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 de-watered 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.
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.
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 pumping 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 1 1/2 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 con-
ditions 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
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*

[Images of cutter types]

**CLOSED NOSE BASKET WITH RENEWABLE EDGES**

**CLOSED NOSE BASKET**

**STRAIGHT ARM**

**OPEN NOSE BASKET**
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 su-
tion. 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) pipe-
line 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 con-
ected 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 opera-
tion 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 maxi-
imum 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 vac-
uum 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 booster. 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
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