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An Evaluation of Tailings Ponds Sealants

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AN EVALUATION OF TAILINGS PONDS SEALANTS

by

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ABSTRACT

This report presents a summary of the rather limited information available in the literature pertaining to the use of sealants for mine and mill tailings ponds. Included in the report is a discussion of currently employed seepage detection methods, as well as the various types of sealants currently in use--compacted earth, clays, chemicals, waste tailings solids, asphalt, and synthetic membranes. Only properly installed synthetic liners will prevent all seepage. Installation costs of the sealants, including labor, are discussed and graphs for estimating costs based on pond size are presented. Regulations governing the amount of seepage allowed are ill-defined or non-existent in the majority of States.

CONTENTS

SECTION I

CONCLUSIONS

1. A literature search has not revealed data showing seepage rates from mining and milling tailings ponds. Minimal data is available on sealants for irrigation canals, brine ponds, and reservoirs; however, satisfactory liners for these purposes might prove unsatisfactory for mining wastes due to their chemical characteristics. The sealing method most widely used is compacted earth, but the majority of tailings ponds are not sealed prior to use.

2. To ascertain the continuing performance of a liner, a seepage detection system should be operated continually. A water-budget detection system would substantiate the volume of waste lost through seepage within its limit of accuracy. Monitoring detection systems will determine the type and concentration of pollutants seeping from the pond.

3. Current seepage restrictions are non-existent or poorly defined. The degree of seepage is unknown in almost all instances due to the lack of detection systems. The fate of pollutants from mining wastes that seep into the soil has not been investigated sufficiently. Increased attention to environmental control of pollution will probably result in seepage restrictions approaching zero.

4. Most liners allow seepage of one foot per year and often appreciably more. Even in arid regions seepage losses of one foot per year result in 25 percent of the total waste volume. "Zero" seepage is only obtained from properly installed and maintained synthetic liners.

SECTION II

RECOMMENDATIONS

1. Research should be conducted to determine effects of metal and mineral mining wastes on pond sealants. Individual waste characteristics will necessitate testing different lining materials to determine maximum performance. Factors to be considered are liner deterioration upon prolonged contact with the waste and alterations in liner permeability with time.

2. Research should be conducted to determine the movement of mining and milling waste pollutants through the soil and groundwater surrounding tailings ponds. The information would be beneficial in planning more efficient seepage detection systems, and defining the magnitude of seepage resulting from mine tailings ponds.

3. A comprehensive research study of all seepage detection systems should be undertaken to determine their reliability. Efforts should be made to improve the accuracy of the water-budget method. Improved systems should be developed that allow the identification and quantification of seepage pollutants to be determined routinely.

4. Investigations should be conducted to determine the suitability of waste slimes as pond sealants, since waste slimes gradually reduce seepage from ponds. Slimes are readily available from old tailings ponds and might serve to seal ponds in the same manner as clay sealants.

SECTION III

INTRODUCTION

Tailings ponds are utilized to contain both solid and liquid wastes for recycle, treatment to remove contaminants prior to discharge, or disposal by evaporation. Most industrial wastes contain pollutants that contaminate soil, surface and groundwater through seepage from inadequately sealed tailings ponds. Factors that must be considered in the selection of a sealant are as follows:

1. nature of pollutants in the waste
2. soil characteristics
3. geographical location
4. geological structure of the underlying strata
5. seepage restrictions set forth by regulating agencies
6. cost of sealant

Careful consideration of all factors will enable a proper sealant to be chosen for testing prior to installation in the pond.

Soils of low permeability allow seepage of approximately one foot per year. This amount of seepage accounts for 25 percent of the total loss from ponds in an arid region where evaporation rates are high. At the present time, most regulations governing the degree of seepage permitted by the individual states are inadequate or non-existent. Current attention to environmental problems will probably result in the establishment of seepage standards in all states. Seepage rates of one foot per year or less have been considered satisfactory in sealant research studies for brine ponds.[1] Some states have restrictions on seepage ranging from 3.8 to 7.6 feet per year.[2] Under these regulations, seepage would contribute more to waste loss from ponds than evaporation, the intended means of disposal. The trend in regulating seepage rates will be toward reduced seepage, thus greatly restricting the sealants that may be employed. Only membrane liners can, at present, provide "zero" seepage. The sealing proficiencies of other types of liners fluctuate depending on the soil characteristics and uniformity of their installation; hence, the method of seepage prevention chosen will be dependent upon the degree of restrictiveness specified in the regulations.

Most studies of sealants have dealt with their use for brine ponds, irrigation canals, and reservoirs. In general, the sealing characteristics for tailings ponds should be the same except for the effect of chemical constituents in the tailings pond solutions on the sealant. These effects should be studied for each type of tailings solution before use of the sealant in the holding pond.

SECTION IV

SEEPAGE DETECTION

While seepage at the ground surface is obvious, underground seepage may go completely undetected unless observed through a monitoring system. Though the geological structure of the area is well-known and the directional flow of the groundwater previously determined, monitoring wells may not detect a pollutant due to the slow band-like dispersion of seepage liquid in the groundwater system. Faults and fissures in the formation may allow the pollutants to travel to an unexpected point; hence, the ultimate solution to the prevention of pollution from seepage is complete elimination.

Two methods, the water-budget and a monitoring system, are presently utilized to measure seepage rates. The water-budget method, with a limit of accuracy of 12 to 30 percent, measures seepage by determination of the difference between all inputs and outputs to the pond. Many variables are involved that may introduce errors into the calculation of accurate seepage rates.

The following information must be known for a period of time to calculate the amount of seepage:

1. evaporation rate
2. rainfall
3. area of water surface
4. gallons of solid and liquid waste discharged to pond
5. gallons of waste discharged from pond
6. water level change in pond

Seepage may be calculated from the following formulas:

$$E = 0.7\,P \tag{1}$$

$$E_n = \frac{A\ (E - R)}{0.13368} \tag{2}$$

$$C_t = G_i + G_o + E_n \tag{3}$$

$$C_a = \frac{H \times A}{0.13368} \tag{4}$$

$$S = C_t - C_a \tag{5}$$

where P = pan evaporation (ft)

E = pond evaporation (ft)

A = pond surface area (sq ft)

R = rainfall (ft)

0.13368 = conversion factor (cu ft/gal.)

E_n = net evaporation corrected for rainfall (gal.)

G_i = waste discharge to pond (gal.)

G_o = waste discharge from pond (gal.)

C_t = theoretical change in pond volume (gal.)

H = pond waste level change (ft)

C_a = actual change in pond volume (gal.)

S = seepage loss (gal.)

Note: The discharge and evaporation from the pond are entered into the calculation as a negative value.

The 0.7 factor is an approximate correction for lake evaporation when using a Class A Weather Bureau pan and may vary from 0.60 to 0.97 at different locations.[3, 4] Rainfall introduces another source of error because of the difficulty in determining the surface area funneling run-off into the pond. Additional errors are introduced in calculation due to the masking effect of the larger inflow and outflow volumes of waste. If two ponds are available for use, the inflow and outflow could be transferred to one pond while seepage measurements are made on the other pond, thus increasing the accuracy of the measurement by eliminating G_i and G_o. Seepage determination during periods of zero rainfall eliminate R and the associated error from the calculation.

Seepage may be monitored by a number of methods. The most common involves the drilling of monitoring wells in the immediate vicinity to detect contamination of the groundwater. The number, location, and depth of the wells should be governed by prior knowledge of area geology, direction and rate of groundwater movement. Routine analyses of monitoring well samples will indicate fluctuations and trends of pollutant concentrations. Monitoring of city, farm, and stock wells in the tailings pond area may also be utilized to detect pollutants. A seepage collection system may be installed under a tailings pond during construction. Perforated or porous pipe installed under the lining material drains seepage liquids into a collection basin located outside the pond dikes. An electrical sensing system, employing a series of metal pins inserted in the pond bottom prior to liner installation, has been used. Waterproof cables connect the pins through a selector switch to a resistivity meter. Resistance readings may be taken between selected pins to detect leaks in the liner. The use of these methods to obtain quantitative and qualitative information on seepage is desired. At best, some seepage may go undetected because of deficiencies of the methods; therefore, more accurate seepage detection methods are needed.

SECTION V

COMPACTED EARTH

Compaction of the soil reduces the porosity, thus restricting the flow of liquid through the soil. A soil suitable for compaction should have low permeability, high stability, and good resistance to erosion. Soil permeability is inversely proportional to the thickness of the compacted layer. The soil is compacted in six-inch layers up to depths of three feet.

Laboratory tests should be conducted on representative soil samples to determine natural permeability and thickness of the compacted layer that will reduce permeability to the desired level. Permeabilities of soil for any combination of treated or compacted thickness and liquid head may be calculated by the following formula developed by Casagrande.[5]

$$K = \frac{v \Delta L}{h} \qquad (6)$$

where K = Casagrande permeability (cm/sec)

v = linear velocity of liquid (cm/sec)

ΔL = thickness of treated layer (cm)

h = liquid head (cm)

For the special case $h = \Delta L$, then $K = v$. This condition does not exist under normal pond conditions; therefore, K must not be confused with actual seepage rates.

The moisture level in the soil affects the degree of compaction and thus the permeability.[6] Soils from two different areas were tested and showed maximum compaction and minimum permeability at 14 to 17 percent moisture respectively. An optimum moisture level existed for maximum compaction after which an increase in permeability occurred. Also, the optimum moisture level for maximum compaction depended upon the type of soil; therefore, compaction tests must be performed on each soil to determine optimum conditions. When the moisture content of the soil is optimum, a compaction greater than 95 percent of maximum density may be obtained by approximately six passes with a tamping roller followed by four passes with a rubber-tired roller.

Even under optimum conditions of compaction, soil permeabilities may change over a period of time. Uncompacted soil becomes more impermeable in ponds due to the filling of interstices by dispersed fine solids; e.g., one uncompacted test pond seepage rate decreased from 163 to 36 cubic feet per year over a one-year period.[2] Compaction of a pond located on the same soil type resulted in a decreased seepage rate from 35 to 6 cubic feet per year over the same period of time. Although tests indicate that soil compaction reduces the seepage rate, the permeability of the soil may remain too high for some seepage requirements.

The seepage rate of compacted earth liners is often greater than the evaporation rate from the pond. Should strict standards for seepage be imposed, this method of pond sealing would be inadequate in many cases.

The contained waste may have either detrimental or beneficial effects on the permeability of the soil. Acid wastes may react with the soil and destroy its expansion capabilities. Alkaline wastes may contain compounds, such as sodium carbonate, that are beneficial in reducing the soil permeability. Prior tests should be conducted to determine the soil permeability effects of the waste to be contained.

Physical factors, including freezing, thawing, drying, and wetting, may affect the lining. Cracking of the lining caused by one or more of these factors results in large increases in permeability. If possible, the lining should be kept moist to maintain stable conditions.

SECTION VI

CLAY SEALANTS

High-swell clay minerals have been widely used to control excessive seepage in soil by decreasing the permeability. Bentonite is a heterogeneous substance composed of montmorillonite and small amounts of feldspar, gypsum, calcium carbonate, quartz, and traces of other minerals. Bentonite has colloidal properties due to the small size of the particles and negative charge. Seventy to ninety percent of the particles are finer than 0.6 micron.[7] Bentonite has the capability of absorbing approximately five times its weight in water and occupies a volume 12 to 15 times its dry bulk at maximum saturation.[8]

The sodium content of the clay has a significant effect upon the swelling characteristics of the clay.[7, 9] In the presence of a high ratio of sodium to calcium, much larger quantities of water are sorbed and swelling increases. Clays with a low ratio have a tendency to flocculate and settle from suspensions. The use of chemicals to increase the sodium to calcium ratio in the clay minerals will be discussed in a later section of the report.

High-swell bentonites are found in Wyoming, South Dakota, Montana, Utah, and California. An application rate of two pounds per square foot is desirable. The cost including application is about $1.30 per square yard for short transportation distances.

Various methods have been investigated for the application of bentonite seals.[10] Bentonite may be applied by mixing with soil in a ratio of one to eight either in the surface or buried under a layer of soil. Another method, buried membrane, involves placement of a layer of bentonite one-half inch thick on the subsurface topped with six inches of soil. A bentonite suspension applied to the soil or a gravel surface has proved unsuccessful. Large quantities of bentonite are required to seal coarse soils; therefore, the method may be prohibitive in cost. The buried mixture and the buried membrane were found to be the most effective bentonite sealing methods. Application of a buried mixture reduced the seepage rate of one soil from 1.8 to 0.06 feet per day. The buried membrane reduced the seepage rate of the same soil to 0.01 feet per day.

Low-swell clays have had limited use as sealants, but some research has been conducted on their sealing characteristics.[11] Low-swelling clays, such as hydrated mica and kaolin, are located in Nevada and other western states. These clays are economical and possibly more stable than high-swell clays. Research has indicated that low-swell clays are affected less by increased concentrations of magnesium or calcium in water than high-swell clays, and damage from drying may be less severe. Further investigations are warranted.

SECTION VII

CHEMICAL SEALANTS

Under certain conditions soil permeability is reduced through the application of chemicals.[2, 6, 12, 13] Chemical sealing agents physically fill the interstices of the soil or chemically react with the soil constituents to form a more impermeable membrane. Sealant tests must be performed on each type of soil due to the highly variable seepage rates that are obtained. No single chemical has been found to effectively seal all soils. The life of the seal is affected by freezing and thawing, wetting and drying, reaction with constituents in the pond wastes, and leaching of the sealing agent by waste liquid.

Chemical sealants are applied by surface spraying, mixing with the soil, or as additions to the waste discharge to the pond. The chemical is mixed with the soil to a depth of approximately six inches followed by compaction or is sprayed on the previously compacted surface.

Research investigations have established a relationship between the sodium adsorption ratio (SAR) and soil permeability.[7, 9] Several cations may be attached to a negatively charged clay soil particle. The cations exchange with other cations contained in liquid seeping through the soil. The exchange process alters the soil characteristics, producing either a more dispersed or flocculated soil aggregate. As the ionic ratio of sodium to calcium and magnesium increases, the clay particles become more dispersed and fill the pores of the soil. The ratio may be adjusted to obtain minimum permeability. Too high a ratio will produce a liquid state of the soil that increases the permeability and weakens the physical structure of the pond. Generally, laboratory tests indicated the permeability decreased by a factor of ten as the sodium adsorption ratio changed from 10 to 80. The formula used for calculating the ratio is as follows:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} \qquad (7)$$

Note: Ionic concentrations expressed in milliequivalents per liter.

Sodium carbonate, sodium silicate, and sodium pyrophosphate were the most effective sodium-bearing chemicals tested. Sodium carbonate was the superior of the three, remaining an effective sealant after five years.[12] Treated ponds that have become more permeable over a period of years have been restored to their original state of impermeability by reapplication.

The effect of clay and sodium carbonate on sand may be seen in Table 1. Each type of clay was added to three composites of sand having natural permeabilities of 1,732, 713, and 135. The percentage of clay added was different for each sand composite. The percentage of montmorillonite was low but resulted in reducing permeabilities comparable to the other clays. Further investigations are needed to determine the sealing effects of higher percentages of montmorillonite clay. Further reductions in permeabilities ranging from 45 to 93 percent were obtained by adding sodium carbonate to a sand-clay mixture. The wide range in permeabilities after treatment indicates the effect of the individual soil characteristics and proves the necessity of prior soil testing to determine the benefits of clay and chemicals.

Sodium pyrophosphate and sodium silicate are also promising soil sealants.[5, 15] The choice of these sealants was based on sealing efficiency and costs. Soil treated with sulfuric acid and sodium silicate prior to compaction resulted in significant seepage reduction. Ponds receiving sulfuric acid-bearing effluents should be compatible with this sealant. Zeogel, an attapulgite clay drilling mud, was a promising sealant used in another sealant study.[6] Seepage was reduced to less than six inches per year by application of a two percent solution.

Table 1. PERMEABILITIES OF OTTAWA SAND COMPOSITE[14]

Clay type	Percent clay	Hydraulic Conductivity, ft/yr Natural composite	With clay added	With Na_2CO_3 added 0.4 lb/sq yd
Illite	7.5	1,732	326	22
"	4.0	713	161	22
"	3.0	135	79	12
Kaolinite	10.0	1,732	297	30
"	5.0	713	215	72
"	5.0	135	108	24
(Bentonite) Montmorillonite	1.5	1,732	757	67
"	0.25	713	182	100
"	0.25	135	34	13

Polymer compounds have also been investigated.[1, 16, 17] In one group of sealants studied, a sprayable, water soluble, liquid vinyl polymer was utilized with success as a soil stabilizer and deserves further study for use as a pond sealant. Polymer application requires that the subsurface be smooth and firm; pre-wetting of the soil prevents pinhole formation in the film.

Rubber latex has been used in sealant studies for control of acid mine drainage.[18] The seal penetrated the top ten inches of soil which was unsatisfactory for the testing purposes; however, additional investigations might prove the suitability of latex as a pond sealant.

Soil permeability tests are extremely time consuming; however, investigations have shown a relationship between permeability and liquid limit.[19] Liquid limit is the percent water content corresponding to the arbitrary limit between the liquid and plastic states of soil consistency. Liquid limit measurements on soils may be made rapidly, thus reducing the time required to select the most promising sealant from a group of sealants. Final selection may be made on the basis of permeability tests.

SECTION VIII

WASTE TAILINGS SOLIDS

Mining industries discharge large quantities of sand and slimes following extraction of the desired material. For example, uranium ore is ground to a minimum size of 200 mesh; slimes, the finest particles, represent 20 percent of the total waste. The fine solids have a sealing effect on tailings ponds by reducing the seepage rate as solids accumulate on the pond bottom.

Due to the sealing characteristics, ore wastes are beneficial in reducing seepage in ponds. Covering a new pond bottom with tailings solids should produce a condition similar to an old pond with accumulated tailings, thereby eliminating initial high seepage rates.

Research into the utilization of waste solids as sealants is needed to prove their value. Advantages of using waste solids include proximity to the site and negligible material cost.

SECTION IX

ASPHALT SEALANTS

Asphalt for membrane liners is specially prepared at the refinery by forcing air in the presence of a catalyst through the mixture to produce characteristics of resistance to low temperatures, toughness, and durability.[2] Compaction of the top six inches of the subsurface produces a firm smooth base for the liner. Soil sterilants are used to prevent growth of vegetation on the subgrade that would puncture the liner. The subsurface is sprinkled with water prior to asphalt application to prevent small holes from occurring in the liner due to dust. The asphalt is applied at 400° F under pressure of about 50 pounds per square inch through slot-type spray nozzles as used in highway application. An application rate of 1.25 gallons per square yard produces a suitable liner one-fourth inch thick. The sections are joined by overlapping one to two feet. An earth cover is added to protect the liner from puncture. Aging characteristics have been investigated in the laboratory to provide a means of predicting the useful life of a liner.[20] Penetration, ductility, and softening point tests were performed on samples from asphalt liners that had been in use for periods as long as 18 years to determine an aging index. Laboratory accelerated aging methods were used to predict the life expectancy of new asphalt liner material. A 14-day oven exposure of asphalt to 140° F resulted in an aging index similar to that obtained by 14-year field exposure. The asphalt must exhibit a life expectancy of 14 years to qualify as a liner material. Seepage losses have been 8.5 feet per year in one brine test pond.[1]

Studies have shown that addition of rubber (three to five percent) improves the properties of asphalt: greater resistance to flow, increased elasticity and toughness, less brittleness at low temperature, and greater resistance to aging.[12]

Asphalt concrete linings are composed of a carefully controlled hot mixture of asphalt and well-graded aggregate. The mixture is designed for water tightness and an optimum degree of plasticity. Standard road-paving equipment is used to apply a two to three inch layer. Seepage losses have been reduced to 0.7 feet per year with this type of liner.[1, 2] A service life of 14 to 20 years can be expected and the liner will support traffic without damage.[20]

A cationic water-borne sealant has been developed by addition of a cationic surfactant as an emulsifer to an asphalt base material.[21] A cationic surfactant was chosen over an anionic and nonionic surfactant because it possessed a high degree of affinity for almost all surfaces and adhered to soil particles in the presence of large volumes of water. The flow of the seeping water carries the asphalt droplets to the soil particles below the pond bottom. The asphalt droplets are deposited on the soil and eventually adhere to form a membrane that reduces seepage. Seepage reductions of 99 percent, or less than one foot per year, have been obtained with application rates of 0.75 gallons per square yard. The effect of waste constituents on this sealant should be studied.

A new type of asphalt liner has been developed that uses a polypropylene fabric base followed by the application of two coats of asphalt.[22] The liner panels are field-sewn by means of a portable machine, and asbestos fibers are mixed with the second asphalt application to prevent cold flow on pond slopes.

SECTION X

SYNTHETIC MEMBRANE LINERS

Synthetic membrane liners are the only liners that prevent all seepage, and have become increasingly popular since their introduction in 1953. Synthetic liners may be broadly classified as latexes, plastics, and fiberglass; the most widely used are polyvinyl chloride (PVC), butyl rubber, and hypalon.[23, 24] Polyethylene, chlorinated polyethylene (CPE), neoprene, and ethylene propylene diene monomer (EPDM) are used to a lesser extent. The liners range in thickness from 10 to 60 mils with life expectancies of 20 years.

Nylon reinforced liners are used on steep slopes where added strength is required. The type of effluent to be contained, composition of the subsurface, and nearness of earth cover must all be considered in order to choose the best liner for the pond.

Available plastic liners include polyvinyl chloride (PVC), polyethylene, and chlorinated polyethylene (CPE). The liners resist inorganic chemicals but are attacked by organic substances. Polyethylene liners are seldom used now because of the development of improved plastics.[25] Polyvinyl chloride is the most widely used because of low installation cost, puncture resistance, and durability. Polyvinyl chloride liners are subject to deterioration from sunlight; therefore, the liner must be covered. An earth cover of six to twelve inches will protect polyvinyl chloride from sunlight and from animal and vehicle traffic. Chlorinated polyethylene is less affected by sunlight, but is more expensive. A polyvinyl chloride bottom cemented to chlorinated polyethylene sides has been used to prevent deterioration and reduce liner costs.

Available rubber liners include butyl, ethylene propylene diene monomer (EPDM), neoprene, and hypalon. Butyl rubber and hypalon are the most widely used. The liners, although more costly than plastic, may be more economical for some locations as the material does not require an earth cover. Exposed butyl rubber was selected as the most economical liner for a 110-acre reservoir.[26] Butyl rubber is durable, watertight, and flexible. One disadvantage of this liner is that cemented seams have only 60 percent strength; therefore seam separation is more likely, increasing the possibility of leakage. Hypalon liners are inert and long lasting; however, shrinkage from sunlight exposure poses a problem. Liners of EPDM material are also susceptible to shrinkage from sunlight when not properly formulated and cured, but are more resistant to ozone than butyl.[27]

Fiberglass liners are newer than other types of synthetic liners and have not been time tested for durability and seepage prevention.[28] Composed of a fiberglass mat impregnated with epoxy resin, the liners are thicker and stronger than other types (0.1 inch) and can support traffic without puncturing. Although more expensive than other types of liners, earth covers are not required. Some liners tested for permeability showed flow areas of poorly impregnated mats which resulted in a porous and structurally weak liner.

All synthetic liners are installed similarly and site preparation is important to prevent punctures in the lining.[29] The surface must be graded smooth and sharp rocks, sticks, and vegetation removed. Objects not removable are covered with a layer of earth. If air bubbles are anticipated, the bottom should be sloped to allow the bubbles to escape. Covering the liner after installation provides weight to aid in gas removal.

An anchor trench for the liner is dug at the top of the berm. Liners, in sheets as large as 60 feet by 700 feet, are unfolded on the pond bottom with one end buried in the anchor trench. Sheets are overlapped two to four inches to allow bonding. A flat board may be used under the liner to provide a smooth surface for cementing the edges. The seam develops shear strength in about 15 minutes and must be carefully inspected to detect and reseal any flaws in the seam.

The pond side slopes should not be steeper than 3:1 when an earth cover is to be installed. A six to twelve inch cover is adequate to protect the liner from traffic and exposure. Equipment must be moved only on previously covered areas to prevent damage to the liner.

SECTION XI

COST OF POND LINERS

Approximate costs of installed liners, ranging from $0.02 to $0.55 per square foot, are shown in Table 2. The cost of earth cover was included only for polyvinyl chloride. Esimated labor costs included in Table 2 are as follows:

1. chemical application = $0.02/sq ft
2. uncovered synthetic liner = $0.04/sq ft
3. covered synthetic liner including cover costs = $0.07/sq ft

The installation and labor cost are identical for sodium carbonate and sodium silicate because chemical costs are less than $0.005 per square foot.

The total cost of a tailings pond liner may be approximated from Table 2, Figure 1, and Figure 2 if the waste discharge rate, evaporation rate, and annual rainfall are known. The pond size, obtained from Figure 1, is used to determine the total cost from Figure 2. For example:

1. 300 gal./min waste discharge to pond for disposal by evaporation
2. Evaporation = 36 in./yr
3. Annual rainfall = 12 in./yr
4. Liner of 20 mil polyvinyl chloride with earth cover

The net annual waste loss is 24 inches after correcting the evaporation for the rainfall. From Figure 1, a 243-acre pond is required to contain a 300 gallon per minute waste discharge at the 24 inch per year net annual waste loss. Table 2 shows an installation cost, including labor and earth cover, of $0.18 per square foot for 20 mil polyvinyl chloride. From Figure 2, a cost of $1.8 million would be incurred in lining a 243-acre pond at $0.18 per square foot.

Table 2. COST OF INSTALLED LINER

Liner	$/sq ft
Bentonite	
2 lb/sq ft	0.14
Chemical	
Sodium Carbonate	0.02
Sodium Silicate	0.02
Sodium Pyrophosphate	0.03
Zeogel	0.03
Coherex	0.03
Asphalt	
Asphalt Membrane	0.14
Asphalt Concrete	0.20
Rubber[a]	
Butyl	
1/16"	0.42
3/64"	0.36
1/32"	0.30
EPDM	
1/16"	0.41
3/64"	0.35
1/32"	0.29
Synthetic Membrane	
PVC	
10 mils	0.13
20 mils	0.18
30 mils	0.22
Chlorinated Polyethylene (CPE)	
20 mils	0.26
30 mils	0.34
Hypalon	
20 mils	0.26
30 mils	0.34
Fiberglass	
1/8"	0.55

[a]Nylon reinforced rubber costs an additional $0.10/sq ft.

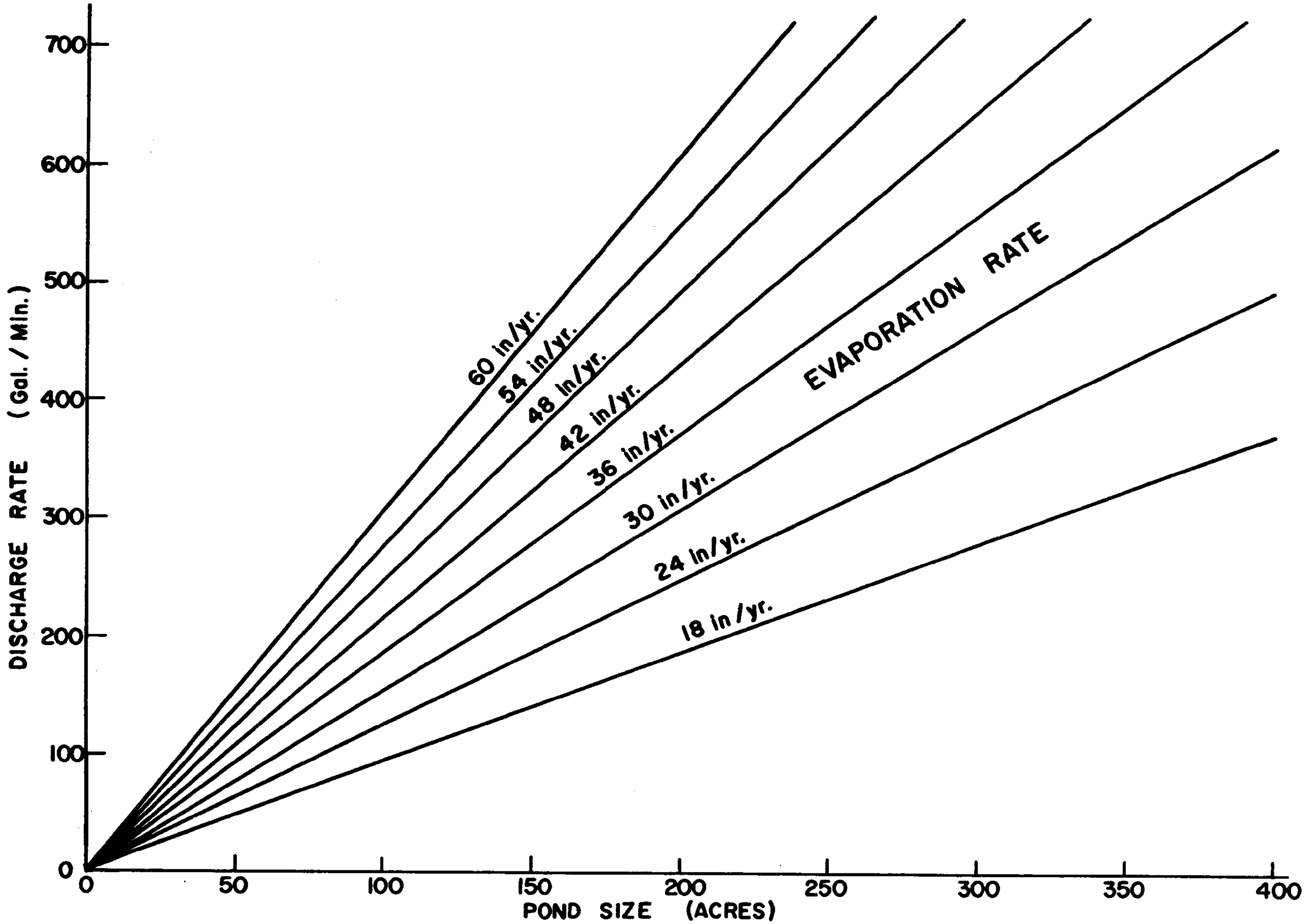

FIGURE 1 - TAILINGS POND SIZE

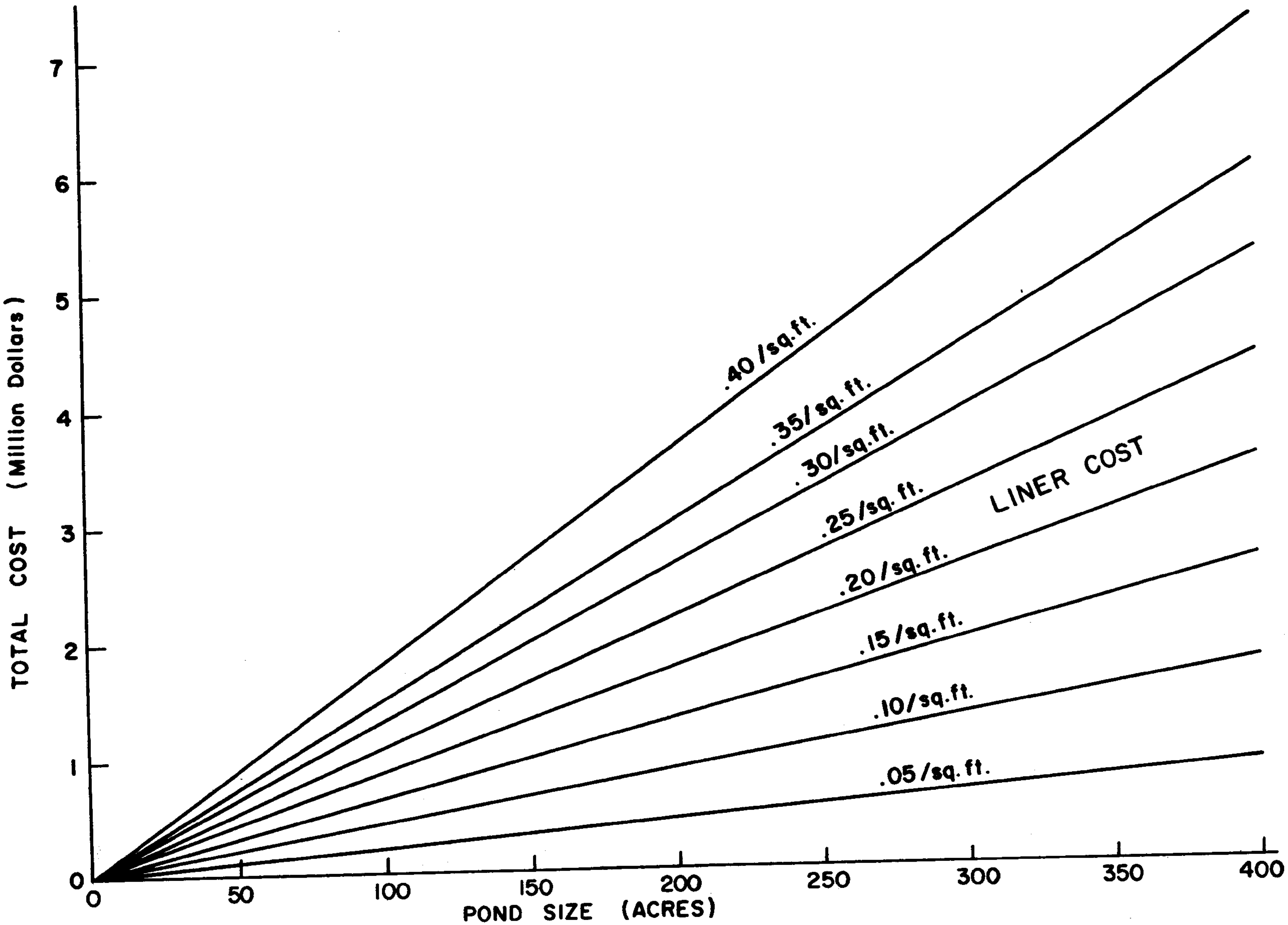

FIGURE 2 - LINING AND INSTALLATION COST

SECTION XII

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16. *Abstract*

This report presents a summary of the rather limited information available in the literature pertaining to the use of sealants for mine and mill tailings ponds. Included in the report is a discussion of currently employed seepage detection methods, as well as the various types of sealants currently in use--compacted earth, clays, chemicals, waste tailings solids, asphalt, and synthetic membranes. Only properly installed synthetic liners will prevent all seepage. Installation costs of the sealants, including labor, are discussed and graphs for estimating costs based on pond size are presented. Regulations governing the amount of seepage allowed are ill-defined or non-existent in the majority of States. (Clark - EPA)

17a. *Descriptors*

*Linings, *Soil sealants, *Impervious membranes, Waste disposal, Liquid wastes, Solid wastes, Permeability, Seepage, Monitoring, Liquid limits, Plastics.

17b. *Identifiers*

Liner costs, Latexes, Fiberglass, Seepage detection.

17c. *COWRR Field & Group* 04A, 05A, 05E, 05G

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