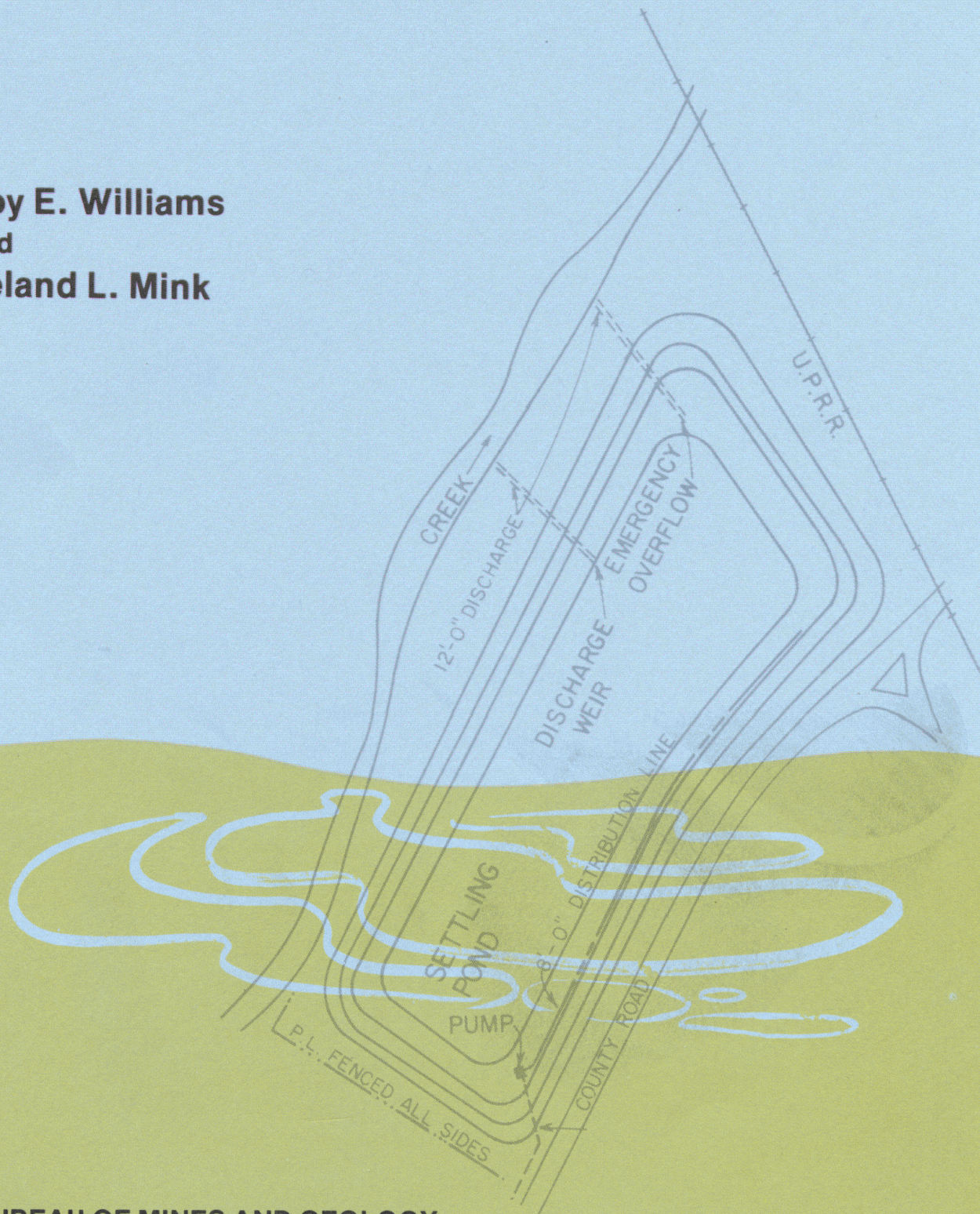


Settling Ponds

As A Mining Wastewater Treatment Facility

By
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SETTLING PONDS AS A MINING WASTEWATER
TREATMENT FACILITY

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ABSTRACT

The Coeur d'Alene mining district of northern Idaho is world famous for its production of lead, zinc, and silver. Mining operations within the district have been continuous since 1890. Presently, several mines which rank among the nation's top producers of antimony, lead, silver, and zinc are located there. Operations within the district include mining, concentrating, refining, and smelting the raw ore.

Prior to 1968 much of the effluent produced by mining and related operations was discharged directly into nearby streams, resulting in a gross pollution problem. In the fall of 1968 the major mining operations of the district installed settling basins as a treatment facility for their wastes. Since the data reported in this study were collected one mine has installed additional treatment facilities, including neutralization with respect to pH. From June 1969 to June 1971 a study was conducted to examine these tailings ponds as a treatment facility. The objective was to determine what types of mineral resource wastes settling ponds can be expected to treat adequately. Wastes from seven major mining operations were studied during this period. Temperature, pH, conductivity, suspended solids, and 13 elements were analyzed from inflow(s), outflow(s), and seepages in and around the settling basins. Data revealed that the settling basins can be categorized into two major types: 1) settling ponds receiving effluent from the concentrating process only, and 2) settling ponds receiving effluent from the concentrating process, mine drainage, sewage, and smelting or refining processes.

Comparison of inflow and outflow values of constituents revealed that settling ponds for mines 1, 4, 5, 6, 7, when managed carefully, were effective in stabilizing temperature and reducing suspended solids to an acceptable value in the pond outflow. Results from these five settling ponds, which receive effluent from the concentrating process only, indicate significant reductions at the 0.05 level of significance for pH, electrical conductivity, potassium, and magnesium to an acceptable level in the outflow. Elements chlorine, fluorine, calcium, cadmium, copper, iron, manganese, sodium, lead, antimony, and zinc were low or below detectable limits in the effluent of ponds receiving concentrator waste only.

Two settling ponds received wastes from various industrial processes along with concentrator effluent and acid mine drainage. These ponds were observed to be ineffective in removing several of the elements studied. Electrical conductivity, fluorine, cadmium, copper, iron, manganese, lead, and zinc were observed to be high in the outflow from a pond receiving concentrator effluent, mine drainage, sewage, and a metallurgical process effluent. Another pond receiving concentrator effluent along with effluent from an electrolytic antimony plant was observed to contain high concentrations of sodium and antimony. High pH and electrical conductivity values also characterized the outflow.

Studies of ion exchange properties of the tailings showed that this property is not useful in reducing the concentrations of dissolved heavy metals while the wates are in the settling ponds. Electrophoretic analyses indicated that colloids in the tailings have minimum stability at a pH of 8 or above. When the water in the settling ponds was acid, colloids were stable and ions apparently were stripped from the solids.

Data show that settling ponds can be used successfully as a means of treating effluent from the concentrating process. Settling basins receiving effluent from mine drainage, smelting or refining operations create conditions within the settling basin which cause the settling basin effluent to be unacceptable. Stream pollution results if the effluent is discharged. A means of treatment other than or in addition to a settling pond is required for non-concentrator type wastes.

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INTRODUCTION

PURPOSE AND SCOPE

Mining operations in northern Idaho have been criticized for several years because of their detrimental impact on the environment. The Coeur d'Alene mining district is one of special significance because of a long history of mining and because several mines are rated among the top ten in production on a national scale. As a result, much work has been done by the mining industry and related governmental agencies to help solve pollution problems.

From 1890 to 1968 most of the effluent from the mining operations of the Coeur d'Alene district was discharged directly into the Coeur d'Alene River system. In 1968 the mining companies established settling ponds to eliminate the tremendous suspended solid load being carried by the South Fork of the Coeur d'Alene River. Mink, Williams, and Wallace (1971) found that, when carefully and properly managed, the ponds were effective in reducing suspended solids. In some cases, however, the effectiveness of these ponds in removing other elements contributed by mining, metallurgical, or smelting operations, notably dissolved heavy metal ions, remained in question.

Wastewaters produced by mining and metallurgical operations are known to contribute acidity, suspended material, and dissolved heavy metal ions to the aquatic environment. This discharged material in some instances is known to exert a toxic effect on biological life and causes unsightliness and discoloration of the receiving waters.

Because precise measurements of the degree of reduction of heavy metals by settling ponds of the type used in the Coeur d'Alene district have not been determined previously, this study was designed to evaluate the performance of settling ponds as a means of minimizing the effects of dissolved or suspended material in mineral resource wastewater. Also, it was the purpose of the study to determine whether other types of treatment were necessary to improve the efficiency of the settling ponds. Other problems associated with weathering and leaching of mine tailings after disposal in the environment were investigated concomitantly.

DESCRIPTION OF AREA

The Coeur d'Alene mining district is located near the base of the panhandle region of northern Idaho in Shoshone County (Figure 1). The district is in the Bitterroot Range, which is part of the northern Rocky Mountain chain and lies entirely within the local mountain range known as the Coeur d'Alene Mountains. The major portion is in the valley of the South Fork of the Coeur d'Alene River. The South Fork of the Coeur d'Alene River is a tributary of the Coeur d'Alene River system which discharges into Coeur d'Alene Lake near the Idaho-Washington border. The outlet of Coeur d'Alene Lake forms the Spokane River, which is a major tributary of the Columbia River.



Figure 1

A Map of Western United States Showing
Coeur d'Alene Mining District

The relief of the Coeur d'Alene district is very rugged with many slopes inclined at an angle of 30° or more. The valley is quite narrow with few areas exceeding a half mile in width. The surrounding mountains attain a maximum elevation of 6838 feet while the valley floor near the mouth of the South Fork has an elevation of 2190 feet, giving a maximum relief of 4648 feet in the district. All of the area discussed in this paper is drained by the South Fork of the Coeur d'Alene River and its tributaries.

The population of the Coeur d'Alene district is approximately 18,804 (U.S. Department of Commerce, 1971, p. 14-16). The main industry along the South Fork portion of the basin is mining and processing of extracted ores. At the present time, there are ten large mines and several smaller mines operating in the basin. Major industries associated with processing the ore from the mines are also located in the basin. These include an antimony plant, a lead-silver smelter, an electrolytic zinc plant, a phosphoric acid plant, and a fertilizer plant. Lumbering is also an important industry, and the majority of the products are used locally in connection with the mines. Nearly all other industry in the basin is associated with the mining industry or people engaged in the mining industry.

The district produces a significant portion of the antimony, lead, silver, and zinc for Idaho and the nation (U.S. Bureau of Mines, 1969, p. 253; and U.S. Bureau of Mines, 1970, p. 3-6). The seven mines studied in this report include the nation's leading antimony producer, five of the nation's top 20 lead producers, five of the nation's top 25 silver producers, and three of the nation's top 25 zinc producers (U.S. Bureau of Mines, 1969, p. 173, 363, 1004, and 1156).

The climate is seasonal with mild summers and below freezing winters. The mean annual temperature for 1969 was 44°F with extremes for 1969 of 106°F on August 23 at Wallace and -18°F on January 31 at Kellogg.

The majority of the precipitation occurs in the form of snow during the winter months. Average precipitation is 30.31 inches with 9.42 inches occurring in January and 0.06 inches occurring in August. This seasonal precipitation has an appreciable effect on the variability of concentrations of dissolved constituents in the waters of the Coeur d'Alene River system.

Vegetation in the area is dependent on location. Trees found throughout the area include stands of Lodgepole pine, Douglas fir and Western larch. The lower dry areas of the valley contain yellow pine and deciduous trees such as willow and alder. Brushy plants and grasses cover the district in uneven distribution depending on availability of soil and ground water. Higher elevations contain a much greater density of vegetation of various types (Hobbs, et al., 1965, p. 6 and Idaho Department of Commerce and Development, 1963, p. 47-73). Mine tailings, smelter SO₂, and forest fires have devastated the vegetation in much of the area.

The rocks of the area consist mainly of the Precambrian Belt Supergroup. They are composed of fine-grained argillites and quartzites associated with smaller amounts of carbonate-bearing dolomitic rocks. Quartz and sericite are the principal minerals within the Belt Supergroup; accessory minerals

include feldspar, muscovite, magnetite, illmenite, zircon, tourmaline, rutile, and titanite. Average chemical analysis of the Belt rocks is presented in Table 1. The Belt supergroup is an ancient siliceous sedimentary rock which has undergone metamorphism and deformation. Prevailing theory is that a prominent fault, the Osburn Fault, produced a structural deformation in the sediments into which the metalliferous ores were deposited by thermal solution emanating from igneous bodies intruded about Cretaceous time.

The ore deposits are tabular veins with a few irregular replacement bodies along or adjacent to steeply dipping fault shear zones. There are two distinct types of ore in the Coeur d'Alene district. The first consists of a mixture of lead and zinc sulfide containing subordinate amounts of tetrahedrite. In this ore, the lead and zinc is of primary commercial importance. The second type of ore consists of silver-bearing tetrahedrite in which silver and copper are commercially important. Associated with the second type of ore are commercially significant values of copper, lead, and antimony. Lead-zinc ore has been abundant north of the Osburn Fault Zone in the Wallace-Burke-Mullan area and south of the Osburn Fault area in the Wardner-Kellogg-Pine Creek area. Silver ore has been found in the central portion of the district between Wallace and Wardner, and south of the Osburn Fault (Idaho Bureau of Mines and Geology Pamph. 133, 1963, p. 1-2; and Mink, Williams, and Wallace, 1971, p. 6).

BRIEF HISTORY

The history of mining in the area dates back to 1882 when Andrew J. Prichard reported a gold discovery north of Wallace. This resulted in a rush to the Murray-Eagle area which in turn led to important silver and lead discoveries and a silver rush in the South Fork Basin in 1884 and 1885. Railroads were built into the district in 1887, and in 1890 the first concentrating mills were erected. These early mills utilized gravity type jigs and tables for ore separation. By 1891 there were 40 developed mining properties in the basin, 26 of which were classed as producers, and of these, 13 had concentrators. Labor difficulties in 1892-1894, World War I in 1917-1918, the depression of the Thirties, and World War II had an adverse effect on the mining operations of the valley; but the majority of the mines continued operation through these difficult times (Idaho Bureau of Mines and Geology Pamph. 133, 1963, p. 57). The flotation method of processing ore was initiated by the industry around 1916, replacing the outdated "jig" method of handling tailings which had been used up to that date (Ellis, 1940, p. 12; and Idaho Bureau of Mines and Geology Bull. 18, 1961, p. 24).

ORE TREATMENT

Jigging is a mechanical gravity concentration process which is used to separate heavy and light grains resulting from the crushing of ore. In its simplest form, a jig consisted of a box without a top and with a perforated bottom. A shallow bed of grains was formed by fluctuating water currents. The heavy grains passed to the bottom; intermediate mixtures remained in the

Table 1
Chemical Analysis of Belt Rocks in Percent of Unaltered Rock
in Coeur d'Alene District¹

<u>Oxides</u>	<u>Percent</u>
SiO ₂	67.4
Al ₂ O ₃	13.8
Fe ₂ O ₃	2.4
FeO	1.28
MgO	2.78
CaO	2.11
Na ₂ O	1.76
K ₂ O	3.6
TiO ₂	0.49'
P ₂ O ₅	0.12
MnO	0.05
CO ₂	2.51
H ₂ O	<u>1.85</u>
	100.15

¹From: Hobbs, et al., 1965, p. 28

middle, and the lightest rose to the top of the bed. Some devices were hand-operated or power-driven units in which the jig was moved up and down in the water; others were stationary jigs in which the water was pulsated by plungers or paddles.

During the years 1887-1928 when jigging was the major method of concentration, no attempt was made to recover zinc, all of which went to the tailings. This explains the high zinc concentrations that occur in the deposits along the valley bottoms at the present time. Typical tailings for this period showed lead assays of 0.90 percent to 1.5+ percent. No assays were conducted on the zinc in the feed, concentrate, or tails, but the majority of the zinc obviously went with the tails (Mink, Williams, and Wallace, 1971, p.8-9).

The selective flotation process of concentrating ore involves first grinding the ore to a fine-grained pulp. This pulp is then treated with chemicals which react with the surface of some of the minerals and create an oily, water-repellent coating. The pulp is then sent to a series of flotation cells containing agitators. The agitators serve the purpose of keeping the pulp in suspension and allowing air bubbles to circulate through it. The water-repellent surfaces of the ore particles cling to rising air bubbles and form a froth on the surface. This froth resembles the lather of soap, but each bubble is covered with particles of ore. Revolving paddles sweep the froth into a launder where a water spray breaks down the bubbles and the resulting suspension is sent to thickeners where it settles and is filtered into the final concentrate.

The process is termed selective flotation because the nature of chemicals added will cause different concentrates to be produced from a given ore. The initial flotation process usually involves forming a lead concentrate. The pulp is then treated with reagents which make zinc sulfide a froth. The treated pulp then goes through a series of flotation cells, similar to the lead flotation cells, to remove the zinc mineral. The remaining pulp from the zinc flotation cells circuit is normally discharged as tailings to be used either as mine fill or sent to a settling pond (Idaho Bureau of Mines and Geology Bull. 18, 1961, p. 37-38).

SAMPLING PROGRAM

COLLECTION SCHEME

This report is based on samples collected from the settling ponds of seven major mines in the Coeur d'Alene district (Fig. 2). The samples were collected from June 12, 1969 through June 22, 1971, a period after the mining industry constructed settling ponds to curb pollution. The ponds were established by the fall of 1968, but prior to this period the tailings from most mining operations were discharged directly into the South Fork of the Coeur d'Alene River.

Points of collection at each mine included inflows and outflows to and from each settling pond, pond water (if no outflow existed), and seepages or springs which may be affected or caused by the settling pond. Stream samples both above and below the settling ponds were collected when applicable to determine if the settling pond had any effect on the water quality of the stream. Maps showing the location of the mines, tailings ponds, and sample location are presented in Figures 8-14.

Sample analysis

Samples were collected in one-liter polyethylene bottles which were washed first in a dilute HCl solution and then rinsed with distilled water prior to sample collection. Stream samples were obtained from the current near the bank of the stream, avoiding stagnant areas. The sample bottles were rinsed thoroughly with the water being sampled at the time of collection. Immediately after collection, the samples were analyzed for temperature, pH, and electrical conductivity. The samples were then transferred to the laboratory where chloride, fluoride, and suspended solids were analyzed using methods outlined in "Standard Methods for Examination of Water and Wastewater" (1971).

Acidification of samples

Experimentation with acidified and unacidified samples prior to analysis for lead and zinc revealed that acidification increased the concentrations of both ions. Two explanations are possible. Acidification is known to minimize adsorption of these ions onto the walls of the container; however, experimentation revealed that acidification also strips off ions adsorbed to the solids suspended in the sample, especially when those suspended solids are mine tailings.

All samples analyzed during this project were collected in polyethylene bottles; consequently, adsorption of ions onto container walls would be expected to be minimal. Therefore, the higher concentrations of lead and zinc which we have observed in acidified samples are attributed to removal of ions from suspended matter in the sample. Filtering of samples was avoided because of the arbitrary definition of what is dissolved. Perhaps the most important complication with respect to acidification occurred with samples collected from the parts of the basin where pH values were very high. Acidification caused a precipitate to form which obviously changed concentrations of some dissolved constituents.

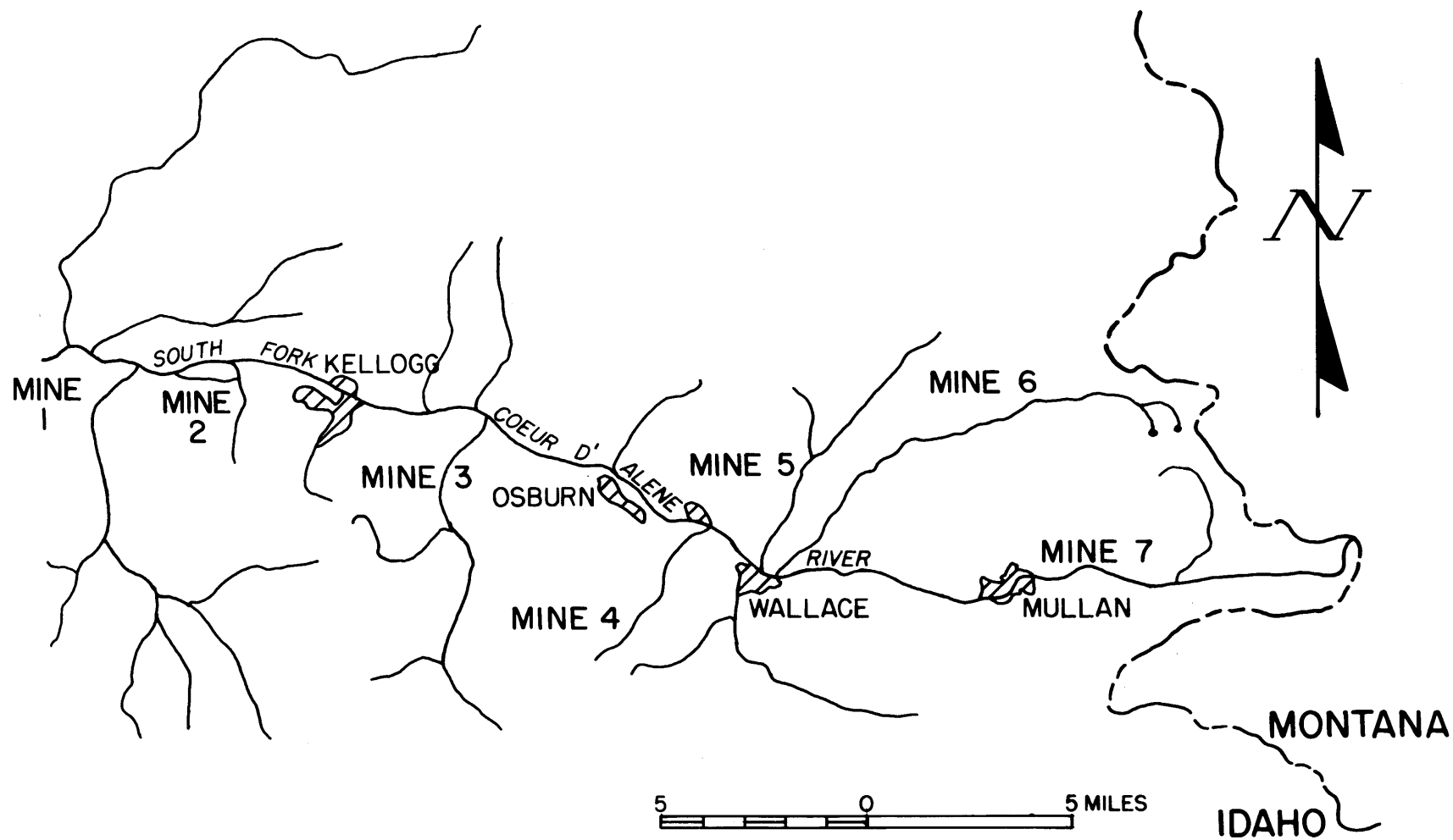


Figure 2 Coeur d'Alene Mining District

Because of the afore mentioned complications, the decision was made to utilize unacidified samples for analysis. The suspended solids were allowed to settle and the supernatant was analyzed. Inherent in this approach is the assumption that the partition of ionic species between water and solid was at equilibrium over the wide range of pH values observed (approximately 2 to 11). The data represented herein are believed to be representative as possible of ion concentrations actually in the water, rather than a combination of ions in the water and ions added to, or removed from the water by a change in the physical-chemical environment within the samples after collection.

Finally, extraction techniques were not utilized in this study. Such techniques are frequently used to lower the detectability limit of dissolved ions by the atomic absorption spectrophotometer. However, it was observed that results were difficult to reproduce consistently when this technique was employed so the decision was made to settle for slightly higher limits of detectability.

Statistical analysis

The statistical procedures used to analyze the data were taken from two programs stored at the University of Idaho Computer Center.

Utilizing these two statistical tests one can determine whether there is any correlation between treatments and whether the treatments differ significantly from one another. Specifically, one can determine if there has been any significant change between inflow and outflow, among seepages, or between a stream above and below any given settling pond for any given element.

Detectable limits for the elemental concentration which was present in trace amounts but below the detectable limit of the instrument or procedure used. The final decision was to use the maximum value possible for the computer analysis (Table 2).

Table 2

Minimum Concentrations Used in Statistical Tests

<u>Parameter</u>	<u>Detectable Limit</u>	<u>Computer Value Used</u>
E.C.	50 mmhos	49 mmhos
Cl	2.0 ppm	1.9 ppm
F	0.1 ppm	0.09 ppm
S.S.	10 ppm	9.0 ppm
Ca	0.1 ppm	0.09 ppm
Cd	0.02 ppm	0.01 ppm
Cu (6/69-8/70)	0.1 ppm	0.09 ppm
(9/70-6/71)	0.05 ppm	0.04 ppm
Fe	0.1 ppm	0.09 ppm
K	0.1 ppm	0.09 ppm
Mg	0.1 ppm	0.09 ppm
Mn (6/69-8/70)	0.1 ppm	0.09 ppm
(9/70-6/71)	0.04 ppm	0.03 ppm
Na	0.1 ppm	0.09 ppm
Pb	0.1 ppm	0.09 ppm
Sb (6/69-9/70)	1.0 ppm	0.9 ppm
(10/70-6/71)	2.0 ppm	1.9 ppm
(2/71)	5.0 ppm	4.9 ppm
Zn	0.1 ppm	0.09 ppm

DISCUSSION

The quality of water discharging from a mining operation can be greatly altered through the use of a settling basin. This change in water quality is, in the majority of cases, an improvement. Comparison of inflow, outflow, and seepage values provides insight into what can be expected to have occurred within a settling pond.

Temperature of the effluent from most operations is near 20°C. This temperature is above the recommended limit for trout survival (McKee and Wolf, 1963, p. 33). The outflow from the settling ponds was near 15°C, which is within the limits of fish survival and very near the mean temperature of the ground water of the area as reflected by seepage temperatures. These data indicate that the settling ponds have retention periods long enough to stabilize the temperature of the mining effluent prior to the discharge of the pond water into the streams of the area. The only mines showing no significant difference in water temperature between inflow and outflow were those in which the effluent was piped a considerable distance prior to entering the settling pond. This transmission allowed the water to cool prior to entering the settling ponds.

The pH values were variable depending on the mining operation. All mines, except Mine 1, revealed a significant change in pH within the settling pond when mean pond inflow and outflow values were compared. A significant reduction in pH was observed in the ponds at Mines 4, 5, 6, and 7, all of which receive only mill wastes. Outflow pH values for these ponds were from 7.4 to 8.4 pH units, which is within the range of values of natural, unpolluted waters of the area.

The Mine 2 pond mean pH effluent value of 2.97 pH units denotes an acid waste.* This low pH is the result of mixing of acid waters from mine drainage (mean pH 3.33), concentrator effluent (mean pH 10.05), and phosphoric acid pond discharge (mean pH 2.39). The larger acid discharge rates for mine drainage (2000-3000 gpm) masks the basic effluent from the concentrator (500 gpm). Also discharging into the settling pond during the period of this study was approximately 1000 gpm of raw sewage with an essentially neutral pH. In combination, these effluents result in an extremely acid condition within the settling pond. Seepage from the pond at Mine 2 is acidic; for example, seepage 2, located adjacent to the settling pond, has a pH of 3.69. This low pH value is the result of seepage from the settling pond complex.

The pond at Mine 3 presented an initial problem when mean inflow and outflow pH values were compared. The mean inflow pH value of 8.83 was significantly lower than outflow pH values of 9.88 for outflow 1 and 10.08 for outflow 2. However, review of the data revealed that on several occasions inflow values were above 11.0 pH units. During a sample set in which samples were taken every six hours over a 24-hour period, a pH value of 11.5 was observed at 5:00 a.m. (Figure 3). This indicated that at certain times during the day the discharge of the mining operation had an extremely high pH, while the majority of the time the effluent had a pH of approximately 8. This high pH water, upon entering the pond, resulted in an apparent mean outflow pH value.

*as noted previously Mine 2 has installed additional treatment facilities, including neutralization facilities, since these data were collected.

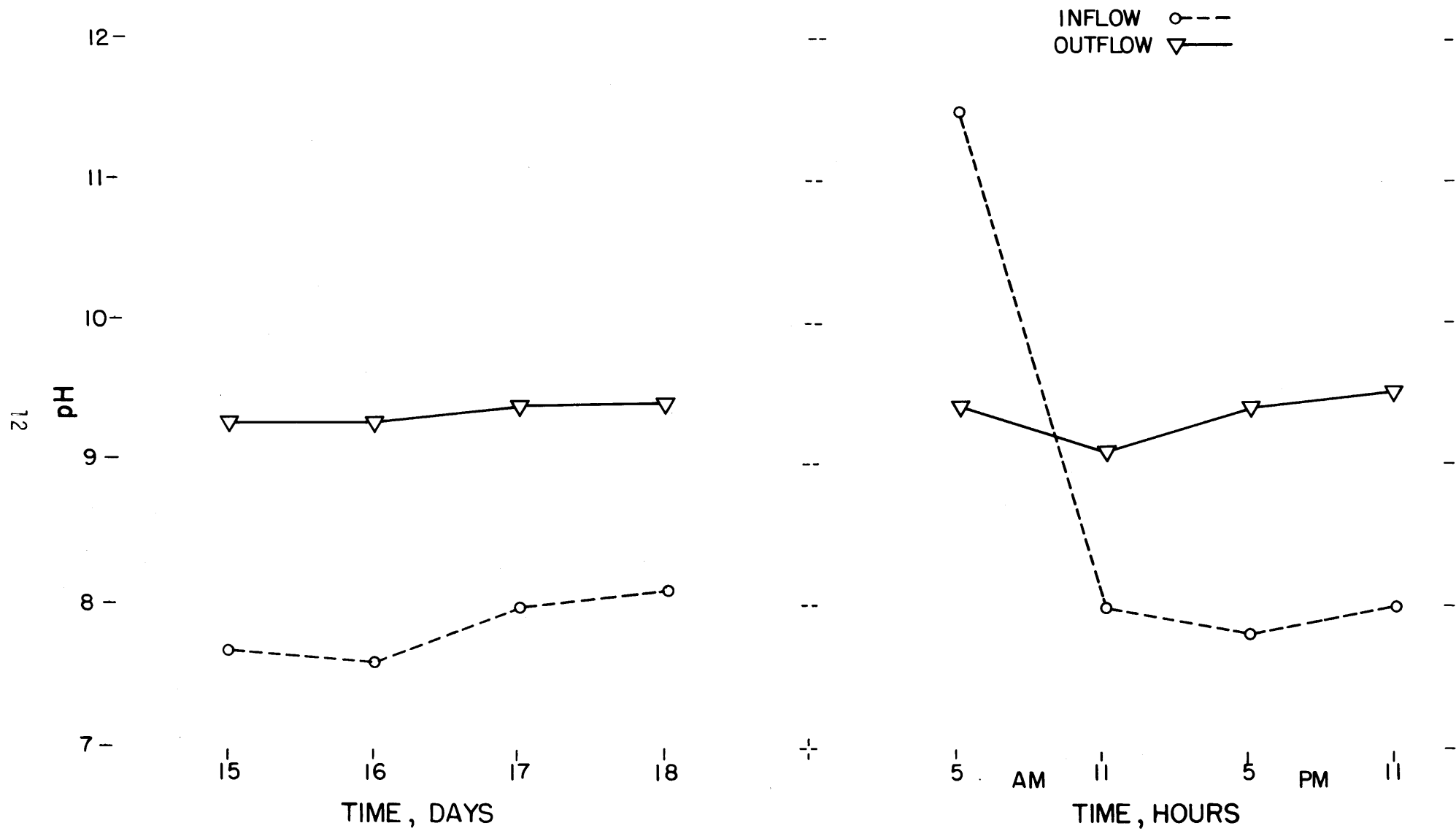


Figure 3 pH vs. Time for Mine 3 Settling Pond Inflow and Outflow (15-22 June 1971)

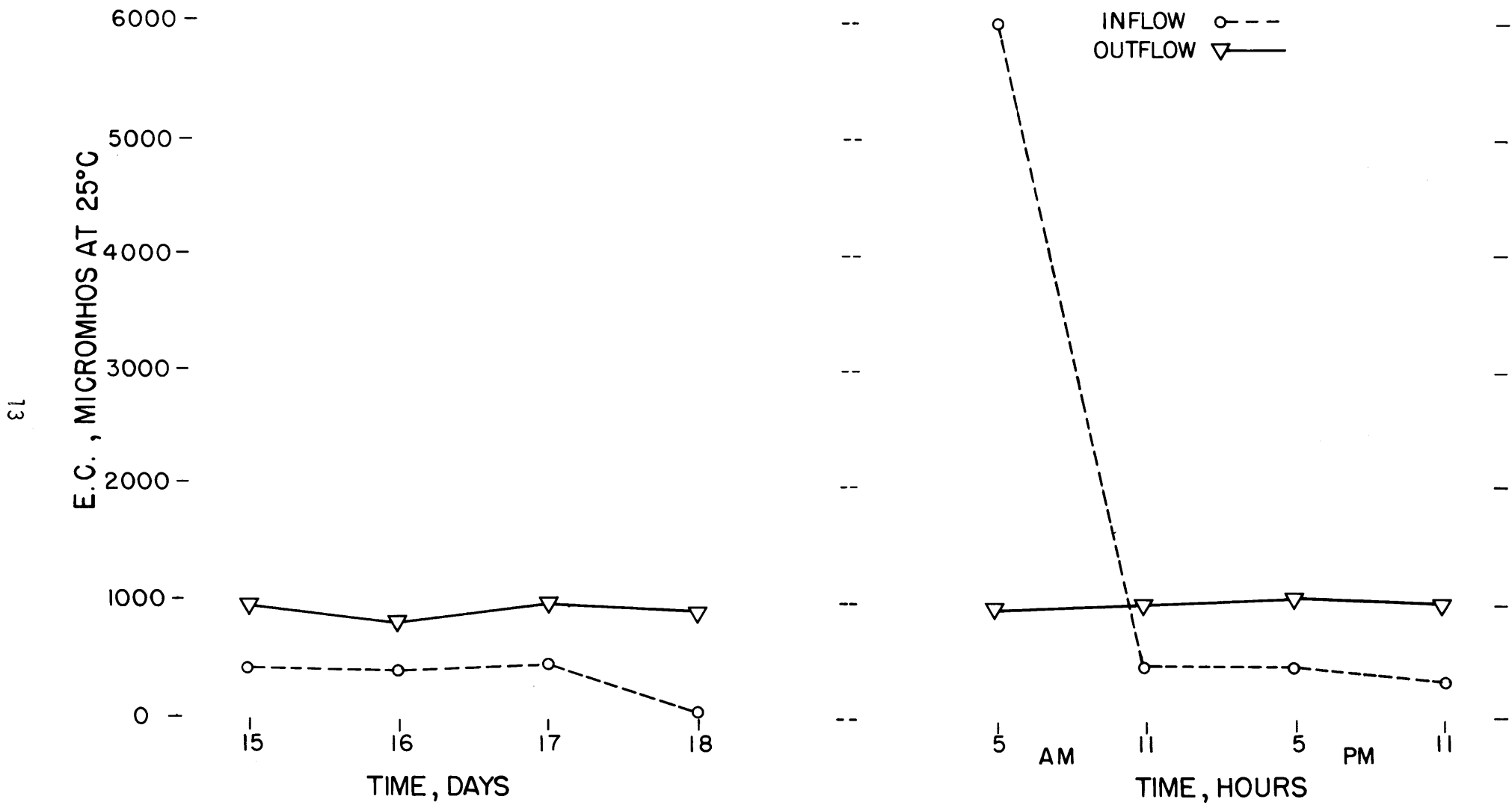


Figure 4 Electrical Conductivity vs. Time for Mine 3 Settling Pond Inflow and Outflow (15-22 June 1971)

higher than the mean inflow pH value. The high pH observed at 5:00 a.m. was the result of discharging the "fouled anolyte" from the electrolytic antimony plant into the settling pond. This waste product is usually discharged into the settling pond during the night shift but is dependent on the production of the antimony plant. This observation points out the difficulty in relying on grab samples to characterize the pond inflows. The same objection does not hold for analysis of pond outflow and seepages because of the mixing and blending they reflect. Seepage water from Mine 3 pond was observed to be slightly more basic than ground water from other seepages and springs indicating some pond water is entering the ground-water flow system through leakage.

Seepage water below pond 6 was observed to become more acidic with increasing distance down-gradient from the settling ponds. The settling pond outflow had a mean value of 8.14 while water from seepage 1 had a significantly lower pH of 6.03. The pH of the ground water decreases to a mean value of 4.32 pH units at seepage 4 located 2300 feet down-gradient from the settling ponds. The decrease in pH of the ground water down-gradient indicates that a mechanism is present which causes the metal sulfides of old mine tailings to be solubilized. The sulfide ion then becomes oxidized to sulfate ion. This reaction creates sulfuric acid which accounts for the increase in H^+ ion concentration and the decrease in pH. Another possible explanation is the role played by microorganisms such as the oxidizing bacteria, *Thiobacillus ferrooxidans*, which are found in some acid mine waters (Lundgren, Vestal, and Tobita, 1970, p. 6; Schmidt and Conn, 1969, p. 54-60; and Galbraith, 1971, p. 48-56). The pH and associated statistics at Mine 6 pond will be discussed in a subsequent section.

Significant decreases in electrical conductivity occurred within four of the seven settling ponds studied. The electrical conductivity of the outflow of these ponds ranged from a mean of 182 micromhos at pond 7 to a mean of 727 micromhos at pond 6. Mean inflow values ranged from 214 micromhos to 824 micromhos. Therefore, some precipitation or adsorption occurred in some of these ponds. The outflow values are within the range stated to be safe for most aquatic life in the western states (McKee and Wolf, 1963, p. 114). Two ponds 2 and 3, displayed considerably higher conductivity values (1155 micromhos and 2615 micromhos respectively) in their outflow than in their inflows. For pond 2 the high conductivity reading in the outflow is the result of mixing of high conductivity values from the mine drainage and phosphoric acid pond overflow with lower readings from the concentrator inflow and sewage water. Because of the higher discharge from mine drainage and phosphoric acid pond discharge, the overall conductivity of the settling pond is high.*

Mine 3 pond outflow was higher in mean conductivity than the inflow to the settling pond. Upon investigation of the data, it was observed that on several occasions electrical conductivity values in the inflow were in the range of from 5000 to 7000 micromhos. During a 24-hour sampling period it was observed that at 5:00 a.m. the conductivity in the inflow reached a maximum value of 6000 micromhos while during the remainder of the time the conductivity of the inflow was approximately 400 micromhos (Figure 4). Because a majority of the sampling was carried out during the day, these high electrical conductivity values were not encountered except on a few occasions. As a result, the water

*Since these data were collected the sewage and phosphoric acid plant overflow have been removed from the Tailings pond at mine 2.

within the pond, and consequently the outflow, would have a higher mean conductivity value than the inflow because of sampling schedules

Chloride concentrations observed within the settling ponds were not high enough to be harmful to animals or most aquatic life. Mine 3 had the only settling pond in which an increase in mean chloride concentration was detected in the outflow when compared to inflow concentrations. This increase is thought to be from the same cause as described for pH and conductivity. All other pond outflows sampled indicated a decrease in chloride concentration in the outflow and were below 11 ppm chloride. Seepage chloride concentration was also low; below 10 ppm for most of the stations.

Fluoride concentration is a problem in only one of the operations studied. Mine 2 phosphoric acid inflow had a mean concentration of 503.64 ppm fluoride which results from the manufacturing process for phosphoric acid. This high concentration is reduced by dilution to some extent within the settling pond. Outflow from the phosphoric acid pond had a mean of 348.3 ppm fluoride and this is further reduced by dilution from mine water, sewage water, and concentrator effluent to a mean value of 116.8 ppm fluoride in the settling pond complex outflow. This concentration (116.8 ppm fluoride) is exceptionally high and, at the discharge point, creates a significant increase in fluoride concentration within the South Fork of the Coeur d'Alene River (Mink, Williams, and Wallace, 1971, p. 14)*. Seepage at Pond 2 is also high in fluoride concentration indicating discharge of pond water to the ground-water flow system of the valley. All other stations sampled were low in fluoride concentration; most exhibited mean concentrations of less than 2 ppm fluoride.

Suspended solid values of pond inflow, outflows, and seepages indicate that when carefully and properly managed, the settling ponds can do an effective job of removing suspended solids. All ponds studied reflected a 99+ percent removal of suspended solids. All outflow values were below 70 ppm suspended solids except Mine 3 pond outflow, which had a mean value of 708 ppm suspended solids. This high value was the result of an inadequate seal around the decant pipe within the settling pond and resulting leakage through the pipe. Suggested limits on suspended solids within streams are below 200 ppm for aquatic life (McKee and Wolf, 1963, p. 280) however recently issued waste discharge permits limit suspended solids much more stringently. Seepages from all ponds studied were below detectable limits of 10 ppm suspended solids.

High concentrations of calcium were observed in the phosphoric acid plant effluent of Mine 2. This, in turn, caused a high reading of 153.8 ppm to exist in the outflow of the settling ponds for Mine 2. Although the calcium readings for Mine 2 were higher than concentrations observed in other mines, they are not at levels which would be toxic to aquatic life and would possibly help reduce the toxicity of other elements (McKee and Wolf, 1963, p. 151-152). However since these data were collected the source has been removed from the pond.

Cadmium concentrations were above detectable limits at two operations, (all stations at Mine 2 and within the seepages at Mine 6). Both mine drainage and phosphoric acid plant effluent were sources of cadmium in the outflow of the settling pond for Mine 2. A mean concentration of 0.30 ppm cadmium in the out-

*as noted previously the phosphoric acid plant effluent has been removed from the pond since these data were collected. However preliminary data collected more recently suggest that fluoride is still high in seepages around the pond.

flow of Pond 2 caused a significant increase in cadmium concentration in the South Fork of the Coeur d'Alene River below the discharge point of the settling ponds. The concentrations within the South Fork were high enough to be toxic to aquatic life when these data were collected (Mink, Williams, and Wallace, 1971, p. 14) however, additional treatment facilities have now been installed by Mine 2. Seepages located adjacent to the settling ponds for Mine 2 are also high in cadmium and add to the cadmium concentration detected in the South Fork of the Coeur d'Alene River via the ground-water flow system.

Cadmium concentrations within the seepages below Pond 6 are not the result of the settling pond inflow or outflow as these two stations were below 0.03 ppm cadmium. Mean cadmium concentrations for seepages 2 and 4 were 0.21 ppm, although seepage 1 had a mean cadmium concentration of 0.03 ppm. The low concentration of cadmium within the inflow, outflow, and seepage 1 along with the high concentration in the ground water at a distance below the settling pond indicate the source of cadmium is located within the aquifer.

Ponds 1, 2, and 6 had detectable copper concentrations in inflow, outflow, and seepage samples. Ponds 1 and 6 had a 41.5 percent and 51.2 percent decrease, respectively, in copper concentration within the settling pond; however, the outflows of both ponds were sufficiently high to cause concern. Seepage concentrations below these mine settling ponds were below the detectable limit of 0.1 ppm copper. Although settling ponds with neutral or high pH reduce copper concentrations, some copper escapes.

*Pond 2 had high mean copper concentration in all inflows with the concentrator effluent being 30.7 and 66.7 percent greater than the mine drainage and phosphoric acid plant effluent, respectively. These high copper sources and the low pH of the settling pond result in a high reading of 0.75 ppm copper in the outflow of the settling pond. Seepage 2, located adjacent to the settling pond, had a mean copper concentration of 1.13 ppm. Higher concentration in seepage is the result of leaching tailings used in construction of the pond dike.

The only significantly high iron concentration was observed in the mine drainage of Mine 2. This station had a mean of 51.5 ppm iron which caused a mean concentration of 36.1 ppm iron to occur in the outflow of the settling pond. The high iron concentration in Mine 2 pond is associated with the low pH of the acid mine drainage. At this low pH (2.97), iron will stay in solution and neither become oxidized nor removed from solution. This concentration, coupled with low pH, has been reported lethal for some forms of aquatic life (McKee and Wolf, 1963, p. 34) and could cause toxic conditions to exist within the South Fork of the Coeur d'Alene River. All other stations had low iron concentrations and no significant difference could be detected between inflow and outflow concentrations. The pH in all other ponds except Mine 2 pond was alkaline, causing any iron in solution to oxidize and precipitate or be adsorbed as a ferric hydroxide.

A decrease in potassium concentrations was observed in all settling ponds. In all cases, the potassium concentrations observed in the outflows and seepages were below toxic limits recommended by McKee and Wolf (1963, p. 243).

*Mine 2 has installed additions treatment facilities since these data were collected.

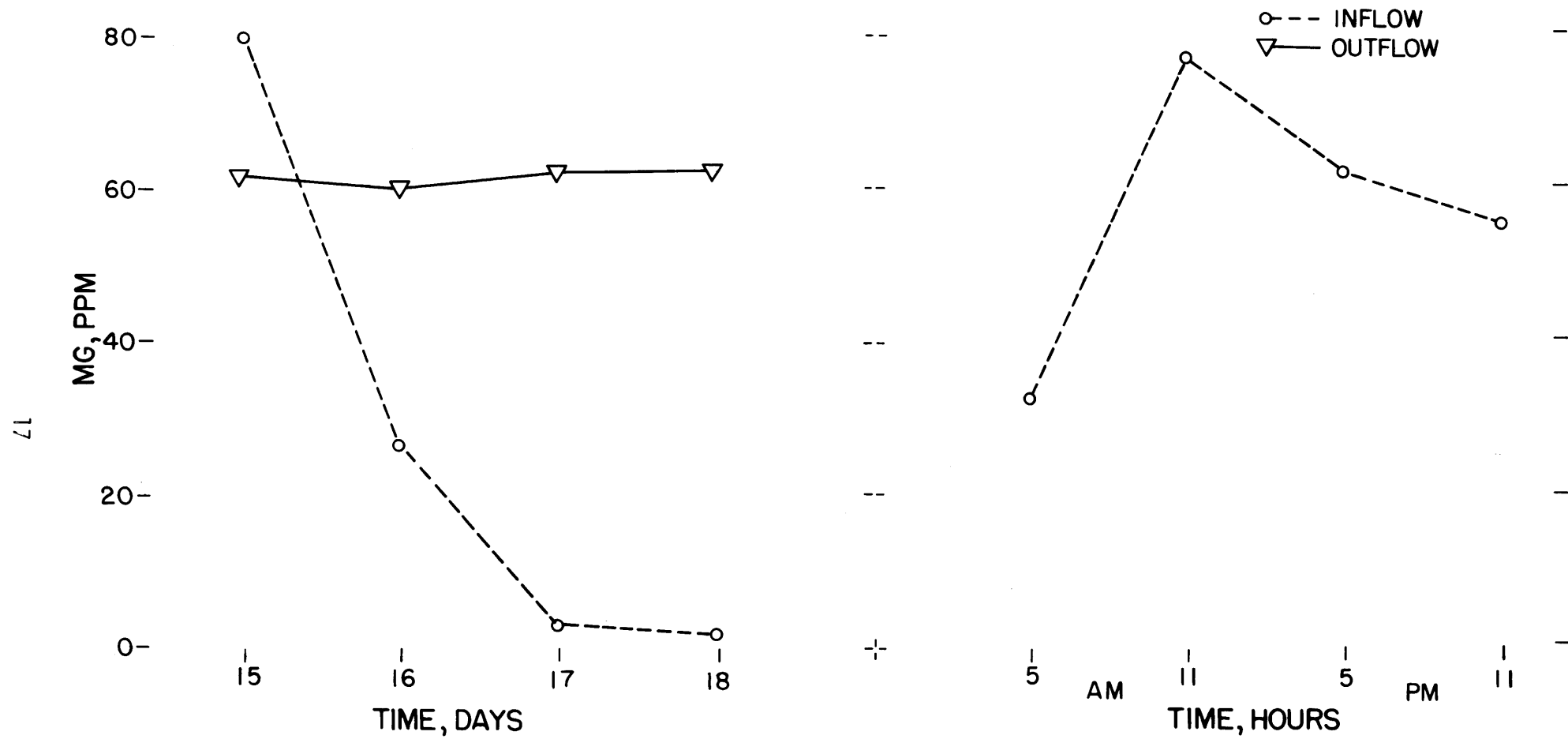


Figure 5 Magnesium Concentration vs. Time for Mine 6 Settling Pond Inflow and Outflow
(15-22 June 1971)

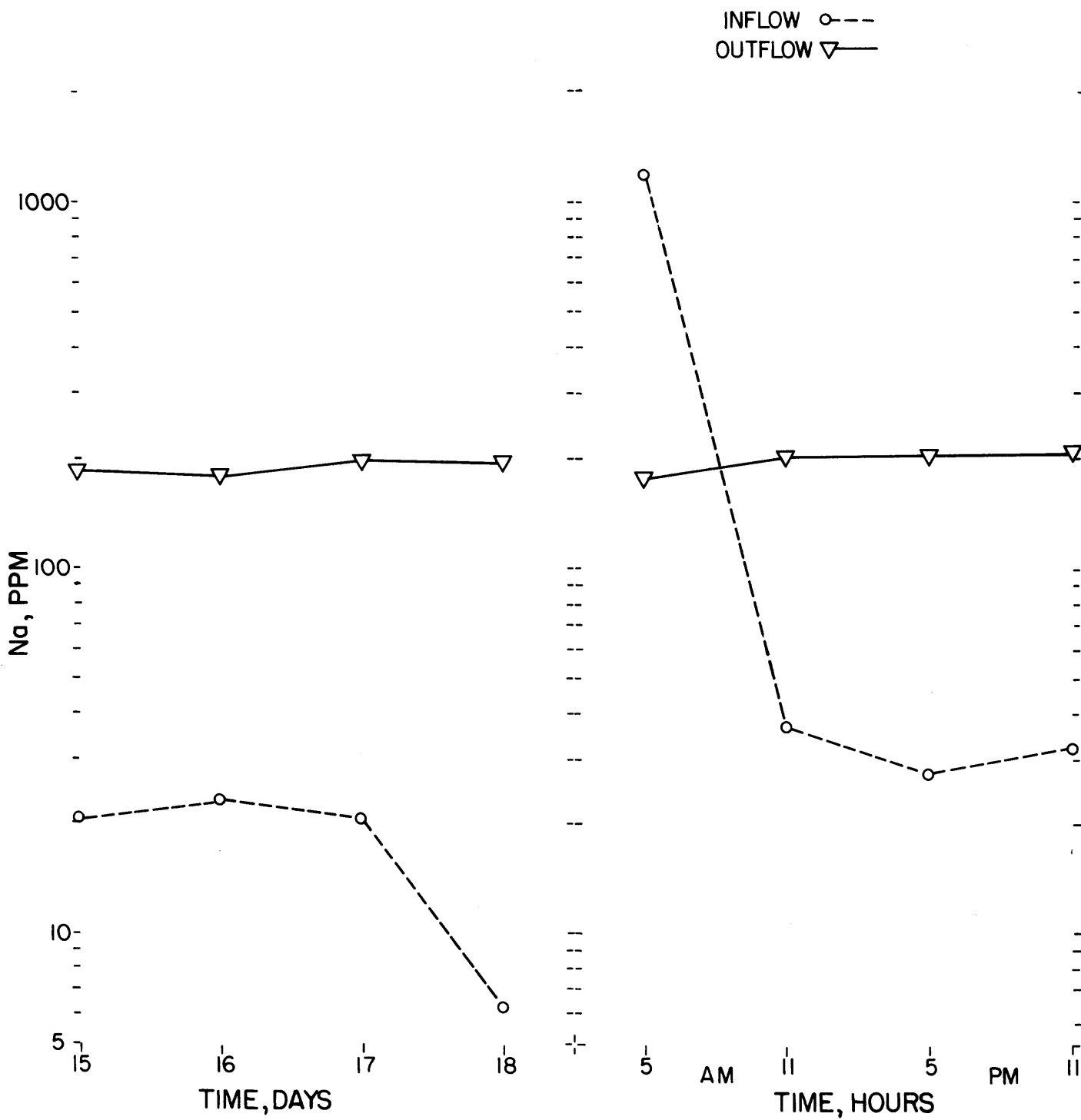


Figure 6 Sodium Concentration vs. Time for Mine 3 Settling Pond
Inflow and Outflow (15-22 June 1971)

All settling ponds except that at Mine 5 showed significant decreases in magnesium concentrations from inflow to outflow values. Mine 6 pond had a significant increase in magnesium concentration between inflow and outflow due to variability within the inflow (Figure 5). Sampling in a 24-hour period showed the inflow magnesium concentration ranged from a low of 32.5 ppm to a high of 77.0 ppm. A range of from 2.3 ppm to 80.0 ppm magnesium was observed during a 5-day sampling period. Considering the time of day and the day of the week that a majority of the samples were collected, the mean magnesium value obtained for the inflow was slightly low. The mean outflow value, however, is the result of mixing within the pond and would not be influenced as readily as the inflow value. The magnesium concentrations observed in the settling pond outflows or seepages are not of high enough concentration to be toxic to aquatic or animal life.

The only significant source of manganese within the mines studied is the mine drainage of Mine 2. Mean manganese concentration at this station was 30.3 ppm, which is the cause of the high mean concentration of 38.7 ppm detected in the outflow of the settling pond. Seepage water at both Mines 1 and 2 was significantly higher in manganese than seepage concentrations at the other mines. The high manganese concentrations at Mines 1 and 2 are not high enough to be toxic to animal life but may be detrimental on an economic or esthetic basis and are above recommended limits for aquatic life.

Higher concentrations of sodium were observed in the phosphoric acid plant effluent of Mine 2 and in the pond at Mine 3 than in other ponds. These two settling ponds had mean sodium concentrations in excess of 100 ppm. After dilution, the concentration of sodium within Mine 2 settling pond was reduced to 34.6 ppm, which is within acceptable limits.

Mine 3 sodium concentration was observed to be nearly twice as great in outflow 2 and the seepage, and almost four times as great in outflow 1 as the sodium concentration observed in the pond inflow. The source of the high sodium concentration in the outflow is similar to that described for the anomalous pH and electrical conductivity values. During early morning hours, the sodium concentrations were observed to reach 1200 ppm while during the majority of the day sodium concentration was approximately 30 ppm (Figure 6). This surge of high sodium effluent was not detected in the inflow during most of the sampling but would affect the settling pond concentration through mixing and result in higher apparent sodium concentrations in the pond effluent and seepage water than in the inflow.

Lead concentrations are high at two locations. Mine 2 displays high lead concentrations in the mine drainage which caused lead concentrations over 2 ppm in the outflow of the settling pond and values of over 1 ppm in seepage samples adjacent to the settling pond during the period of this study. No decrease in lead concentration within Mine 2 pond could be detected except for dilution; this is probably due to the low pH of the settling pond water. This amount of lead exceeds recommended limits for water used for animal or aquatic life (McKee and Wolf, 1963, p. 206-207). Subsequent to this study the operation installed additional treatment facilities.

The second source of lead is in the seepages below Mine 6 settling ponds. These seepages have lead concentrations ranging up to 0.95 ppm. Since the mean values for the inflow and outflow of the settling ponds are at or below 0.1 ppm, the source of lead must be other than the pond water. High concentrations of lead and zinc in soil samples (Galbraith, 1971, p. 96) indicate that the source

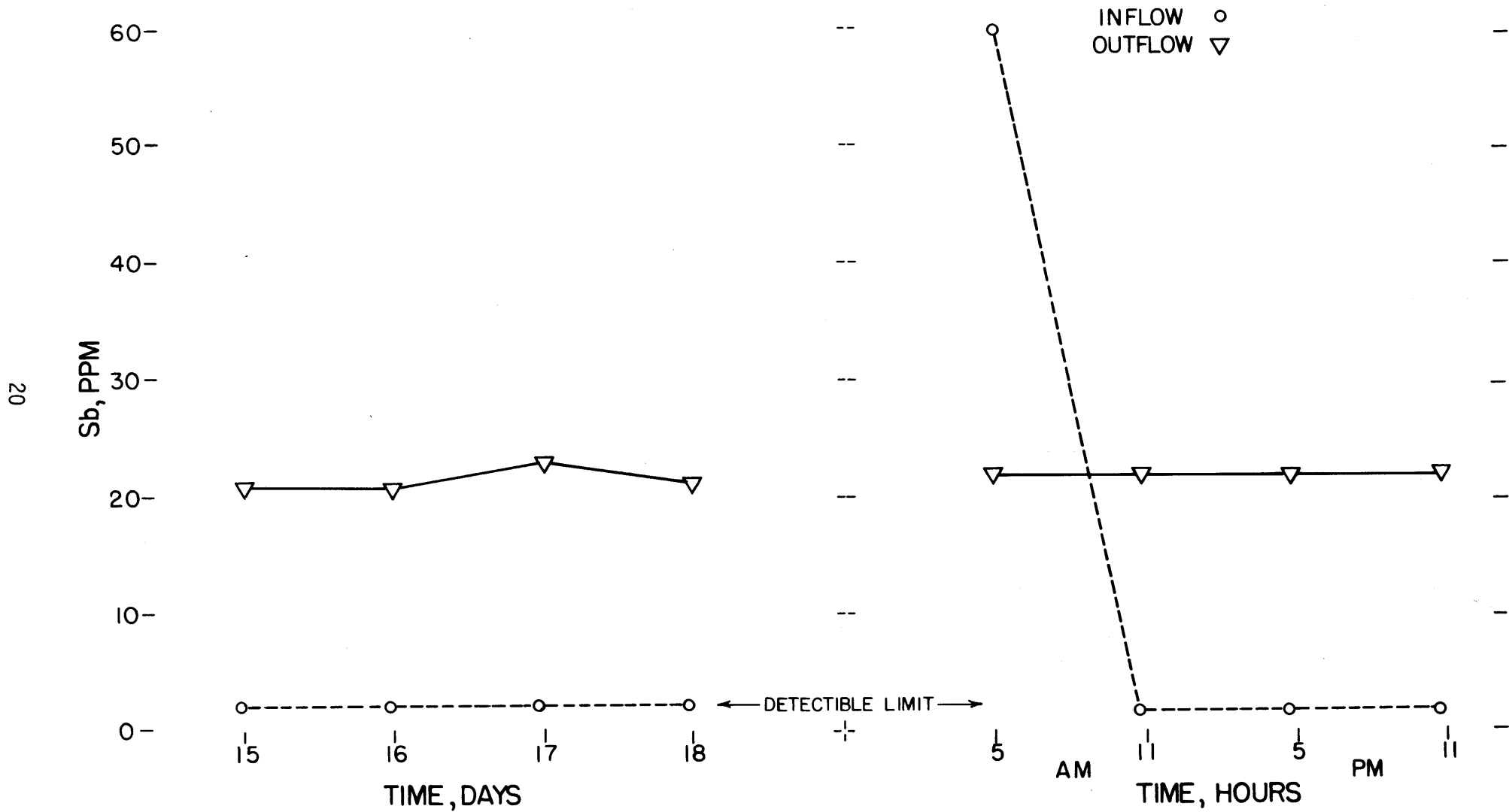


Figure 7 Antimony Concentration vs. Time for Mine 3 Settling Pond Inflow and Outflow (15-22 June 1971)

of metals may be within the aquifer (discussed subsequently).

Antimony was detected only in Mine 3 pond (detectable limit of 5.0 ppm). Mean inflow values of 8.9 ppm antimony were observed to be much less than outflow values of 79.8 ppm and 33.3 ppm. Analysis on a 24-hour basis revealed that during the early morning hours the inflow to the settling pond had antimony concentrations above 60 ppm, while during the rest of the day the inflow antimony concentrations were below the detectable limit of 5 ppm (Figure 7). Since sampling of this pond occurred during mid-day throughout most of the study, this high concentration of antimony was not measured and, as a result, the observed mean inflow antimony concentrations were below detectable limits. The high antimony concentration of the outflow is at a level which is considered toxic (McKee and Wolf, 1963, p. 138-139) and causes a detrimental effect to the stream below the pond outflow. It has been observed that, upon contact with stream water of a lower pH value, the antimony in the effluent precipitates and settles to the bottom eliminating all benthic life in the stream.

Zinc concentration was observed to be high in the mine drainage at Mine 2 and within seepages at Mines 1, 2, and 6. Mine drainage at Mine 2 resulted in mean zinc concentrations in excess of 100 ppm being discharged in the outflow of the settling pond during the period of this study. The high mine drainage concentration plus seepage values along the banks of the settling ponds, (as high as 44 ppm zinc) caused a significant increase in zinc concentration to exist in the South Fork of the Coeur d'Alene River prior to the installation of new treatment facilities (Mink, Williams, and Wallace, 1971, p. 14). More recent data suggest that seepage is still contributing zinc to the river.

Because of the low pH in Mine 2 pond, there could be substantial stripping of zinc and other heavy metals from the sediments in suspension and on the bottom and sides of the settling pond. Inadequate flow rates for various inflows to the settling pond and the variable chemical nature of the inflows cause insurmountable problems in calculating the amount of ions going into solution because of the low pH.

PROPERTIES OF MINE TAILINGS

A study was recently completed which determined the cation exchange properties of the mine tailings. Tailings samples from Mine 6 were used in the analyses, and it was observed that the cation exchange capacity of the tailings is low compared to most soils. Equilibrium equations have shown that zinc will be released from the sediments to increase the concentration of zinc in the pond effluent in spite of the favorable selectivity coefficient of the tailings for zinc over sodium. A pH dependency was also observed with a maximum exchange capacity at a pH of 10.0 and a minimum exchange capacity from 4.0 to 6.0 pH units (Toukan, 1971, p. 18-25).

Ellsworth (1972) found the cation exchange for the sediments from the inflows of settling ponds 2, 3, 4, 5, 6, and 7 was also very low, ranging from 0.31 m.e.q./100 gm to 2.10 m.e.q./100 gm. The one exception was the phosphoric acid plant discharge which had a total cation exchange capacity of 73.66 m.e.q./100 gm (Ellsworth, 1972, p. 23, 45). Both authors concluded the natural cation exchange process for the removal of appreciable concentrations

of heavy metals is unlikely. However, this observation should not be viewed as a generalization applicable to other mining districts because the parameters are heavily dependent on rock type present.

Electrophoretic mobility data for the particulates were observed to be similar for concentrator wastes discharging into Ponds 2, 3, 4, 5, 6, and 7. The maximum colloidal stability occurred between pH 4 and 7 with minimum stability at pH 4 or below, and pH 9 or above. Maximum agglomeration of the colloids occurred at a pH of 10 and above and produced a sizable increase in particular size. The maximum zeta potential for the concentrator wastes for Mines 2, 3, 4, 5, 6, and 7 ranged from a -12.0 mv to -21.0 mv; an indication that the colloids are on the threshold of agglomeration. Mine 2 phosphoric acid plant discharge and mine drainage had positive maximum zeta potentials of +26.0 and +9.0 mv, respectively (Ellsworth, 1972, p. 23-32).

Analyses of the data indicate that problems exist at three ponds studied (ponds 2, 3, and 6). These problems stem from sources of inflow to the settling pond for Mines 2 and 3 and seepage or ground-water movement through old tailings below the ponds at Mine 6. The problem at pond 6 will be discussed in a subsequent section (see page). Both ponds 2 and 3 discharge industrial effluent into the settling ponds and this is the source of a majority of the problems. The exception is mine drainage from Mine 2 which is discharged into the settling pond. The Mine 2 drainage has a low pH and is high in electrical conductivity, cadmium, iron, manganese, lead, and zinc concentrations. Pond 2 also has similar problems with the phosphoric acid plant effluent which is low in pH and high in conductivity, fluoride, calcium, cadmium, and sodium concentrations.

Because of the low pH of the settling pond, these elements stay in solution, and the concentration decreases only through dilution. All elements mentioned, except calcium and sodium, are found in the discharge of the settling pond in toxic amounts or above recommended limits with respect to some forms of life. Seepage from the settling pond is also observed to be high in a majority of the elements mentioned above. This indicates some of the water from the settling pond is entering the ground-water flow system and affecting the ground-water quality.

The pond at Mine 3 also receives industrial waste from an electrolytic antimony plant. This plant produces effluent with high pH, electrical conductivity, sodium, and antimony. However, part of the problem at Mine 3 is due to inefficient operation of the settling pond. Outflow 1 has a poor seal, and pond water is seeping into the decant line. This causes solids to be discharged into the stream along with sodium and antimony.

Several of the settling ponds studied are effective in treating the effluent received. In each of these cases, the inflow to the settling pond consists of only the concentrating process effluent and no effluent from any smelting or refining process. This includes Mines 1, 4, 5, 6, and 7. The major function of these ponds has been the reduction of suspended solids. In every pond studied there has been a 90 to 99 percent reduction in suspended solids. As a result of this reduction, these ponds enhanced the establishment of benthic life in the South Fork of the Coeur d'Alene River (Savage, 1970, p. 24).

The ponds also have stabilized the temperature of the effluent from the mining operation to either equal or nearly equal the temperature of the receiving waters. The ponds for Mines 1, 4, 5, 6, and 7 have also reduced the pH slightly to a range close to that of natural surface water of the area. Electrical conductivity, potassium, and magnesium were reduced in all ponds, and copper content was reduced from 40 to 50 percent in the ponds at Mines 1 and 5. All other elements in outflows of settling ponds at Mines 1, 4, 5, 6, and 7 are in low concentrations.

Settling pond design and operation has caused problems with respect to seepage water at Ponds 2 and 6. These problems and their solutions will be discussed in a subsequent section. Settling ponds 4, 5, and 7 utilize a method of peripheral inflow resulting in an adequate seal around the pond dike and, consequently, minimum seepage. A discussion of design techniques will be given in the next section.

MINE SETTLING PONDS AND GROUND-WATER POLLUTION

Seepage from some of the settling ponds has contributed to the pollution problem along the South Fork of the Coeur d'Alene River and its tributaries. Some tailings ponds have high concentrations of heavy metals in their seepage waters. Seepages at Mine 1 contain 19 to 20 ppm zinc and are the result of leaching of sediments within the settling pond. The settling pond is one of the oldest in the Coeur d'Alene Valley and contains a large portion of sediment which may contain an appreciable amount of zinc sulfide because of inefficient recovery methods used in the past. More study should be done on the pond to determine the effect of the pond on the ground water of the area and to ascertain whether correction measures are possible.

Pond 2 also displays high concentration of some constituents in seepage water. Two seepage sources analyzed during the study were located along the outside of the north dike of the settling pond (Figure 4). Seepage 1 and 2 were observed to be significantly high in several elements analyzed during the study. Table 3 gives concentrations observed in seepages for pond 2.

As shown in Table 3, concentrations of fluoride, cadmium, copper lead, and zinc are high and could have a detrimental effect on the aquatic environment. Considering the characteristics of the sand and gravel aquifer below the pond, the seepage water is undoubtedly entering the local ground-water flow system and discharging into the South Fork, Coeur d'Alene River.

A peripheral discharge system was installed by the mining company to seal the dike around the settling pond. The system reduced the amount of water being discharged in the seepages analyzed and, in fact, dried up a number of smaller seepages around the dike and along the South Fork of the Coeur d'Alene River.

The settling pond at Mine 3 also has leakage problem around the sides and lower end where water with high sodium and antimony concentration escapes. This seepage affects the quality of the stream flowing beside the settling pond. Significant increases in pH, sodium, antimony, magnesium, and potassium have been observed below the settling pond. During the study a distinct odor of H_2S was detected in the vicinity of the settling pond; the gas emanated from the seepages. Much of the problem with the Mine 3 pond could be eliminated through proper pond design and operation.

Table 3
Water Quality for Mine 2 Seepage
(mean values)

	Seepage	
	<u>1</u>	<u>2</u>
Temp.	13.4 ⁰ C	15.6 ⁰ C
pH	5.20	3.69
E.C.	1675 micromhos	3459 micromhos
Cl	9.47 ppm	26.28 ppm
F	24.85 ppm	138.22 ppm
Ca	129.71 ppm	220.97 ppm
Cd	0.15 ppm	0.26 ppm
Cu	0.07 ppm	1.13 ppm
Fe	13.41 ppm	35.18 ppm
K	18.59 ppm	29.05 ppm
Mg	45.61 ppm	40.06 ppm
Mn	35.53 ppm	34.31 ppm
Na	44.32 ppm	78.35 ppm
Pb	0.21 ppm	1.26 ppm
Sb	<5.0 ppm	<5.0 ppm
Zn	44.15 ppm	36.29 ppm

Mink, Williams, and Wallace (1971, p. 13) observed that the station adjacent to the Mine 3 settling pond was considerably higher in mean sodium concentration than other stations on the South Fork of the Coeur d'Alene River. It was concluded that seepage from the settling pond was affecting the water chemistry of the South Fork and the station was discarded as a comparative station to determine the effect of the pond on the South Fork of the Coeur d'Alene River. Seepage samples collected along the bank of the South Fork of the Coeur d'Alene River were observed to be high in sodium, with a mean value of 243.65 ppm.

Effect of jig tailings on water quality

Metals in the stream flowing beside Pone 6 were observed in a study by Mink, Williams, and Wallace in 1971. Prior to that study, the anomalous metal concentrations had been attributed directly to settling pond effluent. An increase in zinc, cadmium, and fluoride concentrations were observed in the South Fork of the Coeur d'Alene River downstream from its confluence with the creek. A mean concentration of 3.1 ppm zinc was observed below the confluence of Canyon Creek with the South Fork while upstream portions of the South Fork of the Coeur d'Alene River showed a mean zinc concentration of 0.2 ppm zinc. Thus, Canyon Creek adds considerable zinc to the South Fork.

Mink, Williams, and Wallace (1971) noted that the concentration of zinc in the creek was approximately three times that in the effluent from the settling pond located near the stream. Springs and seeps analyzed down-gradient from the settling pond gave preliminary evidence of an increase in zinc concentration in ground water with distance downgradient from the settling pond.

More recently, soil and sediment samples (much of which consist of old tailings) collected from the creek bed and along the sides of the stream have been found to contain up to 6.0 percent lead and 4.4 percent zinc. Copper concentrations of the sediments have a mean value of 430 ppm.

Analyses of plants collected from the Canyon Creek area have mean zinc, lead, and copper concentrations of 80 ppm, 60 ppm, and 10 ppm, respectively. These values are about four times greater than respective concentrations in plants growing in areas which did not receive tailings in early mining days.

The valley containing settling ponds for Mine 6 is not the only area where this problem is occurring within the Coeur d'Alene district. Zinc concentrations are also high in the stream where Mine 5 settling ponds are located. Old jig tailings are mixed with the alluvial deposits at several locations in this valley. Several of these deposits are immediately upstream from the present location of Mine 5. The mechanisms proposed for the Mine 6 valley could account for the high zinc concentration within the stream flowing adjacent to Mine 5. The deposits within the Mine 5 valley are not as extensive as those described in the previous discussion for Mine 6, but could contribute substantially to the dissolved metal load of the stream. Also the settling pond for Mine 5 has been constructed with a peripheral discharge system, and, as a result, leakage from the pond is minimal, and it does not act as a major recharge source for the valley aquifer.

Other evidence of the ground-water pollution problems exists near Osburn along the South Fork of the Coeur d'Alene River (Mink Williams, and Wallace, 1971, p. 20). The Zanetti well, an industrial well penetrating alluvium of the valley, is reported to contain a mean concentration of 12.9 ppm zinc concentrations observed during periods of heavy pumping.

Norbeck (1972) observed several wells in the South Fork Valley which were anomalous in heavy metal concentration and low in pH. A well located near the Zanetti well at Osburn contained 12 ppm zinc, and a well in the valley bottom at Silverton contained 9.2 ppm zinc. Wells located between Kellogg and Smelterville operated by Mine 2 were observed to have a pH of 5.4 and zinc concentrations from 30 ppm to 50 ppm. The sediments in the vicinity of all of these wells contain deposits of jig tails mixed with the alluvium of the valley and could be subject to the same leaching mechanism previously described for the area below the ponds of Mine 6.

Solution to the problem

The data presented herein indicate that ground-water contamination can result from tailings ponds constructed under certain conditions. In the case of Mines 1, 3, and 6 the settling ponds have a single point inflow for tailings. The ponds are installed in a sand and gravel aquifer, the upper portion of which is intermixed with old jig tailings. Under the present design, clean water lies against permeable embankments causing leakage and recharge of the ground-water flow system. A portion of the decanted effluent from Pond 6 also flows onto the aquifer. Consequently, the water table is raised into contact with the old jig tailings, causing leaching of metals. If contact of the ground-water table with old jig tailings in the upper portion of the sand and gravel aquifer is to be minimized, both sources of recharge water should be minimized. Elimination of recharge from the decant system effluent can be accomplished by diverting the effluent directly into the adjacent creek instead of allowing it to flow onto the aquifer or by lining the ditch carrying the effluent.

The rate of leakage by seepage from settling ponds can be minimized by utilizing a technique described by Kealy (1972) during an investigation of a settling pond located in northeastern Washington. The physical features of that pond are presented by Kealy (1970), Kealy and Busch (1971), and Kealy and Williams (1971). It contains tailings from a lead-zinc mine which produces approximately standard grind mill tailings. The pond has a peripheral discharge system and the water is decanted from the clean portion of the free water area near the center of the pond.

Observed field ground-water conditions indicated that two basic types of ground-water flow systems exist beneath the settling pond depending on the time of the year: (1) a saturated connected system; that is, tailings, embankment, and substrata are hydraulically connected during high ground-water condition; and (2) a disconnected system during low ground-water in which an unsaturated zone exists directly beneath the tailings. Both the hydraulically connected and hydraulically disconnected systems were modeled using the finite element method. However, the model output showed that maximum flow occurs with the hydraulically disconnected system. If the flows from each of the elements at the bottom of the slime zone are summed and the unit width of the two-dimensional cross section extended to cover one acre, then the rate of leakage from the bottom of the pond, as predicted by the model, is 140 gallons per day per acre.

Further, manipulation of the free water body in the settling pond revealed that the most significant ground-water outflow beneath the pond must come from the natural ground-tailings contact and from the slime-coarse fraction interface. Therefore, by controlling the pond water level, the leakage along the slime-coarse fraction contact can be minimized, if not eliminated. In addition, proper preparation of the natural ground-pond contact would eliminate leakage along this contact also. Therefore, the transmission from the pond of water or water containing detrimental substances can be essentially eliminated. However, it is critical that this condition results only if the pond water level and permeability (slime distribution) at the two contact areas are controlled. Control can be maintained with a peripheral discharge system and with a decant system designed to maintain the free water surface over the slime zone. This type of system is also more stable structurally because the phreatic line intersects the embankment near its base; thereby providing for a maximum factor of safety. The relation between the phreatic line delineated by the mathematical model and slope stability is presented by Kealy and Williams (1971).

The field piezometer water levels are in close agreement to pressures produced by the mathematical model, thus confirming that a pond "yet-to-be-built" can be designed.

The model output also shows that if a pond is properly designed and managed (according to the above recommendations) and placed on a somewhat permeable base, an impervious zone will soon develop which inhibits rapid recharge of the ground-water flow system. Thus, even an initially "environmentally bad" seepage system becomes environmentally safe if the peripheral discharge system is used and properly managed, if the water pool level is controlled properly, and if the free water body is large enough to permit good retention time.

To summarize the proper design techniques which should be employed on settling pond constructions where the so called upstream method is utilized, initial corrective measures consist of preparing the site to minimize pond leakage and diversion of the decant water to non leachable discharge points. Elimination of leakage to the ground-water flow system is complex. A field study and the output of a finite element model of a second pond reveals that leakage from the first pond studied (and from other ponds receiving standard mill grind tailings) can be at least minimized by:

- 1) employing a peripheral discharge system to inject the tailings into the settling pond,
- 2) insuring that the tailings supply contains a coarse fraction sufficient to provide an outer embankment with a permeability three to four orders of magnitude greater than that of the inner slime zone. This permeability distribution will result in a phreatic line which will provide acceptable slope stability,
- 3) designing and managing the decant system so as to maintain the free water body over the slime zone so that leakage through the outer coarser portion of the embankment is prevented,
- 4) lowering the permeability of the natural ground-tailings contact with chemicals or by other means so that early leakage along this contact is minimized,
- 5) designing the settling pond free water area so that sufficient retention

time for removal of all suspended solids is provided throughout the life of the pond. Settling velocities can be predicted from knowledge of the tailings to be produced. The addition of flocculating agents and pH control agents may be required at this stage,

- 6) insuring that no waters other than mill wastes (or similar wastes) enter the pond. In particular, wastewater with low pH and high concentrations of heavy metals should not be allowed to enter the pond unless further treatment of the effluent is anticipated.

Other Tailings pond construction techniques which can minimize leakage are discussed by Williams (1975).

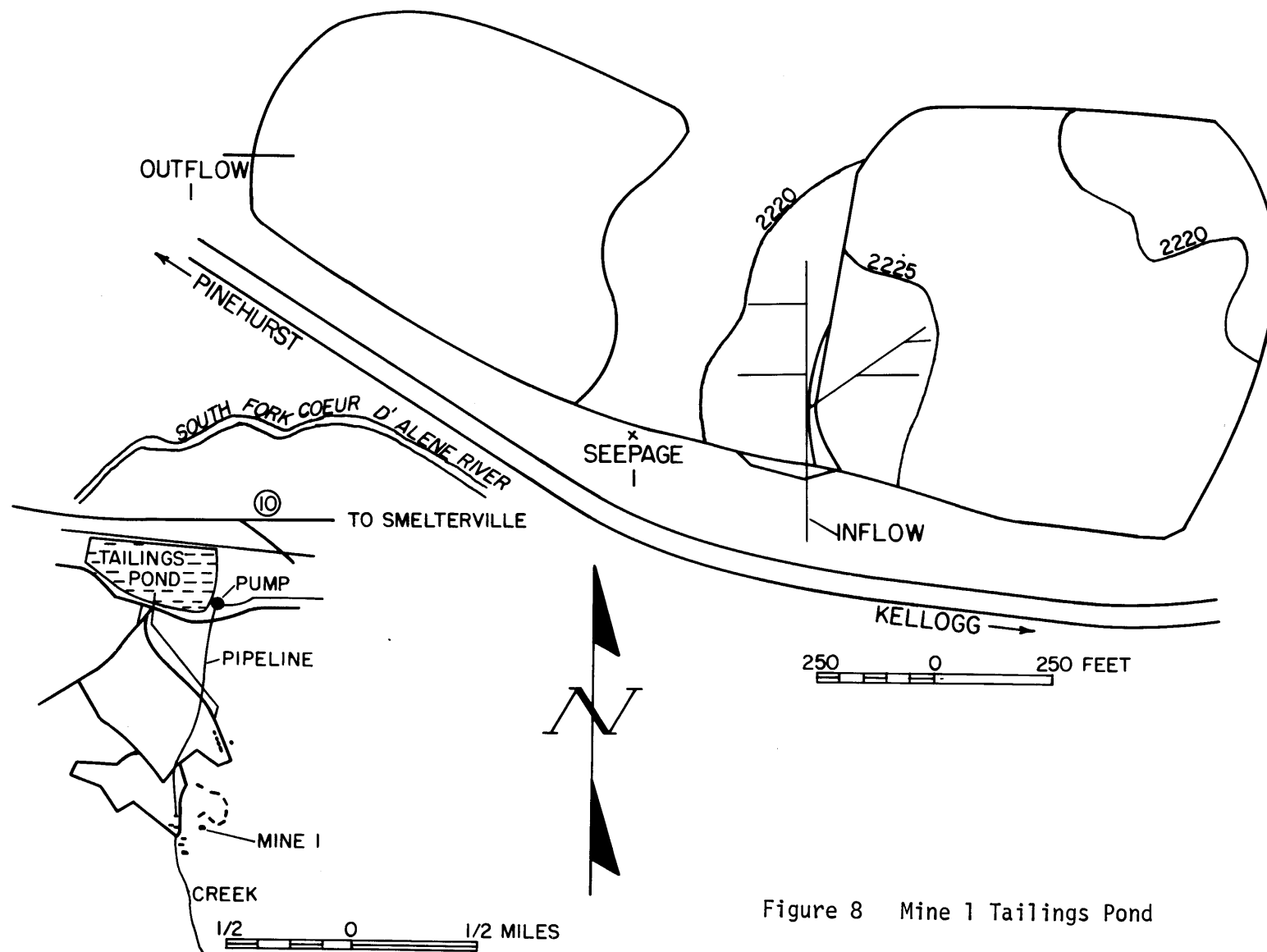


Figure 8 Mine 1 Tailings Pond

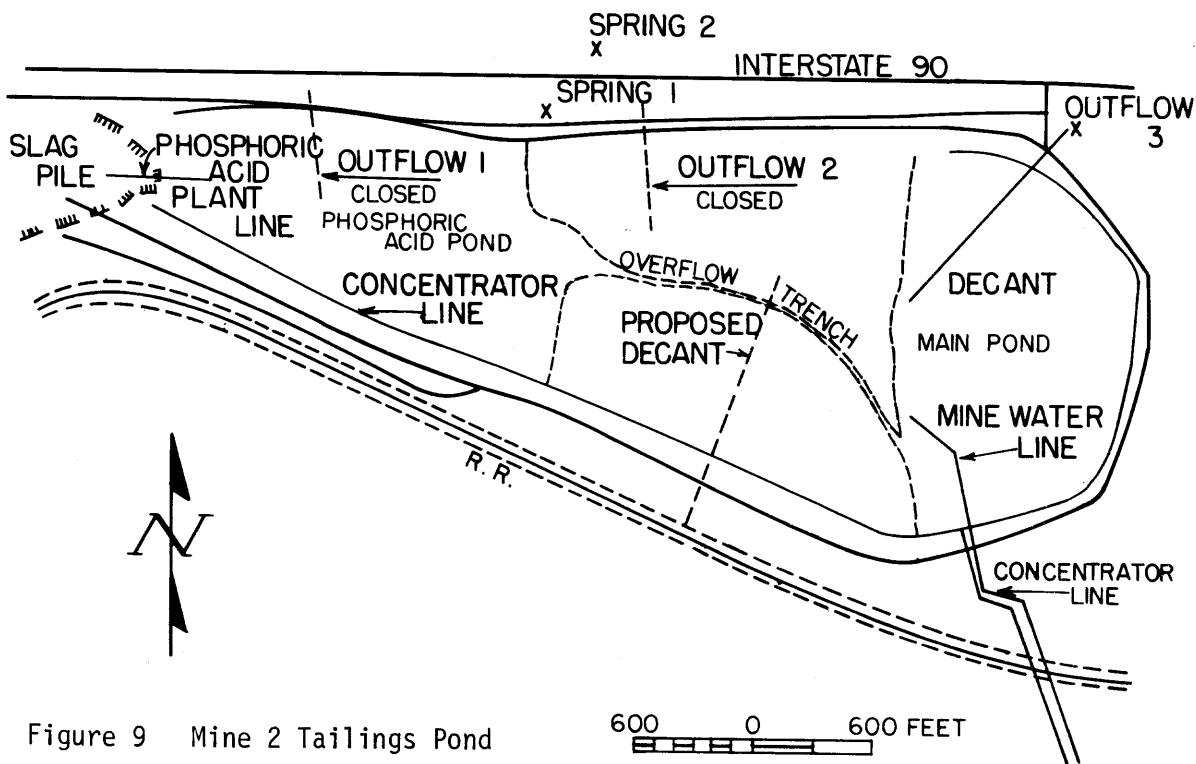
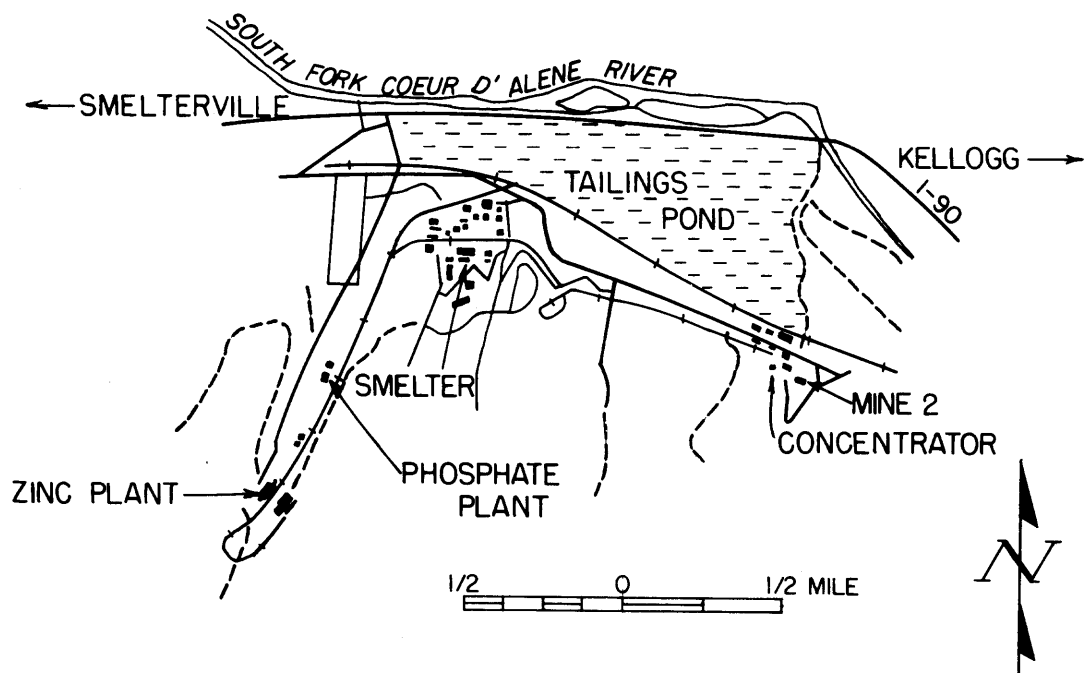


Figure 9 Mine 2 Tailings Pond

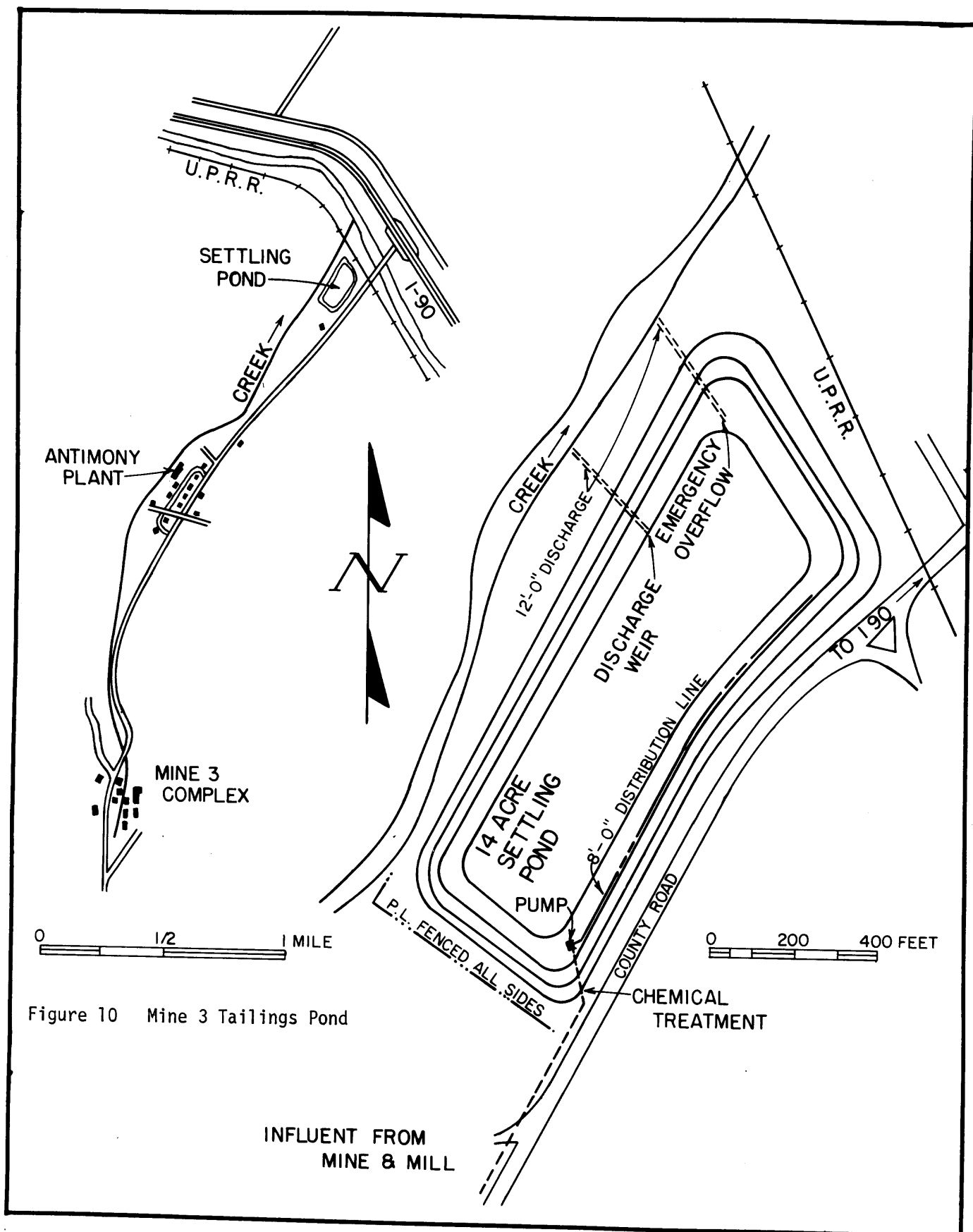


Figure 10 Mine 3 Tailings Pond

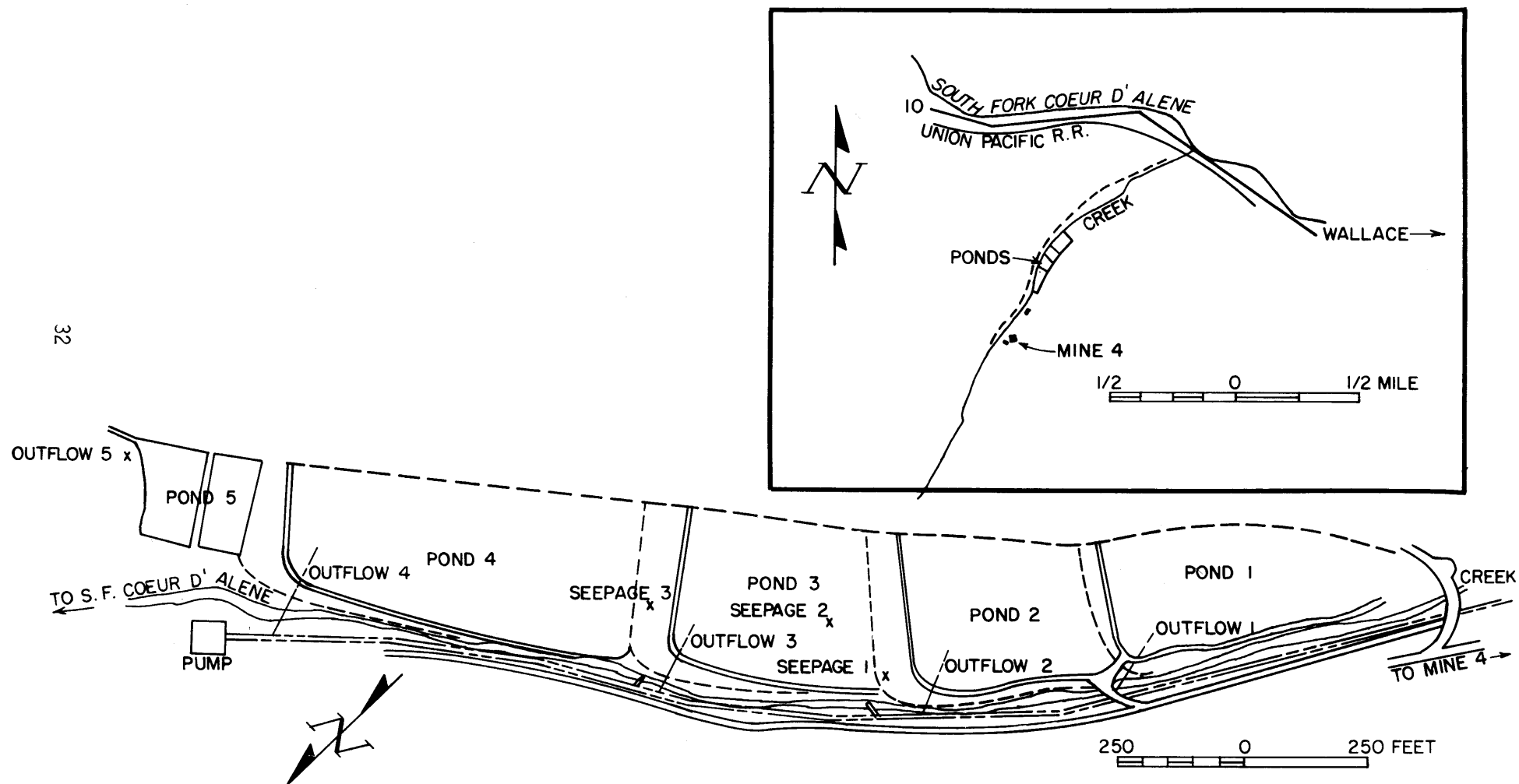


Figure 11 Mine 4 Tailings Pond

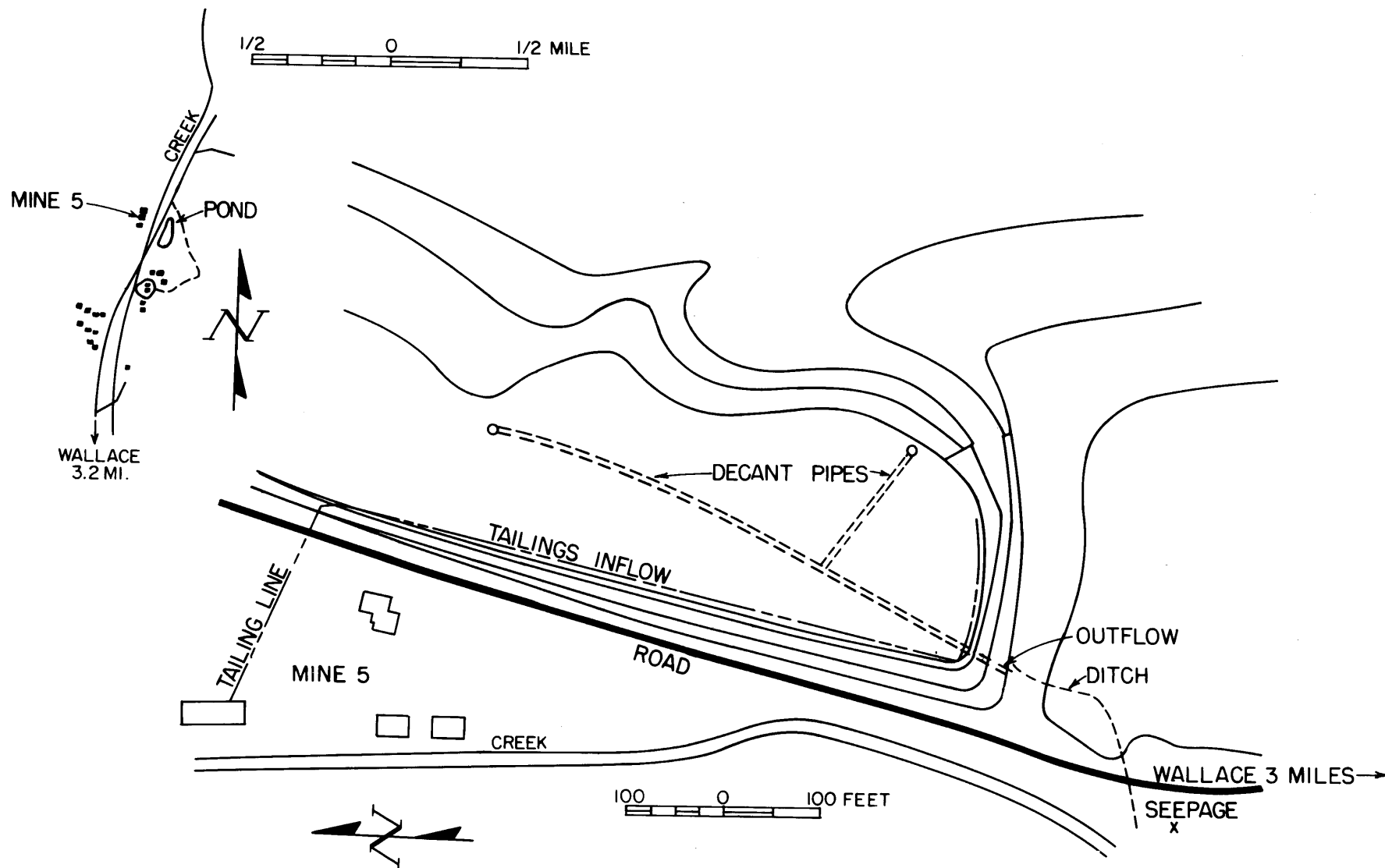
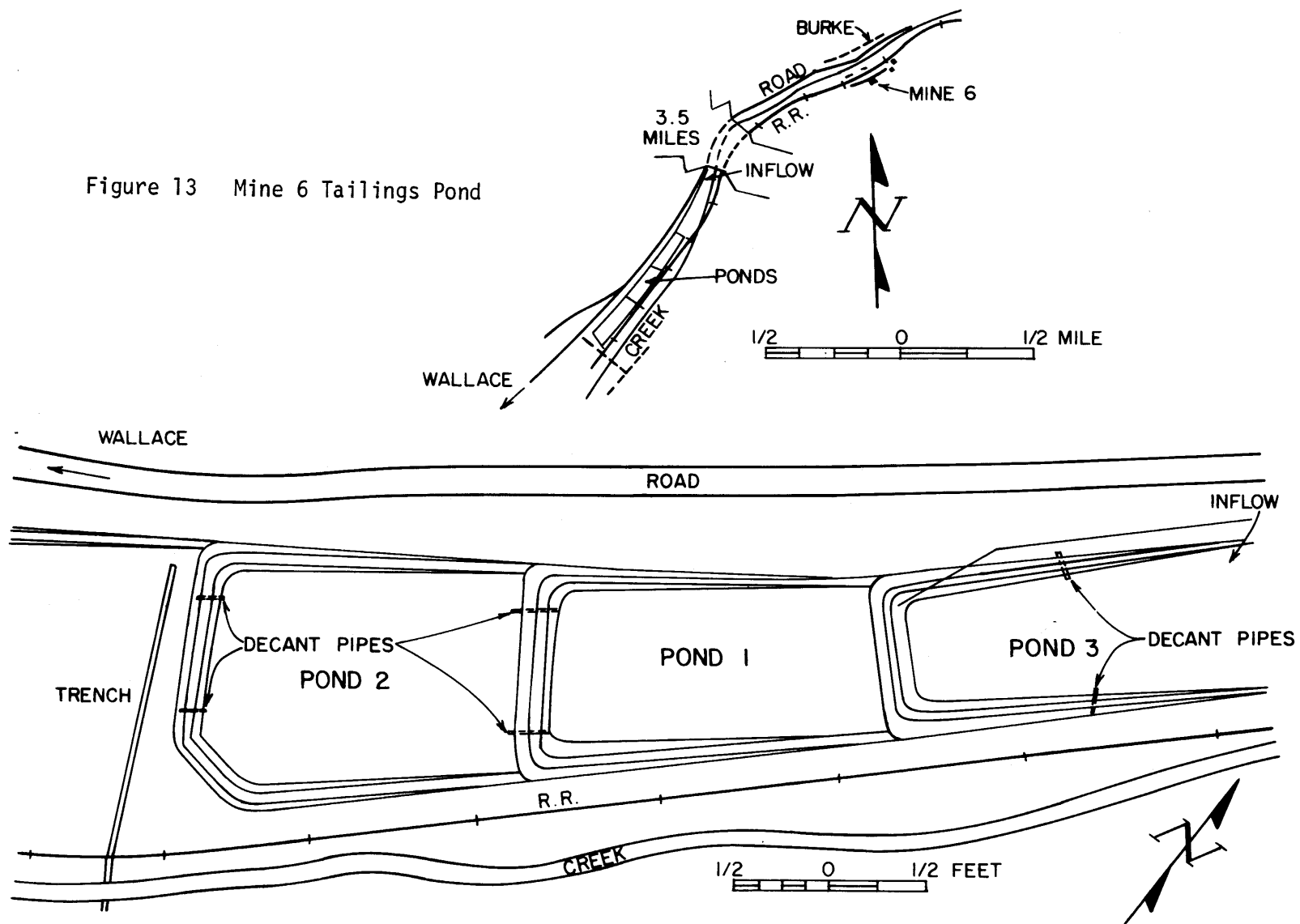


Figure 12 Mine 5 Tailings Pond

Figure 13 Mine 6 Tailings Pond



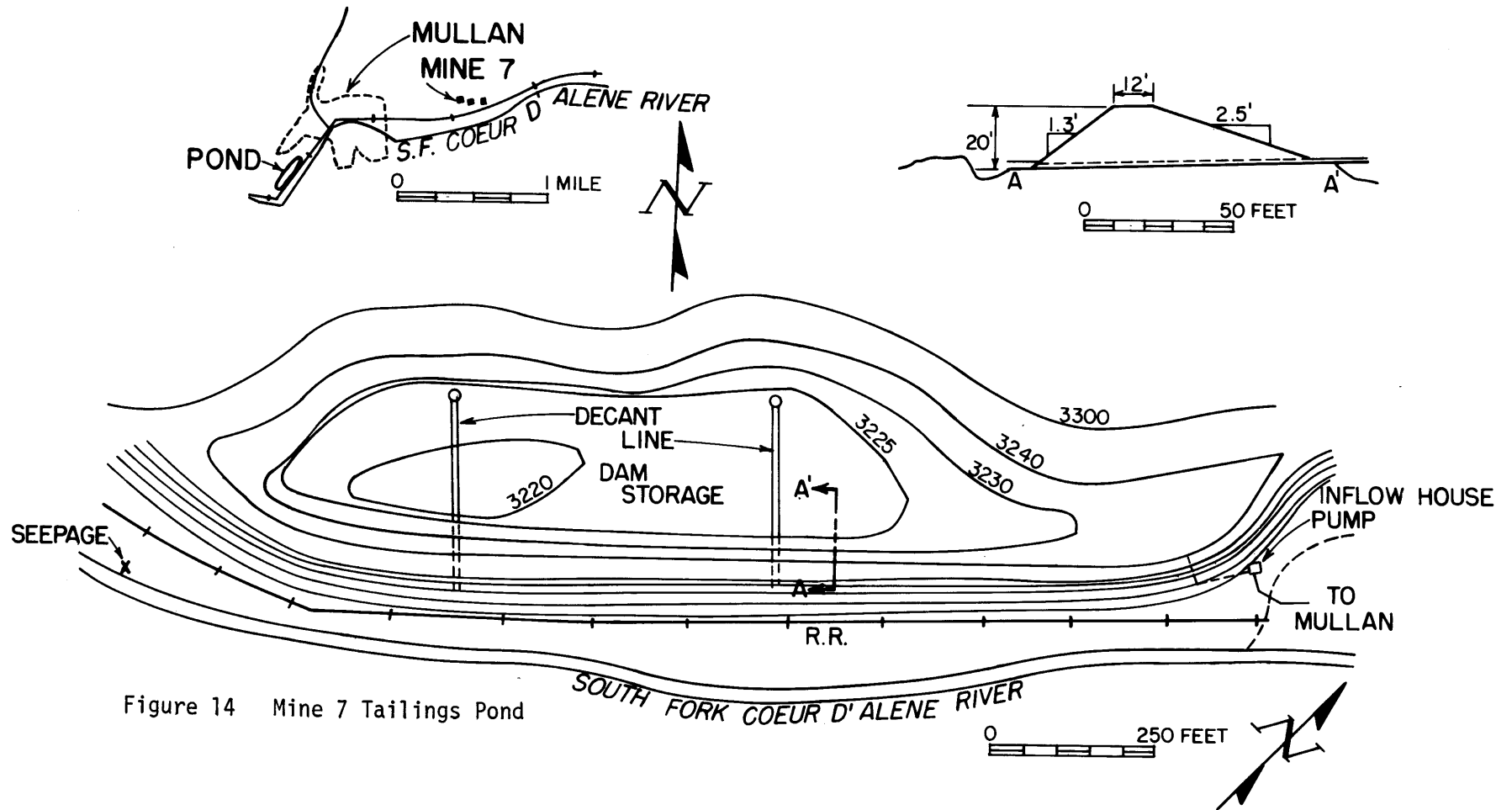


Figure 14 Mine 7 Tailings Pond

SUMMARY

1) Mining operations in the Coeur d'Alene district of northern Idaho have existed continuously since 1890, and until 1968 most of the effluent from mining operations was discharged into the Coeur d'Alene River system. Settling ponds were constructed in 1968 to eliminate the suspended solids load being contributed to the South Fork of the Coeur d'Alene River.

2) Samples were collected from June 1969 through June 1971 from the waste disposal operations of seven major operating mines in the Coeur d'Alene district. Samples of settling pond sediments, inflows, outflows, seepages, and stream water above and below the settling ponds were collected and analyzed for thirteen metal cations, along with chlorides, fluorides, electrical conductivity, pH, and temperature. The objective of the sampling program was to investigate types of mining wastes settling ponds can be expected to treat adequately.

3) Mineral extraction at the present time involves a process of selective flotation to concentrate the ore. Effluent from this process is the only material received by the settling ponds at five of the operations. The pond at one mine receives effluent from the concentrating process, along with effluent from a phosphoric acid plant, mine drainage, and raw sewage from a nearby town. The pond at a second mine received effluent from a concentrator and effluent from an electrolytic antimony plant. The addition of these wastes other than tailings is the source of most of the pollution problems observed to be associated with tailings ponds.

4) The five ponds receiving only tailings were found to reduce suspended solids by 99+ percent when properly managed. The outflows of these ponds do not contain toxic elements in dangerous concentrations provided some dilution is available. The settling ponds receiving other types of wastes are not effective in adequately reducing concentrations of antimony, cadmium, iron, manganese, lead, zinc, and fluoride. These elements in the effluents are above recommended toxic limits. The pH of one pond is very low due to mine drainage and industrial effluent* while the pH of a second pond is above recommended limits as a result of industrial effluent (i.e., an inflow other than tailings).

5) Quality of water in streams receiving effluent from the two ponds receiving effluents other than tailings was adversely affected due to settling pond discharge. Quality of water in one location is poor due to leaching of "jig tailings" deposited below the settling pond. The associated settling pond acts as a ground water recharge source due to inefficient sealing of the settling pond dike and is in part responsible for the quality of water below the pond.

6) The improper design of settling ponds and their mode of operation is a cause of ground-water contamination in several cases where problems were observed. For example, a peripheral discharge system for settling ponds would prevent or minimize leakage and resulting ground-water contamination. Settling ponds studied at several mines have switched to peripheral discharge systems, and with continued proper management, these ponds may be able to minimize seepage and concomitant ground-water contamination problems.

*Since these data were collected this operation has added additional treatment facilities to solve this problem.

7) More research needs to be conducted on minimizing seepage from ponds that have been in operation for long periods of time. Many such ponds were not designed with mining seepage in mind. Corrective measures may not be simple.

8) Metallurgical processes need to be optimized with respect to water use so that waste water production rates can be minimized.

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