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INLAND LAKE DREDGING EVALUATION

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INLAND LAKE DREDGING EVALUATION

By Ned D. Pierce

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FOREWORD

This study was undertaken to survey inland lake dredging projects that have been accomplished in the Great Lakes region. The results of this survey are presented here, along with a discussion of factors to be considered in lake dredging and methods of sediment removal.

This report should not be interpreted that the Department of Natural Resources is promoting dredging. Because of the wide spectrum of natural resource values characteristic of inland lakes, any proposal for dredging must be appraised on its own merits. In this respect, a major consideration is the preservation of undisturbed shallow water habitat to adequately protect fish, wildlife and scenic values.

L. P. Voigt
Secretary
Department of Natural Resources

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Edited by Ruth L. Hine

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CONCLUSIONS

1. Public awareness of the need for lake rehabilitation has increased markedly in the past ten years. This awareness is creating definite interests in lake dredging throughout the upper Midwest. Dredging can increase the amount of "usable" lake area, can be used in some situations for control of rooted aquatic plants, and may in some circumstances result in improved water quality. However, little information is available in the literature on equipment and techniques previously used or on the effects of dredging on the total lake environment.
2. A survey of 49 inland lakes and ponds was conducted to accumulate information on relatively small lake-dredging projects that have been undertaken in the Great Lakes Region and to evaluate various considerations involved in accomplishing a lake-dredging project.
3. Highlights of the survey were:
   a. **Past experience:** There is no finished lake-dredging project in the upper Midwest from which complete and reliable data can be obtained on the effect of lake dredging on the total lake environment.

   b. **Costs:** When all costs are included, contract unit prices for lake dredging vary from $0.45 to $1.00 per cubic yard of material removed. The major factors influencing costs are: (1) the project size, (2) the type of material to be excavated, (3) distance to disposal sites, and (4) the availability of properly equipped dredging contractors.

   c. **Disposal:** The procurement of adequate disposal areas for the dredged material is a major problem in lake dredging.

   d. **Obstructions:** Obstructions in the lake, such as stumps and boulders, can be excavated, removing only those which can be readily handled with land-based equipment. The presence of these obstructions will increase the project cost.

      In some instances, bog can be removed with the hydraulic cutterhead dredge, and in others, it can be loosened with the dredge, floated to shore and removed with a crane.

   e. **Equipment:** The hydraulic cutterhead dredge is used almost exclusively for underwater lake excavation. Normal dry-land-excavation equipment, such as the dragline, is mainly used on small shoreline improvement projects.

   f. **Sponsorship:** The majority of lake-dredging projects which have been concerned with improvement of the entire lake were sponsored by state and local government units. Numerous small projects, however, have been concerned only with the littoral zone and have been carried out largely by private individuals or organizations.

4. State government should encourage lake dredging when no adverse environmental influences will result. Lake dredging is too expensive for riparian owners to pay the entire cost of a complete lake-dredging project. A cost-sharing plan, by which governmental bodies pay at least a portion of the cost, is necessary if other than nominal short-term benefits are to be achieved.
5. Initiation of a lake improvement project will normally come from persons owning frontage property who have formed into a citizens' group. Contact with local and state governments results usually in a contract for or direct provision of necessary technical and construction services.
6. A study must be made of all biological and physical conditions which may contribute to the eutrophic status of the lake in order to effectively determine the scope, requirements, and possible benefits of a lake dredging plan. This study should include: an assessment of erosion in the lake watershed, analysis of both surface and ground water as they affect the lake and the effect of dredging on them, hydrographic mapping of the lake, and sampling of the lake bottom.
7. Lake dredging can be accomplished through either dry land excavation or underwater dredging. In order to decide upon the most feasible method to use it is essential that the physical factors of the lake basin be studied in conjunction with the types of excavation equipment available.
   a. Dry land excavation is accomplished by mechanical dredging equipment operated from shore or directly on the dewatered bottom. The most commonly used equipment for operation from the shore is the track-mounted dragline. Most lakes that have been dewatered prior to excavation are artificial lakes and millponds.
   b. Underwater dredging is accomplished by either mechanical or hydraulic dredges, which operate from the water surface. Mechanical dredges include: the dipper, clamshell and the bucket-ladder types. Hydraulic dredges include the dustpan, hopper and cutterhead dredges. The majority of lake-dredging projects completed to date have been accomplished with hydraulic cutterhead dredges.

INTRODUCTION

The continued deterioration of many lakes in the Upper Great Lakes Region is a principal cause for concern by many responsible citizen and governmental groups. It is becoming more apparent that strict management and renewal techniques are necessary to protect and improve our limited surface water resource. Dredging, as one method of renewing a lake, is believed to have merit in improvement of the lake environment. Lake dredging on a large scale is a recent innovation. Literature on the dredging industry is meager, and literature on the application of hydraulic dredging to lake improvement is almost nonexistent.

The purpose of this study was to survey inland lake-dredging projects that have been accomplished in the Great Lakes Region. The information accumulated was then evaluated in an attempt to arrive at conclusions on the methods available for lake dredging, problems encountered and the anticipated costs.

In this report the results of the survey are briefly presented, followed by a discussion of the factors to be considered in lake dredging and the methods of sediment removal. A hypothetical example of the steps involved in analyzing a lake-dredging proposal appears in the Appendix.

The intent is to provide background information and guidelines to scientists, resource managers, other technicians and interested citizens who are concerned with problems of lake renewal.

REVIEW OF SURVEY FINDINGS

Investigation of 49 lakes and ponds reveals that there is no finished lake dredging project in the upper Midwest which offers complete and reliable data. Especially lacking is basic information relating to the effects of dredging on the ecosystem of a lake. There is also presently very little concern relating to how dredging can or does improve a lake environment, or, most importantly, to possible damages that may result from lake dredging.

Lake-dredging projects which included dredging of the entire lake are almost always accomplished through a state or local government. Most of these are located close to large population centers where frontage property has high value.

There have also been numerous minor lake-dredging projects which were concerned with improvement of the littoral zone only. In many instances, these projects included only several hundred feet of the lake shoreline. These small-scale projects have been handled by private individuals or organizations. Riparian owners, who are usually the instigators of a lake-dredging project, are mostly concerned with improvement of the beach and shoreline areas. If the project improves the beaches for swimming and permits unrestricted usage of boats, they are quite satisfied in that easily defined benefits have resulted.

Present scientific and technical knowledge of lakes and the lake environment has been applied to only a very limited extent to lake-dredging projects in the past. Some of the lake-dredging projects which were investigated and for which information was obtainable are summarized in Table 1 (Appendix A). Information in the table is often incomplete. In the majority of cases, the volumes of material removed were estimated using expected hourly dredge production as a basis. This, of course, results in construction unit costs which are based on estimates of production rate.

A discussion of the important points relating to some of the surveyed projects is also presented in Appendix A.

Costs

Cost data on completed lake-dredging projects are difficult to obtain and in most cases are unreliable. Unit costs for removal varied from a low of $0.10 to a high of $1.32 per cubic yard of material removed. Most of the projects which show prices at the low side of this range were accomplished by governmentally owned dredge equipment and did not include all project costs such as engineering, administrative, maintenance, depreciation and disposal site costs.

Anticipated excavation costs for an average project which includes in excess of 50,000 cubic yards of excavation would be from $0.45 to $0.75 if done on a contract basis. As the size of the project increases, the unit cost will normally decrease to the low side of this range. Projects smaller than 50,000 cubic yards can be expected to cost between $0.60 and $1.00 per cubic yard of material removed. Factors which have the greatest effect on the project cost are the project size, the type of material to be excavated, the distance from the lake to disposal sites and the availability of properly equipped dredging contractors. If materials being pumped are highly abrasive, contractors — when formulating their bid — will add in the cost of replacement pumps and other equipment which is expected to need replacement. Percentage wise, this can have a great effect on the total cost of smaller-size projects. Additional costs such as engineering, legal, administrative, and those incurred by disposal sites would be in addition to the above values. If the work were done by force account, savings might be realized in contractor's profit.

Critical Factors

Disposal Sites

The most prevalent problem in lake-dredging projects is the lack of availability of adequate disposal sites. As the project size increases, this problem becomes more pronounced and can result in material increase of the project cost. If adequate disposal sites are not located close to the lake, booster pumps in a hydraulic dredge discharge line may be necessary or increased haul distances will result. This will increase the project cost. In cases where disposal sites result in land improvement, the cost of these disposal sites is not charged against lake dredging. Many communities use disposal sites for park purposes and consider this as a secondary benefit from lake dredging.

Obstructions

A second problem encountered in lake dredging is created by the presence of tree stumps, large boulders and refuse. When these items are present, the dredging process is slowed and costs will increase. Normal procedure is to excavate around these obstructions, or to remove them with cranes operated from shore or from a floating barge.

Equipment Alternatives

The hydraulic cutterhead dredge is the most common piece of excavation equipment presently used for lake improvement by dredging. This type of dredge excavates, transports the excavated material and places it at the disposal site. Major attendant equipment required with a hydraulic dredge is a workboat and possibly a dozer at the disposal site. Although its possible advantages are widely known, many considerations necessary for its most economical operation are not widely known. In many instances, common misconceptions and lack of operational knowledge are increasing unit costs. As an example, all of the dredging projects visited used the standard closed-nose basket cutter. Other specially designed devices could more successfully and economically dislodge many materials and direct them toward the suction entrance. Dredge owners do not always give sufficient attention to the type of cutterhead used in the varying materials encountered.

The efficiency of ordinary land-based excavation equipment can be easily observed by counting the trips per hour. A hydraulic dredge is a much more complicated piece of machinery and technical knowledge is required if it is to be operated to its best efficiency under varying conditions. Lake-dredging projects investigated reveal a widespread lack of this required technical knowledge.

Sponsorship

By far the majority of lake-dredging projects which have been concerned with improvement of the entire lake were sponsored by state and local governmental units. It is becoming more common for cities and towns to purchase and operate hydraulic dredges as a renewal and maintenance tool. As these communities use and demonstrate the effectiveness of the hydraulic dredge, more interest is created. Contacts made during this study reveal that many local governments are interested in and considering purchase of hydraulic dredges.

ORGANIZATIONAL STRUCTURE FOR LAKE IMPROVEMENT

Suggested Practice

Initiation of a lake improvement project will normally come from persons owning frontage property on the lake. As they observe continued deterioration and loss of the lake as a desirable resource, interested persons will normally instigate formation of a citizens' group. The purpose of this group will be to create widespread interest in correcting the lake problem and to investigate ways and means of accomplishing their goal. As interest does develop, it is desirable that formal action be taken through a governmental body or a legally created citizens' organization. By this means, funds can be generated for the necessary preliminary phases of the project.

One of the first and most apparent routes for a citizens' group to follow is to contact local and state governmental bodies. The history of various lake improvement projects in the Upper Midwest reveals that, in many instances, state and local governmental bodies act as the project sponsor and either contract for or directly provide the necessary technical and construction services. Projects which involve more than just dredging of shoreline areas on small and medium size lakes are most commonly accomplished through a governmental body. In cases of small projects, where sediment removal is restricted to shoreline areas, the work is normally contracted for and paid for by riparian property owners, either as an informal group or through a lake association.

Most states in the Midwest provide the necessary legal means for creation of a property owners' association. Laws permitting formation of an association are usually governed by the state's corporation laws. Powers of these associations and their ability to appropriate or otherwise raise funds vary from state to state. In some states they are given the power to bond and levy taxes and function as an autonomous governmental body. In other states they do not have diverse powers and obtain their funds through assessment of association members.

In order for an association to operate most effectively, it is desirable that all area property owners who will benefit from an improvement project be enlisted into membership. Attempts should be made to include properties which do not front directly on the lake, but will acquire distinct benefits from the improved lake environment. In some instances, area businesses either become members or at least provide donations to the association. Assessments by the association will have to be based on the benefits received by the various properties.

Under ideal circumstances, a lake property owners' association would include the membership of all benefited area property owners. This can probably best be accomplished by providing the necessary corporate structure prior to sale of the first lot. Provisions, obligations and duties of the association members will then become protective covenants attached to the deeds. Creation of a property owners' association in built-up areas usually results in less than 100% membership. The effectiveness of the association will, of course, be related to the membership percentage of benefited property owners.

The property owners' association can, and should be, a very important organization in the initial and implementation phases of a lake improvement program. Even though the association may not become directly involved in the detailed study or the construction phase, it is their action and persistence which can result in completion of the project. If the association itself acts as the project sponsor and maintains complete control of the project, it is desirable that legal and other professional services be obtained for guidance and advice.

Review of Existing Practices

The extent of involvement in lake improvement projects by the various levels of government is different in most states. In Iowa, the majority of lake renewal and rehabilitation is accomplished at the state level. The Iowa Legislature, in response to public demands and need, appropriates funds and either contracts for the construction or employs state-owned equipment. The situation is unique in Iowa in that there are only a limited number of lakes, and development of a priority system of rehabilitation is not unduly complicated. Other states in the Midwest operate under the doctrine that state funds cannot be used for improvement of privately owned lakes. In these cases, state involvement is confined to advice, review of the proposed improvement, and issuance of the necessary permits.

During 1966, Michigan enacted the Inland Lake Improvement Act of 1966. This act is an outgrowth of the apparent need for improvement of many lakes in Michigan. Under this act, a two-thirds majority of the riparian property owners can petition the local governing body to take the necessary steps for improving the lake. A lake board is appointed and a special assessment district is established. This assessment district includes all parcels of land and local units of government which will be benefited. The lake board has a feasibility report prepared, which includes consideration of the economic and physical characteristics of the proposed lake improvement project. Counties involved in a lake improvement project may provide up to 25% of the improvement cost on any public inland lake.

Lower levels of government, such as counties, towns and cities, are normally vested with the right to perform lake improvement projects. In Wisconsin, riparian owners situated on any one lake can, by a majority vote, petition the town board to make lake improvements. Further, a town board in Wisconsin, upon their own determination, has the right to cause improvements to be made to any lake within the township. The cost of improvement under town board action may be paid for by the town, by riparian property owners on the improved lake, or a combination of both.

Presently, very few towns or counties are actively engaged in lake improvement projects. Since a lake, in most instances, is an area resource and is generally available to the public, town and county involvement should probably be greater. In Wisconsin. the Legislature provides legal means for town involvement in lake improvement and thus implies that towns have a responsibility to improve and protect surface water resources. Impetus to county and town action in this regard will have to come from persons who are concerned about lake resources.

Recent developments indicate that many cities are either actively engaged in lake renewal projects or are considering becoming involved. City-sponsored projects are most commonly handled through the parks department. However, in some instances, the city water utility will accomplish the renewal as a capital investment in their supply works. Lakes within a city are considered as a valuable aesthetic, economic and recreational resource by local citizens, and they will demand and expect that city government preserve and protect that resource. City government has the advantage that the departmental structure is usually at hand and financial means are available to accomplish lake renewal. Financing through city sponsorship is usually handled through an appropriation from the general tax fund so that all citizens participate in payment of the project cost or by direct appropriation from a utility fund.

Many small-size improvement projects are being accomplished. These are usually confined to excavating sediment from beach areas for enhancement of swimming and boating activities. The majority of these projects are contracted for and paid for by the riparian property owners owning frontage in the improved area. In some cases, as few as six property owners band together, hire a contractor, and have their shoreline and beach areas improved. Long-term benefits to the affected area are questionable and beneficial effects on the total lake environment are probably negligible in these instances.

Most states require that a permit be obtained from a delegated state department prior to removal of material from a lake bottom or shoreline area. This procedure is in accordance with state responsibility to preserve and protect our surface water resources. Prior to issuance of a permit for removal of materials, the issuing authority will require information on the subject lake and details of the proposed improvement program. In general, state personnel will be concerned with the effect of the improvement program on the total lake environment. In many instances, the state will require that a hydrographic map of the lake be submitted along with other specific sampling and sounding data. It is, therefore, wise to determine the state requirements prior to commencing a program of field measurements. In addition, some states may require that specific information be submitted on local groundwater conditions and other facets of the lake environment.

CONSIDERATIONS IN LAKE DREDGING

General

In order to effectively determine the scope, requirements, and possible benefits of a lake-dredging plan, it is essential that a study be made of all biological and physical conditions which may contribute to the eutrophic status of the lake. Existing physical conditions greatly influence the method of accomplishing lake dredging and can have a marked effect on the project costs.

A eutrophic lake may be defined as one which is rich in dissolved nutrients, is frequently shallow, and may support rich organic production; at times throughout the year a severe oxygen deficiency may exist in the bottom waters. As these conditions continue to increase in effect, a lake is said to be going through the process of eutrophication. It may be possible to detect a eutrophic lake by observing an increase in water turbidity, increased areas of rooted aquatic plant growth, extensive algae growth, and in some cases the nauseous odor of decaying animal and plant life. These observed conditions are the result of many less apparent changes which are occurring in the water environment. Reversal of a eutrophic condition is difficult to achieve and progress can only be made if the various problem causes are defined and corrected.

The fact that inorganic sediments are present indicates that erosion problems in the lake drainage basin have been or are a cause of the problem. Long-term benefits from removal will be greatest if strict soil conservation plans are devised and enforced throughout the lake watershed. Renewal and maintenance of a desirable lake environment cannot be achieved without total commitment to good soil conservation practices.

Common objectives of lake renewal are to improve the aquatic environment for recreational use and to improve aesthetics of the lake. Past practice indicates that riparian property owners are primarily interested in improvement of the littoral zone for recreational uses such as swimming and boating. Sedimentation along the shallow shoreline, in many instances, makes beaches less desirable and in some lakes precludes all swimming activity; it may also interfere with boating and construction and use of dock facilities. Many eutrophic lakes are characterized by high rates of sediment infilling. In such lakes, fishing may be severely curtailed due to the incidence of summerkill and winterkill.

Deterioration of a lake as a desirable recreational resource can have a compound effect on the total lake environment. Property maintenance and improvement in areas adjacent to a eutrophic lake are many times neglected resulting in a decrease in valuation of the property. In the major population centers, where many of the lake front homes are used as permanent residences, this can have a marked adverse effect on the area economy. In some cases, resale of lake front property is only possible during winter months when the lake is frozen and snow covered, and then at a financial loss. This fact of economics is readily discernible by investigating purchase prices for lake front property. The more desirable a lake is for aesthetics, swimming, boating, and fishing, the higher the price that frontage property will command. This effect on property values should be an important consideration when determining the feasibility of any lake improvement project. A lake with excellent recreational assets, which are available to the public, will promote area business and can have a significant beneficial effect on the total area economy. Development of a highly desirable water resource will increase property values and profits from resale of frontage property.

Sediment Characteristics

Past lake improvement projects indicate that generally the products of sedimentation and organic decomposition are physically quite similar in lakes throughout the upper Midwest. Since sheet, gully and shoreline erosion contribute most to the sedimentation process, the soil characteristics of the lake watershed will be evident in the lake bottom materials. These sediments may combine with the products of organic decomposition and form deposits commonly known as muck. In lakes where little aquatic plant growth is present, the deposited materials below the sediment — water interface may become very dense and exhibit close relationship to the soils in the watershed.

In attempting to define the existing conditions which are contributing to the status of lake sedimentation, an assessment of erosion in the lake watershed must be made. Rainfall on bare soil carries soil particles, organic matter and soluble nutrients to the downstream end of the drainage basin. Since most lakes are the storage areas in a drainage basin, they will receive an abundance of these materials. The Soil Conservation Service can provide valuable assistance in studying the existing erosion conditions and making recommendations on corrective action. Because erosion control of agricultural land is currently not subject to management by state or local government, persuasion and, possibly, some financial assistance from a local source will be the most influential factors in implementing a soil conservation program.

Erosion control of developed riparian land and lake banks will normally be accomplished by the property owners after they are fully informed of the problem and benefits to be derived from bank erosion protection. In some cases, it may be desirable or necessary to acquire riparian property and maintain it in public or semi-public ownership and, through this medium, exercise the necessary controls.

Most commonly, the materials at the sediment — water interface are highly flocculent and may consist of 80%, or more, water. At increased depths in the sediment profile, densities will become greater down to hard lake bottom. These flocculent materials can cause major handling problems if attempts at removal are made with conventional excavation equipment.

Knowledge of the chemical composition of the deposits is important in order to assess the effect of removal on the lake biological community and the effect of the deposits on other environmental factors at the disposal site. The amount of the various chemical constituents present in bottom sediments from different lakes will vary widely. Any study of the chemicals present in the lake bottom materials must also consider the chemical content of the overlying water and the interrelationship between the two. Through study of the various chemicals present, along with their concentration, evidence may be obtained on the sources of nutrients.

The physical characteristics, which will define the depth, location and classification of the sediment, are necessary in considering the most feasible method of removing the material and the total extent of removal.

In cases where sediments are disposed of in upland basins composed of coarse-grained soils, the possibility of groundwater contamination may be an important consideration. As water-borne chemicals from the sediment leach into the ground, the possibility exists that they may enter the groundwater. Consideration will, therefore, have to be given to locating disposal sites so that any adverse effects on local groundwater will be minimized or eliminated.

Other physical and chemical factors of the lake environment which require detailed study are: water temperature, water turbidity, lake area and water volume, hydrology of the lake basin, lake depth, and the interrelationship of all the various physical, chemical, and biological factors.

Hydrological Aspects

When studying existing conditions, due consideration should be given to the hydrological aspects of the lake watershed. This study should include analysis of both surface water and groundwater as they affect the lake, and the effect of lake dredging on the surface water and groundwater. Under certain conditions it may be possible to ruin a lake by removing the bottom seal. It would then be impossible to keep water in the lake. Although the possibility of this occurring in the upper Midwest is remote, necessary investigations should be made to determine if it might be a problem.

If removal of the lake sediments is accomplished with a hydraulic dredge, it is possible to lower the lake level to such an extent that the dredge cannot operate. This is a fairly common problem in small lakes when the dredge water is not returned to the lake. A feasible way to eliminate this problem is to drill a well or wells adjacent to the lake and pump groundwater into the lake. After dredging, these wells can then be used as supply for a local water system.

Lake Mapping

One of the first steps in determination of project feasibility is to estimate the total project cost. In order to accomplish this, it is necessary that a hydrographic map be prepared of the lake bottom. This map should show the elevation of the top of sediment and the depth of sediment. Normal procedure is to take measurements on a grid, or checkerboard pattern, and to reference these measurements to a known datum so that the measurements can be converted to elevations. For adequate accuracy in quantity calculations, water depth measurements should be taken on a 25- or 50-foot grid. When taking measurements, it is important to develop a procedure which results in the required accuracy. If highly flocculent materials are present on the lake bottom, the use of a light-weight disc at the end of a tape can give accurate results. Attempts at measuring with a graduated pole may give grossly inaccurate results as the pole is pushed or sinks into the bottom materials. In some instances, it may be desirable to employ the services of a skindiver in order to visually inspect bottom conditions and to aid in development of accurate measuring techniques.

One of the best ways to obtain hydrographic data is to bore holes through the ice on a grid pattern and measure depths from the ice surface. This eliminates the difficult problem of maintaining a grid pattern from a boat in open water and results in more accurate data. Scheduling of this method should be arranged in the early winter when ice thickness is about 6 inches. Conditions will then be safe and excessive work in boring ice holes will be eliminated. By using an adequate number of personnel, proper equipment, and developing an efficient work procedure, it is possible to obtain data over a large area in a matter of several days. An experienced, fully manned crew should be able to obtain data on 10 to 20 acres of lake surface area per day.

Sounding data, to determine depth of sediment, can be obtained most efficiently by combining it with the water depth measurements. It is then a simple matter to locate the sounding stations from the grid pattern. Also, the work can be more easily accomplished from the ice than from a boat.

Sounding data are obtained by merely pushing a steel rod, usually 3/8-inch to 5/8-inch diameter, into the bottom materials. The primary purpose of sounding data is to determine the elevation of the solid lake bottom and the depth of sediment present. These data are then used to compute the quantity of sediment present.

The spacing of sounding stations will depend on the extent of relief found in the solid lake bottom. Preliminary sounding stations should be widely spaced so that an idea can be obtained on the relief present in the solid lake bottom. It is then possible to determine the final spacing necessary in order to obtain accurate quantity computations. This spacing may vary throughout the project limits, but should be kept to a normal maximum of 50 feet on small- and medium-sized projects. For larger projects in excess of 100 acres, desirable results may be achieved by using a spacing of up to 100 feet. It must be kept in mind that payment for removal of sediment will probably be made on the basis of the quantity of material actually removed. Inaccurate quantity computations, because of insufficient or unreliable field data, can result in grossly inaccurate preliminary cost estimates.

Bottom Sampling

The extent of sampling data required will vary from lake to lake and is dependent on variation in lake bottom soil conditions throughout the project limits. Preliminary, widely spaced sampling stations can be used first in order to make an assessment of the detail required. Generally, the type of sediment present will not vary markedly throughout the lake and something less than twenty sampling stations should suffice. The widest variation will probably be found between samples taken near shorelines and those taken beyond the limits of dense aquatic plant growth.

It is important to make every attempt possible in order to obtain representative samples of the materials present at the various depths. The samples will be used to assess the effect of their removal on the lake environment and in the preliminary analysis of removal costs. In order to obtain reliable sampling data, due consideration must be given to the type of sampling equipment used. There are many different types of soil sampling kits available commercially, such as the Acker peat sampler. Other types which reportedly give better results are not available commercially and must be manufactured locally. The Livingston sampler, or a variation thereof, has proven itself a highly effective tool in obtaining representative samples at shallow and great depths. Figure 1 shows a sketch of a variation of the Livingston sampler. In most

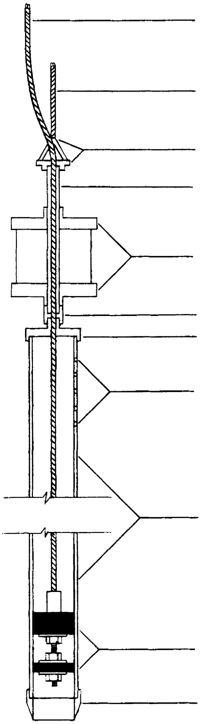


Figure 1.

Variation of Livingston sampler

instances, samples can be obtained by hand operation of the sampling equipment. It is therefore essential that the sampler be light in weight and easily handled.

After sampling has been completed at any one station, and the depth to solid lake bottom determined, the sounding rod is then used to feel the resistance to penetration at that depth. This "feel" can then be correlated with the known materials present and will be the guide in determining solid lake bottom at other stations. There is usually a very definite difference in resistance to penetration when the rod passes through the bottom sediments and contacts the solid lake bottom. The individual operating the sounding rod can develop a sense of "feel" as he observes the resistance to penetration, and he can detect wide variations in the materials present.

METHODS OF SEDIMENT REMOVAL

There are several methods available for dredging material from the bottom of a lake. These methods can be classified as either mechanical dredging or hydraulic dredging. Mechanical dredges are analogous in operating principle to land-based excavation equipment such as the dragline, shovel, or trenching machine, and can be operated from either dry land or the water surface. Hydraulic dredges employ a pump to lift the material from the lake bottom and transport it by boat or pump it through a pipeline to the point of disposal.

Lake excavation can be accomplished by excavating underwater or by draining all or a portion of the water from the lake and excavating in the dry. Underwater excavation can be accomplished with mechanical dredges operated from the shore or with either mechanical or hydraulic dredges floating on the water surface. In order to perform excavation in the dry, it is necessary that an unusual set of circumstances exist which permits draining and refilling of the lake. This set of circumstances is most common in an artificial lake which has been created by damming a stream or river.

Physical factors of the lake basin, the project size, and the project location in the lake will have a great influence in arriving at a decision on the most feasible method to use. Misapplication of the wide variety of excavation equipment available usually results in unnecessary time delays and cost increases. It is, therefore, essential that the physical factors of the lake basin be studied in conjunction with the types of excavation equipment available. Some of the important considerations necessary in determining the type of equipment to use are: (1) Access to the lake and shoreline area and characteristics of the shoreline, (2) location and distance to disposal sites, (3) location and area to be dredged in the lake, (4) original water depth and volume of water present, (5) final water depth required, (6) volume of material to be removed, (7) type of material to be removed, (8) inflow to the lake and outflow from the lake, (9) possibility of lowering the lake level or emptying the lake, and (10) availability of water for lake refilling. One or more of these considerations may immediately rule out some methods of lake excavation as impractical and too costly.

Dry Land Excavation

As discussed here, dry land excavation refers to the operation of excavation equipment from the shore or directly on the dewatered lake bottom. Dry land excavation is accomplished by mechanical dredging equipment.

Dragline

The most commonly used type of dry land equipment for operation from the shore is the track-mounted dragline. The dragline consists of a long boom from which a bucket is suspended. In operation, the machine traverses the shoreline and casts its bucket out into the lake. The bucket is then dragged toward the shoreline and the excavated material is dumped into trucks or to an adjacent disposal site which is within reach of the machine. The distance out into the lake which can be excavated is controlled by the reach of the dragline. A large size dragline can cast its bucket 100 to 125 feet, whereas a small machine may be able to reach only 50 to 75 feet. It is this limited reach which restricts the usefulness of the common dragline to small projects which are concerned with beach improvement only. A second handicap is the inability of a dragline to efficiently handle the flocculent sediments which are most commonly encountered in the upper sediment layers.

The dragline requires stable and level ground adjacent to the lake shore, and wide unobstructed areas for operation of its boom. Without these conditions, the operation will be hindered and highly inefficient, resulting in excessive project cost.

A dragline in operation at Marion, Wisconsin

As a dragline excavates material from the lake bottom and deposits it on shore, it may be necessary to use auxiliary equipment to dispose of the material. Rehandling of the material in this manner will increase the cost and require that more open space be available for the operation. In addition, considerable disruption of frontage property improvements will result in a sizeable cost for restoration.

The dragline, within its own element, is an efficient and profitable piece of excavation equipment. When existing conditions are not conducive to efficient operation of a dragline, project costs will not be commensurate with the benefits achieved in the lake environment. Use of this machine for lake improvement projects has been limited in the past to small projects because of the restrictive conditions under which it must operate, and the marginal benefits which accrue from its restricted reach.

Sauerman Bucket

A second type of excavation equipment which has been used from the shore is known as the Sauerman Crescent bucket (Fig. 2). The Sauerman bucket operates on the same principle as a track-mounted dragline, except that its reach can be extended over greater distances. Essentially, the Sauerman bucket is a specialized design of the common dragline bucket. A major difference between the two is that the Sauerman bucket cannot be used for loading because it has no bottom.

In operation, the bucket is hauled across the lake by two cables and a drum hoist which is mounted on the near shore. The load cable is attached to the front of the bucket and transmits the power for pulling the bucket across the lake bottom. The second cable is known as the track cable and acts as the carrier for returning the bucket toward the far shore. This cable is aerial and is attached to the hoist on the near shore and is anchored on the far shore.

Commencing on the near shore, the bucket is carried all the way or partly across the lake by trolleys on the track cable. The track cable is then slackened off, lowering the bucket and causing it to come in contact with the lake bottom. The bucket is then dragged across the lake bottom from the far to near shore by pulling with the load cable. When the bucket reaches the near shore, the track cable is tightened raising the bucket and emptying the load in front of the hoist. The bucket is then returned to the far shore and the procedure repeated. In order to effectively cover the entire lake bottom, it is necessary that both the hoist and anchor systems be frequently moved.

Maximum practical reach with a Sauerman bucket is about 1,000 feet when using special hoist machinery. This distance is limited by the size of power equipment, spooling capacity of the hoist drums, bucket size, and economical considerations of probable trips

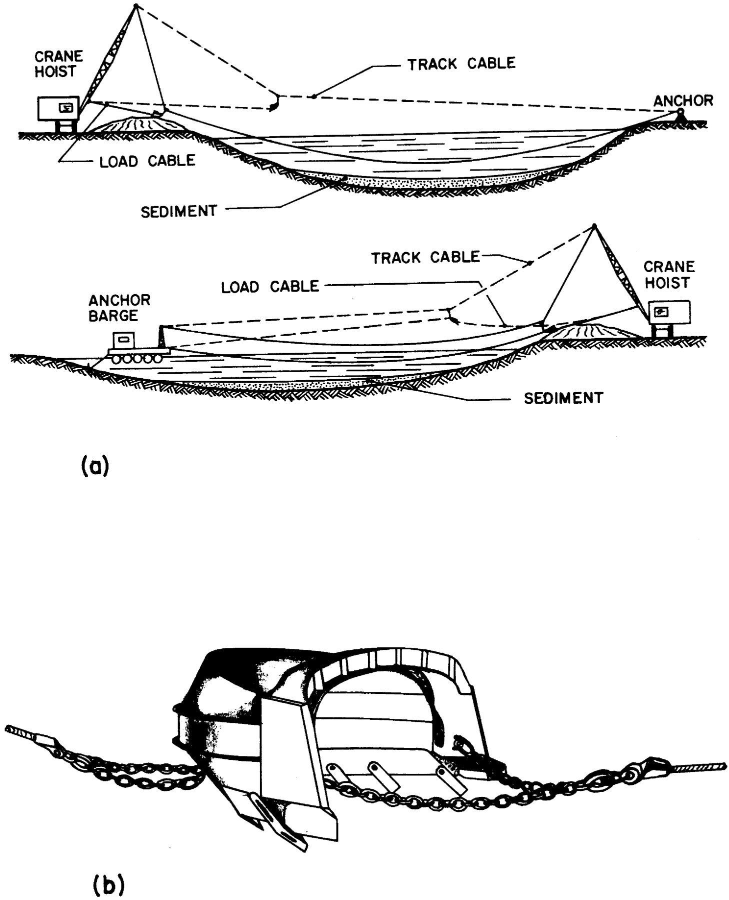


Figure 2. Sauerman Bucket Installations (a) and Sauerman Lightweight Bucket (b)

per hour. In many instances, land-based cranes are being used in conjunction with the Sauerman bucket. The crane then serves as the hoist mechanism, and the maximum reach into the lake is controlled by size of the crane and the amount of cable which can be stored on the hoist drums. It may be possible on some cranes to extend the end flanges of the drums and thus increase the cable holding capacity. The maximum practical reach with a crane is less than that which can be achieved with special hoist equipment.

Use of the Sauerman bucket in lake bottom excavation has been confined mainly to small ponds and lakes. Because they are readily available, cranes have been used almost exclusively on these projects.

A major problem in use of the Sauerman bucket is that of handling the excavated material once it is dumped at the shoreline. Since the material is usually quite viscous, normal earth-handling techniques are very inefficient and costly. If space is available, it may be feasible to store the material at the shoreline until it dries sufficiently for handling purposes.

Although the Sauerman bucket has not been used extensively for lake improvement, under certain conditions it is an economical method. Conditions must be present along the shoreline so that the equipment can be operated and the volume of material to be excavated can be dumped and handled. A maximum lake width of about 1,000 feet seems to be the practical limit for use of this machine. This will provide for a maximum bucket travel of about 500 feet by operating from both shores, which is within the realm of economical application of a Sauerman bucket.

Lake Dewatering

Dewatering of a lake or millpond prior to removal of bottom materials has been practiced in the past and is a practical method worthy of consideration. The majority of projects accomplished in this manner have been restricted to artificial lakes and millponds. Most water bodies of this type have a bottom that slopes from the lake inlet to outlet and a dam at the outlet end. Therefore, it is generally possible to drain the majority of water from the lake by gravity. This undoubtedly is the main reason why most lakes that have been dewatered prior to excavation are of the artificial type.

Recent development of the Crisafulli pump has increased the practicability of pumping large volumes of water from a lake. These pumps are designed to pump large volumes at low heads and can be operated with an electric motor or from the power take-off of a farm tractor. A 24-inch pump of this type can lower the level of a 100-acre lake one foot in one day when pumping at the rate of 25,000 gallons per minute. As the level to which the pumped water must be raised above lake level is increased, this rate of pumpage will decrease.

One of the major problems in pumping out a natural lake is disposing of the high volumes of water at the pumped rates. Most lakes have outlet streams but they may not be large enough to handle the pumped flows. In these cases, it is necessary that the cross-sectional area of the stream be increased or supplemental flow channels be constructed to carry the water away. Flow velocities in the stream or channel should be kept low enough so that severe erosion does not occur. Maximum velocity in an earth channel should be about 1½ feet per second.

In consideration of the feasibility of lake dewatering, it is essential that characteristics of the drainage basin be studied. This study should include all facets of the water balance in the basin. Of primary importance will be the rate of surface drainage contributed to the lake and the rate of inflow to the lake from groundwater with the lake in an empty or near empty condition. It is common in the upper Midwest that the flow of groundwater into a lake will increase as the lake level is lowered. This is due, at least in part, to the increased slope of the groundwater surface and disruption of the sealing effect of the bottom sediments. The net rate at which the water level is lowered will be the difference between the total pump capacity used and the inflow to the lake.

In areas where shallow private wells are near the lake, consideration must be given to the effect of lake dewatering on these wells. If certain soil and groundwater conditions exist, it may be possible to dry up wells and completely cut off the local potable water supply. Existence of this condition probably rules out the possibility of lake dewatering.

In the event that it is not feasible or possible to completely dewater a lake, consideration should be given to lowering the water level sufficiently so that dry land excavation equipment can remove material from the littoral zone and accomplish shoreline improvements. The extent to which the water level is lowered will determine the area of the littoral zone which can be improved. In particular, this technique appears to be worthy of consideration when used in conjunction with a hydraulic dredge. On small lakes, a hydraulic dredge may, as part of its operation, lower the lake level. This may then permit the operation of land-based excavation equipment along the shoreline areas, while the hydraulic dredge performs excavation in deeper water areas.

If it is possible to dewater a lake, excavation can then be accomplished with the variety of land-based excavation equipment available. Determination of the most efficient equipment to be used will be governed by the type and volume of the material to be excavated and the location of the disposal areas. In most instances, a drying-out period will be required prior to removal of the sediment. The type and depth of existing materials present will affect the length of time required for drying. If the materials are dense and have a high silt and clay content, months may be required for drying. Consideration should be given to draining the lake during the summer and then performing the excavation during the winter months when the material is frozen.

Past experience indicates that draining of an artificial lake in order to accomplish excavation in the dry can be a practical and economical technique for lake improvement. Prior to attempting lake draining, it is essential that knowledge be accumulated which substantiates the practicability of such a plan. Groundwater conditions will, in the majority of cases, rule out the feasibility of completely draining a natural lake, because of the extremely large volumes of water which would have to be pumped. The groundwater table surrounding the vast majority of natural lakes in the upper Midwest slopes toward or across the lake. Under these conditions, the lake is merely an exposed part of the groundwater table and, as such, may require an impractical amount of pumping to lower the level an adequate amount.

Costs for excavating material from a dried-up lake bed will closely parallel the cost for other dry land excavation projects. Cost advantages may be possible during the winter months because it is the off season for excavating contractors. The major cost-influencing factors will be (1) the type and volume of material to be excavated, and (2) the haul distance to disposal areas. Costs for dewatering the lake will be in addition to normal excavation costs. Power costs for pumping one foot of water from a 150-acre lake will vary from about $40.00 to $120.00, depending upon the pump head and efficiency.

Underwater Dredging

Marine dredges, which operate from the water surface, can be either of the mechanical or hydraulic type. Typical floating mechanical dredges are the dipper, clamshell, and the bucket-ladder types.

Mechanical Dredges

The dipper dredge is a floating adaptation of the common shovel which is used in gravel pits and quarries for loading purposes. Principal application of the dipper dredge is in excavating consolidated materials, such as hard clays and rock.

The clamshell dredge consists of a boom, hoisting mechanism, and a clamshell bucket, which is mounted on a floating hull. This unit can be made up of a barge-mounted land-based crane with clamshell bucket attached, or can be an integrally designed unit intended only for use on the water. Principal use of the clamshell is in digging soft materials or removal of stumps, logs and boulders.

The bucket-ladder dredge operates on the same principle as a trenching machine. An endless chain on tracks, with buckets attached, is lowered into the material to be excavated. As the buckets make the continuous circuit around the track, they dig into the bottom material and carry it to a hopper, barge, or conveyor above the water surface. The bucket ladder dredge is used most commonly in production of sand and gravel for the construction industry, in levee construction, and placer mining of gold and tin deposits.

All three of the mechanical dredges described above are incapable of transporting the excavated material great distances. This requires that the material be rehandled and carried to the disposal area by some other means. In most cases, the excavated material is deposited in adjacent barges and then removed to the disposal area. Because of this restriction, marine-type mechanical dredges have been developed for large size projects and are principally used in large rivers, lakes, and in the ocean where disposal or dumping grounds are located in adjacent, deep water areas.

Most presently used floating mechanical dredges are of large size, and are not adaptable to use in small- or medium-size inland lakes. Unless unusual circumstances exist which require the use of a floating mechanical dredge, the practicality of their use in lake improvement is limited. Conditions which would warrant consideration of a mechanical dredge would be the presence of many underwater logs, stumps, and boulders. A floating clamshell would then be an effective piece of equipment.

Hydraulic Dredges

Hydraulic dredges can be classified into three distinct categories: (1) dustpan dredge, (2) hopper dredge, and (3) cutterhead dredge. The hopper dredge is an ocean-going vessel and will not be discussed here, since it has no application for dredging of inland lakes.

Dustpan and cutterhead dredges consist of three main components: (1) a device for loosening the bottom materials, (2) a dredge pump which sucks the loosened material from the lake bottom and pumps it through a floating pipeline to the disposal area, and (3) a power plant, along with its appurtenant machinery.

Dustpan Dredge

Dustpan dredges vary in operating principle from a cutterhead dredge in the manner by which they loosen the bottom material. The suction head resembles a dustpan and is equipped with jets through which water is pumped at high velocity. Since the water jets are actually doing the digging, use of this principle is confined to soft materials. Dustpan dredges have not been used for lake improvement projects in the upper Midwest. Reasons for this are believed to be the lack of familiarity with this principle and the unavailability of small, portable dustpan dredges. The dustpan technique, or some variation thereof, may have distinct advantages in dredging of the highly flocculent and organic bottom materials present in many lakes.

During 1961-1962, Green Lake in Seattle, Washington was dredged to remove up to 5 feet of sediment which had accumulated in the lake bottom. This organic material was very colloidal and consisted of up to 60% water. The contractor who was engaged to do the work developed a unique and apparently workable type of dredge which could be considered as a variation of the dustpan technique.

A 50-foot-long suction manifold, with slotted openings, was lowered to the lake bottom by hoisting equipment. Both ends of the manifold were connected to a diesel driven pump with flexible hoses. Total inlet port area of the manifold was sized to produce an inlet velocity of at least 10 fps. As the material became more dense in lower layers, some of the inlet ports were plugged to increase velocities. This barge-mounted dredge swung a 180-degree arc at the end of a floating 20-inch discharge pipe which had a maximum length of about 2,600 feet. Velocities in the discharge pipe were apparently as high as 21 fps, resulting in discharge head losses greater than 140 feet. The dredge made at least two passes over all sections of the lake and removed a total of 1,200,000 cubic yards. Total contract cost for the entire dredging project was reported at $168,000, not including engineering and administrative costs, for a unit cost of about $0.13 per cubic yard. Continued development of the type of equipment as used at Green Lake is desirable in order to increase the economic feasibility of lake improvement.

Cutterhead Dredge

The portable hydraulic cutterhead dredge, which can be dismantled into its component parts, was introduced about 30 years ago. This development was a result of the known efficiency which had been demonstrated by large cutterhead dredges operating in the coastal waterways. Advances in the field of metallurgy and refinement of the diesel engine subsequent to the Second World War have aided development of the portable cutterhead dredge. By far the majority of lake dredging projects completed to date have been accomplished with this type of dredge.

Cutterhead dredges are described by the size of their discharge pipe, and vary in size from 6 inch to 36 inch. Sizes commonly used for inland lake renewal are 6 inch to 14 inch. Figure 3 shows a typical hydraulic cutterhead dredge.

Cutterhead dredges are usually designed and built to operate under one given set of circumstances. Variation of these circumstances will tend to reduce the operational efficiency and raise the unit excavating cost.

Description. Hull — The hull is made of steel and varies in size and design as dictated by the project requirements. Portable dredges have hulls composed of at least three parts — the center hull and two detachable adjacent outboard pontoons for added flotation. The center hull contains the motive power plant, pump, and other operating machinery. Fuel supplies are commonly stored in the outboard pontoons. A 12-inch dredge hull would have a typical assembled hull size of 50 x 20 x 4 feet. A dredge hull must be of sufficient strength and rigidity to resist the constant vibration

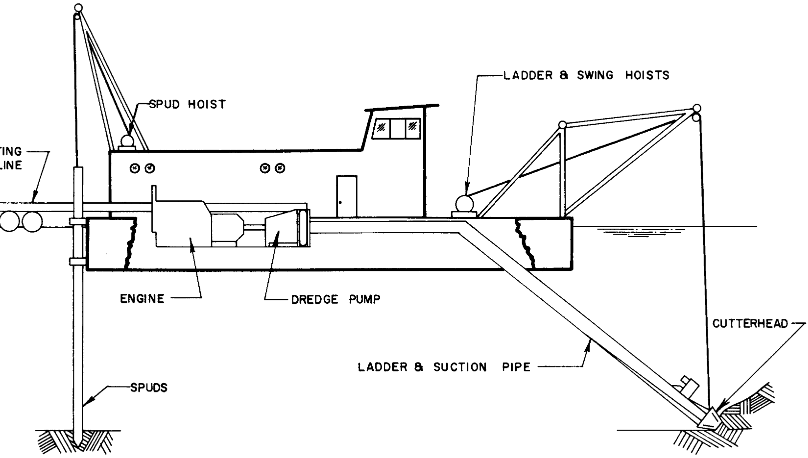


Figure 3. Hydraulic cutterhead dredge

when excavating consolidated materials. The hull must be of sufficient depth so that it is a seaworthy vessel.

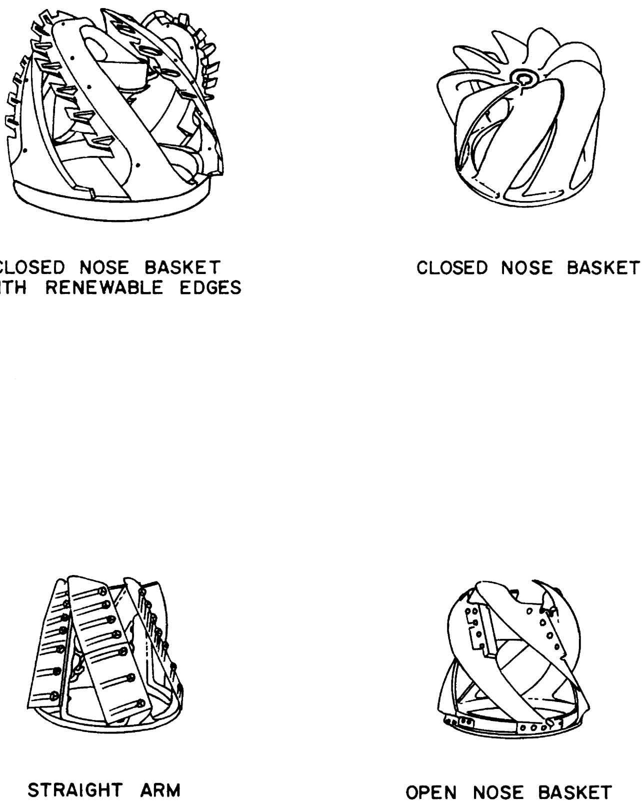
Cutter — The cutter is the cutting device which dislodges the bottom material and directs it into the pump suction line. It is shaft connected to a power source that is mounted above or below water level. Hydraulic motors are commonly used for cutter drives on smaller size dredges. Cutters have from 3 to 6 blades of a spiral design with either fixed or renewable blade edges that are oriented to direct the dislodged material into the pump suction. Blades are made with plain knife edges or with various types of teeth. There are many design variations of cutters, with closed nose basket type being the most common. Rotational speed of cutters varies from 5 rpm to 40 rpm. Most cutter design to date has been directed toward providing an efficient unit for digging hard material such as sand, clay, and rock. Available literature includes very little reference to cutter design for digging soft lake bottom sediments. Typical cutters available are shown in Figure 4.

Ladder — The ladder is a steel boom that is attached to the hull at its upper end and carries the cutter at its lower end. Length of the ladder determines the maximum dredging depth of the machine. The ladder must be sufficiently strong to resist the rotational effect of the cutter and the constant shock and vibration. The ladder also carries the main pump suction pipe and, in most cases, the cutterhead drive motors and shaft. The outboard end of the ladder is suspended by cable from an A-frame which projects out from the bow of the hull. This cable is connected to the hoist machinery located in the center hull.

Recent cutterhead dredge development has resulted in the direct suction pipe cutter drive. The pump suction line acts as the rotating shaft for the cutter, which is directly attached, and also becomes a major structural element of the ladder. This tends to reduce the ladder weight and cost. Research and performance to date indicate that the rotating pump suction line reduces the suction head losses by providing a better hydraulic entrance condition and lower suction pipe friction losses. Improvement of these suction conditions will result in higher dredge pump efficiency and increased production.

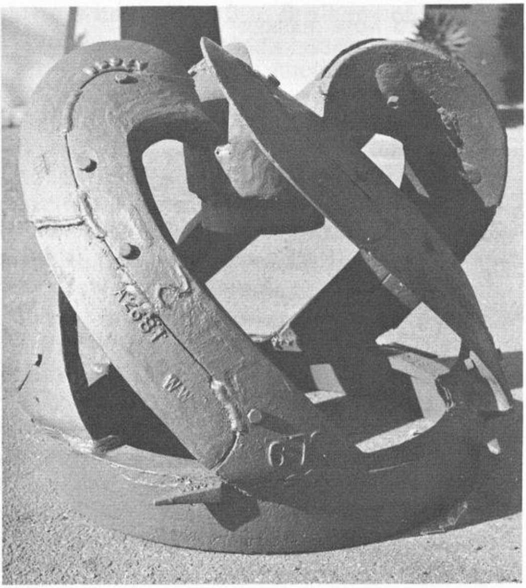
Spuds — Spuds are vertically mounted circular pipes located at both rear corners of the dredge hull. They vary in size from about 12-inch diameter on 10-inch dredges to as large as 48-inch diameter on the larger dredges. They are raised or lowered by either cable

Figure 4. Typical cutters



or hydraulic hoists. Spuds are used to hold the dredge in position and to "step" the dredge forward into the face of the cut. Spud length must be sufficient to penetrate into solid bottom materials.

Dredge Pump — The dredge pump is located in the center hull section with its horizontal center line at about the water line. Dredge pumps are of the end suction, radial, centrifugal type especially designed for pumping solids. The dredge pump is the heart of any dredge, since it is the device which lifts material from the lake bottom and pushes it through the discharge pipeline to the point of disposal. Variations in the pump size, impeller and casing design, and the speed of operation greatly affect the dredging efficiency. Many modern dredge pumps have replaceable casing liners made of special alloy steels to resist abrasion. Liners can be used until their walls have been worn completely through, and pump discharge pressure is then absorbed by the outer casing which prevents pump bursting. The liner is then replaced and the pump restored to operation. In order to facilitate liner replacement, pump casings should be sectionalized so the top half can be removed separately. When pumping mostly organic materials, which are not very abrasive, the economics of using special alloy liners must be thoroughly analyzed. Dredge pump impellers are cast or welded of abrasion resistant alloy steel and usually have 4 or 5 impeller vanes. Shape of the impeller vanes determines the suction and cavitation characteristics of the pump. Motive power for the smaller size dredge pumps is most commonly furnished by a diesel engine.



Five-blade renewable edge cutter with plain edges for soft material digging

Discharge Pipeline — Size of the discharge pipeline describes the dredge size and indicates the productive capacity of the excavating plant. The on-board section of the discharge pipe is rigidly connected from the dredge pump discharge to a point on the hull where it is connected to the floating line. Connection between the on-board and floating line is made with a ball-joint or reinforced rubber sleeve. Floating pipelines are assembled from sections of pipe varying in length from 20 feet to 60 feet. These sections are connected together with flanges, ball joints, or reinforced rubber couplings. It is essential that the floating pipeline be assembled so that the adequate flexibility is provided. A common plan is to use flanged and either ball or rubber joints alternately throughout the total length of floating line. Pontoons are attached to each section of pipe in order to provide adequate flotation. The center of gravity of the pontoons and floating pipeline should be kept low enough to prevent overturning. Pontoon design should take into account the flotation requirement when the pipe is filled solid with the dredged material. Shore pipe is available in lengths from 14 to 60 feet. Connections for shore pipe include victaulic couplings, dresser couplings, slip joints with anchoring device, or rubber couplings. Most pipe fabricated especially for dredging is made of special abrasion-resistant steel that greatly extends its life. All sections of the discharge pipeline, including the joints, should be designed to resist the maximum pump discharge pressure anticipated.

Operation. In operation, a cutterhead dredge swings from side to side using one of its spuds as a pivot point. Power for swinging is provided by swing hoist cables which extend from the hoist, through sheaves at the outboard end of the ladder, to swing anchors. The swing anchors are located ahead of and to the right and left of the dredge, and must be continually moved forward to keep up with the dredging process.

Commencing first with a swing to the starboard, the dredge will pivot on the starboard spud to the limit of its arc. The port spud is then lowered, the starboard spud raised, and direction of swing reversed to the port with the port spud acting as the pivot point. In this fashion, the dredge progresses into the cut. As can be seen, the length of arc through which the dredge is swung determines the width of cut and the "set" or distance forward that the dredge moves with each successive swing.

The type of material being dug and the depth of cut will determine the rate of progress into the face of the cut. In hard materials, it may be necessary to make several swings from the same set in order to remove all the material, digging successively deeper on each swing. When dredging highly organic, colloidal materials, they will tend to run toward the cutterhead and will influence the length of arc swing and the set. In some cases, contractors will reverse the direction of swing and proceed through part of the return arc length before changing the pivot spud. This procedure will increase the width of cut and will keep runny materials from filling the entire width of cut.

The type of material being dug will also influence the rotational speed of the cutterhead. When digging soft flocculent materials, excessive cutterhead speed will create too much turbulence at the cutterhead and will disturb surrounding materials. Some of these materials will float away instead of entering the pump suction. A cutterhead speed of less than 10 rpm is adequate in these soft materials.

Because of the many variables which are a part of the cutterhead dredging process, no precise method exists for determination of the production rate of the portable cutterhead dredge. These variables include: (1) The type of material being pumped, (2) continuous variation in the percent of solids in the discharge pipeline, (3) pipeline velocities, (4) performance of the dredge operator, and (5) the rate of solids intake or loading of the pump suction line. One available method for determining production rate is by use of the usual earthwork computation methods. This requires before and after cross-sectioning of either the lake bottom or the fill area. If cross-sectioning is done on the fill, recognition must be made of the change in volume between the in situ state and the material as placed on the fill. Many dredging contractors and others connected with the dredging industry have the habit of guessing at hourly production rates. Dredge pump manufacturers normally publish an expected production range for their pumps. This range varies from the ideal condition, which is infrequently encountered, to something less than ideal. Most guesses are on the high side of this range.

The best tools which the dredge operator has to guide his operation are the vacuum and pressure gages. The vacuum gage is a measure of the suction-operating conditions of the pump and is an indication of the percentage of solids being pumped. The maximum suction lift possible from a pump is equal to the barometric pressure less the water vapor pressure and less the head required to force the liquid into the pump impeller. When pumping clear water, a well-designed dredge pumping system will create a vacuum at the inlet side of the pump ranging from 5.5 to 8.0 feet of water. This figure is controlled by the pump and suction piping design. A drop in the vacuum created when pumping clear water will be indicative of pump wear or leakage in the suction line. A raise in the vacuum when pumping clear water may indicate an obstruction at the cutterhead or in the pump suction line.

When pumping the dredged material, pump vacuum may be as high as 20 to 27 feet of water. In lake dredging where the material being pumped is of a highly flocculent nature, it may be difficult or impossible to get sufficient solids into the pump suction in order to realize these high vacuums. The difference in vacuum between pumping clear water and dredged material indicates the amount of suction lift available for carrying solids from the lake bottom to the pump.

The pressure gage, which is located on the discharge side of the pump, indicates the discharge head against which the pump is working. This head varies with (1) the length of discharge line, (2) the type and percentage of solids being pumped, (3) diameter of the discharge line, (4) velocity in the discharge line, and (5) the difference in elevation between the lake level and point of discharge. Discharge pressures up to 100 pounds per square inch (psi) are not uncommon for a portable dredge.

The relationship between the vacuum gage and the pressure gage is an indication of the production rate. Both the pump vacuum gage and pressure gage readings are directly related to the percentage of solids in the material being pumped. Generally, these gage readings will increase with an increase of the solid to water ratio when pumping under normal conditions. By keeping the vacuum gage at its highest steady reading, maximum continuous solids handling in the suction line will be achieved. Readings below this will indicate that the suction line is not being loaded to its best potential with solids. Higher readings will indicate that too much solid material is being cut and drawn into the suction line. If this condition is allowed to persist, the pump suction line will become at least partially clogged, cutting down the supply of liquid to the pump. Because the pump does not then have a sufficient supply of the solid mixture to discharge, velocity in the discharge pipeline will decrease. If this discharge velocity is allowed to decrease below the point at which the solids being pumped are held in suspension, the discharge pipeline will become clogged.

The dredge operator controls both the vacuum and pressure gage readings through his manipulation of the rate of swing, depth of cut, and in some cases by rotational speed of the cutterhead. In the event of a sudden rise in the pump vacuum, rate of solids feed to the pump suction should be immediately reduced by slowing or stopping the swing and raising the ladder. This will increase velocity in the discharge pipeline to its former level and prevent suspended solids from settling out and clogging the discharge pipeline.

Many dredge manufacturers and contractors, in order to avoid the above clogging problem, utilize handmade or patented devices in the pump suction line to introduce clear water in the event of overloading with solids. These devices are essentially a branch in the suction line with a quick opening valve attached. When a sudden rise in the vacuum occurs, this valve is opened either automatically or by hand. The automatic valves are operated through the use of vacuum and pressure sensors on the suction and discharge lines. These sensors integrate variations between the vacuum and pressure readings and open or close the valve on the suction branch.

Automatic valves of this type reportedly increase production by up to 5%.

Lake bottom materials which contain a high percentage of organic matter may entrap quantities of gas in small pockets. Also, reduction of pressure in the suction line below atmospheric pressure causes the gases which are dissolved in the liquid to come out of solution. This gas is a result of decomposition of the organics and can cause pumping problems. As the gas enters the pump suction line, it will proceed upward until it becomes trapped at high points in the suction line or at the top of the pump casing. Good dredge construction should eliminate high points in the suction pipeline. As the volume of this gas builds up, it will affect the suction capability of the pump and cause reduction of the volume of solid-water material being pumped. This in turn will reduce discharge velocity and cause clogging of the discharge pipeline.

Since it is impossible to eliminate the intake of gas, the best corrective measure is to collect it at the high point and then disperse it into the atmosphere or out the pump discharge line. Gas ejectors are available which should be attached at the high point of the suction pipe or at the top of the pump casing. These systems collect and remove the gas automatically. A second method of removing the gas is to slope the pump suction line upward toward the pump throughout its length and orient the pump discharge so that its center line is horizontal and projects horizontally from the top of the pump casing. This eliminates the collecting points for gas in the suction pipe and at the top of the pump casing. A third method is to merely install a small diameter vent pipe at the top of the pump casing and carry it over the side of the hull. This pipe will discharge liquid whenever the main pump is operating and will thus carry off any gas. It is desirable to install facilities for backflushing of this vent line.

The maximum distance that a cutterhead dredge can economically pump material is a function of the dredge size and design. The dredge pump characteristics and the continuous horsepower rating of its power source are the major determining factors. All dredges of any one size do not have the same production capability for equal lengths of discharge line. If the material being pumped remains uniform, the hourly rate of production will go down as the length of discharge line is increased. Increase in the length of discharge line will increase the pipeline friction head against which the pump must deliver. As this friction head increases, the volume of the solid-water mixture discharged will decrease and so will the velocity. On excessively long lines, the increased friction head may lower velocity in the discharge pipe to a point where it cannot transport solids. A discharge velocity of 10 to 14 feet per second is generally required to keep materials in suspension. Velocities as high as 20 feet per second are common in large-size dredges.

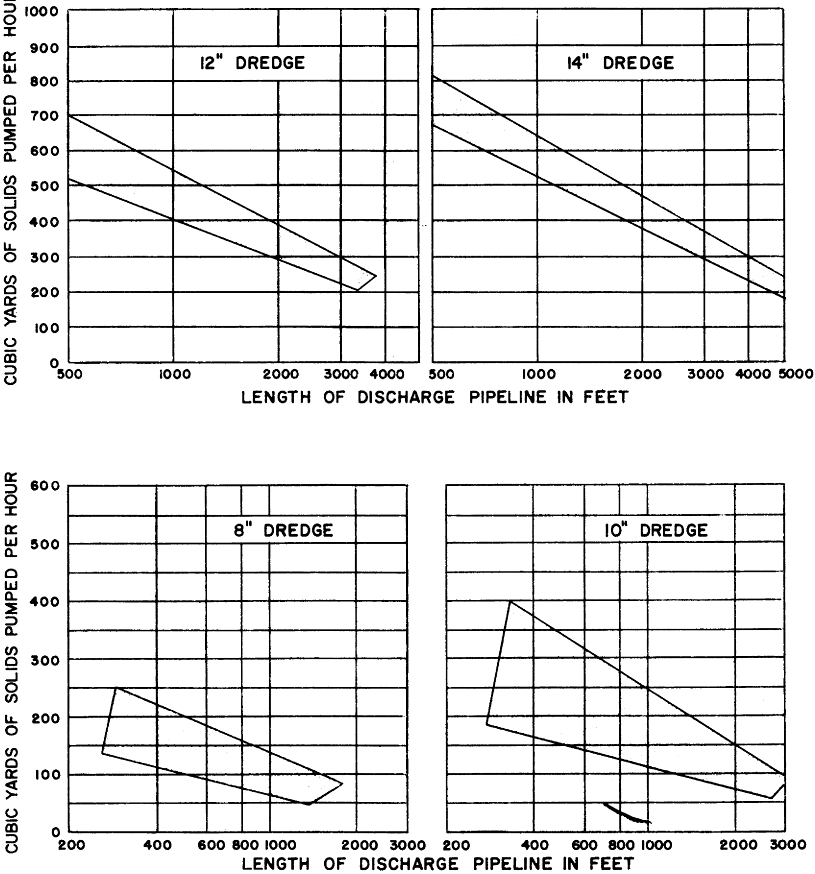


Figure 5. Dredge capacity charts

When it becomes necessary to increase the length of discharge pipeline beyond the economic conditions dictated by the dredge pump, booster pumps are used in the discharge line. The dredge pump then discharges to the suction side of the booster pump, which in turn pumps the material through the remaining length of line to the disposal site.

The use of a booster pump or pumps will determine the total length of discharge line which can be used. The major limiting factor would be the economics of using one or more boosters. Economical considerations for any one project may reveal that it is cheaper to use a larger size dredge, with increased capacity, than booster pumps in conjunction with a smaller dredge. These are facts which must be determined for each individual dredging project. Typical production characteristics for various size dredges are shown in Figure 5.

When a booster pump is installed in a discharge line of given length, it will increase the volume of discharge, the velocity in the discharge pipe, and the production capacity of the total dredge plant. When operating a booster pump in series with the dredge pump, the combined head for any flow is equal to the sum of the heads of both pumps. If both pumps have identical head-discharge characteristics, the head developed at any flow is twice that for either pump operating alone.

Location of a booster pump or pumps in the discharge line must take into account the head-discharge characteristics of all pumps, total length of the discharge line, discharge elevation head, discharge friction head, and the pressure rating of both the floating and shore pipeline. Booster pumps should be located close enough to the dredge so that they are operating under a positive suction head. However, due consideration must be given to increased discharge pressure which will result if boosters are located too close to the dredge pump. The closer that the booster pump is to the dredge, the higher will be the maximum pressure in the discharge line.

The hydraulic cutterhead dredge is becoming the most commonly used piece of equipment for underwater excavation in lake renewal projects. It is the most practical and economical tool for removal of lake sediments in areas other than along the lake shorelines. One disadvantage of the hydraulic cutterhead dredge is its inability to excavate in shallow water along shoreline. The minimum depth of water required for dredging is determined by the draft of the hull and the size of the cutterhead. The minimum digging depth of a 12-inch dredge is 3.5 to 4 feet. If it becomes necessary to excavate to the water line, this will have to be accomplished with auxiliary equipment. On past projects draglines have been used for this inshore work. They have been operated both from the shore and from barges in the lake. When operating from a barge, the material is dragged out into deeper water where it can be handled by a hydraulic dredge.

A sample problem showing considerations in selection of a hydraulic cutterhead dredge is presented in Appendix B.

Dredge in operation

Disposal area . . .

. . . with water drained off

APPENDIX A

Data on Selected Individual Lakes Surveyed

TABLE 1

Summary of Data Obtained From Survey of Lake Dredging Projects

	LAKE WAZEECHA Wood County	NORTH TWIN LAKE Calhoun County, Iowa
Project Sponsor	Wood Co. Park Dept.	State of Iowa
Lake Depth		
Original	———	2 ft. to 3 ft.
New	Removed 4 to 5 ft.	12 ft. to 14 ft.
Area	148 acres	510 acres
Area Dredged	Upstream end of lake	Entire lake, Beyond 150 ft. from H.W.L.
Contractor	Wood Co. Park Dept.	Simpson Dredge Co. Blackhawk Dredging Co. Waterloo, Iowa
Type and Size Dredge	Hydraulic cutterhead, 8 inch	Hydraulic cutterhead, 12 inch and 14 inch
Excavation		
Volume	174,627 cubic yds.	1,992,397 cubic yds.
Cost	$66,859	$934,931
Unit Price	$0.38 per cubic yd.	$0.47 per cubic yd.
Measurement	Cross sections of lake	Bottom sounding thru ice
Remarks		This project extended over a period of 8 to 9 years.

	CRYSTAL LAKE Beaver Dam	TAMBLING LAKE Vilas County
Project Sponsor	City of Beaver Dam	Vilas County
Lake Depth		
Original	4 ft. to 5 ft.	———
New	7 ft. to 10 ft.	To 12 ft.
Area	1¾ acres	169 acres
Area Dredged	Entire lake	Part of north bay
Contractor	Amery Dredge Company	Amery Dredge Company
Type and Size Dredge	Hydraulic cutterhead, 6 inch	Hydraulic cutterhead, 6 inch
Excavation		
Volume	15,000 cubic yds.	9,000± cubic yds.
Cost	$11,162	$5,600 ($30 per hr.)
Unit Price	$0.76 per cubic yd.	$0.62 per cubic yd.
Measurement	Cross sections of lake	Cross sections of lake

TABLE 1 (Cont.)

	FOREST LAKE Fond du Lac County	LAKE GEORGE Lake Sisseton Fairmont, Minnesota
Project Sponsor	Lake Association	City of Fairmont
Lake Depth		
Original	4.5 ft. @ 50 ft. from shoreline 5.2 ft. @ 100 ft. from shoreline 8.5 ft. @ 150 ft. from shoreline	6 to 6.5 ft.
New	8 ft. @ 50 ft. from shoreline 12 ft. @ 100 ft. from shoreline 12 ft. @ 150 ft. from shoreline	25 ft. or hard bottom
Area	50 acres	———
Area Dredged	Shoreline to 150 ft. from H.W.L.	Entire lake — Beyond 150 ft. H.W.L.
Contractor	TEP Inc., Racine, Wis.	City of Fairmont
Type and Size Dredge	Hydraulic cutterhead	Hydraulic cutterhead, 12 inch
Excavation		
Volume	48,735 cubic yds.	500,000 cubic yds. per year
Cost	$40,000 - $50,000	$35,000 to $50,000 per year
Unit Price	$0.82 to $1.02 per cubic yd.	$0.12 per cubic yd.
Measurement	Cross sections of lake	Estimated on hourly production basis
Remarks	Assessment to riparian property owners was approximately $8.00 per front foot	

	BEYERS COVE Green Lake	FIELDS MEMORIAL LAKE Hillsboro
Project Sponsor	Alfred H. Raasch	City of Hillsboro and Vernon County
Lake Depth		
Original	1.5 ft. to 3 ft.	———
New	5 ft. to 6.5 ft.	5 ft. to 12 ft. along main thread
Area	2.5 acres	43 acres
Area Dredged	———	Entire lake
Contractor	Alfred H. Raasch	Blum Construction Co., Sauk City, Wisconsin
Type and Size Dredge	Hydraulic cutterhead, 10 inch	Scrapers, Dozers, etc.
Excavation		
Volume	80,000± cubic yds.	55,000 cubic yds.
Cost	$38,500 (700 hrs. @ $55)	$22,000
Unit Price	$0.48 per cubic yd.	$0.40 per cubic yd.
Measurement	Estimated from cut area and hourly production	Cross section lake bottom

TABLE 1 (Cont.)

	DANE LAKE FOUNTAIN LAKE EDGEWATER BAY Albert Lea Minnesota	DEPARTMENT OF NATURAL RESOURCES SPRING PONDS State of Wisconsin
Project Sponsor	City of Albert Lea and Township	State Dept. Natural Resources
Lake Depth		
Original	3 ft. to 4 ft.	1 ft. to 3 ft.
New	7 ft. to 8 ft.	6 ft. to 8 ft.
Area	———	Variable
Area Dredged	Entire lake except shoreline	Entire Pond
Contractor	City of Albert Lea	Indianhead Dredging Co., Webster Wis. State of Wisconsin, Dept. Natural Resources
Type and Size Dredge	Hydraulic cutterhead, 10 inch	Hydraulic cutterhead, 6 and 8 inch
Excavation		
Volume	100,000 cubic yds. per year	9,000 to 17,000 cubic yds. per pond
Cost	$25,000 to $35,000 per year	$2,200 to $7,300 per pond
Unit Price	$0.24 to $0.33 per cubic yd.	$0.25 to $0.43 per cubic yd.
Measurement	Cross section fill area and estimated on hourly basis	Cross section lake and disposal areas

	PINE LAKE Waushara County	LONG LAKE Waushara County
Project Sponsor	Nine property owners	Private Property Owner
Lake Depth		
Original	———	———
New	7 ft. @ 180 ft. from shoreline	5 ft.
Area	143 acres	272 acres
Area Dredged	600 ft. of shoreline to 180 ft. from shoreline	Shoreline and boat channel (2 acres)
Contractor	Amery Dredge Co., Amery, Wis.	Amery Dredge Co., Amery, Wis.
Type and Size Dredge	Hydraulic cutterhead, 6 inch	Hydraulic cutterhead, 6 inch
Excavation		
Volume	4,900 cubic yds.	10,000± cubic yds.
Cost	$6,500	$6,000
Unit Price	$1.32 per cubic yd.	$0.60 to $0.70 per cubic yd.
Measurement	Cross sections of lake	Cross section of lake
Remarks	Cost per front foot of shoreline was $10.80	

TABLE 1 (Cont.)

	BRYANT LAKE Marquette County	SAND LAKE Burnett County
Project Sponsor	Private Property Owner	Private Property Owner
Lake Depth		
Original	———	Above water bog
New	8 ft.	6 ft. to 10 ft.
Area	6 acres	962 acres
Area Dredged	Entire lake	(less than 3 acres)
Contractor	Amery Dredge Co., Amery, Wis.	Indianhead Dredge Co., Webster, Wis.
Type and Size Dredge	Hydraulic cutterhead, 6 inch	Hydraulic cutterhead, 8 inch
Excavation		
Volume	50,000 to 60,000 cubic yds.	15,555 cubic yds.
Cost	\$32,500 - 500 hrs. @ \$35 500 hrs. @ \$30	\$12,000±
Unit Price	\$0.60 to \$0.70	\$0.77 per cubic yd.
Measurement	Estimate on hourly production basis	Cross sections of lake

	STORM LAKE Buena Vista County Iowa	PETITE LAKE Isaca County Minnesota
Project Sponsor	State of Iowa	3 M Company
Lake Depth		
Original	0 ft. to 3 ft.	2 ft. to 12 ft.
New	8 ft.	20 ft. to 24 ft.
Area	———	40 acres
Area Dredged	———	30 acres
Contractor	State of Iowa	3 M Company
Type and Size Dredge	Hydraulic cutterhead, 12 inch	Hydraulic cutterhead, 10 inch
Excavation		
Volume	———	500,000 cubic yds.
Cost	———	\$50,000
Unit Price	———	\$0.10
Measurement	———	Cross sections in lake

Wazeecha Lake — This lake is an impoundment of Buena Vista Creek, Wood County, Wisconsin, and prior to dredging contained from 4 to 5 feet of sediment at its upstream end. The dredging project was accomplished with a county-owned, second-hand, 8-inch dredge which was purchased specifically for this project at a cost of $18,250. Costs as shown in Table 1 include this purchase price. Dredged material was pumped onto the shoreline for improvement of shoreline areas. Easements were obtained from riparian property owners so that the material could be placed along the lake shoreline. One area was diked off and filled for park use. This project was accomplished over a period of four to five years which results in an average yearly production of from 35,000 to 44,000 cubic yards. Since this lake is an impoundment, existing stumps created problems and slowed the dredging process. Large stumps were worked around, and some of the smaller ones were removed with a crane. The volume of material dredged was measured in the lake by taking before-and-after depth measurements.

The quantities and costs as shown in Table 1 are considered to be accurate and representative of a good governmentally operated dredging project. Benefits from this project include improvement of shoreline areas, increased water depths, elimination of undesirable bottom sediments at two beach areas and construction of a park area.

North Twin Lake — This lake has a total surface area of 510 acres and is situated in the west-central plain country of Iowa. The lake is part of a large drainage basin which is chiefly agricultural. At some time in the past the lake level was raised approximately 1.5 feet, which resulted in severe bank erosion along the shoreline. This bank erosion, along with sheet erosion from surrounding agricultural land, had filled the lake with as much as 12 feet of sediment.

Most lake dredging projects in Iowa are financed by the State. A lake association was formed and lobbied for lake dredging at the State level. In about 1940, State funds were appropriated and dredging was commenced. About 135 acres of the lake were dredged to a depth of 14 to 18 feet. Dredging was then discontinued until about 1960 when a second series of State funds were appropriated. Under this second program, five dredging contracts were let to private dredging contractors. The first four contracts were held by the same contractor. The last of these contracts was completed in 1969 by a second contractor and accomplished dredging of all lake areas beyond 150 feet from the water line.

It is interesting to note that the first four of these contracts, which included 1.25 million cubic yards of excavation, were performed over a period of at least six years; whereas, the fifth contract, 0.75 million cubic yards of excavation, was performed over a period of about 4½ months in 1969. This represents a wide variation in production rate, and demonstrates the difference between experienced and inexperienced contractors. Some of this variation can be attributed to the fact that the last contractor used a 14 inch dredge; whereas, the first four contracts were accomplished with a 12 inch dredge. As indicated in Table 1, the overall unit cost for excavated material, as measured in the lake, was $0.47 per cubic yard. Unit cost for the fifth contract was $0.38 per cubic yard of material measured in the lake, plus an undetermined amount for dike work at the disposal site. The contractor estimated that the dike work would bring the total unit cost for the fifth contract to slightly in excess of $0.40 per cubic yard. None of these unit costs include administrative and engineering costs.

Permission was obtained from the owner of a farm immediately adjacent to the lake to use the farm as a disposal site. The area used for disposal was low, agricultural land which was filled by as much as 18 feet in some areas. Apparently, no qualitative determination was made of the dredged material composition. However, the State authorities anticipate very definite benefits to the farm from a crop production standpoint. By observation, the material appeared to be mostly fine silt with low organic content. The material was relatively unabrasive and caused little wear of the dredging equipment. Almost no wear was visible on the 14 inch pump after pumping 0.75 million cubic yards.

Purpose of the dredging was to improve the lake for swimming, boating activities and fishing. The lake had become so shallow in certain locations that boating was impossible. During the summer months, boating and wind action caused high levels of turbidity affecting the fishing and general recreational use. Other than financial, and long delay in work completion by the first contractor, this project encountered few problems. These delays were apparently caused by faulty equipment and lack of experienced supervision. Other than increased water depths, benefits to the lake environment cannot as yet be defined.

Forest Lake — Dredging of Forest Lake, which is located in Fond du Lac County, Wisconsin, consisted of improvement of the shoreline area to a point 150 feet out from the water line. Dredging was accomplished with a hydraulic cutterhead dredge and was sponsored by a local lake association. New water depths are 8 feet at 50 feet from water line and then 12 feet to a point 150 feet from shoreline. Purpose of the project was to remove sediment along shoreline areas for improvement of swimming and boating activities and to increase lake water quality.

Reliable cost data on the project was not obtainable. However, estimates of the final project cost by the engineer indicate that the unit cost for dredging was about $1.00 per cubic yard of material removed. This resulted in a cost per front foot to riparian property owners of about $8.00.

During dredging, it was found that a sufficient supply of lake water was not available for continuous dredging. Permission was obtained and a pump was installed to transfer water from a creek outside of the lake drainage basin to the lake. This, of course, resulted in interruption of the dredging and caused an increase in the project cost.

Several citizen complaints were made during the construction phase as a result of inadvertent deposit of dredge material in deep water areas of the lake instead of in the provided disposal sites.

Conditions of the lake environment since dredging show a marked improvement, according to observations of the engineer. Water turbidity has decreased to an acceptable level, and swimming, boating, and fishing activity has been returned to near its former level.

Lake George and Lake Sisseton — In 1966, the City of Fairmont, Minnesota, purchased a 12 inch portable, hydraulic cutterhead dredge. Total investment in the dredge and all appurtenant equipment is about $175,000. This dredge is presently being used to excavate sediment from a chain of five lakes that are located within the City. To date, two lakes have been dredged.

The dredging work is part of an overall lake improvement program which included annexation of all land areas fronting on the lakes and construction of a complete sanitary sewer system. The City of Fairmont obtains its municipal water supply from these lakes and their eutrophic condition was contributing to high water treatment plant operating cost and a warm municipal supply. Water depth in the lakes prior to dredging averaged 6 to 6.5 feet. The lakes are being dredged in all areas beyond 150 feet from the water line. From this limit, the bottom is sloped down to a maximum depth of 25 feet. In areas where hard clay or gravel bottom is encountered at depths less than 25 feet, dredging is stopped.

The City purchased a 170 acre farm adjacent to Lake Sisseton which is presently being used as a disposal site. This large disposal site permits adequate settling so that the dredge water which returns to the lake is very low in suspended solids content. Material dredged from Lake George was pumped to a different disposal site which is presently being developed into a park.

Financing for the dredging is obtained from the City-owned liquor store receipts and from the electric and water utility. Each of these sources contribute $25,000 annually for a total of $50,000. There is no assessment made against riparian property owners and no appropriation from the general tax fund. Yearly expenditures to operate the dredge have been about $35,000. The difference between the appropriation and expenditure will be used for maintenance and purchase of future disposal sites.

Yearly production from the dredge is estimated to be 500,000 cubic yards by the City Engineer. Based on the hours operated yearly, this would result in an average daily production rate of about 3,000 cubic yards, which is reasonable. This production rate indicates that the unit costs are $0.07 per cubic yard, an extremely low value. The City Engineer estimates that by adding administrative and engineering this unit cost would be $0.10 to $0.12 per cubic yard. Costs for disposal sites are not included in this figure.

The City Engineer also states that since sewers were installed, there was a marked improvement in water quality. He further states that since dredging in Lake George has been completed, there is a fantastic improvement in the appearance and condition of the water. There is no qualitative data available on the change in water quality which reportedly has occurred as a result of sewer installation and lake dredging. Reportedly, the combination of sewers and dredging has reduced the cost of water treatment.

It is estimated that it will take 20 years to complete the dredging of all five lakes, which have a total surface area of about 1,000 acres, at a cost of about one million dollars. Benefits from this project include increased water depths and volume, lower water temperatures, improvement of the fish habitat, a better environment for desirable aquatic life, and a general increase in recreational value. This project demonstrates what can be done if properly handled by a local governmental body.

Fields Memorial Lake — Fields Memorial Lake, which is an impoundment at Hillsboro, Wisconsin, was excavated in the dry during 1965 and 1966. Failure of the dam in 1962 drained the lake and caused an unsightly condition in the old lake bed. Public reaction resulted in formation of a lake association and forced local governmental bodies into action. The dam was reconstructed and sediment was excavated from the lake bed. Excavation was performed with scrapers, dozers and other land based excavation equipment. The material was deposited on shoreline areas at a contract unit cost of $0.40 per cubic yard for hauls less than 1,000 feet, and $0.47 per cubic yard for hauls greater than 1,000 feet. There was also in excess of 10,000 cubic yards of rock removed. Bid price for the rock removal was $1.35 per cubic yard. Cost for furnishing, hauling, and placing riprap around portions of the lake edge was $15.00 per cubic yard. Costs for excavation and riprap were shared between the City of Hillsboro and Vernon County. City share of the project cost was obtained from the general tax fund with no direct assessment against riparian property owners.

Benefits which have accrued from the project include increased water depths and area, improvement of fish habitat and shoreline areas, and removal of rooted aquatic vegetation. Conditions presently indicate that some sedimentation is occurring at the inlet end of the lake. This sediment is contributed by a branch of the Baraboo River, of which Fields Memorial Lake is a part. The extent of sedimentation is unknown.

Dane Lake, Fountain Lake, Edgewater Bay — The City of Albert Lea, Minnesota, purchased a 10 inch hydraulic cutterhead dredge in about 1963. This dredge is being used to remove sediment from a chain of lakes in the City and adjacent townships. Prior to dredging, the lakes averaged 3 to 5 feet deep. Depth of sediment is in excess of 6 feet. The dredge averages about six hours per day of pumping and pumps six days per week, from May 30 until freeze up. Yearly production has been between 65,000 and 113,000 cubic yards. Available cost data indicates that the unit cost for removal varies from $0.25 to $0.32 per cubic yard of material removed. Indications are that these figures do not include all costs for engineering, administrative, equipment maintenance, equipment depreciation, and work at the disposal sites. The cost of dredging is paid for by a general tax levy in the City and adjacent townships. The City pays 90% of the costs and the townships 10%. The dredge crew is paid a $0.10 per hour wage premium with no time and a half for overtime. This was found to be an incentive, since the crew cannot take vacations during the dredging season.

To date, disposal sites have been readily available. One disposal site has been turned into a park that is presently being used. A second, larger area, will be used for park purposes when the material can be handled and reworked. During the 1969 operation, a bay of Fountain Lake was filled. As dredging continues in other lakes, the availability of disposal sites will become a critical problem. It is anticipated that the City may have to purchase adjacent farm land for disposal sites.

New depth of the dredged lakes is 7 to 8 feet, which probably does not provide sufficient depth to prevent winterkill of fish which has previously been experienced. The main reason for dredging, as indicated by the City Engineer, is to improve conditions for boating. Improvement of fish habitat would be considered a secondary benefit.

When dredging in Dane Lake, junk and large rocks were a problem. This resulted in slowing of the dredging process and presumably increased costs. During 1964, major equipment problems were encountered. When operating in hot weather, the engine continuously overheated requiring frequent shutdown. This problem was solved by reconstruction of the engine heat exchanger. Other major engine repair requirements were probably a result of the overheating problem.

Sand Lake — This lake, located in Burnett County, Wisconsin, is a clear water lake, highly desirable for recreational use. A bay at the north end of this lake had filled in over the years so that it was completely filled with bog. Shoreline property around this bay was undesirable for building upon and was assessed at $3.00 to $3.50 per front foot, as estimated by the property owner. About 2,000 lineal feet of property fronting on this bay was owned by one individual who is a dredging contractor. During 1969, he received a permit and began dredging of the bay. New water depths vary from about 6 feet to 10 feet. Purpose of the dredging was to increase the land value around the bay and to provide an open water area for recreational use. The property owner expects that he will be able to market the frontage property, after dredging, for $40 to $45 per front foot. Material dredged from the bay was pumped into a pot hole about 400 feet from the bay shore. This pot hole was also owned by the same individual, thus eliminating the problem of obtaining rights to a disposal site.

The major problem encountered during this project was handling of the bog material. The contractor, as he advanced the dredge into the face of the cut, excavated beneath the bog. This loosened it and made it possible to float the bog to the shoreline where it was removed by a crane and hauled away. The total contractor cost for this project is estimated at $12,000 by the contractor. This results in a unit cost of about $0.77 per cubic yard for the material removed. Additional cost caused by the bog is undetermined.

This project demonstrates what can be done in order to increase the availability of recreational surface waters. Prior to dredging, the bay was unavailable for water oriented recreation. Dredging has exposed a clean sandy bottom, has increased the open water area, and has created a marked increase in riparian property values.

Storm Lake — Lake dredging activity began in Storm Lake, in the State of Iowa, in about 1940. At that time, the State owned its own dredge and it operated in Storm Lake. The dredge operated for several years and was then sold. Information on this initial dredging activity is sketchy. In about 1961, the State of Iowa again began dredging in Storm Lake. This was done by contract and continued for several years. In 1966, the State purchased another dredge, which is 12 inch, and again began dredging in Storm Lake. Dredging has been continuous since 1966. Storm Lake is shallow and has a surface area of about 3,000 acres. Wind is a constant problem and causes a turbid condition to exist in the water.

Lack of areas for disposal of dredged material is a severe problem at Storm Lake. During the early dredging, dikes were constructed in the lake and an island was constructed. Under the current program, an area at the northwest corner of the lake has been diked off and is being filled. There have been problems in obtaining good material for construction of these dikes. The present dike has begun to fail and resulted in a halt in the dredging.

Although dredging has been going on intermittently in Storm Lake since 1940, material benefits have not as yet been realized. Information on the total quantity of material removed is not available. However, discussion with State personnel and local persons indicates that the total quantity of material removed is almost insignificant compared to the lake area. Volume of the diked off area, along with the size of the artificial island, confirms this.

APPENDIX B

Sample Problem Showing Considerations In Selection Of A Hydraulic Cutterhead Dredge

The following example problem is presented to demonstrate some of the considerations required when analyzing a lake dredging proposal. Data on proprietary products, such as the dredge pumps, is assumed for demonstration purposes and is not intended to represent any actual manufactured equipment.

Eutrophication of Mud Lake in Frank County has reached the point where the lake is almost unusable as a recreational resource. Organic decomposition and sedimentation from the surrounding agricultural land have reduced the water depth so that 40% of the lake area is less than 4 feet deep and the remaining 60% has an average depth of only 6½ feet. Six percent of the lake area is greater than 10 feet deep with a maximum depth of 16 feet. Sounding data shows that thickness of the soft sediment deposits varies from about 6 feet at the north end to a maximum of about 12 feet at the south end. Sediments are composed of organic silty deposits which can generally be classified as muck. Water content of the muck varies from about 60% at the sediment-water interface to about 30% at mid-depth. Material beneath the sediment is granular which is reflected by the excellent groundwater aquifer characteristics. Private wells in the area show that groundwater flows in a northwesterly direction through the lake basin.

A feasibility study made on the renewal of Mud Lake reveals that removal of the accumulated bottom sediments will enhance the water quality and restore the lake as a valuable recreational resource. Excavation with a hydraulic cutterhead dredge is recommended as the most economical method. The study indicates that there are three disposal sites available for use which will more than handle the material removed. Other recommendations of the study are as follows:

1. All accumulated sediments should be removed and placed in the disposal sites, as shown on Figure 6.
2. At least 15% of the total lake area should be deepened to at least 20 feet. This deep water area should be at the south end of the lake where sediment deposits are thickest and will result in a maximum water depth of about 28 feet.
3. New water depth at 200 feet from shoreline should be 8 feet. The bottom should then be sloped at a grade of 5% to a depth of 12 feet. Minimum water depth beyond 280 feet from normal water level shoreline should be 12 feet.
4. The existing fish spawning grounds at the north end of the lake should be preserved in their present condition.

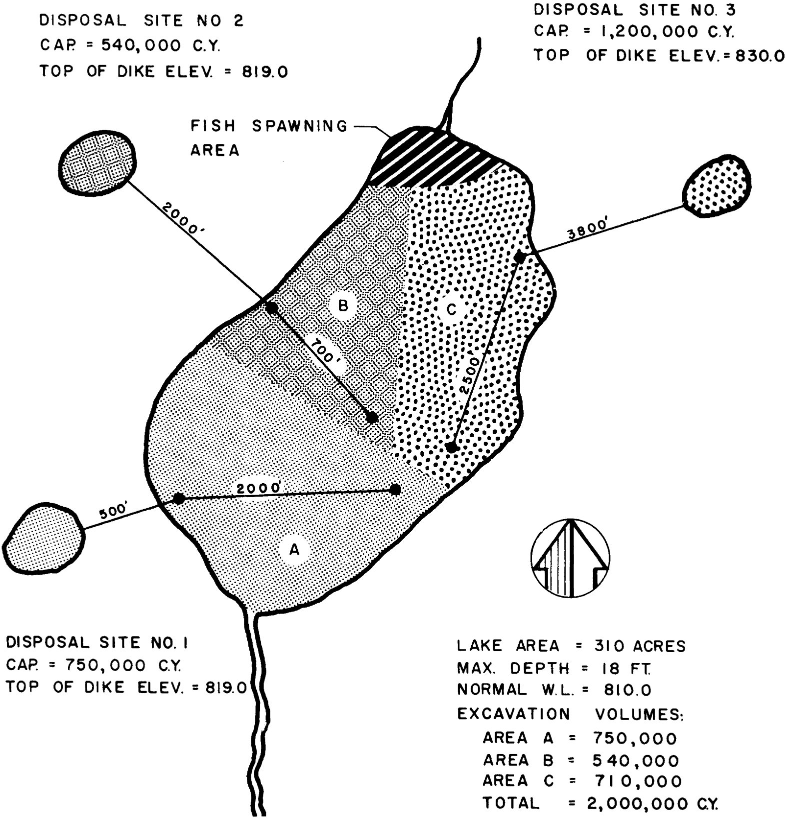


Figure 6. Mud Lake

5. By proper application of equipment, it is possible to complete the project within 2 years. If dredging is started next spring, this time schedule will concur with completion of the sewerage system which is presently under construction.

In order to implement the recommendations as listed in the feasibility study, it is necessary that the project be analyzed in order to determine equipment required. Following is a step by step analysis of the project which is intended to demonstrate various points to be considered when selecting a hydraulic cutterhead dredge for a specific project.

Step 1

Study of Figure 6 reveals that a minimum of 710,000 cubic yards of material will have to be pumped to disposal site No. 3. By dividing the lake into three sections, it is possible to develop a plan for the dredging program. An attempt was made to select the areas so that the most economical discharge pipeline lengths will result. Since disposal sites 1 and 2 are closest, they will be filled to capacity. Minimum pipeline length will be 1,000 feet when pumping from area A to disposal site No. 1. Maximum pipeline length will be about 6300 feet when pumping from area C to disposal site No. 3. Average pipeline length when pumping from area B to disposal site No. 2 will be about 2700 feet.

Step 2

Since completion of the project within a 2-year period is required, an analysis of the production capacity of various size dredges is necessary. Investigation of contractor-owned equipment in the area reveals that the largest dredges presently in use are 12 inch. It is felt that the project size is not large enough to interest distant contractors who own larger equipment. Preliminary investigation will therefore, be limited to a 12-inch-maximum size dredge.

Because of the constantly varying conditions, dredge and dredge pump manufacturers generally show a production range for any one size dredge. The following production ranges are possible with various size dredges as furnished by one dredge manufacturer (Fig. 5):

1000 lineal feet of pipeline

8 inch — 60 to 130 cubic yards per hour, average = 95
10 inch — 110 to 250 cubic yards per hour, average = 180
12 inch — 400 to 540 cubic yards per hour, average = 470

2000 lineal feet of pipeline

8 inch — Booster pump required
10 inch — 70 to 145 cubic yards per hour, average = 110
12 inch — 290 to 380 cubic yards per hour, average = 335

2700 lineal feet of pipeline

8 inch — Booster pump required
10 inch — 60 to 110 cubic yards per hour, average = 85
12 inch — 230 to 320 cubic yards per hour, average = 275

Figure 5 also reveals that a booster pump will be required in conjunction with a 12-inch dredge when pumping from area C to disposal site No. 3.

An analysis of the sounding data reveals that the major quantities of sediment are located near the center of the lake. This indicates that most of the material will have to be pumped through a pipeline more than 2000 feet long.

Step 3

Using the preceding average production rates, compute the number of days required to complete the dredging work. Average production rates of 100 and 300 cubic yards per hour will be used for the 10-inch and 12-inch dredge, respectively. As indicated, an

8-inch dredge would require the use of a booster pump when the discharge pipeline is 2000 feet long. Normal operation would be to operate the dredge on a 3-shift, 24-hour per day, 6-day per week basis. This usually results in about 20 hours of actual dredge operation per day with 4 hours allowed for maintenance and pipeline work.

10 inch

$$\frac{2{,}000{,}000 \text{ cu. yds.}}{(100 \text{ cu. yds./hr.})\ (20 \text{ hours})} = 1000 \text{ days}$$

12 inch

$$\frac{2{,}000{,}000 \text{ cu. yds.}}{(300 \text{ cu. yds./hr.})\ (20 \text{ hours})} = 334 \text{ days}$$

Frank County is located in the Upper Great Lakes Region and a normal dredging season would extend from about April 15 to November 15, resulting in 185 work days. From this, it is apparent that it would take more than 2 dredging seasons for the 10-inch dredge to complete the work; whereas, the 12-inch dredge can complete the work in slightly less than 2 dredging seasons. Therefore, a 12-inch dredge will be used. When pumping to disposal site No. 3, a properly sized and located booster pump will be used in conjunction with the dredge pump.

Step 4

Determine the head-discharge characteristics required from the main dredge pump when pumping dredged material with a specific gravity of 1.20. In order to properly analyze the pump characteristics required, it is necessary that both the minimum and maximum head conditions be investigated. As indicated previously, the longer the discharge pipeline — the higher the total head required from the dredge pump. Job conditions for Mud Lake will result in a minimum discharge pipeline length of 1000 feet, consisting of 500 feet of floating line and 500 feet of shore pipe. Maximum pipeline length for the dredge pump alone will be 2700 feet. This will consist of 2000 feet of shore pipe and 700 feet of floating pipe.

The total dynamic head against which a pump must work is the sum of the total suction lift and total discharge heads. These heads can be computed from basic hydraulic formulas with proper correction for specific gravity of the mixture being pumped. Suction lift is composed of the suction elevation head, suction velocity head, and friction head in the suction pipe. The total discharge head is the sum of the discharge elevation head, friction head in discharge pipeline, and pump velocity head. Minor losses are usually neglected.

Suction Head

The suction elevation head is caused by the difference in weight between the dredged material and the lake water. It can be described as the difference in height between a column of lake water as high as the lake is deep and the height of a column of the dredged mixture of equal weight. Since the dredged mixture is heavier than lake water, the top of a column of dredged mixture will always be below the lake surface. The suction elevation head is referred to the horizontal center line of the pump. It can be computed from the following formula:

$$h_{ss} = S_1A - S_2B \qquad (1)$$

where:

h_{ss} = the suction elevation head in feet of fresh water
S_1 = specific gravity of the lake water
S_2 = specific gravity of the material being pumped
A = distance, in feet, between the bottom of the cut and the water surface
B = distance, in feet, between the pump center line and the bottom of the cut

With the pump center line located at lake level, the static suction head will be:

$h_{ss} = 1.00\ (28) - 1.20\ (28)$
$h_{ss} = -5.6$ feet, the minus sign indicates a suction lift exists and that this number must be added to the sum of other heads in the suction system.

The suction velocity head is the energy required to start the dredge mixture moving into the suction pipe and can be computed from the following formula:

$$h_{sv} = S_2 \frac{V_s^2}{64.4} \qquad (2)$$

where:

h_{sv} = velocity head in feet of fresh water
S_2 = specific gravity of the material being pumped
V_s = velocity of the mixture in the suction pipe in feet per second.

Velocity in the suction pipe should be between 10 and 14 feet per second in order to carry the solids into the pump. Pump suction lines on smaller dredges are usually made one size larger than the discharge pipe diameter in order to reduce suction losses. A 12-inch dredge would then have a 14-inch suction line with an I.D. of 1.17 feet. In order to operate within this range, we will assume a discharge velocity of 16 feet per second in the 12-inch discharge line. This will give a velocity in the 14-inch suction line of 11.75 feet per second. Velocity head will, therefore, be:

$$h_{sv} = (1.20)\ \frac{(11.75)^2}{64.4}$$

$$h_{sv} = 2.6 \text{ feet}$$

Friction losses caused by flow of water create the major portion of the head against which a dredge pump must work. There have been many theories and formulas developed for computing these friction losses. Friction loss is dependent on the type of pipe, diameter of pipe, velocity of flow, and the length of pipeline. The designer must consider all of the variables which affect dredge pipeline friction losses and apply these variables to a proven formula. The Darcy-Weisbach pipe friction formula is generally accepted and will be used as a basis for computing pipe friction losses in this example. As with any friction loss formula, the percentage and type of solids in the pumped mixture must be taken into account.

The suction friction head is the energy required to overcome friction losses in the pump suction line and can be computed from the following formula:

$$h_{sf} = 0.015 \left(1 + \frac{P-10}{100}\right) \frac{LV_s^2}{64.4D} \qquad (3)$$

where:

h_{sf} = friction head in feet of fresh water per foot of pipe
P = percentage, by volume, of solid material in suspension
L = equivalent length of suction pipe, in feet
V_s = velocity of the mixture in the suction pipe in feet per second
D = inside diameter of the suction pipe, in feet

Figure 7 is a graphical representation of the above formula for 10% and 20% concentrations, by volume, and various velocities. For average conditions, we will assume 20% solids are being handled. Ladder length required on the dredge will be assumed as 50 feet which will permit digging to 28 feet of depth. Total equivalent suction pipe length will be about 85 feet. Friction head in the suction pipe will therefore be:

$$h_{sf} = 0.015 \left(1 + \frac{20-10}{100}\right) \frac{85(11.75)^2}{(64.4)\ (1.17)}$$

$$h_{sf} = 2.6 \text{ feet}$$

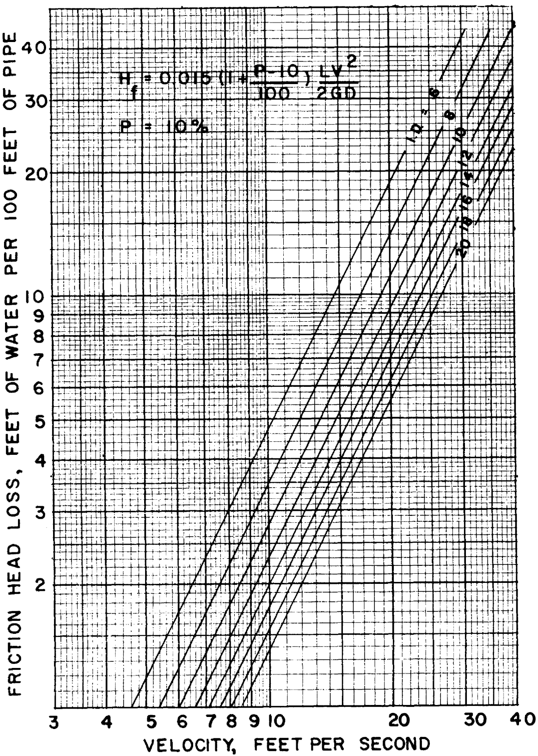
Total suction head on the dredge pump will be the sum of the above and is equal to:

$$H_s = h_{ss} + h_{sv} + h_{sf} \qquad (4)$$
$$= 5.6 + 2.6 + 2.6$$
$$H_s = 10.8 \text{ feet of fresh water}$$

Discharge Head

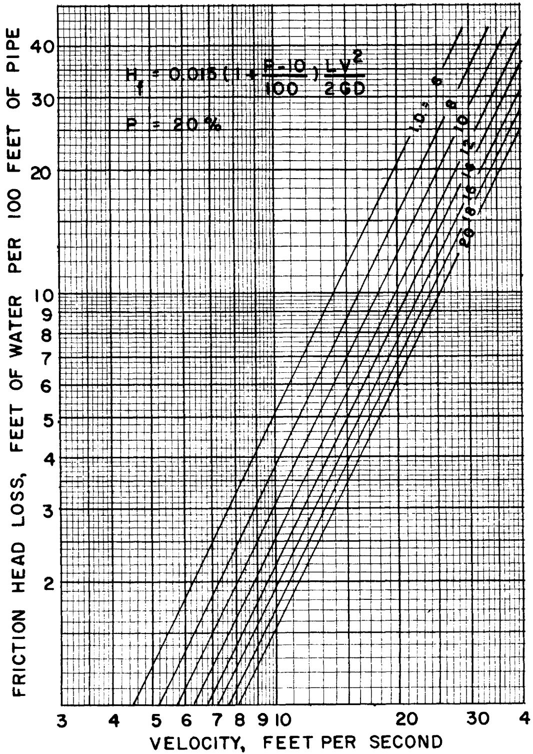
The discharge elevation head is the difference in elevation between the pump center line and the end of the discharge pipeline corrected for specific gravity of the mixture. Elevation of the top of dike for disposal site No. 1 and No. 2 is 819.0, which will be taken as the elevation of the discharge point. Discharge elevation head can be computed from the following formula:

$$h_{de} = S_2\ (E_D - E_p) \qquad (5)$$



$H_f = 0.015 \left(1 + \frac{P-10}{100}\right) \frac{LV^2}{2GD}$
P = 10%
I.D. = 6
8
10
12
14
16
18
20
FRICTION HEAD LOSS, FEET OF WATER PER 100 FEET OF PIPE
2
3
4
5
6
7
8
9
10
20
30
40
3
4
5
6
7
8
9
10
20
30
40
VELOCITY, FEET PER SECOND

(a)



$H_f = 0.015 \left(1 + \frac{P-10}{100}\right) \frac{LV^2}{2GD}$
P = 20%
I.D. = 6
8
10
12
14
16
18
20
FRICTION HEAD LOSS, FEET OF WATER PER 100 FEET OF PIPE
2
3
4
5
6
7
8
9
10
20
30
40
3
4
5
6
7
8
9
10
20
30
40
VELOCITY, FEET PER SECOND

(b)

where:

h_{de} = discharge elevation head in feet of fresh water
S_2 = specific gravity of the mixture being pumped
E_D = elevation of the center line of the discharge pipe at its end
E_p = elevation of the center line of the dredge pump

When pumping to disposal sites No. 1 and No. 2, the discharge elevation head will be:

$h_{de} = 1.20\ (819 - 810)$
$h_{de} = 10.8$ feet

The discharge friction head is the energy required to overcome friction losses in the discharge pipeline and is computed from formula (3). The maximum friction head on the dredge pump alone will be experienced when pumping from area B to disposal site No. 2. Pipeline length will then be about 2700 feet. As indicated for formula (3), the length used should be the total equivalent length of discharge pipe. Equivalent length is determined by multiplying the actual length of discharge line by a factor to allow for the additional friction head losses created by elbows and joints in the line. This factor varies from 1.1 to about 1.5. Typically, floating pipeline has joints with more flexibility than shore pipe. Ball joint deflections of up to 16½ degrees are possible. These deflections create additional friction head loss which must be included as part of the total equivalent length. By applying a factor of 1.35 to 1.5 on the floating line and 1.1 to 1.25 on shore pipe, the equivalent length can be obtained. We will use a factor of 1.5 for floating pipeline and 1.1 for shore pipe. Our equivalent length would, therefore, be:

Floating — 700 (1.5) = 1050 feet
Shore — 2000 (1.1) = 2200 feet
Total equivalent length = 3250 feet

This length can now be used in formula (3) to compute the total discharge friction head. Since velocity in the discharge line was assumed at 16 feet per second, this will result in a discharge pipeline friction head loss of:

$$h_{df} = 0.015\ \left(1 + \frac{20 - 10}{100}\right) \frac{3250\ (16)^2}{64.4\ (1.0)}$$

$h_{df} = 213$ feet

This value can also be obtained from Figure 7. Enter the graph at a velocity of 16 feet per second on the bottom scale and proceed vertically to the intersection with the 12-inch-diameter pipe size. Then proceed horizontally to the vertical scale and read 6.55 feet per 100 feet of discharge pipeline. Multiplying 6.55 times 32.5 (total equivalent length of the discharge pipeline in hundreds of feet) gives a friction head loss of 213 feet.

The pump velocity head is the energy required to increase the velocity of the mixture from that in the pump suction line to the discharge pipeline velocity and can be computed from the following formula:

$$h_{dv} = S_2 \frac{V_d^2 - V_s^2}{64.4} \quad (6)$$

where:

h_{dv} = pump velocity head in feet of fresh water
S_2 = specific gravity of the material being pumped
V_d = velocity of the mixture in the discharge pipeline in feet per second
V_s = velocity of the mixture in the suction pipe in feet per second

For our example, which has a suction velocity of 11.75 feet per second and a discharge velocity of 16 feet per second, the pump velocity head will be:

$$h_{dv} = (1.20) \frac{(16)^2 - (11.75)^2}{64.4}$$

$$h_{dv} = 2.2 \text{ feet}$$

The total discharge head on the dredge pump will be the sum of the above and is equal to:

$$H_d = h_{de} + h_{df} + h_{dv} \quad (7)$$
$$= 10.8 + 213 + 2.2$$
$$H_d = 226 \text{ feet of fresh water}$$

The total dynamic head on the dredge pump is the sum of H_s and H_d.

$$H_{TDH} = H_s + H_d \quad (8)$$
$$= 10.8 + 226$$
$$H_{TDH} = 236.8 \text{ feet of fresh water}$$

Having the total dynamic head against which the dredge pump must operate, it is now possible to compute the required continuous horsepower rating of the power plant. First, it is necessary to know the dredge pump output in gallons per minute (gpm). This can be calculated from the following formula:

$$Q = 352.5\, D^2 V_d \quad (9)$$

where:

Q = output of the dredge pump in gallons per minute
D = inside diameter of the discharge pipeline, in feet
V_d = velocity of the mixture in the discharge pipe in feet per second

The output of the 12-inch dredge when delivering at a velocity of 16 feet per second will be:

$$Q = 352.5\ (1.0)^2\ (16)$$
$$Q = 5640 \text{ gpm}$$

A dredge pump should, therefore, be selected which most nearly gives the required head-discharge characteristics of 5640 gpm at a total dynamic head of 237 feet of fresh water. Figure 8, curve A,

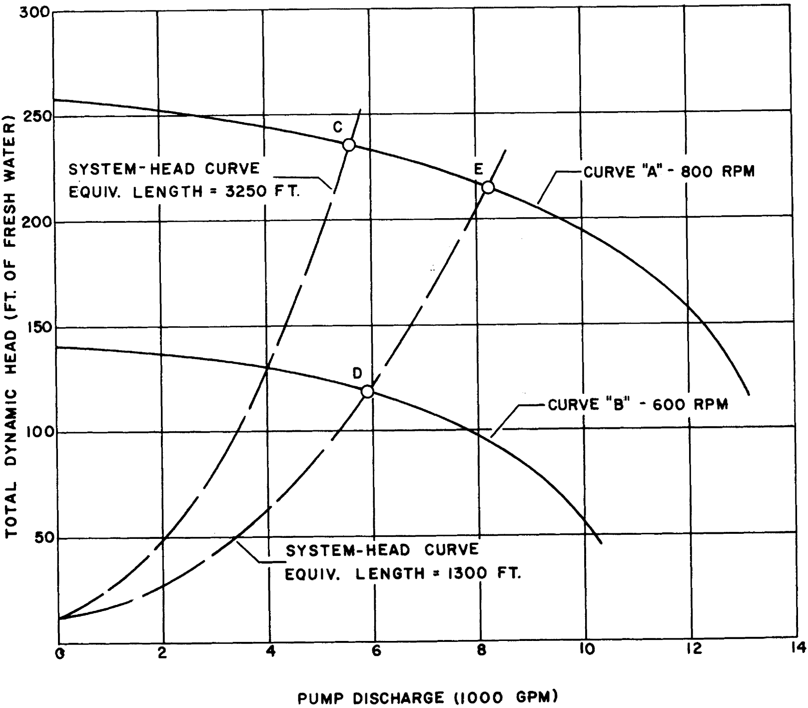


Figure 8. 12-inch dredge pump

shows the performance curve of a 12-inch dredge pump which most nearly meets the required head-discharge conditions. Also shown is the system-head curve for the 3250-foot equivalent length discharge line. This system-head curve was computed and shows the head at varying capacities. The intersection of the system-head and the head-discharge curves, point C on Figure 8, is the point at which the pump will operate under the assumed conditions. Point C shows that the pump will deliver 5600 gpm at 235 feet when operated at 800 rpm. This slight reduction in the pump discharge rate will result in a discharge pipeline velocity of 15.9 feet per second, which is not enough below the assumed value of 16 feet per second to warrant recomputing the heads.

The horsepower rating of the engine must be capable of providing sufficient power to force the dredge output through the piping and also overcome all mechanical and hydraulic losses in the pumping plant. The power required to accomplish this is called brake horsepower and is computed from the following formula:

$$BHP = Q \frac{H_{TDH} S_2}{3960E} \qquad (10)$$

where:

BHP = continuous brake horsepower required at the pump shaft
Q = dredge output, in gpm
H_{TDH} = total dynamic head against which the pump must work, in feet of fresh water
S_2 = specific gravity of the material being pumped
E = efficiency of the dredge pump, in decimals

Efficiency of the smaller size dredge pumps varies between 50 and 65%. Keeping in mind the fact that dredge pump efficiency goes down with pump wear, it is good practice to be somewhat conservative when selecting the pump power plant and we will use 55% for dredge pump efficiency.

$$BHP = \frac{(5600)\ (235)\ (1.20)}{3960\ (.55)}$$

BHP = 725, required at the pump shaft

When sizing diesel engines for continuous pump duty, the manufacturer's rated capacity for continuous duty at any rpm should be discounted by a minimum of 10%. Applying this factor, we will need an engine with a continuous rating of 725 times 1.10 or 798 horsepower at an rpm which will rotate the pump at the required speed of 800 rpm. By following this type of planning when sizing the pump engine, the engine will have longer life and will require less maintenance.

It is now possible to select an engine which will provide the necessary continuous horsepower. A selection will be made using a 1.5 to 1 reduction gear between the engine and pump. This will result in a maximum engine speed of 1200 rpm and a pump speed of 800 rpm. The engine selected should not exceed the manufacturer's recommended maximum speed at the required continuous horsepower.

Results of the foregoing analysis lead to the following conclusions:

1. A 12-inch dredge should be the minimum size used, and it should have a ladder of sufficient length to excavate at 28 feet of water depth.
2. A 12-inch dredge will have an average production rate of 300 cubic yards per hour when pumping through at least 2000 feet of discharge pipeline.
3. A 12-inch dredge can complete the project in two dredging seasons.
4. Disposal sites 1 and 2 result in shorter discharge pipeline lengths and should be filled to capacity.
5. Maximum head on the main dredge pump will be 235 feet when pumping from area B to disposal site No. 2.
6. The dredge pump engine should have a minimum continuous horsepower rating of 798 at 1200 rpm.

As previously stated, it is necessary that both the minimum and maximum head conditions on the dredge pump be investigated. Step 4 is an analysis of the maximum head which would result from the assumed operating conditions. It is now required that minimum head conditions be investigated.

Step 5

As length of the discharge pipeline is decreased, the total head decreases, the dredge pump output increases, and the velocity of flow increases. Under this condition, it is possible that more power would be required to drive the dredge pump. Assumed conditions stated that the minimum discharge pipeline length will be 1000 feet when pumping from area A to disposal site No. 1. By going through the same computations as for the 2700 foot long line, the following results are obtained:

1. Average production rate of a 12-inch dredge with 1000 feet of discharge line is 370 cubic yards per hour.
2. The system-head curve when pumping through the 1000 foot line is shown on Figure 8. Equivalent length of this line is 1300 feet. By inspection of Curve A, Figure 8, it can be seen that at 800 rpm the pump discharge would be in excess of 8000 gpm (point E) which would result in a discharge pipeline velocity greater than 22 feet per second. At this high velocity there will be increased pump and pipeline wear and pump cavitation may result. At this output, the engine horsepower requirements would be extremely high and the engine size selected above would be overloaded.
3. The two solutions to this problem would be to reduce the engine speed or install a smaller diameter impeller, or possibly a combination of both. Both of these solutions are based on reduction of the peripheral velocity of the impeller which determines the head developed by a centrifugal pump.

   When selection of the engine drive was made, it was found that in order to furnish the necessary continuous horsepower at maximum head conditions, the selected engine must operate at 1200 rpm. A 1.5 to 1 reduction gear reduced this speed to 800 rpm as required by the pump in order to meet the computed head-discharge conditions for a 2700 foot discharge line. Figure 8 shows that if the selected pump is operated at 600 rpm, the head-discharge relationship will be as indicated by Curve B. Using this curve and the system-head curve for an equivalent length discharge pipe of 1300 feet, the operating point can be determined. This appears as point D on Figure 8 and shows that the pump will deliver 5900 gpm at 118 feet when operating at a speed of 600 rpm. At this capacity, discharge velocity will be 16.8 feet per second.

4. The continuous horsepower rating required under the above head-discharge and speed conditions is 425. By using the 1.5 to 1 reduction gear, the engine will have to be operated at 900 rpm in order to turn the pump at 600 rpm. The engine selected will meet these conditions.

It is apparent from the above two cases that velocity in the discharge pipeline is related to the discharge pressure and the speed of the pump. Dredging contractors should insist that the pump manufacturers furnish head-discharge curves for the pump over its recommended speed range. By observation of the suction and discharge pressure gages and use of these head-discharge curves, the proper pump speed can be selected for the various lengths of discharge line. This proper speed will result in the optimum discharge line velocity and maximum solids handling. As can be seen on Figure 8, the intent is not to maintain a constant discharge pressure for various lengths of discharge, rather to maintain a fairly constant pump discharge rate.

It must be kept in mind that once a dredge pump is put into service, parts wear, impellers are built up and, in general, the pump characteristics change. This indicates that the manufacturer's curves must be continually checked in order to assure operation at the most desirable discharge rate. The most satisfactory method of checking pump performance is to make an initial check on clear water when the pump is first put into service. Subsequent checks can then be compared with the original characteristics.

Step 6

The long length of discharge line when pumping from area C to disposal site No. 3 will cause increased friction head and reduced output from the selected pump. A booster pump will be used which increases the total discharge rate in order to maintain a minimum discharge pipe velocity of 16 feet per second.

As stated previously, the booster pump should be located so that it will operate under a positive suction head, and far enough away from the main dredge pump so that maximum pipeline pressures are not excessive. Figure 9 shows the head-discharge curve for the dredge pump operating alone and the curve when two identical pumps are operated in series. In order to determine the operating point on the two pump curve, the system-head curve for the 6300-foot discharge line must be calculated. We will assume a velocity in the 12-inch discharge line of 16 feet per second.

Equivalent length of the discharge line will be:

Floating — 2500 (1.5) = 3750
Shore — 3800 (1.1) = 4180
Total Equivalent Length = 7930 feet

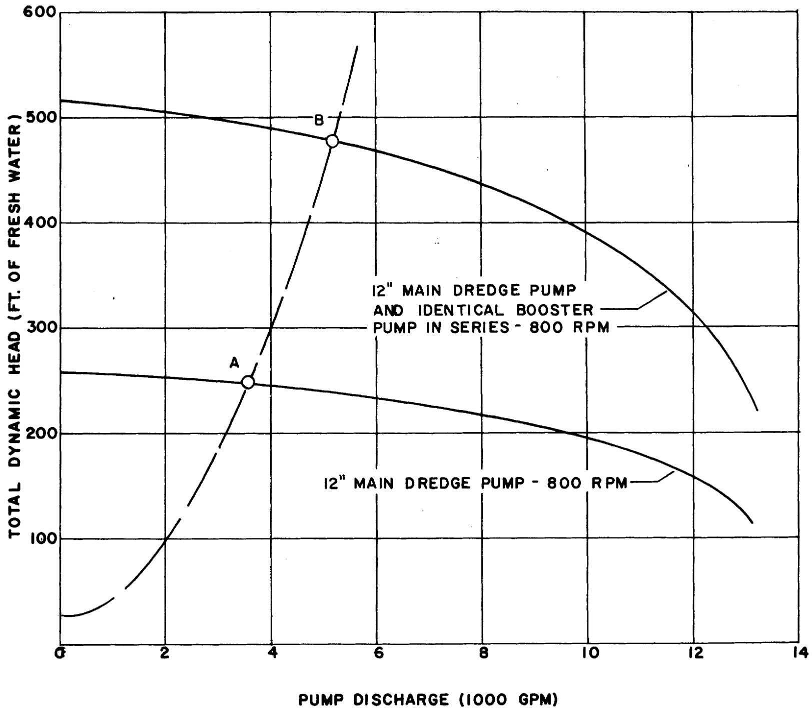


Figure 9. 12-inch dredge pump and 12-inch booster pump

The system-head curve as shown on Figure 9, for the 6300-foot discharge line, can be computed as follows:

$$h_{ss} = 1.0(28) - 1.20(28) = -5.6 \text{ feet}$$

$$h_{sv} = 1.20\frac{(11.75)^2}{64.4} = 2.6 \text{ feet}$$

$$h_{sf} = 0.015\left(1 + \frac{20 - 10}{100}\right)\frac{85\,(11.75)^2}{64.4(1.17)} = 2.6 \text{ feet}$$

$$H_s = 5.6 + 2.6 + 2.6 = 10.8 \text{ feet}$$

$$h_{de} = 1.20\,(830 - 810) = 24 \text{ feet}$$

$$h_{dv} = 1.20\,\frac{(16)^2 - (11.75)^2}{64.4} = 2.2 \text{ feet}$$

$$h_{df} = 6.55\,\frac{(7930)}{100} = 519 \text{ feet (using Figure 7)}$$

$$H_d = 24 + 2.2 + 519 = 545.2 \text{ feet}$$

$$H_{TDH} = H_s + H_d = 10.8 + 545.2 = 556 \text{ feet}$$

$$Q = 352.5\,(1.0)^2\,(16) = 5640 \text{ gpm}$$

This head-discharge relationship defines one point on the system-head curve. Additional points can be computed to plot the complete system-head curve as shown. Point A, Figure 9, shows that the dredge pump alone would deliver 3580 gpm at a head of 246 feet. This would result in a discharge velocity of slightly more than 10 feet per second, which is too low for economical operation. Point B, Figure 9, shows that when the dredge pump and an identical booster pump are used, they would deliver 5190 gpm at 476 feet. This series operation would result in a discharge velocity of 14.75 feet per second, which would be acceptable.

Further investigation of area contractors reveals that the only booster pump available locally is a high head 14-inch model. The head-discharge curve for this booster pump is shown on Figure 10 along with the 12-inch dredge pump curve. Also shown on Figure 10 is the series operation pump curve and the system-head curve for the 6300-foot discharge line.

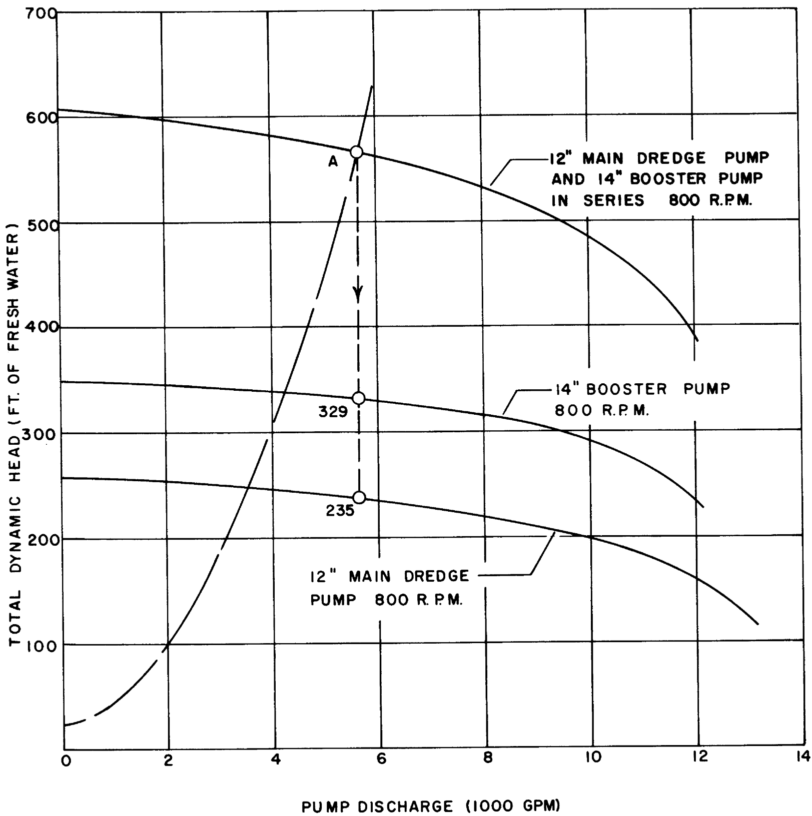


Figure 10. 12-inch dredge pump and 14-inch booster pump

Point A, Figure 10, which is the intersection of the system-head curve and the pump head-discharge curves, is the capacity at which the pumps will deliver through 6300 feet of 12-inch discharge pipeline. This point shows a discharge rate of 5650 gpm at 564 feet. Actual velocity at this discharge rate will be about 16.1 feet per second.

By referring again to Figure 10, we can determine that portion of the total head which will be contributed by each pump. This can be done by extending a line vertically down from Point A. As shown, the main dredge pump will develop 235 feet of total head and the booster pump will develop 329 feet of total head. Added together, these two numbers equal the performance point head of 564 feet. Continuous brake horsepower required to operate the dredge pump and booster pump will be as follows:

Dredge Pump

$$BHP = \frac{(5650)\ (235)\ (1.20)}{3960\ (.55)}\ (1.1)$$

$$BHP = 804$$

Booster Pump

$$BHP = \frac{(5650)\ (329)}{3960}\ \frac{(1.20)\ (1.1)}{(.55)}$$

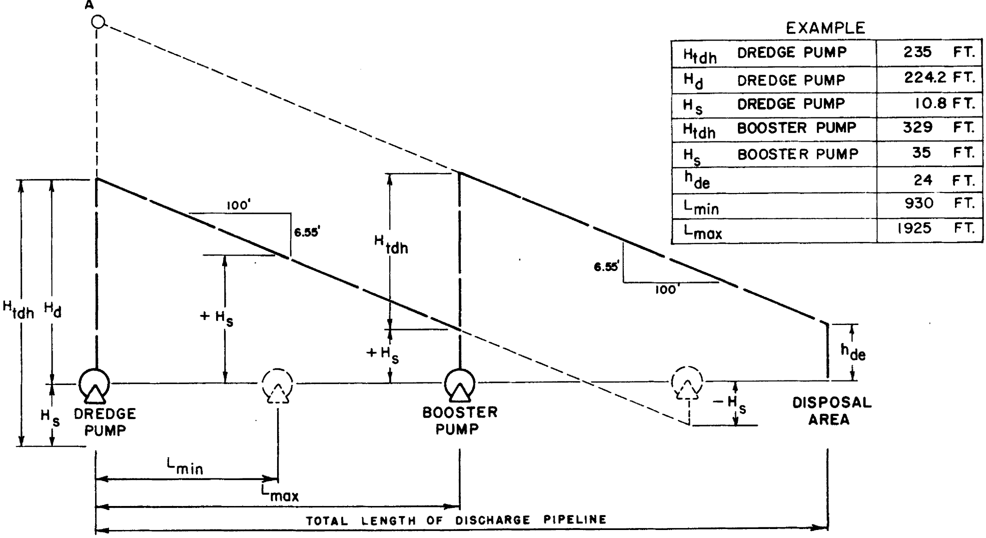
$$BHP = 1125$$

The horsepower requirement of the dredge pump is slightly in excess of the 798 previously computed for the dredge pump when operating alone. However, this difference is so small that it will not affect the dredge pump engine operation. The value of being somewhat conservative in selection of the dredge pump engine is evident in this case. An engine should be selected for the booster pump to provide the above continuous horsepower. Depending on the engine selected, a speed reduction gear should be used so that the booster pump will operate at 800 rpm.

Now that we have the discharge rate and discharge head for the dredge and booster pump combination, we can plot an energy diagram which is a pictorial representation of the heads developed throughout the length of pipeline (Fig. 11). Shown are the heads developed at both the dredge pump and booster pump and the distances between the dredge, booster pump, and end of pipeline.

In order to allow for variables in the dredging process, we will provide for a positive suction head at the booster pump of 35 feet. We can then compute the maximum allowable distance between the dredge and the booster pump. Knowing the discharge friction head loss per 100 feet (as obtained from Fig. 7), the maximum pump spacing in equivalent length of pipe will be:

$$\frac{(224.2 - 35)\ 100}{6.55} = 2890 \text{ feet (equivalent length)}$$



EXAMPLE

H_{tdh}	DREDGE PUMP	235 FT.
H_d	DREDGE PUMP	224.2 FT.
H_s	DREDGE PUMP	10.8 FT.
H_{tdh}	BOOSTER PUMP	329 FT.
H_s	BOOSTER PUMP	35 FT.
h_{de}		24 FT.
L_{min}		930 FT.
L_{max}		1925 FT.

Figure 11. Energy diagram — 12-inch dredge pump and 14-inch booster pump

Converting this to actual feet of pipeline by dividing by 1.5 gives a maximum pump spacing, in feet, of 1925. Therefore, the booster pump will have to be barge mounted on the lake surface. The plus and minus signs used as a prefix to H_s on Figure 11, indicate a suction head or a suction lift. It can be seen that if the booster pump is located a distance greater than L_{max} from the dredge, it will operate under a suction lift.

If we assume that the discharge pipeline has a working pressure of 200 pounds per square inch (462 feet), the minimum spacing between the dredge and booster pump can be computed. If the two pumps were placed immediately adjacent to one another, the total discharge head developed would be the sum of the discharge heads of the dredge pump and booster pump, as indicated by point A on Figure 11. For our example, this would be 224.2 plus 329 or 553.2 feet (239 psi). It is, therefore, necessary that the booster pump be located a sufficient distance from the dredge so that pipeline friction will lower this maximum discharge pressure to some value below the working pressure of the pipeline. This distance should be such that the dredge pump discharge pressure, plus the booster pump discharge pressure and less the pipeline friction head loss between the two pumps, is less than the pipeline working pressure. Since the slope of the energy gradient is essentially constant throughout the discharge line, the minimum distance should create a friction head loss equal to:

$$329 + 224.2 - 462 = 91.2 \text{ feet of head}$$

We can now calculate the length of pipeline required to develop this amount of friction head as follows:

$$\frac{(100)\ 91.2 \text{ ft. of head}}{6.55 \text{ ft. per } 100 \text{ ft.}} = 1390 \text{ feet of equivalent length}$$

We can now convert this to length of actual pipeline:

$$\frac{1390}{1.5} = 930 \text{ feet}$$

From the above example it is possible to develop two formulas which will give the maximum and minimum spacing between the dredge and booster pump for smaller size dredges. If more than one booster pump is used in the discharge line, the same theory can be used.

$$L_{MAX} = \frac{100(H_d - 35)}{1.5\ h_{df}}, \text{ in feet} \qquad (11)$$

$$L_{MIN} = \frac{100(H_d + H_{TDH} - W_p)}{1.5\ h_{df}}, \text{ in feet} \qquad (12)$$

where:

L_{MAX} = maximum distance between the main dredge pump and the booster pump in feet of discharge pipeline.

L_{MIN} = minimum distance between the main dredge pump and the booster pump in feet of discharge pipeline.

H_d = dredge pump discharge head in feet of fresh water (this will be equal to the discharge pressure gage reading at the dredge pump).

h_{df} = friction loss in the discharge pipeline, in feet of fresh water per 100 feet of discharge pipeline.

H_{TDH} = total dynamic head developed by the booster pump in feet of fresh water (this will equal the discharge pressure gage reading at the dredge pump).

W_P = allowable working pressure of the discharge pipeline in feet of fresh water.

The number 35, in formula (11), provides a suction head on the booster pump of 35 feet (15 psi). This value could be reduced somewhat, but it should be high enough to insure that the booster pump will not have to operate under a suction lift. The 1.5 figure is the factor which was used to convert the pipeline length to equivalent length. This number depends on the pipeline joints and the type and number of fittings. As mentioned previously, it varies from 1.1 to 1.5.

When pumping from area C to disposal site No. 3, the above analysis leads to the following conclusions:

1. In order to increase discharge velocities to the point where minimum unit production costs will result, a booster pump is required in the discharge line.

2. Either a 12-inch booster pump, identical to the main dredge pump, or the 14-inch high-head model will increase discharge velocities to a point within the recommended range.
3. Proper selection of the booster pump head-discharge characteristics is intimately dependent upon the head-discharge characteristics of the main dredge pump.
4. It is possible to locate the booster pump too close to the dredge. This can result in excessive pressures in the discharge pipeline.
5. If a booster pump is located too far from the dredge, it may operate under a suction lift. If this suction lift is excessive, it can cause booster pump cavitation resulting in decreased output and possible severe decrease in equipment life.
6. There is no valid reason, from a hydraulic standpoint, for using a booster pump that has characteristics identical to those of the main dredge pump.

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