Matthew Shumaker

2

GOLD PLACER MINING

Placer Evaluation and Dredge Selection

By C. M. Romanowitz, H. J. Bennett, and W. L. Dare

~~Cover Sheet Page~~

. . . on circular 8462

1970

May Need binding offset

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

Matthew Shumaker

2

GOLD PLACER MINING

Placer Evaluation and Dredge Selection

By C. M. Romanowitz, H. J. Bennett, and W. L. Dare

* * * * * * * * * * * information circular 8462

1970

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

This publication has been cataloged as follows:

Romanowitz, Charles M

Gold placer mining: placer evaluation and dredge selection, by C. M. Romanowitz, H. J. Bennett, and W. L. Dare. [Washington] U.S. Dept. of the Interior, Bureau of Mines [1970]

56 p. illus., tables. (U. S. Bureau of Mines. Information circular 8462)

Includes bibliography.

1. Gold mines and mining. 2. Gold dredging. I. Bennett, Harold J., jt. auth. II. Dare, Wilbert L., jt. auth. III. Title. (Series)

TN23.U71 no. 8462 622.06173

U.S. Dept. of the Int. Library

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 – Price 60 cents

(60¢)

CONTENTS

ILLUSTRATIONS

TABLES

GOLD PLACER MINING

Placer Evaluation and Dredge Selection

by

C. M. Romanowitz,[1] H. J. Bennett,[2]
and W. L. Dare[2]

ABSTRACT

This report deals with the factors which should be considered in evaluating a placer deposit and selecting a dredging system for mineral recovery. Overall dredging feasibility and the design of dredging systems are reviewed. Excavation methods, each with its advantages and disadvantages, are compared.

Direct operating costs, both original and updated, of gold dredges with bucket capacities of 6 to 18 cubic feet are included. Costs vary with digging depth, changes in environmental conditions, and physical characteristics of the placer, all of which affect excavation rate and recovery. The costs, updated with appropriate indexes, should be used only as guidelines to evaluate potential dredging projects with similar characteristics. The relation of direct dredging costs to annual production is graphically illustrated by a family of curved envelopes that span dredge sizes from 2-1/2 to 18 cubic feet. A curve fitted to the data expresses the relation of direct costs to annual production for 151 dredge-years.

INTRODUCTION

At present dredge mining in this country is at a low level. The last gold dredge in California stopped operating in October 1968. Gold dredging in the adjacent States had already ceased because of increasing operating costs, decreasing placer values, and the fixed price of gold.[3] Two gold dredges and one platinum dredge were still operating in Alaska in September 1969.

[1]Consultant, Marine Minerals Technology Center, Bureau of Mines, Tiburon, Calif.
[2]Mining engineer, Denver Office of Mineral Resources, Bureau of Mines, Denver, Colo.

[3]Gold's position as a monetary metal changed in March 1968 when a two-tier price system was established by a seven-nation "Gold Pool" (Belgium, West Germany, Italy, The Netherlands, Switzerland, United Kingdom, and United States). International monetary transactions remained at the official price of $35 per ounce; purchases and sales by the "Gold Pool" countries in the private market were terminated; and a floating price for all private transactions began. As a result the free price in the United States averaged approximately 16 percent higher than the $35 monetary price through December 1969. A decided drop in the price of gold began in June 1969; the December average was approximately $35.60.

Because of the increasing national requirements for gold the Bureau of Mines in 1966 initiated a Heavy Metals study to investigate and appraise potential gold-bearing deposits that might contribute to domestic gold production. Emphasis was given to large deposits which would permit the economies of large-scale production methods.

This report is focused on placer mining by dredging. It brings together the old and proven dredging concepts with newer and more current techniques integrating these ideas with actual cost experience standardized to 1967. It provides data concerning current application and identification of the natural and unchangeable environmental conditions to be considered in selecting a system. Like any mineral deposit, a placer deposit should be evaluated on the basis of the most practical and efficient system suited to it. The risk involved can be reduced by a thorough exploration program balanced with a sound engineering study. There are no current publications that describe modern design and operation of dredges. Charles Janin's "Gold Dredging in the United States" (21)[4] is an excellent general reference although written 50 years ago. Peele's Mining Engineers' Handbook (15) is another general reference of considerable value. Two of the more current papers that cover foreign gold dredging are McFarland's paper on dredging in the Yukon, Canada (48), and O'Neill's paper on dredging in Colombia and Bolivia, South America (28). The bibliography in this report was prepared primarily as a source of references for placer exploration and dredging.

HISTORY OF EQUIPMENT DEVELOPMENT

The first floating bucket-line dredges were developed in Europe during the 16th century to excavate harbors. Over time their design and efficiency improved. Their adaptation to placer mining began in New Zealand in 1882 when gold-saving equipment was added behind the excavators. The first successful dredging operation in the United States started at Bannock, Mont., in 1895. The dredge design incorporated the bucket-line equipment already found successful in the Eastern United States. To it was added a washing and treating system similar to that used in New Zealand. The first gold dredge to operate in California was a New Zealand type at Oroville in 1898. Not versatile enough to operate under the varied and often rugged dredging conditions in California, it was soon discarded and a variation called the California type was developed after the Montana design.

The California-type dredge, because of the need to dig in gravel containing large boulders and in cemented, clayey, or tightly compacted formations, was strongly built and was equipped with spuds, heavy vertical movable piles, to hold the dredge firmly in place. It had short tail sluices and relatively long stackers to dispose of oversize gravel, usually plus 5/8 inch. The New Zealand dredges, which were lighter in construction, were designed primarily to excavate softer formations. They used headlines instead of spuds because of the easier digging and because there were no high banks ahead to hinder their use. Often long sluices were used to dispose of the waste. In

[4] Underlined numbers in parentheses refer to items in the bibliography preceding the appendix.

California stackers combined with sluices were found more practical. The California dredge produced more yardage and operated more efficiently considering all types of formations. Long stackers for gravel disposal made it possible to dredge relatively deep placers and to work against high banks not possible with a headline system.

After a very successful and profitable period of mining from 1895 to 1942, most gold-placer operations in the United States were closed down by Government Order L-208 issued during World War II. The dredging industry continued to produce war-needed scheelite in Montana (41), platinum in Alaska, and columbium in Idaho. Some gold dredging operations were resumed after the war, but most remained closed because of the widening gap between mining costs and the fixed price of gold. The last gold dredge of the more than 60 operating in California in the 1930's was shut down on October 1, 1968 (27). Its earlier version is shown in figure 1. In September 1969, two gold dredges and one platinum dredge were operating in Alaska. One gold dredge was on Bear Creek, Hogatzu River, and the other on the Ungalik River, and the platinum dredge was in the Goodnews Bay district.

DREDGING SYSTEMS

Dredging systems are classified as hydraulic or mechanical depending on the method of digging; both are capable of large production. A floating dredge consists of a supporting hull with a mining-control system, excavating and lifting mechanism, beneficiation circuits, and waste-disposal systems all designed to work as a unit to dig, classify, recover values, and dispose of waste. Design and operation of a dredge will not be discussed except as they influence the choice of system.

Hydraulic System

Hydraulic dredging systems, whether the lifting force is suction, suction with hydrojet assistance, or entirely hydrojet, have been used much less in placer mining than mechanical systems. However, in digging operations where mineral recovery is not the objective, the hydraulic or suction dredge has greater capacity per dollar of invested capital than any mechanical system because the hydraulic system both excavates and transports. Thus the hydraulic dredge is superior when the dredged material must be moved some distance to the point of processing. Because it is much more economical to treat the placer gravels aboard the dredge the hydraulic systems with their inherent dewatering problems are at a disadvantage.

Hydraulic digging is best suited to relatively small-size loose material. It has the advantages over mechanical systems in such ground when the material must be transported from the dredge whether by pipeline or barge. In easy digging, excavation by hydraulic systems has reached depths of about 225 feet, but excavation for mineral recovery to date has been much less, only about one-quarter of that depth. In the same way as equipment developments benefited open-pit mining, hydraulic mining dredges have benefited greatly from the developments brought about by the need to solve civil-engineering problems. The mounting interest around the world in offshore mining has spurred research and development of hydraulic dredging equipment considerably.

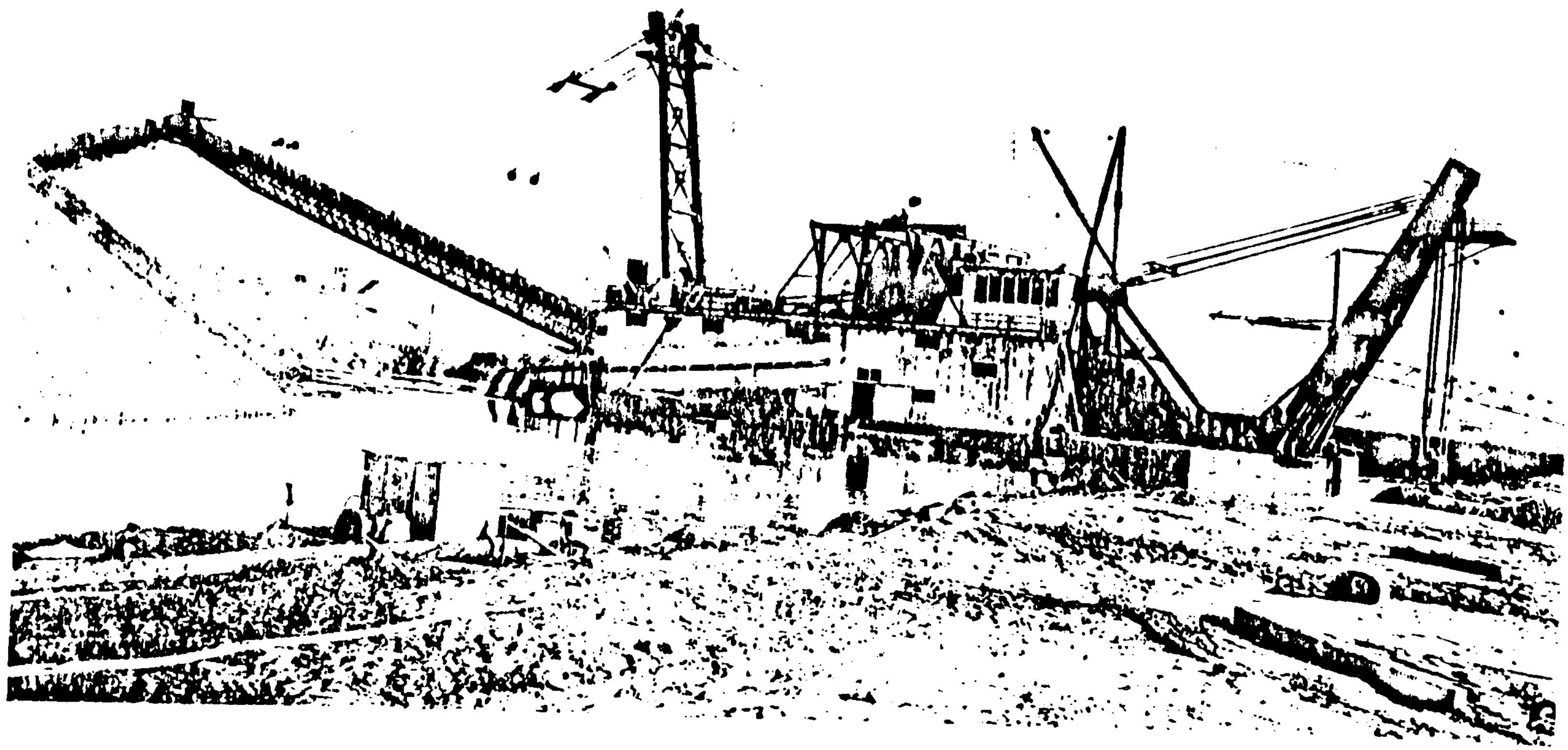

FIGURE 1. - Last 18-Cubic-Foot Dredge To Operate in California Before Being Moved to Its Yuba River Operation Where It Often Dug to 107 Feet Below Water Level.

Even with efficiently designed units and powerful pumps, the size of the gold that can be captured by hydraulic dredging is limited. The ability of a hydraulic system to pick up material in large part depends upon intake and transport velocities that must be increased relative to specific gravity and size of the particles. If the gold occurs as nuggets, especially large nuggets, the velocity required for capturing the gold can cause excessive abrasion in the entire system. In addition, higher velocities require more horsepower. On the other hand, when the flake size of the gold is very fine, higher velocities make gold recovery very difficult during dewatering.

The digging power of hydraulic systems has been greatly increased with underwater cutting heads. One disadvantage of a cutterhead is that it must be designed with either right- or left-hand cutting rotation, which results in less efficient digging when the dredge is swung in one direction, especially in tough formations. As digging becomes more difficult and the cutterhead is swung across the face in the direction so that its blades are cutting from the old face to the new, the cutterhead tries to climb onto and ride the scarp. This produces considerable impact stress through the power-delivery system and reduces the capacity of the cutter. Davis and McKay in a creditable up-to-date paper on potential dredge applications (55) discuss this difficulty. Because hydraulic dredges, even with cutterheads, dig less effectively than mechanical dredges, gold particles trapped in bedrock crevices are more difficult to recover. Disadvantages include--

1. High wear when endeavoring to capture large-nugget gold.

2. Dewatering problems when trying to capture small-fraction gold.

3. Less digging capacity when swinging in one direction.

4. Less hard digging ability especially where needed on bedrock.

5. Relatively low power efficiency because of the large volume of the water that must also be transported.

6. The problem of moving and mining around sunken logs, bedrock pinnacles, and oversize material. The latter tends to collect along the face, interfering with good bedrock cleanup, often so vital in gold placers.

7. Loss of some material left as a ridge on the bottom each time the dredge is stepped forward to start a new cut.

8. Detrimental effect in the treating plant caused by mud-ladened water pumped off the bottom of the pond.

9. Fluctuations in the feed to the treating plant.

The principal uses of hydraulic dredges have been for nonmining jobs such as in digging, deepening, reshaping, and maintaining harbors, rivers, reservoirs, and canals; in building dams and levees; and in landfill and reclamation projects. Hydraulic systems in mining have been used to produce sand and gravel (39, 62), to mine marine shell deposits for cement and aggregate (36), to reclaim mill tailings for additional mineral recovery (42), to recover coal from streams (33), and to mine deposits containing diamonds (40) and minerals of tin (35, 101), tungsten (41), columbium-tantalum, titanium (34), monazite (37), and rare earths. An interesting example of everyday dredge mining in this country is the offshore shell industry, concentrated mainly along the gulf coast although some is being done off California and the mid-east coast. Dredging the buried reef deposits of dead oystershells is a simple and inexpensive method of mining, and barging the shells to coastal market areas is an inexpensive and flexible method of transportation. From Texas to Florida, an average of 25 small hydraulic cutterhead dredges have been recovering an average of over 25 million cubic yards of shell annually over the last 5 years. Using suction pumps up to 18 inches in size, a few of which are equipped to go as deep as 50 feet, these dredges are the prime suppliers of high-grade calcium carbonate for a number of cement and lime plants along the coast, and of roadstone and aggregate to coastal areas that lack stone.

In recent years hydraulic systems have been used to strip unconsolidated overburden--(1) often more cheaply, (2) often with considerably less effort, and (3) often as the only logical method when the material to be stripped is water saturated or lies wholly under water--from ore, coal, and aggregate deposits in North and South America and Europe in preparation for conventional open-pit mining systems. Dredge stripping is not new. It was first tried in 1914 (61) when a method cheaper than steam-shovel stripping had to be found to uncover a marginal iron-ore deposit on the Mesabi Range. Stripping overburden from offshore tin deposits has been done using both hydraulic (55) and bucket-line systems (101).

Some examples of how hydraulic dredges have performed mine stripping seem in order. In Surinam (formerly Dutch Guiana) a 24-inch cutterhead dredge was used to strip the overlying silt, sand, and clay from a 2,200- by 4,000-foot bauxite ore body at an average two-shift rate of about 300,000 cubic yards per month and pumped a maximum of about 2 miles to the spoil area (53). On the Steep Rock iron range in Ontario, Canada, a large river was diverted, a large lake drained, and up to 400 feet of overburden removed from three ore bodies laying beneath Steep Rock Lake. The A and G, or Hogarth and Roberts, ore bodies were together stripped of about 106 million cubic yards of silt up to 300 feet thick with two 900-ton cutterhead dredges (55, 72). At the C, or Caland, ore body 162 million cubic yards of silt, sand, gravel, and clay overburden were stripped by two 36-inch hydraulic dredges and pumped a maximum of about 6 miles against static heads totaling about 780 feet (65, 67). Again a river was diverted and a lake drained at the Black Lake project in Quebec, Canada, where 35 million cubic yards of silt, sand, gravel, and glacial till were stripped from atop an asbestos deposit by a 30-inch hydraulic dredge and pumped over 3 miles against a static head of 200 feet (55, 64). About 15 million cubic yards of muskeg, silt, and clay will be stripped from an area 3,700 by 2,000 feet to expose a nickel ore deposit in northern Manitoba (63). In Scotland the National Coal Board stripped up to 40 feet of peat and sand cover to expose four coal seams across some 270 acres with a hydraulic dredge that averaged 90,000 cubic yards per week (54). Two general papers that cover hydraulic dredging developments are by Kaufmann (73) and Giroux (58). The proceedings of the first World Dredging Conference, held in New York in 1967 (89), cover a variety of technical subjects primarily on hydraulic dredging.

Mechanical Continuous System

Digging systems on continuous mechanical dredges can be a bucket-ladder, rotary-cutter, or bucket-wheel excavator, each with advantages peculiar to specific situations. The bucket-ladder or bucket-line dredge has been the traditional placer-mining tool, and is still the most flexible method where dredging conditions vary. Placer dredges, rated according to bucket size, have ranged from 1-1/2 to 20 cubic feet, although larger equipment has been used in harbor work. Lines of 34- and 54-cubic-foot buckets on the dredge Corozal were used in digging the Panama Canal in 1913-15 (57). Excavation equipment consists of a chain of tandem digging buckets that travel continuously around a truss or plate-girder ladder, scooping a load as they are forced against the mining face while pivoting around the lower tumbler, and then dumping as they pivot around the upper tumbler. The ladder is raised or lowered as required by a large hoisting winch through a system of cables and sheaves. Before the development of the deep digging dredges, the maximum angle of the ladder when in its lowest digging position was usually 45° below the horizontal. During the last few years in Malaysia, 18-cubic-foot dredges digging from 130 to 158 feet below water level have often been operating at angles of 55° and sometimes more. At its upper position the ladder inclines about 15° below the horizontal. Figure 2 is a side elevation of the 18-cubic-foot Yuba Manufacturing Division, Yuba Industries, Inc., No. 110 dredge that was designed to dig 85 feet below water level.

Compared with any hydraulic system the bucket-line dredge is more efficient in capturing values that lie on bedrock or in scooping up the material which sloughs or falls from the underwater face. It is more efficient when digging in hard formations, because its heavy ladder can be made to rest on the buckets providing them with more ripping force. Bucket size and speed can be varied with formation changes in the deposit according to the volume of material that can be processed through the gold-saving plant. Most bucket-line dredges used in placering have compact gravity-system processing plants mounted on the same hull as the excavating equipment. The waste stacking unit, also mounted on the same hull, combines with other dredge functions to make the dredge a complete and efficient mining unit. The advantages of an integral waste distributing system trailing behind the excavator become readily apparent because up to 10,000 cubic yards of oversize waste must be disposed of each day on a large dredge. To assure a high percentage of running time, dredge components must be designed for long life and relatively easy and quick replacement of parts. Dredging experience has shown that most parts need to be larger and heavier than theoretical engineering designs indicate, and the simpler their design, the less their replacement and installation costs.

Summing up, the advantages of the bucket-line dredge as compared to the hydraulic dredge are as follows:

1. It lifts only payload material, whereas a hydraulic system expends considerable energy lifting water.

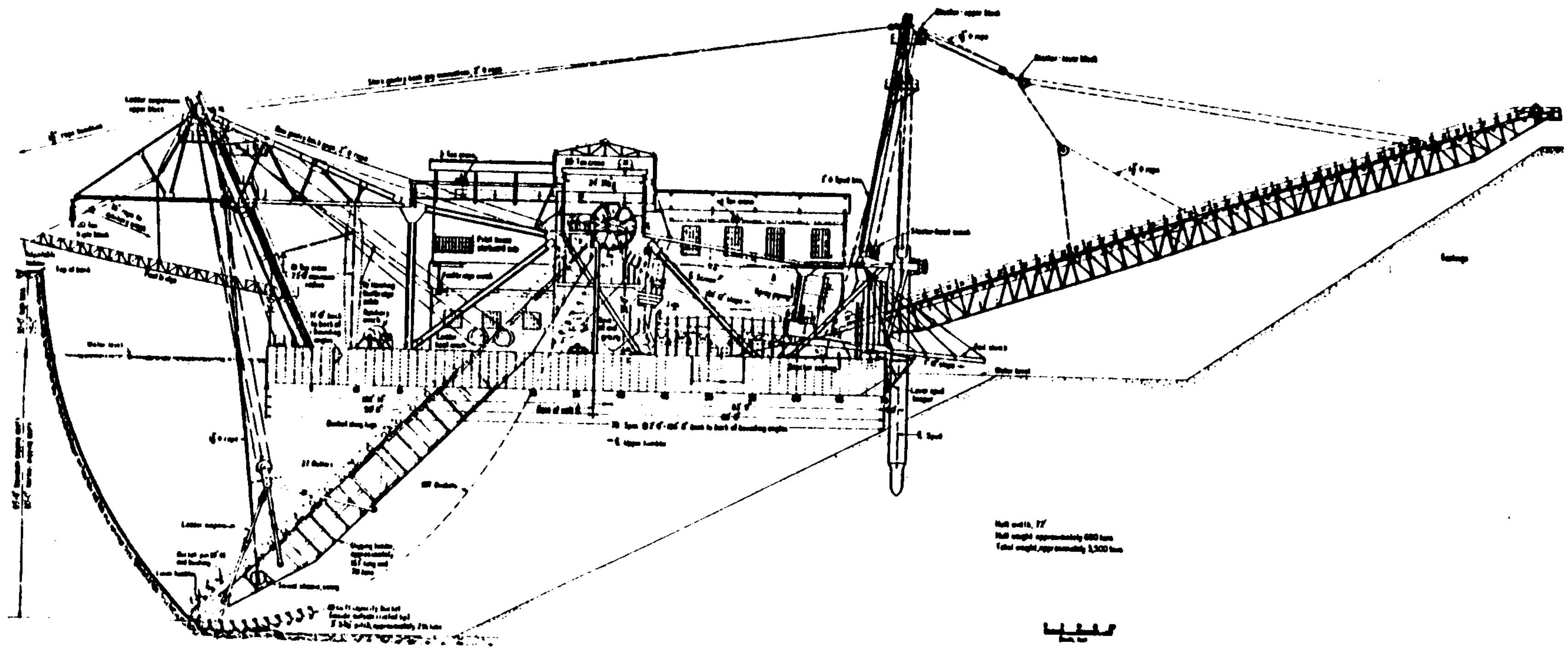

FIGURE 2. - Elevation of 18-Cubic-Foot Yuba Manufacturing Division No. 110 Dredge Designed To Dig 85 Feet Below Water.

2. It loses fewer fines, which contain most of the fine or small fraction gold.

3. It can dig more compact materials.

4. It can clean bedrock more efficiently.

5. It allows more positive control of the mining pattern.

6. It has a simpler waste disposal system as compared to a hydraulic system with an onshore treatment plant.

7. It requires less horsepower.

The disadvantages with respect to hydraulic systems are as follows:

1. It requires more initial investment capital per unit of capacity.

2. It requires a secondary pumping system if the excavated material must be transferred to a treating plant distant from the dredge.

The main and interrelated reasons why bucket capacity has not increased during the last half century are (91) as follows:

1. Larger placer deposits, which could justify the added expense of larger equipment, have not been found.

2. Treatment-plant capacity and recovery need to be bettered to deal with the more complex treatment problems, which have developed as placer values have decreased.

3. New equipment development has been retarded by the lower cost of available secondhand equipment.

To date a bucket-wheel excavator has not been used as part of a mining dredge, but conceivably if integrally designed into the total unit it could have distinct advantages. Bucket-wheel control would be similar to that of a bucket line, its ladder maneuvered vertically by a winch-cable-sheave system. Its outstanding advantage on land, to discharge directly onto its ladder conveyor, cannot be fully utilized to dig underwater unless the diameter of the bucket wheel is sufficiently large with respect to the depth of the gravel and possibly unless the bucket transfer and conveying systems are modified. The bucket wheel would seem to have its greatest promise on a hydraulic dredge to replace the cutterhead. With hydraulic lift and transport it should compare favorably with the bucket-line system. Capable of working in either direction, it could overcome the weakness of the cutterhead, which can operate efficiently in only one direction, and in tough formations it should increase output.

Mechanical Repetitive System

Repetitive mechanical excavators such as shovels, draglines, and clamshells have a place in placer mining primarily in small operations where the conditions are less favorable for continuous machines. The principal disadvantage of repetitive digging is lack of mining control. A dual clamshell mounted on a ship-type hull was used to mine offshore tin deposits in Thailand, but after 9 years it was replaced by a much more efficient bucket-line dredge. Even in its best year, 1962, it proved more expensive and less efficient than its replacement. In that year it recovered only 65 percent of the yardage available on the sea bottom while the bucket line made nearly complete recovery. Working underwater, particularly where conditions are not uniform, the operator of a repetitive excavator is unable to see how well his excavator is performing or how to reposition his excavator for maximum recovery.

Onshore placer deposits have been exploited using dragline excavators, shovels, and clamshells. Treating plants, separate from the excavating equipment, can be either floated on a pond or placed onshore, but in almost every instance the treating plant is portable. The onshore dragline excavator feeding a floating treatment plant was very popular in California during the depression after the price of gold was increased to $35 per ounce (23). It was reported that over 150 of these dragline dredges were operating in gold-bearing gravels in the United States during the late 1930's. Their principal drawback was a general inefficiency.

Advantages of a dragline excavator operation are as follows:

1. Less setup and moving time, factors particularly suitable to mining small and scattered placers.

2. More utility in narrow, shallow, or bouldery deposits.

3. Ready adaptability to irregular deposits where the variable length of cast can be advantageous.

4. More adaptability to irregular and steep topography.

5. Generally advantageous to the smaller miner because of lower capital costs and the possibility of buying used equipment.

Disadvantages are as follows:

1. Inefficiency in gold recovery introduced by surges in feed.

2. Higher unit operating costs than for continuous systems.

3. More difficult to fully recover the gravel because of less control in bucket positioning, especially as depth increases--the maximum depth of efficient digging with a dragline is approximately 60 feet.

Power shovels, because of their relatively low capital cost and proven design as an excavating tool, were often mounted on floating dredges to mechanize placer operations between 1890 and 1910. Primarily because of their relatively low and intermittent capacity to supply the treating plant, their high energy consumption per unit of capacity, and their lack of control to effectively clean up bottom gravel, shovels have not proven successful. In the 1930's G. E. Becker and H. H. Hopkins of San Francisco, Calif., invented and patented a modified shovel excavator (86) which, mounted on a floating hull, had its bucket at the end of a pivoting flume instead of a conventional dipper stick. Moving vertically, the bucket emptied its load at its elevated position into the tilted flume from where it was sluiced to the trommel. One of the first units was worked in Alaska and reported very successful. The Yuba Manufacturing Co. then obtained the manufacturing rights and an operation was started on Butte Creek, Tehama County, Calif. It proved unsuccessful because intermittent feed to the hopper and screen adversely affected the treating system, which in turn resulted in poor recovery and high operating costs. The power shovel, however, does have distinct advantages in tight and bouldery formations where its greater digging capabilities can be put to maximum use.

DEPOSIT APPRAISAL

The functioning and capacity of a dredging system must be keyed to the environmental and natural conditions of climate, water availability, location, and the physical and geologic characteristics of the deposit. The investigation of a placer deposit should be made by or be in charge of an experienced person or organization familiar with how these factors affect placer evaluation and successful dredging. In sampling to determine gold content the engineer must be aware of the differences between his calculated content, the actual content, and that recoverable. While the engineer strives to achieve an estimate approaching the actual content, his appraisal must consider the recoverable, for on this depends the success of the dredging that follows.

Most dredging companies do not contract exploration drilling. They have found that they get more accurate results and can better determine depths of values and types of formation if they can keep drilling crews under direct supervision. The experience and judgment of the engineer on the job is extremely important.

Preliminary holes should be sampled very carefully to determine the lateral and vertical distribution of the gold, whether the gold occurs in wide or narrow channels and whether distribution is fairly uniform or in irregular pay streaks. Ground that shows a spotty or irregular gold distribution will obviously need more tests than ground yielding fairly uniform samples. Where sampling discloses a channel or narrow belt having a higher value than that of the whole, its outline should be determined as closely as economically purposeful. Rows of holes normal to the channel best do this job. It might prove desirable to concentrate later mining only within it and avoid working the whole deposit. Usually it is feasible to segregate certain parts of a property and eliminate low-grade areas. When a tract is large and the time for examination is limited, tests to confirm the results of preliminary prospecting may be concentrated in an area large enough to determine the advisability of purchasing the property and installing at least one dredge.

Properly obtained samples from adequately spaced shafts give the most accurate results, but the technique is so slow and costly that it is usually used only to check the results of specific churn-drill samples and to give additional details on stratification and gold distribution throughout the depth of the placer. Shaft sinking is best applied to terraces or benches above the stream beds or to large level deposits where heavy flows of underground water will not cause trouble.

The use of the churn drill for placer evaluation was first tried in 1898 at the Boise Basin operation of the Boston and Idaho Gold Dredging Co. (5) and has been a standard placer sampling tool since that time; it is the quickest and cheapest method, and the best to use in water-saturated gravel. As a general caution, any sample from a hole not cased as it progresses is subject to considerable doubt. A method using noncirculating water, churn drilling is the technique of driving heavy drill casing to bedrock carefully recovering the material from within on predetermined intervals, usually 1 to 2 feet, or at formation changes by a bailer often called a sand pump. Water, normally supplied by that in the formation, sometimes must be added to increase fluidity for bailing. Much of the time a heavy churn or cable bit is necessary to break or churn up the "core" of material standing within the casing and sometimes the large material ahead of the casing. Results can be erroneous even with constant care. The object is to obtain all of the core material representative of the outside diameter of the casing and the depth interval that is being tested. In general, the tighter the formation the better the sampling results. A careless driller (1) may neglect to keep the casing shoe slightly ahead of the bit or bail and thus recover more material from a caving hole below the shoe than is representative; (2) may drive the casing too far ahead in loose ground so that it becomes plugged and subsequently forces the underlying material out into the walls such that less material is recovered than is representative; (3) may neglect if in very loose, water-saturated and running ground to purposely drive the casing farther ahead of the bit than usual to reach firmer ground and thus prevent taking a sample that is excessive and not representative; (4) may not follow driving with bailing if in fine loose ground where the bit can pound the core down and out of the casing so that the sample is less than representative; and (5) may not drill a few feet into bedrock to recover the gold on bedrock and to make sure that the casing is not resting on a boulder. Sometimes the bit can strike a fracture in bedrock containing gold that should be kept separate from the gold in the gravel. In bouldery ground where the bit might force the boulders downward and outward, the sample may be less than representative, despite all precautions. Knowing the exact depth of the casing shoe relative to the top of the core within the casing at all times, and the volume of the sample collected with respect to its theoretical in-place volume is a must in any alluvial drilling project. Possibly two of the better papers that cover the assignment of various compensation factors for core-value calculations, in one case a safety allowance for excess sample material and in the other for an anticipated loss of gold because of its settling to the bottom of the hole, are by Jackson and Knaebel

(9) and Avery (2). Avery first suggested that compensation be based on in-place measurements of core rise rather than on arbitrary factors.

3 In frozen ground in Alaska and the Yukon Territory, Canada, exploration engineers often drill their holes uncased, except for setting one length of casing to seal out surface water, and claim results to be more reliable than from cased holes drilled in unfrozen ground. Advantages of drilling in frozen ground are--

1. The mechanics of drilling without casing are considerably less involved.

2. There is less sloughing so there is less chance of inadvertent salting of samples.

3. In-place sample volumes can be determined more correctly.

Patty reports that an experienced driller can put down a hole in frozen ground as smooth as a rifle bore with minor raveling only if the hole intersects gravel that was dry when frozen (51). Sample reliability is reportedly increased in "open-hole" drilling because water-displacement measurements can be made to correct for variations of in-place "core" volumes, a point sometimes of considerable controversy when in unfrozen ground. Engineers unfamiliar with frozen ground might be reluctant to drill without casing, but open-hole drilling is standard procedure by engineers experienced in northern placers.

Mechanized panning equipment is available to concentrate the heavy minerals in the samples. For a single drill operation, one man skilled in the use of the pan can often evaluate probable recovery and keep up with the drill. Total or actual gold content will also require checking the gold content of the tailings. Normal procedure is to evaluate exploration results utilizing low-cost gravity-concentration techniques comparable to those used on a dredge.

It should be remembered that gold placers as a whole are nonuniformly distributed low-grade deposits and that 25-cent gravel, or gravel that averages 25 cents worth of gold (at $35 per ounce) per cubic yard contains by weight just 1 part gold in about 6.5 million parts waste. Churn drilling is not an exact procedure and there are no mathematical processes to precisely determine the actual gold content of most placers from churn drilling results. Although large bulk samples from shaft sinking will give more accurate results, they are slower and costlier to obtain. It is recommended, however, that a shaft be sunk occasionally if ground water does not prohibit it both to check drill-hole results and to examine the gravel, particularly the size and number of boulders, and bedrock in place. Sinking should go a few feet into bedrock to determine the depth of weathering and the gold it might contain. Even then, placer estimates from sample values should be considered as estimates.

Case histories that point up the sometimes inconsistent results of placer values, when tested by both churn drilling and shaft sinking, are covered in a two-part paper written by C. W. Gardner (5-6). The methods are compared against one another and against actual recovery by dredging. Two other papers, one by Hutton (8) and the other by Smith (12), similarly cover the problems in placer sampling and their relation to dredge recovery. Smith's paper, if considered on the basis of modern dredge treating systems, especially in washing and jigging, is thought to be one of the better papers for evaluating placers, for it also covers the conditions that effect ultimate recovery.

The proper location of holes and the interval at which samples should be taken can be determined only after a preliminary study of the ground has been completed. There are no hard and fast rules to follow. Some areas have been considered sufficiently prospected with one drill hole to as much as 10 acres, while in other areas the engineer has not been fully satisfied with one hole to an acre.

As part of the placer appraisal, the engineer must be aware of the following operational problems that can affect gold recovery, but which can be overcome or greatly reduced if fully understood and planned for:

1. Gold left in depressions and crevices in bedrock.

2. Gold left as a result of a poor mining pattern.

3. Gold lost because of a caving bank.

4. Gold lost due to high density of muddy water in the pond, which, together with the turbulence set up by the digging action, hinders settling and permits some fine gold to be carried away from the face.

5. Gold lost because of material dropping from the bucket as it moves up the ladder.

6. Gold lost in the treating plant when not washed free of the oversize or when it adheres to clay.

7. Gold lost as an occasional nugget too large to go through the screen.

8. Some coated gold lost if mercury is used in conjunction with tables.

More or less in the order of importance, evaluation of a dredging prospect should consider:

1. Value, character, and distribution of gold.

2. Physical characteristics of the formation.

3. Character and contour of bedrock.

4. Availability of water and problems inherent in stream operations.

5. Topography.

6. Power.

7. Labor.

8. Land acquisition.

9. Adverse climate.

10. Local and national regulations.

Value, Character, and Distribution of Gold

To repeat, gold values assigned to a deposit should be based on that recoverable by the mining and treating methods to be used. The gold must be free to be effectively processed in modern gravity concentrating equipment. The size and occurrence of the gold particles and other minerals to be recovered should be noted in any engineering evaluation. If the particles are coated or rusty, a ball mill in series ahead of the amalgamator is needed to polish the gold particles, or a modern jigging system is necessary. Extremely fine flaky particles can affect the design of the jig system. Processing time can increase as the flake size of the gold decreases, which could mean an enlarged gold saving circuit or a decrease in the production rate. Pilot evaluation becomes more critical as the size of the gold flakes decreases.

Physical Characteristics of Formation

Gold dredging is most applicable to large, flat-lying deposits. Dredging is most applicable on surface grades up to 2 percent although there have been isolated instances where grades up to 6 percent have been traversed (26). The quantity of material in a deposit or in a group of deposits to be dredged influences not only the capacity of the dredge to be selected, but whether the dredge should be portable. As the size of a deposit decreases, portability should increase. The initial capital cost of portable equipment, however, is somewhat higher than for nonportable equipment. A 6-cubic-foot-capacity portable dredge has been dismantled in 30 to 35 days and reassembled in 40 to 45 days. This type of dredge, if used on some of the California properties during the 1930's, would have been more profitable than the shore-mounted dragline dredge actually used.

The depth, character, and quantity of gravel to be mined influences the shape and size of the buckets which in turn influences the design and capacity of the processing equipment. Depths that should be determined are those from water or pond level, whether natural or developed, to bedrock and from water level to the ground surface. Within certain ranges, bucket capacity is increased as the thickness of the material from water level to bedrock increases. The relation of bucket capacity to digging depth is generally as follows:

Bucket capacity, cubic feet	Depth below water level, feet
3	<30
4	15-40
6	20-50
7-8	25-60
9-10	30-80
11	40-90
18-20	60-160

There are near lineal relationships between the above maximum and minimum digging depths and their respective bucket sizes. As the dredging depth increases the ladder design must be changed to support the increased weight of the buckets and the increased strain of digging. The maximum digging depth to date has been 162 feet. Future depth will be increased as demand and designs take advantage of the metallurgical improvements in lightweight metals. Also, a catenaryless bucket-line design should extend digging depths. The shape of the bucket is also influenced by the character of the bank above water level. Where a bank stands firm and it must be dug to the top or to a predetermined shelf height, the face of each bucket is at a high angle and all material in excess of its natural repose in the bucket will spill out onto and over the side of the ladder. This can reduce recovery.

A high bank can reduce digging depth which in turn can reduce capital equipment cost by reason of a shorter ladder. A high bank, however, requires a longer stacker and tail sluices. Bank height depends upon the type of ground, the thickness ratio of that above water to the total being worked, and the length and draft of the hull. Water depth must be sufficient to insure maneuverability and to preclude shoaling of the stern of the hull on the rejects. The optimum bank is one in which the upper part of a high bank spalls relatively easily and continuously as it is undercut by the buckets, while the ladder is well below the top. Usually if the bank is over 15 to 20 feet high, monitoring to a 15- to 20-foot shelf some 25 feet ahead of the main digging face is required. Banks as high as 50 feet above pond level have been handled this way to keep them from caving in large chunks onto the ladder. Serious accidents, however, have been caused by a caving bank. In the deep digging operations at Hammonton, Calif., intermittent 56-foot banks were monitored ahead of the ladder (15), but this was in tailings of a previous operation rather than in virgin ground and the problems of waste disposal in regards to swell were not present. In frozen gravel, records tell of broken ladders and near swamping of the dredge by waves initiated by large caves of frozen bank. An interesting reversal of this situation developed at an operation near Fairbanks where a high bank of naturally thawed silty overburden had to be partially frozen by piping a refrigerant through a system of vertical holes drilled in the bank so as to keep it out of the pond (50).

Bank height should also be considered on the basis of clay content. With high quantities of clay, bank height should be limited. As the sloping pile of fines from the tail sluices build up on the bottom of the pond behind the dredge, the superimposed weight of the overlying oversize can slide the whole pile forward and downward on mud slickened shear planes toward the stern of the dredge. Excessive amounts of fines, together with heavy amounts of clay slime, can worsen this condition. Large amounts of fines, usually from a thick layer of overburden, can also slide forward on the bottom of the pond to crowd the digging line. There have been instances where it was found that the buckets were bringing up some material that had already been put through the treating plant, a problem primarily one of deeper digging dredges. Length of hull should be sufficient to insure that digging is forward of the natural toe of the tails. Slides onto the stern can be more serious than a caving bank ahead.

Bucket design is also influenced by the size of the boulders and the cohesiveness of the formation. Buckets of standard design can jam and become damaged if boulders larger than the pitch become wedged between them as they straighten out when leaving the lower tumbler. Large boulders cramped between buckets can tear off or damage bucket lips, tear or crush the hoods, or cause other trouble. Special rock buckets have been developed by increasing the bucket pitch or the distance between buckets, and setting the cutting or leading edge of the lip below or lower than its normal position. This also allows easier dumping. On a dredge in Trinity County, Calif., large boulders were handled with 12-cubic-foot capacity buckets which had the bucket pitch of a standard 18-cubic-foot bucket line. Yuba built several dredges of various capacities using this design. The extra cost to move or mine around oversize boulders or to handle them aboard a dredge can become an important factor in near marginal deposits. Large surface boulders are usually broken with explosives.

When lenses or islands of cemented gravels are encountered, it is often better to grind through these if possible, rather than break them up by blasting. In addition to the extra cost, blasting often breaks such rock to a size too large to be handled by the buckets, but too small for the buckets to break them down further. If the cemented gravels are too thick or too large to grind through, they must be bypassed. If extensive, they might rule out dredging altogether. Large boulders within the cemented mass can complicate the problem even more.

In permafrost areas frozen ground is generally thawed prior to dredging. Cold-water thawing, the most economical method for large scale thawing because artificial heat is not supplied to the ground (44), was first tried about 1915-17 in both Alaska and Yukon by a number of experimenters (45). Thawing is accomplished by circulating water from 40° to 55° F through a system of drive points driven to bedrock. Steam thawing in the United States was discontinued because of its cost--only high-grade deposits could stand the expense--but reportedly is still being done in the U.S.S.R. The deepest gravel thawed has been 110 feet, accomplished through churn-drill holes (49). About two summers are ideal to thaw and properly season the gravel in Alaska, but at some mines in shallow gravel it was common to dredge the same season the ground was thawed. This, however, was not the general practice. A system of naturally thawing 12 to 20 feet of gravel was developed by stripping off the overlying barren muck, and allowing three seasons for the thaw to penetrate 2 to 3 feet of bedrock (51). The general rule of thumb near Fairbanks is that each foot of depth requires 1.25 to 1.50 days to thaw (49). Until recent years when dredges were started late in the season, steam thawing was sometimes used to break up an average of 4 to 5 feet of seasonal surface frost just ahead of the dredge (50), which later in the summer was discontinued when solar thawing could take over.

Clay content also affects the design of the bucket as well as that of the treating plant. Clay is often found as barren overburden or as lenses or layers within the deposit. Disseminated throughout the deposit, it causes the least trouble. To facilitate dumping clayey material, some buckets have holes at the back of their hoods to relieve the partial vacuum as they dump. In addition, high-pressure water jets can be applied to cut between the clay and back of the bucket. Operators often find that when in clay, smaller bucket loads, which are easier to empty, actually increase digging rate. Some mechanical clay extractors triggered by the travel of the bucket line are used in Malaysia to pull the clay free. Some clays are called "gold robbers." Sliding along with the fines in the screen or rolling across the tables or jigs, small balls of clay can pick up the gold particles which are consequently lost as tailings. Most clay must be disintegrated or slurried prior to tabling or jigging using either a hammer mill or a log washer. The problem becomes more acute if the clay is from false bedrock layers or from the bottom of a deposit where the gold is richest. As the size of the gold flakes decreases, a more complete job of slurrying becomes necessary. Sometimes the clay can be partially broken down before it is sent to the hammer mill or log washer with thrashing chains, high-pressure jets of water, or puddle knives placed within the revolving screen. Other times, materials such as seashells occurring naturally within the clay can help break it down. In extreme conditions, some clayey formations cannot be dredged profitably. Often the upper shell-plate area or intake end of the screen has been used effectively as a grinding mill. In one case very hard angular blocks of granite were added and retained within the trommel as an aid in scrubbing. The Olson patented lower shell-plate area at the discharge end of the screen was also used for an additional washing and screening area.

Redredging placer ground can be economical when one or more of the following hold:

1. Undisturbed placer ground remains at depth, possibly even an enriched bedrock zone, that can be reached with deeper digging equipment.

2. Sufficient gold remains in previously dredged gravel that can be recovered with improved treating equipment.

3. Gravel and clay material loosened and broken down by previous operation can increase productivity and lower operating costs of redredging. Because of easier digging, larger dredges can often be used.

Character and Contour of Bedrock

The character of bedrock and the manner in which gold is concentrated or trapped there can affect not only the design of the buckets but also that of many of the dredge components. Bedrock that is soft or so fractured and weathered that it can easily be dug offers a distinct advantage toward maximum recovery. Similarly, recovery is better if bedrock is flat. Where the bedrock is hard, blocky, and uneven, a heavier ladder, heavier spuds, sturdier design of the driving mechanism, and heavy wear plates placed on the bottom of the ladder where it rides the buckets are then usually necessary. Change in bucket design is toward smaller and heavier construction with decreased capacity. Smaller buckets provide greater digging capability with lower energy requirements because the lip alternately wedges, compresses, and shears the rock loose. It is common practice to dig 1/2 to 1 foot of bedrock, but in one extreme situation it was reported (47) that 10 feet of blocky and slabby bedrock was removed to recover the gold. Knowledge of the fracture pattern on bedrock, its contour, and its slope may influence the direction and pattern of dredging as well as the height of the pond level and the bank. Mining slows down and recovery drops as bedrock becomes more irregular. The final swing of the ladder across the bottom is slowed down depending upon the irregularity of bedrock and the difficulty of cleanup, the value of its gold, and the amount of material that has sloughed from the face and has spilled from the buckets. Blasting channels through hidden protrusions of hard bedrock for the necessary depth to float the dredge has caused costly delays. This happened at one foreign operation in shallow gravel where prospect holes had been drilled on 100-foot centers. Blasting through buried dikes of hard rock was one of the causes that closed down a 9-cubic-foot operation in Featherville, Idaho. Buried fault escarpments have also been the source of costly delays.

Availability of Water and Problems Inherent in Stream Operations

The quantity of water required varies with the size and type of dredge and with the character of the formation to be dredged and treated. The fresh water that runs into the dredging pond does not necessarily indicate the quantity of water needed in the operation, because the water from the dredge pond is constantly reused. Dredges of the 9-cubic-foot class often use about 75 gallons of water per minute and those in the 18-cubic-foot class about 150 gallons per minute. This, however, depends on the conditions mentioned previously.

Of primary importance in the recovery system is the condition of the water--the cleaner, the better. Heavy clay sediments are detrimental to most treating systems. Slimes are mostly a product of the treating plant but considerable amounts can come from the digging operation, especially in deposits with thick layers of fine overburden. If the water becomes too contaminated with clay, it is usually cycled to a settling pond for clarification. In Malaysia where muddy water conditions have been severe, the treating water is taken off the top of the pond where it is clearest. In the ponds of the deep digging dredges at Hammonton, Calif., although little clay was present, the accumulation of sediments was so great that a pump had to be set to remove the thickened sludge off the bottom of the pond. The pump suction was dropped overboard at the bow of the dredge, where it did not interfere with operations, to a depth of at least 90 feet. The sludge was pumped through a line fixed to the stacker to discharge it at some distance to the rear on the rock tailings pile where the water could filter back to the pond.

Dredging in rivers requires modifications in the design of the dredge hull as well as in the design of the dredging pattern. River dredging requires that:

1. The hull be enlarged to assure more freeboard--as much as 5 feet is sometimes necessary.

2. The hull be cut back on the bottom at the bow and the stern to allow swift water to flow easily under the bow and out again at the stern.

3. The dimensions of the hull be properly balanced for stability when maneuvering in rapid water.

4. Headlines be used to hold the dredge in its digging position in waters that are swift or subject to rapid rises.

5. The course of dredging be upstream.

6. Care be exercised to see that logs or other floating materials do not damage the hull in rapid waters.

7. Sidelines be as high as possible to prevent entanglement with floating debris.

If the river is navigable, arrangements must be ready to allow other boats to pass. If the current is not swift, passing can be accomplished by dropping the sidelines. Most dredge hulls have a vertical bow wall set square with the deck to increase bow support under the forward gantry, which in turn supports most of the digging ladder. In swift water, however, a beveled or raked bow wall will minimize the height of the "piling up" effect of the water and its frontal or downstream thrust, and the strain on the shorelines. Rake at the corners of the stern, in addition to that across the stern, will permit the flow to be displaced into the low-pressure zone astern to lessen its downstream pull.

Topography

The surface of a deposit should be mapped and contoured. This is most important with respect to bedrock contours to obtain maximum recovery. Surface contours will assist when plotting the course of the dredge to make sure that all of the gold-bearing gravel is reached. In a South American project the undredged yardage lost because of inadequate planning might have been the difference between loss and profit. If the placer is shallow, a contour map of bedrock can be critical in charting the dredge course. Contours of the surface are needed to determine where dams should be placed to make ponds sufficiently deep to dredge and to advance upgrade.

Power

If public power is economically available it can be transmitted aboard the dredge by the standard flexible power cable especially designed for dredge service. When not available, then the type and location of the generating plant must be determined. For a small operation it may be more economical to generate power aboard the dredge with a diesel-electric set or in some cases use diesel power direct. The decision will depend upon the needs, economics, and time to complete mining. If the project requires a large dredge or more than one small dredge, the generating plant should be onshore and centrally located. In each of the above cases the one thing that must be kept in mind is dredge efficiency and operating time. The object is to provide enough power to cover the unusual conditions so as not to overload the equipment. Demand power loads will vary primarily as the difficulty in digging varies.

Labor

As a mining unit, the labor required to operate a dredge in terms of yards excavated is no doubt the least of all types of mining. A dredge is a completely mechanized, large-volume, self-contained, mine-mill unit that digs, treats, and backfills its waste in a matter of minutes. Dredging crews are usually the minimum essential to maintain an efficient operation and it seldom pays to try to reduce labor costs by further reducing the crew. The percentage of labor costs in unit-dredging costs bears this out. Overall, as dredge size and production increase, the ratio of direct labor costs to total direct costs decreases. Stated differently, the more a dredge has produced and the lower its direct costs, the lower in turn has been the percentage of labor in those costs. While the ratio of labor to total costs increased for all dredges during 1930-60, the amount of increase varied depending upon the size--the smaller the dredge, the greater the change; the larger the dredge, the less the change. In 1930, the average ratios of labor to total cost going from the 3-1/2-cubic-foot size to the 18-cubic-foot size were about 42 and 28 percent. By 1960 these averages had increased to about 65 and 43 percent.

The smaller dredges require a crew of three per shift--a winchman-dredge master combination, an oiler, and a shoreman. As the dredge size increases more men are required, but even for the largest dredge the number need seldom exceed five to six men per shift, consisting of a dredge master who is on call 24 hours, a winchman, two oilers, a spare man for jig attention, and one or two shoremen. Additional help must be provided for swing-shift duties so as not to work the men more than 40 or 48 hours per week. However, in Alaska and isolated short-season areas, it is customary to work 12-hour shifts. A repair crew is required when more than one dredge is operated. The repair crew can start with one man who has a combination of skills as an electrician, surveyor, and welder, and be increased when necessary. In many single-dredge operations it has been the practice to use the regular crews on overtime to make almost all repairs, large and small, whether of maintenance or emergency. Usually the dredge master is busy with surveying and limited office work.

Generally, the best dredge crews are those trained on the job. However, it is well to start with an experienced winchman if possible, but that is not necessary for the smaller operations. It has been found that men who have built dredges usually become efficient workers on a dredge. In the past it was customary to look for an alert, mechanically oriented man and develop him into a winchman and possibly into a dredge master, and occasionally into a superintendent. With a limited crew, labor turnover should be minimal, and companies that have fewer labor problems have the better operating records.

Land Acquisition

Where the economics dictate, it is usually better to mine the land on a royalty basis for the cost of the land in effect is paid for as the project proceeds. This usually suits the operator with small working capital. The usual royalty is 10 percent, but if high values are present, the landowner may want his royalty paid on a sliding scale proprtional to the gross recovered. Prospecting placer ground under an option to buy if sufficient values are found can prove to be the best plan to follow if there is reason to suspect that the deposit might contain higher than average values. Mining on claims is in order if a properly secured contract is negotiated. It is assumed that care will be taken to insure that the claims are valid and negotiable.

Adverse Climate

Climate can determine the length of the working season, the number of yards produced per season, and the return on invested capital. In general, the minimum gold content of a placer must increase as the working season decreases. Cold weather may require that the dredge, except for the ladder, be completely closed in and heated (fig. 3). To prevent the ladder from freezing, steam pipes can be placed under its pan. Steam directed into the hopper will keep the gravel free. Operating costs increase because of these heating costs and the need to frequently remove the ice that forms on the digging ladder, hull, and stacker. The stacker is the most vulnerable place on the dredge and heating it begins before it does on any other dredge component. Freezing of spill material and ice buildup on the head pulley and underside of the belt require prompt and steady attention. O'Neill's paper (50) is one of the better accounts of arctic dredging conditions.

Some operations in Alaska, Canada, and the Northwestern States are usually suspended in severe cold weather. Operations in Alaska and the Yukon Territory are normally down for at least 5 months. In most parts of interior Alaska the average temperature by the middle of April is usually above freezing, but the ice and winter frost are not often thawed until the middle of May. The season can be increased by as much as 2 months by removing the 2-1/2 to 5 feet of pond ice and the last winter's frost ahead of the dredge (50). Operations in Montana or equally cold areas close down for approximately 1 month.

Suspension of operations during cold periods also increases yearly operating costs, but experience has shown it to be less costly than running. Some companies, like the Goodnews Bay Mining Company of Platinum, Alaska, which shuts down for about 5 months, have proven that preventative maintenance after closedown in the fall and before restarting in the spring yields a much higher trouble-free period of operation. Goodnews Bay has compiled a 97-percent running time for its 7-month operating period. One advantage of winter downtime is that dredges can be moved in larger sections on sleds; this reduces the cost of dismantling and erection compared with rail or truck freight costs. The Fairbanks Department of U.S. Smelting, Refining and Mining Co. did this on

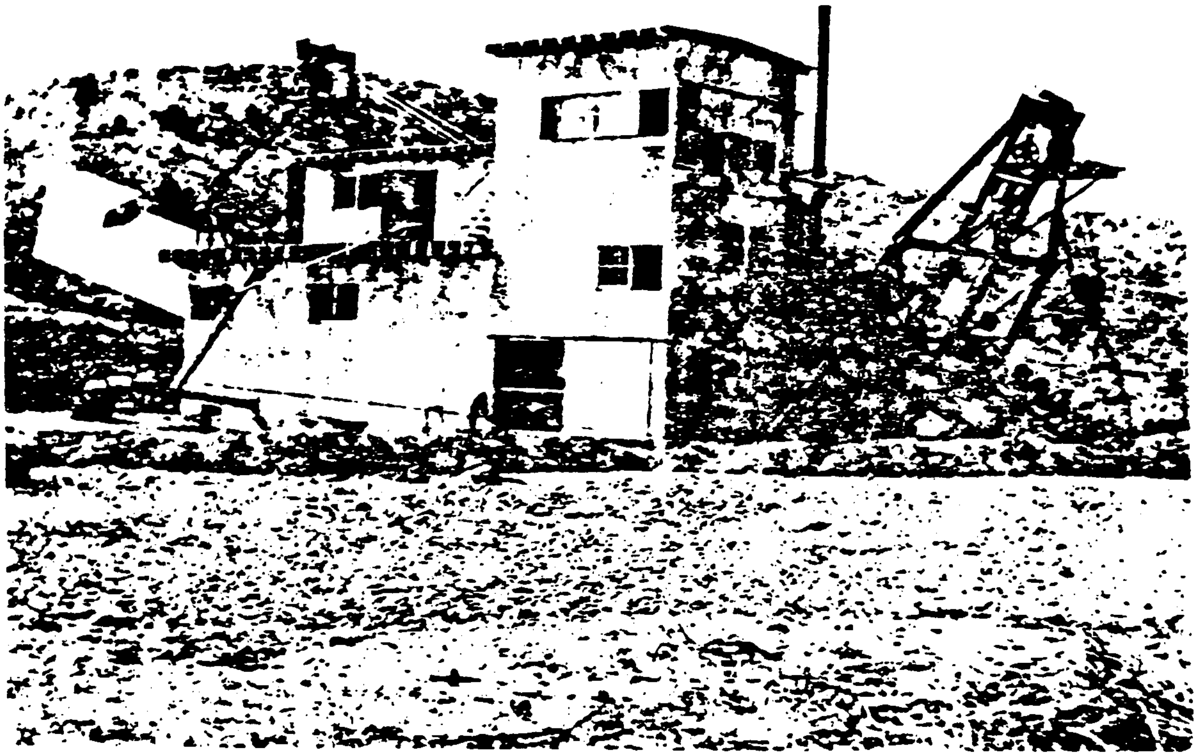

FIGURE 3. - A 3-Cubic-Foot Dredge Equipped for Winter Operation With Heating System and Enclosure.

several occasions in the Fairbanks area. Ludwig's (46) account of how a 1,200-ton dredge was sledded across 7 miles of frozen ground in three sections, the largest weighing 680 tons, by 18 large diesel tractors over grades up to 11 percent is fascinating reading.

To have a good crew return when dredging is restarted, some special arrangements may be necessary. In Montana one company during downtime kept part of its crew on maintenance while the rest took their annual paid vacation.

Local and National Regulations[5]

State mining laws, fish and game laws, and Federal regulations and tax statutes should be investigated. In addition, all existing or prospective

[5] In foreign countries, other factors to be considered would be taxes, duties, and stability of the Government. These items again are legal matters and suitable advice should be obtained. This generally should come from attorneys experienced in the country, as well as attorneys who have foreign practice. Often excellent advice is available from domestic banks having foreign branches.

legislation governing pollution of streams and restoration of land surfaces should be fully understood and evaluated from the viewpoint both of cost and public relations. This is generally a task that requires legal advice.

The importance of placer deposits as a primary source of gold will in some cases cause land-use conflicts that must be equitably resolved. Romanowitz and Cruickshank (80) go into the problems of surface disturbance and future dredging. In some areas, especially in agricultural land, the exposure of rocks and gravel in the waste piles has caused serious objections. In California, the "resoiling dredge" was developed, which reversed the disposal methods and made possible agricultural reuse of the lands. The New Zealand-type dredge, by virtue of its natural disposal methods, left the dredged areas in a condition somewhat similar to predredging. This dredge has been used with a limited bank where the formation consisted of mostly fines with gravel sizes generally limited to less than 1-inch diameter. Where coarse gravels were encountered, the California dredge is the more practical. When dredging in the United States is renewed, most of the operations will have to use the resoiling type in order to conform where State laws are more stringent on the use of land resources. The added cost of operating the resoiling-type dredge is of no real consequence to the profitable operation, but their capital costs in many cases will be as much as 20 percent more.

DETERMINING SUITABLE DREDGE SIZE

After the placer deposit is properly prospected the miner has a reasonable knowledge of the volume and grade of the placer together with information on its geometry, formation, and the distribution of values by size and location as well as information on bedrock topography, surface topography, water supply, and a host of other information that is pertinent to future decisions.

If the results are generally favorable and suggest the probability of a profitable operation, then the next step is to test that thesis by a cost analysis to determine the optimum type and size dredge. It is best not to assume that a dredge of standard design will suit all deposits. In general, if the ground is deep, if the gravel is not cemented, and if the property is large, the larger the dredge the lower the unit cost of mining. If the ground is shallow, 30 feet or less, a large dredge will have difficulty or cannot operate. With a hull depth of 10 to 12 feet the pond beneath the dredge can cause flotation trouble. For the same reason, if the ground is shallow, the slope of bedrock becomes a very important factor in pond depth and thereby in the size of the dredge. In one shallow relatively high value dredging operation in the Western United States, 52 inches of placer material was being excavated with a 3-cubic-foot dredge that drew 50 inches of water. Coarse gravel that contained little fines, a good waste-disposal system, and careful advance made dredging possible. High-surface gradients might require additional bedrock to be dug or pond dams to be built. If the ground is tightly cemented the buckets should not be too large, but should be smaller and strongly built. Emphasis should be given to a smaller bucket line such as a 9-cubic-foot line designed for hard digging and equipped with extra horsepower. Where boulders are present and rock-type buckets are necessary, bucket size might actually have to be increased over that first anticipated. Larger buckets in this case designed with a longer than normal pitch and running at a somewhat reduced bucket speed will possibly not materially change the production rate or the need to redesign the capacity of the treating plant.

The capital and operating costs of continuous mechanical dredges should be compared with those of hydraulic or other types that have their treating plants separate from the excavator and which have lower capital costs but higher operating costs. The study should appraise the purchase of used dredges available at lower costs, even though they may be somewhat less efficient.

Size and type of hull, whether standard or portable, for a proposed dredging project require considerable study. The judgment of a qualified engineer experienced in dredging will be particularly valuable.

DREDGE CAPACITY

The estimated annual capacity of a dredge in cubic yards of bank is $\frac{Cfs \times S \times M \times D}{27}$, where C equals bucket capacity in cubic feet; f equals average estimated fill factor; s equals average estimated swell factor; S equals average bucket-line speed in buckets per minute; M equals estimated average minutes of running time per day; and D equals estimated days of operation per year.

The fill factor might drop to as low as 0.50 when dredging a flowing sand and the ladder is elevated. Usual limits are 0.75 to 1.25, the latter being heaped loads when digging in cohesive clay. When estimating dredge capacity in new ground, a unity fill factor might be the best to use until experience is gained. The swell factor, the reciprocal of one plus the decimal equivalent of percent swell, can vary from 0.72 for a clay and gravel mixture to 0.89 for a loose sand. In new ground an average of 0.80 might be used for a 25-percent swell until more experience is gained.

The running time of a dredge is the time when gravel is being dug and treated. The yearly average based on a three-shift, round-the-clock operation will vary as the time required for moving ahead, greasing and oiling, repairing and cleanup, recovery from power failures, and the more unusual disruptions brought on by adverse weather and water conditions cutting into operating time. A placer dredge is usually shut down for cleanup, the collecting of concentrates, once each week. Taking advantage of this 5 to 8 hours of downtime, repairs are made to keep the dredge operating as continuously as possible between cleanup days. For many dredges, digging is hard and it requires all the effort that the dredge is capable of producing. Running under these conditions usually requires a general overhauling every 3 or 4 years not possible during regular cleanup days. Actual yearlong digging time has ranged from 75 percent or less when digging conditions are difficult to about 93 percent when digging conditions are very favorable. The aim of most projects is to attain a yearly average of approximately 21.5 digging hours per day, or approximately 90 percent of available time. However, dredges have been called upon to dig ground so difficult that a running time of 18 hours per day was considered satisfactory. As reported earlier, dredging in the far north requires that the dredge be put in top operating condition during the down months to minimize repair time during the 7- to 8-month operating season. Breakdowns that require more than a few hours of repair time are intolerable. Patty (51) reports that meticulous preseason care has resulted in some dredges compiling running times of as much as 99 percent excepting cleanup time. Winter weather conditions permitting, a dredge normally operates 365 days per year with downtime only on Christmas and Independence Days and then dredges close down for only two of the three shifts. Design capacity of a gold-saving circuit depends upon the estimated percentage of fines at theoretical capacity of the excavator with an added safety allowance, the percentage of blacks within the heavy portion, and the size of the gold particles.

The stress to minimize downtime increases with the size of the dredge. Not only are their direct and indirect costs higher, especially capital-cost recovery, but the larger dredges are often working in lower grade gravel.

There have been cases where an operator mistakenly thought he was exceeding the rated capacity of his dredge when digging in very sandy or loamy overburden, but actually a large percentage of the material was sloughing into the pond and not going through the dredge. When in some clayey formations where dumping is not a problem, heaped buckets can greatly boost dredge output, but where a clay seam is sticky, decreased bucket loads that lessen a dumping problem can in effect maximize a drop in output. Any time when digging is tough and power is insufficient, output will drop. Digging should slow down when crossing a high-grade streak or channel to make sure that the treating plant can make maximum recovery.

Bucket speed will definitely vary as the characteristics of the formation vary. High-speed bucket lines with buckets up to 9-cubic-foot capacity will travel from 28 to 40 buckets per minute. For high-speed lines of larger buckets this becomes 28 to 35 buckets or more per minute. Often when bucket speeds are increased smoother running conditions result.

In determining operating efficiency, therefore, the following conditions are to be considered:

1. Lost time to service and repair.

2. Lost time to maneuver dredge.

3. Lost output when buckets not filled to capacity.

4. Lost time due to conditions beyond control such as weather, accidents, and power failures.

When formations can be dug without undue difficulties, the productive capacity for various size buckets generally considered standard are as follows:

Bucket capacity, cubic feet	Monthly production, cubic yards	
	Slow speed	High speed
3	60,000	85,000
4	75,000	110,000
6	120,000	185,000
7-8	175,000	290,000
9-10	225,000	390,000
11	275,000	425,000
18	350,000	475,000
54	[1] 900,000	[1] 1,350,000

[1] Estimated.

Dredges with 54-cubic-foot buckets have been used for harbor excavations but have not been adapted to placering. The monthly production estimates shown for this size dredge are believed conservative. Production will vary from that shown above when variations are necessary to meet special digging conditions.

The above monthly production averages plotted against bucket sizes according to line speeds in figure 4 show a nonproportional relationship in the form of relatively smooth and somewhat similar "S" shaped curves. The averages used are just that, averages, and specific relationships can differ. Monthly production per cubic foot of bucket capacity increases almost proportionately with bucket size up to the 9- to 10-cubic-foot class. The maximum production per unit of capacity occurs at about the 10-cubic-foot size on the slow-speed curve and at about the 9-cubic-foot size on the high-speed curve. Beyond these, the rate of change decreases. This decreasing rate is in some considerable part due to the greater depth at which dredges equipped with larger buckets operate. Slower relative line speeds and longer pitch distances that come with heavier and larger buckets running on longer and more ponderous ladders, which must be supported on larger and less maneuverable hulls, in part exemplify the sequence in design problems that overall have the decelerating effect on production as dredge size exceeds the 9- to 10-cubic-foot class.

In operation, the deeper digging dredges have not produced as much in proportion to their bucket capacity as have the smaller size dredges working in shallower depths mainly because the operator does not have the control he does at the shallower depth, his line speeds are usually slower, it takes longer to raise the ladder, and downtime to service and repair is longer. Other things being equal, the deeper digging dredge has produced less per cubic foot of its capacity because of the increased lag time before corrections can be made for partially filled buckets. As more modern electrical controls take over the responsibility of keeping the buckets full, the effect of lag time will lessen.

The approximate percentage increase in production that comes with the change in line speeds is shown by the upper curve in figure 3. This curve indicates that with present dredging technology faster line speeds produce the greater gain for the middle-size dredges. This curve together with the lower

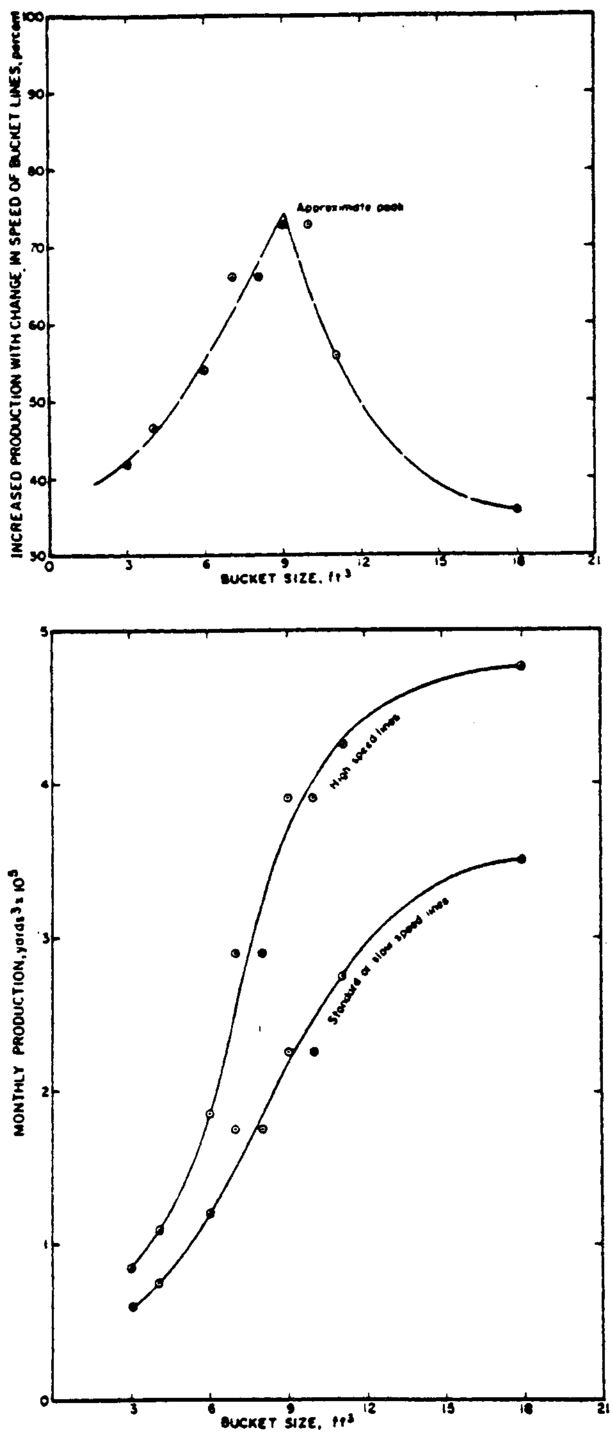

FIGURE 4. - General Relation of Average Monthly Production to Size and Speed of Bucket Line and Approximate Percentage Effect of Speed Change.

two points up the difficulties in lineally scaling production with bucket capacity and at the same time designing for greater depth.

One of the initial adaptations to automation was the use of electrical sideline winch controls early in the 1930's (69). As more automatic and precise controls can be built into dredge systems, production, especially for the larger dredges, will increase.

Experience has proven that the dredge with 9- to 10-cubic-foot buckets is generally the most economical size, but digging depth should not exceed 80 feet. In Malaysia a 9-cubic-foot bucket dredge is digging to 125 feet, but its efficiency is probably less than if larger buckets were used. Care must be taken to be sure that demand for increased production does not result in decreased recovery. In one case where the operation was under good management, the decision was made to greatly increase the yardage with the accepted loss of approximately 5 percent in gold recovery. The end result was an annual increase in the total ounces of gold produced at lower unit operating costs. Opposite to this is the case of a large dredge that was digging in a clayey formation. The dredge was averaging about 125,000 cubic yards weekly, but without the expected recovery. When the yardage was cut to 90,000 cubic yards, the losses were reduced. The manager explained that he was mining for gold and not trying to make high-yardage records. Maximum yardage that can be efficiently treated with minimum loss is the prime objective, not maximum digging. In still another case where management's policy was high yardage, the dredging crew under pressure to produce did not go to bedrock, especially the crew on the third or graveyard shift. Later, when the same area was redug in crossing to an unmined section, it was found that approximately 3 feet above bedrock had not been dug. Gold recovery on this second pass equaled that on the first. In some foreign dredging fields, inefficient equipment first used and lack of attention to mining patterns have warranted redredging a second and sometimes a third time.

PRINCIPAL TREATING PLANT SYSTEMS

Once aboard the dredge, the dredged material is classified, its valuable portion recovered, and its waste portion disposed in a coordinated recovery-disposal system designed to handle the capacity of the digging system. Also on board are the dredging-support equipment of the spuds, winches, and controls, and the water-supply systems. The recovery equipment consists of a hopper, revolving screen, distributor systems, and gold-saving equipment.

The first bucket-line dredges used deck-type shaking screens, some single and others double in tandem. These were inefficient and were soon replaced by inclined revolving screens or trommels that have the dual capacity of sizing and attrition scrubbing. They break down cemented or compacted material and scrub the gold-bearing fines from the oversize. The perforated plates on the revolving screen are either manganese steel cast with tapered holes or abrasive-resistant, low-manganese, high-carbon steel with drilled tapered holes. The cast-manganese steel has proven most economical with coarse gravel and boulders which cause it to work harden. With coarse sand and fine gravel where work hardness is not developed, the cast-manganese plates wear very fast and have proved uneconomical as compared to alloy-steel plates. Yuba Manufacturing Co. of Benicia, Calif., supplied most of these plates to the dredging industry.

Holes are tapered from 1/4 inch to 3/16 inch in 3/8-inch plate but in the more generally used 3/4-inch plate they tapered from 3/4 to 5/8 inch, outside to inside. When in sand and fine gravel in which the minerals to be recovered are less than 1/8 inch, the screen with smaller holes is generally used. For subsequent selective concentration based on particle size, a trommel with graduated hole sizes, increasing downslope, is often used. On dredges where the holes in the trommel are all of the larger size, the materials are distributed from one bulk collection point to the usual jigging system.

To trap the occasional nugget that is larger than the standard-size hole, a set of wider slotted holes is added at the lower end of the trommel. The treating system for this limited area is usually either tables with coarse riffles, cocoa matting with expanded metal, or a heavy-media system.

Clayey placer material must be broken up to free the entrapped gold before concentration. This is a serious problem in any placer operation and one that requires more research.

From the trommel the undersized must be uniformly delivered to the concentrating units. Dewatering, accomplished by dewatering cones or hydrocyclones, is almost always necessary. The hydrocyclone has greater capacity, is far more efficient, and requires less space. Various combinations of jig circuits and auxiliary equipment are used to treat the undersize. The old-fashioned standard gold-saving tables with Hungarian riffles and mercury have been replaced to a large extent with jigging systems because of the inefficiency of the former method, especially in the recovery of fine gold and that which resists amalgamation. For a small one-dredge project it may still be economic to use the old system, but the decision should be based on a detailed study. A riffle has certain limitations as a gold-saving device. A riffle system, to accomplish its primary duty of recovery, must be on the proper slope to first accomplish transport. Riffle design must entrap the gold particles in a current of water swift enough to transport all sizes of material in the feed yet slow enough to permit capture of the gold. Of riffles in general it might be said that the design of the riffle is not so important as are the adjustments of feed, water, and slope with respect to the design in question. Often required to treat volumes larger than its designed capacity, recovery on a riffle drops as higher velocity along with excessive turbulence lowers the chances of capture, especially the fine-particle, coated, rusty, or refractory gold. Increasing the exposure time by lengthening the riffled surface has limited application on dredges. One idea of increasing riffle length was tried in 1914 when a long gold sluice was mounted on a separate hull towed behind the dredge (110). An enlarged treating plant mounted on a separate hull is presently recovering ilmenite in Florida (34).

Much of the credit of improved dredge recovery over the last 55 years belongs to the evolution of jigs. Jig improvement in the way of better recovery and larger capacity has been one of the more important reasons why dredging has been able to move into lower grade gravels. One of the earliest, large-scale jig tests on a gold dredge was by J. W. Neill aboard the 3-1/2-cubic-foot Yosemite Dredging and Mining Co. No.2 dredge in California in 1914 (109). The success of these tests was not so much in the way of better recovery but in the adaptation of heavy and cumbersome milling equipment to a design that could conform to the limited space aboard a dredge. Following these tests, the Natomas Consolidated Co., later Natomas Co., in 1915 made subsequent tests and used modified Neill jigs with Hardinge mills to grind the concentrate on its No. 7 dredge (105). In both cases the jigs were installed after the riffles to save some of the gold normally lost in the tailings. Hartz-type jigs, a plunger-type, were installed on the Pacific Tin Consolidated Corp. No. 2 dredge to recover cassiterite soon after it was sent to Malaya in 1923 (43). This rebuilt dredge was formerly the Dawson No. 5 of Yukon Gold Co., the predecessor of Pacific Tin. In 1932 the Bulolo Gold Dredging Co. made a successful Bendilari jig (a diaphragm jig) installation aboard a dredge in New Guinea where jigs handled the total output of the dredge (108). Placer Development Ltd. engineers designed a new jig, patented it in 1936, and made an arrangement with Pan-American Engineering Corp. for manufacturing rights. Several dredges in New Guinea and Colombia were later equipped with this newer jig, thereafter called the Pan-American Placer Jig. Manufacturing rights were later sold to Dorr-Oliver with Placer Development retaining the right to use the jig. In 1936 and 1937 Fisher and Baumhoff in Idaho and Yuba Consolidated Goldfields in California made their initial jig installations aboard their dredges. The jig designed by Yuba Manufacturing Division, Yuba Consolidated Industries, Inc., in 1948 is currently being built in Great Britain and is being used mostly on tin dredges. This jig was found to be one of the more practical dredge jigs until the advent of the circular Cleaveland-IHC jig.

Jigs (1) can handle relatively large-volume feeds in relatively compact space; (2) can better capture fine-particle gold by reason of quieter action on top of the jig bed; (3) can better capture coated, rusty, and refractory gold, which resists amalgamation when mercury is used in riffles; (4) can better handle large amounts of black sands, which in a riffle can pack the spaces to hinder gold settling, because forced-water pulsations through the jig bed keep the bed open and "live;" (5) can better handle limited surges in the feed, which in a riffle can overload and suppress its required action; (6) can be adjusted to more readily meet changing conditions; and (7) require less but a controlled supply of water. The advantages of better recovery are based on the condition that the volume and pressure of the water be properly controlled. Jigging has its limitations too, and trapping all of the finest particle gold is still not economically possible.

Currently most concentrating units are composed of primary or rougher-jig circuits followed by secondary and tertiary circuits. The primary jigs are arranged in parallel banks or flowlines of one to four cells in series. The number of cells in a flowline is a point of much discussion, but for most gold operations two cells are adequate. This is especially so if sufficient flowlines are used to handle the screened materials on an approximate 12-1/2 cubic yards per hour per flowline basis. The flowsheet of the 18-cubic-foot Yuba Consolidated Dredge No. 21 is shown in figure 5.

The concentrates from the secondary system are often treated in a ball-mill amalgamator. If some of the gold is not amalgamable, the tails are further jigged in a small scavenger cell. Usually after the last jigging, the scavenger concentrate is put over a small section of tables with standard Hungarian riffles or cocoa matting overlain with expanded metal.

Recently a circular jig has been patented and placed in tin, gold, and diamond-placer operations. Previously, circular jigs used in onshore treating plants were not practical on floating dredges as they required steady and firm foundations. The new Cleaveland-IHC jig was designed by Norman Cleaveland when he was president of Pacific Tin Consolidated Corporation of New York, a company now engaged in dredging tin in Malaysia. Interestingly, this company with others started the first bucket-line dredging operation for diamonds and byproduct gold in Brazil. Possibly this type of jig will someday replace the standard square-shaped pulsating jigs because of its greater efficiency and capacity, lessening the number required and conserving deck and height space. The jig is fed at the center with the overflow at the periphery. As the feed moves toward the perimeter, its radial velocity drops, increasing the recovery time, a basic aim in any gravity-concentrator design. Radial arms help to move the larger gravels toward the perimeter.

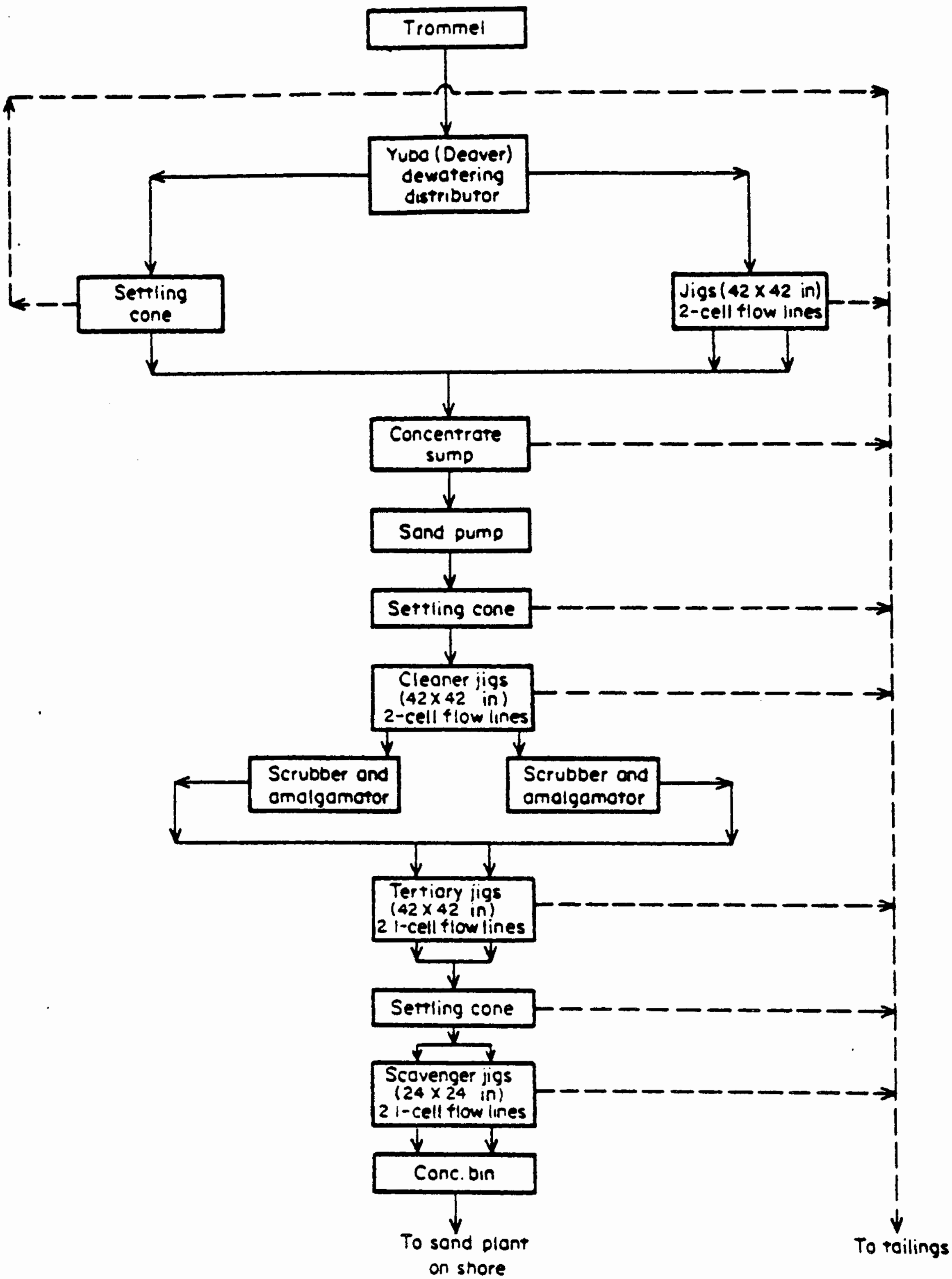

FIGURE 5. - Treatment-Plant Flowsheet of the 18-Cubic-Foot Yuba Consolidated Dredge No. 21.

COST OF DREDGING

In the section that immediately follows, specific cost data for dredge operations considered representative in the industry have been updated and listed. Following this is a section on general cost data that correlates operating costs to annual production according to bucket size. These costs cover dredge operations in the Western States. Cost of dredging in subarctic areas, including that for stripping and thawing, can be two to three times higher (15, 48, 50, 77). One of the most recent accountings of Yukon gold dredging costs is McFarland's paper (48).

Specific Cost Data

Published dredging costs are pre-1939. While some of the costs that follow overlap this earlier period, most cover later periods through 1962. To illustrate what current dredging costs might be at various production rates, the specific examples of dredging costs that follow, which exemplify good dredging operations, were updated to 1967. Updating to a standard base year using yearly indexes of labor and commodities provides an approximate and practical means of comparing yearly costs. Except for one, all operations had standard-speed bucket lines. As explained throughout this report, dredging costs depend upon a great number of conditions, the most important being digging conditions. Another is whether a dredge is operating alone or is part of a fleet that can share service costs. The most difficult to assess is management. Over 50 years ago, Janin (20, p. 55) made a statement concerning dredging costs relative to digging conditions that is as true today as it was then, but which assumes more importance today as the allowable margins in operating costs lessen. "Dredging costs vary in different districts according to conditions encountered and methods of calculation employed, and even in the same district and under the same management dredges of similar size and design or the same dredge in different parts of the same property will show a wide difference in operating cost owing to the character of the ground dug." While the use of "wide" does not reflect large monetary variations in unit costs, possibly only a few cents, percentage variations may be large.

The 1967 capital-cost estimates in the specific examples that follow are a 25-percent increase over those of 1960. The capital-cost estimates, f.o.b. San Francisco, include onsite erection but not applicable sales taxes. Unless otherwise noted, the dredges are standard steel-hull and superstructure design, electrically driven by power delivered from shore. Dredge housing, normally a wood-frame, sheet-steel structure, is included. Capital costs include jig treating systems on all size dredges. In the actual specific operating-cost tabulations that follow, however, only the 18-cubic-foot dredges were equipped with jigs; the others had standard gold saving tables with Hungarian-type riffles.

The operating costs include those for labor, materials, power, general, and miscellaneous. In all instances these were direct field operation costs only. To reflect the fluctuating value of the dollar in terms of what was then being purchased, whether labor, supplies, or power, the yearly unit costs were standardized by price indexes to their 1967 equivalents. While this became increasingly important as the updating period spanned longer intervals of time because of the general inflationary trend, it also became important even when updating costs for relatively short spans if they occurred at peaks and lows in the economy. The indexes listed in the appendix used to update were (112-114) as follows:

Table A-1.--Index based on metal mining production workers' average weekly earnings, for labor costs.

Table A-2.--Commodity wholesale price index of industrial commodities, for material costs.

Table A-3.--Commodity wholesale price index of fuels and related products and power, for power costs.

Table A-4.--Commodity wholesale price index of all commodities, for general and miscellaneous costs.

An index is a ratio, mean, or factor derived from a series of observations and used as an indicator or measure of a certain condition. The discrepancy of using most cost indexes is that they must necessarily be averages from various industries taken as a group so they lose some identity for the individuals within the group. The costs in an industry being updated, therefore, may not exactly be represented by the average, but for lack of more specific costs it is the best means possible.

It was evident in analyzing the original data that the labor rates in the dredging industry after World War II even after unionizing in 1947 somewhat lagged behind the national trend. While often peculiar to the more isolated locales where the dredges operated, this lag to some considerable part was because the unions recognized the need of continuing employment in an industry in which the margin of profit was narrowing. This situation was advantageous for an industry where the price of its product was controlled as was gold prior to March 1968. After workers of the dredging industry in California acquired union representation in 1947, wage rates increased annually from 5 to 10 cents per hour. The wage rates in October 1968 when the last dredge stopped were as follows:

Description	Wage, dollars per hour	Maximum number of men required	
		6-cu-ft dredge	18-cu-ft dredge
Dredgemaster.........	[1]740	1	1
Winchman.............	2.54	4	4
Oiler................	2.30	8	8
Shoreman-extra.......	2.24	6	6
Welder, apprentice...	2.44	-	-
Jigman...............	[2]2.50	-	4
Retorter.............	2.54	-	1
Sand plant operator..	2.42	-	1

[1]Per month.
[2]Estimated.

Mechanic, electrician, and cleanup-crew rates are not shown.

The number of employees required is based on a 7-day-per-week operation with employees working 48 hours per week with time and one-half over 40 hours. Normal fringe benefits are in addition to these rates. The pension fund of $0.36 per hour paid by the dredge companies far exceeds that paid at metal mines.

The appended labor index was constructed primarily from the annual average gross weekly earnings in the industry considered most allied to dredging, metal mining, as contained in the Department of Commerce's Business Statistics, 1967 (112). This tabulation, however, began in 1939 so part of the index, 1930-38, had to be developed from rather meager sources of hourly wage rates paid in the dredging industry during that period. The index was built on the base of the 3-year average metal-mining gross weekly earnings during 1957-59, the base years used in the power and commodity indexes. With this 3-year average set equal to 100, the annual labor-index factors were the products of 100 times the quotients of the annual weekly average over the 3-year base average. The unit-labor cost, in cents per cubic yard, for any year can be updated to that for any other year by multiplying it by the ratio of the new to the older index factor. Weekly earnings from other industries, which varied during the depression, could not be used to develop the 1930-39 portion of the index. From both published (15, 25, 96) and unpublished sources, the following hourly rates were paid through the 1930's for the three general labor classifications of winchman, oiler, and shoreman-extra. To obtain an average hourly labor rate, the distribution of men across the three above scales for an average 14-man crew was 3, 6, 5.

	1932	1935	1937	1939
Winchman................	$0.67	$0.70	$0.75	$0.825
Oiler....................	.55	.55	.575	.675
Shoreman-extra..........	.52	.53	.56	.56
Average[1]..........	.564	.575	.607	.672

[1]Based on 3 winchmen, 6 oilers, and 5 shoremen-extras.

Labor index factors based on 40-hour earnings at the above rates divided by the 1957-59 base average, progressed from 23.0 to 26.9 through the years 1930-38.

Some errors develop in updating from an index based on ratios of the average weekly earnings in the metal mining industry because the average weekly hours worked varied. The metal mining average in 1967 was 42.1 hours whereas the 1930-38 weekly earnings are based on 40 hours and the years after 1938, excluding war years of 1942-45 when most of the dredges were not working, ranged from the 1952 high of 43.8 hours to the 1958 low of 38.6 hours. The maximum error in the updated labor cost for the high hours of 43.8 is about 5 percent, or the labor costs in the 1952 updated unit-dredging costs are 5 percent too low. The maximum error in the updated labor cost for the low hours of 38.6 is about 10 percent, or the labor costs in the 1958 updated unit-dredging costs are 10 percent too high. In terms of a total unit-dredging cost of 14 cents per cubic yard of which the labor cost amounts to an average of 58 percent, the maximum minus error will amount to 3 percent of the total unit cost and the maximum plus error will amount to 6 percent. The straight time and overtime labor costs of dredging regardless of the rates paid or the hours worked are incremental in the unit-dredging costs and for purposes of updating do not have to be considered. The use of the index-factor ratios in updating is only a tool to standardize labor costs to a base year to free them of dollar fluctuations.

The cost data overall indicated a trend towards greater efficiency in the industry as a whole most noticeably after World War II. This probably resulted from the general updating of equipment on some of the older dredges, particularly the conversion to jigs that began in 1936-37 and continued after the war. An average 1967-equivalent decrease of about 0.12 cent per cubic yard per year was found to have developed in the operating costs of 11 dredges, which worked each in one area at about the same depth through continuous operating periods of 5 to 20 years. The operating spans for these dredges were staggered through the period 1934-64, irregularly overlapping each other. Going back, when the 1967 equivalent operating costs for each of the 11 dredges were first plotted against production, decreasing cost with increasing production was evident. To compare the costs through a span of years, they were therefore first corrected to a base production equal to the average for the span covered; or, the annual costs were weighted by the ratio of the production of the year in question over the span average. With the costs standardized as well as could be for dollar and production variations, costs against years were then plotted for each dredge, and the average change in cost per cubic yard per year was determined from the slope of the cost regressions. The supposition is that the average slope was a measure of the change in cost brought about primarily by increased efficiency in the design and use of equipment resulting in higher dredge productivity. Considerable variations were seen in the data used to compute the slopes, which individually varied from 0.05 to 0.40 cent per cubic yard per year.

The following specific cost records, other than that for one, are for dredges with standard-speed, 6- to 18-cubic-foot bucket lines. Operating conditions are provided as well as possible to explain the resulting differences in costs. Changing digging conditions have been the main cause in changing costs. Not included are depreciation, general overhead, interest, royalty, and a return on invested capital. While dredge depreciation for tax purposes can be set up for a 10-year straight-line period, recovery of capital investment from dredging returns is often set up for longer periods depending on the size of the deposit or deposits to be mined and the long-range plans of the company. Again, the updated costs are approximate and because they are isolated examples for specific years they could not be adjusted to reflect the general change in productivity that took place in the industry.

Table 1 contains data of one 6-cubic-foot portable dredge. This was the first of many of this type and capacity built by Yuba Manufacturing Co. The dredge worked in six different locations in Montana, California, and South Korea. The first operation, in Montana, covered 448 days. It was then moved to the example 2 site in California, losing only 83 days moving time, where it worked 1,398 days. Again it was moved to another site in California 150 miles away where it worked intermittently (examples 3 and 4) over a 12-year period (delay due to World War II) for 1,532 days. It was moved again to another property (example 5) where the formations and conditions were tough, which resulted in increased costs. Its maximum monthly production was in July 1942 when it dug 205,527 cubic yards for a daily average of 6,630. After the last operation it was moved to South Korea and worked two known properties. This 6-cubic-foot dredge proved popular for its capacity fitted many properties, its capital cost was comparatively low, and its size and construction permitted moving with limited cost.

TABLE 1. - Operational data for 6-cubic-foot standard-speed portable dredge

Example	Year	Weight of dredge, tons	Digging depth, feet	Days of operation	Total volume dug, yards^3	Unit operating costs, cents per yard^3: Labor	Material	Power	General	Total cost,[1] cents per yard^3	Capital cost, dollars[2]	Remarks
1	1934-35 original data.	500	26	448	2,098,072	2.23	1.10	0.72	0.20	4.25	-	Montana operation; difficult winter conditions, closed down 1 month; formation difficult.
	1967 updated data.	-	-	-	-	13.52	2.65	1.37	.50	18.04	$1,250,000	
2	1935-39 original data.	500	26	1,398	7,149,255	2.14	1.44	.55	.30	4.43	-	Same dredge; required 83 days to dismantle and move to central California; varied digging conditions; good weather.
	1967 updated data.	-	-	-	-	11.50	3.40	1.08	.74	16.72	1,250,000	
3	1939-42 original data.	500	26	956	5,019,743	2.52	1.43	.61	.14	4.70	-	Same dredge; moved to a new location 150 miles distant in 120 days; formation easy digging; good weather.
	1967 updated data.	-	-	-	-	12.09	3.04	1.13	.31	16.66	1,250,000	
4	1950-51 original data.	500	26	576	2,689,303	3.76	1.28	.95	.22	6.21	-	Same dredge and location; dredge previously down 8 years due to war.
	1967 updated data.	-	-	-	-	11.12	1.56	1.07	.25	14.00	1,250,000	
5	1952-53 original data.	500	26	599	1,805,966	7.53	2.94	1.42	.45	12.34	-	Same dredge moved to another California location; increased costs due to tough formations and higher labor and material costs.
	1967 updated data.	-	-	-	-	12.29	3.48	1.60	.51	17.88	1,250,000	

[1] Does not include general overhead costs, interest, return on invested capital, or depreciation.
[2] Estimated 1967 costs.

Table 2 contains cost data for 8-cubic-foot dredging operations. It provides a comparison between dredges operating in similar difficult digging formations but at different digging depths. In easier digging ground, costs would have been lower. These were sturdily built early-day dredges that had their 7- and 7-1/2-cubic-foot buckets replaced with 8- and 8-1/2-cubic-foot buckets when the dredges were modernized. The Goodnews Bay Mining Co. dredge, which was recovering platinum-group metals and byproduct gold in 1968, was a standard nonportable 8-cubic-foot dredge. Another dredge of this size, but a portable type, was especially designed to operate under extreme bouldery conditions in a gold placer in Colombia, South America. It had a sectionalized pontoon hull fastened with bolts that stood up well under tough digging conditions.

Cost data pertaining to 9-cubic-foot-size dredges are in table 3. The dredge in example 1 was operating in a very tight and bouldery formation while the dredge in example 2 was operating in a fine gravel and loose sandy formation and at a slightly deeper digging depth.

The 9-cubic-foot-bucket capacity dredge has made outstanding records which have proven it to be the most economical size to use between digging depths of approximately 30 and 80 feet. Under certain conditions, mainly favorable digging formations, bucket capacity was often increased to 10 cubic feet to increase yardage and decrease operating cost.

Table 4 shows operating costs on three 10-cubic-foot dredges. These made up a three-dredge project in which two dredges worked in adjacent areas while the other operated about 15 miles distant. The formations were similar and classed as easy digging and washing. Location was in the upper San Joaquin Valley, California. Dredges in examples 1 and 2 were equipped with normal-speed ac-powered bucket lines while the third dredge was equipped with a high-speed dc-powered bucket line using Ward Leonard controls for digging and swinging and ac motors for other powered equipment.

The general expenses and miscellaneous costs were not evenly divided as the dredge described in example 1 bore about half of these charges; the remainder of the charges was equally divided between the other two dredges. However, this does not seem to be reflected as much in the costs as would be supposed. This operation had good, experienced management and more than one dredge in an organization to carry the overhead costs.

Table 5 contains operating data of an 18-cubic-foot dredge in 1949 and 1962. Example 1 presents cost data of a dredge operating in tight clayey formation, which was difficult to dig. Digging depth was approximately 80 feet below water level. The clay in the formation required that the pond water be changed frequently for better treatment. The digging rate had been reduced from about 5-1/2 million cubic yards in prior years to increase recovery. Example 2 presents data again of the same dredge, but it had been moved to a new location where it was digging 105 feet below water level in an easily dug formation.

TABLE 2. - Operational data for 8-cubic-foot standard-speed dredges[1]

Example	Year	Weight of dredge, tons	Dig-ging depth, feet	Days of oper-ation	Total volume dug, yards[3]	Unit operating costs, cents per yard[3] Labor	Mate-rial	Power	Gen-eral	Total cost,[2] cents per yard[3]	Capital cost, dollars[3]	Remarks
1	1936 original data.	925	25	364	2,613,640	1.62	0.72	0.68	0.39	3.41	-	Firm formation containing a large percentage of clay; difficult digging.
	1967 updated data.	-	-	-	-	9.50	1.71	1.25	.75	13.21	$2,313,000	
2	1936 original data.	1,325	50	364	2,610,735	1.61	1.34	.84	.38	4.17	-	Very firm formation containing a large percentage of clay; difficult digging. Costs include that of water for flotation and of additional water for treatment of material because of large percentage of suspended mud.
	1967 updated data.	-	-	-	-	9.46	3.17	1.54	.73	14.90	3,313,000	

[1] Dredge was formerly 7-1/2-cubic-foot capacity, but when redesigned was changed to 8-cubic-foot. Dredges had standard-speed bucket lines.
[2] Does not include general overhead costs, interest, return on invested capital, or depreciation.
[3] Estimated 1967 costs.

TABLE 3. - Operational data for 9-cubic-foot standard-speed dredges

Example	Year	Weight of dredge, tons	Dig-ging depth, feet	Days of oper-ation	Total volume dug, yards[3]	Unit operating costs, cents per yard[3] Labor	Mate-rial	Power	Gen-eral	Total cost,[1] cents per yard[3]	Capital cost, dollars[2]	Remarks
1	1949 original data.	1,425	45	363	2,763,670	2.55	2.09	0.99	0.04	5.67	-	Very tight and bouldery formation where 2 smaller dredges had failed.
	1967 updated data.	-	-	-	-	5.72	2.78	1.15	.05	9.70	$3,563,000	
2	1941 original data.	1,375	50	363	3,941,624	1.28	.85	.56	.10	2.79	-	Fine gravelly and loose sandy formation; these costs represent the lowest costs and best yardage for this dredge.
	1967 updated data.	-	-	-	-	5.35	1.80	1.03	.22	8.40	3,438,000	

[1] Does not include general overhead costs, interest, return on invested capital, or depreciation.
[2] Estimated 1967 costs.

TABLE 4. - Operational data for 10-cubic-foot standard- and high-speed dredges

Example	Year	Weight of dredge, tons	Dig-ging depth, feet	Days of oper-ation	Total volume dug, yards[3]	Unit operating costs, cents per yard[3]					Total cost,[1] cents per yard[3]	Capital cost, dollars[2]	Remarks
						Labor	Mate-rial	Power	Gen-eral	Miscel-laneous			
1	1938-42 original data.	1,400	40	1,815	17,956,855	1.66	0.88	0.69	0.39	0.76	4.38	-	Dredge equipped with a standard-speed bucket line.
	1967 updated data.	-	-	-	-	7.09	1.87	1.24	.84	1.65	12.69	$3,500,000	
2	1938-42 original data.	1,400	40	1,815	17,298,970	1.45	.89	.60	.23	.57	3.74	-	Dredge equipped with a standard-speed bucket line.
	1967 updated data.	-	-	-	-	6.20	1.89	1.08	.50	1.25	10.92	3,500,000	
3	1938-42 original data.	1,400	40	1,815	25,184,650	1.12	.84	.48	.16	.27	2.86	-	Dredge equipped with a high-speed bucket line.
	1967 updated data.	-	-	-	-	4.77	1.79	.87	.34	.58	8.35	3,600,000	

[1] Does not include general overhead costs, interest, return on invested capital, or depreciation.
[2] Estimated 1967 costs.

TABLE 5. - Operational data for 18-cubic-foot standard-speed dredge

Example	Year	Weight of dredge, tons	Dig-ging depth, feet	Days of oper-ation	Total volume dug, yards[3]	Unit operating costs, cents per yard[3]				Total cost,[1] cents per yard[3]	Capital cost, dollars[2]	Remarks
						Labor	Mate-rial	Power	Gen-eral			
1	1949 original data.	2,650	80	363	4,010,000	2.21	1.75	1.22	0.20	5.38	-	Difficult digging, tight clay; 80 feet deep.
	1967 updated data.	-	-	-	-	4.95	2.33	1.42	.25	8.95	$6,625,000	
2	1962 original data.	3,150	105	362	4,408,400	3.08	2.23	1.61	.37	7.29	-	Same dredge moved to another area; digging was easy but deeper.
	1967 updated data.	-	-	-	-	3.59	2.35	1.67	.39	8.00	[3]7,875,000	

[1] Does not include general overhead costs, interest, return on invested capital, or depreciation.
[2] Estimated 1967 costs.
[3] Increased capital costs reflect additional ladder length required for deeper digging.

With only one exception in the United States--in California, the largest bucket capacity dredge used in gold placer mining operations was 18 cubic feet. For digging depths of over 75 feet, this capacity dredge has proved to be most economical. The maximum depth this size dredge has dug in California gold placers was 124 feet below water level. Reports have been made over the last several years that such a dredge will be digging to 162 feet in the U.S.S.R.

Generalized Relations Between Direct Costs and Production

In figure 6 is plotted a family of curved envelopes that generalize the relationship between direct dredging costs for standard-speed bucket lines and the annual cubic yards produced according to bucket size. The data consist of 151 dredge years grouped in five bucket-size ranges of 2-1/2 to 3-1/2; 6; 7 to 7-1/2; 8 to 10; and 15 to 18 cubic feet. The choice of ranges, while in part a matter of the data available, was to simplify their presentation by classes of similar potential. Their years of operation are scattered through the

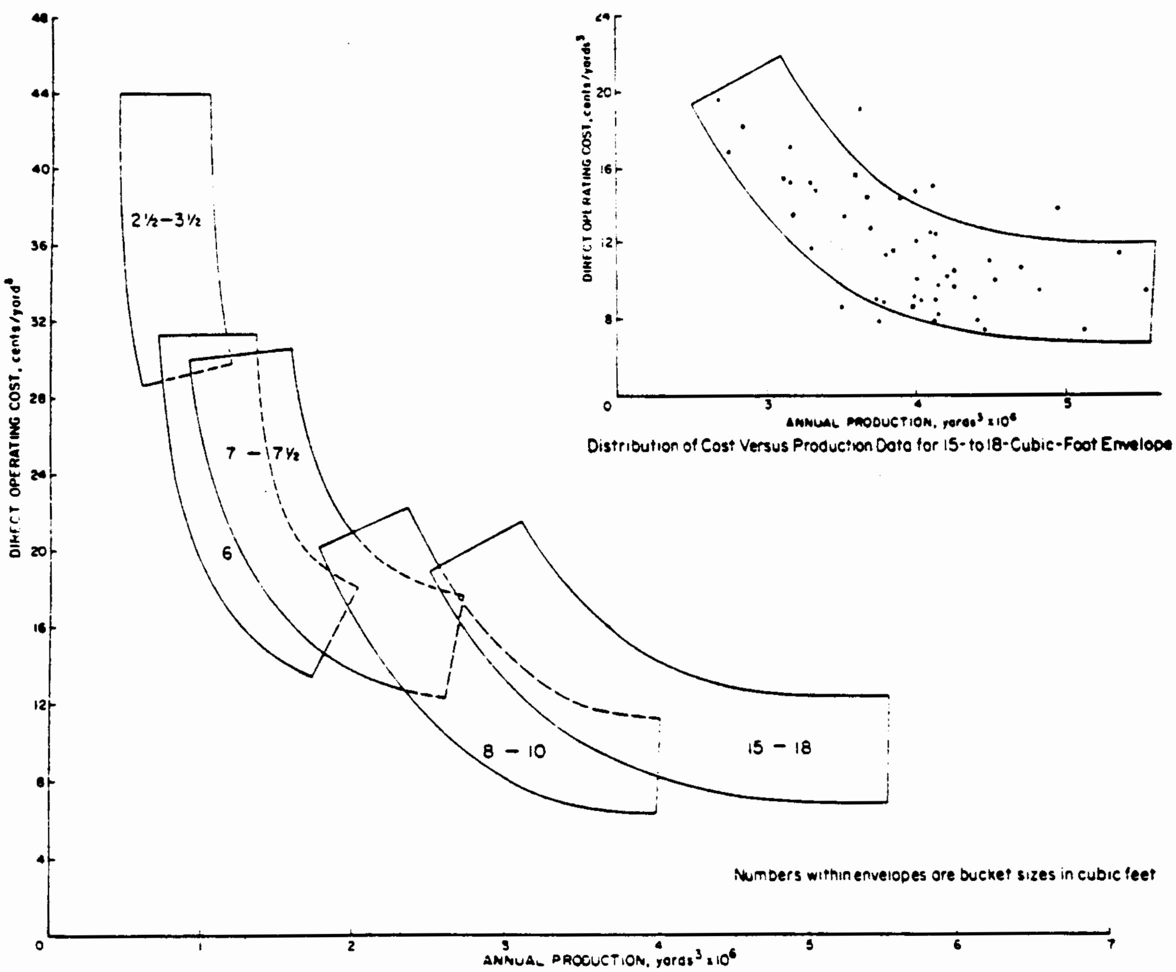

FIGURE 6. - Envelopes of Direct Operating Costs Versus Annual Production for Various Size Dredges With Standard Speed Bucket Lines.

period of 1930-66, all operating costs updated to 1967 by the same index systems covered previously. The costs do not include overhead and administration, equipment depreciation, royalty, or taxes. While improvements in dredge capacity had some improving effects on the mean costs of individual or group operations, these were probably minor with respect to the larger cost fluctuations brought about by wide variations of good to difficult digging conditions, of efficient to less efficient equipment design and utilization, and of good to less than good management. The dredges were not all up-to-date equipment; many were as much as 30 years old and most through the 1930's and 1940's incorporated various stages of dredge improvements.

The size of each envelope is a measure of the span of its data, which reflects the range of operating conditions under which the dredges worked--in general, the more data the larger the envelope. This does not hold for the 8- to 10-cubic-foot size, which contains 60 data points as compared to 50 for the larger 15- to 18-cubic-foot size. Not all of the data lie within their respective envelopes either although a maximum limit of 10 percent outside each envelope was a preestablished aim. The distribution of points in and around the 15- to 18-cubic-foot envelope, the envelope with the widest outside dispersion, is shown in the upper right-hand corner of figure 4. Of its 50 points, six or 12 percent lie outside reflecting still wider variations in cost. Lying outside their respective envelopes are 12 percent, seven of 60, in the 8- to 10-cubic-foot size; 5 percent, one of 19, in the 6-cubic-foot size; and none in either the 7- to 7-1/2- or the 2-1/2- to 3-1/2-cubic-foot sizes. Altogether, 9 percent, or 14 of the 151 points, lie outside envelopes.

Each envelope takes on the general trend of its data and lays sickle-shaped in echelon with those on each side. Some liberty was taken to make the sides of each envelope symmetrical, but where an extreme point was included, the envelope was laid out so that it would not indicate a more extreme possibility. As might be suspected, some portions in the higher cost, lower production areas of each are overlapped by the lower cost, higher production areas of the next smaller size. Overlapping is irregular, again indicative of the great variety of conditions that affected costs.

The trends through the envelopes, whether taken together or individually, show that production costs become less dispersed as production increases. Within each envelope the trend is toward steeper cost gradients as production decreases and flatter gradients as production increases. Going from left to right a general pattern develops where the envelopes trend from a cost-oriented direction to more of a production-oriented direction. The envelope of the smallest size dredges indicates a relatively wide possible variation in cost through a limited range in production while that of the largest indicates a more limited variation in cost relative to a wider range of production.

There appears an inconsistency where the low-cost end of the 8- to 10-cubic-foot envelope dips lower than the 15- to 18-cubic-foot envelope, even at its low-cost end. The points that affect this low can be seen clustered below the minus-3-standard-deviation line (lower dashed line) on figure 7. The difference in the minimum costs for these two size ranges is not a factor of a slightly larger sample for the smaller size range but reflects the cost

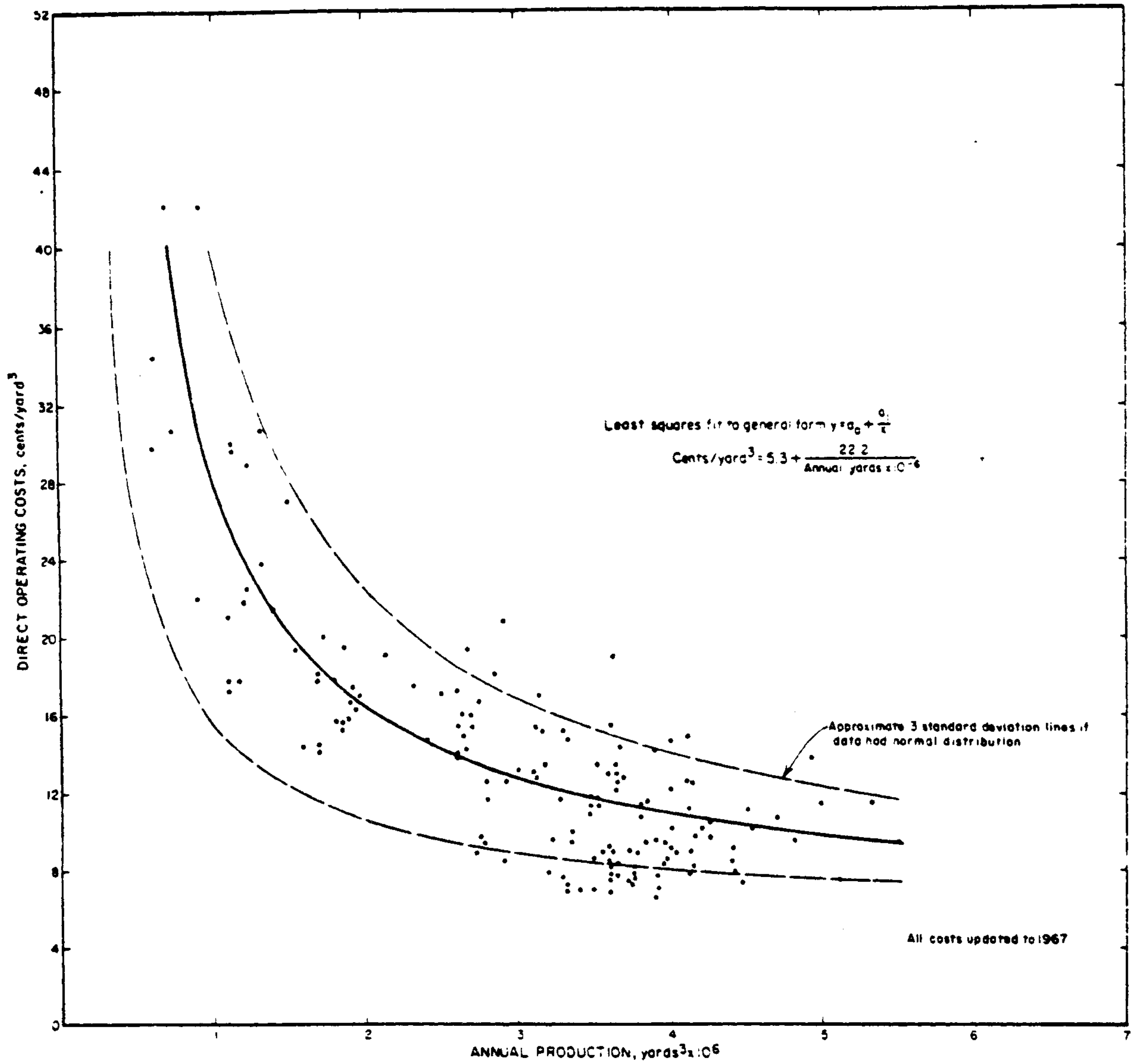

FIGURE 7. - Least Squares Fit of Direct Costs Versus Annual Production for All Dredge Data Regardless of Bucket Size.

increment of digging deeper with the larger sizes. As previously noted, when working in gravel no deeper than 80 feet, the 9- to 10-cubic-foot dredge has a history of being the most economical size to use. The effect of depth--124 versus 80 feet at Hammonton, Calif.--on dredging costs were first reported in 1940 by Romanowitz (15), "The unit operating costs of these deep-digging dredges are higher than those of shallower dredges, due to the smaller yardage and higher cost of replacements." In 1941 it was generalized that the unit costs for deep-digging dredges averaged about 1 cent more per cubic yard than that for shallower dredges in the same field operating under similar conditions (31), and in 1948 the difference in operating cost between 124- and

80-foot-deep dredges was estimated to range from 15 to 20 percent (66). The latter 15- to 20-percent difference between 80 and 124 feet, however, contained the factor of tougher digging beginning at 90 feet where the dredges were operating. The axes through the high production ends of both the 8- to 10- and the 15- to 18-cubic-foot envelopes in figure 6 show that the average for the smaller size is about 1 cent per cubic yard less than the average for the larger. There is no doubt that the envelope data cover a wider range in operating conditions than that earlier reported, but the data points that shaped the high-production end of the largest envelope represented an average of 95 feet as against the above-cited 124 feet.

To develop some overall trend that might better picture operating costs as an effect of annual production regardless of how or what controlled the amount of production as bucket size, digging conditions, management, etc., a number of curves were fitted to all of the data taken together. The best fit (fig. 7) was the least involved, a first-degree polynomial with the general form of $y = a_0 + \frac{a_1}{x}$, where y equals costs in cents per cubic yard and x equals production in cubic yards. As expected from the shapes of the individual envelopes, the distribution of the data was not normal about the general curve. Clusters of points, about one-fifth of the total, lie outside the approximate 3-standard-deviation lines. These outside points are valid and in part account for the end shapes of the envelopes. The 3-standard-deviation lines were calculated from an approximate formula based on normally distributed data. The cost-production equation as noted in figure 7, therefore, has limited meaning for cost estimation. If the plus-3-standard-deviation is thought of as an upper limit of costs, it would contain all but 6 percent of the data and would seem to be a safe estimator. Going back to the earlier statements in this report that deposit-evaluation and dredge-feasibility appraisals should be left to those competent, the relations in figures 6 and 7 should take on more meaning.

SUMMARY

The success of any dredging project rests ultimately with the nature of the deposit to be mined. Seldom are conditions completely favorable. A successful dredge operation begins with an adequate exploration program. The cost to properly evaluate a placer is small with respect to the cost of a dredge, especially if dredging later proves an unfortunate choice. Choosing dredge equipment should be left to those competent for there is no standard dredge. Getting maximum recovery, first from the ground and then in the treating plant, requires continuous effort. The more complicated the recovery problems, the more capable must be the dredgemen. A low-grade placer containing a high-specific-gravity, high-value metal such as gold means an extremely low metal-to-waste ratio, volume-wise. Add to this the usually small--sometimes extremely small--gold-particle size, its tendency to collect where digging conditions are often most difficult, and its recovery on basically simple gravity equipment that must handle large volumes continuously with little downtime, and an appreciation of gold dredging develops.

The bucket-line dredge is the traditional gold-placer tool. It was developed for gold placers. Capable of continuously mining and treating low-value placer material at a unit cost lower than that for any other type of mining, the bucket-line dredge is a completely mechanized, large-volume, self-contained, coordinated mine-mill unit that digs, treats, and backfills its waste in a matter of minutes. A flexible system, the bucket-line dredge has qualified to mine other types of onshore and offshore placer and bulk-product deposits and to strip the waste that overlies them.

Gold placers are seldom easy to dig. The digging mechanism on a spud-equipped, bucket-line dredge is a rugged but relatively simple piece of machinery that evolved from many successes and failures. It has the ability to run almost continuously under difficult digging conditions, sometimes requiring all the effort it is capable of producing. It is the best and sometimes the only system that can dig in extremely tough clays, cemented gravels, oversized boulders and buried timber debris, and most important in hard, often blocky, and irregular bedrock, on or in which the gold is often concentrated. Digging equally well in both swing directions, the bucket ladder has distinct advantages over cutterhead hydraulic systems that inherently dig less effectively in one direction. The treating plant aboard a bucket-line dredge is a compact gravity mill matched to the capacity of its digging system and the nature of the placer being worked. Not confronted with dewatering problems of the magnitude encountered on hydraulic dredges, it is built to work efficiently in limited space. Progress in dredge-developed gravity equipment has played an important part in keeping gold dredges working while operating costs rose, placer values dropped, and the price of their product stayed the same.

Hydraulic dredging, also a continuous system that can develop a good mining pattern, is particularly adaptable to the more easily dug bulk deposits and to the more easily dug and evenly distributed placer deposits of lower specific gravity minerals that do not require stringent cleanup of bedrock to make dredging successful. Improved digging and depth capabilities developed since World War II have come about primarily from better designs to handle bigger and more difficult earth-moving jobs. The principal advantage of the hydraulic system, its built-in facility to transport the mined material to an off-dredge recovery or collection site, usually becomes a disadvantage when the recovery site is aboard the dredge. Dewatering a large volume of variable-size placer material from a relatively high-velocity stream in limited space and yet not lose its small-fraction gold is difficult.

Some of the future of dredging will lie in overburden stripping and marine mining. Dredging unconsolidated overburden from mineral deposits can often be done more cheaply and with considerable less effort if the material to be stripped is water saturated or lies wholly under water. The outstanding efficiency records set by large dragline equipment in most dry formations can hardly be touched by dredges. However, because of these records there has been a tendency to use dragline equipment in stripping and mining underwater formations that often could have been done more efficiently with dredges. Too, there have been other cases where dry formations could have been ponded, stripped, and mined more efficiently with dredges. In saturated deposits, especially in agricultural or low-lying coastal areas, some problems can develop when the water table is lowered to prepare for dry stripping. A lowered fresh-water table might complicate nearby agricultural use of the land, might increase the cost of potable water, and in some instances can initiate its replacement with salt or brackish water.

Mounting interest in offshore mining has accelerated new thinking in dredge developments, primarily in hydraulic designs. This could be the system with the most promise to someday reach many of the unconsolidated mineral deposits on the continental shelf. The First World Dredging Conference (89) held in New York in May 1967 brought to light the world-wide interest in new dredging ideas, applications, and developments keyed primarily to marine use. Similarly, the Offshore Technological Conference held in Houston in May 1969 is an example of the national effort to pool present engineering knowledge on the development and recovery of marine resources. The growing awareness of the importance of one nation's position in the sea-dredging industry and the emphasis needed to keep abreast with world-wide dredging research is outlined in a current paper (59).

Although the use of bucket-line dredges has slowed, as gold dredging has in North America since World War II, these machines will always have an application in mining. New bucket-line developments in depth, capacity, and recovery, which are bound to take place if the system is to continue, will come in such forms as enlarged bucket capacities, faster line speeds, better support of the bucket chain, continued improvements in the use of more sophisticated electric-control gear, conversion to strong light-metal alloys, and improvements in scrubbing and treating efficiency especially in the treatment of clayey materials. New approaches that combine the rugged mechanical capabilities of a bucket-wheel digging system and the efficient transport capabilities of either the hydraulic or modern bucket-chain system should develop more versatile machines.

BIBLIOGRAPHY

Placer Evaluation

1. Averill, C. V. Sampling. Placer Mining for Gold in California. Calif. Div. of Mines, Bull. 135, 1946, pp. 219-226.

2. Avery, W. W. Computing Drill-Hole Data in Placer Prospecting. Eng. and Min. J., v. 129, No. 10, May 1930, pp. 493-495.

3. Clark, V. V. Core Control in Alluvial Drilling. Eng. and Min. J., v. 135, No. 7, July 1934, pp. 293-297.

4. Daily, A. Valuation of Large, Gold-Bearing Placers. Eng. and Min. J., v. 163, No. 7, July 1962, pp. 80-88.

5. Gardner, C. W. Drilling Results and Dredging Returns-I. Eng. and Min. J., v. 112, No. 17, October 1921, pp. 646-699.

6. _____. Drilling Results and Dredging Returns-II. Eng. and Min. J., v. 112, No. 18, October 1921, pp. 688-692.

7. Harrison, H. L. H. Valuation of Alluvial Deposits. Mining Publications, Ltd., London, 1954, 308 pp.

8. Hutton, G. H. Placer Prospecting Practice. Min. and Met., v. 1, No. 176, August 1921, pp. 15-17.

9. Jackson, C. F., and K. B. Knaebel. Sampling and Estimation of Ore Deposits. BuMines Bull. 356, 1932, pp. 6-31.

10. Ludlum, A. C. Placer Prospecting Practice. Min. and Met., v. 1, No. 179, November 1921, pp. 27-28.

11. Prommel, H. W. C., and P. M. Hopkins. Preliminary Evaluation and Sampling of Gold Placer Deposits. Deco Trefoil Bull. M4-B129, January-February 1967, pp. 9-16.

12. Smith, R. G. The Discrepancy Between Drilling and Dredging Results. Eng. and Min. J., v. 122, No. 21, November 1921, pp. 812-814.

Dredging for Placer Gold

13. Averill, C. V. Gold Dredging in Shasta, Siskiyou, and Trinity Counties. Report of State Mineralogist, Calif. J. of Mines and Geol., v. 34, No. 2, April 1938, pp. 96-126.

14. Blanchard, F. M. Gold Dredging in West Africa. Eng. and Min. J., v. 137, No. 4, April 1936, pp. 175-177.

15. Blanchard, F. M., and C. M. Romanowitz. Chain-Bucket or Bucket-Ladder Dredges. Ch. 10, art. 127, in Mining Engineers Handbook, ed. by R. Peele. John Wiley & Sons, Inc., New York, 3d ed., 1941, v. 1, pp. 577-606.

16. Chemical Engineering and Mining Review. Spud Dredges for Heavy Ground in New Zealand. V. 31, No. 368, May 1939, pp. 323-327.

17. _____. Dredging in New Zealand, 1938. V. 32, No. 373, October 1938, pp. 25-26.

18. Collins, G. A. Dragline Gold Dredging. Trans. Canadian Inst. Min. and Met., v. 48, 1945, pp. 717-725.

19. Hutil, J. B. How Natomas Keeps a Large Dredge Operating in the Desert. Eng. and Min. J., v. 151, No. 10, October 1950, pp. 96-99.

20. Janin, C. Placer Mining Methods and Operating Costs. Ch. in The History and Development of Gold Dredging in Montana. BuMines Bull. 121, 1916, 63 pp.

21. _____. Gold Dredging in the United States. BuMines Bull. 127, 1918, 226 pp.

22. Leaver, E. S., and J. A. Woolf. Gold Dredging in California and Methods Devised To Increase Recovery. AIME Tech. Pub. 792, March 1937, 6 pp.

23. Magee, J. F. A Successful Dragline Dredge. AIME Tech. Pub. 757, November 1936, 16 pp.

24. Merrill, C. W. Dragline Dredges, A New Way To Mine Placer Gold. Min. and Met., v. 19, No. 12, December 1938, pp. 521-525.

25. Metzger, O. H. Reconnaissance of Placer Mining in Boise, Idaho. BuMines Inf. Circ. 7028, 1938, 34 pp.

26. Mining and Scientific Press. Dredging at Iditarod, Alaska. V. 108, No. 18, May 2, 1914, p. 735.

27. Oakland Tribune (Oakland, Calif.). Last Gold Dredge Silent. Oct. 2, 1968, p. 17.

28. O'Neill, P. H. Gold and Platinum Dredging in Colombia and Bolivia, South America. Paper 8 in Symp. on Opencast Mining, Quarrying, and Alluvium Mining, London, Nov. 16-19, 1964. Institution of Mining and Metallurgy, London, 1965, pp. 156-179.

29. Requa, L. K. Description of the Property and Operations of the Lewiston Dredge, Lewiston, California. BuMines Inf. Circ. 6660, November 1932, 15 pp.

30. Romanowitz, C. M., and H. A. Sawin. Bucket-Line Dredging, Placer Mining for Gold in California. California Div. of Mines Bull. 135, 1946, pp. 51-62.

31. _____. Extending the Scope of Placer Dredging. AIME Tech. Pub. 1347, July 1941, 6 pp.

32. Thurman, C. H. Cost of Dredging in Dragline Gold Mining. Trans. AIME, v. 163, 1945, pp. 467-472.

Dredging for Other Minerals

33. Coal Age. Coal From Water. V. 55, No. 6, June 1950, pp. 84-87.

34. Engineering and Mining Journal. Black Sand Is Mined From Traveling Lake. V. 151. No. 1, January 1950, p. 106.

35. _____. Comiren Uses Dredge To Mine French Tin. V. 164, No. 6, June 1963, pp. 104-105.

36. Levine, S. The Shell Game. Rock Products, v. 72, No. 7, July 1969, pp. 68-75.

37. Mining Engineering. Monazite Sands Are Spurring Idaho Dredging Operations. V. 6, No. 3, March 1954, p. 267.

38. Mining Magazine. Tin Dredging in Europe. V. 110, No. 3, March 1964, pp. 189-191.

39. _____. Improved Techniques for Dredging Silica Sands. V. 111, No. 4, October 1964, pp. 256-257.

40. Nesbitt, A. C. Diamond Mining at Sea. Paper in Proc. First World Dredging Conf., New York, May 6-8, 1967. World Dredging Conf., Palos Verdes Estates, Calif., 1967, pp. 697-725.

41. Noon, W. A. Unique Bucketline Dredge Recovers Placer Scheelite. Eng. and Min. J., v. 151, No. 5, May 1950, pp. 82-84.

42. Rice, H. R. Tailings Dredge on Great Bear Lake. Canadian Min. J., v. 74, No. 7, July 1953, pp. 59-61.

43. Romanowitz, C. M. Dredge No. 2's First 50 Years--From Alaska to Malaya Tin. Min. World, v. 21, No. 2, February 1959, p. 47.

Placer Evaluation and Dredging in Frozen Ground

44. Beistline, E. H. Placer Mining in Frozen Ground. Proc. Permafrost Internat. Conf., Purdue Univ., Nat. Acad. Sci. Nat. Res. Coun., Pub. 1287, November 1963, pp. 463-467.

45. Janin, C. Recent Progress in the Thawing of Frozen Gravel in Placer Mining. BuMines Tech. Paper 309, 1922, 34 pp.

46. Ludwig, R. G. Sled Transportation of Heavy Single Loads in Interior Alaska. Pres. at Fourth Ann. Min. and Petrol. Conf., AIME, Anchorage, Alaska, Apr. 3-5, 1959. Copy on file at Engineering Societies Library, New York.

47. McFarland, W. H. S. Operations of the Yukon Consolidated Gold Corporation. Trans. Canadian Inst. Min. and Met., v. 42, 1939, pp. 537-549.

48. _____. Operations of the Yukon Consolidated Gold Corporation, Canada. Paper 9 in Symp. on Opencast Mining, Quarrying, and Alluvium Mining, London, Nov. 16-19, 1964. Institution of Mining and Metallurgy, London, 1965, pp. 180-195.

49. Mining World. F. E. Company Thawing. V. 4, No. 13, December 1942, pp. 13-17.

50. O'Neill, P. H. Arctic Gold Dredging. Min. Eng., v. 6, No. 111, November 1954, pp. 1068-1071.

51. Patty, R. M. Placer Mining in the Sub-Arctic. Western Miner, v. 18, No. 4, April 1945, pp. 44-49.

52. Wimmler, N. L. Placer Mining Methods and Costs in Alaska. BuMines Bull. 259, 1927, 236 pp.

Stripping and General Dredge Excavation

53. Cazort, J. G., Jr. Stripping Overburden With a Dredge. Min. Eng., v. 12, No. 10, October 1960, pp. 1083-1089.

54. Coal Age. Dredge Stripping at Westfield. V. 64, No. 9, September 1959, p. 81.

55. Davis, C., and E. McKay. Mine Planners See Wider Use of Dredging. Eng. and Min. J., v. 170, No. 1, January 1969, pp. 68-71.

56. Engineering and Mining Journal. Canada Moves a Lake To Mine Asbestos. V. 157, No. 1, January 1956, pp. 91-93.

57. _____. New Eight-Inch Dredge Will Enable Reynolds To Increase British Guiana Bauxite Production. V. 163, No. 7, July 1962, pp. 76-77.

58. Giroux, C. H. Modern Hydraulic Dredging--A Product of Experience. Civil Eng., v. 22, No. 9, September 1952, pp. 740-745.

59. Hydrospace. Need for a Clear-Cut Government (British) Policy on Dredging for Aggregates. V. 2, No. 3, September 1969, pp. 50, 52.

60. Jacquette, Z. H. Role of the Dredge in Modern Earthmoving. Australian Civil Engineering and Construction, v. 6, No. 7, 1965, pp. 66-71.

61. Kellogg, L. O. Stripping With Harbor Dredge. Eng. and Min. J., v. 97, No. 10, March 1914, pp. 501-502.

62. Lenhart, W. B. Strip Overburden With Dredge; Recover Sand and Gravel With Cable-Way Excavator. Rock Products, v. 57, No. 11, November 1954, pp. 66-68.

63. Mining and Minerals Engineering. Dredger for Inco's Pipe Mine. V. 3, No. 12, December 1967, p. 477.

64. Mining World. Lake Asbestos, How the Hydraulic Problems Were Solved. V. 20, No. 13, December 1958, pp. 35-36.

65. Pearson, P. D. Dredging at Steep Rock Lake. Min. Eng., v. 9, No. 8, August 1957, pp. 898-902.

66. Romanowitz, C. M. Proposed Bucket-Ladder Dredges for the Panama Canal Sea-Level Project. Pres. ASCE annual meeting, New York, Jan. 21-24, 1948. Copy on file at Office of Chief Engineer Library, U.S. Corps of Engrs., Washington, D.C.

67. Scott, N. S. The Caland Dredging Project. Trans. Canadian Inst. Min. and Met., v. 44, 1961, pp. 478-487.

68. Shipbuilding Equipment. Hydraulic Dredging. V. 1, No. 12, April 1959, pp. 4-5.

Dredge Evolution and Design

69. Boissonnault, F. L. Dredge Yardage Improved. Eng. and Min. J., v. 135, No. 9, September 1934, pp. 392-393.

70. Engineering and Mining Journal. Dismantling and Rebuilding a Gold Dredge. V. 128, No. 19, November 1929, pp. 736-737.

71. _____. Ellicott Outlines Design Advances. V. 164, No. 6, June 1963, pp. 105-106.

72. Hancock, S. G. Giant Moving Operation at Steep Rock Lake. Canadian Min. J., v. 76, No. 5, May 1955, pp. 57-59.

73. Kaufmann, C. P. Dredges Meet "Sink or Swim" Challenge of Underwater Deposits. Rock Products, v. 66, No. 6, June 1963, pp. 89-93, 140.

74. Paulson, F. O. Hydraulic Dredge Design. Paper in Proc. First World Dredging Conf., New York, May 6-8, 1967. World Dredging Conf., Palos Verdes Estates, Calif., 1967, pp. 39-51.

75. Romanowitz, C. M. New Digging-Ladder Bucket Idler. Eng. and Min. J., v. 137, No. 1, January 1936, p. 49.

76. _____. The Dredge of Tomorrow. Eng. and Min. J., v. 163, No. 4, April 1962, pp. 84-91.

77. _____. Floating Dredges Used for Mining Purposes. Mineral Information Service, California Div. Mines and Geol., v. 20, No. 7, 1967, pp. 82-87.

78. _____. High Speed Bucket Lines. Min. World, v. 22, No. 8, July 1960, pp. 39-43.

79. Romanowitz, C. M., M. J. Cruickshank, and M. P. Overall. Offshore Mining--Present and Future. Eng. and Min. J., v. 169, No. 1, January 1968, pp. 84-91.

80. Romanowitz, C. M., and M. J. Cruickshank. The Evolution of Floating Dredges for Mining Operations. Sec. 5, ch. 20, in Case Studies of Surface Mining, ed. by H. L. Hartman. American Institute of Mining, Metallurgical, and Petroleum Engineering, New York, 1969, pp. 287-311.

81. Romanowitz, C. M., and H. A. Sawin. Bucket-Ladder Dredges Pay Off. Civil Eng., v. 22, No. 9, September 1952, pp. 746-748.

82. Romanowitz, C. M., and G. J. Young. $35 Gold Stimulates the Dredge Designer's Ingenuity. Eng. and Min. J., v. 135, No. 8, August 1934, pp. 338-341.

83. Sawin, H. A. Deep Gravels Dredged Successfully. California Div. Mines Bull. 135, 1946, pp. 317-322.

84. _____. Bucket Dredge Installed at Goodnews Bay, Alaska. Eng. and Min. J., v. 139, No. 5, May 1938, pp. 40-41.

85. _____. Continued Improvement--The Trend in Dredging. Min. Cong. J., v. 23, No. 8, August 1937, pp. 19-21.

86. _____. Becker-Hopkins Single-Bucket Dredge. California Div. Mines Bull. 135, 1946, pp. 61-62.

87. Sawin, H. A., and C. M. Romanowitz. Metals Used in the Dredging Industry. Min. J. (Phoenix), v. 22, No. 4, July 1938, pp. 3-5.

88. Terry, L. E. It's What's Up Front That Counts. Paper in Proc. First World Dredging Conf., New York, May 6-8, 1967. World Dredging Conf., Palos Verdes Estates, Calif., 1967, pp. 91-113.

89. World Dredging Conference. Proceedings of First World Dredging Conference, New York, May 6-8, 1967. Palos Verdes Estates, Calif., 1967, 725 pp.

90. Young, G. J. Elements of Mining. Ch. 13 in Alluvial Mining. McGraw-Hill, New York, 4th ed., 1946, pp. 468-493.

Alluvial Mining, General

91. Cleaveland, N. Some Comments on Dredging as a Mining Method. Paper in Proc. of First World Dredging Conf., New York, May 6-8, 1967. World Dredging Conf., Palos Verdes Estates, Calif., 1967, pp. 9-19.

92. Cooper, R. Practical Dredging. Brown, Son & Ferguson, Ltd., Glasgow, Scotland, 1958, 270 pp.

93. Gardner, E. D., and P. T. Allsman. Power Shovel and Dragline Placer Mining. BuMines Inf. Circ. 7013, 1938, 68 pp.

94. Gardner, E. D., and C. H. Johnson. Placer Mining in the Western United States. I. General Information, Hand Shoveling and Ground Sluicing. BuMines Inf. Circ. 6786, 1934, 73 pp.

95. _____. Placer Mining in the Western United States. II. Hydraulicking, Treatment of Placer Concentrates, and Marketing of Gold. BuMines Inf. Circ. 6787, 1934, 89 pp.

96. _____. Placer Mining in the Western United States. III. Dredging and Other Forms of Mechanical Handling of Gravel and Drift Mining. BuMines Inf. Circ. 6788, 1935, 81 pp.

97. Griffith, S. V. Alluvial Prospecting and Mining. Pergamon Press, New York, 1960, 2d ed., rev., 245 pp.

98. Harrison, H. L. H. Alluvial Mining for Tin and Gold. Mining Publications, Ltd., London, 1962, 313 pp.

99. Jenkins, O. P. Geology of Placer Deposits (7 parts), Miner. Inf. Service, California Div. Mines and Geol., v. 17, Nos. 1-6, 8, 1964.

100. Orsberger, R. Drilling for Placer Tin in Indonesia. Min. Magazine, v. 118, No. 5, May 1968, pp. 306-313.

101. Orsberger, R., and C. M. Romanowitz. How the Off-Shore Indonesian Tin Placers Are Explored and Sampled. World Min., v. 3, No. 12, November 1967, pp. 24-30.

102. Thomas, B. I., D. J. Cook, E. Wolff, and W. H. Kerns. Placer Mining in Alaska. BuMines Inf. Circ. 7926, 1959, 34 pp.

103. Thorne, W. E., and A. W. Hooke. Mining Alluvial Deposits by Dredging and Hydraulicking. Mining Publications, Ltd., London, 1929, 171 pp.

Mineral Beneficiation and Recovery

104. Collins, F. W. Notes on Jigs for Gold Dredges, Placer Mining for Gold in California. California Div. Mines Bull. 135, 1946, pp. 73-76.

105. Eddy, L. H. Jigs on a California Dredge. Eng. and Min. J., v. 101, No. 5, January 1916, pp. 207-208.

106. Hazard, F. H. The Saving of Fine Placer Gold. Eng. and Min. J., v. 92, No. 9, Aug. 26, 1911, pp. 394-396.

107. Janin, C. Recovery of Gold in Dredging. Min. and Sci. Press, v. 109, Nov. 7, 1914, pp. 717-721.

108. Malozemoff, F. P. Jigging Applied to Gold Dredging, Placer Mining for Gold in California. California Div. Mines Bull. 135, 1946, pp. 63-71.

109. Neill, J. W. Application of Jigs to Gold Dredging. Min. and Sci. Press, v. 109, Nov. 28, 1914, pp. 839-842.

110. Stovall, D. H. Sluices and Riffles in Dredging. Min. and Sci. Press, v. 94, No. 18, May 4, 1907, pp. 575-576.

111. Vedensky, D. N. The Application of Jigs in Placer Mining Operations. Min. Cong. J., v. 24, No. 5, May 1938, pp. 84-87.

Cost Updating, General

112. U.S. Department of Commerce. Business Statistics. 1967, 16th Biannual Edition, 262 pp.

113. _____. Statistical Abstract of the United States. 1968, 1034 pp.

114. U.S. President 1963-1969 (Lyndon B. Johnson). Economic Report. January 1967, 314 pp.

APPENDIX

TABLE A-1. - Index based on metal mining production workers' average weekly earnings

(1957-59 = 100)[1]

Year	Index number	Year	Index number	Year	Index number	Year	Index number
1930	23.0	1940	30.2	1950	65.8	1959	104.5
1931	23.0	1941	33.3	1951	74.8	1960	113.1
1932	23.0	1942	38.7	1952	82.0	1961	115.4
1933	23.0	1943	43.2	1953	88.5	1962	119.5
1934	23.2	1944	44.5	1954	84.7	1963	120.7
1935	23.4	1945	45.8	1955	92.7	1964	124.6
1936	23.8	1946	47.1	1956	97.2	1965	129.5
1937	24.7	1947	55.2	1957	98.9	1966	136.0
1938	26.9	1948	61.4	1958	96.6	1967	139.2
1939	29.0	1949	62.1				

[1] 1930-38 index based on average weekly earnings of dredge workers; 1938-67 index based on average weekly earnings of metal mining production workers (112, p. 78; 113, p. 221).

TABLE A-2. - Commodity wholesale price index of industrial commodities

(1957-59 = 100)[1]

Year	Index number	Year	Index number	Year	Index number	Year	Index number
1930	48.1	1940	46.8	1950	82.9	1959	101.3
1931	42.4	1941	50.3	1951	91.5	1960	101.3
1932	39.7	1942	53.9	1952	89.4	1961	100.8
1933	40.2	1943	54.7	1953	90.1	1962	100.8
1934	44.2	1944	55.6	1954	90.4	1963	100.7
1935	44.0	1945	56.3	1955	92.4	1964	101.2
1936	44.9	1946	61.7	1956	96.5	1965	102.5
1937	48.1	1947	75.3	1957	99.2	1966	104.7
1938	46.1	1948	81.7	1958	99.5	1967	106.3
1939	46.0	1949	80.0				

[1] (113, p. 342); (114, p. 264).

TABLE A-3. - Commodity wholesale price index of fuels and related products and power

(1957-59 = 100)[1]

Year	Index number	Year	Index number	Year	Index number	Year	Index number
1930	58.2	1940	53.2	1950	90.2	1959	98.7
1931	50.0	1941	56.6	1951	93.5	1960	99.6
1932	52.1	1942	58.2	1952	93.3	1961	100.7
1933	49.3	1943	59.9	1953	95.9	1962	100.2
1934	54.3	1944	61.6	1954	94.6	1963	99.8
1935	54.5	1945	62.3	1955	94.5	1964	97.1
1936	56.5	1946	66.7	1956	97.4	1965	98.9
1937	57.5	1947	79.7	1957	102.7	1966	101.3
1938	56.5	1948	93.8	1958	98.7	1967	103.6
1939	54.2	1949	89.3				

[1] (113, p. 342); (114, p. 264).

TABLE A-4. - Commodity wholesale price index of all commodities

(1957-59 = 100)[1]

Year	Index number	Year	Index number	Year	Index number	Year	Index number
1930	47.3	1940	43.0	1950	86.8	1959	100.6
1931	39.9	1941	47.8	1951	96.7	1960	100.7
1932	35.6	1942	54.0	1952	94.0	1961	100.3
1933	36.1	1943	56.5	1953	92.7	1962	100.6
1934	41.0	1944	56.9	1954	92.9	1963	100.3
1935	43.8	1945	57.9	1955	93.2	1964	100.5
1936	44.2	1946	66.1	1956	96.2	1965	102.5
1937	47.2	1947	81.2	1957	99.0	1966	105.9
1938	43.0	1948	87.9	1958	100.4	1967	106.1
1939	42.2	1949	83.5				

[1] (113, p. 342); (114, p. 264).

☆ U. S. GOVERNMENT PRINTING OFFICE : 1970 O - 380-061

THIS PAGE
INTENTIONALLY
BLANK

THIS PAGE
INTENTIONALLY
BLANK