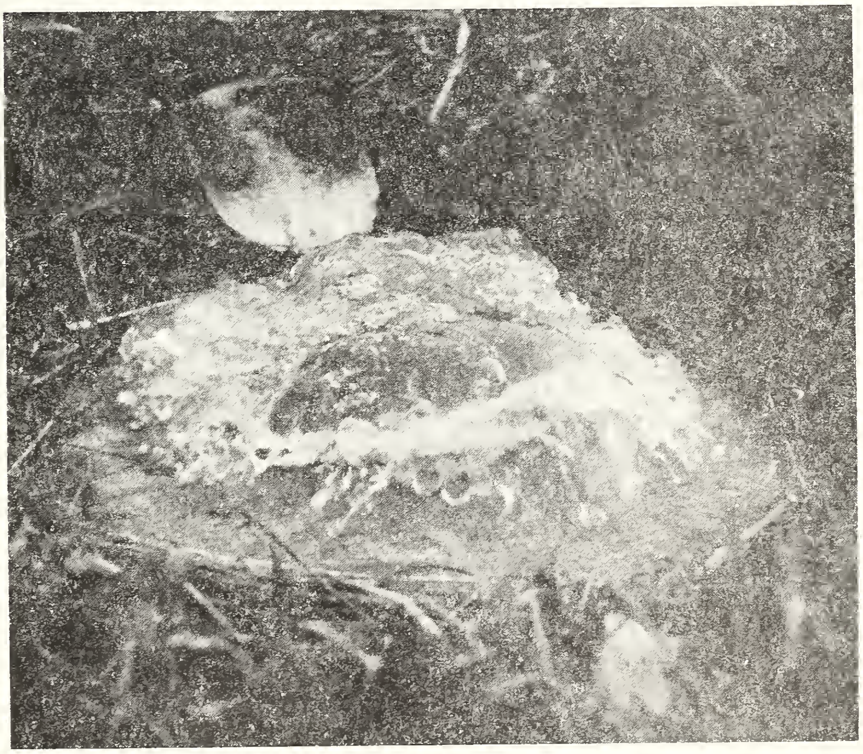


Figure 60.--Violently turbulent fountain with photo at one five-hundredth second.

Observations to date (courtesy of Jim Bondurant and cooperating farmers) show that the following screen diameters and feed pipe diameters operate satisfactorily at the indicated flow rates when 10- to 20-mesh screen is used. This range of mesh includes the window-screen meshes commonly available.

Flow rate	Screen diameter	Feed pipe diameter
1 ft^3/s =450 gal/min	36-inch	8-inch
2 ft^3/s =900 gal/min	42-inch	10- or 12-inch
3 ft^3/s=1,350 gal/min	48-inch	12-inch
4 ft^3/s=1,800 gal/min	54-inch	15-inch
5 ft^3/s=2,250 gal/min	60-inch	15-inch

Studies by Rosenau and Kemper (unpublished data) show that 30-mesh screen removes practically all the weed seeds from irrigation water, whereas 20-mesh screen removes only about half of them. Consequently, where the water contains appreciable amounts of weed seeds, 30-mesh screen is recommended. When the 30-mesh/inch screen is used, screen diameters three inches larger than those shown above are suggested.

With the above dimensions, a splash of water over the edge will often occur. Under some conditions, the splash may amount to a few gallons per minute. If this splash loss can be tolerated and directed back to the lateral or to a drain, the trash will often be pushed off the screen automatically. However, if such splash cannot be tolerated, an additional foot of screen diameter is recommended. This generally prevents the splashover but also results in trash piling up around the outer edge of the screen and necessitates occasional manual cleaning.

Circular screens up to 60 inches in diameter can be built using 1 1/2-by 3/16-inch steel strap stock for all structural members. Galvanized hail screen (1/2-inch mesh) has been used to support the finer mesh screen. Some screens have been made using flat expanded metal for support. The screens have been tightened and held in place by retaining hoops.

Screens with Practically Zero Head Loss Using Electric Power

In some installations, there is no head to spare for cleaning the water, but the water must still be cleaned. If electrical power is available at such locations, it is possible to design a screen with sufficient area and cleaned by electric powered means to result in negligible head loss.

One means of accomplishing this is to mount a coarse support screen and a finer screen on a bicycle wheel at the opening from the canal to the farm system as shown in figure 61 (developed and tested by Allan Humpherys, Snake River Conservation Research Center). As the electric motor turns the bicycle wheel at a speed of about 30 rpm, water is carried up with the screens and runs out of the double screen, washing lodged organic debris off and back into the canal. A couple of these screens designed by Humpherys have operated successfully for four irrigation seasons. They do leave the trash in the canal, which tends to accentuate the problem for downstream water users.

Selecting the Best Screen for the Situation

When 6 inches or more head drop is available and power for the cablegation control does not need to be generated by the screen system

Under these conditions, the rectangular, horizontal screen or turbulent fountain screen will generally be most suitable because of their low initial costs ($100 to $500 installed) and low maintenance requirements and costs. Both types should be built so there is a place for the trash to fall freely from edges of the screen. The turbulent-fountain screen will generally operate for longer periods of time without manual cleaning. However, under conditions of less than 10 gallons of trash per day in the irrigation water and twice daily removal of trash from the end of the screen, the rectangular, horizontal screen is generally satisfactory.

In cases where the logical point of screen installation is at a free-flow rectangular headgate whose opening is a rectangle several times wider than its height, there is often more than 6 inches of head behind the gate. This head can provide the energy needed to cause turbulent self-cleaning of a horizontal screen. However, a mechanism to develop turbulence is needed that will not affect the flow rate through the gate. Wide, small-diameter paddle wheels of the type indicated in appendix J, figure 72 can provide this function in a rectangular, horizontal-screen installation. Elevation of the clean water surface can be as close as 4 inches from the bottom lip of the gate opening if the screen and paddle wheel are properly designed.

When 2 inches or more of head loss is available and both screening and cablegation control power are needed.

In this case, the paddle-wheel screen (appendix J, figs. 107 and 108) can be used. The installed cost of the system, including the paddle-wheel screen, cablegation control mechanism, and gear train and shift mechanism will probably be in the range of $800 to $1,200. While the initial cost of this option is relatively high, it eliminated battery changing and recharging that was contemplated

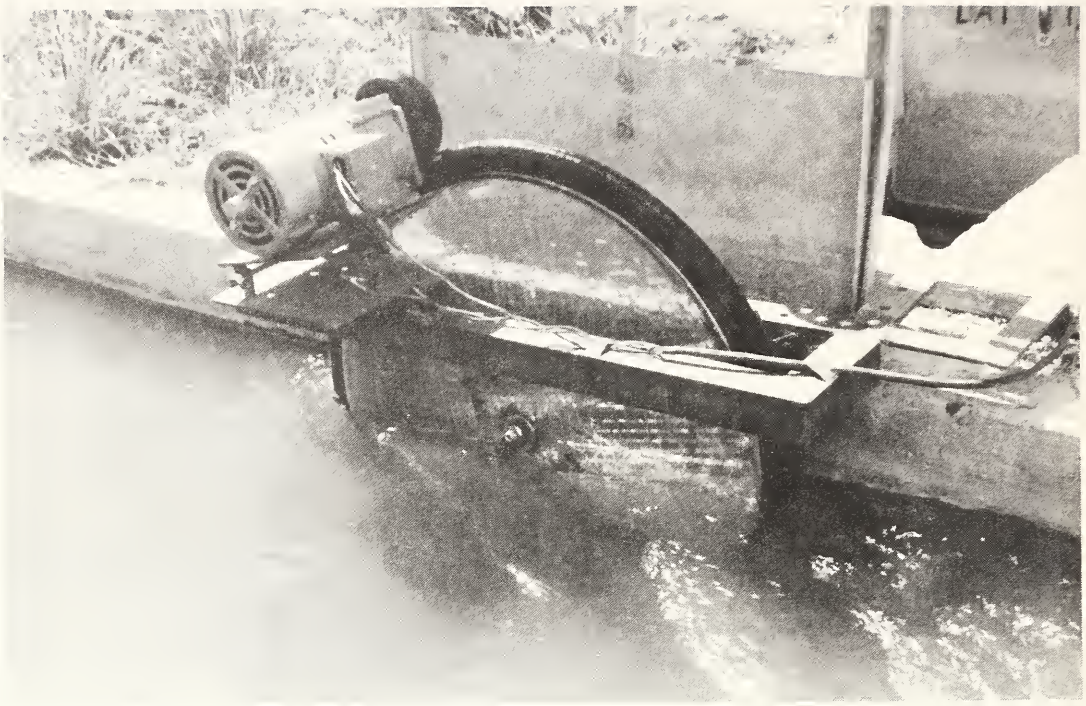


Figure 61.--Bicycle wheel framed rotating screen with negligible head loss.

with a d.c. electric controller. A system of this type operated without problems for Max Baker of Powell, Wyo., during the 1982-84 irrigation seasons.

When Appreciable Head Loss is Not Available

If no head loss can be allowed, an external source of power may be required to remove trash from the screen. Screens such as that shown in figure 61 can serve this purpose. However, the relatively low head losses indicated in the hydraulic laboratory tests of the paddle-wheel mechanical screens (fig. 55 top) indicate possibilities of running such screens with as little as 1 inch of head loss. In most systems, it will be possible to save 1 inch of head loss at some other point in the conducting system using larger conduits, streamlining entrances to pipes, etc. In cases where even this is not possible, minor land leveling to allow lowering the head end of the field and the cablegation pipe by an inch or two may provide the head needed to operate a paddle-wheel screen.

The cost of these measures, relative to the cost of bringing electric power to the screening point, and the costs of the electric-powered and paddle-wheel screening systems and of the electric power, will determine the most suitable screening system for these systems where there is little affordable head loss.

APPENDIX I - MATCHING INFILTRATION RATES TO SYSTEM DELIVERY CAPACITY

Adjusting Delivery to Infiltration Rate Changes

If the infiltration rate of a soil did not change with time, it would be relatively easy to design an automated water delivery system to provide optimum distribution of the water. However, because of changes in cultivation, vegetation and soil-water content, infiltration rates often vary by a factor of 2 or more. Delivery systems can be designed to provide water at rates sufficiently high to get the water down the furrows when they have their maximum infiltration rates. However, since erosion is generally about a second power function of flow rate, these high rates of flow often cause unacceptably high rates of soil erosion. Reaching these high supply rates may also require adjustment of the size of each of several hundred outlets. Because of these factors, some farmers prefer to manage their land and irrigation practice to keep infiltration rates in a relatively narrow range, matched to their delivery system.

Compaction of Furrows in Newly Tilled Soils

One method of keeping infiltration reasonably low, which has been obvious to farmers, is compaction. Kemper et al. (1982) found that infiltration in furrows compacted by tractor wheels ranged from 20 to 88 percent of that in adjacent noncompacted furrows and averaged about 60 percent. A study by Akram and Kemper (1979) on the effects of water content and compaction pressures on subsequent infiltration rates of several soils showed that reduction in infiltration rate was greatest when the water content of the soil was near field capacity at the time of compaction.

Surge Irrigation

Another recently recognized method of reducing infiltration rates is to supply water to the soil intermittently. Bishop et al. (1981) and Walker et al. (1982) found that the infiltration rates on nonwheel furrows were reduced by as much as 50 percent when the supply rate was intermittent (surge flow) compared with when the supply was continuous. A short term of water supply followed by a short term of drying or water-tension development in the soil tends to pull the particles closer together in the soil mass and reduce the infiltration rate.

An Evaluation of Compaction and Surge Irrigation Effects

We conducted the following study at the Snake River Conservation Research Center to evaluate the effects of tractor compaction and surge irrigation on the distance to which water could be "pushed" by a cablegation system with 3/4-inch-diameter outlets.

After the third cutting, alfalfa was crowned, plowed, disked, and harrowed in early September 1981. After planting of winter crops, the field was corrugated using the tractor and corrugator shown in figure 62, which provided three non-wheel and two wheel-compacted rows per pass. This resulted in a pattern of wheel furrow, non-wheel furrow, wheel furrow, then two non-wheel furrows before the pattern repeated. As shown in figure 63, this pattern was apparent during the irrigation as the water advanced more rapidly in wheel-compacted furrows than in non-wheel furrows. An irrigation for germination was started 2 days after planting took place. The soil was dry, well-aggregated, and relatively loose.

Inflow and outflow rates and water advance rates were measured on most of the corrugates. As anticipated, the infiltration rate on most of the field was found to be about twice as large as it had been prior to plowing. Water applied by the system was not reaching the ends of most corrugates. Water reached the end of the field (350 feet) only in a few of the wheel-compacted corrugates when supplied at about 5 gallons per minute.

Figure 62.--Tractor and corrugator showing pattern of wheel compaction in corrugates responsible for differences shown in figure 52.

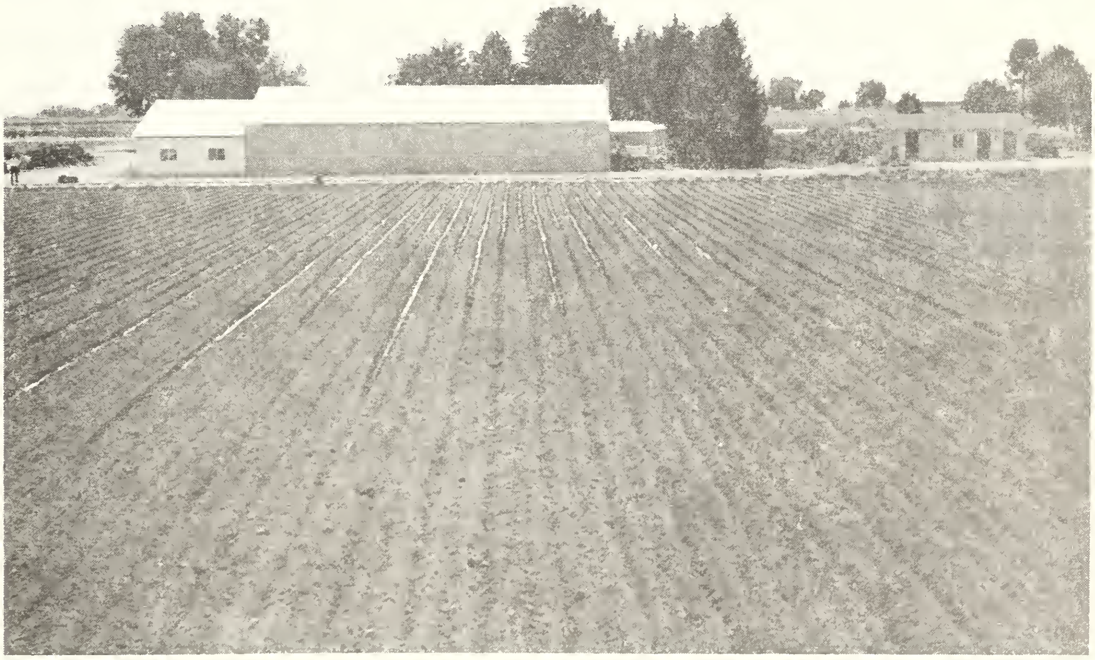


Figure 63.--Differences in water advance rates in furrows due primarily to wheel compaction.

Modification of a Cablegation System to Provide Surge Irrigation

Since intermittent (surge) irrigation has allowed a given supply rate to wet longer lengths of corrugates, surge irrigation was planned for the east portion of the field. To provide the intermittent supply to the corrugates, a system diagrammed in figure 64 was used. Floating curtains were made with lengths of polyethylene tubing (manufacturers names will be supplied on request), with wall thickness of 6 mil and inflated diameter of 5 inches, sleeved around strips of flexible, light-weight polyfoam which were one-eighth inch thick, about 7.5 inches wide and 5, 7.5, and 10 feet long. The polyethylene tubing was about 6 inches longer than the polyfoam in each case and was heat-sealed about 1 inch from each end, leaving the polyfoam about 4 inches from one end. The 4-inch polyethylene ends were folded over and clamped in a tow plate whch consisted of two pieces of wood as indicated in the lower right of figure 64. These assemblies were attached by a short tow cable to a Y-splice in the main cable. When in the water-filled pipe, these floating curtains rose to the top of the pipe, conformed to the top as shown in the lower left of figure 64, and effectively closed the holes along the length of each curtain. Three of these curtains, 5, 7.5, and 10 feet long, were attached to the main line as indicated in the top of figure 64. When the plug traveled 10 feet per hour past outlets spaced at 2.5-foot intervals, water supply to the furrows was on for 30 minutes, off 30, on 45, off 45, then on for an hour, off for an hour, and then on for the remainder of the irrigation (several hours).

Infiltration Rate with Time

In most soils, the furrow infiltration rate tends to decrease with time continuously so that prolonged irrigation results in water proceeding farther down the furrow. Infiltration rates in Portneuf silt loam commonly decrease for 2 to 4 hours but then reach a relatively constant rate of intake (Goel et al. 1982) after which the length of furrow occupied by water remains relatively constant.

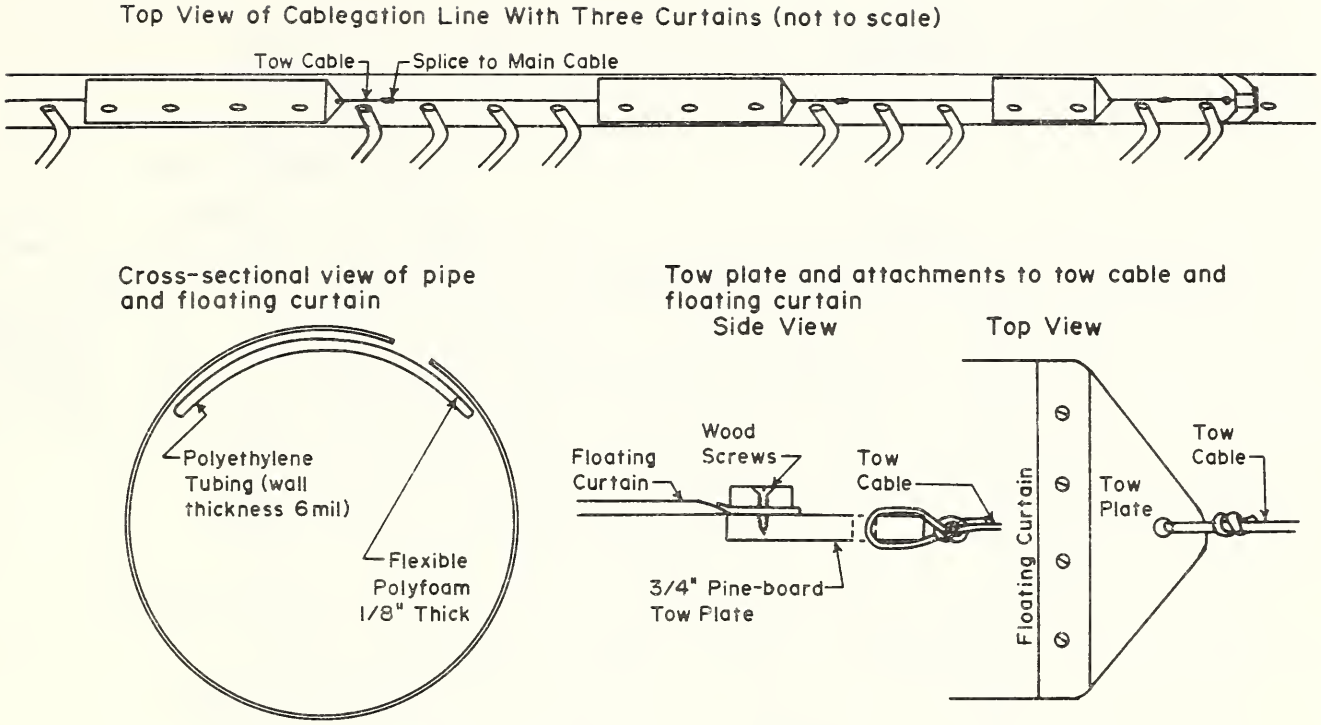


Figure 64.--Modification of cablegation system to provide surge irrigation.

In a few rows there may be some advance, but in others there will be a retreat as the water-supply rate remains constant.

Length of furrow containing water is plotted against the time interval after beginning of water supply to furrow in the University of Idaho field in figure 65. The lines representing wheel-track furrows are the averages for four furrows. Lines representing non-wheel track furrows are averages of six furrows. For continuous flow, water in the wheel-track furrows progressed about 43 percent farther than in the nontrack furrows.

Effects of Surge Irrigation and Compaction

The furrows in which the flow rate was interrupted were about 100 feet farther east in the field, where general infiltration rates were apparently slightly higher than in the set in which the supply flow was continuous. However, it is apparent that interruption of the flow results in a decrease in the furrow infiltration rate when water enters the furrow again. This

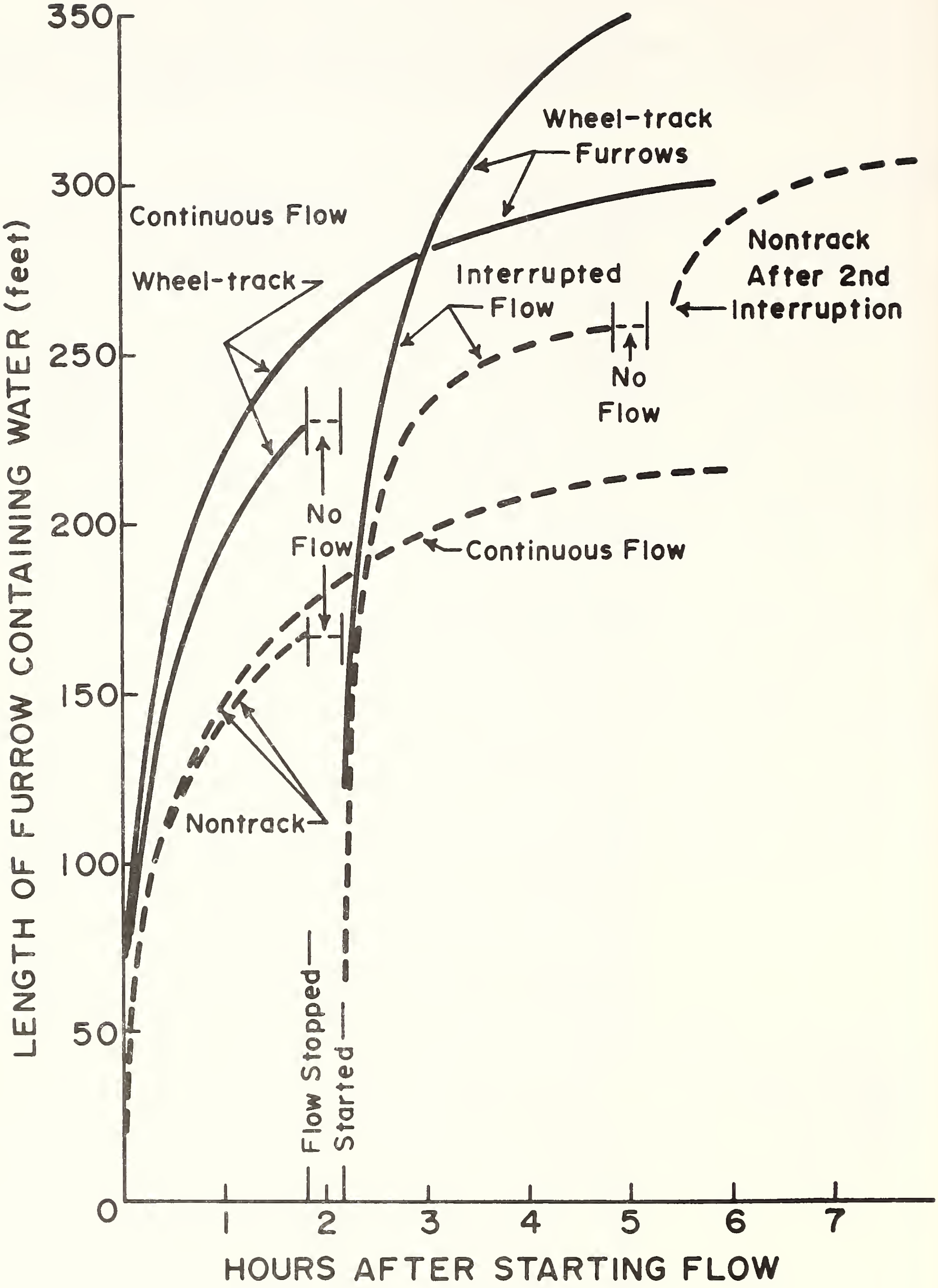


Figure 65.--Effects of compaction and interrupted flow on length of furrow watered.

decrease in furrow infiltration rate was sufficient to enable the water to reach the ends of the wheel compacted furrows. In the noncompacted furrows, the interruption of flow had a similar effect, with water advancing farther down the furrow after each of the two interruptions.

From about 150 feet farther down the field to the end of the field, the flow pattern involved three interruptions provided by the floating curtains attached to the cable and described in figure 64. The curtains blocked nine outlets and consequently backed the water up slightly higher in the cablegation line so the furrow supply rate in the curtained section (fig. 66) ranged from 5.2 down to 4.5 gallons per minute, while in the section from which the lines in figure 65 were drawn, the furrow supply rates ranged from 5.0 down to 4.2 gallons per minute. There is a trend for furrows to have slightly higher infiltration rates toward the east side of this field, so furrow advance rates before interruption of the supply were slightly slower in the furrows described in figure 66 than those described in figure 65.

Figure 66 shows that surging enabled the water in the wheel-compacted rows to reach the end of the field. The percentage of increase in length of furrow wetted following flow interruption appeared to be greater for the noncompacted furrows than for the compacted furrows. This is probably because the effect of both the compaction and the interruption of the flow is to reduce the amount of large-size pores in surface soil. In the case of interrupted flow, surface tension of the water pulls the soil particles closer together. If they have already been pressed together by the pressure of the tractor wheels, the particles do not have as far to go to arrive at the highest normal density that can be achieved by successive wetting and drying.

During intermittent supply irrigation, it was noted that the water in the furrows was all absorbed by the soil within 5 to 10 minutes of when the supply stopped. Within 5 minutes of the time when water disappeared, the surface tension had started pulling the soil particles together in the more dense portions of the soil, resulting in shrinkage cracks along the lines of weakness in the bottoms of the furrows. When the water was supplied to the furrows again, it generally carried bedload sediment which rapidly filled these cracks. In another field on this same type of soil where a large amount of stubble had been incorporated into the soil, the intermittent furrow supply did not appreciably increase the length of furrow wetted. The large amount of straw in the furrows had practically eliminated sediment movement in most sections of the furrows. These

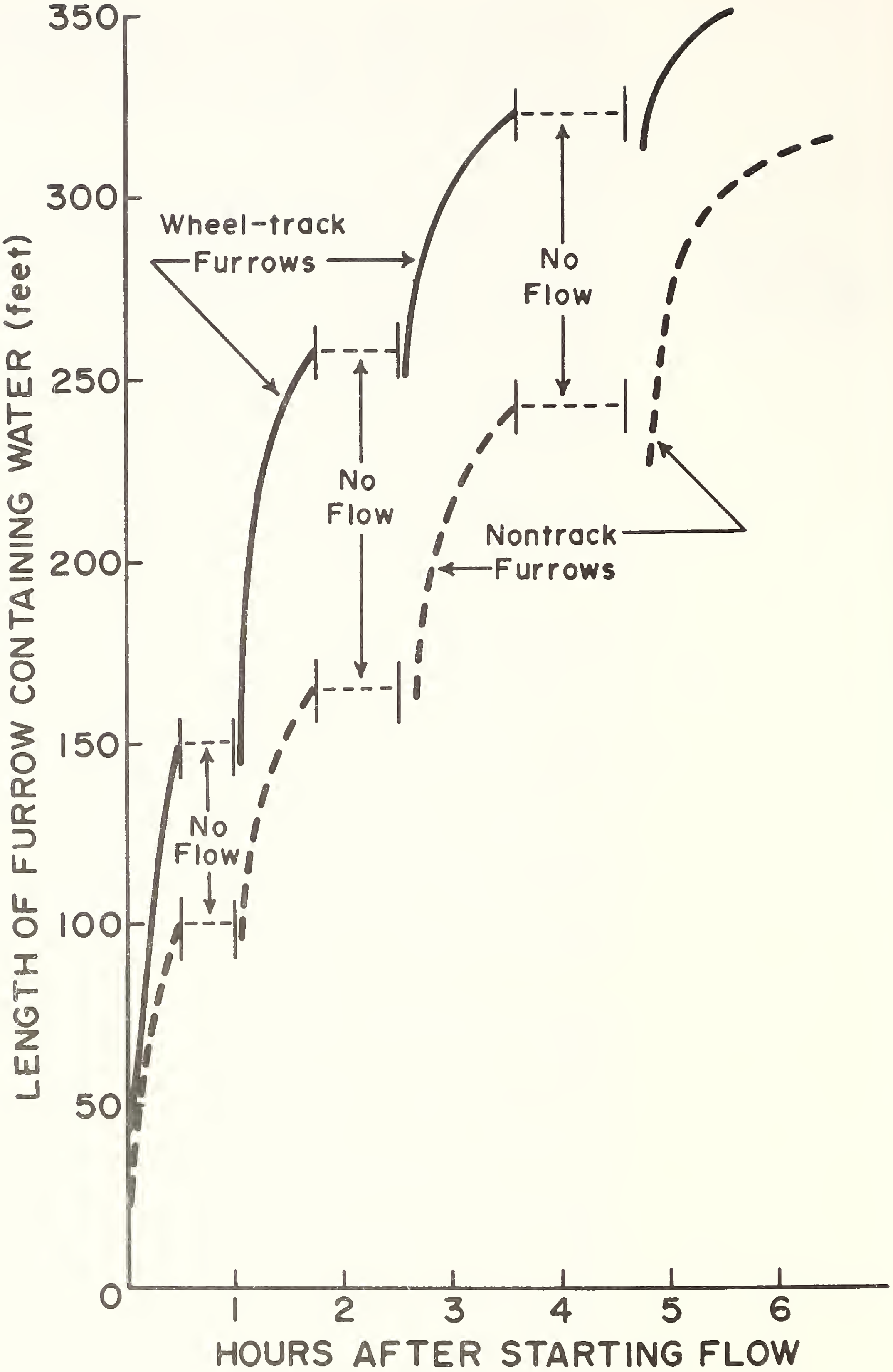


Figure 66.--Water advance in furrows with intermittent supply as indicated in figure 41.

observations suggest that a major factor contributing to increased length of furrow wetting because of surge irrigation is the amount of bedload sediment moving in the furrow.

Conditions Under Which Infiltration Rates Can Be Matched to Delivery Capacity

In general, this study showed that outlet size and furrow supply rate could be held constant as soil condition changed from mature corrugates in alfalfa to new corrugates in a freshly plowed field if the water carrying corrugates were on wheel packed soil and intermittent-flow (surge) irrigation was used.

In designing an automated irrigation system, one of the major decisions is whether outlets should be one fixed size or made to be adjustable. The flow rate from outlets in a cablegation system can be reduced by reducing the rate of supply to the system as Don Craig (app. J) does in his system after the first irrigation. However, the pipe size and outlet size place a definite upper limit on the rate of outlet flow, and the practical lower limit is about 50 percent of this upper limit. Craig, Baker, and Hood (app. J) have been able to keep infiltration rates in their soils within a range that can be served by fixed-size outlets. In general, the slopes of their furrows are fairly low and the soils are not highly erodible, so extra water passing over their fields does not damage them appreciably. In most of these cases, the tail water is reused so there is no appreciable soil or water "loss" involved in designing reasonably high outlet-flow rates which are high enough to get water to the end of the fields in the irrigation following plowing, and provide appreciable runoff during subsequent irrigations. (In most cases this was done using wheel-compacted furrows and/or surge irrigation to get the water to flow through during the first irrigation following plowing.)

APPENDIX J - SYSTEMS INSTALLED IN 1981 AND 1982

University of Idaho Research Farm System

Initial Installation

The first cablegation system was installed on the University of Idaho Research Farm 1 mile north and 1 mile east of Kimberly, Idaho. The field dimensions and elevations along the cablegation line and the elevations and pertinent details of the inlet structure are indicated in figure 67.

The soil is Portneuf silt loam. Furrows ran north on a slope of about 0.6 feet per 100 feet (0.6 percent). The maximum water-supply rate was 340 gallons per minute (0.76 ft^3/s). Existing slope from west to east along the proposed cablegation line averaged 0.0028, so the 8-inch diameter PVC line was designed with that slope. The cablegation line ran east from the inlet structure at the southwest corner of the field. About two-thirds of the way down the line, it curved around a 20-foot jog in the south edge of the field. The S curve had a radius of curvature at its tightest section of 230 feet. This gave no problem in passing the plug through this section. Details of this system were outlined by Kemper et al. (1981).

Performance of Initial System

Details of the performance of this system during the third irrigation of 1980 are presented by Goel et al. (1982). In summary, they found the initial supply rates to the furrows were within ± 13 percent of the designed flow rates. Sixty percent of the variation was associated with deviations of the pipe elevation from the designed grade, which were as large as 1.5 inches. The computer model of this system predicts that deviations in flow rates due to deviations from the designed grade will decrease as grade increases and thus will be less in systems laid on steeper slopes.

Seventy-three percent of the water applied to the field was retained on the field during the evaluated irrigation. Intake opportunity times averaged 11.0 hours at the top end and 8.3 hours at the bottom. The intake rate, I_r, was related to the time since water application started, T, by the equation $I_r=48.6+214/T$. From these facts, it was calculated that water applications at the bottom of the field averaged 84 percent of those applied at the top end.

Runoff rate from the field was relatively constant, and total runoff was only about half of that which would have occurred under fixed set types of surface irrigation. Variability of furrow infiltration rates was high, due largely to use of both wheel-compacted and non-wheel furrows. A ten-percent reduction of application rates would have resulted in water not reaching the ends of some furrows.

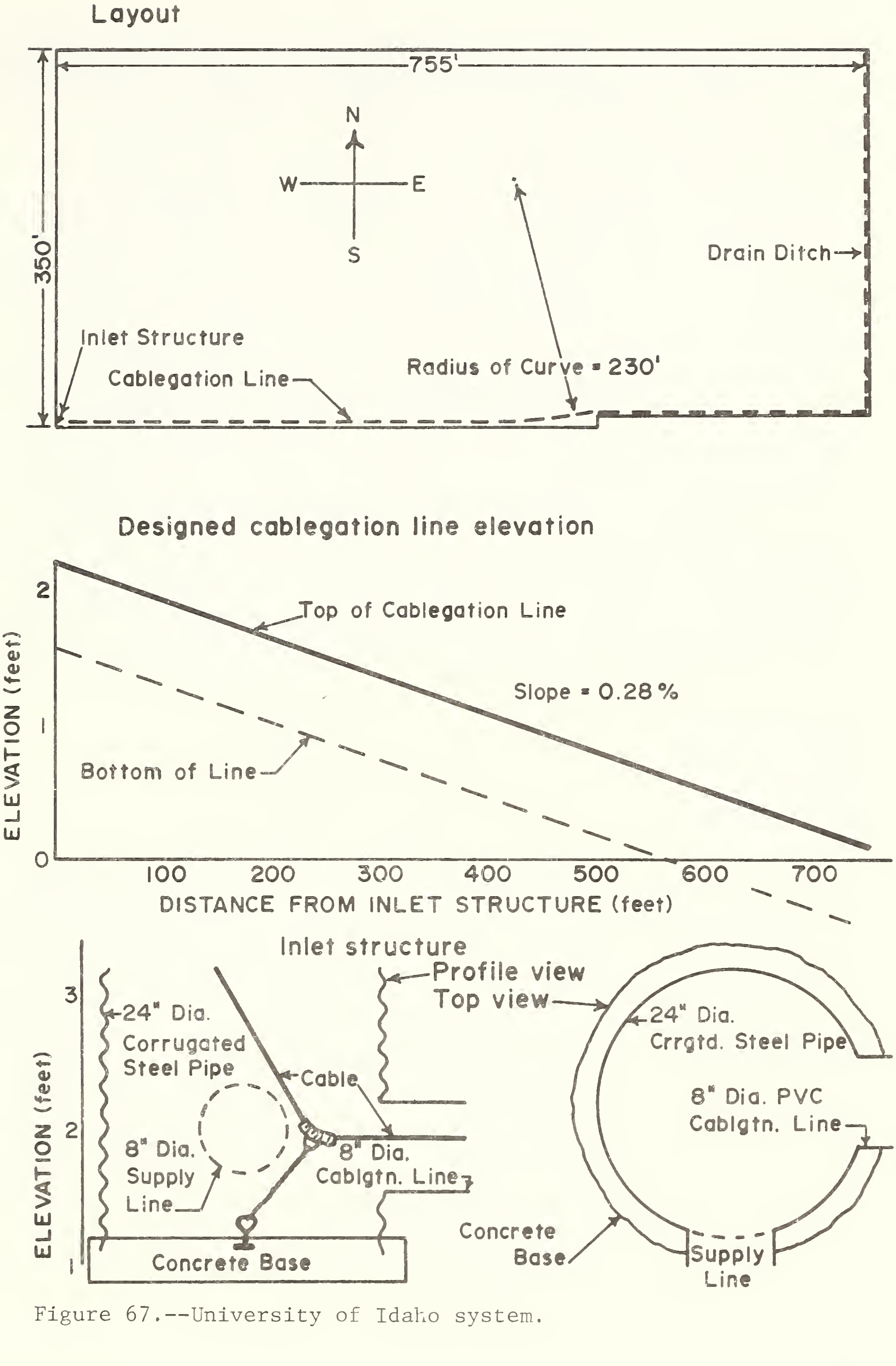


Figure 67.--University of Idaho system.

In general, the cablegation system provided more uniform water application than had been achieved with siphon-tube irrigation systems. The automatic cutback in supply reduced runoff, and the runoff was more easily reused because of its continuous nature.

Outlets in this system were holes drilled in the pipe 30 inches apart, and most of them were three-fourths of an inch in diameter. Since it was foreseen that furrows served by the top and bottom ends of the pipe would not go through a complete supply cycle of the type indicated in figure 5, the sizes of the holes in these end sections were increased as discussed in more detail by Kemper et al. (1981). However, due to entrance head loss as the water passed from the inlet structure into the cablegation line and inadequate height of the inlet structure to allow compensation for this, there was inadequate irrigation in the extreme northwest corner during the first four irrigations with this system. Partially to remedy this situation, the first 60 outlets were used as a test section for four types of experimental, adjustable outlets. One of these was of the type shown in figure 48. These allowed the operator to provide bigger outlets at the top end of the cablegation line (as indicated in the bottom of figure 19) and adequately water the northwest corner during the last two irrigations of the alfalfa field in 1981.

The Bypass to Provide End Sections with More Uniform Irrigations

The attempt to compensate for reduced intake opportunity time by increasing flow rate was partially successful because the increase of flow rate generally increases wetted perimeter of the furrow. However, the irrigation from the top and bottom ends of the cablegation line was not the same as in the middle section resulting in differences of water retained in the soil of as much as 20 percent. To further reduce these differences, a bypass system of the type shown in figure 21 was installed. When the moving plug was started at the inlet structure with one outlet flowing, water level in the inlet structure rose until the sum of flow rates of water from that outlet and down the bypass were equal to the supply rate to the inlet structure. Thus, initially most of the water was flowing through the bypass to the tail end of the cablegation main line. The lower end of this line was plugged so the water backed up in the bottom end of the line and flowed out of the orifices into the rows as indicated in figure 21. As the moving plug opened more outlets at the top end, the water level in the inlet structure was lowered and less water flowed through the bypass. This decreased the flow out of the bottom end outlets in practically the same manner as if all the water were coming down the main line and the moving plug was continuing down a section of main line extending beyond the end of the existing main line on the same slope. As a result of this preirrigation during the bypass stage, when the moving plug reached the end of the main line, total flow into the furrows near the bottom end has been practically equal to the flow in the central sections of the pipe, and the irrigation can be terminated. Receiving the flow in two increments, rather than one, at the bottom end of the cablegation line, can increase the amount of water absorbed by the soil if the moving plug takes 6 or 8 days to reach the bottom end of the line. This absorbed water can be less than in the central sections if the moving plug takes less than 2 days to reach the bottom end. (See discussion on surge irrigation for explanation.) In either case, the differences are considerably less than 20 percent, and, for the case where from 2 to 6 days elapse, the amount of retained water in the rows of the field served by the end sections of the cablegation line can be practically the same as that in those served by the central section. Details of the inlet structure and bypass intake are indicated in figure 68.

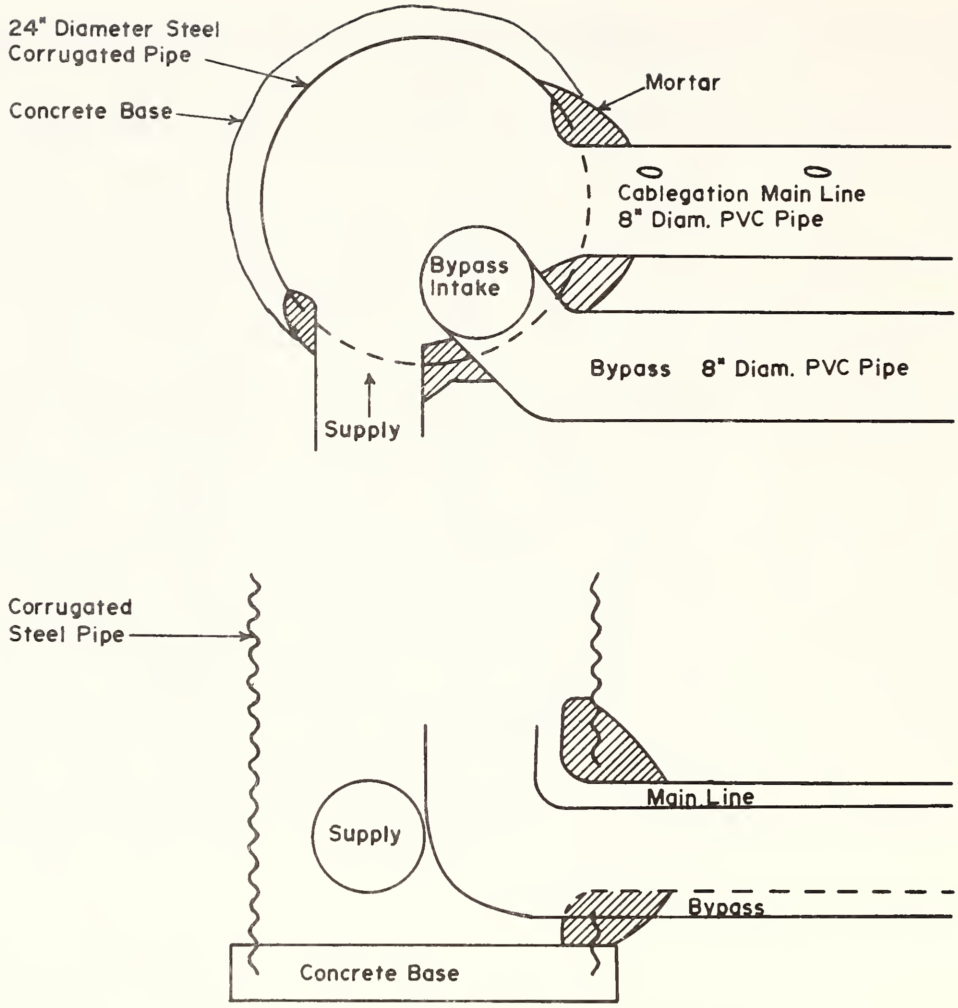


Figure 68.--Inlet structure and fittings for bypass system (University of Idaho Research Farm)

Effects of Wheel Compaction and Surge Irrigation on Water Advance in Furrows

The studies and findings conducted under this cablegation system on these factors are presented in appendix I.

The different rates of furrow supply occurring at the tail end of the system during the bypass phase of the irrigation are plotted vs the maximum distance of water advance in those furrows in figure 69. There is considerable scatter from the straight lines, but these data indicate that length of furrow wetted is reasonably proportional to the rate of water supply to the furrow. These data were part of the basis for our suggesting in appendix B that furrow supply rate be proportional to row length in the design of cable reels and plug speeds for the cablegation system.

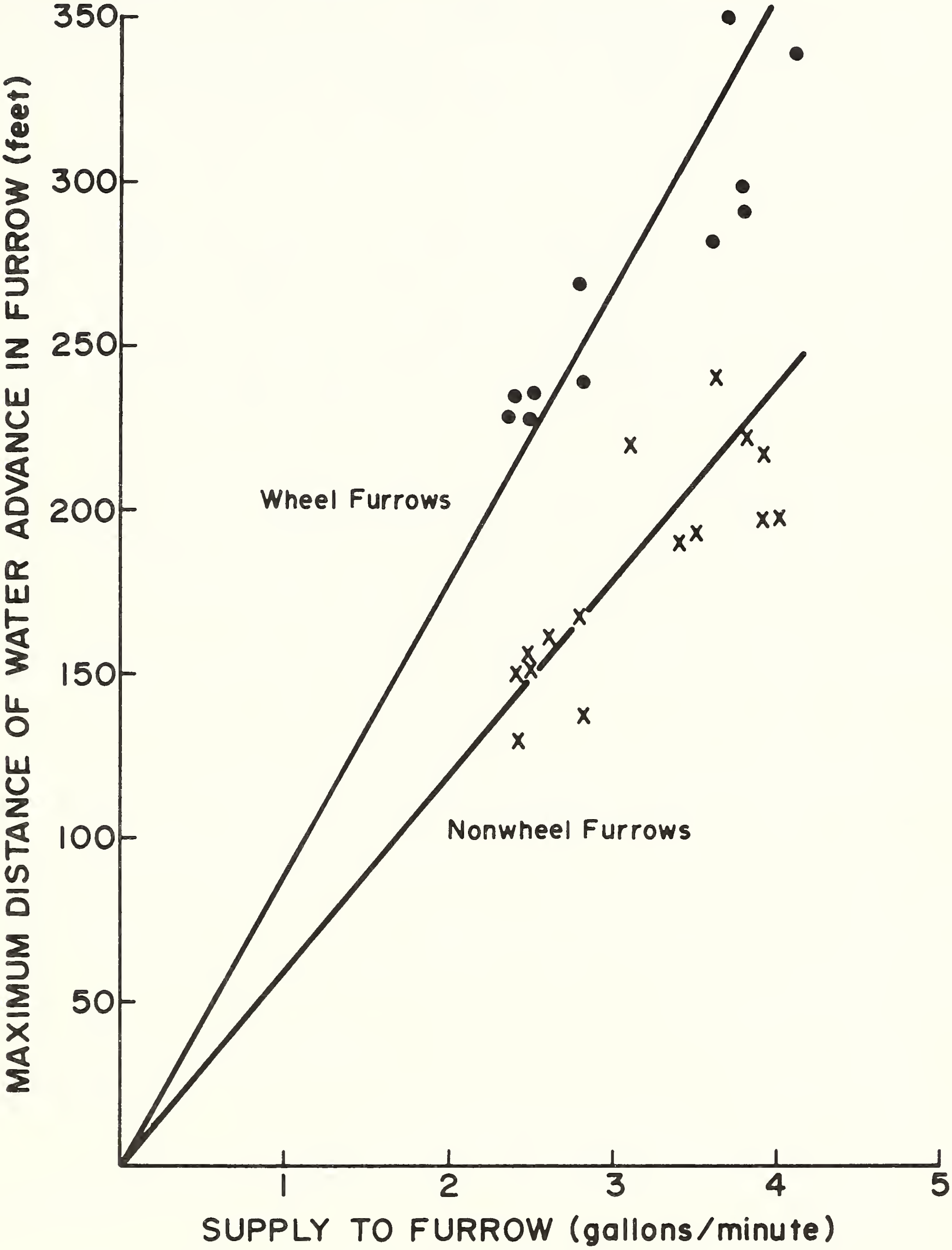


Figure 69.--Effect of furrow supply rate on length of furrow wetted in Porneuf silt loam.

The apparently linear relationship was surprising, because it had been anticipated that larger flow rates would result in a larger area of the furrow surface being wetted, higher infiltration per unit of length of furrow, and consequently less length of furrow wetted per unit of water supply rate. Recent observations indicate that faster rates of wetting cause more slaking of the aggregates and lowered infiltration rates. This factor may counterbalance the greater-wetted-perimeter factor in the furrows with higher flow rates.

John Klompien System

Field Shape, Slopes, and Earth Moving

John Klompien's field, 3 miles south of Kimberly, Idaho, has an irregular shape, containing approximately 25 acres as shown in figure 70. The soil is Portneuf silt loam on slopes that range from 1 to 9 percent at the topside of the field. These slopes generally decrease significantly as the furrows approach the north edge of the field where deposition has occurred in past years.

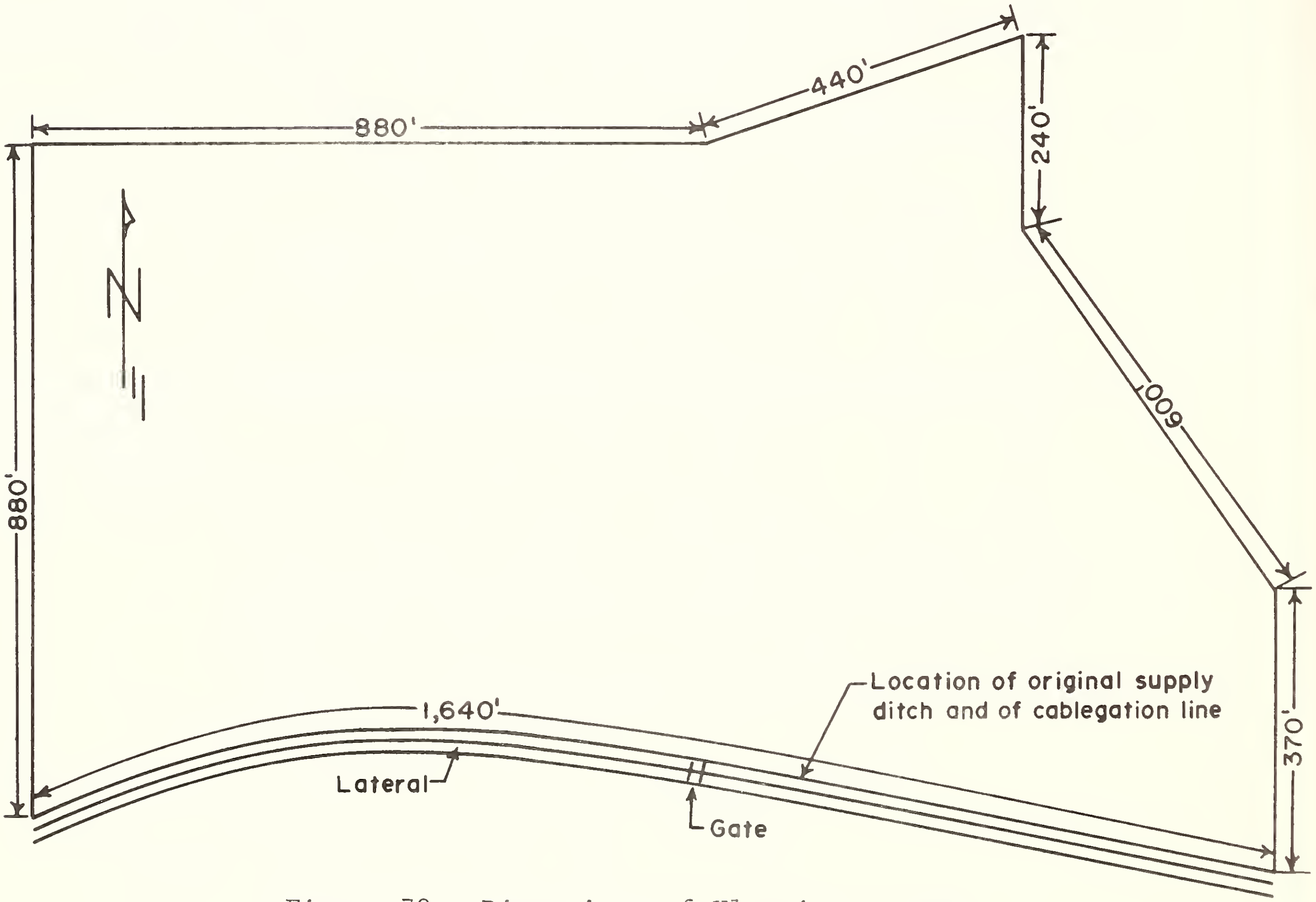


Figure 70.--Dimensions of Klompien system.

The field was in the second year of alfalfa hay. It had previously been irrigated with a low-gradient, sod banked ditch infested by rodents, which made water control difficult.

The original soil-surface elevations along the cablegation line are indicated in figure 71, along with the elevation of the bottom lip of the gate. To obtain the slopes on the cablegation line indicated in figure 71 required moving soil away from the line location to downfield positions. The earthmoving to achieve downfield slopes of 0.4 percent or greater at all points required moving about 1,000 cubic yards of soil. Klompien moved this soil with a front-end loader on his farm tractor and smoothed it with his land plane. Following this leveling, the cablegation line was installed as indicated in figure 71.

An alternative to the use of 10-inch pipe could have been to use 8-inch pipe with the 1.4-ft^3/s supply split at the box and two plugs moving at the same time. This would have been less costly than the 10-inch line but would have decreased the flexibility of some farming operations.

The earthmoving, smoothing, and grading along the cablegation line required about 40 hours of Klompien's tractor work. He also applied about 60 cubic yards of manure to the 4.5 acres of land which had been cut or filled, disked the manure into the

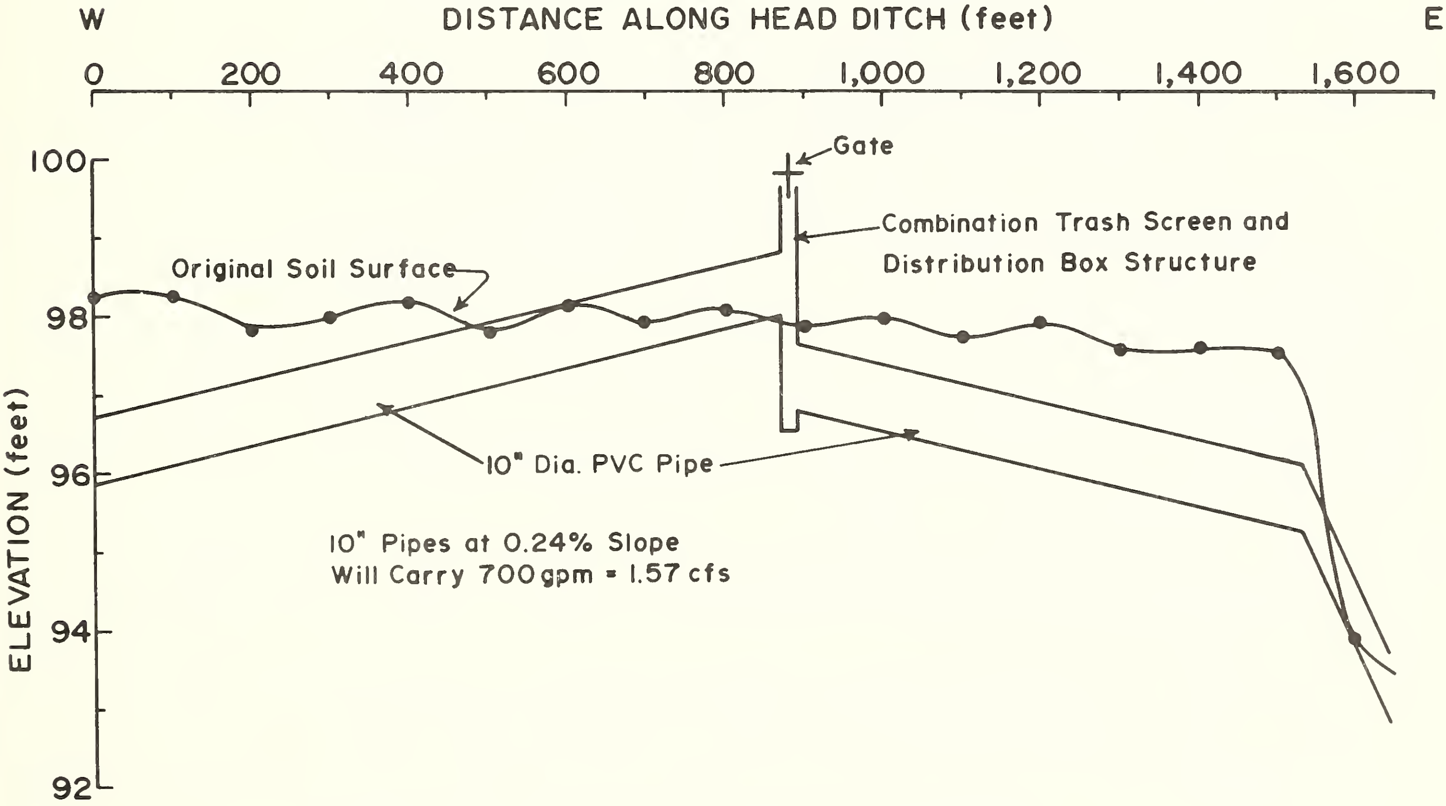


Figure 71.--Elevation plan for Klompien cablegation system.

soil, seeded alfalfa with barley as a nurse crop, and corrugated the whole field. Two consecutive irrigations resulted in an excellent stand of alfalfa--even in areas where the older alfalfa stand had been sparse and where alfalfa seed was broadcast to improve the stand.

Multipurpose Structure for Low Head Loss

The water delivery point was at approximately the mid point along the south edge, which curved along a medium-size irrigation lateral. The water comes from the lateral through a free flow gate as indicated in figure 72. A 20-mesh horizontal screen was installed on an input structure placed immediately below the gate structure as indicated in figure 72. The drop from the bottom lip of the outlet to the screen was designed to be only four inches to maintain as much elevation as possible at the input of the cablegation pipes. Considerable head behind this gate caused the water to spurt out and impact near the far end of the screen. To bring the area of impact back to the middle of the screen and generate more turbulence in the flow from the gate to the screen, a small paddle wheel was added, as indicated, to help keep the screen from plugging (see appendix H, Rectangular and Horizontal Screens).

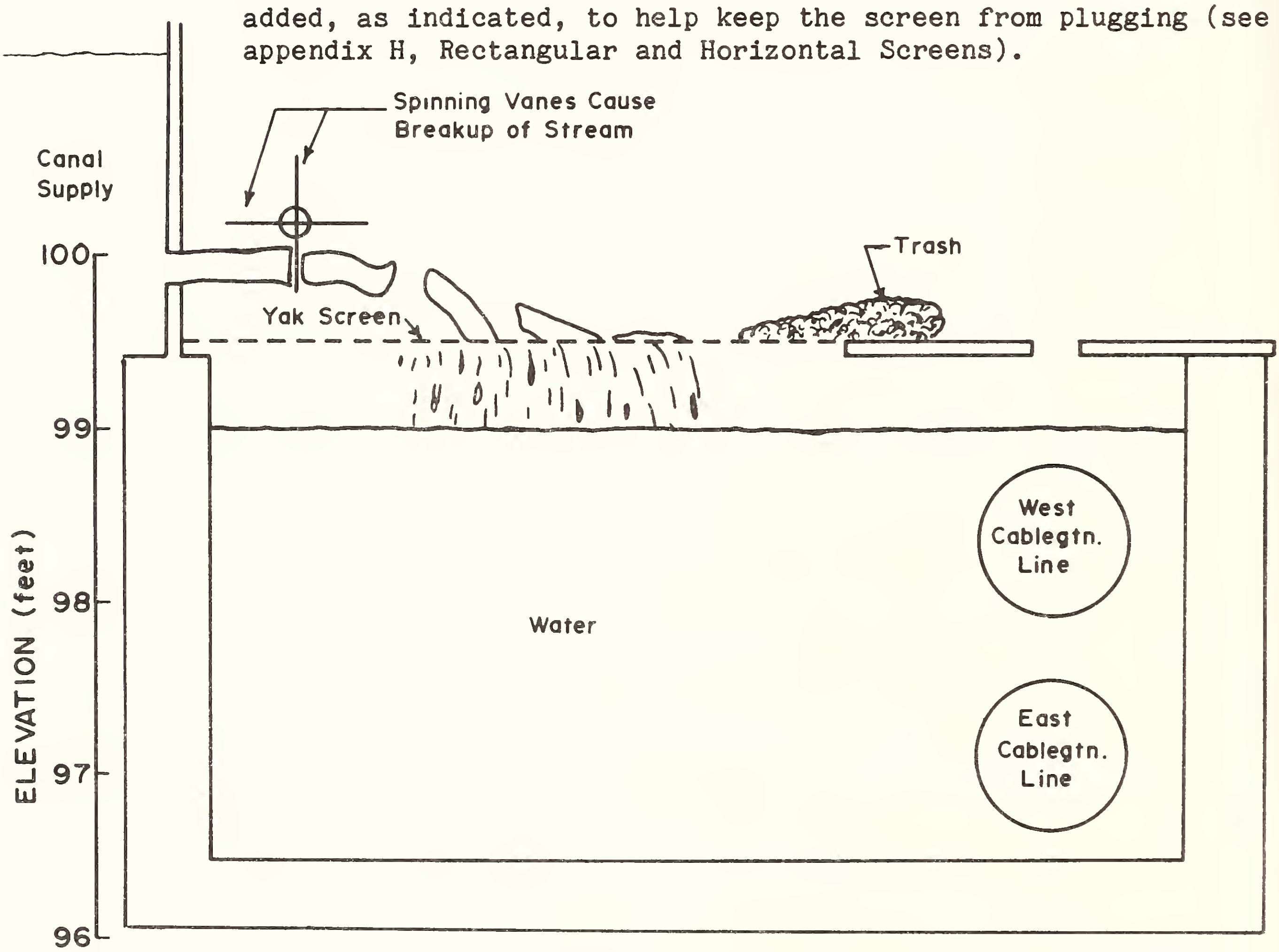


Figure 72.--Combined inlet and screen structure on Klompien system.

The input structure at the midpoint was designed to deliver water sequentially into two separate cablegation pipes as shown in figure 73. Streamlining the inlets to the pipes avoided about 1.5 inches of head loss, which was important in this situation. The pipeline running west was operated first from the upper outlet in the structure to irrigate about 14 acres of the field. When the plug stopped at the lower end of this line, the plug in the pipeline running east was started to complete the irrigation of the east 11 acres of the field. The flow was gradually diverted from the west line to the east line as the plug passed more outlets in the east line, and these lower outlets dissipated the water. Two controlled reels (as indicated in figure 73) were used in this system. Sequencing of the two reels will eventually be done automatically by a switch that will stop the west reel and start the east reel when the tension on the cable running west is decreased as the plug stops against a pin at the far west end of that pipe.

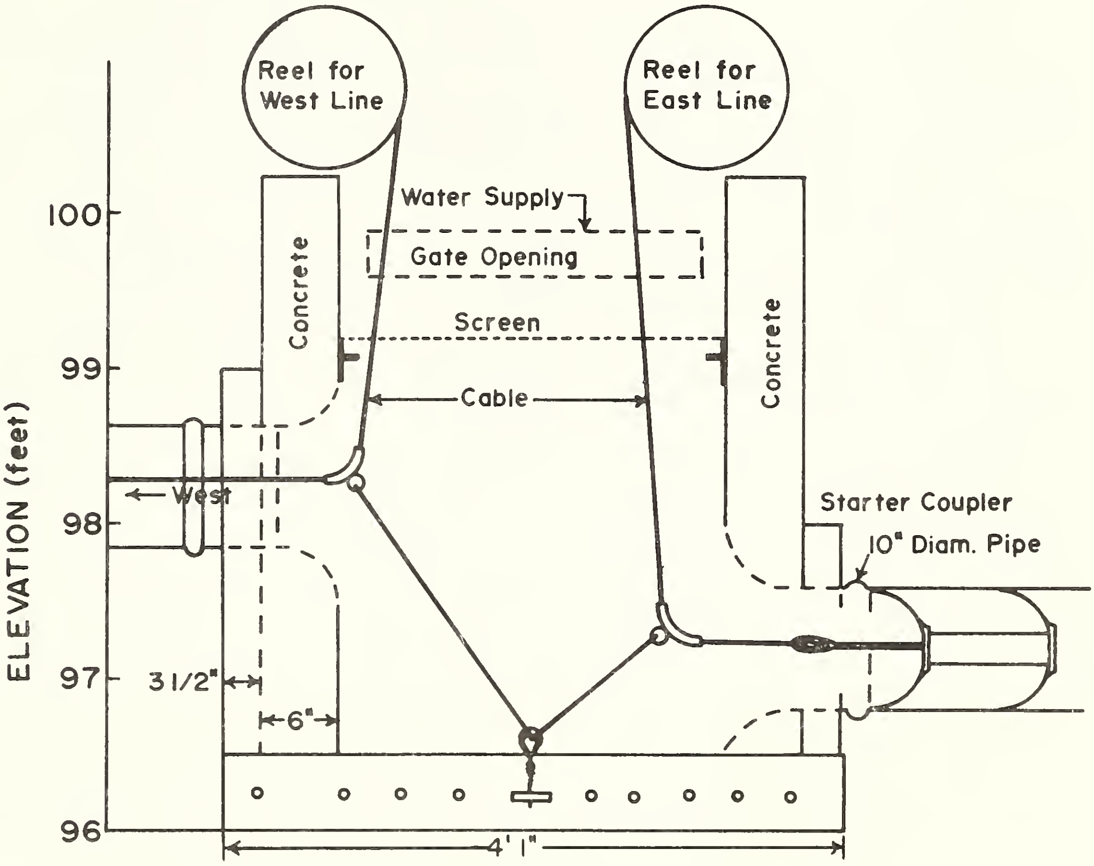


Figure 73.--Front view of Klompien screen (looking north) and inlet structure including reels and cables.

Pipeline Design and Installation

Each of the two 10-inch diameter cablegation pipes was installed on a uniform slope of 0.0024 (or 0.24 percent) as indicated in figure 71. This called for cuts of over 1 foot along the pipe location near the west side of the field. The field slope in this area was about 2 percent, so these cut areas extended about 100 feet into the field with the soil spread into the field beyond. The cuts at midfield were less, and the field slope was greater, so the earthwork was much less extensive. The cuts along the alinement of the east pipeline were greater than 1 foot at some points, since the pipe entrance was 1 foot lower than the west pipeline. The field slope was much greater in this area, so the cut areas extended into the field less than 25 feet and the soil was deposited just beyond. Further shaping of this fill may be required to get a more uniform field slope that will increase uniformity of infiltration.

The 10-inch diameter PVC pipes were installed in a shallow trench along the south edge of the field, and the elevation of each length of pipe was adjusted so that the gradient was maintained within ±one-half inch. Holes 1.25 inches in diameter were drilled in the pipe on 30-inch spacings and offset 30 degrees toward the field from the center line on top of the pipe. Polyethylene inserts of the type indicated in figure 13 were put into these holes and secured in place by forcing a finishing nail through the walls and across the diameter of these inserts just outside the PVC pipe. This prevented the outlet fixture from being pushed into the pipe when a polyethylene cap or reducing outlet was pressed on over the insert. Holes of the desired size were punched in the caps.

The system was first operated with 3/4-inch diameter (about 19-mm) holes, but the water advanced to the end of the furrows in 30 minutes so the outlet diameters were reduced to one-half to five-eighths of an inch (about 13-16 mm) in diameter, depending on the length of the furrow. This provided adequate flows for the beginning of the season. However, the corrugates accumulated trash and the field was allowed to become rather dry during mid season when the water supply was needed to irrigate beans on other fields of the farm. Later, when the water was returned to the field, pushing it completely across was difficult, and the outlet sizes were enlarged to the maximum size (1-1/4 inch) by removing the polyethylene insert. Runoff from the field was low even under the resulting high furrow supply rates. Water was still not reaching the ends of some corrugates, but it was found that most of these cases involved gopher holes or trash accumulations which diverted the water. Eradicating the gophers and cleaning the corrugates more frequently could solve this problem. Otherwise, getting water through each corrugate would require careful monitoring of the flow and considerable handwork in the field.

The design of the inlet structure and cablegation lines caused the top of the pipe to be as much as 10 inches above field level just west of the structure. This required that energy dissipating tubes be added to the outlets along this reach. These tubes were made long enough to carry the flow out to the head end of each corrugate, and they controlled erosion.

The cables on this system, which were 200-pound-test nylon line, were broken once or twice during the season when extra loads were placed on them while the plug's location was being manipulated in an abnormal manner. The small rubber coupling tube between the motor and the first gear-reduction assembly was replaced about three times during the season because of damage from fatigue and sunlight. This coupling was modified and strengthened for the 1982 season.

Kemper System

Field Shape, Slopes, and Supply Rate

The Kemper fields, 2 miles east and one-half mile north of Kimberly, Idaho, were shaped as shown in figure 74. The water supply entered the field near the southeast corner, and it was decided to have the cablegation system serve the large south field first and then the smaller north field as the plug moved first north and then west through the line. Original soil-surface elevations along the proposed cablegation line were irregular, and about 4 days of grading along that line was done with a small farm tractor and scraper to bring the soil level to approximately the level of the top of the pipe as shown in figure 75. The slope along the pipeline changed at two points. It dropped 0.0038 feet per foot for 860 feet, then 0.023 feet per foot for 350 feet, then dropped 0.0141 feet per foot for the last 1,100 feet. The 0.0038 slope required an 8-inch diameter pipe to carry one-cfs flow, but this same flow could be carried on the steeper slopes with a 6-inch-diameter pipe. This permitted reducing the cost of the system by reducing the pipe diameter at a point 850 feet from the control standpipe. Greater resistance to flow of the smaller diameter pipe also helped dissipate some of the gravitational energy of the water as it flowed down the steeper slopes.

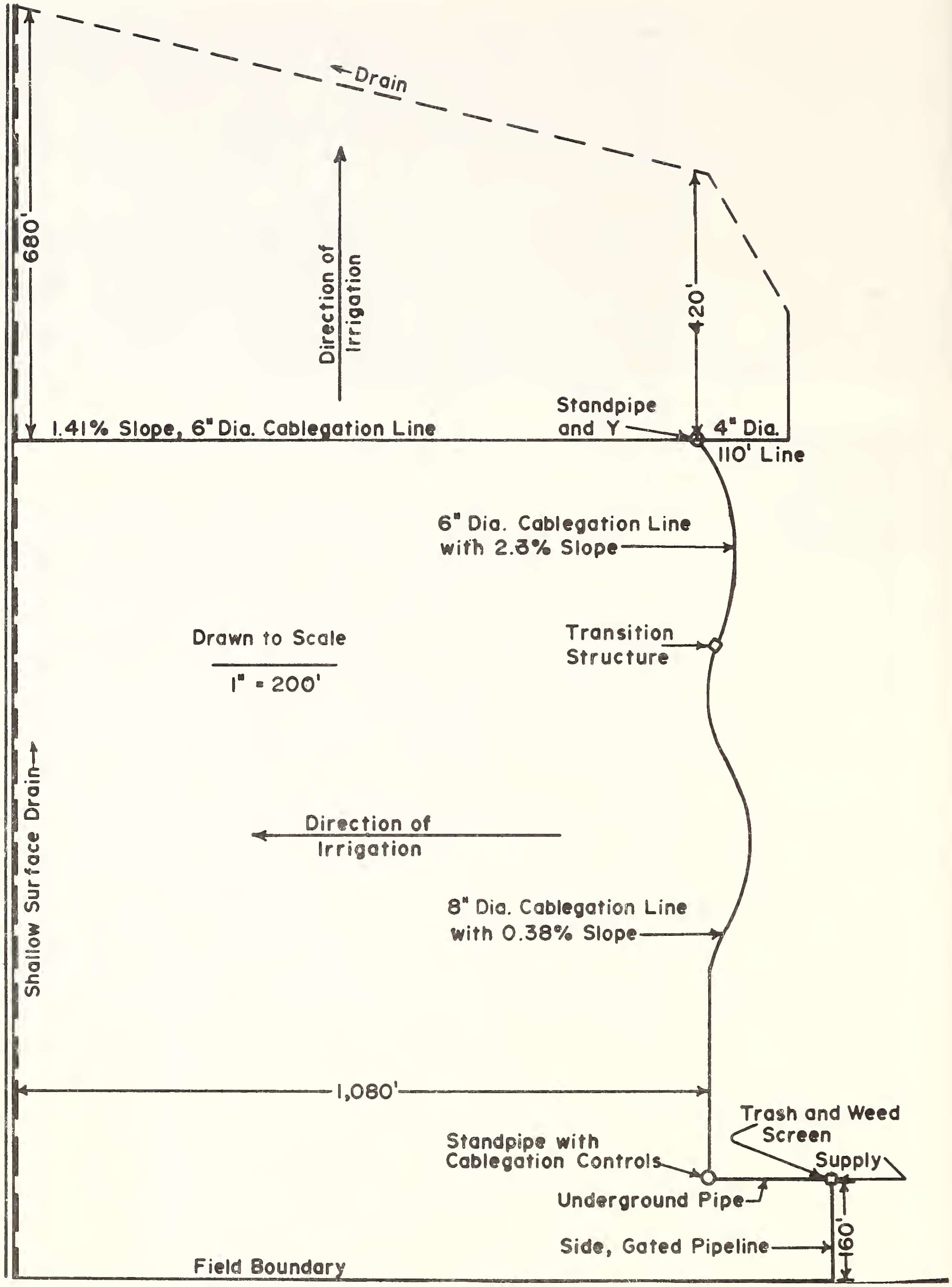


Figure 74.--Dimensions of Kemper system.

Structures, Operations, and Energy Dissipators

The four structures indicated along the pipeline in figure 75 are sketched in some detail in figures 76, 77, 78 and 79. The trash screen structure shown in figure 76 was essential since the water supply was extremely trashy--yielding over a gallon of trash per hour during much of the irrigation season. The horizontal screen was 20-mesh, 32 inches wide, and 33 inches long (names of manufacturers can be furnished on request). When this screen and its metal frame were placed on top of the structure, some trash tended to migrate around the edges and back into the water. To prevent this migration, mortar was applied to the top of the walls outside the screen to provide a tight fit and shaped so that trash and splashes of water falling outside the screen would slide off the structure to the adjacent soil surface. The screen cleaned the trash from the water and generally functioned effectively if the accumulated trash was removed from the end of the screen about twice a day. However, this supply contained a large amount of return irrigation flow, and, during certain periods, the trash content of the water was so high that trash removal about every four hours was required to keep the screen from plugging. Additional observations on this screen and the subsequent development of the turbulent-fountain screen are outlined in detail in appendix H.

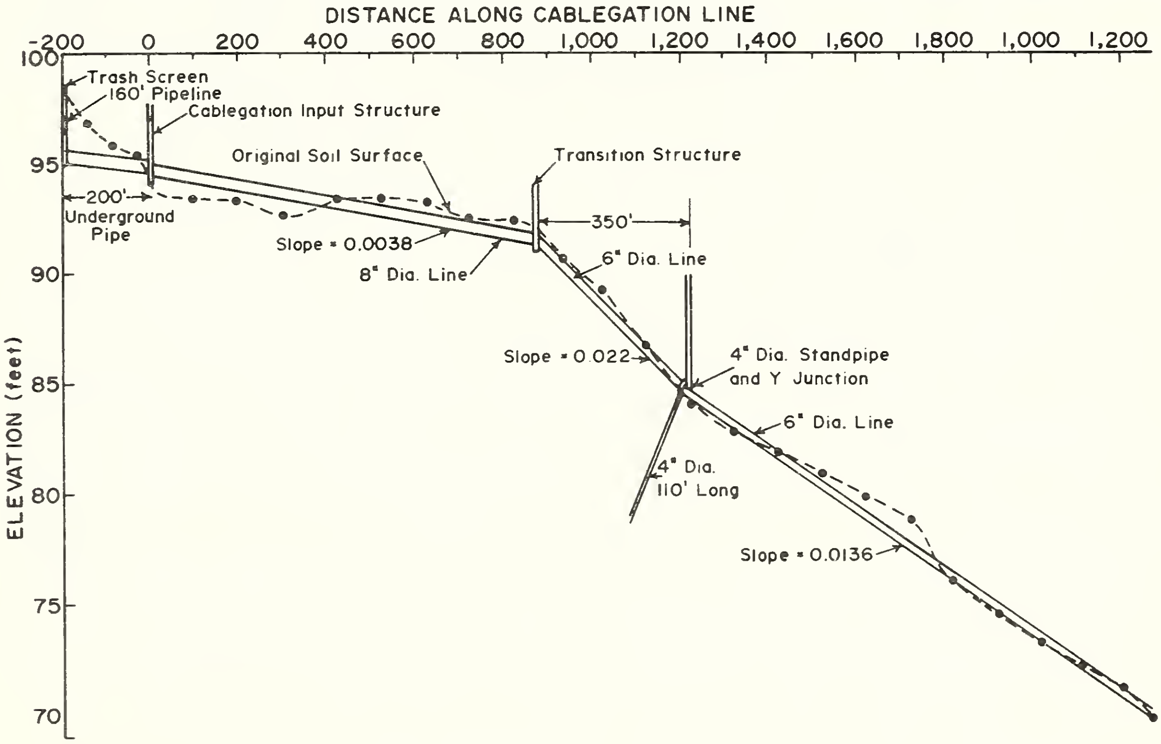


Figure 75.--Elevations of original soil surface and of the installed line and structures along the Kemper cablegation line (bottom lip of headgate=100-ft elevation).

This trash screen structure (fig. 76) also distributes water to the 160-foot gated pipeline indicated in figure 75. That line required only about 0.2 feet of drop in the 160 feet to maintain a relatively even pressure head during operation at the orifices from the inlet to the south end. A modified plug and transition structure were designed so that the field could be irrigated with one speed-control system (fig. 77) rather than two.

The 33.0-acre field had long lengths of corrugates since a midfield ditch had been removed earlier. The slope of the field was steep in the area immediately below this ditch. Erosion occurred on the steep slopes of the corrugates, and sediment deposited in the corrugates where the slope became flatter.

Corrugates in these reaches required considerable manual cleaning to maintain flow through them to the end of the field.

As a consequence of this problem, some corrugates did not irrigate through to the end in a normal pass of the plug through the pipe. The methods described above in "Flow Adjustment to Handle Problem Furrows" (p. 44) were developed to cope with these problem rows. It is also helpful in managing these rows if they are staked and numbered at the upper and lower ends at regular intervals across the field so that the irrigator can quickly and confidently make adjustments to the flow in the desired corrugates after the crop canopy has covered the furrows.

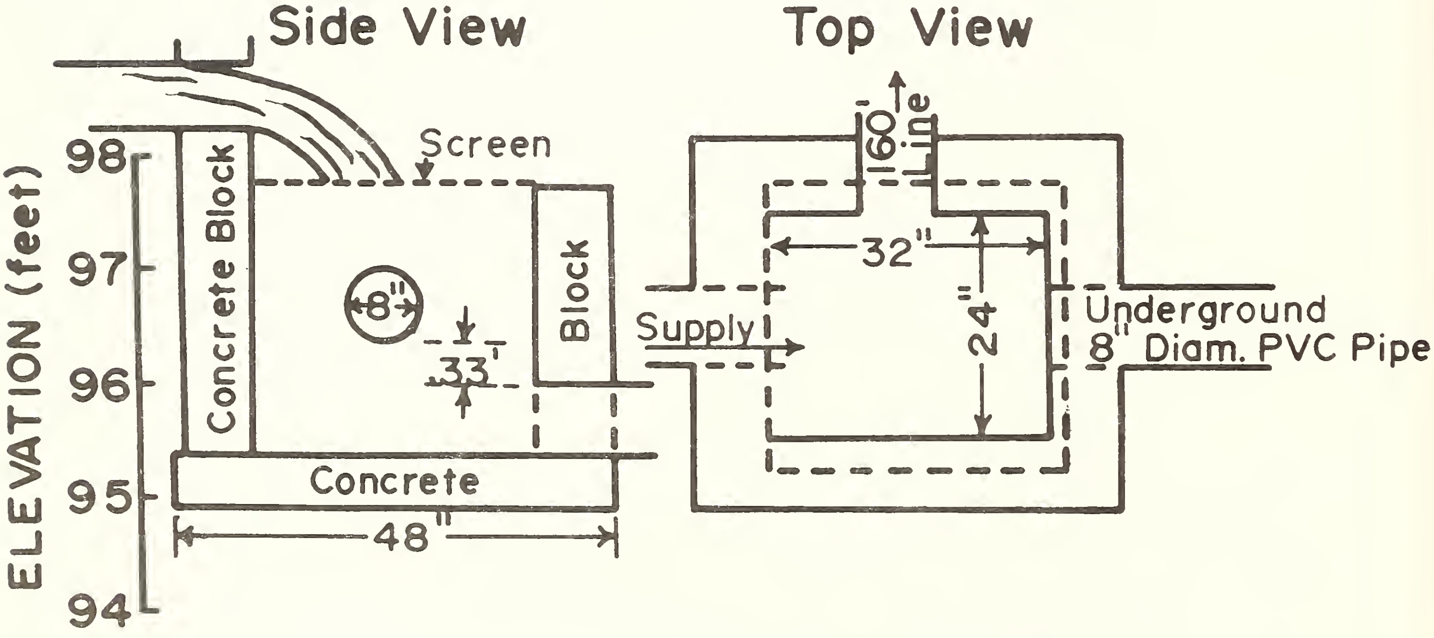


Figure 76.--Detail of trash screen structure.

The cablegation input structure is shown in figure 77. The elevation of sidewalls allowed water to rise when the plug was in the cablegation line so that it was up to 9 inches above the top of the 160-foot pipe in both this input structure and the trash-screen structure (fig. 76) which served as the input structure for the 160-foot line.

The irrigation was generally started with the plug about 30 corrugates down the cablegation line so that those 30 corrugates plus the 44 along the 160-foot pipeline were being supplied. Since the head on the outlet near the inlet structure was about 4 times as high as in the 160-foot line, the cross-sectional area of these outlets was reduced to about 42 percent of the area of the outlets in the 160-foot line. Since flow rate from an outlet is proportional to the area of the outlet and is proportional to the square root of the head of water, this provided rates of flow from the outlets immediately below the inlet structure on the main line which were about 84 percent of the flow from the outlets in the 160-foot line. When water reached the ends of the corrugates in this initial set, the plug was set in motion, opening additional outlets downstream and reducing flow to the corrugates in this initial set. The initially high heads near the inlet structure required energy dissipators of the type shown in figure 16. During the first irrigation, when the inserts and energy dissipators were being installed, the wind was blowing from the west at velocities from 15 to 39 miles per hour. Water emitting from the outlets was blown back over the pipe, and a large portion of it was not reaching the intended corrugates. Where energy dissipators of the type shown in figure 16 were being used, they kept the water directed to the corrugates. These energy dissipators, including the polyethylene tubes, were attached to the outlets prior to the arrival of the water, and the polyethylene tubes were commonly blown back over the pipe before the water arrived. However, in almost all cases, as the water entered the polyethylene tubing it rolled back into the designated furrow. As a result of this experience, the operators decided to attach this type of energy dissipators to all the outlets.

Where the pipeline completes its service to the south field and begins serving the north field, there is a need to stop the plug on occasions when irrigation of the north field is not desired. The possibility was considered of clamping a split lead shot on the line which would trip a switch at the inlet structure and stop the reel just before the plug reached this junction. However, stretch of the line with time made it impossible to stop the plug and hold it in the precise position desired for the several hours needed to complete irrigation of the south field. Consequently, the standpipe indicated in figure 78 was constructed so a 6.5-foot long 2- by 4-inch board could be inserted in the pipe and stop the plug at this point.

The right arm of the Y in this structure provided a siphon which started when irrigation of the second field was started and served the steep 110-foot line indicated in figure 74. Supply to this line stops when the plug travels sufficiently far downstream that the water level in this standpipe drops below the crotch of the Y, allowing air to break the siphon action. This provided water to these short corrugates for about 80 percent as long a time as on the corrugates immediately downstream from this standpipe. When irrigation of the north field was desired at times other than immediately following the south field, about 40 outlets upstream from the Y structure were closed by removing the outlets and attached energy dissipation tube and inserting a plug in the hole. This required about 30 minutes and was done twice during the first season of operation.

The transition structure where pipe size changed from 8- to 6-inch diameter is indicated in figure 79. The double plug is sketched in the side view as it appears just before the 8-inch and 6-inch plugs separate. This double plug is shown in more detail in figure 18. The cable is attached to the 6-inch plug with a line that passes through a large outlet in the 8-inch plug. While this assembly is in the 8-inch line, the 8-inch plug pushes against the 6-inch plug, completing the closure. When they reach the transition structure, the 8-inch plug lodges in the reducer and the 6-inch plug proceeds down the 6-inch line. A portion of the water passing down the line goes through the large opening in the 8-inch plug. However, forcing all the water through this outlet would have caused over a foot of head loss at this structure, which could not be tolerated. Perforating the 8- and 6-inch pipes as indicated in figure 79 allowed the water to flow around the 8-inch plug and reduced head loss, when 1.0 cfs was flowing through this structure, to about five inches, which was acceptable.

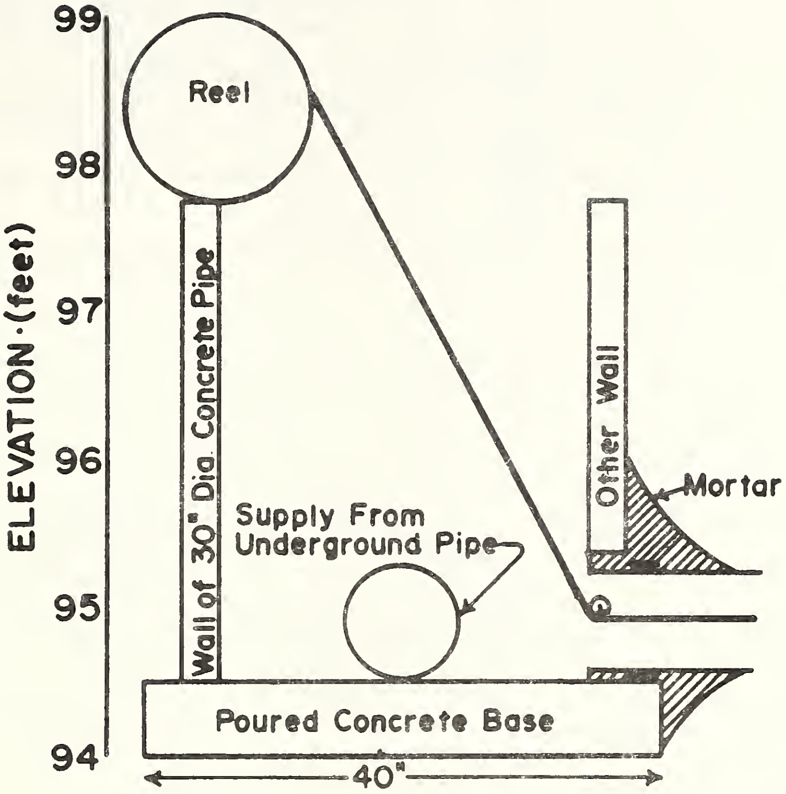


Figure 77.--Side view of cablegation input structure.

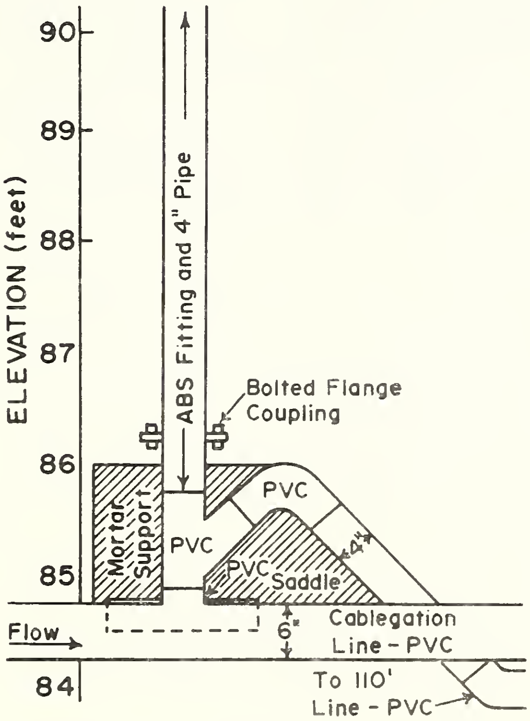


Figure 78.--Standpipe and Y-junction.

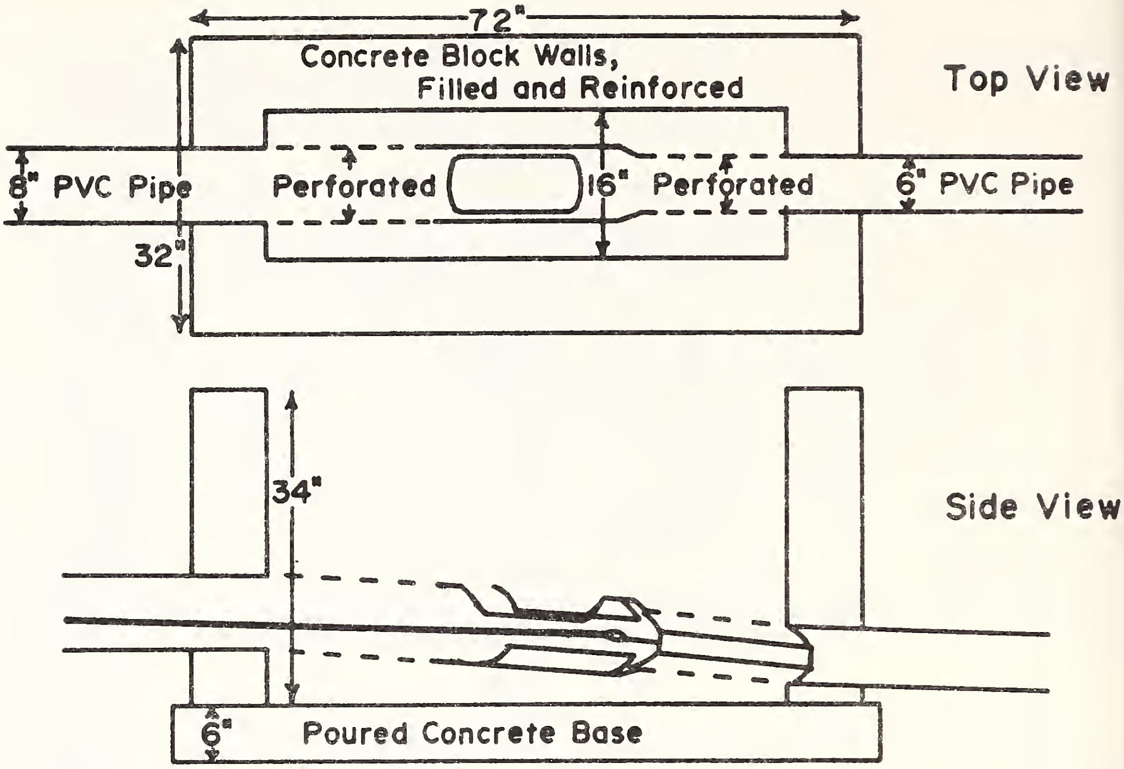


Figure 79.--Transition structure (from 8- to 6-inch pipe).

Changes in Water Intake Due to Tractor-Wheel Compaction

As the plug moved down the line, flow from outlets in the initial set eventually stopped and an average of about 90 corrugates were being provided with water. Initial supply rate to corrugates below the first set was about 8 gallons per minute. However, the field was planted and cultivated using a four-wheel tractor which compacted the soil under two corrugates out of each three that were used for irrigation. During the first irrigation, it became apparent that water was reaching the end of the corrugates which were on the wheel tracks, with appreciable runoff, while it was not reaching the ends of the corrugates on uncompacted soil. To enable water to reach the ends of the uncompacted corrugates and to have about the same runoff as from the compacted corrugates, it was necessary to increase the size of outlets delivering to uncompacted furrows so they were 56 percent larger in area and delivered 56 percent more water. These larger outlets continued to serve the non compacted corrugates during the whole irrigation season for this sugarbeet crop, and there were no obvious differences in runoff at the tail ends of these corrugates. Enlarging the outlets serving the noncompacted corrugates solved the immediate problem of getting water to the ends of those corrugates. However, the irrigation was uneven, with about 60 percent more water being absorbed by beet rows adjacent to noncompacted corrugates than by beet rows adjacent to compacted furrows. Normal irrigation practice in this area is to irrigate every second furrow so each row is served with water from only one corrugate.

In spite of the lower furrow-infiltration rates in the compacted furrows, the rates at which the wetting front, observed at the soil surface, advanced from the corrugate to the row appeared to be slightly more rapid from the compacted furrows. These general surface observations and a few excavations indicated wetting-pattern differences of the type indicated in figure 80. However, observations on the University of Idaho field indicated that, when tractor wheels compacting the corrugates were wider than those used on this field, the lateral advance of wetting from the furrow toward the row was not faster than in adjacent noncompacted corrugates. These observations indicate potential for using narrow-wheel tractors to compact soil immediately below the corrugates and thereby direct a higher portion of the water toward a relatively uncompacted root zone.

Effects of Furrow Slope on Infiltration

In the smaller field on the north, the outlets ranged in diameter from three-sixteenths of an inch at the extreme east end of the 100-foot line, which served rows about 150 feet long and had an initial head of about 10 feet, to five-eighths of an inch at the west end where initial heads were about 4 feet and corrugates were about 700 feet long. This resulted in initial delivery rates to the 150-foot corrugates that were only 15 percent of those to the 700-foot corrugates. The water was reaching the ends of the furrows with only about 10 percent runoff in both cases. This indicated considerably lower furrow-infiltration rates on the short rows with low supply rates than on the longer rows with the higher supply rates. The shorter corrugates were on grades ranging from 5 to

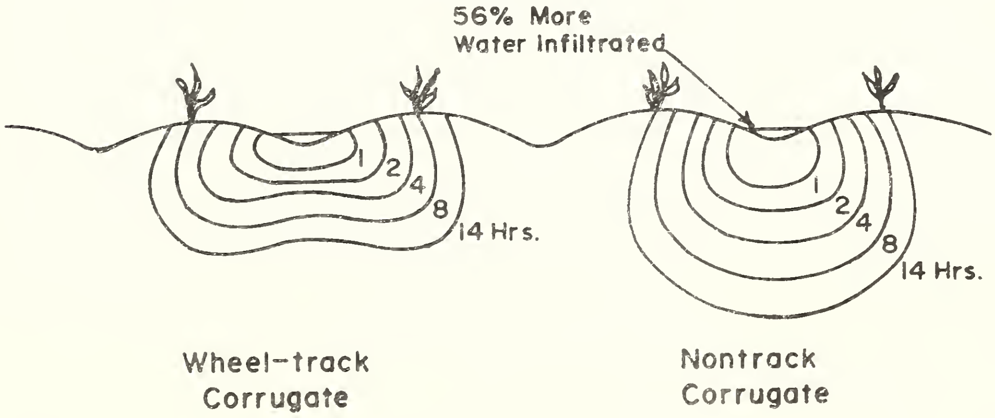


Figure 80.--General differences in wetting patterns observed when soil beneath corrugates had been compacted by tractor wheels.

10 percent while the long rows were on a grade ranging between 1 and 2 percent. The lower supply rate and steeper grade resulted in wetted perimeters of the 150-foot long corrugates being less than half the wetted perimeters on the 700-foot long corrugates. The reduced infiltration resulting from lower infiltration rates of these short corrugates was also reduced by shorter duration of application which was caused by early cutoff by the siphon, which stopped flowing as soon as water in the standpipe dropped to the crotch of the indicated Y in figure 78. Consequently, this structure was rebuilt with a T instead of Y. The leg of the T leaves the main cablegation line at one inch above the top of the line, and water runs for practically as long from outlets in the 110-foot line as from outlets in the main cablegation line. As described in appendix B, the reel for this system was designed to provide water supplies for uniform times to outlets in all segments of the main cablegation line.

In spite of the fact that beans in these short furrows were probably irrigated better than they had been before, they ripened a few days earlier than the rest of the field, indicating some water stress. It is not feasible to make the supply time longer for these corrugates. However, increased infiltration on these short steep corrugates can be attained by application of organic matter to increase infiltration rates and decrease erosion (Aarstadt and Miller 1980); irrigation in the noncompacted corrugates (the three-wheel tractor used on these beans compacted every second furrow), and irrigating both the noncompacted and compacted furrows.

Surging to Get Water to Ends of Furrows on Recently Plowed Field

As discussed in more detail in appendix D, water was not reaching the end of longer corrugates in the smaller field during the first irrigation following plowing down the alfalfa. Rather than change the size of about 150 outlets and accept higher erosion rates with the higher waterflow rates, the plug speed was accelerated providing supply to each wheel-compacted corrugate for about 4 hours, which wetted about three-fourths of the length of these furrows. Then the plug was taken back to the inlet structure, the line was reeled in and the plug was attached to the line and reeled back down to the point where incomplete wetting of the corrugates started. The rate of plug travel was adjusted to keep water in the corrugates for 12 hours. The water quickly advanced to the ends of the corrugates, and a satisfactory irrigation was achieved. This surging was not required on the second and subsequent irrigations.

Runoff, Erosion and Sedimentation

During the first two irrigation seasons the fraction of the applied water which ran off was low on these fields. Runoff was 15 percent and 10 percent from the large 33-acre sugarbeet field and the 15-acre bean field, respectively.

These low runoff rates were a result of furrow application rates that were lower than those used by most farmers in this area for rows of these lengths. The primary reason for keeping the supply rates so low on the large field was the high erodibility of soil at the east end of the field, which had been in beans and sugarbeets for 5 years and had a slope of about 1.4 percent. Appreciable erosion of soil occurred at the top ends of these corrugates with initial supply rates of 6 to 8 gallons per minute. The eroded soil deposited in the middle and lower reaches of the corrugates where flow rates were lower. This movement of top-soil is a long-term negative factor, but was not an immediate problem as long as cultivation was cleaning out the corrugates. However, there were five irrigations after the last cultivation of the beets, and deposited sediment filled corrugates in the middle sections, causing water to break over into adjacent furrows. Keeping water in the desired corrugates required about 50 hours of labor, and the west ends of some rows received inadequate irrigation.

This problem can apparently be solved to some degree by crop rotations. For instance, in the north field, erosion was negligible in most portions of the field even though furrow supply rates were as high in the western portions of the north field as on the south field. The north field had been plowed out of alfalfa that spring, which resulted in higher infiltration rates and reduced erodibility. Studies indicate that fibrous-rooted winter crops, such as wheat or barley grown for silage, stabilize soil and reduce erosion from following row crops planted into the stubble. (Results of this study indicate that the amount of soil eroded from corrugates in beans which had been seeded into wheat stubble was less than 20 percent of the amount eroded from soil which had been winter-fallowed and cultivated prior to seeding the beans. The wheat was chopped for silage about mid-June).

Curvature of the Pipeline and Associated Problems and Solutions

The compound reel diagrammed in appendix B, figures 33 and 34 was constructed, and a shelter was built over the assembly as shown in figure 81. An unforeseen problem with this 2,300-foot line was the large force required to pull the cable (200-pound test, lay-flat, nylon, braided line) back up the line after the plug had been detached. This force was measured on one occasion when the bottom end of the cable was near the bottom end of the line and was over 50 pounds. On the Meuleman installation, the cablegation lines were also over 2,000 feet long, but the force required to pull the cable up the line on that system was only 10 or 20 pounds. The greater force required to pull the cable up the line on the Kemper system was associated with the curve in the pipeline (fig. 74). As the line went around these curves, it pulled against the inside of them and developed friction in a manner similar to that of a rope wound around a windlass or capstan. The lay-flat nature of the braided nylon line allowed it to form against the walls on these curves and develop the high level of friction that made reeling in the line an arduous task.

The high tension on this cable also wore grooves in the male ends of some of the pipes at joints which were on curves, as indicated in figure 82. When the pipes were laid on the curve in this system, they were staked into position in an effort to prevent abrupt change in direction at the joints. After the soil had been placed around these pipes, the stakes were removed. With time, large diurnal temperature fluctuations, and resulting expansion and contraction of the pipe sections, the pipes on these curves tended to straighten and impose more of the change in angle on the joints. The lips of the pipe on the male portion of the joint and the inside of the curve extended farther into the pipe as indicated in figure 82(top). As the braided Dacron cable was pulled up with 50 or 60 pounds of tension on the line, the force pulling the taut cable against the extended pipe lip was much higher than on other portions of the bend. The sliding braided Dacron line, and included sediment, sawed a groove into these extended lips which soon deepened into slits as indicated in figure 82(bottom). By the end of the first irrigation season when the cable was being reeled in, knots or splices in the cable would catch in these grooves in a manner similar to a nailhead in a claw hammer.

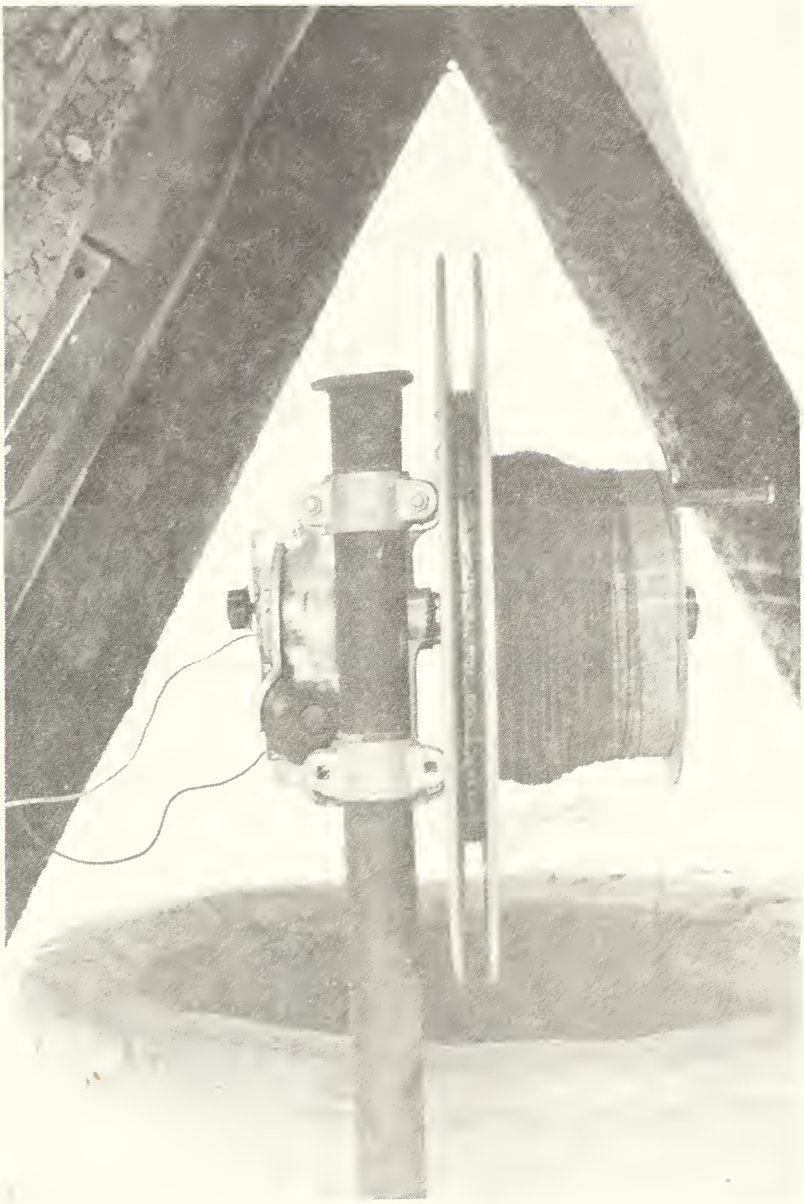


Figure 81.--Compound reel on control system.

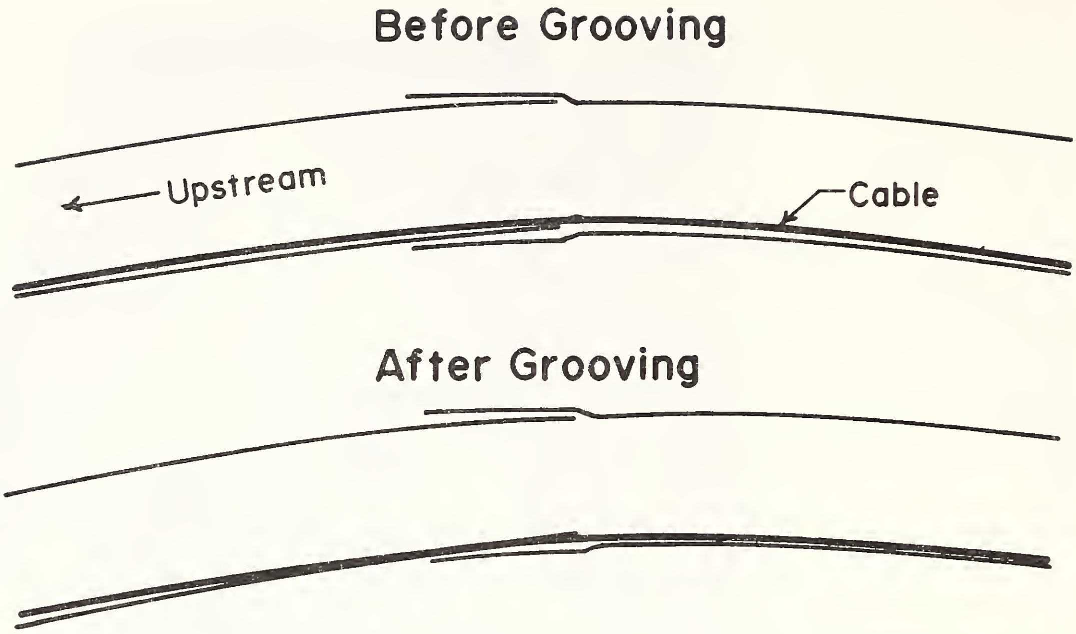


Figure 82.--Geometry of joints on curves which can cause the cable to groove or cut through the male end.

Large holes (about 3 by 8 inches and similar to those described as supplying water for diked strips) were cut in the pipes next to these problem joints to allow observation and development of solutions to this problem. One solution was to use an electric heat gun, powered by a portable gasoline generator, to soften the slotted PVC lip and push it back against the bell of the joint. In some cases, epoxy glue was placed between the bell and the lip before the lip was pushed against the bell. To date, both procedures appear to have been effective.

This problem can be avoided by heating and putting the gentle permanent curvature that is needed into the PVC pipes, so no tongue will develop at the joints. Methods of putting gentle permanent curves into PVC pipes are being developed and evaluated at the Snake River Conservation Research Center. Manufacturers have been identified who will bend pipes to the desired curvature, and their names will be supplied on request. However, because of the tendency of the braided line to lie flat and hold to the inside walls, initial forces required to pull up the line still exceeded 60 pounds. Replacing this nylon braided line with a twisted polypropylene rope one-eighth inch in diameter resulted in over threefold reduction in the force required to pull up this line. The polypropylene line does not lie flat against the inside curves of the pipe, which greatly reduces the friction around such curves.

The high tension on the cable while it was being reeled in caused a strong force tending to push the walls of the narrow reel outward. While the cable was wound tightly on this reel, the space between the walls on the outer circumference was double the designed width, and, even when the cable was wound off, the walls of this portion of the reel retained some of this splayed-out geometry as shown in figure 81. Another negative effect of the high tension on the line was that the operator, pulling on the cable, generally used one hand on the crank handle and another on the outside of the reel. This did not leave a hand free to guide the line uniformly on the reel and resulted in nonuniform winding of the type shown on the wide section of the reel in figure 81. Other actions contemplated to reduce this high tension when the line is reeled in include modifying the transition structure so it would become another control structure and thereby decreasing the length of the lines and dividing the curvature between the two shorter lines or constructing a standpipe and control structure at the division between fields where the four-inch standpipe and Y are presently located.

The latter of these alternatives would require a 30-inch-diameter standpipe extending about five feet above the pipeline.

Richard Wilcox Field, Loma, Colorado

Cooperation and Relation to Upper Colorado Salinity Control Program

This cooperative study and demonstration on Richard Wilcox's field at Loma, Colorado, was requested by the U.S. Department of Agriculture Soil Conservation Service (SCS), which is advising the Agricultural Stabilization Conservation Service (ASCS) and farmers in the Upper Colorado Salinity Control Program. A primary objective of this program is to reduce the amount of salt brought back to the Colorado River by groundwater seepage caused by excessive irrigation applications. The SCS, United States Bureau of Reclamation (USBR), and Colorado State University have identified areas where the irrigated lands are underlain by saline parent materials and have conducted studies showing that reduced percolation through these soils would be an effective method of reducing salinity in the lower reaches of the Colorado River.

Because of strong economic and political reasons for reducing the salt input into the Colorado River, Congress has approved a program to assist farmers in these areas to improve their irrigation systems and practices to decrease deep percolation. This assistance includes technical guidance by the SCS and cost sharing of the improvements through the ASCS. The costs of land leveling, lining, and piping the distribution systems, and improved and automated irrigation systems are shared.

Physical Features Determining System Design

Wilcox, with SCS guidance, has consolidated smaller fields and graded them to achieve the 40-acre field indicated in figure 83.

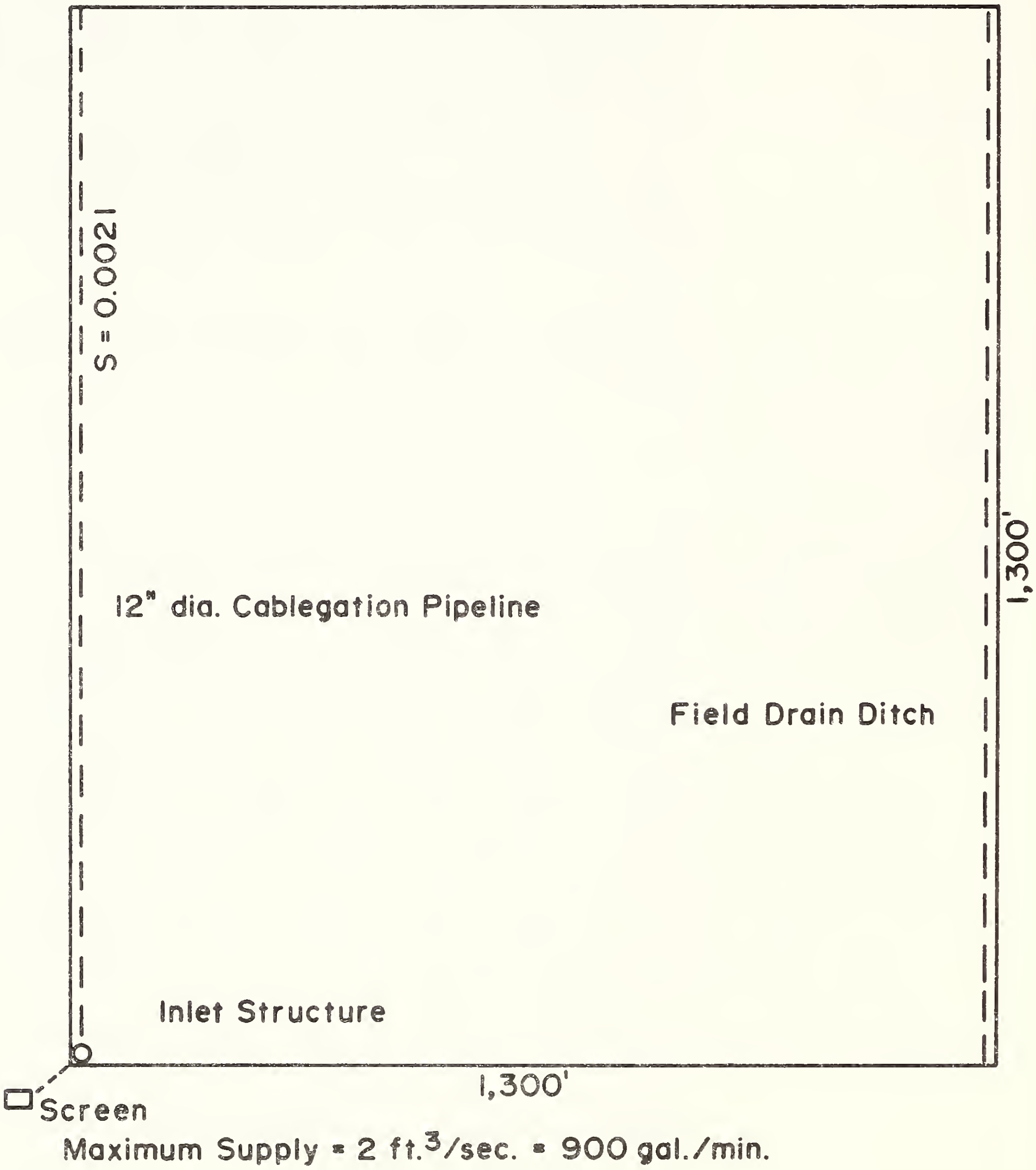


Figure 83.--Richard Wilcox field, Loma, Colorado.

Slopes going northward along the west boundary averaged about 0.002, or 0.2 percent. The existing soil-surface elevations and distances indicated in figure 84 were furnished by Harold Delfelder and Kristi Faust of the SCS.

It was determined from Hazen-Williams calculations (app. A, fig. 25) that the maximum supply rate of 900 gallons per minute could be handled on the 0.002 (0.2 percent) grade in a 12-inch diameter pipeline. Gated pipe size was chosen, since its formulation contains metallic oxides which reduce damage to the pipe by the sunlight. It was also decided to cover this pipe with an inch or two of soil and to have the outlet elevations at approximately the level of the normal soil, which is about 3 inches above the bottoms of the furrows as indicated in the inset of figure 84.

Wilcox' farm is near the end of the lateral; he has flexibility in his water supply and is able to provide flow rates from 450 up to 900 gallons per minute to his cablegation line. The inlet structure for his cablegation line is diagramed in figure 85. Furrow supply rates predicted for this system are indicated in figure 86 as a function of distance upstream from the plug and as a function of two plug speeds at the indicated total supply rate and outlet diameters. When higher rates of flow were supplied to the line, the initial outlet-flow rate increased, number of outlets flowing increased, and the outlet flow cutoff at the end of the irrigation period was more gradual.

Coarse Sediments Collecting in Pipeline and How to Eject Them

An immediate problem in this system was the accumulation of coarse, sandy sediment in the cablegation line. The supply water comes from a steep section of a lateral in which turbulent flow keeps a bedload of coarse sediment suspended and traveling in upstream sections. As this sediment-laden water comes down the nonemitting portion of the cablegation line, velocity of the water is great enough to keep the sediment moving. As the water passes through the emitting section, part of it leaves the pipe from the top side where sediment content is least. The water in the pipe has a slower and slower velocity as it approaches the plug, and most of the sandy sediment settles out in the bottom of the pipe in the reach from 0 to 50 feet upstream from the plug. As the plug moves slowly downstream, this sand dune follows it and grows. In the other cablegation systems, the sediments were finer, and enough of them left with the water from the outlets so that the mud dune following the plug did not

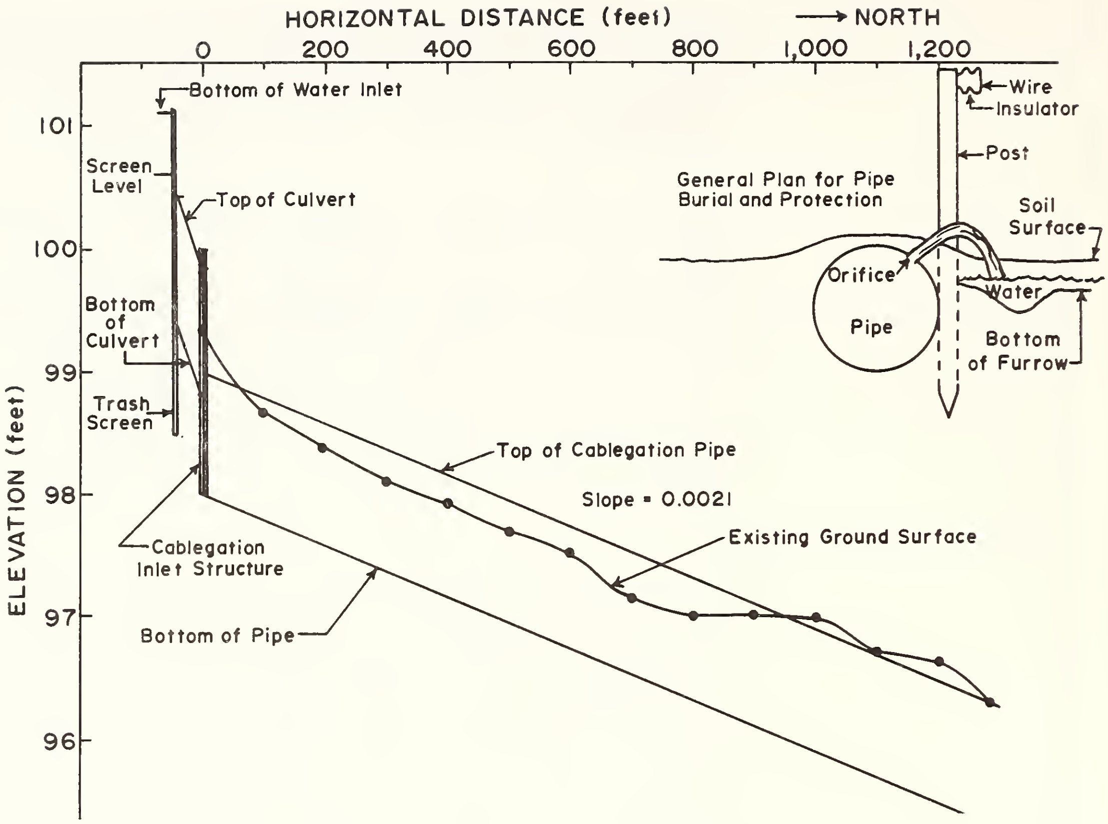
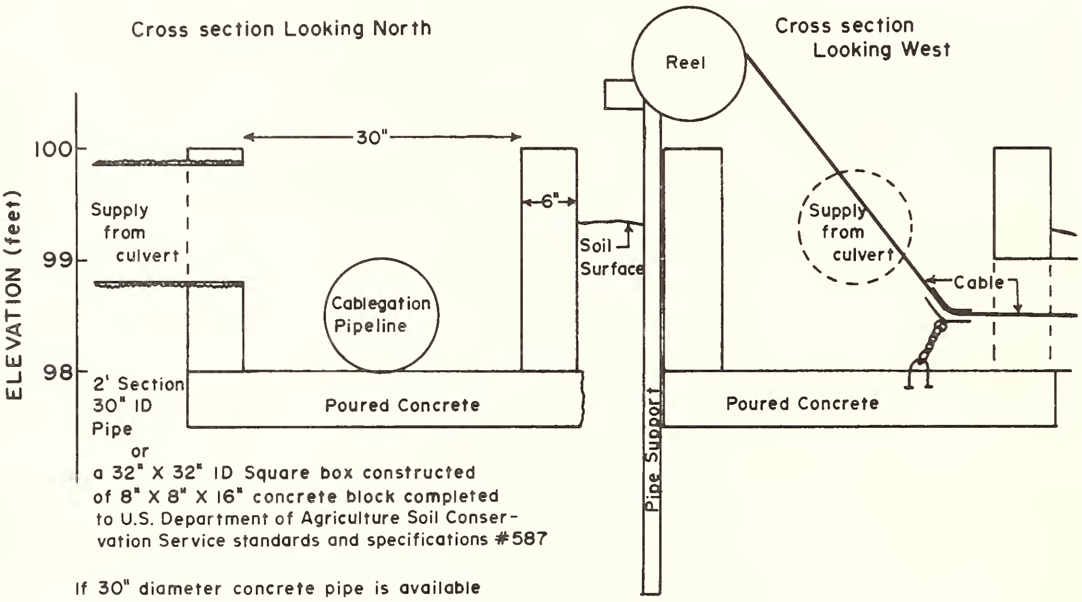


Figure 84.--Elevation of structures and pipe on the Richard Wilcox farm.



2' Section 30" ID Pipe or a 32" X 32" ID Square box constructed of 8" X 8" X 16" concrete block completed to U.S. Department of Agriculture Soil Conservation Service standards and specifications #587

If 30" diameter concrete pipe is available only in 3' sections, the standpipe should be set 6" deeper in the soil and the bottom 6" be filled with concrete, leaving the top of the standpipe 6" higher than shown.

Figure 85.--Inlet structure on Wilcox cablegation system.

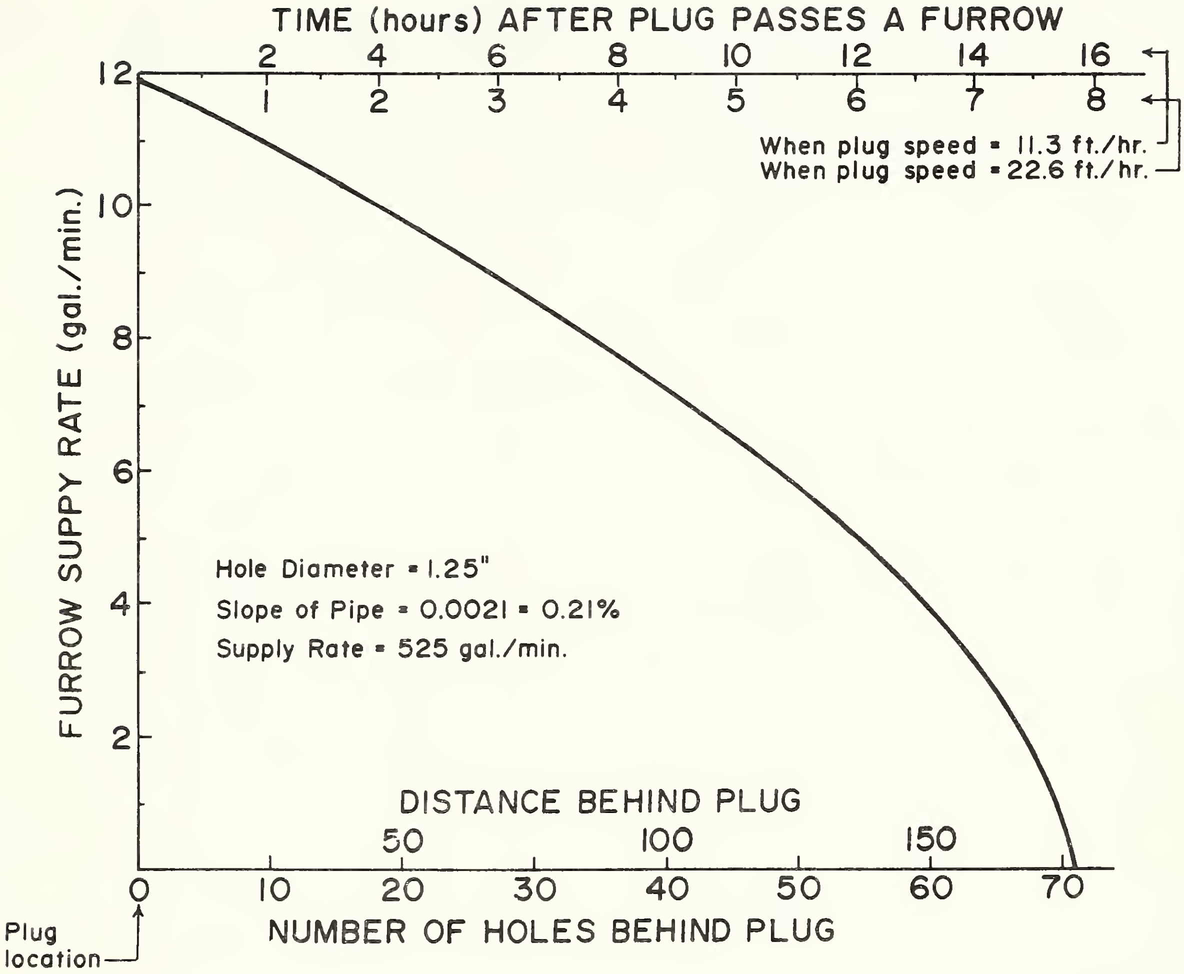


Figure 86.--Supply rates from holes along the pipe at a given time and change of rate of supply to a furrow as time passes with plug traveling at 11.3 or 22.6 ft/hour.

grow high enough to impede the water flow. However, in the Wilcox system, the sand dune following the plug by about 30 feet built up to within a couple of inches of the top of the pipe and caused flow rates from outlets immediately upstream from the dune to be larger than flow rates from outlets between the plug and the dune.

This sediment was successfully handled by providing outlets in the bottom of the pipes, as shown in figure 17, with an elbow and pipe of small diameter bringing the water up to the same level as the normal outlets. The position of these underslung outlets and the relatively high velocity of water through the outlets and pipes carries the coarse sediment out into the furrow. One of these underslung outlets every 60 feet along the cablegation line was sufficient to avoid the build up of an appreciable sand dune. On a typical day, sediment content of the supply water was 0.05 percent. Sediment content of water coming out of the regular top-side outlets was 0.03 percent, and sediment content coming out of the underslung outlets was 0.30 percent. Rates of waterflow from the underslung outlets were about 50 percent higher than from the topside outlets but could be adjusted somewhat by sliding the pipes up or down in the elbows. From the measurements of sediment in the water, it was concluded that the average irrigation brought about ten tons of sandy sediment to this 40-acre field.

Intake Rates and Amounts and Consequent Corn Yields

On this soil, the decreasing intake rate combines with the relatively rapid furrow advance to result in intake at the bottom ends of the furrows being nearly 90 percent of intake at the top ends. Generally, reducing furrow supply rates about 25 percent would have reduced runoff from about 33 percent to about 10 percent of the water applied but may have resulted in a few furrows not being irrigated to their ends. Wilcox has access to as much water as he desires. Surface runoff goes to the river at essentially the same point as does the excess water in the lateral from which he takes his water. The amount of salt in surface runoff and in the lateral is not significantly different. Pushing the water through the furrows rather quickly with somewhat oversized flows results in the high top-to-bottom-end uniformity, thus avoiding prolonged irrigation at the top end, which could contribute to deep percolation.

Measurements of soil-water contents indicated that the irrigation applied did not fill the soil to the field capacity, and available soil-water content of the top 2 feet of soil was commonly 60- to 90-percent depleted before the next irrigation. This is ideal for prevention of deep percolation but is less water than is optimum for corn production.

Yields on the south half of the field, which had been leveled and irrigated the previous year, were about 160 bushels per acre. On the north half of the field which was leveled just a few weeks before the corn was planted, the yield was about 100 bushels per acre. In this newly leveled area, there were many strips, which had served as traffic ways during the leveling process, where infiltration rates were low. It is probable that freezing and thawing during the winter months and long-term root activity will loosen the lower layers of this soil. However, it appeared on both this and the Craig fields that short-term irrigation, filling the plowed layer, provided the best row-to-row intake uniformity. Frequent short-term irrigations of this type appear to be a water-management practice by which the deleterious effects on crop production of traffic-compacted subsoils can be minimized immediately after leveling.

Matching Infiltration and Supply Rates

Furrow supply rates of about 25 gallons per minute were required to push water to the ends of the furrows in reasonable time during the first irrigation following plowing, whereas a supply rate of ten gallons per minute was adequate to get water through the furrows during the eighth irrigation. To allow relatively easy adjustment to these changing infiltration rates, adjustable gates were constructed and installed. (Commercially available adjustable gates generally protrude into the pipe so they will not be damaged when the pipes are moved. The original gates were designed to protrude outside the pipe so they would not hinder plug travel. However, following development of plugs that are compatible with gates protruding into the pipe [see app. J, fig.109], the standard slide gates were installed in this gated pipe.) When Wilcox irrigates every second furrow, adjustment of 260 outlets is necessary each time he makes the change to a different outlet size. If the adjustments require 20 seconds per outlet, this requires about one and one-half hours per adjustment for this 37-acre field.

Most of the change in infiltration rate took place between the first and second irrigations. Consequently, in a normal irrigation season a farmer would probably need to adjust outlet size two times per season, opening them wide prior to the first irrigation and closing them down to smaller size between the first and second irrigations. This would require about 3 hours per season. If a farmer's water supply was limited, further adjustments to reduce runoff to a minimum would probably be desirable.

An alternative to adjusting furrow supply rate to change the infiltration rate is to decrease the high infiltration rate commonly found during the first irrigation after plowing so it is similar to infiltration rates of following irrigations. As discussed in appendix I and appendix J (University of Idaho Research Farm and Kemper system) this can commonly be accomplished by irrigating in furrows compacted by the tractor wheels and providing surge-type irrigation. Maintaining relatively constant infiltration rates in this manner may eliminate the costs of installing the adjustable outlets, the labor involved in the adjustments, and the deep-percolation losses that commonly result at the head ends of furrows during the first irrigation following plowing.

Calvin Le Beau System

Situation, Objectives, and Cooperation

Calvin LeBeau's farm is located in the Uintah Basin about 2 miles north of Gusher, Utah. His primary crops are small grains, alfalfa, and pasture. The water supply is plentiful (up to 6 cfs) in the spring but decreases to 2 or 3 cfs in the late summer. Karen Wilson, Larry Searle, and Bill McMullin of the U.S. Department of Agriculture's Soil Conservation Service were working (as part of the Colorado River Salinity Control Program) with LeBeau to help him improve his irrigation system, reduce deep percolation to his saline subsoil, and thereby reduce salt loading to the Uintah River, which is tributary to the Green River and eventually the Colorado River.

The form of irrigation commonly used by LeBeau and his neighbors is a surface type, with shallow corrugates which direct the water when small flow rates are applied. However, when the crops are established and there is no erosion potential, but there is a high roughness factor, high rates of application are necessary to push water 600 + feet, which is the common length of run. These high rates of application coupled with vegetation in the corrugates cause the corrugates to overtop, and the surface generally becomes completely covered with water.

Infiltration Rates

In an attempt to determine infiltration rates, ring infiltrometers were used. They indicated infiltration rates from 8 to over 20 inches per hour during the first hour and more than half that rate during the second hour. Measuring rates of supply and area wetted plus depth of coverage at successive times, T. J. Trout showed that actual intake rates during this type of irrigation were about two or three inches per hour during the first hour, dropping about 40 percent each hour as compared to the previous hour. This infiltration rate was consistent with infiltration rates estimated from LeBeau's previous irrigation practices. The extremely high infiltration rates indicated by the ring infiltrometer measurements were apparently a result of extensive subsoil cracking, which allows water entering the soil to fan out under the infiltrometer and enter the ring-enclosed area 3 to 5 times as fast as when the surrounding soil is also flooded.

This was an example of the general fact that past irrigation practices of farmers generally provide better estimates of infiltration rates for designing automated systems than do static infiltration measurements on limited soil areas. It is true that we are generally trying to help the farmers improve their irrigation practices. However, infiltration measurements are so variable with location, time, crop, etc., and so prone to misinterpretation when taken out of the framework of an actual irrigation, that we need all the past irrigation information the farmer can provide to get reasonable approximate values. The system must then have adequate flexibility to allow the fine adjustments that will achieve the improved irrigation.

Field Dimensions, Slopes, and Planned System (Including Diked Strip Irrigation)

LeBeau's land area and pertinent elevations are shown in figure 87 along with the general cablegation irrigation plan that was agreed upon. The cablegation lines going east and west on the north boundary were the surface type similar to those used on the other farms, with outlets 1.75 inches in diameter, approximately at ground-surface level. However, the three lower cablegation lines were designed to have their top side 30 inches underground with 10-inch risers bringing water to the surface at 80-foot intervals as indicated in figure 88. These risers were designed to come up in every second dike of a field with diked strips. The outlets at the top of the risers (figure 89 top) can be adjusted by swiveling or removing the inner pipe so that water coming up the riser flows to the strip on one side of the dike or to the strips on both sides. If the water is directed to both strips, all the strips receive water in one pass of the plug. If that rate of water delivery does not push the water to the end of the strip fast enough, LeBeau can direct the water from each riser to just one diked strip, resulting in a higher rate of application per strip. This irrigates every other strip in one pass of the plug. A second pass of the plug is then required to water the alternate strips. The inner rotatable PVC-pipe sections could also be rotated to reduce the initial flow rates to the borders. This raises the water level in the risers near the plug and causes a continuing but lower rate of flow at the riser upstream. Rectangular-gated types of riser outlets shown in figure 89 (bottom) were also installed in LeBeau's system.

These experimental risers had the flexibility to provide the desired rates and duration of flows, but considerable erosion took place where this large stream of water hit the soil, and they were not sturdy enough to survive cattle, which found them attractive for rubbing themselves. Several of the risers were

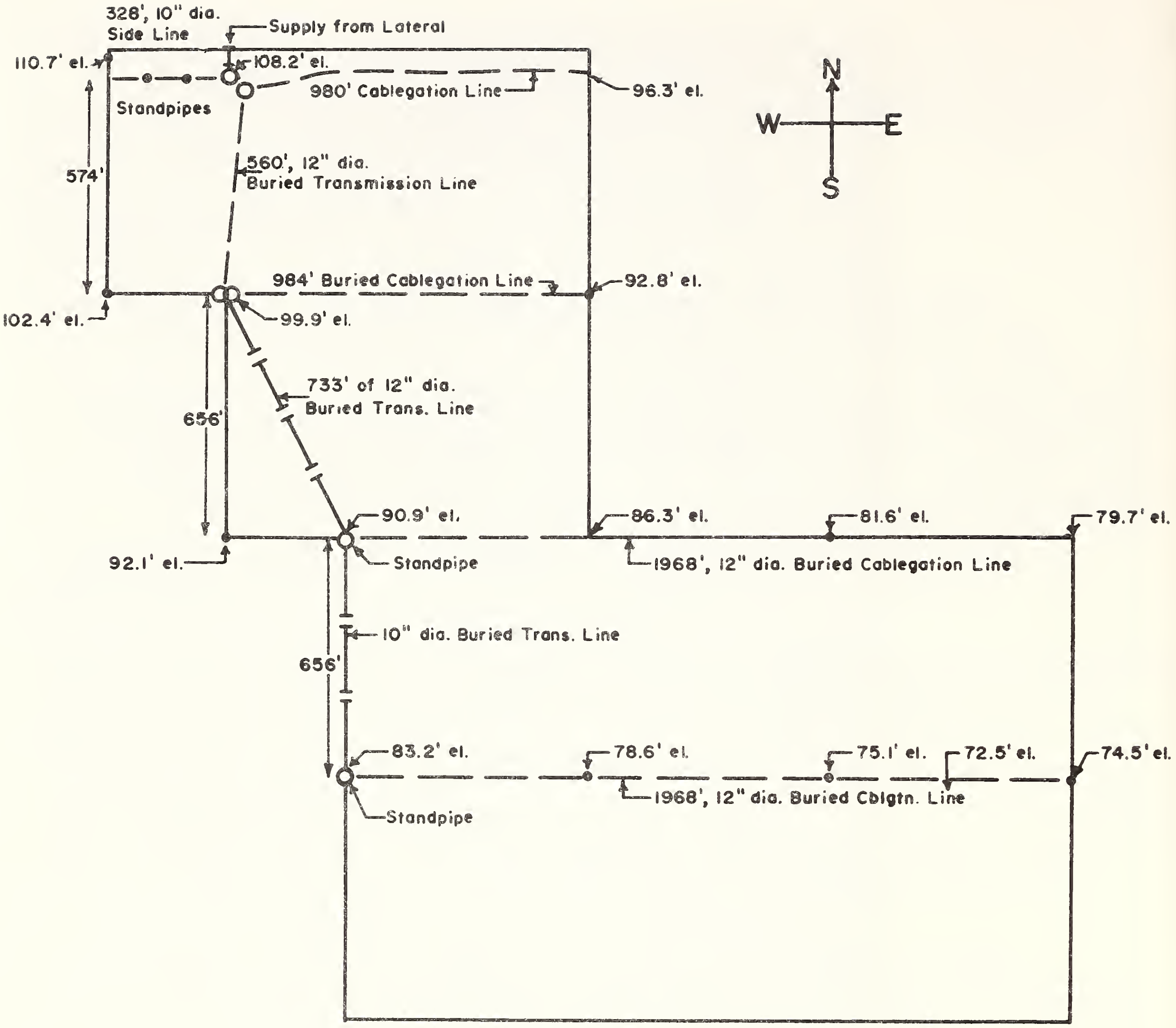


Figure 87.--General plan for the LeBeau farm.

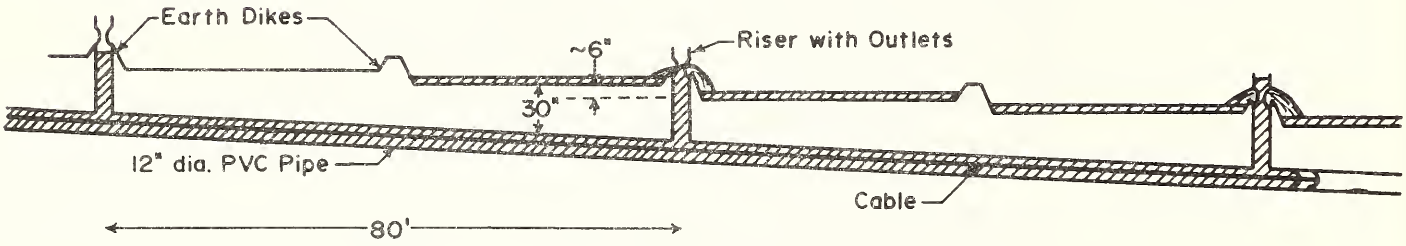


Figure 88.--Cablegation with risers in borders as designed originally for the three lower lines on the LeBeau farm.

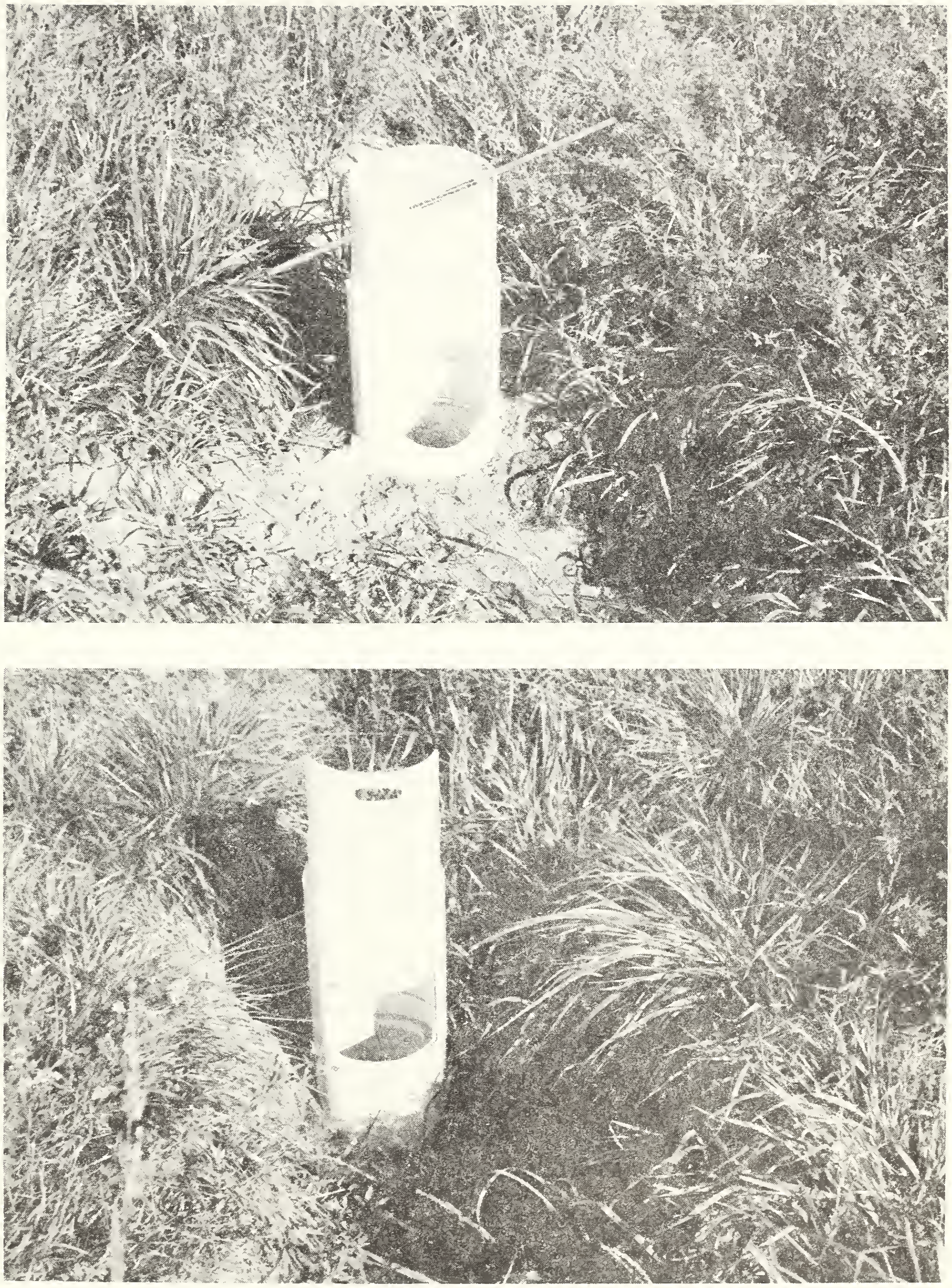


Figure 89.--Experimental risers initially installed on LeBeau's buried cablegation line. (Top) Swivel type with round outlets on each side and swiveling inner pipe. (Bottom) Slide type with rectangular outlets on each side.

broken during the first winter. Subsequently, LeBeau designed and constructed the risers shown in figure 90. The concrete aprons around these risers practically eliminated the erosion problem. The inner pipe can be pushed down into the riser, and the three-sixteenths-inch-thick hinged steel lid can be closed over the riser as indicated in figure 90 (left). In this position, cattle and machinery cannot damage it. When the plug passes one of these risers, the water comes up and pushes the lid into the open position. Water then flows at equal rates to the two strips adjacent to this dike as indicated in figure 90 (center).

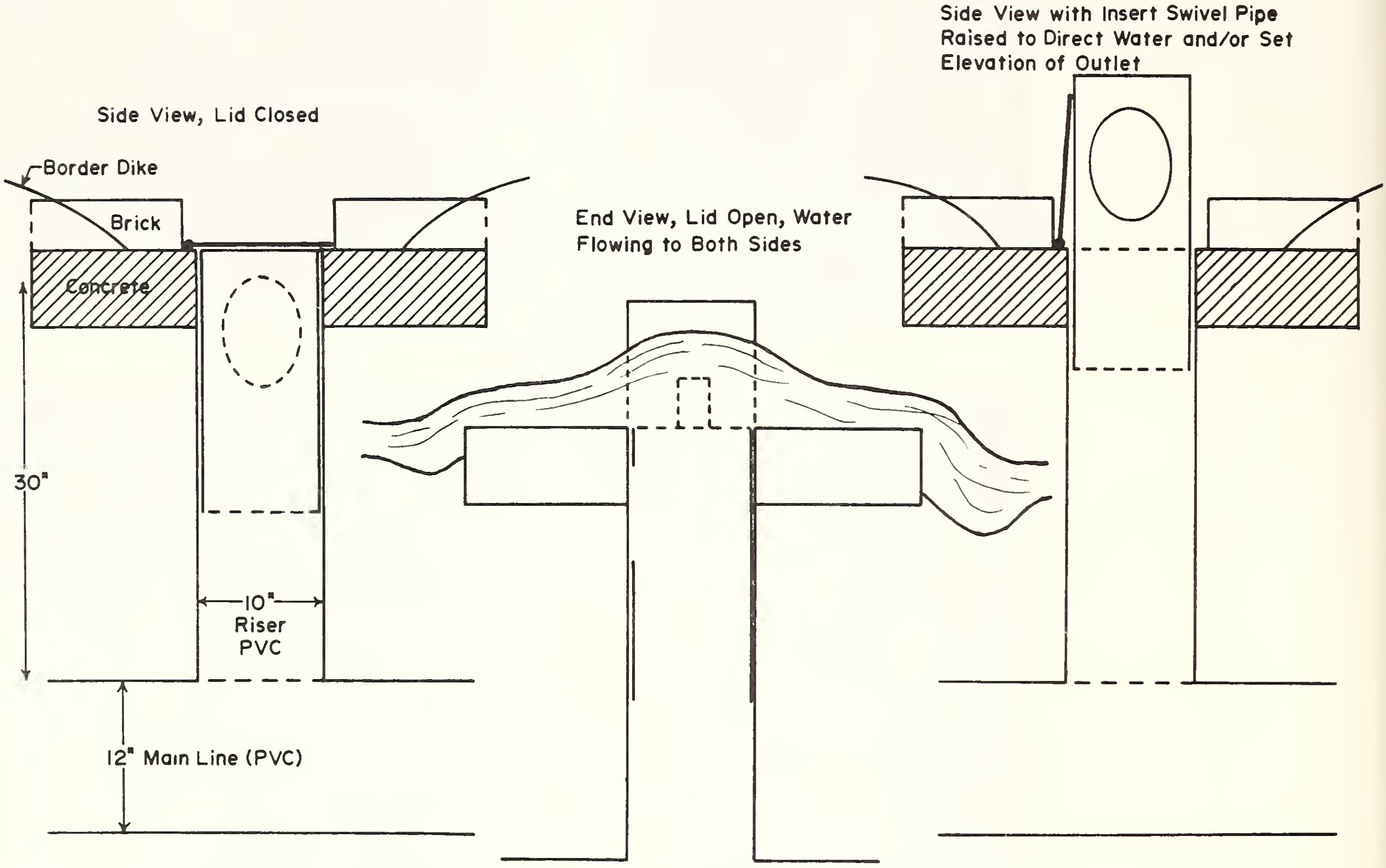


Figure 90.--Risers designed and constructed by LeBeau.

If LeBeau wants all the flow in one strip, the inner pipes can be raised with the holes in each of them directed to one strip before the irrigation starts. If the inner pipe is raised so only a part of the opening is above the concrete apron, the initial flow rate at that opening is reduced, creating more pressure in the line and maintaining cutback flow in the upstream riser.

The elevations of the opening of the risers must be on grade for the cablegation system to provide the same amount of flow at each riser. Consequently, when the concrete aprons are on grade, the inner riser pipe at each riser must be elevated by the same distance above the apron.

LeBeau had permanent pasture in the south 60 acres, which are fairly rough. He plans to reshape this area into diked strips using his own equipment during seasons when he is not busy with crop production. This will probably take a few years. Meanwhile, he was convinced that he could save a lot of time if he had a cablegation line serving this field. He also decided, with our concurrence, to install the line on the north border of the south 60 acres prior to reshaping the field. The cablegation pipe was laid so there were no uphill sections, but no attempt was made to keep it on grade. The concrete aprons were poured with their surfaces slightly above existing ground level, each 80 feet along the line, and are not on a uniform line grade. We then provided him with elevations above each of these aprons that are needed to bring the opening of the riser to the uniform grade line. He has marked the inside sliding riser pipes accordingly and raises them to these levels prior to his irrigation.

This flexibility of the sliding riser is allowing him to utilize the advantages of his cablegation system while he is making improvements on his land, which helps optimize utilization of his resources. It will also allow him to keep the elevations of the land around these risers near existing soil levels. He will thereby avoid deep cuts and fills and their attendant displacement of topsoil.

One problem that must be solved when cablegation lines are installed deep, as indicated in figures 88 and 90, is how to achieve drainage of the lines. Drainage is needed primarily to keep sediment from accumulating but may also be needed in some locations to avoid winter damage due to freezing. On LeBeau's line, midway on the north 40 acres, there is some dropoff at the end of the field, and the end of this line exits to a deep drainage ditch. On the next line down, the land begins to rise at the east end of the line. Consequently, a perforated 6-inch-diameter PVC drain was installed. It proceeds from the northwest corner of this field in a southwesterly direction for about 400 feet, where it reaches a low region of the field and then proceeds south along this draw, which needs drainage.

Hydraulic Cylinder Controls for the Cable Reel

During the winter of 1981-82, LeBeau also conceived and built a model of a cable speed controller which utilized hydraulic cylinders. He did not have the shop facilities needed to build an operational model, so the Snake River Conservation Research Center shop completed the development of hydraulic controllers of the type shown in figure 91.

Each end of each cylinder is connected by a flexible plastic tube to an accumulator about two-thirds full of lightweight hydraulic oil (or kerosene). Needle valves regulate the flow in each of these tubes. When the valves are closed, the pistons cannot move in the cylinders and the reel remains stationary in spite of the pull on the cable. The speed of the reel is determined by the pull on the cable and how wide the valves are opened.

The pin connecting the reel shaft to the control crank is removable. When it is removed, the reel is controlled only by the handcrank. In some cases, where pull on the line was large (greater than 150 pounds), the hydraulic cylinders tended to imbibe air on the suction side of the piston.

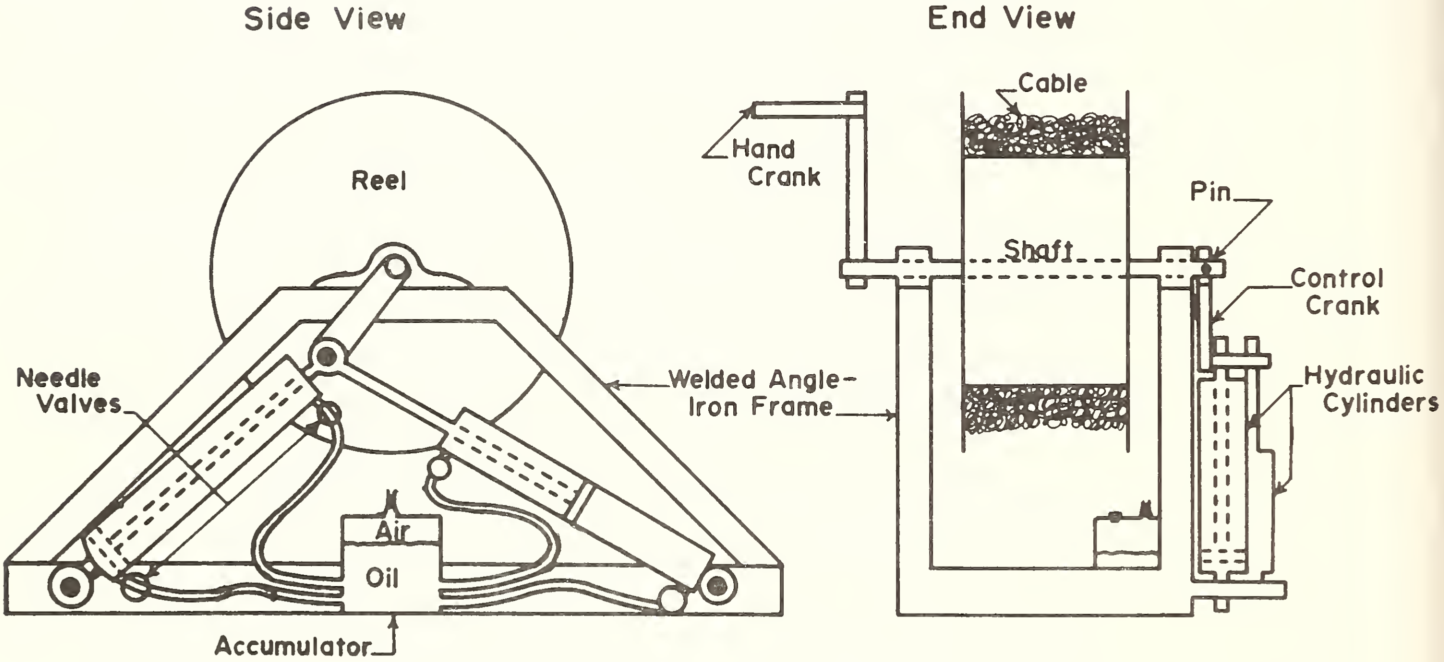


Figure 91.--Hydraulic reel control developed and tested by Calvin LeBeau and the Snake River Conservation Research Center.

Most hydraulic cylinders have seals around the shaft that are made to seal only when there is positive pressure in the cylinder. To keep these pressures positive, the accumulator is constructed to be airtight, a valve stem at the top accommodates entry of air from a common tire pump, and an air pressure of 25 to 40 lb/in^2 is maintained on top of the oil.

As another means to help avoid imbibition of air by the cylinders, on one controller the pulley shaft was geared to another shaft by a 1- to 3-ratio. This made the second shaft go 3 times faster, and the torque required on this second shaft to which the control crank was attached was only one-third as large. These controllers performed well and eliminated battery cost and recharging that were needed for the electrically controlled systems.

Kerosene was used in place of hydraulic oil in some of the controllers, since it has a smaller change in viscosity as the daily fluctuations in temperature occur. In the hot afternoon, speed of the plug with oil in the cylinders was as much as 135 percent of the speed in the early morning. With kerosene in the cylinders, afternoon speeds were only about 110 percent of the early morning speeds.

Don Craig System

Cooperation, Field Dimensions and Slopes and Pipe Diameter

With technical assistance from the U.S. Department of Agriculture Soil Conservation Service (Russell Manwaring and Harold Klug), Don Craig leveled 80 acres of his farm near Letha, Idaho, and consolidated several fields into the two large fields indicated in figure 92. This required deep cuts and fills and movement of about 100,000 cubic yards of soil, which was done during the spring of 1981. Wet weather delayed the leveling operations, so installation of the cablegation system was in mid-June. Slope along the cablegation line was 0.002 (0.2 percent) as indicated in figure 93. His allocated supply rate was 1.2 cubic feet per second, and this is near the upper limit (1.33 cfs) of flow rate that can be carried in 10-inch gated pipe size of this diameter as indicated in figure 25. Due to a miscommunication during design, it was assumed that the pipe was a full 10 inches in diameter, which would have had a maximum carrying capacity of 1.40 cfs at 0.2 percent slope (figure 24) and would have given the recommended design capacity of 115 percent of planned flow. Since the actual inside diameter of the pipe was 9.76 inches, the pipe was slightly undersized for this flow rate and slope.

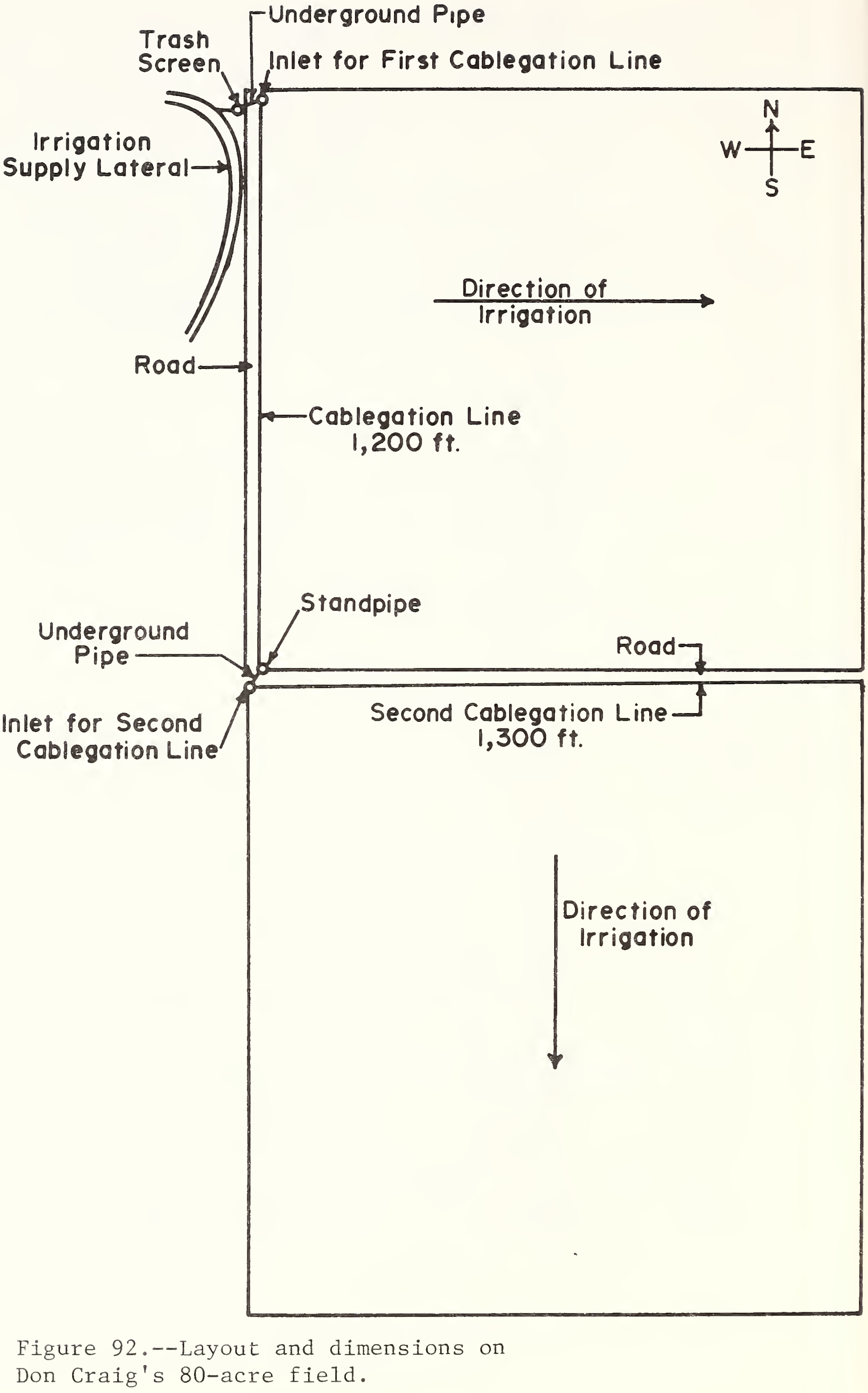


Figure 92.--Layout and dimensions on Don Craig's 80-acre field.

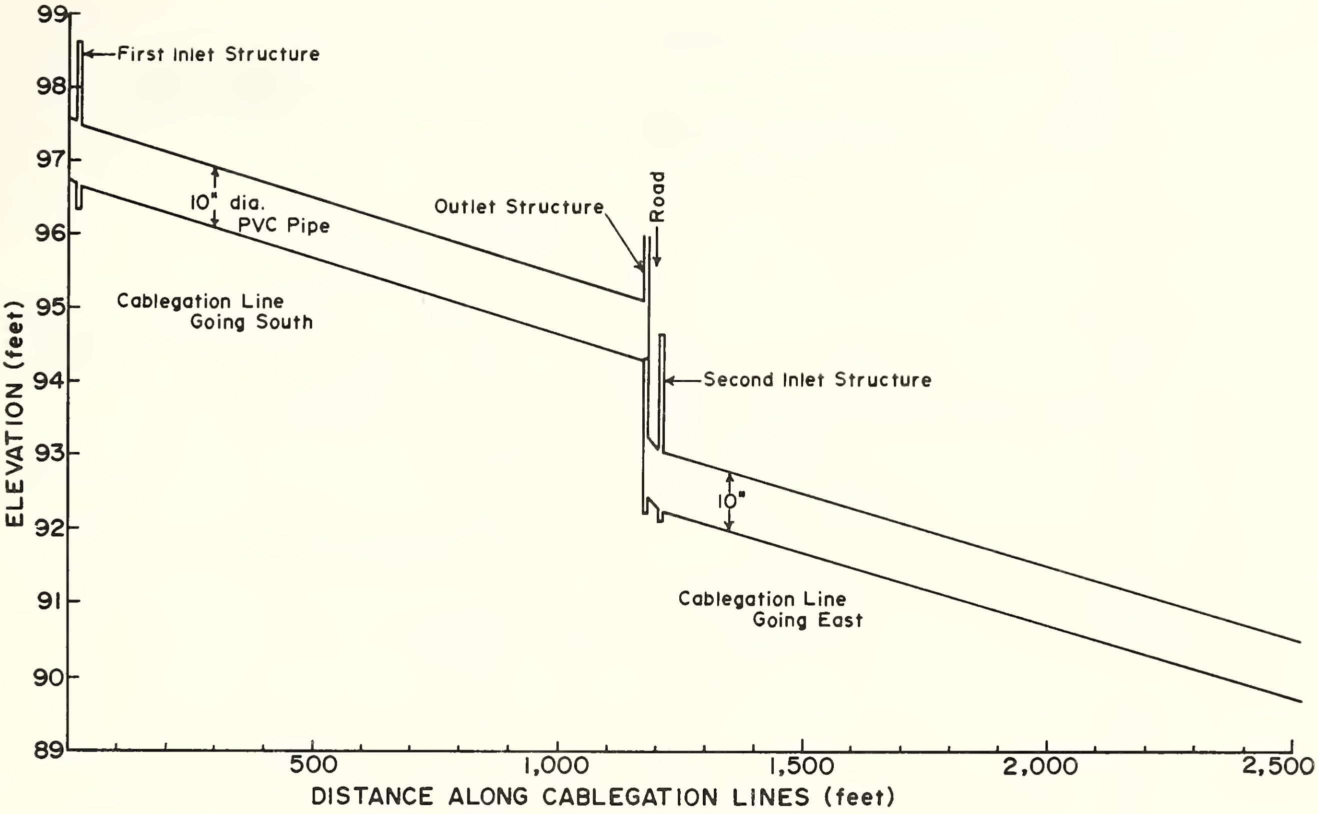


Figure 93.--Elevation plan for cablegation line on Craig field.

Structures and Installation

The structures indicated in figure 94 were constructed of 30-inch diameter corrugated steel pipes set into poured concrete pads. Holes were cut in these pipes after they were installed in the field at the proper elevation to accept the PVC pipes. The trash-screen structure was the turbulent-fountain type shown in more detail in figure 58.

Control System and System Operation

The reel speeds at the first and second inlet structures were controlled by d.c. electric motors operated from 12-volt car batteries via rheostats. This arrangement of two cablegation lines in series gives Craig options of irrigating one field at a time or irrigating both fields at the same time by having a plug in the first line which lets about half the water pass through to the second line. The outlet flow rates predicted by the computer model are indicated as a function of distances above the respective plugs in figure 95. Outlets were spaced 30 inches apart and were 1.75 inches in diameter.

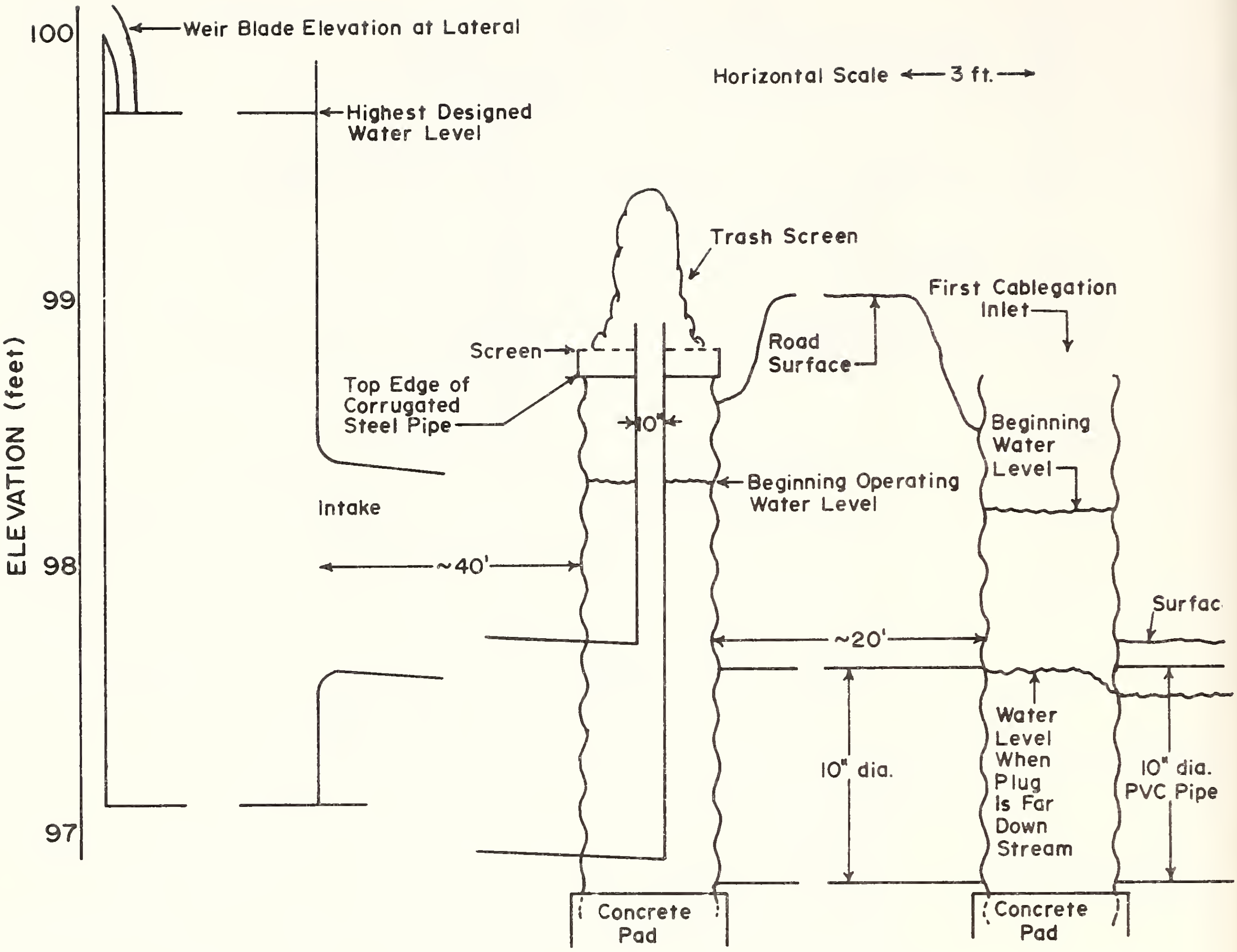


Figure 94.--Structure elevations at top of field #1 Don Craig installation.

For his first irrigations, following plowing when infiltration rates were high, Craig irrigated one field at a time, which gave him the higher flow rate as predicted by the computer in the top curve of figure 95. In subsequent irrigations, when infiltration rates were lower, Craig generally uses a plug in the upper cablegation line, which bypasses half the water to the lower line, and a normal plug in the lower line. As indicated by the two bottom curves in figure 95, the distribution of flow from outlets in the line in the upper field is more prolonged than that in the lower field. This is because the pipe in the upper field carries a flow rate that is near its maximum capacity. Use of 12-inch-diameter pipe in the upper field would have caused the distribution of flow in the top field to be similar to that in the bottom field.

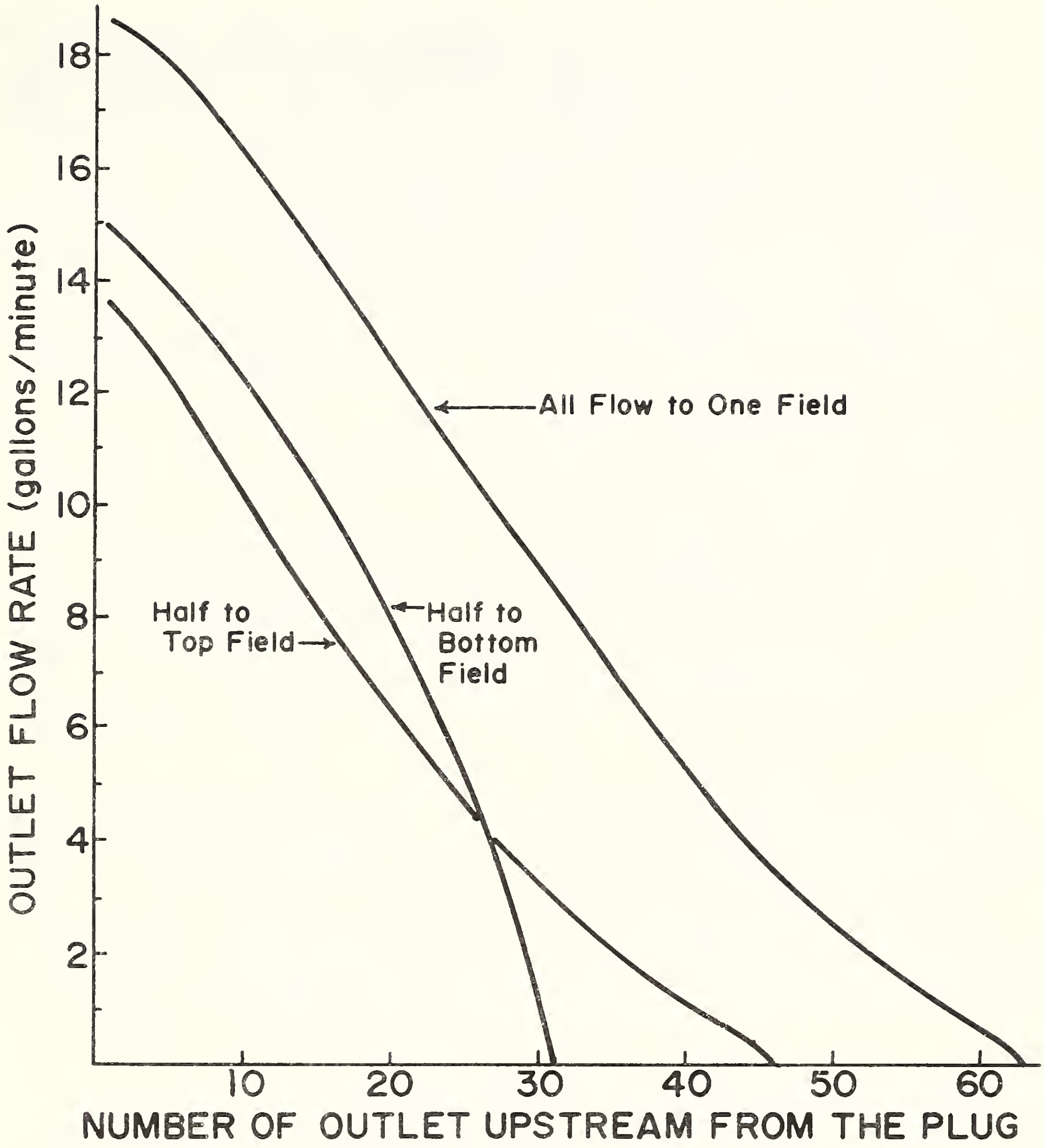


Figure 95.--Predicted furrow supply rates in Craig system when all flow was to one field compared to when the plug in the first line bypasses half the flow to the second line.

The type of furrow supply distribution shown when half the flow was to the bottom field is generally considered preferable because when furrow supply rates drop below two gallons per minute on this field, flow does not reach the end of many of the furrows. Consequently, intake of water at the bottom end of the top field is closer to intake at the top end in the bottom field. However, in the case of these particular fields, a slightly higher portion of the total water applied to the top field was retained because the water supply to the furrows was continued for a longer period of time.

Means for cutting off the furrow supply rates after they recede to values lower than required to reach the ends of the furrows are discussed in appendix F. In the actual system the flows were similar to those predicted in figure 96, except the original plug used in the upper line bypassed less than half the water. A new plug was designed for subsequent irrigations, which could be adjusted while in the line to allow bypass of 40 to 60 percent of the water.

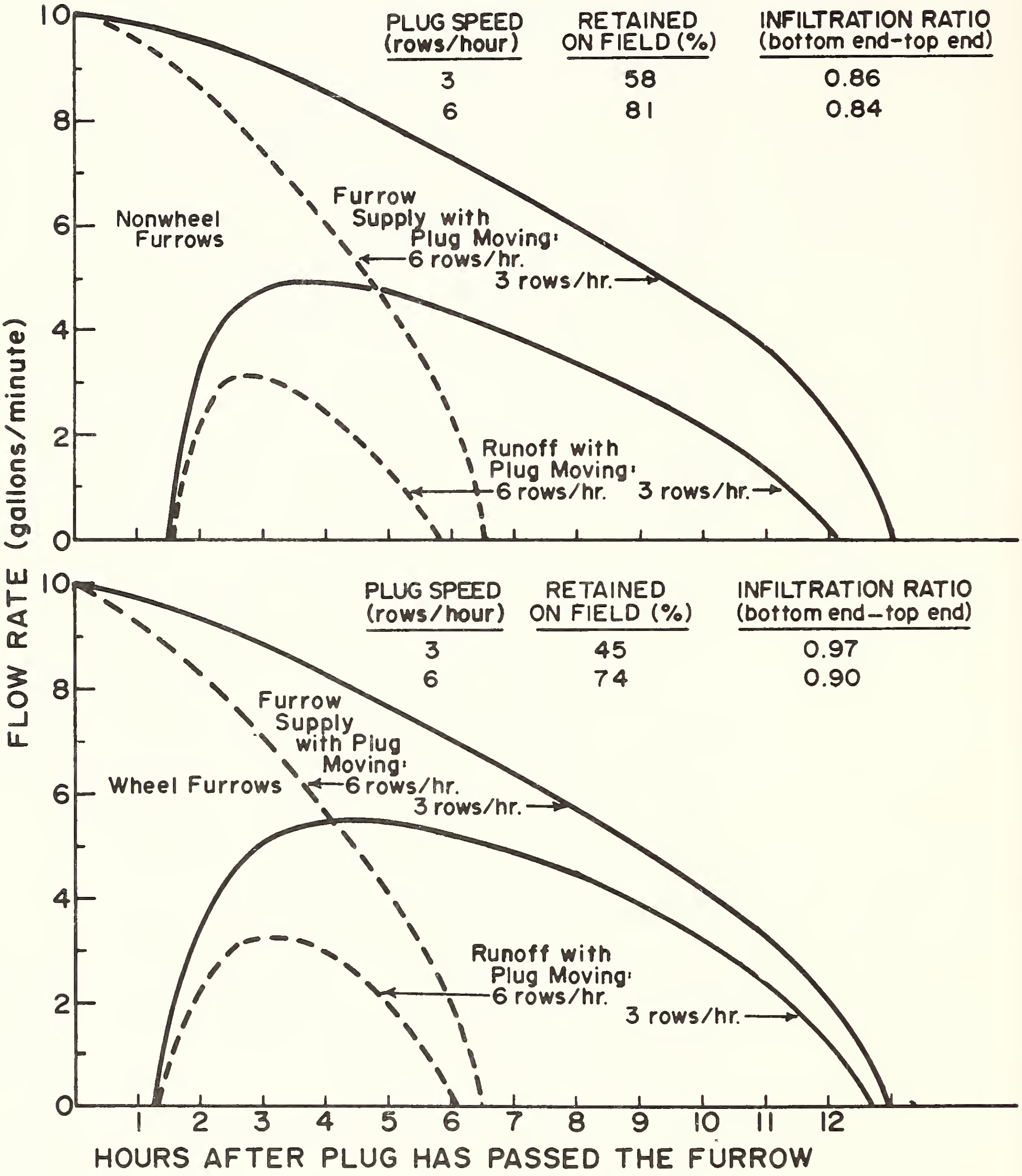


Figure 96.--Furrow supply and runoff rates (lower field of Craig system during second irrigation).

Furrow Supply, Intake, and Runoff Rates as Affected by Plug Speed

Furrow supply and runoff rates were measured in 12 rows in the upper and lower fields during the third irrigation. On that day, the supply to the system was considerably less than designed for, so the shape of the curve of distribution of furrow supply rates on the top field was similar to that predicted for the bottom field in figure 95. Consequently, averages of the rates measured on both fields are plotted together as the solid lines in figure 96. There were consistently lower intake rates in furrows which were in tractor wheel tracks than in furrows which were not, so these were averaged separately and are plotted separately in figure 96.

This was a light irrigation with about 2.2 inches of water applied to the field and only about 1.25 inches retained on the non-wheel furrows and 1.0 inch retained on the wheel furrows. The corn canopy was not covering the ground, and corn was still extending its roots, so it was drawing part of its water from soil storage. It was not suffering from lack of water. However, it was apparent that a larger portion of the supplied water had to be retained by the field if evapotranspiration requirements were to be supplied by irrigation when the corn canopy was complete.

One alternative to achieve more retention of the water would have been to decrease the outlet size as indicated in figure 7. This would decrease the initial flow rates and prolong the flow. However, Craig is a busy farmer with a herd of dairy cows. He did not feel he had time to adjust outlet sizes. (More easily adjustable outlet sizes could make outlet size adjustment a more attractive alternative.) Consequently, he wanted an alternative which would require little of his time.

Assuming that plug speeds were doubled and infiltration rate as a function of time would follow the same pattern as found in the third irrigation, the dashed lines shown in figure 96 were predicted. This calculation indicated that doubling the speed of the plug would result in retention on the non-wheel furrows, increasing from 58 to 81 percent, and on the wheel furrows increasing from 45 to 74 percent. Increasing the speed of the plug in this manner causes proportionately larger differences in the intake opportunity time at the top and bottom ends of the furrows. These calculations indicated that ratio of intake at the bottom ends of the non-wheel furrows to that of intake at the top would drop from 0.97 to 0.90 on this soil.

The intake ratio between wheel-track furrows and non-wheel-track furrows would be 0.78 for the plug speed of three rows per hour and 0.91 for the plug speed of six rows per hour. Considering all these factors, Craig concluded that he could retain more water on his field and obtain equal or possibly better overall uniformity of application if he increased the speed of his plug. This resulted in lighter and more frequent irrigations, which would have required about 10 hours of labor per week with regular gated-pipe or siphon systems. However, with the cablegation system, doubling the frequency required no more than one extra hour per week. This low cost of increased irrigation frequency provides flexibility which surface irrigators without automation do not have.

If the frequency of irrigation had been increased early in the season before the corn had completed canopy cover, a major portion of the extra water retained by the soil would have been lost as a result of increased evaporation from the soil. However, canopy cover was essentially complete following the fourth irrigation. In spite of late planting and the field being newly leveled, Craig's corn silage yield on this field was about 20 tons per acre--slightly higher than average for the area.

Potential Improvements

When asked what he would do differently if he were starting to construct the system, Craig said he would increase the size of the pipeline in the top field from 10 to 12 inches in diameter so it would carry more water to his field when it is available and provide the sharper cutoff on furrow supplies. As a possible alternative, he is watching for availability of low-cost or used PVC pipe (6 or 8 inches in diameter) which he can run directly from his trash-screen structure to his second cablegation-inlet structure. This second alternative would not help appreciably when all his water is going to one field, but he believes he will normally be irrigating two fields at a time.

Guy Meuleman System

Field Dimensions and Slope, Water Supply and Pipelines

Guy Meuleman's system, south of Hazelton, Idaho, is designed to irrigate two adjacent fields of approximately equal size as shown in figure 97. The south field lies above the north field and is irrigated first. A 10-inch-diameter pipe was laid along the south edge of each field on the slopes shown. The slopes fall toward the west and north. The length of each pipe is 2,050 feet. The south pipeline has a slight curve in the alinement, and the other pipeline is straight. Each pipe lies just north of a concrete ditch which was used previously to irrigate the field with siphon tubes. Water delivery to these fields is at a rate of 2 ft^3/s, and the time for which a set is allowed to run has commonly been 24 hours. The water is delivered from a canal at a point about 30 feet south of the southeast corner of the south field. It is measured by a weir which is only slightly above the high corner of the field. Because of this limit on the water-supply elevation, no screen was installed on this system in 1981. The water supply is relatively free of trash except for moss that tends to be a problem in late summer. Occasionally, small fish and frogs have plugged a few of the outlets. The designed pipeline slopes are shown in figure 97.

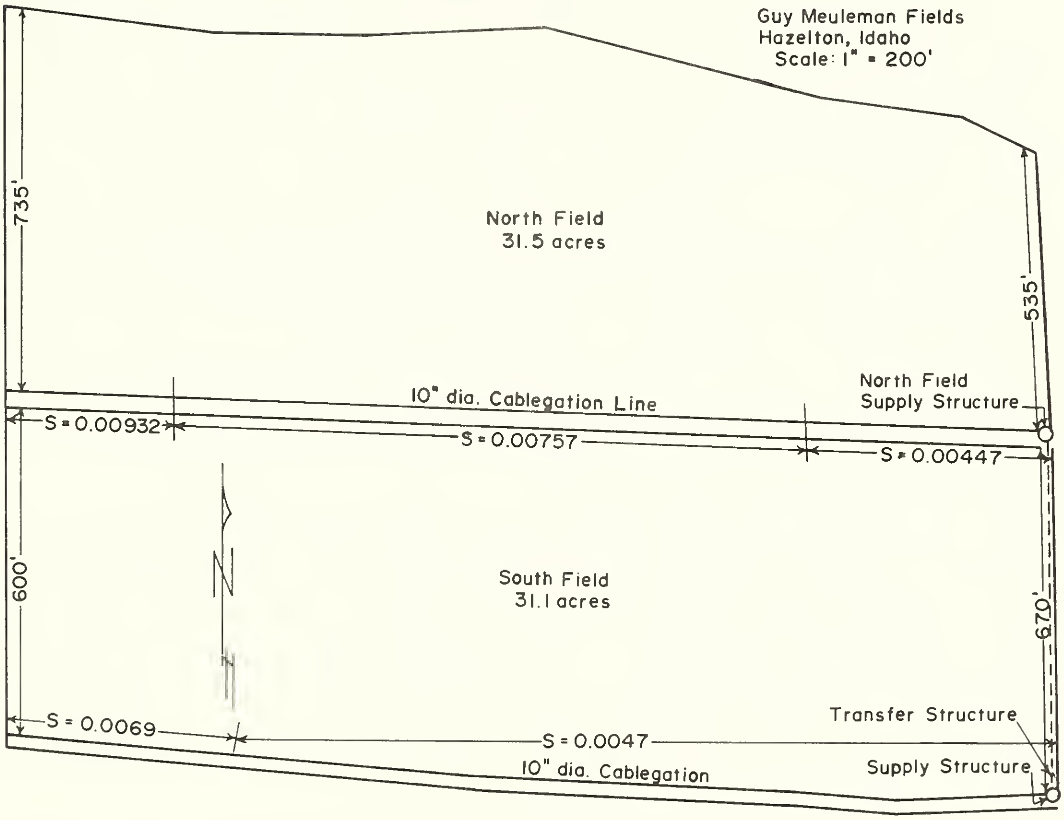


Figure 97.--Guy Meuleman fields, Hazelton, Idaho.

Orifices, Energy Dissipators, and Furrow Erosion

The outlets were made by drilling the pipe with 1.25-inch holes on 30-inch centers set 30 degrees off the top centerline of the pipe toward the field. Polyethylene outlets were inserted in each hole and secured in place by forcing a nail across the diameter just above the outside surface of the pipe (fig. 13). Based on information that 1-inch siphon tubes had been used with about 8 inches of head from the concrete ditch to irrigate these fields, the computer printout called for outlet holes that varied from 23 mm down to 19 mm in diameter along the south line running from east to west. After initial trials, these were all reduced 3 mm in diameter, which provided adequate flow rates and reduced furrow erosion. The north field was then equipped with outlets that ranged from 17 mm in diameter down to 14 mm, which was also 3 mm smaller than called for by the computer printout based on previous application rates. Some of these at the east end of the line for the north field had to be increased again to get the water to flow the complete length of the furrows. This was an area planted to grain with less than one percent slope in the corrugates. Most of the furrows in these fields had slopes of one and one-half to two percent.

All the outlets on these two fields were equipped with energy-dissipator socks fashioned from thin wall (0.004-inch) polyethylene tubing (fig. 16). Pressures up to 39 inches of water were measured near the west end of the pipe supplying the north field. In the high-pressure reach, caps holding the energy-dissipator socks had to be secured in place with corsage pins to prevent them from popping out.

There was appreciable erosion in some of the corrugates; therefore, in some of the later irrigations, a flow-through plug was used to dissipate energy (fig. 8) about 75 feet upstream from the regular plug. The outlet diameter in this plug was 3.5 inches. Maximum flow was decreased by approximately 12 percent. This is a rather small change in flow rate, but on this highly erodible soil erosion appears to vary as the third or fourth power of the flow rate. Meuleman was convinced that the rate of erosion decreased by about 50 percent.

Insertion of the two plugs into the cablegation pipe requires extra manipulation and coordination to avoid tangling the 75 feet of line between the two plugs and to avoid entangling the irrigator in this line. Meuleman solved the problem by mounting a special rod in the input structure to support the upstream plug in a position opposite the pipe inlet. The 75 feet of cable between the two plugs is carefully laid out on the ground so it can quickly feed into the pipe when the first plug is inserted into the pipe. When all the intervening cable is in the pipe, the cable pulls the upstream plug off the rod into the pipe and completes the startup sequence.

Cable Problems and Solutions

Initially there was a problem with cables breaking on this system. The 200-pound-test cable in the south line would break when the plug was 1,300 to 1,600 feet down the line although the maximum measured water pressure was less than 3 feet near the plug. This would account for about 112 pounds of load on the cable. There was some oscillating of the plug inside the pipe at about 150 cycles per minute, but the surges from the outlets indicated that the pressure amplitude was increasing only an inch or two with each oscillation.

Lines manufactured for parachute shrouds were tried but broke within a few minutes. A one-sixteenth inch-diameter stainless steel cable rated at 500-pounds test strength was used to operate the system for several irrigations, but it is expensive and hazardous if a hand or finger should get caught in a loop of cable. A plastic-covered steel cable was difficult to reel in and was not satisfactory.

A source of polypropylene cable was located near the end of the season, and 500-pound test, one-eighth-inch-diameter polypropylene cable performed satisfactorily and at much less cost than stainless steel cable. (This cable costs only about $25/1,000 yards because it is used and manufactured in large quantitites for pulling electric wires through conduits. Names of manufacturers and suppliers will be provided on request.)

Structure for Regulated Transfer of Water from one Line to Another

This sytem was equipped with a transfer structure (fig. 98) to transfer the water supply from the upper field to the lower field. The pipe connecting the supply structure to the transfer structure was actually longer than indicated in figure 98 to allow flexibility in the time at which the microreel could be set in motion. Sometime during the day preceding the arrival of the plug at the lower end of the south field, the plug in the line to the transfer structure was set in motion by swiveling the microreel and its attendant gear reducer into position where it could be coupled to the shaft of the main reel. The plug moving into the transfer structure moves only a few inches per hour and is set to start moving into the perforated section of the pipe in the transfer structure when the plug in the south-field line reaches the end of the field. This begins a supply of water to the north-field structure shown in figure 99 and reduces the supply to the outlets in the south field at a rate equivalent to that which would have occurred if the south line had been longer and the plug had proceeded down that line.

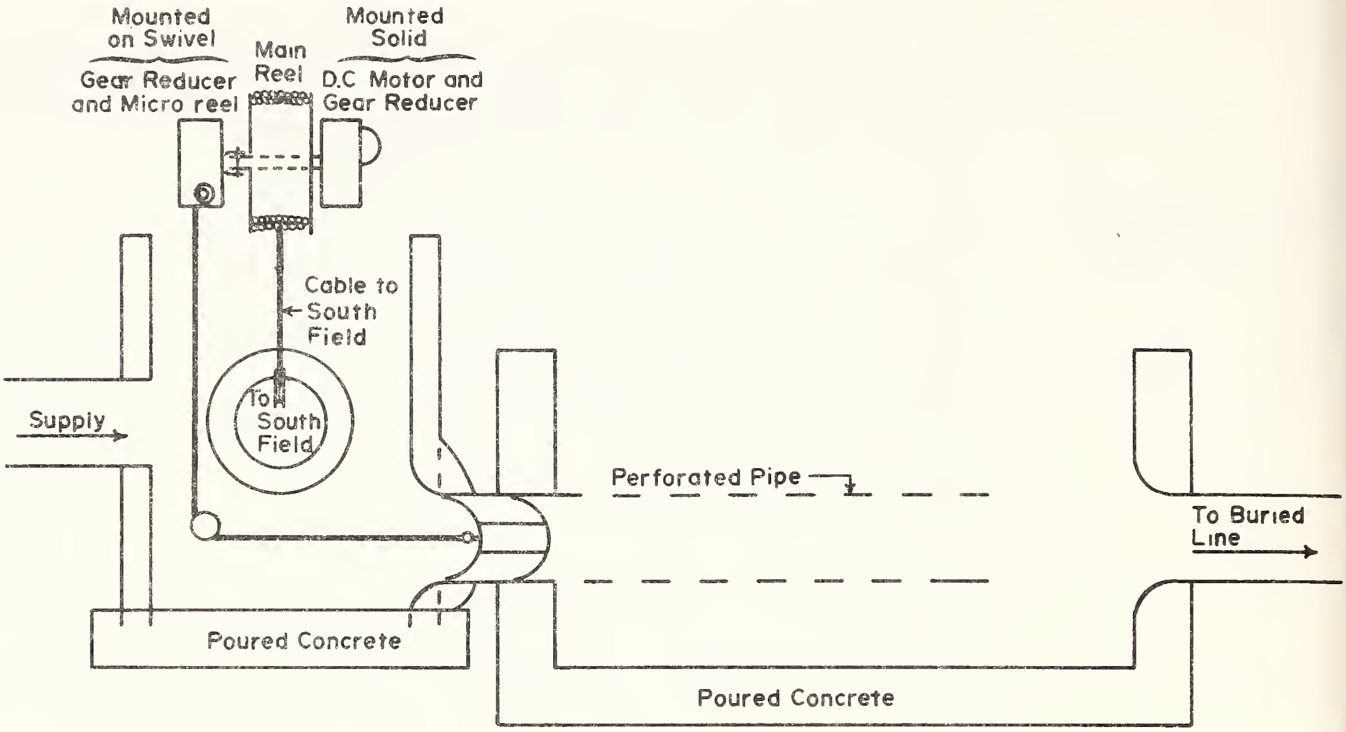


Figure 98.--Transfer structure for gradually moving water from the south to the north field.

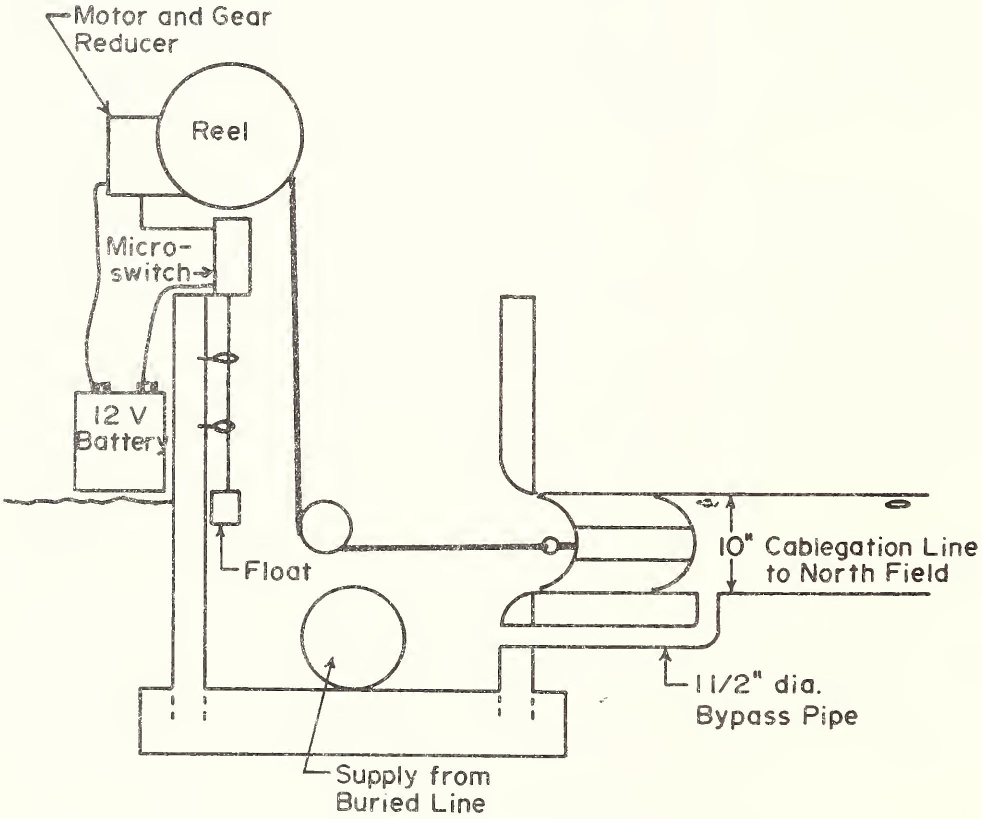


Figure 99.--Supply structure for cablegation line serving the north field.

The bypass pipe in the supply structure for the line serving the north field was necessary to make sure that leakage past the plug leading into the transfer structure did not raise the float and start the north-line plug moving prematurely. As soon as appreciable water came through the transfer structure, sufficient head developed to raise the float, trip the switch, and start this plug moving. Within a few inches, this movement allowed the plug to intercept water from the small bypass pipe.

Potential Improvements

Meuleman feels that the cable problem is solved and that the primary potential for improving his system lies in the development of easily adjustable outlets, which will help him adjust flow rates to match seasonal changes in infiltration and thereby minimize soil movement on his land, which is highly erodible.

Roy Hood System

Cablegation Line and Its Installation

The cablegation line in Roy Hood's field, (1049-22nd Rd., Grand Junction, Col.), was a 12-inch-diameter PVC pipe, 1,100 feet long, with 0.4 feet of drop per 100 feet of run. A pad was made, approximately to this grade, and then a laser-controlled trencher constructed a trapezoid-shaped trench on this pad. Extra excavation about 1-inch deep was made with shovels at each joint to accommodate the gasketed bell joints. Harold Delfelder and other U.S. Department of Agriculture Soil Conservation Service personnel from the Grand Junction office supervised the leveling, grading, and trenching and participated in the cablegation-system installation. A small stream of water (about 20 gallons per minute) was directed down the pad in a furrow for about 20 hours 2 days prior to trenching and gave the excavated material a moisture content which was ideal for filling and packing around the pipe after it was in place.

The furrows ran 850 feet perpendicular to this pipe at an average grade of about 0.7 percent.

Turbulent Fountain Screen and Water Powered Control System

The irrigation water was known to carry large amounts of organic trash. Consequently, the turbulent-fountain-screen structure shown at the left of figures 100 and 101 was constructed immediately upstream from the structures in which the reel and its speed control mechanism were mounted. The speed control mechanism, also shown in figures 100 and 101, is driven by a paddle wheel whose vanes project halfway into the 1-foot-diameter pipe supplying water from the screen structure. The shaft of the paddle wheel is mounted in the center of a vertical 12-inch-diameter PVC pipe. Elliptical holes were cut in the two pipes to allow them to fit together as indicated, and

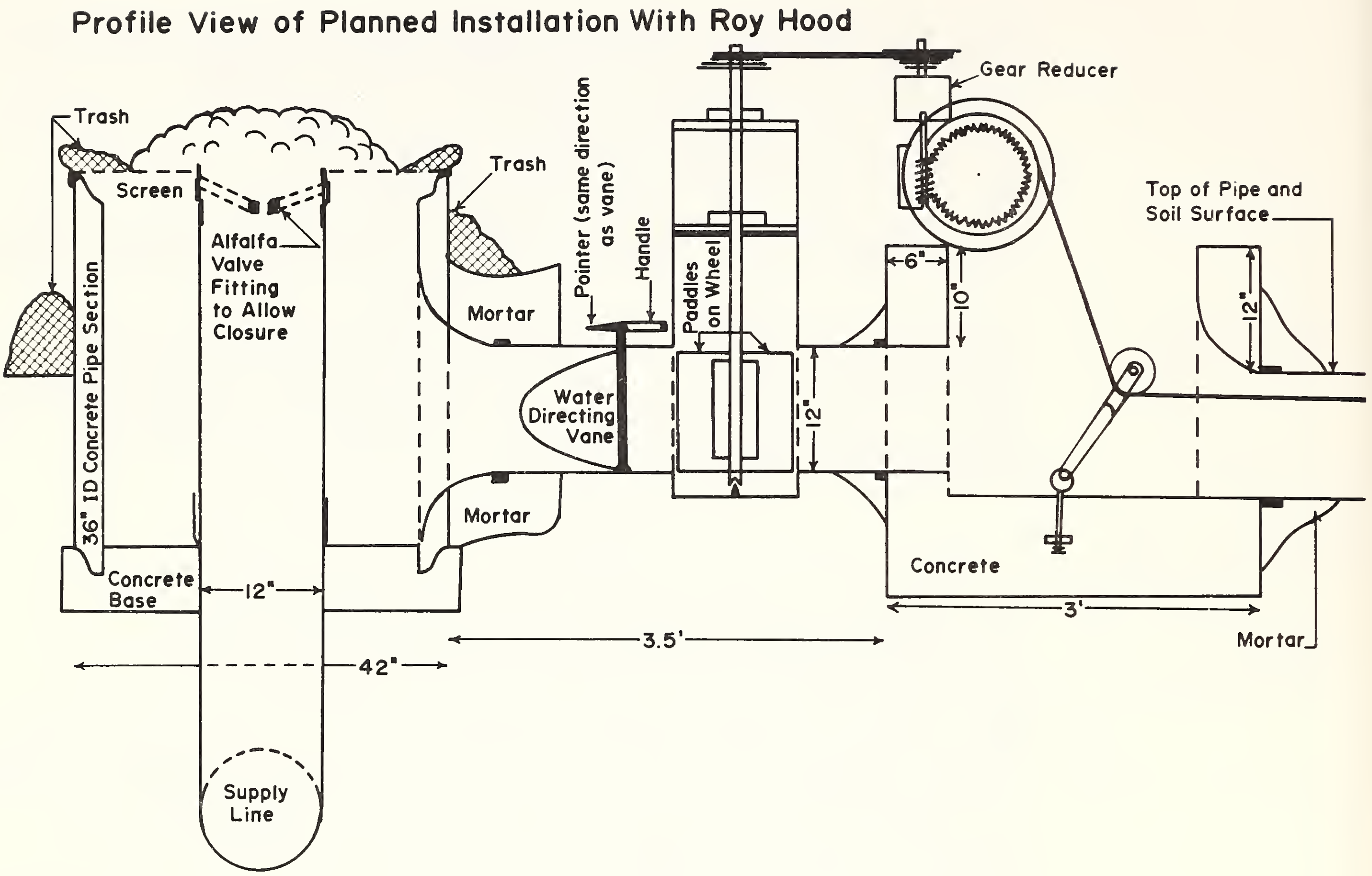


Figure 100.--Profile view of screen and control structures for the Roy Hood installation.

the pipes were then welded together with a PVC welding gun and welding compound. An elliptical vane about 9 inches long was positioned about 6 inches upstream from the paddle wheel in the supply pipe so that it could be turned to direct the water toward or away from the paddle-wheel vanes. This vane could be fixed in any position desired by clamping the handle to the slotted plate shown in figure 101. Revolutions per minute of an 8-inch-diameter pipe paddle wheel of this type were determined for different flow rates and vane positions in the hydraulics laboratory at the Snake River Conservation Research Center and are shown in figure 102. Head losses at the paddle wheel were also determined. The speed at which the paddle wheel rotates increases as the rate of waterflow increases but was not a proportional function.

Sprocket gangs, manufactured for 10-speed bicycles, were mounted on the shaft of the paddle wheel and on the input to a 50 to 1 gear reducer. A bicycle chain with a spring tightener (not shown) connected the sprockets. The numbers of teeth per sprocket in each of the sprocket gangs were 14, 17, 20, 24, 28,

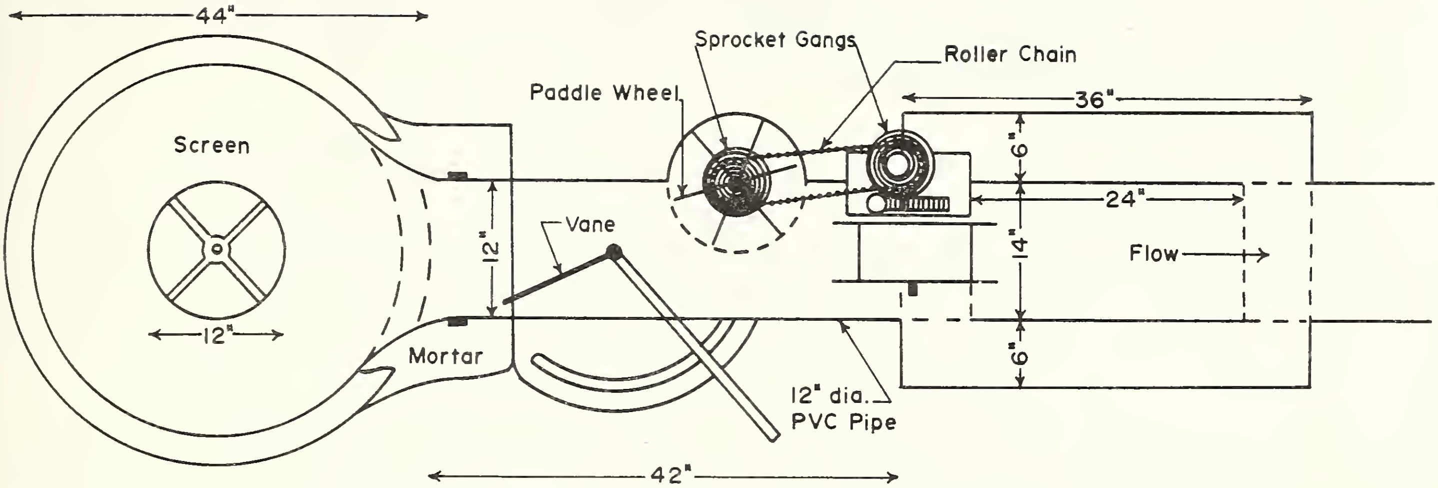


Figure 101.--Top view of screen and control structures of the Roy Hood installation.

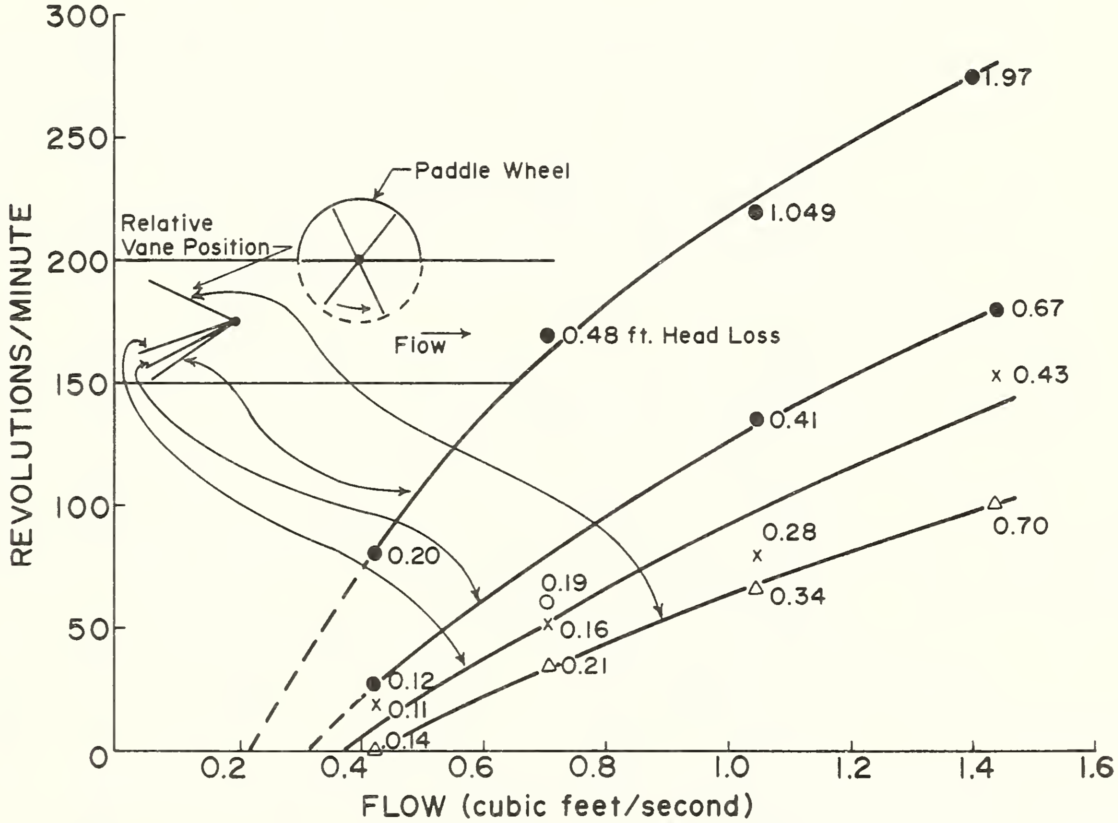


Figure 102.--Effect of water-supply rate and vane position on paddle-wheel speed and head loss across an in-pipe paddle wheel (8-in diameter).

and 34, providing the gear reducer with an input speed range of 0.41 to 2.43 times the speed of the paddle-wheel shaft. Intermediate speeds could be attained by adjusting the vane. Cable speeds could be attained from less than 6 feet per hour to over 40 feet per hour.

Infiltration Rate Differences Due to Differences in Water Content of Recently Tilled Surface Soil and Tractor-Wheel Compaction

This system was used to irrigate furrows on 30-inch centers in a field that had been planted to barley. Irrigation was started about noon on a hot day in late May. The soil had been worked and the grain planted when the soil was extremely dry. The surface included many large aggregates and small clods. Initial flow rate at which water was supplied to each furrow was about 15 gallons per minute from 1.25-inch-diameter holes cut in the pipe. Water moved down the furrows surprisingly fast and was generally to the end of the wheel-compacted furrows within 1 hour following starting of the flow. In the non-wheel-compacted furrows, water reached the ends in about 90 minutes. Infiltration rates as a function of time were estimated from the advance rates and are presented as the curves in the lower left corner of figure 103.

From 6:00 AM to 12:00 noon the next morning, intermittent light rains delivered 0.2 inches of water to the fields, moistening the soil to a depth of less than 1-inch. Shortly after the beginning of this rain, the rate of advance of the water in the furrows decreased. During the afternoon and evening, it was taking water about 4 hours to reach the ends of the wheel-packed furrows. In the non-wheel furrows, water was reaching the ends about 6 hours after the supply began.

Flume measurements at the top and bottom ends of the furrows were used with advance-rate data to estimate the infiltration rate as a function of time as given in figure 103. The increase in furrow infiltration rates from before to after the light rain was surprising, but in line with infiltration measurements on this same soil (Akram and Kemper 1981). When dry aggregates on this soil surface are wetted quickly, they generally break down and the soil becomes a structureless mass. Slow wetting, as occurred during this light rain, does not destroy the stability of the aggregates, which remain intact when contacted by the irrigation water. The soil has high infiltration rates when its surface is composed of intact aggregates between which the water penetrates easily. When these aggregates disintegrate into individual clay and silt particles, the infiltration rate is much slower, as indicated in figure 103. However, this observation was not replicated, and part of the differences in intake rate may have been due to differences in texture sodicity and compaction in the two areas.

The amount of water added to the soil is proportional to the area under the curves in plots such as figure 103. Where irrigation began when the soil was hot and dry, infiltration was so small that not all the barley was moistened, and a second irrigation was required on these furrows to get the soil adequately wetted.

Trash Screen Outlet Modifications to Achieve Adequate Turbulence

The turbulent-fountain trash screen indicated in figures 100 and 101 allowed some splash that went over the sides of the screen. However, that amounted to less than 2 gallons per minute and was considered negligible since there was a drain ditch close at hand to which it was diverted.

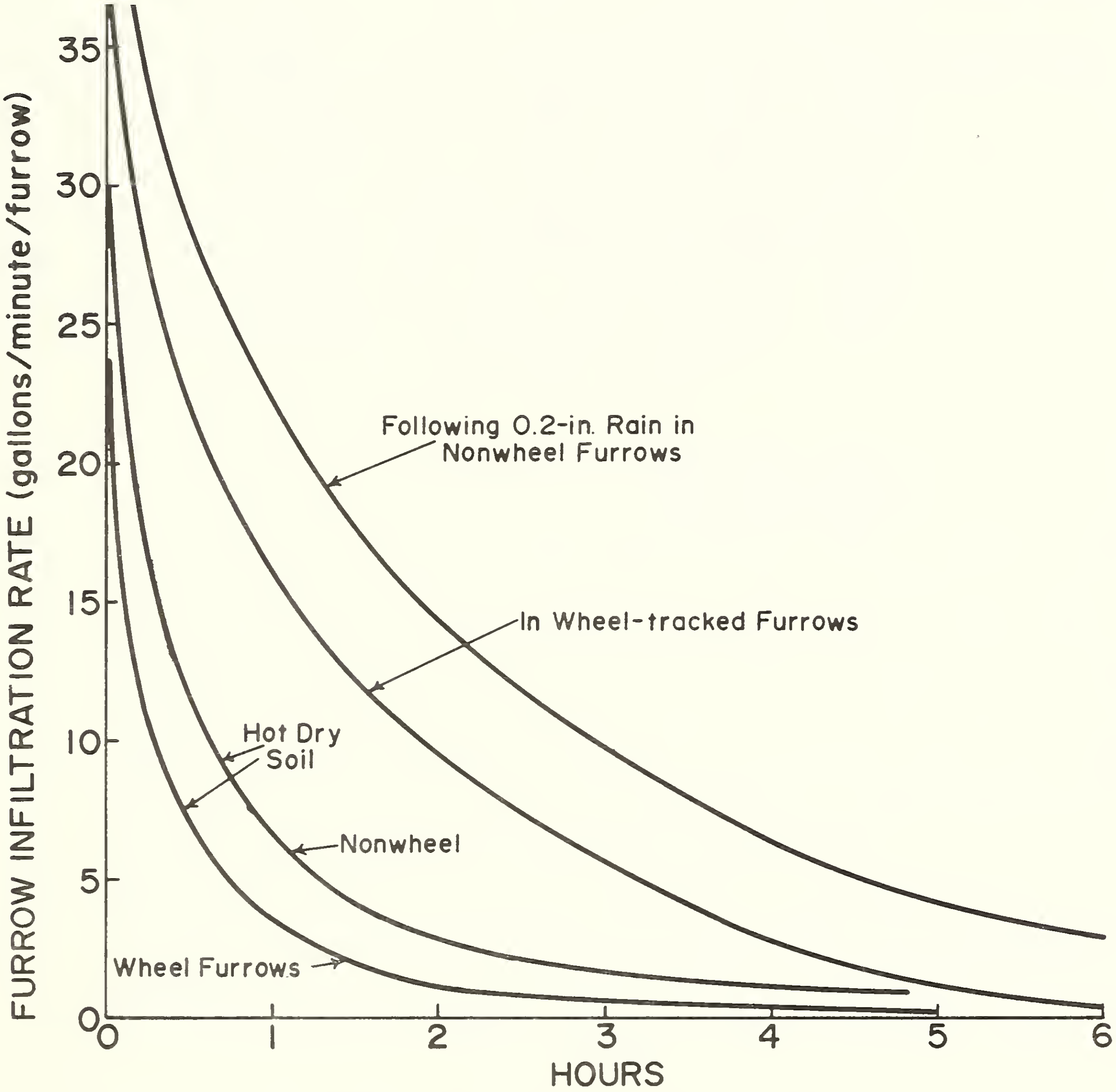


Figure 103.--Furrow infiltration rates on Roy Hood's field.

When Roy Hood was running less than 2.0 cfs through this screen, the flow through the 12-inch pipe was not turbulent enough to keep the screen clean. Decreasing the size of the opening for flow increased the turbulence. Consequently, rings were made of sheet metal with outside diameters about one-fourth of an inch smaller than the inside diameter of the supply pipe and inside diameters of 8, 9, and 10 inches. These rings were used when the flows were in the 1.0- to 1.4-, 1.5- to 1.9-, and 2.0- to 2.4-cfs ranges, respectively. They were clamped or wired to the alfalfa-valve fitting. This provided adequate turbulence to keep the screen clean.

Max Baker System

Field Layout and System

The dimensions of the Max Baker field, (563 Lane 7, Rt 1, Powell, Wyo.) and elevations along the proposed cablegation line were determined by Baker and the personnel of U.S. Department of Agriculture Soil Conservation Service and are indicated in figure 104. Rates of supply to the system can be varied from 1.5 to 2.5 cfs. Outlets were spaced at 30-inch intervals in the 12-inch-diameter PVC pipe, and holes drilled in the pipe were 1.75 inches in diameter. Polyethylene inserts and plugs were provided which allow plugging of some holes for different row spacings or reduction of outlet size to less than 1.75 inches in diameter.

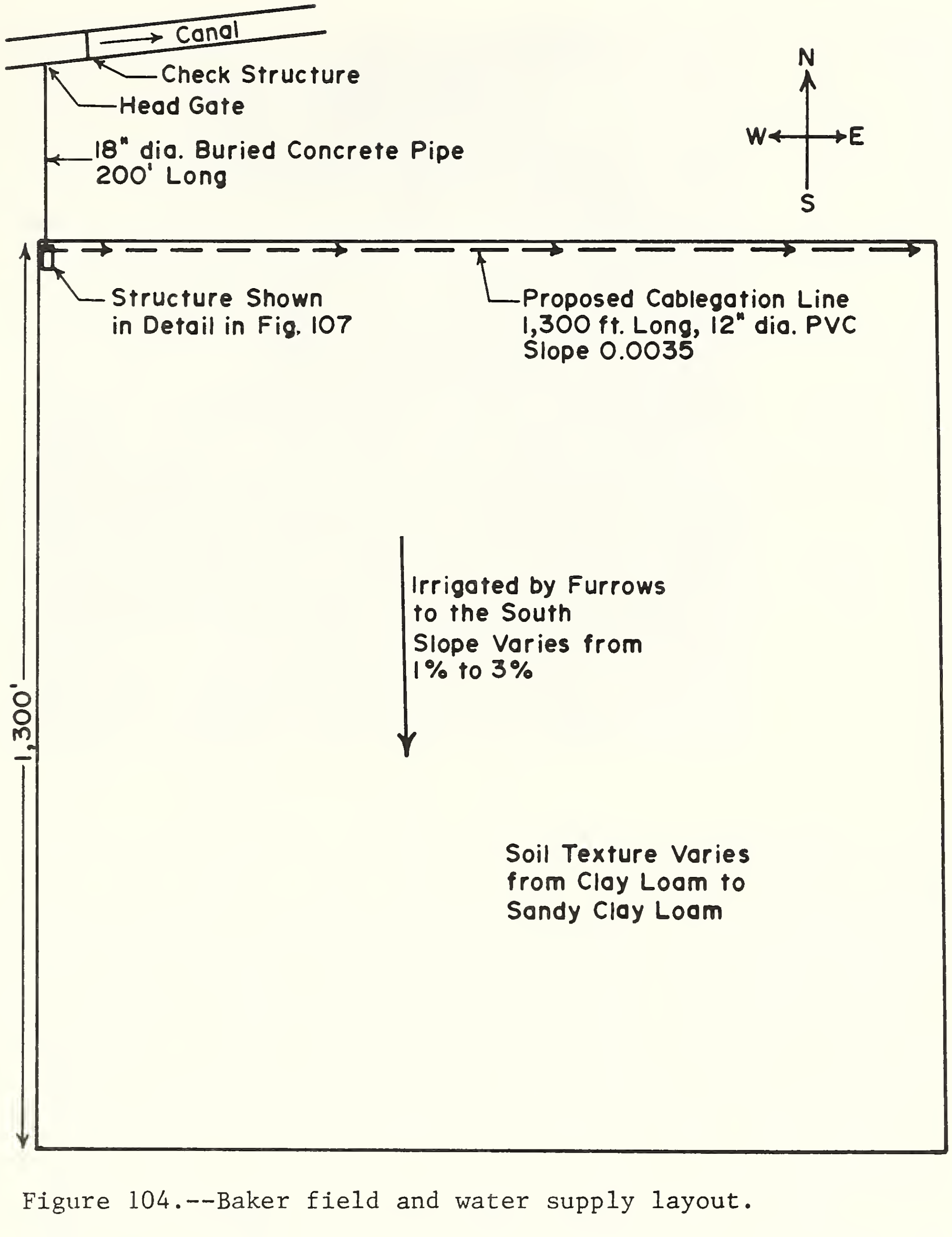


Figure 104.--Baker field and water supply layout.

The computer model was used with supply rates of 1.5 and 2.5 cfs. Number of flowing outlets and their rates of flow are plotted in figure 105. Pressure heads at the outlets nearest the plug were about 5 and 7 inches, respectively, for the 1.5- and 2.5-cfs supply rates.

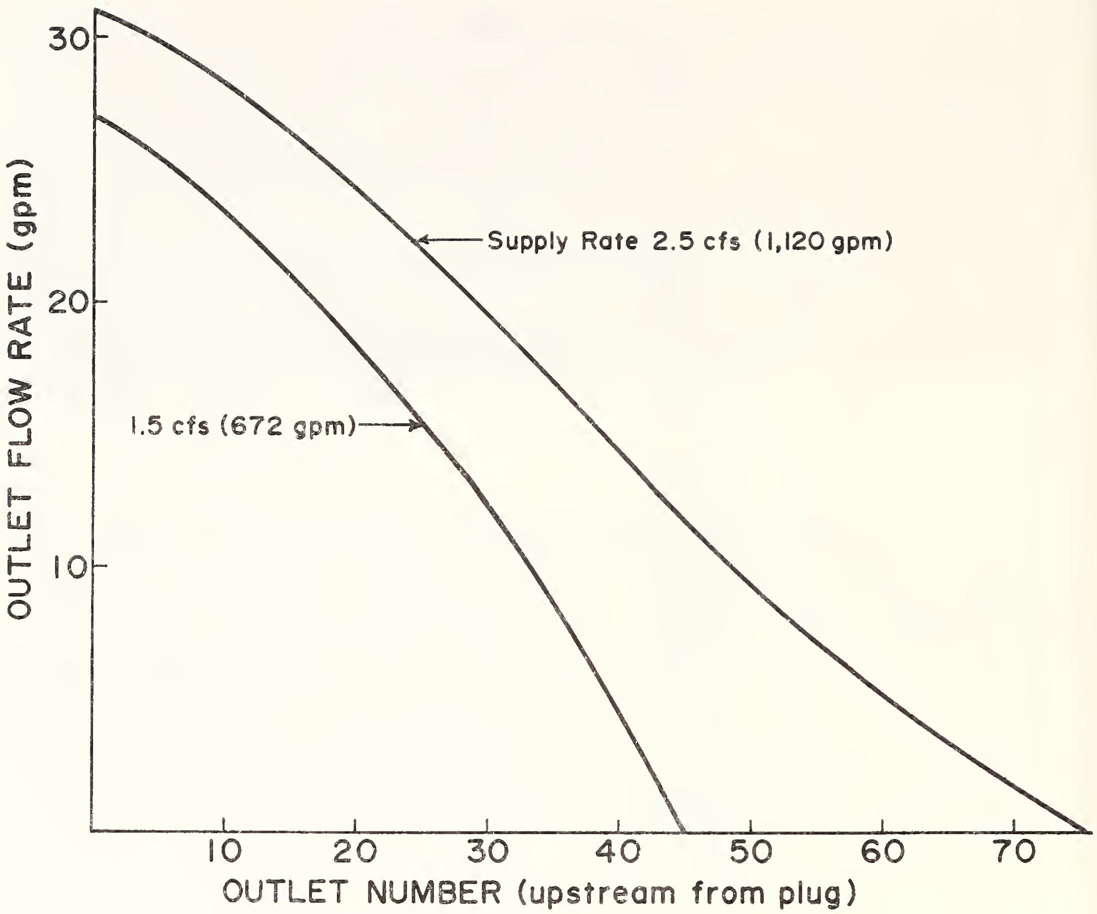


Figure 105.--Predicted outlet flow rates at given supply rates.

Head Limitations, Trash Removal, and Cable Control

One of the longstanding challenges on this field was to remove the trash from the water and deliver adequate flow to the top (northwest) corner. The water level at the check structure in the canal is only 8 inches above soil level. A commercially available screen (names of suppliers will be furnished on request) (fig. 106) selected and purchased by Baker was tested at the Snake River Conservation Research Center hydraulics laboratory and found to operate satisfactorily with only 0.2 feet of head loss. Moreover, at that head loss, there were several foot-pounds of torque available on the turning shaft of the paddle wheel which could be used to operate the cable control. Consequently, the existing concrete structure was remodeled to incorporate the trash screen and cablegation control as diagramed in figure 107. The actual installation is shown in figure 108.

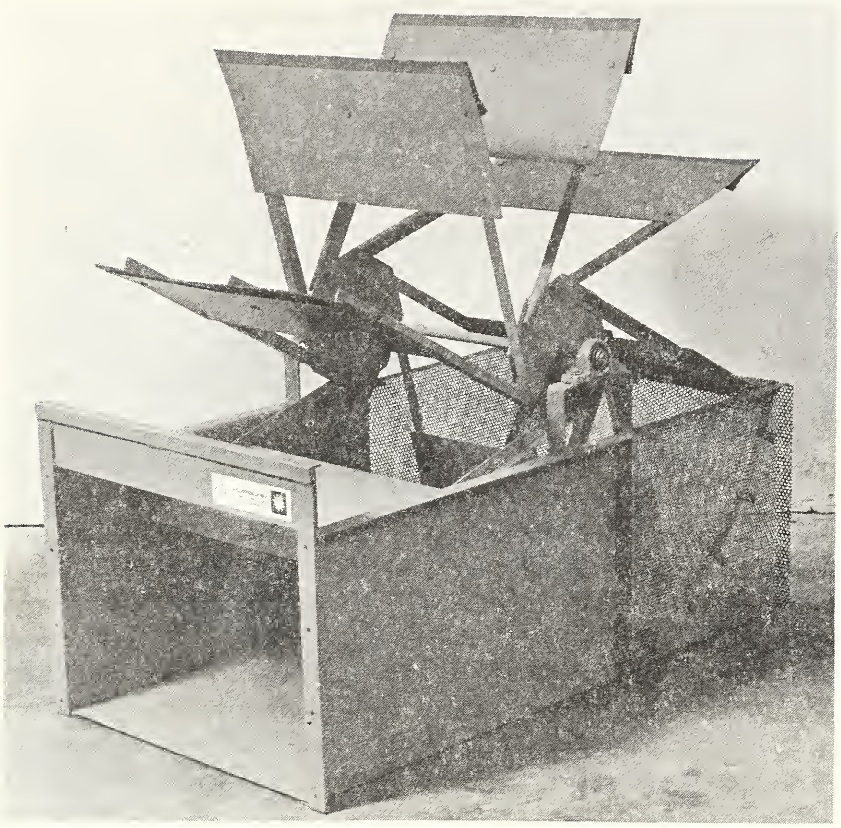


Figure 106.--Commercial trash remover.

When the plug starts at the top end of the cablegation line, the structure shown in the figures fills with water almost to the canal level, since there is little water flowing and practically no head loss in the 18-inch-diameter supply pipe. The outlets in the cablegation line in this top corner are essentially at ground level, which is only about 8 inches below canal water level. Consequently, there is little flow and little head difference across the paddles on the trash remover. The result is slow movement of the paddle wheel and the plug until the plug has progressed 20 or 30 furrows down the field. This slow movement can be compensated somewhat by placing the chain on sprocket pairs, which turn the reel faster. Such changes in speed of plug with respect to paddle wheel can be made relatively easily because a spring-loaded chain tightener (not shown in the figures) allows easy transfer of the chain to the next sprocket set.

When the plug has traveled down the line a full set of outlets, the water level drops to near the level of the top of the cablegation line. Then the flow rate and speed of rotation of the paddle wheel becomes essentially constant.

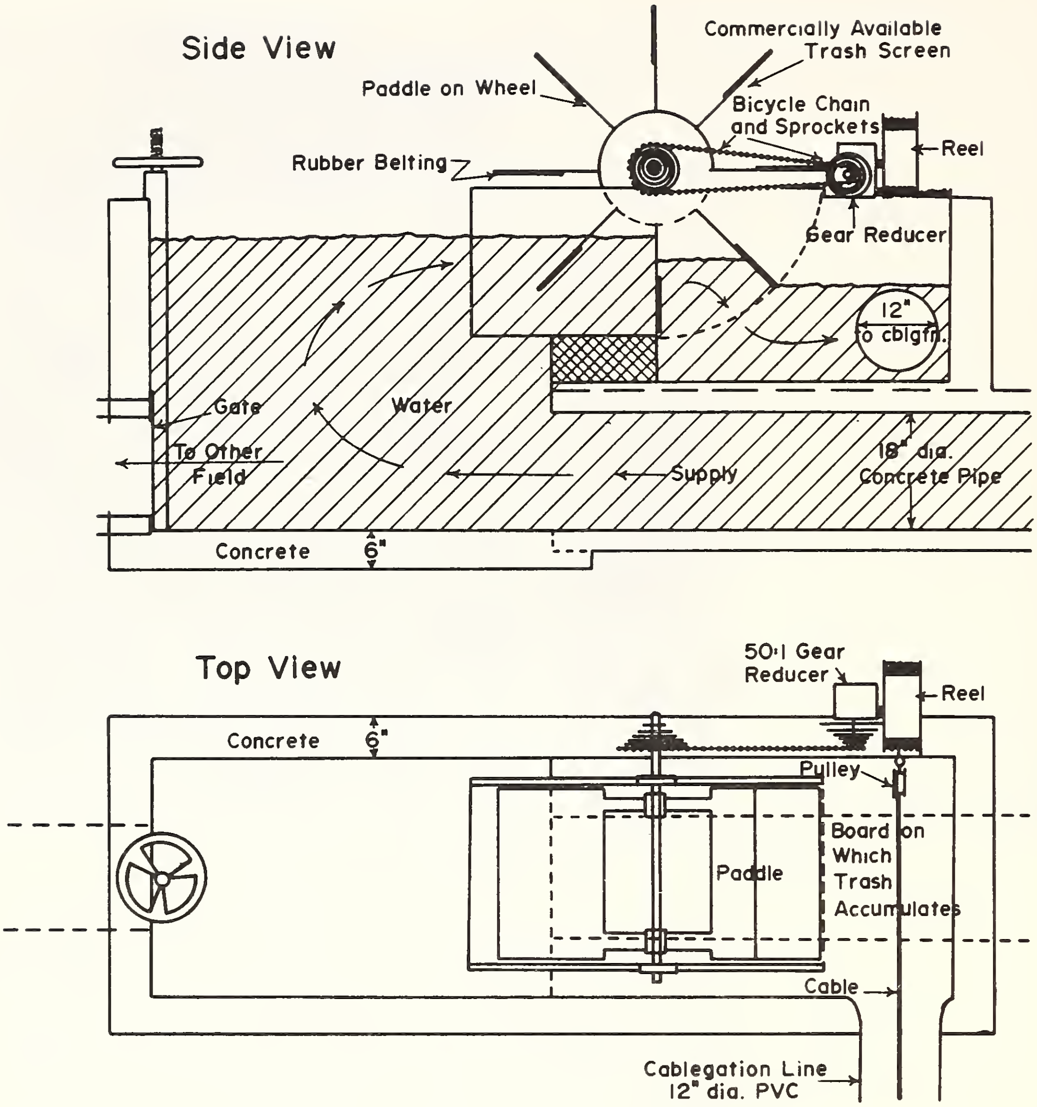


Figure 107.--Plan drawing for Baker trash removal and cablegation control structure.

Plug Design and Pipe Configuration

The coordination between the Snake River Conservation Research Center personnel and Baker on this project was by mail. Baker installed the 12-inch-diameter line and had the concrete structure built by the time the SRCRC personnel brought the control system and plug. The pipe suppliers had provided Baker with pipe on which the male end is bowed in about 0.5 inches, as indicated in the bottom of figure 109. This reduces the carrying capacity of the pipe which is a minor inconvenience when the whole 2.5 cfs is flowing. However, the main problem was that the plug which had been designed for this diameter pipe would not pass through these restrictions. After several cut and try attempts on locally available plastic bowls, buckets, and wastebaskets, the plug indicated in figure 109 was developed. Wastebaskets made of relatively soft, flexible

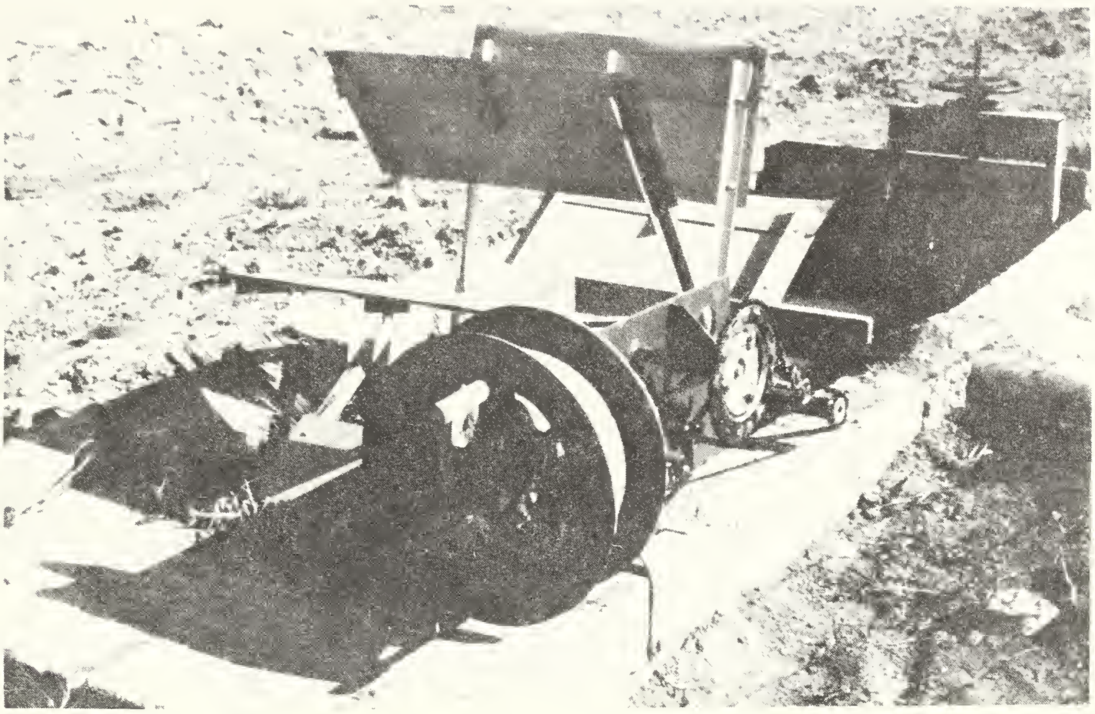


Figure 108.--Baker's combination structure for trash removal and cable control.

plastic were obtained whose maximum diameter exceeded the regular diameter of the pipe. These baskets were pushed into the open end of a regular section of the pipe until they were snug. A line was drawn around the basket at that plane, and the basket was cut along this line to allow a snug fit in the pipe. The trimmed basket was then pushed into regular sections of the pipe down to the male-end section until it was snug against the constricted male end. Small holes (three-sixteenths of an inch in diameter) were drilled, next to the pipe, through the walls of the protruding basket at about 30 degree intervals around the basket as indicated in the upper left of figure 109. The basket was then pushed out of the nonconstricted end of the pipe, and slits were cut in the walls of the basket at a sharp angle, as indicated in the upper right of figure 109, so the side segments will overlap when the plug goes through the constrictions. These slits end at the drilled holes which help prevent cracking of the plastic walls, which would have happened when the plastic adjacent to the slits flexed as the plug passed through the constrictions.

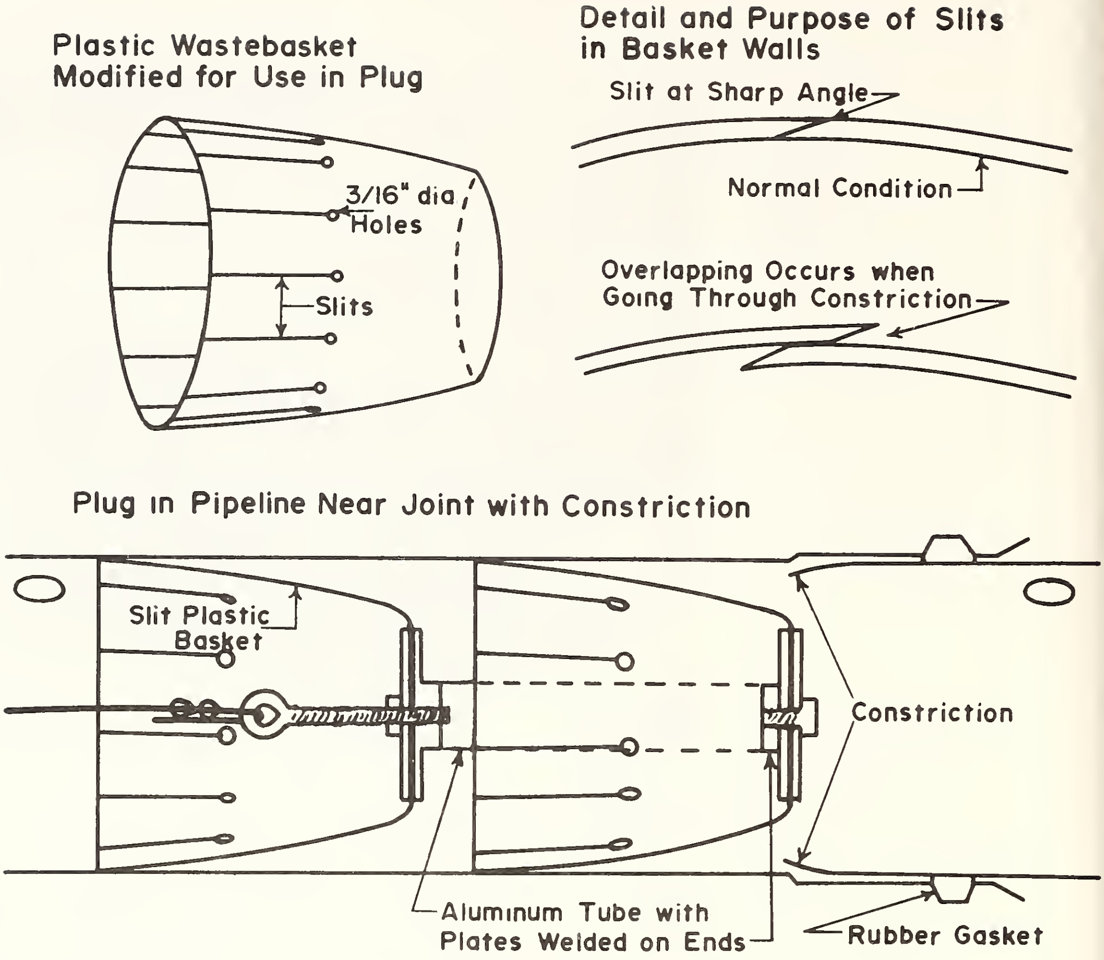


Figure 109.--Constrictable plug made for the Baker pipeline.

Two of these modified baskets were attached to the previously constructed aluminum frame as indicated in the bottom of figure 109. This plug passed all the constrictions in the cablegation pipeline for irrigations and provided distribution of water from the pipeline as shown in figure 110. In spite of the 10 or 12 small holes (three-sixteenths of an inch in diameter) drilled in the baskets and the associated slits, leakage past this plug was less than 3 gallons per minute.

Assessment of System Performance

Because of the distance between the Snake River Conservation Research Center and his farm, Baker has been on his own in operating and monitoring the system.

At the end of his first year of operation he reported: "The system has worked pretty well for me after I learned how to run it. In most of the irrigations, there were a few furrows in which water didn't get completely across the field. During the last irrigation several failed to make it. When I checked on these rows, I found that a couple of ridges in the field

Figure 110.--Baker's system in operation.

were backing up the water in these furrows causing the water to break to the east. Overall, I am happy with the system. Nancy says she wishes all our fields had cablegation."

The type of plug developed for this system was also found to be usable in regular gated pipe as is discussed in appendix J (John Glenn Field).

John Glenn Field

Adapting Cablegation to Standard Gated Pipe

Many farmers have gated pipe and use it as a part of their irrigation system. In many instances, this could be developed into a cablegation system, which would give the farmer an automated irrigation system at low cost. The barrier to use of standard PVC gated pipe for cablegation has been that the gates protruded inside the pipe sufficiently to obstruct the movement of the plug or to be moved by the plug as it passed.

A length of standard PVC gated pipe was set up in the Snake River Conservation Research Center's hydraulics laboratory, and the system was observed as several types of plugs moved through the pipe. Most of them did not stop at the protruding gates, but most of the plugs pushed on the sliding gates hard enough to cause some of them to open or close. However, a plug similar to that used on the Baker system (fig. 109) did not move the gates as it went through the gated pipe. John Glenn, who farms acreage just north of the Snake River Conservation Research Center, 1 mile north and 1 mile east of Kimberly, Idaho, then cooperated with the SRCRC to convert his gated-pipe irrigation system into a cablegation irrigation system.

Field Layout and System Design

The cablegation line is about 1,200 feet long and the furrows run 520 feet, which makes the field approximately 14 acres. The elevations were determined along the headline, and it was determined that the conversion could be made by lowering the stub pipe connecting the gated pipeline to the inlet structure by 0.5 feet and laying the gated pipe on a grade of 0.0104 feet per foot, with the gates 30 degrees from vertical toward the furrows to be served.

Installation

A local company, which owns a laser-controlled, rotary ditcher was hired to cut a graded trench for the pipe (names furnished on request). The pipe which Glenn had used for several years was then laid in the trench, with the center of the gates being 30 degrees down from the top of the pipe toward the furrow. There were two lengths which had been damaged (warped) by a weed burner and could not be laid to grade. They were replaced with new pipe by Glenn. The trench was then backfilled, with the top of the pipe a minimum of 0.2 feet and a maximum of 0.5 feet above the field.

Plug Design

The plug was made using a 12-inch-long piece of 3-inch-diameter aluminum pipe as a connector between the "bowls." Plastic wastebaskets were trimmed at the length where the large end would fit snugly into the gated pipe. Holes were drilled in the walls of the wastebasket at 2-inch intervals, and angled slits were made from the holes to the end of the wastebasket. This shape of the baskets and the flexible nature of the plastic enabled the plug to flex past the gates in the gated pipe without opening or closing them (See fig. 111 for sketch of plug). The wastebaskets were attached to the aluminum pipe as shown in the drawing. More detail of this type of plug is given in figure 109.

Hydraulic Speed Control Unit

The original hydraulic control unit was similar to the one built for Calvin LeBeau (fig. 91). This unit was built and its performance tested on Glenn's system before the other one was sent out to LeBeau. During the initial run, the holes in the plates connecting the hydraulic cylinders to the crank on the reel were snug and sufficient binding occurred at one point on the cycle to cause the reel to stop. Reaming out those holes so they fit loosely on the crank solved that problem.

On the initial runs, the lower temperatures during the night caused higher viscosity of the hydraulic oil and about a 30-percent reduction in plug speed at night.

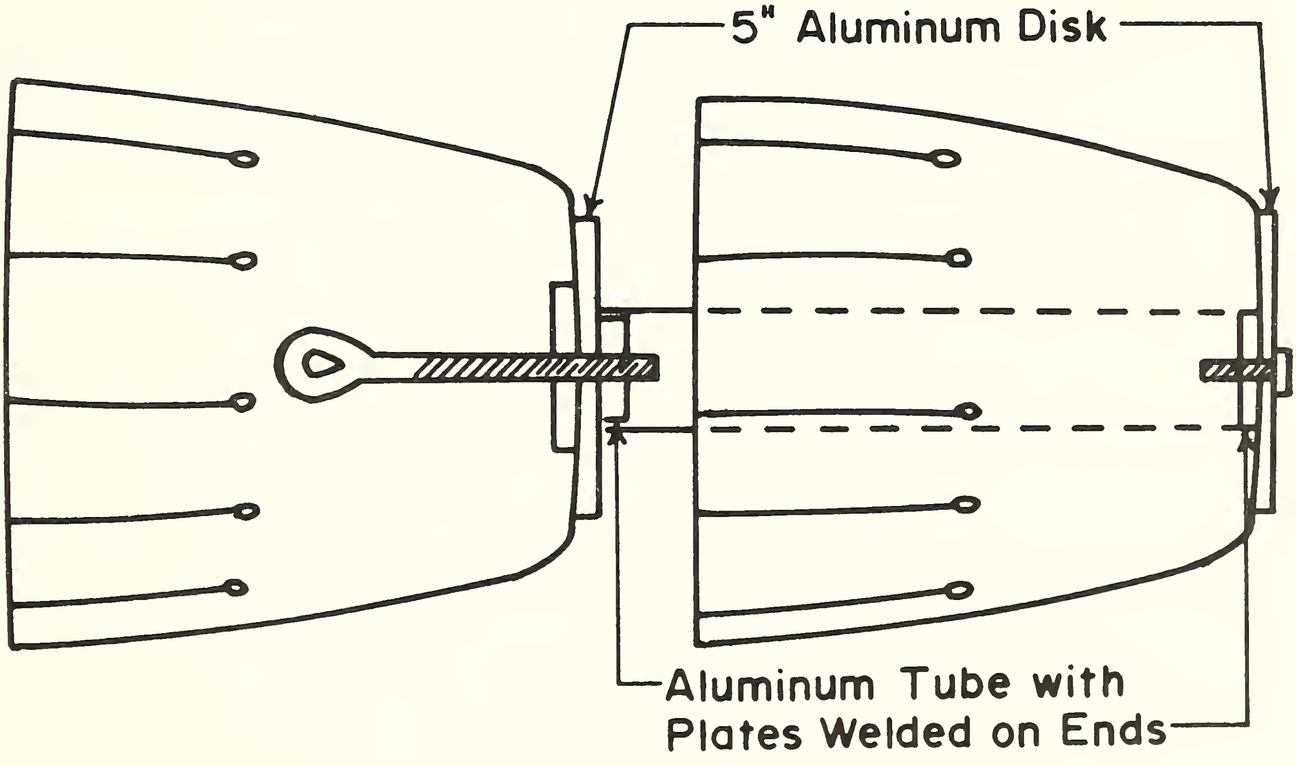


Figure 111.--Cablegation plug made for John Glenn pipeline.

Data on viscosity indicated that the change in viscosity of diesel fuel would be less than half of this amount. Consequently, the hydraulic oil in the cylinders was replaced with diesel fuel. This reduced the day-to-night speed variation to less than 15 percent, which was tolerated for the remainder of that irrigation season. During the following seasons this system has served for testing battery operated electronic controllers developed by a private company. This type of controller allows one revolution of the reel at any desired time interval and is now commercially available. (Controllers of this type could, by addition of a microprocessor, provide any desired sequence of speeds.)

Energy Dissipation

Generally, there were approximately 60 corrugates running at one time. Since the irrigated furrows were 44 inches apart, the water was backed up so it filled about 220 feet of pipe. With a slope of one foot per hundred feet, the water at the outlet next to the plug would have approximately two-foot head pressure. With the water jetting that far above the pipe, it created two major problems: there was excessive erosion, and on windy days, the wind would misdirect the water.

To correct this problem, energy-dissipation screens were built and installed (names of manufacturers will be provided on request). Aluminum screen was folded so it was eight layers thick, 3 inches wide, and 4 inches long. This was bent to give the water the proper direction, and a screw was twisted into the top of the screen. One-eighth-inch diameter holes drilled in the tops of the gates accept these screws and hold the gates in front of the outlet. The water was deenergized, but the screens were a nuisance if the farmer had to adjust the gates.

As discussed in detail in appendix G, energy dissipators were designed for this system which were attached to the cable, restricting the flow cross section. These proved to be successful in dissipating the energy of the flowing water so there was less than a foot of head at the outlets.

Summary

Before we started the project, we felt the major problem to overcome was to get the plug to move through the pipe without moving the gates. However, the Baker type of plug (fig. 109) achieved this without further modification. The two most difficult problems were dissipating the excess energy and getting the plug speed controller to function properly. Snake River Conservation Research Center personnel operated the system for the first two irrigations, and then Glenn operated it for the balance of the first season. Glenn feels this is definitely an improvement over the previous system, and it also provided his crop with more uniform irrigations.

Meyer Lewis System

Field Layout, Structures, and System Design

The Meyer Lewis system near Cove, Oreg., is installed as indicated in figure 112 on a 33-acre field. The soil is a gravelly silt loam with a reported sustained intake rate of 0.35 inch per hour. A drawing of the input structure is shown in figure 113. The original drive mechanism for the control system is a water driven paddle wheel similar to the one used on the Hood farm (app. J, Roy Hood farm).

Water is diverted from the supply ditch into a 10-inch pipeline at a distance approximately 100 feet upslope from the high corner of the field. The intake was provided with a gate to control the inflow rate and with two stilling wells so that the inflow rate can be measured either by a meter gate or a submerged outlet, depending on the type of gate selected.

This upstream diversion into a pipeline was necessary to provide the 3 feet of head needed to bring the water into the input structure at an elevation that permits running it through a commercial horizontal screen to remove trash and weed seeds (names of installers will be provided on request). This head also provided the 2-to 5-inches of head needed to operate the enclosed water-wheel system to run the reel which controlled the rate of travel of the plug.

Pipeline Grade, Size Selection, and Outlet Sizes

The pipe was installed on a prepared pad and the trench constructed accurately to the designed grade by a laser-controlled ditcher (names of installers provided on request). This permitted rapid assembly of the pipeline and facilitated uniform discharges from each outlet along its length. Checking the grade of the pipe with a surveyor's level showed that it was generally within ± one-half inch of grade at the time of installation.

The slope along the principal length of the field is approximately 0.0048 feet per foot for 850 feet and then increases to 0.0080 feet per foot for the last 570 feet of its length (fig. 112).

The normal flow rate available on this field is about 500 gallons per minute (1.11 cfs), but as much as 700 gallons per minute (1.56 cfs) could be available. A 10-inch-diameter (PIP) PVC pipe was selected (app. A) to deliver the water to the corrugates. This provided sufficient capacity to carry the highest flows.

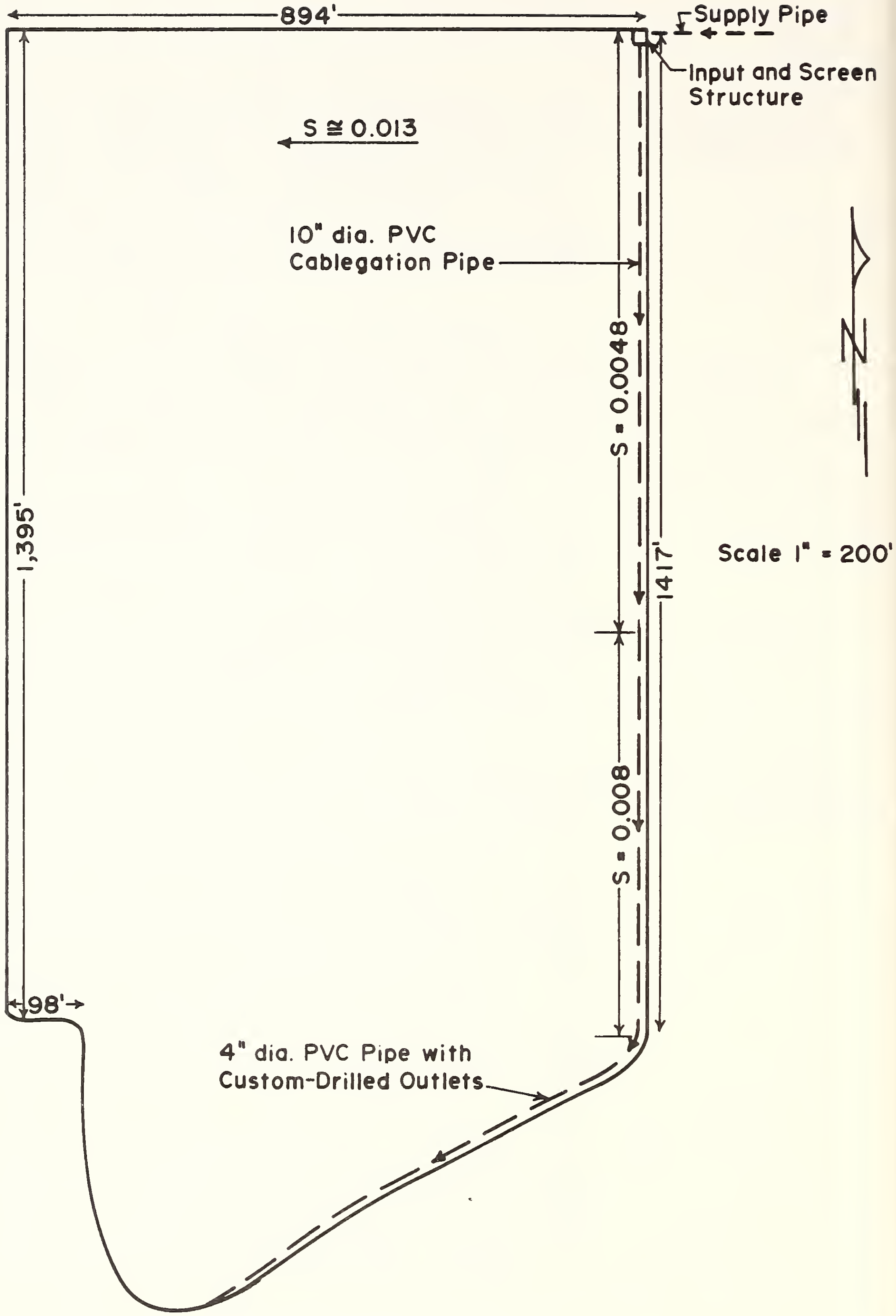


Figure 112.--Meyer Lewis field and proposed system layout.

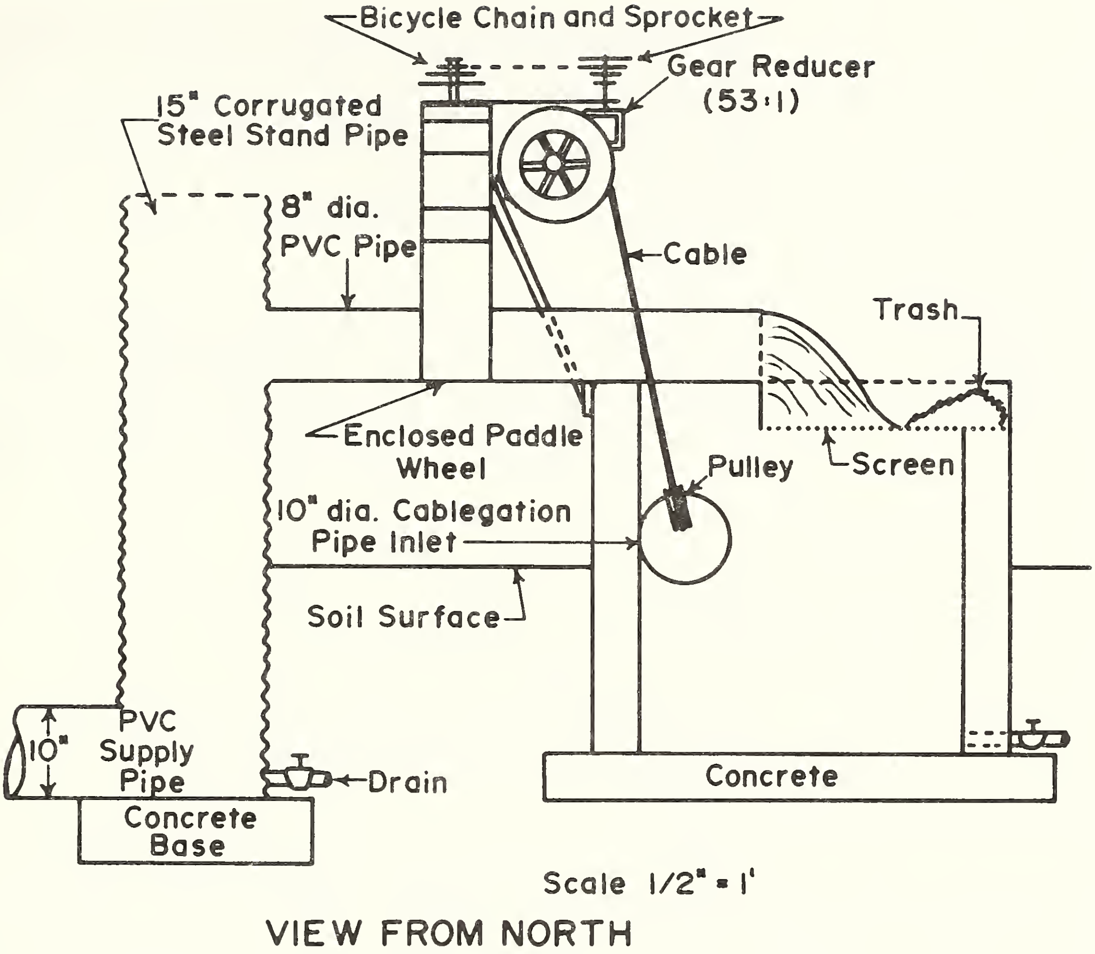


Figure 113.--Cablegation input and screen structure (Meyer Lewis farm).

The round outlet holes are 1.25-inch diameter, spaced at 30 inches center to center, and are near the top of the pipe--offset 30 degrees to the west from the top centerline of the pipe. Some outlets will be capped or plugged when wider corrugate spacings are used for other crops in future seasons.

The 1.25-inch diameter holes are reduced by stages to 1-inch size at a point approximately 900 feet along the pipeline where the pipe slope increases to 0.008 feet per foot. The slope increase causes increased pressure in the pipe, and the flow rate and time are kept nearly uniform by the reduction of outlet size.

At the far end of the main pipeline, a 4-inch diameter-line will take water from the main at a point just upstream from the final position of the plug. This line will be laid along the southeast edge of the field to supply water to a 1.8-acre triangular area at the south end of the field. This area will be irrigated as a unit by the 4-inch line. The 4-inch line will be equipped with a removable cap or plug at the lower end so that it can be flushed if sediment accumulates. The outlets near the lower end of the 4-inch line will be placed in the lower half of the 4-inch pipe to aid in carrying out the sediment.

Predicted System Operation

A computer analysis of how the system operates is shown in figures 114 and 115. This analysis was for the 0.0048 slope, 10-inch-diameter pipe, an input supply of 500 gallons per minute, a plug travel speed of 8.7 feet per hour, and a soil-water intake rate based on the function

$$V=AT^{0.5}+CT$$

where V=total intake in liters per meter at time T hours, A=23 and C=1.0.

In the absence of detailed intake data, a U.S. Department of Agriculture Soil Conservation Service 0.3 intake family was used to develop the above relationship.

The output of the computer analysis showed inflow rate and runoff rate functions for a typical furrow for a 6-inch gross application as shown in figure 114. The area between the two curves represents the volume of water that infiltrated into the soil, and the area below the runoff curve represents the volume of runoff. The vertical distance between the two curves at any time represents the rate of intake for the total corrugate at that time.

The predicted runoff amounted to about 17 percent of the total application. Water was applied to the rows for almost 15 hours and ran off the end for about 9 hours.

Figure 115 shows the infiltration as a function of distance down the furrow. This analysis shows how the system was expected to work. After installation, it required monitoring and adjustment of the plug travel speed and the outlet size so the system operated in a manner that fit actual field conditions and applied the irrigation water as efficiently as possible.

During the initial trials, there was considerable trash coming with the water. Some of the trash tended to catch in the water wheel and reduce its turning rate. Later in the season, there

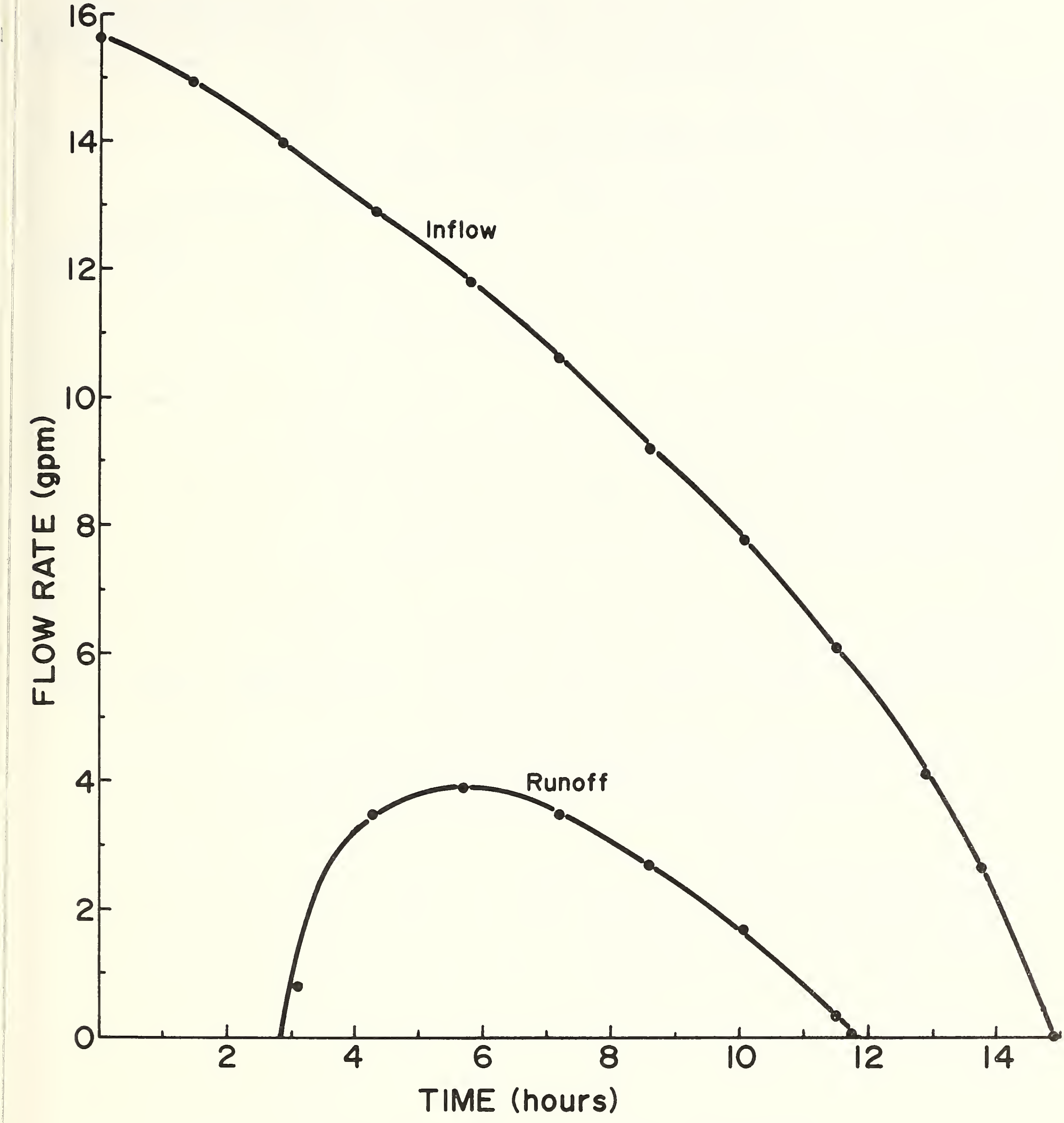


Figure 114.--Inflow and runoff curves from computer model of typical furrow on the Meyer Lewis field.

was less trash and this was not so much of a problem. It was concluded that the trash screen should be built upstream from the paddle-wheel control system (as was later done at Roy Hood's farm, app. J).

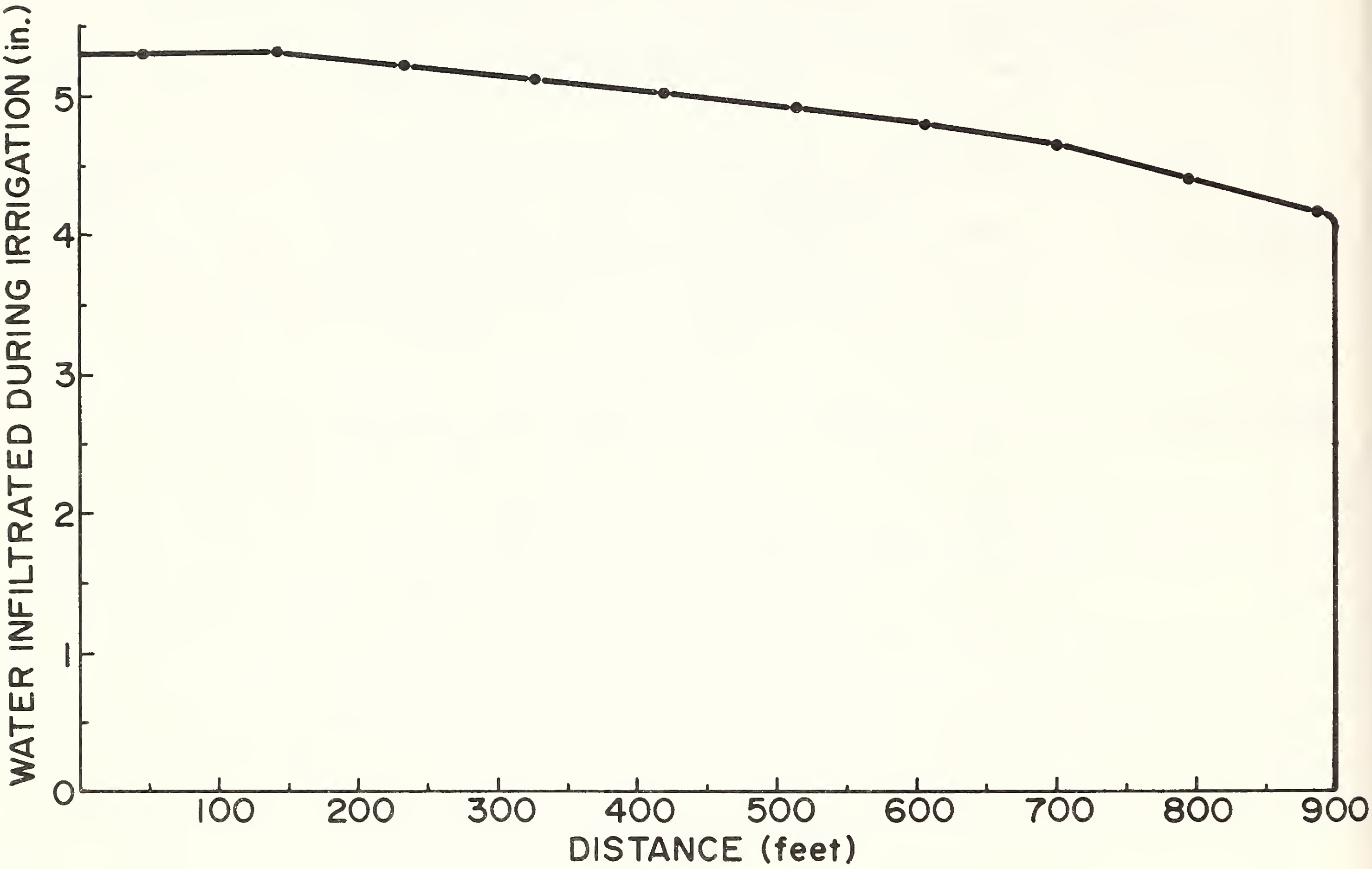


Figure 115.--Water infiltrated along length of typical corrugates from computer model of Meyer Lewis field.

Lamar Gilbert Field

Introduction

Lamar Gilbert saw an article which told about cablegation in a farm magazine. He felt this type of system would be an asset to his farming operation, 14 miles west of Othello, Wash., so he drove to Kimberly where he could see a cablegation system in operation. Gilbert and Snake River Conservation Research Center personnel developed a cooperative agreement, and they jointly made plans to install a system on the Gilbert farm.

Field Layout and Design

The cablegation line is 1,080 feet long. The inlet standpipe is 15 feet from the corner of the field, with a stub pipe extending back to irrigate that 15-foot portion of the field. The cablegation pipe was designed with a slope of 0.00322 feet per foot.

Installation

A company which owns a laser-controlled rotary ditcher was hired to cut a graded trench for the pipe. During cutting of this trench, several large boulders were encountered. A backhoe was required to move them from the trench location. When the trench holes were backfilled, the tractor was used to compact the soil before the final trenching operation; however, these areas appeared to settle more than the undisturbed areas of the trench when the pipeline was put into use.

Because of the small amount of head loss which was available at the upper end of the pipeline, 1.75-inch outlets were drilled for the first 40 corrugates, then 1.25-inch outlets were drilled thereafter.

A battery operated plug speed control unit was installed initially; however, this was replaced prior to the 1983 irrigation season with a waterbrake control unit of the type described in appendix K.

The first time the plug was sent through the pipe, it hung up at several joints, and there was one length of pipe (20 feet) where the plug had to be pushed the entire length. By the time the plug reached the end of the pipeline, the bowls were damaged. Rubberized plastic washbasins which had a little more flexibility were used to replace the bowls. The first time through the pipe, this plug had the same problems as the original plug except that the washbasins were not damaged. After the basins were shaved to a slightly smaller diameter, the plug went through smoothly with less than 3 gallons per minute leakage.

The sizes of the holes in the pipes had been calculated on the basis of estimated infiltration rates and were made oversized so that commercially available fittings diagramed in figure 13 could be used (names will be furnished on request).

Fittings with 3/4-inch openings were found to be about the right size to get water to the ends of the furrows without causing excessive erosion. This size of outlet caused water to back up farther in the pipe, supplying water to more furrows than were supplied by the larger outlets. This also put more pressure on the water in the pipe near the plug, causing the water to jet higher in the air. To reduce the pressure near the bottom plug and to reduce the associated water flow rates and thereby further reduce the furrow erosion, a bypass plug, similar to that shown in figure 53, was hooked on the cable about 100 feet upstream from the primary plug. The bypass was modified so that it could be adjusted by inserting a special tool through an outlet and turning a crank mechanism which adjusted the bypass flow to that desired. This decreased the pressure at the bottom plug, backing the water up farther and causing flow to 5 or 6 additional furrows.

Additional Cablegation Systems Installed to Date Include:

Muhammad Akhtar Bhatti	Aix-en-Provence, France
Richard Gilbert	Othello, Washington
Donald Walton	Quincy, Washington
John Squires	Marsing, Idaho
Donald MacRae	Burley, Idaho
Vern Mix	Jerome, Idaho
Barrett McClure	Jerome, Idaho
Hugh Sharp (bordered strips)	Iona, Idaho
Richard Wilcox (2 more systems)	Loma, Colorado
James Bernal	Loma, Colorado
Larry Peach (2 systems)	Loma, Colorado
Kenneth Inouye	Sedgewick, Colorado
Gene Haarberg	Imperial, Nebraska
Don Arrington	Kimberly, Idaho
Kevin Anderson	South of Hazelton, Idaho
Robert Smith (3 systems)	Wendell, Idaho
Chris Matheson	Moses Lake, Washington
Bill Bellomy, Jr.	Moses Lake, Washington
Murray VanDyke	Quincy, Washington

APPENDIX K - A WATER-BRAKE CONTROLLER FOR CABLEGATION SYSTEMS

The water-brake controller consists of a series of containers mounted on a vertical rotating frame. The containers or compartments are connected by valved connectors forming a circular closed system. Figure 116 shows one prototype constructed of plastic pipes and elbows. The system is divided into two compartments by gluing two plastic disks into elbows at opposite corners. The system is partially filled with water. The frame is mounted on a horizontal shaft which transmits torque to and from the cable reel either directly or through a speed reducer. As torque is applied to the shaft, the frame begins to rotate, raising the water to a position which balances the applied torque. If the valves are open, the water flows, allowing the frame to rotate at a constant average speed. The system can be designed to handle any desired range of cable force and speed.

The design procedure is as follows. The cable force, f, in pounds is given by,

$$f=0.028\ D^2(H_m+D/2), \qquad [K-1]$$

where D is pipe size in inches, and H_m is outlet head in inches.

The maximum expected force, f, is calculated by equation [K-1]. The maximum torque on the frame is

$$T=fr/S \qquad [K-2]$$

where T is torque in pound-inches, r is the reel radius in inches, and S is the ratio of the frame speed to the reel speed.

The containers are then designed using the maximum torque. The frame will develop maximum torque when the system is about one-half full of water. Based on a 50-percent full system, this maximum allowable torque is given approximately by

$$T=0.04R^2d^2, \qquad [K-3]$$

where T is torque in pound-inches, R is average radius to the container centerline in inches, and d is the diameter of the containers in inches.

The distance, R, and diameter, d, are selected to produce a torque at least as great as the required torque and preferably about 30 percent greater to provide a factor of safety. The length of the containers is then determined so that their ends are as close as possible. If the elbows are used, the pipe lengths are cut to produce the required radius, R. The pipe-elbow construction produces a rigid system which is mounted on a simple steel angle frame.

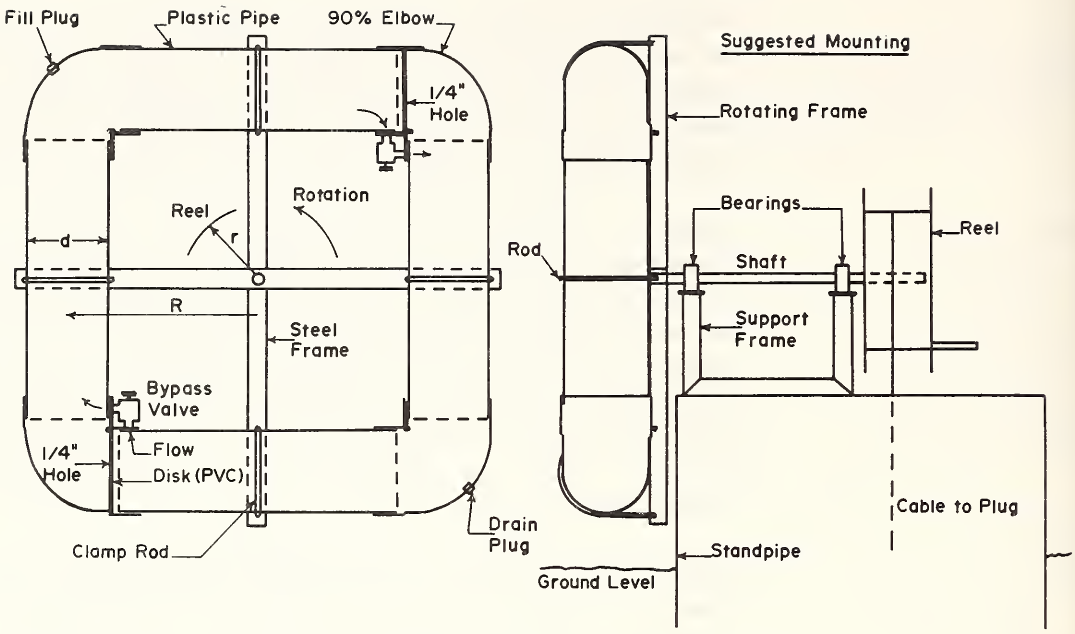


Figure 116.--Water brake with two compartments constructed of pipes and elbows.

The desired maximum rotation speed is determined as follows: The plug travel speed is given by

$$P=19.3\ Q/EG, \quad [K-4]$$

where P is plug speed in inches per minute, Q is total flow in gallons per minute, E is furrow length in feet, G is gross application in inches.

The rotation speed of the frame in revolutions per minute is

$$w=PS/2\pi\ r \quad [K-5]$$

The size of the bypass valves and bypass tubes is given approximately by

$$b=0.07wd^3R^{1.5}T^{-.07} \quad [K-6]$$

where b is tube inside diameter in inches.

The tube size should be selected somewhat larger than the size calculated by equation [K-6] to insure that the maximum desired speed can be obtained. The valves can then be adjusted to slow the rotation to any desired speed less than the maximum or to stop the rotation completely.

Since the system should be half full of water, only two valves in opposite corners are needed to control the speed. The valves should have approximately equal settings. The valve settings can be calibrated for specific speeds after a system is operational.

Equation [K-6] can be rearranged to determine speed as a function of torque or cable force. The speed is proportional to the torque to the 0.7 power, when the unit is approximately one-half full. The plug speed will thus vary with the cable tension. For systems with variable plug head caused by changing pipe slope, this is undesirable. With an increasing pipe slope, the speed can be kept relatively constant by using a narrow reel so that the reel radius decreases as the cable tension increases.

For systems with variable furrow length, it is desirable to increase the plug speed as the furrow length decreases (the outlet size decreases, and the plug head increases). Equation [K-6] can be used with the computer model to design a variable reel for use with the water brake to obtain the desired speeds for a particular system.

A solution of $CaCl_2$ can be used to increase the density of the liquid and prevent freezing. One kilogram of calcium chloride per two liters of water will produce a specific gravity of 1.28 g/cm^3. With this solution, the allowable torque (as determined in eq. [K-3]) can be increased by about 30 percent.

An example will illustrate the design. A 12-inch-pipe cablegation system is designed and Hm=8 inches. The cable force is f=56 pounds. The water brake is to be designed for direct drive, S=1. The reel radius is 5 inches, so the torque is 280 pounds per inch. If 4-inch-diameter tube is chosen, the distance, R, should be 19 inches, from equation [K-3]. $CaCl_2$ solution will be used to provide the factor of safety.

The total flow is 1,200 gallons per minute, furrow length is 1,200 feet and a 4-inch gross application is desired. The plug travel speed is 4.83 inches per minute. The reel rotation speed is 0.15 revolutions per minute. The tube size, from equation [K-6] is 0.28 inches. A tube and valve size of one-half inch is appropriate for the bypass valves.

Installation of commercially available valves into pipes at right angles to each other was difficult. Moreover, the complete range of reel speeds from stopped to faster than needed was spanned within less than one rotation of the valve handle. The baffle disk and valve assembly indicated in figure 117 was fitted into pipe elbows by a local machine shop at reasonable cost. They provide more graduated speed control and are easy to assemble. Most of the recently constructed water-brake systems have used baffle disk and valves of this type.

Bits of plastic left in the tube from drilling or threading holes in the pipe can partially block the valves and change the calibration between their opening and the cable speed. Consequently, the system should be thoroughly rinsed out before it is taken to the field.

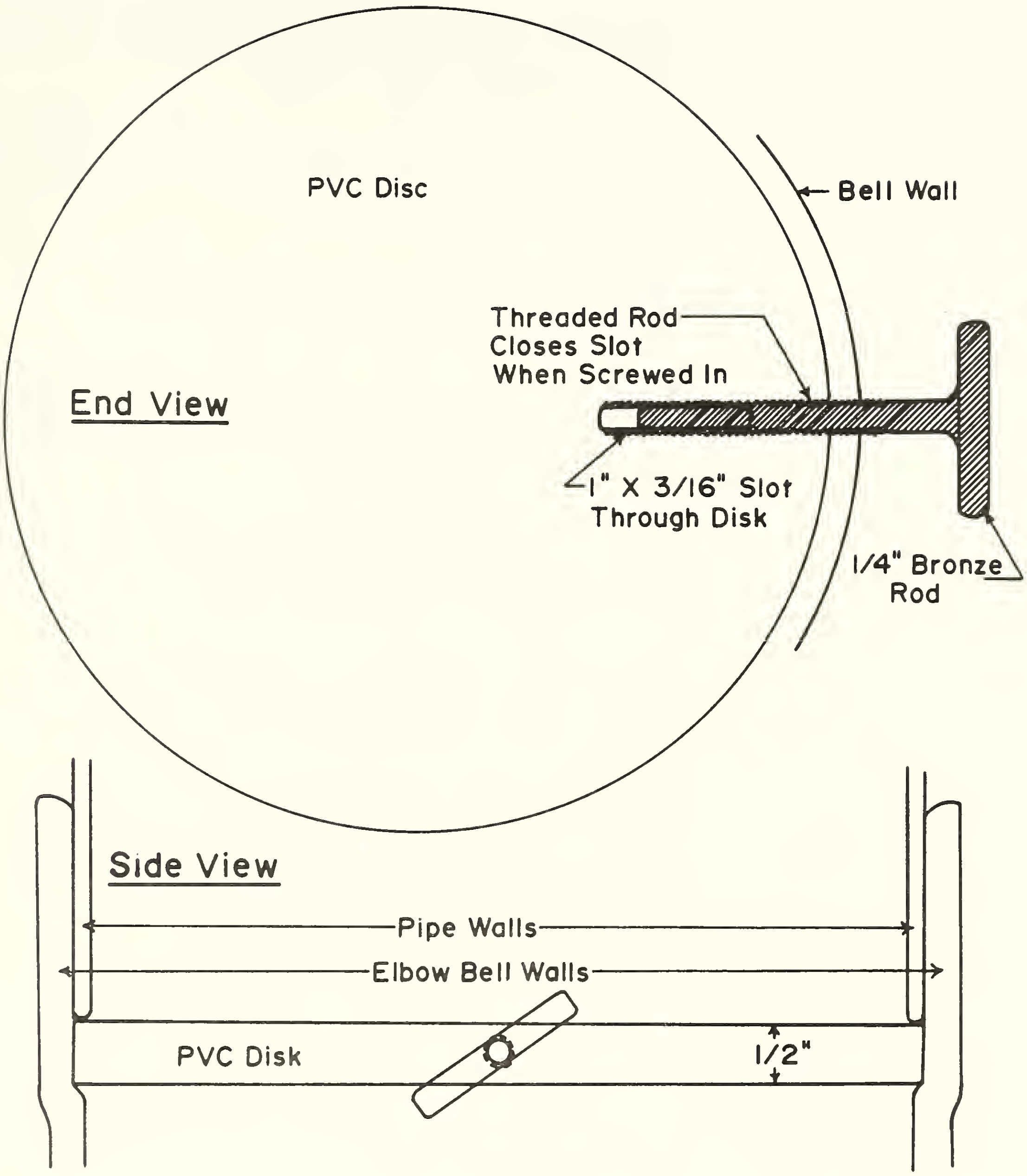


Figure 117.--Baffle disk and valve used to regulate speed of the waterbrake controller.

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