

Information Circular 9170

Cost Estimation Handbook for Small Placer Mines

By Scott A. Stebbins

UNITED STATES DEPARTMENT OF THE INTERIOR
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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

BCY	bank cubic yard	LCY/h	loose cubic yard per hour
d/a	day per year	μm	micrometer
ft	foot	min	minute
ft ²	square foot	min/h	minute per hour
ft ² /yd ³	square foot per cubic yard	st	short ton
ft/h	foot per hour	st/h	short ton per hour
gpm	gallon per minute	tr oz	troy ounce
h	hour	tr oz/yd ³	troy ounce per cubic yard
h/shift	hour per shift	wt %	weight percent
hp	horsepower	yd/h	yard per hour
in	inch	yd ³	cubic yard
kW	kilowatt	yd ³ /d	cubic yard per day
kW/yd ³	kilowatt per cubic yard	yd ³ /ft ²	cubic yard per square foot
lb/LCY	pound per loose cubic yard	yd ³ /h	cubic yard per hour
lb/yd	pound per yard	yr	year
lb/yd ³	pound per cubic yard		
LCY	loose cubic yard		
LCY/a	loose cubic yard per year		

COST ESTIMATION HANDBOOK FOR SMALL PLACER MINES

By Scott A. Stebbins¹

ABSTRACT

This Bureau of Mines publication presents a method for estimating capital and operating costs associated with the exploration, mining, and processing of placer deposits. To ensure representative cost estimates, operational parameters for placer equipment and basic principles of placer mining techniques are detailed.

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INTRODUCTION

In 1974, the Bureau of Mines began a systematic assessment of U.S. mineral supplies under its Minerals Availability Program (MAP). To aid in this program, a technique was developed to estimate capital and operating costs associated with various mining methods. This technique, developed under a Bureau contract by STRAAM Engineers, Inc., was completed in 1975, then updated in 1983. During the course of the update, it was noted that few provisions were made for estimating the costs of small-scale mining and milling methods typically associated with placer mining. The popularity and widespread use of placer mining methods indicated that a cost estimating system for placer mining would be of value to prospectors, miners, investors, and government evaluators.

This report has been written to aid those involved with placer mining in the estimation of costs to recover valuable minerals from placer deposits. It relies on the principle that cost estimates will be representative only if calculated for technically feasible mining operations. Because the design of such an operation can be difficult, provisions have been made to assist the user in achieving this goal.

Section 1 of the report describes the processes involved in placering, and may be used to aid in designing a viable mine. Operational parameters for equipment commonly used in placer exploration, mining, and processing are discussed, as well as basic principles of successful placer

mining techniques. If the reader is unfamiliar with this form of mining, section 1 should be thoroughly understood prior to estimating costs.

Section 2 contains cost equations that enable the user to estimate capital and operating costs of specific placer techniques. Cost equations are designed to handle the wide variety of conditions commonly found in placer deposits. This allows the reader to tailor estimates to the characteristics of a particular deposit, which ensures representative costs. Although based primarily on gold placer operations, cost equations are valid for any other commodity found in deposits of unconsolidated material. Equations are geared to operations handling between 20 and 500 LCY/h of material (pay gravel plus overburden). Estimated costs are representative of operations in the western United States and Alaska, and are based on a cost date of January 1985.

The appendix provides an example of placer mine design and cost estimation using the information contained in this report.

This report is not intended to be an exhaustive discussion of placer mining. Many detailed texts have been written on this process, any one of which will assist the reader in method design. A number of these are listed in the bibliographies accompanying sections 1 and 2.

ACKNOWLEDGMENTS

A special debt is owed to the late George D. Gale, metallurgist, Bureau of Mines. This handbook, and many

of the ideas and facts it contains, are the product of his ingenuity.

SECTION 1.—PLACER MINE DESIGN

The complete design of a placer mine involves the integration of exploration, mining, processing, and supplemental systems for the efficient recovery of valuable minerals from an alluvial deposit. This design is the first step in accurate cost estimation.

In this section, individual systems are categorized as follows:

1. **Exploration.**—The phase of the operation in which resources are delineated. Because the amount of time and effort spent on discovery is difficult to tie to any one specific deposit, only the processes of delineation and definition are costed. Field reconnaissance, drilling, and panning are representative of items in this category.

2. **Mining.**—Deposit development, material excavation and transportation, and feeding of the mill are all included in this category. Items such as clearing and overburden removal are also included.

3. **Processing.**—Processing is defined as all tasks required to separate the desired mineral products from valueless material.

4. **Supplemental.**—Any items not directly related to mineral recovery, but necessary for the operation of the mine. These might include buildings, employee housing, and settling pond construction.

Before designing a placer mining operation, the evaluator will need information concerning the deposit under evaluation. Preliminary information helpful in exploration program, mine, mill, and supplemental function design includes

1. Description of deposit access.
2. Anticipated exploration and deposit definition requirements.
3. An estimate of deposit geometry and volume.
4. Distribution and location of valuable minerals within the deposit.

5. Geologic characteristics, volume and depth of overburden.

6. Depth, profile, and geologic characteristics of bedrock.

7. Local topography.

8. Physical characteristics and geologic nature of valuable minerals.

9. Availability of water.

10. Availability of power.

11. Environmental considerations.

12. Labor availability and local wage scales.

13. Housing or camp requirements.

Information should be as detailed as possible. By providing such items as exact haul distances and gradients, accurate estimates of overburden thickness and deposit area, the evaluator will increase the precision of cost calculations.

With the preceding information in hand and the help of the material contained in the following pages, the user will be able to design a technically feasible operation. The following sections will assist the evaluator in planning each phase of the mine. When designing systems for individual areas of operation, the evaluator must keep in mind that these systems will interact and must be compatible. For instance, hourly capacity of pay gravel excavation should equal mill feed rate, and the mill must be set up to easily accept gravel from the equipment used for material transportation.

Most of the information contained in the following pages is based on average operating parameters and performance data for the various types of equipment used in placer mining. Costs and conclusions derived from this manual must be considered estimates only. Because of the many variables peculiar to individual deposits, the stated levels of equipment performance and costs may not be realized on any given job.

EXPLORATION

It can be safely stated that far more people seek placer deposits than actually mine them. Exploration for placer gold can be enjoyable work and has achieved a recreational status in the western United States. For the serious miner, however, exploration is only the initial phase of a complete mining operation. Consequently, it incurs a cost that must be repaid by the recovery of valuable minerals.

For the purposes of this report, exploration is divided into two phases. The first phase involves locating the deposit, and the second consists of defining enough of a resource to either justify development or to eliminate the deposit from further consideration.

Costs for the first phase of exploration are difficult to attribute to any one deposit. This type of exploration is typically regional in nature and deposit specifics are rarely considered. For cost estimation purposes, expenses associated with a specific deposit are the main concern. Only costs directly related to the definition of that particular deposit will be calculated. Accordingly, this discussion deals mainly with the deposit definition phase of exploration.

Time, effort, and money spent on resource definition vary greatly from one deposit to the next. Some miners are satisfied with the degree of certainty obtainable with shovel, pan, and physical labor. Others, wishing more security, systematically trench or drill the deposit and process samples using some sort of mechanical concentrator. Still others, hoping for greater assurance, follow up drilling or trenching by bulk sampling using machinery intended for mining. These samples are then processed in a scaled-down version of the proposed mill. The extent of effort spent on deposit definition is related to

1. Degree of certainty desired.
2. Availability of capital.
3. Experience of the operator.
4. Historical continuity of similar or local deposits.

It is intuitively obvious that the degree of certainty of success is related to the extent of exploration undertaken, and it is desirable to delineate the deposit as extensively as is practical prior to production. In many cases, however, lack of exploration capital and the need for cash-flow limit

the exploration phase, and mining commences on the limited information at hand. Goals of a thorough exploration program include determination of

1. Deposit volume.
2. Deposit and overburden geometry.
3. Deposit grade.
4. Distribution of valuable minerals within the deposit.
5. Geological and physical characteristics of the valuable minerals.
6. Geological and physical characteristics of waste material.
7. Location, geology, and physical nature of the bedrock.
8. Water availability.
9. Environmental concerns.

Much of the information needed to estimate costs of developing and operating a placer mine is gathered during deposit exploration. Consequently, costs estimated after exploration are much more precise than estimates made prior to exploration.

In section 2 of this report, two methods are presented for estimating exploration costs. With the first, a cost can be calculated by simply estimating the total resource of the deposit. This method is based on total exploration expenditures for several active placer operations, but is not considered as precise as the second method.

The second method requires that the evaluator design an exploration plan. This plan should include the type and extent of each exploration method required, for example

1. General reconnaissance, 5 days with a two-person crew.
2. Seismic surveying, 10,000 linear ft.
3. Churn drilling, 4,000 ft.
4. Trenching, 1,000 yd³.
5. Samples panned, 2,000.
6. Camp facilities, four people for 20 days.

To aid in developing this plan, some techniques commonly employed for sampling and subsurface testing of placer deposits are discussed in the following paragraphs. These include panning, churn drilling, bucket drilling, rotary drilling, trenching, and seismic surveying.

PANNING

One of the most versatile and common sampling devices in placer mining is the gold pan. It is used as a reconnaissance tool, a sampling tool, and a concentrate refining tool. With a gold pan, the prospector has the ability to, in effect, conduct his or her assay work on-site with immediate results. Although accuracy may be poor, the prospector can determine in the field if gold is present and in roughly what amounts.

The gold pan uses gravity separation to concentrate heavy minerals. Pans come in a variety of sizes, ranging in diameter from 12 to 16 in. An experienced panner can concentrate approximately 0.5 yd³ gravel daily. Because of this limited capacity, panning can be costly when large volumes must be processed; however, low capital expense, ease of use, versatility, and portability make the gold pan invaluable.

Immediate feedback when exploring or mining is a prime advantage of the gold pan. This one feature is extremely important for eliminating areas of low potential during exploration, and for separating pay gravel from

waste during production. Skilled use of a gold pan during the mining sequence can make or break the small mining operation.

CHURN DRILLING

Methods of drilling placer deposits are quite varied, but the most common technique is churn drilling. Typically, the churn drill uses percussion to drive casing down through the material being sampled (in some instances, casing is not used). After a length of casing is driven, the contents are recovered (bailed), another length of casing is added, and the process is repeated. Depths are usually restricted to less than 150 ft, and hole diameters range from 4 to 10 in.

One advantage of this method is that sample processing keeps pace with drilling, allowing good control of drill-hole depth and instantaneous logging. A churn drill is generally operated by two people; the driller operates the drill, bails the sample, and keeps track of the depth of each run; the panner estimates the volume of the samples, pans them as they are recovered, and logs the hole.

Drilling rates average about 2 ft/h but can reach as much as 4 ft/h in clay, soil, sand, pebbles and soft bedrock. The machine is suitable for drilling through cemented gravels and permafrost, although productivity will diminish. Penetration is drastically reduced in ground containing boulders and in competent or hard bedrock.

Samples recovered from churn drill casings are often subject to volume changes caused by compaction or expansion of material within the casing. Sample volume changes can also be caused by compaction around the bit forcing material out into the surrounding formation, and by material "run-in" due to high deposit water content. One or more of these conditions may be encountered in any one deposit, requiring the application of volume corrections. This task is often difficult and requires the experience of a qualified driller or engineer.

BUCKET DRILLING

Bucket drilling, although not as popular as churn drilling, has important applications in placer deposit evaluation. Under ideal conditions, this technique is relatively fast and provides large samples. In this system, a standard rotary drill is equipped with a special "bucket" bit consisting of a 30- to 48-in-diam cylinder, 3 to 4 ft long. The bit is driven down through the deposit, using the rotational force of the drill, until the cylinder is full. As the bit is withdrawn, a mechanism closes off the bottom of the bit retaining the sample. The process is then repeated until the desired depth is reached.

Bucket drills perform best in sands, soils, pebbles, and clays. Progress is slow, and sometimes impossible, in ground containing boulders, cemented gravel layers, and bedrock. The size of the bit tends to disperse drilling force over a large area, thereby reducing the effective penetration rate. For this reason the bucket drill quickly becomes inefficient in hard or compact material. Problems are also encountered in saturated ground, where water often washes away a portion of the sample as the bit is withdrawn.

Bucket drilling extracts a much larger sample than other drilling methods. Consequently, the influence of the bit on compaction and expansion of material is reduced.

ROTARY DRILLING

This type of drill, commonly used for drilling large-diameter blastholes in surface mining, has found limited use in placer exploration. The only way to obtain a sample with this machine is to analyze drill cuttings. Because the method does not provide a core, it is difficult to associate a volume with the recovered material, and it is hard to estimate the depth horizon of the sample.

Rotary drills are useful in that they provide a fast, inexpensive way to determine the depth of bedrock. Holes provided by rotary drills range from 6 to 15 in. in diameter and reach any depth required for placer mining. Virtually any material can be drilled, and penetration rates are far superior to any other placer drilling method. Regardless of the steps taken, however, it is difficult to accurately estimate deposit grade with samples obtained from rotary drilling.

TRENCHING

In fairly shallow, dry deposits, trenching with a backhoe is an extremely effective sampling technique. The procedure involves digging a trench to bedrock, then obtaining material from a channel taken down one side of the trench. This material is then measured and analyzed, providing a grade estimate. Another method relates an assay analysis of all the material extracted by the backhoe to the volume

of the trench. The disadvantage of this method is the inability to determine the horizon of valuable mineral concentration. With either method, large-volume samples are available at a low cost.

In sampling situations, backhoes can excavate from 20 to 45 LCY/h. Sample control is typically good with little volume distortion or material dilution under properly controlled circumstances. Backhoes are relatively inexpensive, easy to operate, versatile, and readily available. The machine can dig a variety of formations, and digging depths as much 30 ft below the machine platforms are possible. In saturated ground, keeping the trench open for sampling is normally a major problem.

SEISMIC SURVEYS

In placer mining, bedrock depth plays a key role. Although not always the case, gold tends to concentrate near, on, or even in bedrock in a majority of placer deposits. Consequently, it is imperative to understand the nature of the bedrock and to design a mining method and select equipment based on its depth.

One method of determining bedrock depth is seismic refraction or reflection. In simple terms, the technique involves bouncing sound energy off the relatively resistant bedrock to determine its depth. The method is much cheaper than drilling a series of holes and, if bedrock proves to be too deep for practical mining, may prevent unnecessary drilling.

MINING

Next, a method for excavation and transportation of material contained in the deposit is needed. Mining methods are typically dictated by several basic factors. Deposit depth, size, and topography are of primary importance. The geologic nature of the deposit and accompanying overburden both play key roles. Types of equipment obtainable locally, sources of power, and the availability of water are all important factors. In some cases, operators may simply feel more confident using one method of extraction as opposed to another, even if local conditions are unfavorable.

In any event, the mining method should be designed with one fundamental goal in mind: To extract pay gravel from the deposit and move it to the mill at the lowest possible overall cost. Several basic concepts should be designed into the mining method to keep costs low. These include

1. Haul only pay gravel to the mill. Eliminate hauling and processing unprofitable material.
2. Handle both overburden and pay gravel as few times as possible. Do not pile overburden or tails on ground that is scheduled for excavation.
3. Locate the mill at a site that minimizes average pay gravel haul distance. In most instances, it is cheaper to pump water than to haul gravel.
4. Do not mine gravel that is not profitable even if it contains gold. Money is lost for every yard of gravel mined if that gravel does not contain enough value to pay for the cost of mining and processing.

As can be seen, common sense plays a large role in the proper design of a placer mine. The same holds true for mine

equipment selection. Countless combinations of equipment have been tried in attempts to effectively mine placer deposits. Equipment typically used in the western United States includes

1. Backhoes (hydraulic excavators).
2. Bulldozers.
3. Draglines.
4. Dredges.
5. Front-end loaders.
6. Rear-dump trucks.
7. Scrapers.

Each type of equipment is suited to a particular task. In some instances, only one piece of equipment may be used to remove overburden, excavate and haul pay gravel, and place mill tailings and oversize (i.e., bulldozers). More often, several different types of equipment are utilized to take advantage of their specific attributes.

When selecting placer mining equipment, the evaluator must consider two important concepts. First, the volume of earth in place is less than the volume of the same earth after excavation. This point is critical in cost estimation and must be remembered. Because placer gravel is relatively light, placer mining equipment is typically limited by volume capacity, not weight capacity. For this reason, mine equipment capacities and associated cost equations in this report are based on volume *after* accounting for material swell—in loose cubic yards. Resource estimates are typically stated in bank cubic yards—the volume *before* accounting for material swell. This has a significant meaning to the design of a placer mining system. To mine a 500,000-BCY

deposit, equipment will have to move 570,000 LCY of gravel if the material swells 14% (typical for gravel deposits). Although the total weight of material moved is constant, equipment will have to move a larger volume of gravel than the in-place estimate indicates. As a result, the mining system should be designed around the total loose cubic yards of gravel to be moved, not the total bank cubic yards.

Second, mine equipment equations in section 2 of this report are based on the *maximum* amount of overburden, pay gravel, and mill tails moved daily. Although average volume handled might be less, equipment must be selected to handle the maximum load.

To aid in mine planning, and to obtain reasonable capital and operating mine costs, the following information will typically be required:

1. Total length and average width of haul and access roads.
2. Total surface area of deposit.
3. Nature of ground cover.
4. Topography of deposit area.
5. Total loose cubic yards of overburden, and maximum amount of overburden handled daily.
6. Total loose cubic yards of pay gravel, and maximum amount of pay gravel handled daily.
7. Total cubic yards of mill tails handled daily.
8. Type of equipment desired.
9. Average haul distances and gradients for overburden, pay gravel, and tailings.

The following is a discussion of the principal types of equipment used in excavating and hauling overburden, placer gravel, and mill oversize and tails, and may be used to aid in mine design and equipment selection.

BACKHOES (HYDRAULIC EXCAVATORS)

The backhoe is one of the most efficient types of equipment for bedrock cleanup. It is most often used for the extraction of pay gravel, but can also be used for excavation of overburden. The machine has almost no capacity for transportation of material and for that reason is used in conjunction with either front-end loaders, trucks, or in some cases, bulldozers. Depending on bucket selection, the machine can handle a variety of ground conditions including clays, poorly sorted gravels, tree roots, and vegetation. Digging depths of over 30 ft are obtainable with certain backhoes, but production capability decreases rapidly as maximum digging depth is approached.

Backhoes typically used in the western United States are capable of excavating from 95 to 475 LCY/h. Sizes range from 105-hp machines with 0.5-yd³ buckets to 325-hp units with 3.75-yd³ buckets. Capacity is contingent upon digging difficulty, operator ability, swing angle, digging depth, and obstructions.

The backhoe is ideal for situations where bedrock cleanup is critical, obstructions exist in the mining area, and other means of transporting gravel are available.

BULLDOZERS

The bulldozer represents an extremely versatile tool in placer deposit extraction, and is the most popular. It can be used for overburden removal, pay gravel excavation,

bedrock cleanup, overburden and pay gravel transportation, road construction, tailings placement, and a variety of minor functions. The bulldozer is the only device capable of handling all tasks required for placer mining in a practical manner and must be considered if capital is scarce.

Although bulldozers can handle all placer mining functions, they are not necessarily the most efficient machine for any one task. With its ripping capacity, the bulldozer is capable of cleaning up bedrock; however, the backhoe is much more selective and efficient. The bulldozer can, and often is, used to transport gravel, but in most cases trucks, scrapers, and front-end loaders can each do the job cheaper if haul distances are more than a few hundred feet. In addition, bulldozers are not well suited to more large volumes of gravel or to dig to excessive depths. In both instances, draglines exhibit superior performance.

A major advantage of the bulldozer is its ability to excavate, transport, and load the mill all in one cycle, eliminating the need for expensive rehandling. Dozer capacities for excavating and hauling range from 19 LCY/h for a 65-hp machine up to 497.5 LCY/h for a 700-hp dozer (based on a 300-ft haul distance). Capacity is dependent upon ripping requirements, operator ability, cutting distance, haul distance, digging difficulty, and haul gradient.

Dozers are best suited for situations where deposit and overburden thicknesses are not excessive, few large obstructions are present, and haul distances average less than 500 ft.

DRAGLINES

Draglines are well suited for excavating large quantities of overburden, gravel, and waste. Although their material transporting ability is limited, draglines with booms up to 70 ft long are capable of acting as the sole piece of mining equipment. As with the bulldozer, draglines can excavate overburden and pay gravel, load the mill, and remove tailings; however, draglines are relatively inefficient at bedrock cleanup, and do not handle difficult digging as well as backhoes or dozers.

Depths of over 200 ft are obtainable with this type of machine, and when used in conjunction with front-end loaders or rear-dump trucks, large-capacity operations are possible. Draglines handle from 28 LCY/h for a 84-hp unit to 264 LCY/h for a 540-hp machine. Capacity is dependent upon bucket efficiency, swing angle, and operator ability.

Draglines are ideal for overburden removal and for large, deep deposits where bedrock cleanup is not critical. They must, however, be matched with the right equipment (i.e., portable mills or gravel transportation machinery).

DREDGES

Cost estimation equations for dredging are not included in this report. Dredges, except for recreational units and small machines used in active channels, are designed for high-capacity excavation of specific placer environments. The machines are best utilized in large volume, relatively flat-lying deposits that occur below water level. Because of large capital investment requirements and a scarcity of ground suitable for large-scale dredging, they are uncommon in the western United States.

Operating costs for large-capacity dredges average approximately \$0.70/yd³. Purchase and refurbishing costs are often more than \$3 million, and can run over \$10 million. In large-volume situations, dredges must be considered. Because suitable applications are rare, however, they have not been included in this report.

FRONT-END LOADERS

This versatile machine is capable of many functions. In the western United States, its primary use is hauling previously excavated gravels, and the subsequent loading of the mill. Although front-end loaders are not the most efficient hauling unit, their self-loading ability provides many advantages. One is the elimination of the need to match the excavation machine with the haul unit. With a front-end loader, the excavator can operate at its own pace and simply stockpile material. The loader then feeds from the stockpile and transports gravel to the mill feed hopper. This removes the problem of matching excavator output with truck cycles or mill feed rates.

The machine is also capable of removing and transporting mill oversize and tailings; however, front-end loaders are not particularly adept at excavating consolidated material. If overburden or gravel are at all compacted, a backhoe or bulldozer should be used for a primary excavation.

Front-end loaders are capable of hauling from 24 LCY/h for a 65-hp, 1-yd³ machine to 348 LCY/h for a 690-hp, 12-yd³ machine (based on a 500-ft haul distance). Capacity varies with haul length, haul gradient, operator ability, bucket efficiency, and type of loader.

Front-end loaders are best utilized as haul units over distances of less than 1,000 ft. Their versatility makes them useful for pay gravel and overburden transportation, mill oversize and tailings removal, and general site cleanup.

REAR-DUMP TRUCKS

Trucks represent the least expensive method of material movement over long distances; however, since other machinery is required for loading, total gravel transportation expenses over short distances may be higher than for front-end loaders or scrapers. Trucks generally serve two

purposes: Material movement and mill feed. They have relatively low capital costs and require little maintenance compared to other placer equipment. Trucks do need fairly good road surfaces and require careful matching with loading equipment to achieve acceptable efficiency.

Capacities for units at small placer operations range from 3 to 47.5 yd³. Trucks are most productive over haul distances of 1,000 to 10,000 ft and can travel faster than equivalent-sized scrapers or front-end loaders. Production capacities range from 32.3 LCY/h for a 3-yd³ truck to 444.8 LCY/h for a 47.5-yd³ truck (based on a 2,500-ft haul distance). Capacity is contingent upon loader capacity, haul distance, and haul gradient.

Trucks are suited to operations where a fixed mill is situated more than 0.5 mile from the minesite. They are equally effective hauling pay gravel, overburden, or mill tailings and oversize, but must be accompanied by a method of material loading.

SCRAPERS

These machines are noted for their high productivity when used to transport overburden, pay gravel, and tailings. As with front-end loaders, scrapers are self-loading, although bulldozers or other scrapers often assist. They are capable of much higher speeds and greater capacity than front-end loaders, and exhibit haulage characteristics similar to rear-dump trucks. Scrapers, however, are more costly to purchase and maintain.

Scrapers are limited in their ability to excavate consolidated or unsorted material. A bulldozer equipped with a ripper must precede them in overburden or gravel that is not easily drifted. If boulders are present, they must either be blasted or removed by other means. The nature of the scraper-dumping mechanism renders them unsuitable for direct mill feed. When used to haul pay gravel, scrapers will typically unload near the mill, and bulldozers will then be used to feed material.

Capacities range from 201 LCY/h for a 330-hp machine to 420 LCY/h for a 550-hp machine (based on a 1,000-ft haul distance). Capacity is contingent upon haul distance and gradient, and loading procedure.

In placer mining, scrapers are best utilized for transportation of unconsolidated overburden or mill tailings over distances ranging from 500 to 5,000 ft.

PROCESSING

Often the most difficult part of placer mining is achieving the desired recovery of valuable minerals from mine-run gravel. The design of a successful mill is a specialized science and often proves difficult even for those actively involved in placer mining. Great care must be taken to ensure the recovery of a high percentage of contained valuable minerals. Obviously, the profitability of an operation is directly related to the percentage of contained valuable minerals recovered by the mill.

Although mill design can be difficult, the basic premise used in heavy mineral recovery is quite logical. In placer deposits, high-density minerals have been concentrated by

combinations of natural phenomenon such as gravity, turbulent fluid flow, and differences in mineral density. Consequently, it would seem practical to utilize these conditions to further concentrate heavy minerals. This form of mineral recovery is referred to as gravity separation and is the basis for most placer mills.

Gravity processes must consider both particle specific gravity and size for effective separation. Differences in specific gravity alone will not distinguish various materials. It is the differences in weights in a common medium that creates efficient separation. Consequently, a particle of high specific gravity and small size may react the same as a large

particle with low specific gravity in a given fluid. If gravity separation is to be effective, size control must be implemented to take advantage of differences in particle specific gravity.

Equipment used for gravity separation ranges from gold pans to prebuilt self-contained placer plants. In general, the most widely employed devices in the western United States are

1. Jig concentrators.
2. Sluices.
3. Spiral concentrators.
4. Table concentrators.
5. Trommels.
6. Vibrating screens.

Of these devices, trommels and vibrating screens are used for particle size classification, and the remainder are forms of gravity concentrators. In addition, feed hoppers and conveyors are needed for surge capacity and material transportation. These items, which are commonly neglected in plant costing, must be carefully selected to ensure proper plant operation.

Although the complete design of a placer recovery plant cannot be thoroughly covered in the space available here, three sample flowsheets illustrating basic placer mill design are included at the end of this section on processing. Along with a flow sheet detailing equipment type, size, and capacity required for the mill, the following will be needed to obtain an accurate cost estimate using this report:

1. Maximum feed capacity of the mill.
2. A material balance illustrating feed, concentrate, and tailings rates.
3. The purpose of each gravity separation device (rougher, cleaner, scavenger, etc.).
4. Method of removal and transportation of mill tails and oversize.

The following discussion details equipment used in gravity separation and may prove useful in mill design.

CONVEYORS

As material travels through a mill circuit, it can be moved by conveyor, pumped in a slurry, or transferred by gravity. In placer processing mills, material is most often transported in a slurry or by gravity. In some cases, however, conveyors are necessary. Conveyors are typically used for situations of extended transport where material need not be kept in a slurry, such as the removal of oversize or tailings. They provide an inexpensive method of transporting large quantities of material over fixed distances. In the case of placer processing plants, this distance typically ranges between 10 and 120 ft. Conveyors used in these plants are typically portable, and consequently come complete with framework and support system ready to operate.

Conveyor capacity is related to belt width, belt speed, and material density. For most placer gravels, capacities range between 96 yd³/h for an 18-in-wide belt to 480 yd³/h for a 36-in-wide belt.

FEED HOPPERS

The initial piece of equipment in most mill circuits is a feed hopper. The hopper is used in conjunction with a

feeder to smooth out material flow surges introduced by loading devices with fixed bucket sizes (front-end loaders, rear-dump trucks, etc.). Hoppers often contain a grizzly in order to reject large oversize material. The feeder, typically a vibrating tray located under the hopper, transfers gravel at an even rate to the circuit. Although the hopper-feeder combination may appear to be a minor piece of equipment, a steady flow of material through the mill is very important for effective gravity separation.

Hopper capacity and feeder capacity are two separate items. Generally, hoppers are designed to hold enough material to provide a steady flow of gravel despite surges inherent in mining cycles. Feeders are set to provide the appropriate flow rate to the mill. So even though a hopper may have a 100-yd³ capacity, the feeder might provide material at 20 yd³/h.

Feeders are not always used in placer mills. When they are not used, feed rate is regulated by the size of the opening in the bottom of the hopper. The cost estimation curves in this report calculate hopper-feeder costs based on feeder capacity, which typically equals mill capacity. Factors are provided for situations where feeders are not used.

JIG CONCENTRATORS

Jigs are gravity separation devices that use hindered settling to extract heavy minerals from feed material. They typically consist of shallow, perforated trays through which water pulsates in a vertical motion. In most instances, a bed made up of sized shot, steel punchings, or other "ragging" material is placed over the perforations to promote directional currents required for separation. Slurried feed flowing over the bed is subjected to the vertical pulsations of water, which tend to keep lighter particles in suspension while drawing down heavier constituents. These heavy minerals are either drawn through the bed and discharged from spigots under the jig or, if too large to pass through the perforations, are drawn off near the end of the machine. Lighter particles continue across and over the end of the jig as tailings.

Jigs are sensitive to feed sizing. They are generally utilized for feeds ranging from 75 μ m to a maximum of 1 in, but recoveries improve if feed is well sized and kept to minus 0.25 in. Efficiency is maximized when feed materials have been deslimed and sized into a number of separate fractions for individual treatment. Optimum solids content for jig plant feed ranges from 35% to 50%—the object being to avoid excessive dilution of the material. Capacities for jigs range from 0.1 to 400 yd³/h and are dependent upon desired product as well as equipment size.

SLUICES

The most common gravity separation device used in placer mills, sluices are simple to construct, yet effective heavy mineral recovery tools. Sluice design is quite diverse and opinions differ widely with respect to capacity, riffle design, and recovery. In general, capacities and performances vary with box width and slope, gold particle size, nature of feed, and availability of water.

Sluices are primarily used for rough concentration and are capable of processing poorly sorted feeds. As with other methods, however, recovery is related to the degree of previous sizing.

Sluice design can be quite complex but usually is a matter of trial and error. Several basic principles typically apply. Width is determined by the maximum and minimum volume of water available, the size and quantity of oversize feed that must be transported, and the slope. Length depends principally on the character of the gold. Coarse gold and granular gold settle quickly and are easily held in the riffles, while fine gold and porous gold may be carried some distance by the current. Velocity of the water is controlled primarily by the slope. In general, the sluice should be constructed and installed so that water flowing through the box will transport oversized material and prevent sand from packing the riffles.

If the surface of the water flowing through the sluice is smooth, the bottom of the sluice is probably packed with sand, allowing little gold to be saved. The desired condition occurs when waves form on the surface of the water flowing through the sluice, and these waves, along with the wave-forming ridges of material on the bottom of the sluice, migrate upstream. This indicates an eddying or boiling activity on the lee side of the ridges, which maximizes gold recovery and tailings transport. Consequently, the sluice attains maximum efficiency when riffle overloading is incipient.

Sluices are generally considered to be high-capacity units, with a 12-in-wide sluice box capable of handling 15 yd³/h if sufficient water is available. A 24-in-wide sluice can handle up to 40 yd³/h, and 48-in-wide sluices have reportedly processed up to 200 yd³/h. Of course, a sluice will handle as much gravel as the operator wants to push through it. However, to ensure reasonable recovery, capacity is limited by box width and slope, water availability, and feed characteristics.

Feed slurry densities are highly variable and range from 1% to 35% solids by weight, averaging 10%. Water use can be reduced significantly if the larger of the oversize is eliminated from the feed. Sluices require no power to operate unless a pump is needed to transport water or slurry. One disadvantage of the sluice is the necessity to halt operations in order to recover concentrates.

SPIRAL CONCENTRATORS

Spirals are used infrequently in the western United States but may be applicable for certain types of feed. These gravity separation devices exhibit several desirable features. They accept sized slurry directly, and require no energy to operate other than perhaps pumps for material feed. Pumps can be excluded if gravity feed is used. Selectivity is high because of adjustable splitters within the slurry flow. Spirals can be used to produce a bulk concentrate, scavenge valuable minerals from tailings, or in some instances, recover a finished concentrate. The ability to produce a finished concentrate will be limited to feeds that contain a higher concentration of desired product than typically found in most gold placer feeds.

To save space, two or three spiral starts are constructed around a common vertical pipe. This arrangement takes little floor space, allowing banks of multiple units to be set up for large-capacity requirements. In this situation, slurry distributors are required to sectionalize feed for individual spirals.

Maximum feed rates vary according to feed particle density, size, and shape. Rates generally range from 1.0 to 1.4

yd³/h roughing down to 0.3 to 0.5 yd³/h cleaning per start. Feed slurry density is typically less than 25% solids by weight, necessitating the use of larger pumps than needed for jigs or tables.

TABLE CONCENTRATORS

Concentrating tables (shaking tables) are one of the oldest methods of mechanical gravity concentration. Although capable of handling a variety of feed types and sizes, their optimum use is wet gravity cleaning of fine concentrates ranging from 15 μ m to 1/8 in. The unit consists of a large, flat, smooth table, slightly tilted, with riffles attached to the surface. A longitudinal reciprocating motion is introduced to the deck by means of a vibrating mechanism or an eccentric head action.

Although limited in capacity, tables have the advantage of being easily adjustable by regulating the quantity of wash water and altering the tilt angle of the deck. The results of these changes are immediately observable on the table. With the addition of splitters, efficient control of high-grade concentrate recovery, middling recovery, and tailings production is possible.

Solids content for table feeds averages approximately 25% by weight. Stroke length and speed are adjusted according to feed. Long strokes at slow speeds are used for coarse feeds; fine material responds better to short strokes at higher speeds. A reciprocating speed of 280 to 380 strokes/min will handle most feeds. Table capacities range from 0.05 to 8 yd³/h and depend on desired product as well as equipment size.

TROMMELS

This machine is the most common size classification device used in gold placer mills and is well suited for this task if properly designed. Trommels consist of a long rotating cylinder that is typically divided into two sections.

In the first section, lengths of angle iron or similar material are fastened to the inside of the rotating drum. These act as lifters to carry feed up the side of the rotating cylinder. As material reaches the top of the rotation, it falls back to the bottom of the cylinder and breaks upon impact. This action, along with water introduced under pressure, serves to break up compacted soils and clays, and liberate valuable minerals.

The second section consists of perforations in the cylinder walls positioned along the length of the drum. Typically, perforation size will graduate from 1/8 in. to 3/16 in. to 1/4 in. as the feed progresses down the trommel.

Sized fractions are drawn directly below the section of the trommel in which they are separated. They generally flow to either a vibrating screen to be sized further or to a gravity separation device. Oversize material is discharged out the end of the trommel as waste.

Trommels are particularly well adapted to placer feeds because of their ability to handle a diversity of feed sizes and to break up material in the scrubber section. Capacity ranges from 10 to 500 yd³/h and is dependent on feed characteristics, screen perforation sizes, and machine size. Water requirements are contingent upon the amount of washing desired.

VIBRATING SCREENS

Vibrating screens are often used for secondary size classification in circuits treating alluvial ores and, in some cases, may provide primary sizing. The machines consist of a deck, or decks, containing inclined screening surfaces that are vibrated in either a rectilinear or elliptical motion. Screening medium can be woven wire cloth, parallel bars, or punched sheet metal.

High capacity, ease of installation, and reasonable operating costs have all contributed to the popularity of vibrating screens. The practical minimum size limitation for production screens is about 100 mesh, although 325-mesh separations have been achieved. Capacity is, of course, dependent on many factors. These include type of material, amount of oversize, amount of undersize, moisture content, particle shape, screen opening size, and screen medium. In general, from 0.40 to 0.75 ft² of screen surface area will be needed for every cubic yard of feed handled per hour.

SAMPLE MILL DESIGN

It is not possible to provide complete instruction on mill design within the constraints of this manual. Mills must be planned with the intention of treating the size, shape, and grade characteristics of a specific feed. Sample gold mill flowsheets shown in figures 1, 2, and 3 are included to aid the evaluator in cost estimation only. They are provided to demonstrate that, in most instances, material will have to be fed, washed, sized, and separated for proper recovery.

Tables 1, 2, and 3 provide sample material balances for these mills.

Table 1.—Sample material balance, sluice mill

(Specific gravity: Gold, 17.50; waste, 2.81)

	Feed	Concentrate	Tails
Rate yd ³ /d	120	0.1	119.9
Composition wt %	100	0.08	99.92
Specific gravity	2.81	2.82	2.81
Grade tr oz Au/yd ³	0.040	42.24	0.005
Gold distribution:			
tr oz/d	4.8	4.224	0.576
%	100	88	12

Table 2.—Sample material balance, jig mill

(Specific gravity: Gold, 17.50; waste, 2.65)

	Feed	Concentrate	Tails
Rate yd ³ /d	700	0.1	699.9
Composition wt %	100	0.01	99.99
Specific gravity	2.65	2.71	2.65
Grade tr oz Au/yd ³	0.030	199.50	0.002
Gold distribution:			
tr oz/d	21.0	19.95	1.05
%	100	95	5

Table 3.—Sample material balance, table mill

(Specific gravity: Gold, 17.50; waste, 2.73)

	Feed	Concentrate	Tails
Rate yd ³ /d	250	0.2	249.8
Composition wt %	100	0.08	99.92
Specific gravity	2.73	2.75	2.73
Grade tr oz Au/yd ³	0.045	53.44	0.002
Gold distribution:			
tr oz/d	11.25	10.688	0.562
%	100	95	5

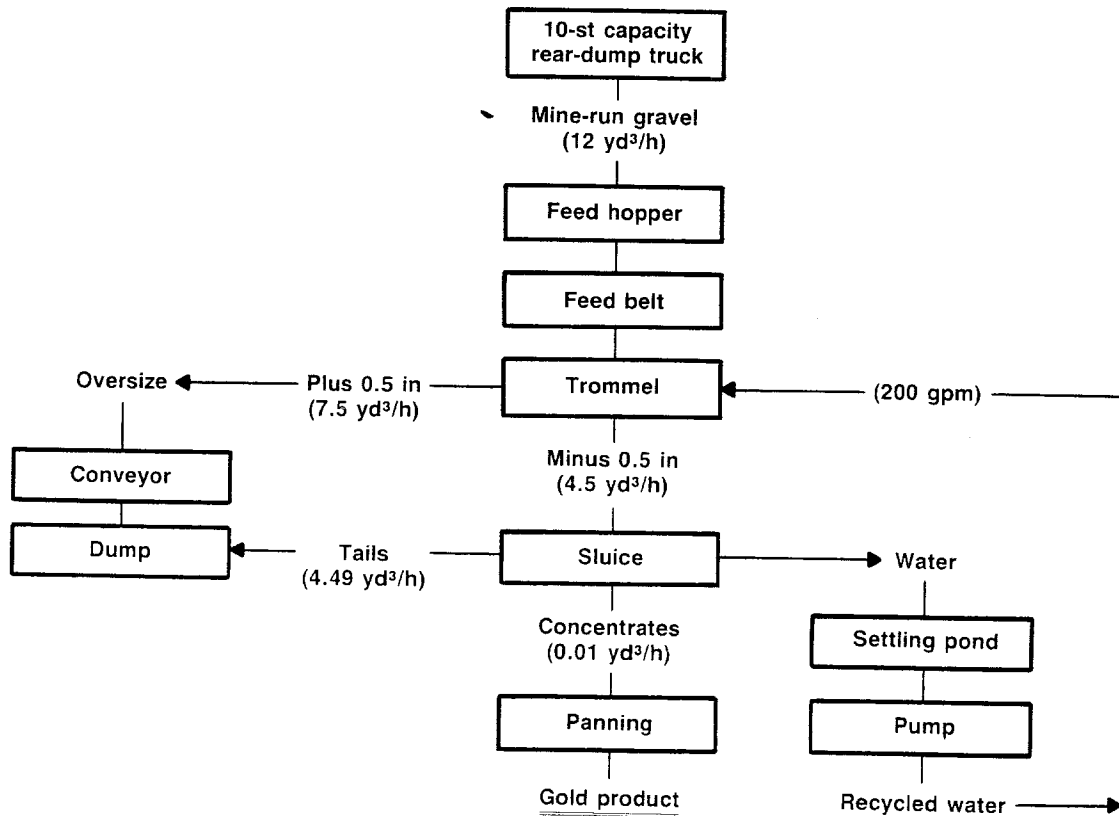


Figure 1.—Sample flow sheet, sluice mill.

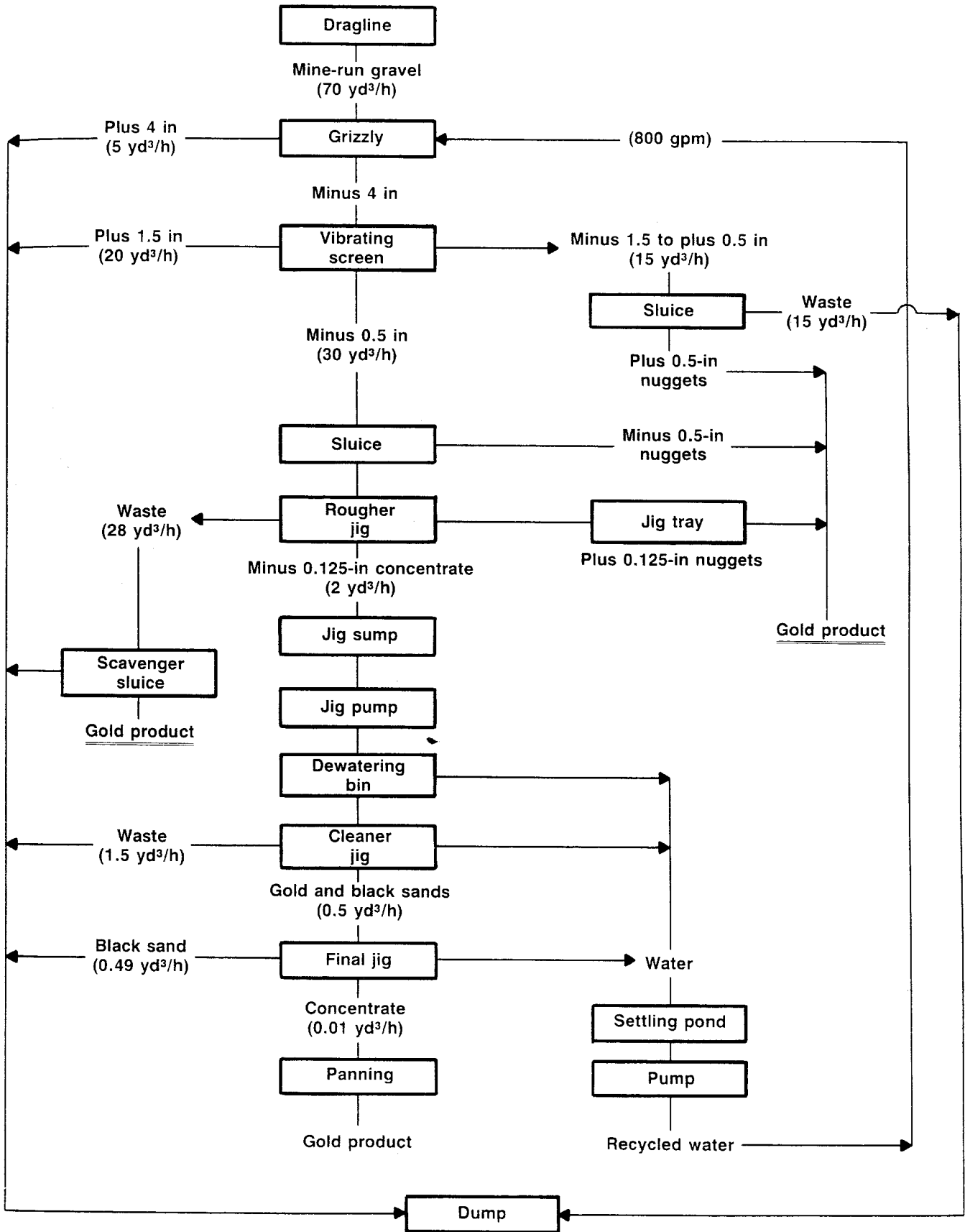


Figure 2.—Sample flow sheet, jig mill.

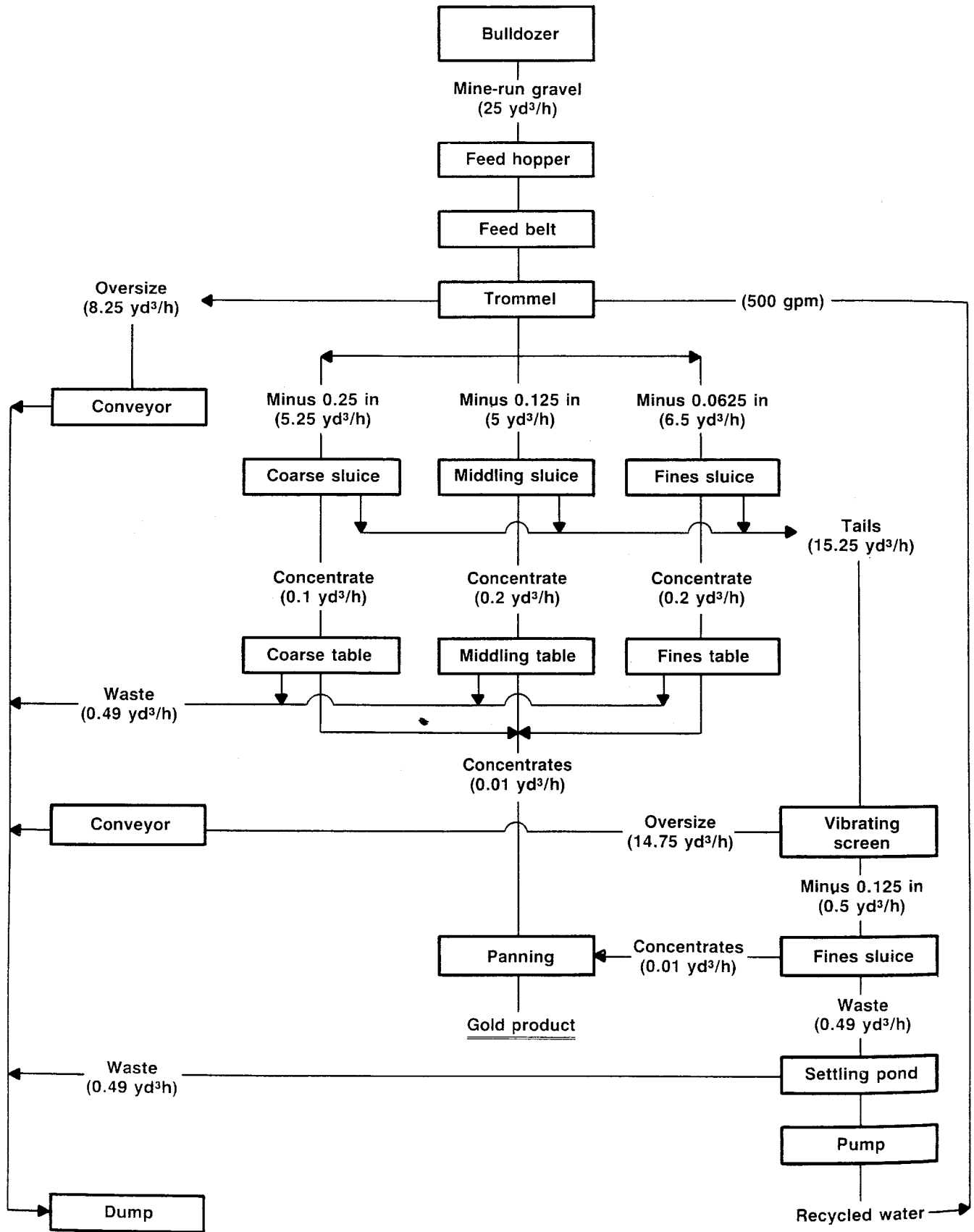


Figure 3.—Sample flow sheet, table mill.

SUPPLEMENTAL SYSTEMS

Commonly neglected in costing and design work, supplemental systems gain importance in placer operations. Because of the relative low cost of placer mining and milling equipment and systems, the expenses associated with supplemental items represent a larger percentage of the total cost than with other types of mining. For costing purposes, any system, structure, or equipment not directly related to production but necessary for continued operation is categorized as supplemental. These include

1. Buildings.
2. Camp facilities.
3. General services and lost time.
4. Generators.
5. Pumps.
6. Settling ponds.

Each item included in the supplemental section should be examined to determine if it is needed at a particular operation. To aid in this determination and to assist in cost estimation of supplemental items, the following information will prove helpful:

1. Location and elevation of available water in reference to the millsite.
2. Ecological sensitivity of the area.
3. An estimate of the number and capacity of pumps needed.
4. Maximum hourly capacity of mill.
5. Building requirements.
6. An estimate of workforce size.

BUILDINGS

Many placer operators consider any building to be a luxury; however, if weather is a factor or if operators desire to safely store equipment, some buildings will be needed. Typically, a small placer mine will have one structure that serves as a shop, a concentrate cleanup area, and a storage room. More elaborate operations, or those in areas of bad weather, will cover the mill and often construct several small storage sheds. These buildings are usually temporary structures of minimal dimensions constructed of wood or metal.

The size of each building must be estimated for costing purposes. For the typical operation, the main structure will be capable of housing the largest piece of mobile equipment at the mine with enough additional room for maintenance work. Shops often have concrete floors, and power and water facilities are typically provided. Storage sheds are usually of minimum quality, have a wood floor if any at all, and often contain power for lighting. Factors for all these variables are provided in the building cost estimation curve.

CAMP FACILITIES

The provision of facilities for workers is an important part of placer operations. In most situations, workers will stay at the site during the mining season to take advantage of good weather. The needs of these workers must be met, and that typically involves providing living quarters and food. In almost all cases, employee housing at placer mines consists of mobile homes or trailers with a minimum amount of support equipment. Cooking is generally done

by the workers in their trailers with an allowance provided for the cost of food.

To calculate the expense of camp facilities, it is necessary to estimate the number of people staying at the mine. Guidelines for this estimate are provided with the cost equations in section 2 of this report. It must be remembered that the number of people working at any one operation can be quite variable, and if the number of intended or actual employees is available, this figure must be used.

GENERAL SERVICES AND LOST TIME

Compared with other methods of mineral recovery, placer mining is relatively inefficient. Because of limits in workforce size, delays and tasks not directly related to mining have a noticeable effect on productivity. This inefficiency strongly influences costs associated with placer mining, and must be taken into account.

In placer mining, most costs associated with inefficiency can be attributed to three distinct areas:

1. Equipment downtime.
2. Site maintenance.
3. Concentrate refinement.

Specific expenses can be further delineated.

1. Equipment downtime.
 - A. Productivity lost by the entire crew because of breakdown of key pieces of equipment.
 - B. Productivity lost by individual operators because of breakdown of single pieces of equipment.
 - C. Labor charges of outside maintenance personnel.
2. Site maintenance.
 - A. Road maintenance.
 - B. Stream diversion.
 - C. Drainage ditch construction and maintenance.
 - D. Site cleanup.
 - E. Reclamation grading and recontouring.
 - F. Settling pond maintenance.
 - G. Mill relocation.
3. Concentrate refinement.
 - A. Concentrate panning.
 - B. Mechanical separation.
 - C. Amalgamation.

Estimates indicate that in placer mining up to 37% of the total labor effort is spent on the above tasks. The lost time and general services cost curve must be used in all placer mine cost estimates.

GENERATORS

In all but the most simple gravity separation mills, power will be needed to operate equipment. A minor amount of power will also be required for camp functions. Typically, power is provided by one of three sources:

1. Individual diesel engines driving each piece of equipment.
2. Diesel generators.
3. Electrical power brought in through transmission lines.

The third source generally requires excessive initial capital expenditures. Transmission lines are considered only

when the mill capacity is well over 200 yd³/h, existing transmission lines are located near the site, or the mine life is expected to be 15 yr or more. Power source selection should be based on lowest overall cost and minimum environmental impact. For most small- to medium-sized gravity separation mills in remote locations, diesel generators are selected to provide power.

Cost estimation curves in this report are based on diesel generators providing all power to mill equipment. Electric power costs contained in individual processing equipment operating cost curves account for diesel generator operating costs.

PUMPS

Water, used to wash gravel and to initiate slurring of the feed, is typically introduced as gravel enters the trommel or screen. More water is added as needed throughout the circuit to dilute the slurry or assist in washing. To provide adequate washing, this water must be introduced under pressure which, in many cases, necessitates the use of pumps. Pumps will also be needed if mill water is to be recycled through settling ponds. Under certain circumstances, one pump can handle all tasks required in a placer processing plant utilizing recycled water. It is preferable to minimize the use of pumps by taking advantage of gravity.

Water use is dependent on several factors, including

1. Washing required to properly slurry feed.
2. Type of separation equipment used.
3. Availability of water.
4. Size and nature of valuable mineral constituents.

For costing purposes, the evaluator must estimate the volume of water pumped per minute and the pumping head.

A separate estimate must be made for each pump. Water requirements can either be calculated using parameters given in the processing portion of section 1, or roughly estimated using the following equation:

$$\text{Water consumption (gpm)} = 94.089(X)^{0.546},$$

where X = maximum cubic yards of mill feed handled per hour.

This equation provides the total gallons of water per minute consumed by the mill. Although not technically accurate, for the purposes of this report, head may be estimated as the elevation difference between the pipe outlet at the mill or upper settling pond, and the pump intake.

SETTLING PONDS

With the current level of environmental awareness, it is almost assured that mill water will have to be treated prior to discharge. Placer mines typically recycle mill effluent through one or more settling ponds to control environmental impact.

To calculate the cost of settling pond construction using this report, only the maximum mill feed rate is required. Cost curves provide the construction expense of unlined ponds sized to comply with most regulations. In some instances, the pond will have to be lined with an impervious material. This is often required in ecologically sensitive areas, or in situations where underlying soils do not properly filter mill effluent, thereby increasing the turbidity of nearby streams. A factor is provided in the settling pond cost curve for impervious linings.

ENVIRONMENT

Environmental costs are often decisive in placer mine economic feasibility. Costs associated with water quality control and aesthetics are inescapable and can represent a significant percentage of total mining expenses. Methods to minimize ecological disturbance are now considered an integral function of the mining sequence and are treated as such in cost estimation.

Stream siltation from mill effluent and land disturbance from excavation are the main environmental problems facing placer miners. Reduction of water quality is often the biggest problem, and many techniques have been devised to lessen the impact caused by mill operation. One method involves limiting mill operation to short periods of time, thus allowing effluent to disperse before additional mill discharge is introduced. Often the mill is designed with the intent of using as little water as possible for valuable mineral separation. The most common solution is mill water recirculation facilitated by the construction of settling ponds. These ponds are used to hold mill effluent until particulate matter has settled; water from the ponds is then reused in the mill circuit.

Mining of alluvial deposits necessitates disturbance of large areas of land. Typically all trees, brush, grasses, and ground cover will be cleared. This task alone may present

a major stumbling block, because some States restrict open burning. Next, a layer of overburden is removed to expose the deposit. Finally, the valuable mineral-bearing gravel can be excavated.

Current technology suggests that control of land disturbance be incorporated into the mining sequence. Mill tailings and oversize are typically dumped back into worked-out areas. Soil cover and overburden are removed just prior to pay gravel excavation, then hauled to mined-out areas to be graded and contoured over replaced tails. Often the surface is revegetated. In most instances, the operator will have no choice but to implement ecological control and reclamation procedures. Operators are typically required to post a bond to cover the cost of reclaiming mined lands, and if the surface is left disturbed, these bonds will be forfeited.

Regulations vary from State to State, and may appear difficult and confusing at first; however, by contacting information services at State capitals, operators will be directed to the agencies concerned. These agencies will detail regulations concerning placer operation and will also point out which Federal agencies might be involved (U.S. Forest Service or U.S. Bureau of Land Management). In most instances, contact will have to be made with both State

and Federal agencies. Typically, meeting environmental requirements for the State will satisfy Federal regulations.

As stated earlier, environmental control is an integral part of mine and mill design, and costs are treated accordingly. Equations are provided for calculating the cost of mill tails and oversize placement. Expenses associated with grading and contouring are contained in the lost time and

general services curve. An equation is also provided for the construction of settling ponds, if water is to be recycled.

Bond costs are not included since requirements are highly variable. One other cost may arise that is not covered in section 2. This is the expense of replanting, and usually ranges from \$100 to \$200 per acre.

COST ESTIMATION

After selecting exploration, mining, milling, and supplemental techniques, the next step in cost estimation is the choice of appropriate cost curves. If the evaluator has completed the mine design prior to attempting cost estimation, this task consists of simply going through section 2 of this report and selecting the proper equations. The list of capital and operating categories at the beginning of section 2 will aid in choosing individual curves.

Costs used in deriving the estimation equations were collected from several sources. These include

1. Placer mine operators.
2. Mine equipment suppliers.
3. Published cost information services.

In all cases, cost figures quoted in the text and points used in cost equation derivations are averages of all data available. A bibliography of cost information publications follows section 2. Many of these sources contain both cost and capacity information and can be used to supplement this manual.

Cost estimation methodology in this handbook is based on the Bureau's Cost Estimation System (CES), first published in 1977 as "Capital and Operating Cost Estimation System Handbook," by STRAAM Engineers, Inc. Procedures for cost estimation using this report closely follow that publication. The cost estimation portion of this report is divided into operating and capital costs. Cost equations are similar for both with the only difference appearing in the units of the final answer. Capital costs are given in total dollars expended and operating costs in dollars per year.

Using the appropriate curves, a separate cost is calculated for each capital and operating cost item. Only costs directly associated with the operation under evaluation need be calculated. All other cost items should be ignored. After calculation, item costs should be entered on the respective capital and operating cost summary forms (see figures 5 and 6 in section 2).

Upon summation of individual expenses, a contingency may be added to both capital and operating costs. It is difficult to anticipate every condition that may arise at a particular operation, and the purpose of the contingency is to account for unforeseen expenditures. This figure is typically based on the degree of certainty of the evaluation in relation to available information, and ranges from 10% to 20%.

Cost per cubic yard of pay gravel processed is determined by dividing the sum of all annual operating costs by the total amount of pay gravel processed per year. Summation of individual capital expenditures produces the total capital cost.

Use of the individual curves is described in the following paragraphs.

COST EQUATIONS

Capital and operating costs are divided into labor, equipment, and supply categories. One, two, or all three of these categories will be present in each cost equation. The sum of costs from each of these categories provides the total cost for any single cost item. To facilitate cost adjustments respective to specific dates, the labor, equipment, and supply classifications are further broken down into subcategories.

Typically, each cost item will have a number of site adjustment factors. These are provided to account for characteristics specific to a particular deposit. These factors determine the precision of the final cost, so they must be selected and used carefully. Assistance in determining the correct use of a factor, or in understanding the parameters involved in a cost item, may be found in the preceding pages.

To further improve cost estimates, labor rates are also adjustable. Rates can vary greatly for small placer operations. For this reason, adjustments can be made to the fixed rates used in this report for specific known rates at individual operations.

COST DATE ADJUSTMENTS

All cost equations were calculated in January 1985 dollars. Costs calculated for any particular cost item are broken down into specific categories and subcategories to facilitate adjustment to specific dates. These include

Labor.

1. Mine labor.
2. Processing labor.
3. Repair labor.

Equipment.

1. Equipment and equipment parts.
2. Fuel and lubrication.
3. Electricity.
4. Tires.

Supplies.

1. Steel items.
2. Explosives.
3. Timber.
4. Construction materials.
5. Industrial materials.

For placer mining, most general maintenance and non-overhaul repairs are accomplished by the equipment operator, so repair labor rates are assumed to be equal to those of the operator. If information available to the evaluator indicates that this is not the case, repair labor

portions of the total labor cost are stated to facilitate adjustment.

Equipment operating costs are broken down into respective percentages contributed by parts, fuel and lubrication, electricity, and tires. These percentages, listed immediately following the cost equations, are used to calculate specific costs for each subcategory so that they may be updated. Supply costs are broken down and handled in a similar manner.

Cost date indexes for the preceding subcategories are provided in table 4. These and other cost indexes are updated every 6 months and are available from the Bureau of Mines, Western Field Operations Center, East 360 Third Avenue, Spokane, WA 99202. To adjust a cost to a specific date, divide the index for that date by the index for January 1985, and multiply the resulting quotient by the cost calculated for the respective subcategory. An example of such an update follows.

Example Cost Update

Calculate the cost in July 1985 dollars of extracting and moving pay gravel 300 ft over level terrain using bulldozers. Assume a 200-LCY/h operation, and use the operating cost equations provided in the operating costs—mining-bulldozers portion of section 2.

Operating costs per LCY
(from section 2):

Equipment operating cost	$0.993(200)^{-0.430} =$	\$0.102
Labor operating cost	$14.01(200)^{-0.945} =$.094
January 1985 total		<u>.196</u>

Subcategory costs per LCY
(from section 2):

Equipment parts	$0.47 \times \$0.102 =$	\$0.048
Fuel and lubrication	$0.53 \times \$0.102 =$	\$0.054
Operator labor	$0.86 \times \$0.094 =$	\$0.081
Repair labor	$0.14 \times \$0.094 =$	\$0.013

Update indexes
(from table 4):

Subcategory	July 85/Jan. 85	Quotient
Equipment parts	Equipment .. 362.3/360.4	1.005
Fuel and lubrication	Fuel .. 630.7/636.2	0.991
Operator labor	Mine labor .. \$11.98/\$11.69	1.025
Repair labor	Mine labor .. \$11.98/\$11.69	1.025

Updated costs per LCY:

Equipment parts	$1.005 \times \$0.048 =$	\$0.048
Fuel and lubrication	$0.991 \times \$0.054 =$.054
Operator labor	$1.025 \times \$0.081 =$.083
Repair labor	$1.025 \times \$0.013 =$.013
July 1985 total cost per LCY		<u>.198</u>

SITE ADJUSTMENT FACTORS

As stated earlier, adjustment factors determine the precision for cost estimates and must be used carefully. Several factors are provided for each curve, and their use

will significantly alter the calculated cost. The following example illustrates factor use.

Example Adjustment Factor Application

Calculate the cost of extracting pay gravel in a hard digging situation and moving it 800 ft up an 8% gradient using bulldozers. Assume a 200-LCY/h operation (January 1985 dollars), and use the operating cost and adjustment factor equations provided in the operating costs—mining-bulldozers portion of section 2.

Operating costs per LCY
(from section 2):

Equipment operating cost	$0.993(200)^{-0.430} =$	\$0.102
Labor operating cost	$14.01(200)^{-0.945} =$.094
January 1985 total		<u>.196</u>

Factors (from section 2):

Distance	$F_D = 0.00581(800)^{0.904} =$	2.447
Gradient	$F_G = 1.041e^{[0.015(8.0)]} =$	1.174
Digging difficulty		1.670
Used equipment:		
Equipment	$U_e = 1.206(200)^{-0.013} =$	1.126
Labor	$U_l = 0.967(200)^{0.015} =$	1.047

Factored cost per LCY:
From total cost equation
for bulldozers:

$[\$0.102(1.126) + \$0.094(1.047)] \times 2.447 \times 1.174 \times 1.670 =$

January 1985 total cost per LCY \$1.023

The 500% increase in operating cost, from \$0.196 to \$1.023 per loose cubic yard, demonstrates the dramatic effect of using the proper factors. If a cost category contains a factor not applicable to the deposit in question, then simply leave that factor out of the total cost equation.

The variables inserted in the factor equations are generally self-evident. An exception to this is the digging difficulty factor. Parameters for this factor are based on the following:

1. Easy digging.—Unpacked earth, sand, and gravel.
2. Medium digging.—Packed earth, sand, and gravel, dry clay, and soil with less than 25% rock content.
3. Medium to hard digging.—Hard packed soil, soil with up to 50% rock content, and gravel with cobbles.
4. Hard digging.—Soil with up to 75% rock content, gravel with boulders, and cemented gravels.

It can be seen from these parameters that many deposits will fall into one of the last two categories. Digging difficulty has a dramatic effect on the cost of extraction, so these factors must be chosen carefully.

Bulldozer and backhoe curves both contain a digging difficulty factor. Other excavation equipment, such as draglines, scrapers, and front-end loaders, are generally suited for special digging conditions and are not used in harder ground. Consequently, no digging difficulty factor is provided for these.

Table 4.—Cost date indexes¹

	Mining labor ²	Equipment and repair parts	Fuel and lubrication	Electricity	Tires	Bits and steel	Explosives	Timber	Construction material ³	Industrial material
1960 ...	\$2.61	85.8	95.5	100.1	113.1	97.1	94.5	92.1	99	95.3
1961 ...	2.64	87.3	97.2	100.7	109.9	97.2	97.0	87.4	97	94.8
1962 ...	2.70	87.5	96.1	101.9	94.7	95.8	97.0	89.0	96	94.8
1963 ...	2.75	89.0	95.1	101.1	96.9	95.7	100.4	91.2	98	94.7
1964 ...	2.81	91.2	90.7	100.3	97.6	97.0	100.0	92.9	98	95.2
1965 ...	2.92	93.6	92.8	100.3	98.8	97.9	99.6	94.0	97	96.4
1966 ...	3.05	96.5	97.4	99.8	101.3	98.7	98.1	100.1	99	98.5
1967 ...	3.19	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	100.0
1968 ...	3.35	105.7	98.1	100.9	102.7	101.9	102.3	117.4	127	102.5
1969 ...	3.61	110.4	99.6	102.2	98.3	107.0	104.7	131.6	108	106.0
1970 ...	3.85	115.9	101.0	106.6	105.4	115.1	106.7	113.7	109	110.0
1971 ...	4.06	121.4	106.8	115.5	110.3	121.8	113.3	135.5	133	114.0
1972 ...	4.41	125.7	108.9	123.9	111.3	128.4	115.2	159.4	151	117.9
1973 ...	4.73	130.7	128.6	132.6	115.7	136.2	120.1	205.2	154	125.9
1974 ...	5.21	152.3	223.4	172.3	141.6	178.6	150.0	207.1	167	153.8
1975 ...	5.90	185.2	257.5	209.7	155.4	200.9	178.0	192.5	186.3	171.5
1976 ...	6.42	198.9	276.6	226.7	172.8	215.9	187.2	233.0	205.5	182.4
1977 ...	6.88	213.7	308.1	257.0	181.5	230.3	193.1	276.5	237.7	195.1
1978 ...	7.67	232.8	321.0	279.5	192.0	253.5	208.7	322.1	247.7	209.4
1979 ...	8.50	256.2	444.8	305.3	219.6	283.5	225.6	354.3	269.28	236.5
1980 ⁴ ..	8.70	275.4	582.4	334.8	236.9	297.3	237.1	336.3	280.86	260.3
1980 ⁵ ..	9.08	290.9	693.3	376.0	250.4	300.4	254.4	327.3	289.05	275.6
1981 ⁴ ..	9.78	304.9	736.0	393.9	256.2	322.8	268.5	331.6	298.25	289.9
1981 ⁵ ..	10.07	324.0	818.4	429.9	289.6	338.7	292.8	330.1	312.11	306.0
1982 ⁴ ..	10.58	337.0	802.9	454.0	271.6	343.1	293.2	310.6	324.74	311.7
1982 ⁵ ..	10.91	346.1	777.1	471.5	272.6	337.4	294.8	319.2	330.56	313.0
1983 ⁴ ..	11.10	348.6	727.1	482.6	285.4	333.2	300.4	324.2	342.01	314.0
1983 ⁵ ..	11.31	352.7	694.9	492.2	256.6	341.3	302.8	372.5	357.28	316.6
1984 ⁴ ..	11.56	354.3	669.7	492.0	258.0	354.1	301.3	353.2	355.52	319.2
1984 ⁵ ..	11.62	358.2	674.6	525.5	256.3	357.2	312.4	343.3	357.90	324.0
1985 ⁶ ..	11.69	360.4	636.2	524.9	262.0	357.4	313.4	343.2	358.32	323.2
1985 ⁵ ..	11.98	362.3	630.7	540.3	246.0	354.6	312.1	354.9	363.63	324.3

¹ Unless otherwise noted, based on U.S. Bureau of Labor Statistics (BLS) "Producer Price Indexes," base year 1967 = 100.

² Based on BLS "Employment and Earnings: Average Hourly Earnings, Mining."

³ Based on Engineering and News Record "Market Trends: Building Cost."

⁴ January.

⁵ July.

⁶ January (base cost year for this report).

LABOR RATES

The cost of labor in placer mining is highly variable and cannot be precisely estimated in every case. For the purposes of this report, only two separate labor rates are used: \$15.69/h for mining functions, and \$15.60/h for milling. These rates apply to operation, maintenance, installation, and construction labor. The labor portions of each specific cost category are broken out and in this way can be adjusted to the estimator's particular labor rate. To accomplish this, multiply the labor cost for each category by the ratio of desired labor rate to mining or milling labor rate (\$15.69/h or \$15.60/h). The following example illustrates this adjustment.

Example Labor Rate Adjustment

Calculate the cost of extracting and moving pay gravel 300 ft over level terrain using bulldozers with an operator labor cost of \$18.00/h. Assume a 200-LCY/h operation (January 1985 dollars), and use the operating cost equations provided in the operating costs—mining-bulldozers portion of section 2.

Operating costs per LCY

(from section 2):

Equipment operating cost	0.993(200) ^{-0.430}	= \$0.102
Labor operating cost	14.01(200) ^{-0.945}	= .094
January 1985 total		<u>.196</u>

Labor adjustment:

Labor operating cost per LCY	(\$18.00/\$15.69) × \$0.094	= .108
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Adjusted cost per LCY:

Equipment operating cost	.102
Labor operating cost	<u>.108</u>
January 1985 total cost per LCY	<u>.210</u>

Labor rates are based on wage scales for the western United States (including Alaska) and include a 24% burden. This burden consists of 9.8% workers compensation insurance, 7.0% Social Security tax, 3.7% State unemployment insurance, and 3.5% Federal unemployment tax. If other costs such as health and retirement benefits are to be included, they must be added to an estimated labor rate.

To familiarize the reader with the use of this cost estimating system, an example of a complete cost estimate is included in the appendix.

FINANCIAL ANALYSIS

The purpose of this report is to provide an estimate of capital and operating costs for small placer mines. A distinction must be made between a cost estimate and an economic feasibility analysis. Capital and operating costs are simply two separate variables in a complete economic analysis. To determine the economic feasibility of an operation, the evaluator must consider each of the following:

1. Recoverable value of commodity.
2. Local, State, and Federal taxes.
3. Capital depreciation.
4. Depletion allowances.
5. Desired return on investment.
6. Costs and methods of project financing.
7. Inflation.
8. Escalation.
9. Environmental intangibles.

Economic feasibility analysis is a subject in itself, and will not be covered here. The preceding list is included to emphasize the following: *A prospect is not economically feasible simply because the apparent commodity value exceeds the total capital and accrued operating costs calculated from this manual.*

The costs associated with the preceding list are real and must be considered when determining the feasibility of a prospect. Any attempt to provide guidelines for determination of feasibility based solely on estimates of capital and

operating costs would be highly misleading. There is no quick and easy way to account for the wide variety of situations encountered in economic analysis. Each one of the preceding items must be examined individually to provide accurate economic feasibility estimates, and a complete cash-flow analysis is the only way to ensure that proper results are obtained. To accomplish this, *all* yearly income and expenses must be tabulated. Then the rate of return over time must be calculated from the resultant profits or losses. The evaluator must consider all factors influencing income and include all expenses as well as account for the value of money over time and choose an acceptable rate of return.

In brief, the operator will have to receive adequate revenues from commodities recovered to

1. Cover all operating expenses.
2. Recover initial equipment expenditures.
3. Provide for equipment replacement.
4. Cover all exploration and development costs.
5. Pay taxes.
6. Compensate for inflation and cost escalation.
7. Supply a reasonable profit.

Only when enough revenue is produced to cover all of the above can an operation be considered economically feasible.

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