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A GUIDE TO THE PLANNING AND HYDRAULIC DESIGN OF JET PUMP REMEDIAL SAND BYPASSING SYSTEMS

by

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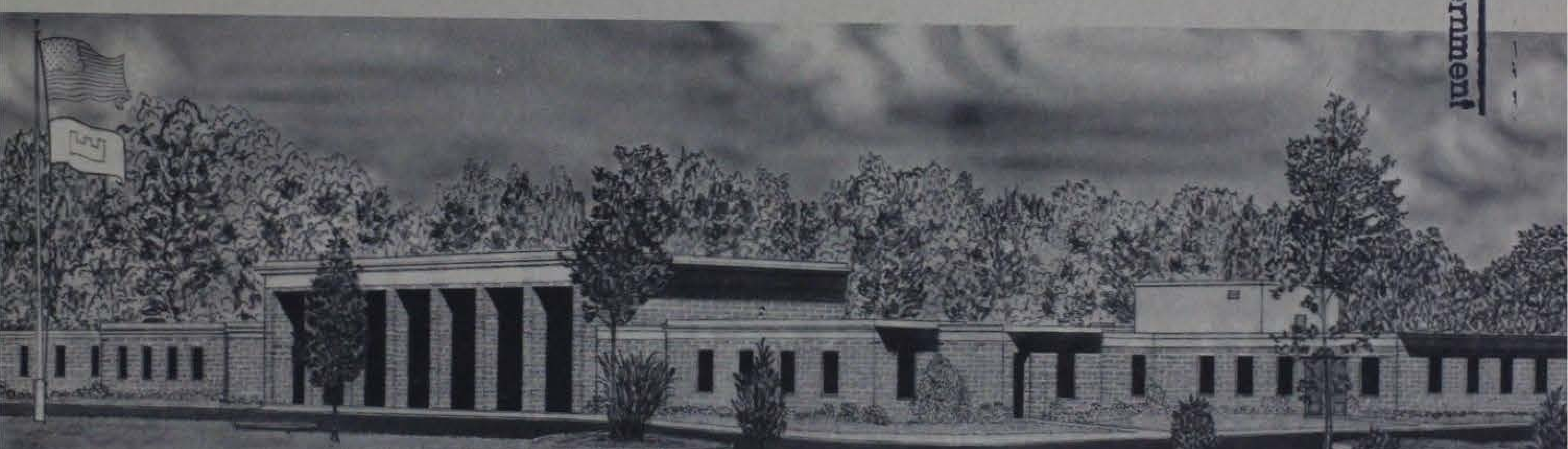

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This report is intended as an aid to engineers studying alternative solutions to a coastal sand bypassing problem. Using this report, engineers already familiar with coastal processes and centrifugal pumping systems will be able to: (a) determine the feasibility of a jet pump remedial bypassing system at a given site, (b) develop initial layouts for such a system, and (c) perform the system basic hydraulic design. A set of considerations and

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guidelines relative to feasibility and intial layout are discussed in varying degrees of detail. Two step-by-step hydraulic design procedures are presented, one being an iterative type adaptable to computer solution, the other a graphical approach. Both procedures are keyed to a simple system with one jet pump and one booster pump. Additional considerations are given for systems using multiple jet and/or booster pumps. A companion report to be issued at a later date will describe techniques and equipment for building, operating, and monitoring a jet pump bypassing system.

PREFACE

This report is the result of research performed under the Improvement of Operations and Maintenance Techniques (IOMT) research program which is sponsored by the Office, Chief of Engineers (OCE), and conducted at the U. S. Army Engineer Waterways Experiment Station (WES). This report contains guidance for the planning of a jet pump remedial sand bypassing system and also contains specific instructions for preparing the basic hydraulic design for such a system.

A companion report will be issued at a later date describing techniques and equipment for building, operating, and monitoring a jet pump bypassing system. This companion report will also include example designs illustrating the procedures and recommendations from both reports. Both reports are based on testing conducted by WES investigators in both laboratory and field installations.

The IOMT work unit was entitled "Eductor Systems for Sandtrap Bypassing" and was performed during the period 1973-1979. The study was performed under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, F. A. Herrmann, Jr., Assistant Chief of the Hydraulics Laboratory, and R. A. Sager, Chief of the Estuaries Division. The work was performed by Messrs. W. B. Fenwick, T. W. Richardson, P. L. Chandler, J. C. Roberge, S. R. Bredthauer, and E. W. Flowers under the supervision of Mr. E. C. McNair, Jr., Chief of the Research Projects Group. This report was prepared by Messrs. Richardson and McNair. This report was reviewed in draft form by several CE Division offices, by the U. S. Army Coastal Engineering Research Center, by the Engineering and Operations Divisions of OCE, and by Dr. D. R. Basco of E_2O Consultants, Inc., as a consultant to WES.

Commanders and Directors of Wes during the conduct of this work unit and the preparation and publication of this report were COL G. H. Hilt, CE, COL John L. Cannon, CE, COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsuis degrees or Kelvins*
feet	0.3048	metres
feet of water	2988.98	kilograms per square centimetre
feet per second per second	0.3048	metres per second per second
gallons per minute	0.06308	litres per second
inches	25.4	millimetres
square feet	0.0929	square metres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

A GUIDE TO THE PLANNING AND HYDRAULIC DESIGN OF JET PUMP REMEDIAL SAND BYPASSING SYSTEMS

PART I: INTRODUCTION

1. Sand bypassing is a term used to denote the transfer of cohesionless sediments past man-made or natural barriers that trap, divert, or otherwise interfere with the natural process of coastal sediment transport. This bypassing can be accomplished by natural forces, as is the case in most uncontrolled and unimproved tidal inlets, or bypassing can make use of pumps or other means for excavating and transporting littoral materials.

2. This report provides specific guidance in the design of remedial bypassing systems that employ jet pumps for initial solids handling. The term "remedial" refers to bypassing for the purpose of alleviating an existing problem, as opposed to preventing a possible future problem. However, many of the techniques and approaches used can be applied to either situation. Although jet pumps have been used as suction boosters on hydraulic dredges for many years, their use in sand bypassing was developed as new technology in a research program sponsored by the Office, Chief of Engineers (OCE). Work under this program was performed by the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES).

3. This report also provides some general guidance in the coastal engineering approach to sand bypassing problems. The approach presented in this report is oriented toward the requirements of jet pump systems, but useful information will result regardless of the type of bypass system finally selected.

4. PART I of this report is devoted to evaluating a site and defining the parameters on which the bypassing system can be designed. Characteristics of jet pump bypassing systems and potential jet pump system configurations are also presented. PART II of this report deals with preparing a preliminary system layout. Methods are presented for

preliminary selection of portions of a jet pump system based on site requirements and characteristics. Specific design procedures and calculations are presented in PART III of this report. A subsequent report will contain instructions and suggestions for building, operating, and monitoring a jet pump bypassing system, as well as example designs.

The Bypassing Problem

5. Any activity in the coastal zone that impounds or diverts littoral sediments implies the need for sand bypassing. The earliest planning stages of such an activity should include consideration of ways to accomplish sand bypassing. When consideration for bypassing was not made prior to construction, the need for such a capability must be determined and remedial action taken if necessary.

6. There are several indicators of the need for a sand bypassing system of some type. Navigational problems caused by channel shoals and downdrift beach erosion coupled with updrift beach accretion (Figures 1 and 2) are by far the most common indicators that natural processes are being altered and that mechanical bypassing of some type may be needed. In many of these circumstances, complaints of local citizens and navigation interests will be heard.

7. Confirmation that a situation does exist which may be alleviated with a bypassing system can be made by personnel versed in coastal engineering who perform the following steps:

- a. Site visits and inspections. First-hand, visual inspections of a site will usually provide evidence of updrift accretion/downdrift erosion, indicative of littoral interruption. Visual inspection may even show evidence of channel shoal or offshore bar formation by unusual breaking wave patterns in or near channel areas.

- b. Review of site history. A review of photographs, charts, and maps will provide an excellent indication of the behavior of the site. General beach recession or aggradation, both updrift and downdrift, can often be diagnosed. Such studies are not only helpful in diagnosing problems, but may later prove invaluable in establishing magnitudes. For instance, comparisons of high-water marks in aerial photographs of a jetty accretion fillet may help identify the

Figure 1. Aerial view of Mexico Beach, Florida, showing updrift accretion, downdrift erosion, and channel shoaling

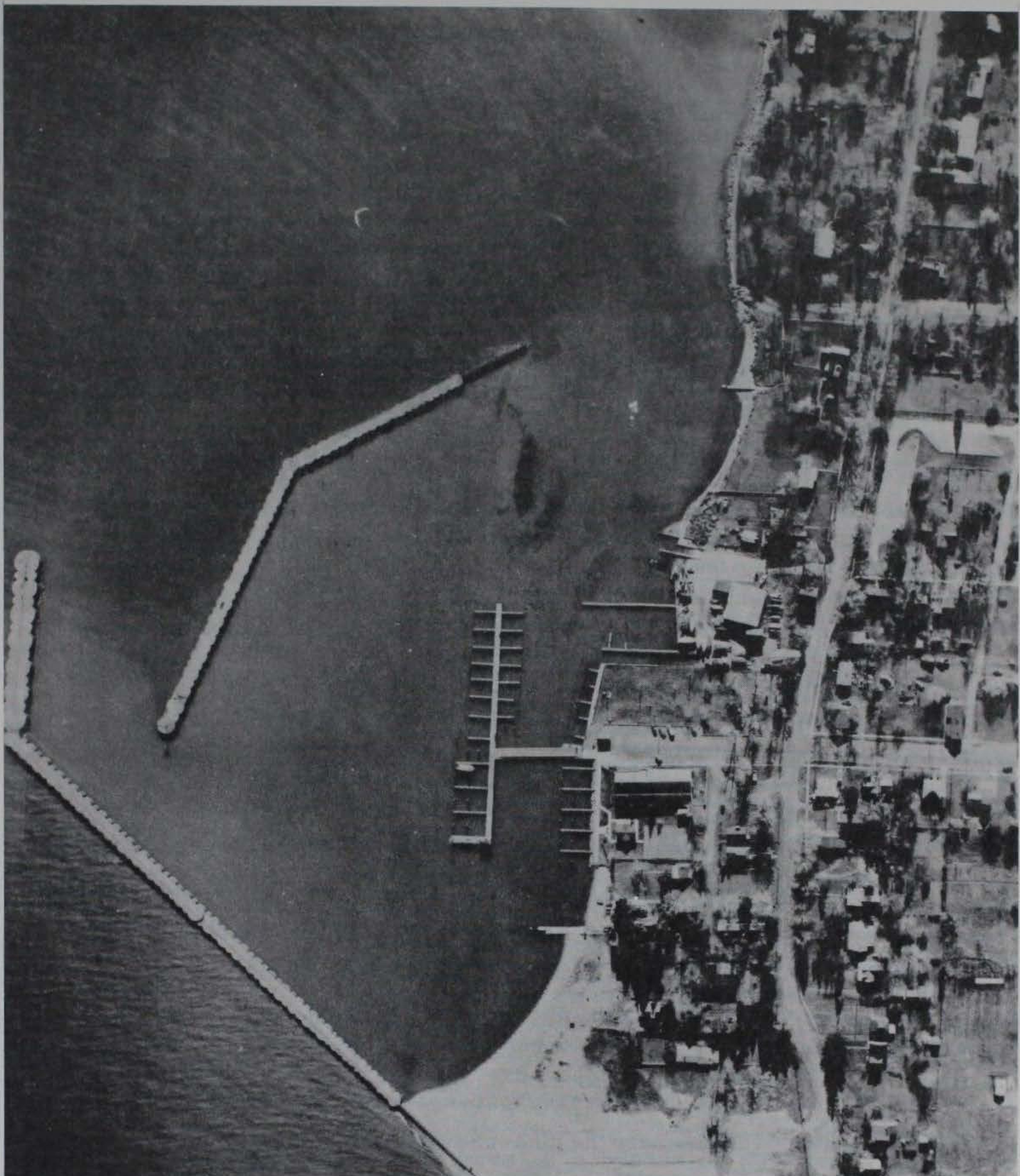

Figure 2. Aerial view of Port Sanilac, Michigan, showing accretion fillet and downdrift erosion

rate of accretion of littoral drift for a particular period of history.

c. Hearings and interviews - Dialogue with local citizens who have observed the site over an extended period is helpful in establishing behavioral patterns. Such discussions may define events that occur during and immediately following severe storms. Extent of wave runup or overtopping, extent of beach damage, rate of beach rebuilding following storms, areas of concentrated wave attack, etc., are examples of site characteristics that might be identified by this method. Reports of wind speeds, wave heights, and water levels should be used judiciously since these parameters are extremely difficult to quantify by casual observation.

These steps should provide sufficient information to decide whether a problem exists that might require further site study and investigation.

Site Study and Problem Formulation

8. Design and employment of a sand bypassing system require a specialized coastal processes study of the site. Results of such a study provide the basis on which to select the most appropriate sand bypassing approach. If a field data collection program is needed, the cyclic nature of many coastal phenomena requires that the collection period be at least one year. Periods exceeding one year usually give more complete results. Because of this relatively long observation period, the coastal processes study should be implemented as soon as possible following the decision to investigate a mechanical bypassing solution.

9. Coastal processes studies are complex and the methods for carrying out such studies are beyond the scope of this report. Engineer Manual 1110-2-3300, "Beach Erosion Control and Shore Protection Studies," published by the Office, Chief of Engineers, in 1966 and the Shore Protection Manual (SPM) prepared and published in 1977 by the U. S. Army Coastal Engineering Research Center (CERC) may be consulted for guidance in designing and implementing such a study. However, to provide additional explanation, some of the important items of a coastal processes study for a jet pump bypass system are listed in approximate order of

importance, together with explanatory remarks:

a. Littoral transport. Transport vectors (rates and directions) as a function of time should be determined. The smaller the time increment for which transport vectors can be quantified, the better. Especially important are vectors for storm events, when large transport rates may be expected. In addition, an attempt should be made to establish the confidence limits of these vectors, taking into account such factors as data accuracy and effects of any simplifying assumptions used in processing the data.

b. Movement paths and deposition patterns. Of equal importance to identifying transport vectors is the determination of paths along which the transport is moving and the patterns in which it is depositing. This is especially important in the vicinity of structures, for two reasons:

   (1) Structures have complicated and often unpredictable effects on littoral transport. The only reliable way of determining movement paths and deposition patterns near structures is to collect and analyze field data on them. Model test results may be used to supplement such data, but should not be considered a substitute.

   (2) A jet pump bypassing system is usually used near structures to take advantage of the channelization of sand movement and the concentrated deposition that often occurs there. Also, the structures can provide protection and a foundation for the land-based portion of such a system.

c. Waves. Waves have direct effects on a jet pump sand bypassing system mainly in the restrictions they place on jet pump deployment and in their effect on pumphouse location and characteristics. The wave climate has many indirect effects, however, such as being a prime cause of littoral transport and causing alterations in water levels due to setup. A frequency distribution of significant wave heights at the site, the representative wave periods, and possibly yearly directional roses of significant height and period usually provide information for the direct effects which waves have on a bypassing system. For determining indirect effects, however, a much more detailed description of the wave climate at the site may be required.

d. Sediment characteristics. A description of the sediment to be bypassed is essential to design of the bypass system. Characteristics that must be determined include but are not limited to:

   (1) Grain size distribution.

   (2) In situ porosity.

(3) Specific gravity of sediment solids.

(4) Presence of cohesive material or cementing agents.

(5) Presence of large objects such as cobbles, shells, or debris.

(6) Subsurface profiles in areas where jet pump system may operate, preferably obtained from core samples.

e. Water-level fluctuations. The magnitude and frequency of water-level fluctuations due to tides, wave setup, surges, seiches, and other causes should be determined. Of special importance is identifying what combinations of these fluctuations might be expected over different time periods.

f. Morphology. Detailed surveys should be made to determine nearshore bathymetry at and adjacent to the bypassing site. Yearly morphologic cycles as well as longer term trends should be identified using these surveys, previous ones, and other data. An attempt should be made to predict future morphological trends.

g. Currents. The only direct effect which currents might have on a jet pump bypassing system would be on jet pump deployment. Maximum expected currents, their location, and direction should be identified. Indirect effects of currents include the potential to transport sediment to jet pump locations or even past these locations in suspension if strong enough.

10. Other information that is needed for preliminary design of the jet pump system but would not necessarily result from a coastal processes study includes:

a. Above-water layout of bypassing site, to include plan views and cross sections of structures, topographic features, rights of way, locations of utilities, etc.

b. Physical description of areas to which bypassed material will be pumped, and identification of possible routes for pipelines.

c. Design characteristics of structures in the vicinity of the bypassing system (design parameters and criteria, armor unit sizes, etc.).

Consideration of Bypassing Alternatives

11. A number of bypassing methods and approaches should be considered for any given bypassing problem. Very rarely will a problem

be so well defined and limited in scope that it can be alleviated only by one type of system. The designer then has the task of selecting the system which most nearly satisfies the bypassing requirements of that site. The following is a brief discussion of some aspects of the spectrum of bypassing systems.

Classification

12. Many ways of classifying sand bypassing systems are possible. However, aside from capacity, the single characteristic of any system that most affects its suitability for a particular project is the degree of mobility which it possesses. Mobility in this sense is defined as the ease with which the system can reach various areas of the project site. Accordingly, the following classifications are suggested:

a. Fixed systems, in which the entire physical plant is fixed as to location. Examples could be dredge pump systems operating from a house or platform or jet pump systems using fixed jet pumps. Such systems require a high degree of predictability of littoral transport vectors, movement paths, and deposition patterns.

b. Mobile systems, in which the entire physical plant can be relocated readily to reach various areas of the bypassing site or other sites. Examples could be floating dredges or jet pump systems mounted on trailers. Such systems may be more vulnerable to the physical environment than other types. Dredges, for instance, may be affected by wave action.

c. Semimobile systems, in which mobility is restricted to a single, well-defined area of the project site, the scope of which can be a determining factor in system design. Examples could be dredge pump systems mounted on tracks or rails, or jet pump systems using mobile jet pumps.

13. An important aspect of the classification system described in paragraph 12 is that particular equipment may fit more than one category, depending on site conditions and how it is used. For instance, a land-based clamshell crane might be used in one location only, making it essentially fixed. If a suitable roadway exists on a jetty, the clamshell might be moved back and forth along the jetty's length, in which case it could be termed a semimobile system. Driven onto a barge, the clamshell crane could become the major part of a mobile system. While this situation may appear confusing at first, in fact a

mobility-type classification is useful to the designer. Since it is based not just on system characteristics but on the interrelationship between these characteristics and project conditions and requirements, it deals directly with the problem at hand: choosing the best system for a particular situation.

Equipment

14. The list of equipment that can be used to form a bypass system is extensive. Anything from a hand shovel to a hopper dredge could conceivably be employed. The following list, not at all complete, gives items of equipment that exist at present and that have been or could easily be used in a bypass system:

a. Floating dredges.
   (1) Trailing suction hopper.
   (2) Cutter suction.
   (3) Plain suction.
   (4) Bucket ladder.
   (5) Clamshell.
   (6) Dipper.
   (7) Backhoe.

b. Land-based mechanical equipment.
   (1) Dragline.
   (2) Clamshell.
   (3) Backhoe.

c. Hydraulic equipment.
   (1) Dredge pump.
   (2) Jet pump.
   (3) Other types of solids-handling pumps.

Structures

15. The role of structures as part of a total sand bypassing system should never be underestimated. Structures can perform the following important functions, among others:

a. Direct and channelize movement of littoral drift.

b. Cause deposition of littoral drift at predetermined locations.

c. Provide access to areas of project site seaward of shoreline.

d. Provide foundation for part or all of bypass system.

e. Shelter bypass system from wave action.

Any bypass system design should try to make maximum use of the benefits that existing structures can offer. In addition, serious consideration should be given to structural changes or additions that might help in operation or design of a bypass system. Such additions might include the creation of deposition areas for littoral drift by means of breakwaters or weir sections in jetties.

16. The engineer responsible for the solution of a bypassing problem will undoubtedly study a number of possible methods in detail and will develop several potential solutions that will be studied even further. If a jet pump bypassing system is identified as a possible alternative, the remainder of this report will serve as a guide in developing designs for such a system.

Site Conditions Affecting Feasibility of Shore-Based Jet Pump Bypassing System

17. Certain site characteristics and bypassing requirements could make a jet pump bypassing system viable at a given site. Assuming that such a system would be deployed from shore (as opposed to a floating base), these characteristics and requirements are:

a. Need for continuous bypassing. Such a requirement definitely indicates that a jet pump system should be considered. Jet pump systems operate at a relatively low pumping rate compared with a large hydraulic dredge. Bypassing performed by a jet pump system can be made to proceed at a rate of the same order of magnitude as the average littoral drift rate.

b. Littoral transport near shore or structures. Littoral transport moving close to shore or to structures at the site can usually be handled by a shore-based jet pump system. At most sites, at least one location can be identified where this occurs. More specific criteria will be given later.

c. Moderate peak transport rates. Although not an absolute requirement, the less littoral transport rates at a site vary with time over a yearly cycle, the better suited the site is for jet pump bypassing. Those sites with significant variation can be dealt with using concepts that will be explained later.

d. Littoral drift impoundment area. An existing sheltered impoundment area, such as that created by a detached breakwater or a weir section in a jetty, is of great benefit in making a jet pump system viable. An exposed impoundment area, such as a jetty accretion fillet, may be helpful depending on other factors in the system design.

18. Many other, more site-specific factors will have to be considered in determining the viability of jet pump bypassing at a particular site. In addition, not all of the above factors are necessary in order for a site to be suitable for a jet pump system. However, a site that possesses all of these factors can be considered a prime possibility for jet pump bypassing unless one or more conditions exist that preclude use of a jet pump system.

19. Some site conditions will probably preclude the use of a jet pump bypassing system. These are:

a. Presence of cohesive or cemented materials. Cohesive clays and cemented sands cannot be effectively dislodged by the jet pump using presently available cutting techniques. Even relatively thin layers of such material may cause problems.

b. Transport and/or accretion over a broad area. If littoral transport and/or accretion of such transport occurs over broad or poorly defined areas at the site, it may be difficult to design a reasonable jet pump bypassing system. In many ways, this situation would be the converse of the factors described in paragraphs 17 b and d.

c. Absence of suitable location for clear water intake. This will be discussed fully in later parts of this report, but a relatively sheltered, accretion-free location must be available from which clear water can be drawn to drive the jet pump.

Other considerations may impact upon the feasibility of a bypass system, such as property ownership, aesthetics, and local attitudes. Such items must be dealt with but are beyond the scope of this report.

Description and Configurations of Jet Pump Bypassing Systems

20. The center-drive* jet pump, the primary component of the jet pump bypassing system, is different from other pumps in that it contains no moving parts and is powered by a jet of water. The jet pump operates completely submerged, resting on the bottom with its suction tube buried in the material to be pumped. The basic principle behind the operation of the jet pump is the exchange of momentum within the pump. Clear water, normally supplied by a centrifugal pump, enters the jet pump through a nozzle as a turbulent jet (Figure 3). In the mixing chamber, turbulent

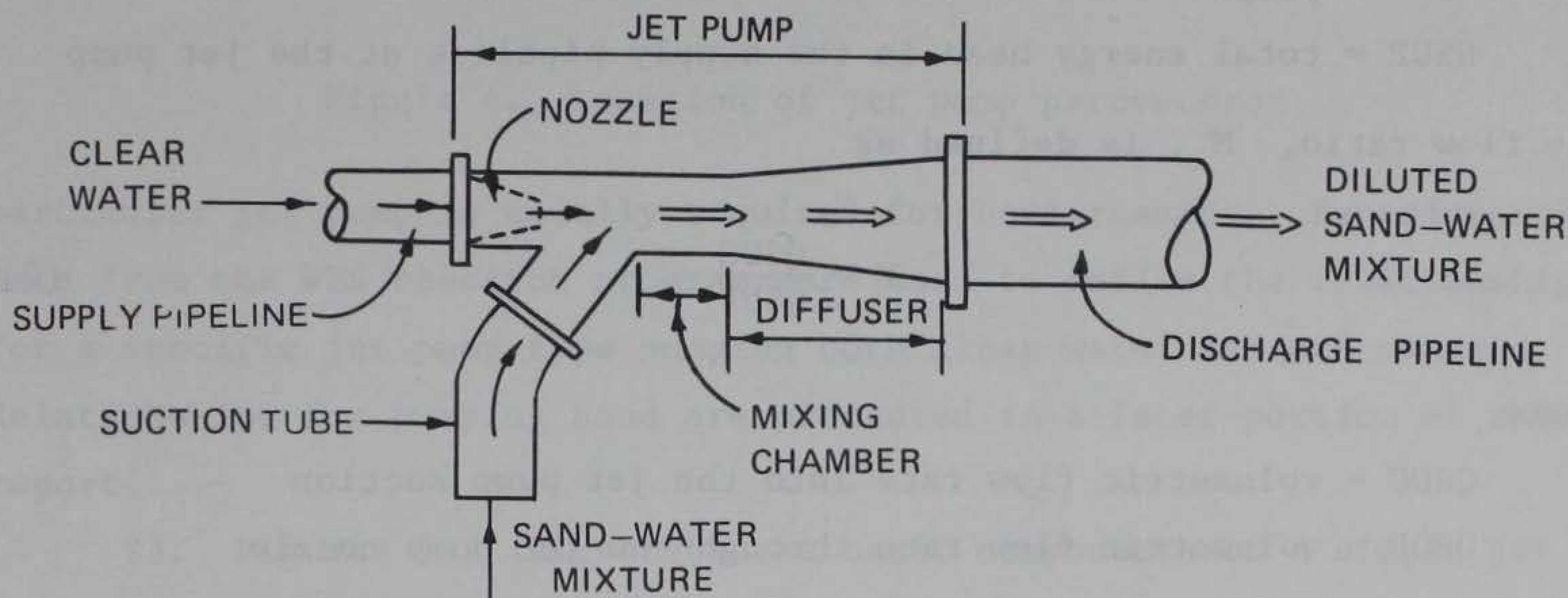

Figure 3. Jet pump principles of operation

mixing occurs between the water jet and a sand-water mixture drawn into the suction tube. This mixing causes a transfer of momentum from the jet to the sand-water mixture. At the same time, the sand-water mixture is diluted by the jet water. The diluted mixture then passes into the diffuser section of the jet pump, causing more sand-water mixture to be drawn into the suction tube in a continuous process. In the diffuser, a gradual expansion of the jet pump walls results in some flow energy changing from velocity to pressure. After exiting the diffuser, the diluted mixture moves through a discharge pipeline, usually to a

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* The term "center-drive" refers to a jet pump with a nozzle located on the center line of the main pump body. "Side-drive" or "peripheral-drive" jet pumps, on the other hand, have one or more nozzles located on the periphery of the main pump body.

conventional dredge pump acting as a discharge booster.

21. The performance of the center-drive jet pump in a given medium can be defined in terms of three dimensionless parameters. These parameters are: (a) head ratio, N ; (b) flow ratio, M ; and (c) area ratio, R . The head ratio, N , is defined as

$$N = \frac{HDIS - HSUC}{HSUP - HDIS} \quad (1)$$

where

HDIS = total energy head in the discharge pipeline at the jet pump

HSUC = total energy head in the jet pump suction tube at the jet pump

HSUP = total energy head in the supply pipeline at the jet pump

The flow ratio, M , is defined as

$$M = \frac{QSUC}{QSUP} \quad (2)$$

where

QSUC = volumetric flow rate into the jet pump suction

QSUP = volumetric flow rate through the jet pump nozzle

The area ratio, R , is defined as

$$R = \frac{ANOZ}{AMIX} \quad (3)$$

where

ANOZ = area of the opening at the tip of the jet pump nozzle

AMIX = inside area of the mixing chamber of the jet pump

Locations of these parameters on a center-drive jet pump are shown in Figure 4.

22. Gosline and O'Brien (1934), Mueller (1964), Reddy and Kar (1968), and others have worked on defining the relationships between M , N , and R for various jet pump configurations pumping water. Several investigators, such as Fish (1970), Zandi and Govatos (1970), and Silvester and Vongvisessomjai (1970), have worked on comprehensive theories for jet pumps pumping solids. However, experimentation with a

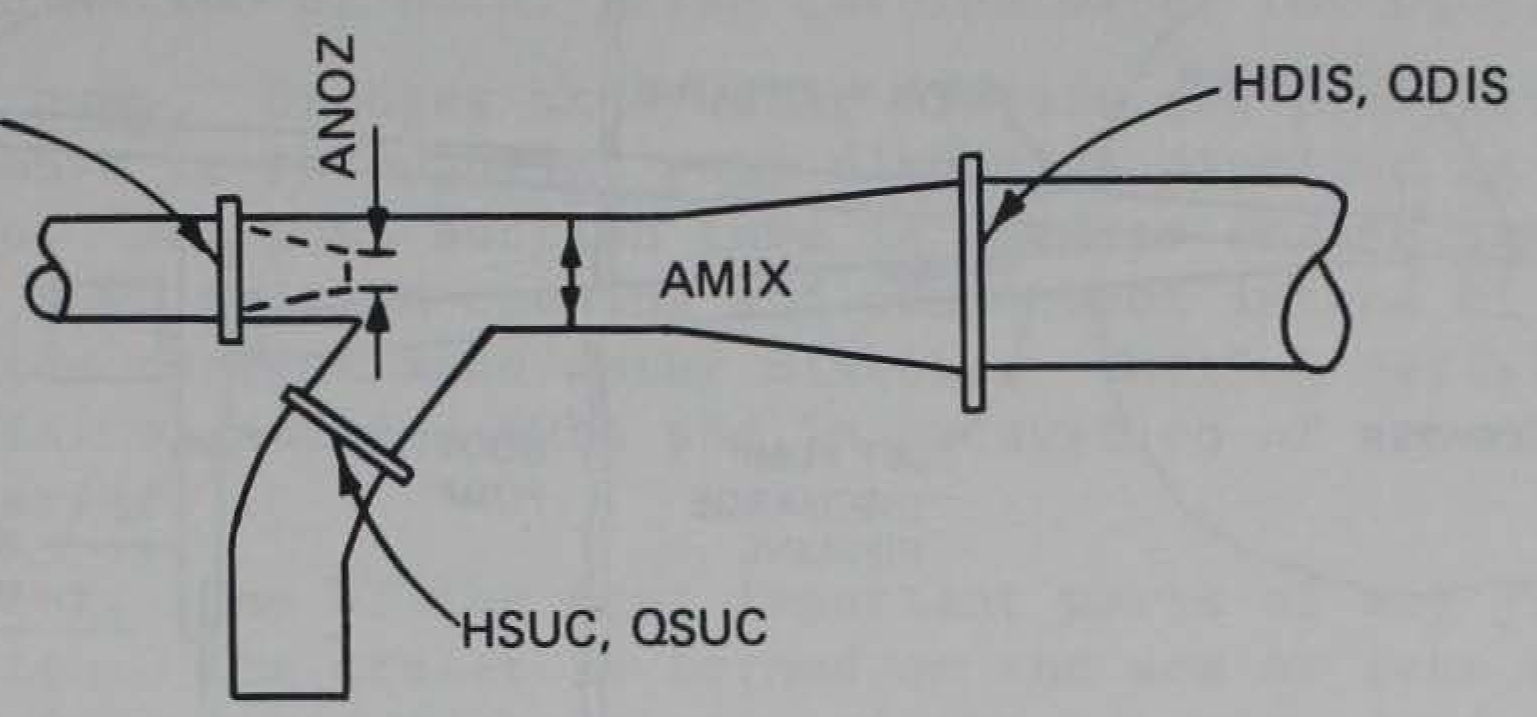

Figure 4. Location of jet pump parameters

particular jet pump is usually required for best results. Experimental data from the WES research program were used to define the relationships for a specific jet pump type pumping both clear water and medium sand. Relationships for pumping sand are presented in a later portion of this report.

23. Figures 5-7 illustrate the basic components of a simple jet pump bypassing system. More complex configurations are possible and

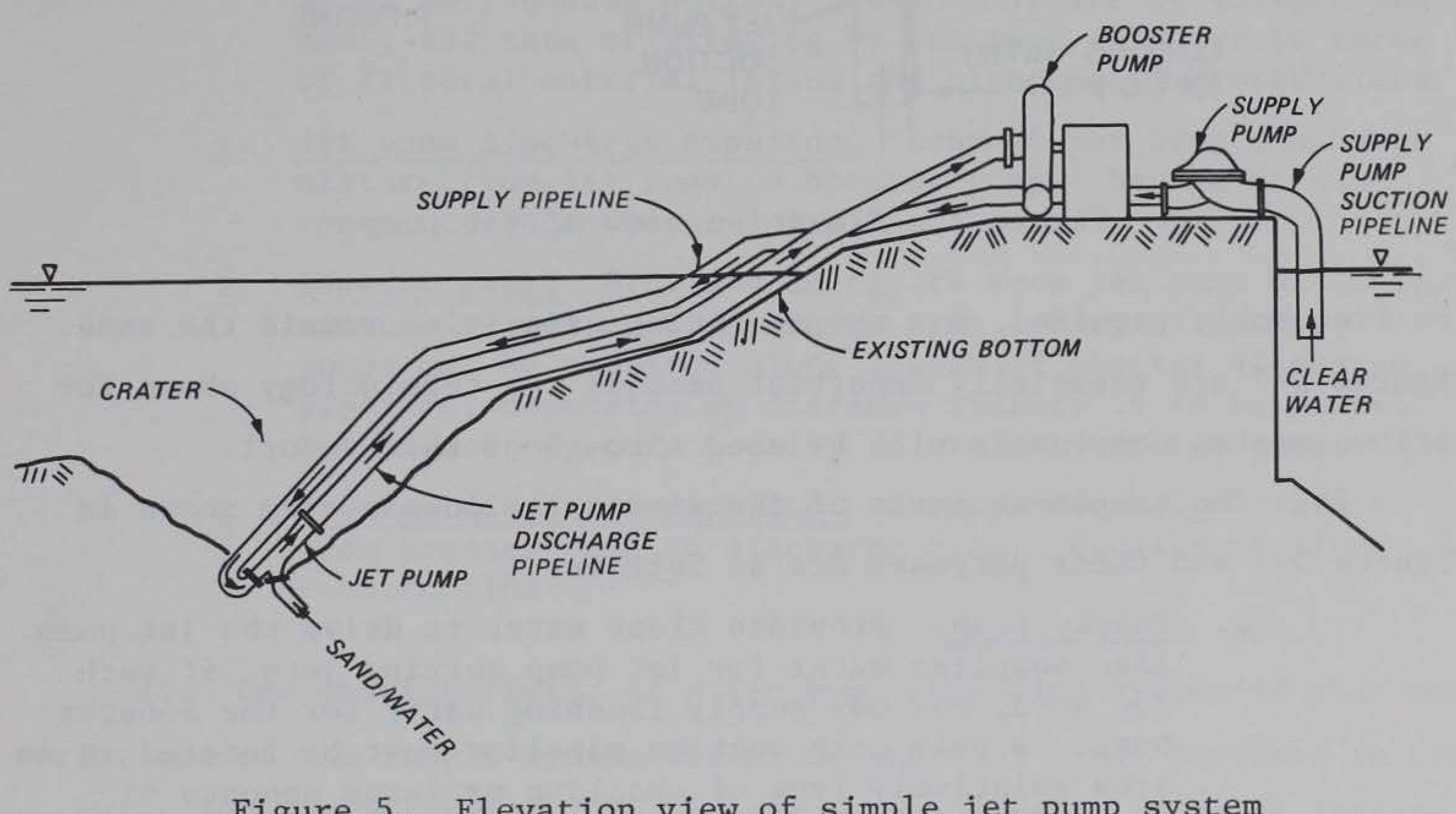

Figure 5. Elevation view of simple jet pump system

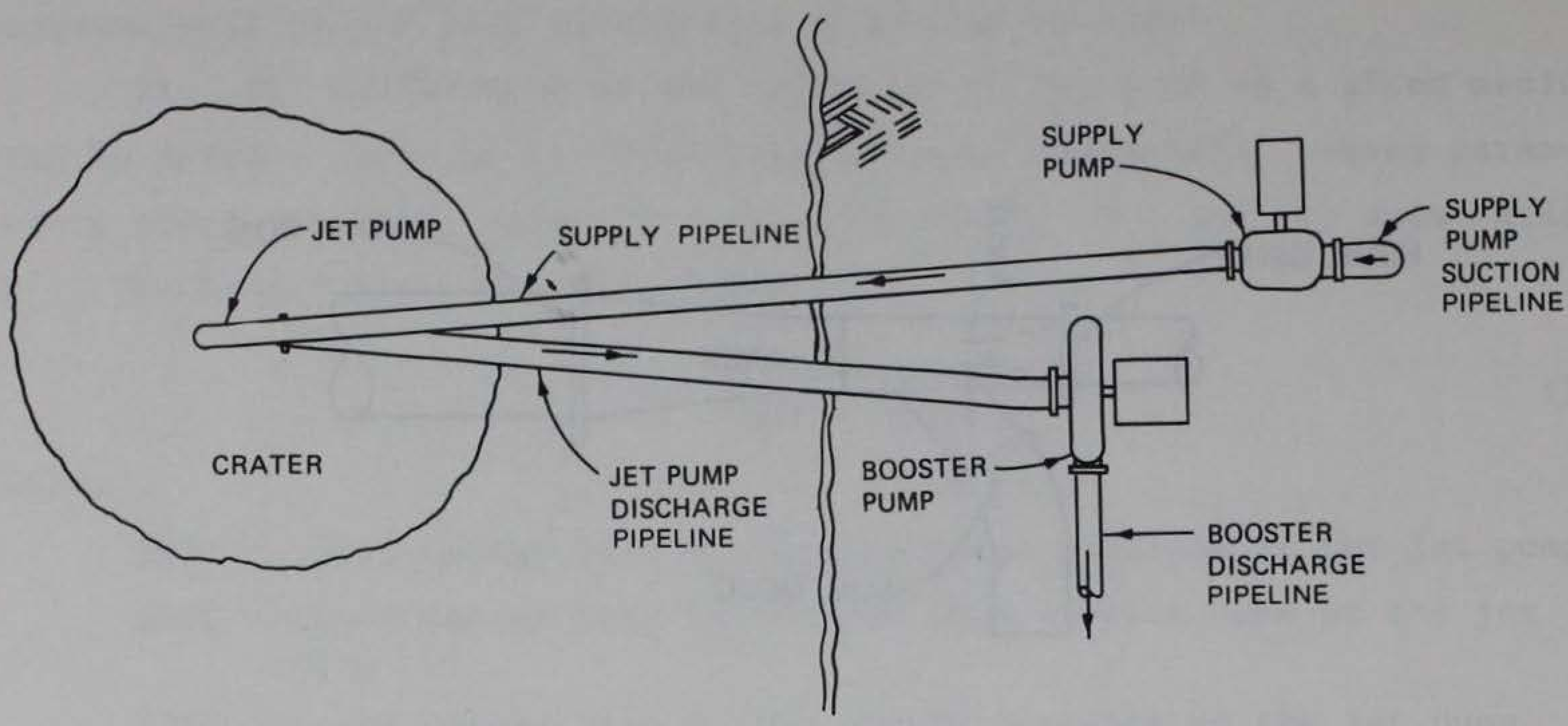

Figure 6. Plan view of simple jet pump system

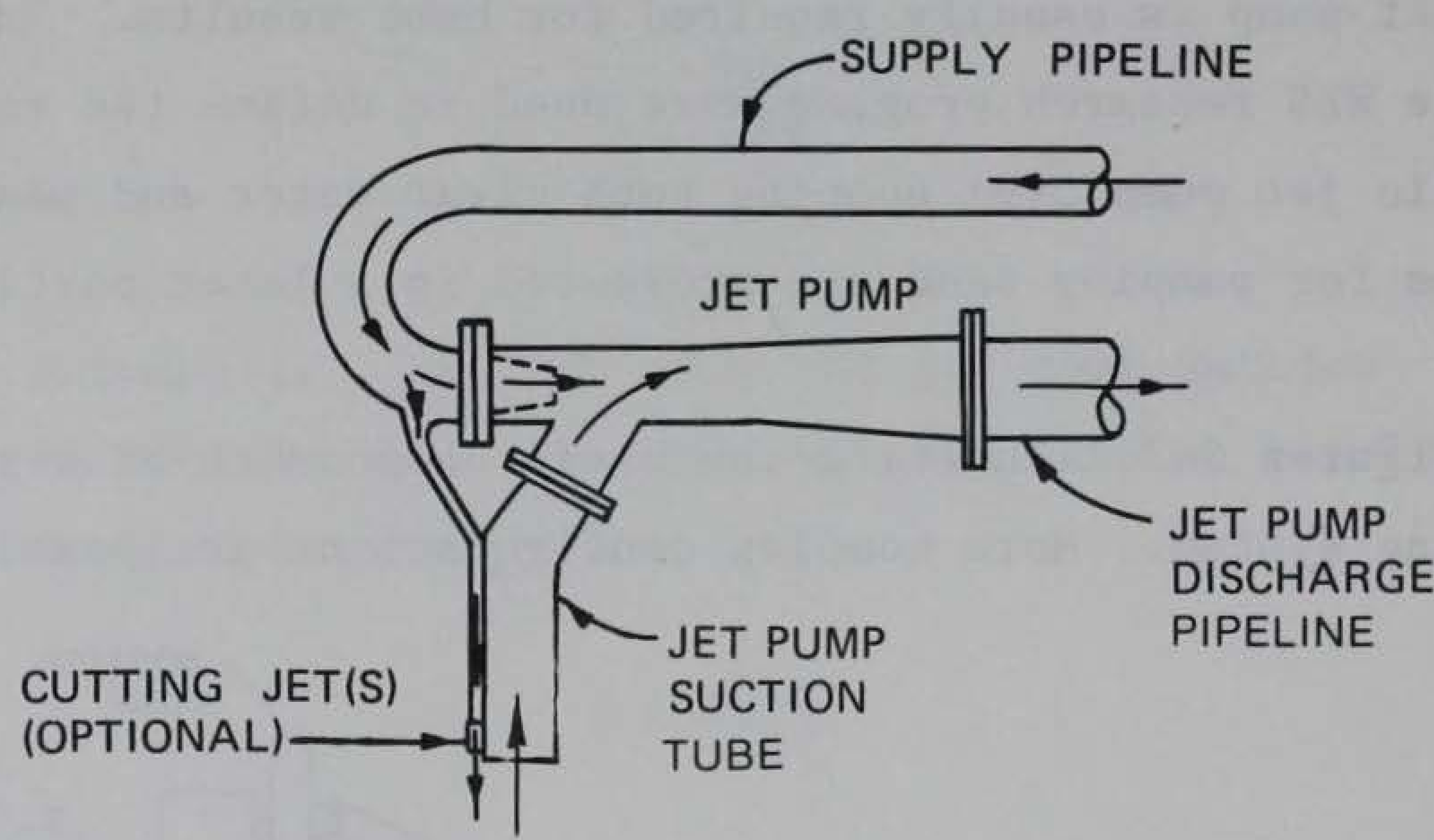

Figure 7. Elevation view of jet pump

are frequently required, but the operating principles remain the same. Figures 5-7 are especially important because the terminology shown for various system components will be used throughout this report.

24. The component parts of the simple jet pump system shown in Figures 5-7 and their purposes are as follows:

a. Supply pump. Provides clear water to drive the jet pump. Also supplies water for jet pump cutting jets, if such are used, and may supply flushing water for the booster pump. Supply pump suction pipeline must be located in an area relatively free of shoaling or large amounts of suspended sediment or small debris. The supply pump is usually an ordinary centrifugal pump.

b. Supply pipeline. Carries clear water from supply pump to jet pump. May be made of rigid pipe, flexible hose, or a combination of both. Also carries water for cutting jets.

c. Jet pump. Dredges sand/water mixture and provides head to move it through jet pump discharge pipeline to booster pump. Jet pump suction tube is used to ensure burial of jet pump suction opening and consequent intake of high solids content sand/water mixture. Cutting jet(s) aid in burial of suction tube and in excavation of consolidated material.

d. Crater. One of the most important parts of any jet pump system. The crater is formed on the sea or lake bottom and is maintained by virtue of the jet pump dredging below the level of the surrounding bottom. If the jet pump supply and discharge pipelines are flexible, a jet pump resting on an undisturbed bottom will excavate a crater by simply following the bottom of the crater downward as it removes sand. This process is illustrated in Figure 8. A jet pump buried below the undisturbed bottom, on the other hand, with rigid supply and discharge pipelines will excavate a crater above itself by removing sand from underneath. Figure 9 illustrates the formation of such a crater. The crater acts as a trap for littoral drift that would otherwise pass by. Without a crater or an array of craters, the jet pump has no chance of intercepting moving littoral drift. Crater size and shape are functions of many factors, such as depth of the jet pump below surrounding bottom, characteristics of in situ sediment, and rate of dredging by jet pump relative to rates of littoral material influx and slumping of crater sides.

e. Jet pump discharge pipeline. Conveys jet pump discharge mixture from jet pump to booster pump. May be of same construction as supply pipeline.

f. Booster pump. Provides energy to move jet pump discharge mixture to selected discharge area. Several booster pumps may be required along length of booster discharge pipeline, depending on distance mixture is to be pumped. The booster pump is usually an ordinary dredge pump.

g. Booster discharge pipeline. Carries discharge mixture from booster pump to discharge area. Usually of rigid construction.

25. One characteristic of a jet pump bypassing system is that many variations on the simple system shown in Figures 5-7 are possible in order to adapt the system to specific requirements. Some of these variations are:

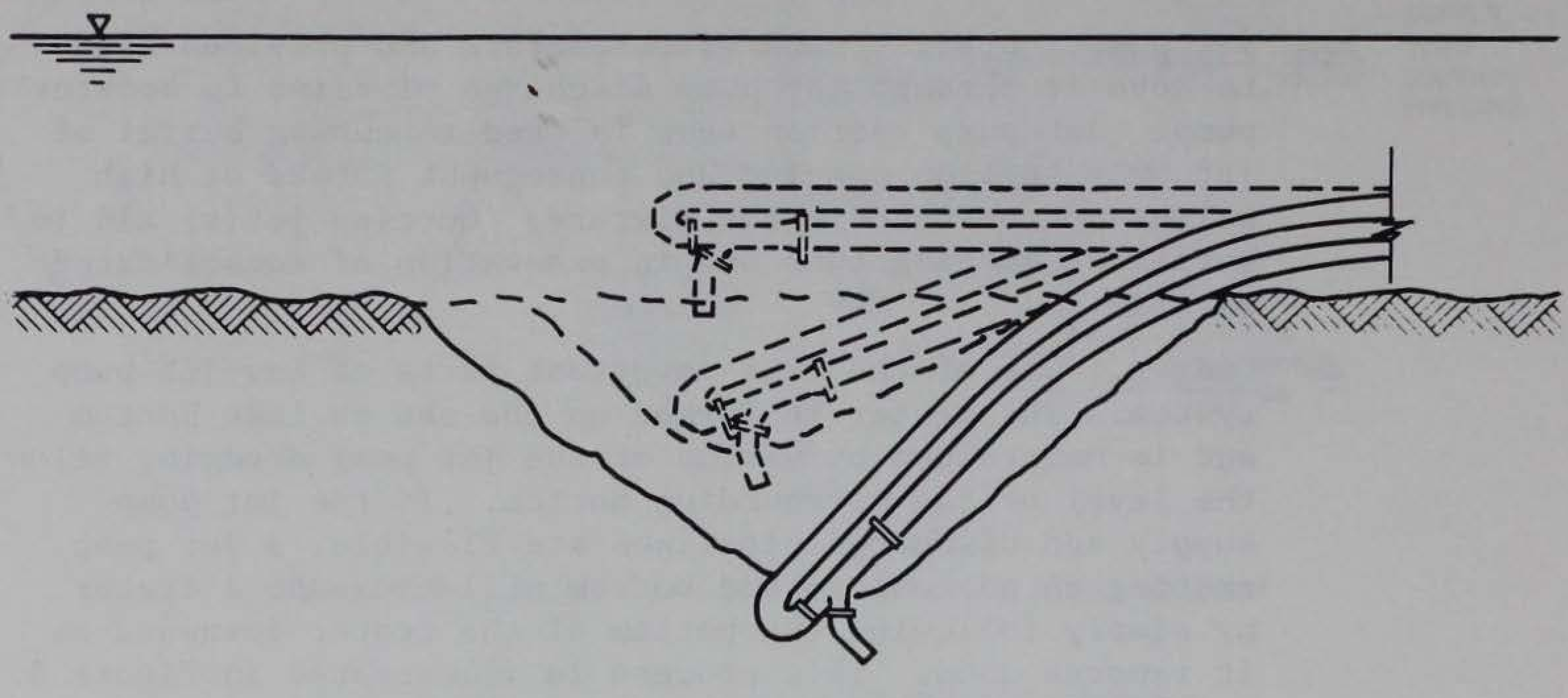

Figure 8. Excavation of crater by jet pump resting on bottom

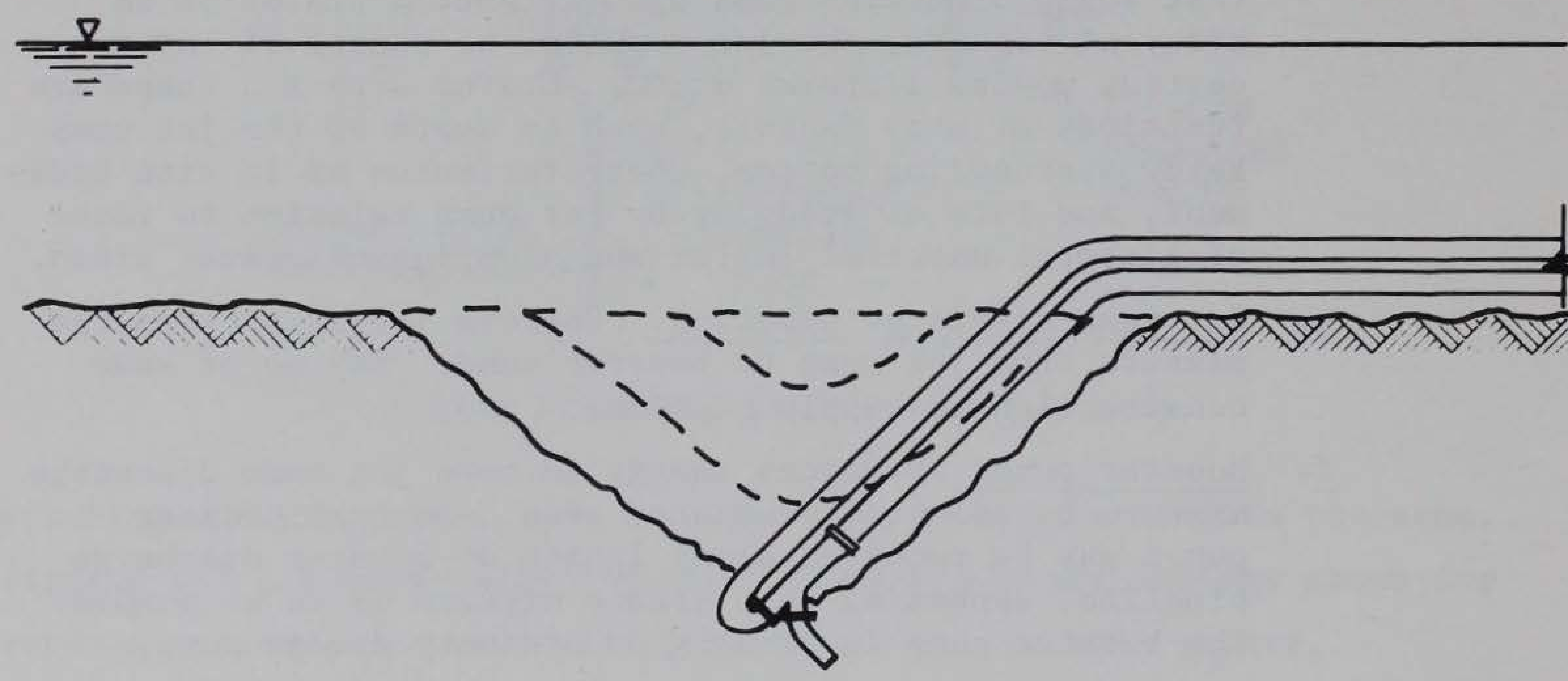

Figure 9. Excavation of crater by jet pump buried below bottom

a. Mobility of on-shore components.

(1) Permanent. Onshore system components, such as the supply and booster pumps, are located on fixed foundations onshore or on a structure such as a jetty. Usually, they are protected from the elements by an enclosure.

(2) Portable. Onshore components are mounted on a movable platform, such as a truck or trailer, and operate from parking locations onshore or on a structure. These components can then be used at several locations within a site or at different sites.

b. Mobility of jet pump(s).

(1) Fixed. Jet pump is installed permanently at a certain elevation, below the existing bottom. In such a configuration, the jet pump is virtually immune to wave action or the effects of currents. Multiple fixed jet pumps can be installed to create craters which cover a certain area.

(2) Mobile. Jet pump is equipped with a variable buoyancy float and flexible hoses, allowing it to be raised from its crater, moved a certain distance, and sunk to create another crater. This configuration of jet pump is best employed in areas sheltered from severe wave action.

c. Flexibility of jet pump pipelines.

(1) Rigid. Jet pump supply and discharge pipelines are constructed of steel pipe or other rigid material. Usually, this type of piping is used in conjunction with fixed jet pumps and can, in fact, be the means by which the jet pump is fixed in place.

(2) Flexible. Flexible hose, such as rubber dredging hose, is used for jet pump pipelines. This hose is normally used with a mobile jet pump to allow easy relocation of the jet pump. In such a use, the hose would be equipped with floats of fixed buoyancy to prevent it from being buried in the existing bottom or in the jet pump crater.

(3) Combination. Lengths of rigid pipe are connected by lengths of flexible hose to form the supply and discharge pipelines. Such a configuration provides a certain degree of flexibility at less cost than an all-flexible system. With floats attached, this type of pipeline can be used with mobile jet pumps in areas subject to very mild wave action. Without floats, such piping could be used with fixed jet pumps, provided that the jet pumps are supported by some means independent of the pipelines.

d. Number of jet pumps operating simultaneously.

(1) Single. System in which only one jet pump operates at a time. Such a system is the simplest to design and operate. A number of jet pumps may be installed at a site and operated individually, although the complications of piping and valving arrangements will increase rapidly as the number of jet pumps increases. In general, however, a single-type installation is preferable to a multiple one.

(2) Multiple. System in which two or more jet pumps operate at a time. This type of system should be considered only where the requirements of the bypassing project cannot be met by a single-type system, or where an excessive number of independent jet pumps are required for a single-type system. If a multiple system is necessary, the number of jet pumps operated simultaneously should be kept to a minimum.

Except as noted, any of the system variations discussed above can be used in conjunction with any of the others.

26. It should be noted that all discussion in this report deals with shore-based bypassing systems. However, there is no reason why a jet pump system designed using the techniques presented in this guide could not be placed on a floating platform. Such deployment would place the system philosophically in the category of dredges; therefore, no discussion of that deployment technique is presented in this report.

PART II: INITIAL SYSTEM LAYOUT

27. The aim of this part of the report is to provide guidance for the designer in arriving at general system configurations for which more detailed designs can be made. Although subsequent discussions will be in terms of a single system layout, in reality the designer should consider several alternative layouts simultaneously. All the alternatives should be treated equally until economics or other factors influence the choice of a final design.

28. Two points regarding this part of the report should be understood at the outset:

a. A series of topics are discussed that relate to the initial system layout. These topics are not presented in sequential order; in fact, no such order can be applied to them. Most of the topics interact with one or more of the others, the degree of interaction sometimes depending upon other factors as well. The designer must develop a grasp of the concepts being presented rather than trying to follow the presentation in a step-by-step fashion.

b. The success of the initial system layout in meeting the actual bypassing requirements of the site will depend primarily upon the quality of the coastal processes study. THE IMPORTANCE OF THE COASTAL PROCESSES STUDY CANNOT BE OVEREMPHASIZED. It is the foundation upon which the bypassing system is designed. Designing a jet pump bypassing system without detailed information on items such as littoral transport vectors is not advised.

29. The principal purpose of the initial system layout is to provide an approximation of a bypassing system that can be refined and altered using the design procedures presented in PART III. A secondary purpose of the initial system layout is to identify problem areas at the site that may be independent of coastal processes or system pumping performance.

30. Certain guidelines are presented relating to the initial layout. These guidelines pertain to selecting the mode of operation, location, operating time, capacity, sizing of various elements, and certain other system features. It should be remembered that the guidelines are only aids and that significant modifications may be needed after

more detailed calculations are performed. In general, however, use of the guidelines should result in reasonable selections of components for the system.

System Purpose

31. There are two basic purposes for which any bypassing system can be designed:

- a. Reduction of navigation shoaling caused by littoral drift.
- b. Alleviation of undesirable beach changes caused by interruption of littoral drift.

The purpose that the system is to serve should be specifically identified so that requirements pertaining to that purpose can be satisfied. For example, a bypassing system whose purpose is to reduce channel maintenance will be designed, installed, and operated so as to bypass material causing shoals in the navigation channel. On the other hand, a system whose purpose is to provide periodic nourishment for a downdrift beach may be installed and operated quite differently.

32. The designer should be especially wary of attempting to design a "dual-purpose" bypass system; i.e., one that tries to reduce navigation shoaling and alleviate beach changes at the same time. Although the problems of shoaling and beach changes are often interrelated at a particular site, attempting to solve both simultaneously with one bypass system can be difficult for the following reasons:

- a. The interrelationship between the two problems is often far more complex than it appears.
- b. The optimum approach to solving one of the two problems with a bypass system can be very different from the optimum approach to solving the other problem.

The end result of such a compromise design will often be a bypass system that solves neither problem very well. A better approach is to design the system to help solve one problem only. Then, at the end of the design process, review the projected effects of the system on the other problem. Many times it will be found that a system designed for one problem will have significant beneficial effects on the other as well.

The review may also suggest some modifications to the system design that would aid in solving the other problem without affecting performance on the primary problem.

Mode of Operation

33. A jet pump bypassing system has two possible modes of operation:

a. Removal of littoral materials from a deposition area.

b. Interception of moving littoral drift.

In making the initial system layout, one of these two modes should be selected as the primary mode of operation and the system designed accordingly. Generally speaking, mode a is preferable to mode b, all other factors at a site being equal. A system designed for mode a will probably be of smaller capacity and consequently cost less. The deposition area will provide a trap for littoral drift moving at high rates, allowing the accumulated drift to be bypassed later during times of lower drift rates. This fact in turn implies a more regular operating schedule for the system. A system designed for interception, however, must be operated when drift is moving, whether day or night. The dependence of system configuration on mode of operation is illustrated in Figure 10, where the choice of interception as the primary mode indicated the use of fixed jet pumps located in the path of active transport movement. Sand moving along this path will (hopefully) fall into the jet pump craters and be bypassed by the system. An existing sheltered impoundment basin at the site, on the other hand, might be well suited to mobile jet pumps digging craters at different locations to maintain the basin as a trap for littoral drift. Figure 11 shows a system of this type. The possible negative effects of interception should be considered at this stage, also. If the system is effective in intercepting drift at a certain point, it may cause erosion immediately downdrift of that point. Serious stability problems with adjacent structures could be caused by such erosion.

34. The preceding two examples should not be taken as firm guidance. For instance, there is no reason why mobile jet pumps cannot

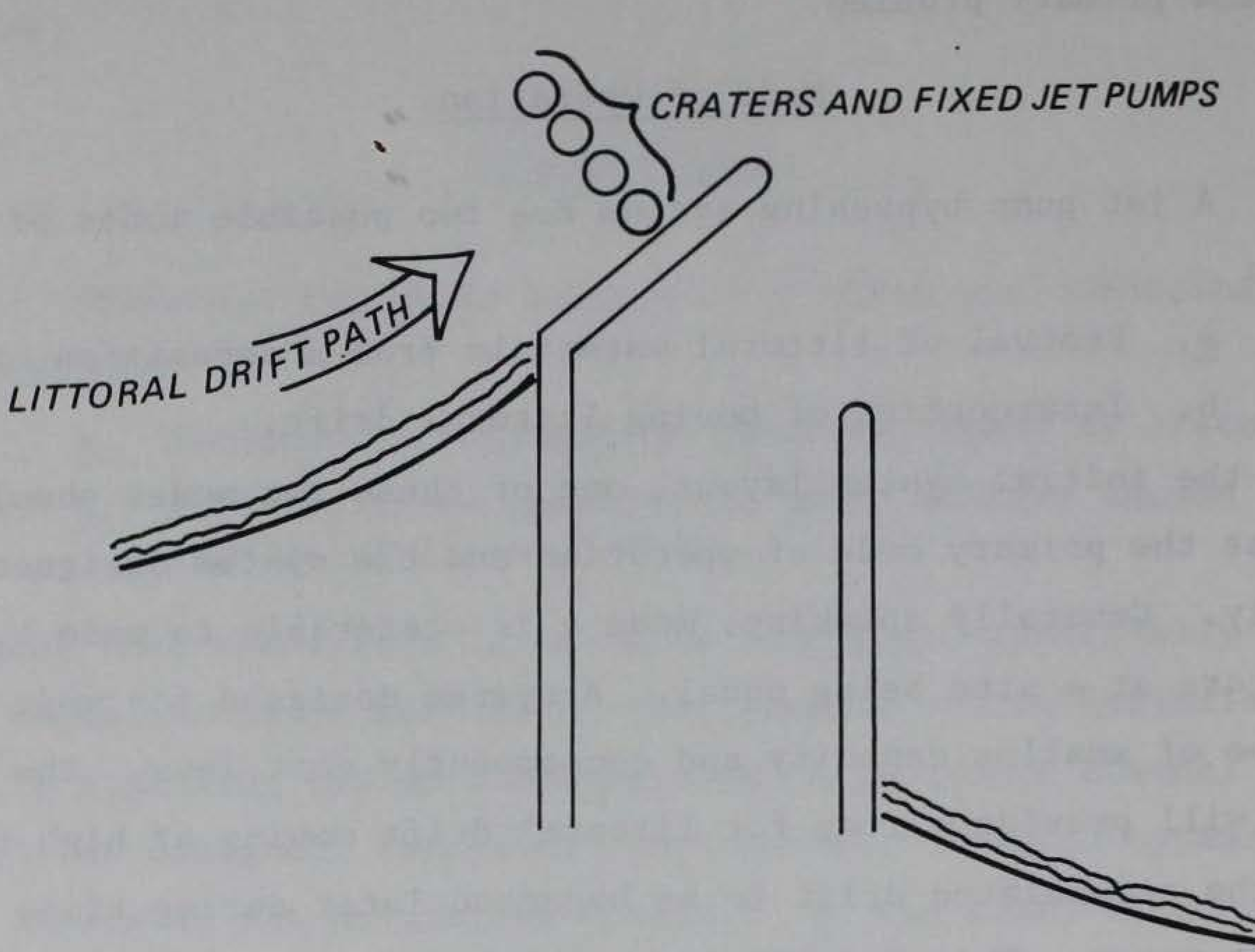

Figure 10. Fixed jet pumps in interception mode

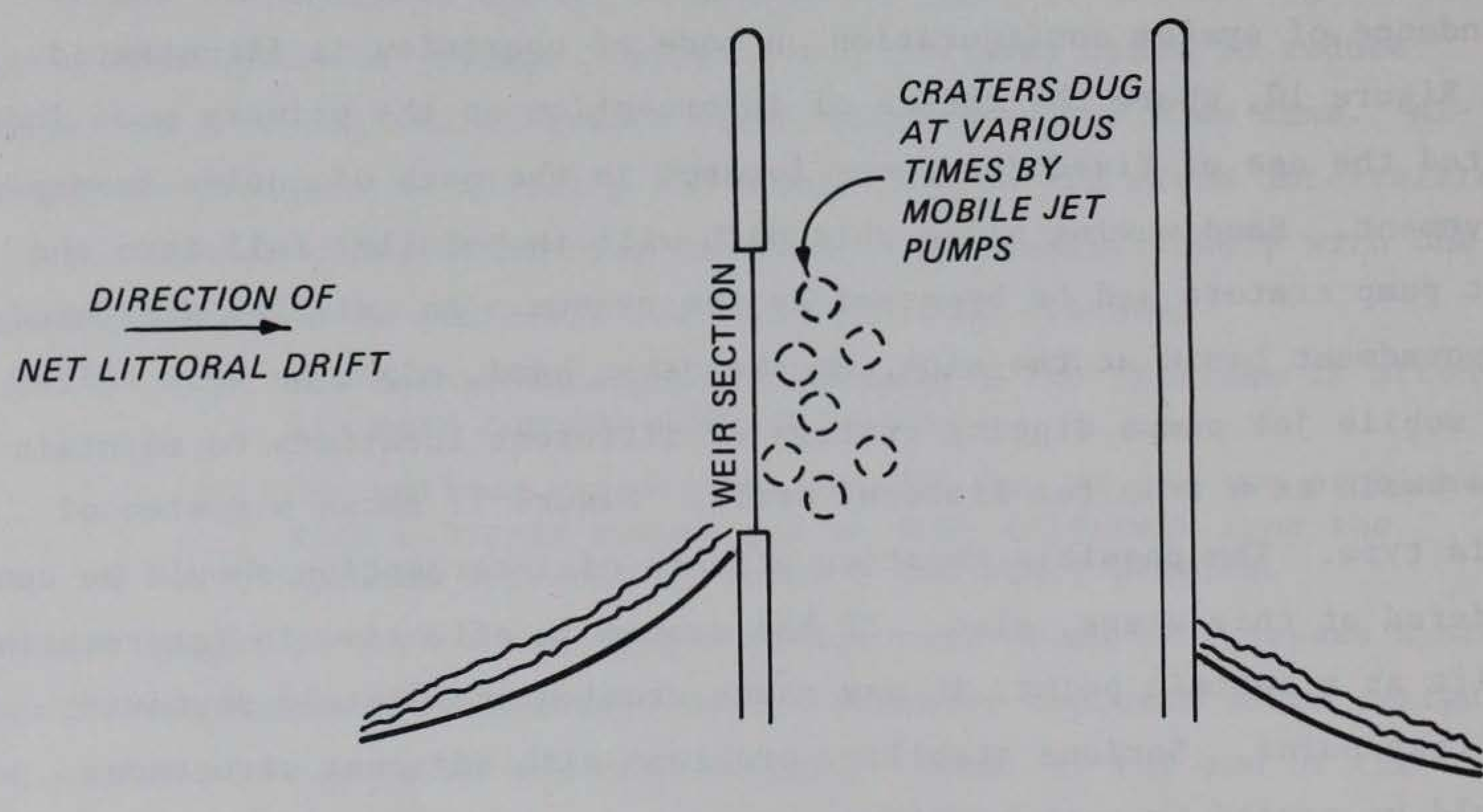

Figure 11. Maintenance of impoundment basin by mobile jet pump(s)

operate in an interception mode or why a field of fixed jet pumps cannot be placed in an impoundment basin. The final choice of mode/system combination must be dictated by the requirements and restrictions of each individual site.

Interaction with Structures

35. A number of general areas are possible for placement of the jet pumps, depending upon the purpose of the bypass system, results of the coastal processes study, and arrangement of structures at the site. The first two items have already been discussed. Some types of structures that may be found at a site and that pertain directly to bypassing are:

- a. Jetty.
- b. Offshore breakwater.
- c. Shore-connected breakwater.
- d. Weir section.

36. Figures 12-15 show some possible configurations of these structures at a site and possible locations for system jet pumps. THESE FIGURES ARE BY NO MEANS DEFINITIVE. Initial selection of jet pump locations should be based on consideration of a number of factors, including the following:

- a. Littoral transport vectors.
- b. Transport movement paths and deposition patterns.
- c. Mode of operation.
- d. Proximity to shore-based equipment.

However, Figures 12-15 indicate some locations that might prove feasible and that present themselves as a direct result of structural configurations. Hatched areas in the figures indicate regions within which jet pumps might be located.

37. An implied assumption in Figures 12-15 is the existence of a strongly predominant net drift direction. At many potential bypassing sites, however, the littoral drift may be approximately equal from both directions. In such cases it may be necessary to utilize jet pumps on

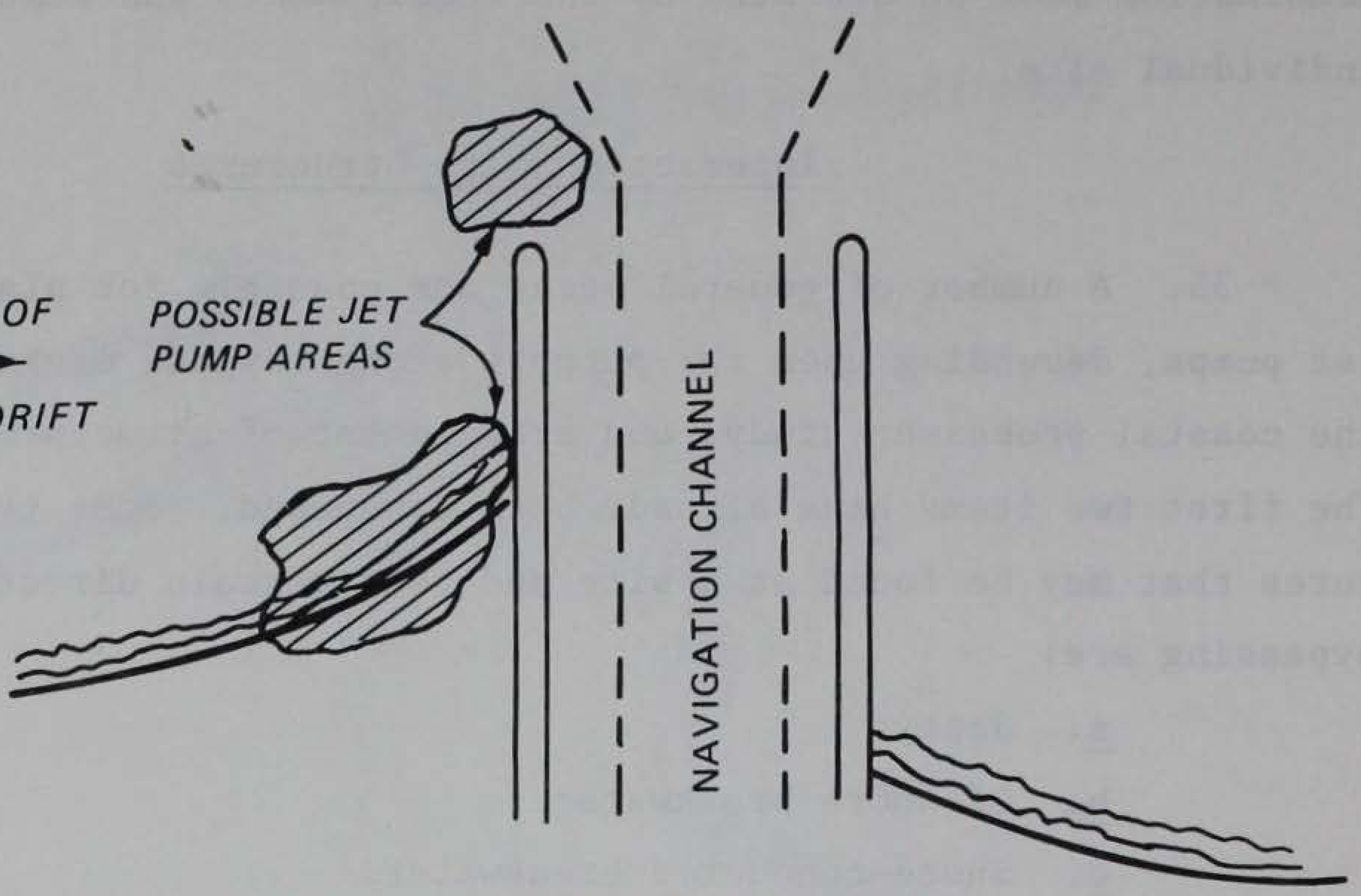

Figure 12. Jettied navigation channel

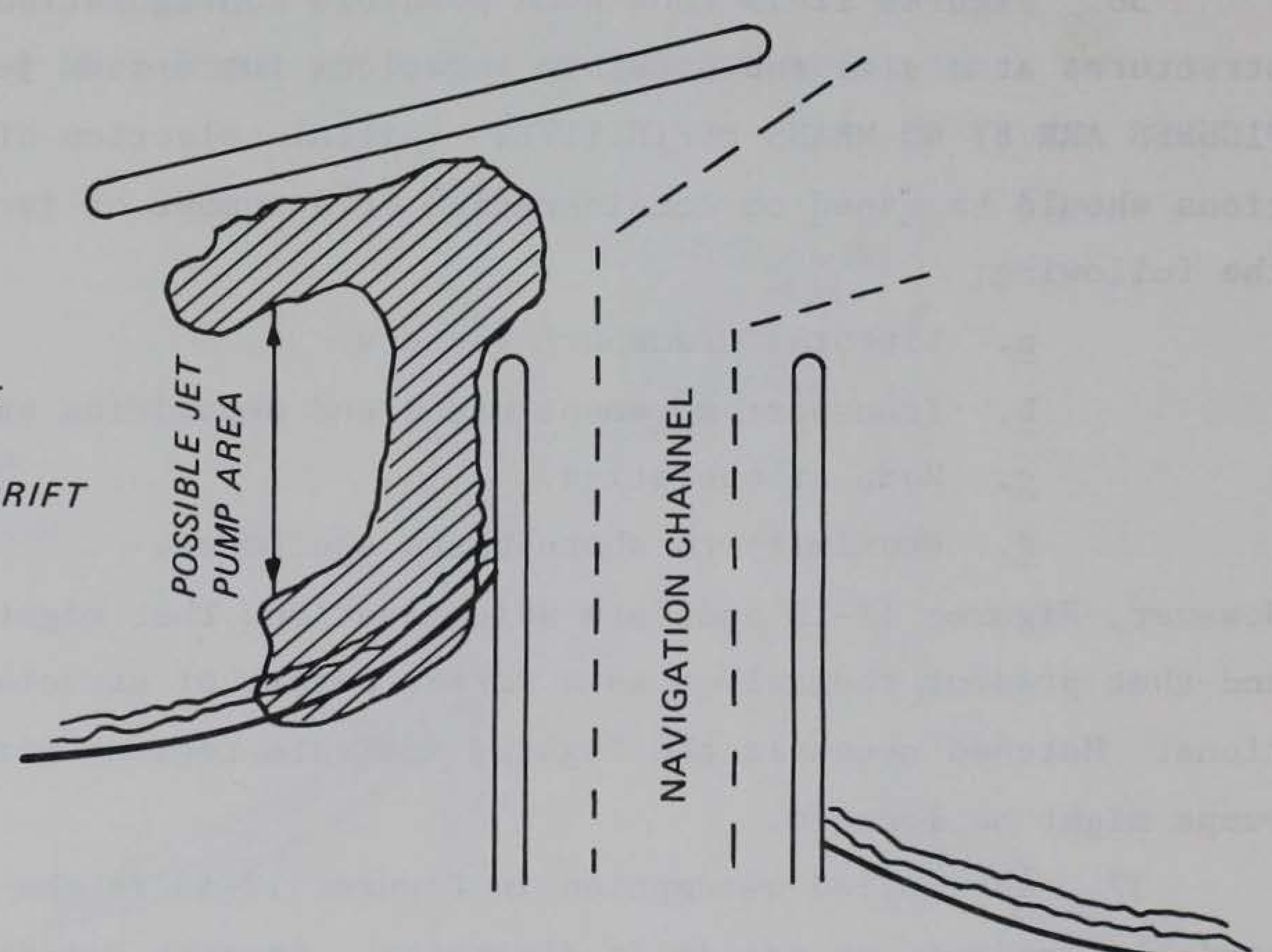

Figure 13. Offshore breakwater and jetties

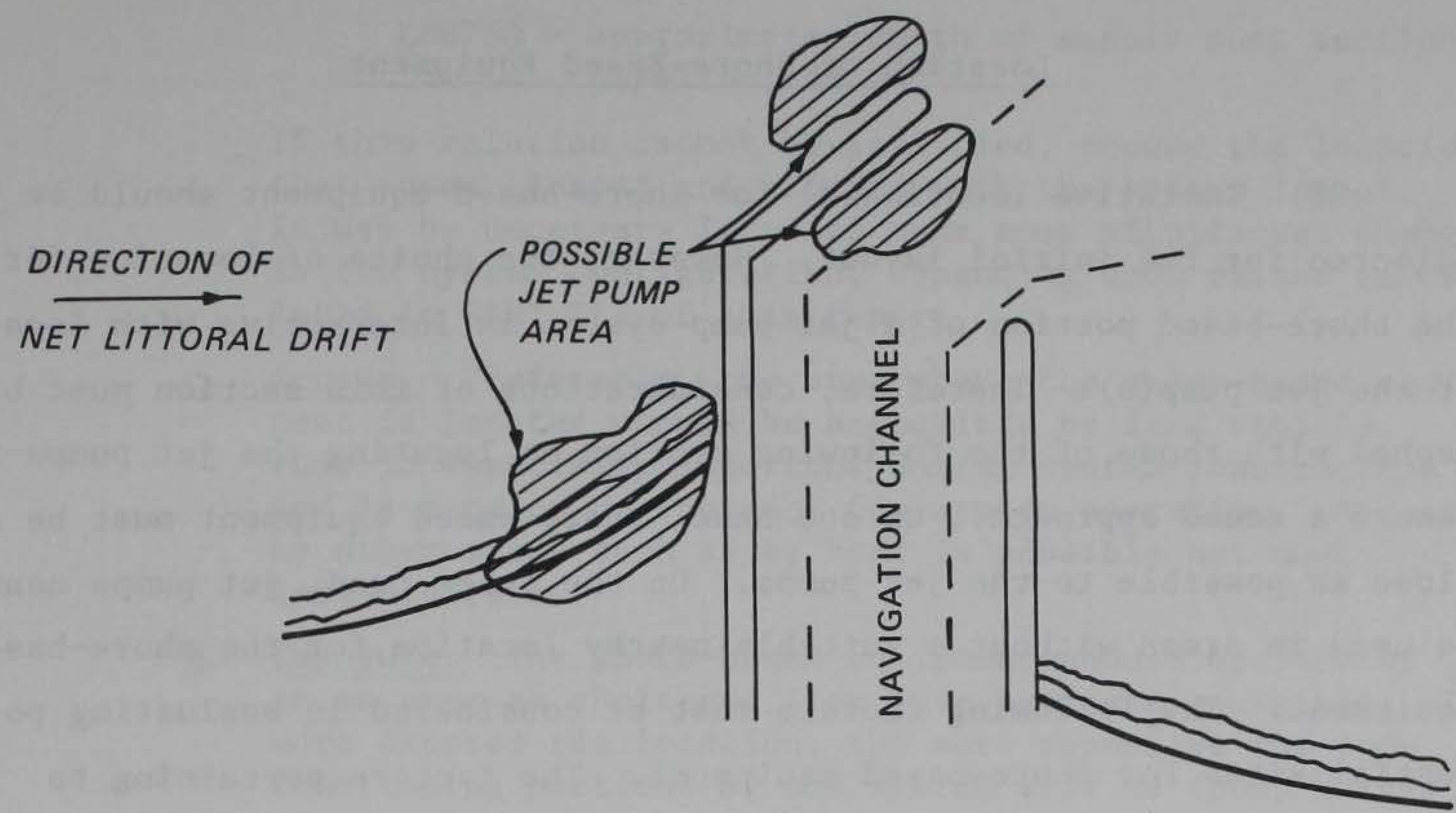

Figure 14. Shore-connected breakwater and jetties

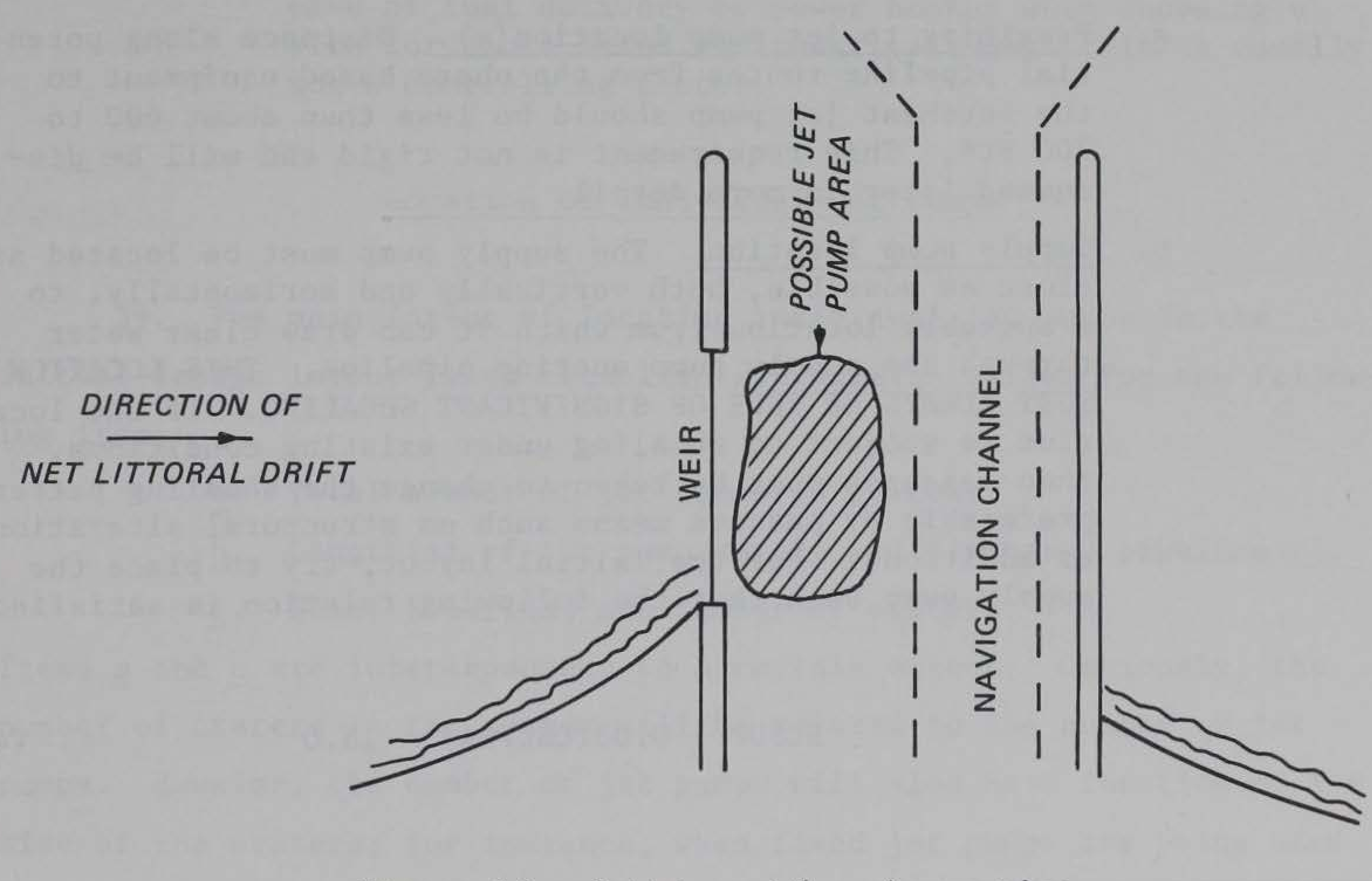

Figure 15. Jetties with weir section

both sides of the site to bypass littoral drift approaching from either direction.

Location of Shore-Based Equipment

38. Tentative location(s) for shore-based equipment should be selected for the initial layout. However, the choice of location for the shore-based portion of a jet pump system is interactive with location of the jet pump(s). Therefore, considerations of this section must be meshed with those of the following section on locating the jet pumps to assure a sound approach. On one hand, shore-based equipment must be as close as possible to the jet pumps. On the other hand, jet pumps cannot be used in areas without a suitable nearby location for the shore-based equipment. The following factors must be considered in evaluating potential sites for shore-based equipment. The factors pertaining to shore-based equipment are listed in approximate order of importance, although this will vary somewhat from site to site:

a. Proximity to jet pump location(s). Distance along potential pipeline routes from the shore based equipment to the farthest jet pump should be less than about 600 to 700 ft*. This requirement is not rigid and will be discussed later in more detail.

b. Supply pump location. The supply pump must be located as close as possible, both vertically and horizontally, to a suitable location from which it can draw clear water through the supply pump suction pipeline. THIS LOCATION MUST ALWAYS BE FREE OF SIGNIFICANT SHOALING. If the location is subject to shoaling under existing conditions, then measures must be taken to change the shoaling pattern preferably by passive means such as structural alterations or additions. For the initial layout, try to place the supply pump such that the following relation is satisfied:

$$\text{ELSUP} + 0.03(\text{LSUPSA}) \leq 15.0 \tag{4}$$

---

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

where

ELSUP = elevation of supply pump center line above mean low water, ft

LSUPSA = approximate length of supply pump suction pipeline, ft

If this relation cannot be satisfied, choose the location that comes closest and proceed with the system layout. It may be necessary later to make some significant changes in the system configuration, depending upon values calculated in PART III of this report.

c. Access. Preferably, the area where the shore-based equipment is located should be accessible by land vehicle. This is especially important during system construction and is a major convenience for system operation. Access by other means such as by boat is possible but much less desirable.

d. Exposure. The shore-based equipment should be located in an area as sheltered from wave action as possible. The more exposed the location, the more expensive the nonfunctioning portions of the system will be (pump houses, pipe anchors, etc.).

e. Fuel or power. Consideration should be given to the ease of fuel delivery or power hookup when choosing a site for shore-based equipment, although this is usually not a controlling factor.

Location of Individual Jet Pumps

39. The main intent of locating individual jet pumps in the initial design layout is to establish approximate values for the following items:

a. Total number of jet pumps in system.

b. Length(s) of jet pump supply and discharge pipeline(s).

c. Size, location, and number of craters.

Items a and c are interdependent to a certain extent. Obviously, the number of craters in the system will be related to the number of jet pumps. However, the number of jet pumps will also be a function of the size of the craters; for instance, when fixed jet pumps are being used to cover a certain area with craters. In such case, the larger the craters, the fewer jet pumps are needed. For the initial layout, craters can be assumed to be conical in shape, with relative dimensions as shown in Figure 16.

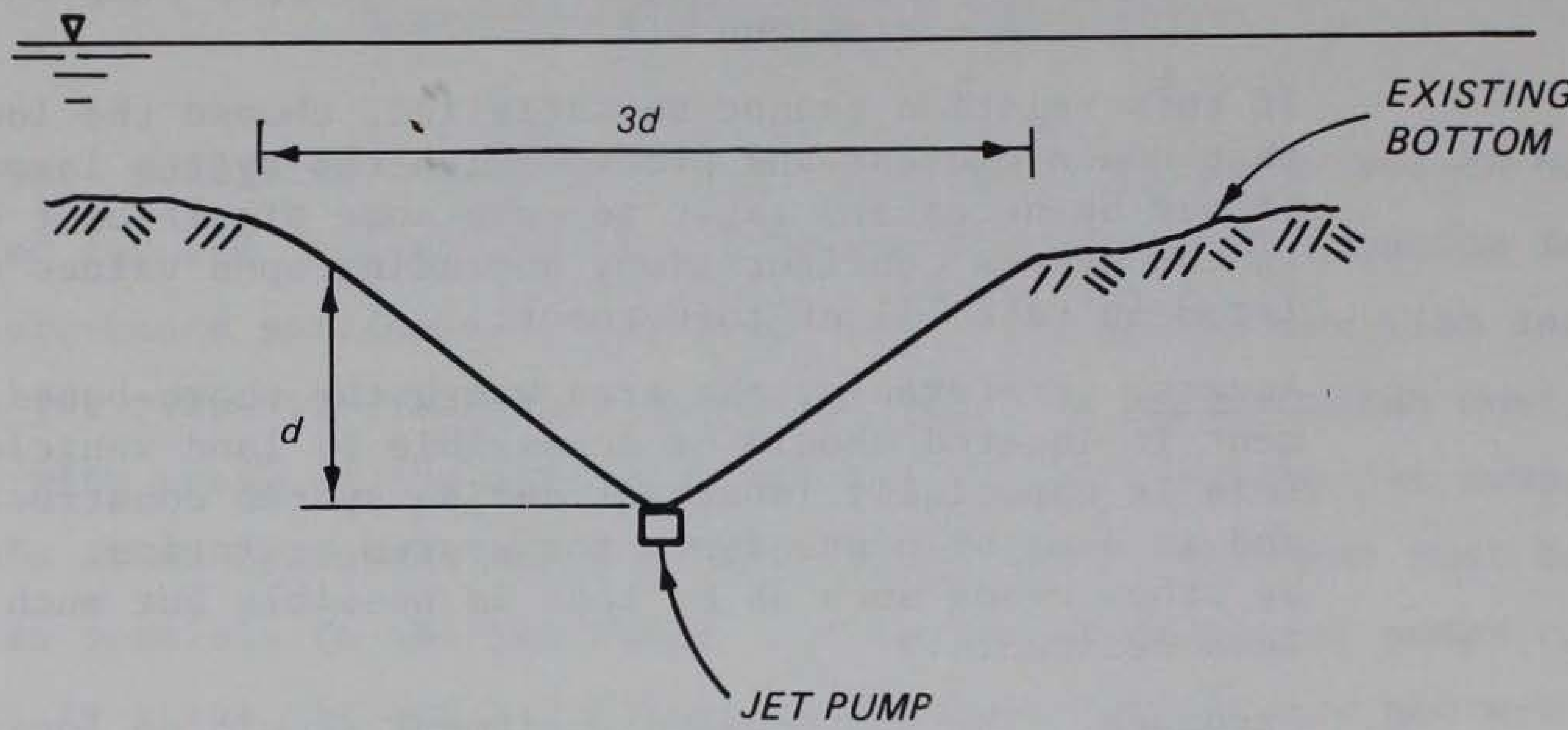

Figure 16. Suggested design crater dimensions

40. The depth, d , of the jet pump below the existing bottom is limited by several factors. A practical maximum is approximately 25 ft, although theoretically no real limit exists. The presence of hard or cohesive strata will limit d to the depth at which they begin. If such strata occur within 5 or 6 ft of the existing bottom, the applicability of jet pumps at that location is doubtful. Also, the proximity of a particular jet pump to rubble-mound structures such as jetties or breakwaters imposes an indirect limit on d at that location. In such a case, placement of the jet pump too close to the structure may result in localized undermining of the structure foundation. Conversely, if the jet pump is placed too far away, a significant portion of the littoral transport may move past the system next to the structure face. A rule of thumb to use for initial jet pump location adjacent to a structure is shown in Figure 17. This rule is based on an isolated jet pump adjacent to a structure. A group of such jet pumps might pose a greater threat to structural stability. The possible stability effects of such a group should be investigated thoroughly on a case-by-case basis.

41. For mobile jet pumps, the term "location" implies determining the area in which each jet pump will operate. The following guidelines

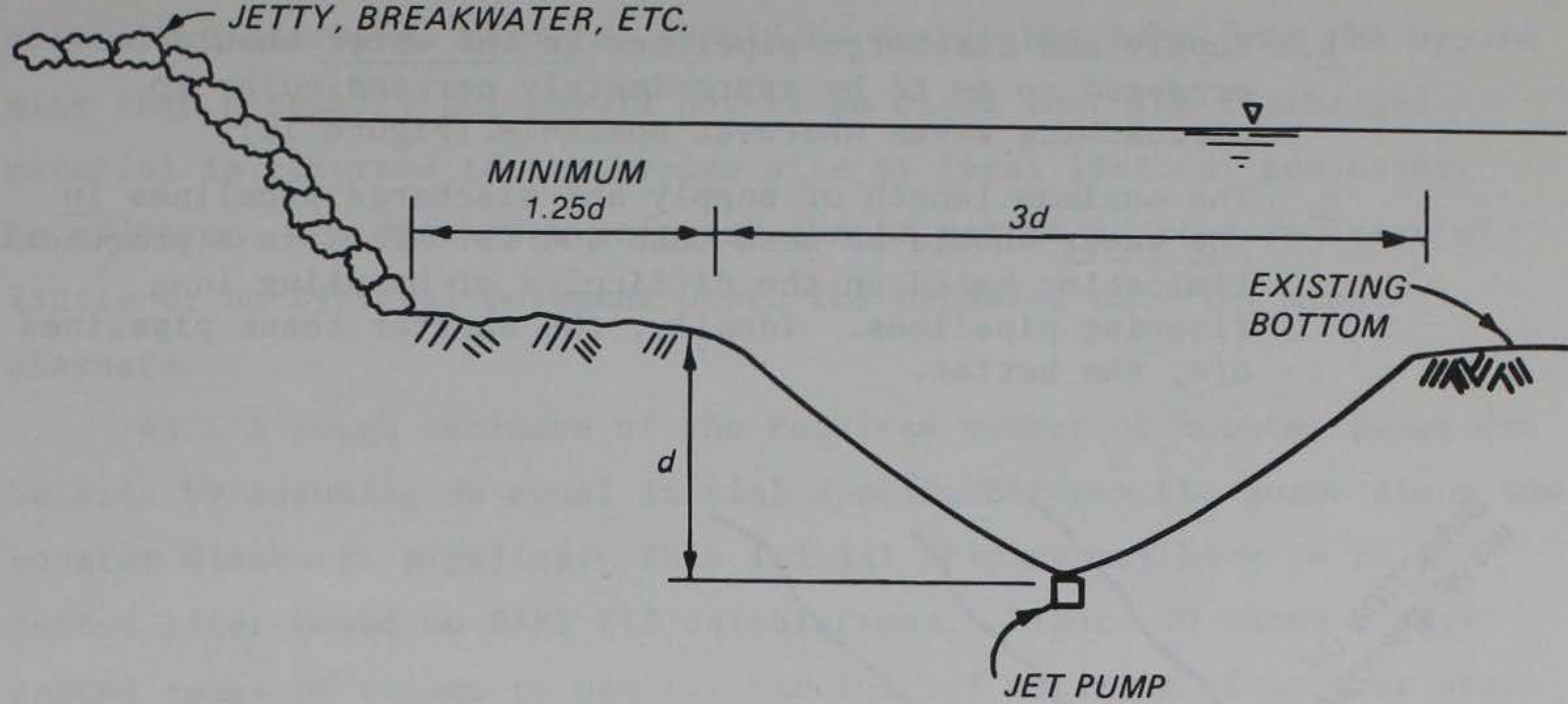

Figure 17. Suggested design dimensions for jet pump location adjacent to structure

should be kept in mind in mobile pump layout:

a. Mobile jet pumps are moved much more easily along an arc than back and forth along a radius (Figure 18). The latter type of movement usually involves lengthening or shortening the supply and discharge pipelines.

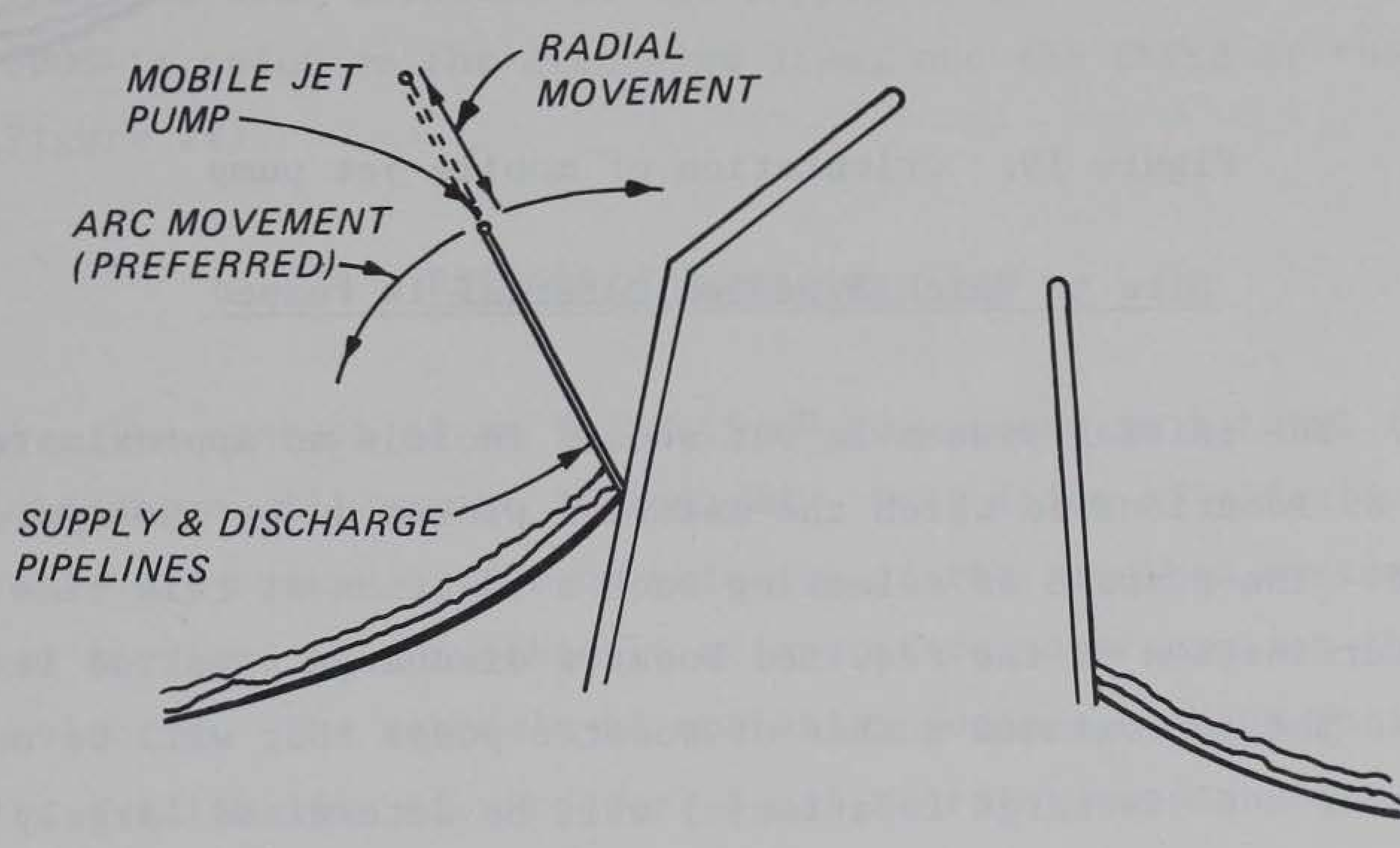

Figure 18. Movement of mobile jet pump

b. Supply and discharge pipelines in the water should be arranged so as to be approximately perpendicular to approaching waves wherever possible (Figure 19).

c. The maximum length of supply and discharge pipelines in the water should be less than 400 ft. This is a practical limitation based on the difficulty of handling long floating pipelines. Ideally, the shorter these pipelines are, the better.

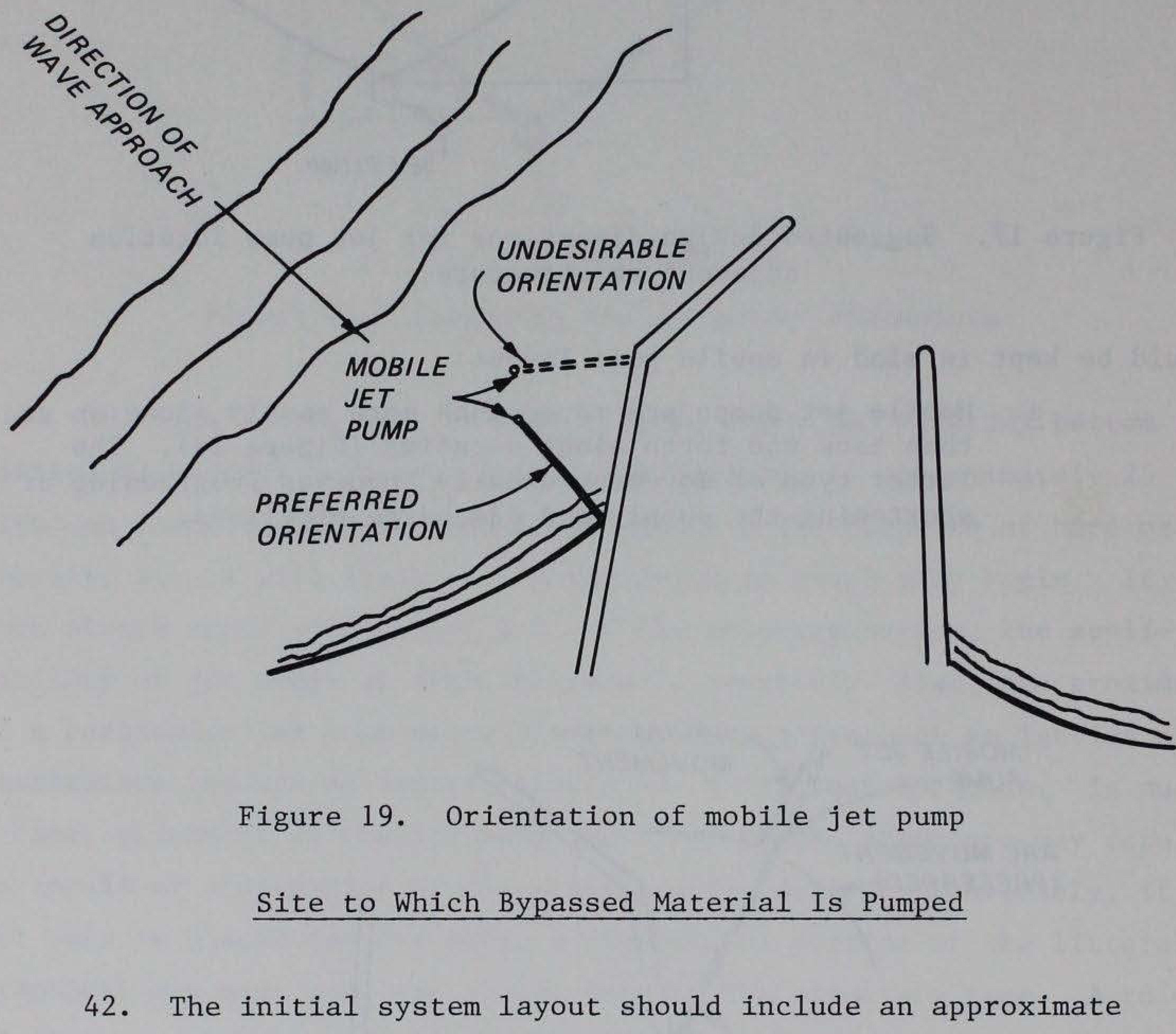

Figure 19. Orientation of mobile jet pump

Site to Which Bypassed Material Is Pumped

42. The initial system layout should include an approximate location or locations to which the material picked up by the system will be pumped. The purpose of selecting such a location at this time is to allow determination of the required booster discharge pipeline length, as well as the approximate number of booster pumps that will be needed. Selection of the discharge location(s) will be determined largely by the information gathered in the coastal processes study, the purpose of the bypassing system, and special requirements and restrictions of the

site. The discharge point(s) should be no farther away from the bypass site than necessary but should not be so close that the discharged material is returned to the bypass site by local littoral processes. In addition, the discharge point(s) should not be located in areas of little or no littoral movement where the bypassed material might stagnate.

43. A rough estimate of the required number of booster pumps can be made by assuming an equal initial spacing between the pumps along the booster discharge pipeline. This initial spacing may have to be adjusted later based on PART III calculations. Figure 20 shows a suggested range of values to use for the initial estimate of booster spacing as a function of the median size, or d_{50}, of the sediment to be bypassed. The designer should choose a value from this figure that falls in the shaded area for the applicable sediment size, then use this value in laying out the booster system. For example, suppose the sediment to be bypassed has a d_{50} of 0.20 mm. Based upon the physical layout of the site, the designer might then choose an initial booster spacing of, say, 3000 ft. If the total discharge line length is 9000 ft, the inital system layout will then include three booster pumps. The first would be located as close as possible to the jet pump(s) (usually at the same location as the supply pump). The second would be at the 3000-ft point on the discharge line, and the third at the 6000-ft point (Figure 21).

Effective Operating Time

44. The concept of an "effective" as opposed to a total time of system operation will now be introduced. Definition of effective time of operation is necessary for computation of the required system capacity. This step requires that a schedule of operation to accomplish the bypassing be selected. The schedule of operation depends on many factors including availability of manpower, local restrictions on operation of the system, availability of material to be bypassed, and other factors that may be peculiar to the site such as ice during parts of the year.

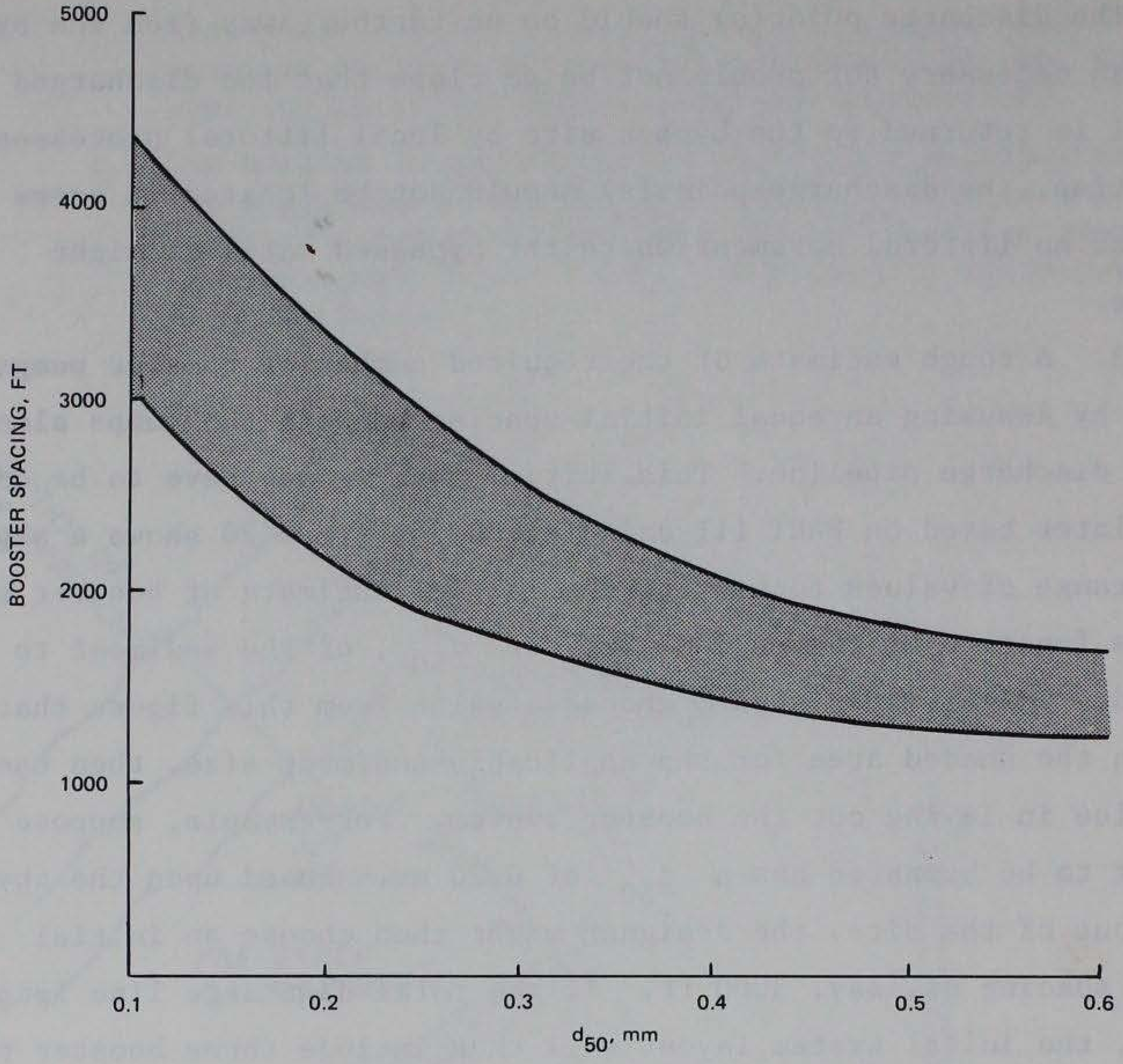

Figure 20. Initial estimate of booster station spacing as a function of sediment size

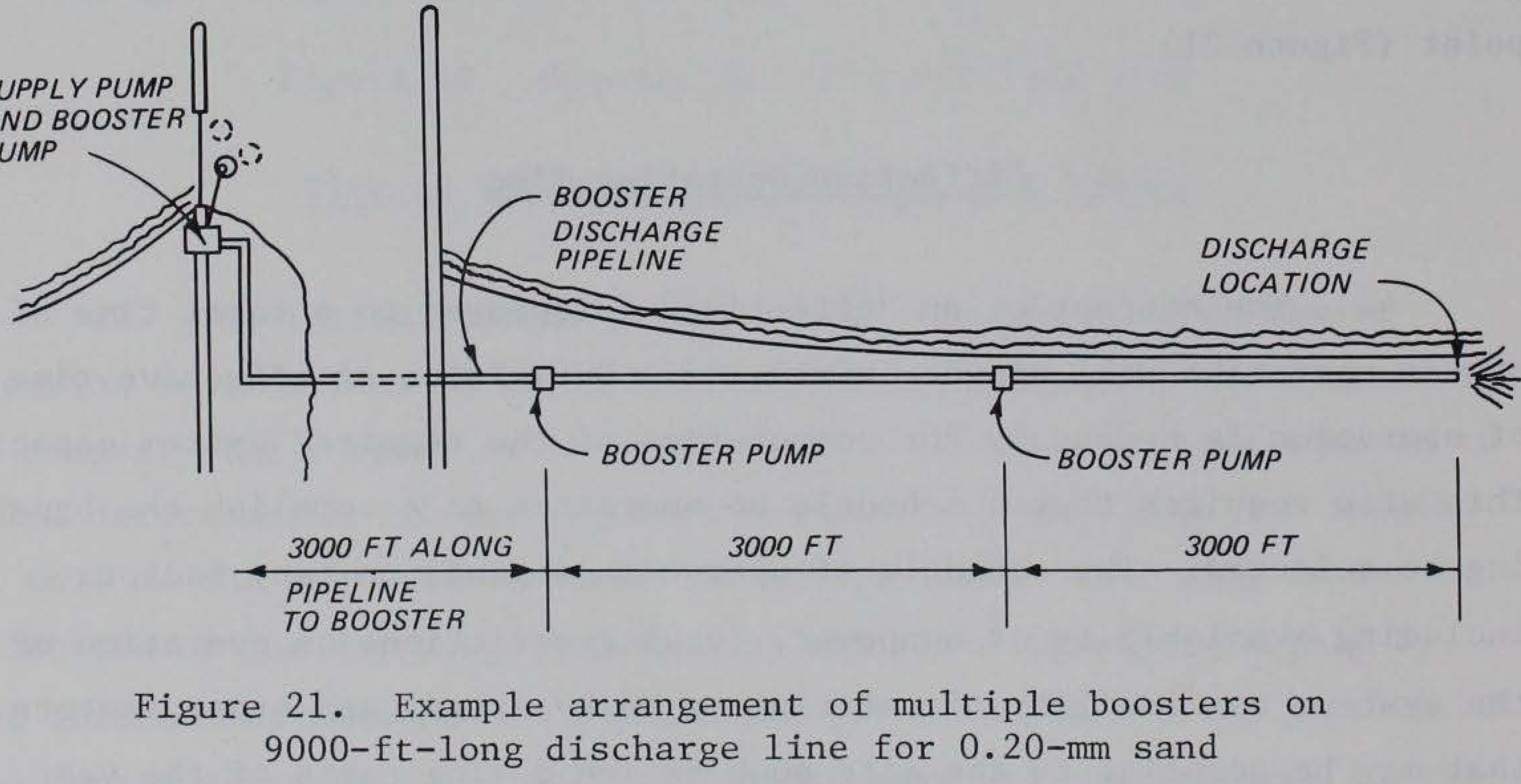

Figure 21. Example arrangement of multiple boosters on 9000-ft-long discharge line for 0.20-mm sand

The basic schedules that should be considered are:

Daily: Operation for a regular period each day on a 5- or 6-day-per-week basis.

Intermittent: Operation only when conditions are such that bypassing is needed. This means that the system may be idle for days at a time and may be operated 24 hours a day during other periods.

Either of the above two schedules can be employed year-round, or only on a seasonal basis, or as a mixture of the two. For instance, it might be decided to operate a system on a daily basis during times of the year when drift rates are high, and on an intermittent basis at other times.

45. The total operating time is the number of hours per year when personnel are present and the system could be in operation. The effective operating time is defined as the number of hours per year that the bypassing system is actually pumping sand. The effective time of operation can be approximated by estimating the number of working days per year, multiplying by the operating hours per day to get the total operating hours per year, and correcting this value for work or operational interruptions. A system of correction factors is presented below to assist in determining an effective operating time.

46. The correction factor for interruptions due to system repair and replacement is applicable to both daily and intermittent operation but should be less for the latter. Intermittent operation should allow a higher level of preventive maintenance to be performed, reducing the frequency of repairs. No standard correction factor is available to apply to jet pump bypassing systems, but a reduction in total operating time of 10 to 15 percent was observed during the WES research program and appears to be a reasonable long-term average for daily operation. The system should perform with less downtime during early life, but may have more during later years.

47. Other work interruptions take many forms, but the most prevalent are jet pump suction blockages, temporary lack of littoral materials, and need to relocate mobile jet pumps. The reduction factor for suction blockages should be greater for sites with a high number of

shell fragments or cobbles or where sea grasses or debris are present. Mobile jet pumps also call for a higher correction factor than do fixed pumps. Factors for pump blockages should range from 5 percent for fixed pumps in relatively clean sandy shoals to 10 percent for mobile pump assemblies in clean sandy shoals to 20 percent for pumps in areas that have a high shell or cobble content or other debris. In general, fixed pumps are more susceptible to blockage by moving causes (seaweed, debris, etc.) while mobile pumps are affected by in situ causes (cobbles, for instance) and to a lesser degree by moving causes. A high incidence of blockages from in situ and moving causes may make frequent relocation of a mobile pump necessary.

48. Temporary lack of littoral materials is a situation that primarily affects fixed jet pump assemblies. In theory, a properly planned bypassing system will have littoral materials available for pumping at one location or another in the bypassing area throughout the period constituting the total operating time. However, there may be occasions when transport and deposition patterns and rates change enough to "starve" the system of littoral material. There is no set way of estimating this effect, but a factor of 5 percent might be applied to areas with known transport and deposition anomalies.

49. Relocation of mobile pump assemblies for reasons exclusive of suction blockages is a variable dependent on pumping rate, depth to which craters are dug, and rate of littoral material influx. When the pumping rate and the littoral influx rate to the crater are similar, the pump may require only occasional repositioning. When the influx rate is low and crater depth shallow, however, frequent movement of the pump may be necessary. Obviously, this is a highly variable situation, but a factor of 10 percent might be applied to mobile assemblies under average conditions as a first guess. A high anticipated incidence of pump movement might increase this factor to 15 or 20 percent.

50. The Effective Operating Time, EOT , in hours per year for the bypassing system can be determined from the relationship:

$$\mathrm{EOT} = (\mathrm{NOD} \times \mathrm{HD}) \left[1.00 - (\mathrm{RR} + \mathrm{PB} + \mathrm{ALM} + \mathrm{RMP})\right] \tag{5}$$

where

NOD = number of operating days per year

HD = number of working hours in an operating day

RR = correction factor for system repair and replacement ÷ 100

PB = correction factor for pump blockages ÷ 100

ALM = correction factor for absence of littoral materials ÷ 100

RMP = correction factor for relocation of mobile pump assemblies ÷ 100

51. Proper application of the factors presented here should result in a realistic estimate of the effective operating time for the bypassing system. This analysis shows that the effective operating time could be as little as 50 percent or less of the total operating time. If the effective operating time seems to be relatively low, it should be remembered that many dredging systems have similar characteristics. Hopper dredges may spend a large amount of time in transit to and from the discharge site, while cutter suction dredges have to cease operation to periodically move swing wire anchors or to allow vessels to pass in a navigation channel. If the dredging site is subject to significant wave action, floating dredge downtime may be further increased.

System Capacity

52. The short term relationship between the rate of littoral influx, the production capacity of the bypassing system, and the available storage volume at a site is given by the expression

$$Q_L(\Delta t) - STORE_{\Delta t} = EXC(EOT_{\Delta t}) \tag{6}$$

where

Q_L = average rate of net littoral influx to storage area(s) during interval Δt, cu yd/hr

Δt = a time interval of the bypassing season, hr; should be as short as possible consistent with available data

$STORE_{\Delta t}$ = storage volume available during interval Δt, cu yd

EXC = required capacity of bypassing system, cu yd/hr

$EOT_{\Delta t}$ = system effective operating time over interval Δt, hr

53. $STORE_{\Delta t}$ is not a fixed quantity, but is dependent upon factors such as the condition of the storage area at the start of Δt. Storage of littoral material in one form or another takes place at all littoral barriers. Often, it is this very storage or a portion of it that makes bypassing necessary. Evaluation of storage for bypassing purposes is complicated by the fact that only a part of the total storage at a site may be available for transfer by a bypassing system. Material stored in locations not reachable by the system cannot be included in the system analysis. Also, because of the variation of littoral rates during the year, the system may temporarily remove all the material within the effective storage area. This temporary removal may result in deepening of the adjacent bottom and localized slumping into pumping areas. This readjustment of the adjacent area must occur without endangering nearby structures.

54. For purposes of the initial layout, areas that are potentially within reach of a bypassing system should be identified as storage areas. As a rule of thumb, all areas below mean high water and located such that the total length of the jet pump discharge line will not exceed 600 to 700 ft can be considered to be potentially within reach of a jet pump bypassing system. The figure of 600 to 700 ft is given here for initial estimating purposes, not as an absolute limit. The range of mobile jet pumps will be determined more by the practical limitations of handling long reaches of floating pipelines and may therefore be less unless special measures are taken. For fixed jet pumps, where floating components are not a problem, the range of the system is a function of hydraulic and power considerations only. In most cases, however, the designer will find rapidly increasing power requirements if the jet pump discharge lines become too long. Areas such as jetty fillets, offshore bars, shoals, and prepared impoundment areas should be considered for use as potential storage areas. Past surveys of these areas together with estimates from the coastal processes study of transport vectors should be analyzed to determine: (a) that littoral transport does in

fact enter each area, and (b) what deposition patterns occur and how these patterns change with time. Only after this sort of analysis has been performed can a reasonable value of storage capacity (the amount of material that the area is capable of retaining at any one time) be determined.

55. Q_L as used in Equation 6 is an average net influx from all directions. In other words, it is the average rate at which littoral material moves into the storage area and remains there during Δt. The maximum value for Q_L is the average gross transport rate from all directions into (but not out of) the storage area during Δt. Use of this value would be based on the assumption that the storage area "traps" all littoral material which moves into it. In some instances, total trapping may not be the case, and a portion of the gross influx will continue on through the storage area. This might occur during periods of high wave activity or strong currents. The portion that moves through would not be available for bypassing; consequently, less storage and/or a smaller system production capacity would be indicated. Operation of the bypass system in the storage area will affect the value chosen for Q_L. Usually, the trapping capability of the storage area will be increased due to the craters formed by the system jet pumps. The amount of this increase will depend on variables such as the number, size, location, and condition of the craters.

56. An earlier section of this report (paragraph 50) outlined how to determine EOT, the Effective Operating Time per year. The same techniques can be applied to determining $EOT_{\Delta t}$ for a particular time interval.

57. Once $STORE_{\Delta t}$, Q_L, and $EOT_{\Delta t}$ have been determined, Equation 6 can be used in a rearranged form to determine various values of EXC, the system production capacity:

$$EXC = \frac{Q_L(\Delta t) - STORE_{\Delta t}}{EOT_{\Delta t}} \qquad (7)$$

Equation 7 can be incorporated into many possible schemes for arriving at a final design value of EXC . The following approach is given only as an example of such a scheme:

a. For a Δt corresponding to a particular time interval of the year, a value or possible range of values for Q_L is determined from the coastal processes study, keeping in mind the discussion in paragraph 53.

b. $EOT_{\Delta t}$ is calculated, using the considerations described in paragraphs 44-51. Several values may be possible.

c. The storage capacity of the storage area(s) is determined (see paragraphs 53 and 54). If the storage capacity varies during the year, this effect should also be taken into account, since this calculation is for a particular time of the year.

d. Reasonable estimates are made of what range of initial conditions might exist in the storage area(s) at the beginning of the Δt interval. The bounds of this range are that the storage area is either completely full or completely empty. However, the actual condition or range of conditions will probably lie in between these bounds.

e. A range of $STORE_{\Delta t}$ values is calculated, based upon the range of initial conditions determined in paragraph d. For any particular initial condition,

$$STORE_{\Delta t} = STCAP - STIN \tag{8}$$

where

STCAP = storage capacity of storage area, cu yd

STIN = initial condition of storage area; i.e., volume of material already there at beginning of interval Δt , cu yd

f. Reasonable combinations of Q_L , $EOT_{\Delta t}$, and $STORE_{\Delta t}$ are determined. Although a range of values for each variable may have been identified, it does not necessarily follow that each value within the range of a particular variable can occur in combination with all values of the other two variables. Also, some combinations of the three variables may be more likely to occur than others.

g. Equation 7 is solved using the combinations determined in paragraph f. The values of EXC thus calculated are recorded.

h. Steps a through g are repeated for other Δt intervals occurring at other times of the year. The result is a number of possible values for EXC . From these, a design value or set of values is chosen to use in sizing the system components. The criteria for choosing a value or values for EXC will have to be determined by the designer. One criterion, and possibly a wasteful one in terms of system construction costs, would be simply to use the largest value of EXC. Another method might involve constructing a frequency distribution graph of EXC, plotting the relative frequencies of occurrence of classes of EXC values based on data from the above calculations. Then, from this graph, some value or values of EXC would be chosen corresponding to predetermined frequency criteria. Inherent in such a method is the understanding that on occasion, the storage capacity of the system will be exceeded.

58. Again, it is emphasized that the preceding approach is given only as an example. The important aspect of this section of the report is to understand the basic concepts of effective operating time and storage, and how their interaction with littoral drift rates should determine the design capacity of the system.

Considerations for Interception Type of System

59. Occasionally, the designer may find that little or no storage capacity is available at the site, and that the bypass system must function by intercepting sand which is in continuous motion. In this situation, of course, the concept of storage does not apply in determining a design value of EXC. The relationship expressed in Equation 6 then becomes simply:

$$Q_L(\Delta t) = EXC(EOT_{\Delta t}) \tag{9}$$

60. Q_L as used in Equation 9 takes on a somewhat different character than for Equation 6. None of the littoral material remains in the vicinity of the system; it is either all caught by the jet pump(s) or else moves past the system and is gone, presumably forever. Therefore, Q_L is now simply the rate at which littoral material approaches the system during Δt. It is imperative that Q_L values be determined for Δt intervals which are as small as possible. The ideal

situation would be to have estimates of hourly rates of Q_L . The major concept here, however, is that the bypass system capacity is a direct function of the littoral drift rate for an interception type of system.

Distribution of System Capacity

61. The number of jet pumps to be operated simultaneously should be decided in the initial system layout. Factors such as the system mode of operation, littoral transport vectors, and required system capacity must be considered. The size of jet pumps employed in the system will have an influence as well. WES experience thus far with jet pump bypassing systems has indicated that two sizes of the Pekor center-drive jet pump* have pumping capacities which match the requirements of many bypassing situations. The manufacturer's designation of these sizes, the 4 × 4 × 6 and the 6 × 6 × 8, describes the nominal inside diameters of the suction, mixing chamber, and discharge, respectively. For each pump, the approximate range of pumping capacity suggested for use in this report is shown below.

Jet Pump	Pumping Capacity, cu yd/hr
4 × 4 × 6	Up to 100
6 × 6 × 8	Up to 200

62. The tabulated values given are intended only as guidelines and not guarantees. The actual pumping capacity depends on a number of site-specific conditions. Simply because a pump is capable of moving, say, 100 cu yd/hr, does not mean that it will be able to pump at that rate in a given situation. Final determination of jet pump size based on site conditions will be made in PART III of this report. However, the tabulated values will allow the designer at this stage of design to identify available options in the number of simultaneously operating jet pumps. For example, if a design value for EXC of 140 cu yd/hr has been selected, the designer might choose to operate one 6 × 6 × 8 jet pump at

* Manufactured by Pekor Iron Works, Columbus, Georgia.

a time with a capacity of 140 cu yd/hr. Or, he might elect to operate two 4 × 4 × 6 jet pumps simultaneously, each pumping 70 cu yd/hr. Depending on circumstances at the site, he might even investigate using three or more 4 × 4 × 6 jet pumps at a time, each with the appropriate pumping rate. KEEP IN MIND, HOWEVER, THAT THE BETTER SYSTEM WILL USUALLY HAVE THE LEAST NUMBER OF JET PUMPS OPERATING AT ONE TIME. IF THE JOB CAN BE DONE WITH FEWER JET PUMPS, DON'T USE MORE.

63. Once the number of simultaneously operating jet pumps has been determined, the required capacity of a single jet pump, EXC1 , should be estimated. This is actually a complex task if done rigorously, involving a series of iterative calculations for a pipeline network. One of the characteristics of a multiple jet pump system is that all other variables being equal, the capacity of each jet pump relative to the others will vary inversely with jet pump discharge pipeline length. For example, in Figure 22, jet pump #1 would have a greater capacity

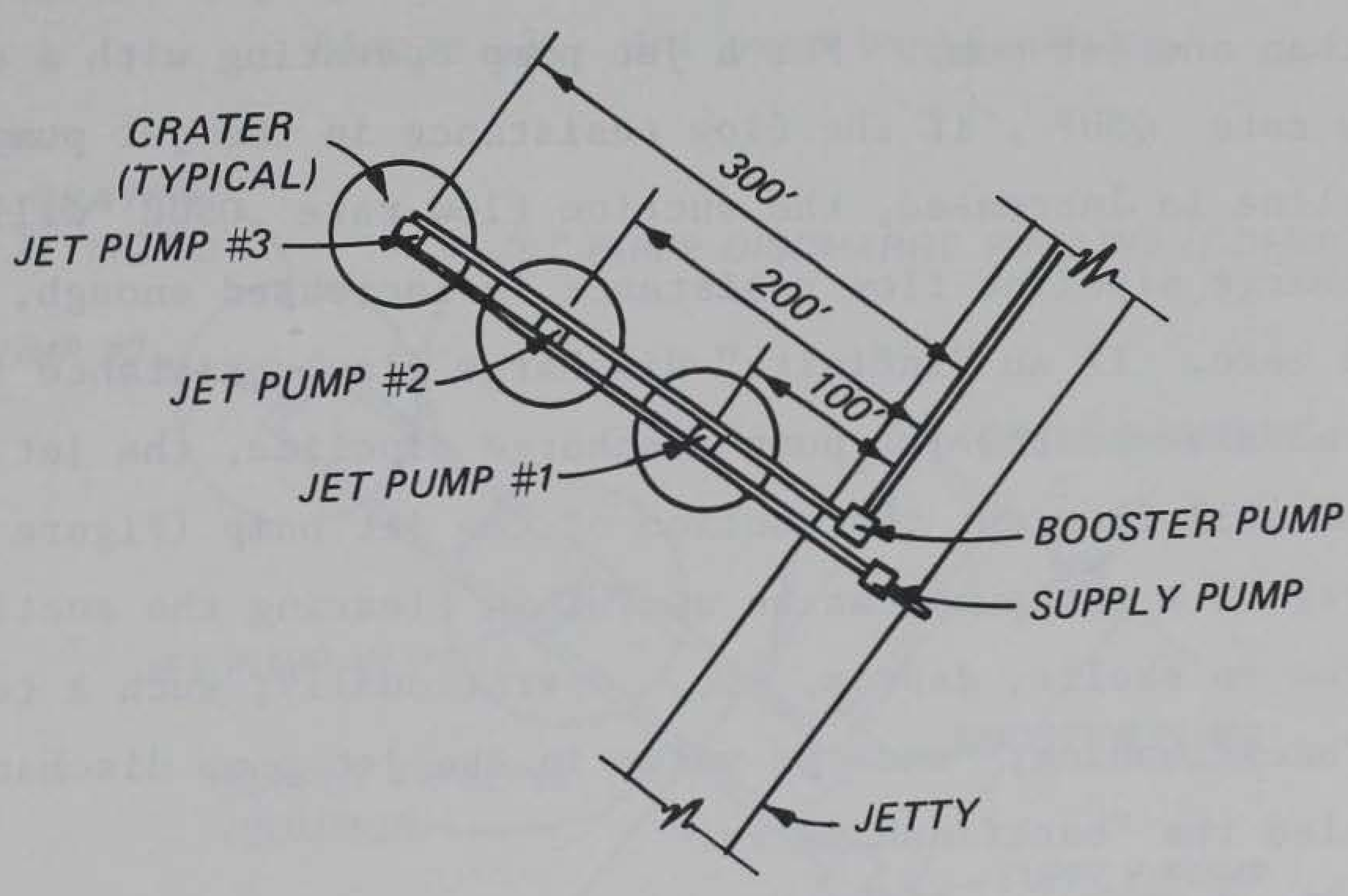

Figure 22. Example jet pump discharge pipeline lengths, multiple jet pump system

than #2, which in turn would pump more than #3. EXC1 can be approximated from the following simple relation:

$$\mathrm{EXC1} = \frac{\mathrm{EXC}}{\mathrm{NUM}} \qquad (10)$$

where NUM is the number of jet pumps operated simultaneously. However, the designer must remember that in a multiple system with different jet pump discharge pipeline lengths, it is extremely difficult to obtain exactly the same output from each jet pump. Also, it may be necessary, due to local transport vectors, for one jet pump to have a capacity in excess of EXC1 as calculated above. The point of all this is that a value for EXC1 should be chosen not calculated for a multiple jet pump situation, taking local conditions and requirements into account. In PART III of this report, the designer will be shown how this chosen value is used to arrive at a design for the complete multiple system.

Backflushing

64. Backflushing, an operational technique peculiar to jet pumps, must be discussed in the initial layout phase of system design, since it influences the layout and selection of discharge pipelines in systems with more than one jet pump. For a jet pump operating with a certain supply flow rate QSUP , if the flow resistance in the jet pump discharge pipeline is increased, the suction flow rate QSUC will decrease. If the discharge pipeline flow resistance is increased enough, QSUC will become zero. If an "infinite" discharge flow resistance is created by closing a valve in the jet pump discharge pipeline, the jet pump supply water will flow out the suction of the jet pump (Figure 23). This property of a jet pump can be useful in clearing the suction of blockages due to shells, debris, etc. Operationally, such a technique is called "backflushing," and the valve in the jet pump discharge pipeline is called the "backflush valve."

65. The influence of backflushing requirements on discharge pipeline layout is illustrated by Figures 24 and 25. Each figure shows a system with two jet pumps operated simultaneously. In Figure 24, the jet pumps share a common discharge pipeline, while in Figure 25 they have separate pipelines that join just before the booster pump. The common discharge pipeline in Figure 24 has one backflush valve, while each pipeline in Figure 25 has its own.

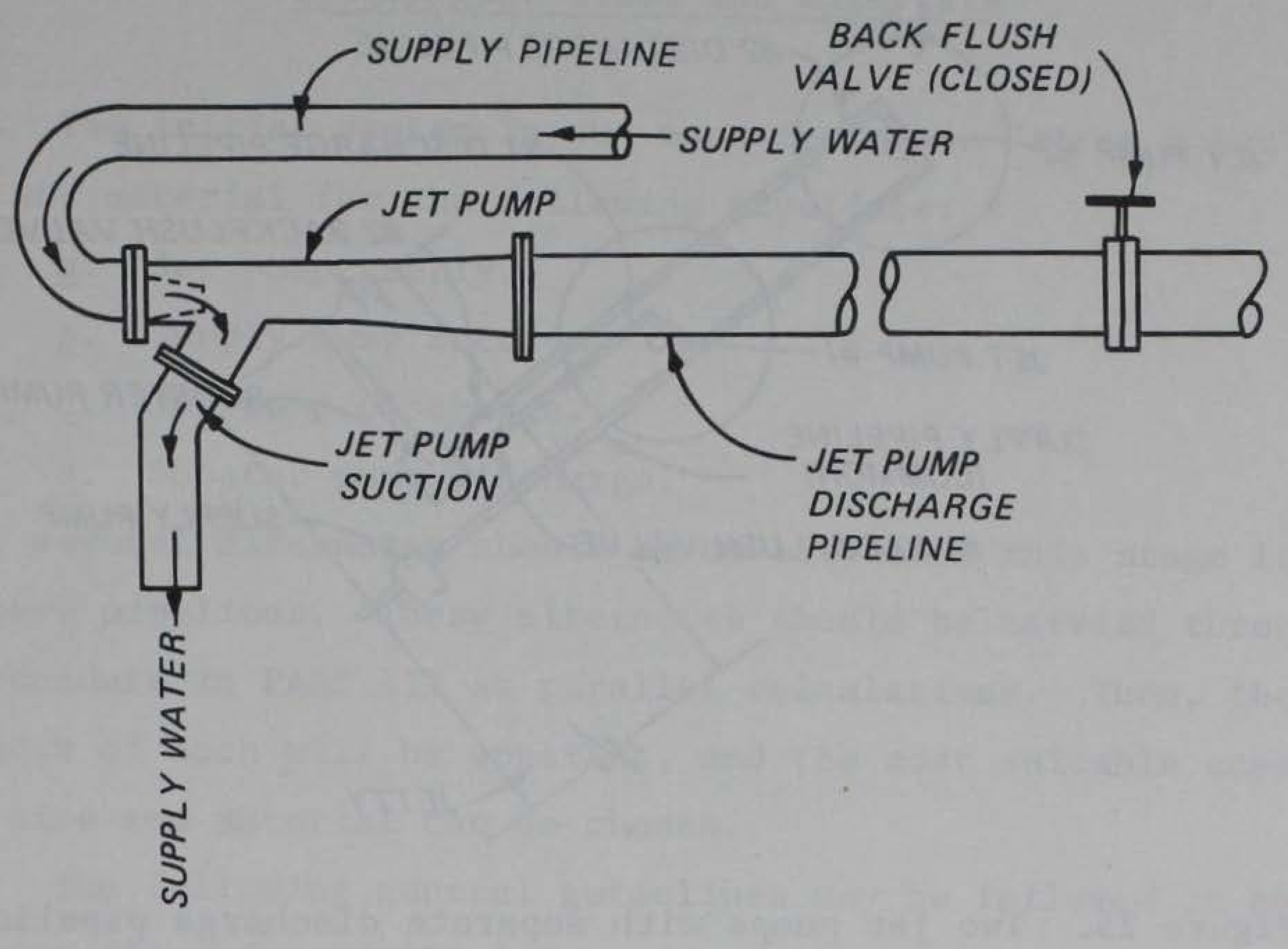

Figure 23. Jet pump backflushing

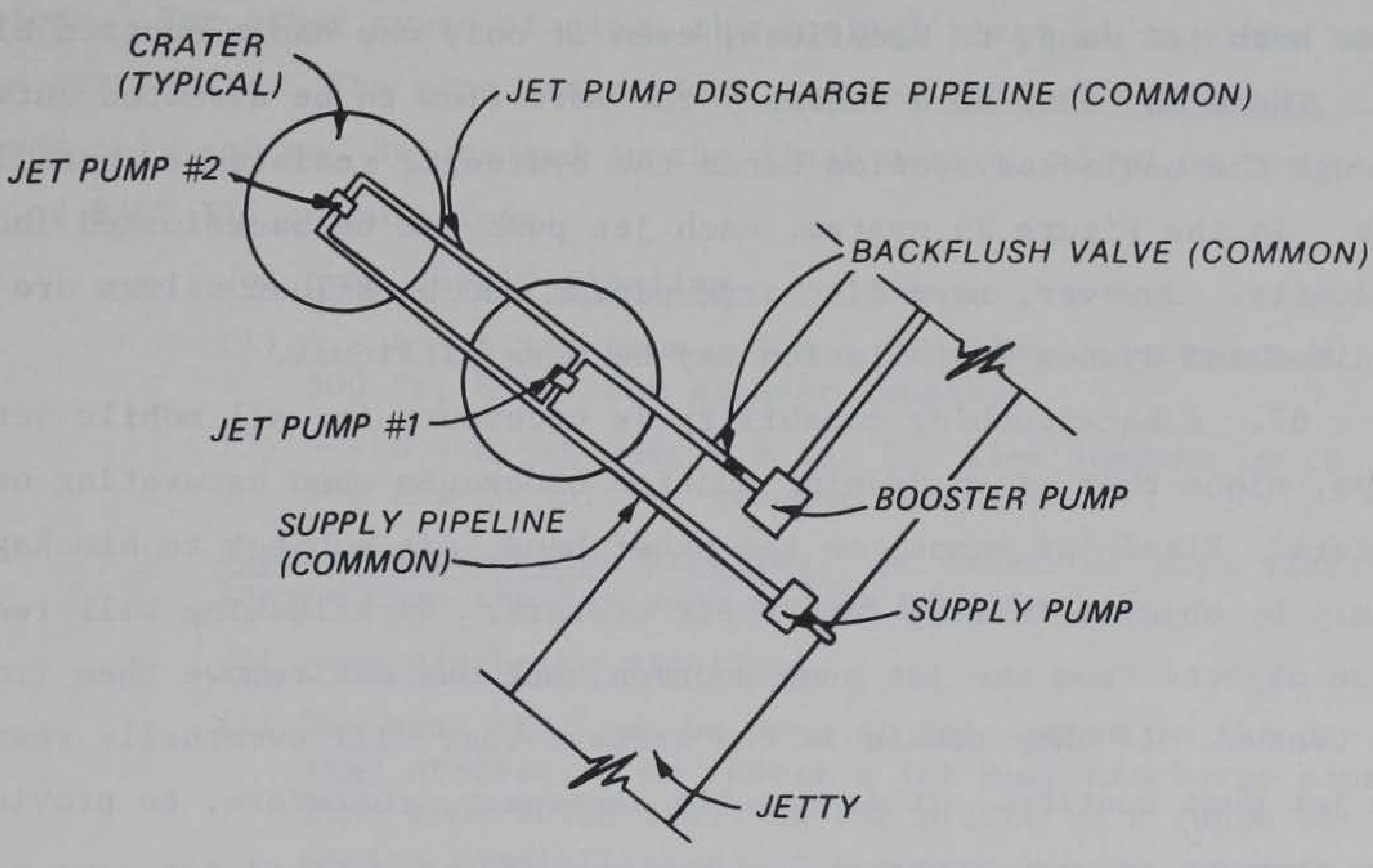

Figure 24. Two jet pumps with common discharge pipelines

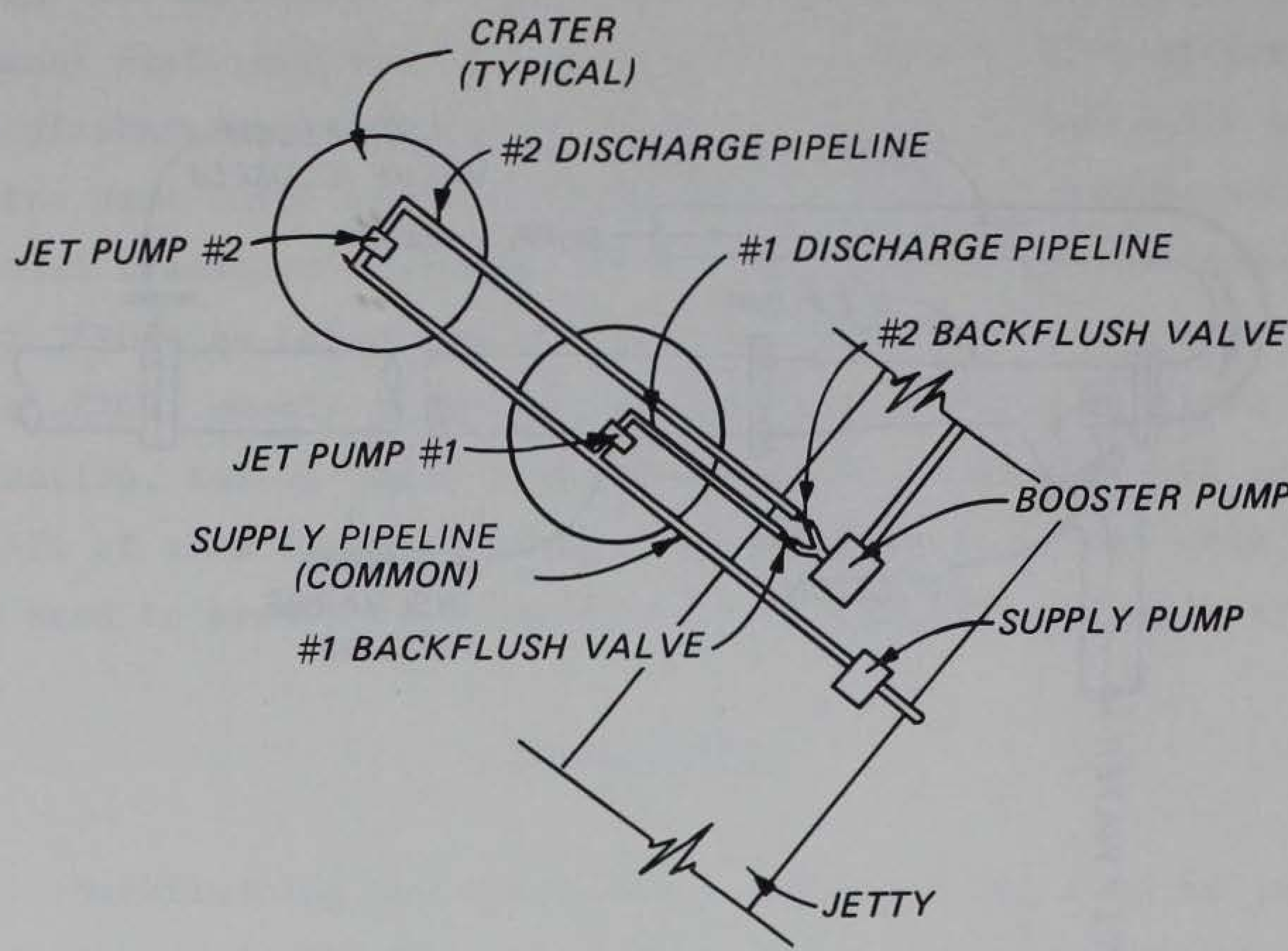

Figure 25. Two jet pumps with separate discharge pipelines

66. In the Figure 24 system, closure of the backflush valve will cause both jet pumps to backflush, even if only one has a suction blockage. There may also be a tendency for more flow to be directed outward through the unblocked suction since the hydraulic resistance there is less. In the Figure 25 system, each jet pump can be backflushed independently. However, more discharge piping and backflush valves are required and system installation may be more difficult.

67. A backflushing capability is necessary for all mobile jet pumps, since they often develop suction blockages when excavating new craters. Fixed jet pumps, on the other hand, are subject to blockage mainly by objects falling into their craters. Backflushing will remove these objects from the jet pump suction, but may not remove them from the crater. If they remain in the crater, they will eventually reenter the jet pump suction. It is usually necessary, therefore, to provide some type of coarse screen around the suction of a fixed jet pump to prevent large objects from entering. Then, the question of how to provide a backflushing capability will be answered by the degree of

discharge pipeline complexity the designer is willing to introduce.

System Pipe Sizes and Materials

68. The initial system layout must include a "first guess" at the size and material for the following pipelines:

a. Jet pump supply.

b. Supply pump suction.

c. Jet pump discharge.

d. Booster pump discharge.

Actually, several alternates should be developed at this stage for each of the above pipelines. These alternates should be carried through the design procedure in PART III as parallel calculations. Then, the relative effects of each will be apparent, and the most suitable combinations of size and material can be chosen.

69. The following general guidelines may be followed in choosing initial pipe sizes for single jet pump systems. These guidelines apply only to pipe with inside dimensions corresponding to Schedule 40 specifications. For other types of pipe, the nominal sizes given below may not be acceptable. The pipe sizes given are for initial estimating purposes only and may be changed in the final design, based on the results of PART III calculations:

a. Jet pump supply pipeline.

(1) 4 × 4 × 6 jet pump - 6 in. for line lengths up to 500 ft; 8 in. for greater lengths.

(2) 6 × 6 × 8 jet pump - 8 in. for line lengths up to 500 ft; 10 in. for greater lengths.

b. Supply pump suction pipeline. At least one pipe size larger than the jet pump supply pipeline.

c. Jet pump discharge pipeline.

(1) The best that can be done at this stage in the design process is to choose a jet pump discharge pipeline size which falls in the middle of a range of design possibilities. The approach used consists of choosing a pipe size based on the calculated value of EXC1 , then adjusting the jet pump discharge pipeline length so that the combination of EXC1 ,

pipe size, and pipeline length fall within a predetermined range of values. The designer may later have to revise his initial layout following more detailed calculations in PART III.

(2) The designer should enter Figure 26 using the value of EXC1 from paragraph 63 and move vertically to the first line encountered corresponding to a particular pipe size, which then becomes the "first guess" at the jet pump discharge pipeline size. Then, the approximate center of the range of pipeline lengths possible for EXC1 and that pipe size can be found from the vertical axis. If the value from Figure 26 is greater than 700 ft, the designer may lengthen the pipeline to the new value, if necessary. If the Figure 26 value is substantially less than the value used up to now, the designer <u>must</u> shorten the jet pump discharge pipeline to the new value. If the discharge pipeline cannot be shortened to the new value, the designer may move upward on Figure 26 to the line corresponding to the next larger pipe size. This pipe

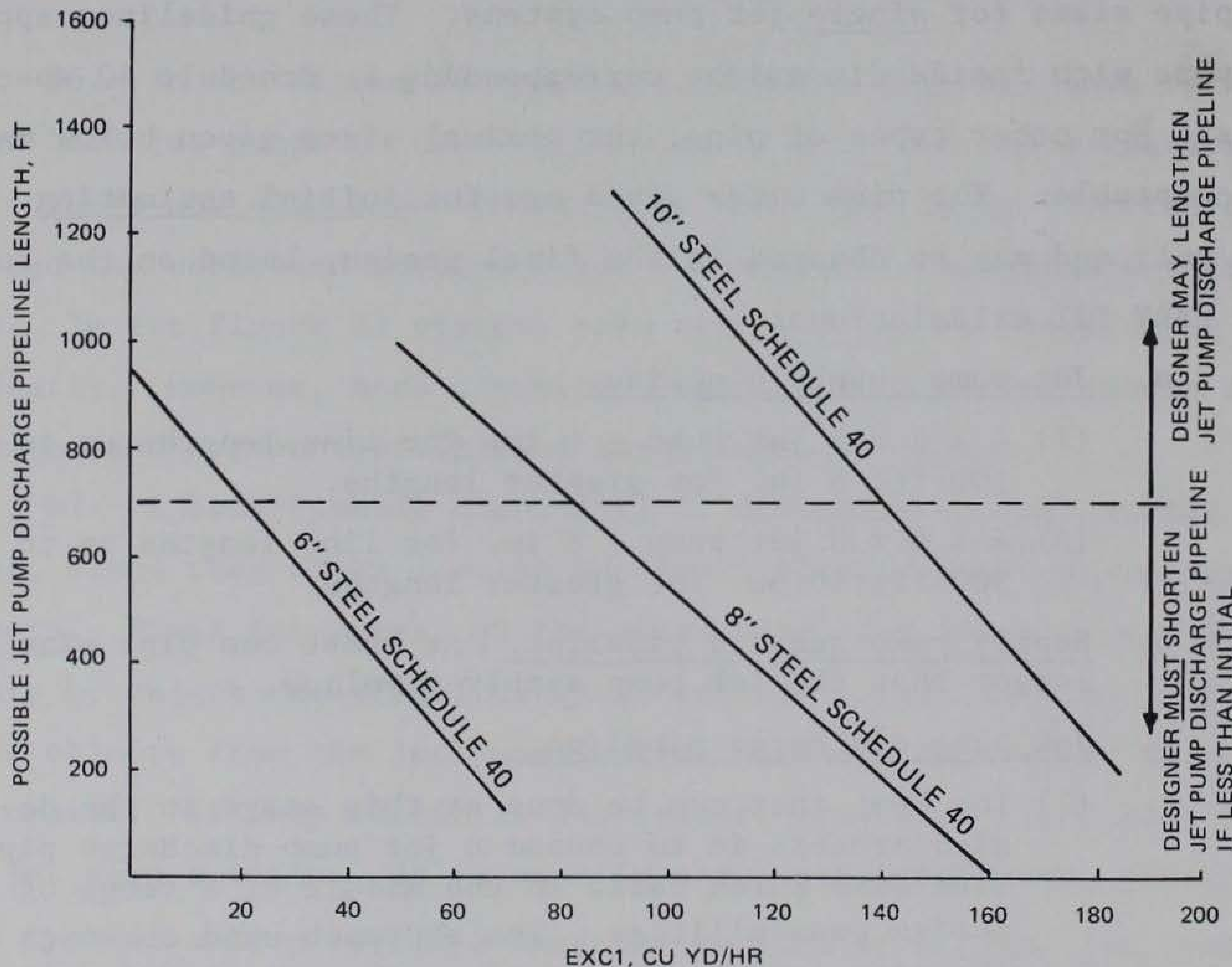

Figure 26. Possible jet pump discharge pipeline lengths versus EXC1 for various pipe sizes

size then becomes the "first guess" in subsequent calculations. The designer should resist the urge to use longer or larger pipelines than necessary, since the system will be more expensive to build and operate. Also, the designer should not use 6-in. pipe with a 6 × 6 × 8 jet pump or 10-in. pipe with a 4 × 4 × 6. If the discharge pipeline length is changed, the designer should review all aspects of the initial layout to see whether other changes are necessary. In particular, if the area of influence of the jet pump(s) is altered, a new system capacity will have to be calculated.

d. Booster pump discharge pipeline. Same size as jet pump discharge pipeline, or possibly one pipe size larger if flow in the jet pump discharge pipeline is near maximum for that pipe size.

For multiple jet pump systems that use common supply and discharge pipelines to serve all simultaneously operating jet pumps, pipe sizes for items a and c should be chosen such that their inside areas are roughly the appropriate multiple of the areas for the sizes shown above for single systems. For instance, if a 6-in. supply pipeline would be chosen for a certain single jet pump system, then an 8-in. pipeline is indicated for a two-jet pump system with the same pipeline lengths (the inside area of an 8-in. pipe is slightly less than twice that of a 6-in. pipe). The instructions given above for items b and d apply to multiple jet pump systems as well.

70. An initial selection of pipe materials should be made at this stage, so that the complete hydraulic characteristics of the pipelines will be known for PART III. Although different materials will have different hydraulic characteristics, no adjustments for pipe material (such as changing pipeline lengths) should be made to the initial system layout at this stage. Some options that may be considered and that have performed satisfactorily in WES field tests are:

a. Jet pump supply pipeline.

(1) Steel - For fixed jet pumps.

(2) Flexible rubber hose - For mobile jet pumps.

(3) High density polyethylene (HDPE) - For fixed jet pumps where the pipe will not have to support any external load, such as the weight of the jet pump.

b. Supply pump suction pipeline.

(1) Steel.

(2) HDPE.

c. Jet pump discharge pipeline. Same as jet pump supply pipeline.

d. Booster pump discharge pipeline.

(1) Steel.

(2) HDPE.

Other Considerations

71. Two other items must be considered by the designer before proceeding with the system hydraulic design: (a) booster pump flushing water and (b) jet pump cutting jets. Flushing water is clear water (i.e. no solids) which is continually provided to the booster pump stuffing box to prevent solid particles from entering. The flushing water must be at a pressure greater than the discharge pressure of the booster pump. The system supply pump may be able to provide flushing water to a nearby booster pump if the supply pump discharge pressure is sufficiently greater than that of the booster pump. If this arrangement is used, the supply pump will have to be sized to provide this additional flow.

72. As described previously, cutting jets are often used around the jet pump suction to aid in suction burial and in excavating consolidated material. Mobile jet pumps should always be provided with cutting jets, due to the range of conditions they often encounter. For fixed jet pumps, cutting jets may or may not be needed depending on the size and characteristics of the material that enters the jet pump crater. Fine sand that tends to pack quickly may require some cutting action to loosen it. Coarse, well-graded sand, on the other hand, may flow easily under the influence of suction alone. The point is that for fixed jet pumps, the question of whether to provide cutting jets should be answered by sediment information gathered in the coastal processes study. The water for cutting jets has to be provided by the supply pump (Figure 7), imposing an additional flow requirement on it.

System Schematic Drawings

73. The final aspect of initial system layout is the preparation of system schematic drawings in both plan and elevation. Schematic drawings should show the following information as a minimum:

- a. Major system components (jet, supply, and booster pumps and structures).
  - (1) Location.
  - (2) Elevation.
- b. Pipelines.
  - (1) Routing.
  - (2) Length.
  - (3) Size.
  - (4) Material.
- c. Valves and pipe fittings (bends, reducers, etc.).
  - (1) Location.
  - (2) Size.
  - (3) Type.
- d. Craters.
  - (1) Location.
  - (2) Dimensions.
- e. Jet pump excavation rate(s).

74. A set of example schematic drawings for a mobile jet pump system with two jet pumps, one of which operates at a time, is shown in Figures 27-31.

Equivalent Lengths

75. A convenient method to account for hydraulic energy losses caused by bends, valves, or other fittings in a pipeline is to replace these fittings in the calculations with lengths of straight pipe which give the same energy losses as the fittings. These "equivalent lengths" of straight pipe are added to the actual length of the pipeline. Then, a calculated loss factor is applied to the total equivalent pipeline

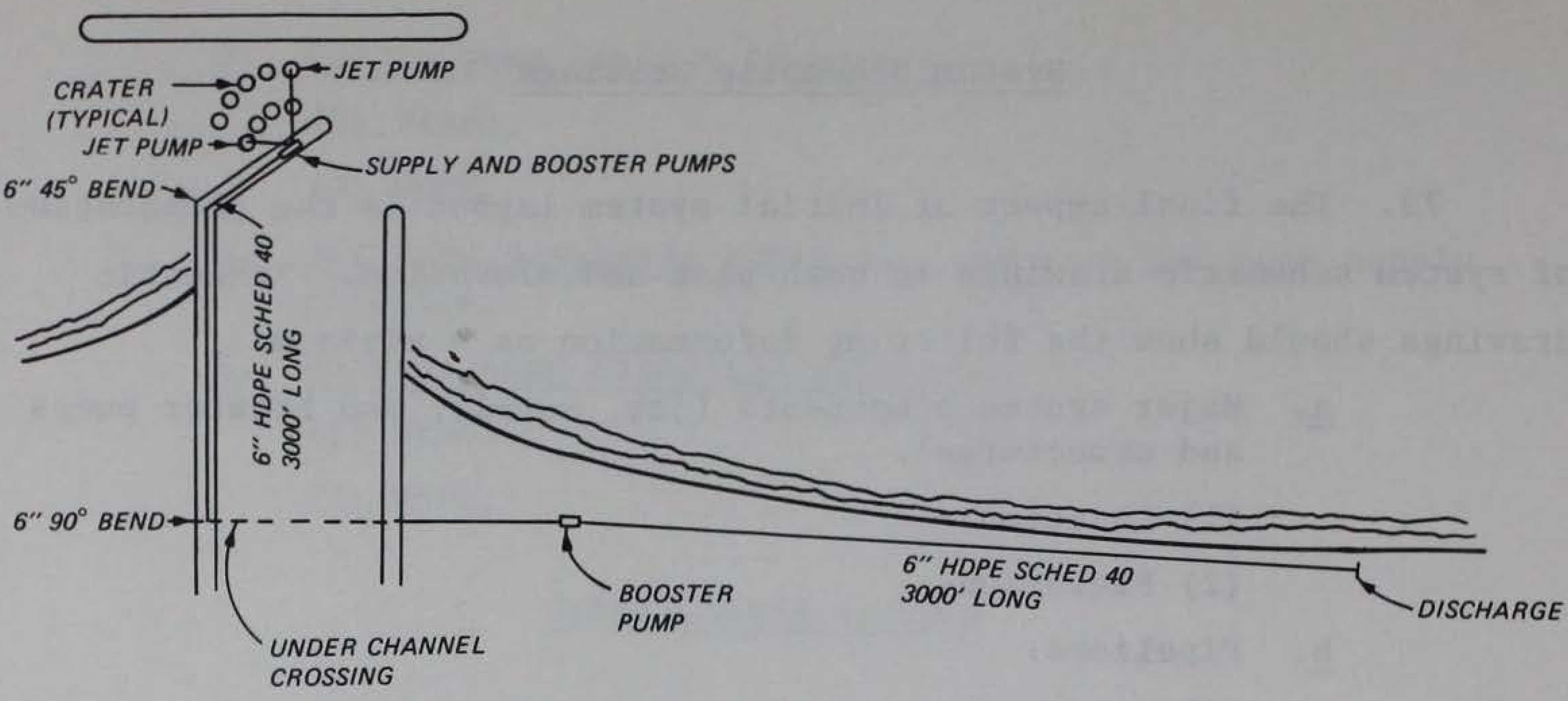

Figure 27. Overall system schematic

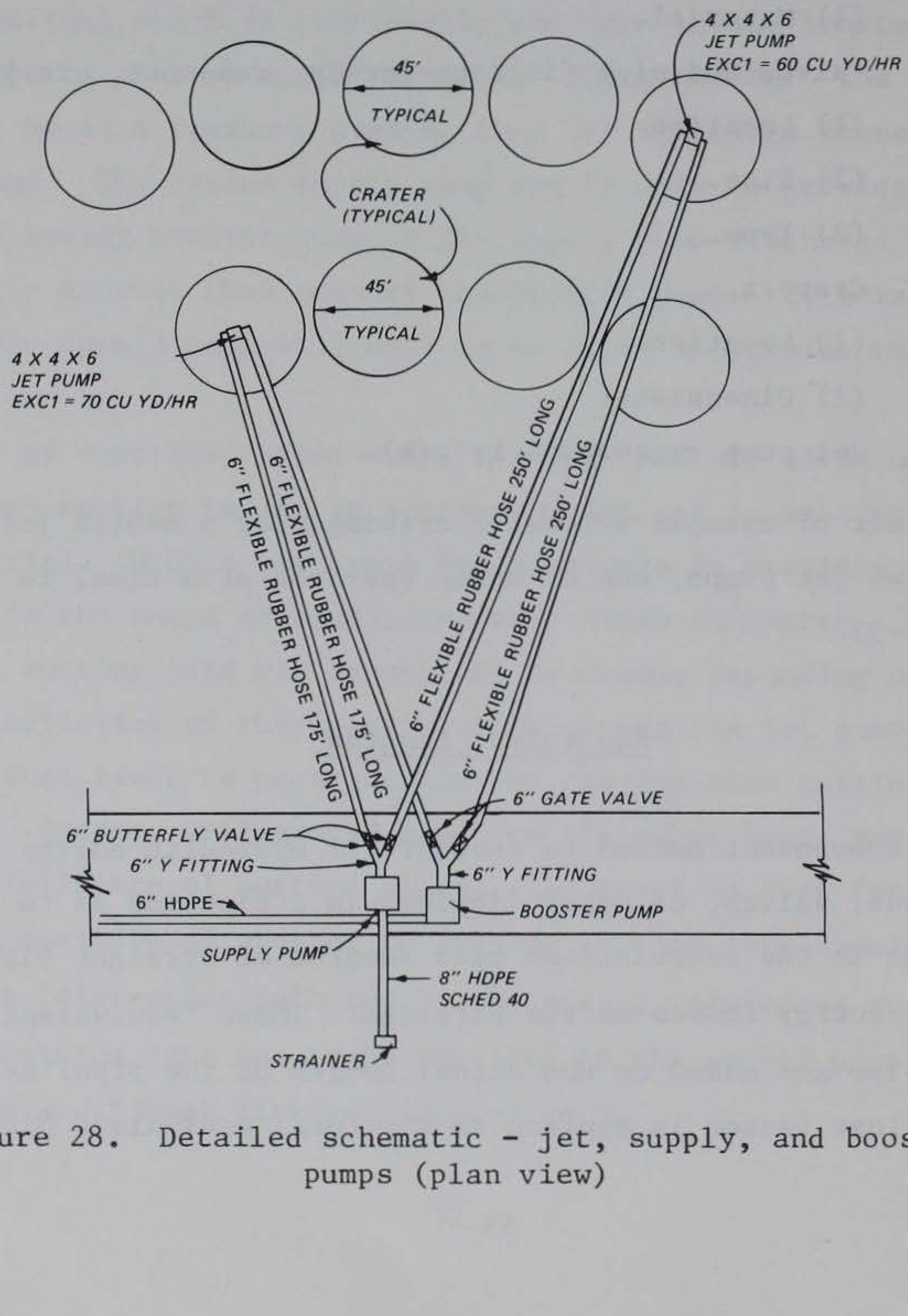

Figure 28. Detailed schematic - jet, supply, and booster pumps (plan view)

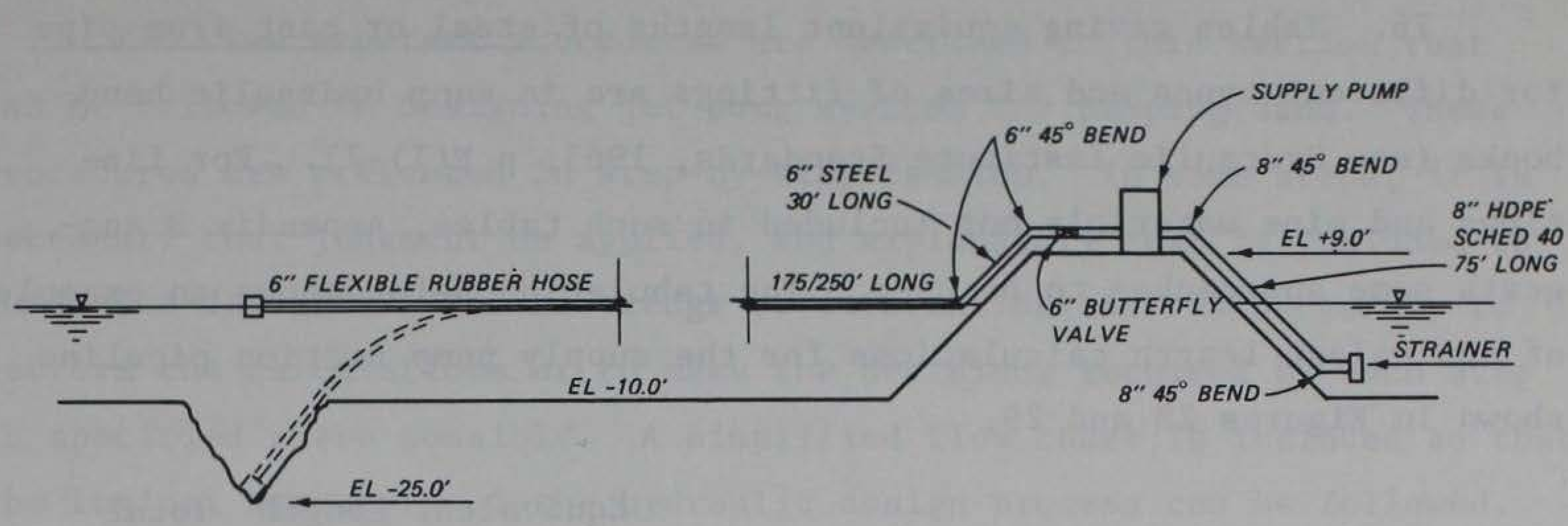

Figure 29. Jet pump supply system (elevation view)

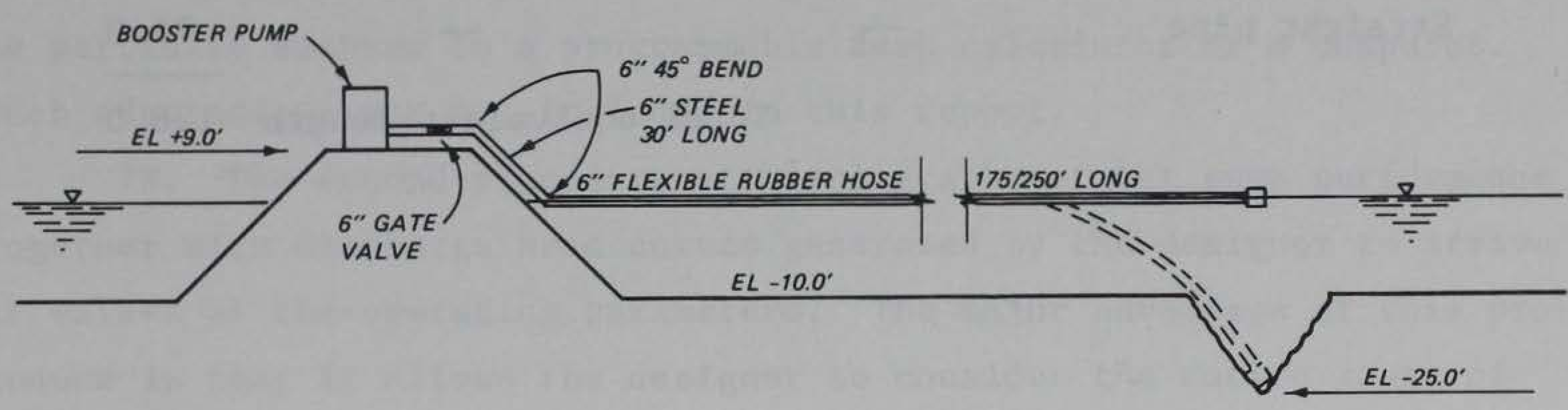

Figure 30. Jet pump discharge system (elevation view)

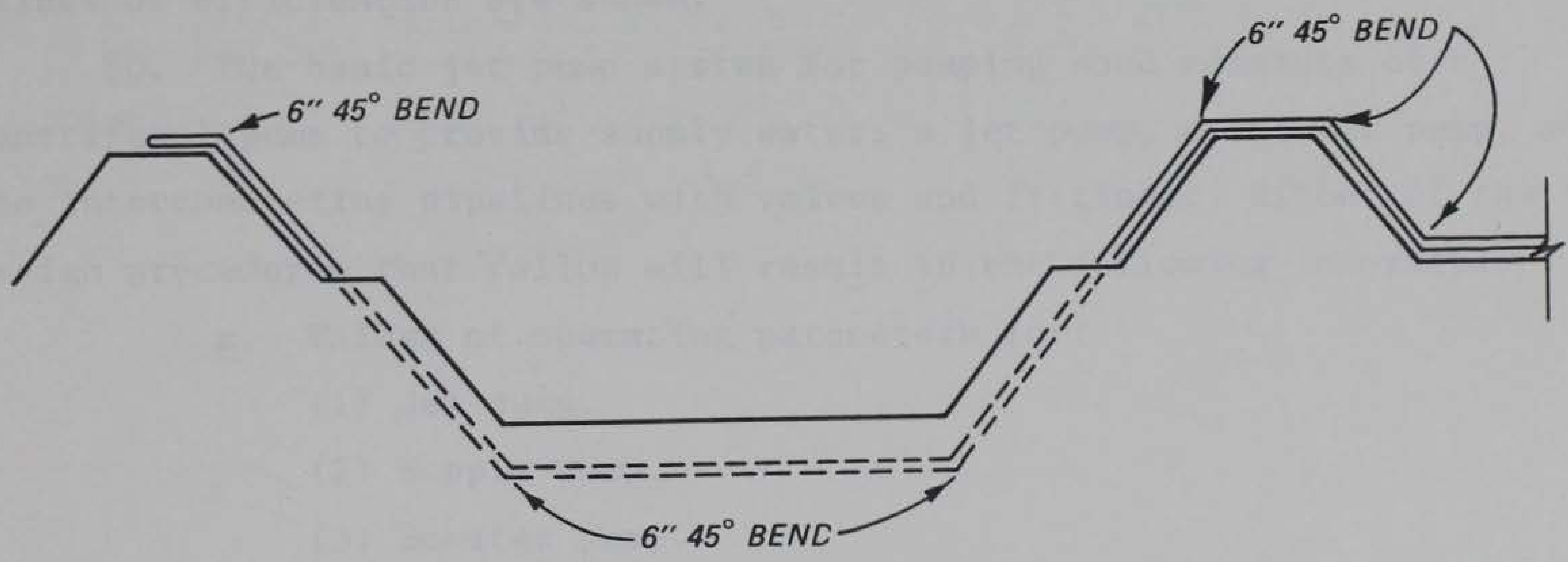

Figure 31. Booster discharge pipeline underchannel crossing (elevation view)

length (actual plus fitting equivalents), giving the total system energy loss in one computation.

76. Tables giving equivalent lengths of steel or cast iron pipe for different types and sizes of fittings are in many hydraulic handbooks (see Hydraulic Institute Standards, 1965, p E(I)-7). For fittings and pipe materials not included in such tables, Appendix B suggests some approaches to be used. The tabulation below shows an example of equivalent length calculations for the supply pump suction pipeline shown in Figures 28 and 29.

Type of Fitting	Number of Fittings	Equivalent Length per Fitting, ft	Total ft
Strainer	1	35.6	35.6
45-deg bend	2	7.7	15.4
Straight pipe	--	--	75.0
		Total equivalent length	126.0

PART III: HYDRAULIC DESIGN

77. Two separate procedures are described in this section that can be followed in designing jet pump systems for pumping sand. These procedures are presented in step-by-step fashion. In some steps, it is necessary that judgment be applied, and explanatory text is included to guide the designer. The knowledge or information that is necessary to perform the calculations or to make the decisions required by each step is specified where possible. A simplified flow chart is included so that the logical structure of the hydraulic design process can be followed.

78. The first procedure consists of a series of well-defined calculation steps. Included in the procedure is an iteration loop to determine values of the jet pump operating parameters. This procedure can be partially adapted to a programmable desk calculator or a computer. Such adaptations are not included in this report.

79. The second procedure utilizes graphs of jet pump performance together with discharge head curves generated by the designer to arrive at values of the operating parameters. The major advantage of this procedure is that it allows the designer to consider the entire range of jet pump possibilities at once, without having to recalculate design values. Also, jet pump cavitation limits are built into the graphs and values of efficiencies are shown.

80. The basic jet pump system for pumping sand consists of a centrifugal pump to provide supply water, a jet pump, a booster pump, and the interconnecting pipelines with valves and fittings. Either of the design procedures that follow will result in the following information:

- a. Values of operating parameters for:
  - (1) Jet pump.
  - (2) Supply pump.
  - (3) Booster pump.
- b. Flow rates and velocities at all points in system.
- c. Values of energy losses in all pipelines.
- d. Percent solids pumped at design operating point.
- e. Methods for selecting:

(1) Supply pump.

(2) Booster pump.

81. The given procedures are for the basic single jet pump system with one booster pump. Procedures for systems with multiple jet and/or booster pumps are similar except for some additional hydraulic considerations. These will be discussed at the end of PART III.

82. The design calculations make use of the initial layout and schematics of the bypassing system generated in PART II. If the design calculations show that a system element is inadequate or produces inefficient operation, a more reasonable selection should be inserted into the layout together with other associated corrections. By this method, the designer is assured of considering the bypassing system as an entity rather than as a group of components.

83. In both design procedures described in this part of the report, the total system design develops as a function of the jet pump design operating point. A major consideration in choosing the jet pump design operating point is efficiency of the jet pump at that point. Since the other demands on the jet pump at that point (excavation rate, pumping distance, etc.) resulted directly from project considerations discussed in PART II, such an approach will usually produce a well-designed system. However, the designer must remember that overall system efficiency, i.e., accomplishing the required bypassing with the least amount of total energy, is what really matters. Jet pump efficiency is a major factor in overall system efficiency, but the supply and booster pump operating characteristics play a role as well. Therefore, the designer should consider several alternative designs and compare the projected energy consumptions for each.

Iteration Design Procedure

84. The following design calculations are presented as a number of discrete steps. At the beginning of each step the information necessary to perform the calculations is given. The necessary relationships and equations are either presented in the step or are specifically

referenced. Some steps are check points and may show that reselection of system components and recalculation of new system values are necessary. These steps are specifically identified. A detailed flow chart showing relationships between steps as well as decision points in the design procedure is presented in Plate 1.

Step 1: Objective - Determine the minimum discharge pipeline velocity, often called critical velocity, necessary to maintain solids in suspension for all pipelines with solids flow. Also, determine the representative settling velocity of the sediment particles to be bypassed. This calculation should be done for each size of pipe used in the sediment-carrying portion of the system.

Information required - (a) Pipe inside diameter, D, ft; (b) median diameter of sediment to be bypassed, d_{50}, mm; and (c) specific gravity of the sediment solids, SGSOL (for quartz sand, SGSOL = 2.65).

Method - The first sediment parameter that will be determined is the settling velocity, W, of the d_{50} sediment particle. W can be determined from the curves in Figure 32, which shows plots of both empirical data and equations from several investigators for quartz particles settling in water at 68°F. For $d_{50} < 0.6$ mm, the center of the plots may be used. For $d_{50} > 0.6$ mm, the plots diverge rapidly, indicating that variables such as the particle shape become more important. In this range of particle sizes, it is suggested that plot 9 be used, since it is based on data using naturally occurring particle shapes. It should be noted that d_{50} is expressed in millimetres and W in millimetres per second in Figure 32. The value of W from Figure 32 should be multiplied by 0.00328 to convert it to feet per second for use in subsequent calculations.

The following empirical relationship from Durand (1953) is suggested as a means of determining the minimum discharge pipeline velocity, VCRIT:

$$\mathrm{VCRIT} = F_L \sqrt{[2gD(\mathrm{SGSOL} - 1)]} \qquad (11)$$

F_L, a proportionality coefficient, can be determined from Figure 33. C_v in Figure 33 is the expected volumetric concentration of solids in the discharge pipeline. It is suggested at this stage in the calculations to use the curve marked $C_v = 15\%$ as a conservative value.

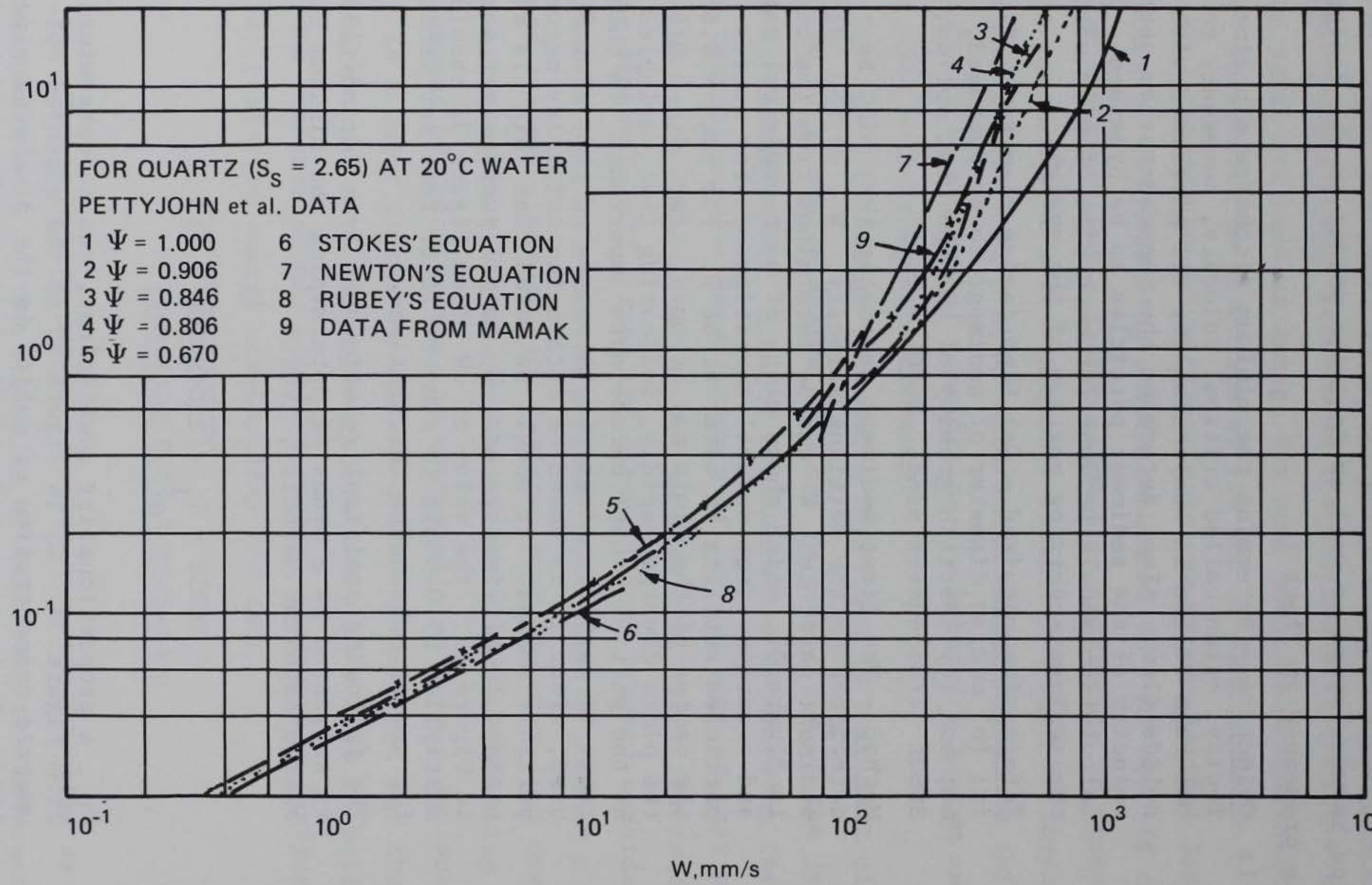

Figure 32. Settling velocity of quartz particles (from Hydraulics of Sediment Transport by Graf (1971). ©1971 by McGraw-Hill Inc. Used with permission of McGraw-Hill Book Company)

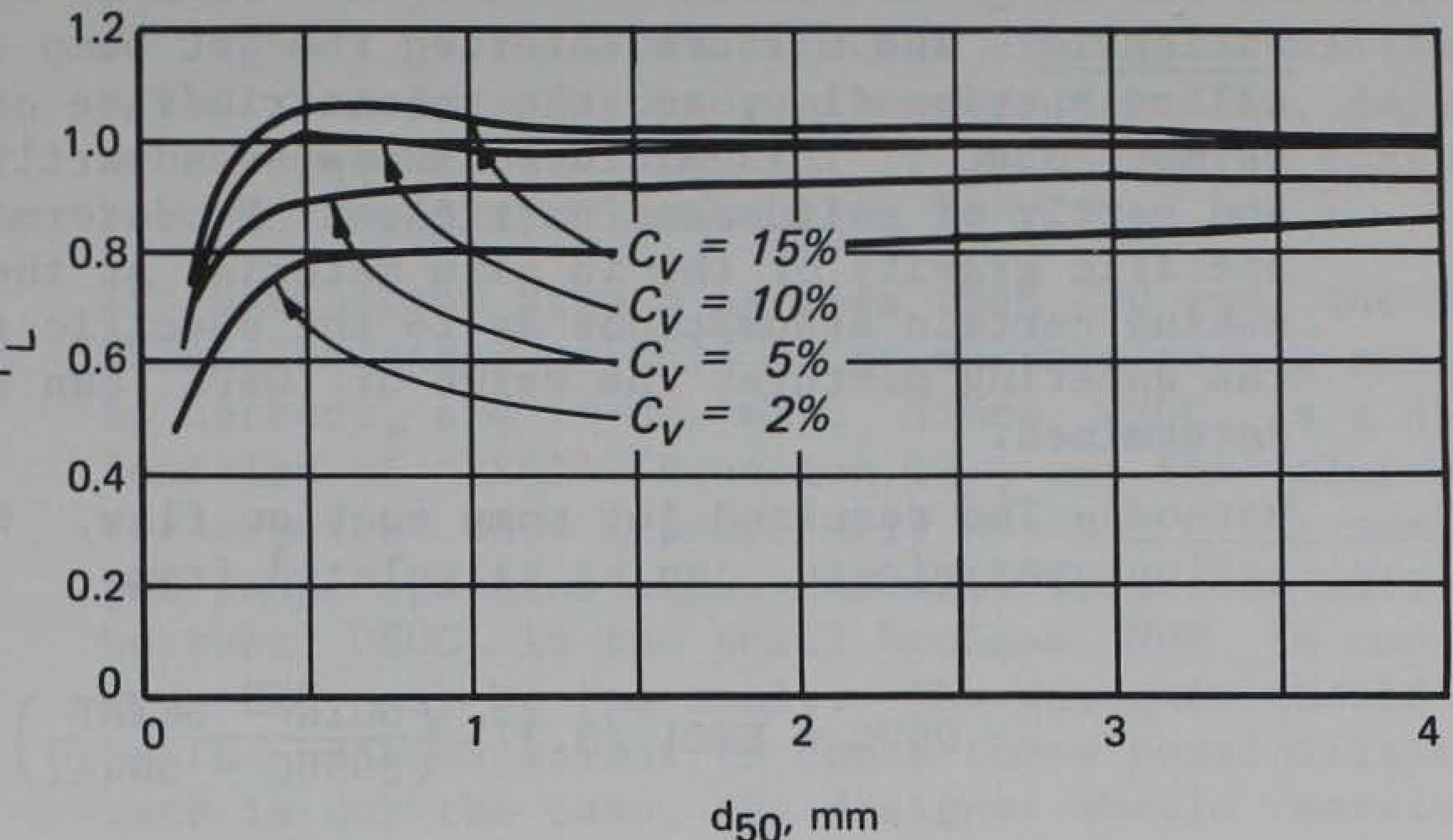

Figure 33. F_L versus d_{50} for Durand relationship (from Hydraulics of Sediment Transport by Graf (1971). ©1971 by McGraw-Hill Inc. Used with permission of McGraw-Hill Book Company)

Step 2: Objective - Determine the minimum required volumetric flow rate, $QSUP_{min}$, in the system discharge pipelines to assure conveyance of solids in suspension.

Information required - (a) VCRIT from Step 1, fps; (b) discharge pipe maximum inside area, ADIS, ft^2. ADIS should be the inside area of the largest pipe in the sediment-carrying portion of the system.

Rationale - The flow rate calculated in this step is the minimum clear water flow rate that should be supplied to the jet pump nozzle. Such a minimum flow rate will help ensure that sediment in the discharge pipelines can still be carried in suspension even if the jet pump intake plugs completely.

Method - Perform the following calculation to obtain $QSUP_{min}$ in gallons per minute (gpm):

$$QSUP_{min} = (448.831)(ADIS)(VCRIT) \quad (12)$$

Step 3: Objective - Determine the jet pump suction flow necessary to produce the required project site bypassing rate.

Information required - (a) Individual jet pump required bypassing rate, EXC1, cu yd/hr; (b) in situ porosity, n, of sediment to be bypassed; (c) specific gravity, SGSOL, of solids.

Rationale - The mixture entering the jet pump suction is called suction flow, and the volumetric rate of entry is termed QSUC . This mixture is composed partly of fluid and partly of solid sand particles. By determining the specific gravity of the in situ material at the site and making certain assumptions as to the specific gravity of the entering mixture, the value of QSUC can be determined.

Method - The required jet pump suction flow, QSUC , in gallons per minute, can be calculated from

$$QSUC = EXC1\ (3.37) \left(\frac{SGIN - SGWAT}{SGSUC - SGWAT}\right) \qquad (13)$$

where

SGIN = in situ material specific gravity = SGSOL(1 - n) + n(SGWAT)

SGWAT = specific gravity of ambient water (1.00 for fresh water, 1.025 for seawater)

SGSUC = assumed average specific gravity of mixture entering jet pump suction

In WES field tests, SGSUC varied between about 1.40 and 1.85 depending on pumping conditions. It is suggested that a value of SGSUC = 1.70 be used for preliminary estimation.

Step 4: Objective - Select a jet pump size to use in subsequent calculations.

Information required - Value of QSUC , gpm, from Step 3.

Rationale - Two sizes of the Pekor center-drive jet pump, the 4 × 4 × 6 and the 6 × 6 × 8, have pumping capacities that match the requirements of many bypassing situations. The same dimensionless performance characteristics are assumed for each, but flow rates in the larger pump are higher. It is therefore necessary to know which pump is being considered for steps later in this procedure.

Method - Compare the value of QSUC with those given below:

QSUC Range, gpm	Jet Pump
200 to 500	4 × 4 × 6
500 to 700	Transition
700 to 1500	6 × 6 × 8

Select the jet pump corresponding to the correct range of QSUC. For values of QSUC in the transition range either jet pump may prove the most feasible, depending on other system requirements. It is suggested that both types be considered simultaneously.

If QSUC from Step 3 is less than 200 gpm, the designer should consider at this point whether such a small capacity is correct, and if so, why. Since QSUC is a direct function of EXC1 (Equation 13), and the value of EXC1 for a given EXC depends only on NUM, the number of jet pumps operated simultaneously (Equation 10), it may be that QSUC is too small because NUM is too large. Or, EXC may be too small. The designer should return to the initial layout to check these possibilities. If such is not the case, the designer should reevaluate the entire situation to make sure the problem is of sufficient magnitude to warrant a sand bypassing system.

If QSUC is larger than 1500 gpm, the designer should also recheck his determination of EXC, NUM, and EXC1. If the value chosen for EXC still appears reasonable, the only option left is to increase NUM, the number of jet pumps operated simultaneously. As a general guideline, if adding more than one additional jet pump to NUM is required to make QSUC less than 1500 gpm, the designer should at this point reconsider the entire system layout. If the layout still looks sound, then there is a good possibility that the bypassing problem is beyond the feasible range of a jet pump solution. THE DESIGNER MUST RESIST THE TEMPTATION OF FORCING A JET PUMP SYSTEM TO FIT THE PROBLEM. For many situations, a jet pump system is not practical. Results of this step may be indicating just that.

Step 5: Objective - Determine the flow ratio M, the head ratio N, and the area ratio R, of the jet pump.

Information required - (a) $QSUP_{min}$, gpm, from Step 2, (b) QSUC, gpm, from Step 3, (c) jet pump dimensionless performance curves, Plate 2.

Rationale - As discussed earlier (paragraphs 20-22), the behavior of jet pumps of a given design when pumping a given medium can be described by three dimensionless ratios. These are:

$$\text{Head Ratio } N = \frac{HDIS - HSUC}{HSUP - HDIS} \qquad (1\text{ bis})$$

$$\text{Flow Ratio } M = \frac{QSUC}{QSUP} \qquad (2\text{ bis})$$

$$\text{Area Ratio } R = \frac{ANOZ}{AMIX} \qquad (3\text{ bis})$$

As part of the WES research program "Eductor Systems for Sandtrap Bypassing," the relationships between these ratios were defined for a Pekor center-drive jet pump under the condition of pumping medium sized sand (d_{50} = 0.5 mm). These relationships are shown graphically in Plate 2. It is evident from the plots shown in Plate 2 that if two of the ratios are selected, the third is uniquely defined. Since the effects of different grain sizes on M vs N relationships have not been measured, it is suggested that the plots in Plate 2 be used only for naturally occurring beach sands (d_{50} = 0.1 to 1.0 mm). More detailed performance data for a particular beach sand or data for coarser or finer sediments should be obtained by pump testing.

The operating efficiency, E , of the jet pump can be defined at any point from the relationship

$$E = M \times N \tag{14}$$

Peak operating efficiency is a goal of any design procedure and is a consideration in the accomplishment of this step.

Method - The optimum* flow ratio, M_{op} , can be found from the previous calculations of drive water flow rate requirements and jet pump suction flow rate requirements. Therefore

$$M_{op} = \frac{QSUC}{QSUP_{min}} \tag{15}$$

Enter Plate 2 at M_{op} and trace vertically to the jet pump dimensionless performance curve which gives the largest possible value of head ratio, N_{max} . Note the area ratio, R , associated with this curve. Determine the operating efficiency, E , of the jet pump at that point from the relation

$$E = M_{op} \times N_{max} \tag{16}$$

If E is approximately 0.20 or greater, the jet pump operating ratios have been selected. If E is between 0.14 and 0.20, the designer must choose whether to use

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* This flow ratio is "optimum" in the sense that it derives directly from bypassing requirements and the minimum flow rate in the discharge line. "Optimum" in this context does not necessarily imply a degree of efficiency.

the M and N values just calculated, or try for a higher E value.

If E is less than 0.14, compare the value of M_{op} with values of M in the following tabulation corresponding to the proper R . If M_{op} is greater than the value from the tabulation, the value of $QSUP_{min}$ should be increased and the operating ratios recalculated. If M_{op} is less than the tabulated value, QSUC should be increased for recalculating the operating ratios. Once new ratios are calculated, use them to recalculate E . Continue this process until an acceptable value of E is found.

R	M
0.096	1.063
0.138	0.745
0.175	0.614
0.202	0.537
0.246	0.463
0.311	0.205

Step 6: Objective - Calculate the discharge flow from the jet pump, QDIS .

Information required - Jet pump suction flow, QSUC , and supply flow, QSUP , gpm, used in the final determination of M in Step 5.

Rationale - Flow rates in various segments of the discharge system must be calculated in determining the system design operating point. The input to the calculations of this step should be the rate of flow of the mixture entering the jet pump through the suction tube, QSUC , and the dimensionless flow ratio, M . These values must reflect any adjustments made in Step 5.

Method - The volumetric discharge flow rate from the jet pump, QDIS , can be calculated from the relationship

$$QDIS = QSUC + QSUP \tag{17}$$

Step 7: Objective - Calculate the expected maximum volumetric concentration of solids, CVMAX , in the jet pump discharge pipeline.

Information required - (a) Jet pump flow ratio, M , from Step 5; (b) specific gravity of sediment solids, SGSOL;

(c) in situ specific gravity, SGIN , of sediment to be bypassed (from Step 3); (d) jet pump discharge, QDIS , gpm, from Step 6; (e) porosity, n , of in situ sediment to be bypassed; (f) specific gravity of ambient water, SGWAT , from Step 3.

Rationale - Head loss calculations should be based on the maximum slurry concentration conditions that are reasonably expected to occur. The WES research program indicated certain relations that could be used for different jet pump configurations to estimate what the maximum sustained specific gravity of the mixture entering the jet pump might be. These relations are used in the following calculations.

Method - CVMAX can be determined from the relationship

$$\mathrm{CVMAX} = \left(\frac{M}{1 + M}\right)\left(\frac{\mathrm{SGSUCM} - \mathrm{SGWAT}}{\mathrm{SGSOL} - \mathrm{SGWAT}}\right) \tag{18}$$

where SGSUCM is the assumed maximum sustained specific gravity of the slurry entering the jet pump suction. Experiments at WES developed the following relationships between SGSUCM and SGIN :

For fixed jet pumps with no cutting assists:

$$\mathrm{SGSUCM} = \mathrm{SGIN} \tag{19}$$

For fixed jet pumps with cutting assists:

$$\mathrm{SGSUCM} = 0.85(\mathrm{SGIN}) + 0.15 \tag{20}$$

For floating jet pumps, which almost always require cutting assists:

$$\mathrm{SGSUCM} = 0.80(\mathrm{SGIN}) + 0.20 \tag{21}$$

Note - The solids concentration determined in this step is to be used for subsequent calculation of energy losses and booster pump requirements only. No attempt should be made to return to previous steps with this value since the bypassing system will not consistently attain solids concentrations as high as those calculated in this step.

The expected maximum specific gravity of slurry in the jet pump discharge pipeline, SGDISJ , can be computed from:

$$SGDISJ = CVMAX(SGSOL) + (1 - CVMAX)SGWAT \quad (22)$$

The maximum excavation rate of in situ material by one jet pump, EXCMAX , cu yd/hr, can be calculated by the expression

$$EXCMAX = \frac{0.297(CVMAX)}{1 - n} (QDIS) \quad (23)$$

EXCMAX as given by this expression should exceed EXC1 as used in Step 3. If it does not, a mistake was made somewhere in Steps 3 through 7. Calculations in these steps should be checked.

Step 8: Objective - Calculate the required jet pump discharge head, HDIS .

Information required - (a) Description of jet pump discharge pipeline including inside diameter and length (D and LDISJ), both in feet, with adjustments for valves, fittings, and bends; (b) hydraulic characteristics of jet pump discharge pipe; (c) total flow rate delivered by jet pump, QDIS , gpm, from Step 6; (d) settling velocity, W , of d_{50} particle diameter, fps (see Step 1); (e) maximum concentration of solids, CVMAX , in jet pump discharge pipeline; (f) specific gravity of sediment solids, SGSOL ; (g) elevation of booster pump center line, ZBOO , ft, relative to water surface datum; (h) maximum specific gravity of slurry in jet pump discharge pipeline, SGDISJ , from Step 7; (i) expected maximum water depth over jet pump while operating, DEPMAX , ft; (j) design pressure or vacuum head at the booster pump suction flange, PHSUCB , in feet of water. Suggestions for selecting a value of PHSUCB are given in this step.

Rationale - The jet pump discharge head represents the total energy output of the jet pump. It is composed of the energy required to overcome friction losses in the discharge pipeline, of velocity head energy, of energy required to raise the mixture to the level of the booster pump, and of the pressure or vacuum at the booster pump. Friction losses in pipelines carrying fluids and solids are calculated in two steps. First, losses attributable to the fluid flow alone are calculated. Then, these losses are adjusted to account for the presence of the solids. Equivalent lengths of pipeline should be used in the calculations.

Fluid energy losses: the Darcy-Weisbach formula is often used to calculate the rate of head loss per unit length of pipeline for fluid flow, $(\Delta h/\Delta L)_w$:

$$\left(\frac{\Delta h}{\Delta L}\right)_w = \frac{f}{D}\frac{V^2}{2g} \tag{24}$$

where

f = dimensionless friction factor; a function of pipe relative roughness and Reynolds number

D = pipe inside diameter, ft

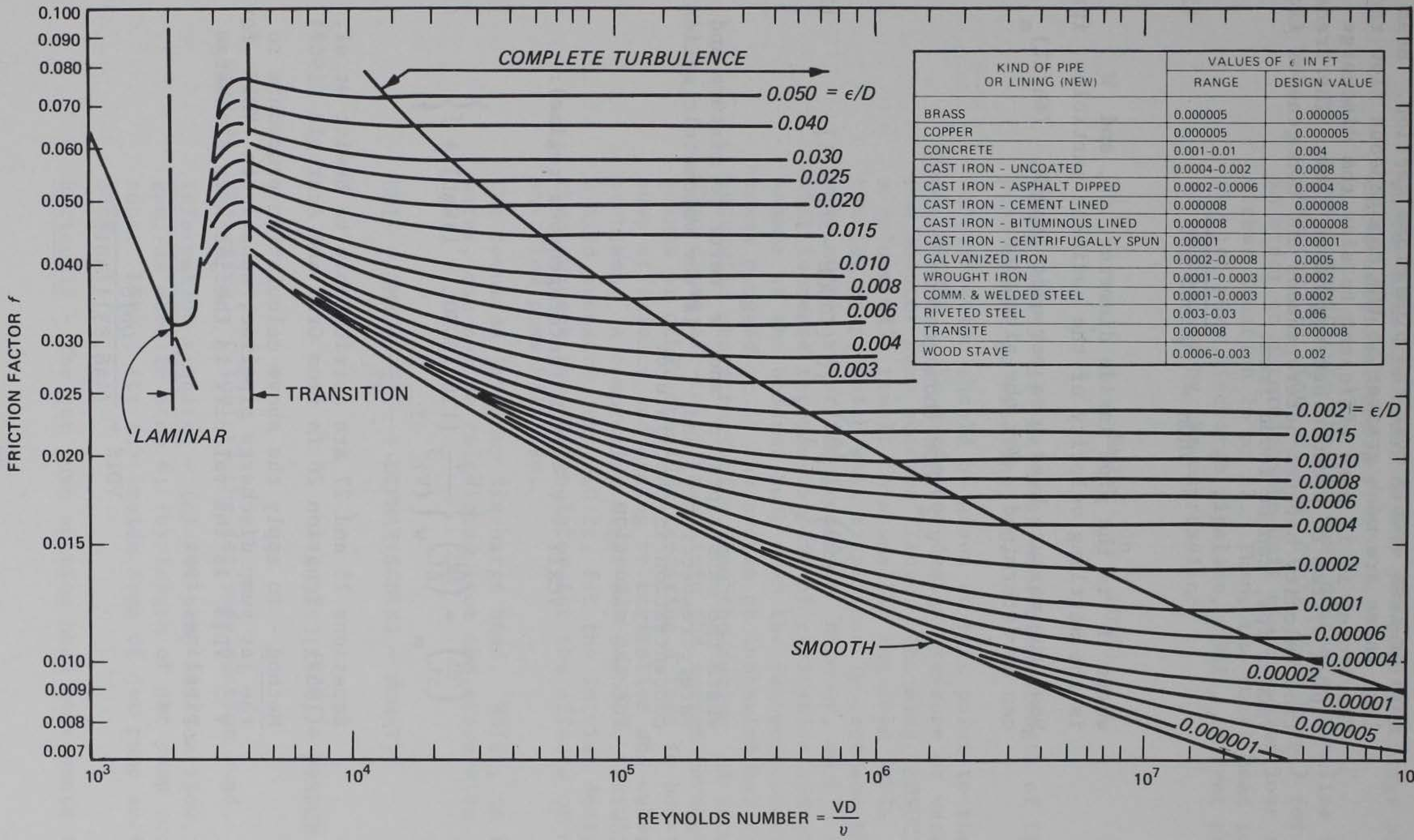
V = flow velocity in the pipe, fps

g = acceleration due to gravity, ft/sec^2

The friction factor, f , can be found from a Moody diagram such as that shown in Figure 34 (Moody 1944). f can also be found directly by an iterative solution of the Colebrook-White equation (Colebrook 1939). This method is described in Appendix B. Other relationships such as the Hazen-Williams formula are available to define fluid head loss rates, and the appropriate one should be selected by the designer on the basis of what information is available on the hydraulic characteristics of the pipe being used.

A word of caution is necessary at this point against using so-called "rules of thumb" for estimating head loss rates or any other hydraulic parameter. While such methods may indeed give answers approximating those of more complex formulas, their range of validity is often not known. At the very least, their use can result in wasteful overpowering of a system. In the worst case, they may give results which underestimate head losses, causing the system to be inadequate.

Mixture energy losses: the flow regime existing in the booster discharge pipeline must be determined before adjustments are made to fluid-only head loss rates to account for the presence of solids. The piping system has been designed to carry the mixture in a nonsettling mode, so the only test necessary is whether the mixture is a heterogeneous or homogeneous slurry. A heterogeneous slurry has a vertical concentration gradient in the pipe; i.e., more solid material is carried at the bottom of the pipe than at the top. In a homogeneous slurry, velocities in the pipe are high enough that solids are distributed



KIND OF PIPE OR LINING (NEW)	VALUES OF ε IN FT	
	RANGE	DESIGN VALUE
BRASS	0.000005	0.000005
COPPER	0.000005	0.000005
CONCRETE	0.001-0.01	0.004
CAST IRON - UNCOATED	0.0004-0.002	0.0008
CAST IRON - ASPHALT DIPPED	0.0002-0.0006	0.0004
CAST IRON - CEMENT LINED	0.000008	0.000008
CAST IRON - BITUMINOUS LINED	0.000008	0.000008
CAST IRON - CENTRIFUGALLY SPUN	0.00001	0.00001
GALVANIZED IRON	0.0002-0.0008	0.0005
WROUGHT IRON	0.0001-0.0003	0.0002
COMM. & WELDED STEEL	0.0001-0.0003	0.0002
RIVETED STEEL	0.003-0.03	0.006
TRANSITE	0.000008	0.000008
WOOD STAVE	0.0006-0.003	0.002

Figure 34. Moody diagram (after Moody 1944)

more or less evenly over the pipe cross section. Head loss rates are much greater in the homogeneous flow range. Therefore, it is more efficient to size the discharge piping system to produce heterogeneous flow. The transition velocity between heterogeneous and homogeneous flow, VHOM , fps, can be found from:

$$VHOM = \sqrt[3]{1800\ gWD} \tag{25}$$

where D is the pipe inside diameter, ft, and W is the settling velocity of the sediment particles, fps.

Now, the mixture head loss per unit length, $(\Delta h/\Delta L)_m$, can be determined. For the situation

$V \geqq$ VHOM (homogeneous regime):

$$\left(\frac{\Delta h}{\Delta L}\right)_m = \left(\frac{\Delta h}{\Delta L}\right)_w [C_v(SGSOL - 1) + 1] \tag{26}$$

where the subscripts m and w refer to mixture and water, respectively, and C_v is the volumetric solids concentration in the mixture.

For the situation

VCRIT < V < VHOM (heterogeneous regime):

$$\left(\frac{\Delta h}{\Delta L}\right)_m = \left(\frac{\Delta h}{\Delta L}\right)_w \left\{\frac{C_v}{(V)^3} [1100(SGSOL - 1)WgD] + 1\right\} \tag{27}$$

Equations 25 and 27 are attributable to Newitt et al. (1955). Equation 26 is from Graf and Acaroglu (1967).

<u>Method</u> - To apply the above calculation procedure to the jet pump discharge pipeline, substitute VDIS for V . VDIS is the velocity in the jet pump discharge pipeline, fps:

$$VDIS = \frac{QDIS}{(448.831)(ADIS)} \tag{28}$$

where ADIS is equal to the jet pump discharge pipe cross-sectional area, ft^2.

Also, substitute the jet pump discharge pipeline inside diameter, ft, for D and CVMAX from Step 7 for C_v in order to determine the unit mixture head loss from either Equation 26 or 27. Then, the total head loss in the jet pump discharge pipeline, HMJ , in feet of water, is calculated by the expression:

$$HMJ = \frac{\Delta h}{\Delta L}_m \; LDISJ \tag{29}$$

where LDISJ is the total equivalent length of the jet pump discharge pipeline, ft.

Consideration should be given at this point to the choice of PHSUCB , the estimated design pressure or vacuum at the booster pump suction flange. Choosing PHSUCB to be a vacuum will result in a smaller required HDIS from the jet pump, which will significantly decrease the jet pump supply water requirements. However, such a choice will increase the possibility of cavitation and water hammer at the booster pump when the jet pump suction becomes plugged or if the system as installed has different hydraulic characteristics from the design. A vacuum may also cause air to be drawn into the system through pipe joints or other openings, creating a loss in booster pump efficiency and adding to cavitation and water hammer problems. A compromise might be to choose PHSUCB as a mild pressure, say +10 ft, for the initial design and then recheck the design later for the effects of different flow possibilities.

The required jet pump discharge head, HDIS , in feet of water, can now be calculated from the expression

$$HDIS = HMJ + \frac{VDIS^2}{2g} + DEPMAX(SGDISJ - SGWAT) + SGDISJ(ZBOO) + PHSUCB \tag{30}$$

Step 9: <u>Objective</u> - Calculate the jet pump suction head, HSUC .

<u>Information required</u> - (a) Jet pump suction flow, QSUC , gpm, as used in Step 6; (b) length of jet pump suction tube, LSUC , ft; (c) inside area of jet pump suction, ASUC , ft^2.

<u>Rationale</u> - The jet pump suction head represents the

total energy available at the jet pump suction. This value is composed of the velocity head of the suction fluid minus the head losses of the sediment/water mixture as it enters and flows through the suction tube.

Method - The jet pump suction head, HSUC , in feet of water, can be calculated from the expression

$$HSUC = \frac{VSUC^2}{2g} - \left[2(LSUC) + 4\left(\frac{VSUC^2}{2g}\right)\right] \tag{31}$$

where

$$VSUC = QSUC/(ASUC \times 448.831) \text{ , in fps}$$

The expression in brackets in Equation 31, developed from laboratory observations, is an estimate of the total mixture head loss in the suction tube. Detailed information on design of the suction tube will be given in a subsequent report. A value of LSUC = 2.0 ft is suggested for the present design purpose.

Step 10: Objective - Calculate the required jet pump supply head, HSUP .

Information required - (a) Jet pump head ratio, N (see Step 5); (b) required jet pump discharge head, HDIS (see Step 8), in feet of water; (c) jet pump suction head, HSUC (see Step 9), in feet of water.

Rationale - The dimensionless jet pump head ratio, N , is a function of the jet pump supply head, the jet pump discharge head, and the jet pump suction head (Equation 1). Therefore, definition of any three of these parameters uniquely defines the fourth.

Method - The required jet pump supply head, HSUP , in feet of water, can be calculated from the expression

$$HSUP = \frac{HDIS - HSUC}{N} + HDIS \tag{32}$$

Step 11: Objective - Calculate QSUP from the standpoint of nozzle hydraulics, to determine whether the value of $QSUP_{min}$ calculated in Step 2 is realistic.

Information required - (a) Jet pump supply head, HSUP , in feet of water; (b) area ratio, R , from Step 5; (c) jet pump suction head, HSUC , from Step 9, in feet of water.

Rationale - This step is the "closing" step of an iterative calculation procedure, the objective of which is to determine the operating parameters of the jet pump. The jet pump operates by means of supply water entering through a nozzle. Therefore, its behavior on the supply side can be characterized by a form of the basic nozzle equation. When the results of calculations from the nozzle equation are approximately the same as those arrived at via Steps 1 through 10, then the values of operating parameters determined in Steps 1 through 10 can be considered valid.

Method - Calculate QSUP, gpm, by means of the following equation, which is conservatively based on the results of laboratory tests of jet pumps:

$$QSUP = B(ANOZ)\sqrt{(HSUP - HSUC)} \tag{33}$$

ANOZ can be calculated from the following relation:

$$ANOZ = R \times AMIX \tag{34}$$

The tabulation below gives values of AMIX for Pekor 4 × 4 × 6 and 6 × 6 × 8 jet pumps:

Jet Pump	AMIX, ft^2
4 × 4 × 6	0.0873
6 × 6 × 8	0.1963

B is a coefficient which varies with the value of R. The following tabulation gives values of B to use with corresponding R values.

R	B, $gpm/ft^{5/2}$
0.096	3533.4
0.138	3429.7
0.175	3633.9
0.202	3776.5
0.246	3682.5
0.311	4544.8

Compare this value of QSUP with the value of QSUP used in the final determination of M in Step 5. If they are not within approximately 5% of each other (and they probably will not be), the iterative calculation procedure must be worked again. Replace the Step 5 QSUP with the value of QSUP calculated in this step, return to Step 5, and work through to this point again. Several runs through Steps 5-11 may be necessary until the two values of QSUP agree. After the first iteration, the value of QSUP calculated in this step is no longer compared with the original Step 5 QSUP, but with the value of QSUP calculated in the previous iteration. Caution: if at any time the value of QSUP calculated in this step is less than the Step 5 QSUP, the iteration must be carried out differently. Either the excavation rate, EXC, or the jet pump discharge pipe diameter can be reduced. The first adjustment will have the effect of reducing QSUC; the second will cause a reduction in QSUP. In either case, the designer must return to the system initial layout.

Step 12: Objective - Check for possible cavitation in jet pump.

Information required - (a) jet pump supply head, HSUP (see Step 10), in feet of water; (b) jet pump suction head, HSUC (see Step 9), in feet of water; (c) jet pump suction velocity, VSUC (see Step 9), fps; (d) jet pump area ratio, R (see Step 5); (e) jet pump flow ratio, M (see Step 5); (f) minimum anticipated water depth over jet pump while operating, DEPMIN, ft; (g) atmospheric pressure, ATMOS, in feet of water; (h) vapor pressure of water, VAP, in feet of water; (i) jet pump supply flow rate, QSUP, gpm, as finally determined in the Step 2 through 11 iteration process; (j) area of opening at jet pump nozzle tip, ANOZ, from Step 11, in ft^2.

Rationale - The exact prediction of cavitation in the Pekor jet pump, especially when pumping solids, has not been experimentally determined at this time. For this reason, it is recommended that the designer check the jet pump operating point as determined in Steps 5-11 against cavitation criteria taken from Silvester and Mueller (1968) and Wakefield (1972). Although those criteria do not apply directly to the Pekor pump, they will serve to indicate whether the operating point is near a "danger zone" of possible cavitation.

Method - The criterion from Silvester and Mueller is expressed in the terminology of this report as:

$$\frac{\text{HSUP} + \text{DEPMIN}}{\text{ATMOS} - \text{VAP} + \text{HSUC} - \left(\frac{\text{VSUC}^2}{2g}\right) + \text{DEPMIN}} \leq \left[\frac{0.95(1 - \text{R})}{\text{M} \times \text{R}}\right]^2 \qquad (35)$$

Cavitation is assumed not to occur if this inequality is satisfied.

The criterion as given in Wakefield's publication involves use of a graph. For purposes of this manual, the graph is eliminated and the following expression used:

$$\frac{\left(\mathrm{HSUC} - \frac{\mathrm{VSUC}^2}{2g} + \mathrm{DEPMIN} + \mathrm{ATMOS}\right)2g}{\mathrm{VNOZ}^2} \qquad (36)$$

$$> 0.046 - 0.126X + 1.44X^2 + 4.44X^3 - 9.18X^4$$

where

$X = \mathrm{VSUC}/\mathrm{VNOZ}$

VNOZ = velocity of water jet at tip of nozzle, fps

Again, cavitation is assumed not to occur if the inequality is satisfied. VNOZ may be calculated from the following expression:

$$\mathrm{VNOZ} = \frac{\mathrm{QSUP}}{(448.831)(\mathrm{ANOZ})} \qquad (37)$$

If cavitation is indicated by either of these criteria, the designer has two alternatives: (a) decrease QSUC or (b) select a larger size jet pump. From Equations 13 and 10, it is seen that QSUC is a direct function of EXC1 , and that EXC1 depends solely on EXC and NUM . Therefore, choosing alternative (a) means returning to the initial system layout to see what can be altered to reduce EXC1 and thereby decrease QSUC . Alternative (b) is feasible only if QSUC falls in the transition zone defined in the tabulation in Step 4, p 62. If alternative (b) is chosen, the designer should also return to the initial system layout to determine if changes in pipe sizes are necessary.

Step 13: Objective - Calculate all expected energy losses in the booster pump discharge pipeline.

Information required - (a) Description of booster discharge pipeline, including inside diameter and length, both in feet, with equivalent length adjustments for valves, fittings, and bends; (b) hydraulic characteristics of booster discharge pipe; (c) total flow rate delivered by jet pump to booster pump, QDIS (see Step 6), gpm, (d) settling velocity, W , of d_{50} sediment particle (see Step 1); (e) maximum concentration of solids, CVMAX , in jet pump discharge pipeline (see Step 7); (f) specific gravity of sediment solids, SGSOL .

Rationale - The methodology for calculating friction losses in pipelines conveying sand/water slurries was presented in Step 8 and will not be repeated here.

Method - The velocity in the booster pump discharge pipeline, VDISB , fps, should be calculated on the basis of the total discharge of the jet pump plus the quantity of flushing water introduced into the booster pump. Therefore

$$\mathrm{VDISB} = \frac{\mathrm{QDIS} + \mathrm{QFL}}{\mathrm{ADISB}(448.831)} \tag{38}$$

where

QFL = flushing water volumetric flow rate into booster, gpm

ADISB = inside area of booster pump discharge pipe, ft^2

Recommended values of QFL vary from pump to pump, but QFL may usually be assumed as 100 to 150 gpm. The expected maximum volumetric concentration of solids in the booster discharge pipeline, CVMAXB , may be calculated from:

$$\mathrm{CVMAXB} = \mathrm{CVMAX}\left(\frac{\mathrm{QDIS}}{\mathrm{QDIS} + \mathrm{QFL}}\right) \tag{39}$$

Using the relations from Step 8, and by substituting VDISB for V , the booster discharge pipe inside diameter, ft, for D , and CVMAXB for C_v , the head loss per unit length of pipeline, $(\Delta h/\Delta L)_m$, can be calculated.

Total head loss in the booster discharge pipeline, HMB , in feet of water, is calculated by the expression

$$\mathrm{HMB} = \left(\frac{\Delta h}{\Delta L}\right)_m \mathrm{LDISB} \tag{40}$$

where LDISB is the total equivalent length, ft, of the booster discharge pipeline.

Step 14: Objective - Calculate the operating requirements to be placed on the booster pump. These requirements include the total dynamic head of the booster pump, TDHB , the flow rate of the booster pump, QDISB , and the specific gravity of the booster pump discharge, SGDISB .

Information required - (a) Total frictional head loss in booster discharge pipeline, HMB , in feet of water (see Step 13); (b) estimated design pressure or vacuum at the booster pump suction flange, PHSUCB , in feet of water (see Step 8); (c) elevation of the end of the booster discharge pipeline, ZDIS , relative to water-surface datum, ft; (d) elevation of booster pump center line relative to water surface, ZBOO , ft; (e) maximum concentration of solids in the booster discharge pipeline, CVMAXB (see Step 13); (f) jet pump discharge flow rate, QDIS , gpm (see Step 6); (g) flushing water flow into booster pump, QFL , gpm (see Step 13); (h) specific gravity of sediment solids, SGSOL ; (i) manufacturers literature describing booster pumps.

Method - The total dynamic head required of the booster pump, TDHB , is composed of the total head loss in the booster discharge pipeline, HMB , in feet of water; a design pressure or vacuum at the booster pump suction flange, HSUCB , in feet of water; and the difference in elevation between the center line of the pump and the discharge pipe end at the disposal site, ft. TDHB may be calculated in feet of water from:*

$$\mathrm{TDHB} = \mathrm{HMB} - \mathrm{PHSUCB} + (\mathrm{ZDIS} - \mathrm{ZBOO}) \tag{41}$$

Note - Kinetic (velocity) energy terms are not included in this calculation because their only contribution to TDHB is the negligible difference between velocity heads at the pump suction and pump discharge.

At this point, the designer should review the manufacturers' literature and make a preliminary selection of a class of booster pumps so that the reasonableness of the flushing water flow rate estimates, QFL , can be

* Equation 41 must be modified for systems with multiple booster pumps. See paragraph 91 for details.

verified. If possible, a more accurate value of QFL should be selected for subsequent use. The volumetric discharge flow rate of the booster pump, QDISB , gpm, can be determined from the expression:

$$QDISB = QDIS + QFL \tag{42}$$

The maximum specific gravity of the booster pump discharge slurry, SGDISB , is calculated from the expression

$$SGDISB = CVMAXB(SGSOL) + (1 - CVMAXB) \tag{43}$$

Step 15: Objective - Calculate the required production flow rate of the clear water supply pump.

Information required - (a) Jet pump supply water flow rate, QSUP , gpm, as determined in Step 5; (b) flushing water flow rate required by booster pump, QFL , gpm (Step 13).

Rationale - The production flow rate of the clear water supply pump is determined principally by the jet pump supply water requirements. Added to this will be the total flow rate requirement for jet pump cutting jets, QJET , if such jets are used. Finally, it may be possible in some cases to provide flushing water for the booster pump from the clear water supply pump. In such cases, this flow rate must also be added to the required clear water supply pump flow rate. Before finalizing a design using such a flushing water system, however, it would be advisable to contact the booster pump supplier about his specific requirements.

Method - The value of QJET has not been determined, but as a general rule, the relationship

$$QJET = 0.2(QSUC) \tag{44}$$

will provide a realistic estimate.

The required total volumetric flow rate of the supply pump, QSUPT , is given by the expression

$$QSUPT = QSUP + QJET + QFL \tag{45}$$

Note - QJET and QFL should be included in this calculation only if they are to be provided by the supply pump. The ultimate feasibility of providing QFL with the supply pump will not be known until the supply pump discharge head is calculated and compared with the booster pump discharge head.

It should be noted that in most cases the quantity QFL will be included in the pump suction water, but will be removed and introduced into the booster pump very near the supply pump discharge flange. Therefore, for the purpose of calculation, QFL is included in supply pump suction flow but not in the flow between supply pump and jet pump.

Step 16: Objective - Calculate the required total dynamic head of the clear water supply pump.

Information required - (a) Inside areas of supply pump suction and jet pump supply pipes, ASUPS and ASUPD, ft^2; (b) inside diameters of supply pump suction and discharge pipes, ft; (c) equivalent lengths of supply pump suction and jet pump supply pipelines, LSUPS and LSUPD, ft; (d) description of hydraulic characteristics of supply pump suction and discharge pipes; (e) required total production flow rate of clear water supply pump, QSUPT, gpm (Step 15); (f) elevation of supply pump, ZSUP, above water-surface datum, ft; (g) jet pump supply head, HSUP (Step 10), in feet of water; (h) supply flow to the jet pump, QSUP, gpm (Step 11); (i) supply flow to jet cutting assists, QJET, gpm (Step 15); (j) expected flushing water requirement, QFL, gpm (Step 13).

Rationale - The total dynamic head, or total head as it may be called, of the clear water supply pump represents the energy imparted by the supply pump to the liquid. This energy can take the form of a change in elevation, velocity, or pressure of the liquid being pumped. The sum of these changes expressed in feet of water is, by definition, the total dynamic head of the pump. For a centrifugal pump supplying water to a submerged jet pump, the change in elevation of water passing through the centrifugal pump is zero. The change in velocity may be approximated by the velocity head in the centrifugal pump discharge pipe. The change in pressure is due to two factors: (a) the required supply head HSUP at the jet pump and (b) the total frictional losses in the centrifugal pump suction and discharge pipelines.

Method - Use the method described in Step 8 for calculating the rate of head loss per unit length of pipeline for fluid flow (the Darcy-Weisbach formula). This method should be applied separately to the centrifugal pump suction and discharge pipelines. Velocity in the suction pipeline, VSUPS , fps, can be calculated by:

$$VSUPS = \frac{QSUP + QJET + QFL}{(448.831)(ASUPS)} \qquad (46)$$

Velocity in the jet pump supply pipeline, VSUPD , fps, can be obtained from:

$$VSUPD = \frac{QSUP + QJET}{(448.831)(ASUPD)} \qquad (47)$$

As in Step 15, QJET and QFL should be included in these calculations only when they are to be provided by the supply pump. QFL is not included in VSUPD calculations since it is normally removed from the discharge pipeline shortly after leaving the supply pump.

Using the appropriate values of velocity, inside diameter, and hydraulic characteristics, head loss rates per unit length should be calculated for the suction pipeline $(\Delta h/\Delta L)_{WSS}$ and jet pump supply pipeline $(\Delta h/\Delta L)_{WSD}$. Then, the total head loss in the supply pump suction pipeline, HWSS , in feet of water, can be calculated by:

$$HWSS = \left(\frac{\Delta h}{\Delta L}\right)_{WSS} \times LSUPS \qquad (48)$$

An important adjustment to include in LSUPS is an allowance for entrance losses into the suction pipe.

The total head loss in the jet pump supply pipeline, HWSD , can be obtained in feet of water from:

$$HWSD = \left(\frac{\Delta h}{\Delta L}\right)_{WSD} \times LSUPD \qquad (49)$$

The required total dynamic head of the supply pump, TDHS , in feet of water, is then:

$$TDHS = HSUP + HWSS + HWSD \qquad (50)$$

Step 17: Objective - Calculate the available net positive suction head, NPSHA , at the supply pump suction flange.

Information required - (a) Head loss in supply pump suction pipeline, HWSS (Step 16), in feet of water; (b) atmospheric pressure, ATMOS , in feet of water; (c) water vapor pressure, VAP , in feet of water; (d) maximum expected elevation of supply pump suction center line above free water surface, ZSUPM , ft; (e) velocity in supply pump suction pipeline, VSUPS , fps (Step 16).

Rationale - The available net positive suction head represents the absolute pressure in the liquid at the supply pump suction flange above its vapor pressure. Different types of centrifugal pumps require different values of NPSHA at a given operating point in order to avoid cavitation within the pump itself. This required value is often denoted NPSHR . NPSHR varies for a given pump with the operating point.

Method - ZSUPM should take into account low tide, low lake levels, seiches, surges, and the change in water surface due to waves propagating past the suction pipe. In other words, ZSUPM should be the elevation, ft, of the supply pump suction center line above the lowest water level, transient or otherwise, that could reasonably occur during regular pumping operations. The net positive suction head available, NPSHA , of the supply pump can be calculated in feet of water from the expression:

$$\mathrm{NPSHA} = \mathrm{ATMOS} - \mathrm{VAP} - \mathrm{HWSS} - \mathrm{ZSUPM} - \frac{\mathrm{VSUPS}^2}{2g} \tag{51}$$

Step 18: Objective - Select supply pump to drive jet pump system.

Information required - (a) The required total dynamic head of the supply pump, TDHS (see Step 16), in feet of water; (b) the required total flow of the supply pump, QSUPT , gpm (see Step 15); (c) the net positive suction head available at the supply pump suction flange, NPSHA (see Step 17), in feet of water; (d) manufacturers' literature for centrifugal water pumps.

Method - The required operating point of the supply pump has been defined through calculation of TDHS , QSUPT , and NPSHA . Various pump curves from several manufacturers should be examined to locate a pump that can produce the desired operating point for the least shaft horsepower input, and that has a required net positive suction head, NPSHR , at the operating point equal to or less than the value of NPSHA .

Selecting a centrifugal pump inherently involves selecting a particular impeller diameter for that pump. The electric motor or diesel engine used to drive the pump should have a continuous horsepower rating not less than the maximum horsepower that the pump with the selected size of impeller will draw at "runout," or the maximum flow rate shown on the pump curve for that size impeller. For pumps that will be primed by a vacuum method, consideration should be given to specifying mechanical stuffing box seals instead of packing to reduce air leakage into the pump during priming. A horizontally split-case type of pump should be specified wherever possible to facilitate access to the impeller for repair or replacement. Corrosion-resistant materials should be specified for use in saltwater environments.

Step 19: <u>Objective</u> - Select booster pump to deliver slurry to discharge site.

<u>Information required</u> - (a) Required total dynamic head of the booster pump, TDHB (see Step 14), in feet of water; (b) required total flow rate of the booster pump, QDISB , gpm (see Step 14); (c) specific gravity of booster pump mixture, SGDISB (see Step 14); (d) sediment d_{50} grain size, mm; (e) maximum concentration of solids in the booster discharge pipeline, CVMAXB (see Step 13); (f) manufacturers' literature on dredge pumps.

<u>Rationale</u> - The terminology "booster pump" has been used to describe the pump that has the responsibility of supplying the majority of energy needed to deliver the mixture of bypassed sand and water to the discharge site. In actuality, the pump selected will probably be a dredge pump, which is a centrifugal pump that is specifically designed with large internal clearances and specially hardened and strengthened parts to allow handling of solids. Selection of the dredge pump is essentially the same as selection of the clear water supply pump in Step 18. The difference is that the presence of solids in the dredge pump has the combined effects of reducing the efficiency of the pump while increasing the horsepower required to convey a certain flow rate at a certain discharge pressure. Dredge pump performance curves are usually given for clear water pumping. Therefore, the information available from these curves must be corrected to account for the effects of solids.

<u>Method</u> - The first step is to convert the total dynamic head of the booster pump, TDHB , which is in feet of

water, into feet of mixture, TDHBM . This is done by using the relationship:

$$\text{TDHBM} = \frac{\text{TDHB}}{\text{SGDISB}} \tag{52}$$

Next, the ratio of efficiency when pumping slurry, EMIX , to efficiency when pumping water, EW , is determined by entering Figure 35 with the sediment d_{50} grain size and determining the ratio of EMIX/EW that corresponds to CVMAXB . The total dynamic head is then corrected for this decrease of efficiency by the relationship:

$$\text{TDHBME} = \frac{\text{TDHBM}}{\frac{\text{EMIX}}{\text{EW}}} \tag{53}$$

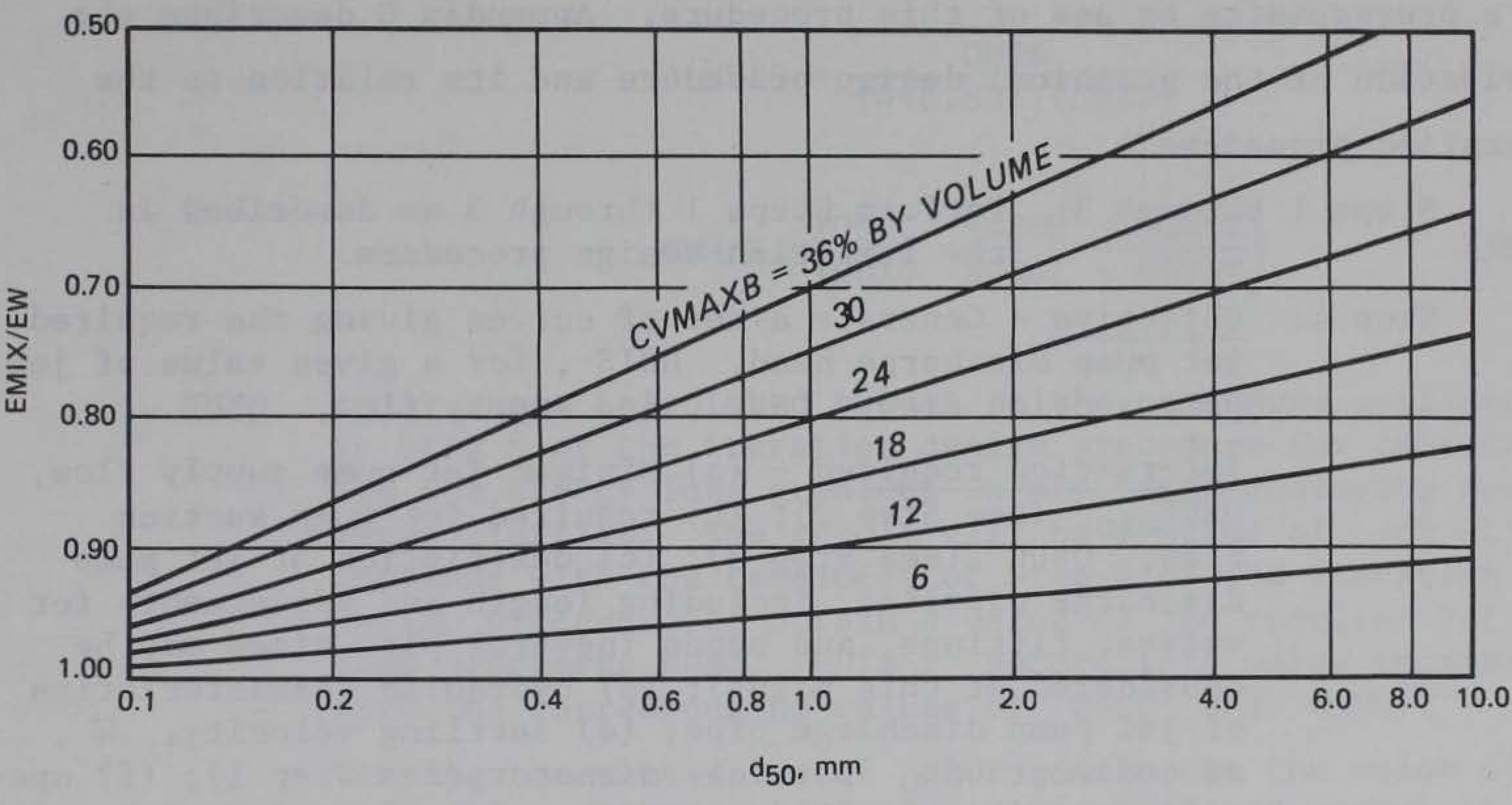


Figure 35. Ratio of efficiency mixture/efficiency water versus grain size (after Stepanoff 1969)

Select a pump by entering the manufacturer's pump performance curves for water with the required total dynamic head corrected for specific gravity and efficiency, TDHBME , and with the total flow required of the booster, QDISB .

The input shaft horsepower indicated at this point on the manufacturer's curves for water will represent the power required to pump water, BHPW . This must also be corrected to account for the heavier mixture being pumped. Assuming that the dredge pump will be operating near its point of peak efficiency, the required horsepower to pump the mixture, BHPM , is given by the relationship

$$BHPM = BHPW(SGDISB) \tag{54}$$

Graphical Design Procedure

85. This design procedure incorporates portions of the iteration design procedure. Such portions will not be repeated here but simply referred to. Therefore, familiarity with the iteration design procedure is a prerequisite to use of this procedure. Appendix C describes the derivation of the graphical design procedure and its relation to the iteration procedure.

Steps 1 through 3: Perform Steps 1 through 3 as described in the iteration design procedure.

Step 4: Objective - Generate a set of curves giving the required jet pump discharge head, HDIS , for a given value of jet pump suction flow, QSUC , and supply flow, QSUP .

Information required - (a) Minimum jet pump supply flow, $QSUP_{min}$ (see Step 2); (b) required jet pump suction flow, QSUC (see Step 3); (c) description of jet pump discharge pipeline, including length and adjustments for valves, fittings, and bends (several pipe sizes may be considered at this point); (d) hydraulic characteristics of jet pump discharge pipe; (e) settling velocity, W , of sediment d_{50} particle diameter (see Step 1); (f) specific gravity of solids, SGSOL ; (g) elevation of booster pump suction flange relative to water surface, ZBOO ; (h) estimated design pressure or vacuum at the booster pump suction flange, HSUCB (see discussion of this subject in Step 8 of the iteration design); (i) assumed maximum specific gravity of suction mixture, SGSUC , as discussed in Step 7 of the iteration design procedure.

Rationale - The required discharge head at the jet pump discharge is a function of the discharge flow rate, solids concentration, pipeline characteristics, and conditions at the booster pump suction. By assuming various values for some or all of these parameters, required discharge heads can be calculated for a variety of discharge conditions. Doing this in a systematic manner will result in a table of values that can be used to generate sets of required discharge head curves.

Method - If more than one diameter or material is being considered for the jet pump discharge pipeline, choose a size and type of pipe to begin calculations. Next, choose a starting value of jet pump supply flow, QSUP , equal to or somewhat less than $QSUP_{min}$. Also, choose a starting value of jet pump suction flow, QSUC , which is several hundred gallons per minute less than the QSUC value determined in Step 3.

Using these starting values, perform the following calculations:

$$QDIS = QSUP + QSUC \qquad (55)$$

$$VDIS = \frac{QDIS}{(448.831)(ADIS)} \qquad (28\ bis)$$

$$CVMAX = \left(\frac{QSUC}{QDIS}\ \frac{SGSUC - SGWAT}{SGSOL - SGWAT}\right) \qquad (56)$$

Apply these calculated values to the procedure outlined in Step 8 of the iteration design procedure for calculating the energy loss gradient in pipelines conveying sand/water slurries. The result will be a value of $(\Delta h/\Delta L)_m$. Continue with the remainder of Step 8 of the iteration design procedure to obtain a value of the required jet pump discharge head, HDIS . Record this value together with the corresponding values of QSUP and QSUC .

Keeping the same value of QSUP , increase the value of QSUC by an increment of 100 gpm or less and repeat the above procedure. Continue this process until QSUC is several hundred gallons per minute greater than the Step 3 value, recording each time the corresponding values of HDIS , QSUP , and QSUC .

Next, increase QSUP by an increment of 100 gpm or less and begin the calculation procedure again with the value of QSUC used initially. Execute this entire procedure several times until QSUP is several hundred gallons per minute greater than $QSUP_{min}$. The result will be a set of values of required HDIS corresponding to particular values of QSUC and QSUP for a certain size and type of discharge pipe. This information can be summarized in tabular form. Table 1 shows the hypothetical results of a set of such calculations for the same system layout but with two different sizes of discharge pipe.

The final task in this step is to use the tabulated information to generate a set of curves of QSUC versus HDIS . Figure 36 shows a set of such curves drawn using the information for the 6-in. discharge line in Table 1. Each curve represents a row from Table 1. To be compatible with the scale of the jet pump performance curves discussed in the next step, these curves should be drawn using axes with the following scales:

Horizontal (QSUC): 1 in. = 200 gpm

Vertical (HDIS): 1 in. = 20 feet of water

The curves should be drawn on or transferred to a transparent medium such as tracing paper so they can be used as overlays in the next step.

Table 1

Example: Required HDIS , ft

QSUP gpm	QSUC, gpm 300	400	500*	600	700	800
			6-in. Discharge Pipe			
500	35.6	39.3	43.1	47.1	51.4	62.1
600 ($QSUP_{min}$)	37.4	41.6	45.9	50.4	60.4	68.3
700	40.0	44.6	49.3	58.8	66.5	74.9
800	43.3	48.2	57.1	64.8	73.0	81.9
Heterogeneous flow ←|→ Homogeneous flow						
			8-in. Discharge Pipe			
1100	29.0	31.0	33.0	34.9	36.8	38.7
1200 ($QSUP_{min}$)	29.9	32.0	34.0	36.0	38.0	40.1
1300	31.0	33.1	35.3	37.3	39.5	41.6
1400	32.3	34.5	36.6	38.8	41.0	43.3

* QSUC from Step 3.

Step 5: Objective - Correlate the curves of required HDIS from Step 4 with curves of actual jet pump performance.

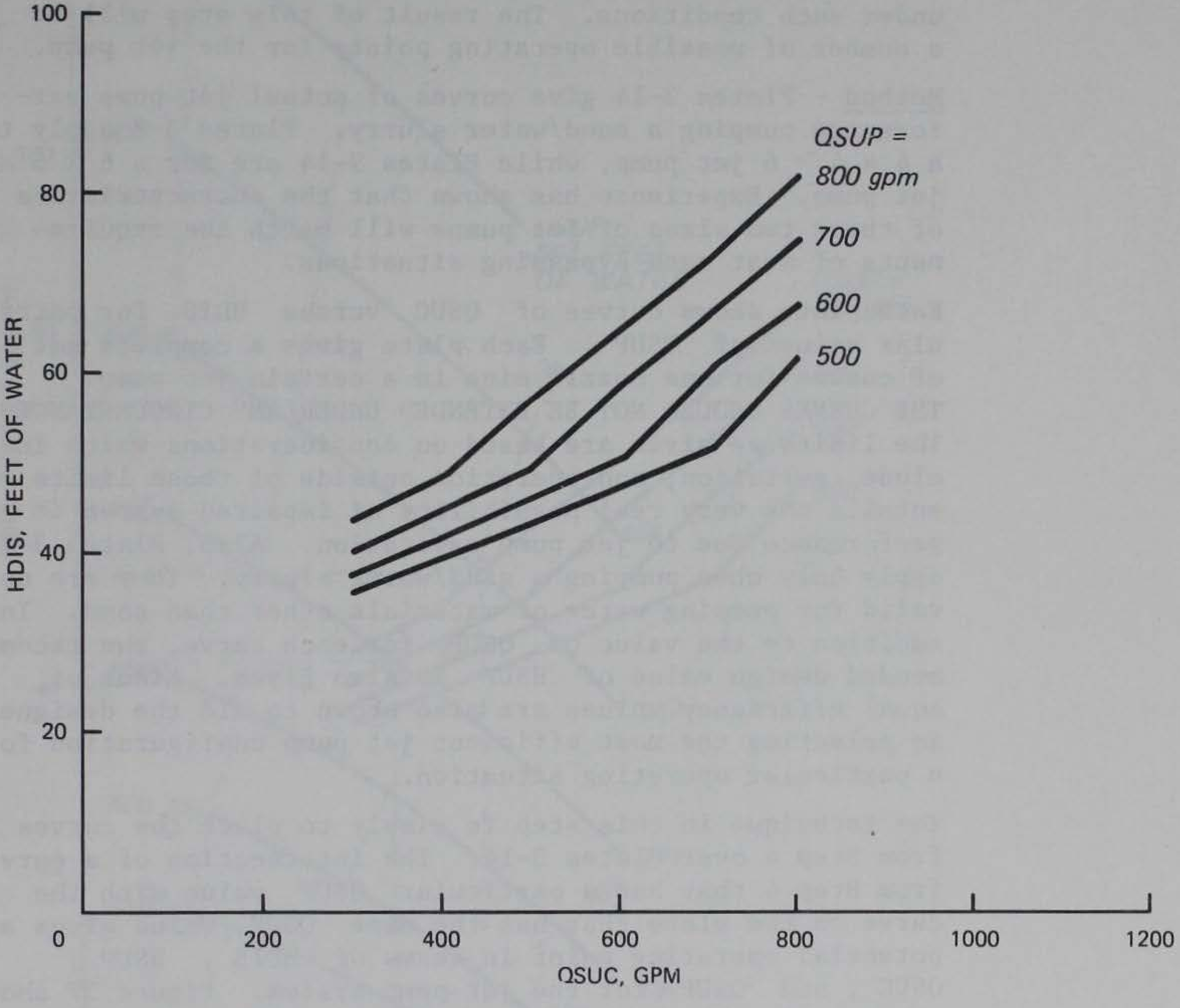


Figure 36. Example jet pump discharge pipeline curves for 6-in. pipe

Information required - Curves from Step 4 drawn on transparent paper.

Rationale - The information calculated in Step 4 is based solely on conditions in the jet pump discharge pipeline. The physics of operation of a jet pump are such that the values of three of its other operating parameters (HSUC , QDIS , and QSUC) also depend in part on conditions in the discharge pipeline. The purpose of this step, therefore, is to match what is required by the discharge piping system with what a particular jet pump is capable of producing under such conditions. The result of this step will be a number of possible operating points for the jet pump.

Method - Plates 3-14 give curves of actual jet pump performance pumping a sand/water slurry. Plates 3-8 apply to a 4 × 4 × 6 jet pump, while Plates 9-14 are for a 6 × 6 × 8 jet pump. Experience has shown that the characteristics of these two sizes of jet pumps will match the requirements of most sand bypassing situations.

Each plate shows curves of QSUC versus HDIS for particular values of QSUP . Each plate gives a complete set of curves for one nozzle size in a certain jet pump. THE CURVES SHOULD NOT BE EXTENDED UNDER ANY CIRCUMSTANCES. The limits as given are based on considerations which include cavitation, and operation outside of those limits entails the very real possibility of impaired system performance due to jet pump cavitation. Also, Plates 3-14 apply only when pumping a sand/water slurry. They are not valid for pumping water or materials other than sand. In addition to the value of QSUP for each curve, the recommended design value of HSUP is also given. Lines of equal efficiency values are also shown to aid the designer in selecting the most efficient jet pump configuration for a particular operating situation.

The technique in this step is simply to place the curves from Step 4 over Plates 3-14. The intersection of a curve from Step 4 that has a particular QSUP value with the curve on the plate that has the same QSUP value gives a potential operating point in terms of HDIS , HSUP , QSUC , and QSUP for the jet pump system. Figure 37 shows the example curves from Figure 36 superimposed on Plate 4. It is seen that two potential operating points have been identified by curve intersections. These operating points are as follows:

a. QSUP = 700 gpm
HSUP = 271 feet of water
QSUC = 350 gpm
HDIS = 42.5 feet of water
Efficiency = 14%

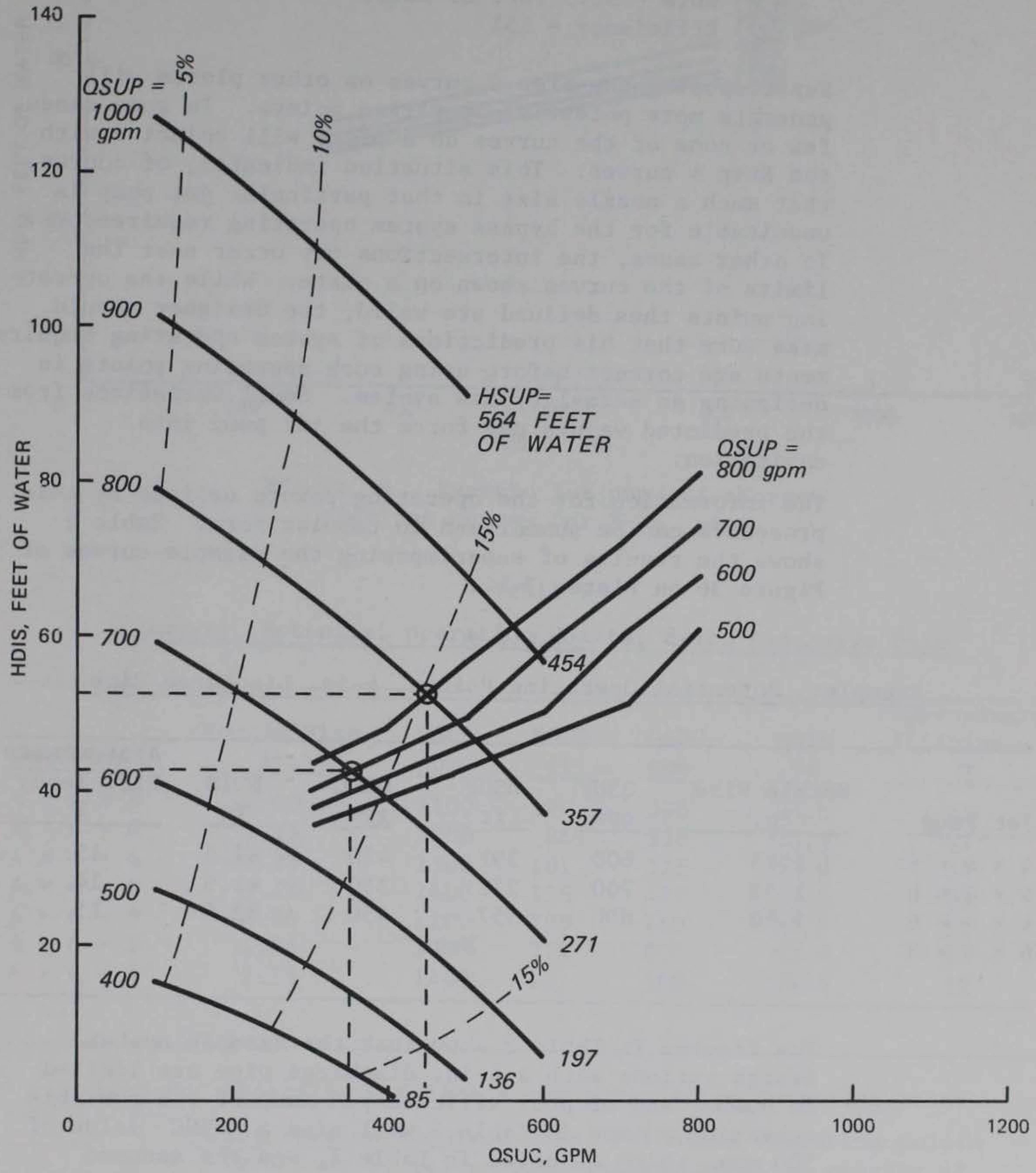


Figure 37. Example jet pump discharge pipeline curves for 6-in. pipe superimposed on Plate 4

b. QSUP = 800 gpm
HSUP = 357 feet of water
QSUC = 450 gpm
HDIS = 52.5 feet of water
Efficiency = 15%

Superimposing the Step 4 curves on other plates will generate more potential operating points. In some cases, few or none of the curves on a plate will coincide with the Step 4 curves. This situation indicates, of course, that such a nozzle size in that particular jet pump is unsuitable for the bypass system operating requirements. In other cases, the intersections may occur near the limits of the curves shown on a plate. While the operating points thus defined are valid, the designer should make sure that his predictions of system operating requirements are correct before using such operating points in designing an actual bypass system. Small variations from the predicted values may force the jet pump into cavitation.

The information for the operating points defined by this procedure can be summarized in tabular form. Table 2 shows the results of superimposing the example curves of Figure 36 on Plates 3-14.

Table 2

Example: Potential Operating Points, 6-in. Discharge Pipe

Jet Pump	Nozzle Size in.	QSUP gpm	HSUP ft	QSUC gpm	HDIS ft	Approximate Efficiency %
4 × 4 × 6	1.25	600	391	420	42.5	13
4 × 4 × 6	1.50	700	271	350	42.5	14
4 × 4 × 6	1.50	800	357	450	52.5	15
6 × 6 × 8			None			

The figures in Table 2 show that the example system design options with a 6-in. discharge pipe are limited in number and of poor efficiency. None of the possible operating points in Table 2 will give a QSUC value of 500 gpm, which as noted in Table 1, was the assumed design value from Step 3.

Figure 38 shows the curves of QSUC versus HDIS from Table 1 for an 8-in. discharge pipe for the same example system. Table 3 gives the results of superimposing these example curves on Plates 3-14.

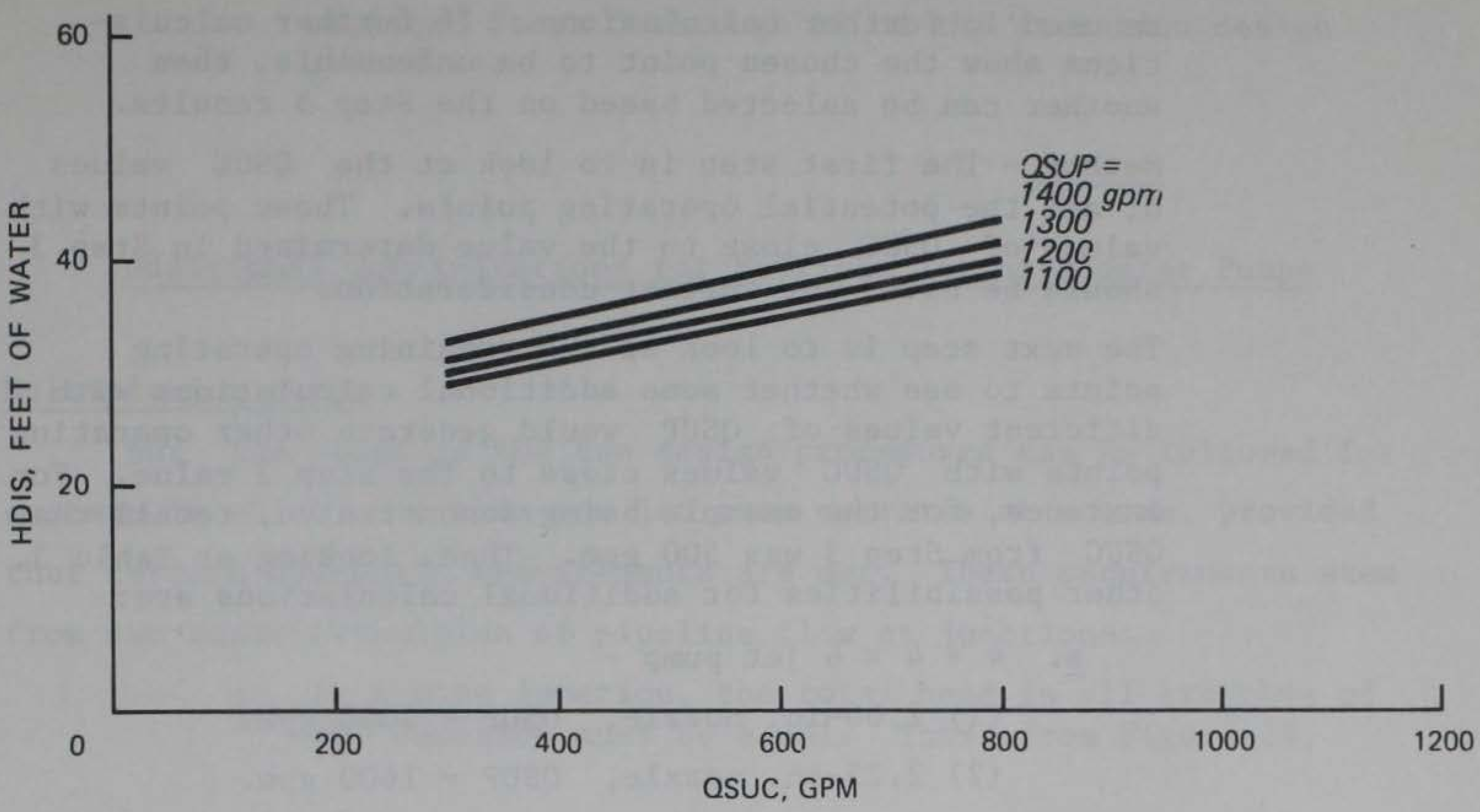


Figure 38. Example jet pump discharge pipeline curves for 8-in. pipe

Table 3

Example: Potential Operating Points, 8-in. Discharge Pipe

Jet Pump	Nozzle Size in.	QSUP gpm	HSUP ft	QSUC gpm	HDIS ft	Approximate Efficiency %
4 × 4 × 6	2.00	1100	180	580	34.5	25
4 × 4 × 6	2.25	1200	86	320	30.5	27
4 × 4 × 6	2.25	1300	101	375	33.0	24
4 × 4 × 6	2.25	1400	118	420	35.0	23
6 × 6 × 8	1.88	1200	299	660	37.0	12
6 × 6 × 8	1.88	1300	354	800	42.0	12
6 × 6 × 8	2.25	1400	207	500	36.5	12

Step 6: Objective - Select a jet pump design operating point.

Information required - (a) Potential operating points from Step 5, (b) assumed maximum specific gravity of suction mixture, SGSUCM , as discussed in Step 7 of the iteration design procedure.

Rationale - A number of potential jet pump operating points were determined in Step 5. This step requires a decision as to which of these points, if any, should be used in further calculations. If further calculations show the chosen point to be unfeasible, then another can be selected based on the Step 5 results.

Method - The first step is to look at the QSUC values of all the potential operating points. Those points with values of QSUC close to the value determined in Step 3 should be noted for further consideration.

The next step is to look at the remaining operating points to see whether some additional calculations with different values of QSUP would generate other operating points with QSUC values close to the Step 3 value. For instance, for the example being demonstrated, recall that QSUC from Step 3 was 500 gpm. Then, looking at Table 3, other possibilities for additional calculations are:

a. 4 × 4 × 6 jet pump -

   (1) 2.00-in. nozzle, QSUP = 1000 gpm.

   (2) 2.25-in. nozzle, QSUP = 1600 gpm.

b. 6 × 6 × 8 jet pump - Efficiencies shown are relatively low; additional calculations would probably not be worthwhile.

The designer should now return to Step 4 and perform the additional calculations indicated by this review. The resulting points together with the ones first noted constitute the group of potential design operating points.

If the potential design operating points identified in this step have uniformly low efficiencies, or if the points with acceptable efficiencies lie near the limits of the applicable jet pump performance curves, the designer may want to reconsider certain aspects of his system layout before proceeding any further. It is important at this point to carry on only with what appears to be a feasible design. Step 5, if performed properly, will show a range of possibilities for a particular design.

If the operating points within this range are inefficient or marginal, then the basic system layout may be at fault.

Once the design point has been selected, the design values of QSUP , HSUP , QSUC , and HDIS are automatically determined. Values of QDIS and CVMAX needed for subsequent calculations can be determined from Equations 55 and 56.

Remaining calculations - The remainder of the graphical design procedure can be accomplished by performing Steps 13 through 19 of the iteration design procedure. In effect, Steps 4, 5, and 6 of the graphical procedure have replaced Steps 5 through 12 of the iteration design procedure.

Additional Considerations for Multiple Jet or Booster Pumps

Multiple jet pumps

86. The steps in the two design procedures can be followed for systems in which more than one jet pump operates at a time, provided that certain hydraulic requirements are met. These requirements stem from two basic principles of pipeline flow at junctions:

a. At a pipe junction, the total head in all branches of the junction must be equal. Thus, from Figure 39,

$$H_1 + \frac{V_1^2}{2g} = H_2 + \frac{V_2^2}{2g} = H_3 + \frac{V_3^2}{2g} \tag{57}$$

b. Total flow away from the junction must equal total flow into the junction. Again, from Figure 39,

$$Q_1 + Q_2 = Q_3 \tag{58}$$

87. Figure 40 shows these two principles as applied to a system of two jet pumps without cutting assists operating simultaneously. The hydraulic requirements that would have to be met are as follows:

a. Supply pipeline

$$HSUP = HSUP1 = HSUPA$$

$$HSUP2 = HSUPA - HWSD_{1-2}$$

$$QSUP = QSUP1 + QSUP2$$

where

HSUP , HSUP1 , HSUPA , and HSUP2 are the total heads at the following respective locations:

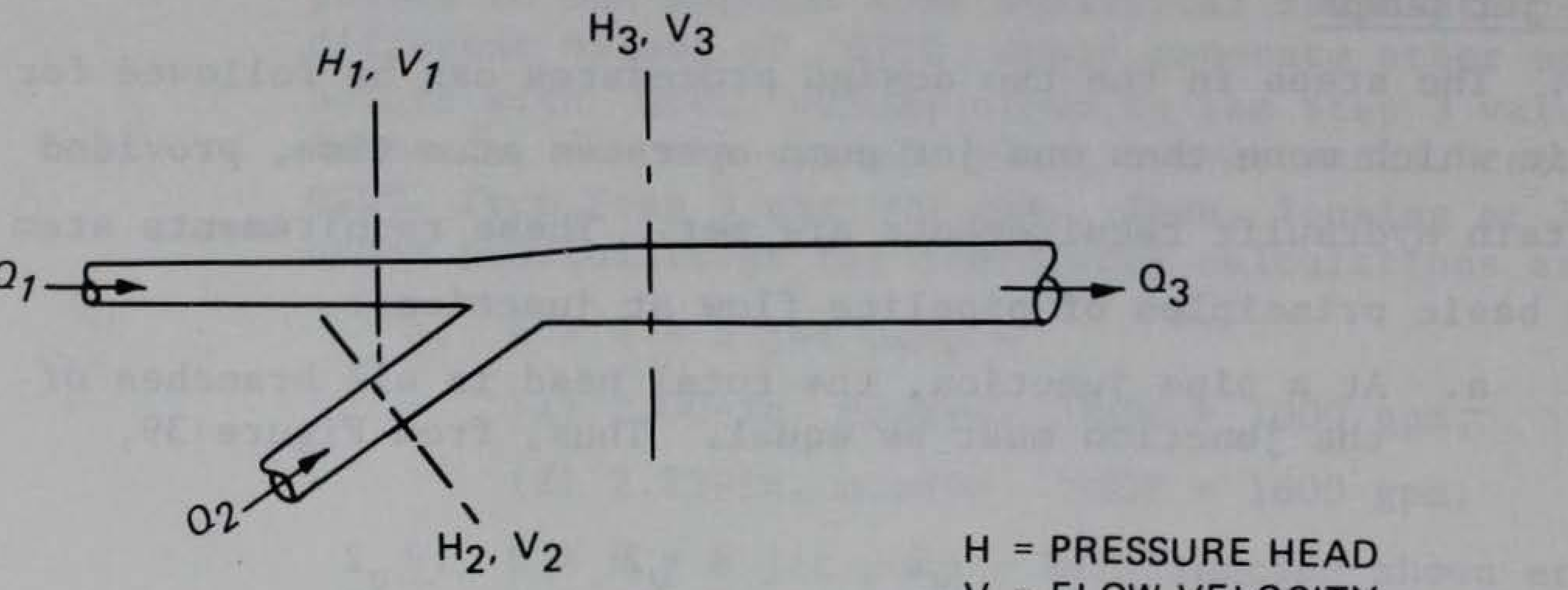


Figure 39. Junction of three pipes

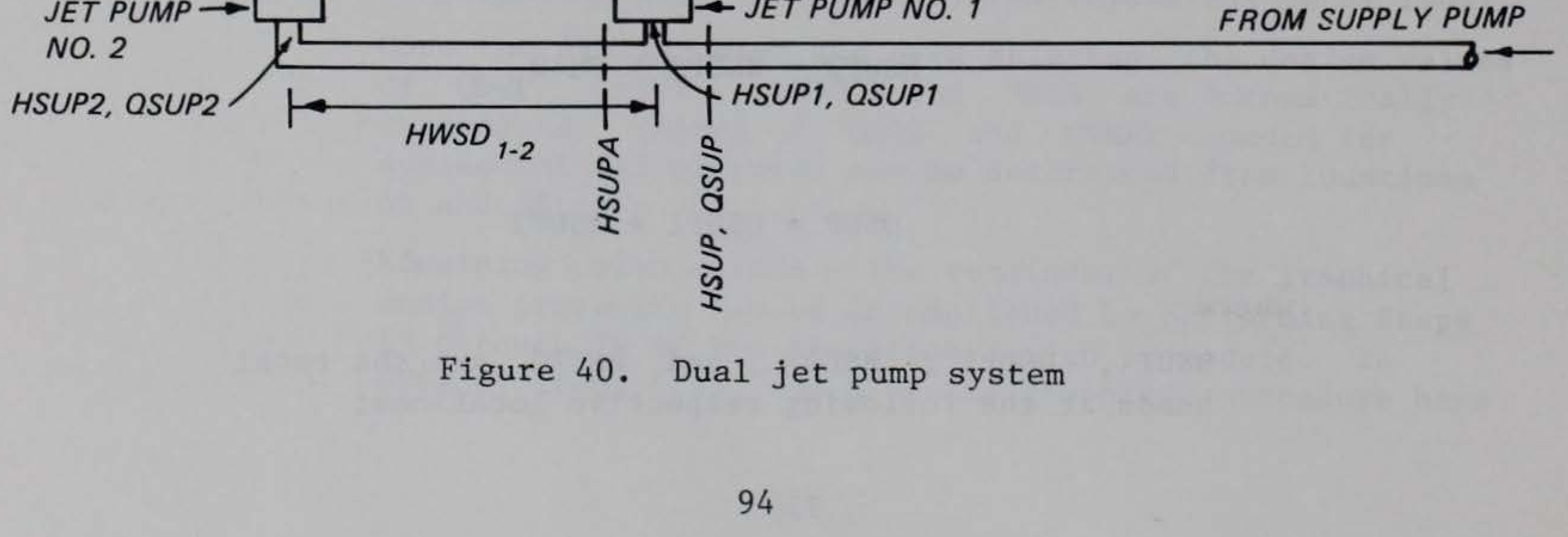


Figure 40. Dual jet pump system

(1) In the supply pipeline immediately before the junction of jet pump #1

(2) At jet pump #1 (on the supply side)

(3) In the supply pipeline immediately after the junction of jet pump #1

(4) At jet pump #2 (on the supply side).

$HWSD_{1-2}$ is the head loss in the supply pipeline between jet pumps #1 and #2

QSUP , QSUP1 , and QSUPA are the volumetric flow rates at the same locations as the respective total heads.

b. Discharge pipeline

$$HDIS = HDIS1 = HDISA$$

$$HDIS2 = HDISA + HMJ_{2-1}$$

$$QDIS = QDIS1 + QDIS2$$

where

HDIS , HDIS1 , HDISA , and HDIS2 are the total heads at the following respective locations:

(1) In the discharge pipeline immediately after the junction of jet pump #1.

(2) At jet pump #1 (on the discharge side).

(3) In the discharge pipeline immediately before the junction of jet pump #1.

(4) At jet pump #2 (on the discharge side).

HMJ_{2-1} is the head loss in the discharge pipeline between the junctions of jet pumps #2 and #1.

QDIS , QDIS1 , and QDIS2 are the volumetric flow rates at the same locations as the respective total heads.

88. The end result of these requirements is to increase the complexity of iterative calculations to determine values of the jet pump operating parameters. The number of iterations can be reduced if as

many system variables as possible are made into constants. Some ways of doing this are:

a. Use the same size jet pump for all jet pumps.

b. Use the same nozzle size in all jet pumps.

c. Space jet pumps equal distances apart where possible.

d. Choose pipe sizes to give similar flow velocities in all branches of a junction.

89. The number of iterations can be reduced further by choosing values of EXC1 for each jet pump that decrease with increasing distance to the booster pump. For instance, in Figure 40, jet pump #2 should have a smaller value of EXC1 than jet pump #1.

Multiple booster pumps

90. Multiple booster pumps located at intervals along the discharge pipeline require additional considerations not needed for a single-booster system. Monitoring, control, and sequencing of booster operation become very important to prevent cavitation or water hammer, either of which can ruin an expensive pump. Designing for a positive pressure head, PHSUCB , at each booster suction will aid in preventing such problems as well as helping keep air out of the discharge system. Booster pumps should be spaced at intervals along the discharge pipeline such that their operating points are roughly the same. Each pump must be provided clear flushing water at a pressure greater than the booster discharge pressure. After the initial hydraulic design, the entire bypass system should be analyzed for the effects of different possibilities, such as plugging a jet pump suction or stopping a booster pump unexpectedly.

91. Two adjustments must be made to the hydraulic design procedure to allow for multiple booster pumps. First, total flow in the discharge pipeline will increase at each booster due to the addition of flushing water. This must be accounted for in determining flow rates, velocities, and solids concentrations at each booster. Second, the total dynamic head required of a booster pump will depend on conditions somewhat different from those considered in Equation 41 of the iteration design procedure. For example, if the first and second boosters in a pipeline are

numbered 1 and 2, Equation 41 becomes:

$$TDHB_1 = HMB_{1-2} - PHSUCB_1 + (ZBOO_2 - ZBOO_1) + PHSUCB_2 \qquad (59)$$

where HMB_{1-2} is the total frictional head loss in the discharge pipeline between boosters 1 and 2. Equation 59 should be used for all boosters in a multiple booster system except the final one, where Equation 41 applies.

PART IV: SUMMARY

92. This report is designed to be used by an engineer or group of engineers with a basic knowledge of coastal processes and a rudimentary knowledge of centrifugal pumping systems. Using this report, such a person or group will be able to perform the following tasks:

- a. Determine the general feasibility of a jet pump remedial sand bypassing system for a specific problem.
- b. Develop the initial layout(s) for a jet pump sand bypassing system.
- c. Perform the basic hydraulic design for such a system.

93. A set of factors relative to tasks a and b are discussed. Detailed instructions are given for aspects of the initial layout such as determining the system effective operating time and capacity. A format consisting of schematic drawings is suggested for presenting the results of the initial layout. Examples of such drawings are shown.

94. The designer is provided with two step-by-step procedures for performing task c. The first procedure, called the iteration procedure, consists of calculating in an iterative manner an operating point for the jet pump portion of the system. Then, the hydraulic characteristics of the total system are calculated linearly. The jet pump operating point reflects the results of the initial layout and is based upon the premises of having a minimum total flow in the system and of achieving a high jet pump efficiency. The second procedure utilizes a set of graphs to replace the iterative part of the first procedure. Use of these graphs gives a number of potential operating points for the jet pump portion of the system. One or more of these operating points is chosen by the designer to use in further calculations.

95. The specialized information resulting from use of this report, together with more routine design data, should allow the designer to estimate the approximate cost of a jet pump sand bypassing system relative to other solutions for a given problem. A subsequent report will provide information about the detailed design, construction, operation, and monitoring of a jet pump system, as well as design examples.

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APPENDIX A: NOTATION

The following notation is used in a general sense in this report:

C_v	Volumetric concentration of solids in a slurry
D	Inside diameter of a pipe
H	Pressure head
h_f	Energy loss due to a pipe fitting
L	Length of straight pipe
Q	Volumetric flow rate
V	Flow velocity

The following notation identifies specific quantities or parameters:

ADIS	Discharge pipe maximum inside area, ft^2
ADISB	Inside area of booster pump discharge pipe, ft^2
ALM	Correction factor for absence of littoral materials
AMIX	Inside area of mixing chamber of jet pump, ft^2
ANOZ	Area of opening at tip of jet pump nozzle, ft^2
ASUC	Inside area of jet pump suction, ft^2
ASUPD	Inside area of jet pump supply pipe, ft^2
ASUPS	Inside area of supply pump suction pipe, ft^2
ATMOS	Atmospheric pressure, feet of water
B	Coefficient in nozzle equation for QSUP , $gpm/ft^{5/2}$
BHPM	Horsepower required by dredge pump pumping slurry
BHPW	Horsepower required by dredge pump pumping water
CVMAX	Expected maximum volumetric concentration of solids in jet pump discharge pipeline
CVMAXB	Expected maximum volumetric concentration of solids in booster pump discharge pipeline
d_{50}	Median diameter of sediment to be bypassed, mm
DEPMAX	Maximum anticipated water depth over jet pump while operating, ft
DEPMIN	Minimum anticipated water depth over jet pump while operating, ft
E	Operating efficiency of jet pump
EMIX	Efficiency of dredge pump pumping slurry

EOT	Effective operating time of jet pump bypassing system over one-year operating period
$EOT_{\Delta t}$	Effective operating time of jet pump bypassing system over interval Δt operating period
EW	Efficiency of dredge pump pumping water
EXC	Required capacity of jet pump bypassing system, cu yd/hr
EXC1	Required capacity of one jet pump in bypassing system, cu yd/hr
EXCMAX	Maximum excavation rate of in situ material by one jet pump, cu yd/hr
f	Dimensionless friction factor used in Darcy-Weisbach formula
F_L	Dimensionless parameter in Durand relationship for critical velocity
g	Acceleration due to gravity, ft/sec^2
HD	Number of working hours in an operating day
HDIS	Total energy head in the discharge pipeline at the jet pump, feet of water
HMB	Total head loss in booster pump discharge pipeline, feet of water
HMJ	Total head loss in jet pump discharge pipeline, feet of water
HSUC	Total energy head in the jet pump suction tube at the jet pump, feet of water
HSUP	Total energy head in the supply pipeline at the jet pump, feet of water
HWSD	Total head loss in jet pump supply pipeline, feet of water
HWSS	Total head loss in supply pump suction pipeline, feet of water
K	Pipe fitting resistance coefficient
LDISB	Total equivalent length of booster discharge pipeline, ft
LDISJ	Total equivalent length of jet pump discharge pipeline, ft
LSUC	Length of jet pump suction tube, ft
LSUPD	Total equivalent length of jet pump supply pipeline, ft
LSUPS	Total equivalent length of supply pump suction pipeline, ft
LSUPSA	Approximate length of supply pump suction pipeline, ft
M	Jet pump flow ratio

M_{op}	Optimum jet pump flow ratio
n	In situ porosity of sediment to be bypassed
N	Jet pump head ratio
N_{max}	Largest possible value of N corresponding to a particular value of M
NOD	Number of operating days per year for jet pump bypassing system
NPSHA	Available net positive suction head at supply pump suction flange, feet of water
NPSHR	Required net positive suction head at supply pump suction flange, feet of water
NUM	The number of jet pumps operated simultaneously in a jet pump bypassing system
PB	Correction factor for pump blockages
PHSUCB	Design pressure or vacuum head at booster pump suction flange, feet of water
Q_L	Average rate of net littoral influx to storage area(s) during interval Δt operating period, cu yd/hr
QDIS	Jet pump volumetric discharge flow rate, gpm
QDISB	Booster pump volumetric discharge flow rate, gpm
QFL	Flushing water volumetric flow rate into booster pump, gpm
QJET	Volumetric flow rate through jet pump cutting jets, gpm
QSUC	Volumetric flow rate into jet pump suction, gpm
QSUP	Volumetric flow rate through jet pump nozzle, gpm
$QSUP_{min}$	Minimum required volumetric flow rate in discharge pipelines of jet pump bypassing system, gpm
QSUPT	Supply pump required total volumetric flow rate, gpm
R	Jet pump area ratio
Re	Reynolds number
RMP	Correction factor for relocation of mobile jet pumps
RR	Correction factor for system repair and replacement
SGDISB	Maximum specific gravity of booster pump discharge slurry
SGDISJ	Maximum specific gravity of jet pump discharge slurry
SGIN	In situ specific gravity of sediment to be bypassed
SGSOL	Specific gravity of sediment solids
SGSUC	Assumed average specific gravity of slurry entering jet pump suction

SGSUCM	Assumed maximum sustained specific gravity of slurry entering jet pump suction
SGWAT	Specific gravity of ambient water
STCAP	Storage capacity of storage area, cu yd
STIN	Initial condition of storage area, cu yd
$STORE_{\Delta t}$	Storage volume available during interval Δt , cu yd
TDHB	Total dynamic head required of booster pump, feet of water
TDHBM	Total dynamic head required of booster pump in terms of mixture being pumped, feet of mixture
TDHBME	Total dynamic head of booster pump corrected for decrease in pump efficiency due to presence of solids, feet of mixture
TDHS	Total dynamic head required of supply pump, feet of water
VAP	Vapor pressure of water, feet of water
VCRIT	Minimum velocity necessary to maintain solids in suspension in discharge pipelines, fps
VDIS	Velocity in jet pump discharge pipeline, fps
VDISB	Velocity in booster pump discharge pipeline, fps
VHOM	Velocity of transition between heterogeneous and homogeneous flow regimes, fps
VNOZ	Velocity of water jet at tip of jet pump nozzle, fps
VSUC	Velocity of mixture in jet pump suction tube, fps
VSUPD	Velocity in jet pump supply pipeline, fps
VSUPS	Velocity in supply pump suction pipeline, fps
W	Settling velocity of the d_{50} particle of sediment to be bypassed, fps
X	Ratio of VSUC to VNOZ as used in cavitation calculations
ZBOO	Elevation of booster pump center line relative to water surface datum, ft
ZDIS	Elevation of end of booster discharge pipeline relative to water surface datum, ft
ZSUP	Elevation of supply pump center line relative to water surface datum, ft
ZSUPM	Maximum expected elevation of supply pump suction center line above free water surface, ft
$(\Delta h/\Delta L)_m$	Head loss per unit length of pipeline for slurry flow
$(\Delta h/\Delta L)_w$	Head loss per unit length of pipeline for fluid flow

$(\Delta h/\Delta L)_{WSD}$ Head loss per unit length of pipeline for jet pump supply pipeline

$(\Delta h/\Delta L)_{WSS}$ Head loss per unit length of pipeline for supply pump suction pipeline

Δt Time interval of the bypassing season, hr

ε Equivalent roughness of pipe wall (Nikuradse roughness), ft

ν Kinematic viscosity of fluid, ft^2/sec

APPENDIX B: ADDITIONAL EQUATIONS

Colebrook-White Equation

1. For the range of conditions covered by this report, the friction factor, f , used in the Darcy-Weisbach formula for energy loss in pipe flow can be found via an iterative solution to the Colebrook-White equation:

$$\frac{1}{\sqrt{f}} = -2 \log\left(\frac{2.51}{Re\sqrt{f}} + \frac{\varepsilon}{3.71D}\right) \tag{B1}$$

where

$Re = VD/\nu$, the Reynolds number

V = average flow velocity in pipe, fps

D = inside diameter of pipe, ft

ν = kinematic viscosity of fluid, ft^2/sec

ε = equivalent roughness of pipe wall, sometimes called "Nikuradse roughness," ft

2. Values of ε for different pipe materials can be found in standard references on fluid flow in pipes. Values of ν can be found in hydraulic handbooks or similar references.

3. To solve Equation B1 by iteration, begin with an assumed value for f , say 0.007. Using this assumed value, solve the right-hand side of the equation. The result will be of the form:

$$\frac{1}{\sqrt{f}} = C \tag{B2}$$

where C is the value of the right-hand side of Equation B1 using the assumed value of f and the appropriate pipe characteristics and flow conditions.

4. Next, solve Equation B2 for f . If this value of f and the assumed one are reasonably similar (say within 0.0005 of each other), f has been determined. If not, repeat the iteration process using f from Equation B2 as the assumed value. The iteration should converge

to an acceptable degree of accuracy in a few such calculations.

5. Obviously, this process is easily adapted to a computer, eliminating the need for a Moody diagram.

Equivalent Lengths

6. For pipe fittings not included in tables of equivalent lengths, the energy loss h_f is often given by an equation of the form:

$$h_f = K \frac{V^2}{2g} \tag{B3}$$

where K is a resistance coefficient for a particular fitting type and size.

7. For straight pipe, an equation in common use for calculating energy losses is the Darcy-Weisbach equation in the form:

$$h_L = f \frac{L}{D} \frac{V^2}{2g} \tag{B4}$$

where

h_L = energy loss in straight pipe

f = friction factor

L = length of straight pipe

D = pipe inside diameter

8. Equating Equations B3 and B4, an expression for an equivalent length can be obtained:

$$L = \frac{K \cdot D}{F} \tag{B5}$$

where L now represents the length of straight pipe of inside diameter D equivalent to a fitting with resistance coefficient K and the same nominal pipe size.

9. For steel pipe and the range of flow velocities and pipe sizes commonly encountered in jet pump bypassing systems, Equation B5 can be approximated by:

$$L = \frac{K \cdot D}{0.014} \qquad \text{(B6)}$$

10. Equation B6 will give an estimated equivalent length of steel pipe of inside diameter D for a fitting of the same nominal pipe size with resistance coefficient K .

11. For pipelines made of material other than steel, the method of equivalent lengths is more difficult to apply. In such cases, it is suggested that losses for fittings be calculated by Equation B3. These losses can then be added to the losses for straight pipe calculated by the Darcy-Weisbach equation to obtain the total pipeline energy loss.

APPENDIX C: DERIVATION OF GRAPHICAL DESIGN CURVES

1. The purpose of this appendix is to show, briefly, how the design curves of Plates 3 through 14 (main text) were derived from equations outlined in the iteration design procedure.

2. The dimensionless parameters describing the performance of a jet pump with a certain area ratio R are given by Equations 1 and 2:

$$N = \frac{HDIS - HSUC}{HSUP - HDIS} \tag{1 bis}$$

$$M = \frac{QSUC}{QSUP} \tag{2 bis}$$

3. The relationship between these parameters is assumed to be of the form:

$$N = a \cdot M + b \tag{C1}$$

which is the equation for a straight line where a and b are constants. The values of these constants can be obtained from the M versus N relations shown in Plate 2.

4. Substituting Equations 1 and 2 into Equation C1,

$$\frac{HDIS - HSUC}{HSUP - HDIS} = a\left(\frac{QSUC}{QSUP}\right) + b \tag{C2}$$

5. The relationship between QSUP , HSUP , and HSUC must satisfy Equation 33:

$$QSUP = B(ANOZ)\sqrt{(HSUP - HSUC)} \tag{33 bis}$$

From Equation 34,

$$ANOZ = f(R\ ,\ AMIX) \tag{C3}$$

For a given jet pump size, AMIX is constant. For a given R value, B is constant (see tabulation on p 73 of main text). Therefore, for a given jet pump size and R value,

$$QSUP = f(HSUP\ ,\ HSUC) \tag{C4}$$

6. Equation 31 gives a suggested expression for calculating HSUC :

$$HSUC = \frac{VSUC^2}{2g} - \left[2LSUC + 4\left(\frac{VSUC^2}{2g}\right)\right] \tag{31 bis}$$

For a given jet pump size,

$$VSUC = f(QSUC) \tag{C5}$$

7. Therefore, for a given jet pump size and assumed LSUC value,

$$HSUC = f(QSUC) \tag{C6}$$

Equation C4 can now be rewritten:

$$QSUP = f(HSUP\ ,\ QSUC) \tag{C7}$$

or

$$HSUP = f(QSUP\ ,\ QSUC) \tag{C8}$$

8. Substituting Equations C6 and C8 into Equation C2,

$$\frac{HDIS - f(QSUC)}{f(QSUP\ ,\ QSUC) - HDIS} = a\left(\frac{QSUC}{QSUP}\right) + b \tag{C9}$$

9. Equation C9 is the basis for the design curves of Plates 3-14. It contains three variables (HDIS , QSUC , and QSUP) and two known constants (a and b). By holding one variable constant, a unique relationship is defined between the other two variables. The

graphical design curves were generated by holding QSUP constant and solving for HDIS for different values of QSUC . Then, the value of QSUP was changed, and the process repeated. The only departure from the iteration design procedure was in assuming a certain LSUC value. However, this assumption can be shown to have a minimal effect on the calculated value of HDIS .

10. The values of HSUP shown on the graphical design curves were calculated using a rearranged form of Equation 33:

$$\mathrm{HSUP} = \left[\frac{\mathrm{QSUP}}{\mathrm{B(ANOZ)}}\right]^2 + \mathrm{HSUC} \qquad \text{(C10)}$$

11. For a given jet pump size and R value, if HSUC is held constant in Equation C10, then HSUP depends only on the value of QSUP . For each design curve shown in Plates 3-14, the value of HSUC at the curve midpoint was used as a constant in calculating HSUP from Equation C10. Therefore, the value of HSUP given for each curve is exactly correct at the curve midpoint, with an increasing error toward either end of the curve. The magnitude of this error at the curve ends, in most cases, is in the range of 5 percent. For any design operating point, therefore, the error involved in using an HSUP value from the graphical design curves instead of one rigorously calculated from the iteration procedure will be much less than the error envelope of the entire design process.