Estimated Water Requirements for Gold Heap-Leach Operations

By Donald I. Bleiwas

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Front cover: Aerial photograph of the Round Mountain gold operation in Round Mountain, Nevada, looking towards the south. Note the waste rock storage in the lower one-half of the photograph. The expandable and reusable heap-leach pads (which appear as rows of rock) are to the upper right and right of the open pit. Photograph courtesy of Round Mountain Gold Corp., used with permission.

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square meter (m^2)	10.76	square foot (ft^2)
	Volume	
liter (L)	0.2642	gallon (gal)
	Flow rate	
meter per hour (m/hr)	3.281	foot per hour (ft/hr)
meter per year (m/yr)	3.281	foot per year (ft/yr)
liter per minute (L/min)	0.2642	gallon per minute (gal/min)
liter per hour (L/h)	0.2642	gallon per hour (gal/h)
liter per month (L/mo)	0.2642	gallon per month (gal/mo)
millimeter per day (mm/d)	0.03937	inch per day (in/d)
liter per square meter per hour ($L/m^2/h$)	2.592	gallon per square yard per hour ($gal/yd^2/h$)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
megagram (Mg); metric ton (t)	1.102	ton, short (2,000 lb)
metric ton per year	1.102	ton per year (ton/yr)
gram per metric ton (g/t)	0.0292	troy ounce per short ton

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Introduction

This report provides a perspective on the amount of water necessary for conventional gold heap-leach operations. Water is required for drilling and dust suppression during mining, for agglomeration and as leachate during ore processing, to support the workforce (requires water in potable form and for sanitation), for minesite reclamation, and to compensate for water lost to evaporation and leakage. Maintaining an adequate water balance is especially critical in areas where surface and groundwater are difficult to acquire because of unfavorable climatic conditions [arid conditions and (or) a high evaporation rate]; where there is competition with other uses, such as for agriculture, industry, and use by municipalities; and where compliance with regulatory requirements may restrict water usage.

Estimating the water consumption of heap-leach operations requires an understanding of the heap-leach process itself. The task is fairly complex because, although they all share some common features, each gold heap-leach operation is unique. Also, estimating the water consumption requires a synthesis of several fields of science, including chemistry, ecology and environmental economics, geology, hydrology, and meteorology.

The Heap-Leach Process

Briefly stated, gold heap leaching is a hydrometallurgical process designed to treat amenable low-grade gold ores that contain roughly 0.5 gram per metric ton (g/t) gold to 1.5 g/t gold (Marsden and House, 2006; Wong Wai Leong and Mujumdar, 2010). The ore is stacked by various types of equipment on an impermeable barrier, and a water-based solution, or leachate [most often containing sodium cyanide (NaCN)], is applied to the surface of the stacked ore. Gold, silver, and other materials contained in the ore are dissolved to various degrees by the leachate as it percolates downward through the stack of ore and are collected at the bottom of the heap. The cyanoaurite ion is produced when gold is exposed to the cyanide solution (Australian Department of Health and Ageing, 2010). The pregnant solution, or metal-bearing leachate that contains the precious metals, is directed to facilities where the metals are extracted, and barren solution is then reapplied to the top of the stack. Overall, gold recovery using heap leaching generally ranges from about 50 to 90 percent, although this percentage depends on many variables (Kappes, 2002; Marsden and House, 2006). Figure 1 is a simplified flow diagram of the gold heap-leach process.

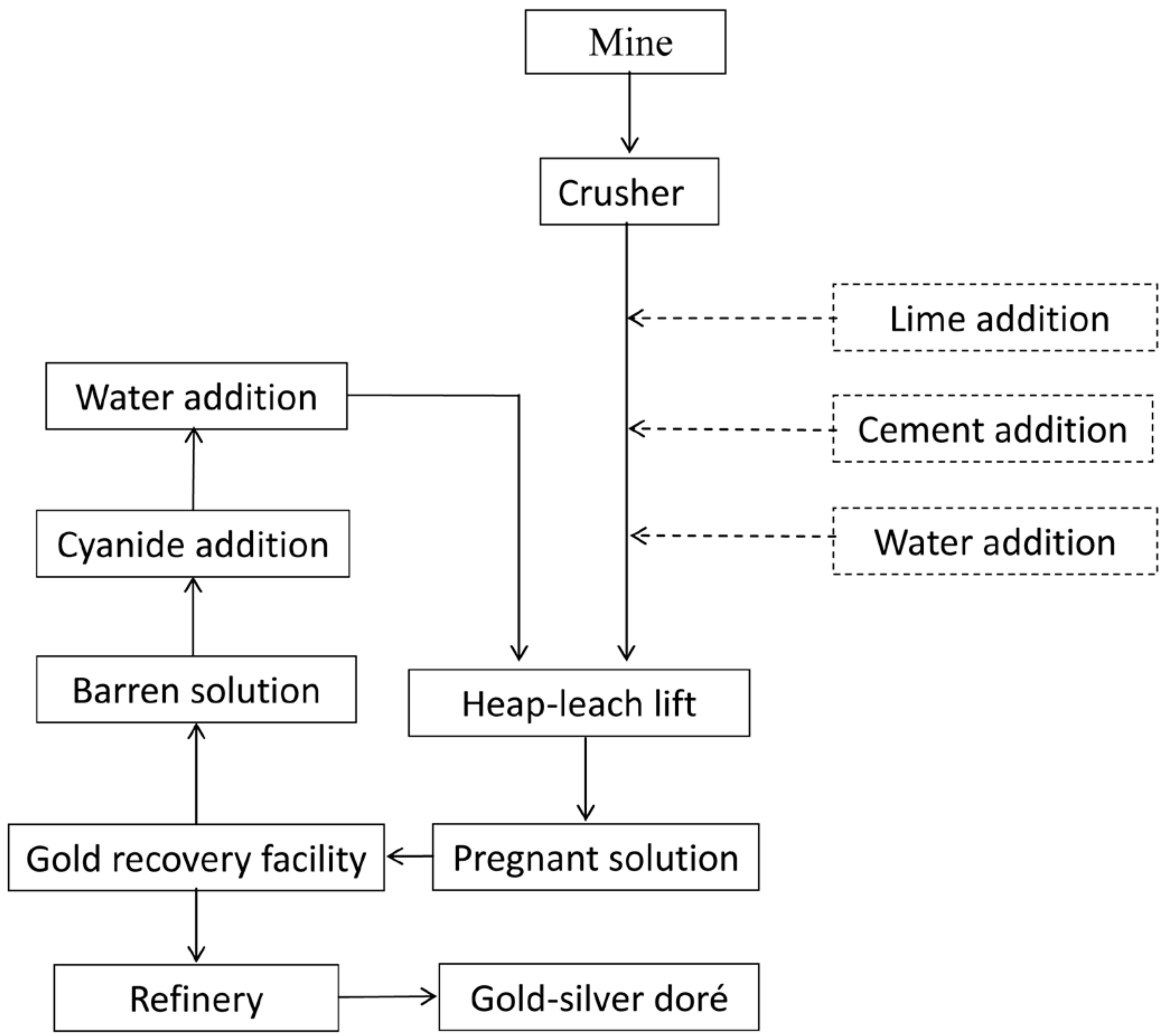

Figure 1. Generalized flow of a gold heap-leach operation. Dashed lines represent additions, if necessary. Some operations use run-of-mine ore.

Ore Preparation and Placement

Oxidized ores, which are usually extracted during surface mining, are the most common type of ore leached and are the most amenable to heap-leach methods, although gold ores that contain up to a few percent sulfide, usually as pyrite, can also be treated by the process. Ores with relatively high sulfide content and carbonaceous ores usually require pretreatment prior to leaching to achieve acceptable gold recoveries (Marsden and House, 2006). Other metals contained in the ores, such as cobalt, copper, and zinc, are also dissolved by cyanide and adversely affect overall gold recovery.

Following extraction of the ore, the ore is either delivered to a crusher and reduced to a specific size before placement on the leach pad or hauled directly from the mine to the leach pads. Because leaching is most effective at a pH ranging from about 9 to 12, lime may be added to the ore to adjust the pH level prior to placement on the heap.

Agglomeration may be required if the ore is accompanied with significant amounts of clays, fines, and other materials. If not agglomerated, the fine-grained materials can prevent the efficient flow of solution through the leach pile by occupying interstices between ore fragments that can result in internal ponding and (or) channeling of solution in the stack. When this occurs, there is limited interaction between the leachate and ore, which results in reduced gold recovery. A common method for agglomerating ore is by adding approximately 2 to 5 kilograms (kg) of portland cement per metric ton of ore on a dry weight basis and tumbling the mixture to produce permeable agglomerates that incorporate the fines. From 5 to 35 liters (L) of water or strong cyanide solution per metric ton of ore may be added to the mix of ore and cement if the moisture content of the ore is below 8 percent (McClelland, Pool, and Eisele, 1983; Hoye, 1987; Randol International Ltd., 1992, p. A-699, 5,750, 5,796; Bouffard, 2005). The agglomerated feed must set for a period of roughly 8 hours before being placed on the heap (McClelland, Pool, and Eisele, 1983).

Ore is placed on a pad or previously leached lift by various means, including ramp conveyor belts, radial-arm and self-leveling stackers, and trucks. The ore is then graded and ripped or scarified (roughened up) with wheeled or tracked equipment to produce shallow cuts so as to increase surface area exposure to the leachate.

Ore Leaching Process

Gold recovery using the heap-leach method is based on the process of applying a leachate that usually contains about 100 to 600 parts per million (ppm) (0.01 to 0.06 percent) NaCN in a water-based solution to a large pile of crushed or run-of-mine rock and, occasionally, mill tailings (Hoye, 1987; van Zyl and others, 1988; Kappes, 2002; Thiel and Smith, 2003). NaCN consumption ranges from about 0.1 to 1 kg for each metric ton of ore placed on the stack. Depending on the individual site characteristics, relatively small amounts of other materials may be added to the solution, but water is the critical medium for the movement of the reagents and metals through the entire system.

Leachate is applied to the stack by several methods. Drip systems (the most common method) employ a network of plastic pipes placed on the surface or buried to a depth below frost level to prevent freezing. Sprinklers and wobblers (a modified sprinkler) are also used. Some operations employ several methods in combination. Typical solution application rates of barren and under-saturated leachate were reported to range from 7.2 liters per square meter per hour ($L/m^2/h$) to 10.8 $L/m^2/h$ (van Zyl and others, 1988). Based on a survey of 19 heap-leach operations that treated crushed ore, application rates ranged from about 7 to 20 $L/m^2/h$ and averaged 11 $L/m^2/h$. In a survey of 17 heap-leach operations that treated run-of-mine ores (ores placed on the heap directly from the mine), the average was 8.3 $L/m^2/h$ (Kappes, 2002). The amount and rate of leachate application at a particular site must account for a number of variables, including the design of the heap, the climate, the ore chemistry and physical characteristics (which include the initial moisture content), the rate at which the ore is added, the site topography, and the efficiency of the equipment, such as pumps and solution dispersal equipment used to apply the leachate. The solution storage capacity internal to the heap—roughly 10 to 20 percent, by weight, of the active heap—must be exceeded before any solution flows out the bottom of the stack of ore (Hoye, 1987). In ores that contain less moisture (usually a moisture content that ranges from about 5 to 10 percent), the solution must continue to be applied until the moisture content reaches 10 to 20 percent, by weight, of the active heap before efficient flow through the stack is attained (Hoye, 1987; Larry Newcomer, Vice President, Cripple Creek & Victor Gold Mining Co., oral commun., February 1, 2012).

The leachate mobilizes the gold and silver from the ore into the solution, which drains downward through the stack of ore until it contacts the impermeable membrane, or lining, at the base of the heap. All heap-leach operations are lined so as to contain the leach solutions for optimum recovery and to prevent leakage to the environment. Virtually all gold heap-leach facilities are designed to operate on a zero discharge basis. The solution is collected in a series of perforated pipes and pumped or drained to a holding pond from which the solution is withdrawn as needed or is sent directly to facilities for the recovery of the precious metals. It is not unusual for undersaturated leachate to be returned to the top of the heap for reapplication until its precious metal content is sufficiently high to send to the recovery plants (Larry Newcomer, Vice President, Cripple Creek & Victor Gold Mining Co., oral commun., February, 1, 2012; Gordon Nixon, Metallurgical Engineer, oral commun., March 7, 2012). Some operations, such as the Yanacocha Mine in Peru, use intermediate ponds to hold the solution, which can then be directed back to the heap (Chadwick, 2011).

A leaching cycle may range from 45 to more than 100 days, during which time the solution continues to be placed on top of the heap. At the end of the leaching cycle, additional ore is either placed on top to form another lift or the depleted ore is removed from the pad and replaced with fresh ore [U.S Environmental Protection Agency, Office of Solid Waste, 1994; Rosemount Analytical Inc., 2008; Telesto Nevada Inc., 2011; Barrick Gold Corp., 2012; Kubach, 2012(?)]. Figure 1 shows the flow of gold recovery from ores for a heap-leach facility.

Gold and Silver Recovery

The two most common methods to recover gold and accompanying silver from pregnant solution are (1) carbon adsorption followed by desorption and recovery by electrowinning, and smelting to produce doré, and (2) the Merrill-Crow method, by which precious metals are recovered by zinc precipitation followed by smelting of the precipitate to produce doré. These methods are discussed in greater detail in van Zyl and others (1988), Kappes (2002), and Kappes, Cassiday & Associates (2012). Overall gold recovery using heap leaching is dependent on many variables and generally ranges from about 50 to 90 percent (Kappes, 2002; Marsden and House, 2006).

Stack Rinsing

At some facilities, following the leaching cycle, depleted ore is thoroughly rinsed with water or water-based solutions containing chemicals to aid in the oxidation of residual cyanide or removal of residual cyanide. The process may be performed during the decommissioning stage of an operation and is usually performed at the end of the leaching cycle for ore placed on reusable leach pads. The time required to rinse a heap depends on the tonnage treated, the amount and strength of the cyanide solution remaining in the heap, the rate of application of rinse water, and other variables. Following 50 days of leaching and one day of draining, a 15,000-metric-ton (t) heap of leached ore on a reusable pad may require 2 to 3 days of rinsing at a rate of about 610,000 liters per hour (L/h) of water solution (Hoye, 1987). It was estimated that approximately 1.8 million L/h of water solution over a period of roughly 200 days will be needed to treat about 150 million metric tons (Mt) of ore in the Walter Creek large valley-fill heap at Fort Knox, Alaska, when the operation is decommissioned (U.S Environmental Protection Agency, Office of Solid Waste, 1994; Fairbanks Gold Mining, Inc., 2006).

Rinse solutions are usually applied by the same methods used to apply leachate and at about the same rate of application. The evaporative losses, therefore, are similar. The annual requirements for makeup water for this process are not addressed in this report because of the great variation in the amounts of water and time required to detoxify a heap.

Heap-Leach Designs

Gold heap-leach designs are generally subdivided into three major types: valley-fill leach; permanent expanding heap; and reusable pad. A generalized description of these three major types of heap-leach methods are presented below and are illustrated in figures 2 and 3. Papers by van Zyl and others (1988), Randol International Ltd. (1992), and Kappes (2002) discuss the major types of heap-leach designs and associated technologies in detail.

Figure 2. (A) Expanding heap-leach operation with multiple lifts. (B) Valley-fill heap-leach operation. Note the impoundment dam in lower portion of the image. Photographs courtesy of R. Thiel, P.E., and M. Smith, P.E.; used with permission.

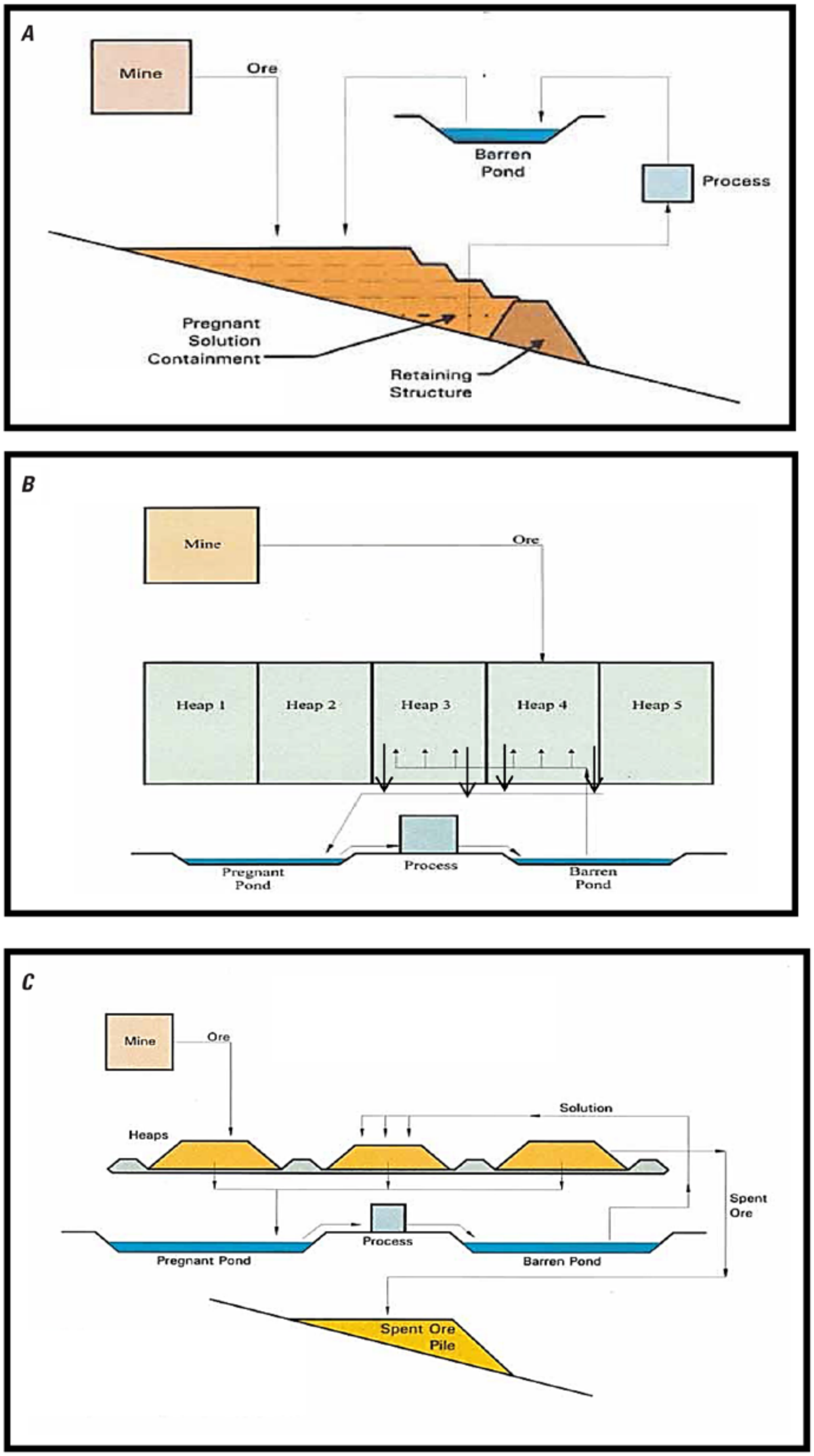

Figure 3. Generalized flow diagrams of the three major types of gold heap-leach methods: (A) Valley-fill leach; (B) Expandable leach pad; and (C) Reusable leach pad. Images courtesy of Golder Associates Inc.; used with permission.

Valley-Fill Leach Design

The valley-fill leach or valley leach design takes advantage of the topography of a site by occupying natural valleys—either a dam is built at the bottom of the valley or a valley is leveled with fill. A few valley-fill operations, such as the one operated by the Cripple Creek & Victor Gold Mining Co. in Cripple Creek, Colorado, have reached or exceeded thicknesses of roughly 200 meters (m) (Thiel and Smith, 2003; Larry Newcomer, Vice President, Cripple Creek & Victor Gold Mining Co., oral commun., February, 1, 2012). Most valley-fill operations are designed to store pregnant solutions internally (inside the heap); the solutions flow from the base of the heap directly to a precious metals recovery plant. Internal storage of the solution serves to minimize losses from evaporation and saves the added cost of constructing and monitoring external ponds. After the barren solution is passed through the recovery facility, adjustments are made to the solution's cyanide concentration and pH, and makeup water is added; at most valley-fill operations, the barren solution is then placed directly back on top of the heap. Some valley-fill operations store barren solution in ponds from which the solution is later withdrawn, treated, and applied to the surface of the heap. These operations tend to require more makeup water because of evaporative losses (Thiel and Smith, 2003).

Expandable Leach Pad Method

The expandable leach pad method, which is the most common type of heap-leach design, entails the placement of ore on a pad followed by loading and subsequent leaching, with successive layers of ore added on top. The process is repeated as long as the supply of ore, space, and relatively flat topography permits lateral expansion of the pads to continue. Some expandable pad operations contain heaps of ore that are more than 150-m thick (Thiel and Smith, 2003). The pregnant solution that drains through the stack of ore is captured at the bottom of the stack, conveyed by pump or gravity to a pond for storage, and subsequently withdrawn for the recovery of the precious metals. In some cases, solutions may be stored in tanks or sent directly to the gold recovery facility (James Bosch, Process Control Engineer, Barrick Cortez Mines, oral commun., February 22, 2012).

The storage capacity of ponds for all types of leaching operations is designed to contain the solution required for the operation and to account for climatic conditions, such as high evaporation rates and sudden inflow that results from storm events, power outages that cause pump failure, and other events that might shut down the operation. A heap-leach facility can have several ponds for storing pregnant solution, barren solution, and overflow. Most operations have the ability to contain the inflow caused by a 100-year 24-hour storm event. Following the recovery of metals, the barren solution is usually pumped to and stored in ponds for eventual chemical adjustment and placement back onto the heap.

For a perspective on the volume of ponds, a proposed expandable heap-leach operation that would leach approximately 2.7 million metric tons per year (Mt/yr) in Nevada is anticipated to require about 14 million L of storage capacity for pregnant solution and 55 million L of storage capacity for barren solution. About 80 percent of the barren solution pond storage would be designed to accommodate inflow from storm events [SRK Consulting (U.S.), Inc., 2012].

Reusable Leach Pad Method

Reusable leach pads are designed to have a substantial impermeable pad on which ore is placed and leached. When the ore is depleted, it is usually rinsed, neutralized, and placed in a waste ore pile to make room for the next load of ore, and the process is repeated. Reusable pads, which are also referred to as on/off leach operations, are most commonly used in areas that have limited space for leaching but available space for depositing waste; these operations are relatively short-lived (van Zyl and others, 1988). Ore is usually piled on the pad to a thickness of approximately 10 m (Thiel and Smith, 2003). The appearance of the stack is similar to a single lift, and the process used to apply the barren solution and the methods for collecting and processing the pregnant solution are similar to those described for expandable heap-leach pads.

Ore Capacity and Production of Gold Heap-Leach Operations

Kappes (2002) considered a small "basic" heap-leach operation as one that mines approximately 1 Mt/yr. In a sample of approximately 27 heap-leach operations, the average ore leaching capacity was about 6 Mt/yr (Kappes, 2002). The Cripple Creek & Victor Gold Mining Co.'s valley-fill gold heap-leach operation in Colorado, which is one of the world's largest valley-fill operations, leaches approximately 21 Mt/yr of ore. The Round Mountain operation in Nevada, which is one of the world's largest reusable and expandable heap-leach pad operations, places about 55 Mt/yr of ore on the facility's heap-leach pads. Peru's Yanacocha Mine complex, which is also among the largest gold operations in the world, contains six open pit mines, four areas for leaching, and four precious metals recovery plants; the combined operation processes about 600,000 metric tons per day of ore, or about 219 Mt/yr (Golder Associates Inc., 2008; InfoMine, Inc., 2012).

Estimated Annual Water Requirements

The major use categories considered for the estimation of annual water use and makeup requirements at heap-leach operations can be broadly separated into the following six major categories: (1) water for ore preparation, leachate (pregnant and barren solution), and stack rinsing, if required; (2) water for dust suppression; (3) water for exploration and development drilling at the mine and for environmental testing, planning for leach pad placement, and design; (4) potable water and water for sanitation (a low consumptive use that ranges from roughly 230 to 760 liters per employee per day); (5) water for re-vegetation (highly variable owing to such factors as area, climate, and regulatory requirements); and (6) solution lost through punctures in linings or breaches of barriers (considered minor, barring catastrophic events). The water requirements for leaching and dust suppression are generally the largest consumers of water during heap leaching and are discussed below.

Evaporative Losses of Water from Heaps and Storage Ponds

The requirement for water-based solutions used in a gold heap-leach operation depends primarily on such factors as the method used to apply leachate, the surface area to be leached, and the thickness of the lift; the character of the ore, including its absorbency and the amount of fines that accompany the ore; climate; and the initial ore moisture when the ore is placed on the stack. Makeup water requirements compensate for evaporative losses that occur during application of leachate on top of the stack, losses from air passing through voids in the heap, and losses caused by evaporation from barren and pregnant solution ponds. Pond evaporation can range from 5 to 13 millimeters per day (Kappes, 2002). A relatively minor amount of solution is also absorbed by the ore (Hoye, 1987). Most valley-fill leach operations with internal pregnant solution ponds and direct placement of the solution onto the stack are less vulnerable to these types of losses. Also some heap-leach operations are located in areas where there is a positive average annual water balance on a regular basis because of low evaporation rates and high rates of precipitation, but these locations are the exception.

It has been estimated that with a typical heap application rate of 10 $L/m^2/h$, incident solar radiation could account for an evaporation rate of 2 to 5 percent of applied solution when sprinklers are used and somewhat less (1 to 4 percent) when drip irrigation is used (Kappes, 2002). The numbers of operations that use sprinklers have decreased whereas the numbers of operations that use drip irrigation have increased over the past two decades. In extreme high-heat and low-humidity situations, the use of sprinklers rather than drip emitters may result in the loss of up to 30 percent of the solution that is pumped. This is because the droplets generated by the sprinkler mechanism trace an arc through a zone of air, which is very seldom saturated at 100 percent humidity, and even a light wind displaces any humidity built up over the stack (Kappes, 2002). Wind can also blow spray to the flanks or completely off of the stack and contributes to solution loss (van Zyl and others, 1988). The makeup water requirement as a result of evaporation at expansion-type heap-leach operations that use coarse-drop sprinklers in Nevada-type climates (arid and temperate) was estimated to be as high as 15 to 20 percent of solution pumped on summer days to a low of 2 to 4 percent on summer nights, and averages about 7 to 10 percent annually. The typical solution application rate is 10 $L/m^2/h$, or 88 meters per year (m/yr). Evaporative loss of 7 percent is equal to 6.2 m/yr of solution on the areas being sprinkled (Kappes, 2002). A "typical" heap-leach gold operation can lose an estimated 2,700 to 3,600 liters per hour per hectare (2.7 to 3.6 L/m^2) on top of the heap as a result of evaporative losses (Hoye, 1987).

The Rain (a past producer) and Florida Canyon facilities and the proposed Mount Hamilton operation in Nevada are examples of sites that have reported or estimated makeup water requirements. At these sites, the water makeup requirements during the hottest part of summer months exceed 2,300 liters per minute (L/min) and in the cooler months average about 150 to 400 L/min [Randol International Ltd., 1992; U.S Environmental Protection Agency, Office of Solid Waste, 1992; SRK Consulting (U.S.), Inc., 2012]. These sites used or plan to use drip emitters for applying most or all of the solution on the heap. A facility with an annual average makeup water requirement of 700 L/min (9 months at 275 L/min and 3 months at 2,000 L/min) that leaches 365 days per year would require approximately 370 million L of makeup water for its leaching operations annually. Nearly all of the water losses would be the result of evaporation from the ponds and from the surface of the heap.

In tropical climates, noticeable losses occur even during the rainy season. For several tropical heap-leach projects where rainfall is seasonal and total rainfall reaches up to 2.5 m/yr, overall annual evaporative loss from all sources, when using wobbler-type sprinklers operated 24 hours per day, is about 7 percent of the solution pumped (Kappes, 2002).

In summary, evaporative losses and to a much lesser extent absorbance of solution by ore are chiefly responsible for makeup water requirements at a heap-leach operation and can range from about 5 percent to as much as 20 percent of total annual water requirements (James Bosch, Process Control Engineer, Barrick Cortez Mines, oral commun., February 22, 2012; Gordon Nixon, Metallurgical Engineer, oral commun., March 7, 2012).

Tables 1 and 2 show simplified estimates of annual water requirements use and makeup water requirements for 10-m-thick heaps at different annual capacities, leachate application rates of 5 and 10 $L/m^2/h$, and estimated average annual water makeup requirements of 5, 12, and 20 percent. Estimates for 5 percent makeup requirements would apply towards most valley-fill leach operations with internal ponds, whereas higher makeup water percentages would apply to heap-leach operations with evaporative losses from the heap and from pregnant and barren solution ponds.

Dust Suppression

Although water is used in solutions and foams for dust suppression during handling and milling and on stockpiled ore if fines are windswept, generally the single largest amount of water for this purpose is used on haulage roads. The amount of water or water-based solutions sprayed on roads varies significantly from operation to operation and is dependent on factors such as the nature of the ore, the climate (temperature, humidity, precipitation, and wind), the level of traffic, the types of equipment in use, the road base material, the length and width of roads, the safety standards, the environmental regulations, and whether the operation uses water or water-based solution containing chemicals, such as magnesium chloride. The U.S Environmental Protection Agency reported several test results that examined the effectiveness of applying water to haulage roads to suppress dust. The results ranged from a control efficiency of 74 percent for total suspended products (TSP) for the 3 to 4 hours following the application of water at a rate of 2.08 L/m^2 to a control efficiency of 95 percent for TSP for 0.5 hours after the application of water at a rate of 0.59 L/m^2 (Reed and Organiscak, 2007).

It has been estimated that a typical haulage road may require 1 to 2 L/m^2/h on a summer day. Approximately 600,000 L would be required on a daily basis for each kilometer (km) of haulage road when applying this estimate to a 24-hour-per-day operation and a haulage road width of 25 m in order to accommodate trucks in the 120-t range. For haulage trucks in the 250-t range—a popular size used at large mining operations—about 20 percent more water would be required to suppress the dust (Tannant and Regensburg, 2001; Hanson, 2006). Although haulage road length is highly variable, it would not be unusual for haulage roads used for transporting ore and waste to be 20 km in length. Additional water is required for turnouts, parking areas, and other places where dust is generated.

Few actual examples of water consumption for road-dust control are available in the literature, but for perspective, the Cripple Creek & Victor Gold Mining Co.'s valley-fill gold heap-leach operation in Colorado requires the application of approximately 80,000 L/h of water for dust control on haulage roads and other areas, and the Coeur Rochester gold heap-leach operation in Nevada used roughly 57 to 72 million liters per month for dust control in the 1990s (Randol International Ltd., 1992; Larry Newcomer, Vice President, Cripple Creek & Victor Gold Mining Co., oral commun., February 1, 2012). One operating gold mine was using approximately 6 million liters of water per kilometer of haulage road every month but was able to achieve a 90 percent reduction through the application of a recently developed dust control treatment (GE Power and Water, 2011).

An iron-mining operation with an unsealed haulage road in a dry region in Pilbara, Western Australia, required about 4 L/m^2 each day to suppress the dust effectively (Mills, 2010). Applying this estimate and a haulage road width of 25 m to accommodate trucks in the 120-t range, approximately 100,000 liters of water per kilometer of haulage road would be required on a daily basis. For haulage trucks in the 250-t range, about 20 percent more water would be required to suppress the dust (Tannant and Regensburg, 2001).

Based on limited data, the amount of water required for dust suppression can vary substantially from operation to operation based on such uncontrollable natural factors as climate and on mine capacity and types of equipment. The amount can be reduced, however, through careful management and from the application of specially developed water-based dust suppressants.

Summary

Gold heap-leach operations are considered a low-water-use method of recovering gold when compared with conventional flotation methods (Kappes, 2002). Operations that rely on flotation need to contend with water losses from evaporation and from water entrapped in the pore spaces of tailings, which are not easily recovered, and the need to keep tailings below water or wet to prevent oxidation and dispersal by wind.

Gold heap-leach operations are most effective in temperate to semiarid locations where evaporation rates are relatively low, solutions are not diluted by precipitation or do not cause flooding problems, and temperatures remain above freezing for much of the year. The availability of water and gaining access to it can be problematic in arid regions, especially when there is a high requirement for makeup water.

A water-based solution (usually one that contains sodium cyanide) for leaching the gold from the ore and water for dust suppression are the primary uses of water at a gold heap-leach operation. The examples and estimates in this report are intended to provide a perspective for modeling water requirements for gold heap-leach operations of different capacities and application and evaporation rates.

A typical operation utilizes a leach pad surface area of 60,000 m^2 under constant leach with 10-m lifts for every million metric tons of mine ore capacity. Estimated leachate application rates range from 5 to 10 $L/m^2/h$, which results in an average annual leach water requirement of roughly 44,000 to 88,000 $L/m^2/yr$ for one full year of operations. Estimates of makeup water to replace that lost by evaporation add an additional 5 to 20 percent to the leachate requirements. An average heap-leach mine with a capacity of 5 Mt/yr is estimated to require approximately 15 to 30 billion liters per year (L/yr) for one full year operation, plus makeup water requirements that may range from about 1 billion to 6 billion L/yr.

Haulage road lengths are highly variable, but a typical haulage road network of 20 km could require several billion liters of unrecoverable water for one full year of dust suppression. Water requirements are determined by numerous factors, and water-based solutions, such as those that contain magnesium chloride, can significantly decrease water requirements for dust suppression.

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Table 1. Estimated process water and makeup water requirements for modeled gold heap-leach operations at selected annual capacities with an application rate of 5 liters per square meter per hour. All estimates are rounded to two significant figures.

[L/m^2/h, liters per square meter per hour]

Annual ore placed on heaps (metric tons per year with constant rate of replacement)[1]	Square meters of surface area under constant leach with 10-meter lifts	Volume of leachate applied at rate of 5 L/m^2/h	Volume of leachate applied in 1 year (billion liters)[2]	Annual makeup water requirement at 5 percent of applied solution (billion liters)[2]	Annual makeup water requirement at 12 percent of applied solution (billion liters)[2]	Annual makeup water requirement at 20 percent of applied solution (billion liters)[2]
500,000	31,000	160,000	1.4	0.07	0.17	0.28
1,000,000	63,000	320,000	2.8	0.14	0.34	0.56
5,000,000	310,000	1,600,000	14.0	0.70	1.7	2.8
10,000,000	630,000	3,200,000	28.0	1.4	3.4	5.6
15,000,000	940,000	4,700,000	41.0	2.1	4.9	8.2
20,000,000	1,300,000	6,500,000	57.0	2.9	6.8	11
40,000,000	2,500,000	13,000,000	110	5.5	13.2	22

[1] Estimated surface area based on 1.6 metric tons per cubic meter (dry weight).

[2] Based on 365 days per year and 24 hours per day.

Table 2. Estimated process water and makeup water requirements for modeled gold heap-leach operations at selected annual capacities with an application rate of 10 liters per square meter per hour. All estimates rounded to two significant figures.

[$L/m^2/h$, liters per square meter per hour]

Annual ore placed on heaps (metric tons per year with constant rate of replacement)[1]	Square meters of surface area under constant leach with 10-meter lifts	Volume of leachate applied at rate of 10 $L/m^2/hr$	Volume of leachate applied in 1 year (billion liters)[2]	Annual makeup water requirement at 5 percent of applied solution (billion liters)[2]	Annual makeup water requirement at 12 percent of applied solution (billion liters)[2]	Annual makeup water requirement at 20 percent of applied solution (billion liters)[2]
500,000	31,000	310,000	2.7	0.14	0.32	0.54
1,000,000	63,000	630,000	5.5	0.28	0.66	1.1
5,000,000	310,000	3,200,000	28	1.4	3.4	5.6
10,000,000	630,000	6,300,000	55	2.8	6.6	11
15,000,000	940,000	9,400,000	82	4.1	9.8	16
20,000,000	1,300,000	13,000,000	110	5.5	13	22
40,000,000	2,500,000	25,000,000	220	11	26	44

[1] Estimated surface area based on 1.6 metric tons per cubic meter (dry weight).

[2] Based on 365 days per year and 24 hours per day.