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Groundwater Report
Iowa Coal Project Demonstration Mine No. 1

Lyle V.A. Sendlein and David W. Stangl

June 1977

IOWA STATE UNIVERSITY Ames, Iowa 50011

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by

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and

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Mining and Restoration Division

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ABSTRACT

An extensive groundwater monitoring system was placed on a site of active coal stripmining and reclamation. The study site was the Iowa Coal Project Demonstration Mine Number One located ten miles southwest of Oskaloosa Iowa. Twenty nine groundwater sampling tubes or piezometers were installed at various depths to measure groundwater level fluctuations and to monitor groundwater chemical changes. Chemical analyses include pH, specific conductance, chloride, alkalinity, sulfate, nitrate-nitrogen, total and ferrous iron, chemical oxygen demand, total hardness, calcium hardness, and manganese. Chemical analyses, temperature, and water depth measurements were conducted on a monthly basis to identify possible increased sulfate, hardness, alkalinity, cation concentrations, and the effects of an "acid" water plume, possibly generated by mining methods used on the site. Water level data also was used to indicate the extent of dewatering of surrounding "aquifers" near active mining cuts, and to detect the rate of return of groundwater into the reclaimed portions of the mine.

Findings show that water table lowering outside the active mining area is confined to the north hill area in the coals and sands and gravel, no significant acid plume has been generated after a year and one half of mining, and groundwater recharge to reclaimed mine cuts is slow.

INTRODUCTION

Statement of Problem

The stripmining of Iowa and other Midwestern coals has left many counties scared by barren ridges and shallow acid ponds. Acid generated on these ridges and in these ponds flushes out into streams and can infiltrate alluvial, glacial, and bedrock materials causing detrimental chemical changes in surface and ground water supplies (Nessler and Bachmann 1977)(Pietz et.al. 1974).

Recent emphasis in coal stripmining is toward reclamation of lands as they are disturbed by the mining process. The process of reclamation proceeds first, with the removal-segregation of top soils, oxidized and unoxidized non-acid overburden (alluvium, glacial tills, limestones, loess), and then the acid overburden (pyritic shales, claystones, siltstones, and sandstones). Next, immediately after coal removal, the acid overburden is placed in the mining cut followed by the replacement of the non-acid overburden. The final step is replacement of the top soil over the previous fill.(Grim and Hall, 1972)

Burial of acid overburden as quickly as possible after mining is the most critical step in reclamation. The burial of acid overburden "prevents" the oxidation of very fine pyrite (framboidal or sulfur ball) by iron and sulfur oxidizing bacteria (Thiobacillus ferrooxidans and Thiobacillus thiooxidans) and atmospheric oxygen (Smith, 1974). The oxidation products of pyrite are sulfuric acid H_2SO_4, ferric Fe^{+++} and ferrous Fe^{++} iron, and metals occuring in minor sulfide minerials (marcasite FeS_2, sphalerite ZnS, and galena PbS). These chemical species, as well as, metals from minerials made more soluable by acid conditions (Calcium and Magnesium from calcite, dolomite, and gypsum) are largely prevented from occurring and infiltrating into groundwater by proper reclamation activities.

The production of an acid condition is not the only natural disruption that may accompany coal stripmining. Other problems include: 1.) temporary or permanent lowering of water levels in wells near the mine site due to drawdown caused by seepage, pumpage, or evaporation from open mine areas, 2.)temporary or permanent loss of water levels in wells due to disturbance of aquifers in coal seams and overburden strata, 3.) disturbance of horizontal and vertical permeabilities of overburden materials resulting in a lowered water table down gradient from reclaimed mine pit areas (Groenewold, Moran, and Anderson, 1975).

The previously mentioned problems have varying impacts on different coal producing regions. In the Upper Missouri River Basin and Southwestern coal fields there is little problem with acid drainage because of low sulfur contents in the coal overburden. High sodium concentrations, on the other hand, are commonly encountered. In these areas problems develope, because thick subbituminous coal and lignite seams are local aquifers for stockwatering and and perhaps irrigation.

In Midwestern and Appalachian states the coals mined are not generally as thick, and the formation waters are not used extensively for water supply. These coal areas, however, are plagued by acid conditions associated with moderate and high pyrite abundances.

All areas of coal production in the United States will be affected by permiability contrasts and temporary water losses due to coal stripmining and reclamation. The degrees to which these problems occur will vary greatly, and they will depend to a large extent on the methods of mining and reclamation used at each specific site.

The Iowa Coal Project Demonstration Mine number One has been set up as an area for the study of a reclamation plan that possibly holds the answer to some of these problems in Iowa.

Purpose and Scope

The Iowa Coal Project Demonstration Mine number One, here after ICP#1, was initiated to study the economic feasibility of stripmining and reclamation of Iowa's relatively small coal deposits. Mining and reclamation were conducted using highway construction type scrapers. Most of the previous mining done in Iowa was by the cast method utilizing small dragline excavators. Scraper and cast reclamation differ in the amount of swell or volume increase that takes place to the spoil material as it is handled. Cast mining averages 25% in volume increase, while scraper mining yields only 10% to 15% swell. Scraper mining yields a lower swell, because the spoil moving machinery are constantly moving over and compacting the filled spoil.

A portion of the ICP#1 study was designated to monitor environmental effects of this stripming and reclamation. In compliance, twenty nine groundwater piezometers or water sampling tubes were installed between August 1975 and March 1977 to monitor the groundwater environment at the site. A study of this type, although becoming more common in recent years outside the state, has never been conducted in Iowa. The study explored baseline data and research needs for future Iowa surface mining sites.

In recent years a controversy had developed over whether simple burial of acid generating spoil can prevent acid production from pyrite oxidation. Lovering (1948) points out that at certain localities in Arizona pyrite is oxidizing at depths of 600 to 700 feet below the surface. Shumate and Brant (1971) concluded from short duration leaching experiments that no acid was generated from pyrite buried under a few feet or more of soil. Collier (1970) observed that acid generating spoil may be buried as long as two years in cast spoil before producing an acid effluent. Smith (1973) noted that iron and sulfur oxidizing bacteria prosper at pH values below 5. This suggests that if virgin spoil, i.e. acid overburden that has not been allowed to oxidize significantly by bacteria or the atmosphere, is quickly buried and saturated by near neutral groundwater the conditions would not favor the production of an acid groundwater or effluent. With this in mind the monitoring system at ICP#1 will illustrate the probable prevention of long range groundwater pollution.

Other goals of the study are to learn the magnitude and duration of groundwater quantity loss or alteration during mining and after reclamation. These losses occur as the spoil material is pulverized prior to removal and much of the moisture escapes by evaporation. Also the active mine cuts, when below the water table, act as large diameter wells in drawing down water levels in the surrounding areas. As the water moves into the mining pit it is either removed by evaporation or by pumping. Water withdrawals of these types were monitored by placing piezometers along the edge of the last highwall of the mine prior to mining and in replaced fill after reclamation at ICP#1.

Previous Stripmine Groundwater Studies

The study of groundwater alterations due to stripmining began over twenty years ago by members of the United States Geological Survey in Kentucky (Collier 1964). This study, like more recent studies concerned itself with the hydrologic effects of stripmining on a river drainage basin. The study also monitored groundwater quality and movement in unreclaimed spoil and the bedrock below it. The study found that it could take up to two years for acid to be generated in the cast spoils and move into the bedrock. Most other studies up until 1974 dealt with similar problems and the effects of acid drainage on surface stream waters. A large number of papers deal with the quality and hydraulics of groundwater flow from underground coal mines.

Not until the early and mid 1970's did research begin to be published on stripmine spoil reclamation and its effect on groundwater. These papers deal almost exclusively with the reclamation of oxidized spoil. Pietz, Peterson, and Lue-Hing (1974) showed that groundwater in replaced oxidized spoil contained significantly higher sulfates, alkalinities, specific conductance, and dissolved metals and cations. To date no studies have been found which report groundwater quality in spoils replaced simultaneously with progressive mining in acid spoil terrain.

In the last three years groundwater quality and hydrologic research in coal mining areas have literally exploded. The U. S. Geological Survey and the Bureau of Land Management are presently involved in several western coal studies in Colorado, Wyoming, Montana, North Dakota, Utah and New Mexico. Unfortunately these studies are in non-acid coal areas and few if any have reached completion. Preliminary data from these studies indicate a much different groundwater chemistry than that found in the more humid Midwest and Appalachian regions. Van Voast, Hedges, and McDermott, (1976) indicate that common groundwater levels of dissolved solids are between 3000 and 4000 mg/l for non-coal overburden and near 1000 mg/l for coal seams. These authors also state that in addition to sulfate and bicarbonate, sodium is also a very significant constituent of western waters. The pH values of western spoil waters is rarely acidic and accordingly has low metal contents.

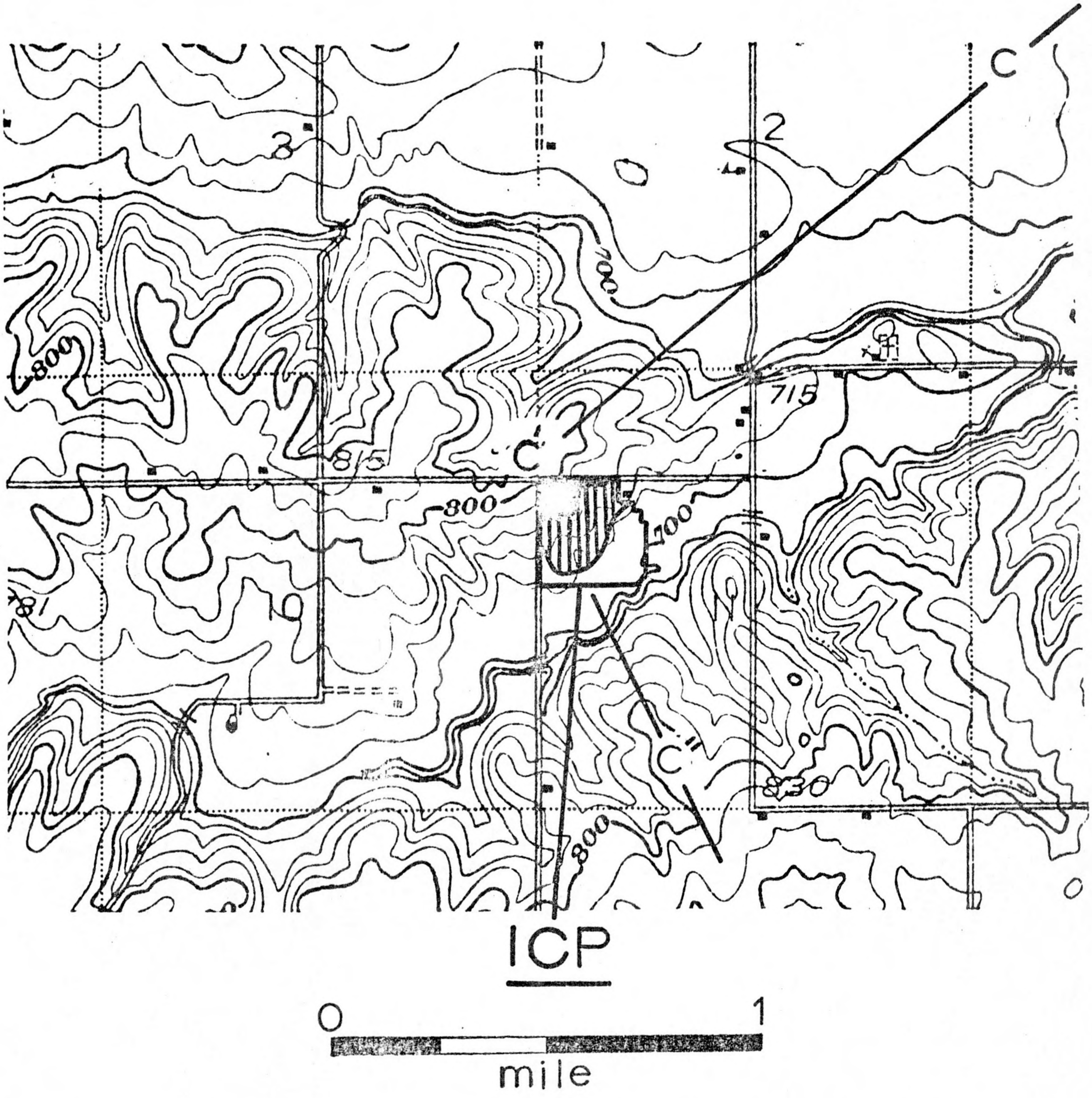
In the eastern coal areas of the United States the emphasis in reclamation has been on correcting the mistakes of past mining. Major concerns for eastern coal reclamation are the refilling and leveling of surface spoil to reduce infiltration into, and drainage out of subsurface coal mine works. Other reclamation activities include formation of recreation areas over old spoil sites.

From present information, no data is assumed to have been published in major journals about the effects of coal stripmining and simultaneous reclamation of unoxidized spoil on groundwater chemical compositions. This lack of information indicates that ICP#1 may contribute one of the first mining-reclamation-hydrologic studies to the mining and scientific community in this area.

Area of Study

The study area, ICP#1, is located on a 40 acre lease about ten miles southwest of Oskaloosa, Iowa in Mahaska county. The legal location of the site is: S. W. ¼, of N. W. ¼, of section 11, Township 74N, Range 17W. ICP#1 is located on the south face of a generally northeast-southwest trending upland ridge. The relief of the area defined by the upland ridge and South Coal Creek is about 140 feet. The premining surface drainage of the site consisted of a dendritic network of shallow broad water ways. These water ways flowed in a northwest to southeast direction, and ultimately drained into Coal Creek which lies adjacent to the site on the southeast (figures 1, 2, and 3). The post-mining surface consists of four flat step terraces that parallel the trend of the upland ridge. The drainage of the terraces is from the backslope of each terrace north to the backslope of the next higher terrace (figure 4).

Figure 1: Iowa Coal Project Demonstration Mine No. 1 Location



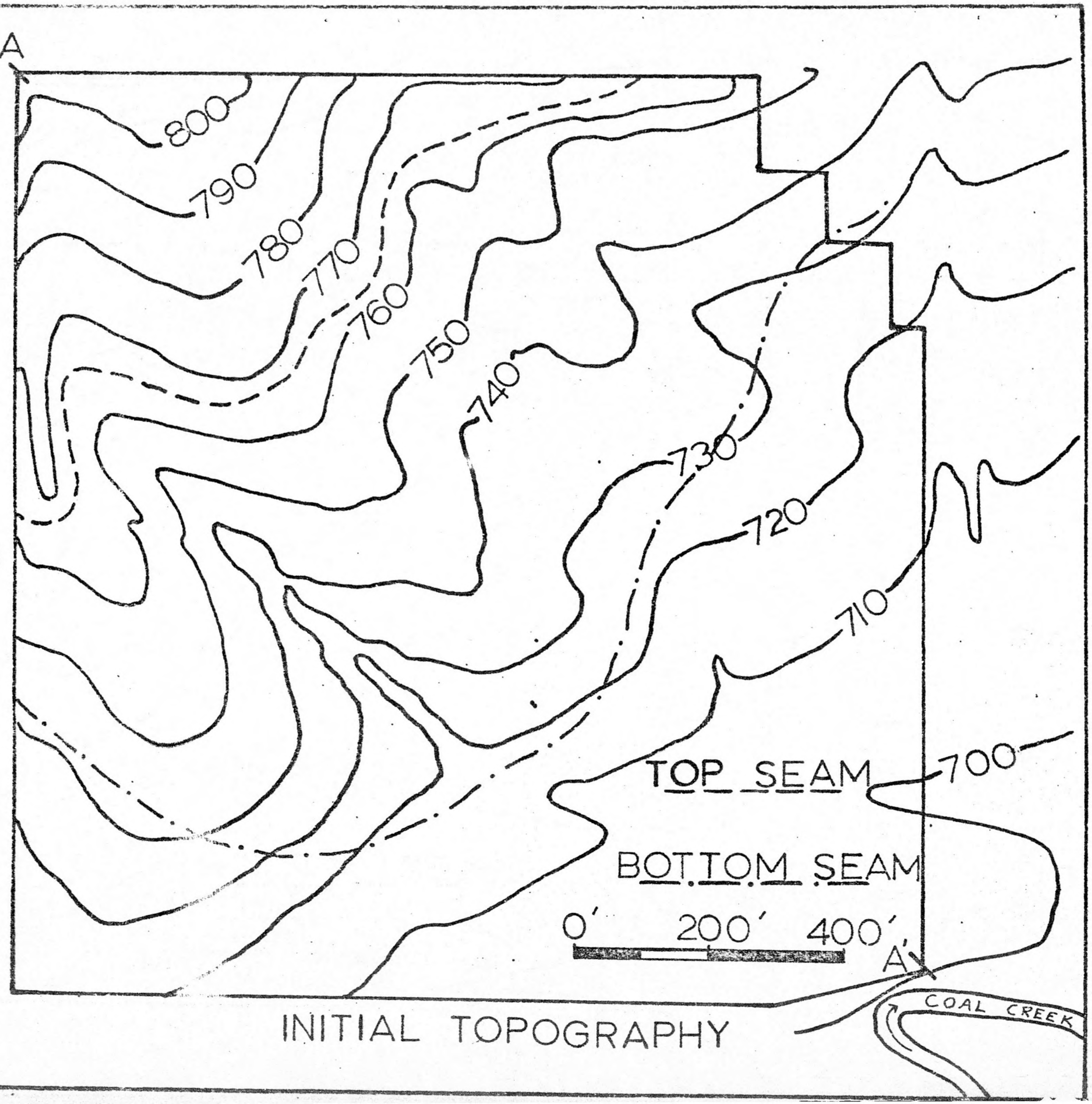


Figure 2: Initial Topography and Coal Seam Extent

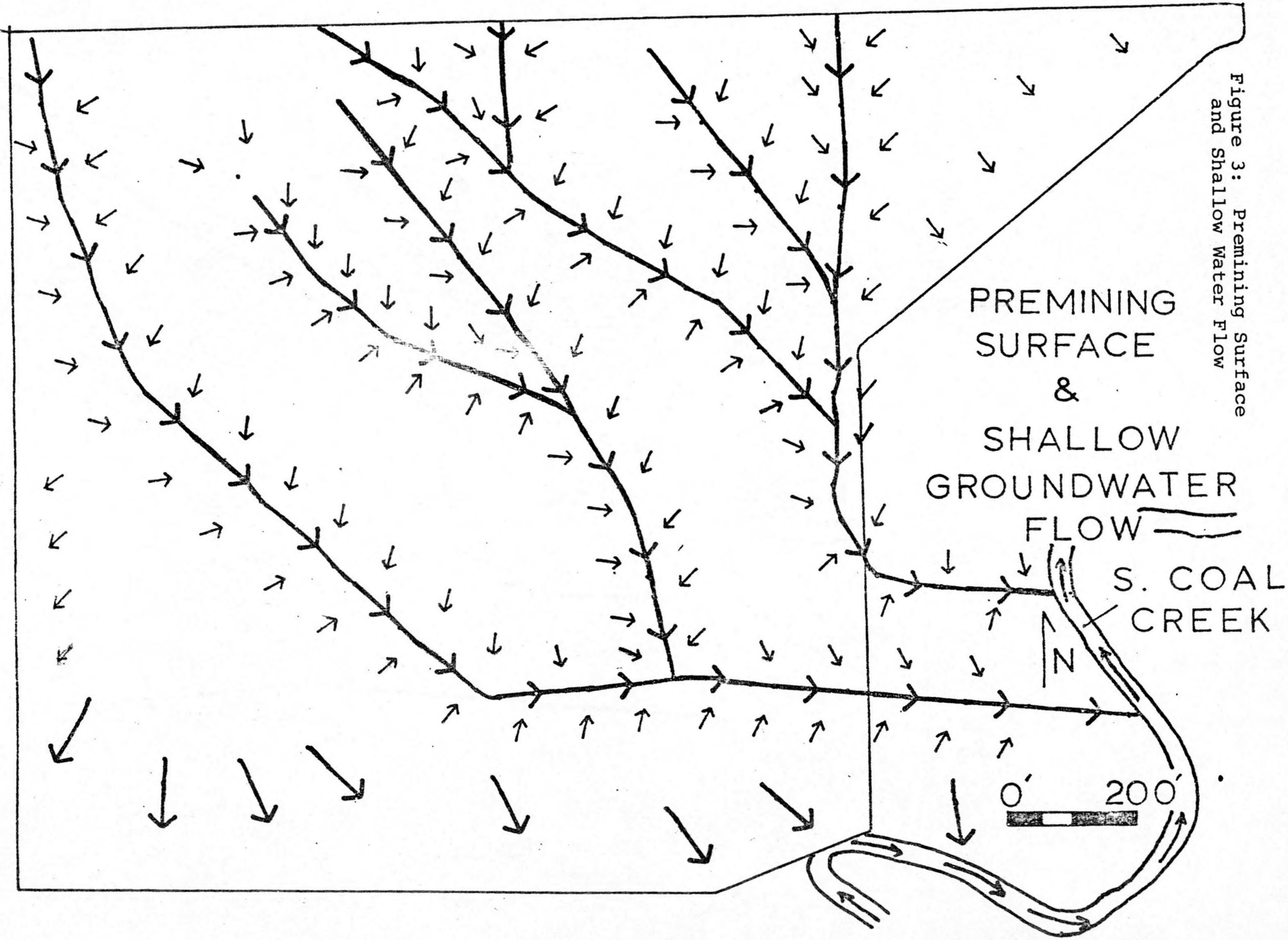


Figure 3: Premining Surface and Shallow Water Flow

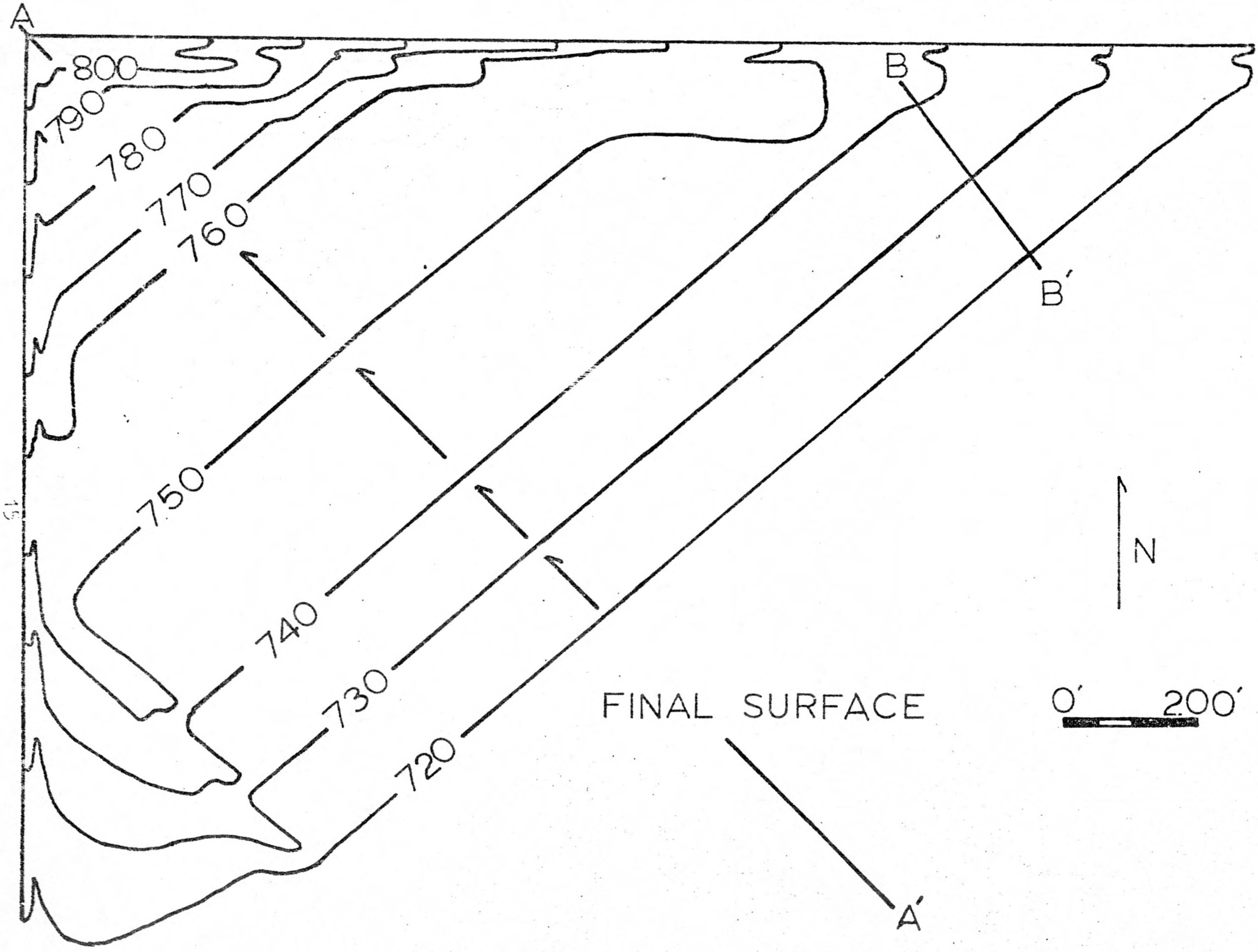


Figure 4: Final Reclamation Surface Topography

General Geology of the Mining Area.

The bedrock of the ICP#1 area consists of units from the Pennsylvanian and Mississippian Systems. Rocks of the Pennsylvanian belong to the undifferentiated Cherokee group of the Des Moines Series. The Cherokee group of the ICP#1 area is composed of 50 to 100 feet of: 1.) dark gray to black pyritic shales, 2.) dark to light gray pyritic siltstone, claystone and mudstone, 3.) light gray and red-brown ferruginous medium to fine grained sandstones, 4.) high sulfur bituminous coal (two seams mined at ICP#1), and 5.) eliptical limestone concretions (figures 5 and 6). The base of the Cherokee consists of a widely distributed green shale. This shale, the Cheltenham clay, is a residual soil developed on the underlying Mississippian rocks (Branson, 1962).

The Mississippian or Saint Louis rocks which lie beneath the Cherokee group consist mostly of limestones. These rocks outcrop at the surface only at two regions along the Skunk and Des Moines Rivers. The top of the Saint Louis contains numerous layers of thinly bedded limestone and interbedded marls. Lower in the section these rocks are replaced by interbedded sandstones and limestones and massive limestone beds (Bain, 1894).

The surficial geology of the ICP#1 area includes:

Figure 5: Northwest-Southeast ICP#1 Premine Crossection

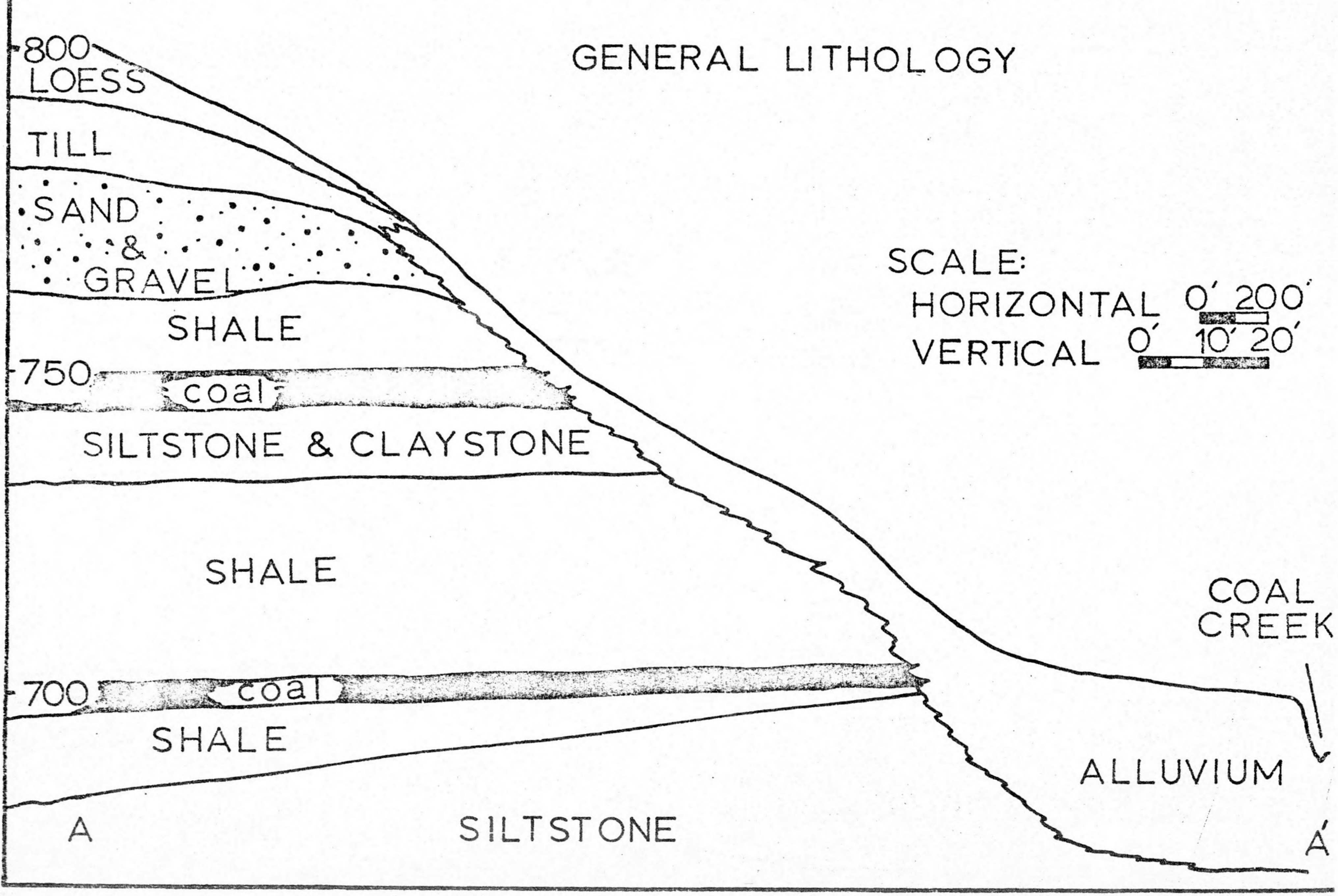
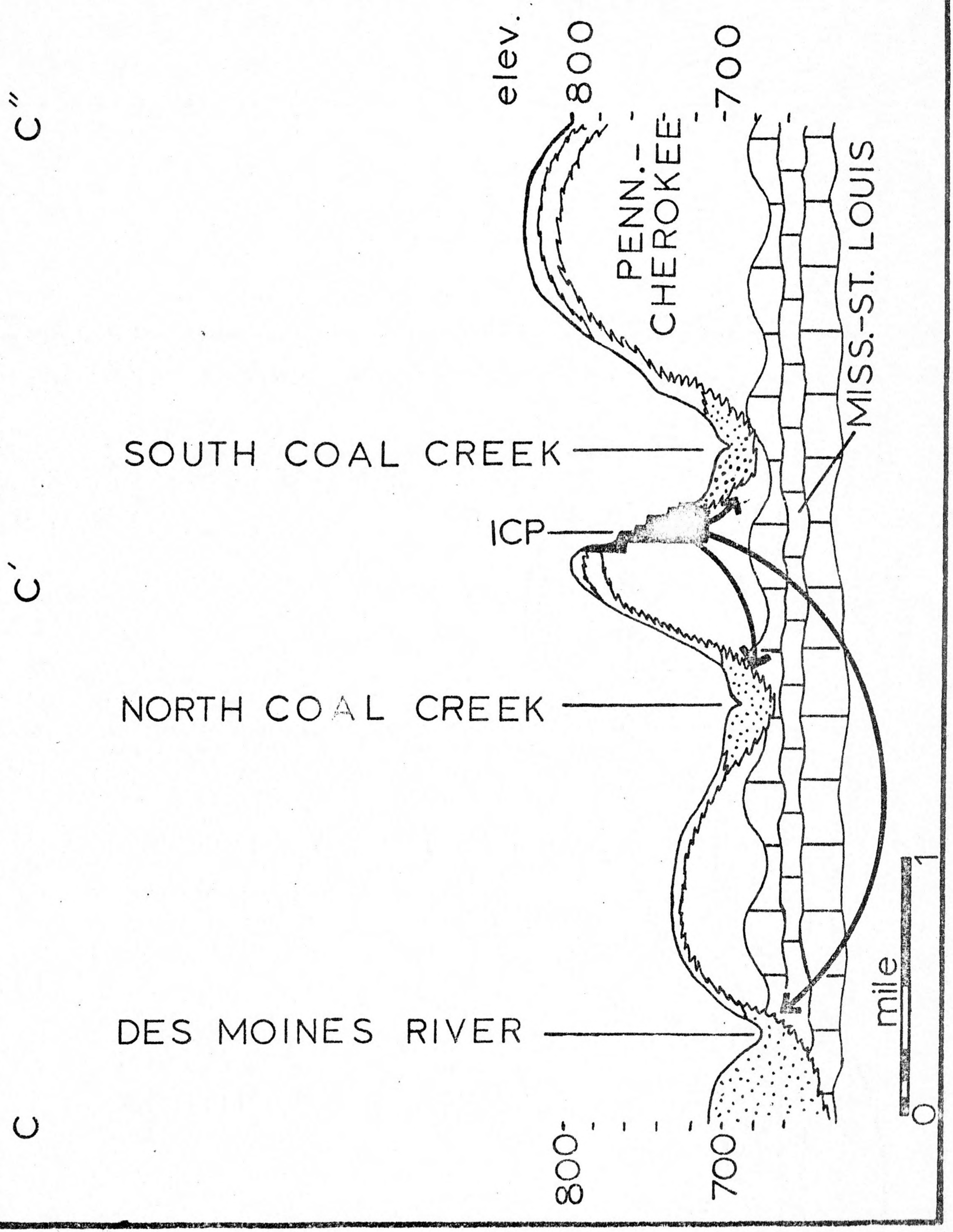


Figure 6: Regional Crossection and Groundwater Flow



1.) Quarternary alluvium consisting of gray and brown gravels, sands, silts, and clays deposited along streams and water ways, and glacial till and loess deposited at the top of upland ridges, 2.) Quarternary colluvium consisting of weathered shale and coarse glacial debris. The alluvial deposits of ICP#1 are located along South Coal Creek as point bar, clay plug, and small terrace deposits. The glacial deposits of ICP#1 are represented by less than 20 and 15 feet of till and sand, repectively. The sand is perhaps an ice channel or outwash feature. The sands often occur in small trough crossbeds with a generally southeast flow direction. Coarse gravels often mark the lower boundry of the crossbeds giving them a fining upward sequence. The sand body is roughly lense shaped. It is about five feet thick at the northwest corner of the site, and thickens to 15 feet about 300 feet farther to the east. At a distance of 600 feet east from the northwest corner, the lense is again about five feet thick. The base of the sand deposit contains a few weathered granitic boulders of up to two feet in diameter. An undulating limonitic and conglomeritic zone is found from three to five feet up from the base of the sands. Within the limonitic zone lie till centered roughly spherical limonite concretions and concretionary layers. The till centers of the concretion are mostly clay with abundant fine white sand. The till above the sand is mostly clay with some cobbles and sand.

A paleosol is located over areas of the study site not covered by sands, loess, or till. The paleosol consists of a very well indurated red to orange ferruginous layer. At the southwest corner of the mining area this paleosol is over six feet thick. At this location it contains some gravels, cobbles, sands, and shale blocks in a much finer well cemented matrix. The ferruginous cementing material of the paleosol is perhaps derived from the pyritic shales below it, or incorporated during weathering and reworking of the paleosol over the bedrock surface. A similar material to the paleosol was also located in a bore hole at a depth of 30 feet (S_2).

Method of Investigation

The method of investigation used for the hydrogeologic study of the ICP#1 coal mining and reclamation area was the placement of 29 groundwater piezometers. The piezometers were placed to various depths at different topographic positions and areas to monitor chemical quality and quantity properties of the shallow groundwater flow system. The placement of piezometers at different depths allows the investigation of hydraulic and chemical conditions for stratified geologic and groundwater bodies. After placement of the piezometers each was packed with gravel through the sampling interval, and then backfilled with bentonite to prevent leakage from shallower strata.

The ICP#1 site is located on a southeast facing hill, with surface drainage to the southeast. The flow of the shallow groundwater is also in a generally southeasterly direction to South Coal Creek, the local discharge point. Monitoring the shallow more permiable geologic materials or aquifers of the site and the refilled mining cuts is the primary concern of the study. These areas are most important, because they serve as local domestic and livestock water supplies. They are also areas of the greatest possible water quality deterioration due to mining. The alluvial sequence is very important also, because it allows a rapid transport of polluted groundwater from the mining site. This allows the earliest possible detection of pollutants as they are introduced into the groundwater regime.

The specific effects on ground water contributed by coal stripmining are: 1.) reduced pH, 2.) increased sulfate, 3.) increased alkalinity, 4.) increased hardness, 5.) high iron and other metals, and 6.) specific conductance.

The piezometers at ICP#1 are located to intercept the shallow groundwater that is flowing into the active mining area from the north and the groundwater that is moving out or away from the mining and sediment pond areas to the southwest, south, southeast, and the east.(figures 7 and 8).

Piezometers were placed along the north to intercept influent water and serve as backround wells, because they give an indication of the natural chemical species and concentrations present in groundwater uneffected by mining. These sampling points also give an indication of the extent to which the different materials of the highwall are dewatered. Piezometers located to the south of the site were so placed to monitor chemical changes in the groundwater as it flowed near the mining pit, spoil storage piles, and the sediment retention pond. The sampling tubes around the sediment pond also monitored the groundwater mound caused by the increased infiltration into the flood plain from the pond. The function

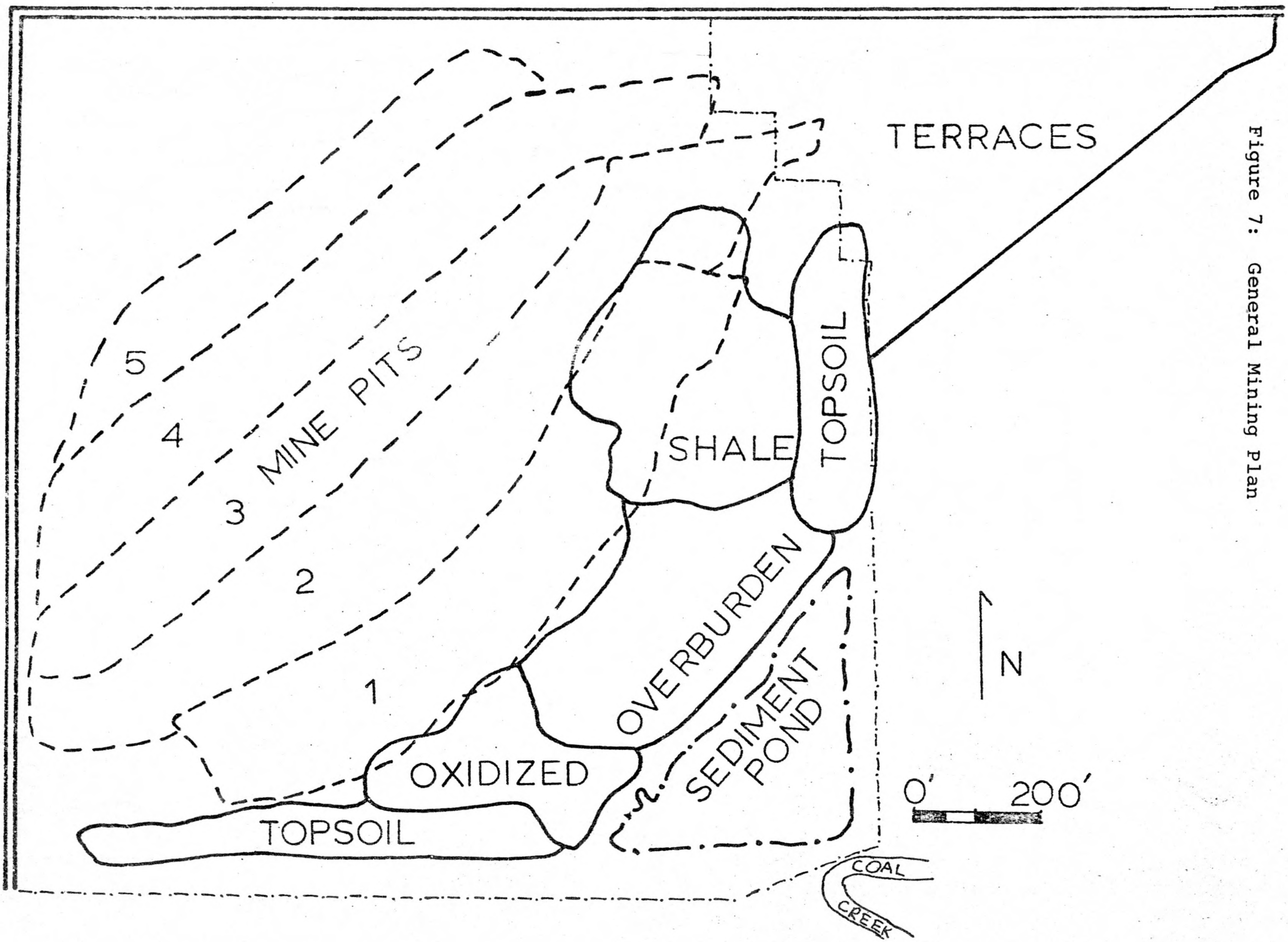


Figure 7: General Mining Plan

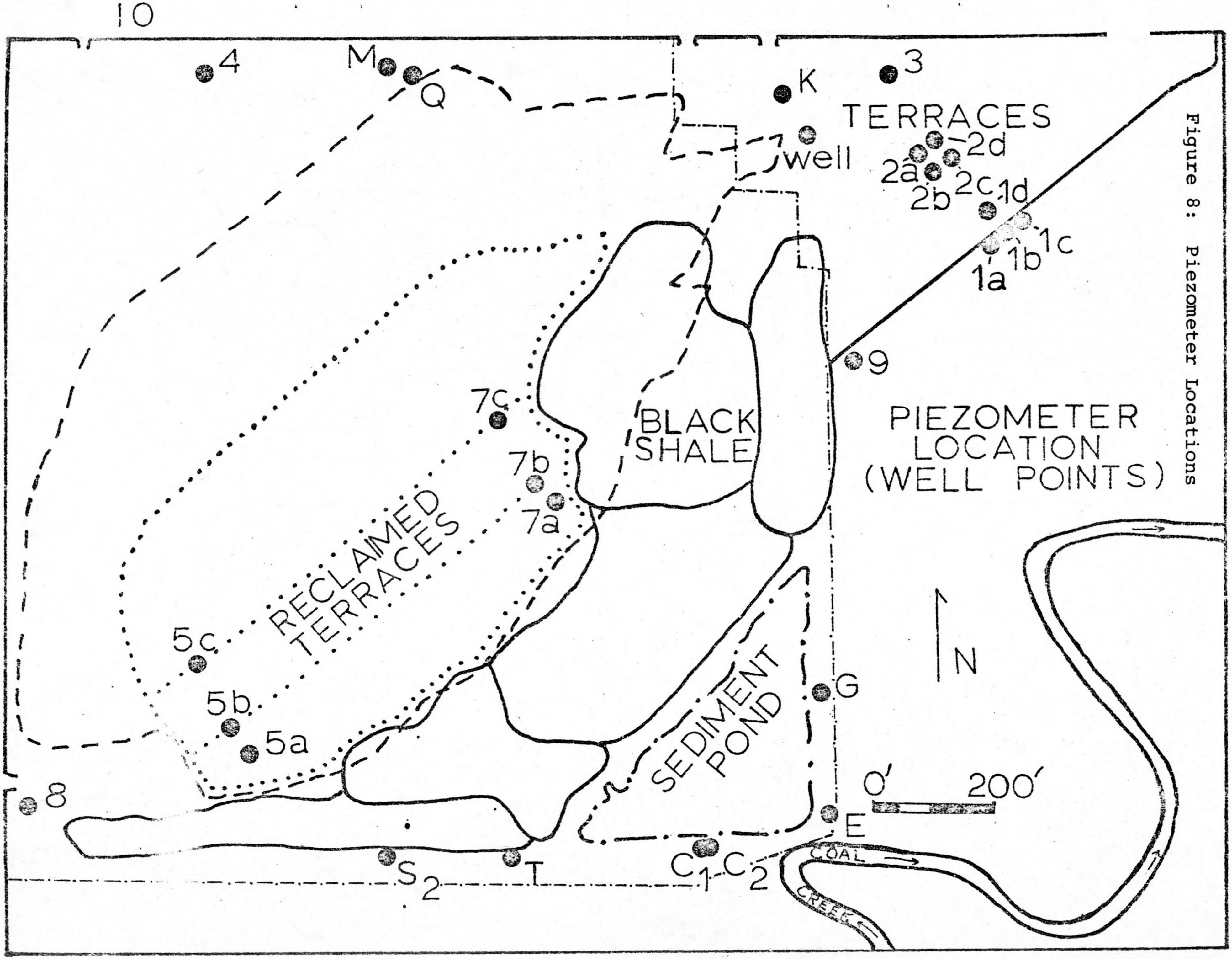


Figure 8: Piezometer Locations

of piezometers located in the spoil cored terraces of the northeast side of the mining site is to detect the possible deterioration of the groundwater in that area. The source of degradation of waters in that area would then be tied to the oxidation of the spoil materials placed above the water table. Unfortunately, from a monitoring standpoint, this area was once the location of an animal feed lot, and is subsequently in bad condition (figures 8 and 9).

The areas of reclaimed mine spoil also are sites of piezometer location. Here the sampling points are placed to determine how rapidly the groundwater will move back into replaced spoil fill, and the quality of this returning fluid. To this date six piezometers have been located in the fill areas.

Water quality samples are taken on a monthly basis from the piezometer tubes after bailing and total or partial recovery. Monthly sampling has been found to be adequate for groundwater monitoring because of its relatively slow flow rate. Monthly sampling also allows the piezometers a significant time to recover lost head caused by bailing and sampling.

The chemical analyses are performed using Hach DR-EL, pH, iron, and 2200 specific conductance field test kits and units. During the course of the study chemical oxygen demands were analyzed by the Engineering Research Laboratory, and trace element scans were performed by Drs. V. Fassel and R. Kniseleys' research groups in Spedding Hall.

Specific chemical parameters under observation are as follows:

Specific Conductance	(as ppm NaCl)
pH	$(-\log (H^+))$
Chloride	(mg/l Cl^-)
Alkalinity	(as mg/l $CaCO_3$)
Sulfate	(as mg/l $SO_4^=$)
Nitrate-Nitrogen	(as mg/l N)
Total Iron	(as mg/l Fe^{++} and Fe^{+++})
Ferrous Iron	(as mg/l Fe^{++})
Chemical Oxygen Demand	(as mg/l O_2)
Total Hardness	(as mg/l $CaCO_3$)
Calcium Hardness	(as mg/l $CaCO_3$)
Manganese	(as mg/l Mn)

Trace elements studied are:

Aluminum
Arsenic
Boron
Barium
Beryllium
Calcium
Chromium
Cobalt
Copper
Iron
Magnesium
Manganese
Nickel
Lead
Antimony
Selenium
Tin
Strontium
Vanadium
Zinc

Temperature and water depth are recorded at the time of sampling. Other water level measurements are made before bailing the wells and two to three times a week by Dennis Struck or a field assistant. Specific Conductance, pH, total and ferrous iron, and ocassionally sulfide are measured in the field to avoid changes before analysis. Lab analysis of samples is usually completed within a month after sampling, but ocassionally

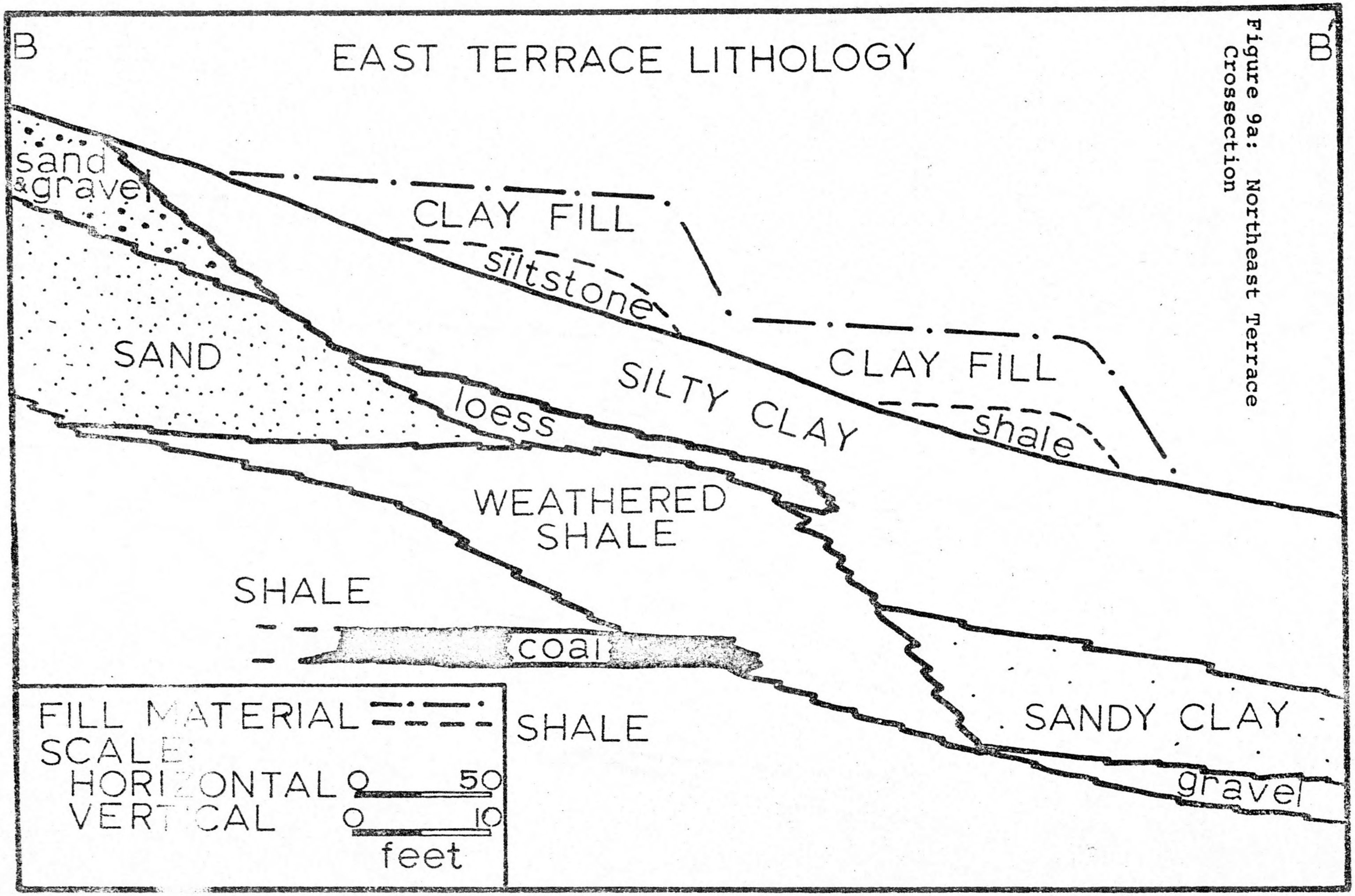


Figure 9a: Northeast Terrace Crossection

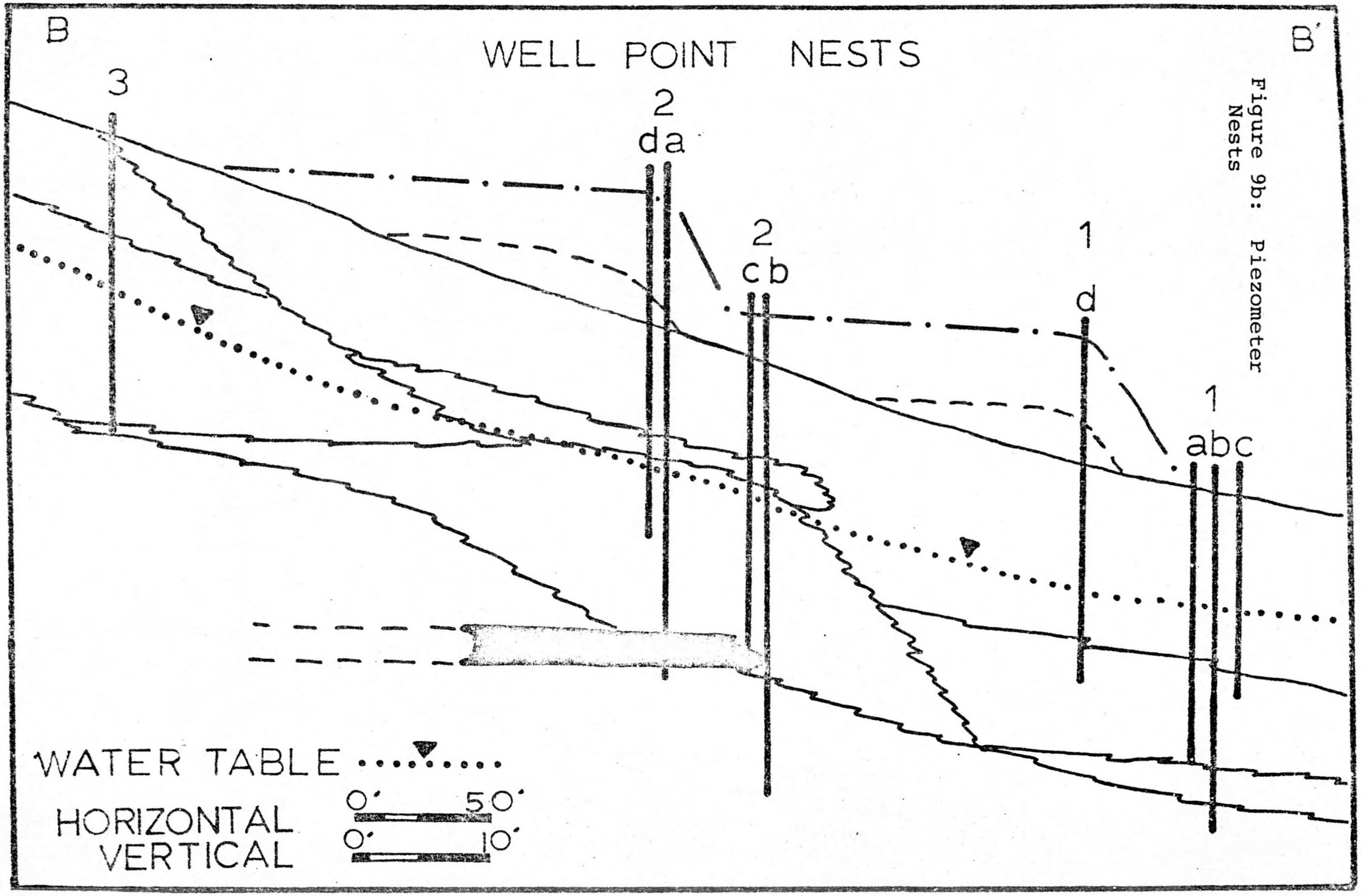


Figure 9b: Piezometer Nests

two months elapse.

Premining Subsurface Water Flow

The subsurface water flow previous to mining at the ICP#1 site occured between particles and in the joints or cracks in the geologic materials present. The greatest amount of water flow was in the unconsolidated surficial deposits. These unconsolidated materials are loess, glacial till, glacial sands and gravels, alluvium, and weathered bedrock debris. The water flow through the loess occurs primarily only after rainfall and snowmelt, because the loess is situated well above the water table. Flow in this material is usually in an unsaturated condition. Occassional saturated flow may occur if water is backed up on the loess-till interface due to a permiability contrast. The primary routes for water movement in the loess are large desiccation cracks that appear in the material during drying periods. These cracks open to widths of one to one and one half inch, and reach depths of several feet. During wet periods these may be closed by sedimentation, swelling, or slumping. As the desiccation cracks close interparticle flow becomes much more important than does the previously mentioned "fissure" flow. Interparticle flow occurs between the silt grains through well connected pores. Pore flowage is also important at depths where drying cracks do not develop.

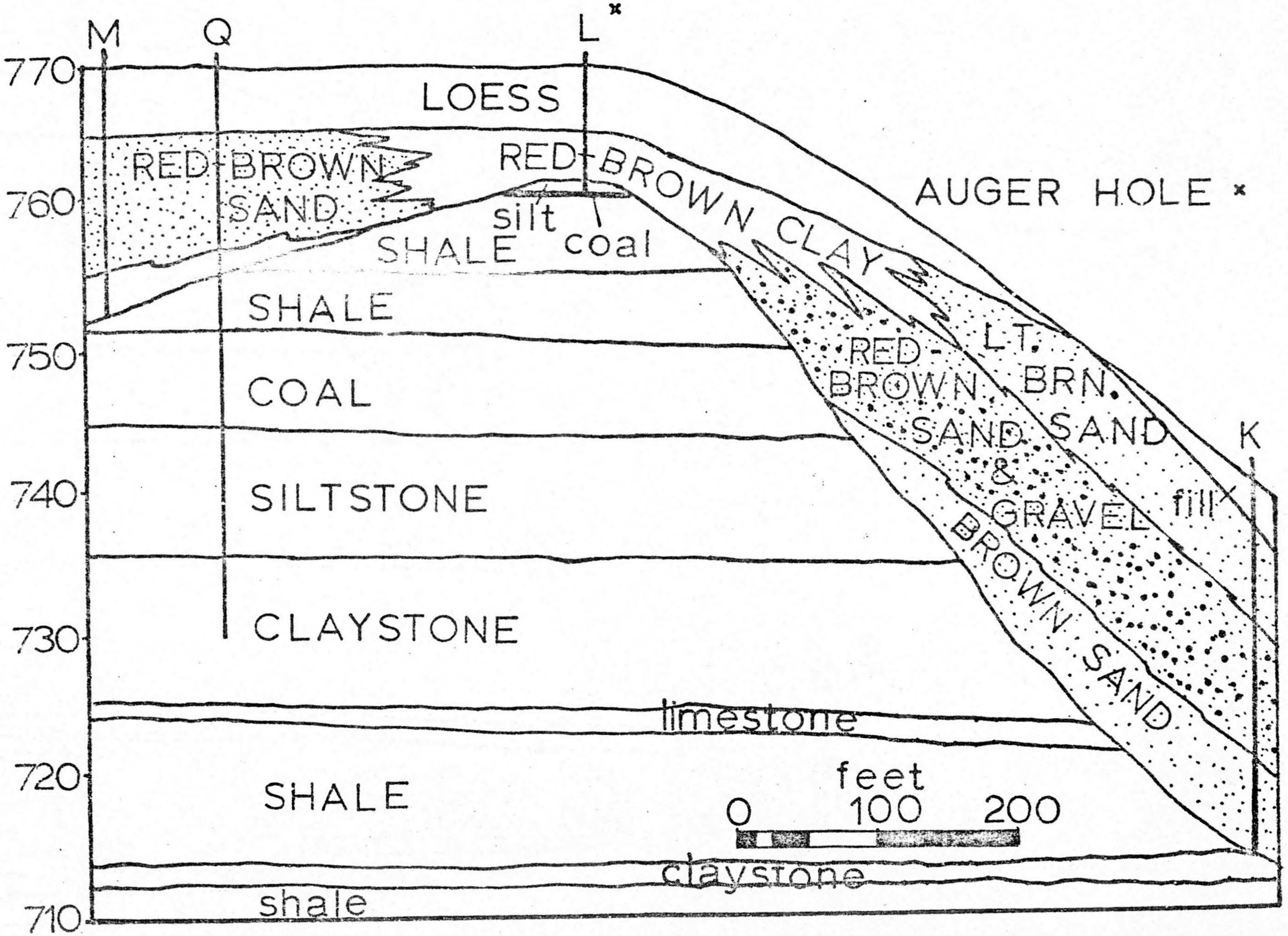
Water flow through the till before mining and in portions undisturbed by mining is credited to fissure or joint flow as in the loess. The joints or cracks in the till probably occur as "fossil" desiccation cracks. The joints were most likely developed just after glacial deposition. In plan view the joints of the till form irregular three to six sided polygons ranging in size from four inches to two feet. Some of the cracks also appear to be deadend, i.e. they do not intersect other cracks. In plan view the central opening of the joints is not apparent, but an orange colored band from one to four inches wide marks their distribution. The color band may be an oxidation zone around the fracture. In crossection the joints appear to be an eighth of an inch wide or less. The wider joints are usually filled with a fine white sand, while the smaller openings have iron coatings on each side. The joints are roughly vertical, and are very wavy. Some water may also flow through the pores in the till, but because of their small size the flow is very slow. As a result of the small pore flow it is likely that most of the till flow charateristics are controled by jointing.

Other glacial materials at ICP#1 are sands and gravels previously described. The water flow through the sands and gravels is mostly between interparticle pores. This is because of the large pores between the particles. No joints are found as such in the sand and gravel deposits, but cross bedding foresets may have a similiar effect. In the lenicular sand body, areas of higher matrix porosity and permiability may occur locally where coarse sands are mixed with finer sands at the base of planer and trough cross beds (figures 5 and 10).

Previous to ICP#1 mining in the area the water level in the lenticular sand body may have been much higher. Prior mining activity on the north side of ICP#1 was curtailed do to an excess of water. This water excess was never experienced at ICP#1, and no apparent seepage was observed from the sands although they were very moist to the touch only a few inches below the surface.

Iron banding parallel to the trough cross beds is another evidence in favor of high matrix porosity in the sands. Several iron bands are often seen branching out from a common bedding plane and interfingering the coarser laminations of trough cross beds. Near the top and bottom of the sand unit are areas of well cemented ferruginous sandstone. This may or may not indicate a once preferred zone of water movement, but surely imposes a barrier at present. The undulating conglomeritic and limonitic layer in the sands also would appear to retard vertical flow.

Figure 10: North Mine Crossection



The alluvium of the ICP#1 site along with coals, and glacial sands compose the greatest water flow regimes of the site. The saturated alluvium of the site consists of a series of very local and complex point bar, back swamp, clay plug, and low level terrace deposits. In upland areas alluvium may be less than one foot thick, while on the flood plain of South Coal Creek it is over 30 feet thick. The permiability of the saturated alluvium is relatively high due to the interconnection of point bar sand and gravel deposits. The depth to water varies between five and fifteen feet. Unsaturated portions of the silt consist mostly of overbank silt deposits.

Unsaturated flow through the shallow parts of the alluvium is often by a combination of fissure flow and by flow between pores. In the saturated zone most flow is through the coarser deposits such as sands and the gravel which underlies the east side of the sediment pond (figures 11 and 12).

The last unconsolidated material to have significant groundwater flow properties is the weathered bedrock surface. In this material the natural bedding planes have been inlarged by erosion or chemical break down. Often the bedrock surface is weathered and reworked by gravity to form a semi-colluvial deposit. This type of deposit is commonly found at the flood plain-upland transition. The water flowing through these deposits is

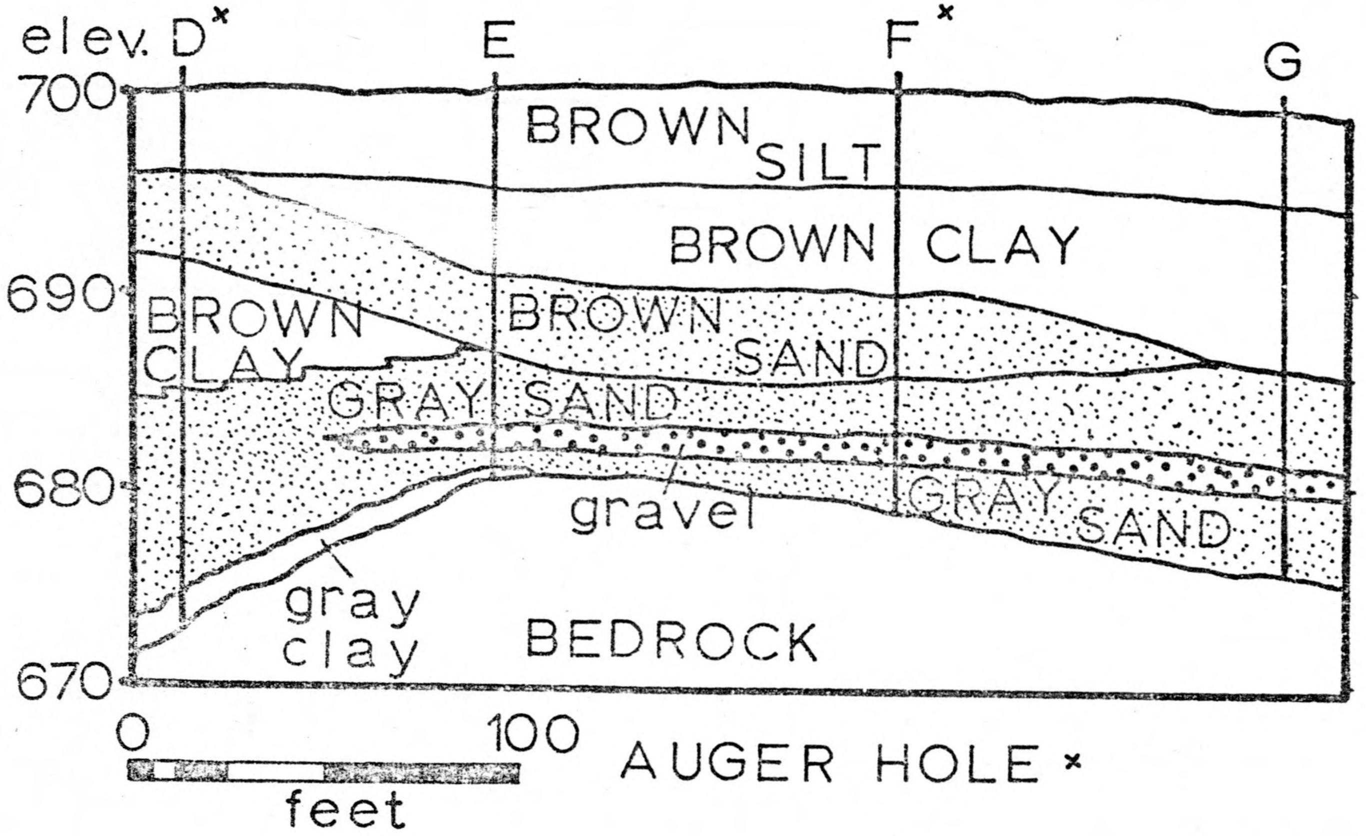
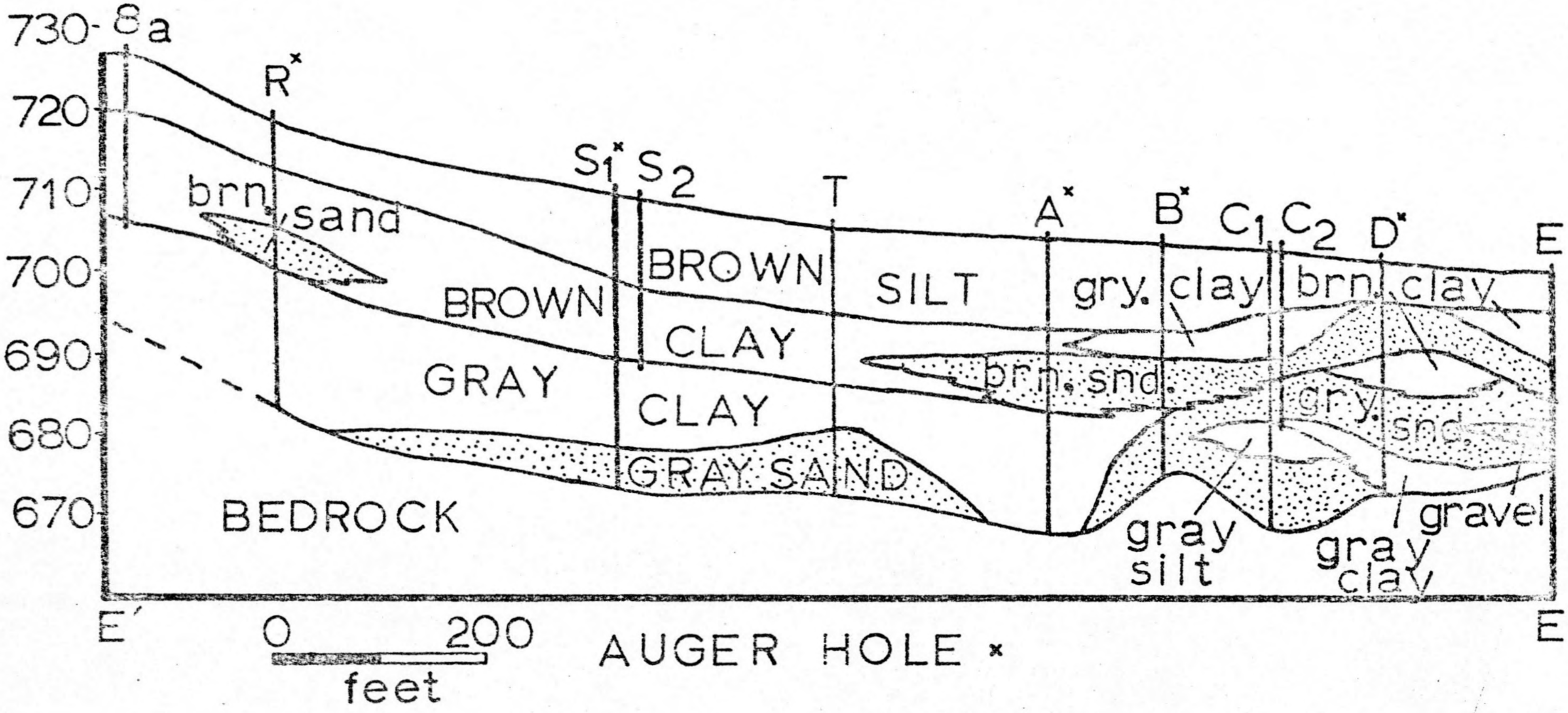


Figure 11: South Coal Creek North-South Alluvial Crossection

Figure 12: South Coal Creek East-West Alluvial Crossection



largely moving in fractures or bedding planes, and again a small amount of water movement will be through the pores of the more consolidated blocks or fragments of the weathered rock (figure 9).

The flow of groundwater through the consolidated bedrock of ICP#1 is in general probably much less than that of the unconsolidated deposits. This is due to the low permeability values typical of shales, siltstones, claystones and mudstones making up the majority of the shallow bedrock of the area. The flow through these rocks is very slow. The largest part of the flow is probably along numerous bedding planes, cross beds, and joints. In shales at ICP#1 the bedding planes are seperated by at most a few inches. A large part of the flow is also along many vertical joints. The joints observed at the ICP#1 site appear to be usually between one and three feet long. These joints also appeared to have a major and a minor trend. These trends are north 60° west and north 60° east for the major and minor respectively. In addition to these joints there are several normal faults in the shales. These fractures show six to eight inches of displacement and dip between 45 and 55 degrees to the east. These features may also be present in the other bedrock lithologies at ICP#1, but surface weathering and slumping prevented inspection of them. The pores of shales, claystones, siltstones, and mudstones are very small or very poorly connected causing their low water flow rates.

The one exception to the low permeability of the bedrock is the coal that is found among the shales and other tight materials. The coals are probably the most permeable of all geologic materials at the mine site. The coals at ICP#1, one at elevation 700 and the other at 750, have very large horizontal fractures. These openings are often an inch wide, and are usually filled with a fiberous material called fusain. These fractures are parallel to the bedding planes, and may actually be a sort of bedding plane. Vertical fractures are also present in the brittle coal, but they are not nearly as well developed. The water carrying ability of the coal is illustrated by the fact that the only groundwater seeps to form in the mining cuts were at the bases of the coal beds.

As mining opened the upper coal seam three seeps developed. The seepage rate was initially estimated at about 10 gallons per hour for a seep at the center of the top seam. Two other seeps also occurred at the upper seam, but the combined flow of these two was perhaps only one half that of the third. Near the end of mining the seepage from the top seam was significantly reduced to about five gallons per hour at the west side of the upper coal seam. A minor seep was formed and maintained with no apparent flow at the east side of the upper coal seam at this time also. No flow data was obtainable for the bottom coal because it was difficult to distinguish water moving out of the coal from water already in the mining pit. The bottom coals, however, always seemed to be nearly saturated as they were uncovered.

Post-Mining Subsurface Water Flow

The most significant changes in subsurface water movement caused by surface coal mining are the removal of the permiable coals, the destruction of the fracture flow system of the bedrock, and the displacement of the water table downward by up to 50 feet. Another indirect mining effect on the groundwater was the creation of a mound in the vicinity of the sediment retention pond.

In place of the lower coal seam a layer of coarse debris and waste coal may be left as a permiable zone, but in other areas of the mine a rather low permiability condition will exist. It remains to be seen if the spoil has a lower permeability than the previous bedrock, but because of the loss of bedding, and joint structures it would not be unlikely. The flow condition that exists in most of the spoil fill is a rather chaotic one, through and around blocks and pulverized claystone, siltstone, mudstone, and shale materials. It is believed that this will allow only a very slow return of the previous equilibrium water table conditions. The low permiability conditions are directly related to the method of reclamation in which the spoil material was packed back into the mining cuts by scrapers.

Some pockets of more permeable material occur in the fill locations of coal washing biproducts and glacial sands and gravels. These coarser materials may allow for a much faster resaturation of the fill around them if they are in connection with a recharge source. If the coarse materials are completely surrounded by fill or fill and the original shale it is unlikely that they will saturate any faster than the other materials.

The loss of water saturation from the disturbed bedrock results from two processes. The first is swell. Earlier it was mentioned that mining causes about a 10 percent increase in volume. This increase in volume is increased pore space. The bedrock materials could thus become unsaturated without losing any moisture to evaporation, although, in this type of handling loss of moisture would be very imminent. Swell occurs even with packing because the scrapers dump the material in larger aggregates in a random order, whereas the original materials were laid down particle by particle and winnowed by currents until a best fit was obtained. The second process by which the spoils lose moisture is evaporation. The mining operations grind up much of the spoil into a very fine powder that has a large surface area and can thus locse moisture rather rapidly. Evaporation would be much more critical for siltstones and claystones because of high porosities than for shale with its very low porosity. On the other hand, shale is much more susceptible to moisture loss by swelling. This is only true if each material undergoes equal swell. The porosities of average siltstone, claystone, and shale are 35, 43, and 6 percent resectively (Morris and Johnson, 1967). If each of these materials experience a ten percent swell their respective porosities increase to 41, 48, and 14.4 percent. This increased pore volume indicates the increased water storage capacity of mined spoil. The increased water storage ability of mine spoil has been documented by many people and is given credit for increasing stream base flow. Spoil materials have been sited as being helpful during dry periods because of recharge to domestic and municipal water supplies and in low flow augmentation of rivers (Agnew, 1966, Cederstrom, 1971, Deane, 1966, and Truax, 1965). These benefits of spoil porosity may not be as important at ICP#1, because of the lower porosity increase experienced with scraper reclamation.

The increased porosity of the spoil materials does not indicate that any permeability increase has occured. In fact, the decrease of permeability is suggested by a significant difference between recovery times in wells 5a and 7a. Piezometer 5a is located in the shale bedrock just below the fill. Piezometer 7a is located in the saturated base of replaced spoil. 7a takes up to twice as long to regain a one foot head drop as does 5a.

The indicated permeability decrease most likely exists due to the loss of joints and bedding planes. This loss may have significant effects on the reclaimed terraces of the mining area. It has been seen that a series of desiccation cracks develope very rapidly in the replaced loess-till spoil placed on top of the low permeabilty bedrock spoil. This development of cracks may create a large permeability contrast between the loess-till and bedrock spoils. This contrast could cause water to pond up above the interface between the bedrock and loess-till spoils. This phenomenon may have occured naturally before mining, but a significant slope was present to drain the accumulated water. At the present reclamation area the slope has been completely reduced in areas of the flat terraces. These conditions may have contributed to the ponding of water on the terrace near piezometer 7c. Auger hole logs show that in this area the interface between the bedrock spoil and the loess-till spoil is only two to three feet below the surface.

Experience in other areas of the country indicate decreased water levels in the down gradient direction from reclaimed mines. At ICF#1 this has not occured, becaused the down gradient areas of the mine are supplied water from the alluvial sequence along South Coal Creek. The water levels at the lower or down gradient side of the mine have also reached the approximate levels observed prior to mining. This indicates that the low permeability of the former bedrock allowed it to contribute a relatively small amount of water to horizontal down gradient flow before mining, and that no new effects have been caused by the reclaimed spoil in this regard.

The recharge of groundwater into the first reclaimed mining cut has contributed between two and three feet of gained head. This recharge occured within 12 months following the replacement of the material. The water levels at this location are very near their pre-mining levels and have completely stabilized at a near constant head. No appreciable water level increases were measured in the cuts filled following the first.

The loss of up to 50 feet of water saturated materials in the mine pit areas has greatly impacted the water flow of the mine area (figures 13, 14, and 15). The groundwater gradient of bedrock has been changed from a pre-mining condition of five feet of head drop per one hundred feet of hoizontal movement to the southeast to a twenty feet per one hundred condition. This gradient increase will be opposed by a smaller gradient from the southeast caused by the groundwater mound from the sediment pond.
Since the sediment pond has been drained this mound has been slighly reduced and its continued decline will have little influence on the movement of water into the mine cut areas.

Figure 13: Premining Water Table

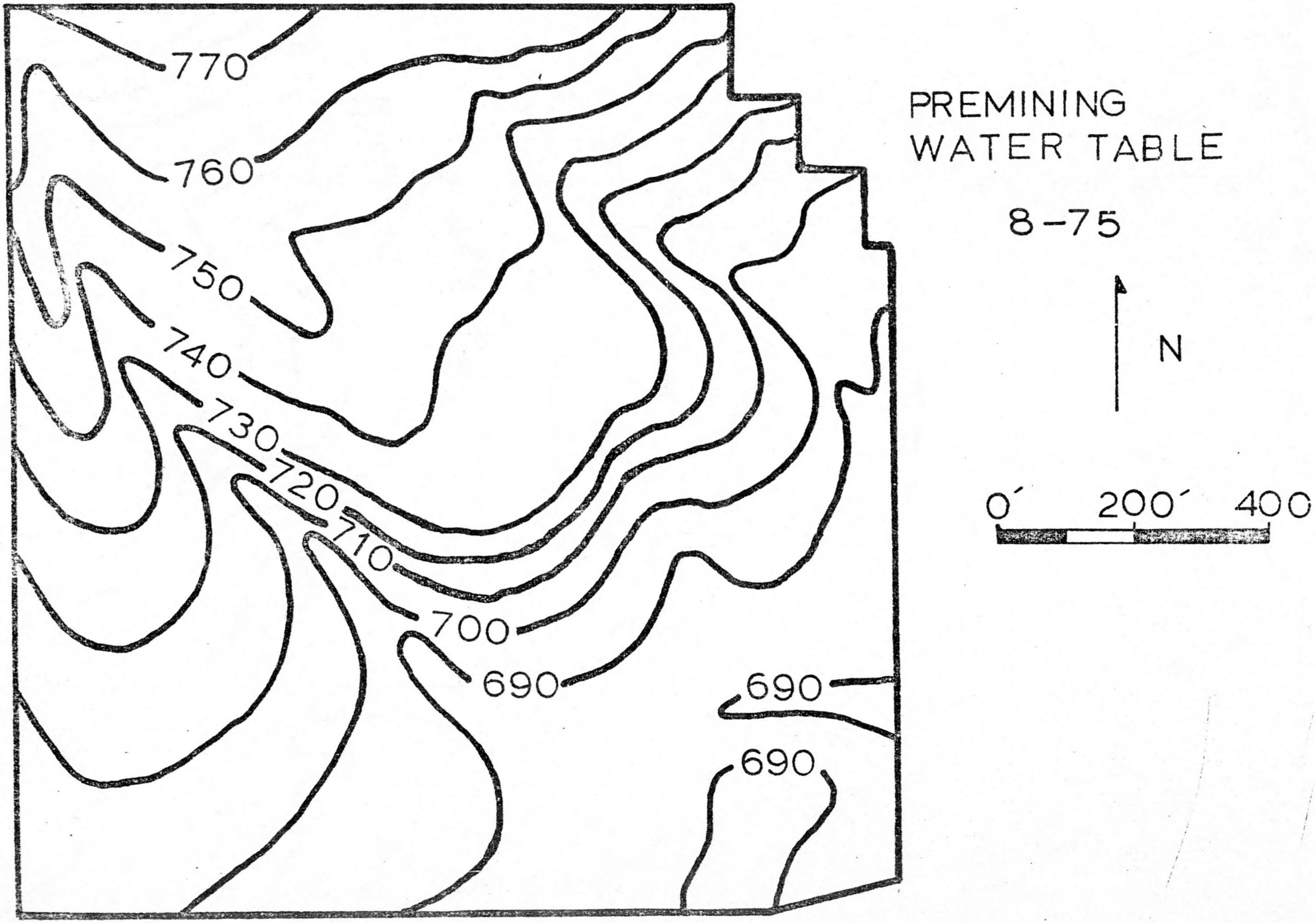
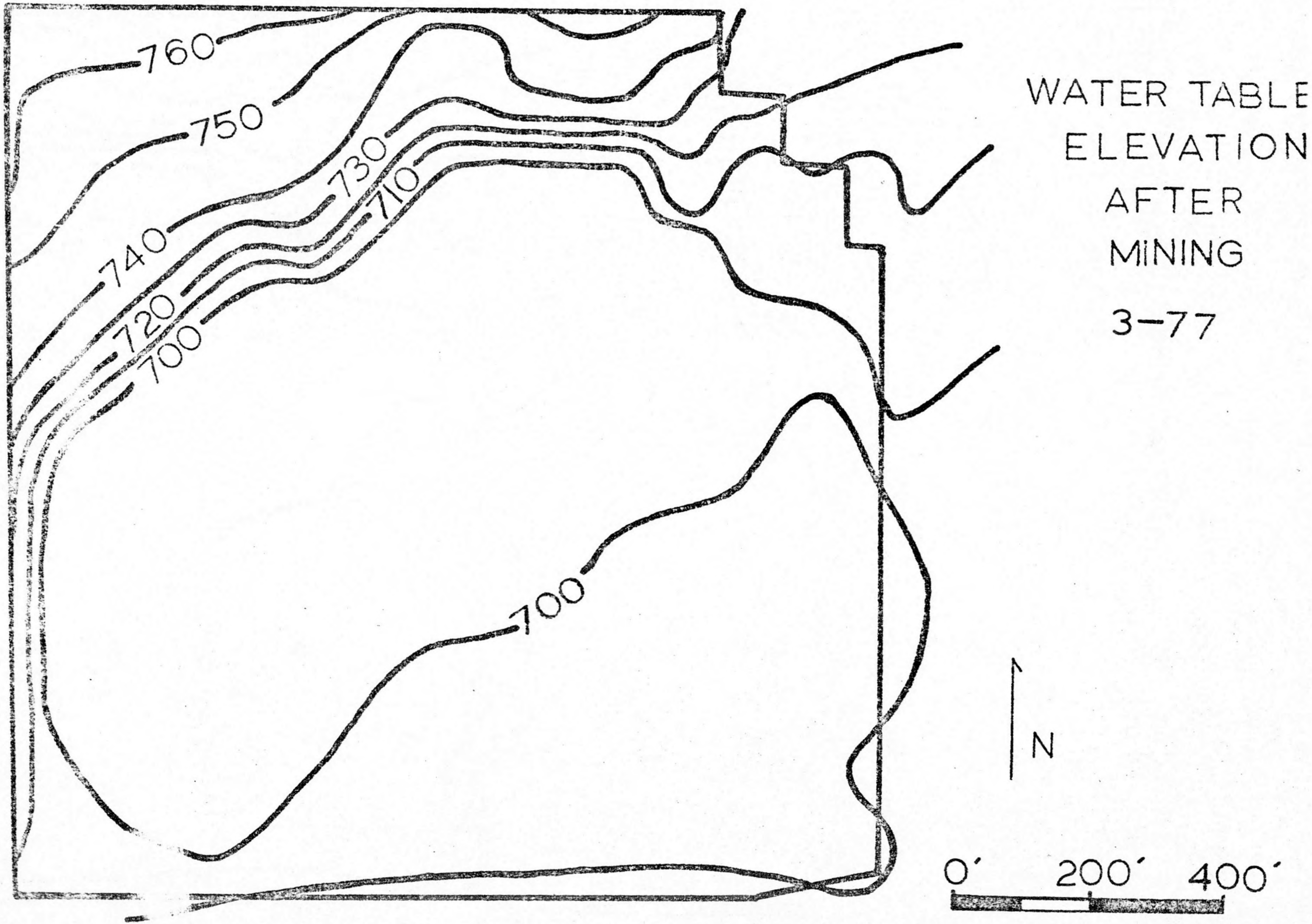
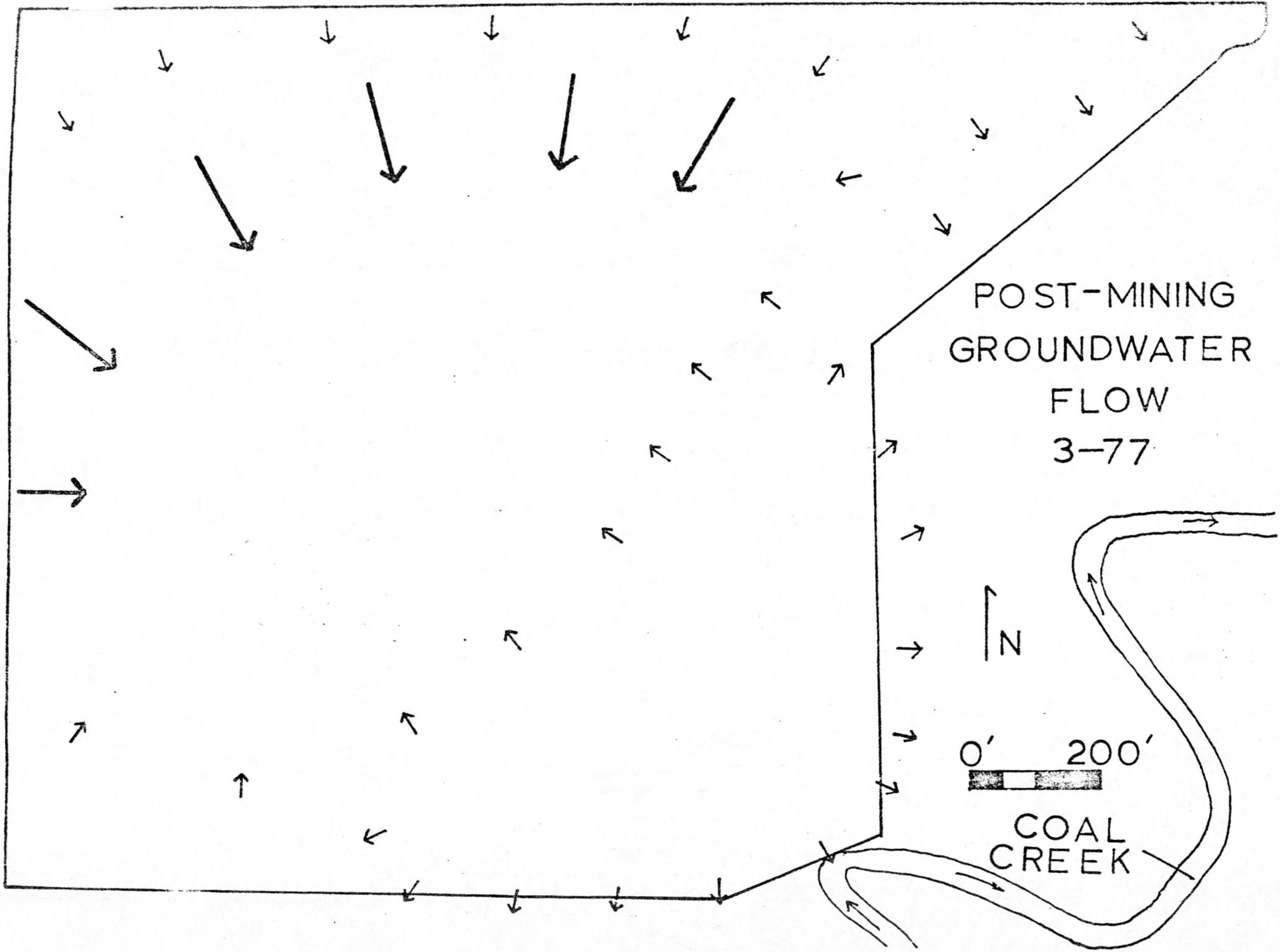


Figure 14: Post-Mining Groundwater Table



ure 15: Post-Mining Groundwater Flow Directions



Another source of recharge into the mine cuts is from the undisturbed shales and siltstones beneath them. This recharge source is significant in the recharge of the first mine cut, but unless head conditions in later cuts are greater than those observed in piezometer 5a, its contribution will be negligible in recharging the thick sequence of dry spoil found near the highwalls.

Dynamic Piezometric Effects of Stripmining

Coal stripmines, as well as, other "quarries" assume characteristics of a large diameter shallow well when extending below the groundwater table or into subsurface aquifers. As these "wells" or mining cuts breach water bearing srtata water will begin to flow into the open excavations. The rate of this flow is determined by the amount of water "standing" above the bottom of the excavation (head), the permeability of the material releasing the water, and the depth to which the water is allowed to accumulate or the rate at which water is removed from the excavation by pumping. With time, for a stationary mine cut, an equilibrium flow rate will establish a cone of depression around the mine. Once mining increases the cut size a new equilibrium will be established, and a larger cone of depression will form. Succesive increases in mine cuts of this type continually influence larger and larger areas reducing their water levels. Problems become apparent where the areas of decreased water occur outside the mining lease. Water level reductions of this nature were observed at ICP#1 as summarized in figures 16-20.

At ICP#1 the materials releasing the water into the mining excavation are claystones, siltstones, mudstones, shales, and coals. With the exception of the coals, these materials probably have very low water transfer properties.

Figure 16: Schematic of Groundwater Loss Associated with ICP#1 Mining

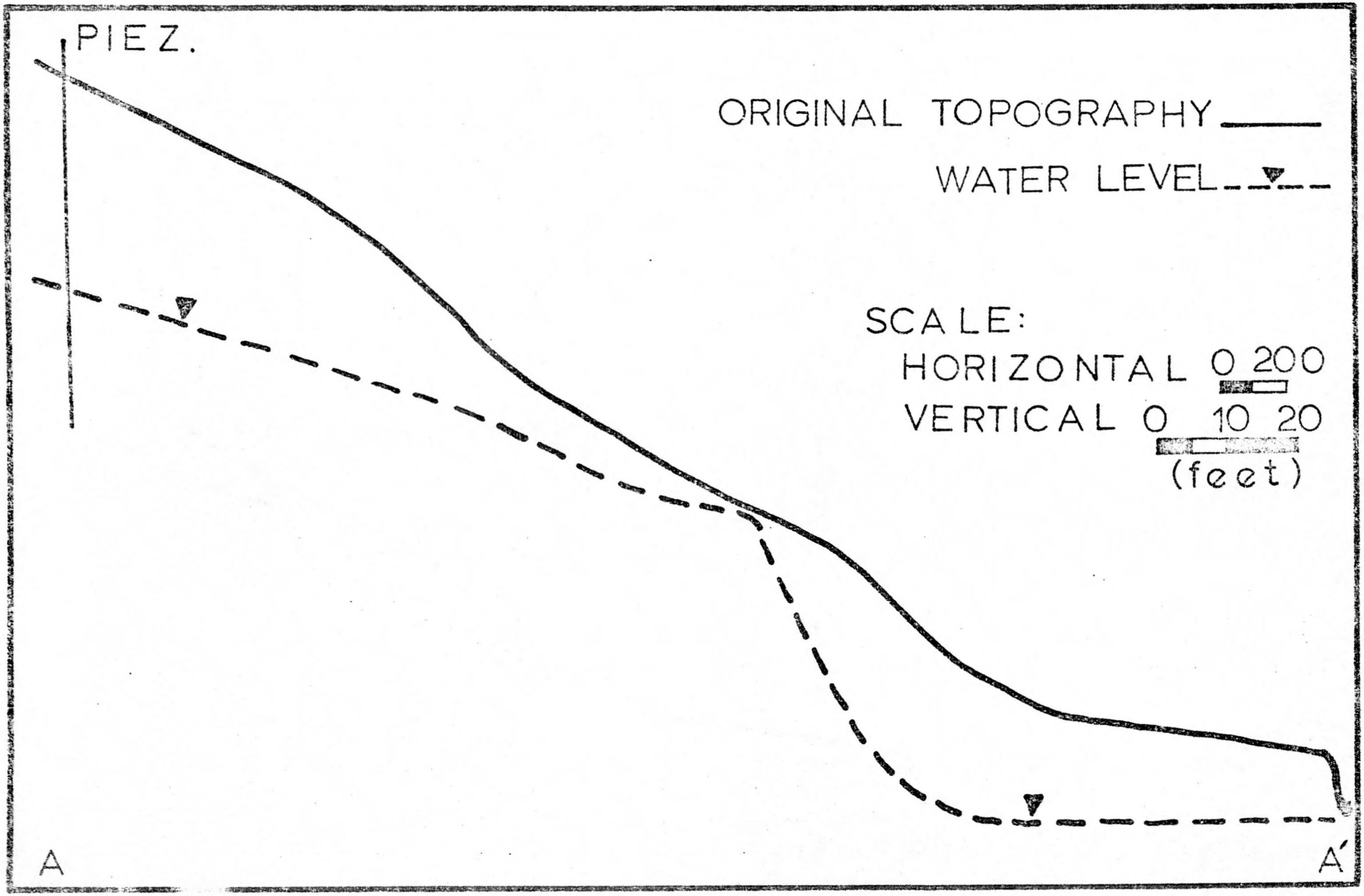


Figure 17: Schematic of Groundwater Loss Associated with ICP#1 Mining

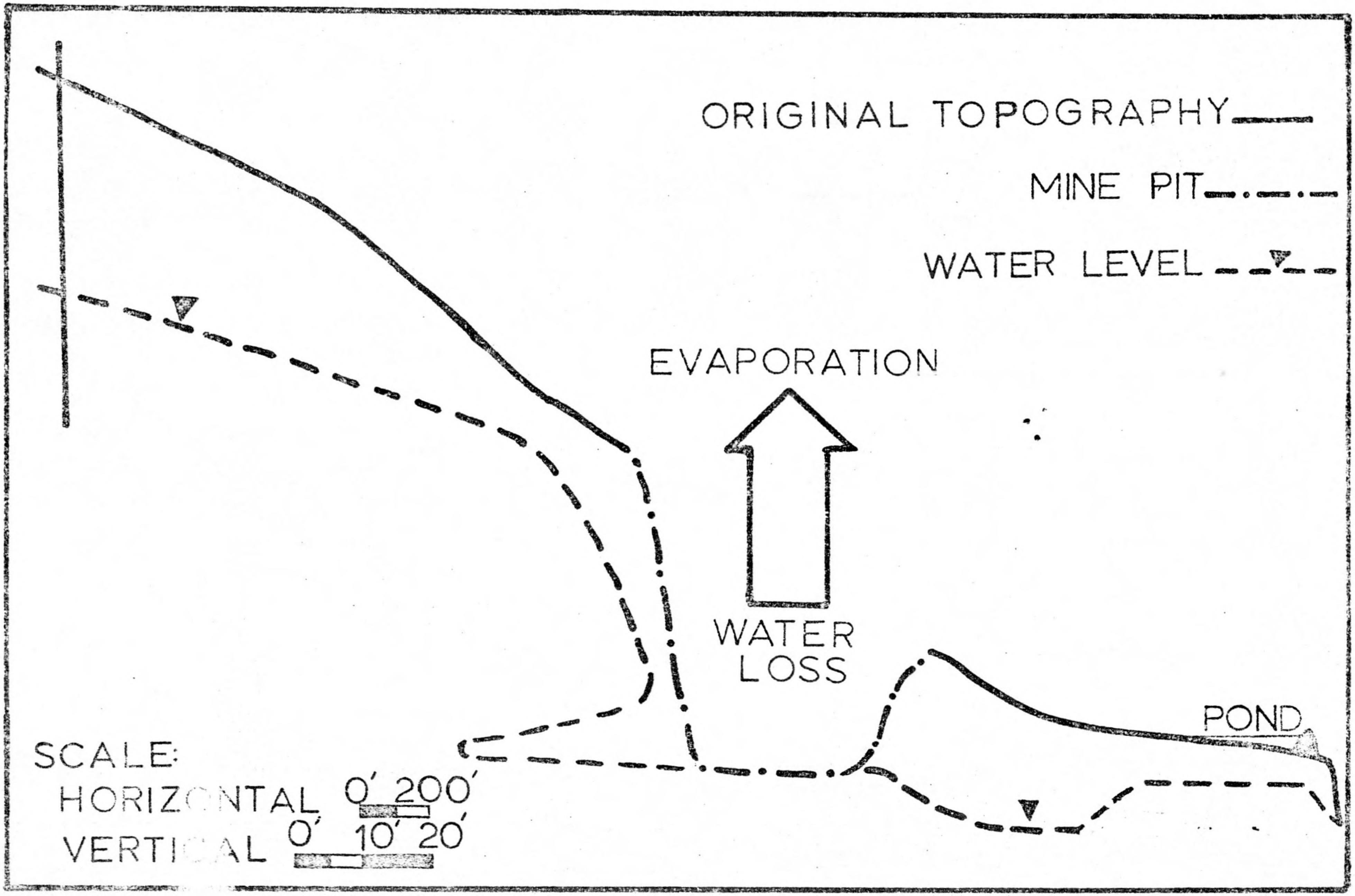


Figure 18: Schematic of Groundwater Loss Associated with ICP#1 Mining

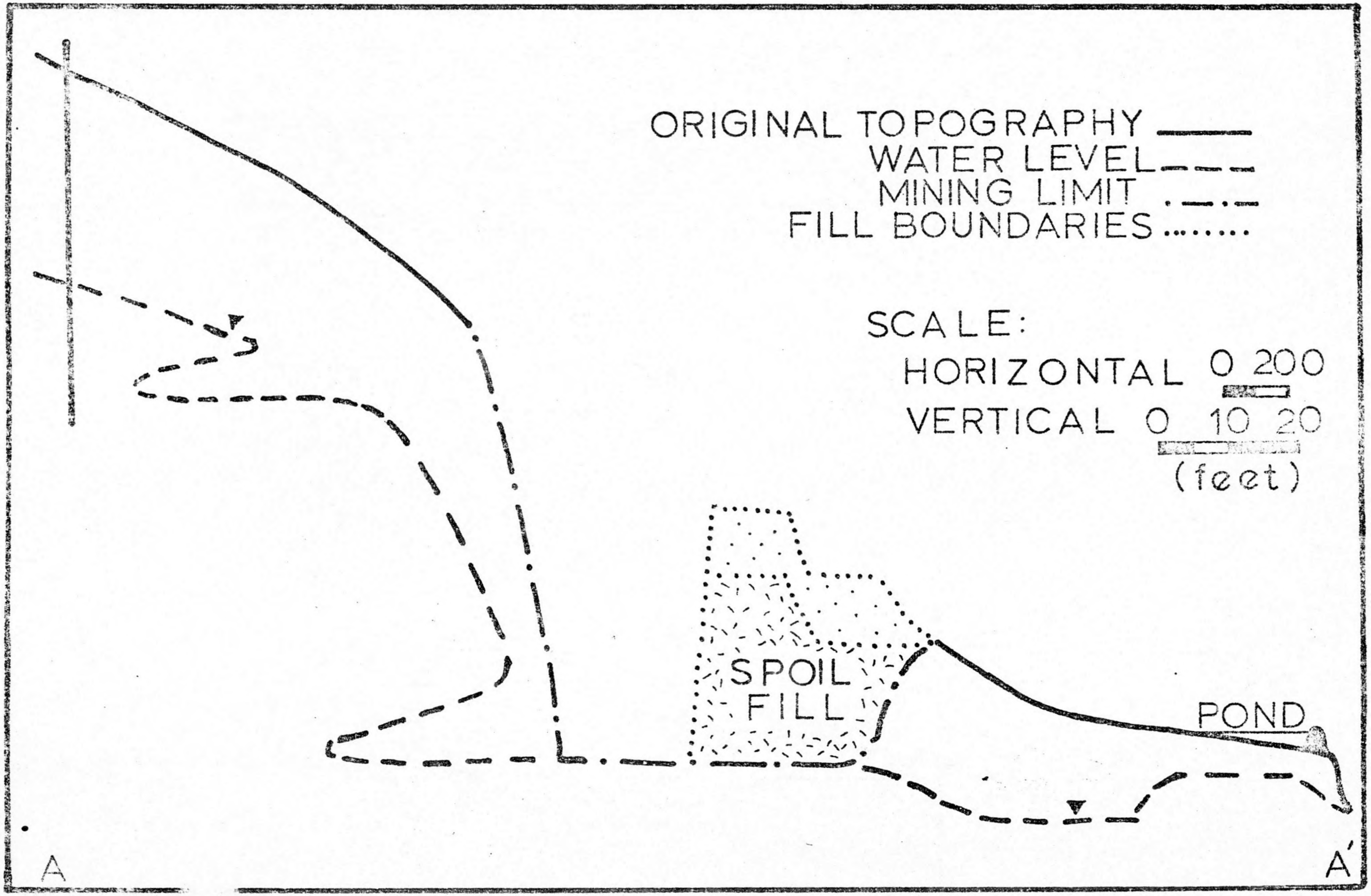


Figure 19: Schematic of Groundwater Loss Associated with ICP#1 Mining

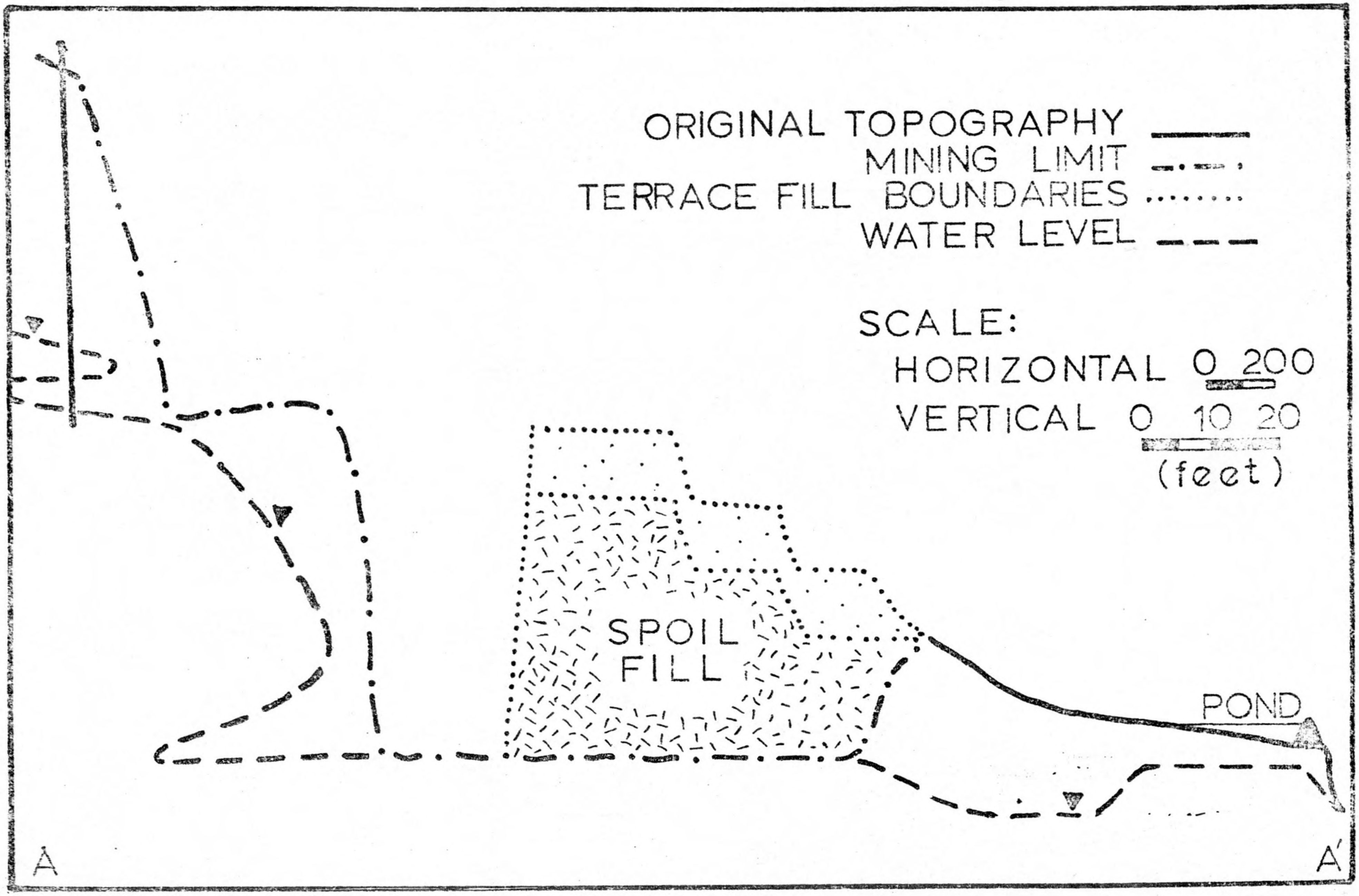
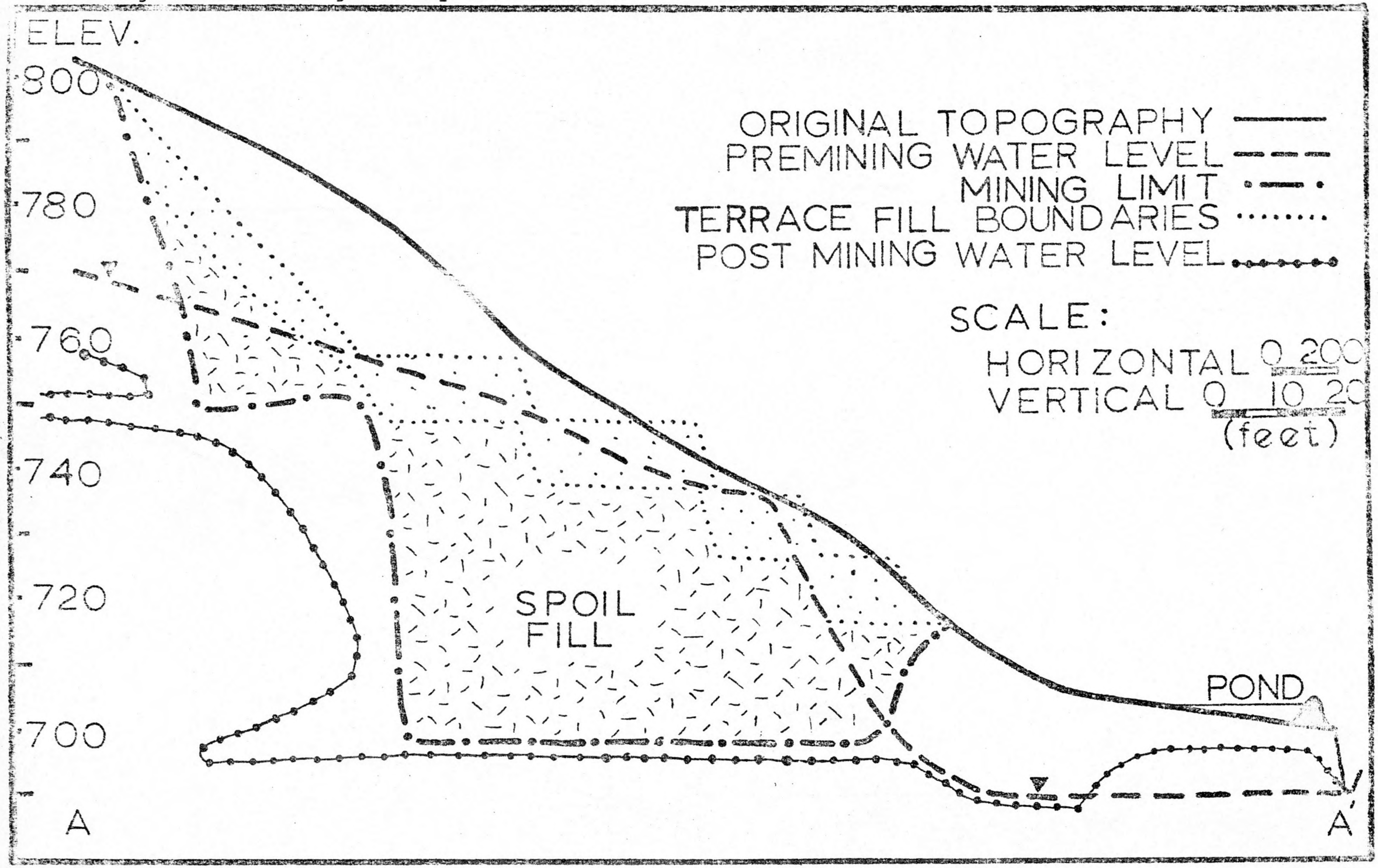


Figure 20: Mining Summary Crossection



No permeability studies were conducted on these tight materials, because instances where these materials contribute significant volumes of water over such a small area are rare. The low permeabilities of the tight materials cause mosture flow to be so slow that any water reaching the outer surface will evaporate before significant accumulations can develop. These materials seemed to contribute very little water to the mine cut, although a situation similar to the under drain effect observed for the upper coal may also exist for the lower. No piezometers at the north of the site were placed into the lower coal. One piezometer on the northeast terraces is open to a weathered portion of the lower coal, but showed no water level decrease from mining as little as 200 feet to the west. The lower coal water system was probably less effected by mining than the upper seam, because it is not as actively mined in the area around ICP#1.

The coal seams, although less than one tenth of the total bedrock exposed in the highwall, contribute the most appreciable amounts of groundwater seepage into the mining cuts. Seepage rates from the upper coal bed at ICP#1 were estimated at about fifteen gallons per hour (about one liter per minute). Most of the seepage was observed coming from the bottom of the seam. Waters draining from the coal may have originally come from the overlying sands and gravels. No seepage was ever observed in these sands and gravels. This may be because the coal again acted as a more permeable under drain and "pirated" the water from the sands and gravels.

The extent of dewatering to the north of the ICP#1 area was observed in three piezometers above the last highwall of the mine. One of these wells was developed in the upper coal seam and part of the weathered shale above it (4), another in the sands and gravels (M), and the third was open to a 35 foot sequence of siltstones, shale, the upper coal, and the sands and gravels (Q). The shale and siltstone were assumed to have contributed little water to Q. The materials that these wells monitored were first disturbed by mining in March and April of 1976, however, no significant changes were observed until late July 1976. At this time the upper coal seam was opened at a distance of about 300 feet from piezometer 4 (figure 21). As the coal was removed the water level dropped very rapidly from an elevation of 760.5 to 759.8, and leveled off at the lower elevation until the end of September 1976 (figure 21). This leveling perhaps indicates a temporary recharge was received from the overlying sands and gravels, and that some water was stored in them near this location in the hill. The leveling may have also been due to a new equilibrium set up as a result of the opening of the seam to mining. The recharge model is favored, becaused of the abrupt leveling, and evidence indicated in the water quality data to be discussed later. A similar but less obvious trend was also observed in piezometer Q.

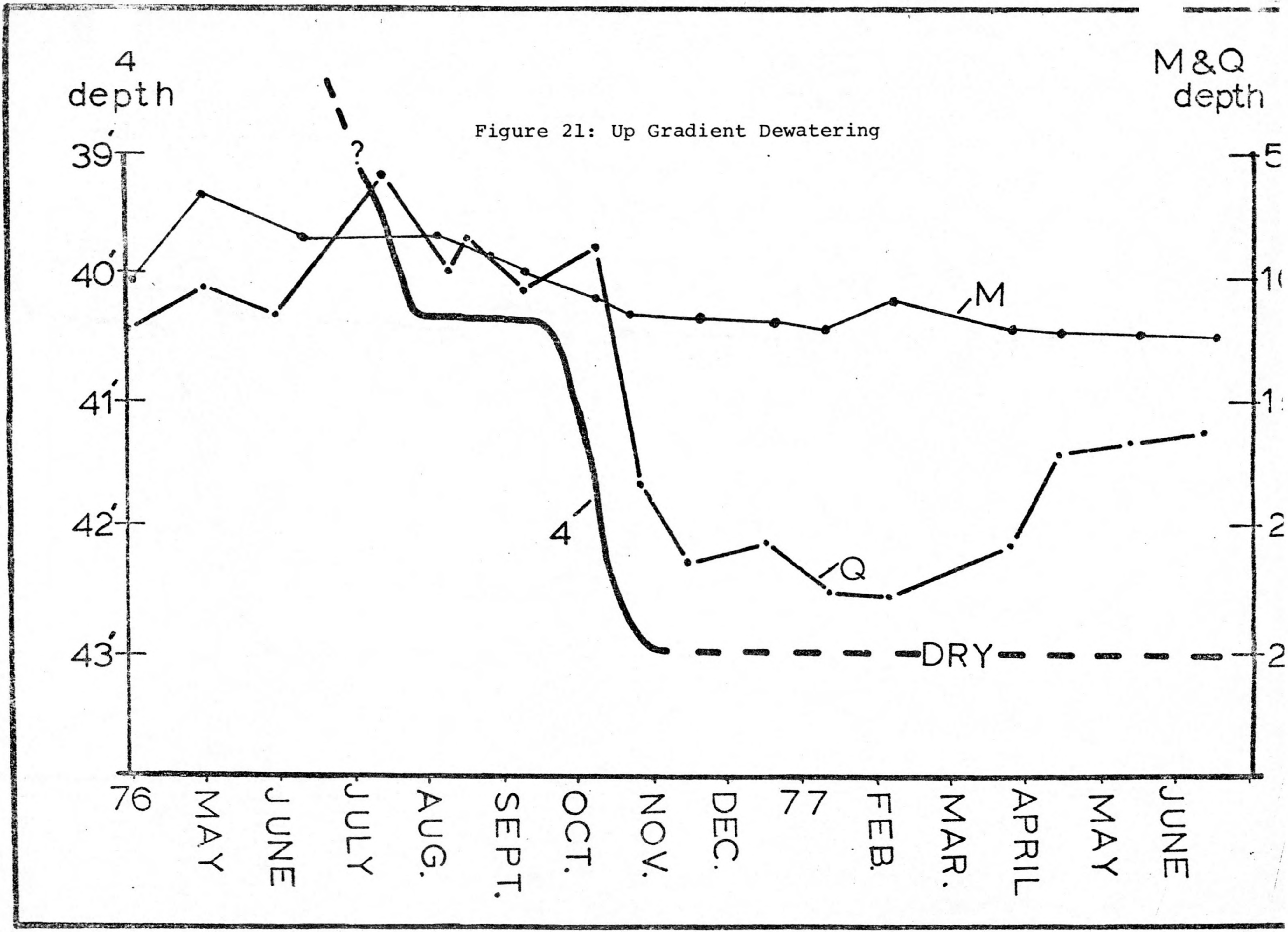


Figure 21: Up Gradient Dewatering

Late in September 1976 a north-south cut was excavated into the upper coal seam at the northwest corner of ICP#1. This allowed a second seepage face to form on the upper coal at a distance of again about 300 feet. This activity was followed by the complete loss of water in piezometer 4. A small amount of water, however, remained seeping from the coal, possibly due to flow from recharge areas to the west. Declining water levels in M and Q wre also noticed at this time. The water level in Q dropped from an elevation of 760.4 to about 750 feet. The level in M dropped also, but only about three feet. The water level in M leveled off at this time and has never gone significantly lower. Q, on the other hand, continued to lose head. From early November 1976 until mid-February of 1977 Q lost an additional four feet due to the previous mining, and to new mining only ten feet to the south. Since mid-February Q regained about seven feet of head from recharge in the sands and gravels, and closure of the seepage face during the reclamation backfill of the upper coal seam bench. Piezometers 4 and M remain unchanged. It appears that the sands and gravels near M and Q are recharging the coal seam, but not in the vicinity of 4. Apparently a larger dewatering impact was felt in this area due to the north-south mining cut which substantially constricted an already narrow recharge path from the northwest. M and Q are also located in hollow that funnels most of the water flow to the center near M and Q.

These results indicate that a substantial portion of the northwest hill above the lower contact of the top coal has been dewatered by mining either at ICP#1 or from mining to the west and north. Earlier mining to the north was obstructed by an overabundance of water when initiated. This may have been caused by the draining of a significant portion of the sands and gravels in the hill (personal communication with Dennis Struck, ICP#1). Recent mining north of ICP#1 has experienced little seepage in upper coal due to the previous drainage.

Identification of Recharge Areas

Possible recharge zones for resaturating the reclaimed fill areas of the mine include the unmined portions of the hill on which the mine is located. Unmined areas rim the mine on north, east and west. Most of the recharge will come from the northeast part of the hill which is hydraulically connected with the mine by the glacial sands and gravels and parts of the undisturbed coal seams.

Secondary recharge zones will be along the north, northwest, and west. To the north mining on both sides of the hill has reduced the recharge capability. A similiar situation may exist to the west. Undisturbed segments of coal underlie the roads ajacent to the mine. These coals may act as hydraulic conduits in carrying recharge water from the west, northwest, and north. Cast mining spoil to the west of the ICP#1 site may yield water to recharge also. Drilling in the area of the Star mine tipple showed water in cast spoil and sand at a depth of only six feet. Other sands and some gravels in glacial deposits located in the undisturbed areas to the northwest will perhaps also contribute to ICP#1 recharge and saturation.

Infiltration of precipitation is expected to be another major source of resaturation water for the mine. Surface infiltration may cause local perched water table conditions at the boundry between the shale fill and the and the replaced loess and till. This may have already occured in certain areas of the mine previously mentioned. Infiltration of precipitation may also cause groundwater to back up behind the north side of the mine near piezometers M and Q. This condition results from the recent back filling of low permeability shale spoil against the fairly permeable glacial sands in the north highwall. Groundwater is funneled to this location by a semicircular drainage-way higher on the hill directly to the north. If appreciable water is backed up seepages may form at the highwall-fill interface.

The last type of significant recharge is vertical upward flow from the bedrock. In lower portions of the mine it has been seen that a head of two feet above the mine pit floor exists in the bedrock. No data has been collected for the other areas of the mine. The two foot head condition caused water flow upward into the fill at an average rate of one foot per month. Recharge rates in other portions of the mine will perhaps be greater due to the larger piezometric gradients in those areas. There is also the possibility that a large part of the recharge in pit one was due to lateral flow, because very little recharge recovery has been noticed in cuts filled since the first.

Groundwater Quality During Mining and Reclamation

Primary concerns in monitoring the groundwater quality at the ICP#1 site include the effects of infiltration of acid waters from a sediment retention pond into the ground water of South Coal Creek flood plain, and the initial and long range water quality of water returning to reclaimed mine spoil. A secondary concern is associated with the water quality changes that occur with the dewatering of the shallow aquifers up gradient from the mine.

One concern in interpreting the groundwater data at ICP#1 is the situation of backround data. No data was collected at the site previous to mining. Another problem is that wells located up gradient from the mine and that were used as quasi-back round data may not actually be unaffected by previous mining, because of the degree to which the area has been subjected to mining. Another concern is the water quality change in the sediments near the sediment pond. It may not be wise to assign all changes in the water quality at that site to the infiltration of the acid water generated by mining. Some degree of these changes may have occured if a neutral pond had been located on the site also.

The mine was not monitored prior to mining, because of the uncertainty of its final location. The lack of data gathered before mining may be atoned for by monitoring the groundwater for a similar period after the mining and reclamation are completed. This type of study seems necessary to complete the understanding of the impact of mining at the ICP#1 site.

Due to the lack of previous data the initial six months of records will be used as a reference or base line. The assumption to use the first six months data can be based on the incipient nature of mining, and the low precipitation recorded during those seasons at the mine. Precipitation would be necessary to move the mining contaminants into the groundwater flow system.

In reviewing the impact of sediment pond water infiltration on groundwater quality it is first necessary to look at its hydrologic setting and its water quality history. The sediment pond is located at the southeast corner of the mining lease (figure 7). It is located in this position to best intercept the surface water flow across the site. The pond is situated over relatively high permeability alluvial sediments of the South Coal Creek flood plain (figures 11 and 12). These sediments include surficial silts underlain by clays, silts, and highly interconnected sands and gravels. Depths to water near the sediment pond ranged from 10 to 15 feet before its initial filling in the late fall of 1975. As water began to accumulate in the sediment pond the groundwater levels around it rose from five to ten feet creating a groundwater mound. This mound developed artesian conditions in piezometer G at the east-central side of the pond. This condition was related to the very good interconnection between the pond and the sediments around G. The interconnection was partially due to a gravel bed lying under the east side of the pond, and partially due to a soil disturbance in that area caused by placing a tile or pipe from the pond to a stock hydrant near G. The situation of the pond on the flood plain of South Coal Creek allows it to influence a large area of alluvium. The mound caused by the pond also changed shallow groundwater flow directions from southeastward to southwestward in areas just west of the pond.

The water quality of the pond remained fairly constant from September 1975 to mid-April 1976. Typical pH values ranged between 7 and 8. Other parameters that were studied also remained fairly constant for this period. Alkalinity was low, typically between five and ten milligrams per liter as $CaCO_3$. Sulfates and total hardness were below 100 mg/l. Specific conductance was measured at about 100 as ppm NaCl, with total iron and chloride concentrations at .3 and 2 mg/l respectively. In late April 1976 after about eight months of mining the sediment pond began to show effects of acid drainage from a black shale spoil stock pile. The stock pile was located adjacent to the sediment pond at the northeast corner (firure 7). The south and east slopes of the pile drained almost directly into the sediment pond by way of a gully between the topsoil and oxidized overburden storage piles. From late April until late September and early October of 1976 the pond tock on the characteristics of an acid mine pit. The following data collected at the beginning and end of this period demonstrate the change.

May 1, 1976		September 17, 1976
6.1	pH	<4.1
210	Specific Conductance	1500
0.0	Alkalinity	0.0
160	Sulfate	1100
0.5	Total Iron	20
210	Total Hardness	1045
210	Noncarbonate Hardness	1045

The very acid conditions of the pond caused the corrosion of the pond drainage pipe and complete drainage of the sediment pond in July 1976. This prompted attemps to reduce or neutralize the ponds acidity with Ag. lime. The first attempt reduced the acidity only slighty, but caused a decrease in iron content from 20 to 6 mg/l. The second Ag. lime treatment reduced the acidity even less than the first, but again significantly reduced the total iron to 2.5 mg/l. One month after the treatment the iron content was back up to 5 mg/l, but was never recorded at a level higher than 5.5 the rest of the ponds life. A manganese determination on the pond showed that it contained near 10 mg/l of manganese prior to final drainage which occured accidently in April 1977 after the old drainage tube eroded open.

The effects of mining on the groundwater surrounding the sediment pond are not nearly as blatant as those observed for those in the pond. This fact may be accounted for by the precipitation and adsorption of the chemical pollutants at the bottom of the sediment pond, and by ion exchange with clays in contact with the infiltrating pond water.

The groundwater below the sediment pond has been altered in differing degrees. These alteration differences appear to be correlated with the degree of hydraulic connection between the pond and the sampling tubes. Wells or sampling tubes intersecting the gravels under the east side of the sediment pond have been more effected than those developed in silts and sands. This means that pie piezometers G and E show more alteration, i.e. higher concentrations of adulterants than do piezometers S_2 and C_2. Piezometers near the bedrock show the least amount of change of any of the wells (T and C_1). The lower alteration in the deep wells may be caused by more influence from bedrock discharge at the lower depths to which T and C_1 protrude. Piezometers E, G, and C_2 show increases in specific conductance from near 180 to 250 (as ppm NaCl) as the sediment pond became acid. C_1 increased accordingly from 225 to 300. The pH and alkalinities of all the wells around the pond except show very little change. This indicates that the acid waters are apparently neutralized very quickly after infiltration. The decrease in pH from 7.0 to 6.3 and alkalinity from 150 to 110 in well G illustrates the high hydraulic interconnection between it and the pond, and the associated lack of residence-reaction time needed for neutralization of the acid infiltrate to occur. The concentrations of chlorides in all piezometers around the pond increased dramatically as the pond went acid, however analysis showed the concentration of chloride in the pond to drop to zero after acidification. This may be due to an interference in the analysis or a change in the infiltrate water chemistry allowing it to carry more chloride. The chlorides in the wells went from less than 2.5 mg/l to greater than 5 mg/l of chloride as the level in the pond fell from 5 mg/l to 0 mg/l. Sulfate levels were very low for the shallower wells around the pond except in G. Sulfate in G dropped from 75 mg/l to 55 mg/l before the pond went acid, and then increased to 85 mg/l in the nine months after pond acidification. A similar trend was observed in C_1 and partially in T before it became plugged with sediment.

Iron presents a very interesting history during mining. Initial total iron concentrations for all well around the pond were well below 1 mg/l. After pond acidification the iron levels increased as much as 60 times their original concentrations. Wells E and G responded most quickly to the iron increase with C_1 and C_2 lagging from one to two months. The iron levels in all the wells around the sediment pond except E tended to reach a peak iron concentration after pond acidification and then decline sharply. E has shown several peaks which may be caused by infiltration from South Coal Creek which is only 25 feet away.

Most of the iron influx can be contributed to ferrous iron. In wells at the mine not located near the pond the iron present is mostly ferric iron. This suggests that a more strongly reducing enviroment was created by the infiltrating pond water. For wells near the sediment pond ferrous iron accounted for from 90 to 100 percent of the total iron, while the highest ferrous to total ratio away from the pond is 40 percent with all others less than 20 percent ferrous iron. The high ferrous iron content of the groundwater occurs in wells 9a and S_2 which suggests that the groundwater can move quite a distance without attenuation of the ferrous iron.

Noncarbonate hardness values for the sediment pond wells are zero except in G. The noncarbonate hardness in G fluctuates between zero and thirty milligrams per liter due again to the connection with the pond. The alkalinities in all the pond piezometers except G are usually much higher than the hardness value which suggest that in the neutralization of the acid pond water bicarbonate from sources other than calcite and dolomite is pulled into solution or the metal ions are being selectively removed by cation exchange in the clays of the flood plain. The latter is probably the better supposition since this phenomenon was observed before the pond went acid and because little increase in bicarbonate have been observed. This indicates that in the cation exchange other cations could be coming into solution. Possible candidates are sodium and perhaps potassium. Phosphate could also cause an interference in the alkalinity determinations and give erroneously high alkalinity values. Many shales contain phosphates and the shale storage pile and the mine cut areas could be sources.

In summarizing the effects of acid pond water on the groundwater it can be seen that a giant acid-base titration is occurring. Sulfuric and other mineral acids generated by by pyrite oxidation are being neutralized by the bicarbonate in the groundwater alkalinity. As can be seen from the presented data, well G is the only area where the acid pond water is not being neutralized before it gets substantially into the groundwater.(firures 22-26).

Another major area of groundwater quality [illegible] is the spoil-fill areas of the reclaimed mine cuts. This area is interesting, because few if any field research data have been published on the groundwater effects of simul-

Figure 22: Groundwater Ferrous-Total Iron Ratio

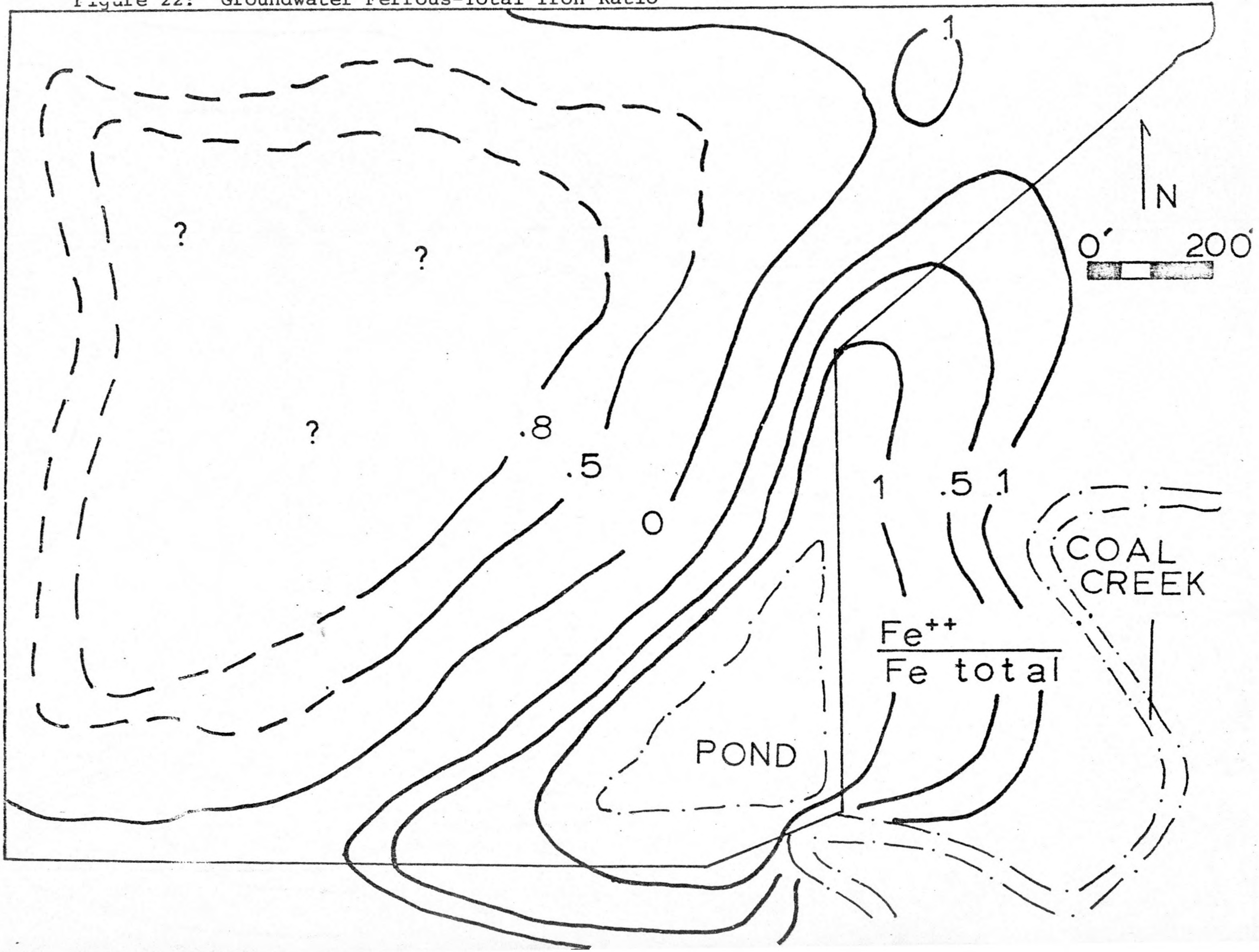
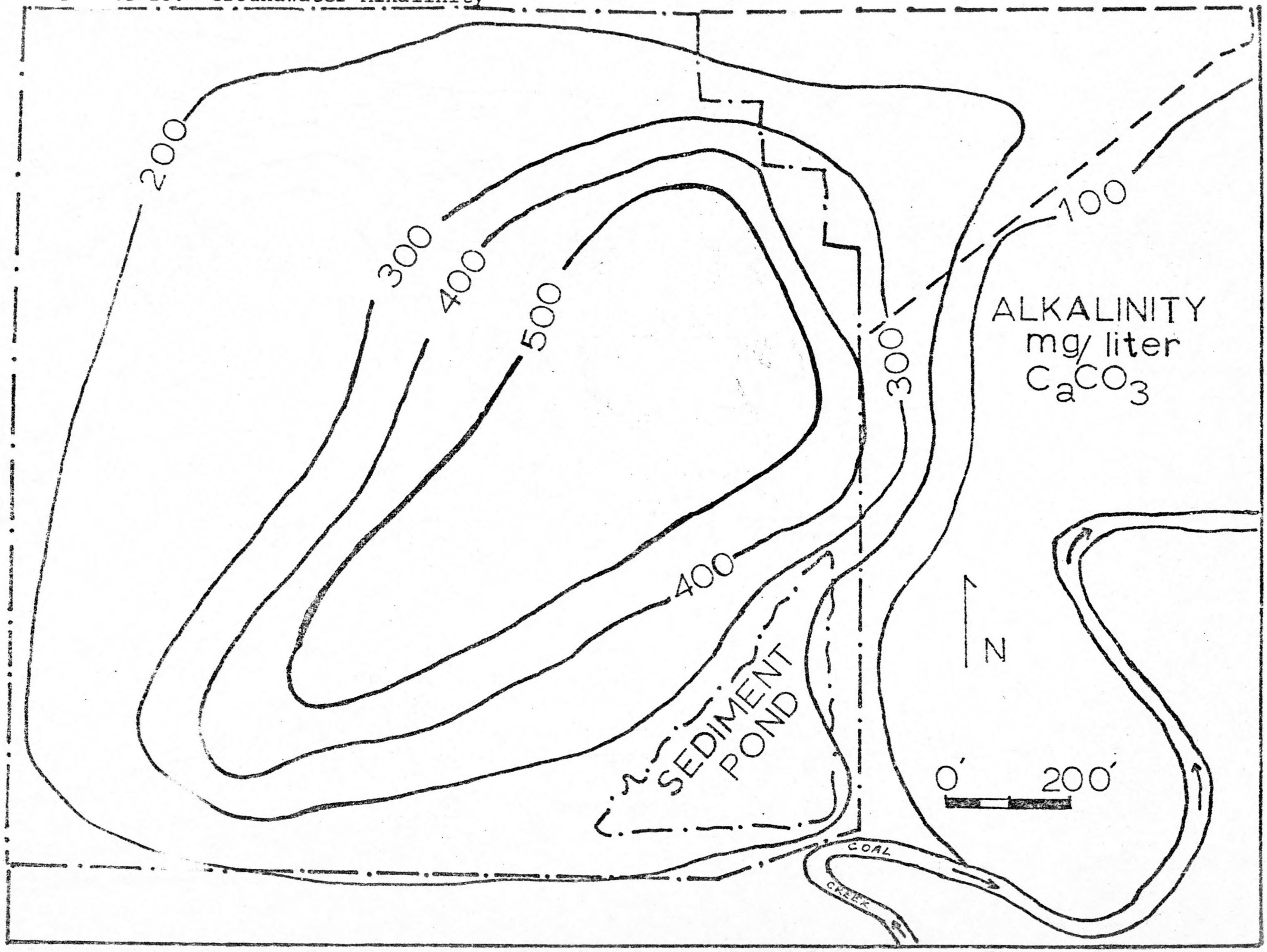
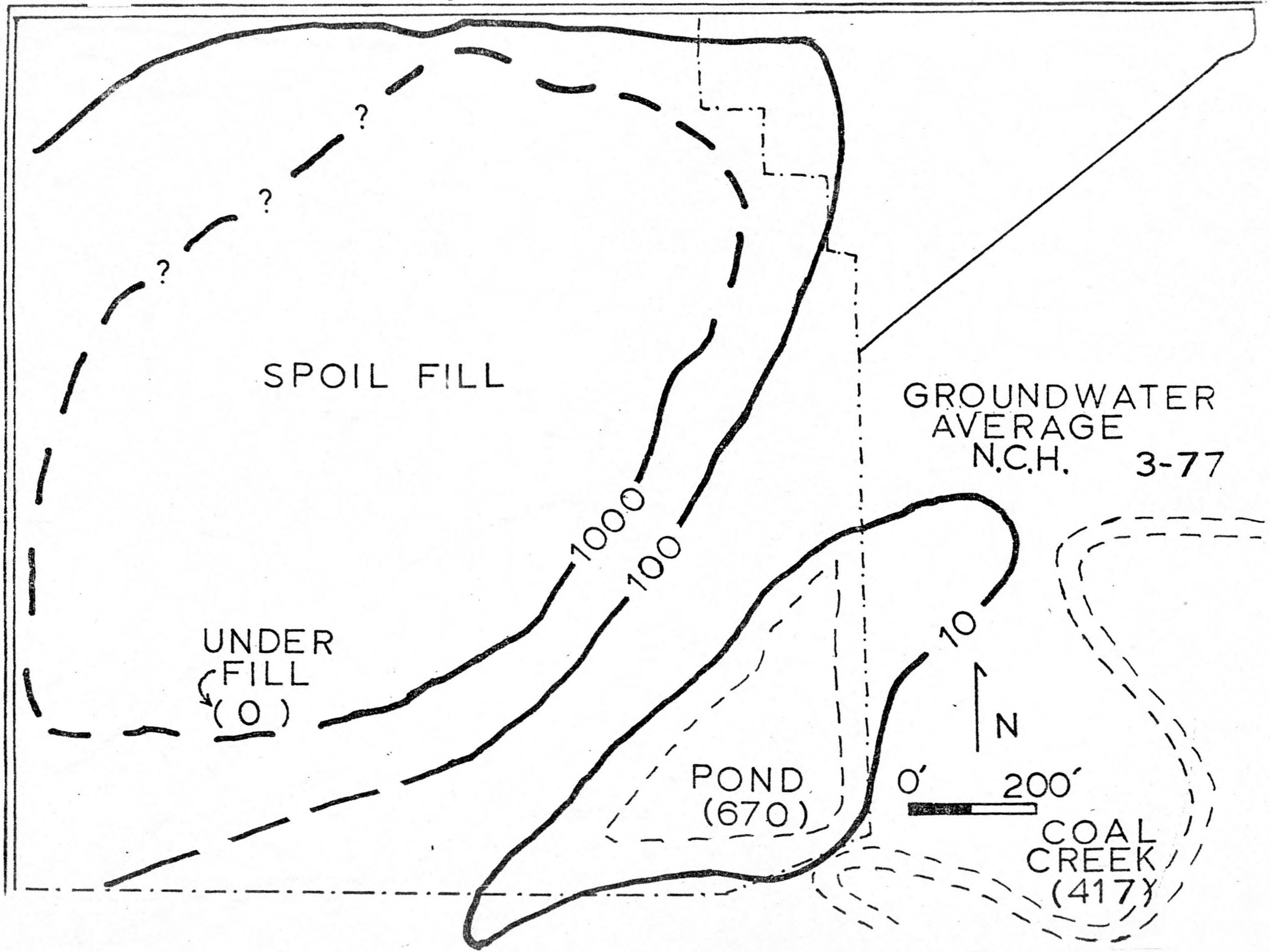


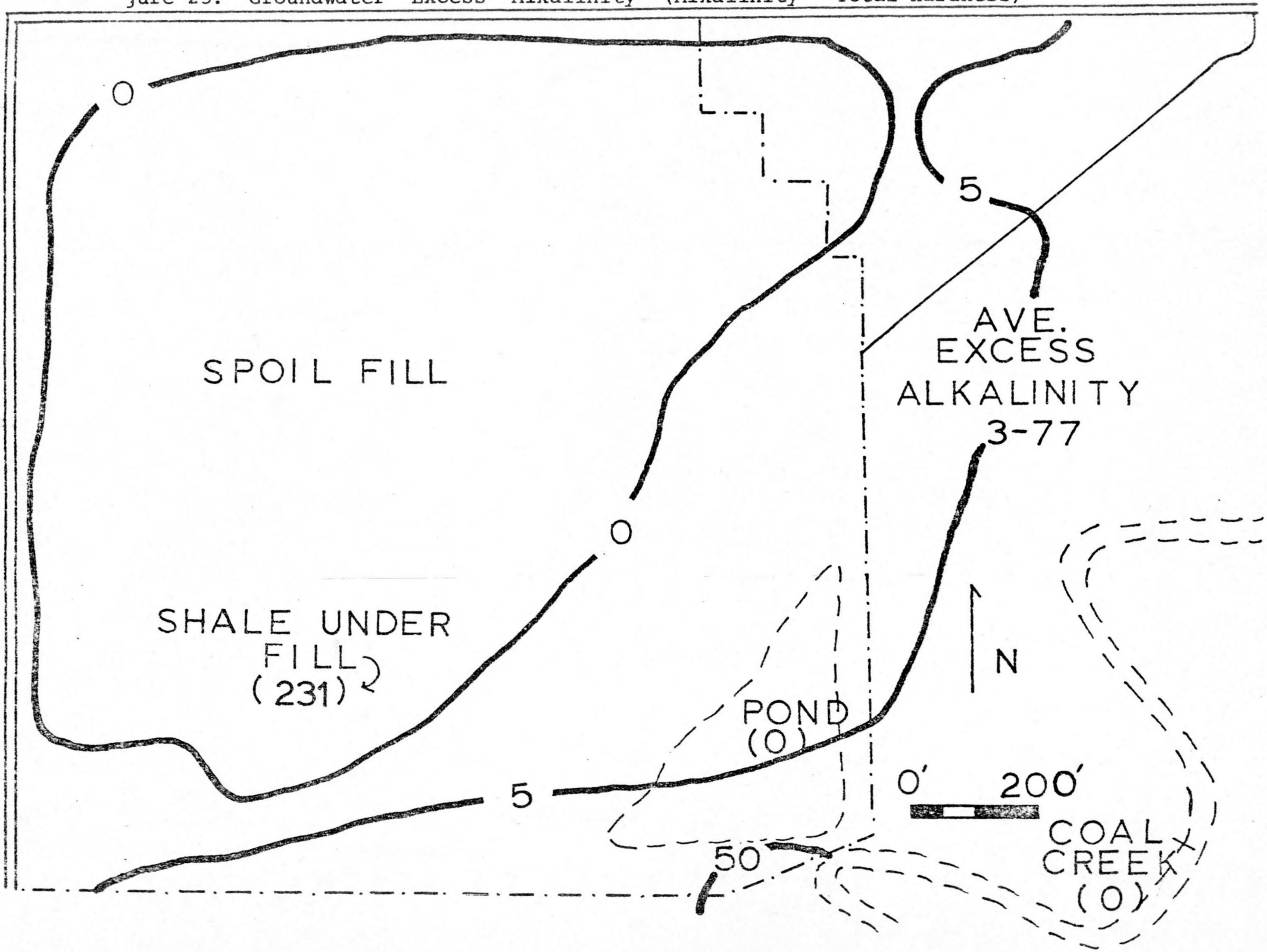
Figure 23: Groundwater Alkalinity



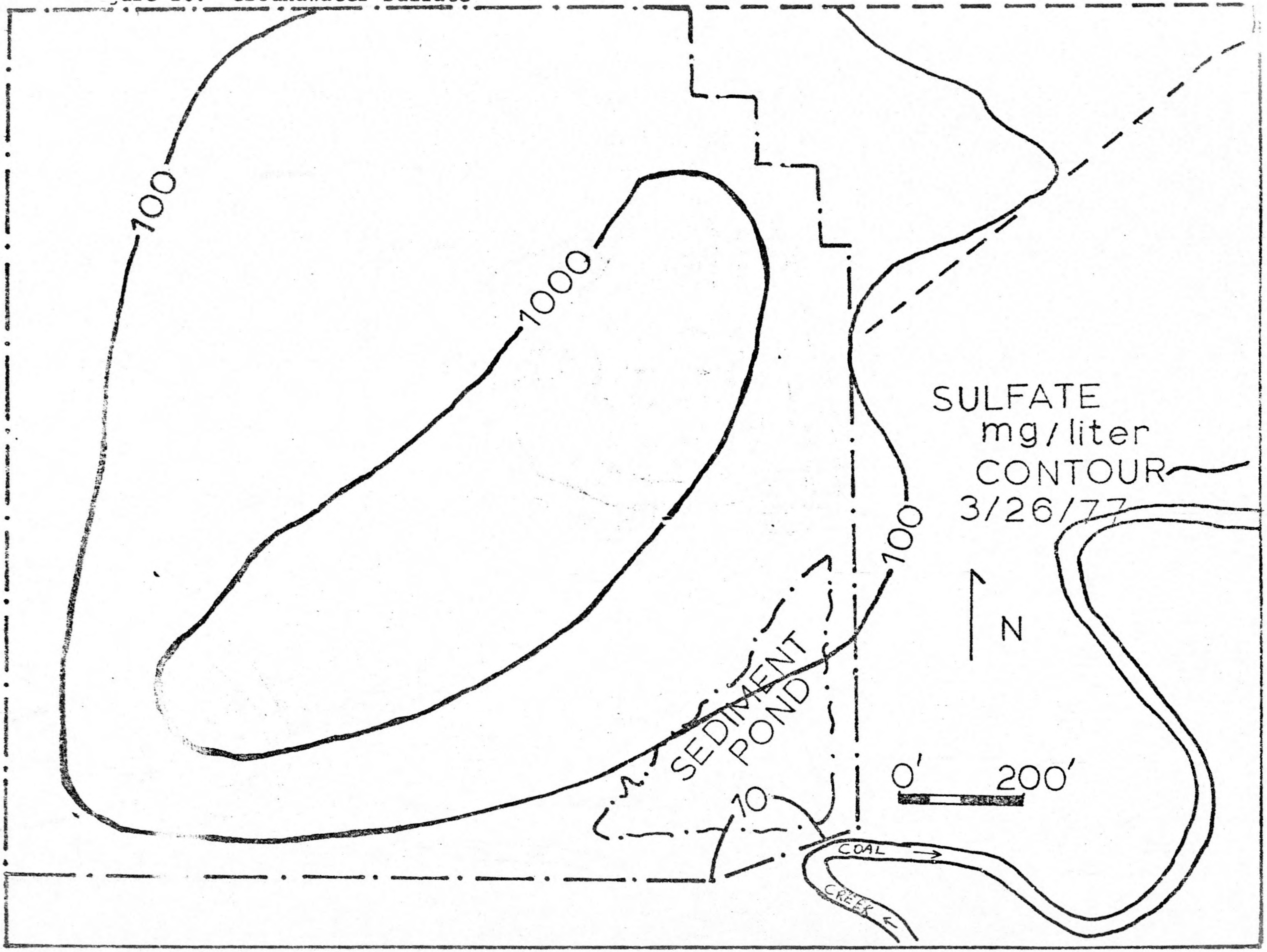
I re 24: Groundwater Average Noncarbonate Hardness



gure 25: Groundwater "Excess" Alkalinity (Alkalinity - Total Hardness)



ure 26: Groundwater Sulfate



taneous stripmining and reclamation. Laboratory leaching studies have been widely conducted to estimate the water quality of groundwater in contact with acid spoil, but no documented studies have been found on acid-spoil reclamation in the field (Ahmad, 1970, Shumate and Brant, 1971, and Pietz, Peterson, and Lue-Hing, 1974). The leaching studies indicate that the first water that moves into the spoil will be very mineralized, but can be flushed out by subsequent water movement. This has been shown to be the case in the western coal fields by the Montana Bureau of Mines (Van Voast, Hedges, and McDermott, 1976). It is not clear if reclamation of any type was carried out on the Montana spoil which is of a non-acidic type.

At ICP#1 the fill water quality is being monitored at the present time by six piezometers. Unfortunately only three of the wells have yielded enough water for analysis, and one of the wells is actually a bedrock backround well. The piezometers monitoring the fill areas include nests 5 and 7. Wells 5b, 5c, 7a, 7b, and 7c are open to the base of the shale fill. Well 5a is open in the bedrock just below the bedrock-shale fill contact.

The head conditions in well 5a are such that two to three feet of water are standing above the shale fill-bedrock contact. This head condition has changed very little since the piezometer was placed. This head condition also explains the reason for the small zone of resaturation in the replaced fill. The low head is very near the pre-mining condition as far as can be determined.

The initial water quality samples from piezometer 5a can be used as typical of the bedrock shale below the mine. Since sampling and bailing of the well have occured it appears to have pulled some of the more mineralized water down from the reclaimed fill. Over a nine month period values for specific conductance, pH, alkalinity, and "excess" bicarbonate (i.e. alkalinity - total hardness) have increased from about 400, 7.1, 400, and 125 to about 525, 7.6, 500, and 275 respectively. Sulfate, nitrate-nitrogen, and total hardness have simultaneously decreased from near 125, 0.6, and 280 to 80, 0.2, and 180. The total iron has been found to contain about 40% ferrous iron. These conditions in general appear to be analogous to the infiltration of acid pond waters, but to a lesser degree. This is seen in the moderately high ferrous iron content, the rising total iron, the increased specific conductance, and the increasing "excess" bicarbonate. As was previously mentioned the increased mineralization is due to downward movement of the water at the base of the shale fill as bailing and sampling occur.

In contrast to the relatively "clean" water in 5a the quality of the groundwater sampled from 7a and 7c are quite "poor". These two piezometers tap waters that appear to be the groundwater analog of buried mine pit water. Piezometer 7a is the only one of the set that has been monitored for a very long period of time, nine months. It was placed in July 1976 at the same time as 5a. The initial water quality observed is as follows:

specific conductance	2100
pH	6.6
alkalinity	430
sulfate	500-1400
total iron	2
total hardness	1600
noncarbonate hardness	1200.

The high sulfate, total hardness, and noncarbonate hardness are all in ranges similar to those found in the mine pit waters during mining and in the pond water tested. The explanation for the highly mineralized waters is that they are in fact the buried remnants of acid mine pit waters. The alkalinity is high because the acid waters from the mine pits have been neutralized by groundwater flowing up from the bedrock shales. Another possible source of the highly mineralized waters could be a break through in a drainage tube draining an acid pond on the surface of the spoil. This tube is a few hundred feet away leaving some doubt as to whether the polluted water could travel such a distance in the rather tight spoil materials. The best explanation seems to be the in situ formation of the mineralized water as acid mine pit water with subsequent burial and alkalinity increase as the fill became resaturated with water from the bed rock below.

As piezometer 7a was sampled there was an increasing influence put on its water quality by less mineralized groundwater from the undisturbed shales below. This is illustrated by decreasing specific conductance and increasing alkalinities to 1500 and about 500 repectively. This is another evidence that flow from the broken drainage tubing is not contributing to the mineralized water condition at this point. Also other parameters appear to have peaked and then dropped. These chemical parameters are:

	(peak value)	(most recent)
Sulfate	2100	1500
Nitrate-Nitrogen	1.55	0.3
Total Iron	4.0	2.5
Total Hardness	2130	1850
Noncarbonate Hardness	1630	1360

The ferrous iron content of 7a is near 80% of the total iron. This also correlates well with water influenced by mining in the sediment pond, surface puddles in mine cuts, and the groundwater around the sediment pond.

A secondary area of groundwater quality interest is the area of dewatering up gradient of the mine. The two major water bearing strata in this location are the upper coal and the sands and gravels above it. These aquifers appear to be separated by a few feet of shale, but evidence exists for their hydraulic connection. The chemical data received from piezometers 4, M, and Q help illustrate this point.

First, the water quality of piezometer M will be summarized. The water quality of piezometer M will act as a reference when looking at that of the coal seam. The specific conductance at M is inversely correlated with the precipitation at the mine indicating a rather quick infiltration and dilution effect in the groundwater. The specific conductance fluctuated between 200 and 375 for the period of study. A rough increase is also seen from about 340 to 375 for most of the data. The increase in specific conductance can possibly be tied to the scarcity of dilution water as the well lost three feet of head due to mining.

The pH of M remained around 7.0 for the entire study with slightly lower values observed during the initial rainfall periods of early spring and late winter. Chloride concentrations fluctuate rather wildly between 2 and 10 mg/l. Sulfate, alkalinity, nitrate-nitrogen, total hardness, and noncarbonate hardness all fluctuate consistantly with the change in water level, and have the following average values respectively: 168, 160, 2.1, 388, 179. The cause for the emphasized relationship between rainfall and water level in piezometer M can be seen from examining its topographic setting. M is located at the base of a semi-circular drainage. This waterway is also blocked by a road just to the north of M that may slow the surface drainage enough to increase infiltration. A examination of the geologic materials at this well show that just below the surface there are coarse sands and some gravel. These materials would be very conducive to rapid infiltration. M was developed in these sands and gravel.

Piezometer Q is open to about 35 feet of siltstones, shale, the upper coal seam and the sand and gravel body. The sands, gravel, and coal seam are probably the major water contributors in this section. As previously mentioned the coal seam is the most permeable of the two strata supplying water to Q. This would indicate that before the coal was dewatered it should contribute the largest portion of water to Q. As the coal is dewatered more rapidly than the sands and gravels the piezometer would take on the water quality characteristics of the sands and gravels and be similar in chemical composition to water in well M. The head in well Q should also reflect the piezometric head of the coal seam better than any of the other strata, because of the low permeability of materials below the upper coal, and because of the lower permeability of the sands and gravels and the tendency for the coal to drain any water higher than its base as long as it is open to mining.

The previous set of condition were very well illustrated by the water quality data contributed by Q. Untill the upper coal seam was opened the water quality of Q was significantly different from that observed in

M. The water quality before mining was characterized by relatively low specific conductance (150-200), chloride (3.3-5.0), alkalinity (50-100), sulfate (70-80), nitrate-nitrogen (0.2-1.2), total hardness (150-200), and noncarbonate hardness (100). As the coal seam was breached it was drained and partially recharged by the sands and gravels. At this time the water in Q became more influenced by the more mineralized waters of the sands and gravels. This influence is illustrated by the close correspondence between Q and M after September 1976. The contribution of significant amounts of water from the sands and gravels increased the water quality parameters by 2 to 5 times their original levels before the coal was disturbed. It should be noted that the water in the coal prior to mining was of good quality in the parameters tested and that as the mining cut was filled the recharge from the sands and gravels into the coal seam greatly reduced its quality.

A different sequence of events was observed in piezometer number 4. This well open to the upper coal and some shale above it, was placed into the upper coal at a time after mining effects had begun. The water initially tested was more similar to the mineralized water of the sands and gravels. Just prior to the drying up of the well the water quality became [illegible] better. This may have been due to a slower movement of the water allowing the coal to better "treat" or remove impurities from the water. Another possibility exists also. At the site of well 4 the sands and gravels are much "cleaner" i.e. they have less silt, clay, and alluvium mixed in with them. This may allow for a higher permiability of the sands and gravels at 4 than at M. This would allow the water to be drained rather rapidly from both the coal and the sands and gravels at 4. The waters in the sands and gravels would tend to drain out through the coals first, because of their higher head condition above the seepage face than the coal waters. This situation fits the data very well as can be seen by the more mineralized water analyzed in the two months immediately following the placement of 4, and the much cleaner water analyzed just before piezometer 4 went dry.

Selected Data from Piezometer #4

	7/16/76	8/11/76	9/12/76
Specific Conductance	420	233	225
Chloride	8.0	7.0	5.0
Alkalinity	316	269	135
Total Hardness	380	300	155
Calcium Hardness	265	215	60
Noncarbonate Hardness	64	31	20
Water Depth	39.6	40.3	42.1
Sulfate	115	69	82

The last specific area of water quality monitoring significance is at the northeast side of the site on spoil cored terraces built above the water table. The purpose of monitoring these terraces is to detect water quality changes due to infiltration of waters that may pick up oxidation products of pyrite

abundant in some of the spoil under the terraces. Monitoring was also to detect water table configuration changes due to an altered infiltration pattern caused by the terraces. No significant water quality or flow changes that could be attributed to mining were observed. The shale cores of the terraces remained unsaturated after one year of placement as proven during piezometer placement drilling in March of 1977.

A significant impact of another sort was detected. This was caused by the situation of a farm feedlot on the site previous to mining. High concentrations of chloride, nitrate, and manganese were observed at various wells in this location that are attributable to the feedlot environment.

Summary and Conclusions

The effects of stripmining on the groundwater at ICP#1 can be classified as primarily a water quality or a water quantity effect, although they do overlap. The water quantity effects of ICP#1 stripmining are:

1.) The loss of groundwater saturation in materials that were initially removed from over the coal, and then replaced;

2.) The dewatering of high permeability geologic strata or aquifers up gradient of the mining area;

3.) The increase in porosity and possible reduction of permeability in spoiled materials;

4.) The change in groundwater gradients in mined out areas and near sediment pond;

The water quality effects of ICP#1 stripmining and reclamation are:

1.) The generation of slightly mineralized and possibly acid enclaves near sediment pond and spoil accumulations.

2.) The generation of thin zones of highly mineralized water near the base of reclaimed spoil due mostly to remnant acid mine water.

3.) Reduction of water quality in coal seam "aquifers" as a result of dewatering at time of mining and subsequent recharge by more mineralized waters.

Most effects of water quantity loss in and around the mine are not permanent. Recharge in aquifers outside the ICP#1 site have begun initial recharge as indicated in piezometer Q. Unfortunatly this recharge ia being pirated from shallower aquifers, but the shallower aquifers are more directly susceptible to infiltration from surface waters. The recharge of the reclaimed mine area and surrounding aquifers will come from areas near the mine that have not been disturbed to a major extent by surface mining. Coal spoil materials to the west of ICP#1 may also contribute valuable recharge waters. Major recharge areas around the ICP#1 site include the undisturbed hill to the northwest, north, and northeast of the mine cut area. The major recharge conduits are the unmined portions of the coal seams and the sands and gravels of the undisturbed surrounding hillsides. Secondary recharge sources appear to be the bedrock below and in the highwalls of the reclaimed portion of the mine cuts and surface infiltration.

An indirect effect of mining is the groundwater mound built by the sediment retention pond. This mound changed the groundwater flow in parts of this area from southeast to west in groundwater west of the sediment pond. The mound generated was significant enough to move pond-mineralized waters in the opposite direction of groundwater flow.

The source of the enclave was water infiltrating from the acid sediment retention pond. Characteristics of the enclave include widespread high ferrous iron, elevated specific conductances, and higher hardness and chlorides. Reduced pH and alkalinity were observed in very restricted areas near the east side of the sediment pond. It is very doubtful that the enclave produced by the sediment pond will have a significant effect on the groundwater environment, because of the low level of mineralization. The mineralized areas of the mine pits on the other hand may be sources of groundwater alteration on a larger scale if the contaminants can move through the shale bedrock or get flushed into flood plain sediments. If these zones infiltrate into the upper portions of the St. Louis the limestones found there may provide routes for regional contamination to the Des Moines river (figure 6). At present the possibilities of this type of regional contamination seem remote, but possible contaminants are metals, hardness, and sulfate.

The loss of permeability indicated in piezometers 5a and 7a, as well as the porosity increase are more permanent water quantity effects caused by stripmining. at ICP#1. The decreased permeability will not be a major problem, because the bedrock of which the spoil is made did not have a high permeability previous to mining. Thus it can be seen that the permeability change is not a large effect, but a rather relative one. The increase of porsity may be beneficial in recharging more surficial aqui-fers but the contribution may be slight.

Water quality disturbances of the fringe areas of the reclaimed spoil areas will be very slow in attenuating, because of the slow groundwater flow through these materials. Areas of thicker spoil and larger potential water level increases are believed to have better water quality, because of dilution as larger quantities of water will return to these areas.

Adultered groundwaters in high permeability areas such as flood plain alluvium will be more quickly attenuated than those in the mine spoil areas, but these enclaves also have a potential to effect much larger areas due to more rapid movement. At ICP#1 a slightly mineralized enclave exists in the flood plain groundwater to the southeast, south, and southwest of the mine.

Recomendations for Further Study

Continued study is needed to establish attenuation rates on the minor enclave introduced by acid water from the sediment pond. Similar work is also needed to study the mineralization and the recharge of the groundwater in the spoil reclamation areas. Further studies will confirm the abilities of surrounding geologic materals to provide recharge water flow to mined and reclaimed fill.

More complete chemical analyses are needed to identify cations that seem to be replacing calcium and magnesium around the sediment pond, and more complete in situ permeabilities should be obtained.

An interesting possibility for Iowa miners in the treatment of acid mine runoff exists in the use of sediment ponds. Sediment ponds could be built to treat acid waters by infiltration into the neutralizing sediments of stream flood plains. Experience at ICP#1 shows that while small enclaves are formed the mineralization is low and preferable to surface acid drainage. It was also noted that certain small wells used in the area for domestic water supplies had higher mineral concentrations than did the enclave waters around the sediment pond. Study is needed to see if it would be economic to pond a significant portion of a sites runoff water for treatment by this method.

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APPENDIX

sample location	3" auger hole	1.5" PVC casing	7" auger hole	2" PVC casing	3' gator screen	2' gator screen	3' drilled screen	5' drilled screen	3' gravel pack	5' gravel pack	bentonite backfill	4" core hole	30" bored well	completion depth	surface elevation
S_2	X	X			X				X		X			20	710.8
T	X	X					X		X		X			33	707.2
C_1	X	X					X		X		X			33	702.6
C_2	X	X					X		X		X			22	702.5
E	X	X					X		X		X			21	700.9
G	X	X					X		X		X			24	700.3
9	X	X			X				X		X			25	711.6
1a			X	X				X		X	X			20	714.4
1b			X	X	X					X	X			25	714.0
1c			X	X	X					X	X			15	714.0
1d			X	X	X					X	X			29	726.0
2a			X	X				X		X	X			35	735.5
2b			X	X	X					X	X			35	725.8
2c			X	X	X					X	X			25	725.7
2d			X	X	X					X	X			25	735.8
3			X	X				X		X	X			23	736.4
K	X	X					X		X		X			34	742.9
Hyd													X	20	
M	X	X					X		X		X			17	771.8
Q				X				X			X	X		39	769.4
4			X	X				X		X	X			43	800.1
8	X	X			X				X		X			25	726.9
5a			X	X				X		X	X			43	733.0
5b			X	X	X					X	X			40	738.7
5c			X	X	X					X	X			43	739.6
6			X	X				X		X	X			18	734.5
7a			X	X				X		X	X			34	734.4
7b			X	X	X					X	X			30	733.5
7c			X	X	X					X	X			34	736.4
Cem			X	X	saw slotted					X	X			48	806.6

WELL DEVELOPMENT PROCEDURE

Cumulative Precipitation
Between
Sampling Intervals

Date of Sampling	Cumulative Precipitation (inches)
10/02/75	2.82
11/04/75	0.60
12/07/75	3.81
01/10/76	0.53
02/07/76	0.00
03/04/76	1.32
04/03/76	3.49
05/01/76	6.24
06/03/76	4.87
07/16/76	9.74
08/17/76	5.11
09/12/76	0.72
10/10/76	2.89
11/23/76	0.64
01/16/77	0.00
02/11/77	0.00
03/26/77	3.09 (incomplete)

WATER QUALITY DATA

Specific Conductance as ppm NaCl
pH as -log (H^+)
Chloride as mg/l Cl^-
Alkalinity as mg/l $CaCO_3$
Total, Calcium, and Magnesium Hardness as mg/l $CaCO_3$
Sulfate as mg/l $SO_4^=$
Nitrate as Nitrate-Nitrogen mg/l N
Total Iron as mg/l Total Fe
Water depth in feet
Temperature in degrees Celsius

SAMPLE LOCATION Piez T

SAMPLE DATE	8/ 8/75	8/30/75	10/ 2/75	11/ 4/75	12/ 7/75	11/10/76	2/ 7/76	3/ 4/76	4/ 3/76	5/ 1/76	6/ 3/76	7/16/76	8/11/76	9/12/76	10/10/76	11/23/76
CHEMICAL ANALYSIS																
SPECIFIC CONDUCTANCE	180	170	245	225	250	270	310	250	250	260	240					
pH	8.6	7.6	7.6	7.5	8.3	8.3	8.2	8.1	8.8	8.2	7.6					
CHLORIDE	4	3	5	9.5	3.5	2.5	3.0	3.0	1.9	7.5	6.5					
ALKALINITY	100	170	265	270	230	245	220	260	300	270	282					
SULFATE	100	39	39	14	15	5	20	13	5	9	5					
NITRATE	***	***	***	***	4.4	.88	2.2	.6		.11	.54					
TOTAL IRON	***	.5	.5	.15	.15	1.5	2.35	1.0	1.3	.62	.7					
CHEMICAL OXYGEN DEMAND	246		74.7	21.6	21	14.4										
TOTAL HARDNESS as mg/l $CaCO_3$	200	160	220	370	300	280	160	270	230	210	205					
CALCIUM HARDNESS as mg/l $CaCO_3$	100	100	140	130	125	135	100	135	150	100	134					
MAGNESIUM HARDNESS as mg/l $CaCO_3$	100	60	80	240	75	145	60	135	80	110	71					
WATER DEPTH	14	13	12	14	15	13	17.6	17.8	17.5	18.4	18.5					
TEMPERATURE °C	17	17	15	14	11.1	10	11.1	9.4	14.5	15	11					

SAMPLE LOCATION: piez. C_1

SAMPLE DATE	8/ 8/75	8/30/75	10/ 2/75	11/ 4/75	12/ 7/75	1/10/76	2/ 7/76	3/ 4/76	4/ 3/76	5/ 1/76	6/ 3/76	7/16/76	8/11/76	9/12/76	10/10/76	11/23/76
CHEMICAL ANALYSIS																
SPECIFIC CONDUCTANCE	110	125	215	---	---	190	210	175	160	140	200	305	210	250	245	275
pH	8.9	8.5	7.0	7.1	---	7.3	7.5	7.6	7.6	7.2	7.1	7.4	7.6	---	7.2	7.4
CHLORIDE	6.0	7.0	5.0	---	---	3.0	2.5	3.0	3.8	7.5	5.0	7.0	8.0	5.0	5.0	5.0
ALKALINITY	90	160	220	---	---	200	210	220	170	190	216	291	248	205	220	255
SULFATE	30.5	17.0	65.0	---	---	25.0	1.0	2.0	7.0	10.0	9.5	32.5	41.0	44.0	62.0	56.0
NITRATE	****	****	****	----	----	2.30	2.20	0.60	---	0.11	0.59	0.50	0.24	2.10	1.70	1.15
TOTAL IRON	21.0	0.4	0.5	----	----	1.0	1.6	1.1	2.0	2.5	5.5	0.2	18.0	----	10.0	6.0
CHEMICAL OXYGEN DEMAND	135.0	-----	-----	-----	-----	-----	13.1	13.5	13.7	9.3	42.7	-----	26.4	-----	15.0	-----
TOTAL HARDNESS as mg/l $CaCO_3$	100	120	220	---	---	160	175	150	150	150	173	200	240	150	260	230
CALCIUM HARDNESS as mg/l $CaCO_3$	60	90	140	---	---	110	120	100	100	100	122	144	155	70	90	140
MAGNESIUM HARDNESS as mg/l $CaCO_3$	40	30	80	---	---	50	55	50	50	50	51	56	85	80	170	90
WATER DEPTH	9.0	14.0	14.5	14.0	15.5	13.0	12.0	12.8	13.0	12.8	8.5	6.0	9.8	15.8	15.0	14.8
TEMPERATURE °C	17	15	16	14	11	10	11	9	11	12	11	12	13	11	14	12

SAMPLE LOCATION

SAMPLE DATE

C_1	1/16/77	2/11/77	3/26/77	4/17/77	5/24/77	6/26/77
CHEMICAL ANALYSIS						
SPECIFIC CONDUCTANCE	330	250	265			
pH	7.8	7.6	8.5	7.5		
CHLORIDE	5.0	5.0	4.0			
ALKALINITY	250	275	240			
SULFATE	47	85	42			
NITRATE	0.4	0.65	0.7			
TOTAL IRON	1.2	5.0	1.5	4.0		
CHEMICAL OXYGEN DEMAND	---	---	---	46.8		
TOTAL HARDNESS as mg/l $CaCO_3$	230	200	215			
CALCIUM HARDNESS as mg/l $CaCO_3$	160	150	150			
MAGNESIUM HARDNESS as mg/l $CaCO_3$	70	50	65			
WATER DEPTH	14.0	15.3	14.4	10.4		
TEMPERATURE °C	8	10	11	10		

SAMPLE LOCATION: piez. C_2 SAMPLE DATE

	8/ 8/75	8/30/75	10/ 2/75	11/ 4/75	12/ 7/75	1/10/76	2/ 7/76	3/ 4/76	4/ 3/76	5/ 1/76	6/ 3/76	7/16/76	8/11/76	9/12/76	10/10/76	11/23/76
CHEMICAL ANALYSIS																
SPECIFIC CONDUCTANCE	110	70	115	175	175	170	170	165	170	190	200	230	135	200	175	200
pH	8.7	9.0	7.6	7.3	7.1	7.5	7.5	7.2	7.2	7.1	7.1	7.0	7.2	---	7.1	7.1
CHLORIDE	2.5	2.5	3.0	7.5	1.5	1.5	1.5	2.0	1.9	2.5	4.5	5.0	6.0	5.0	5.0	5.0
ALKALINITY	135	100	160	195	200	210	200	215	210	230	222	156	208	205	200	210
SULFATE	12.6	7.0	9.0	14.0	4.0	1.0	1.0	1.0	3.0	0.0	1.5	1.0	3.0	3.0	1.0	2.0
NITRATE	****	****	****	****	5.70	3.00	4.00	1.50	----	0.22	0.59	0.63	0.12	0.95	1.25	0.90
TOTAL IRON	5.0	0.3	0.1	0.6	1.6	1.5	2.8	0.8	1.9	3.3	5.5	1.4	14.0	---	6.0	4.0
CHEMICAL OXYGEN DEMAND	353.0	----	62.6	20.6	15.0	7.5	19.0	23.3	26.2	22.7	30.6	----	18.6	15.0	15.0	----
TOTAL HARDNESS as mg/l $CaCO_3$	100	140	170	170	175	165	152	150	155	155	77	145	160	130	160	150
CALCIUM HARDNESS as mg/l $CaCO_3$	60	90	110	140	140	130	110	110	115	110	63	102	111	100	100	100
MAGNESIUM HARDNESS as mg/l $CaCO_3$	40	50	60	30	35	35	42	40	40	45	14	43	49	30	60	50
WATER DEPTH	10.0	9.0	9.0	7.0	6.0	6.0	7.3	6.0	5.0	2.3	2.3	4.2	6.8	7.9	7.8	7.0
TEMPERATURE °C	16	15	16	14	11	9	7	8	12	12	11	12	14	14	14	12

SAMPLE LOCATION	SAMPLE DATE					
C_2	1/16/77	2/11/77	3/26/77	4/17/77	5/24/77	6/26/77
CHEMICAL ANALYSIS						
SPECIFIC CONDUCTANCE	240	190	215			
pH	7.2	6.8	7.1	7.0		
CHLORIDE	5.0	5.0	4.0			
ALKALINITY	210	205	200			
SULFATE	3	5	6			
NITRATE	---	0.7	1.0			
TOTAL IRON	3.0	3.5	6.0	6.0		
CHEMICAL OXYGEN DEMAND	---	---	---	20.6		
TOTAL HARDNESS as mg/l $CaCO_3$	180	150	150			
CALCIUM HARDNESS as mg/l $CaCO_3$	110	95	110			
MAGNESIUM HARDNESS as mg/l $CaCO_3$	70	55	40			
WATER DEPTH	7.3	7.5	5.8	8.0		
TEMPERATURE °C	8	10	10	8		

SAMPLE LOCATION: piez. E

	SAMPLE DATE															
	8/ 8/75	8/30/75	10/ 2/75	11/ 4/75	12/ 7/75	1/10/76	2/ 7/76	3/ 4/76	4/ 3/76	5/ 1/76	6/ 3/76	7/16/76	8/11/76	9/12/76	10/10/76	11/23/76
CHEMICAL ANALYSIS																
SPECIFIC CONDUCTANCE	190	190	110	175	170	175	180	155	160	155	200	235	140	200	185	200
pH	8.6	8.1	7.1	7.2	7.1	7.2	7.2	6.8	7.2	7.1	7.1	7.0	7.5	---	7.0	7.1
CHLORIDE	2.0	1.5	3.0	7.5	1.5	1.3	1.0	2.0	1.9	3.5	5.0	4.5	5.0	5.0	5.0	5.0
ALKALINITY	140	180	210	195	195	185	190	180	175	190	184	183	193	190	180	180
SULFATE	123.0	55.0	9.0	13.0	7.0	5.0	3.0	2.0	5.0	6.0	8.0	8.5	10.8	12.0	12.0	12.0
NITRATE	****	****	****	****	5.70	2.00	2.20	0.44	----	0.22	0.18	0.34	0.16	0.60	0.90	0.65
TOTAL IRON	2.0	---	0.1	0.1	1.1	4.0	3.0	7.0	13.0	11.3	8.5	5.7	14.0	---	5.0	2.5
CHEMICAL OXYGEN DEMAND	68.5	----	7.2	19.7	15.0	5.7	2.0	22.2	45.8	15.7	16.6	----	12.6	19.6	19.8	----
TOTAL HARDNESS as mg/l $CaCO_3$	260	200	180	170	165	165	155	150	155	150	168	155	167	150	145	150
CALCIUM HARDNESS as mg/l $CaCO_3$	180	150	140	140	135	140	113	110	110	115	115	114	100	100	110	110
MAGNESIUM HARDNESS as mg/l $CaCO_3$	80	50	40	30	30	25	42	40	45	35	53	41	67	50	35	40
WATER DEPTH	13.0	10.0	6.0	7.0	6.0	6.0	8.5	6.2	5.8	3.6	3.4	4.5	7.2	7.4	7.3	7.2
TEMPERATURE ^{o}C	15	16	17	15	11	10	10	9	9	11	12	13	16	--	15	13

SAMPLE LOCATION SAMPLE DATE

E

	1/16/77	2/11/77	3/26/77	4/17/77	5/24/77	6/26/77
CHEMICAL ANALYSIS						
SPECIFIC CONDUCTANCE	245	235	215			
pH	7.0	7.1	7.1	7.0		
CHLORIDE	5.0	5.0	3.5			
ALKALINITY	180	230	200			
SULFATE	19	21	20			
NITRATE	0.23	0.35	0.60			
TOTAL IRON	18.0	6.0	5.0	8.0		
CHEMICAL OXYGEN DEMAND	---	---	---	19.9		
TOTAL HARDNESS as mg/l $CaCO_3$	160	165	175			
CALCIUM HARDNESS as mg/l $CaCO_3$	105	115	130			
MAGNESIUM HARDNESS as mg/l $CaCO_3$	55	50	45			
WATER DEPTH	7.3	6.8	5.8	8.4		
TEMPERATURE °C	10	9	3	8		

SAMPLE LOCATION : Piez G

SAMPLE DATE

	8/ 8/75	8/30/75	10/ 2/75	11/ 4/75	12/ 7/75	11/10/76	2/ 7/76	3/ 4/76	4/ 3/76	5/ 1/76	6/ 3/76	7/16/76	8/11/76	9/12/76	10/10/76	11/23/76
CHEMICAL ANALYSIS																
SPECIFIC CONDUCTANCE	170	150	190	175	170		170	170	150	140	200	235	140	175	215	235
pH	8.5	8.0	8.1	7.2	6.8		6.7	6.2	6.6	6.1	6.8	6.6	6.5		6.8	6.9
CHLORIDE	5	5	1.5	10	3.5		2.5	3.0	3.8	3.5	6.0	6.0	6.0	5.0	5.0	5.0
ALKALINITY	120	140	150	140	140		150	100	100	130	114	122	121	125	140	110
SULFATE	81	70	90	73	70		65	55	70	65	56	57.5	61.0	72.0	70.0	75
NITRATE	***	***	***	***	4.4		.44	.22	***	.10	.20	.18	.14	.45	.35	.40
TOTAL IRON	15.0	.6	.1	.1	1.1		1.3	7.5	8.0	7.5	7.5	4.6	10		3.0	2.0
CHEMICAL OXYGEN DEMAND	465		11.3	9.1	13		55.	10	21.0	8.2	10.0		17.4	15.0	12.2	
TOTAL HARDNESS as mg/l CaCO$_3$	160	140	120	170	150		140	120	120	120	120	118	131	125	120	125
CALCIUM HARDNESS as mg/l CaCO$_3$	100	120	110	80	100	Well Frozen	100	90	90	90	93	84	100	90	100	100
MAGNESIUM HARDNESS as mg/l CaCO$_3$	60	20	20	90	50		40	30	30	30	27	34	31	35	20	25
WATER DEPTH	14.0	5.0	+1.0	+8"	+3'	+3'	-6'	+1	+1	+1	+1.25	+2.1	1.3'	1.6'	1'	1.1
TEMPERATURE ^{o}C	15	17	21	22	0	0	0	1.6	11	12	11.5	12	18		16	10

SAMPLE LOCATION	SAMPLE DATE					
G	1/16/77	2/11/77	3/26/77	4/17/77	5/24/77	6/26/77
CHEMICAL ANALYSIS						
SPECIFIC CONDUCTANCE	255	200	225			
pH	6.7	6.3	6.5	6.3		
CHLORIDE	7.5	5.0	5.0			
ALKALINITY	110	105	120			
SULFATE	75	82	84			
NITRATE	0.40	0.60	0.50			
TOTAL IRON	2.5	1.5	4.0	12.0		
CHEMICAL OXYGEN DEMAND	---	---	---	15.6		
TOTAL HARDNESS as mg/l $CaCO_3$	130	135	145			
CALCIUM HARDNESS as mg/l $CaCO_3$	95	100	110			
MAGNESIUM HARDNESS as mg/l $CaCO_3$	35	35	35			
WATER DEPTH	1.6	-1.4	0.7	-2.0		
TEMPERATURE °C	7	7	10	8		

SAMPLE LOCATION Piez K

SAMPLE DATE	CHEMICAL ANALYSIS	SPECIFIC CONDUCTANCE	pH	CHLORIDE	ALKALINITY	SULFATE	NITRATE	TOTAL IRON	CHEMICAL OXYGEN DEMAND	TOTAL HARDNESS as mg/l $CaCO_3$	CALCIUM HARDNESS as mg/l $CaCO_3$	MAGNESIUM HARDNESS as mg/l $CaCO_3$	WATER DEPTH	TEMPERATURE ^oC
8/ 8/75						157		2					15	17
8/30/75		165	8.1	5	120	140	***	.6		246	194	52	15	17
10/ 2/75		300	7.7	12	200	190	***	.5	41.8	340	250	90	12	18
11/ 4/75			7.5						32				14.5	15
12/ 7/75													15	11.6
11/10/76		280	7.9	2.0	210	190	1.0	.3	4.5	300	230	70	15	10
2/ 7/76													14.5	10.5
3/ 4/76		270	8.3	4.0	230	70	.88	.25	35.7	260	185	75	16	9.4
4/ 3/76			8.0	9.4	255	35		1.8		290	190	100	16	13.5
5/ 1/76				4.0	160	42				190	130	60	16	12
6/ 3/76													10' pipe added	
7/16/76													28.2	
8/11/76		252		8.0	140	180	.12			366	250	116		
9/12/76														
10/10/76		415	<4.3	5.0	0	380	.20	1.0	48.8	367	258	109	26	15
11/23/76		50	6.9	5.0	110	190	.20	8.0		330	230	100	26.7	12

SAMPLE LOCATION SAMPLE DATE

K	1/16/77	2/11/77	3/26/77	4/17/77	5/24/77	6/26/77
CHEMICAL ANALYSIS						
SPECIFIC CONDUCTANCE	370	325	365			
pH	6.8	7.1	7.0	7.0		
CHLORIDE	6	5	5			
ALKALINITY	180	180	175			
SULFATE	155	162	165			
NITRATE	0.35	0.35	0.35			
TOTAL IRON	2.0	4.5	3.5	2.0		
CHEMICAL OXYGEN DEMAND	---	---	---	41.1		
TOTAL HARDNESS as mg/l $CaCO_3$	310	320	315			
CALCIUM HARDNESS as mg/l $CaCO_3$	230	230	240			
MAGNESIUM HARDNESS as mg/l $CaCO_3$	80	90	75			
WATER DEPTH	25.7	27.4	26.8	26.7		
TEMPERATURE °C	10	10	13			

SAMPLE LOCATION Piez M

SAMPLE DATE	CHEMICAL ANALYSIS												
	SPECIFIC CONDUCTANCE	pH	CHLORIDE	ALKALINITY	SULFATE	NITRATE	TOTAL IRON	CHEMICAL OXYGEN DEMAND	TOTAL HARDNESS as mg/1 $CaCO_3$	CALCIUM HARDNESS as mg/1 $CaCO_3$	MAGNESIUM HARDNESS as mg/1 $CaCO_3$	WATER DEPTH	TEMPERATURE ^oC
8/ 8/75	250	8.7	5	80	190	***	1	425	280	200	80	10	17
8/30/75	205	8.6	6	85	175	***	.1		266	184	82	9	17
10/ 2/75	110	7.2	6	126	190	***	***	13.6	280	190	90	9.5	16
11/ 4/75	325	7.3	10	175	190	***	.4	5.7	320	250	70	9.5	14
12/ 7/75	330	6.9	3.0	195	190	20.7	.25	7	320	230	90	9	11.4
11/10/76	325	7.2	2.3	185	190	13.3	.75	3.1	375	260	115	10	8.8
2/ 7/76	350	7.0	2.0	200	200	9.0	1.4	6.0	350	295	55	10.2	10
3/ 4/76	350	6.5	2.0	190	190	9.9	.25	28.4	390	270	120	10.3	8.9
4/ 3/76	325	7.0	3.8	200	160		.20	30.2	390	250	140	9.8	12
5/ 1/76	200	7.0	6.3	115	100	2.2	1.3	10.0	212	135	77	6.5	11
6/ 3/76	275	7.1	8.5	79	86	.75	.6	17.9	313	135	178	8.5	12
7/16/76	350	7.3	5.5	126	145	2.1	.68		340	220	120	8.3	13.5
8/11/76	225	7.0	7.0	169	128	1.76	1.5	19.0	336	232	104	9.1	15
9/12/76	325		5.0	175	180	2.5		15.0	340	170	170	9.8	
10/10/76	390	7.2	5.0	200	165	2.25	.15	19.5	380	250	130	10.8	17
11/23/76	345	7.2	10	160	165	2	1.0		350	240	110	11.4	14

SAMPLE LOCATION SAMPLE DATE

M

CHEMICAL ANALYSIS	1/16/77	2/11/77	3/26/77	4/17/77	5/24/77	6/26/77
SPECIFIC CONDUCTANCE	430	375	375			
pH	7.3	7.0	6.7	7.0		
CHLORIDE	6.7	5.0	4.0			
ALKALINITY	230	200	130			
SULFATE	170	190	180			
NITRATE	0.30	1.70	1.75			
TOTAL IRON	0.45	0.25	2.5	2.5		
CHEMICAL OXYGEN DEMAND	---	---	---	28.6		
TOTAL HARDNESS as mg/l $CaCO_3$	430	410	345			
CALCIUM HARDNESS as mg/l $CaCO_3$	305	290	260			
MAGNESIUM HARDNESS as mg/l $CaCO_3$	125	120	85			
WATER DEPTH	12.0	12.6	12.3	12.3		
TEMPERATURE °C	8	10	10	10		

SAMPLE LOCATION Piez Q

SAMPLE DATE	8/ 8/75	8/30/75	10/ 2/75	11/ 4/75	12/ 7/75	11/10/76	2/ 7/76	3/ 4/76	4/ 3/76	5/ 1/76	6/ 3/76	7/16/76	8/11/76	9/12/76	10/10/76	11/23/76
CHEMICAL ANALYSIS																
SPECIFIC CONDUCTANCE										150	175	230	175	125	315	235
pH										6.7	7.1	7.2	7.5		7.6	7.5
CHLORIDE										3.5	5.0	5.0	8.0	5.0	3.0	5.0
ALKALINITY										55	88	79	136	130	190	180
SULFATE										70	77.5	74.0	87.0	28.0	125	125
NITRATE										1.1	.23	.31	.26	.50	0.75	0.65
TOTAL IRON										2.0	.15	.32	.9		0.1	1.0
CHEMICAL OXYGEN DEMAND										8.4	9.4		10.3	16.0	5.1	
TOTAL HARDNESS as mg/l $CaCO_3$										155	184	174	209	210	285	350
CALCIUM HARDNESS as mg/l $CaCO_3$										100	120	122	154	140	195	195
MAGNESIUM HARDNESS as mg/l $CaCO_3$										55	64	52	55	60	90	155
WATER DEPTH										10.1	11.5	5.4	8.6	17.4	8.8	11.4
TEMPERATURE ^oC										11	11	14	16		16	14

SAMPLE LOCATION	SAMPLE DATE					
Q	1/16/77	2/11/77	3/26/77	4/17/77	5/24/77	6/26/77
CHEMICAL ANALYSIS						
SPECIFIC CONDUCTANCE	420	300	400			
pH	7.5	7.7	7.5	7.3		
CHLORIDE	7.5	7.5	4.0			
ALKALINITY	200	300	250			
SULFATE	160	135	170			
NITRATE	0.45	0.55	0.40			
TOTAL IRON	0.1	0.1	0.5	0.7		
CHEMICAL OXYGEN DEMAND	---	---	---	14.9		
TOTAL HARDNESS as mg/l $CaCO_3$	320	320	370			
CALCIUM HARDNESS as mg/l $CaCO_3$	255	250	260			
MAGNESIUM HARDNESS as mg/l $CaCO_3$	65	70	110			
WATER DEPTH	22.8	25.3	26.3	19.8		
TEMPERATURE °C	9	9	13			

SAMPLE LOCATION 4	8/ 8/75	8/30/75	10/ 2/75	11/ 4/75	12/ 7/75	11/10/76	2/ 7/76	3/ 4/76	4/ 3/76	5/ 1/76	6/ 3/76	7/16/76	8/11/76	9/12/76	10/10/76	11/23/76
CHEMICAL ANALYSIS																
SPECIFIC CONDUCTANCE												420	233	225		
pH												---	7.3	---		
CLORIDE												8.0	7.0	5.0		
ALKALINITY												316	269	135		
SULFATE												115	69	82		
NITRATE												0.90	0.98	1.00		
TOTAL IRON												0.75	---	---		
CHEMICAL OXYGEN DEMAND												---	13.6	---		
TOTAL HARDNESS as mg/l $CaCO_3$												380	300	155		
CALCIUM HARDNESS as mg/l $CaCO_3$												265	215	60		
MAGNESIUM HARDNESS as mg/l $CaCO_3$												115	85	95		
WATER DEPTH												39.6	40.3	----	42.1	
TEMPERATURE °C												--	12	--		

SAMPLE LOCATION Piez 1a SAMPLE DATE

	8/ 8/75	8/30/75	10/ 2/75	11/ 4/75	12/ 7/75	11/10/76	2/ 7/76	3/ 4/76	4/ 3/76	5/ 1/76	6/ 3/76	7/16/76	8/11/76	9/12/76	10/10/76	11/23/76
CHEMICAL ANALYSIS																
SPECIFIC CONDUCTANCE												230	120	200	215	225
pH												7.2	7.1	7.1	7.1	7.2
CHLORIDE												6.0	7.5	5.0	5.0	5.0
ALKALINITY												140	130	130	135	130
SULFATE												34.0	34.0	46.0	49.0	74
NITRATE												.37	1.59	1.60	3.4	3.35
TOTAL IRON												.40	.50		1.0	0.1
CHEMICAL OXYGEN DEMAND													7.41	7.0	7.6	
TOTAL HARDNESS as mg/l $CaCO_3$												160	257	90	180	170
CALCIUM HARDNESS as mg/l $CaCO_3$												114	103	65	120	105
MAGNESIUM HARDNESS as mg/l $CaCO_3$												46	154	25	60	65
WATER DEPTH												3.3	3.2	4.5	4	5.7
TEMPERATURE °C												13	18		17	14

SAMPLE LOCATION	SAMPLE DATE					
1a	1/16/77	2/11/77	3/26/77	4/17/77	5/24/77	6/26/77
CHEMICAL ANALYSIS						
SPECIFIC CONDUCTANCE	270	220	190			
pH	7.1	7.0	6.6	6.6		
CHLORIDE	5.0	5.0	7.5			
ALKALINITY	150	150	100			
SULFATE	47	54	49			
NITRATE	3.40	3.45	3.6			
TOTAL IRON	0.2	0.3	1.8	0.7		
CHEMICAL OXYGEN DEMAND	---	---	---	10.2		
TOTAL HARDNESS as mg/l $CaCO_3$	210	205	160			
CALCIUM HARDNESS as mg/l $CaCO_3$	140	125	100			
MAGNESIUM HARDNESS as mg/l $CaCO_3$	70	80	60			
WATER DEPTH	7.3	7.3	3.8	3.8		
TEMPERATURE °C	8	10	9			

SAMPLE LOCATION Piez 2a SAMPLE DATE

	8/ 8/75	8/30/75	10/ 2/75	11/ 4/75	12/ 7/75	11/10/76	2/ 7/76	3/ 4/76	4/ 3/76	5/ 1/76	6/ 3/76	7/16/76	8/11/76	9/12/76	10/10/76	11/23/76
CHEMICAL ANALYSIS																
SPECIFIC CONDUCTANCE												330	243	225	375	375
pH												8.3	7.5	7.5	7.5	7.4
CHLORIDE												9.0	6.5	5.0	7.5	5.0
ALKALINITY												236	302	320	335	290
SULFATE												92	72	45	85	94
NITRATE												.22	.11	.65	.55	.4
TOTAL IRON												2.4	1.0		0.3	0.1
CHEMICAL OXYGEN DEMAND													9.15	11.0	6.3	
TOTAL HARDNESS as mg/l $CaCO_3$												285	341	270	290	320
CALCIUM HARDNESS as mg/l $CaCO_3$												208	260	150	265	215
MAGNESIUM HARDNESS as mg/l $CaCO_3$												77	81	120	25	105
WATER DEPTH												18.7	20.6	19.7	18.8	19.9
TEMPERATURE °C												11	12		14	13

SAMPLE LOCATION	SAMPLE DATE					
2a	1/16/77	2/11/77	3/26/77	4/17/77	5/24/77	6/26/77
CHEMICAL ANALYSIS						
SPECIFIC CONDUCTANCE	405	390	400			
pH	7.6	7.3	7.5	7.5		
CHLORIDE	5.0	5.0	5.0			
ALKALINITY	360	400	330			
SULFATE	103	96	86			
NITRATE	0.45	0.40	0.40			
TOTAL IRON	0.15	0.25	0.3	0.5		
CHEMICAL OXYGEN DEMAND	---	---	---	8.5		
TOTAL HARDNESS as mg/l $CaCO_3$	370	380	340			
CALCIUM HARDNESS as mg/l $CaCO_3$	285	285	300			
MAGNESIUM HARDNESS as mg/l $CaCO_3$	85	95	40			
WATER DEPTH	20.8	21.3	23.3	22.0		
TEMPERATURE °C	10	9	12			

SAMPLE LOCATION Piez 3a

SAMPLE DATE

	8/ 8/75	8/30/75	10/ 2/75	11/ 4/75	12/ 7/75	11/10/76	2/ 7/76	3/ 4/76	4/ 3/76	5/ 1/76	6/ 3/76	7/16/76	8/11/76	9/12/76	10/10/76	11/23/76
CHEMICAL ANALYSIS																
SPECIFIC CONDUCTANCE												325	140	265	225	215
pH												7.2	6.7	6.8	6.8	6.9
CHLORIDE												5.5	6.0	5.0	5.0	5.0
ALKALINITY												152	154	90	160	155
SULFATE												105	54	110	48	53
NITRATE												.19	.18	.60	.50	.25
TOTAL IRON												.15	2.0		0.2	0.1
CHEMICAL OXYGEN DEMAND													7.09	6.0	5.4	
TOTAL HARDNESS as mg/l $CaCO_3$												212	152	195	150	210
CALCIUM HARDNESS as mg/l $CaCO_3$												143	96	120	100	100
MAGNESIUM HARDNESS as mg/l $CaCO_3$												69	56	75	50	110
WATER DEPTH												9.4	7.8	9.9	9.6	10.9
TEMPERATURE °C												12	16		15	13

SAMPLE LOCATION 3a

SAMPLE DATE

CHEMICAL ANALYSIS	1/16/77	2/11/77	3/26/77	4/17/77	5/24/77	6/26/77
SPECIFIC CONDUCTANCE	250	210	215			
pH	6.8	6.8	6.6	6.6		
CHLORIDE	6.0	5.0	4.0			
ALKALINITY	150	155	150			
SULFATE	51	62	78			
NITRATE	0.05	0.55	0.30			
TOTAL IRON	0.20	0.45	0.20	1.00		
CHEMICAL OXYGEN DEMAND	---	---	---	11.4		
TOTAL HARDNESS as mg/l $CaCO_3$	160	160	180			
CALCIUM HARDNESS as mg/l $CaCO_3$	105	110	105			
MAGNESIUM HARDNESS as mg/l $CaCO_3$	55	50	75			
WATER DEPTH	11.8	11.6	10.0	10.5		
TEMPERATURE °C	8	10	9			

SAMPLE LOCATION Piez 5a

SAMPLE DATE

	8/ 8/75	8/30/75	10/ 2/75	11/ 4/75	12/ 7/75	11/10/76	2/ 7/76	3/ 4/76	4/ 3/76	5/ 1/76	6/ 3/76	7/16/76	8/11/76	9/12/76	10/10/76	11/23/76
CHEMICAL ANALYSIS																
SPECIFIC CONDUCTANCE												465	345	525	415	450
pH													7.1	7.1	7.3	7.2
CHLORIDE												7.5	7.0	7.5	7.5	7.5
ALKALINITY												371	452	385	450	470
SULFATE												120	90.5	125	95	100
NITRATE												.60	.11	.50	.10	.2
TOTAL IRON												.05	1.0		.1	.2
CHEMICAL OXYGEN DEMAND													41.7	13	41.4	
TOTAL HARDNESS as mg/l $CaCO_3$												264	282	125	235	200
CALCIUM HARDNESS as mg/l $CaCO_3$												202	195	65	158	140
MAGNESIUM HARDNESS as mg/l $CaCO_3$												62	87	60	77	60
WATER DEPTH												33.5	33.1	34.5	32.5	32.8
TEMPERATURE °C												9	8	11		13

SAMPLE LOCATION 5a CHEMICAL ANALYSIS	1/16/77	2/11/77	3/26/77	4/17/77	5/24/77	6/26/77
SPECIFIC CONDUCTANCE	510	525	425			
pH	7.6	7.2	7.6	7.5		
CHLORIDE	7.5	12.5	2.5			
ALKALINITY	480	500	430			
SULFATE	86	94	78			
NITRATE	0.2	0.3	0.2			
TOTAL IRON	0.35	0.45	0.50	1.50		
CHEMICAL OXYGEN DEMAND	---	---	---	59.4		
TOTAL HARDNESS as mg/l $CaCO_3$	190	210	180			
CALCIUM HARDNESS as mg/l $CaCO_3$	145	145	130			
MAGNESIUM HARDNESS as mg/l $CaCO_3$	45	65	50			
WATER DEPTH	32.2	31.8	30.8	30.9		
TEMPERATURE °C	8	8	9	9		

SAMPLE DATE

SAMPLE LOCATION Piez 7_a SAMPLE DATE

	8/ 8/75	8/30/75	10/ 2/75	11/ 4/75	12/ 7/75	11/10/76	2/ 7/76	3/ 4/76	4/ 3/76	5/ 1/76	6/ 3/76	7/16/76	8/11/76	10/ 2/76	10/10/76	11/23/76
CHEMICAL ANALYSIS																
SPECIFIC CONDUCTANCE														2100	1700	2000
pH														6.6	6.7	
CHLORIDE														5.0	7.5	5.0
ALKALINITY														430	470	490
SULFATE														500	1350	950
NITRATE															.20	.18
TOTAL IRON															2.1	
CHEMICAL OXYGEN DEMAND															22.6	
TOTAL HARDNESS as mg/l $CaCO_3$														1650	1600	1860
CALCIUM HARDNESS as mg/l $CaCO_3$														1200	1160	1310
MAGNESIUM HARDNESS as mg/l $CaCO_3$														450	440	550
WATER DEPTH														31.5	31.5	31.8
TEMPERATURE °C														8		13

SAMPLE LOCATION	SAMPLE DATE					
7a	1/16/77	2/11/77	3/26/77	4/17/77	5/24/77	6/26/77
CHEMICAL ANALYSIS						
SPECIFIC CONDUCTANCE	1635	1800	1500			
pH	6.6	6.7	6.5	6.5		
CHLORIDE	7.5	5.0	3.5			
ALKALINITY	500	450	490			
SULFATE	1200	2100	1200			
NITRATE	0.70	1.55	0.30			
TOTAL IRON	2.5	0.7	4.0	3.5		
CHEMICAL OXYGEN DEMAND	---	---	---	65.0		
TOTAL HARDNESS as mg/l $CaCO_3$	2130	1850	1850			
CALCIUM HARDNESS as mg/l $CaCO_3$	1460	1400	1300			
MAGNESIUM HARDNESS as mg/l $CaCO_3$	670	450	550			
WATER DEPTH	31.5	32.6	31.3	31.8		
TEMPERATURE °C	8	8	12	13		

SAMPLE LOCATION	SAMPLE DATE															
SEDIMENT POND	8/ 8/75	8/30/75	10/ 2/75	11/ 4/75	12/ 7/75	11/10/76	2/ 7/76	3/ 4/76	4/ 3/76	5/ 1/76	6/ 3/76	7/16/76	8/11/76	9/12/76	10/10/76	11/23/76
CHEMICAL ANALYSIS																
SPECIFIC CONDUCTANCE								110	---	210	410	590	665	1500	1600	----
pH								7.6	7.5	6.1	5.7	4.3	4.2	4.1	4.0	<5.5
CHLORIDE								2.0	1.9	2.0	5.0	4.5	0.0	0.0	0.0	---
ALKALINITY								10	15	0	0	0	0	0	0	--
SULFATE								85	90	160	180	340	740	1100	1100	----
NITRATE								0.5	---	0.5	0.69	0.89	4.65	4.9	3.7	---
TOTAL IRON								0.3	0.35	0.50	----	4.60	18.0	---	6.0	2.5
CHEMICAL OXYGEN DEMAND								---	---	---	---	---	---	---	---	---
TOTAL HARDNESS as mg/l $CaCO_3$								90	110	210	270	455	800	1045	900	--
CALCIUM HARDNESS as mg/l $CaCO_3$								60	70	140	182	315	520	625	600	--
MAGNESIUM HARDNESS as mg/l $CaCO_3$								30	40	70	88	140	280	420	300	--
WATER DEPTH																
TEMPERATURE °C								-	-	17	27	28	23	-	16	-

SAMPLE LOCATION	SAMPLE DATE					
sediment pond	1/16/77	2/11/77	3/26/77	4/17/77	5/24/77	6/26/77
CHEMICAL ANALYSIS						
SPECIFIC CONDUCTANCE	1500	1300	850			
pH	<4.0	<4.0	<4.0			
CHLORIDE	0.0	---	6.0			
ALKALINITY	0	0	0			
SULFATE	1650	1800	725			
NITRATE	0.50	1.55	0.50			
TOTAL IRON	5.0	3.8	5.5			
CHEMICAL OXYGEN DEMAND	---	---	---			
TOTAL HARDNESS as mg/l $CaCO_3$	1950	1125	900			
CALCIUM HARDNESS as mg/l $CaCO_3$	1240	800	625			
MAGNESIUM HARDNESS as mg/l $CaCO_3$	710	325	275			
WATER DEPTH						
TEMPERATURE °C	0	2	12			

SAMPLE LOCATION	SAMPLE DATE					
bottom mine cut	04/03/76	05/01/76	06/03/76	07/16/76	10/09/76	03/26/77
CHEMICAL ANALYSIS						
SPECIFIC CONDUCTANCE	---	1100	600	660	---	1300
CHLORIDE	1.9	17.8	14.0	2.5	0.0	22.5
ALKALINITY	25	15	84	0	0	140
NITRATE	--	.9	3.	.3	.9	2.5
TOTAL IRON	0.1	0.8	0.35	4.5	---	0.2
SULFATE	310	1000	280	425	750	940
TOTAL HARDNESS as mg/l $CaCO_3$	395	1480	372	610	900	800
CALCIUM HARDNESS as mg/l $CaCO_3$	350	980	288	452	600	600
MAGNESIUM HARDNESS as mg/l $CaCO_3$	45	500	84	158	300	200
pH	8.5	8.1	9.0	---	---	9.1
TEMPERATURE °C	--	--	31	29	22	18