SEEPAGE CHARACTERISTICS THROUGH AN ABANDONED TAILINGS PILE

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ABSTRACT : Twelve tailings pile have been installed in the Coeur d'Alene Mining District in northern Idaho since 1968. Several of these ponds have recently been filled and abandoned. The abandonment of mine tailings piles may have detrimental effects on the water resource system in the immediate area by leaching of precipitation through the pile material.
The Idaho Bureau of Mines and Geology and the University of Idaho, College of Mines in cooperation with the U. S. Bureau of Mines have conducted a study to determine the hydrogeological factors that control the movement of ground water through the abandoned Page tailings pile in this area in Northern Idaho. A data collection network was designed to collect data on ground water potential and ground water quality. 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 responds both to precipitation events and to periods of no recharge. A finite element steady-state mathematical model was constructed to analyze the ground water flow system in the Page pile. A sampling and testing program of the pile provided information on values of hydraulic conductivity. This data was 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.
A sewage lagoon system was installed on the abandoned pile after the beginning of this study. A previous study reported on the water level rises resulting from the construction and filling of the lagoons. Output data from operation of the model, with the sewage lagoons system located on the pile, showed similar water level rises, and a maximum potential leakage of seven percent of inflows.

RESUME : Depuis 1968 douze bassins de décantation ont été installés au Nord d'Idaho. Plusieurs de ces bassins ont récemment été remplis et abandonnés ; leur abandon peut avoir des effets défavorables sur les ressources hydrauliques de la zone immédiate, en conséquence de la lixiviation des eaux de précipitation à travers les matériaux du bassin de décantation.

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Le Bureau de Mines et Géologie d'Idaho et le Collège des Mines de l'Université d'Idaho, en coopération avec le Bureau U. S. de Mines ont mené une étude pour déterminer les facteurs hydrogéologiques qui contrôlent le mouvement de l'eau souterraine à travers le bassin de décantation abandonné de Page au Nord d'Idaho. Un système fut désigné pour recueillir des données sur l'eau souterraine en puissance et la qualité de celle-ci. L'analyse de données du niveau d'eau a montré l'existence d'un seuil d'eau souterraine dans la partie Est du bassin. L'écoulement dans le bassin de décantation est dynamique et montre tant les influences des précipitations que les périodes de non-recharge.
Un modèle mathématique en régime permanent d'éléments finis fut construit pour analyser l'écoulement de l'eau souterraine dans le bassin de Page. Un programme d'échantillonnage et d'essai du bassin a fourni des informations sur les valeurs de la conductivité hydraulique. Ces données furent incorporées comme entrées dans le modèle mathématique. L'opération du modèle montra que la situation et les fluctuations du niveau piézomètrique régional et la quantité de recharge de précipitation dans le bassin étaient les facteurs primaires de contrôle pour l'emplacement et la hauteur du seuil d'eau souterraine sous le flanc Est du bassin de décantation.
Après le commencement de cette étude, un système de lagune d'eaux résiduelles fut installé sur le bassin abandonné. Une étude préalable informa sur la remontée du niveau d'eau résultant de la construction et du remplissage des lagunes. Les données de sortie de l'opération du modèle avec le système de lagunes résiduelles situé sur le bassin montraient des remontées similaires du niveau d'eau. Les résultats du modèle indiquaient une infiltration potentielle maximum de 7 % des entrées.

RESUMEN : Desde 1968 se han ubicado doce balsas de decantación al Norte de Idaho. Recientemente algunas de estas balsas han sido colmatadas y abandonadas, lo que puede acarrear efectos defavorables en los recursos hidráulicos del área inmediata, como consecuencia de la lixiviación de los materiales apilados, por las aguas de precipitación.
La Oficina de Minas y Geología de Idaho, y el Colegio de Minas de la Universidad de Idaho, en cooperación con la Oficina de Minas de USA han realizado un estudio para determinar los factores hidrogeológicos que controlan el movimiento del agua subterránea a través de una de estas balsas de decantación. Se proyectó un sistema para recopilar datos sobre la piezometría del agua subterránea y su calidad. El análisis de los datos piezométricos mostró la existencia de un umbral de agua subterránea en la parte Este de la bolsa de decantación. El flujo a través de estos sedimentos puso de manifiesto tanto las influencias de las precipitaciones como de los periodos de no-recarga.
Para analizar este flujo del agua subterránea, se ha elaborado un modelo matemático de elementos finitos en régimen permanente. Un programa de muestreo y ensayos en los sedimentos ha aportado información sobre los valores de la conductividad hidráulica. Estos datos fueron incorporados como entradas en el modelo matemático, el cual ha puesto en evidencia que la situación y las fluctuaciones del nivel piezométrico regional y la cantidad de recarga en el apile por precipitación, son los factores condicionantes de la ubicación y altura del umbral piezométrico en la parte E de la balsa de decantación. Tras iniciar este estudio, se instaló un sistema de lagunas para aguas residuales en la balsa abandonada. Un análisis pre-

vio aportaba información relativa a la subida del nivel de agua, como consecuencia de la construcción y llenado de las lagunas. Los datos de salida del modelo, con el sistema de lagunas de aguas residuales localizadas en la balsa, mostraban subidas similares del nivel piezométrico, y una infiltración potencial máxima del 7 % de las entradas.

INTRODUCTION

Abandoned mine tailings piles are potential sources of long-term pollution of water resources. A number of tailings piles have been filled and abandoned in the Coeur d'Alene Mining District in Northern Idaho. This paper includes an analysis of the hydrologic factors that control movement of ground water through an abandoned tailings pile in the Coeur d'Alene Mining District in an effort to gain some understanding of the long term impacts of abandoned tailings piles on the water resources of the area.

PAGE TAILINGS PILE

The Page tailings pile, the oldest abandoned tailings pile in the district, was selected for investigation. The Page pile is located along the South Fork of the Coeur d'Alene River approximately one mile west of Smelterville, Idaho in the Coeur d'Alene Mining District (Figure 2). The pile has a surface area of about 70 acres with an average depth of 25 feet. It contains approximately 2.8 million cubic yards of tailings. The tailings pile was selected as a study area because it was small enough to be instrumented as a unit. The pile is located on a swamp area and is underlain by about 90 feet of alluvial material (Norbeck, 1974). Mine wastes were first discharged into the tailings pond at the study site in 1926 with the development of the flotation technique for metal recovery. The pond was operated continuously until 1969 when mining and milling ceased.

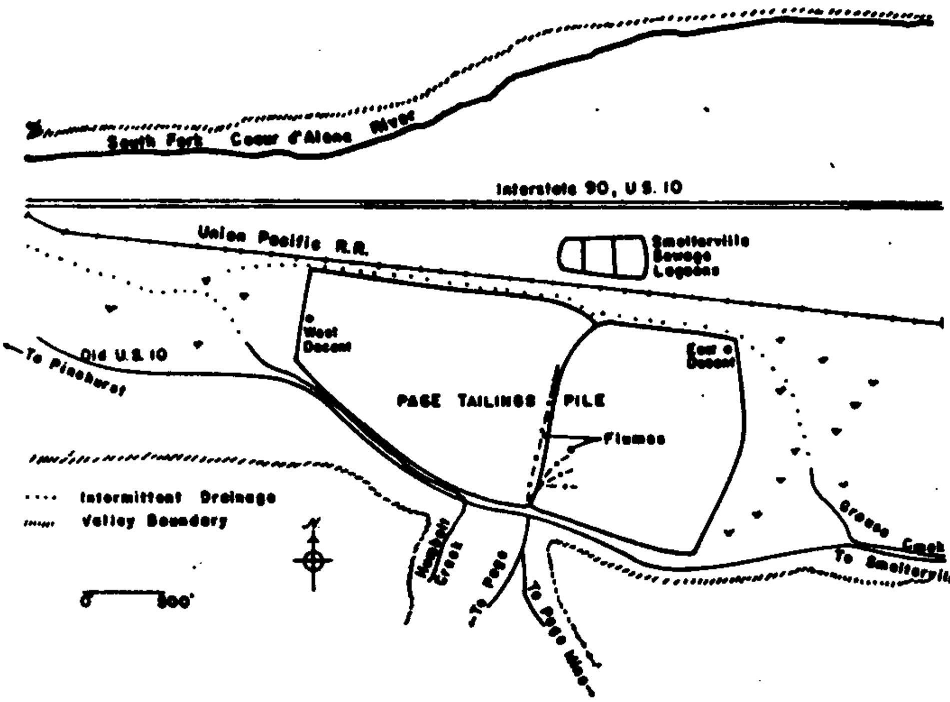


FIG. 2 LOCATION OF THE ABANDONED PAGE TAILINGS PILE

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 occasionally deposited in the east pile.

In 1956, sand backfill was initiated in the operation of the mine. The tailings slurry from 1956 to 1969 was mostly 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 part are believed to be composed of coarser materials than the top of the west pile because most of it was deposited 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. Natural zoning of materials should exist within the pile because of the method of deposition. The size distribution of tailings in the tailings pile should be 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 permeability 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. A major change in land use occurred on the Page tailings pile in 1973. 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 has 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. The ground water flow characteristics that existed prior to the installation of the lagoons will primarily be described in this paper.

Water quality data have been collected to estimate the environmental impact of the abandonment of the Page tailings pile. However, results from that part of the study are not included in this paper.

DATA COLLECTION NETWORK

A data collection network was designed to obtain data on the characteristics of ground water movement through the pile and the impact on the water resource system in the basin. Data collected included 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. Data were collected on the horizontal and vertical distribution of potential both within the tailings pile and in the surrounding alluvium. A total of sixty-eight piezometers were installed at various depths inside the pile with an additional fifty-two sites located in the alluvium surrounding the pile (Figure 3).

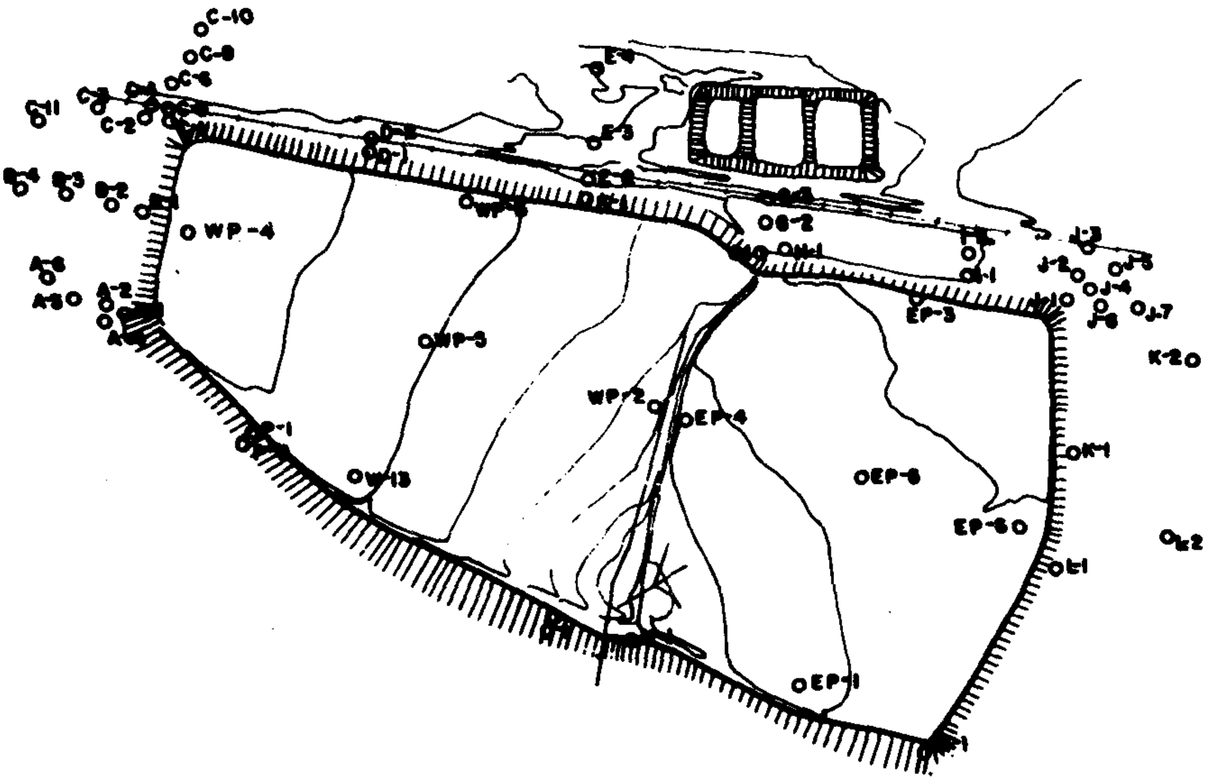


FIG. 3 MAP OF THE PAGE TAILINGS PILE AND VICINITY SHOWING THE LOCATION OF DATA COLLECTION SITES

The only source of ground water recharge to the tailings pile is direct precipitation. The monthly precipitation and typical hydrograph from the flow system are shown in Figure 4. A close correlation may be seen between the cumulative departures from the mean precipitation and the typical hydrograph. The flow system in the tailings is dynamic; it responds to recharge events and to periods of no recharge. The configuration of the water table in the Page pile and surrounding alluvium has been discussed in a previous paper (Ralston and Morilla, 1974) (See Figure 5). A ground water mound is present under the east portion of the tailings pile. The contours of water level elevation of the ground water system in the alluvium indicate that the pile does not have a major impact on the regional flow system. An east-west vertical section, presented in Figure 6, shows the pattern of water 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 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 sand backfilling the mine.

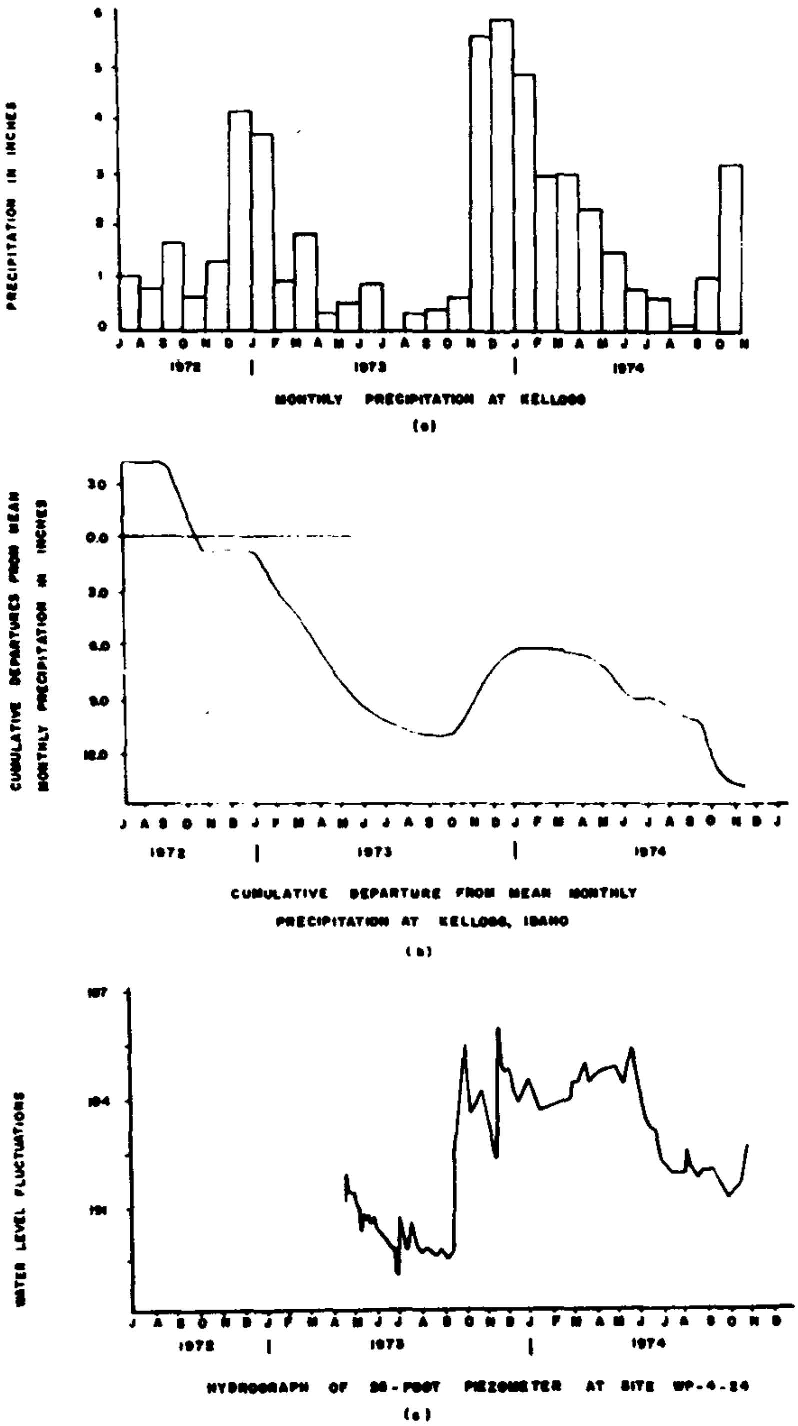
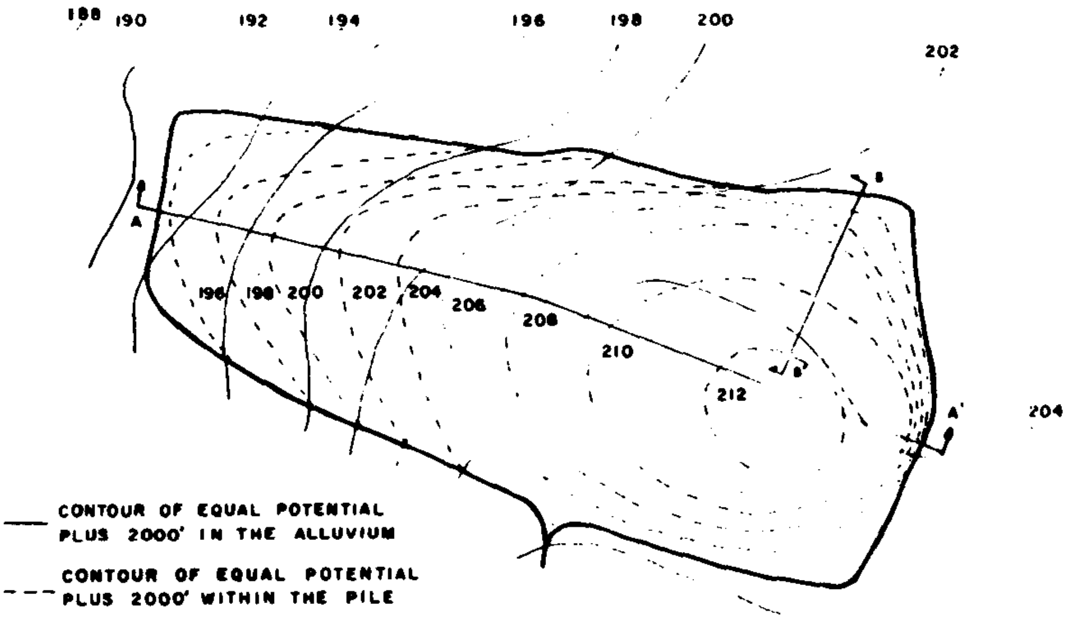


Figure 4 MONTHLY PRECIPITATION, CUMULATIVE DEPARTURES FROM MEAN PRECIPITATION AND RELATED WATER LEVEL FLUCTUATIONS IN PIEZOMETER-PAGE PILE

FIG. 5 CONTOURS OF THE WATER TABLE IN THE PAGE PILE AND SURROUNDING ALLUVIUM



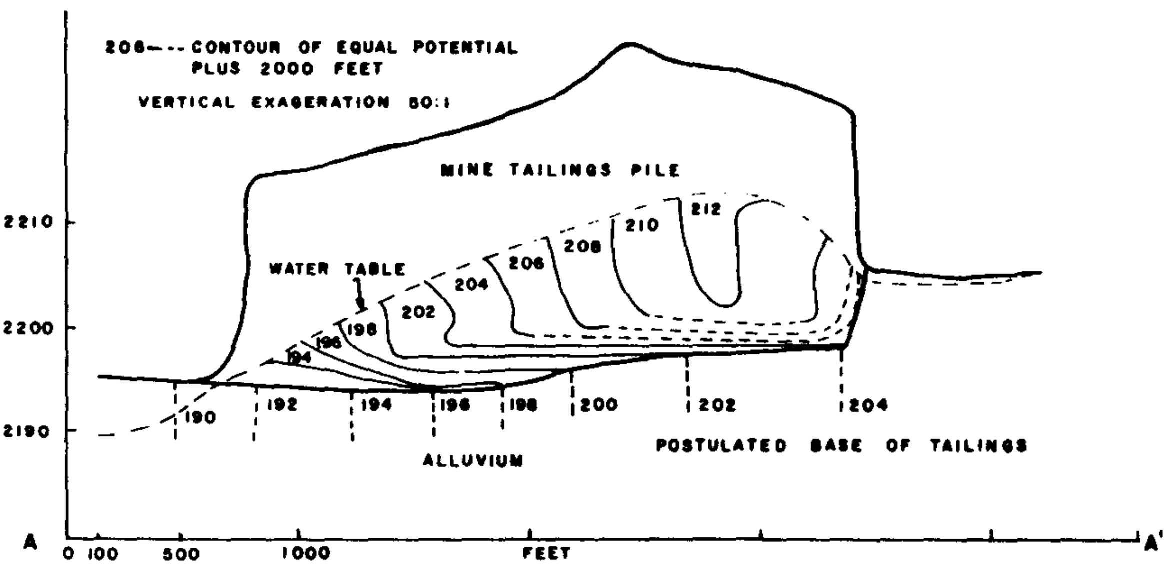


FIG. 6 POTENTIAL DISTRIBUTION WITHIN THE PAGE PILE AND ALLUVIUM ALONG EAST-WEST CROSS-SECTION A-A'

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 of 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 the paper.

HYDROLOGIC PARAMETERS

Determination of the distribution of hydraulic conductivity of the tailings materials required the extraction of undisturbed samples of tailings at various depths and locations in the pile. Six investigation holes were drilled with a hollow-stem power auger. A total of sixteen samples were obtained by inserting Shelby tubes as the holes were being drilled. Data on hydraulic conductivity obtained by the falling head permeameter method are presented in Figure 7. In several piezometers a slight decrease in hydraulic conductivity occurs with depth. Distinct differences in hydraulic conductivity with depth that would indicate the existence of a compacted layer were not observed. A more extensive drilling and sampling program is required to describe the variations of hydraulic conductivity inside the pile.

The above data suggest that the materials that compose the Page tailings pile may be considered as homogeneous. The hydraulic conductivity of these materials was estimated to be 2.9×10^{-6} cm/sec. This computed value of hydraulic conductivity along with a typical value of 30 cm/sec. for the hydraulic conductivity of the alluvial materials was incorporated as input to a steady-state finite element model of the flow system in the Page tailings pile.

FINITE ELEMENT MODEL

A model of the flow system in the tailings pile was constructed using an available finite element computer program. The finite element program was developed by R. L. Taylor at the University of California, Berkeley, and has been used in several studies 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 model points forming a mesh configuration. Each element is assigned its material type and characteristic hydraulic conductivity. The recharge to the pile is modeled

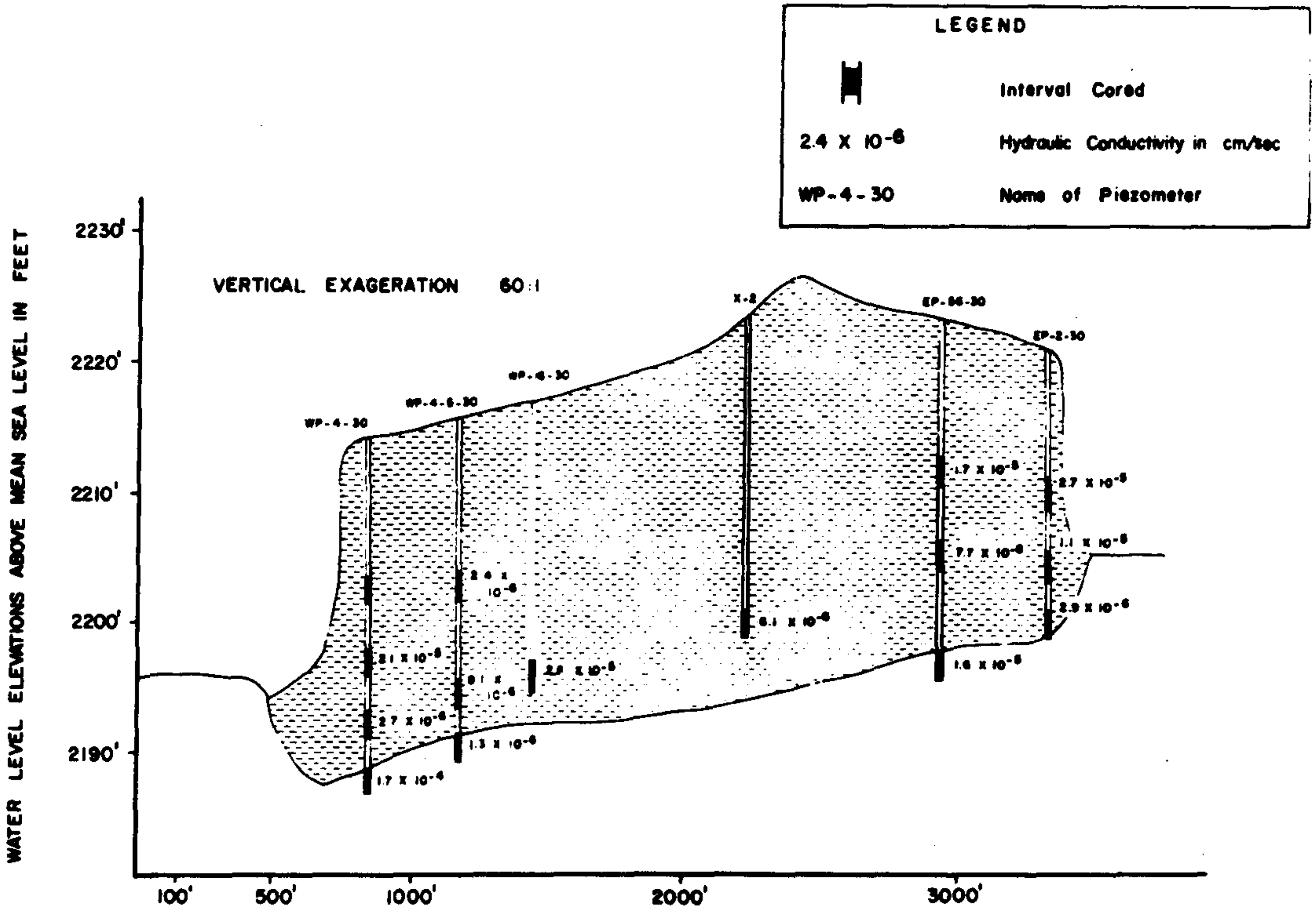


Figure 7. LOCATION OF CORE SAMPLES AND LAB HYDRAULIC CONDUCTIVITY VALUES FOR SAMPLES FROM THE STUDY AREA

as flow into the mathematical model. Output consists of nodal locations, potentials and element velocities and directions, Figure 8. The flow system in the pile is dynamic and the finite element program used depicts the system only as steady-state. The model thus has certain limitations. To gain some experience and knowledge a small model of the cross-section B-B' of Figure 5 was constructed. With the experience gained with the construction of the first model a more efficient model of the full cross-section of the pile was constructed. Several runs using different recharge rates show the dynamic character of the flow system, Figure 9. The extent and location of the ground water mound varies with the recharge input to the tailings. The ground water levels calculated using the model correlate closely with the measured water levels. The model is thus responding in a manner very similar to the physical system. The location of the regional ground water table was found to be an additional controlling factor on the existence and location of the ground water mound in the east side of the pile. Outputs from the finite element program for the same recharge rates and different pressures differentials at the bottom of the pile are illustrated in Figure 10. A distinct drop in water levels occurs for the same recharge rate when the regional water table is lowered.

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 water table on the water levels inside the pile. The mathematical model is also useful in verifying some of the conclusions obtained from an earlier U.S. Bureau of Mines sponsored study on the short term impacts of the location of a sewage lagoon system on the tailings pile, Hitt (1974). The changes in water level were monitored by field piezometers before, during and after lagoon filling. The subsequent impact is shown in Figure 11. Only a localized area beneath the sewage lagoon system responded to the filling of the lagoons. The sewage lagoon system was incorporated in the finite element model. The configuration of potentials before and after filling of the lagoons from model operations are shown in Figure 12. The model results are similar to measured water levels.

The computer program output allowed the calculation of the potential leakage from the sewage lagoon system into the tailings pile. Summation of the element flows normal to the bottom of the lagoons gives a potential discharge from the sewage lagoon system. This discharge is equal to seven percent of the total daily inflow to the system. This would be the maximum leakage that would occur from the system if the hydraulic conductivity of the materials under the lagoons were the same than that of the rest of the pile. The bottom of the lagoons were slightly compacted during the construction period. Solid accumulation on the lagoon floor over a period of time will create an organic mat. The combined effect of these two factors should significantly reduce the potential for discharge of sewage water into the pile.

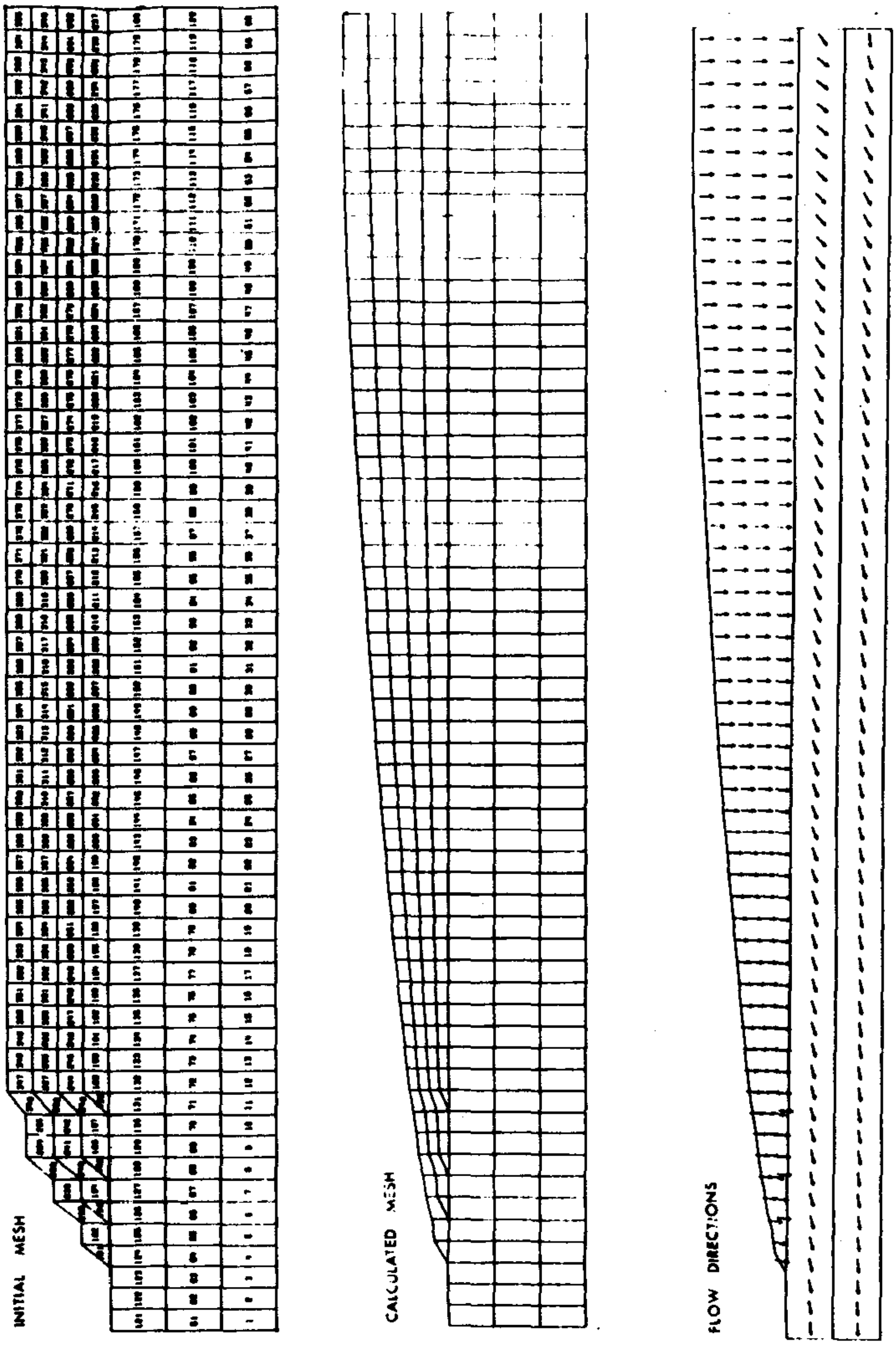


FIGURE 8. COMPUTER GENERATED PLOTS OF THE INITIAL MESH, CALCULATED MESH AND FLOW DIRECTION FROM THE FINITE ELEMENT MODEL OF THE PAGE TAILINGS PILE

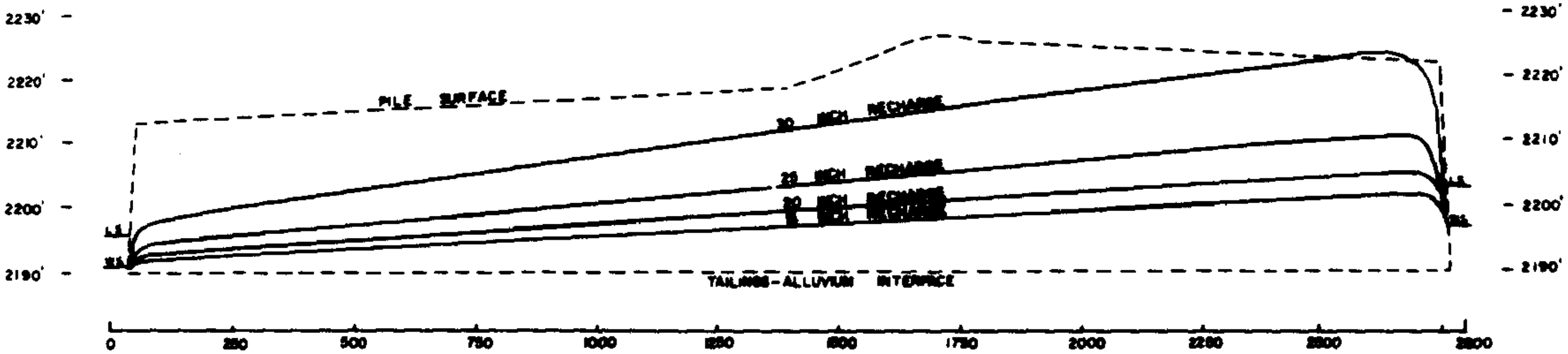


Figure 9. WATER TABLE CONFIGURATION RESULTING FROM DIFFERENT RECHARGE INPUTS TO TAILINGS PILE.

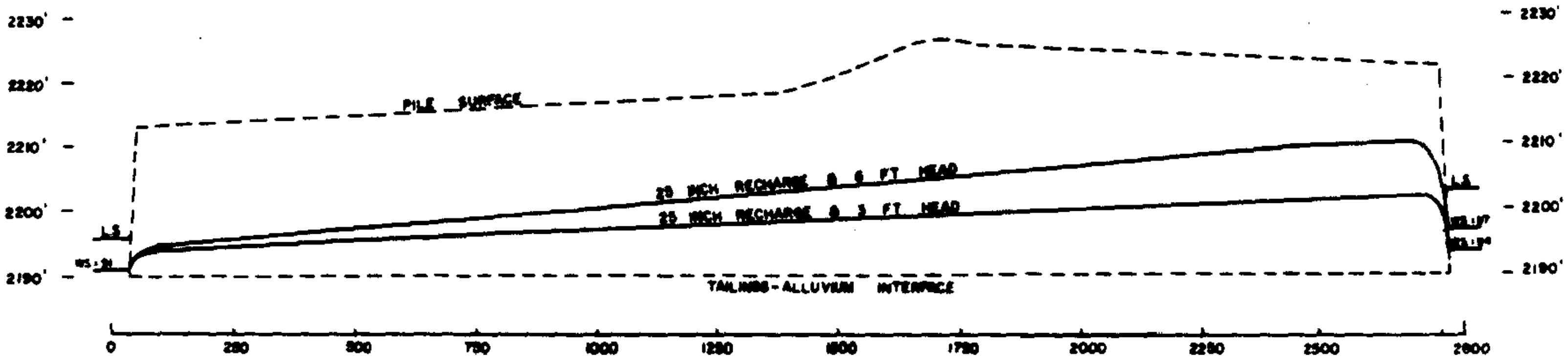


Figure 10. CONFIGURATIONS OF WATER TABLE INSIDE TAILINGS PILE FOR 25 INCH RECHARGE AND 6 AND 3 FEET OF HEAD PRESSURE DIFFERENTIALS ALONG BOTTOM OF PILE.

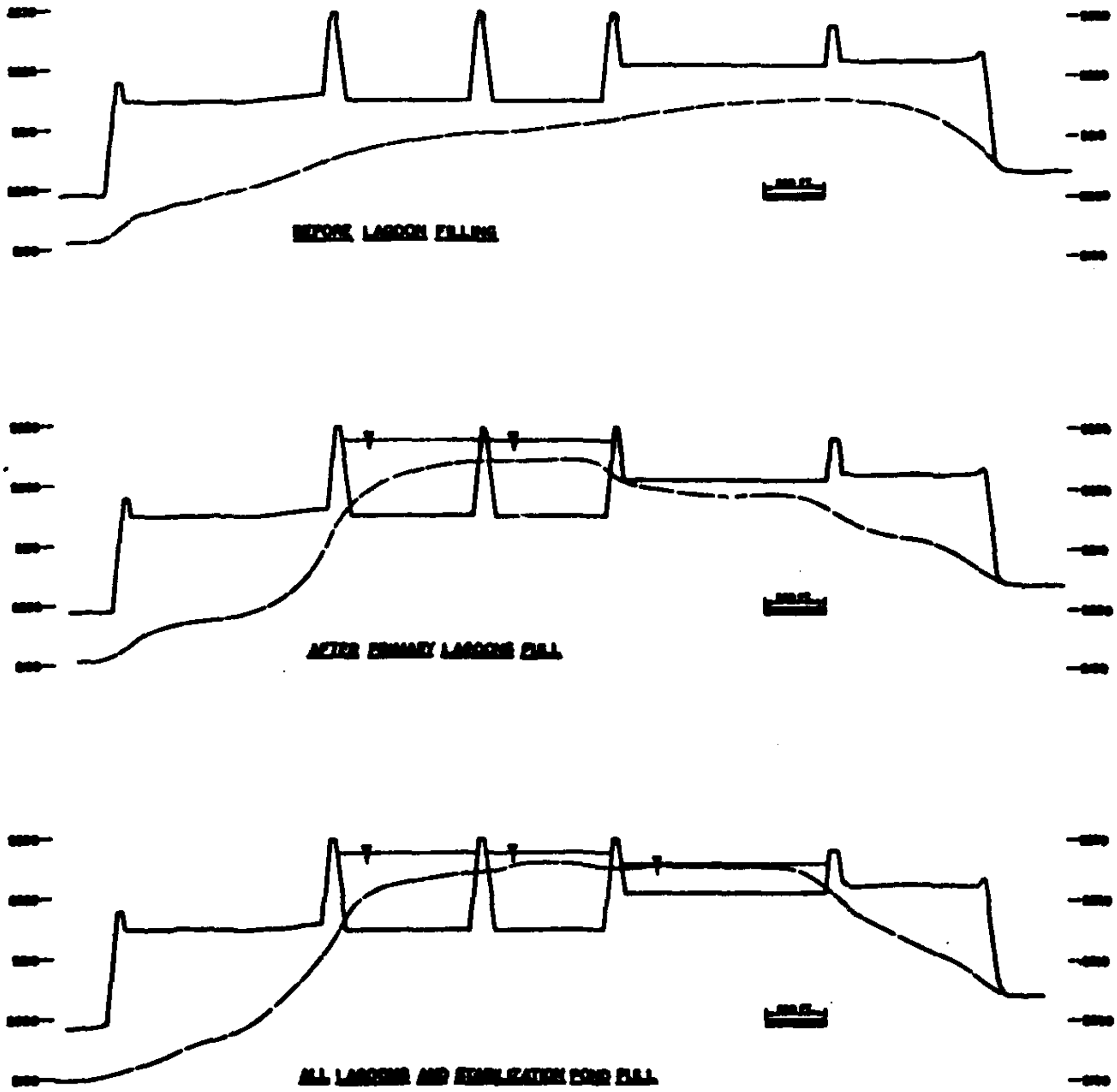
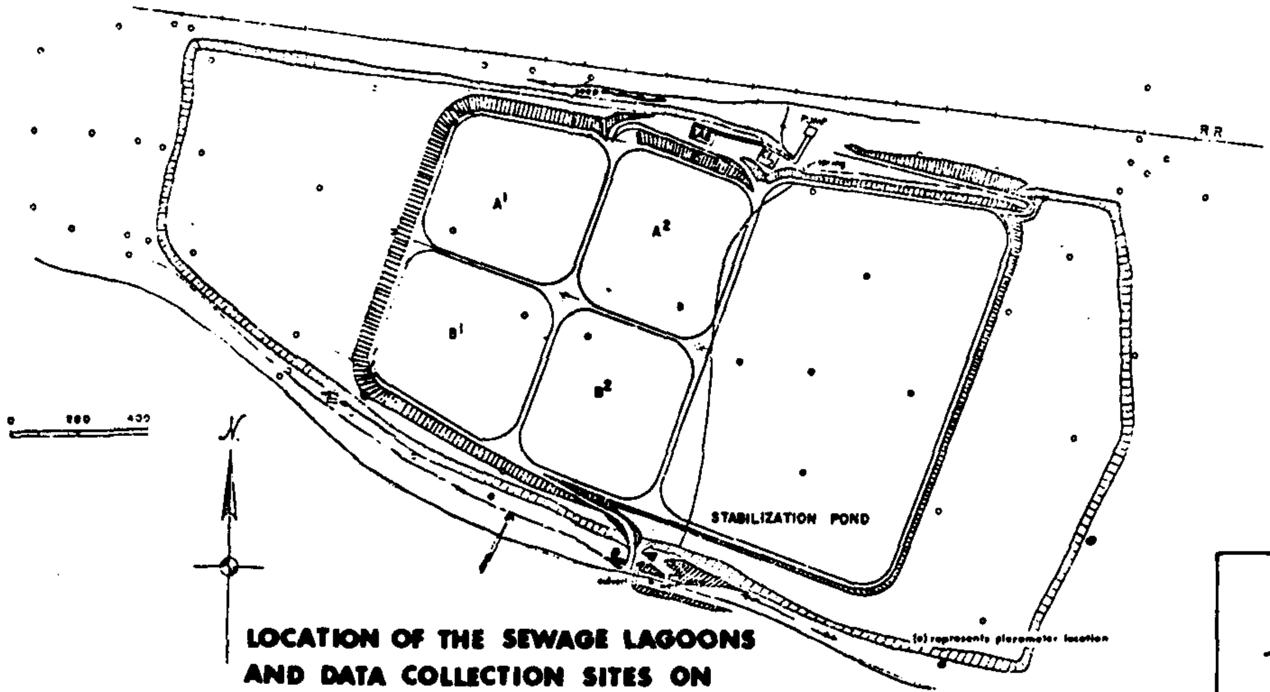


FIG. 11 CROSS-SECTION SHOWING LOCATION OF POTENTIAL LEVEL BEFORE, DURING, AND AFTER LAGOON FILLING



LOCATION OF THE SEWAGE LAGOONS AND DATA COLLECTION SITES ON THE ABANDONED TAILINGS PILE

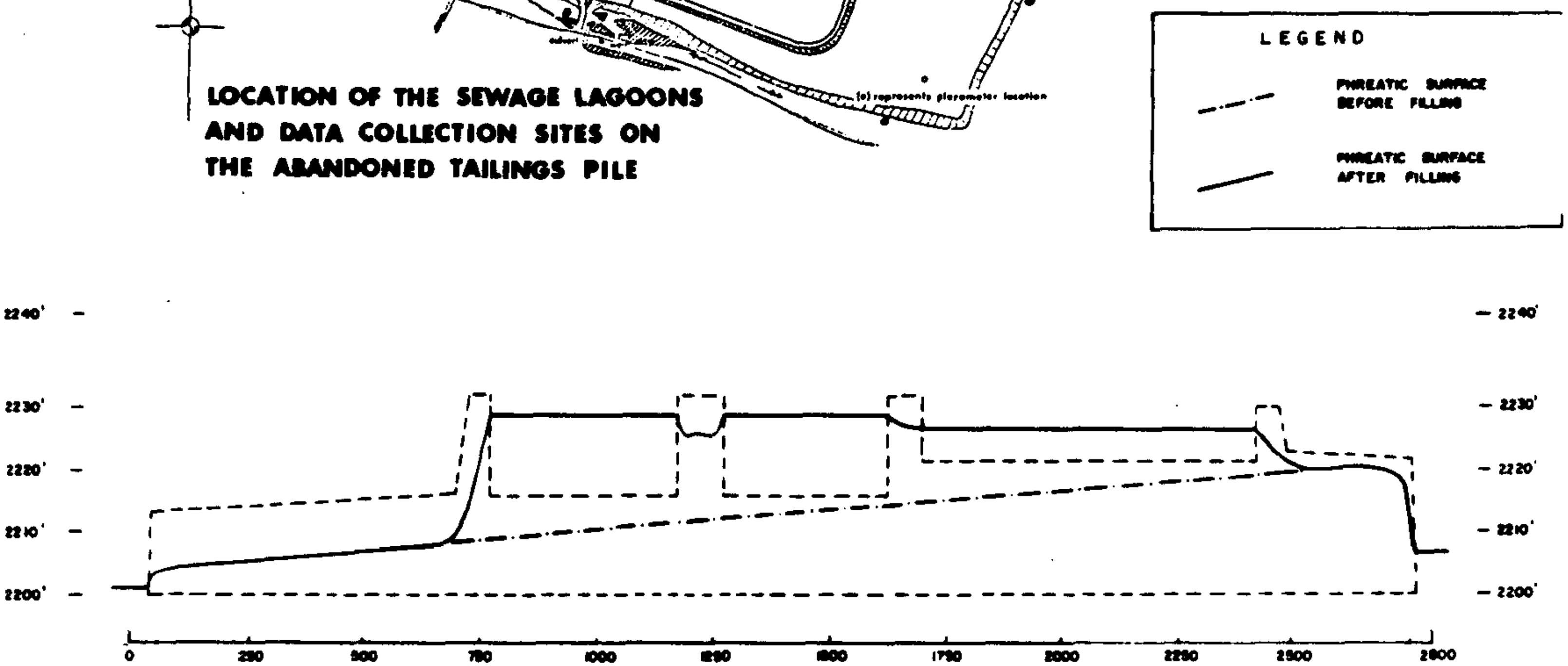


Figure 12 CROSS-SECTION SHOWING DISTRIBUTION OF PHREATIC SURFACE BEFORE AND AFTER LAGOON FILLING AS DETERMINED BY FINITE ELEMENT MODEL.

CONCLUSIONS

1. A sampling and testing program of the tailings pile showed that there are not distinct differences in the hydraulic conductivity of the tailings from various parts of the pile. The tailings pile may be treated as a homogeneous system.

2. Data from the mathematical model support the concept of the existence of a dynamic flow system in the pile.

3. Operation of the model showed that the location of the regional ground water table was an additional factor controlling the existence of the water mounded under the eastern part of the pile.

4. The finite element program allows calculation of the potential leakage from the sewage lagoon system to the tailings pile. This leakage was computed to be about seven percent of the total daily sewage input to the system.

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