HYDROGEOLOGIC ANALYSIS OF AN ABANDONED TAILINGS PILE

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AUTHORIZATION TO PROCEED WITH THE FINAL DRAFT

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ABSTRACT

Several tailings ponds have recently been filled and abandoned in the Coeur d'Alene Mining District in northern Idaho. The abandonment of mine tailings piles may have detrimental effects on the water resource system in the immediate area by leaching of metals from the movement of precipitation through the pile material.

This report presents the results of a study by the Idaho Bureau of Mines and Geology and the University of Idaho College of Mines, in cooperation with the U.S. Bureau of Mines, on the hydrogeologic factors that control the movement of ground-water through the abandoned Page tailings pile in the Coeur d'Alene Mining District in northern Idaho. A data collection network was installed to collect data on ground water flow systems and ground-water quality in and surrounding the pile. Analysis of water level data showed the existence of a ground-water mound under the east portion of the tailings pile. The flow system in the pile is dynamic and responds both to precipitation events and to periods of no recharge.

A finite element steady-state mathematical model was constructed to help interpret the ground-water flow system in the Page pile. A sampling and testing program of the pile provided information on values of hydraulic

conductivity. These data were incorporated as input to the mathematical model. Operation of the model showed that the location and fluctuations of the regional ground-water table and the quantity of recharge to the tailings pile from precipitation were the primary controlling factors for the location and height of the ground-water mound under the east side of the pile.

The rate of discharge of subsurface water from the pile was estimated from model operation to be about 2000 gallons per day per acre. This rate of discharge along with water quality data from the tailings pile showed that zinc reaches the immediate area outside the pile at a rate of about 17.8 pounds per day equal to about 0.1 percent of the total daily quantity of zinc carried by the South Fork of the Coeur d'Alene River at Smelterville during low flow.

INTRODUCTION

Abandoned mine tailings piles are potential sources of long-term pollution of surface and ground-water resources. A number of tailings piles have been filled and abandoned in the Coeur d'Alene Mining District in northern Idaho. This study includes an analysis of the hydrologic and hydrogeologic factors that control the movement of ground water through an abandoned tailings pile in the Coeur d'Alene Mining District. The objective is an understanding of the long term impacts of abandoned tailings piles on the water resources of the area.

Raw effluent from mining operations were discharged into the Coeur d'Alene River system from about 1890 to 1968. During this period, the content of heavy metals and suspended solids in the river reached a level which suppressed many species of fish and biota. New environmental regulations prompted the installation of several new tailings ponds in the district since 1968. The surface area of all existing ponds is greater than 300 acres. All of the tailings ponds have been constructed on permeable alluvial material in the valleys of the South Fork of the Coeur d'Alene River or its tributaries. A number of these ponds have been filled and abandoned in the district during the last few years. The abandonment of tailings piles represents a potential long term source of heavy metals pollution of both the ground water and surface water systems in the area by leaching of metals from the movement of precipitation through the pile materials. The quantity and characteristics of ground-water movement through the piles is the controlling factor in the discharge of poor quality water discharged from the bottom of these piles. A major change in land use occurred in 1973 on the tailings pile selected for study. A sewage lagoon system, which is used to treat sewage from several towns in the area, was located on the abandoned tailings pile. The construction and filling of the lagoons had a major impact on the flow system in the pile. Hitt (1974) described the impact of the construction and filling of the lagoons on the flow system in the pile. This thesis describes the ground-water flow that existed prior to the installation of the sewage lagoon system.

Purpose

The abandonment of tailings piles provides a possible long term source of heavy metal pollution of the ground-water system because of leaching of soluble metals from movement of precipitation through the mine wastes. The general purpose of this study was to determine the impacts of abandonment of tailings piles on the water resource systems.

Objectives

The main objectives of this study are:

1. Determination of the hydrologic factors that control the movement of ground water through the pile material.

2. Calculation of the rate of subsurface discharge via seepage from the bottom of the abandoned tailings pile.
3. Analysis of the impact of the rate of leakage from the tailings pile and the transfer of zinc from the pile to the immediate area surrounding the pile.

Methods of Study

The study is based on a field examination of the abandoned Page tailings pile. A data collection network was designed and installed to obtain information on the characteristics of ground-water movement through the pile and on the quality of ground water and surface waters in the area. Precipitation inputs to the tailings pile and fluctuations of atmospheric pressure were monitored to help interpret the changes in water levels in the pile. A sampling and testing program was used to obtain data on values of hydraulic conductivity of the tailings materials. Hydraulic conductivity data were incorporated as input to a finite element steady-state mathematical model of the ground-water flow system in the pile. Construction of the model helped to define the factors that control the movement of ground water through the pile and to calculate the rates of subsurface discharge from the bottom of the tailings pile.

SCOPE OF THE LITERATURE

Past work in the area of study can be divided into three major subjects:

A. Effect of past mining operations on the water quality of the Coeur d'Alene River.

B. Effects of the installation of tailings ponds on the water resources of the area.

C. Analysis of seepage problems by finite elements.

Effect of Past Mining Operations on the Water Quality of the Coeur d'Alene River

Previous investigations have shown that the gross pollution of the Coeur d'Alene River occurred prior to the construction and operation of mine tailings ponds. During the period 1911-1913, Kemmerer and others (1923) conducted a biological and chemical study of Coeur d'Alene Lake. The investigators noted, ". . . at Harrison it (Coeur d'Alene Lake) receives the muddy waters of the Coeur d'Alene River, which drains an immense area, including the famous Coeur d' Alene Mining District. These waters are so laden with silt that they may be traced far out into the clear waters of the lake."

Ellis (1940) conducted limited analyses of the Coeur a'Alene basin water and found that in 1932: (1) the Coeur d'Alene mine wastes had not disturbed the balance of dissolved gases (including oxygen), carbonates, and acids to any critical degree except in the immediate vicinity of flumes emptying wastes into the river, (2) the specific electrical conductance of the river rose 100 percent or more downstream from the introduction of mine wastes; however, specific electrical conductance remained everywhere low and (3) suspended solids had made the river uninhabitable to most aquatic life. Ellis also conducted experiments which showed that some dissolved constitutent in the Coeur d'Alene River water was lethal to fish in 72 hours. The fish used were native to the rivers in the vicinity of the Coeur d'Alene basin. Ellis' description of the mucous of the gills of the dead fish suggests that death was caused by zinc. Dissolved constituents also killed all plankton within 36 hours. The effects of suspended solids were eliminated by allowing the water to settle before testing. Ellis concluded the only solution for the pollution problem was the exclusion of all mine wastes from the Coeur d'Alene River.

A survey was conducted by Chupp in 1955 to find the extent and cause of waterfowl mortality along the main stem of the Coeur d'Alene River (Chupp, 1956). The study revealed appreciable amounts of lead and zinc in the soil, plants, and at times in the water of the lower Coeur d'Alene valley. Tissue analysis from a number of waterfowl collected in the area also showed abnormally high amounts of lead (Chupp, 1956, p. 94).

In 1964 a waste disposal study was conducted for the county of Shoshone and the cities along the South Fork by the consulting firm of Cornell, Howland, Hayes and Merryfield (1964). It was estimated that an average of 2217 tons per day of mine slimes were being discharged into the South Fork at the time. The sewage from Kellogg, Wallace, Osburn, Mullan, Smelterville, Silverton, Elizabeth Park, and Wardner (an approximately accumulated population of 14,130) was being discharged raw into South Fork (Cornell, et al., 1964, pp. 12A and 34).

A 1970 study showed that residents recognize water pollution as being widespread and severe in the South Fork region (Ellsworth, 1970, p. 30). Other studies of the area include a bioassay study on native cutthroat trout using Coeur d'Alene River water (Sappington, 1969) and a species diversity study of macrobenthic life on the Coeur d'Alene River (Savage, 1970). Since 1968, the Idaho Department of Health has been active in gathering coliform data at stations along the Coeur d'Alene River system (Idaho Dept. of Health, 1968) and in 1962 the Idaho Department of Health conducted a biological survey of the Coeur d'Alene River (Idaho Dept. of Health, 1962).

During recent years, extensive water quality information has been gathered by the U.S. Geological Survey, Federal Environmental Protection Agency and others in the Coeur d'Alene River basin. These data indicate a continuing water quality problem in the area. Mink, Williams and Wallace (1972) conducted a study to determine the causes and sources of high heavy metal concentrations in a creek in an industrialized area in northern Idaho. They found that the concentrations of the elements zinc and cadmium were high in ground water and surface waters. The poor ground-water quality of the lower portion of the creek was the direct result of leaching of the old mine tailings (jig tailings) which intermix with the alluvial deposits and that have been deposited there by the past mining operations. They recommend that a study should be designed to determine the impact of abandonment of tailings piles on the water resources of the area.

Effect of the Installation of Tailings Ponds on the Water Quality of the Coeur d'Alene River

Mink (1973) and Mink et al. (1973) present an evaluation of the performance of settling ponds as a means of minimizing the effects of dissolved or suspended material in mining waste water and to determine whether other types of treatment were necessary to improve the efficiency of the tailings ponds. Data revealed that tailings ponds in the Coeur d'Alene Mining District could be divided into two categories: (1) settling ponds receiving effluent from the concentrating process only and (2) settling ponds receiving effluent from the concentrating process mine drainage, and smelting or refining processes. Settling ponds were observed to be successful as a means of treating effluent from the concentrating process. Settling basins receiving effluents from mine drainage, smelter or refining operations create conditions within the settling basin which cause the settling basin effluent to be chemically unacceptable to receiving streams of ground water.

A study by Mink, Williams and Wallace (1971) reported on the pollution caused to the Coeur d'Alene River by the mining industry in northern Idaho. Water samples collected from 34 stations on the Coeur d'Alene River system over a sixteen month period showed zinc and calcium concentrations above toxic limits for fish survival over much of the South Fork and Main Stem of the river. They found that basin-wide installation of settling ponds for mill wastes (not for all industrial wastes) had greatly improved the quality of water, particularly with respect to suspended solids. As a result, macrobenthic fauna was discovered in the South Fork and a greater number of species were found in the Main Stem, which indicated to them that the river was beginning to recover. They found, however, that raw sewage discharged into the South Fork of the river represented a complex problem and that the effect of the raw sewage on the bacteriological quality of the water is evident. Williams and Wallace (1972) reported on the effect of the installation of tailings ponds on the water quality of the Coeur d'Alene River and found that tailings ponds which are properly designed and properly managed and which receive only mill wastes (concentrator effluent) can be expected to treat mining wastes adequately. They proposed the use of a peripheral discharge system which would minimize seepage, maximize slope stability and would assure a retention time sufficient to permit adequate settling of suspended solids.

Galbraith (1971) analyzed poor quality ground-water discharging from tailings piles to determine the distribution of metals in old tailings piles and the method by which ground water passing through the piles removes the metals. He found that leaching of heavy metals by ground water passing through mine tailings is caused by the oxidation of sulfides through the action of microorganisms.

Norbeck, 1975, mapped the distribution of tailings, defined the aquifer and water-table configuration along the Coeur d'Alene River and provided an overview of the ground-water quality.

Analysis of Seepage Problems by Finite-Elements

The finite-element technique is a numerical method of analysis whereby the region of interest is divided into discrete elements. Originally the method was applied to stress analysis. Subsequently, the system was heavily used in structural engineering for stress analysis. A discrete solution, versus an analytical (or continuous) solution, provides answers to a problem only at discrete points in the body under study rather than a continuous solution, which is obtained by the analytical method. In most cases, discrete solutions are adequate, and they permit the treatment of complex boundary conditions, Further, they allow one to obtain approximate solutions to problems that cannot be obtained via analytical approaches. Zienkiewicz (1966, 1967) provides fuller discussion of the intricacies of this methodology.

In this study the basic finite-element theory was adapted to the selection of the free water surface. In 1967, at approximately the same time, both Taylor and Brown (1967) of the University of California at Berkeley and Finn (1967) of the University of Vancouver utilized a matrix to develop a free-surface formulation by employing the finite-element method. Finn made use of the finite-element technique, coupled with the trial and error method of locating the exit point of the phreatic surface--accomplished by relocating the exit point after each trial.

A finite-element, mathematical model was used in 1971 by Kealy and Busch to locate the phreatic surface within a tailings pond embankment and to define the subsurface flow of water from the pond. Williams, Kealy and Mink in 1973 constructed a finite-element mathematical model of a tailings pond and showed that careful design and handling of a peripheral tailings discharge system would minimize the subsurface leakage from the ponds.

Kealy, Busch and McDonald (1974) used the finite element method to determine the rate of discharge of subsurface water from the Van Stone tailings pond in northern Washington. The slime zone of the pond was sampled and tested for the first time. Output from the numerical model defined critical zones and revealed that proper design and maintenance can reduce pond seepage losses to a minimum.

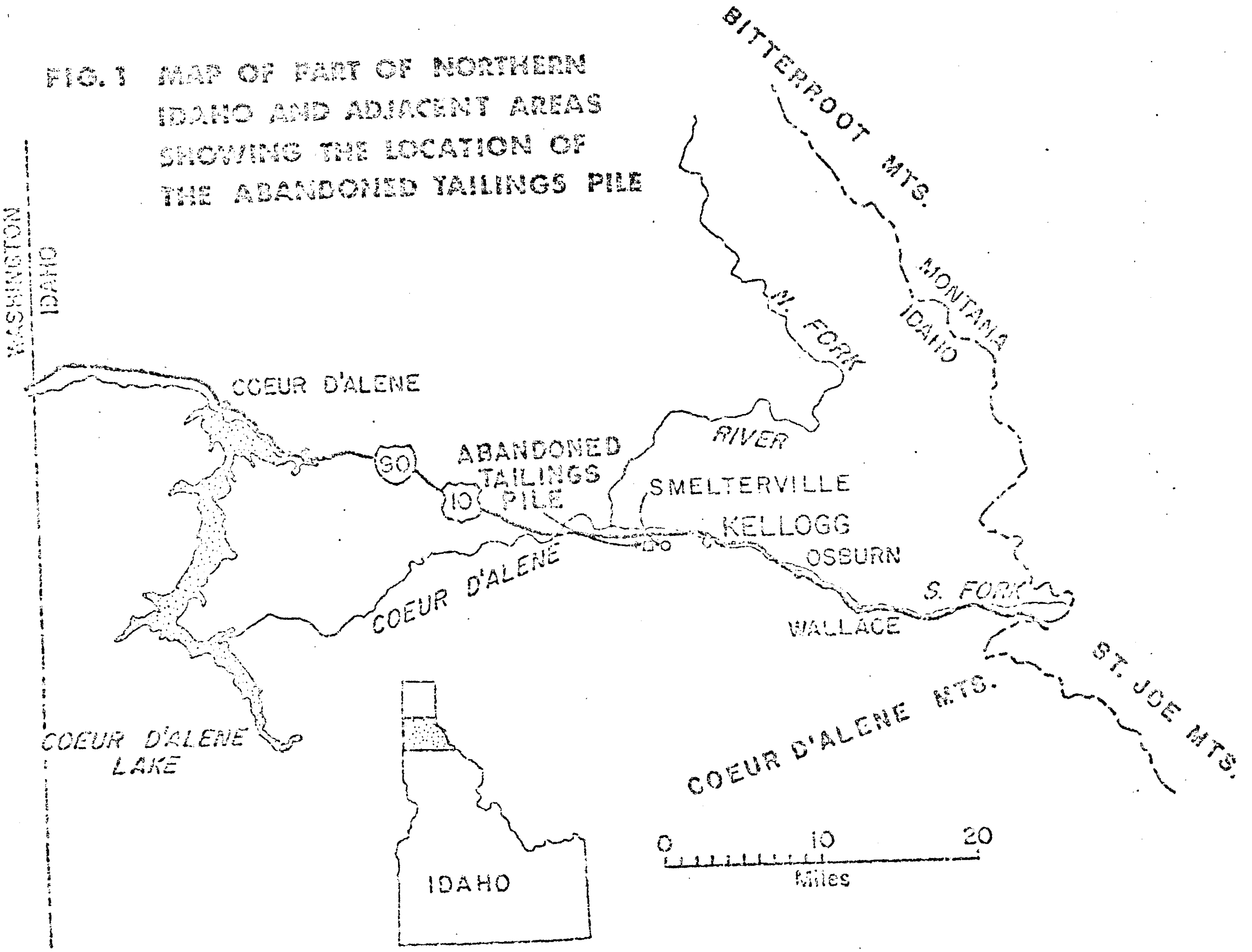
DESCRIPTION OF THE PAGE PILE AREA

Location and History of the Page Mine and Page Tailings Pile

The Page tailings pile, the oldest abandoned tailings pile in the district, was selected for investigation. The Page tailings pile is located in the Coeur d'Alene Mining District in the northern panhandle of Idaho in the valley of the South Fork of the Coeur d'Alene River (Figures 1 and 2). The pile is situated one mile west of Smelterville, one-half mile south of the South Fork of the River and about one and one-quarter miles east of the confluence of Pine Creek and the South Fork. The Pinehurst highway (old U.S. 10) runs the length of the pile on the south side. The Page mine, now abandoned, is located at the head of the draw containing the town of Page, Idaho, approximately one mile south of the tailings pile.

Considerable work had been done before 1906 on the Page mine which was then known as the Corrigan-Blackhawk-Wyoming properties (Timken, 1936). In 1906 the Corrigan was renamed the Page mine. Gravity concentration of the ore was used by the mine prior to 1911. Work at the mine was discontinued in 1911 because of the inefficient method of ore dressing and the prevailing low metal prices. The mine was dewatered in 1925 with the introduction of the flotation method of ore separation and the desire of the company to do additional development. A 300-ton flotation concentrator was constructed and put into operation in December, 1926. Before

FIG. 1 MAP OF PART OF NORTHERN IDAHO AND ADJACENT AREAS SHOWING THE LOCATION OF THE ABANDONED TAILINGS PILE



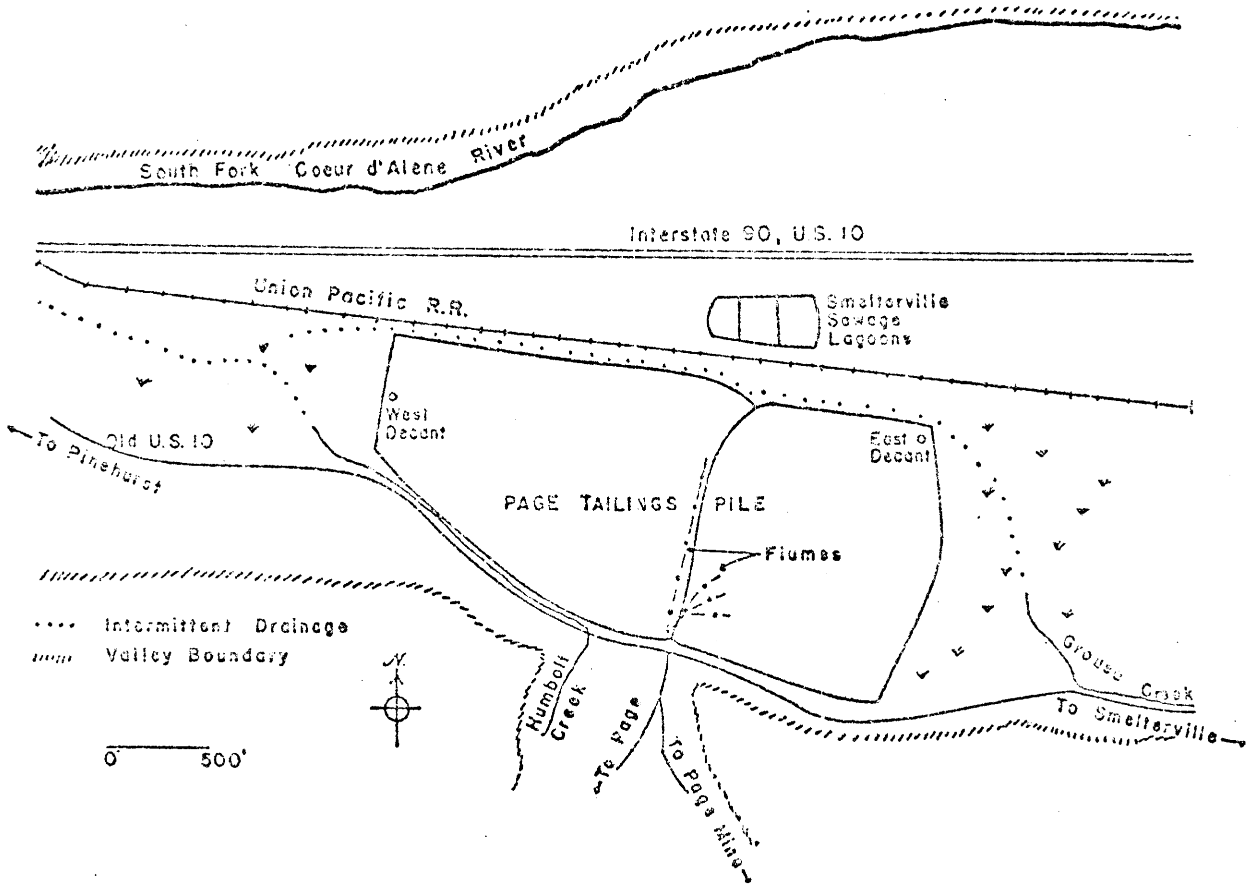


FIG.2 LOCATION OF THE ABANDONED TAILINGS PILE

1926, all waste material was used as fill in the mine. With the employment of flotation, the waste was discharged as a slurry into a tailings pond constructed in 1926. The mine continued in operation up to 1969 using the flotation process. The sand-fill technique was initiated in the Page Mine during 1956 for a new source of back-fill.

The Page tailings pile can be divided into two parts; the east pond was primarily formed by the tailings from 1926 to 1948. The center road that crossed the pile was originally the west embankment of the east pond. In 1948 the west side of the pile was started and materials were only occasionally deposited in the east pile.

Since 1956, when sand back-fill was initiated in the operation of the mine, the tailings slurry has been primarily a slime mixture as compared to the sandy slime mixture deposited earlier. Most of the east part of the pile and the bottom of the west are believed to be composed of coarser materials than the top of the west pile because of deposition prior to the initiation of sandfill operations.

The deposition of tailings was accomplished by a network of flumes. A flume from the mine was located along the center dike road. Decants were located at the extreme west end of the west pile and the northeast corner of the east pile. Sedimentary zoning of materials exists within the pile because of the method of deposition. The size distribution of tailings in the tailings pile is thus controlled by two major factors: (1) the location of discharge points from the flume system and (2) the use or non-use of the sandfill technique. Some consolidation and reduction of hydraulic conductivity may be present at depth in the east portion of the pile because of the greater period of deposition and the greater depth of the pile.

Abandonment of the Tailings Area

The Page mine and mill operations were terminated along with the filling of the Page pile in 1968. Air pollution from blowing tailings has been a problem since abandonment of the pile. Trees were planted in 1971-72 in an attempt to establish wind breaks. In 1972, the American Smelting and Refining Company transferred title to the Page tailings pile to the local sewer district for use in the construction of a collection and treatment system. The sewer district constructed five sewage lagoons on the surface of the pile. Construction of the lagoons eliminated much of the air pollution problem.

Geology of the Page Mine and Tailings Area

Belt series rocks of Precambrian age comprise the rocks of the Page mine. The three formations intersected by the Page mine are the Burke, Revette and St. Regis Formations. The principal ore mineral is galena followed by sphalerite in importance. The galena is mostly fine-grained. Other minerals of importance are tetrahedrite, chalcopyrite and pyrite. The gangue mineral in order of abundance are quartz, siderite, sericite and lencoxene (Timken, 1936).

The Page tailings pile is located on alluvial deposits of recent age. These deposits consist of rounded pebbles, boulders and sand and clay from erosion of the Belt series rocks plus reworked glacial terrane deposits. The alluvial deposits are 90 feet thick (Norbeck, 1974). Jig tailings from mineral recovery operations during the 19th and 20th centuries are interworked with the upper portion of the alluvium and glacial deposits.

Surface Hydrology of the Page Pile Area

The Page tailings pile is located in a marsh and bog area underlain by valley fill. Depth to ground water in the valley fill near the pile is usually between two to four feet below the surface. A perennial swamp is located on the east side of the pile with a seasonal swamp on the west end.

Two tributary valleys supply surface water to the Page pile area. Grouse Creek flows into the main valley near Smelterville. The creek meanders across the flat east of the pile and enters the swamp ponded against the east bank of the east pond. During high water, water flows between the north bank of the pile and the tracks of the Union Pacific Railroad and discharges into the swampy area to the west of the pile.

Humboldt Creek enters the main valley near the center of the Page pile and then flows eastward along the South bank of the west pond. The stream also discharges into the swamp area west of the pile. Surface water discharges from the west swamp only during high flow periods. Both Grouse Creek and Humboldt Creek recharge the ground-water system in the valley fill.

Physical Description of the Tailings Site

The Page pile has a circumference of 1.5 miles which encloses approximately 70 acres. Approximately 2.8 million cubic yards of tailings are contained within the pile. The height of the west pile above the valley floor ranges from 24 feet at the east end to 18 feet at the west end. The east pile ranges in height from 25 feet at the west end to 17 feet at the northeast end. The exact thickness of the tailings is not known because records are not available concerning the excavation and construction of the original pond. The embankment presently rises from zero to six feet above the tailing with an average height of three feet.

DATA COLLECTION NETWORK

Description of the Data Collection Network

A data collection network was designed to obtain data on the characteristics of ground-water movement in the pile and on the water resource system in the basin. Data collected include precipitation, atmospheric pressure, surface water discharge and quality and ground-water potential and quality. A continuous precipitation recorder was installed at the site to verify the data from the precipitation station located at Kellogg. A recording microbarograph was installed near the pile to monitor changes in atmospheric pressure to help interpret the fluctuations of ground-water potentials.

An extensive network of piezometers was installed both in and surrounding the pile to gain information on the ground-water potential and the changes in potential with time and to provide data on ground-water quality. Sixty-four piezometers were installed at various depths inside the pile with an additional fifty-two sites located in the alluvium underlying the tailings materials. The piezometers in the tailings vary in depth from 12 feet to a maximum of 27 feet. Five piezometers penetrate the alluvium underlying the tailings materials. The locations of the piezometer sites are shown in Figure 3. Information on each piezometer is given in Appendix 1. Sites inside the pile provide information on the horizontal and vertical distribution of potential within the pile. The several banks of piezometers were located within the pile

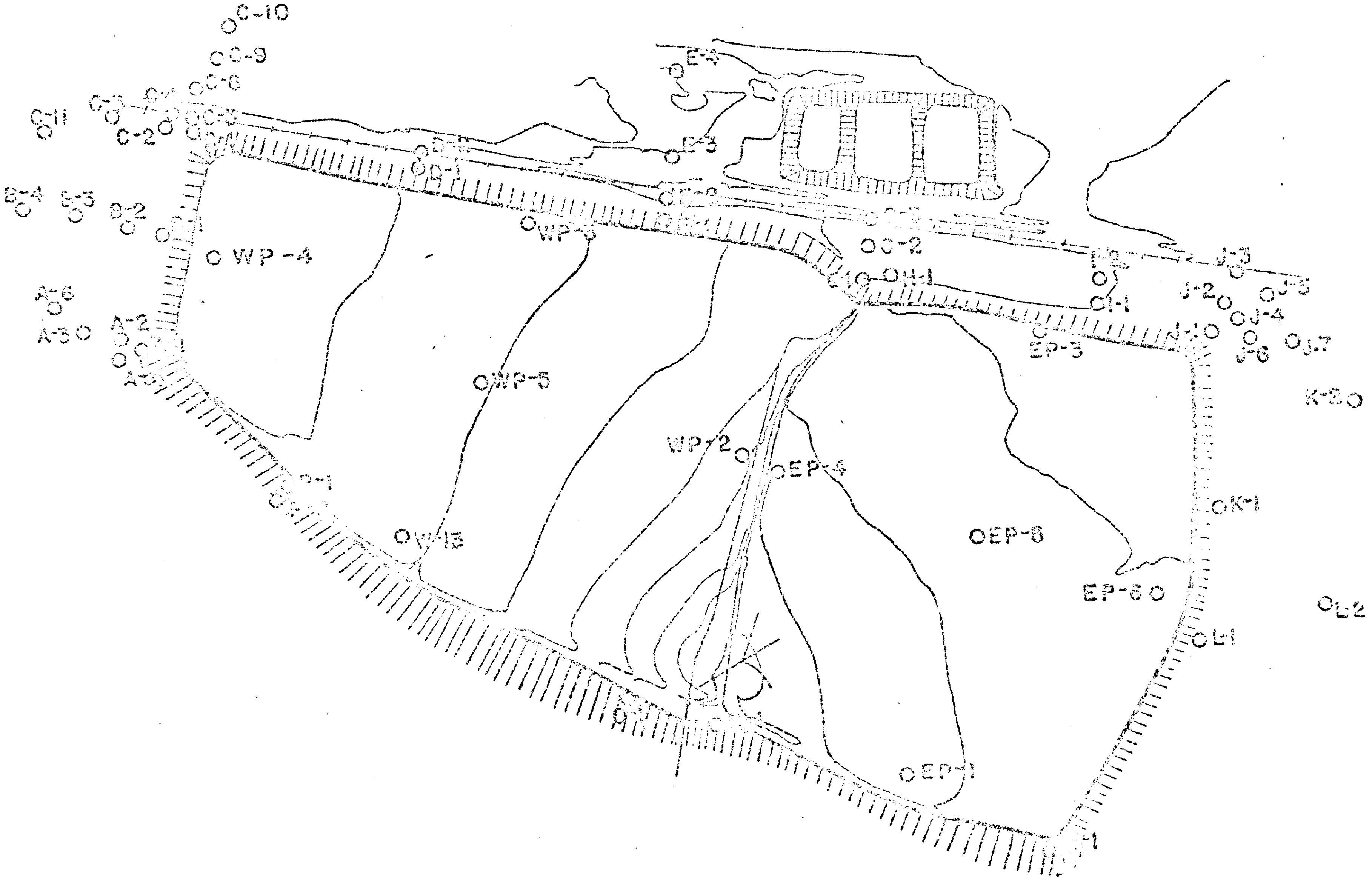


FIG. 3 MAP OF THE PAGE TAILINGS PILE AND VICINITY SHOWING THE LOCATION OF DATA COLLECTION SITES

to provide information on the vertical head changes and changes in water quality with depth within the pile. For example, one site on the west pile includes piezometers installed at depths of 12, 15, 16, 20, 21 and 25 feet. The horizontal distribution of sites was selected on the basis of known physical characteristics of the pile such as the center dike road between the east and west piles. Sites outside the pile were located to detect the impact of the pile on the hydrologic environment. Continuous water level recorders equipped with Keck water seeking devices were installed in several piezometers to obtain more accurate information on the ground-water level fluctuations. The Keck units did not operate satisfactorily during cold weather; continuous water level data were only obtained during the summer months.

Design and Installation of Piezometers

The typical piezometers used in this study consisted of a length of 3/4 inch diameter polyvinyl chloride pipe, perforated and wrapped with fiberglass screen in the selected interval to be monitored (Figure 4). The smaller diameter casing was selected to minimize time lag in water fluctuations. Plastic and fiberglass materials were used to minimize interferences with the water quality determinations.

Piezometers were installed by the following procedure:

1. Two-inch diameter, flush coupled casing fitted with a polyethylene drive point was driven to the desired depth.

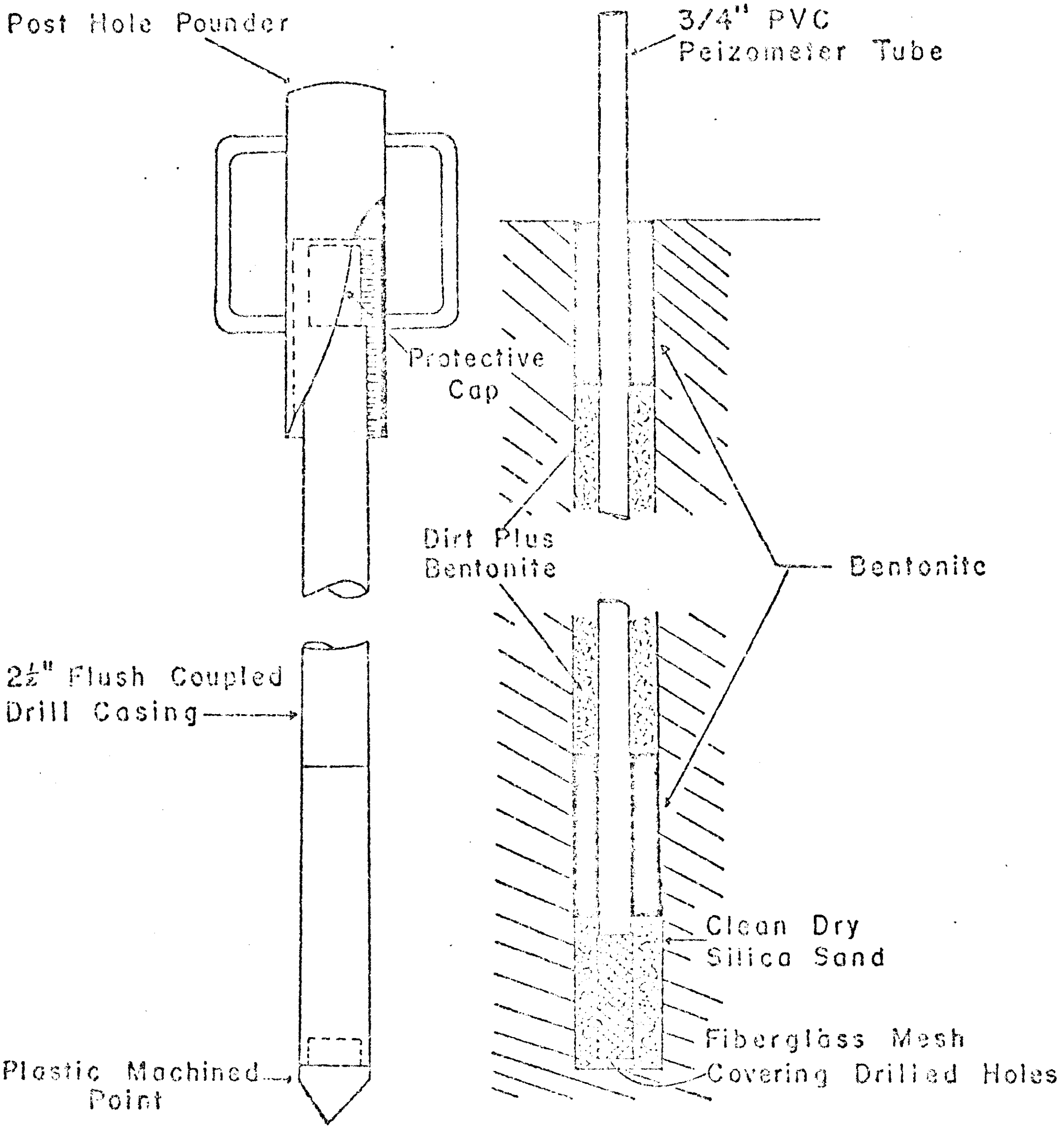


FIG. 4 INSTALLATION SCHEMATIC OF A TYPICAL PIEZOMETER

2. Clean quartz sand was poured into the inside of the two-inch casing to a depth of about one inch and the drive point was knocked off the end of the two inch casing.

3. The 3/4 inch piezometer was then placed inside the two inch diameter casing resting on the sand.

4. Clean quartz sand was placed around the perforated section to a depth approximately one or two inches above the top perforations.

5. The two inch diameter casing was withdrawn, while powdered bentonite was poured to fill the annular space between the 3/4 inch casing and the side of the two inch hole.

6. The procedure was continued until the two inch casing was removed. Bentonite was packed around the 3/4 inch casing as tightly as possible.

It was assumed that the bentonite would provide sufficient seal to prevent vertical movement of water along the casing.

Operation of the Data Collection Network

Data on precipitation, atmospheric pressure and water level elevation have been collected in the area of study since September, 1972. The frequency of the measurements has varied with the station. During the early stage of the study, precipitation data were gathered using the continuous precipitation recorder and several storage type precipitation collection gages. Early analysis of data showed no areal variation in the amount of precipitation over the study area. Collection of precipitation data was then limited to that obtained from the continuous precipitation recorder.

Drilling and Sampling Programs

A sampling and testing program of the Page tailings pile was conducted to determine the distribution of hydraulic conductivity in the tailings pile, the location of a possible compacted zone at the bottom of the tailings pile and the location of the contact between the tailings and the original ground surface. Two problems were of primary concern in testing the materials that compose the different zones within the tailings pile. First, the investigation holes must be prevented from caving when drilling through the saturated zone of the tailings. Secondly, undisturbed sample of tailings must be obtained at selected intervals to define possible layers of different hydraulic conductivities.

Successful results were obtained by drilling the investigation holes with a hollow stem power auger and sampling the tailings with thin-wall samplers or shelby tubes. In this manner, undisturbed samples were collected at selected intervals. Shelby tube samples were in most cases collected at 12, 17 and 22 foot depths in order to establish possible changes in hydraulic conductivity with depth. A fourth sample from between 22 and 27 feet was extracted from almost every hole to help define the interface between the tailings and the alluvium.

A thin-walled sampler or shelby tube (Figure 5) is made of steel tubing (sometimes known as shelby tubing) from two inches to five inches in diameter and with walls of 18 gage (1/20 in.). The lowered end is bevelled to form a tapered cutting edge which reduces wall friction. The upper end is fastened to a check valve that holds the sample in the tube when it is being withdrawn from the ground. The thin-wall sampler minimizes the most serious sources of disturbance, displacement and friction (Sowers and Sowers, 1951). The shelby tube used in this study was two feet long with a two and one half inch outside diameter.

After the hole had been drilled to the desired depth a shelby tube was fitted to a 2½ inch flush coupled drill casing. The tube was then lowered to the bottom of the hole and pushed two feet below it by the driving head of the power auger. An air line was attached to the sampler to brake suction when pulling the sample back up from the hole.

A system consisting of a rubber disk sandwiched between a combination of metal disks and rods (Figure 6) was designed to keep the samples intact in the shelby tubes and to allow for hydraulic conductivity testing. The majority of the samples were safely transported to the laboratory in this manner. Some damage was caused to the samplers at depth greater than 22 feet from driving through the alluvium. In this case the metal disks could not be fitted into the shelby tubes. The surface bottom of these tailings samples were covered with a piece of cardboard and a mold of wax cast into the

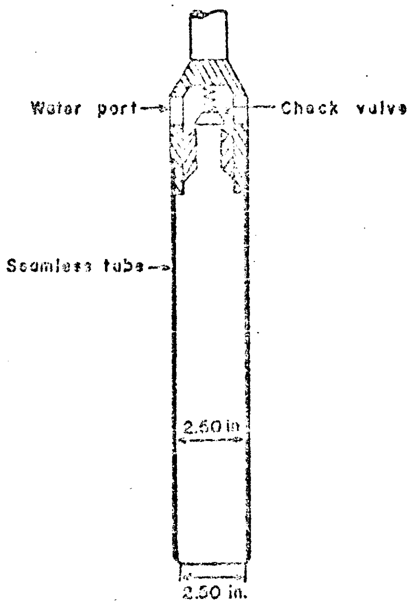


Figure 5. THIN WALL SHELBY TUBE SAMPLER.

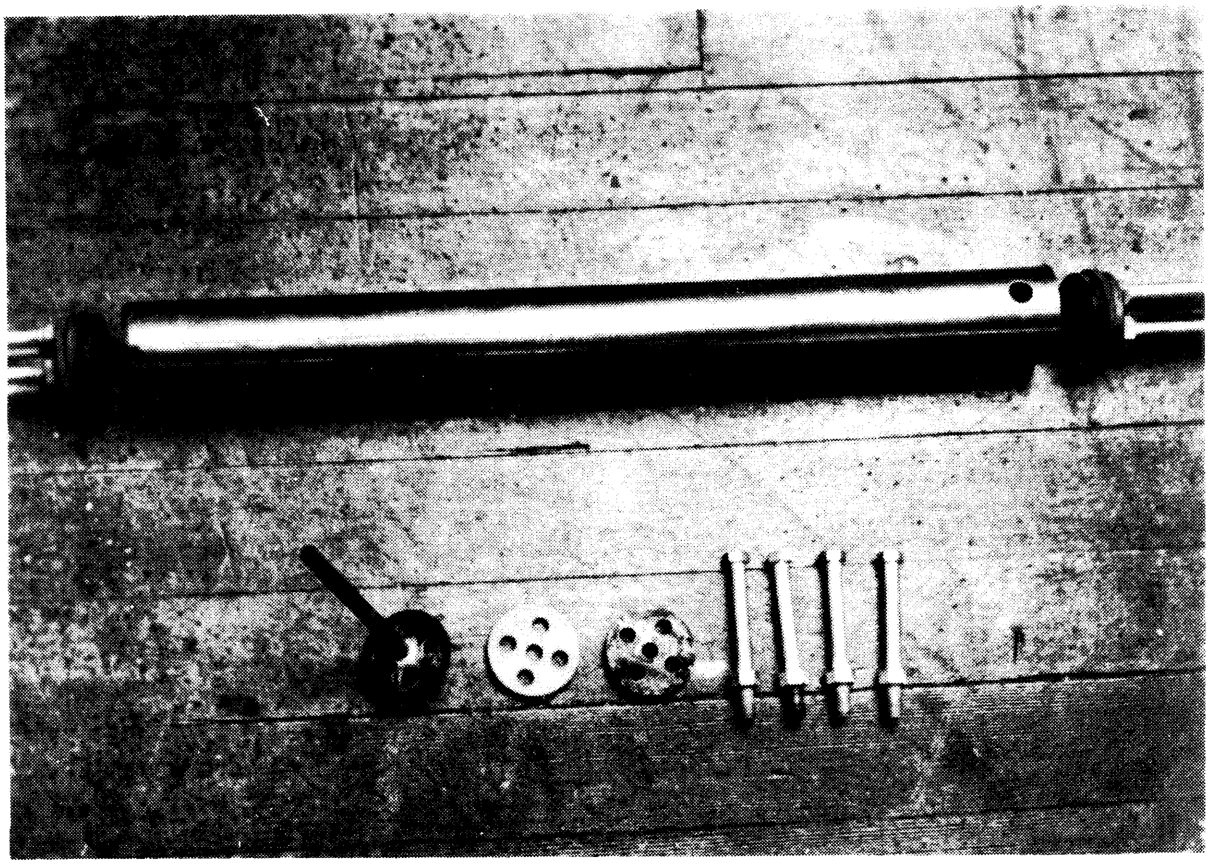


FIG. 6. SHELBY TUBES AND ADAPTERS USED IN THE STUDY.

sampler. This method of tailing sampling proved to give satisfactory results for the purpose of this study.

DESCRIPTION OF THE GROUND-WATER FLOW SYSTEM

Long-Term Water Level Fluctuations

The only source of recharge to the tailings pile prior to sewage lagoon installation was direct precipitation. Table 1 shows the mean monthly precipitation for Kellogg (Idaho) which is located about four miles east of the area of study.

Table 1. Mean Monthly Precipitation at Kellogg (Idaho) Data from the Weather Records of the National Oceanographic and Atmospheric Administration

Month	Mean Monthly Precipitation in Inches
January	3.61
February	2.92
March	2.97
April	2.38
May	2.41
June	2.42
July	0.83
August	0.83
September	1.70
October	3.18
November	3.71
December	4.01
Average Annual Precipitation	30.97

Precipitation data from January, 1972 to November, 1974 are presented in Table 2. The departures and cumulative departures from the mean precipitation are included. Precipitation

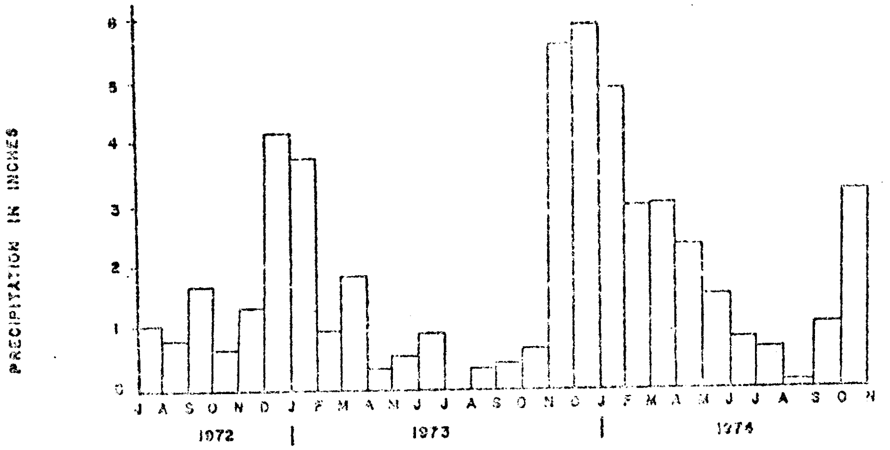
Table 2. Monthly Precipitation at Kellogg, Idaho (All Values in Inches)[1]

Year	Month	Precipitation In Inches	Departures From Normal	Cumulative Departures
1972	January	4.34	0.73	0.73
	February	4.67	1.75	2.48
	March	3.90	0.93	3.41
	April	2.70	0.32	3.73
	May	2.48	0.07	3.80
	June	2.43	0.01	3.81
	July	1.01	0.18	3.99
	August	0.80	-0.03	3.96
	September	1.66	-0.04	3.92
	October	0.65	-2.53	1.39
	November	1.32	-2.39	-1.00
	December	4.09	0.08	-0.92
	Total	30.05		
1973	January	3.70	0.09	-0.83
	February	0.94	-1.98	-2.81
	March	1.82	-1.15	-3.96
	April	0.35	-2.03	-5.99
	May	0.58	-1.83	-7.82
	June	0.92	-1.50	-9.32
	July	0.00	-0.83	-10.15
	August	0.34	-0.49	-10.64
	September	0.42	-0.12	-10.76
	October	0.68	-0.25	-11.01
	November	5.54	1.83	-9.18
	December	5.96	1.95	-7.23
	Total	21.24		
1974	January	4.82	1.21	-6.02
	February	2.93	0.01	-6.01
	March	2.95	-0.02	-6.03
	April	2.34	-0.04	-6.07
	May	1.56	-0.85	-6.92
	June	0.84	-1.58	-8.50
	July	0.69	-0.12	-8.63
	August	0.19	-0.64	-9.27
	September	1.10	-0.60	-9.87
	October	0.03	-3.15	-13.02
	November	3.23	-0.48	-13.50

[1] Precipitation data through March, 1974 obtained from federal station at Kellogg. Data from March, 1974 through November, 1974 provided by Bunker Hill Company.

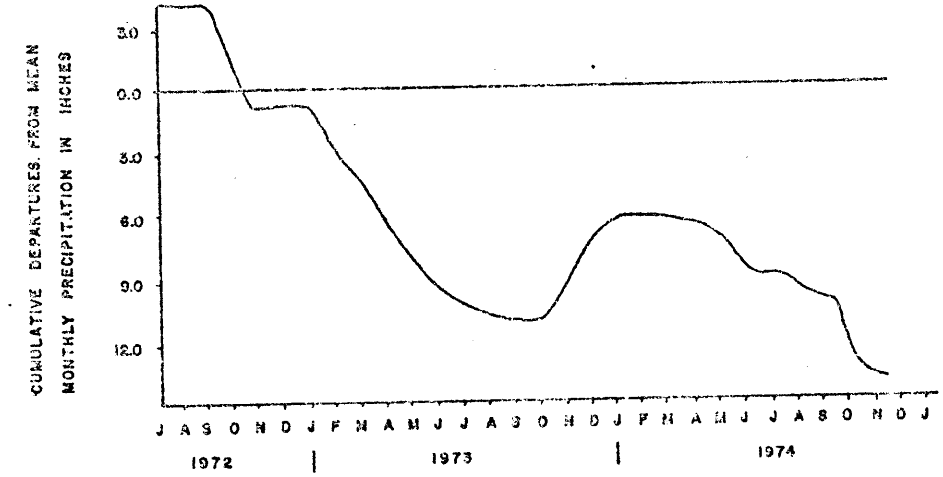
data are plotted versus time and compared with a typical hydrograph from the flow system in the pile on Figure 7. A close correlation is observed between the cumulative departure from the mean monthly precipitation and the typical hydrograph. The flow system in the tailings pile is dynamic; it responds to recharge events and to periods of no recharge. Variations from the typical hydrograph may be seen at different locations in the tailings pile. More water level change is noted in piezometers located at the extreme east and west ends of the tailings pile than at piezometers located near the center road (Figure 8).

Analysis of precipitation data for the period August, 1972 to November, 1974 showed a cumulative precipitation deficiency in the area of study except for the months of July through October of 1972. This below normal precipitation caused the ground-water levels to decline to their lowest stage during the months of June, July and August of 1973 (Figure 8). In August, 1973 the precipitation deficiency was 10.64 inches. Although the precipitation that occurred during the months of November, 1973 through February, 1974 did not completely reduce the cumulative deficiency, it was sufficient to cause the water levels to rise to the stages at which they were during the winter of 1972. During the summer months of 1974 the cumulative deficiency was not as high as that of 1973 and subsequently the minimum water levels during this year inside the pile were about 3 feet higher than the minimum water levels in 1973.



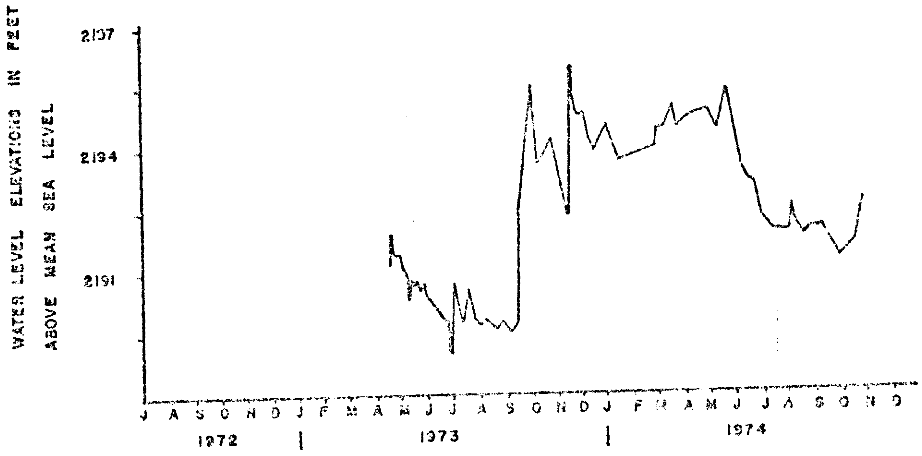
MONTHLY PRECIPITATION AT KELLOGG

(a)



CUMULATIVE DEPARTURE FROM MEAN MONTHLY PRECIPITATION AT KELLOGG, IDAHO

(b)



HYDROGRAPH OF 23-FOOT PIEZOMETER AT SITE WP-4 24

(c)

Figure 7. MONTHLY PRECIPITATION, CUMULATIVE DEPARTURES FROM MEAN PRECIPITATION AND RELATED WATER LEVEL FLUCTUATIONS IN PIEZOMETER-PAGE PILE

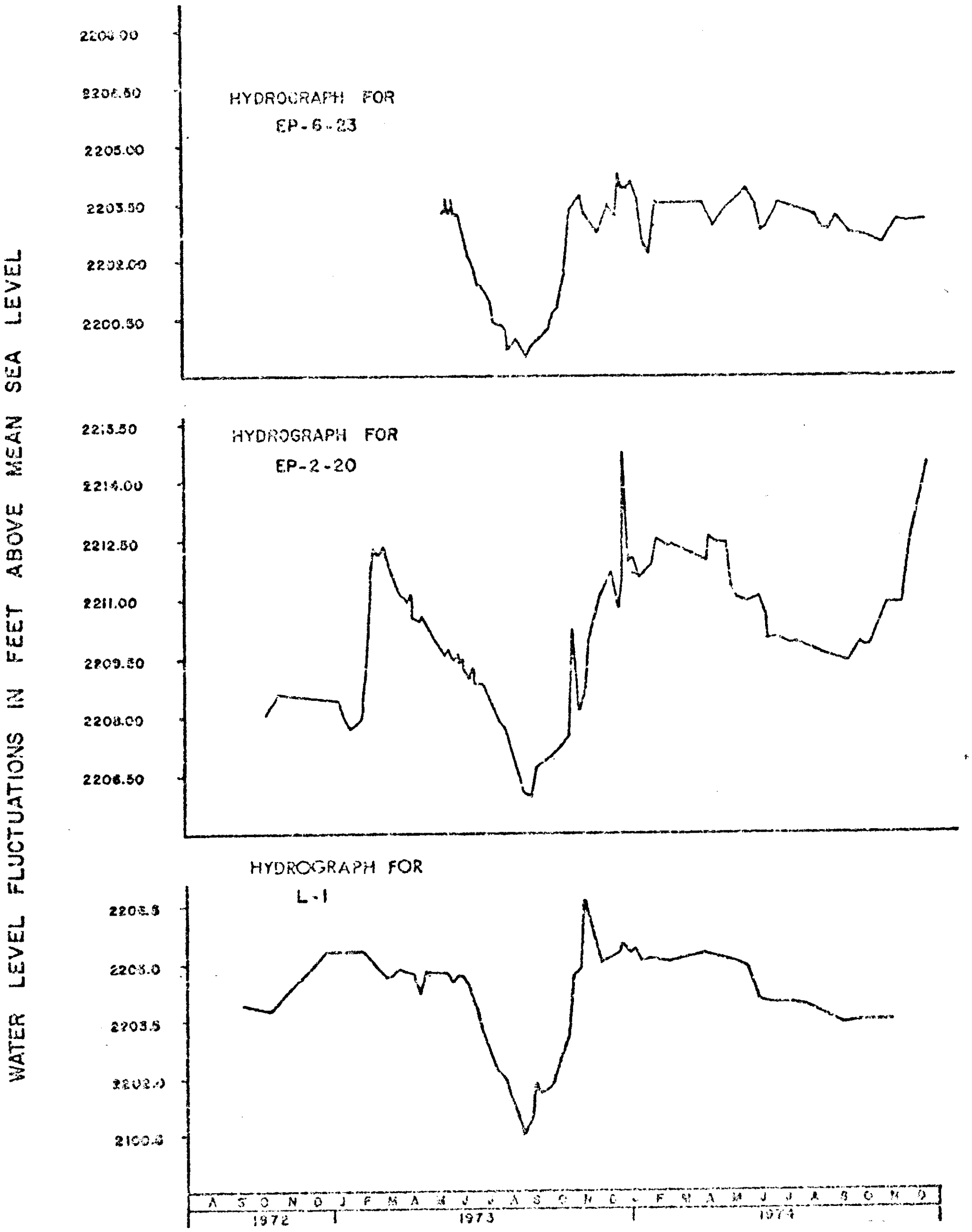


Figure 8. LONG TERM FLUCTUATIONS OF WATER LEVEL IN PIEZOMETERS LOCATED INSIDE AND OUTSIDE THE TAILINGS PILE.

In general, it can be said that the comparison of the Figures 7 and 8 indicates that the elevation of the water table inside the pile is closely related to precipitation. Water levels are at a low stage during dry periods and rise during periods of higher precipitation. No long-term water level trends can be recognized from the data obtained during the period of study. No indication of long-term drainage of the pile has been observed. Water levels recover to previous years elevations during periods of high precipitation. The leaching of heavy metals from the mine wastes thus may be viewed as a long-term problem.

Short Term Water Level Fluctuations

Continuous water level recorders were installed at two sites in the area of study in order to gain a better understanding of the short term fluctuations of water levels inside the tailings piles and in the surrounding alluvium. Piezometer WP-14-20, located inside the pile, and the west well, a 25 foot well, located about 30 feet from the central point of the west embankment of the pile and which taps the alluvial deposits outside the tailings pile, were equipped with recording units. The continuous water level recorders were equipped with Keck water seeking devices. The Keck units did not work efficiently during cold weather; their use was restricted to summer months. Continuous water level data are available from June 9 to October 3, 1974. Figure 9 shows the continuous decline of water levels both inside the tailings

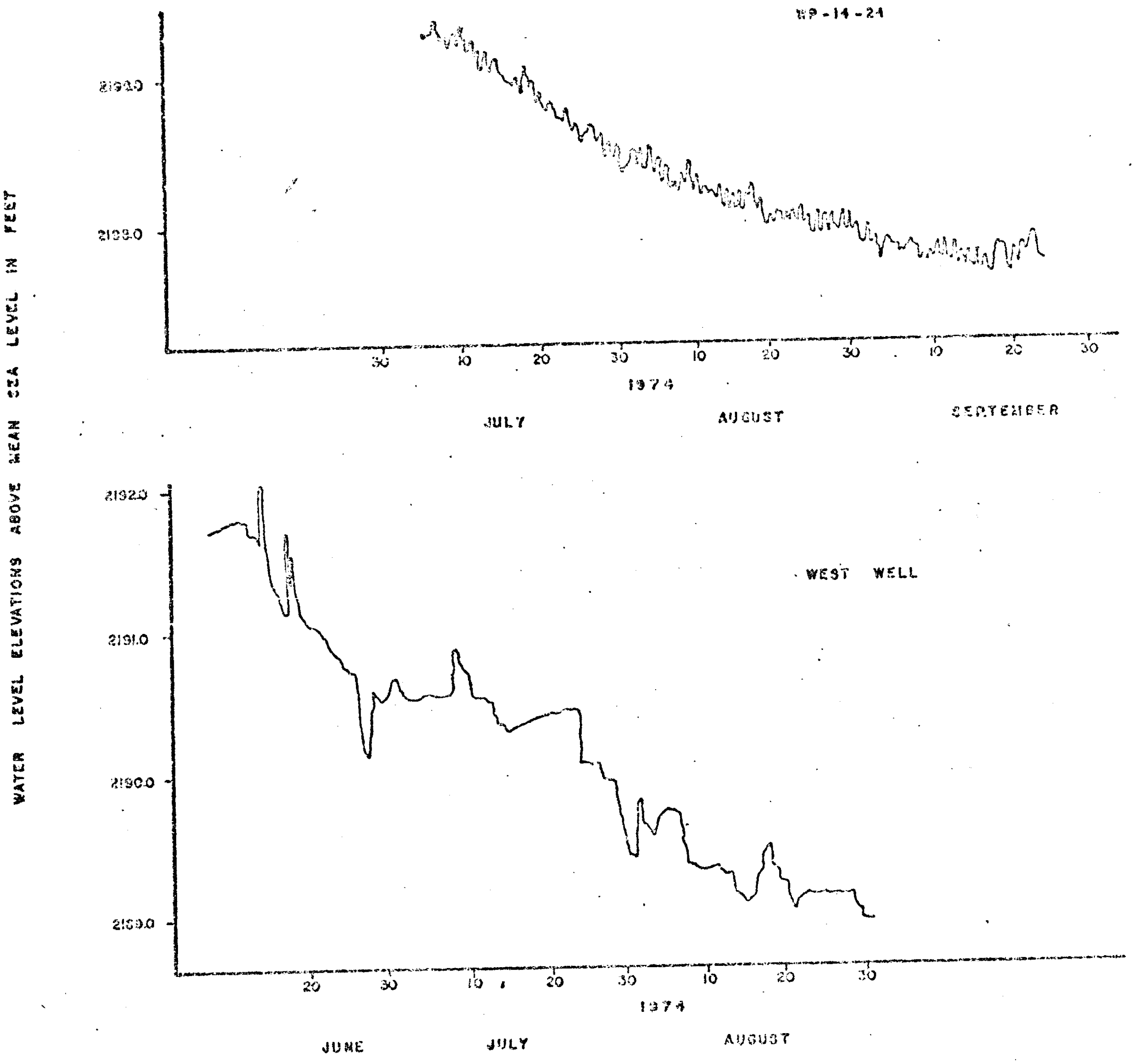


Figure 9. CONTINUOUS WATER LEVEL FLUCTUATIONS IN PIEZOMETER WP-14-24 LOCATED INSIDE THE TAILINGS PILE AND IN THE WEST WELL LOCATED IN THE ALLUVIUM SURROUNDING THE PILE.

pile and in the surrounding alluvium for the above piezometers. Data were compared for the period July 6 to September 2, 1974. A total net drop of water level of 1.51 feet occurred in piezometer WP-14-20 whereas the water level in the well situated in the alluvium dropped 1.57 feet for the same period. These water-level data show that the fluctuations of ground-water potential inside and outside the pile are closely related. A more detailed discussion on the influence of the location of the regional ground-water table on the water levels inside the pile will be given subsequently in this report.

Vegetation is abundant in the area that surrounds the tailings pile. Evapotranspiration may be responsible for some of the sudden drops in water levels shown in Figure 9.

During construction of the sewage lagoons a pump was operated to dewater part of the construction area. Also a number of industrial wells operate in the area. The combination of the above factors may have also caused some of the drops in water levels of Figure 9.

Water Level Fluctuations Due to Changes in Atmospheric Pressure. Water level fluctuations were noted in piezometers in response to changes in atmospheric pressure (Figure 10). Russell (1963, p. 10) described similar fluctuations as follows:

> "Water level in wells recedes when the atmospheric pressure increases and rises when the atmospheric pressure decreases. Diurnal and semidiurnal atmospheric pressure changes, culminating in two maximums and two minimums during the course of 24 hours are recorded by barometers. Diurnal pressure

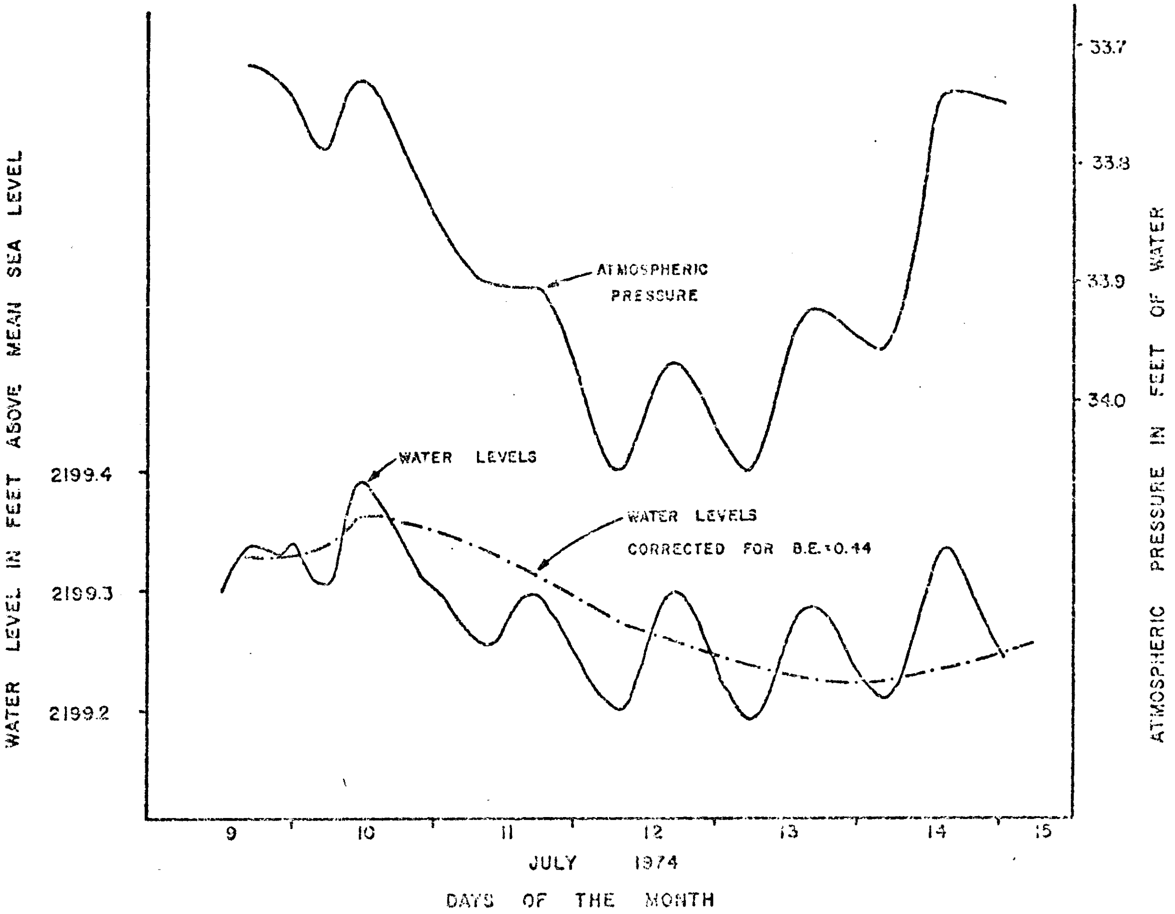


Figure 10. RESPONSE OF WATER LEVELS IN PIEZOMETER WP-14-24 TO ATMOSPHERIC PRESSURE CHANGES AND CORRECTED WATER LEVELS FOR A BAROMETRIC EFFICIENCY OF 44 PERCENT.

> changes produce maximums during the coldest hours and minimum during the warmest hours. Barometric recorders show semidiurnal pressure changes culminating in maximums at about 10:00 a.m. and 10:00 p.m. and minimums at about 4:00 a.m. and 4:00 p.m, depending in part upon the season, elevation, and weather conditions. These diurnal and semidiurnal atmospheric pressure changes persist through all seasons and are produced by daily temperature changes. Water level maximums in some wells occur at about 4:00 a.m. and 4:00 p.m. and water level minimums occur at about 10:00 a.m. and 10:00 p.m."

Water level data from the study area for the month of July differ from the above observations. During the early part of July, water levels reached maximums at about 4 or 5 p.m. and minimums at about 7 or 8 a.m. For this period the atmospheric pressure showed a maximum at around 7:00 p.m. and a minimum at 7:00 a.m. The second part of July showed water level maximums at about 4:00 p.m. and minimums at about 10:00 a.m. Water level data for the months of August and September, 1974 are in accordance with the fluctuations observed by Russell.

Barometric Efficiency. Water level fluctuations in piezometer WP-14-20 showed a distinct response to changes in atmospheric pressure (Figure 10). The barometric efficiency at this site was calculated for the periods July 9 to July 15 and July 24 to August 6, 1974.

Walton (1962, p. 4) defines barometric efficiency as follows:

> "Water levels in confined aquifers are affected by fluctuations in atmospheric pressure. As the atmospheric pressure increases the water level falls, and as the atmospheric pressure decreases the water level rises. The ratio of the changes

> in water level to the changes in atmospheric pressure is the barometric efficiency of the well and is usually expressed as a percentage."

The equation for the barometric efficiency of a well and for the change in water level in response to an atmospheric pressure change is (Walton, 1962):

$$B.E. = (\Delta W/\Delta B)\ 100$$

where: B.E. = barometric efficiency

ΔW = change in water level resulting from change in atmospheric pressure in feet

ΔB = changes in atmospheric pressure in feet

The inverse relationship between atmospheric pressure and water levels is shown in Figure 10 where the upper curve indicates atmospheric pressure inverted. The lower curve shows observed water levels in piezometer WP-14-20.

The barometric efficiency of an artesian well is a measure of the ability of the upper confining layer to transmit atmospheric pressure changes to the water in the aquifer and provides a relative measure of the rigidity of the overlying or confining beds and the aquifer (Gilliland, 1969, p. 245). The method of Taylor and Leggett (1949) was used to calculate the barometric efficiency at site WP-14-24. Instantaneous water levels for the period July 9 to July 15 and July 24 to August 6, 1974 were plotted against the barometric pressure converted to feet of water for the same period (Table 3). Figure 11 shows the correlation between the barometric pressure on the abcissa and the depth to water in piezometer WP-14-24 on the ordinate. Straight lines with approximately

Table 3. Depth to Water in Piezometer WP-14-24 Corrected to a Barometric Efficiency of 0.44

Date	Time	Observed Water Levels Feet Below Measuring Point (1)	Barometric Pressure (Inches of Mercury)	Barometric Pressure (Feet of Water)	Feet of Water	Feet of Water Times B.E.	Adjusted Water Levels (Feet Below Measuring Point)
9	12 p.m.	16.990	29.880	33.735			
"	17 p.m.	16.900	29.860	33.712	-0.023	-0.009	16.909
10	06 a.m.	16.985	29.920	33.780	+0.068	+0.027	16.958
"	13 p.m.	16.900	29.870	33.723	-0.057	-0.023	16.923
11	10 p.m.	17.037	30.020	33.893	+0.170	+0.068	16.969
"	17 p.m.	16.993	30.020	33.893	0.000	0.000	16.993
12	08 p.m.	17.090	30.160	34.051	+0.158	+0.063	17.027
"	17 p.m.	16.990	30.080	33.960	-0.091	-0.036	17.026
13	06 p.m.	17.190	30.160	34.051	+0.091	+0.036	17.064
"	17 p.m.	17.002	30.040	33.915	-0.136	-0.054	17.056
14	06 a.m.	17.080	30.070	33.949	+0.034	+0.014	17.066
"	16 p.m.	16.955	29.880	33.735	-0.214	-0.086	17.041
15	01 a.m.	17.048	29.890	33.746	+0.011	-0.004	17.044

(1) Measuring point elevation = 116.29 feet above mean sea level

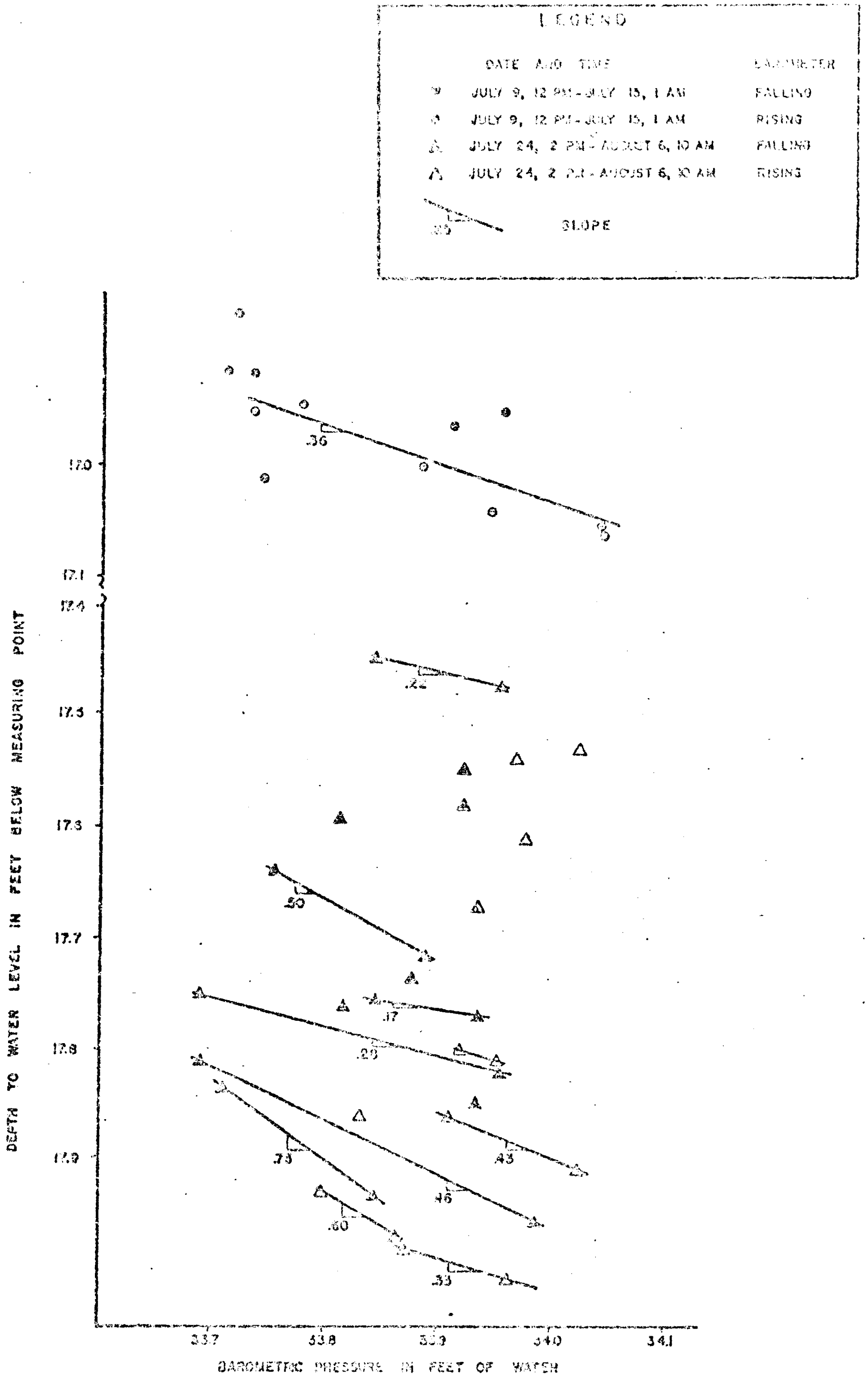


Figure 11. CORRELATION BETWEEN WATER LEVEL IN PIEZOMETER WP-14-24 AND BAROMETRIC PRESSURE AT STUDY AREA.

MEASURING POINT ELEVATION IN FEET
ABOVE MEAN SEA LEVEL = [illegible]

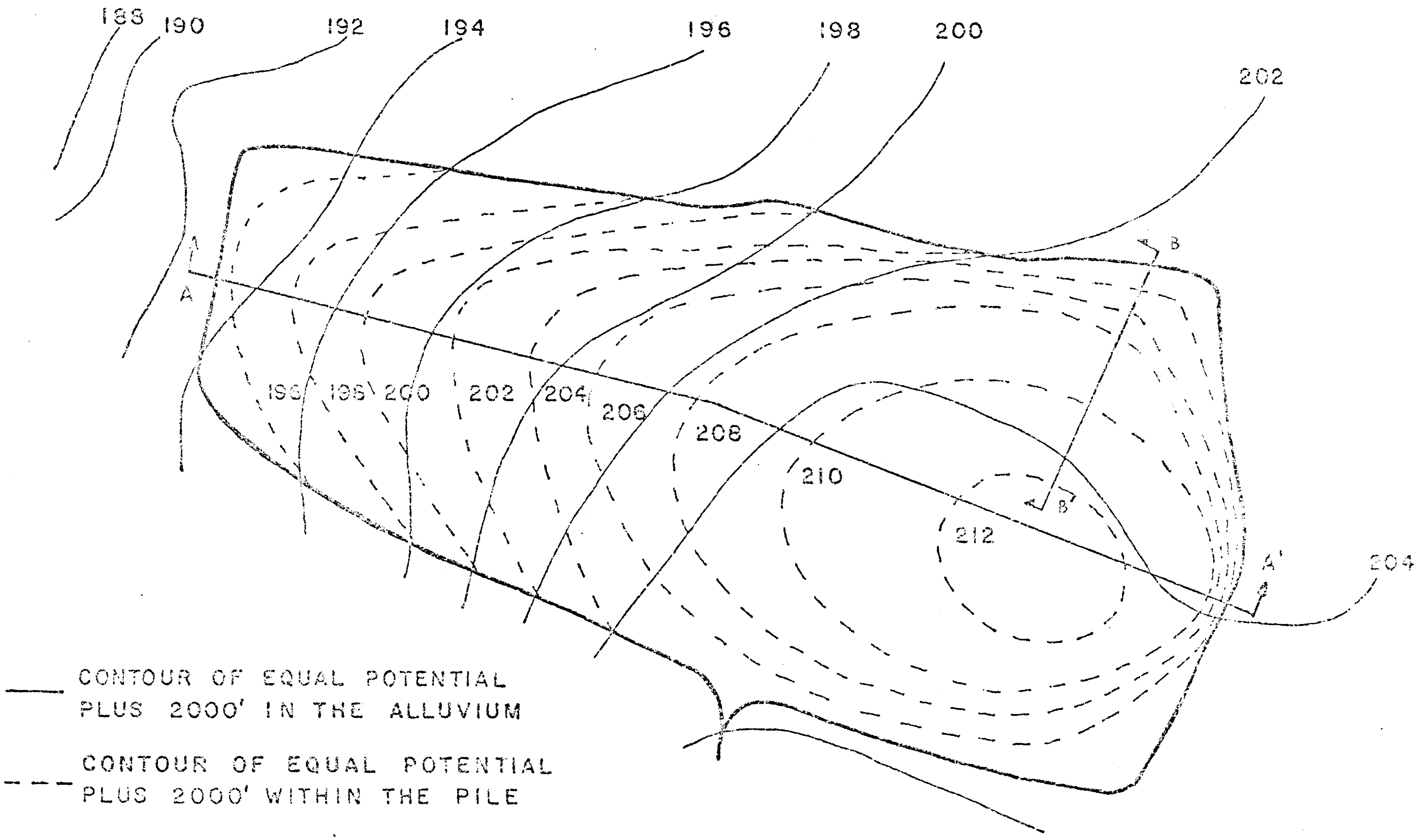
the same slope drawn through each set of points plotted. These have a mean average slope of 0.44. This barometric correction was applied to the water levels obtained during the above period and the adjusted water levels are shown in Figure 10. Table 3 summarizes the data needed to correct the water levels in piezometer WP-14-24.

The presence of barometric fluctuations in the water level record show that some degree of confinement of the ground-water flow system in the pile exists. The physical characteristics of the tailings materials are described earlier in this report. It was stated that the mean size of the materials that compose the top of the west side of the pile is finer than the bottom of the west pile, because of deposition prior to the initiation of sand-fill operations. The top of the west pile may be acting as a semi-confining layer which causes the water levels in the west side of the pile to respond to fluctuations in atmospheric pressure. Barometric efficiency was not calculated for the east side of the pile. It is not possible to conclude whether or not the water levels in that side of the tailings pile respond to fluctuations in atmospheric pressure in the same way than those in the west pile. Another factor which may explain the response of water levels to fluctuations in atmospheric pressure could be lensing of finer and coarser tailings in the pile, which originated from changes in the locations of the flume system in the pile.

Potentiometric Surface in the Tailings Pile and Surrounding Alluvium

Data were collected on the horizontal and vertical distribution of potential both within the tailings pile and in the surrounding alluvium. The configuration of the water table in the Page pile is presented in Figure 12 (Ralston and Morilla, 1974). A ground-water mound is evident under the east portion of the tailings pile. No similar mound was discernible under the west portion of the tailings pile. The contours of water level elevation in the alluvial material indicate that the pile does not have a major impact on the regional flow system. An east-west vertical section presented in Figure 13 shows the pattern of movement within the pile. The equipotential lines in the tailings material are connected with those in the regional flow system to show the direction of water movement. The potential distribution presented in the above figures suggests two main questions: (1) What are the reasons for the existence of the mound under the east side of the pile? and (2) Why does the water table follow a relatively constant slope on the west side of the pile? The existence of the ground-water mound in the east side of the pile may be explained in several ways. First, much of the tailings in the east side were deposited prior to removal of the coarser fraction of the slurry for backfilling the mine. The hydraulic conductivity of the east pile would on the average be greater than that of the west pile. At the same time, the east half of the pile has been in existence approximately twice as long as the west portion. It is possible that a compacted layer with a lower hydraulic conductivity may have formed at the bottom of the east pile as a result of increased loading or overburden. This phenomena has been reported in earlier investigations by researchers working on an operating tailings pond (Williams, Kealy, and Mink, 1973). The downward movement of water would be restrained to some extent by the existence of the compacted layer and the water would be forced to mound under the east side of the pile. An alternative explanation for the mound is presented later in this study.

FIG. 12. CONTOURS OF THE WATER TABLE IN THE PAGE PILE AND SURROUNDING ALLUVIUM



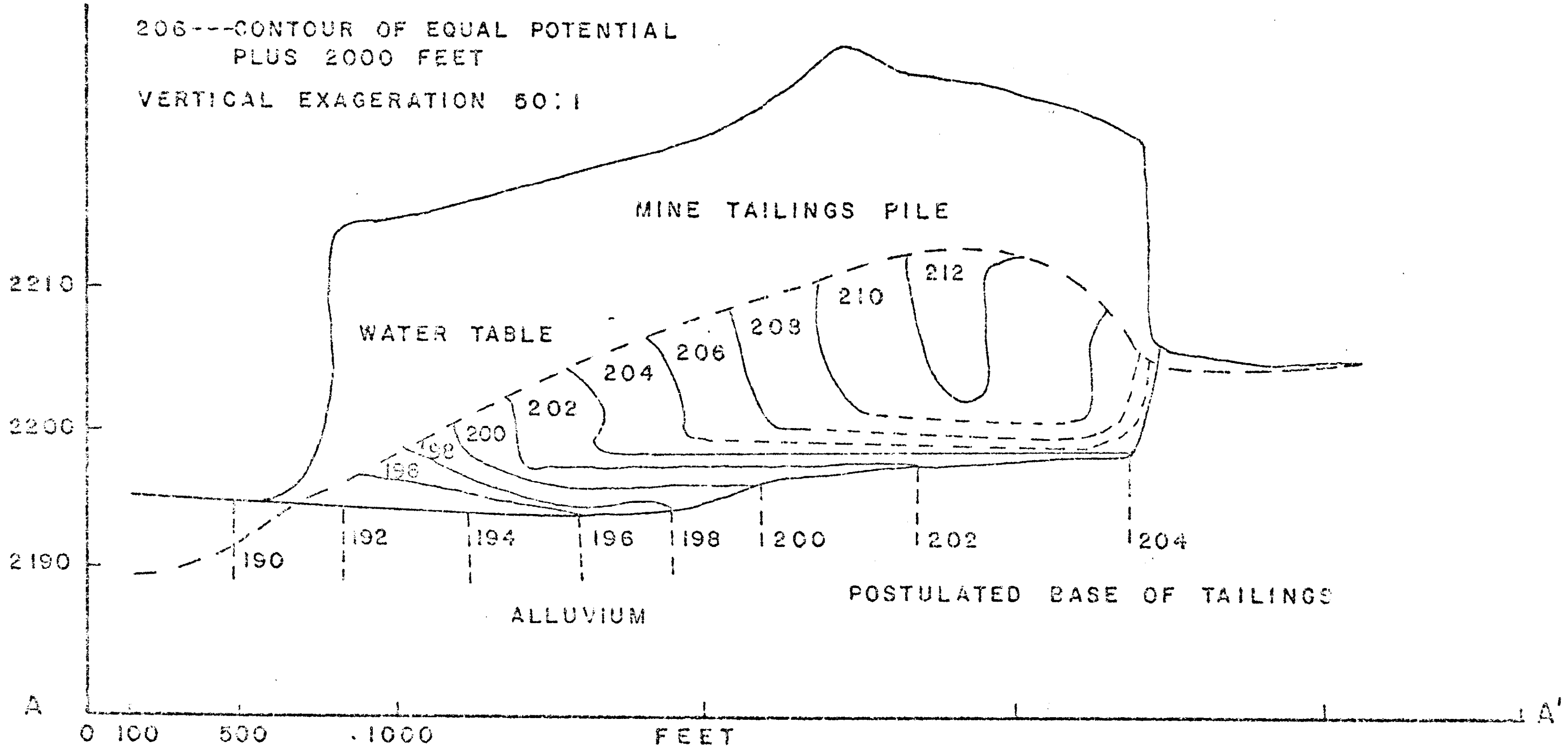


FIG. 15. POTENTIAL DISTRIBUTION WITHIN THE PAGE PILE AND ALLUVIUM ALONG EAST-WEST CROSS-SECTION A-A'

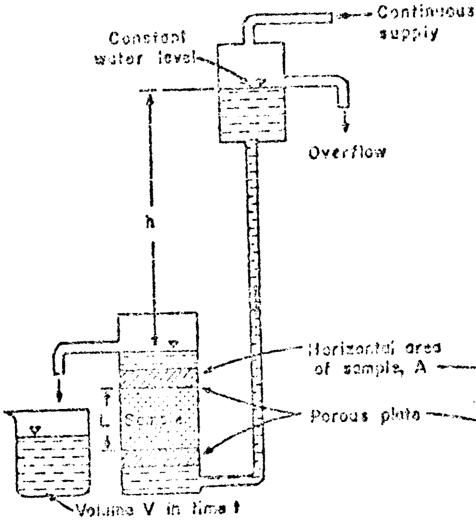
HYDROGEOLOGICAL PROPERTIES
OF THE TAILINGS MATERIALS

Comments on Laboratory Testing of Soils

Permeameters are used for laboratory determination of hydraulic conductivity of soils. There are two basic designs: the constant head permeameter and the falling or variable head type. The constant head permeameter, shown in Figure 14, can be used to determine hydraulic conductivity values of consolidated and unconsolidated formations under low heads. Water enters the medium cylinder from the bottom and is collected as overflow after passing upward through the material. From Darcy's law it follows that the hydraulic conductivity (K) can be obtained from:

$$K = \frac{V \cdot L}{A \cdot t \cdot h}$$

where V is the flow volume. The other factors are shown in Figure 14. In highly impermeable materials, the quantity V is small and accurate measurements of its value are not easily obtained. The constant head permeameter is principally applicable to relatively previous soils (Taylor, 1947). The expected values of the hydraulic conductivity of the materials that compose the Page pile range between $10^{-5} \frac{cm}{sec}$ and $10^{-7} \frac{cm}{sec}$. It was determined to test the tailings samples by the falling head permeameter method. Water is added to the tall column and allowed to flow upward through the medium cylinder and be collected as overflow (Figure 15). The test consists of noting times at which the water lowers to various gradations on



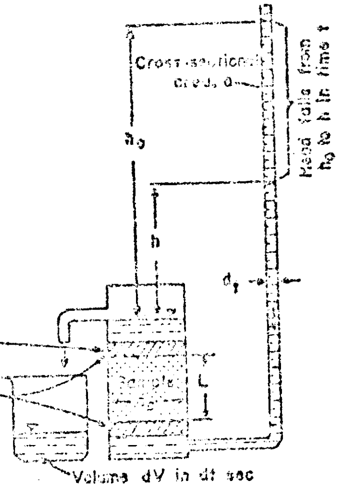


Figure 14. CONSTANT HEAD PERMEAMETER

Figure 15. FALLING HEAD PERMEAMETER

the tube. The hydraulic conductivity can be obtained from

$$K = \frac{(d_t^2)\ (L)}{(d_c^2)\ (t)}\ L_n \frac{h_o}{h}$$

where K is hydraulic conductivity in $\frac{cm}{sec}$ and d_c and d_t are the diameter of the cylinder and the tube respectively, h_o is the initial head and h is the head at any time later t (Todd 1959, p. 56). All the dimensions are shown in Figure 15. The variable head permeameter provides better results for the determination of the hydraulic conductivity of less pervious soils.

Several factors controlling this type of laboratory determination of the hydraulic conductivity must be discussed before the data obtained from the testing program are presented. The derivation of the equation that controls the falling head permeameter from Darcy's law assumes that the soil sample is completely saturated. In other words, it is assumed that all the voids have been completely filled with water. Soils in nature contain generally small amounts of entrapped air. Laboratory specimen frequently contain a high content of entrapped air which is acquired when sampling and shipping and during preparation for testing (Taylor, 1947). In addition to entrapped gas bubbles, certain amounts of air and other gases exist in solution in the pore water at any given temperature and pressure. If this amount of air is in solution an increase in temperature or decrease in pressure results in the freeing of some of the dissolved gases.

Reliable hydraulic conductivity determinations will not be obtained if entrapped air and dissolved gases are present within the laboratory sample. The main disadvantage of using the falling head permeameter is that the measured hydraulic conductivity decreases with time as the water level in the standpipe drops. The change is due to increased entrapped gas resulting from the lower water pressures in the sample as the head in the standpipe lowers. Several other reasons can be stated for the decrease in the hydraulic conductivity of the sample with time. The duration of hydraulic conductivity testing of soil samples by the falling-head permeameter method is controlled by the fluctuations of the measured hydraulic conductivity during the testing period. At the early stages of the test the hydraulic conductivity of the soil sample is constant with time. At some time after the beginning of the test because of a combination of the above factors, the values obtained for hydraulic conductivity decrease with time. The test should then be discontinued and an analysis made of the data obtained prior to the time when distinct fluctuations in hydraulic conductivity with time occurred (Taylor, 1974, Davis and DeWiest, 1966 and Cedergreen, 1966).

Laboratory Testing of Hydraulic Conductivity

Sixteen samples were extracted from the Page pile. The hydraulic conductivity tests were run as soon as the samples reached the laboratory to prevent swelling of the samples and disturbance of the physical properties of the materials. A number of permeameters equal to the number of samples had been previously built and set up in the laboratory (Figure 16). Copper sulfate was added to the tall column in combination with the distilled water to prevent bacteria growth. A thin layer of vegetable oil was added to the tall column of water to minimize the effect of evaporation during the laboratory test. It was observed during our testing program that a decrease in the hydraulic conductivity of the tailings samples a factor of ten occurred after the third or fourth day since the beginning of the test (Figure 17). For this reason, only the measurements obtained during the early portion of the test were considered to yield reliable values for the hydraulic conductivity of the materials tested.

Analysis and Presentation of Results

Satisfactory hydraulic conductivity results were obtained from fourteen of the sixteen samples. Two of the samples were disturbed while being extracted from the investigation holes. Air pockets formed along the wall of the samplers which in turn produced some high flow rates along those critical zones.

Data on hydraulic conductivity obtained by the falling-head permeameter method are presented in Table 4 and Figure 18. Table 4 includes data on the location and depth of the investigation holes, number of reliable measurements, mean hydraulic conductivity for each sample in cm/sec and the highest and lowest hydraulic conductivity measured for each sample. The

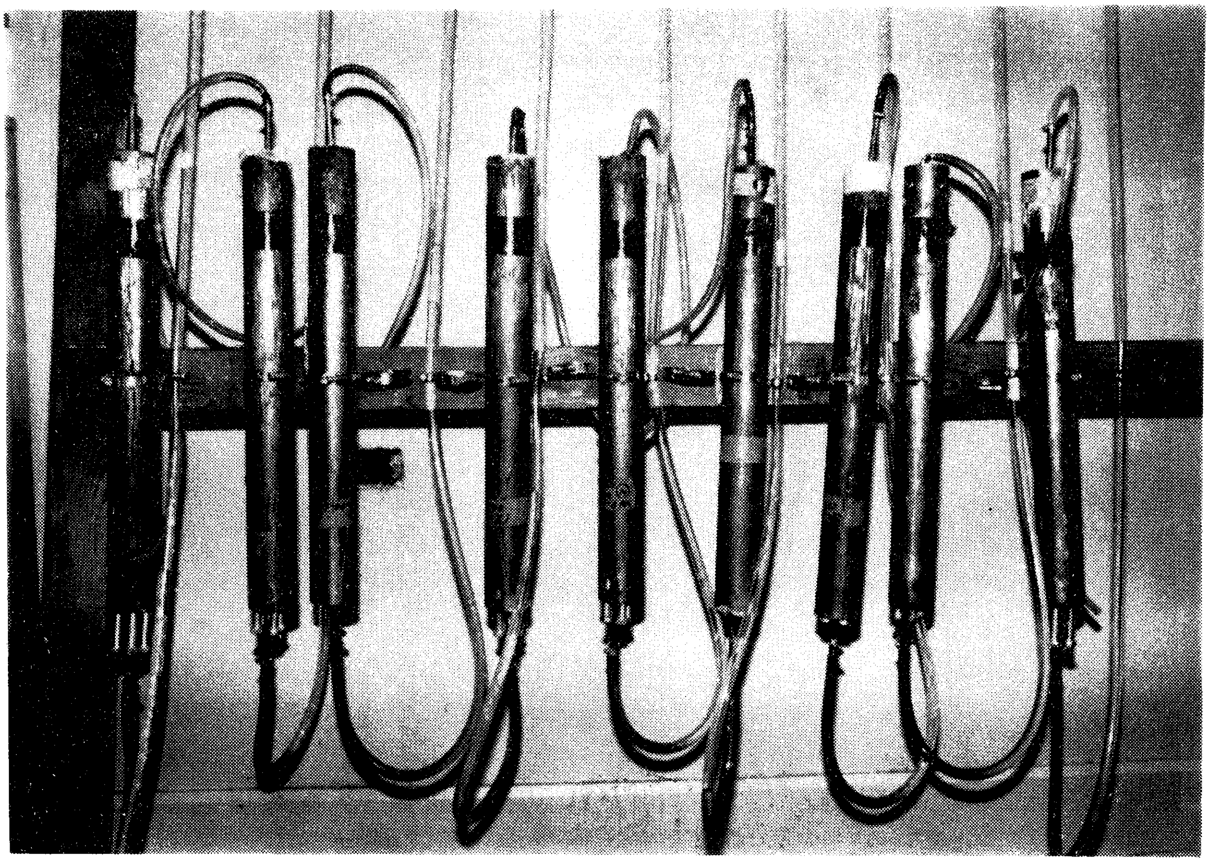


FIG. 16. FALLING HEAD PERMEAMETERS FOR TESTING PERMEABILITY OF SHELBY TUBE SAMPLES OBTAINED FROM THE PAGE TAILINGS PILE.

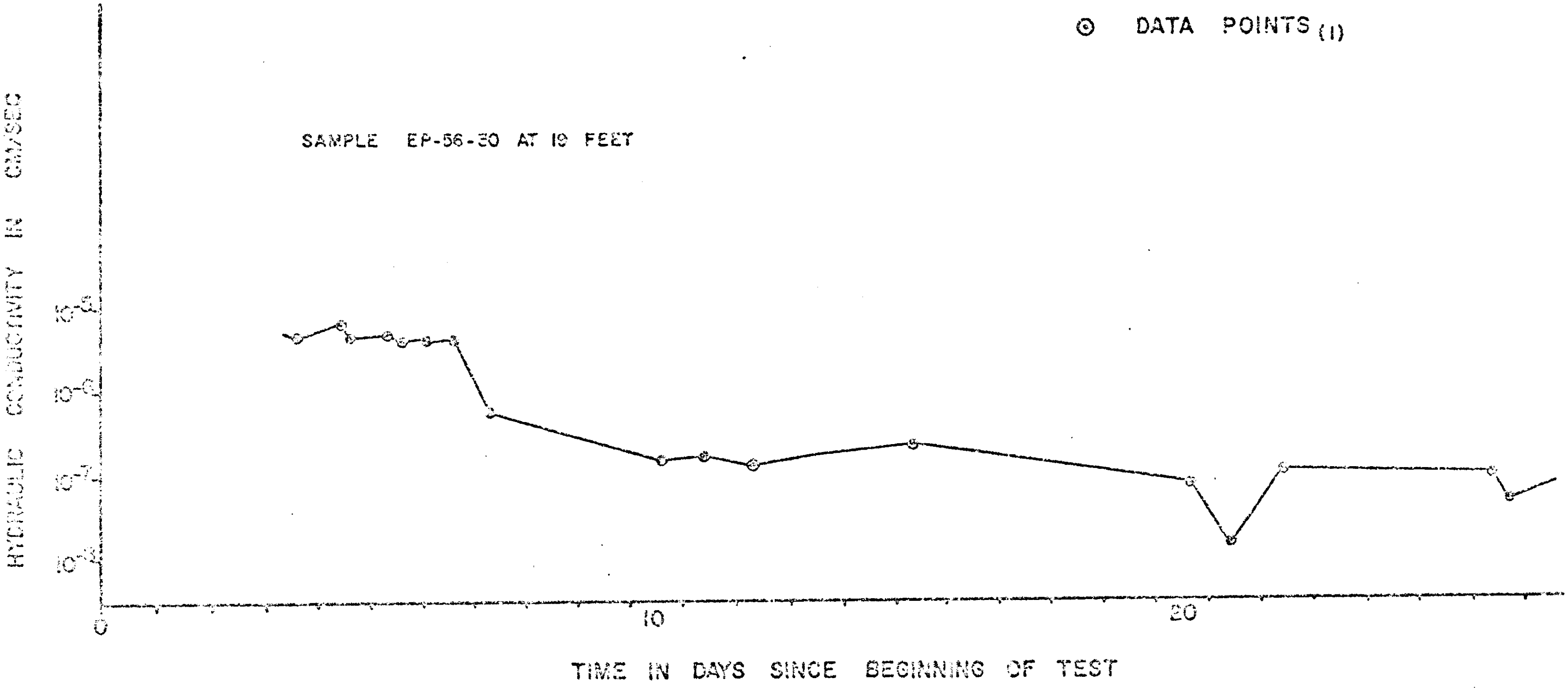


Figure 17. DECREASE IN LAB HYDRAULIC CONDUCTIVITY WITH TIME.

(1) CALCULATED LAB HYDRAULIC CONDUCTIVITY AT VARIOUS TIMES AFTER BEGINING OF TEST

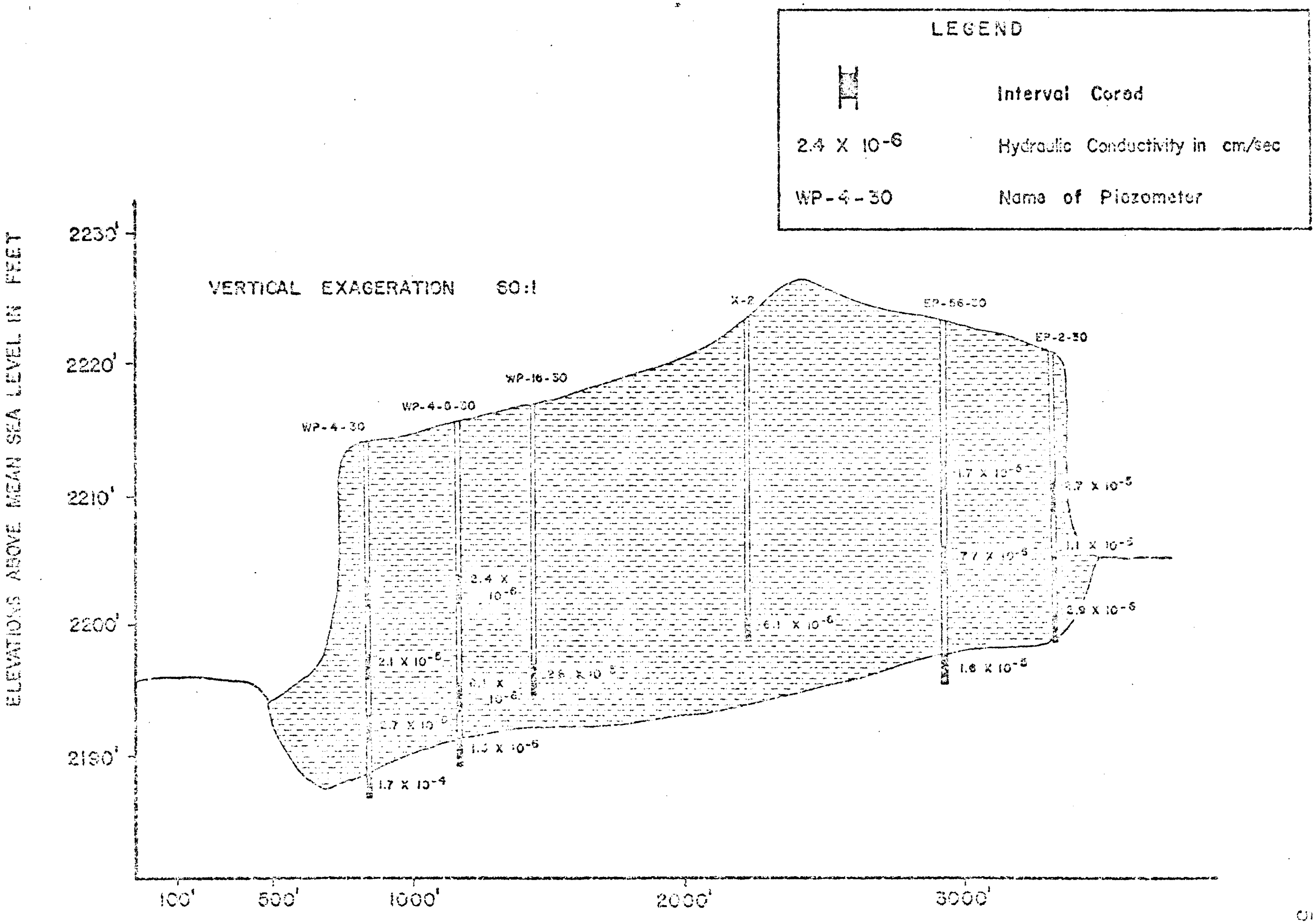


Figure 18. LOCATION OF CORE SAMPLES AND LAB HYDRAULIC CONDUCTIVITY VALUES FOR SAMPLES FROM THE STUDY AREA

distribution of mean hydraulic conductivity values in the tailings pile as obtained by the falling head permeameter method are shown in Figure 18. A slight decrease in hydraulic conductivity occurs with depth at several sites. Distinct differences in hydraulic conductivity with depth that would indicate the existence of a compacted layer were not observed. Samples obtained from investigation holes EP-2-30 at 12 feet and 17 feet and from WP-4-30 at 17 feet show the highest hydraulic conductivity in the pile. Both investigation holes were drilled close to the embankment of the tailings pile. The reason for the higher hydraulic conductivity at these sites is not known.

Four samples were obtained from the alluvial materials underlying the tailings pile. The sample obtained from investigation hole WP-4-30 at 27.7 feet yielded a hydraulic conductivity of $1.7 \times 10^{-4} \frac{cm}{sec}$. This hydraulic conductivity can be considered typical of a very poor aquifer. The other three samples obtained from the alluvial deposits gave results ranging from $1.3 \times 10^{-6} \frac{cm}{sec}$ to $1.6 \times 10^{-5} \frac{cm}{sec}$. These measured values of hydraulic conductivity are not in accordance with the type of alluvial materials sampled. Two factors may explain the low hydraulic conductivity of the alluvial materials immediately underneath the bottom of the tailings pile. First, the tailings probably invaded the coarser alluvial materials to some depth causing a decrease in hydraulic conductivity. Also, older "jig tailings" are intermixed with the alluvial materials in the area of the tailings pile and may to some extent reduce the hydraulic conductivity of the materials

Table 4. Lab Hydraulic Conductivity Values for Samples From the Study Area

Location of Investigation Holes	Depth in Feet Below G.S. of Interval Cored	Number of Valid Measurements	Mean Hydraulic Conductivity in cm/sec	Standard Deviation	Range in cm/sec	
					Low	High
EP-56-30	12	9	1.6×10^{-5}	8.1×10^{-6}	1.5×10^{-5}	1.7×10^{-5}
EP-56-30	19	6	7.6×10^{-6}	7.7×10^{-6}	6.8×10^{-6}	9.0×10^{-6}
EP-56-30	27	6	1.6×10^{-5}	9.9×10^{-6}	1.0×10^{-5}	4.8×10^{-5}
WP-4-30	17	7	2.0×10^{-5}	1.6×10^{-6}	1.2×10^{-5}	3.0×10^{-5}
WP-4-30	22	12	2.6×10^{-6}	1.0×10^{-6}	1.1×10^{-6}	5.0×10^{-6}
WP-4-30	27	2	1.7×10^{-4}	1.8×10^{-5}	1.6×10^{-4}	1.8×10^{-4}
EP-2-30	12	4	2.6×10^{-5}	1.4×10^{-5}	1.8×10^{-5}	4.7×10^{-5}
EP-2-30	18	7	1.0×10^{-5}	8.1×10^{-6}	6.7×10^{-6}	2.8×10^{-5}
EP-2-30	23	5	2.9×10^{-6}	1.6×10^{-6}		
WP-4-5	13	8	2.4×10^{-6}	9.0×10^{-7}	1.3×10^{-6}	4.0×10^{-6}
WP-4-5	22	6	8.1×10^{-6}	6.3×10^{-6}	9.5×10^{-6}	1.5×10^{-5}
WP-4-5	26	7	1.2×10^{-6}	3.8×10^{-7}	9.2×10^{-7}	1.1×10^{-6}
X-2	26	4	6.0×10^{-6}	3.8×10^{-6}	2.3×10^{-6}	1.1×10^{-5}
WP-16-30	22	4	2.8×10^{-5}	8.4×10^{-6}	1.6×10^{-5}	2.6×10^{-5}

located below the tailings-alluvium interphase. A more extensive drilling and sampling program is required to better understand the variations of hydraulic conductivity inside the pile.

The above data suggests that the materials that compose the Page tailings pile may be considered as reasonably homogeneous. The mean hydraulic conductivity of these materials was estimated to be $3.0 \times 10^{-6} \frac{\text{cm}}{\text{sec}}$.

It should be stressed at this point that much more extensive drilling and sampling of the Page tailings pile is needed to delineate the areal variations of hydraulic conductivity.

Analysis of Natural Recession Curves

The hydraulic conductivity values of the tailings materials at three different sites in the tailings pile were estimated using water level recession curves. Water-level data available for the period July 9 to October 3, 1974 during which precipitation did not occur were analyzed to obtain an independent check for the values of hydraulic conductivity obtained by the falling head permeameter. Jacob (1943) demonstrated that the decline of water levels on a peninsula in response to an absence of precipitation can be approximated by the equation:

$$h = h_o \cdot e - \frac{\pi^2 Tt}{4a^2 S}$$

where h_o is the original height of the water table in feet, h is the height of the water table after a given time t in seconds, and is half the width of the peninsula, T is the coefficient of transmissivity in square feet per second and S is the coefficient of storage which is a dimensionless term (Domenico, 1972, p. 51).

For the Page pile analysis, the storage coefficient was estimated using known water levels over a given period of time and the estimated discharge from the bottom of the pile. This method yielded a hydraulic conductivity value of 8.5 x 10^{-2} cm/sec; a value much larger than that determined by the permeameter analysis. It is believed that the method did not work in the Page site because of the violation of one of the basic assumptions of the method. Jacob (1943) assumed that the value (h_o, h) was small compared to the value of h. This was not so for the Page site. The recession curve analysis did not yield useable results.

FINITE ELEMENT MODEL OF THE GROUND WATER FLOW SYSTEM

Description of the Finite Element Model

A mathematical model of the flow system in the tailings pile was constructed using an available finite element computer program to better define the factors controlling the ground-water movement through the tailings pile. The finite element program was developed by R.L. Taylor at the University of California, Berkeley, and has been used in several sudies by the U.S. Bureau of Mines (Kealy and Busch, 1971). The program can handle steady state two dimensional confined and water table flow conditions and uses an iterative technique to locate the steady state phreatic surface for the free surface points. A cross-section defining the geometry of the problem and the boundary conditions serves as the first step for the construction of the mathematical model. The cross-section is divided into discreet elements delineated by nodal points forming a mesh configuration. Each element is assigned its material type and characteristic hydraulic conductivity. The recharge to the pile is modeled as flow into the mathematical model. Output consists of nodal locations, potentials and element velocities and directions (Figure 19). To gain some experience and knowledge, a small model of the cross-section B-B' of Figure 7 was constructed. A more efficient model of the pile was constructed with the experience gained with the construction of the first model. A finite-element mesh was drawn of an east-west vertical cross-

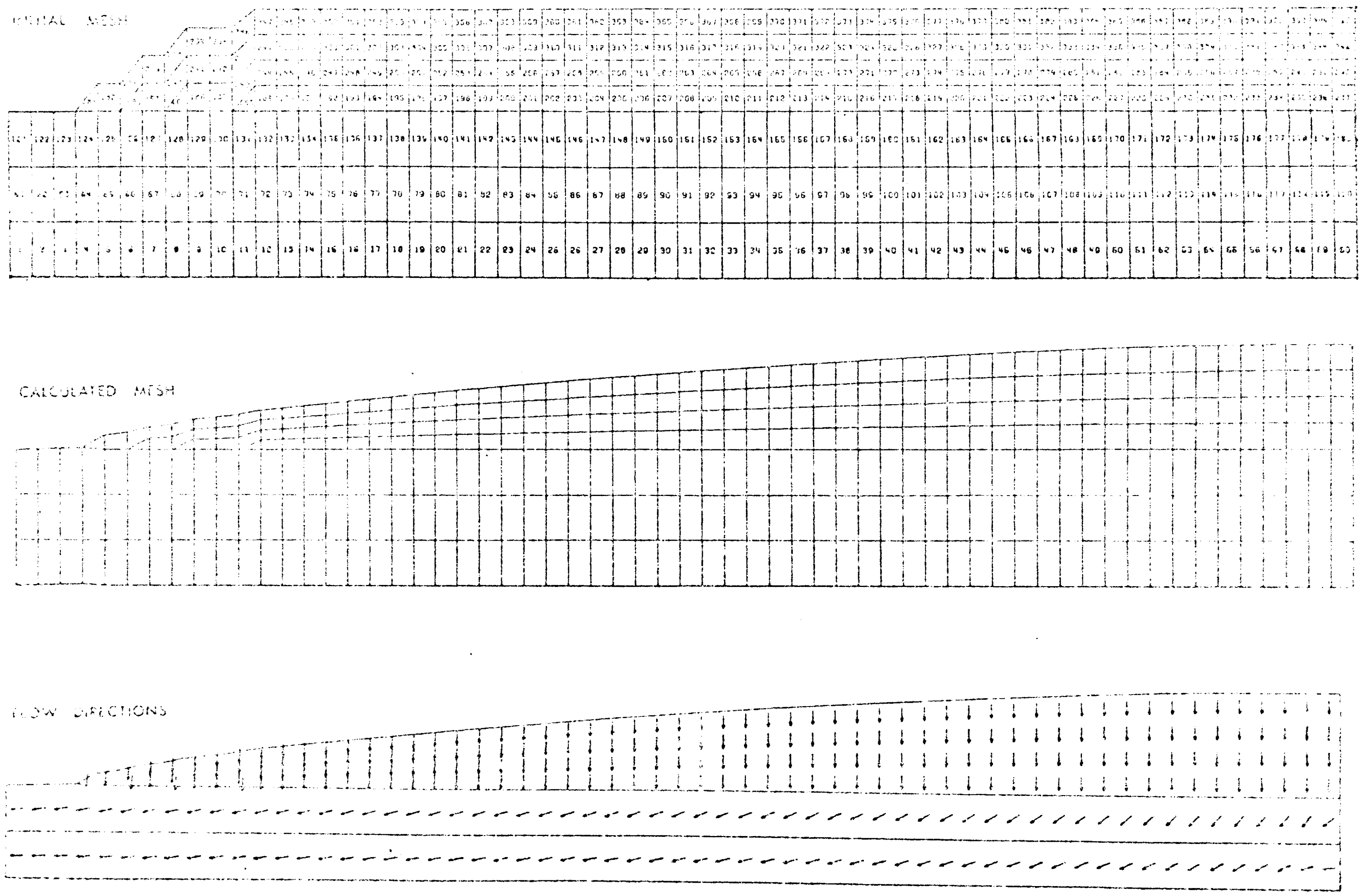


FIGURE 19. COMPUTER GENERATED PLOTS OF THE INITIAL MESH, CALCULATED MESH AND FLOW DIRECTION FROM THE FINITE ELEMENT MODEL OF THE PAGE TAILINGS PILE

section of the Page tailings pile and of the underlying alluvial deposits. Eight hundred and twenty elements were delineated by the location of 940 nodes. Most of the elements and nodes were automatically generated by the finite-element computer program. The calculated hydraulic conductivity for the tailings materials of 3 x 10^{-6} centimeters per second was assigned to the elements defining the tailings pile. The 90 feet of alluvial deposits underlying the pile were also modeled. The hydraulic conductivity of the alluvium materials could not be accurately determined. A typical hydraulic conductivity of 30 centimeters per second was assigned as material type to the elements that compose the section of the model which defines the alluvial deposits underlying the tailings pile. Data on the distribution of horizontal hydraulic conductivity in the pile were not available. A ratio of horizontal to vertical hydraulic conductivity of four to one was input to the mathematical model. Later operation of the model showed that changing the horizontal to vertical ratio to ten to one did not significantly alter the location of the computer generated water-table in the tailings pile. The materials that compose the tailings pile were considered homogeneous. According to this concept, tailings material layering does not exist. An angle of stratification equal to zero was input to each element card.

The ground-surface line defining the top of the tailings pile was divided into 121 free-surface nodes. The mean yearly precipitation for the area of study was evenly distributed among the total number of these nodes. In this manner recharge rates were input to the tailings pile by adding the percentage of the total flow in at each free-surface node. The regional ground-water table in the valley fill near the pile, located from two to four feet below ground-surface was also incorporated to the mathematical model. This boundary condition was inserted into the model by fixing the fluid pressure at the starting and ending node of the alluvium bedrock boundary line.

Operation and Calibration of the Mathematical Model

The first objective to be met with the construction of the model was to find a combination of hydraulic conductivity and recharge values that would generate a computer water-table for the tailings pile which would approximate the configuration of the water-table measured by the field piezometers. It should be noted that the water-table configuration measured in the Page tailings pile could be maintained with a range combination of recharge rates and hydraulic conductivity values. The hydraulic conductivity of the tailings materials was maintained at the calculated 3 x 10^{-6} centimeters per second. Recharge rates of 30, 25, 20 and 15 inches of precipitation per year were input to the model. Outputs from the finite-element program for the different recharge rates are illustrated in Figure 20. The dashed line represents the water-table measured by the field piezometers. It was observed that about 27 inches of yearly precipitation was needed to among the total number of these nodes. In this manner recharge rates were input to the tailings pile by adding the percentage of the total flow in at each free-surface node. The regional ground-water table in the valley fill near the pile, located from two to four feet below ground-surface was also incorporated to the mathematical model. This boundary condition was inserted into the model by fixing the fluid pressure at the starting and ending node of the alluvium bedrock boundary line.

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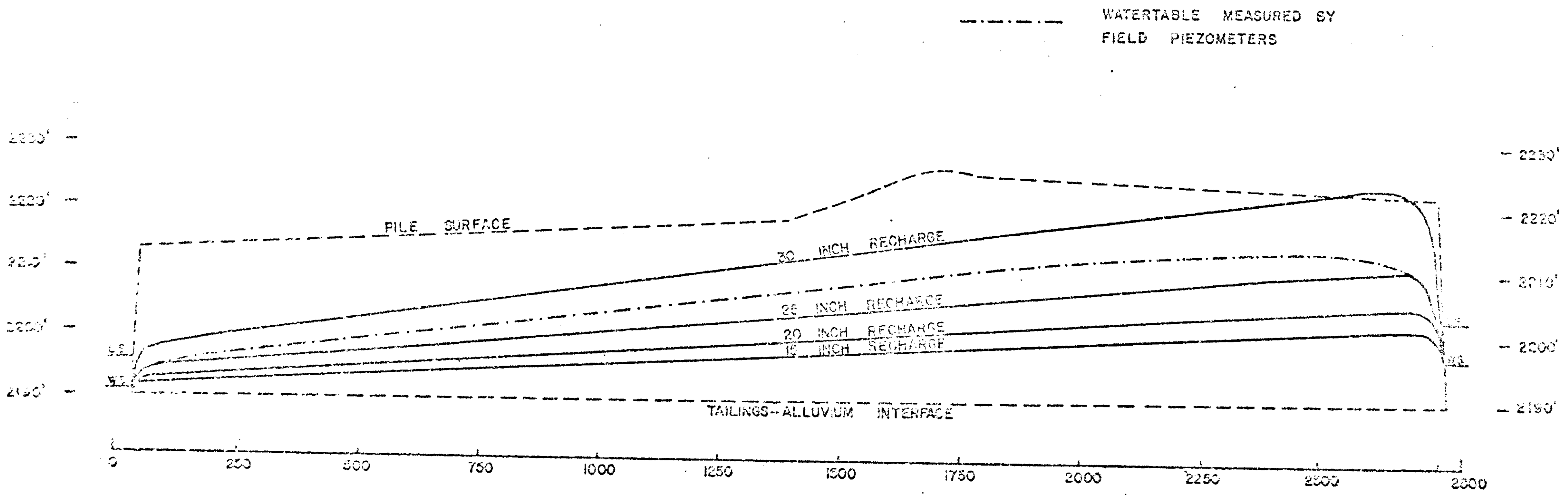

Figure 20. COMPUTER GENERATED WATERTABLE CONFIGURATIONS RESULTING FROM DIFFERENT RECHARGE INPUTS TO TAILINGS PILE AND WATERTABLE MEASURED BY FIELD PIEZOMETERS.

maintain the water-table in the pile at elevations close to those measured by our field piezometers.

The location of the regional water-table below the tailings-alluvium interface was changed by varying the pressure differentials at the bottom of the pile. Figure 21 shows the configurations of the water-table obtained by inputting the same amount of yearly precipitation and lowering the regional water-table from 97 feet above the alluvium bedrock boundary line to 93 feet. A distinct drop in water levels can be observed for the same recharge rate when the regional water level is lowered.

Conclusions Obtained from Operation of Mathematical Model

1. The ground-water levels calculated by the model correlate closely with the measured water levels. A recharge rate of 27 inches of precipitation a year is needed to maintain the water-table in the pile at elevations close to those measured by the field piezometers.

2. Several runs using different recharge rates show the dynamic character of the flow system.

3. The finite-element model is instrumental in illustrating the hydrological interconnection between the flow systems inside and outside the tailings pile by showing the impact of the location of the regional ground-water table on the water levels inside the pile.

4. The ground-water mound under the east side of the tailings pile can be explained on the basis of the location

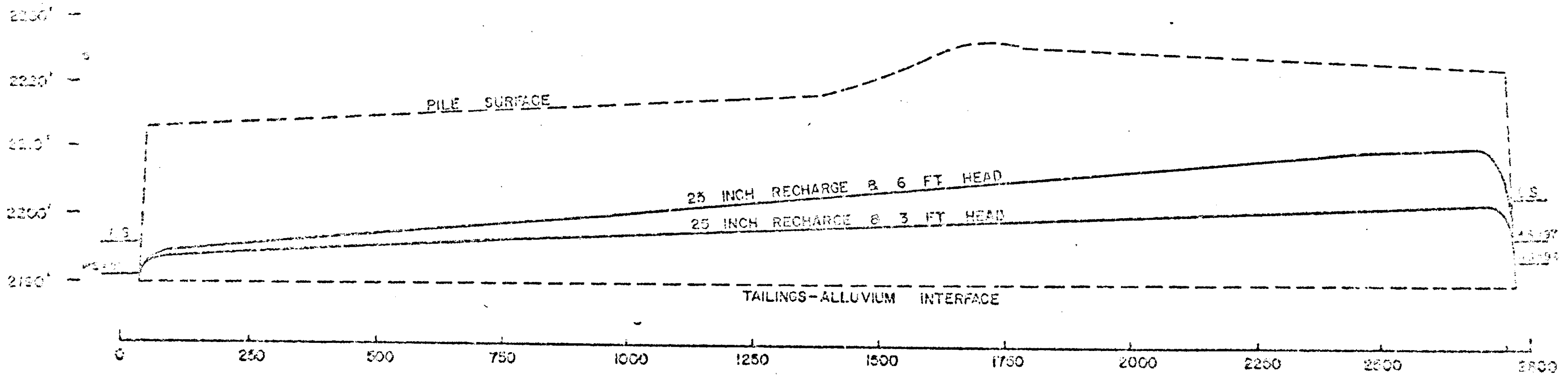

Figure 21. CONFIGURATIONS OF WATER TABLE INSIDE TAILINGS PILE FOR 25 INCH RECHARGE AND 6 AND 3 FEET OF HEAD PRESSURE DIFFERENTIALS ALONG BOTTOM OF PILE.

of the regional ground-water table in the alluvium underlying the pile and the magnitude of recharge to the pile as an alternative explanation to the existence of a compacted layer at the bottom of the east side of the pile.

DISCUSSION OF RESULTS

Correlation Between the Amount of Recharge Needed to Maintain the Ground Water Mound and Related Leakage Rate from the Tailings Pile

Output from the finite element model showed that a yearly input of 27 inches of precipitation was needed to maintain the ground-water mound at levels similar to those measured in field piezometers. A 27-inch recharge to the pile would result in discharge from the bottom of the tailings pile at a rate of 2,000 gallons per day per acre. Calculations using Darcy's equation with a hydraulic conductivity of the tailings materials of 3×10^{-6} centimeters per second, an assumed vertical hydraulic gradient equal to one and the area of the tailings pile equal to 70 acres produced a rate of subsurface discharge from the bottom of the pile equal to 2,800 gallons per day per acre, equivalent to 37.8 inches of precipitation per year. This discharge rate is too high, possibly because the vertical hydraulic gradients at several locations in the pile could be smaller than one. The vertical component of the hydraulic gradient was calculated using the vertical cross section of Figure 13. A total mean value of 0.73 was computed for the vertical component of the hydraulic gradient in the tailings pile. This value was used to compute a discharge of 2055 gallons per day per acre. This value for the rate of discharge correlated very closely with the computer calculated rate of discharge of 2000 gallons per day per acre. It should be noted that there may exist some error in the calculated rate of discharge using Darcy's equation due to the fact that the horizontal component of the hydraulic gradient has not been included in the above calculations.

Calculation of the Contribution of Zinc from the Page Tailings Pile to the Immediate Environment

The mean concentrations of zinc for the piezometers located inside the pile for the 1972-1974 period of data collection ranged from 1.4 to 102 parts per million (Table 5). A pattern in the concentration of zinc inside the pile was not observed either horizontally or with depth. A total mean concentration of zinc of 15.16 ppm was calculated for the piezometers located inside the pile. Using this concentration, the calculated discharge rate from the bottom of the pile of 2000 gallons per day per acre and the size of the pile, 17.8 pounds per day of zinc were estimated to reach the immediate environment surrounding the pile. Groundwater quality data from 52 piezometers located in the alluvium outside the pile were analyzed and a total mean concentration of zinc of 28 parts per million was calculated. Groundwater quality data presented by Norbeck (1974) show a mean concentration of zinc of 33 parts per million for three wells located in the alluvium up-gradient from the Page tailings pile.

Jig tailings have been deposited over much of the valley floor along the south fork of the Coeur d'Alene River. According to Williams and Mink these high concentrations of zinc may be contributed to the flow system by leaching of

Table 5. Mean Concentration of Zinc in ppm for Water Samples From Piezometers Located Inside the Page Tailings Pile. (1)

Piezometer Locations	Piezometer Depth Below Surface of Tailings Pile	Number of Samples	Mean Concentrations of Zinc in ppm
WP-1	12.6	11	19.
WP-2	16.5	11	7.
WP-3	24.8	11	3.
WP-4	19.0	12	3.
WP-4-5-16	15.8	6	9.
WP-4-5-21	19.9	6	9.
WP-5-15	13.7	4	26.
WP-5-25	26.4	7	18.
WP-6-18	18.2	9	0.
WP-6-20	19.6	7	18.
WP-6-21.5	23.1	8	102.
WP-6-25	24.9	9	4.
WP-7-21	21.3	11	1.
WP-7-22	23.4	9	2.
WP-7-25	25.1	9	2.
WP-13	19.8	6	1.
WP-13-16	17.5	6	16.
WP-13-20	21.8	7	7.
WP-14	24.1	6	35.
WP-14-20	21.7	6	38.
WP-14-24	25.2	10	22.
EP-1	25.9	10	17.
EP-2	21.5	7	20.
EP-2-13	14.6	8	7.
EP-2-17	18.5	8	9.
EP-2-20	23.4	11	7.
EP-3	23.8	5	6.
EP-4	21.0	8	27.
EP-5-15	13.7	6	15.
EP-5-16	16.9	6	15.
EP-5-20	20.7	14	3.
EP-5-25	22.2	8	3.
EP-6-17	17.4	8	8.
EP-6-19	18.6	8	1.
EP-6-23	22.7	12	4.
EP-7	14.0	7	20.
EP-7-16	16.4	6	24.
EP-7-23	22.8	5	30.
EP-56	16.5	6	11.
EP-57	17.8		17.
			15.16 ppm (2)

(1) For location of piezometers see Figure 3

(2) Mean for all piezometers

these old deposits.

The amount of zinc discharged from the tailings pile was compared with the amount of zinc carried by the South Fork of the Coeur d'Alene River at Smelterville near the Page tailings site during low flow (Table 6). The data presented below was obtained from the Water Resources Data for Idaho, Surface Water and Water Quality Records (1972, pp. 61 and 40).

Table 6. Flow Rates on Three Dates in 1972. Zinc Concentrations and Total Daily Load of Zinc Carried by the South Fork of the Coeur d'Alene River at Smelterville (Idaho).

Dates of Measurement	Rates of Flow in cfs	Concentrations of Zinc in ppm	Total Daily Load of Zinc in Pounds
July 20	315	6.6	11,316
August 17	180	32.5	31,841
September 6	137	13.6	10,141

Based on this data it was calculated that the South Fork of the Coeur d'Alene River upstream from the Page tailings pile was carrying an average of 17,766 pounds per day of zinc during the above period. The daily amount of zinc provided by the tailings pile to the South Fork is 0.1 percent of the total daily amount of zinc carried by the river during the low flow dates noted above.

SUMMARY AND CONCLUSIONS

A tailings pile in the Coeur d'Alene Mining District in northern Idaho was selected for investigation to determine the impact of an abandoned tailings pile on the water resource system. A network of piezometers was installed both in the tailings material and in the surrounding alluvium. The data revealed that a ground-water mound exists beneath the eastern portion of the tailings pile. Variations in hydraulic conductivity of the tailings material were suggested as the controlling factor for the existence and location of the mound. Temporal fluctuations of ground-water potential indicate the dynamic nature of the flow system in the tailings pile. The flow system in the pile responds to both short term and long term fluctuations in precipitation. A drilling and sampling program of the tailings pile provided information on the distribution of hydraulic conductivity in the pile. Data were obtained by drilling six investigation holes with a hollow stem power auger and sampling the tailings with thin-wall samplers. Falling head permeameters were used to determine vertical hydraulic conductivity values. Distinct differences in hydraulic conductivity with depth that would confirm the existence of a compacted zone at the bottom of the east side of the pile were not observed. Hydraulic conductivity data of the tailings material (3.0×10^{-6} cm/sec) along with a selected hydraulic conductivity value for the alluvial materials of 30 centimeters per second were incorporated as input to a steady state finite element model of the flow system in the Page tailings pile. Operation of the model using different recharge rates showed that the extent and location of the ground water mound under the east side of the pile varies with the recharge inputs to the pile. The finite element model also illustrates the hydrological interconnection between the flow systems inside and outside the pile. The location of the regional ground-water table was found to be an additional factor controlling the existence of the ground-water mound in the east side of the pile. The mathematical model of the Page tailings pile indicated a discharge of 2000 gallons per day per acre of water to the immediate environment surrounding the pile, via subsurface discharge. The mean concentration of zinc of the piezometers located inside the pile was estimated to be 15.16 ppm. Zinc is calculated to reach the pile surroundings at an estimated rate of 17.18 pounds per day. The daily amount of zinc provided by the tailings pile to the area was computed as 0.1 percent of the total zinc load carried by the river during low flow upstream from the tailings pile.

The following conclusions were drawn from this study:

1. The flow system in the Page tailings pile is dynamic; it responds to precipitation events and periods of no recharge. This shows that there is recharge to, and discharge from, the pile.

2. Analysis of the water level fluctuations for the period 1972-1974 indicated that a long-term dewatering of

the tailings is not occurring. The leaching of the mine wastes in the pile may continue for a long period.

3. Data obtained from fourteen tailings samples from the Page pile indicate that there are not distinct differences in the hydraulic conductivity of the tailings materials from various parts of the pile. The tailings pile was treated as a homogeneous system.

4. The location of the regional ground-water table and the rates of recharge to the pile were found to be the controlling factors in the existence of the ground water mound under the eastern part of the pile.

5. Output from the finite-element mathematical model shows that the rate of subsurface water discharge, via seepage from the bottom of the Page tailings pile is approximately equal to 2000 gallons per day per acre.

6. The rate of zinc contributed by the pile is about 0.1 percent of the total daily amount carried by the river upstream for a period of selected records.

Comparison of the daily amount of zinc transferred by leaching from the movement of precipitation through the tailings pile and the daily load zinc carried by the South Fork of the Coeur d'Alene River upstream from the area of study showed that the abandonment of the Page tailings pile does not have a significant detrimental effect on the main streams in the area.

The impacts of abandoning tailings piles in the Coeur d'Alene Mining District and in areas with a less polluted environment will depend on the following factors:

a. Size of the abandoned tailings pile
b. Hydrogeological and chemical characteristics of the mining wastes
c. Recharge rates to the piles
d. Location of the regional ground water table
e. Rate of subsurface water discharge via seepage from the bottom of the piles
f. Geochemical background of the area where abandonment occurs.

RECOMMENDATIONS

Experience gained during the course of this study leads the author to make a number of recommendations that might help future investigators to deal with the same or similar types of problems than those encountered in the Page tailings pile project.

1. More data on both horizontal and vertical hydraulic conductivity are needed to better describe the variation of hydraulic conductivity in the tailings pile.

2. A program to determine the in-situ hydraulic conductivity of the tailings materials should be carried out in existing piezometers prior to the sampling and testing of samples in the lab. In this manner we can obtain a basis of comparison for further lab hydraulic conductivity data generated during the sampling and testing programs. Slug tests (injection tests) provide a means for obtaining data easily and give an overall view of the distribution of hydraulic conductivity in the area to be sampled. This type of testing procedure was utilized in the Page pile. However, successful results were not obtained. Our water injection system did not work efficiently and later efforts to improve the system were not made. A water injection system that allows to measure instantaneous declines of head inside the piezometers should be designed if accurate data are to be obtained from this method.

3. Lensing and layering of tailings materials occurred

with changes in mining and milling techniques during the filling of the pile. This causes the ground-water system in the pile to be in a complex semi-confined state which had a distinct impact on the seepage patterns in the pile. Sampling of the area of study should include not only areas below the water-table but also shallow samples that would help define marked differences in the physical characteristics of the tailings with depth.

4. The main problem when testing soil samples by either the constant head or the falling head permeameter is movement of water along the tube wall. A plexi-glass sampler should be used to allow examination of boundary flow that would distort measured hydraulic conductivity values.

5. The use of the falling head permeameter is limited by a time factor. Sometime after the beginning of the test there is a distinct decrease in the measured hydraulic conductivity. Data obtained after that phenomena is observed are not reliable.

6. The computer generated water-table shows a discrepancy with the water-table measured by our field piezometers only in areas close to the embankment of the tailings pile. More piezometers should be installed in areas close to the edge of the pile to better define the shape of the water-table.

7. The flow system in the Page tailings is dynamic and the finite-element computer program used in this study depicts the system only as steady state. A computer program

which would solve transient flow problems would represent more accurately the flow system in the pile.

8. The regional ground-water table could be lowered by either of the following methods:

    a. relief wells located near the area where the ground-water mound is located would lower the regional ground-water table which in turn would cause the water inside the pile to drain by gravity.

    b. diversion of Grouse Creek and Humboldt Creek, both of which recharge the valley fill in the area of study may also lower the regional ground-water table in the area.

9. The rate of subsurface discharge from the pile could be minimized by a properly designed compaction program that would increase the density of critical surface zones of the tailings pile which would substantially reduce recharge to the tailings pile.

10. A more detailed analysis of the water quality data from the flow system in the pile is needed to describe with more detail the impacts of the abandonment of tailings piles on the water resources of the area where abandonment occurs.

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APPENDIX A

DATA COLLECTION SYSTEM

EAST PILE

Grid Coordinate X	Y	Site	Date Placed	Date Lost	Tube Elevation	Length
5094	3120	EP-1-17	060673	082473	227.62	18.17
5094	3120	EP-1-26	092372	061573	227.55	25.95
5754	2704	EP-2-13	060673		223.43	14.67
5754	2704	EP-2-17	062773		224.24	18.50
5754	2704	EP-2-20	092372		223.76	23.40
5754	2704	EP-2-30	102374		223.94	27.60
5418	2026	EP-3-16.5	060673	082173	223.78	16.52
5418	2026	EP-3-24	092372	082173	224.07	23.88
4776	2479	EP-4-16	060673	080673	228.14	17.40
4776	2479	EP-4-17.5	060673	080673	228.16	19.03
4776	2479	EP-4-21	060673	080673	227.53	21.95
4776	2479	EP-4-22	092372	080673	228.38	22.75
4776	2479	EP-4A	071874		226.84	19.55
5260	2573	EP-5-12	092372	101473	225.31	10.32
5260	2573	EP-5-15	022373	101473	225.21	13.74
5260	2573	EP-5-16	062673	101473	225.52	16.90
5260	2573	EP-5-20	031373	101473	225.37	20.71
5260	2573	EP-5-25	060673	101473	225.71	22.28
5260	2573	EP-5-27	062773	101473	225.60	28.60
5260	2573	EP-5A-12	070874		226.84	17.40
5260	2573	EP-5A-15	071874		226.81	18.65
5260	2573	EP-5A-17	071874		226.16	21.70
5260	2573	EP-5A-27	071874		226.87	29.40
5743	2188	EP-6-17	060673		222.19	18.85

Grid Coordinate X	Y	Site	Date Placed	Date Lost	Tube Elevation	Length
5743	2188	EP-6-19	060673		222.29	20.15
5743	2128	EP-6-20.5	062773		221.94	21.65
5743	2188	EP-6-23	060673		222.71	24.79
5474	3227	EP-7-16	060673		225.34	18.30
5474	2337	EP-7-23	060673		225.33	24.80
5000	1971	EP-8	060673	082173	225.34	26.76
5000	1971	EP-8A	072774		226.94	22.00
4674	3000	EP-9	060673	080673	229.60	19.95
4976	2510	EP-45	071073	080673	226.98	16.60
4947	2510	EP-45A	071874		226.77	17.20
5560	2335	EP-56	070973		223.73	16.50
5560	2335	EP-56-30	102374		224.20	32.40
5343	2908	EP-57	070973		225.44	17.80
5140	2243	EP-58	071873	102273	225.20	16.80
5140	2243	EP-58A	071874		227.49	19.73
4956	2796	EP-59	071073	072573	228.36	17.20
4956	2796	EP-59A	072774		227.76	18.35

WEST PILE

Grid Coordinate			Date	Date		
X	Y	Site	Placed	Lost	Elevation	Length
3730	2590	WP-1-15	060676	081273	217.68	16.95
3730	2590	WP-1-18	030173	080673	217.16	18.78
3730	2590	WP-1-18	062774		218.72	20.90
4660	2430	WP-2-12.6	060673	080673	225.48	14.47
4660	2430	WP-2-16	060673	080673	224.84	22.30
4660	2430	WP-2-21	060673	080673	225.48	20.50
4004	1471	WP-3	092372	072573	218.06	24.80
3211	1859	WP-4-19	092372		214.71	20.64
3211	1859	WP-4-24	060673		214.84	25.65
3211	1859	WP-4-30	102474		214.13	26.90
3860	2128	WO-5-12	060673	072573	217.60	11.20
3860	2128	WP-5-15	020973	072573	217.69	13.76
3860	2128	WP-5-16	060673	072573	217.72	16.32
3860	2128	WP-5-20	031373	072573	217.90	19.50
3860	2128	WP-5-21	062773	072573	217.89	22.50
3860	2128	WP-5-25	092372	072573	217.74	26.46
3181	2142	WP-6-18	060673		215.47	19.90
3181	2142	WO-6-20	060673		214.90	20.70
3181	2142	WP-6-21.5	062873		215.25	22.70
3181	2142	WP-6-25	060673		215.10	26.25
3237	1600	WP-7-21	060673		215.70	24.05
3237	1600	WP-7-22	062873		214.91	23.40

Grid Coordinate		Site	Date Placed	Date Lost	Tube Elevation	Length
X	Y					
3237	1600	WP-7-25	060673		214.80	26.65
4904	1926	WP-8	060673	082173	220.24	27.10
4904	1926	WP-8-16	062673	091473	221.71	17.70
4904	1926	WP-8-18	062673	091473	220.07	19.00
35.42	1965	WP-45-16	060673		216.20	17.35
3542	1965	WP-45-18	061173		215.75	19.95
3542	1965	WP-45-21	101473		216.27	25.30
3542	1965	WP-45-30	102474		216.20	21.40
4515	2950	WP-9	060773	080673	228.67	19.99
4278	2288	WP-12	061273	072673	220.11	19.30
3472	2380	WP-13	160373		216.34	19.80
3472	2380	WP-13-16	101473		216.26	17.50
3472	2380	WP-13-20	101473		216.37	21.85
3695	1672	WP-14	061373		216.73	24.14
3695	1672	WP-14-20	101473		216.25	21.75
3695	1672	WP-14-24	101473		216.76	25.25
4060	2784	WP-15	072774		223.05	14.80
3760	2090	WP-16-15	080774		217.81	19.55
3760	2090	WP-16-28	080774		217.85	26.40
3760	2090	WP-16-30	102574		217.52	18.02

PERIMETER

Grid Coordinate		Site	Date Placed	Date Lost	Tube Elevation	Length
X	Y					
3050	2110	A-1	092372		197.28	8.30
2988	2095	A-2	092372		196.03	7.40
2826	2079	A-3	092372		194.85	7.70
2994	2152	A-4	092372		195.70	7.30
1009	1816	A-5	092372		198.70	5.40
2717	2012	A-6	020973		196.21	10.00
3095	1843	B-1	020973		196.76	8.05
3026	1824	B-2	092372	082173	196.35	5.60
3026	1824	B-2	031874		196.16	9.05
2886	1794	B-3	092372		194.99	8.00
2714	1791	B-4	020973		196.20	9.18
3183	1525	C-1	092372	082873	195.02	7.90
3104	1515	C-2	092372	082873	194.94	6.80
2969	1494	C-3	020373		194.23	10.60
3130	1497	C-4	092372		195.65	7.90
3179	1504	C-5	092372	100573	196.43	6.80
3190	1398	C-6	092372		196.35	8.20
930	1262	C-7	092372	011574	198.40	7.90
368	986	C-8	092372	102773	191.07	12.80
3221	1316	C-9	020973		197.88	9.80
3230	1255	C-10	020973		199.26	12.90
2742	1557	C-11	020973		196.13	10.25

Grid Coordinate X	Y	Site	Date Placed	Date Lost	Tube Elevation	Length
3762	1608	D-1	092372	011574	107.46	7.65
3786	1577	D-2	092372	011574	197.74	7.20
4341	1680	E-1	092372		200.40	5.85
4342	1665	E-2	093272		201.43	7.00
4384	1665	E-3	020973	041674	201.20	6.20
4400	1365	E-4	020973	041574	200.40	8.10
4990	1860	G-1	092372	063073	204.18	3.80
4994	1810	G-2	092372	063073	203.78	8.30
5009	1737	G-3	092372	090773	203.84	7.75
5056	1856	H-1	092372	072073	203.28	2.60
5468	1938	I-1	092372	072073	203.78	4.10
5488	1872	I-2	092372	103073	204.03	7.50
5890	2000	J-1	092372		206.12	5.00
5926	1919	J-2	092372		207.29	8.50
5953	1851	J-3	092372		204.81	6.50
5970	1950	J-4	092372		206.29	8.80
6028	1908	J-5	092372		205.15	6.20
5995	2005	J-6	092372	011574	206.93	9.50
6139	2107	J-7	092372		206.31	9.40
5970	1700	J-8	020073	072574	208.53	10.10
5930	2470	K-1	092372		205.76	8.00
6395	2180	K-2	092372		206.43	6.10
6804	2543	KL-1	092372		211.89	6.20

Grid Coordinate X	Y	Site	Date Placed	Date Lost	Tube Elevation	Length
5818	2927	L-1	902372		207.02	8.20
6404	2780	L-2	092372		208.66	7.70
5556	3382	M-1	092372		211.07	11.90
4613	3069	N-1	092372	110273	214.53	8.20
4515	3056	N-2	060773	101973	212.13	7.30
4410	3012	O-1	092372		208.79	6.40
3450	2489	P-1	092372		198.76	7.50
3431	2504	P-2	020973		199.72	6.80
5528	1940	NP-1	031873		206.82	5.00
5300	1890	NP-2	031873		205.76	5.00
4175	1640	NP-5	031873		200.37	4.91
4035	1620	NP-6	031873		201.09	5.00
4055	2860	SP-1	031873		206.81	8.08
3827	2764	SP-2	031873		203.83	5.00
3628	2635	SP-3	031872		203.87	6.00
5953	1961	EWELL	081473		204.73	
2993	1828	WWELL	081473		194.51	