STANCILL'S INC.
FURNACE BAY SITE
GROUNDWATER ASSESSMENT
AND MODELING REPORT

Prepared For:

Maryland Port Administration
The Maritime Center II
2310 Broening Highway
Baltimore, Maryland 21224-6621

Prepared By:

Maryland Environmental Service
2011 Commerce Park Drive
Annapolis, Maryland 21401

Volume 2 of 2

October 2002

APPENDIX B

Conceptual Geologic Report

CONCEPTUAL GEOLOGIC INTERPRETATION REPORT OF THE STANCILL QUARRY SITE, CECIL COUNTY, MARYLAND

Prepared for
Maryland Environmental Service
2011 Commerce Park Drive
Annapolis, MD 21401

September 2002

URS

URS Corporation
200 Orchard Ridge Drive, Suite 101
Gaithersburg, Maryland 20878
89-00000229.00
15294354.00100

TABLE OF CONTENTS

Table

Figures

TABLE OF CONTENTS

Appendix

APG	Aberdeen Proving Ground
BuB2	Butlertown silt loam
EvD	Evesboro loamy sand
ft/mi	feet per mile
gpm	gallons per minute
Gv	gravel and borrow pits
KCE	KCE Engineering, Inc.
Kp	Cretaceous age Potomac Deposits
KpB2	Keyport silt loam
MES	Maryland Environmental Service
MoB2	Matapeake silt loam
Mr	mixed alluvial land
Qal	Quaternary Alluvium
Qm	Quaternary Tidal Marsh Deposits
SaC2 and SaB2	Sassafras sandy loam
SPT	Standard Penetration Test
Tm	tidal marsh
URS	URS Corporation
USACE	United States Army Corps of Engineers
USCS	Unified Soil Classification System
WES	Waterways Experiment Station

Executive Summary

The Stancill Quarry, located southeast of the Fall Line within the Atlantic Coastal Plain Physiographic Province, is an active sand and gravel mine. The surface of basement rock in the area slopes toward the south and east. Local bedrock dip direction is to the south-southeast at approximately 100 feet per mile.

In the area of Stancill Quarry, three geologic units have been defined based on their age and physical properties: post-Cretaceous (Quaternary/Tertiary) stream-laid sediment, Cretaceous age non-marine sediments, and the underlying crystalline rock residuum, termed saprolite. Sediment thicknesses range up to 150 feet. The sediments consist of interbedded lenses and layers of silt, clay, sand, and gravel. The Cretaceous deposits and post-Cretaceous sediments are of relatively low permeability. They vary vertically and laterally to such an extent as to make them uncorrelatable over even short distances. The Fall Line, located north and west of the site, trends northeast-southwest.

Poorly consolidated Quaternary/Tertiary fluviatile deposits appear to have mantled the site prior to its development as a quarry, although most of these deposits have been removed by quarry operations. Saprolite appears to underlie the entire site. This low-permeability zone of saprolite tends to separate the surficial deposits of the Atlantic Coastal Plain from the underlying crystalline bedrock, which is the principal domestic water source in the vicinity of the quarry. The Cretaceous deposits between the Quaternary/Tertiary deposits and the saprolite were not encountered in all boreholes, suggesting that they were deeply eroded in Tertiary/Quaternary time.

This document presents the conceptual geologic interpretation of the Stancill Quarry and surrounding areas. This work was performed under URS Corporation (URS) Contract I.D. No. 02-07-06 with Maryland Environmental Service (MES). The Scope of Work includes the preparation of a Conceptual Geologic Model Report. This interpretation is based on the available data and discussions at several meetings with MES, Stancill Quarry representatives, and KCE Engineering, Inc. (KCE). This report has been reviewed by an Independent Technical Reviewer as part of URS' corporate Quality Assurance Program.

The purpose of conducting a geologic investigation, interpreting the geologic site characteristics, and preparing a geologic conceptual model of the Stancill Quarry site and surrounding areas is to construct a technical basis for a hydrogeologic conceptual model. The hydrogeologic conceptual model, or groundwater flow model, will be incorporated into scenarios for groundwater migration and used to estimate future concentrations, on a worst-case basis, to determine the impacts of dredge material placement on the local groundwater regime. The hydrogeologic conceptual model is described in a separate report.

This report is divided into eight sections plus a table, figures, and an appendix. The first section, the introduction, presents the contractual authority and basis for the study and report, and introduces the reader to the concepts to be presented. The second section presents an overview of the regional geology. A summary discussion of previous reports is presented in Section Three to form the basis for the present interpretation. The processes used to obtain the present interpretation, including examination of the boring logs included in Appendix A, are presented in Section Four. The conceptual geologic interpretation is then presented in detail in Section Five and is supplemented by a table and figures. The table and figures are provided at the end of the written text. Section Six presents conclusions based on what has been presented, Section Seven discusses the limitations of the study, and Section Eight lists the references used and reports cited.

The Stancill Quarry is located in the northeastern portion of Maryland not far from the Delaware and Pennsylvania borders (Figure 1). The site is located approximately 2 ½ miles east of Perryville, in Cecil County. Access to the site is from Mountain Hill Road. The site is surrounded by Long Creek and Amtrak train tracks (formerly Pennsylvania Railroad tracks) to the north, Mountain Hill Road and a wooded area to the east, a wooded area to the south, and Principio Creek and Furnace Bay to the west. The Chesapeake Bay and Carpenter Point are south of the site. The Stancill Quarry property occupies 130 acres on Carpenter Point Neck.

The Stancill Quarry is close to the boundary of two major geologic provinces, the Appalachian Piedmont province to the northwest and the Coastal Plain to the southeast. The Piedmont Province consists of metamorphosed sedimentary and igneous rocks of early Paleozoic and older ages that have been subjected to sufficient heat and pressure to cause recrystallization of the original rocks, resulting in what is termed a crystalline basement complex. The Coastal Plain consists of a southeast thickening wedge of sedimentary rocks, ranging in age from early Cretaceous to Recent, that overlap the southeastward dipping surface of the crystalline rocks of the Piedmont. The boundary between the Coastal Plain and the Piedmont is called the Fall Line because the gradients of the streams draining the hard rocks of the Piedmont flatten at the Coastal Plain boundary, resulting in rapids and waterfalls upstream of the Fall Line.

The Stancill Quarry site is in the Coastal Plain Physiographic Province, which is characterized by low-lying, gently rolling terrain. The Coastal Plain Physiographic Province is underlain by marine and non-marine sediments deposited on the eastern continuation of lithologies exposed in the Piedmont Crystalline Complex. The Piedmont Crystalline Complex consists of metamorphosed volcanic rocks and is bounded on the southeast by the Fall Line. The Coastal Plain is underlain by the downfaulted eastern extension of Piedmont rocks overlain by younger clays, silts, sands, and gravels. Transgressive and regressive seas and local streams created the Coastal Plain Physiographic Province by depositing layers of clay, silt, sand, and gravel. These interbedded layers form a wedge that begins at the Fall Line and thickens to the southeast. The Fall Line is the boundary between the crystalline metamorphic rocks of the Piedmont Plateau and the sedimentary units of the Atlantic Coastal Plain. The Fall Line lies about half a mile to the northwest of the Stancill Quarry site and roughly parallels US Route 40 and the Baltimore and Ohio railroad tracks.

The Coastal Plain sediments range in age from Cretaceous to Quaternary. The dip of the upper surface of the Piedmont Crystalline Complex basement rocks on average is 100 feet per mile (ft/mi) (Otton and Mandle, 1984), but can range from about 60 to about 150 ft/mi (Overbeck et al., 1958). The materials directly overlying the crystalline bedrock are weathered bedrock, or saprolite.

Variations over small distances, both laterally and vertically, in the lithology and texture of the Coastal Plain sediments are caused by the meandering nature of the streams (including downcutting during periods of marine regression) that deposited the sediments. Extremes in the fluctuation of sea level during late Cretaceous time, along with widespread erosion, explain the absence of stratigraphic units from some areas.

The sediments of the Coastal Plain dip eastward at a low angle, generally less than one degree, and range in age from Cretaceous to Quaternary. In general, younger formations crop out successively to the southeast across Southern Maryland. A thin layer of Quaternary silt, gravel, and sand covers the older formations throughout much of the area.

Mineral resources of the Coastal Plain are chiefly sand and gravel, and are used as aggregate materials by the construction industry. Clay for brick and other ceramic uses is also important. Small deposits of iron ore are of historical interest. Plentiful supplies of groundwater are available from a number of aquifers throughout much of the coastal plain. In addition, the Atlantic Continental Shelf contains abundant sand deposits, useful for beach restoration.

The Stancill Quarry is on the Atlantic Coastal Plain roughly ½ mile south of the Fall Line and is underlain, from the ground surface downward, by (1) undifferentiated stream-laid sediments of presumed late Tertiary and Quaternary age, (2) stream-laid continental deposits of the Potomac Group of Cretaceous age, and (3) weathered residuum and fresh crystalline basement rocks of the Appalachian Piedmont province. Residuum refers to the highly weathered bedrock, which is characterized by variable degrees of chemical weathering, resulting in less weathered structured saprolite and more highly weathered non-structured saprolite. The saprolite is underlain by fresh crystalline rock.

The Cretaceous deposits form a south to southeast dipping, truncated wedge-shaped mass, which rests on the eroded surface of the crystalline basement rocks and is overlain by less steeply dipping non-marine Tertiary/Quaternary deposits of the Potomac Group. Toward the Atlantic Ocean, the Tertiary and Cretaceous deposits grade into marine sediments that thicken rapidly down dip. At Chestertown, Maryland, about 25 miles south of the quarry, the top of the Cretaceous sediments are about 100 feet below sea level, and the base is about 1,400 feet below sea level.

Various earlier reports cited by Higgins and Conant (1990) have attempted to subdivide both the Cretaceous deposits and overlying Tertiary/Quaternary deposits of the Coastal Plain into formational units; however, the modern view (Higgins and Conant, 1990) is that these subdivisions have little validity, particularly in the area between Chesapeake Bay and the Fall Line. This report follows that philosophy, and no attempt is made to differentiate stratigraphic units within the Cretaceous rocks or the Tertiary/Quaternary deposits at the Stancill Quarry. However, the saprolite forms a distinct blanket covering the crystalline basement. This dense, clayey mantle has low permeability and serves to protect groundwater in the crystalline rocks, the main source of domestic water supply in the area, from contamination from surface sources.

2.1 CRYSTALLINE ROCKS

In the Stancill Quarry area, the crystalline basement complex rocks consist of metamorphosed volcanic rocks, chiefly interlayered quartz amphibolite and gneiss, designated the James Run Formation by Higgins and Conant (1990). The James Run Formation is believed to be of Paleozoic age, although it may also include Precambrian rocks.

At the Stancill Quarry, the crystalline metamorphic rocks are capped by a blanket of variable thickness consisting of a residuum formed in place by long-term surface weathering of the crystalline basement rock. This residuum (saprolite) is the residue left in place after the more soluble iron and magnesium-rich minerals of the metamorphic rocks have been altered to clay minerals by the physical and chemical processes of weathering.

In the weathering process, the more soluble minerals are converted into clay minerals, and the saprolite forms a tough, dense silty clayey zone of low permeability. Saprolite commonly ranges from unstructured clayey silt near the upper surface to a clayey decomposed rock, retaining the structure of the parent rock with increasing depth until finally grading into fresh, unweathered rock. Saprolite will typically retain some of the structure of the parent rock, but the fractures that form water-yielding channels in underlying fresh rock are blocked by clay and silt in saprolite. The surface of the underlying crystalline basement rocks is irregular and slopes to the south and southeast at about 60 to 150 ft/mi.

The water-bearing properties of rock depend on the number, size, shape, and distribution of openings (e.g., pores, partings, or fractures). In the crystalline rocks beneath the Atlantic Coastal

Plain, the openings are of two types: primary, formed at the same time as the rock, and secondary, formed later. Primary openings in the crystalline rocks of the Piedmont Crystalline Complex are less than 1% of the total volume, and therefore have little effect on the storage and movement of groundwater. Secondary porosity represents openings formed by dynamic earth forces resulting in fractures, joints, and faults, and openings formed by physical weathering. Fractures, joints, and faults are the main conduits of water to wells in the quarry vicinity.

Weathering includes both physical and chemical processes. The physical processes break down rock by expansion and contraction during temperature changes and by enlargement of cracks by wedging. Chemical weathering mainly involves breakdown of unstable minerals to more stable clay minerals through solution and precipitation. Rock weathering to clay and silt size minerals forms a saprolite typically more porous than the parent material, but generally of low permeability. In Cecil County, the weathered zone ranges from 0 to 150 feet in thickness and averages 48 feet (Overbeck and Slaughter, 1958, p. 28).

Yields of wells tapping crystalline rocks in Cecil County average about 11 gallons per minute (gpm), which is small for municipal and industrial supplies, but adequate for residential use (Overbeck and Slaughter, 1958, p. 29). The main geologic features bearing on well yields are rock type, degree and extent of fracturing, topography, and weathering. Overbeck and Slaughter (1958, p. 30) report that rock type (which influences fracture porosity) is a major influence on well yields, with contact zones and granodiorite producing the highest yield (12 and 14 gpm, respectively), and serpentine and schist having the lowest yields (8 and 7 gpm, respectively). Topography also plays a significant role in well yield, with wells at higher elevations usually yielding less than those on lower slopes and valley bottoms.

Although the saprolite of the weathered zone plays an important role in storing groundwater and feeding recharge to the fracture systems in the crystalline rocks over broad areas, the saprolite generally is of low permeability, and therefore does not provide adequate water supplies to wells.

2.2 CRETACEOUS DEPOSITS

The Cretaceous deposits consist of discontinuous beds and lenses of unconsolidated clay, silt, sand, and gravel. Clay and sandy clay are the most abundant materials, sand is fairly abundant, and gravel least abundant. The clays are generally light colored - white, yellowish, pink, or red. Where clay contains considerable organic matter, it is dark gray. The sand is mainly fine grained, and white, yellowish or brown in color. Sands at places are firmly cemented with brown iron oxide. Gravel is present chiefly as scattered, rounded pebbles in sand or sandy clay.

The Cretaceous deposits form a southeasterly dipping wedge thickening to the southeast. The upper surface slopes about 60 ft/mi and the basal surface slopes about 160 ft/mi, resulting in thickening of about 100 ft/mi down dip (Overbeck and Slaughter, 1958, p. 41).

Although sands make up a substantial proportion of the Cretaceous deposits, the Cretaceous is not known for large well yields in the area west of Chesapeake Bay. Overbeck and Slaughter (1958, table 19) present data from 17 wells nearly all west of Chesapeake Bay, indicating a range of yield from 2.5 to 90 gpm. The highest yield was from a well on Elk Neck on the eastern shore of Chesapeake Bay. For the 15 wells west of Chesapeake Bay, the yield averaged 11 gpm, which suggests low to moderate permeability for the Cretaceous deposits in general in the area west of Chesapeake Bay.

2.3 POST-CRETACEOUS DEPOSITS

The deposits younger than Cretaceous age west of Chesapeake Bay include gravelly deposits of presumed late Tertiary age that occur mainly as isolated patches on hilltops, and younger deposits of Quaternary age that overlie the Cretaceous deposits of the lowlands between Chesapeake Bay and the Fall Line. These Quaternary deposits, believed to be of Pleistocene age, were subdivided into three formations by Overbeck and Slaughter (1958, table 10): the Talbot, Wicomico, and Sunderland formations. However, Higgins and Conant (1990, plate 1) recognized only the Talbot Formation and Upland Gravels as mappable units.

The extent and thickness of the Tertiary/Quaternary deposits to the west of Chesapeake Bay is not well established in the literature. Overbeck and Slaughter (1958) do not show these deposits on a geologic map, and Higgins and Conant (1990, plate 1) on their Geologic Map of Cecil County show the area east of Furnace Bay on Carpenter Point Neck as Cretaceous deposits at land surface. Nevertheless, as described elsewhere in this report, a considerable thickness of post-Cretaceous deposits can be observed in the walls of the Stancill Quarry and in borings on the site.

The Tertiary/Quaternary deposits are distinguished from the underlying Cretaceous deposits mainly by differences in color and density, as determined by ease of drilling and Standard Penetration Tests (SPTs). It appears that the deeper parts of the quarry have reached the Cretaceous deposits, that is, the Tertiary/Quaternary deposits have been largely removed in the quarrying operation.

Several reports and investigations interpreting the geology of the area surrounding Stancill quarry were made available and have been reviewed for this report. Those reports and investigations are summarized here.

3.1 THE GEOLOGY OF CECIL COUNTY, MARYLAND

URS reviewed the report on the geology of Cecil County, including the geologic map of Cecil County (Higgins and Conant, 1986, 1990), to gain an overview of the geology of the area surrounding Stancill Quarry. The report discusses the crystalline bedrock in the area of Stancill Quarry as the James Run Formation (mainly metamorphosed volcanic rocks) and Port Deposit Gneiss. The geologic map shows Cretaceous Potomac Group (Kp) deposits on the surface at the Stancill Quarry site. The Quaternary Talbot Formation is shown in a narrow strip along the western portion of this site, near the upper extent of Furnace Bay. Quaternary Tidal Marsh Deposits (Qm) are shown in a small strip along the northern portion, around the beaver dammed Long Creek. Quaternary Alluvium (Qal) is shown in a small strip along the western portion, on the deltaic-like deposits on either side of Long Creek and Principio Creek where they enter Furnace Bay.

3.2 SOIL SURVEY OF CECIL COUNTY

URS reviewed the report on the soil survey of Cecil County (Soil Conservation Service, 1973). The soil map shows the following:

- Gravel and borrow pits (Gv) - Over the then current extent of the active quarry.
- Mixed alluvial land (Mr) - Borders Long Creek and the deltaic-like protrusion of Long Creek into Furnace Bay and consists of mixed and variable soil material on flood plains of small streams.
- Evesboro loamy sand (EvD) - A very sandy soil that formed mainly in old sand dunes; can be found in the central portion of the site.
- Butlertown silt loam (BuB2) – Well-drained soils that have a little fragipan in the lower part of the subsoil; can be found in the western portion of the site.
- Tidal marsh (Tm) - Along Furnace Bay and Principio Creek.
- Matapeake silt loam (MoB2) - Loamy soils formed in sediments high in silt; can be found in a small spot on the western portion of the site.
- Keyport silt loam (KpB2) – Well-drained soils formed in old deposits of clay or silty clay; can be found in the southeastern portion of the site.
- Sassafras sandy loam (SaC2 and SaB2) – Well-drained soils formed in sandy sediment that contains a moderate amount of silt and clay and gravel in places.

3.3 THE WATER RESOURCES OF CECIL, KENT, AND QUEEN ANNE'S COUNTIES

This report focuses on the groundwater resources of a three-county area, largely on the Eastern Shore of Chesapeake Bay, where the sedimentary deposits of the Atlantic Coastal Plain are thick and well represented. In the area between Chesapeake Bay and the Fall Line, data are generally sparse, particularly for Carpenters Point Neck. The principal geologic units described in this area include the crystalline basement complex, lower Cretaceous age rocks, and Tertiary/Quaternary lowland deposits. The report discusses the extent and water-bearing characteristics of five formations of Upper Cretaceous age in the three-county area and several units of Tertiary age as well; however, these units appear to be absent in the vicinity of the Stancill Quarry. The report also describes three formational units of Pleistocene age: the Sunderland, Wicomico, and Talbot formations; however, these are not delineated on maps or cross-sections in the Quarry vicinity (Overbeck and Slaughter, 1958).

3.4 GEOTECHNICAL REPORT FOR STANCILL SAND AND GRAVEL QUARRY, CECIL COUNTY, MARYLAND

The report entitled "A Preliminary Assessment of the Feasibility of Using Stancill's Inc. Property on Furnace Bay in Cecil County as a Dredge Material Containment Facility," (Maryland Environmental Service, November 2000) is the principal source of detailed information on lithology and physical properties of the subsurface materials at the Stancill Quarry. The report presents boring logs of six test holes drilled on the quarry site, SPT results, and laboratory test results on representative samples. The laboratory tests included grain-size distribution, moisture content, Atterberg limits, Unified Soil Classification System (USCS) classification, and two tests of hydraulic conductivity of cores. Geologic correlations are presented in the form of three cross-sections through the quarry site.

3.5 REPORT ON GEOLOGY AND HYDROGEOLOGY OF ABERDEEN PROVING GROUND

The report on the geology of Aberdeen Proving Ground (APG) indicates that APG is underlain by Quaternary deposits directly overlying Lower (older) Cretaceous age sediments of the Potomac Group (USACE-WES, 1997). A major unconformity was identified between the younger Quaternary and older Cretaceous age sediments. Weathering and erosion during Late Cretaceous, Tertiary, and Early Quaternary time has produced a highly oxidized Cretaceous surface, which is recognizable in APG boring data. The Quaternary Talbot Formation was divided into three different age Pleistocene river terraces based on topography. Three major sand units were identified in the Cretaceous sediments at APG; the lower sand unit may contain some saprolite.

The report on the hydrogeology of APG indicates that the upper surface of the Cretaceous deposits was formed by erosion during a time of lower sea level in the Pleistocene epoch (USACE-WES, 1997). A major stream channel (the ancestral Susquehanna River) was previously located beneath APG and caused the erosion. A Pleistocene age paleochannel is depicted trending northeast to southwest through APG. The study indicates that the Potomac Group was deposited from channels, floodplains, and cutoff-meander streams and swamps.

The report suggests that Pleistocene paleochannel deposits similar to those mapped at APG are common in the Chesapeake Bay region. These deposits typically consist of fluvial and estuarine sediments deposited during periods of rising sea level.

The ultimate goal of the present study is to produce a geologic/hydrogeologic model that can be used as the technical basis for the development of a groundwater flow model. The procedures used to obtain the geologic/hydrogeologic interpretation presented in this report were carried out in three steps as summarized here.

The first step involved interpreting the geologic framework. After a sufficient quality screening of boring (lithologic) logs located within the model area, lines for geologic cross sections were selected and plotted on a base map. Copies of boring logs of all wells/piezometers installed as part of the current study are displayed on Figure 2 and presented in Appendix A. The cross-sections were produced and interpretations of the subsurface stratigraphy were completed. Correlations were based on lithology, color, and available grain-size data. The second step involved delineating mappable hydrogeologic units based on the derived geologic interpretation. This proved to be difficult. Interpretations were based on geologic correlations as well as any available field permeability testing. The third step involved developing a contour map of the top of the saprolitic aquitard.

Since most of the post-Cretaceous deposits at the Stancill Quarry have been mined out, the remaining sediments have been mapped as three geologic units consisting of a Quaternary/ Tertiary unit, a Cretaceous unit, and a saprolitic unit. The units are differentiated based on color of sediment, grain size, ease of drilling, and blow counts during SPTs. The Quaternary/Tertiary and Cretaceous age deposits are mapped as an aquifer, and the saprolite is mapped as an aquitard.

The geology of the Stancill Quarry is presented on seven cross-sections (A-A' through G-G', Figures 3 through 9, respectively). Table 1 lists the borings used in each cross section. The alignment of the sections is shown on Figure 2. On the cross sections, borings installed by E2CR are identified by the letter E preceding the number, those installed during the present study by the letter P, and borings preceding the E2CR program by the letter B. The drilling of the P series borings was supervised by KCE and the borings were logged by URS geologists.

Five principal geologic units are shown on the sections, as follows: (1) Quaternary/Tertiary (post-Cretaceous) deposits extending from land surface downward to underlying Cretaceous deposits or to saprolite, (2) Cretaceous sediments overlying saprolite, (3) saprolite, (4) the weathered bedrock, and (5) a unit of dark brown organic silt recorded in the log of borings E-5 and E-6, which appears to pinch out in the direction of boring E-5 and was not observed in other borings. Artificial fill is also shown on the sections, principally at boring E-5 where it extends from land surface (approximately elevation 38 feet above sea level) to approximately elevation -11 feet, representing about 49 feet of thickness.

These geologic interpretations by URS agree generally with earlier work of E2CR, although not in detail. The URS interpretations used the earlier E2CR interpretations together with boring data collected in the current study. Geologic interpretations were primarily based on lithologic character as recorded on geologists' logs, color changes, and firmness of materials as indicated by SPT blow counts, and drillers' observations.

The most consistent unit recognized is the Quaternary/Tertiary deposits that apparently mantled the site originally and have been largely mined out. These typically are reddish brown to brown, predominantly silty-clayey deposits containing lenses of sand and gravel. These deposits generally are poorly consolidated, as indicated by low SPT blow counts (less than 50 blows per foot). Much of these deposits are above the current water table.

The other highly consistent unit is saprolite, the weathered residuum of crystalline bedrock, which appears to underlie the entire site, although it was not reached in many of the shallower borings. The saprolite typically consists of gray to red-green-brown silty clay that is notably dense, as indicated by high SPT blow counts (commonly greater than 100 blows per foot) and difficult drilling. Cores and large fragments commonly exhibit the original structure of the parent rock. The structured saprolite is generally less weathered than the non-structured saprolite, but cannot be classified as firm rock.

Cretaceous non-marine sediments are encountered in some but not all the borings between the Quaternary/Tertiary deposits and saprolite. Typically these deposits consist of light colored (white, tan to gray) clayey silts and sands. The Cretaceous sediments generally are more consolidated than the Quaternary/Tertiary deposits and less consolidated than saprolite as indicated by intermediate SPT blow counts (about 40-100 blows per foot). However, seams of highly consolidated materials occur sporadically within the Cretaceous section, as suggested by isolated zones of high SPT blow counts (see E2CR, 2000, Figures 3 through 5).

Underlying the entire area is crystalline bedrock distinguished by very hard drilling and no penetration during SPTs. Few of the borings reached the crystalline bedrock, and the lithology of the bedrock has not been characterized.

The only geologic unit not described above is the dark brown organic silt encountered only in borings E-5 and E-6. It was described in E2CR (2000, boring logs) as medium brown to dark brown, moist organic silt with a trace of fine sand and charcoal fragments. Standard penetration resistance was notably low, ranging from 1 to 3 blows per foot in 4 intervals tested at boring E-6 to 7 to 11 blows per foot in a single interval at boring E-5. Just what this unit represents is unresolved with available data. At boring E-6, the organic silt is overlain by Quaternary/Tertiary deposits and at E-5 by artificial fill. The organic silt may be Cretaceous in age, however, URS interprets the low SPT blow counts as indicating these deposits were not buried deeply and, therefore, not consolidated by the weight of overlying sediment. It is more likely the organic silt deposits are Quaternary/Tertiary in age. The organic layer was not treated differently or separately in the model. It was included as part of the Quaternary layer, and the model parameters were based on values obtained from single-well permeability tests (i.e., slug tests) performed at the site.

Regional trends as described in the literature of a steeply southeastward dipping bedrock surface overlain by a thickening wedge of Cretaceous sediments are not readily seen on the geologic sections. Rather it appears that within the quarry site, the natural irregularity of the upper boundary of the saprolite and erratic occurrence of the Cretaceous sediments tend to obscure the regional trends.

Based on the cross sections, the top of the saprolite appears to be an irregular erosional surface with no apparent dip. The crystalline basement rock surface dips to the south-southeast at approximately 100 ft/mi. (USACE-WES, 1997).

The entire Stancill Quarry site is located southeast of the Fall Line within the Coastal Plain Physiographic Province. The base of the geologic model area (top of saprolite) slopes toward the south and east. The crystalline basement rock surface dips to the south-southeast at approximately 100 ft/mi.

The principal conclusions of the geologic investigation are as follows:

(1) Poorly consolidated Quaternary/Tertiary fluviatile deposits appear to have mantled the site prior to development, although most of these deposits have been removed by quarry operations.

(2) Saprolite, the weathered residuum of crystalline bedrock, appears to underlie the entire site. This low permeability zone tends to separate the surficial deposits of the Atlantic Coastal Plain from the underlying crystalline bedrock, which is the principal domestic water supply in the vicinity of the quarry.

(3) The Cretaceous deposits, between the Quaternary/Tertiary deposits and the saprolite were not encountered in all boreholes, suggesting that the Cretaceous sediments were deeply eroded in Tertiary/Quaternary time.

There are certain limitations in preparing an interpretation such as this. Borings are not placed uniformly throughout the study area. Consequently, more detailed data are available in some areas, allowing a reasonable confidence in correlation. Other areas, with sparse data, rely more on professional judgment resulting in a lower confidence in the correlation and interpolation, if correlation is even possible. Most borings are not drilled to bedrock or saprolite. Therefore, more information is available about the upper aquifer and less about the underlying aquitard. Additionally, there is a wide range in the quality of the boring logs. Some logs are based on downhole sampling and have a great amount of detail. Others are based solely on drilling "returns" and simply classify the material as either gravel, sand, silt, or clay. Lastly, the paleodepositional environment of the study area makes it difficult to accurately correlate between the borings; there are no distinct "marker beds" to aid in the interpretation. In spite of these obstacles, a reasonably sound geologic model has been prepared based on the available information.

E2CR, Inc., 2000. Geotechnical Report for: Stancill Sand and Gravel Quarry, Cecil County, Maryland. November 6, 2000.

Higgins, Michael W. and Conant, Louis C. 1986. Geologic Map of Cecil County, Maryland. Baltimore, MD.

Higgins, Michael W. and Conant, Louis C. 1990. The Geology of Cecil County, Maryland. Maryland Geological Survey Bulletin 37.

Maryland Environmental Service. November 2000. A Preliminary Assessment of the Feasibility of Using Stancill's Inc. Property on Furnace Bay in Cecil County as a Dredge Material Containment Facility.

Otton, E.G. and Mandle, Richard. 1984. Hydrogeology of the Upper Chesapeake Bay Area, Maryland, with Emphasis on Aquifers in the Potomac Group. Report of Investigations No. 39. Maryland Department of Natural Resources Geological Survey.

Overbeck, R.M., Slaughter, T.H., Hulme, A.E. 1958. The Water Resources of Cecil, Kent, and Queen Anne's Counties. Maryland Department of Geology, Mines, and Water Resources, Bulletin 21.

Soil Conservation Service. 1973. Soil Survey of Cecil County, Maryland. Washington, DC.

US Army Corps of Engineers Waterways Experiment Station (USACE-WES). 1997. Geology and Geomorphology of Aberdeen Proving Ground, Aberdeen, Maryland.

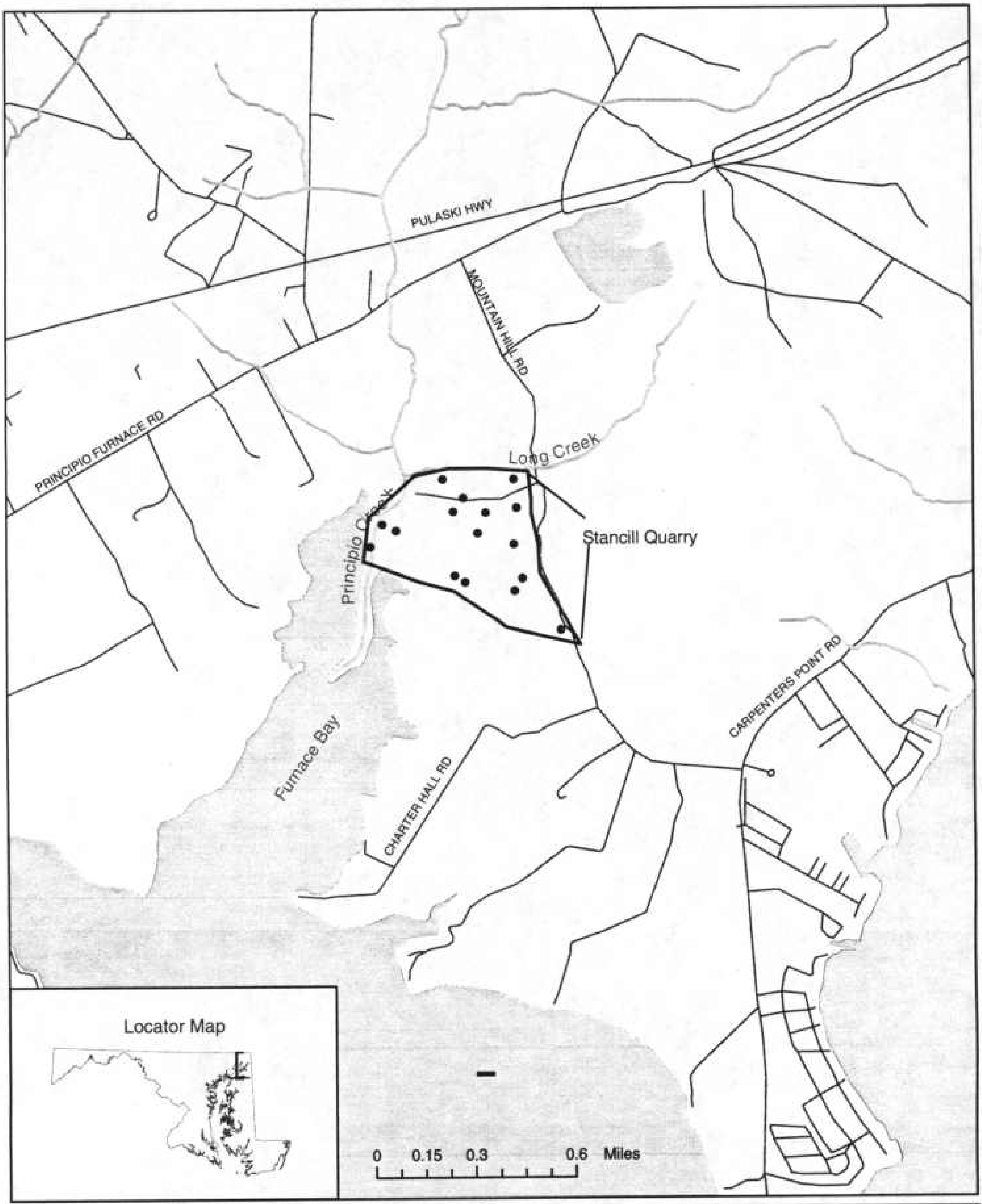
Tables

Table 1: List of Wells and Borings Used in Cross Sections for Stancill Quarry Geologic Conceptual Model

A-A'	B-B'	C-C'
E-6	E-6	E-2
E-5	PZ-5	PZ-2
E-2	E-2	PZ-3
PZ-1	PZ-1	Abandoned Pump Test Well
		PZ-7
		B-2
		PZ-8

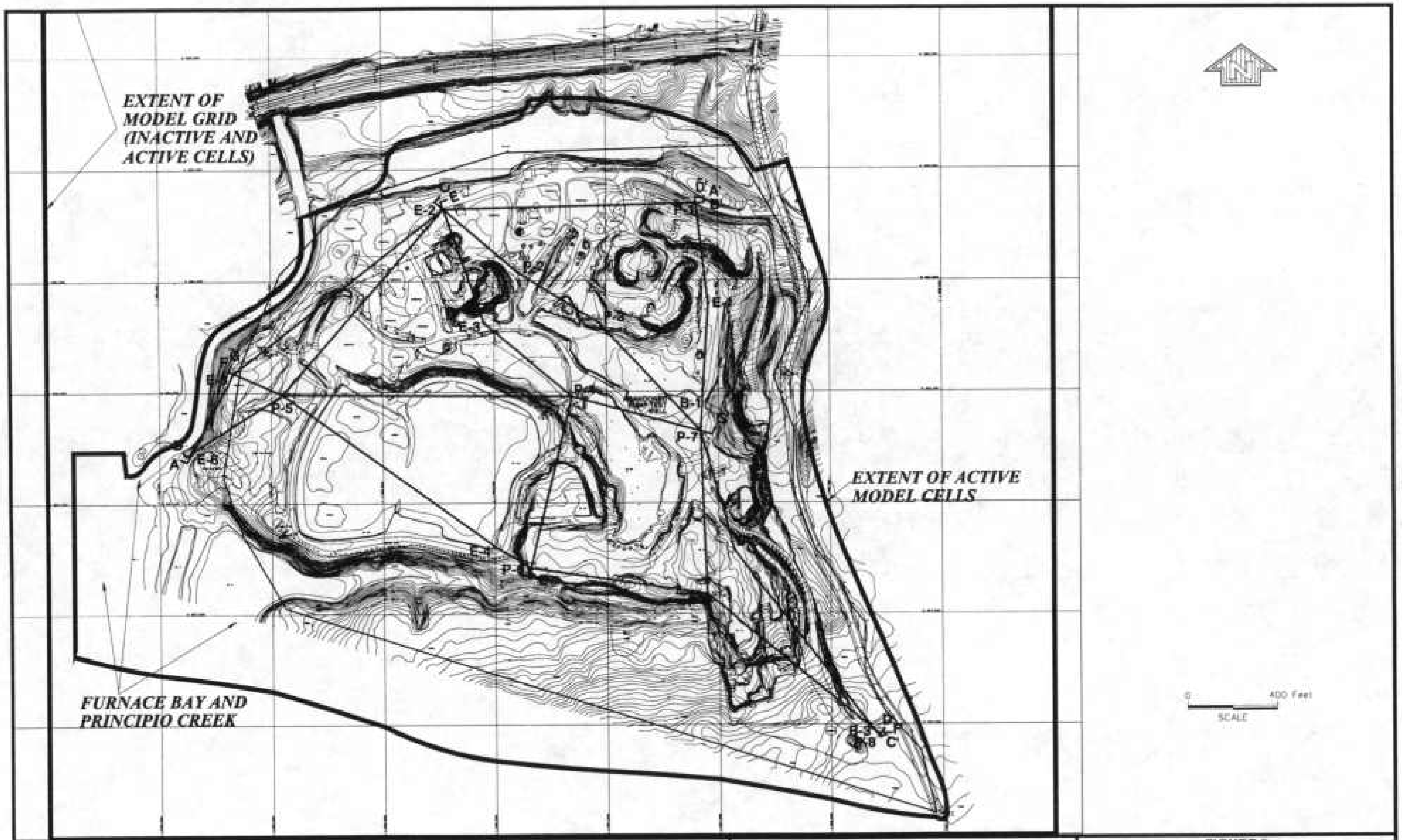
D-D'	E-E'	F-F'	G-G'
PZ-1	E-2	E-5	E-5
E-1	E-3	PZ-5	PZ-5
PZ-7	PZ-4	E-4	PZ-4
PZ-9	PZ-6	PZ-6	PZ-7
PZ-8		PZ-9	
		PZ-8	

Figures



CLIENT: MES			TITLE:	Site Location - Stancill Quarry, Cecil County, Maryland
PROJ: Cecil County				
REVISION NO.	DES BY		URS	FIGURE: 1
SCALE: 1: 25,000	DR BY	SK		
FILE: G:\8900000229\Projects\locator_map.mxd	CHK BY	JK		

P:\Bethesda\15294354 00100-GTB1\99-00000228 00 00100\FIGURE 2.dwg, Layout3, 9/13/2002 9:00:44 AM, sokhons, HP LaserJet 5SI_5SI MX PS pc3, 1:1



URS

SOURCE: KCE ENGINEERING, INC., 2001.

FIGURE 2
LOCATION OF WELLS AND CROSS SECTIONS USED IN THE GEOLOGIC INTERPRETATION OF THE STANCILL QUARRY SITE

P:\Bethesda\15294354 00100-GTB1189-00000228.00 00100\X-SECT A-A'.dwg, Layout1, 9/4/2002 4:13:05 PM, sokhone, HP LaserJet 5Si_5SI MX PS pc3, 1:1

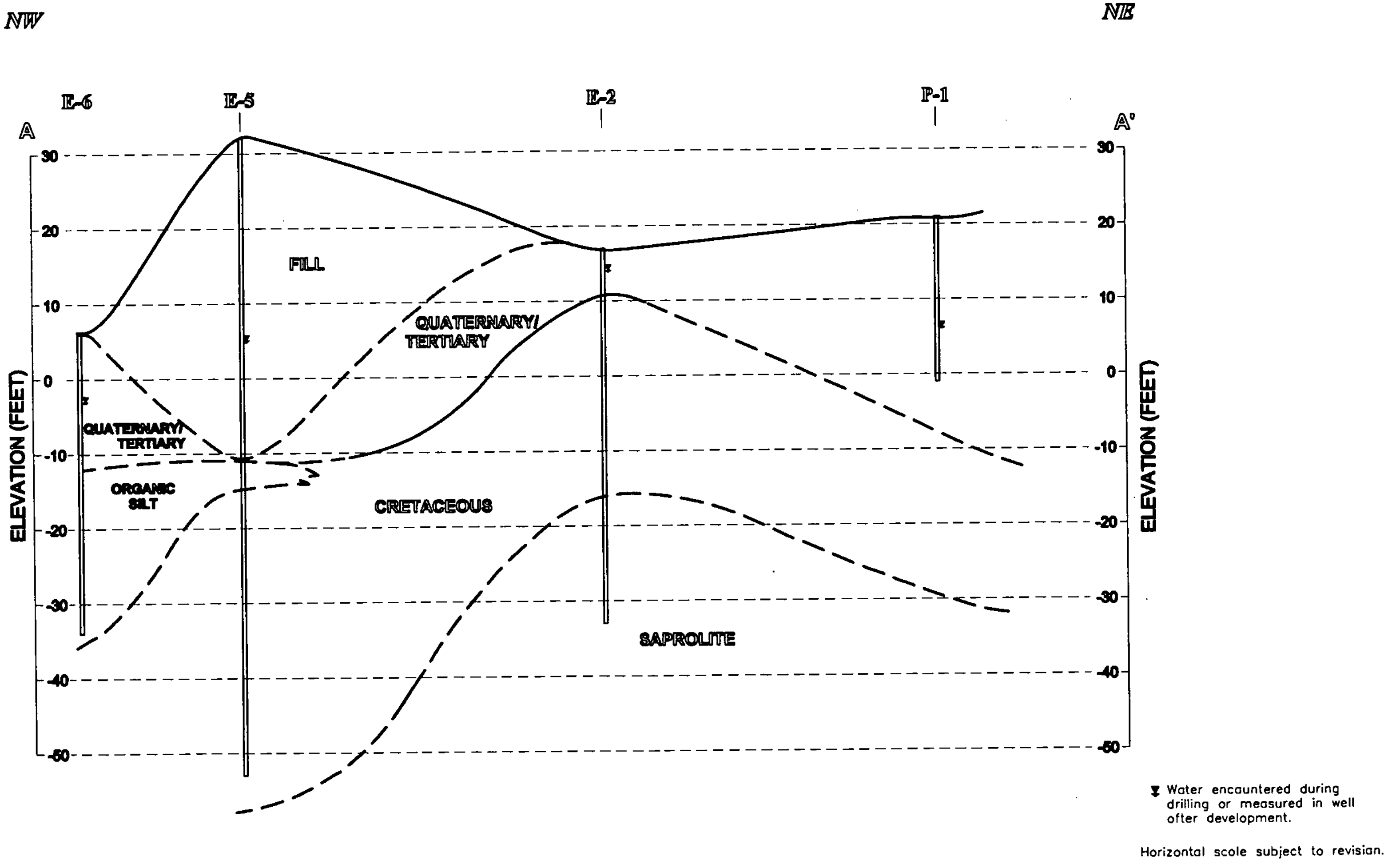
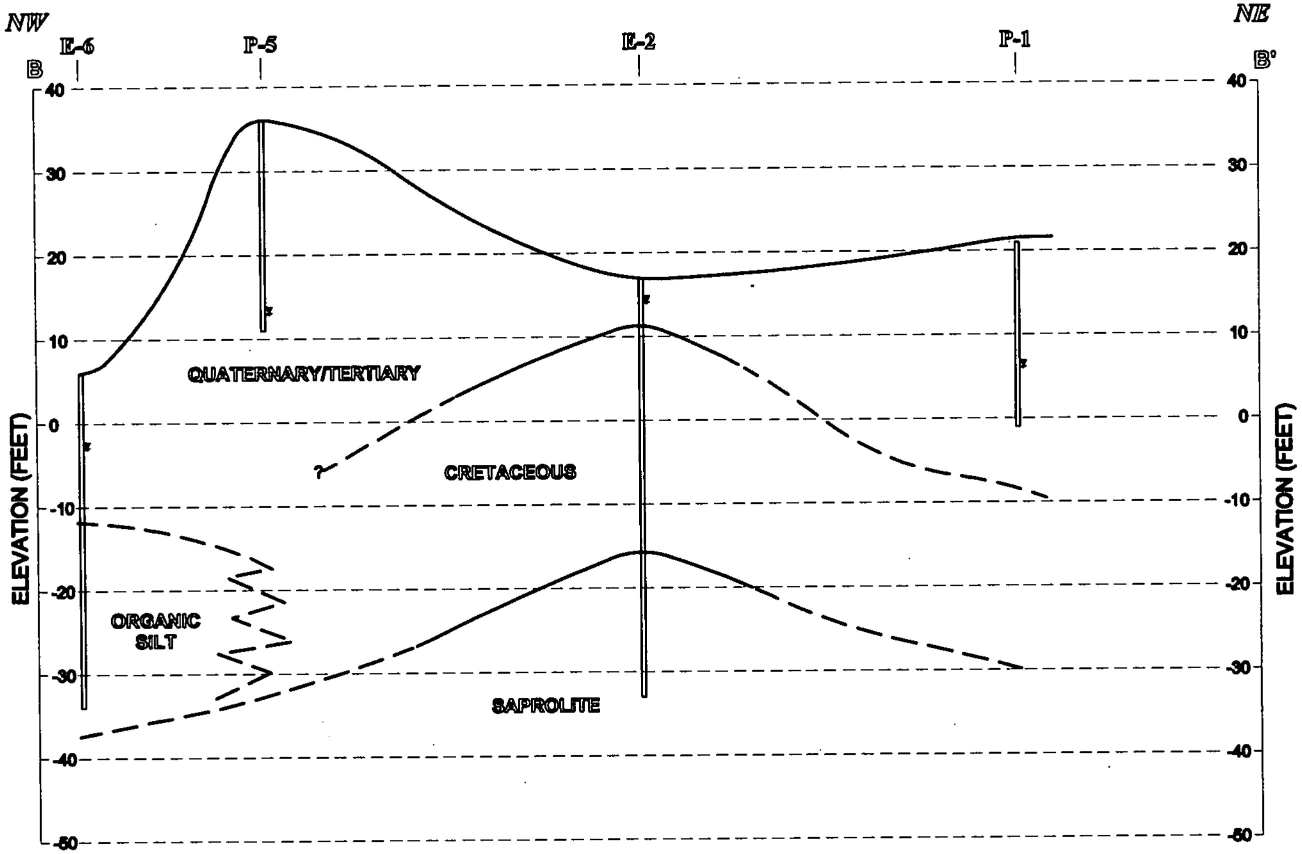


FIGURE 3
STANCILL SAND AND GRAVEL QUARRY
CROSS SECTION A-A'

URS



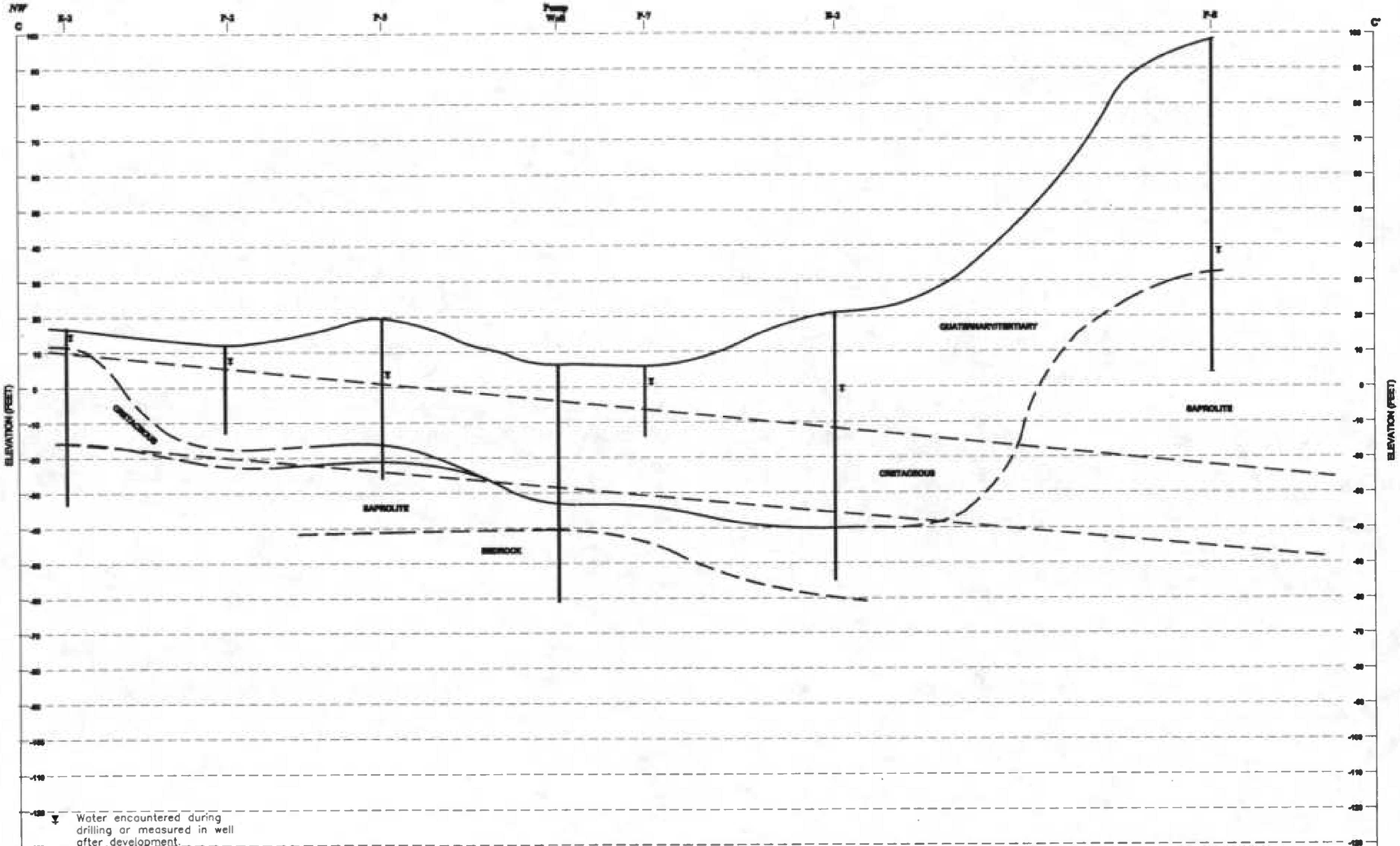
⧗ Water encountered during drilling or measured in well after development.

Horizontal scale subject to revision.

FIGURE 4
STANCILL SAND AND GRAVEL QUARRY
CROSS SECTION B-B'

URS

P:\Bethesda\15294354.00100-GTB199-00000229.00.00100\X-SECT B-B'.dwg, Layout1, 9/4/2002 4:15:08 PM, sokhons, \\bethesda\HP LaserJet 5Si/5SI MX PS, 1:1



Water encountered during drilling or measured in well after development

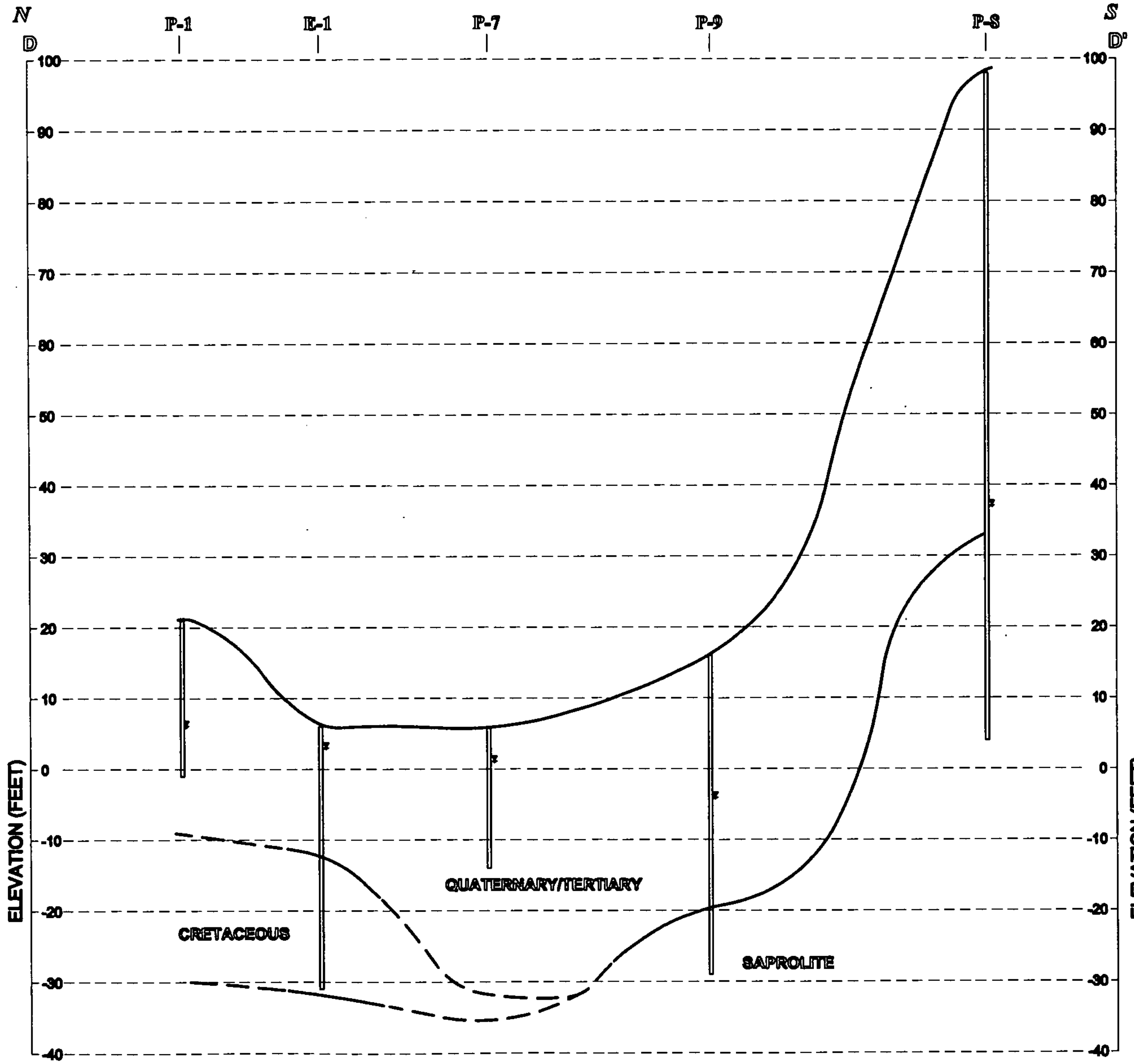
Model Layer Boundaries

FIGURE 5
STANCILL SAND AND GRAVEL QUARRY
CROSS SECTION C-C'

URS

P:\Bethesda\15294354.00100-GTB189-00000229.00.00100\X-SECT C-C'.dwg, Layout1, 9/4/2002 4:20:03 PM, sokhons, \\bethesda\HP LaserJet 5SI/5SI MX PS, 1:1

P:\Bethesda\15294354 00100-GTB189-00000229.00 00100\X-SECT D-D'.dwg, Layout1, 9/4/2002 4:27:38 PM, sections, \\bethesda\HP LaserJet 5SI/5SI MX PS, 1:1



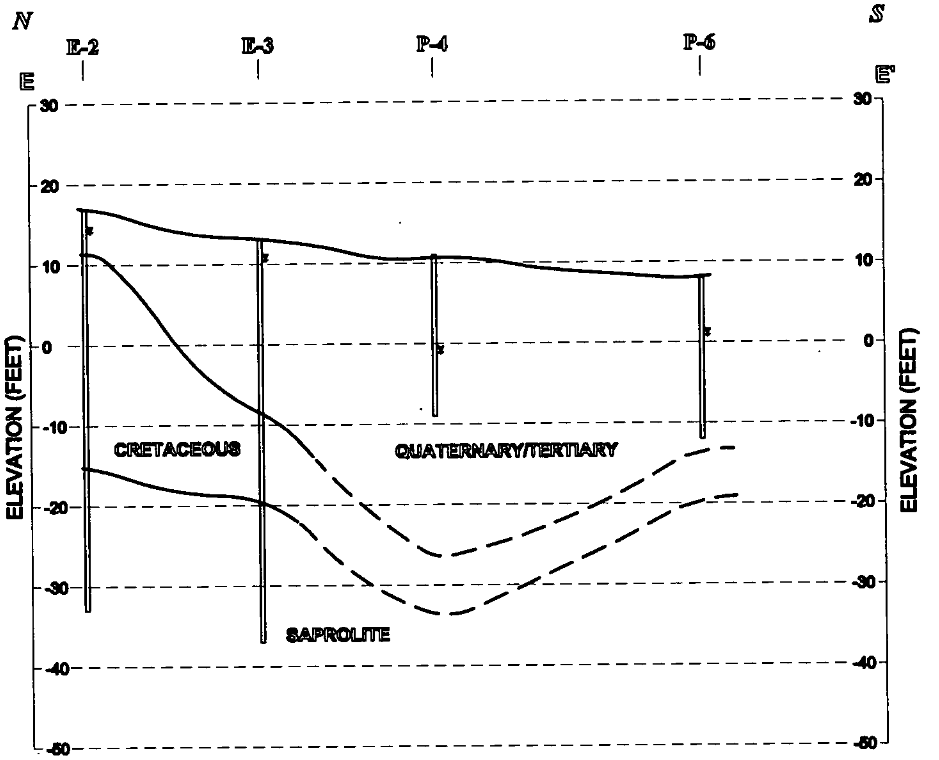
₮ Water encountered during drilling or measured in well after development.

Horizontal scale subject to revision.

URS

FIGURE 6
STANCILL SAND AND GRAVEL QUARRY
CROSS SECTION D-D'

P:\Bethesda\15294354.00100-GTB189-00000229.00 00100\X-SECT E-E'.dwg, Layout1, 9/4/2002 4:28:58 PM, sokhone, \\bethesda\HP LaserJet 5SI/5SI MX PS, 1:1

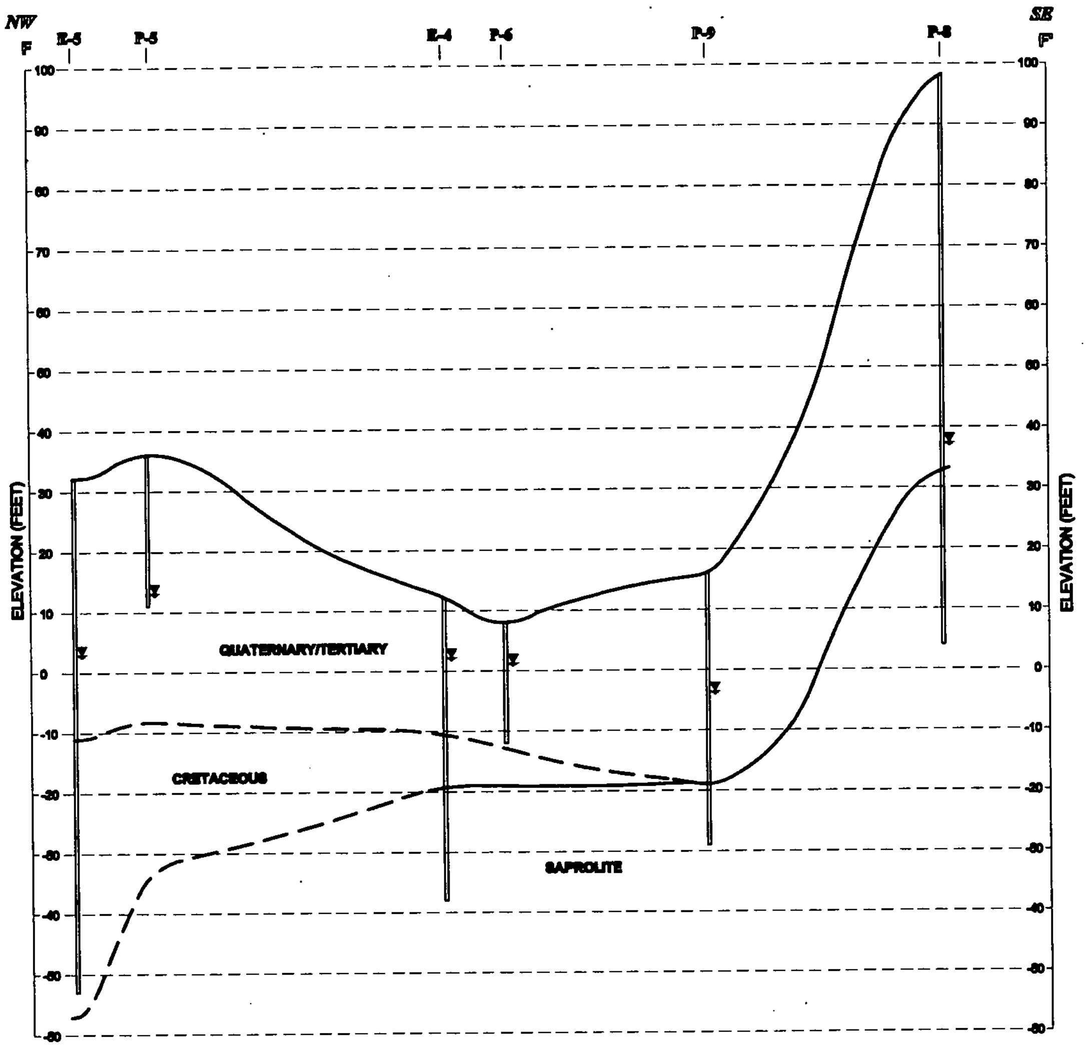


⊻ Water encountered during drilling or measured in well after development.

Horizontal scale subject to revision.

FIGURE 7
STANCILL SAND AND GRAVEL QUARRY
CROSS SECTION E-E'

P:\Bethesda\15294354.00100-GTB1\99-00000229.00 00100\X-SECT F-F.dwg, Layout1, 8/4/2002 4:30:09 PM, sokhons, \\bethesda\HP LaserJet 5Si/5Si MX PS, 1:1

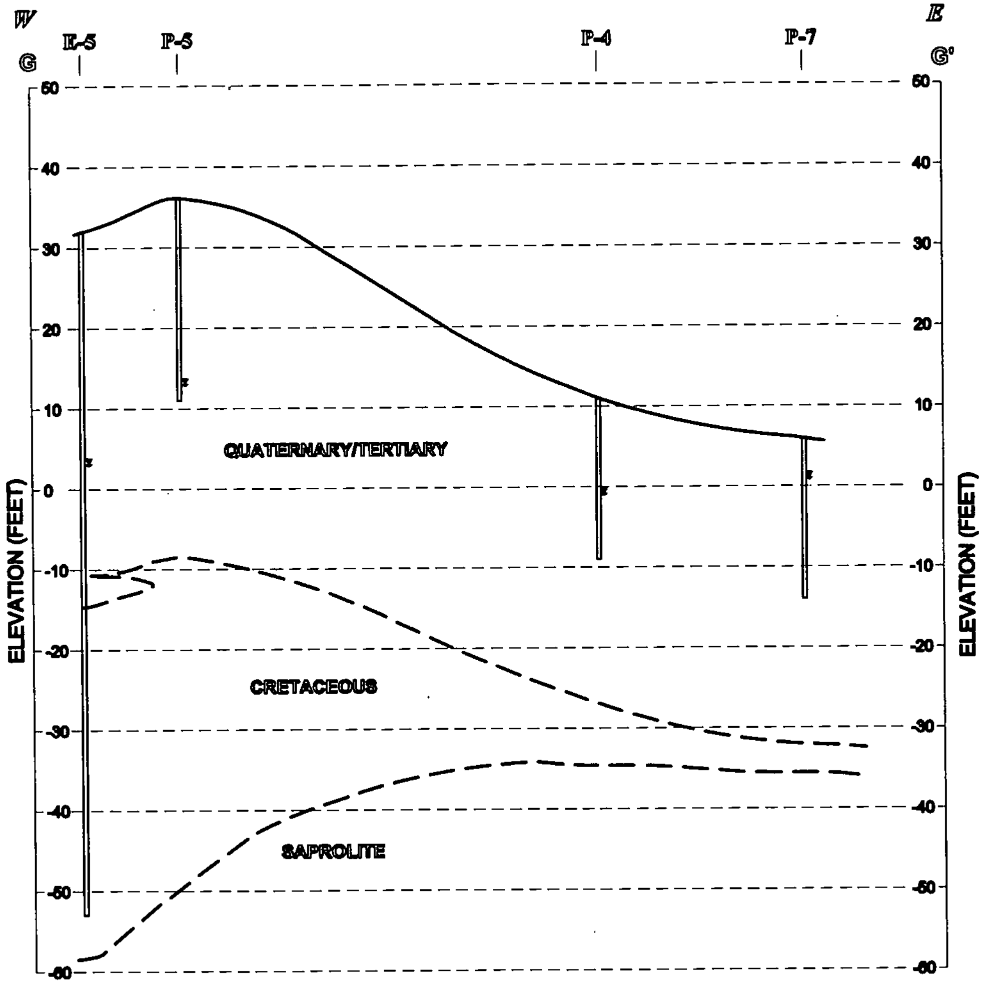


↧ Water encountered during drilling or measured in well after development.

Horizontal scale subject to revision.

FIGURE 8
STANCILL SAND AND GRAVEL QUARRY
CROSS SECTION F-F'

URS



⧗ Water encountered during drilling or measured in well after development.

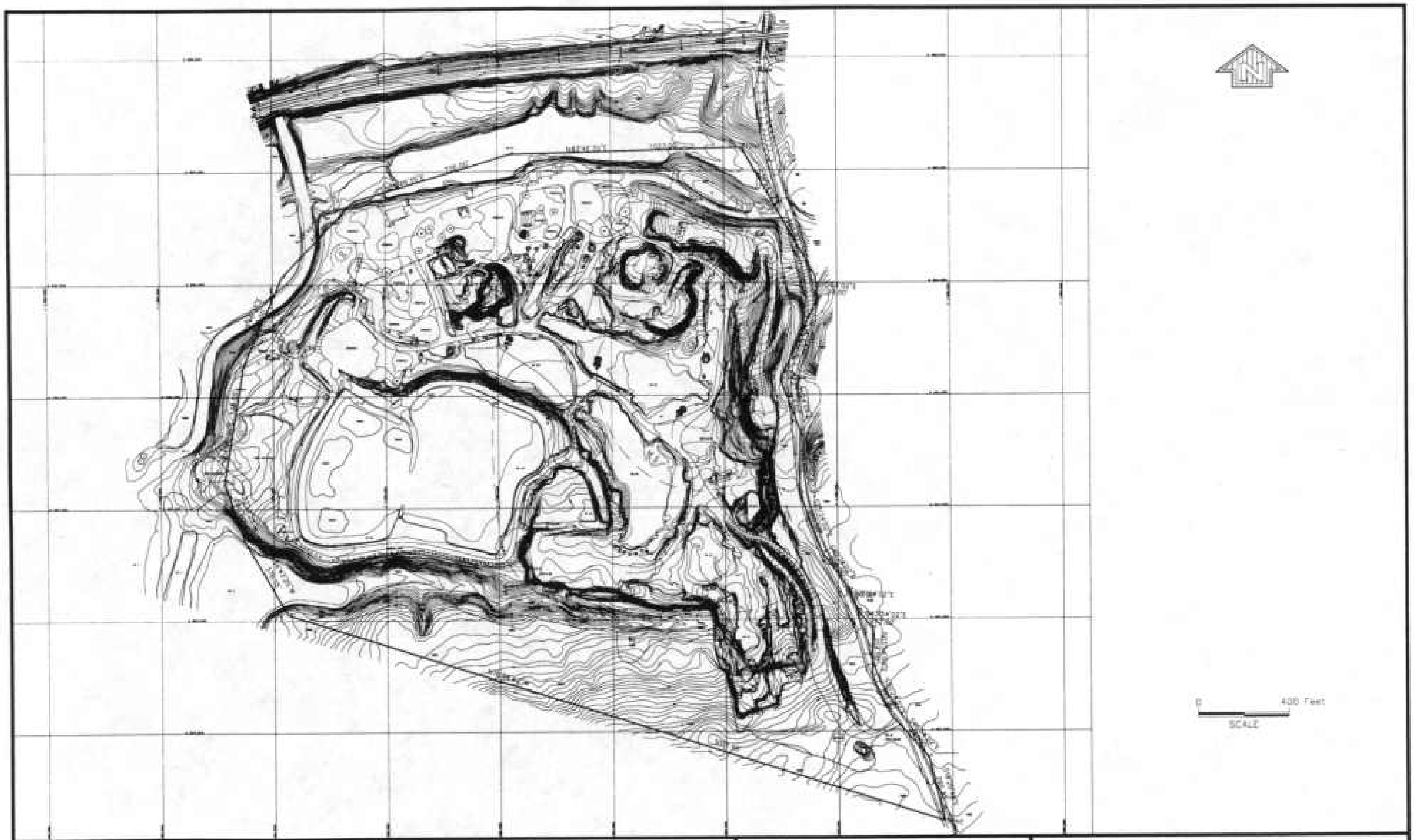
Horizontal scale subject to revision.

FIGURE 9
STANCILL SAND AND GRAVEL QUARRY
CROSS SECTION G-G'

P:\Bethesda\15294354 00100-GTB\99-00000229.00 00100\X-SECT G-G'.dwg, Layout1, 9/4/2002 4:31:40 PM, sokhona, \\bethesda\HP LaserJet 5Si/5SI MX PS, 1:1

URS

P:\Bethesda\15294364 00100-GTB\169-00000229 00.00100\STANCILL QUARRY.dwg, Layout3, 9/4/2002 4:33:18 PM, sochons, \\Bethesda\HP LaserJet 5Si/5Si MX PS, 1:1



PHOTOGRAMMETRY BY
HARFORD AERIAL SURVEYS, INC.
DATE OF PHOTOGRAPHY: NOVEMBER 16, 2001

KCE ENGINEERING, INC.
EXECUTIVE CENTER
3300 NORTH RIDGE ROAD, SUITE 3[illegible]
ELLICOTT CITY, MARYLAND 21043
PHONE (410) 203-9800 FAX (410) [illegible]

FIGURE 10
CONTOUR MAP OF TOP OF SAPROLITE

Appendix A

Logs of Borings

Project: MES Stancill Quarry
Project Location: Cecil County, Maryland
Project Number: 89-00000229.00

Log of Boring P-1

Sheet 1 of 1

Date(s) Drilled	10/22/2000 - 10/22/2000	Logged By	E. Koubek	Checked By	J. Kashatus
Drilling Method	HSA	Drill Bit Size/Type		Total Depth of Borehole	20.0 feet
Drill Rig Type		Drilling Contractor	Earth Matters	Surface Elevation	21.0 ft. msl
Groundwater Level(s)		Sampling Method(s)	NA	Hammer Data	NA
Borehole Backfill	Well installed.	Comments			

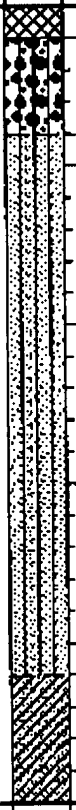
Elevation, feet	Depth, feet	SAMPLES Type	Number	Sampling Resistance, Blows / 6 in.	SPT N-Value, Blows / ft	Recovery, in.	Graphic Log	MATERIAL DESCRIPTION	Water Content, %	ATTERBERG LIMITS Liquid Limit	Plastic Limit	Plasticity Index	REMARKS AND OTHER TESTS
	0							(FILL)					
20													
								Firm SAND, black, dry (SP)					
	5												
								GRAVEL (yellow) mixed with cobbles (GC)					
								Medium to fine SAND, dark brown to black, dry (SM)					
	10							Silty SAND, light brown, moist (SM)					
10													
								Silty SAND, light brown, mixed with clay, wet (SM)					
	15							Sandy CLAY, brown, wet (CL)					
	20												
0													
	25												
	30												
-10													
	35												
	40												

Project: MES Stancill Quarry
Project Location: Cecil County, Maryland
Project Number: 89-00000229.00

Log of Boring P-2

Sheet 1 of 1

Date(s) Drilled	10/24/2000 - 10/24/2000	Logged By	E. Koubek	Checked By	J. Kashatus
Drilling Method	HSA	Drill Bit Size/Type		Total Depth of Borehole	25.0 feet
Drill Rig Type		Drilling Contractor	Earth Matters	Surface Elevation	12.0 ft. msl
Groundwater Level(s)		Sampling Method(s)	NA	Hammer Data	NA
Borehole Backfill	Well installed.	Comments			



Elevation, feet	Depth, feet	SAMPLES Type	Number	Sampling Resistance, Blows / 6 in.	SPT N-Value, Blows / ft.	Recovery, in.	Graphic Log	MATERIAL DESCRIPTION	Water Content, %	ATTERBERG LIMITS Liquid Limit	Plastic Limit	Plasticity Index	REMARKS AND OTHER TESTS
	0							(FILL)					
10								coarse GRAVEL, loose (GM)					
	5							Silty fine SAND, light brown, moist (SM)					
	10							Silty fine SAND, light brown, wet (SM)					
0													
	15							Silty fine SAND, light brown, very wet (SM)					
	20							Silty fine SAND mixed with soft clay, light brown, very wet (SC)					
-10													
	25												
	30												
-20													
	35												
	40												

Project: MES Stancill Quarry

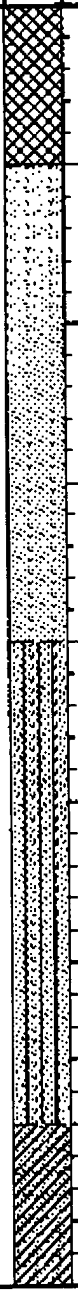
Project Location: Cecil County, Maryland

Project Number: 89-00000229.00

Log of Boring P-3

Sheet 1 of 2

Date(s) Drilled	10/23/2000 - 10/23/2000	Logged By	E. Koubek	Checked By	J. Kashatus
Drilling Method	HSA	Drill Bit Size/Type		Total Depth of Borehole	45.0 feet
Drill Rig Type		Drilling Contractor	Earth Matters	Surface Elevation	19.0 ft. msl
Groundwater Level(s)		Sampling Method(s)	NA	Hammer Data	NA
Borehole Backfill	Well installed.	Comments			



Elevation, feet	Depth, feet	SAMPLES Type	Number	Sampling Resistance, Blows / 6 in.	SPT N-Value, Blows / ft	Recovery, in.	Graphic Log	MATERIAL DESCRIPTION	Water Content, %	ATTERBERG LIMITS Liquid Limit	Plastic Limit	Plasticity Index	REMARKS AND OTHER TESTS
	0							general quarry fill (sand and gravel)					
	5							SAND, brown, mixed with gravel (quarry fill) (SP)					
10													
	10												
	15												
0													
	20							Silty fine SAND, light brown, dry, stiff (SM)					
	25							Silty fine SAND, light brown, moist, soft (SM)					
-10													
	30							Silty fine SAND, light brown, very wet (SM)					
	35							fine SAND, white, moist, stiff (SC)					
-20													
	40												

Project: MES Stancill Quarry
Project Location: Cecil County, Maryland
Project Number: 89-00000229.00

Log of Boring P-3

Sheet 2 of 2

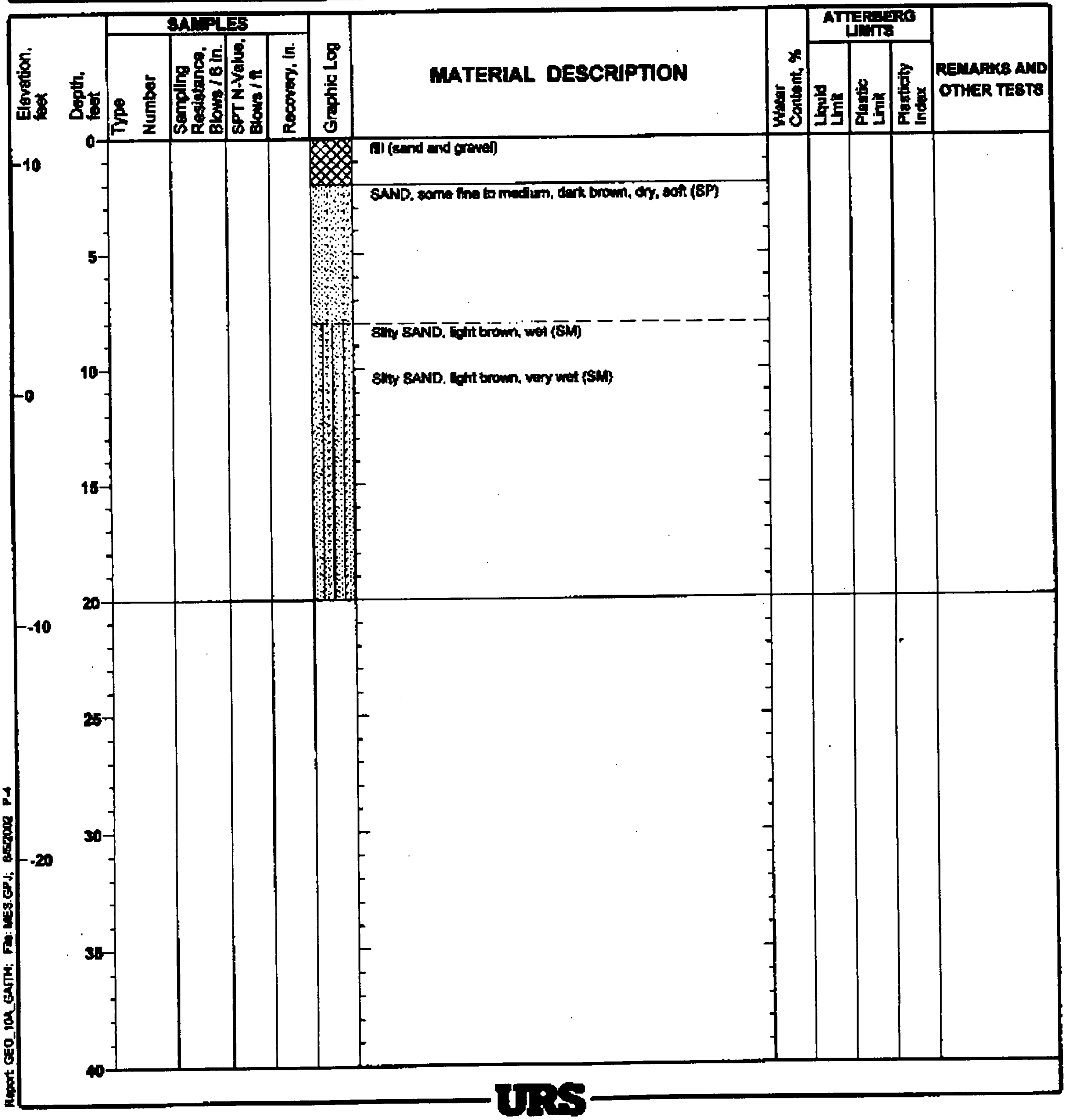
Elevation, feet	Depth, feet	SAMPLES					Graphic Log	MATERIAL DESCRIPTION	Water Content, %	ATTERBERG LIMITS			REMARKS AND OTHER TESTS
		Type	Number	Sampling Resistance, Blows / 6 in.	SPT N-Value, Blows / ft	Recovery, in.				Liquid Limit	Plastic Limit	Plasticity Index	
	40						▨	SAPROLITE, dark brown, dry, very dense					
	45												
-30													
	50												
	55												
-40													
	60												
	65												
-50													
	70												
	75												
-60													
	80												
	85												

Project:	MES Stancill Quarry
Project Location:	Cecil County, Maryland
Project Number:	89-00000229.00

Log of Boring P-4

Sheet 1 of 1

Date(s) Drilled	10/23/2000 - 10/23/2000	Logged By	E. Koubek	Checked By	J. Kashatus
Drilling Method	HSA	Drill Bit Size/Type		Total Depth of Borehole	20.0 feet
Drill Rig Type		Drilling Contractor	Earth Matters	Surface Elevation	11.0 ft. msl
Groundwater Level(s)		Sampling Method(s)	NA	Hammer Data	NA
Borehole Backfill	Well Installed.	Comments			



fill (sand and gravel)

SAND, some fine to medium, dark brown, dry, soft (SP)

Silty SAND, light brown, wet (SM)

Silty SAND, light brown, very wet (SM)

Project:	MES Stancill Quarry
Project Location:	Cecil County, Maryland
Project Number:	89-00000229.00

Log of Boring P-5

Sheet 1 of 1

Date(s) Drilled	10/22/2000 - 10/22/2000	Logged By	E. Koubek	Checked By	J. Kashatus
Drilling Method	HSA	Drill Bit Size/Type		Total Depth of Borehole	20.0 feet
Drill Rig Type		Drilling Contractor	Earth Matters	Surface Elevation	36.0 ft. msl
Groundwater Level(s)		Sampling Method(s)	NA	Hammer Data	NA
Borehole Backfill	Well installed.	Comments			

Elevation, feet	Depth, feet	SAMPLES Type	Number	Sampling Resistance, Blows / 6 in.	SPT N-Value, Blows / ft	Recovery, in.	Graphic Log	MATERIAL DESCRIPTION	Water Content, %	ATTERBERG LIMITS Liquid Limit	Plastic Limit	Plasticity Index	REMARKS AND OTHER TESTS
	0							fill (sand and gravel)					
								SAND, some silt, brown to light brown, dry, firm (SP)					
	5												
30								medium to coarse GRAVEL, dark green, dry to moist (GM)					
								Silty SAND, light brown, moist (SM)					
	10							Silty SAND, trace clay, light brown, very wet (SM)					
	15												
20													
	20												
	25												
10													
	30												
	35												
0													
	40												

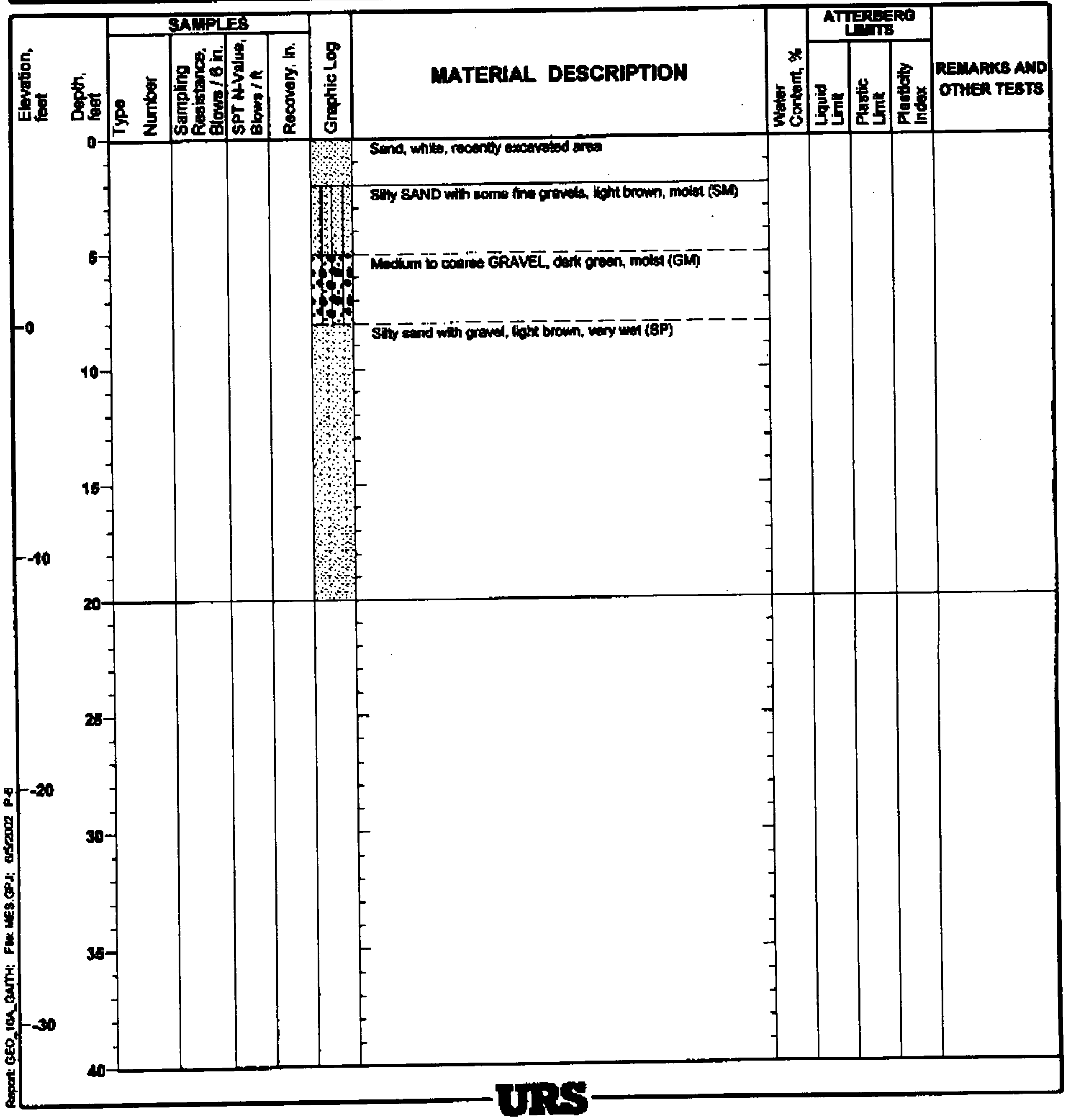
Report: GEO_10A_GAITH; File: MES.GPJ; 6/5/2002 P-5

Project:	MES Stancill Quarry
Project Location:	Cecil County, Maryland
Project Number:	89-00000229.00

Log of Boring P-6

Sheet 1 of 1

Date(s) Drilled	10/23/2000 - 10/23/2000	Logged By	E. Koubek	Checked By	J. Kashatus
Drilling Method	HSA	Drill Bit Size/Type		Total Depth of Borehole	20.0 feet
Drill Rig Type		Drilling Contractor	Earth Matters	Surface Elevation	8.0 ft. msl
Groundwater Level(s)		Sampling Method(s)	NA	Hammer Data	NA
Borehole Backfill	Well installed.	Comments			



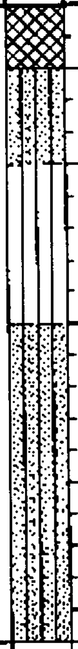
Elevation, feet	Depth, feet	SAMPLES					Graphic Log	MATERIAL DESCRIPTION	Water Content, %	ATTERBERG LIMITS			REMARKS AND OTHER TESTS
		Type	Number	Sampling Resistance, Blows / 6 in.	SPT N-Value, Blows / ft	Recovery, in.				Liquid Limit	Plastic Limit	Plasticity Index	
								Sand, white, recently excavated area					
								Silty SAND with some fine gravels, light brown, moist (SM)					
								Medium to coarse GRAVEL, dark green, moist (GM)					
								Silty sand with gravel, light brown, very wet (SP)					

Report: GEO_10A_GAITH; File: MES.GPJ; 6/5/2002 P-6

URS

Project: MES Stancill Quarry	**Log of Boring P-7**
Project Location: Cecil County, Maryland	Sheet 1 of 1
Project Number: 69-00000229.00	

Date(s) Drilled	10/24/2000 - 10/24/2000	Logged By	E. Koubek	Checked By	J. Kashatus
Drilling Method	HSA	Drill Bit Size/Type		Total Depth of Borehole	20.0 feet
Drill Rig Type		Drilling Contractor	Earth Matters	Surface Elevation	6.0 ft. msl
Groundwater Level(s)		Sampling Method(s)	NA	Hammer Data	NA
Borehole Backfill	Well installed.	Comments			



Elevation, feet	Depth, feet	SAMPLES Type	Number	Sampling Resistance, Blows / 6 in.	SPT N-Value, Blows / ft	Recovery, in.	Graphic Log	MATERIAL DESCRIPTION	Water Content, %	ATTERBERG LIMITS Liquid Limit	Plastic Limit	Plasticity Index	REMARKS AND OTHER TESTS
	0							fill (sand and gravel)					
								Silty SAND, light brown, dry, soft (SM)					
	5							Silty SAND with fine gravel, light brown, moist (ML)					
0													
	10							Silty SAND, trace clay, light brown, very wet (SM)					
	15												
-10													
	20												
	25												
-20													
	30												
	35												
-30													
	40												

Project: MES Stancill Quarry
Project Location: Cecil County, Maryland
Project Number: 89-00000229.00

Log of Boring P-8

Sheet 1 of 3

Date(s) Drilled	10/22/2000 - 10/23/2000	Logged By	E. Koubek	Checked By	J. Kashatus
Drilling Method	HSA	Drill Bit Size/Type		Total Depth of Borehole	95.0 feet
Drill Rig Type		Drilling Contractor	Earth Matters	Surface Elevation	98.0 ft. msl
Groundwater Level(s)		Sampling Method(s)	NA	Hammer Data	NA
Borehole Backfill	Well installed.	Comments			

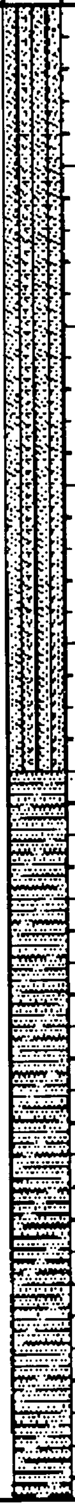
Elevation, feet	Depth, feet	SAMPLES Type	Number	Sampling Resistance, Blows / 6 in.	SPT N-Value, Blows / ft	Recovery, in.	Graphic Log	MATERIAL DESCRIPTION	Water Content, %	ATTERBERG LIMITS Liquid Limit	Plastic Limit	Plasticity Index	REMARKS AND OTHER TESTS
	0							(TOPSOIL) Soil, dark brown					
								CLAY, light brown, some silt, dry (CL)					
	5												
90													
	10							CLAY, light brown to orange, dry, firm (CL)					
	15							SAND, light brown to brown, dry, firm (SP)					
80													
	20							silty SAND, light brown, some gravel, dry, firm (SM)					
	25												
70													
	30												
	35												
60													
	40												

URS

Project: MES Stancill Quarry
Project Location: Cecil County, Maryland
Project Number: 59-00000229.00

Log of Boring P-8

Sheet 2 of 3



Elevation, feet	Depth, feet	SAMPLES Type	Number	Sampling Resistance, Blows / 6 in.	SPT N-Value, Blows / ft	Recovery, in.	Graphic Log	MATERIAL DESCRIPTION	Water Content, %	ATTERBERG LIMITS Liquid Limit	Plastic Limit	Plasticity Index	REMARKS AND OTHER TESTS
	40							silty SAND, light brown, some gravel, trace clay, moist, firm (SM)					
	45												
50													
	50												
	55												
40													
	60												
								Brown, silty SAND with reddish clay, moist, stiff to very stiff (SM)					
	65												
30													
	70												
	75												
20													
	80												
	85												

Report: GEO_10A_GAUTH; File: MES.GPJ; 6/5/2002 P-8

URS

Project: MES Stancill Quarry **Project Location:** Cecil County, Maryland **Project Number:** 89-00000229.00	# Log of Boring P-8 Sheet 3 of 3

Elevation, feet	Depth, feet	SAMPLES Type	Number	Sampling Resistance, Blows / 6 in.	SPT N-Value, Blows / ft	Recovery, in.	Graphic Log	MATERIAL DESCRIPTION	Water Content, %	ATTERBERG LIMITS Liquid Limit	Plastic Limit	Plasticity Index	REMARKS AND OTHER TESTS
10							▨						
	90						▨						NO SIGNIFICANT WATER ENCOUNTERED
	95												
0													
	100												
	105												
-10													
	110												
	115												
-20													
	120												
	125												
-30													
	130												

Report: GEO_10A_GAITH; File: MES.GPJ; 6/6/2002 P-8

URS

Project: MES Stancill Quarry
Project Location: Cecil County, Maryland
Project Number: 89-00000229.00

Log of Boring P-8

Sheet 3 of 3

Elevation, feet	Depth, feet	SAMPLES Type	Number	Sampling Resistance, Blows / 6 in.	SPT N-Value, Blows / ft	Recovery, in.	Graphic Log	MATERIAL DESCRIPTION	Water Content, %	ATTERBERG LIMITS Liquid Limit	Plastic Limit	Plasticity Index	REMARKS AND OTHER TESTS
10							▨						
	90						▨						NO SIGNIFICANT WATER ENCOUNTERED
	95												
0													
	100												
	105												
-10													
	110												
	115												
-20													
	120												
	125												
-30													
	130												

PROJECT:	MES INVESTIGATION	**JOB NO.**	**CLIENT** MES
LOCATION:	STANCILL QUARRY, PERRYVILLE, MARYLAND	**LOCATION**	Quarry
		DRILLING METHOD:	AUGER
		COMPANY:	EARTH MATTERS
		OPERATOR:	Ceasar, Holt
		SAMPLING METHOD:	No Sampling
		LOGGED BY:	Ed Koubek - URS Bethesda
		BORING NO.	P9
		SHEET	1 OF 3

URS

WATER LEVEL			
TIME			
DATE			
CASING DEPTH			

DRILLING

	START	FINISH
TIME	1200	1630
DATE	10.25	10.25

DATUM **ELEVATION**

SURFACE CONDITIONS: ELEVATED ROADWAY ADJACENT TO HOLDING POND. ALONG EDGE OF EXCAVATION.

SAMPLER TYPE	INCHES DRIVEN / INCHES RECOVERED	DEPTH OF CASING	SAMPLE NO. / SAMPLE	BLOW COUNT "N"	SAMPLE NAME	DEPTH (ft)	MONITOR DETAILS	PID READING (ppm)	
NA	NA	NA	NA	NA	NA	0	NA	NA	
						1			
						2			GENERAL FILL FOR ROAD WAY. LOOSE SANDS, GRAVEL. (0'-3')
						3			
						4			
						5			
						6			Light BROWN Silty SAND. FINE to
						7			MEDIUM Mixed with Reddish Clay.
						8			STIFF. DRY. (3-10')
						9			
						0			
						11			
						12			
						13			Light BROWN SAND Silt. FINE to MEDIUM
						14			SOFT. MOIST (10-15')
						15			
						16			
						17			Light BROWN SAND with SOME Silt. FINE WET. SOFT.
						18			(15-19')
						19			
						20			BROWN to Light BROWN

PROJECT:	MES INVESTIGATION	**JOB NO.**	**CLIENT** MES
		DRILLING METHOD:	AUGER
LOCATION:	STANCILL QUARRY, PERRYVILLE, MARYLAND	**COMPANY:**	EARTH MATTERS
		OPERATOR:	Ceasar, Holt
		SAMPLING METHOD:	No Sampling
		LOGGED BY:	Ed Koubek - URS Bethesda

LOCATION Quarry

BORING NO. P9

SHEET 2 **OF** 3

URS

WATER LEVEL			
TIME			
DATE			
CASING DEPTH			

DRILLING		
START		**FINISH**
TIME		**TIME**
DATE		**DATE**

DATUM **ELEVATION**

SAMPLER TYPE	INCHES DRIVEN / INCHES RECOVERED	DEPTH OF CASING	SAMPLE NO. / SAMPLE	BLOW COUNT 'N'	SAMPLE NAME	DEPTH (ft)	MONITOR DETAILS	PID READING (ppm)	SURFACE CONDITIONS: See Sheet 1
NA	NA	NA.	NA	NA	NA	0	NA	NA	
						21			
						22			
						23			
						24			
						25			
						26			
						27			Light Brown to Brown Fine to Medium Silty Sands. Soft
						28			Very Wet.
						29			(19-35')
						30			
						31			
						32			
						33			
						34			
						35			
						36			
						37			Dark Brown Sand with some silt and clay. Very Hard. Moist.
						38			
						39			
						40			

PROJECT:	MES INVESTIGATION	**JOB NO.**	**CLIENT** MES	**LOCATION** Quarry	
		DRILLING METHOD:	AUGER	**BORING NO.**	P9
LOCATION:	STANCILL QUARRY, PERRYVILLE, MARYLAND	**COMPANY:**	EARTH MATTERS	**SHEET**	3
		OPERATOR:	Ceasar, Holt	**OF**	3
		SAMPLING METHOD:	No Sampling		

URS

LOGGED BY:	Ed Koubek - URS Bethesda			
WATER LEVEL				
TIME				
DATE				
CASING DEPTH				

DRILLING	
START	**FINISH**
TIME	**TIME**
DATE	**DATE**

DATUM **ELEVATION**

SAMPLER TYPE	INCHES DRIVEN / INCHES RECOVERED	DEPTH OF CASING	SAMPLE NO. / SAMPLE	BLOW COUNT "N"	SAMPLE NAME	DEPTH (ft)	MONITOR DETAILS	PID READING (ppm)	SURFACE CONDITIONS:
NA	NA	NA	NA	NA	NA	0	NA	NA	
						41			
						42			
						43			
						44			WEATHERED SAPROLITE. VERY HARD. DRY.
						45			BORING TERMINATED AT 45' BGS
						6			
						7			
						8			
						9			
						0			
						1			
						2			
						3			
						4			
						5			
						6			
						7			
						8			
						9			
						0			

PROJECT: Stancill Quarry / MES

LOCATION: Perryville MD

URS

JOB NO.

CLIENT MES

LOCATION STANCILL QUARRY

DRILLING METHOD: Auger

COMPANY: Chesapeake Geo Systems

OPERATOR:

SAMPLING METHOD: Spoon

BORING NO. 10

SHEET 1 OF 4

LOGGED BY: Ed Kobek

WATER LEVEL			
TIME			
DATE	10.24		
CASING DEPTH			

DRILLING	
START	FINISH
TIME	TIME
DATE	DATE

DATUM

ELEVATION

SURFACE CONDITIONS: CENTRAL LOCATION WITHIN QUARRY. Also lowest elevation. LOCATED on the North SIDE OF A ROADWAY THAT SEPARATED TWO ONSITE holding POND. SURFACE WAS MIX. SAND & gravel

SAMPLER TYPE	INCHES DRIVEN / INCHES RECOVERED	DEPTH OF CASING	SAMPLE NO. / SAMPLE DEPTH	BLOW COUNT "N"	SAMPLE NAME	DEPTH (ft)	MONITOR DETAILS	PID READING (ppm)	
						0			
						1			TYPICAL ROAD BASE FILL MATERIAL. MIX OF SAND & GRAVEL
						2			
						3			
						4			DARK BROWN SAND WITH SOME gravel. FINE TO MEDIUM. DRY & SOFT
						5			
						6			2' – 9'
						7			
						8			
						9			Light Brown SILTY SAND. FINE TO MEDIUM MOIST
						0			(8'–11')
						11			
						12			
						13			LIGHT BROWN SANDY SILT. FINE to MEDIUM. SOFT. WET
						14			
						15			(11' – 17')
						16			
						17			
						18			BROWN TO LIGHT BROWN SANDY SILT. FINE to Very FINE. Very WET.
						19			
						20			17' – 24'

PROJECT: STANCILL Quarry

LOCATION: Perryville, MD

URS

JOB NO.

CLIENT

LOCATION

DRILLING METHOD:

BORING NO.

COMPANY:

OPERATOR:

SHEET 2 OF 8

SAMPLING METHOD:

Sheet 1

LOGGED BY:

	DRILLING	
START		FINISH
TIME		TIME
DATE		DATE

WATER LEVEL			
TIME			
DATE			
CASING DEPTH			

DATUM

ELEVATION

SURFACE CONDITIONS: See Sheet 1

SAMPLER TYPE	INCHES DRIVEN / INCHES RECOVERED	DEPTH OF CASING	SAMPLE NO / SAMPLE DEPTH	BLOW COUNT 'N'	SAMPLE NAME	DEPTH (ft)	MONITOR DETAILS	PID READING (ppm)	
						20			
						21			
						22			CONTINUED FROM PREVIOUS PAGE
						23			
						24			
						25			
						26			
						27			
						28			
						29			BROWN TO LIGHT BROWN SANDY SILT. DRY. FINE TO MEDIUM.
						30			24'—40'
						31			
						32			
						33			
						34			
						35			
						36			
						37			
						38			
						39			
						40			

PROJECT:	STACILL Quarry	**JOB NO.**	**CLIENT**	**LOCATION**
LOCATION:	Perryville, MD	**DRILLING METHOD:**		**BORING NO.**
		COMPANY:		**SHEET** 3 **OF** 8
		OPERATOR:		
		SAMPLING METHOD:		
URS		**LOGGED BY:** SHEET 1		

WATER LEVEL				
TIME				
DATE				
CASING DEPTH				

DRILLING		
START		**FINISH**
TIME		**TIME**
DATE		**DATE**

DATUM **ELEVATION**

SAMPLER TYPE	INCHES DRIVEN / INCHES RECOVERED	DEPTH OF CASING	SAMPLE NO / SAMPLE RECOVERY	BLOW COUNT /6"	SAMPLE NAME	DEPTH (ft)	MONITOR DETAILS	PID READING (ppm)	SURFACE CONDITIONS: See Sheet 1
						0			
						41			
						42			GREY HARD WEATHERED SAPROLITE
						43			
						44			
						45			
						46			
						47			
						48			Dry
						49			
						50			
						51			Bedrock
						52			
						53			to 150'
						54			
						55			
						56			
						57			
						58			
						59			
						60			

PROJECT:	Stancill Quarry	**JOB NO.**	**CLIENT**	**LOCATION**	
LOCATION:	Perryville, MD	**DRILLING METHOD:**		**BORING NO.**	
		COMPANY:		**SHEET** 4 **OF** 8	
		OPERATOR: See Sheet 1			
		SAMPLING METHOD:		**DRILLING**	
		LOGGED BY:		**START**	**FINISH**
		WATER LEVEL		**TIME**	**TIME**
		TIME			
		DATE		**DATE**	**DATE**
DATUM	**ELEVATION**	**CASING DEPTH**			

URS

SAMPLER TYPE	INCHES DRIVEN / INCHES RECOVERED	DEPTH OF CASING	SAMPLE NO / SAMPLE DEPTH	BLOW COUNT "N"	SAMPLE NAME	DEPTH (ft)	MONITOR DETAILS	PID READING (ppm)	SURFACE CONDITIONS: See Sheet 1
						0			
						61		↑	Dry Bedrock
						62			
						63			
						64			
						65			
						66			
						67			
						68			
						69			
						70			
						71			
						72			
						73			
						74			
						75			
						76			
						77			
						78			
						79			
						80		↓	

PROJECT:	Stancill Quarry	**JOB NO.**	**CLIENT**
LOCATION:	Perryville, MD	**DRILLING METHOD:**	

URS

COMPANY:
OPERATOR:
SAMPLING METHOD:
LOGGED BY:

Sheet 1

LOCATION
BORING NO.
SHEET 5 **OF** 8

WATER LEVEL			
TIME			
DATE			
CASING DEPTH			

DRILLING	
START	**FINISH**
TIME	**TIME**
DATE	**DATE**

DATUM
ELEVATION

SURFACE CONDITIONS: See Sheet 1

SAMPLER TYPE	INCHES DRIVEN / INCHES RECOVERED	DEPTH OF CASING	SAMPLE NO. / SAMPLE RECOVERY	BLOW COUNT /6"	SAMPLE NAME	DEPTH (ft)	MONITOR DETAILS	PID READING (ppm)	
						0			
						81		↑	
						82			
						83			
						84			
						85			
						86			
						87			Dry Bedrock
						88			
						89			
						90			
						91			
						92			
						93			
						94			
						95			
						96			
						97			
						98			
						99			
						100		↓	

PROJECT:	STANCILL Quarry	JOB NO.	CLIENT
LOCATION:	Perryville MD	DRILLING METHOD: COMPANY: OPERATOR: SAMPLING METHOD: Sheet 1	

URS

LOCATION

BORING NO.

SHEET 6 OF 8

LOGGED BY:

WATER LEVEL			
TIME			
DATE			
CASING DEPTH			

DRILLING	
START	FINISH
TIME	TIME
DATE	DATE

DATUM

ELEVATION

SURFACE CONDITIONS: See Sheet 1

SAMPLER TYPE	INCHES DRIVEN / INCHES RECOVERED	DEPTH OF CASING	SAMPLE NO / SAMPLE	BLOW COUNT "N"	SAMPLE NAME	DEPTH (ft)	MONITOR DETAILS	PID READING (ppm)	
						0			
						101		↑	
						102			
						103			
						104			
						105			
						106			
						107			Dry
						108			Bedrock
						109			
						110			
						111			
						112			
						113			
						114			
						115			
						116			
						117			
						118			
						119			
						120		↓	

PROJECT:	Stancil Quarry	JOB NO.	CLIENT
LOCATION:	Perryville MD	DRILLING METHOD:	

COMPANY:
OPERATOR:
SAMPLING METHOD: Sheet 1

LOCATION
BORING NO.
SHEET 7 OF 8

URS

LOGGED BY:

WATER LEVEL			
TIME			
DATE			
CASING DEPTH			

DRILLING		
	START	FINISH
TIME		
DATE		

DATUM
ELEVATION

SURFACE CONDITIONS:
See Sheet 1

SAMPLER TYPE	INCHES DRIVEN / INCHES RECOVERED	DEPTH OF CASING	SAMPLE NO / SAMPLE RECOVERY	BLOW COUNT "N"	SAMPLE VALUE	DEPTH (ft)	MONITOR DETAILS	PID READING (ppm)	
						0			
						121			Dry Bedrock
						122			
						123			
						124			
						125			
						126			
						127			
						128			
						129			
						130			
						131			
						132			
						133			
						134			
						135			
						136			
						137			
						138			
						139			
						140			

PROJECT:	STANCILL Quarry	JOB NO.	CLIENT	LOCATION
LOCATION:	Perryville, MD	DRILLING METHOD:		BORING NO.
		COMPANY:		SHEET 8 OF 8
		OPERATOR:		
		SAMPLING METHOD: Sheet 1		
URS		LOGGED BY:		DRILLING

WATER LEVEL				START	FINISH
TIME				TIME	TIME
DATE				DATE	DATE
CASING DEPTH					

DATUM

ELEVATION

SAMPLER TYPE	INCHES DRIVEN / INCHES RECOVERED	DEPTH OF CASING	SAMPLE NO / SAMPLE RECOVERY	BLOW COUNT "N"	SAMPLE NAME	DEPTH (ft)	MONITOR DETAILS	PID READING (ppm)	SURFACE CONDITIONS: See Sheet 1
						0			
						141			
						142			
						143			Dry
						144			
						145			
						146			
						147			Bedrock
						148			
						149			BORING TERMINATED @ 150'
						150			
						1			
						2			
						3			
						4			
						5			
						6			
						7			
						8			
						9			
						0			

APPENDIX C

Conceptual Hydrogeologic Report

The available measurements or observations cannot provide complete coverage of all the data types required for model input requirements for the entire range of the groundwater model domain. Data gaps must be filled to develop a reliable groundwater model. For example, hydrogeologic properties are only known for a few locations. Also, much of the hydrogeologic data are from slug tests, which can have errors in accuracy on the order of magnitude. Other data gaps include estimation of the elevations of the top of saprolite in areas with no boring logs, and estimation of the groundwater surface in all aquifer zones in areas distant from the monitoring well data. Data gaps are filled by interpretation of measurements. Information is available to estimate a range of values for these data gaps. These estimates also provide another check on the data generated from actual measurements.

Data gaps in hydrogeologic properties can be estimated by assuming published hydrogeologic values of geologic materials for similar geologic materials identified in the site boring logs. Water-surface elevations can be estimated by drawing contour maps using known values.

A hydrogeologic interpretation of the Stancill Quarry and surrounding area was developed using the available data and information sources. These sources included the geologic interpretation (URS, 2002); piezometric surface data collected from monitoring wells over several months; and hydraulic conductivities estimated from lithologic log interpretations, slug test data, and site observations.

2.1 REGIONAL HYDROGEOLOGY

Cecil County has two distinct types of geologic and physiographic terrains: the Piedmont and the Coastal Plain. The boundary between these terrains is termed the Fall Line. In the Piedmont west of the Fall Line, hard crystalline igneous and metamorphic rock occurs at or near land surface. East of the Fall Line, the surface of the crystalline rock slopes southeastward beneath a progressively thicker cover of unconsolidated sedimentary strata consisting of silt, clay, sand, and gravel.

Drainage is well developed in both the Piedmont and Coastal Plain, except for a few marshes along the margins of the Chesapeake Bay. Stream gradients along some Piedmont streams are 100-to 150 ft./mile, but they are much flatter on the Coastal Plain.

Precipitation is the source of freshwater in the region. Some water from precipitation runs across the ground into streams, some of it soaks into the ground, and some evaporates. Most of the water that soaks into the ground is held in the soil and used by plants. Excess water in the soil moves downward to the water table and recharges the groundwater reservoir.

Almost all groundwater movement in the Piedmont is between interstream drainage divides and adjacent streams. In the Coastal Plain, deeper interbasin flow is also significant. The streams, with rare exceptions, act as drains for the groundwater reservoir. Groundwater discharge to streams is the source of the base flow that sustains stream flow between precipitation events. Higher stream flows are produced by overland runoff during and following storms.

A large percentage of the water derived from precipitation is returned to the atmosphere through evaporation and transpiration (collectively termed evapotranspiration). Most evapotranspiration is from soil moisture, but it also may come directly from groundwater (groundwater evapotranspiration) when the water table is near the land surface.

Groundwater conditions differ considerably between the Piedmont and the Coastal Plain. In the Piedmont, water occurs in openings in the crystalline rock that are caused by fracturing and weathering of the rock. Although water within an individual fracture may be confined by the adjacent rock, the system functions on a somewhat larger scale as a water-table (unconfined) system. In the Coastal Plain, water occurs between grains in the sediments. Except in out-crop areas, these sedimentary units generally function as confined aquifers.

Since the Stancill Quarry is located only about ½ mile from the nearest exposures of crystalline basement rocks along Principio Creek, which is near Principio Furnace, Maryland, the hydrogeologic regime at the site shares aspects of both the Piedmont and Coastal Plain. Although deposits of Cretaceous and Quaternary/Tertiary age are observed in the quarry, their combined thickness is generally less than 65 ft., and they overlie a laterally continuous zone of saprolite, the weathered residuum of the crystalline basement rocks of the Piedmont.

2.2 PIEDMONT HYDROGEOLOGY

The availability of groundwater in the crystalline rock of the Piedmont depends on the nature and distribution of secondary openings resulting from fracturing and weathering. Crystalline rock is highly indurated and contains free water only in openings where the rock has been fractured or decomposed by weathering. Permeability of fractured rock depends on the number of fractures, the size of the fracture openings, and the interconnection of the fractures.

Various stresses have produced complex systems of fractures oriented at numerous angles, including horizontal and vertical. A group of closely spaced vertical fractures may sometimes result in a linear feature that can be mapped. In places where these fractures result in a weakened or otherwise altered zone in the rock, they may show up in the field or on aerial photographs as a straight stream segment or a linear variation in topography, vegetation, or soil.

Weathering increases the size of fracture openings, but it is most significant because of the saprolite zone it produces. The mechanical and chemical breakdown of rock by air, water, temperature, and biological activity has created a mantle of unconsolidated, weathered rock (saprolite) at the land surface in the geologic past. The process works progressively downward from the surface. This unconsolidated zone grades from a soil at the land surface, to decomposed rock, to crumbly gravel-like material where pieces of rock remain in place in a clayey matrix. Below the unconsolidated zone, the rock is generally solid, but some minerals are weathered along the fractures.

The major hydrogeologic significance of the weathered mantle is that it acts as a storage reservoir, providing water infiltrating from the ground surface to the fracture systems in the underlying sound rock that supplies water to wells. Recharge moves into this unconsolidated zone and discharge moves out to streams and to evapotranspiration. A large volume of water remains in storage in this unconsolidated zone.

2.3 COSTAL PLAIN HYDROGEOLOGY

The Coastal Plain sediments consist of unconsolidated, stratified layers of clay, silt, sand, and gravel that rest on a sloping basement of crystalline rock. The basement surface slopes southward at a rate of about 100 ft./mi. The maximum thickness of the Coastal Plain sediments in Cecil County occurs in the extreme southeastern corner of the county and is estimated to be at 1,600 ft.

The major aquifers in Cecil County are the upper and lower Potomac aquifers of early Cretaceous age. The total sequence of sediments comprising the Cretaceous Potomac Group in Cecil County are divided into three hydrogeologic units: (1) the upper Potomac aquifer, (2) the middle Potomac confining unit, and (3) the lower Potomac aquifer (Otton et al., 1988). The lower Potomac aquifer is about 500 ft. thick at Cecilton. The unit thins updip (northward), and at Elkton it is only about 180 ft. thick. The lower aquifer is present throughout most of the southern two-thirds of the county. A series of mostly clayey and silty beds comprise the middle Potomac confining unit above the lower unit. Some water-bearing sand occurs within the confining unit, but finer-grained materials predominant. This unit is about 325 ft. thick at Cecilton. At Chesapeake City, the confining unit is only about 230 ft. thick. Lying above the confining unit is the upper Potomac aquifer, which is about 235 ft. thick at Cecilton. Erosion has removed the upper Potomac aquifer from much of the area and it remains only in the southern one-third of the county.

The hydrologic subdivisions of the Potomac Group used by Otton et al. (1988) are not intended to infer stratigraphic correlation or uniform lithology. All of the units have a high degree of variability, both vertically and horizontally. Somewhat arbitrary boundaries are drawn between units based on predominance, or not, of water-bearing lithologies—sand and gravel.

Sand layers in the Potomac Group are white to orange-brown, cross-bedded, moderately well sorted, and mostly quartzose. Gravel is almost entirely quartz or quartzite clasts, usually less than 3 inches in diameter. Some large cobbles are found in the lower part of the unit. Localized iron-cemented layers occur throughout the section, varying from fractions of an inch to a few feet in thickness. Clay may be silty and runny, or tough, compact, and almost dry in places. The colors of fine materials range from white and yellow to deeper shades of red, purple, and dark gray. Localized occurrences of lignite and pyrite are common.

The Cretaceous deposits encountered at the Stancill Quarry appear to correspond to the Potomac Group, and their lithologic character corresponds closely to the description of the middle Potomac confining unit, which is predominantly silt and clay (Otton et al., 1988).

On the eastern shore of Chesapeake Bay, the Potomac Group is overlain by a considerable thickness of mostly marine sediments, including the Magothy Formation, Matawan Group, and Monmouth Group of late Cretaceous age; and Hornerstown and Aquia Formations of Paleocene age (Otton et al., 1988). However, none of these units is known to extend as far west as the Stancill Quarry, although their updip non-marine age equivalents may be present locally in the Coastal Plain of the western shore.

2.4 TERTIARY/QUATERNARY DEPOSITS

The deposits of post-Cretaceous age in the Coastal Plain west of Chesapeake Bay are poorly known and defined (URS, 2002). As most water wells in the area tap Cretaceous sands or are completed in the crystalline basement rocks (Otton et al., 1988), little specific data are available on the hydrogeology of the Tertiary/Quaternary deposits. As observed in boreholes at the Stancill Quarry, these materials consist mainly of light brown, unconsolidated silty sands and silts. Gravel was reported in several boreholes, generally in the uppermost 10 ft. of the hole. In these holes, gravel and sand generally graded into silts and silty sands near the base of the unit.

The general principles underlying the origin, storage, and movement of groundwater are described in detail in standard textbooks. They are discussed very briefly here and only insofar as they explain technical terms used in the report.

Groundwater is derived almost entirely from precipitation. It is the portion of the precipitation (rain or melting snow) that moves from the land surface into the soil by infiltration and then into underground storage and circulation. Groundwater is defined as water in the zone of saturation. Of the water that falls on the land surface only about one-third gets into the groundwater reservoirs. The greatest losses occur through evaporation and transpiration by vegetation, both of which return water to the atmosphere.

The direct surface runoff is the portion of the precipitation that has not gone underground but runs over the surface as streams. Total runoff includes groundwater that discharges into streams, maintaining their base flow. Total surface runoff in basins studied in Maryland ranges from 29% to 43% of the precipitation (Overbeck and Slaughter, 1958).

The infiltration capacity of the soil depends on many factors, the most important of which are the texture and composition of the soil. Most of the land in the upper Chesapeake Bay area is cultivated and forested areas are small (16%). The soil is generally loamy or sandy. Infiltration capacity varies, however, in conformity with the soil type, as illustrated by the fact that in some areas farm ponds retain water and in others they do not.

The rate and amount of infiltration also depends on climatic conditions. When precipitation occurs, the first requirement it must fulfill is to make up moisture deficiency in the soil. After this has been satisfied, the water is free to move downward or over the surface. If the rainfall is heavy, runoff occurs as a sheet movement over the surface to the streams. This water does not reach the groundwater reservoir unless the streambed is above the water table and loses water to it. A slow long-continued rain or melting snow will contribute most to the groundwater supply. In the growing season or in the winter, when the ground is frozen hard, little water gets into the groundwater system.

The process whereby the water of infiltration becomes groundwater is called recharge. When the groundwater reservoir is full and more water is added, excess water will move out of the reservoir as springs or seeps. This excess water is called groundwater discharge or runoff. It keeps the streams flowing after direct runoff has ceased.

Groundwater is stored in, and moves through, open spaces in the rocks. The property of a rock whereby it contains openings is called its porosity. Porosity, which is expressed in percentages, is the ratio of the total volume of the rock occupied by openings to the total volume of the rock. A rock having a porosity of 25% is three-quarters solid rock and one-quarter openings. Open spaces in rocks differ greatly in size, shape, and arrangement, depending on the physical character of the rock in which they occur. Fresh crystalline rocks are only slightly porous, and openings in them are along fractures, joints, and parting planes, and planes of cleavage or schistosity. In the weathered crystalline rock and in the Coastal Plain deposits, the openings are the interstices or pores between gravel, sand, clay, and silt grains. The shape, assortment, and compaction of the grains determine the porosity of the rock.

The size of openings in an unconsolidated rock is one of the chief properties of the rock that controls the movement of water through the rock or storage in it. Large openings, such as those in a well-sorted coarse gravel bed, permit the free passage of water. In small openings, the effects of molecular forces that impede the flow of water under gravity become marked. In rocks having very small openings, such as silt or clay beds, most of the water under naturally stable conditions is held fast and the bed is said to be impervious. Such beds are called aquicludes. The natural conditions may be changed, however, so that the pressure on the aquiclude is increased or decreased. The withdrawal of water from an aquifer in a confined system, for example, causes an increase of rock pressure and water is squeezed from the aquicludes into areas of lower pressure.

The water in a rock that is not held in storage by molecular attraction is called the specific yield of the rock. This water is free to drain out of the rock under natural conditions.

As water sinks downward from the surface through openings in the rocks, it reaches a certain level, called the water table, below which is a zone in which the openings are filled with water under hydrostatic pressure, which is called the zone of saturation. Above the water table, the openings are only partly filled with water that is downward moving or is held by molecular attraction. The direction of motion of water in the saturated zone generally has a predominately horizontal component in the direction of decreasing groundwater elevations, which is called hydraulic gradient. The water table is a gently undulating surface that commonly conforms roughly to the major undulations of the land surface. The water table is a free surface that fluctuates slowly as water is added to or taken away from the groundwater reservoir. The position of the water surface in a water table in an artesian well (a well that flows without being pumped) coincides with the piezometric surface (the elevation to which groundwater would rise if it was confined to a tube) at the well—that is, the position the surface of the water takes when the aquifer is under artesian pressure. The water level in an artesian well rises above the water-bearing stratum, but an artesian well is not necessarily a flowing well. A flowing well results only when the artesian head is sufficient to raise the level above the collar of the well at the land surface. In some artesian wells drilled near tidewater, tidal forces may cause an artesian well to flow part of the time.

Several terms that are used to describe the hydrologic properties of a water-bearing bed or aquifer require definition. The capacity or ability of a rock or formation to transmit water under pressure is called its permeability. The field coefficient of permeability is the number of gallons per day at the prevailing temperature that would flow through a cross-section 1-ft. square under a unit hydraulic gradient, that is, a difference of 1 ft. in head and 1 ft. of travel. A term more frequently used is coefficient of transmissibility (T), which is the field coefficient of permeability multiplied by the thickness in feet of the saturated part of the aquifer.

The definition of the coefficient of storage as used by the U.S. Geological Survey is:

> "…the coefficient of storage of an aquifer is the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface…"

The coefficient is a ratio expressed as a decimal fraction. It is very small for an artesian aquifer, generally between 0.001 and 0.00001. The coefficient of storage in a water-table aquifer is for practical purposes equal to the specific yield of the aquifer, and it is usually between 1% and 20% or 30%.

The "safe yield" of an aquifer is the yield "at which water can be withdrawn from an aquifer for human use without depleting the supply to such an extent that withdrawal at this rate is no longer economically feasible" (Freeze and Cherry, 1979). Over pumping may cause such great lowering of the water level that neighboring wells may be deprived of water or forced to install other types of pumps. It may lower the hydrostatic pressure of the wells so far as to permit the encroachment of salt or brackish water from bodies of surface water. Or, it may affect the head relationship between two aquifers so that the water from an aquifer containing poor water (water with unacceptable geochemical characteristics) may enter and contaminate the water of an aquifer containing good water.

Groundwater is commonly in very slow motion in the rock or aquifer in which it occurs. A popular misconception is that water moves underground in rivers, analogous to those on the land surface. Under natural conditions, the velocity of water underground rarely exceeds more than a few feet per day. In some of the aquifers in the area, water has traveled hundreds of years to reach its present location. The velocity of the water depends on the permeability of the rock in which it occurs and on the hydraulic gradient or head under which it moves; in areas where these are low, the water barely moves at all.

In the quarry area, discharge from the groundwater reservoirs is almost entirely a natural discharge. Artificial discharge through pumps is a very small part of the total discharge. Natural discharge takes place through seeps and springs, chiefly along the sides and bottoms of streams. Discharge may also take place through evapotranspiration if the plant roots reach the saturation zone or if the water table is very near the land surface. Due to leakage through breaks or slight permeability in the confining beds, water in confined aquifers may move from one aquifer into another or even to the land surface. Some water moves down the dip beneath the coast, eventually to discharge into the ocean.

4.1 WATER-LEVEL FLUCTUATIONS AND GROUNDWATER CONTOURS

Water-level data collected from boreholes P-1 through P-9 are presented in Table 2 and shown graphically on Figure 2. Table 2 summarizes groundwater level measurements taken for the previous (E2CR, 2000) and current studies. Figure 2 graphically represents the monthly groundwater level elevations obtained for the current study in boreholes P-1 through P-9. With the exception of borehole P-5, which showed little change throughout the November 2001 to April 2002 time period, most of the boreholes showed modest declines from November 2001 to March 2002 and a slight increase in April 2002. This trend is consistent with severe drought conditions that prevailed in northern Maryland throughout the period of measurement.

Groundwater flow maps were generated from those readings. The flow was similar in all measurements taken for the current study, but they differed slightly from measurements taken for the previous study (E2CR, 2000). The groundwater flow patterns in the surficial aquifer vary depending on the location within the model area. Groundwater flow patterns are affected by factors such as the distance from natural recharge and discharge points, the location and size of natural recharge zones, changes in lithology, seasonal fluctuations in precipitation, and extraction of groundwater by production wells. As the surficial aquifer, outside of Stancill Quarry, is believed to discharge to surface water bodies, the elevation of the groundwater at the tidal contacts was assumed to be mean water level measured at a tidal gage station near Havre de Grace, Maryland.

Figure 10 is a graph of the monitoring of water levels in piezometer P-6 over the period November 2001 through April 2002. The effect of the drought can be seen more readily on Figure 10, which has an expanded vertical scale and also shows rainfall events at Raintree Airport in Elkton, Maryland, about 8 miles east of Stancill Quarry. Although not all rainfall events were reflected in the water level at borehole P-6, several were marked by a significant rise in water level followed by a pronounced decline. These effects are ascribed to runoff within the quarry to the pond near P-6, followed by pumping from the pond to other reservoirs on the property.

The pronounced decline in water level in P-6 from January 30, 2002 to March 7, 2002 is attributed to a decline in groundwater storage during the drought. The overall trend suggests that a rough balance between recharge and discharge to the quarry was maintained up through January 30, 2002, but that net discharge exceeded recharge from January 30 2002 to March 7, 2002.

Under natural conditions, groundwater flow in the coastal plain deposits in the area of Stancill Quarry would have been generally southwesterly across the Stancill site to areas of discharge along Furnace Bay. However, the excavation of the Stancill Quarry has modified the groundwater and surface flow regime. The quarry now traps precipitation formerly collected by streams discharging to Furnace Bay, and the quarry also largely intercepts groundwater. Moreover, as water plays a major role in processing of the mined product, its management plays a major role in the hydrology of the site. The site includes a series of ponds and impoundments at varying elevations used to contain and treat water used in processing and washing operations. Previous reports (E2CR, 2000) document that there is no surface water discharging from the quarry, and it is difficult to ascertain with available data whether there is net groundwater discharge from or recharge to the site.

An essential element in hydrogeologic evaluation is a water-level contour map, under both confined and unconfined conditions. Such maps are prepared by plotting the elevation of the static water surface in wells and drawing lines of equal elevation or contours of the water surface. These contours delineate the shape of the water table, or confined water surface, as the case may be, in the area under study. As groundwater flows down and normal to the hydraulic gradient, water-level contours portray the direction of groundwater movement, and give a measure of the slope of the hydraulic gradient, which is necessary for calculating the quantity of groundwater flow.

Throughout the current investigation (October 2001 to April 2002), the water-level contours (Figures 3–8) at the Stancill Quarry have consistently shown groundwater flow inward toward the quarry from all directions toward the lowest elevation pond (about mean sea level) in the quarry floor. However, in October 2000, groundwater levels recorded in temporary wells installed in the quarry showed a slightly different flow pattern. A map of the piezometric surface using the October 2000 groundwater measurements shows a groundwater gradient to the south and spreading laterally as it moves southward. Similar to the current data, this drawing is based on limited data points and the contours may exhibit a similar internal accumulation of water that is observed in Figures 3–8 if more data points were available. It should be noted that well E-6 in the southwestern portion of the quarry suggests the possibility of leakance out of the quarry at that point. Based on a slope failure into Principio Creek in the past, it is possible that ponded water may be seeping out of the sides of the pond in that portion of the quarry, or it may be seeping out of the bottom of the settling pond when the settling pond is dredged and the bottom is disturbed. If a monitoring well were installed in the vicinity of abandoned well E-6 as part of the current study, it is possible that the groundwater contours would be altered. It is reported elsewhere (E2CR, 2000) that no water is discharged from the quarry to the waters of the state, although an unmeasured amount is believed to leave the quarry with product, suggesting that most direct precipitation on the site is consumed by evaporation and quarry operations.

4.2 WATER BUDGET

The water budget for the Stancill Quarry can be summarized in the expression:

Recharge ? Discharge = Change in Storage.

Recharge to the quarry consists of direct precipitation on the quarry plus groundwater inflow, as the nearby terrain offers little opportunity for surface runon or runoff.

Discharge from the quarry consists of natural evapotranspiration, water consumed in processing product (mainly by evaporation processes), water exported with product, and possibly leakage from the higher altitude silt settling pond. It is reported that no point discharge, as by pumping, is practiced (E2CR, 2000)

Change in storage can be either as surface storage in siltation ponds, holding reservoirs, and sumps, or as change in groundwater storage, reflected by rises and declines in groundwater levels.

It appears that under current operating conditions, the quarry maintains an approximate balance between recharge and discharge elements, so that neither import or export of water other than those specified above are required to maintain a dry-pit operation.

The recharge components lend themselves to quantification. Precipitation can be estimated from nearby weather stations and groundwater inflow can be calculated with knowledge of the hydraulic gradient and transmissivity of materials in the saturated zone.

The discharge components are less readily quantified. Evaporation and transportation can be estimated from nearby weather station records, but the precision of such estimates is dubious. Water consumed in processing and exported with product is essentially unknown. Finally, there is a possibility of leakage offsite from the large desilting pond on the southwestern part of the quarry. Although the likelihood of large-scale leakage from a siltation pond seems remote, water-level data to exclude this possibility are not available, nor are records of water transferred into or out of the siltation pond. Thus, other than estimates of evapotranspiration all other discharge elements must be arrived at by difference calculations.

Changes in storage in principle are straightforward calculations. Change in surface water storage is simply a matter of accounting for volume changes in the several ponds in the quarry. However, records of such changes are not available. While changes in pond level occur frequently over short time periods due to operational needs, such changes probably are minimal over longer periods of years.

Changes in groundwater storage require knowledge of groundwater level fluctuations beneath and beyond the quarry over time. Except for water-level fluctuation measured during the present investigation, no such data exist. Moreover, specific yield data on materials in the zone of water-level fluctuations are not available, although specific yield can be estimated from lithologic character. It is obvious that over the long-term considerable groundwater-storage depletion has occurred due to excavation of the quarry and the need to maintain a dry pit. A reasonable estimate of water-level decline from natural conditions could be constructed from drillers' records and old topographic maps. Combined with estimated specific yield based on lithologic character of materials excavated in quarrying, this would produce an approximation of change in groundwater storage since quarrying began.

Groundwater modeling studies conducted at Aberdeen Proving Ground 10 miles southwest of Stancill Quarry and within the same geologic and hydrogeologic units (Whitten et al., 1992; McDonald Morrissey Associates, Inc., 1994) included the following hydrogeologic information for use in the MODFLOW model:

- Average precipitation is 45 inches per year (in/yr) from 1969 to 1990; 48 to 49 in/yr respectively for 1989 and 1990 (Whitten et al., 1992)
- Total evapotranspiration rates are 25 to 28 in/yr (Drummond, 1993; Rasmussen and Andreason, 1959)
- Average annual recharge to the aquifer is 12 to 13 in/yr (Advanced Sciences, Inc. and McDonald Morrissey Associates, Inc., 1994) based on:
  - 45 inches of precipitation (Whitten et al., 1992)
  - 52% infiltration (Rasmussen and Andreason, 1959)
  - 23% of total precipitation evaporates from groundwater (Rasmussen and Andreason, 1959)

Pan evaporation averages 40.91 in/yr (Whitten et al, 1997). The adjustment factor or pan coefficient for lakes in the U.S. varies from 0.64 to 0.81 (Bedient and Huber, 1995). Since the ponds on the Stancill Quarry property are shallow water and the water is potentially warmed while it is used for processing, the ponds can heat up and evaporate water quicker than the average lake. Therefore, the higher value of 0.81 is used to convert to evaporation from the ponds, resulting in 33.14 inches of water per year being evaporated from the ponds. Average lake evaporation for this part of the U.S. is 35 in/yr mean annual lake evaporation, based on data collected from 1946 to 1955 (Bedient and Huber, 1995).

As described elsewhere (URS, 2002), the materials at the Stancill Quarry from bottom upward consist of (1) crystalline igneous and metamorphic rocks, of great but unknown thickness; (2) residuum of the crystalline rock, weathered in place, termed sapprolite; (3) non-marine sediments of early Cretaceous age of the Potomac Group; and (4) unconsolidated non-marine deposits overlying the Potomac Group believed to be of Tertiary/Quaternary age. The following sections summarize the information available on the hydrologic properties of these materials. Table 3 is a summary of this information.

5.1 CRYSTALLINE IGNEOUS AND METAMORPHIC ROCKS

Crystalline igneous and metamorphic rocks underlie the entire Piedmont region of Maryland and adjoining states, and are the principle source of groundwater to rural households and small communities throughout the region. Even where overlain by saprolite or unconsolidated younger deposits, wells are generally cased-off opposite the younger material to prevent surficial contamination.

The permeability of unfractured, fresh, crystalline rock is generally near zero. Water moves through crystalline rock only where the rock is weathered or fractured, and the yield of a well depends primarily on the amount of fracture openings penetrated by the well. Rock type influences the yield of wells by affecting the way the rock weathers and fractures. The yield data of Otton et al. (1988), however, only show minor differences between the crystalline units in Cecil County. The median yield of all units is 10 gal/min, except for the upper and lower members of the James Run Formation, the unit underlying the Stancill Quarry, which have a median yield of only 6 gpm (Table 3). The median specific capacity (gpm/ft. of drawdown) of all wells tapping the James Run Formation was between 0.1 and 0.2 (Otton et al., 1988) as compared to a median of 0.3 for all wells in crystalline rocks in the Piedmont of Cecil County. A 210-ft. deep well drilled at the Stancill Quarry into the crystalline bedrock reportedly yielded 11 gpm with 60 ft. drawdown, indicating a specific capacity of 0.2 gpm/ft. Other wells in the general vicinity of the quarry ranged in yield from 0.1 to 30 gpm, and in specific capacity from less than 0.1 to 4.6 gpm/ft. (Willey et al., 1987). The average was 0.9 gpm/ft.(Table 3) for the 12 wells for which specific capacity was reported.

5.2 SAPROLITE

The residuum of the crystalline rock, weathered in place, appears to form a continuous blanket covering the basement rocks at the Stancill Quarry (URS, 2002). Evidently, the saprolite at the quarry was covered in early Cretaceous time (about 100 million years ago) by an unknown thickness of stream deposits of the Potomac Group, and of Quaternary/Tertiary age, which subsequently have protected the saprolite from erosion. The considerable thickness of overlying deposits (not known due to erosion) would have caused compaction and an increase in density of the saprolite.

No information is available regarding the permeability of the saprolite in the vicinity of the Stancill Quarry; however, data from similar deposits elsewhere in Maryland suggest that permeability should be in the range of 1 ? 10^{-4} to 1 ? 10^{-6} cm/sec (Table 3).

5.3 POTOMAC GROUP

The Potomac Group is laterally discontinuous at the Stancill Quarry (URS, 2002), where it has been eroded in past Cretaceous time. Yields of wells in the Potomac Group in the vicinity of Stancill Quarry ranged from 1 to 100 gpm and specific capacity from 0.2 to 3.7 gpm/ft. The average specific capacity for 14 wells for which data were available in the vicinity of Stancill Quarry was 1.2 gpm/ft. (Willey et al., 1987) (Table 3).

Specific data on permeability of the Potomac Group deposits at the quarry is available for two samples reported by E2CR. A sample from 18 to 18.75 ft. at borehole E-1 (Figure 2 and Table 3), tested in the laboratory, showed permeability of 5.6 ? 10^{-6} cm/sec. in material described as white, moist clayey silt and fine to medium sand (ML). Another sample from 13.5 to 15.5 ft. at borehole E-2 (Figure 2 and Table 3) showed a laboratory permeability of 1.1 ? 10^{-6} cm/sec. in material described as white to tan and orange clayey fine to warm sand (SC).

5.4 TERTIARY/QUATERNARY DEPOSITS

The Tertiary/Quaternary stream deposits were 50 to 70 ft. thick and partly saturated under original conditions at the Stancill Quarry. Although these have been largely mined out in the active pit, 30 to 40 ft. remain locally (URS, 2002). The water table, which may have been 20 ft. below land surface, originally was lowered as quarrying progressed and it is now about at sea level in the deepest part of the quarry. The deposits exposed in the quarry walls are now unsaturated.

Little information is available regarding the hydrologic properties of the Tertiary/Quaternary deposits. Otton et al. (1988) grouped together all the non-marine deposits of Tertiary/Quaternary age in the Columbia aquifer, but it was considered to be a minor source of water in Cecil County. Since few modern wells tap these deposits, little data on their water-bearing properties were available.

Borings at the Stancill property suggest that the Tertiary/Quaternary deposits are predominantly silty materials containing sporadic, laterally discontinuous, sand, and gravel stringers. Standard Penetration Test blow counts suggest that these deposits are less dense and therefore more permeable than the older Cretaceous age deposits and underlying saprolite. URS conducted slug tests on eight of the piezometers, the results of which are discussed in Section 6.

Little water is transmitted to the quarry from Long Creek and other nearby drainage courses, despite an inward hydraulic gradient, suggesting that the average permeability of the Tertiary/Quaternary deposits in the zone of saturation is low and not significantly greater than that of the Potomac Group and saprolite.

5.5 IN-SITU HYDRAULIC CONDUCTIVITY TESTS (SLUG TESTS)

In-situ hydraulic conductivity tests (slug tests) were performed at eight piezometers installed by KCE. Slug testing was completed on December 5, 2001 on piezometers P-1 to P-6, P-8, and P-9. The objective of the slug testing was to evaluate hydraulic conductivities of subsurface hydrogeologic units to aid in developing the groundwater model.

Both falling-head and rising-head slug tests were performed. The falling-head tests were performed by the instantaneous insertion of a known volume (slug) into a piezometer in which the water level was at equilibrium, thereby raising the water level within the piezometer. The subsequent fall in water level (falling-head) was measured over time as it returned to the equilibrium level. The rising-head tests were performed by the instantaneous removal of the slug from a piezometer when the water level was at equilibrium, thereby lowering the water level within the well. The subsequent rise in water level (rising-head) was measured over time as it returned to the equilibrium level.

The static water level was measured and a pressure transducer was placed in the piezometer before a falling-head test was begun. The pressure transducer was connected to a Hermitt Model 2000 automatic data logger. A pre-run checkout test was performed on all eight piezometers tested. The checkout test consisted of setting the data logger to the appropriate parameters, initiating recording of measurements on the data logger, and raising and lowering the transducer probe in the piezometer to simulate water level changes. Upon confirmation that the equipment was functioning properly, testing activities were suspended for a minimum of 10 minutes to allow the water level to return to equilibrium.

To start the falling-head test, the data logger was activated and the slug, which consisted of a steel cylinder with capped ends, was simultaneously inserted and submerged in the water column of the piezometer. The data logger incrementally recorded the falling water level as it returned toward the equilibrium level. Once the water level returned to within 90% of its equilibrium level, the data logger was stopped and the falling-head test was completed.

The rising head test was initiated upon withdrawal of the slug and simultaneously restarting the data logger to record the rising head. The rising-head test was completed when the water level returned to within 90% of its equilibrium level and the data logger was stopped. The automated data logger recorded water-level readings at preset intervals on a logarithmic scale during the tests.

Slug test data for both the falling- and rising-head tests were analyzed to calculate hydraulic conductivities (K) using the Bouwer and Rice analytical method (Bouwer and Rice; 1976, 1989). The Bouwer and Rice Solution is a variation of the general Theis equation that accounts for partially penetrating wells and wells that straddle the water table. The hydraulic conductivity (K) is calculated using the formula:

$$K = \frac{(r_c^2)\ \ln(s_0\ /\ s_t)\ \ln(r_e\ /\ r_w)}{2Lt} \quad \text{where:}$$

r_c = radius of well casing [L]
s_o = initial drawdown in well [L]
s_t = drawdown in well at time t [L]
$\ln(r_e/r_w)$ = empirical "shape factor" determined from tables provided in Bouwer and Rice (1976)
r_e = equivalent radius over which head loss occurs [L]
r_w = radius of well (including filter pack) [L]
L = Height of the portion of the well through which water enters
t = Time since start of slug test

Data interpretation was aided by the computer software package AQTESOLV? (HydroSOLVE, Inc., 2000). Plots of the slug-test results are provided in Appendix A, and the results of the analyses are summarized in Table 4. Hydraulic conductivity values interpreted from the slug-tests range from 8.85 x 10^{-3} to 9.50 x 10^{-6} centimeters/second (cm/s), and average 3.57 x 10^{-3} cm/s. These values are consistent with silty sands encountered in the screened interval of all of the piezometers tested.

All results were within the same order of magnitude, except P-8, where the results were three orders of magnitude lower than the other results. It should be noted that water was also slow to enter this well during the initial drilling. The falling-head test (insertion test) generally did not correlate with the rising-head test (withdrawal test) results because the height of the water in all but one piezometer (P-3) was less than the screen length; therefore, the entire sand pack was not saturated prior to the insertion of the slug for the falling head test. The portion of the sand pack affected by subsequently removing the slug for the rising-head test was saturated prior to the start of the test. As such, the results of the falling-head test were not taken into account for all but one piezometer and the hydraulic conductivities obtained by the analysis of the rising-head tests were assumed to be the actual results of the slug tests. In fact, the results of the rising-head tests at all of the wells were taken as the hydraulic conductivities.

This section describes base-line water quality by crystalline rock sources, Potomac Group, and Quaternary/Tertiary deposits. Data on interstitial water of dredge tailings, based on information obtained from MES, are also presented.

6.1 CHEMICAL QUALITY OF GROUNDWATER

In order to evaluate the effect of potential contamination of groundwater by disposal of dredge tailings, the pre-project groundwater quality level must be established. Data on chemical quality of groundwater at the Stancill Quarry were available from three sources: (1) field analyses made during groundwater sampling of borings P-1 through P-9 in the current investigation (Table 5), (2) laboratory analyses of groundwater samples of borings P-1 through P-9 in the current investigation (Table 6), and (3) analyses published by Willey et al. (1987) and the interpretation of these records by Otton et al. (1988). Under the first source, water samples were tested for dissolved oxygen, pH, temperature, specific conductance, and oxidation-reduction potential using field gages. The samples reported by Willey et al. were analyzed for the same parameters in a U.S. Geological Survey laboratory following USGS standard methods for common chemical constituents and trace metals. Samples from 84 wells in Cecil County were reported by Willey et al. and are discussed below; these results are compared to the field and laboratory analysis of groundwater samples obtained from piezometers P-1 through P-9.

In their interpretation of the Willey et al. data, Otton et al. (1988) categorized the sources as crystalline-rock aquifers, Potomac Group aquifers, and all other coastal plain aquifers. The latter category would consist mainly of late Cretaceous and early Tertiary marine deposits, which are not found at the Stancill Quarry; therefore, only the crystalline rock and Potomac Group aquifers are discussed in the following section.

6.1.1 Dissolved Solids and Specific Conductance

The dissolved-solids concentration represents the quantity of dissolved mineral matter in a water sample. Dissolved solids in water may be estimated from the specific conductance of the sample, which is much easier to measure and can be done in the field. Based on the relationship shown in Figure 14 in Otton et al. (1988; Appendix B), a good approximation of the dissolved-solids concentration in Cecil County groundwater can be obtained by multiplying specific conductance by 0.75. Otton et al. showed that the range of dissolved solids in crystalline rock aquifers in Cecil County was 41-1,170 mg/L with a median value of 111 mg/L. The comparable range for Potomac Group aquifers was 16-439 mg/L with a median value of 42 mg/L. Based on the relationship of dissolved solids and specific conductance (dissolved solids in mg/L equals specific conductance in ?S/cm ? 0.75), the range of specific conductance in crystalline rock aquifers would be 55-1,560 ?S/cm with a median value of 148 ?S/cm. The comparable range for Potomac Group aquifers would be 21-585 ?S/cm with a median value of 56 ?S/cm.

Specific conductance measured in boreholes P-1 through P-9 on November 6, 2001 (shortly after completion) ranged from 77 ?S/cm in P-4 to 496 ?S/cm in P-1 and a median value of 119 ?S/cm. Therefore, field data from the Stancill Quarry indicate that the specific conductance of the quarry groundwaters were slightly lower than those of crystalline rock aquifers of Cecil County, but slightly higher than the Potomac Group aquifers.

6.1.2 Hydrogen-Ion Concentration (pH)

The hydrogen-ion concentration of a water sample is indicated by the pH, which is the negative logarithm of the hydrogen-ion concentration in moles per liter of water. The pH is a measure of the extent to which the water sample is acidic or alkaline: a pH of 7 indicates a neutral condition; less than 7, acidic; and greater than 7, alkaline. Water that has a low pH is particularly significant because it may corrode well casings, pumps, and plumbing fixtures and dissolve copper, iron, lead, or zinc from equipment.

The range of pH for crystalline rock aquifers as given by Otton et al. (1988) is 5.4 to 8.1, with a medium value of 6.0. The range for Potomac Group aquifers is 4.7 to 7.3, with a median value of 5.6.

The range of pH tested in the field samples on November 6, 2001 from boreholes P-1 through P-9 was 4.61 to 5.77, with a median value of 5.26. Although the ranges and median values of pH at the quarry are comparable to those cited by Otton et al. (1988), the comparison is probably fortuitous because the water sources are distinctly different. The pH values of the shallow boreholes at the quarry are in the range of modern acid rainfall and probably represent current recharge on the quarry floor, whereas the samples interpreted by Otton et al. were derived from systems with long groundwater storage times. In the case of the Potomac Group, they were mainly confined waters in which the pH was a non-conservative parameter.

6.1.3 Common Dissolved Constituents

Otton et al. (1988) illustrated the common chemical constituents plus iron and manganese in Cecil County groundwater in a single diagram, which is reproduced in Appendix B. The graph shows total range, median value, and the 25th and 75th percentiles of the frequency distribution for each parameter. Consistent with the dissolved solids distribution, the calcium, magnesium, sodium, chloride, sulfate, nitrate plus nitrite, hardness, and alkalinity are all lower in the Potomac Group aquifers than in the crystalline bedrock. Exceptions to these general trends are potassium, iron, and manganese. Potassium values are about equal in the Potomac Group aquifers and crystalline bedrock, and iron and manganese are higher in Potomac Group aquifers than in crystalline rocks. The solubility of these two metals is highly sensitive to pH and oxygen-reduction potential, and it is believed that the lower pH of waters of the Potomac Group is related to the higher iron and manganese content.

Laboratory analyses of 32 parameters were carried out on water samples collected November 6, 2001 from boreholes P-1 through P-9. The parameters analyzed included common chemical constituents plus iron and manganese, trace metals, and several miscellaneous parameters (Table 6). Twenty-two of the parameters analyzed were among those reported by Willey et al. (1987) and interpreted by Otton et al. (1988). Among the constituents illustrated in Appendix B, the samples from boreholes P-1 through P-9 generally were within the range of samples from crystalline rock aquifers. Notable exceptions were iron and manganese. The iron content of water from borehole P-1 was reported to be 120 mg/L, which is nearly 5 times higher than the highest iron value reported by Willey et al. of 24,000 ? g/L (24 mg/L). The highest manganese content in Appendix B is about 2,000 ? g/L (2 mg/L) in the Cecil County analyses versus a maximum of 4.2 mg/L in a sample from borehole P-5.

Boreholes P-1 and P-5 appear to represent special chemical environments. In the field tests (Table 5), P-1 had the lowest dissolved oxygen, highest pH, highest specific conductance, and lowest oxidation-reduction potential of all boreholes sampled; samples from P-5 generally agreed with these trends. In the laboratory analyses, the P-1 sample had the highest dissolved solids, iron, bicarbonate, alkalinity, carbon dioxide, and chemical oxygen demand. Consistent with the field tests, the P-5 samples generally agreed with the P-1 samples. More detailed investigation is necessary to explain more fully the implications of these results.

6.1.4 Minor Constituents

Minor constituents reported by Willey et al. (1987) included fluoride, silica, phosphorous, aluminum, arsenic, boron, cadmium, chromium, copper, lead, lithium, mercury, nickel, zinc, and organic carbon. As discussed in Otton et al. (1988), these constituents generally were found in low concentration in the groundwaters of Cecil County. Where drinking water standards were exceeded, this could be accounted for by local sources of contamination.

Laboratory analysis of samples from boreholes P-1 through P-9 collected November 6, 2001 included the trace metals (arsenic, cadmium, chromium, copper, lead, nickel, selenium, and zinc) as well as several other miscellaneous parameters. Several parameters were reported as non-detect in all samples at the method detection limit (sulfide, potassium, arsenic, and selenium as well as ferrous and ferric iron were reported as indeterminate). In general, with the exception of chromium in borehole P-1, which recorded a concentration level of 0.09 mg/L (versus the maximum contaminant level of 0.05 under the Natural Primary Drinking Water Regulations), the trace metals were in low concentration and within USEPA drinking water regulations. Other than unusual concentrations noted above no significant trends were observed in the analyses of samples from boreholes P-1 through P-9.

6.2 CHEMICAL QUALITY OF DREDGE TAILINGS AND LEACHATES

Tables 7, 8, and 9, and Appendix C present data supplied by MES on six samples of bottom material collected February 20, 2002 from Courthouse Point, Cecil County, on the eastern shore of the Chesapeake and Delaware Canal, and samples collected from 22 "clean" sites from 1985 to 1999. It was assumed that these samples were representative of the tailings to be placed at the Stancill Quarry. Table 7 presents data on the chemical content of the solid materials collected February 20, 2002 from Courthouse Point. Table 7 presents a comparison of results of analyses of leachates by two well-known test methods, the USEPA-TCLP test and the ASTM deionized-water leachate test. Table 8 presents a comparison of the two leachate test results for constituents analyzed in both tests.

Except for carbon dioxide and sulfide, which are low to non-detect in both sets of leachate samples, the ASTM method yields much lower values than the USEPA TCLP method. This is principally ascribed to differences in the quality of the solvent used in the tests, deionized water in the ASTM test versus a weak acidic solution in the USEPA test. Clearly, the acidic solution specified in the USEPA-TCLP test method dissolves far more sodium, bicarbonate, and organic carbon from the bottom materials than the deionized water specified in the ASTM test. Which test is more appropriate for project conditions cannot be established without further investigation and data; however, the ASTM method is probably more indicative of natural conditions that would be encountered at Stancill Quarry. Samples represented in Table 9 did not undergo a leaching procedure prior to analysis.

The Stancill Quarry is projected to be filled with dredge tailings over a 34-year period (E2CR, 2000). The quarry could be filled to an elevation of +45 or +90 ft., depending upon the stability of the containment dike proposed in the western portion of the quarry. If it is filled to +90 ft., the topography upon completion will mimic the present topography. The +90 ft. future condition was modeled to assume a "worst case" scenario for modeling purposes. The dredge tailings most likely would consist of finer grained material, such as fine sands, silts, and clays and occasional coarser grained sands and gravel.

Anderson, M. P. and W.W. Woessner. 1992. *Applied Groundwater Modeling, Simulation of Flow and Advective Transport.* Academic Press, Inc., New York.

Bedient, P.B. and W.C. Huber. 1995. *Hydrology and Floodplain Analysis.* Addison-Wesley, Massachusetts.

Bouwer, H. 1978. *Groundwater Hydrology.* McGraw-Hill Book Co., New York.

Bouwer, Herman and R.C. Rice. 1976. "A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells," *Water Resources Research*, vol. 12, no. 3, pp. 423-428.

Cernica, J.N. 1982. *Geotechnical Engineering.* Holt, Rinehart and Winston, New York.

Cooper, Hilton H., John D. Bredehoeft, and Istavros S. Papadopulos. 1967. "Response of a Finite-Diameter Well to An Instantaneous Charge of Water," *Water Resources Research*, vol. 3, no. 1, pp. 263-269.

Davis, S.N. and R.J.M. DeWiest. 1966. *Hydrogeology.* John Wiley & Sons, Inc., New York.

Dragun, J. 1988. The Soil Chemistry of Hazardous Material. The Hazardous Materials Control Research Institute.

Duffield, Glenn M. 1995. AQTESOLV^{TM}: Aquifer Test Solver Version 2.01. Geraghty & Miller, Inc. Modeling Group, Reston, Virginia.

E2CR (Engineering, Consultation, Construction Remediation, Inc.). 2000. *Geotechnical Report for Stancill Sand and Gravel Quarry, Cecil County, Maryland.* November 6, 2000.

Fetter, C.W. 1988. *Applied Hydrogeology, Second Edition.* Macmillan Publishing Co., New York.

Freeze, R.A. and J.A. Cherry. 1979. *Groundwater.* Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

HydroSOLVE, Inc. 2000. AQTESOLV for Windows 95/98/NT Version 3.0–Professional. Developed by Glen Duffield, HydroSOLVE, Inc. Copyright 1996-2000 HydroSOLVE, Inc., 2303 Horseferry Ct., Reston, VA 20191-2739

McDonald, M. and A.W. Harbaugh. 1988. *A Modular Three-Dimensional Finite Difference Ground-Water Flow Model: U.S. Geologic Survey Techniques for Water-Resources Investigations of the United States Geologic Survey.* U.S. Geologic Survey, Reston, VA.

Maryland Environmental Service (MES). 2000. *A Preliminary Assessment of the Feasibility of Using the Stancill's Inc. Property on Furnace Bay in Cecil County as a Dredged Material Containment Facility.* November 2000.

MES. 2002. *Chemical Analytical Results from Dredge Sediment Sampling of Sites in Chesapeake Bay.*

Otton, E.G., R.E. Willey, R.A. McGregor, G. Achmad, S.N. Hiortdahl, and J.M. Gerhart. 1988. *Water Resources and Estimated Effects of Ground-Water Development, Cecil County, Maryland.* Maryland Geological Survey Bulletin 34.

Overbeck, R.M. and T.H. Slaughter. 1958. *The Water Resources of Cecil, Kent, and Queen Anne's Counties.* Maryland Geological Survey Bulletin 21.

Personal Communication. 2001, 2002. Discussions between representatives of Maryland Environmental Services (MES), Stancill Quarry, KCE Engineering, Inc. (KCE), and URS Corporation (URS) from August 2001 through June 2002.

Rasmussen, W.C. and G.E. Andreason. 1959. *Hydrologic Budget of the Beaverdam Creek Basin, Maryland: U.S. Geologic Survey Water-Supply Paper 1472.* U.S. Geologic Survey, Reston, VA.

Rumbaugh III, J.O. 1993. *ModelCad.* Geraghty & Miller, Inc., Reston, VA.

URS Corporation. 2002. *Conceptual Geologic Interpretation for Stancill Quarry, Cecil County, Maryland.* September 2002.

Whitten, C.B., S.M. Swartzel, S.P. Miller, and K. Blough. 1997. *Conceptual Hydrogeologic Model of Aberdeen Proving Ground–Aberdeen Area.* U.S. Army Corps of Engineers, Waterways Experiment Station, Technical Report GL-97-16

Willey, R.E., R.A. McGregor, J. de Grouchy, and M.D. Tompkins. 1987. *Hydrogeologic Data for Cecil County, Maryland.* Maryland Geological Survey Basic Data Report No. 16.

Tables

Table 1. Table 1: List of Wells, Piezometers, and Borings at Stancill Quarry and Surrounding Area Used to Develop Conceptual Hydrogeologic Model

Piezometers and wells
P-1
P-2
P-3
P-4
P-5
P-6
P-7
P-8
P 9
Abnd. Pump Test Well

Borings (abandoned in 2000)
E-1
E-2
E-3
E-4
E-5
E-6

Borings abandoned earlier
B-1
B-2

Wells in Surrounding Area
Ce720103 - Porter, George on Jackson Station Rd
Ce720104 - Porter, George on Winch Rd
Ce720105 - Porter, George on Winch Rd
Ce730536 - Ingram, Jas J on Burnt Barn
Ce730659 - Spadafora, James W on Carpenters Pt Rd
Ce730741 - Porter, George on Jackson Sta Rd
Ce731295 - Currin, Linda on Mountain Hill Rd
Ce731339 - Better Homes Inc on Mt View Rd
Ce731466 - Algar, Harry on Md 7
Ce732168 - Vansickel, Harold C on Old Rt 7
Ce732386 - Rogerson, Harry on Mountain Hill
Ce732902 - Bostic, Stephen on Burnt Barn Rd
Ce733987 - Stancills Inc on Mountain Hill Rd
Ce811340 - Alexander Joseph on Mountain Hill Rd
Ce812582 - Montgomery Bros Inc on Mountain Hill
Ce880487 - Albanese John on Mountain Hill Rd
Ce881819 - Gray Edward on Mountain Hill Rd
Ce882359 - Jackson James on Mt Hill

Table 2. Groundwater Level Measurements October 2000 and November 2001 through April 2002 at Stancill Quarry

Peizometer #	Elevation of PVC Casing (ft) amsl	Tape Reading (Depth in Ft.)							Ground Water Elevation (Ft.)						
		October 5, 2000	November 6, 2001	December 11, 2001	January 8, 2002	February 6, 2002	March 7, 2002	April 3, 2002	October 5, 2000	November 6, 2001	December 11, 2001	January 8, 2002	February 6, 2002	March 7, 2002	April 3, 2002
P-1	23.51		16.43	16.41	16.87	16.87	16.95	16.74		7.08	7.10	6.64	6.64	6.56	6.77
P-2	13.94		4.89	5.02	5.64	4.96	5.29	4.50		9.05	8.92	8.30	8.98	8.65	9.44
P-3	21.86		18.07	18.58	18.62	18.77	18.84	18.44		3.79	3.28	3.24	3.09	3.02	3.42
P-4	13.59		12.28	13.83	13.44	14.06	14.22	12.97		1.31	-0.24	0.15	-0.47	-0.63	0.62
P-5	38.24		24.59	24.66	24.81	24.74	24.83	24.55		13.65	13.58	13.43	13.50	13.41	13.69
P-6*	11.04		8.15	9.18	9.41	9.85	10.49	9.82		2.89	1.86	1.63	1.19	0.55	1.22
P-7	8.69		6.62	7.78	7.41	8.02	8.19	7.48		2.07	0.91	1.28	0.67	0.50	1.21
P-8	100.66		61.85	61.88	62.22	62.40	62.60	62.70		38.81	38.78	38.44	38.26	38.06	37.96
P-9	18.35		15.13	16.18	16.14	16.77	17.09	16.45		3.22	2.17	2.21	1.58	1.26	1.90
E-1	6.70	2.20							4.5						
E-2	17.90	1.70							16.2						
E-3	13.00	2.60							10.4						
E-4	12.20	8.50							3.7						
E-5	32.10	28.90							3.2						
E-6	9.90	8.30							1.6						

* Level Logger installed on December 11, 2001 to observe continuous water levels

Table 3. Summary of Hydrogeologic Properties of Modeled Units at Stancill Quarry and Vicinity

	Yield of Wells	Specific Capacity	Permeability
Crystalline Units			
Median of all crystalline units in Cecil County	10 gpm(1)	0.3 gpm/ft(2)	
Upper and lower members of the James Run Formation*	6 gpm(1)	between 0.1 and 0.2 gpm/ft(2)	
210-ft. deep well drilled at the Stancill Quarry into the crystalline bedrock	11 gpm(3)	0.2 gpm/ft(3)	
Other wells in the general vicinity of the quarry	range 0.1 to 30 gpm, average 0.9 gpm/ft.(4)	0.1 to 4.6 gpm/ft(4)	
Saprolite			
Similar deposits elsewhere in Maryland(5)			1 ? 10^{-4} to 1 ? 10^{-6} cm/sec (2.8 ? 10^{-1} to 2.8$10^{-3}$ ft/day)
Potomac Group			
Range of values from wells in Map Unit Cc(6)	1 to 100 gpm	0.2 to 3.7 gpm/ft.	
Average for 14 wells for which data were available in Map Unit Cc		1.2 gpm/ft.	
Borehole E-1, 18–18.75 ft. (white, moist clayey silt, and fine to medium sand [ML])(7)			5.6 ? 10^{-6} cm/sec. (1.59 ? 10^{-2} ft/day)
Borehole E-2, 13.5–15.5 ft. (white to tan and orange clayey fine to warm sand [SC])(7)			1.1 ? 10^{-6} cm/sec. (3.1 ? 10^{-3} ft/day)
Average slug test value of P-1 through P-9 (8)			3.57 ? 10^{-3} cm/sec. (10 ft/day)

gpm – gallons per minute
gpm/ft - gals per minute per foot of drawdown
cm/sec - centimeters per second
*Unit underlying the Stancill Quarry
(1)Otton et al., 1988, Table 7
(2)Otton, et al., 1988, p. 19
(3)Willey et al., 1987, Table 7
(4)Map Unit Cc, Willey et al., 1987
(5)Otton et al., 1988
(6)Willey et al, 1987, Table 7
(7)E2CR, 2000, Table 1
(8)See Table 5 below

Table 4. Summary of Slug Test Results

Piezometer	Hydraulic Conductivity				
	cm/sec	**m/sec**	**ft/min**	**ft/day**	**U.S. gal/day/ft^2**
P-1 Withdrawal	5.46E-03	5.46E-05	1.07E-02	1.55E+01	1.16E+02
P-2 Withdrawal	3.40E-03	3.40E-05	6.69E-03	9.63E+00	7.21E+01
P-3 Insertion	2.96E-03	2.96E-05	5.82E-03	8.37E+00	6.26E+01
P-3 Withdrawal	3.15E-03	3.15E-05	6.19E-03	8.91E+00	6.67E+01
P-4 Withdrawal	4.02E-03	4.02E-05	7.91E-03	1.14E+01	8.52E+01
P-5 Withdrawal	8.85E-03	8.85E-05	1.74E-02	2.51E+01	1.88E+02
P-6 Withdrawal	1.50E-03	1.50E-05	2.95E-03	4.24E+00	3.17E+01
P-8 Withdrawal	9.50E-06	9.50E-08	1.87E-05	2.69E-02	2.01E-01
P-9 Withdrawal	2.77E-03	2.77E-05	5.45E-03	7.84E+00	5.87E+01
Range	8.85E-03 to 9.50E-06	8.85E-05 to 9.50E-08	1.74E-02 to 1.87E-05	2.51E+01 to 2.69E-02	1.88E+02 to 2.01E-01
Average	3.57E-03	3.57E-05	7.02E-03	1.01E+01	7.56E+01

Table 5. Results of Field Measurements of Groundwater Samples Taken on November 6, 2001 from Wells Installed in Stancill Quarry for the Current Study

Piezometer #	Dissolved Oxygen (mg/l)	pH	Temperature (°C)	Conductivity (?S/cm)	Oxidation Reduction Potential ORP (mV)
P-1	3.10	5.77	14.06	496	-16
P-2	5.88	5.26	15.60	99	183
P-3	4.26	5.29	14.28	200	-8
P-4	4.03	5.33	16.57	77	132
P-5	3.80	5.38	13.77	247	97
P-6	5.95	4.70	12.76	87	277
P-7	7.37	4.61	12.86	142	277
P-8	8.76	5.18	12.14	101	252
P-9	7.52	4.87	12.14	119	270
Minimum	**3.10**	**4.61**	**12.14**	77	**-16**
Maximum	**8.76**	**5.77**	**16.57**	**496**	**277**
Median	**5.88**	**5.26**	**13.77**	**119**	**183**
Average	**5.63**	**5.15**	**13.80**	**174**	**163**

Table 6. Chemical Analytical Results From Wells Installed in Stancill Quarry for Current Study

Parameter	Detection Limit	Units	Minimum Concentration	Maximum Concentration	Median Concentration	Average Concentration	P-1	P-2	P-3	P-4	P-5	P-6	P-7	P-8	P-9
Methane, dissolved	0.0005	mg/L	0.00053	0.2	0.0063	0.052	0.2	0.0011	0.066	0.09	0.0063	0.0011	0.00053	<0.0005	<0.0005
Carbon Dioxide	1	mg/L	8	140	20	35	140	9	24	8	60	16	20	14	25
Total Petroleum Hydrocarbons	2	mg/L	ND	ND	ND	ND	<2	<2	<2	<2	<2	<2	<2	<2	<2
Sulfide	0.1	mg/L	ND	ND	ND	ND	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nitrate – Nitrite Nitrogen	0.05	mg/L	0.12	1.7	0.29	0.50	0.23	0.35	0.12	<0.05	<0.05	<0.05	1.7	0.18	0.42
Kjeldahl Nitrogen (Total)	0.5	mg/L	ND	ND	ND	ND	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Ammonia Nitrogen	0.2	mg/L	ND	ND	ND	ND	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Chemical Oxygen Demand	20	mg/L	21	230	49	70	230	21	<20	71	65	49	36	21	<20
Phosphorous (total)	0.05	mg/L	0.09	0.65	0.33	0.36	0.49	0.26	0.17	0.57	0.65	0.55	0.33	0.12	0.09
TOC (Total Organic Carbon)	0.1	mg/L	1.8	22	6.9	9.6	20	5	6.9	22	5.9	14	7.2	3.3	1.8
Sodium	0.5	mg/L	3.6	13	7.5	7.5	5.8	13	7	4.9	9	3.6	8.2	7.5	8.5
Potassium	5	mg/L	ND	ND	ND	ND	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Calcium	0.5	mg/L	2.8	9.7	5.5	5.6	5.5	5.9	8	5.6	9.7	3.6	4.8	4.3	2.8
Magnesium	0.5	mg/L	0.9	8.3	2	2.5	1.3	1.9	2	2.3	8.3	2.1	2.4	0.9	1.6
Iron	0.01	mg/L	0.27	120	4.5	17	120	5.7	0.89	7.6	11	2.5	4.5	0.27	0.35
Manganese	0.01	mg/L	0.04	4.2	0.12	0.62	0.26	0.12	0.11	0.35	4.2	0.3	0.09	0.07	0.04
Arsenic	0.005	mg/L	ND	ND	ND	ND	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cadmium	0.0005	mg/L	0.0005	0.0007	0.0006	0.0006	0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0007	<0.0005	<0.0005	<0.0005
Chromium	0.005	mg/L	0.007	0.09	0.035	0.036	0.09	0.018	<0.005	0.047	0.011	0.035	0.047	<0.005	0.007
Copper	0.005	mg/L	0.008	0.027	0.018	0.017	0.02	0.008	0.01	0.027	0.023	0.018	0.014	<0.005	<0.005
Lead	0.005	mg/L	0.007	0.027	0.014	0.017	0.027	0.007	<0.005	0.025	0.016	0.012	0.012	<0.005	<0.005
Zinc	0.01	mg/L	0.03	0.12	0.05	0.05	0.12	0.05	0.03	0.06	0.05	0.04	0.07	0.03	0.03
Nickel	0.005	mg/L	0.007	0.037	0.011	0.014	0.015	0.007	0.008	0.014	0.019	0.011	0.037	0.007	0.009
Selenium	0.005	mg/L	ND	ND	ND	ND	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Bicarbonates (as CaCO3)	1	mg/L	4	39	25	23	39	<1	18	<1	32	<1	<1	4	<1
Chloride	2	mg/L	6	25	14	15	15	13	14	10	13	6	25	19	22

Parameter	Detection Limit	Units	Minimum Concentration	Maximum Concentration	Median Concentration	Average Concentration	P-1	P-2	P-3	P-4	P-5	P-6	P-7	P-8	P-9
Sulfate	5	mg/L	6.1	41	16	16	17	16	6.7	41	20	20	9.2	6.1	11
Nitrate Nitrogen	0.05	mg/L	0.1	1.7	0.2	0.5	0.2	<0.05	0.1	<0.05	<0.05	<0.05	1.7	0.1	0.4
Nitrite Nitrogen	0.02	mg/L	0.02	0.35	0.03	0.10	0.03	0.35	0.02	<0.02	0.03	<0.02	<0.02	0.08	<0.02
Total Nitrogen	0.05	mg/L	0.12	1.7	0.29	0.50	0.23	0.35	0.12	<0.05	<0.05	<0.05	1.7	0.18	0.42
Alkalinity, total (as CaCO3)	1	mg/L	4	39	25	23	39	<1	18	<1	32	<1	<1	4	<1
Solids (dissolved)	1	mg/L	18	210	62	79	210	54	64	18	140	50	69	48	62
Iron (ferrous)	0.01 OR 60						Ind	Ind	Ind	Ind	Ind	Ind	Ind	Ind	Ind
Iron (Ferric by Calculation)	60						Ind	Ind	Ind	Ind	Ind	Ind	Ind	Ind	Ind

Ind=indeterminate; Iron (ferrous) and Iron (Ferric by Calculation) results were indeterminate.

ND=Non detect

Table 7. Furnace Bay Groundwater Study Sediment Sample Results Collected February 20, 2002 at Courthouse Point

Parameter	Detection Limit	Maximum	Average	Units	SS-1	SS-2	DUP	SS-3	SS-4	SS-5
TCLP Method										
Bicarbonate, Alkalinity	1	891	394	mg/L	170	165	130	170	891	840
Carbon dioxide	1.25	6.25	3.75	mg/L	ND	ND	ND	6.25	ND	1.25
Chloride	0.39	24.8	22.1	mg/L	ND	24.8	19.4	ND	ND	ND
Ferrous Iron	0.02	ND	ND	mg/L	ND	ND	ND	ND	ND	ND
Nitrate	0.06	2.14	1.256	mg/L	2.14	ND	ND	0.372	ND	ND
Nitrate/Nitrite	0.08	2.14	1.256	mg/L	2.14	ND	ND	0.372	ND	ND
Total Dissolved Solids	10	4,441	4,352	mg/L	4,262	4,402	4,394	4,204	4,409	4,441
Sulfate	0.38	129	92	mg/L	91.5	129	120	115	18.2	78
Total Alkalinity-Titration	1	891	394	mg/L	170	165	130	170	891	840
Ammonia	0.2	0.73	0.42	mg/L	0.28	0.46	0.21	0.73	ND	ND
Chemical Oxygen Demand	10	5,630	5,478	mg/L	5,440	5,630	5,450	5,240	5,570	5,540
Phosphorous, total	0.02	0.07	0.06	mg/L	0.06	0.05	0.05	0.06	0.07	0.06
Total Kjeldahl Nitrogen	0.2	1.9	1.07	mg/L	1.4	0.85	0.7	1.9	0.77	0.78
Nitrogen, total	0.2	3.5	1.48	mg/L	3.5	0.85	0.7	2.3	0.77	0.78
Total Organic Carbon	100	1,947	1,925	mg/L	1,894	1,943	1,947	1,896	1,939	1,932
Methane		2	2	µg/L	2	2	2	2	2	2
Arsenic	0.1	0.15	0.14	mg/L	ND	0.15	0.12	ND	ND	ND
Chromium	0.1	ND	ND	mg/L	ND	ND	ND	ND	ND	ND
Cadmium	0.1	ND	ND	mg/L	ND	ND	ND	ND	ND	ND
Lead	0.1	ND	ND	mg/L	ND	ND	ND	ND	ND	ND
Selenium	0.1	ND	ND	mg/L	ND	ND	ND	ND	ND	ND
Calcium	5	21.1	14.6	mg/L	15	15	16	13	7.5	21.1
Copper	0.1	0.36	0.36	mg/L	ND	ND	ND	ND	ND	0.36
Nickel	0.1	0.44	0.25	mg/L	0.16	ND	ND	0.16	ND	0.44
Iron	0.5	0.66	0.66	mg/L	ND	0.66	ND	ND	ND	ND
Magnesium	0.5	12	7.13	mg/L	6	12	11	6.2	2.6	4.96
Manganese	0.1	11	7.19	mg/L	6.5	11	11	7.1	3.8	3.71
Sodium	10	1184	1146	mg/L	1,182	1,114	1,072	1184	1180	1143
Zinc	0.1	0.89	0.57	mg/L	0.67	0.45	0.41	0.89	0.33	0.65

Parameter	Detection Limit	Maximum	Average	Units	SS-1	SS-2	DUP	SS-3	SS-4	SS-5
Total Petroleum Hydrocarbons	5.5	21	15.4	mg/L	21	ND	ND	9.7	ND	ND
Sulfide	0.03	ND	ND	mg/L	ND	ND	ND	ND	ND	ND

ASTM Leachate Method										
Sodium	0.2	14	7.42	mg/L	2.76	9.6	14	2.95	7.6	7.61
Bicarbonate, Alkalinity	1	6	3.7	mg/L	4	1	1	6	6	4.2
Carbon Dioxide	1.25	6.25	3.44	mg/L	ND	2.5	3.75	6.25	ND	1.25
Dissolved Oxygen	1	6.1	5.94	mg/L	6.1	5.82	5.74	6.08	MISSING	
Redox Potential		155	140	mg/L	155	147	153	155	91	144
Specific Conductance	1.08	269	195	mg/L	212	269	260	187	53	190
Total Alkalinity- Titration	1	6	3.7	mg/L	4	1	1	6	6	4.2
pH		8	6.64	mg/L	6.31	6.16	6.15	6.58	8.00	6.64
Chemical Oxygen Demand	10	ND	ND	mg/L	ND	ND	ND	ND	ND	ND
Total Organic Carbon	1	2.3	1.7	mg/L	2.3	ND	1	2.1	ND	1.3
Sulfide	0.03	0.06	0.055	mg/L	ND	ND	ND	ND	0.05	0.06

Table 8. **Comparison Of TCLP versus ASTM Analytical Methods For Select Parameters**

Parameters	SS-1		SS-2		DUP		SS-3		SS-4		SS-5	
	ASTM	TCLP	ASTM	TCLP	ASTM	TCLP	ASTM	TCLP	ASTM	TCLP	ASTM	TCLP
Sodium	2.76	1,182	9.6	1,114	14	1,072	2.95	1,184	7.6	1,180	7.61	1,143
Bicarbonate, Alkalinity	4	170	1	165	1	130	6	170	6	891	4.2	840
Carbon Dioxide	ND	ND	2.5	ND	3.75	ND	6.25	6	ND	ND	1.25	1
Total Alkalinity, Titration	4	170	1	165	1	130	6	170	6	891	4.2	840
Chemical Oxygen Demand	ND	5,440	ND	5,630	ND	5,450	ND	5,240	ND	5,570	ND	5,540
Total Organic Carbon	2.3	1,894	ND	1,943	1	1,947	2.1	1,896	ND	1,939	1.3	1,932
Sulfide	ND	ND	ND	ND	ND	ND	ND	ND	0.05	ND	0.06	ND

Table 9. Summary of Chemical Analytical Results from Dredge Sediment Sampling of Sites in Chesapeake Bay

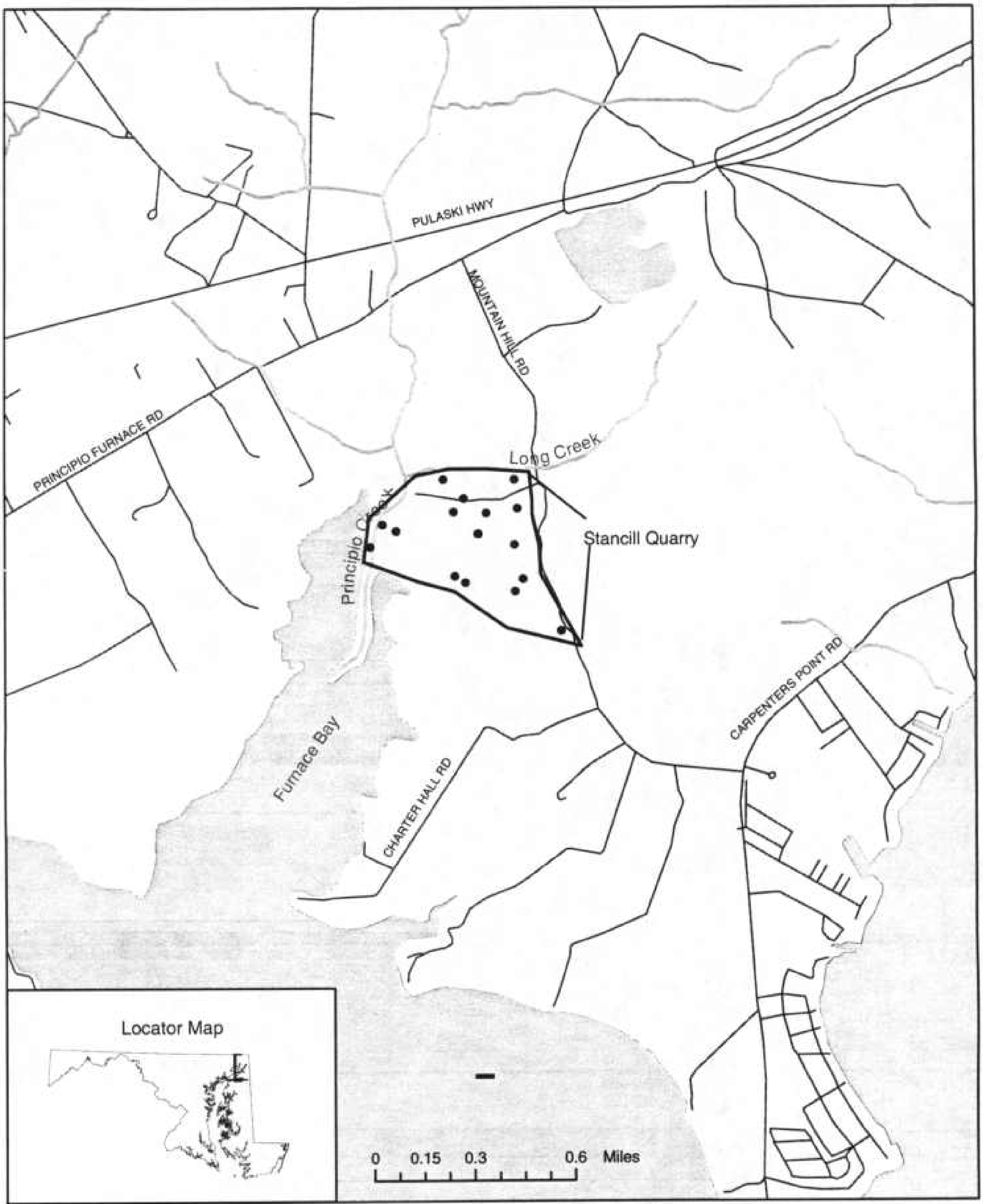
Average of 22 clean sites within the Chesapeake Bay from 1985-1995	TKN* MG/KG	TOTAL P* MG/KG	pH UNITS	O&G* MG/KG	TOC* MG/KG	COD* MG/KG	TS* %
OUTER CHANNEL AVERAGE (1985-1999)	1,456	1,230	7.56	867	24,635	66,236	39
OUTER CHANNEL MAXIMUM (1985-1999)	5,000	14,917	8.50	5,842	90,500	390,909	85
OUTER CHANNEL MINIMUM (1985-1999)	40	14	6.10	1	176	117	18

Average of 22 clean sites within the Chesapeake Bay from 1985-1995	ALUMINUM MG/KG	ANTIMONY MG/KG	ARSENIC MG/KG	BARIUM MG/KG	BERYLLIUM MG/KG	CADMIUM MG/KG	CHROMIUM MG/KG
OUTER CHANNEL AVERAGE (1985-1999)	12,397	5	7	56	1	1	50
OUTER CHANNEL MAXIMUM (1985-1999)	29,400	24	33	250	2	5	640
OUTER CHANNEL MINIMUM (1985-1999)	1,100	0	1	5	0	0	2

Average of 22 clean sites within the Chesapeake Bay from 1985-1995	COPPER MG/KG	IRON MG/KG	LEAD MG/KG	MANGANESE MG/KG	MERCURY MG/KG	NICKEL MG/KG	SELENIUM MG/KG
OUTER CHANNEL AVERAGE (1985-1999)	33	29,365	50	1,967	0	36	3
OUTER CHANNEL MAXIMUM (1985-1999)	240	94,000	464	7,000	2	79	12
OUTER CHANNEL MINIMUM (1985-1999)	1	1,600	2	34	0	2	0

Average of 22 clean sites within the Chesapeake Bay from 1985-1995	SILVER MG/KG	THALLIUM MG/KG	ZINC MG/KG
OUTER CHANNEL AVERAGE (1985-1999)	1	1	197
OUTER CHANNEL MAXIMUM (1985-1999)	8	5	580
OUTER CHANNEL MINIMUM (1985-1999)	0	0	8

Figures



CLIENT: MES

PROJ: Cecil County

REVISION NO.

SCALE: 1: 25,000

FILE: G:\8900000229\Projects\locator_map.mxd

DES BY

DR BY SK

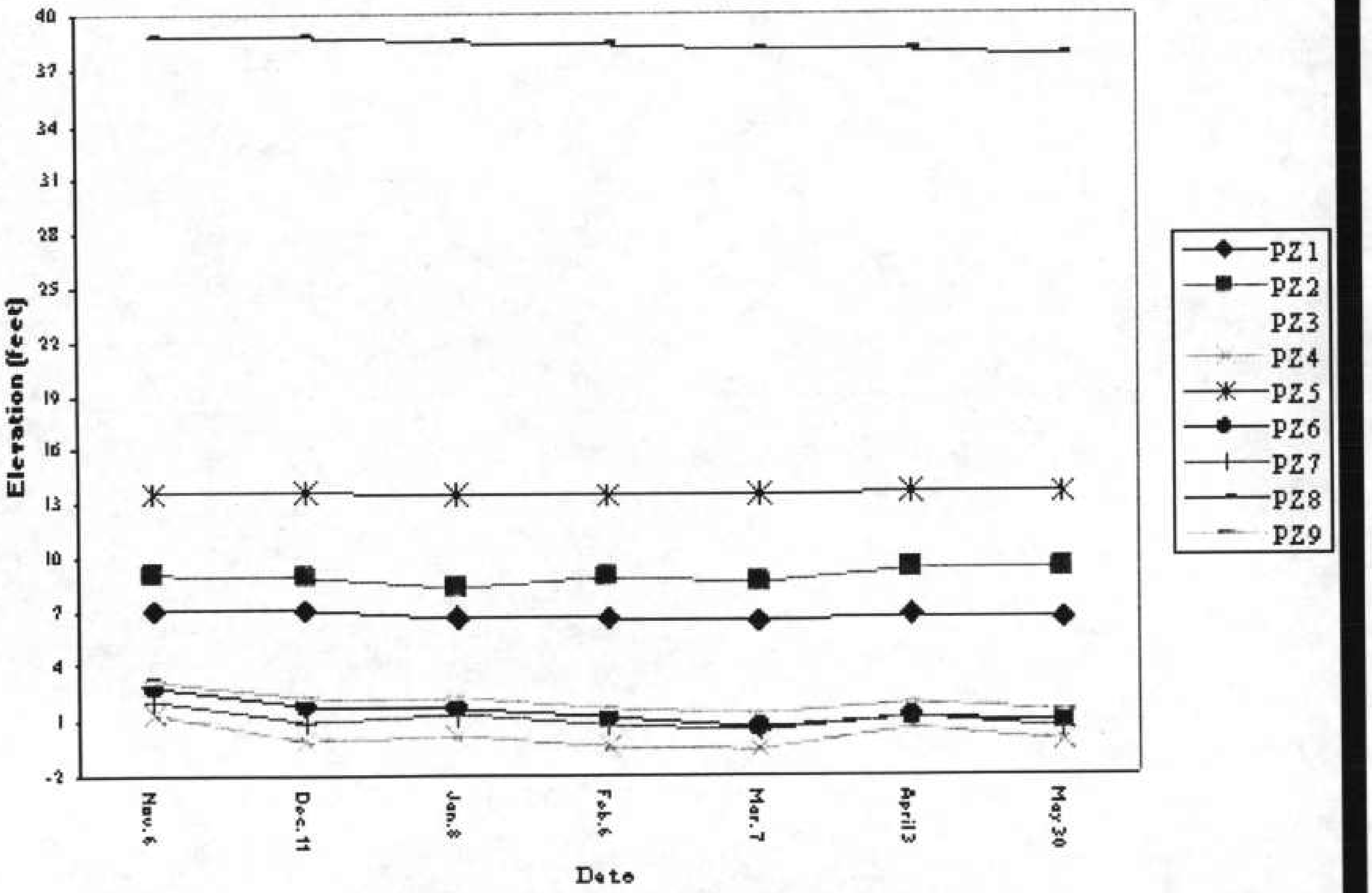
CHK BY JK

TITLE: Site Location - Stancill Quarry, Cecil County, Maryland

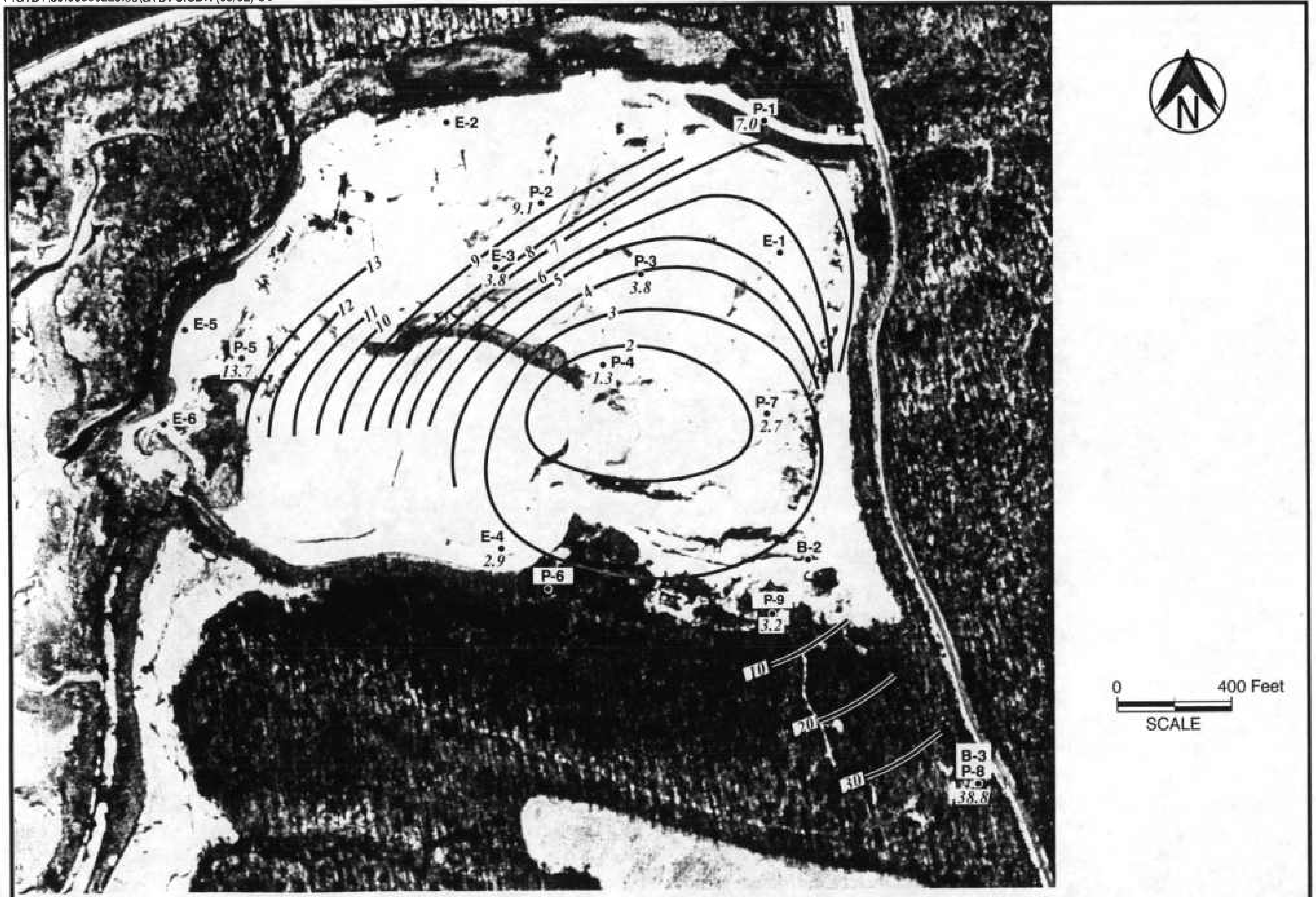
URS

FIGURE: 1

Figure 2: Graph of Monthly Groundwater Level Measurements in Piezometers at Stancill Quarry



P:GTB1\89.00000229.00\GTB1 3.CDR (05/02) SS



URS

Figure 3. Groundwater Contour Map For November 6, 2001

P:GTB1\89.00000229.00\GTB1 4.CDR (09/13/02) SS

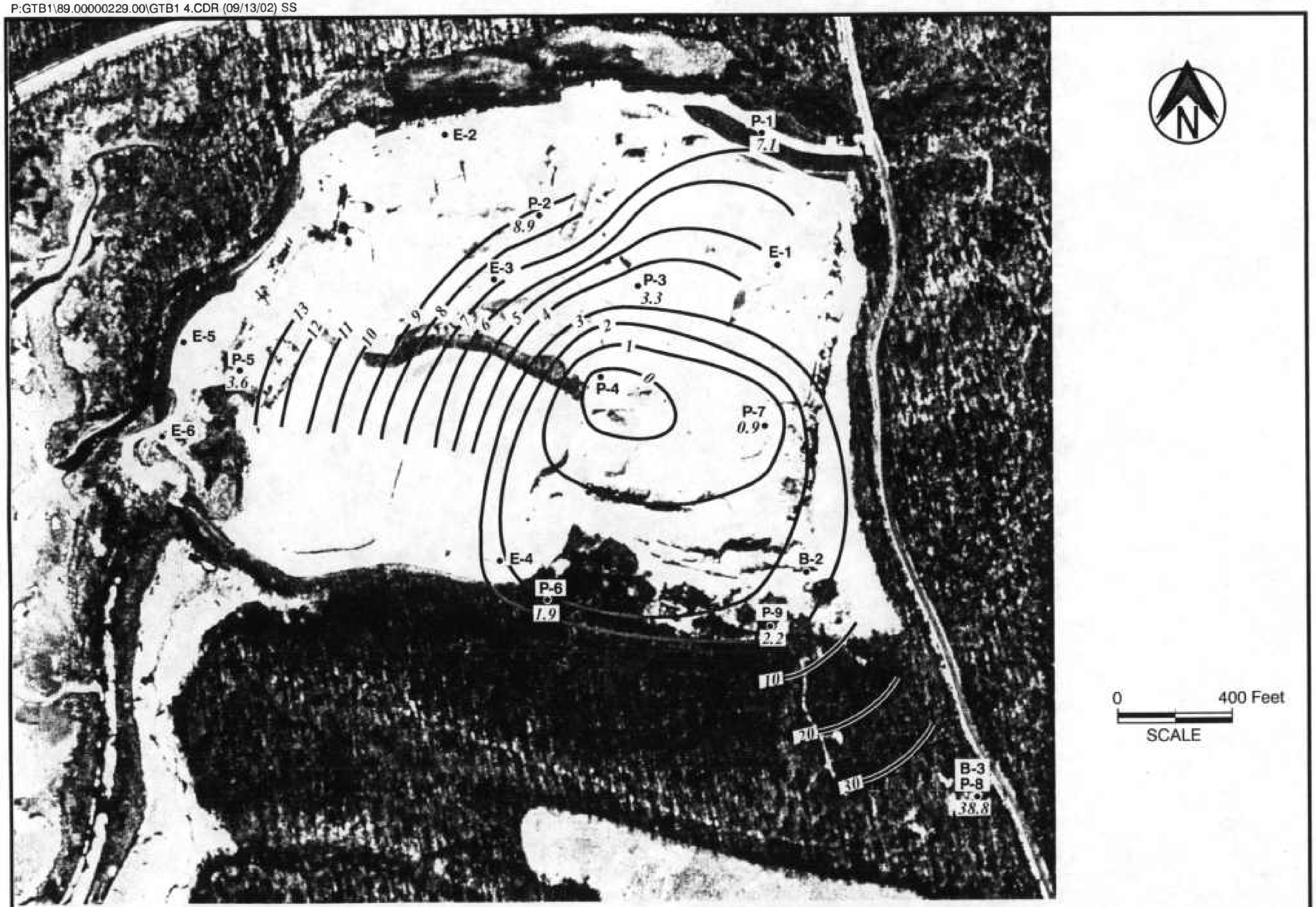
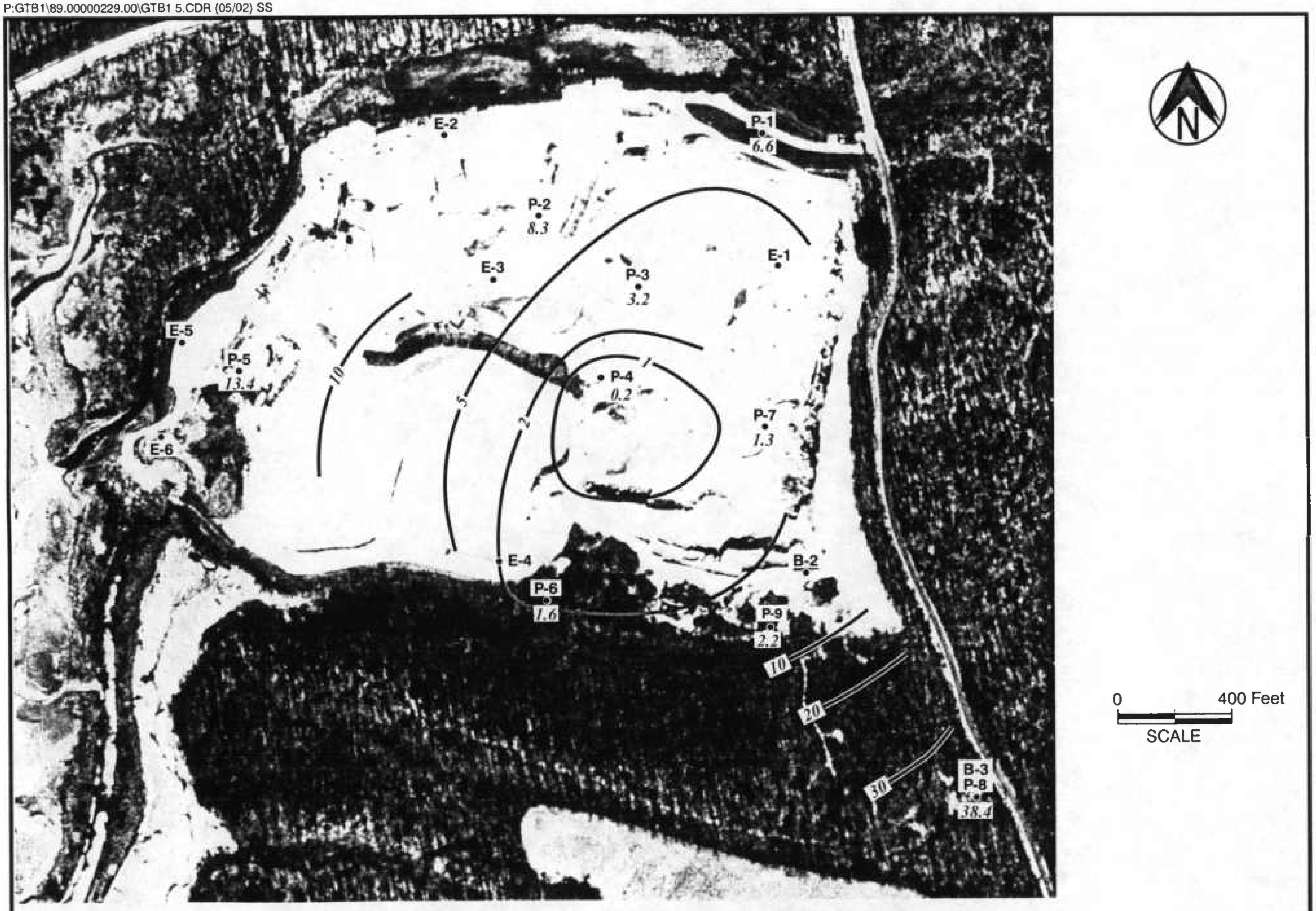


Figure 4. Groundwater Contour Map For December 11, 2001

URS

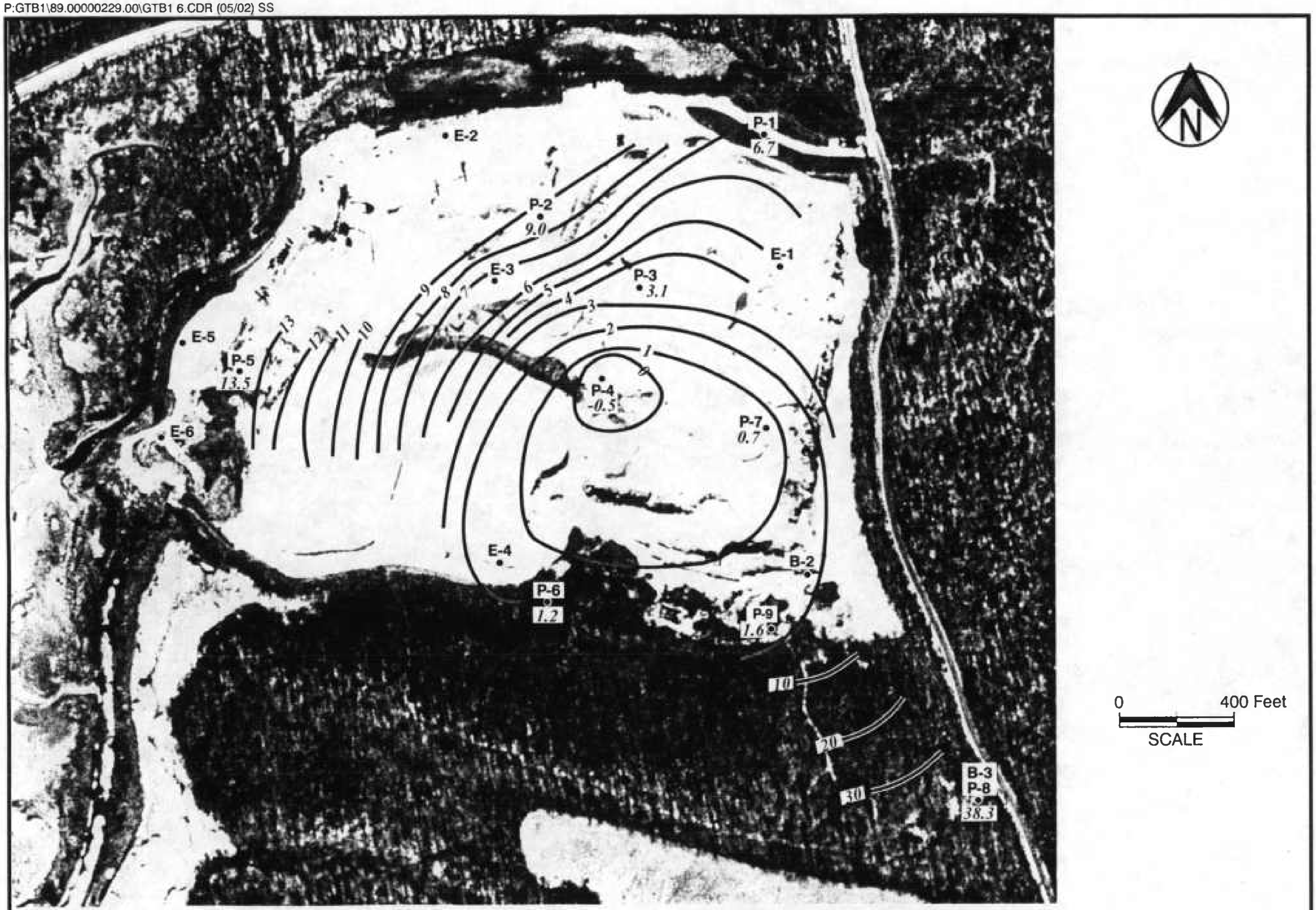
P:GTB1\89.00000229.00\GTB1 5.CDR (05/02) SS



URS

Figure 5. Groundwater Contour Map For January 8, 2002

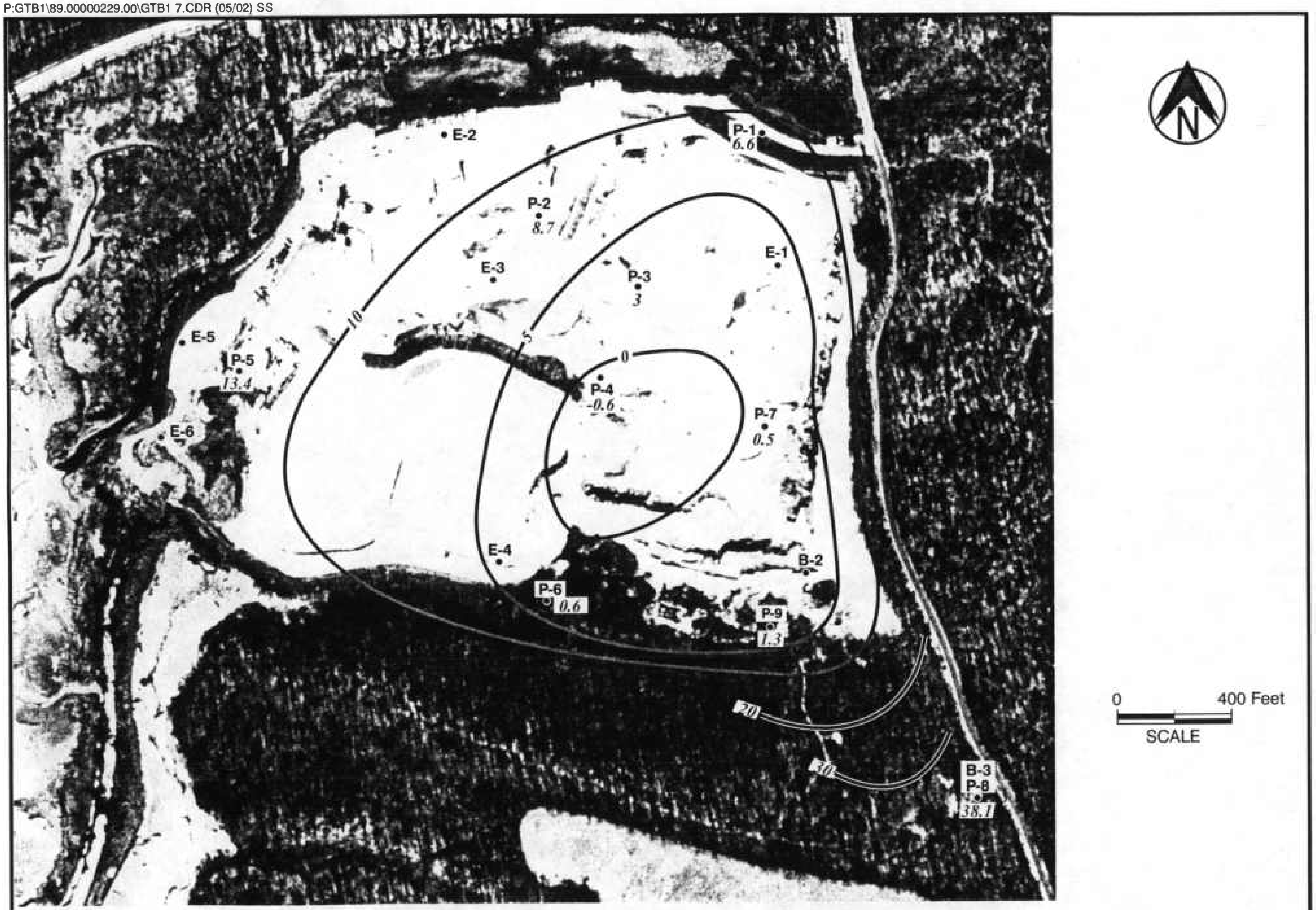
P:GTB1\89.00000229.00\GTB1 6.CDR (05/02) SS



URS

Figure 6. Groundwater Contour Map For February 6, 2002

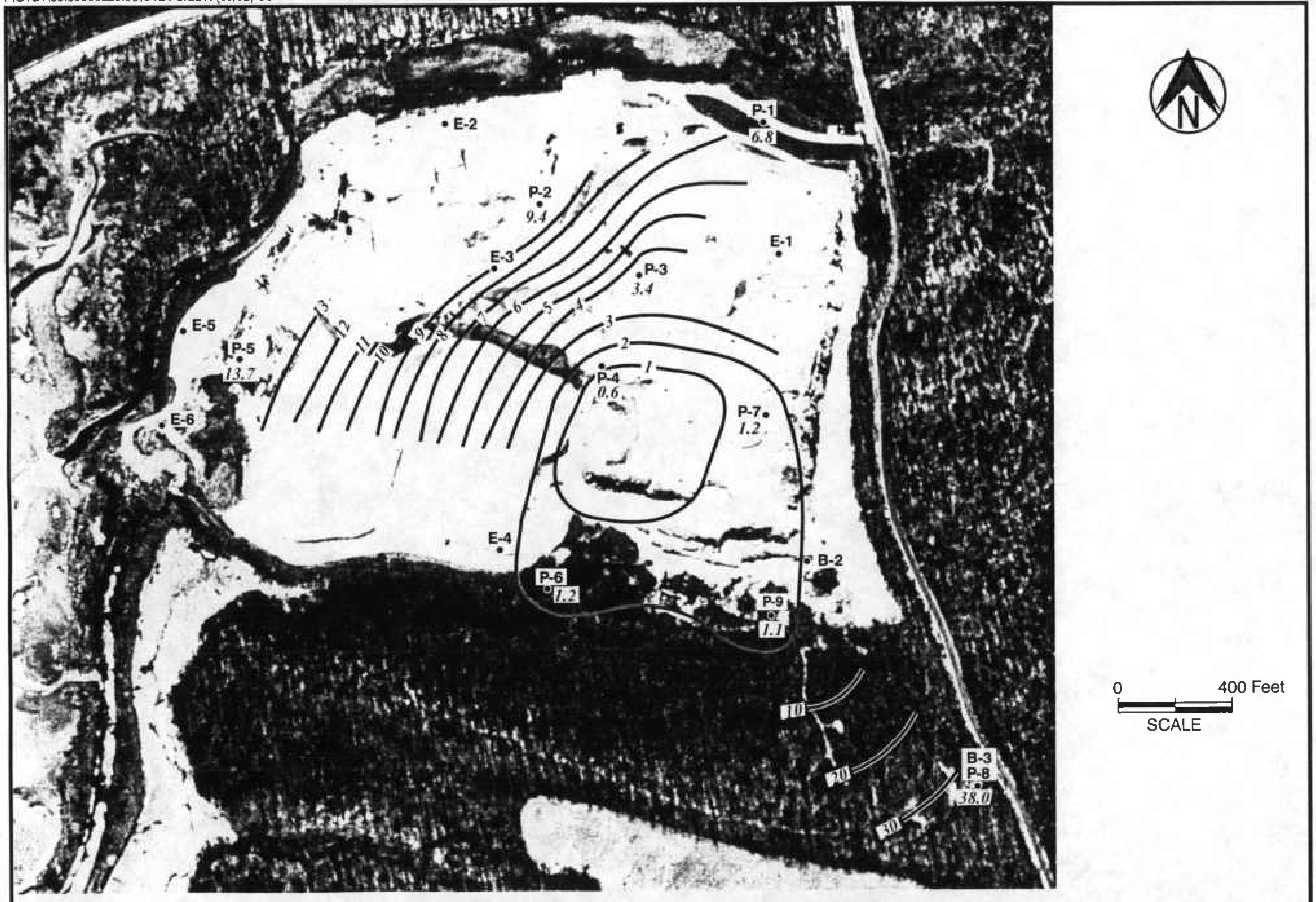
P:GTB1\89.00000229.00\GTB1 7.CDR (05/02) SS



URS

Figure 7. Groundwater Contour Map For March 7, 2001

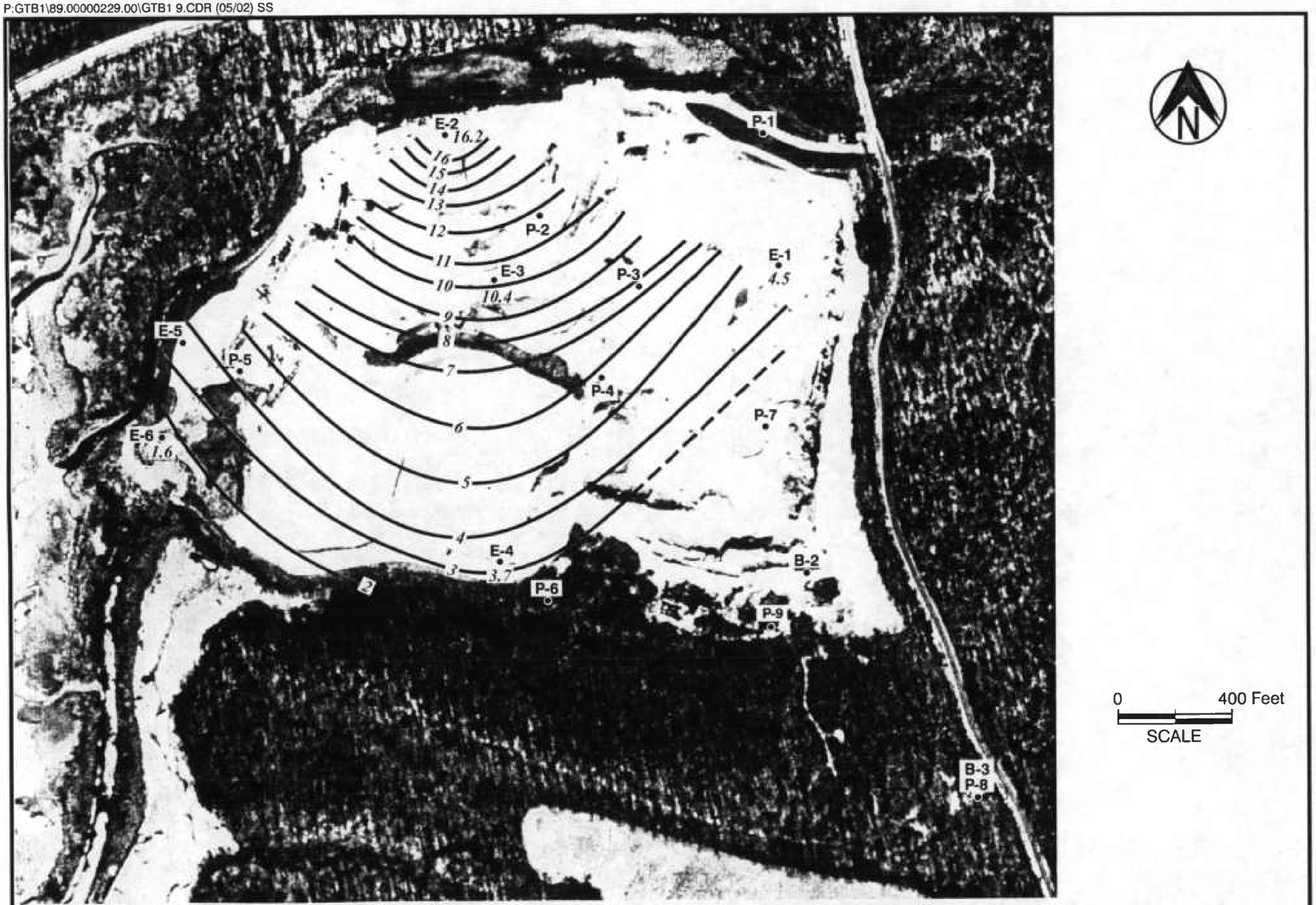
P:GTB1\89.00000229.00\GTB1 8.CDR (05/02) SS



URS

Figure 8. Groundwater Contour Map For April 3, 2002

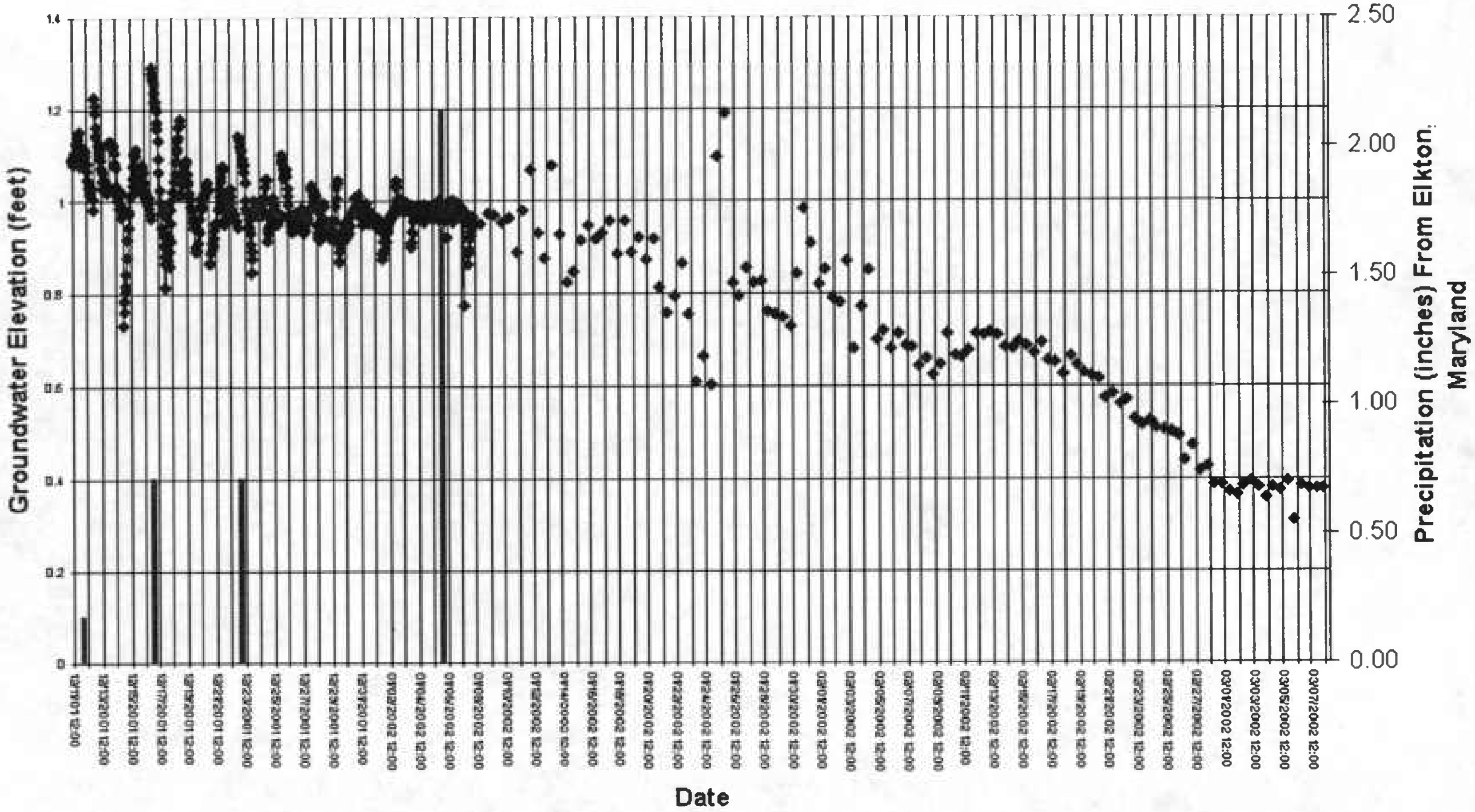
P:GTB1\89.00000229.00\GTB1 9.CDR (05/02) SS



URS

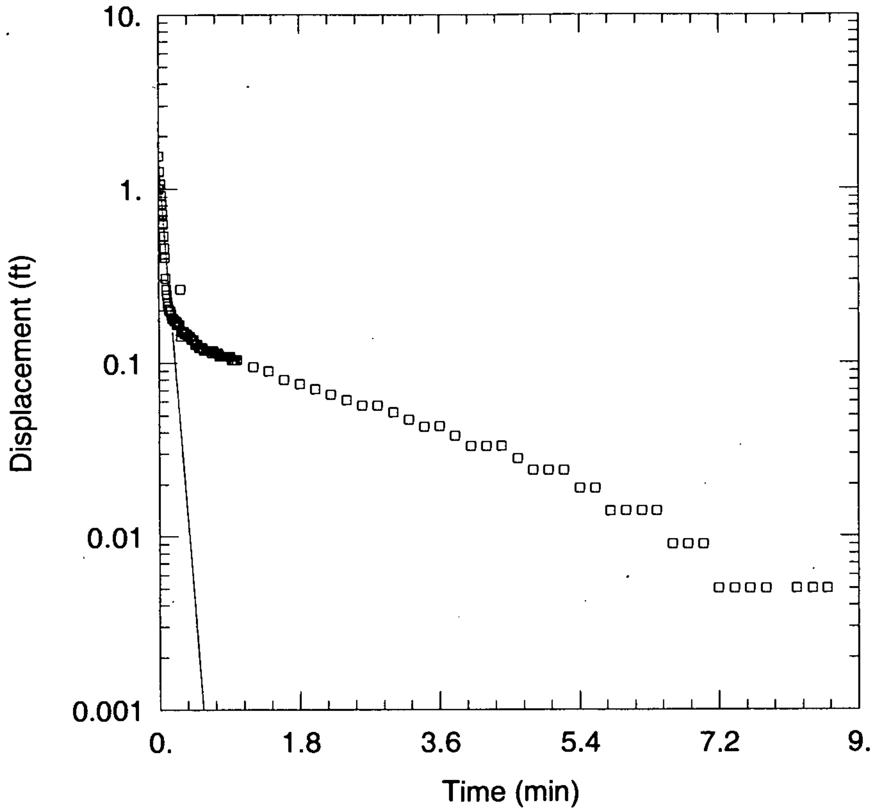
Figure 9. Groundwater Contour Map For October 2000

Figure 10: Graphical Representation of A Continuous Water Level Meter Placed in Well P-6 at Stancill Quarry (Precipitation Data for Raintree Airport in Elkton, Maryland Only Available up to January 6, 2002)



Appendix A

Plots of Slug-Test Results



WITHDRAWAL

Data Set: C:\stancil\P-1 Withdrawal.aqt
Date: 09/03/02 Time: 16:19:20

PROJECT INFORMATION

Company: URS Corporation
Client: MES
Project: 89-00000229.00
Test Location: Stancill Quarry
Test Well: P-1
Test Date: 11/20/01

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.005456 cm/sec
y0 = 1.401 ft

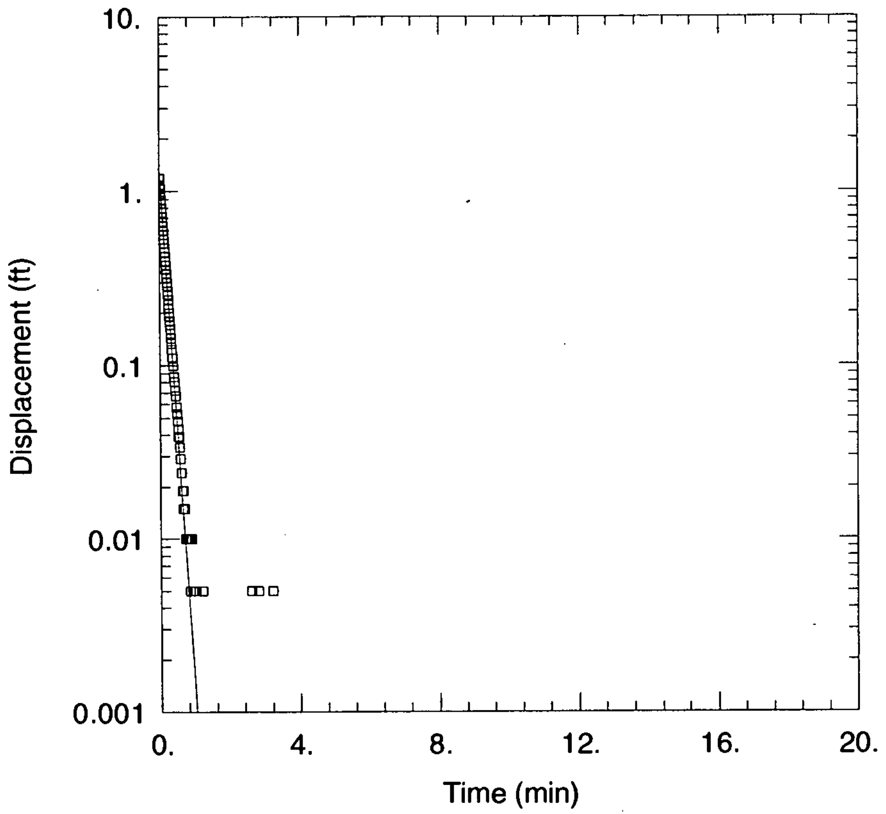
AQUIFER DATA

Saturated Thickness: 10. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (P-1)

Initial Displacement: 1. ft
Wellbore Radius: 0.25 ft
Screen Length: 10. ft
Gravel Pack Porosity: 0.3

Casing Radius: 0.083 ft
Well Skin Radius: 0.25 ft
Total Well Penetration Depth: 8. ft



P-2 WITHDRAWAL

Data Set: C:\stancil\P-2 Withdrawal.aqt
Date: 09/03/02 Time: 16:20:04

PROJECT INFORMATION

Company: URS Corporation
Client: MES
Project: 89-00000229.00
Test Location: Stancill Quarry
Test Well: P-2
Test Date: 11/20/01

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

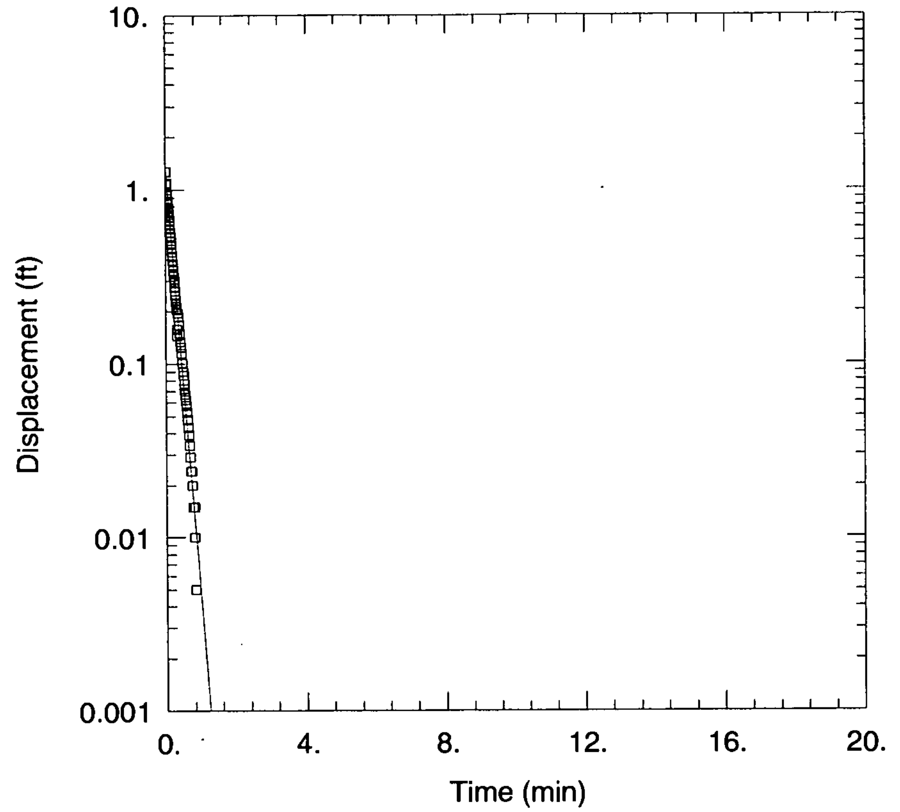
K = 0.003399 cm/sec
y0 = 1.37 ft

AQUIFER DATA

Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (P-2)

Initial Displacement: 1.185 ft
Wellbore Radius: 0.25 ft
Screen Length: 10. ft
Gravel Pack Porosity: 0.3
Casing Radius: 0.083 ft
Well Skin Radius: 0.25 ft
Total Well Penetration Depth: 16.47 ft



P-3 INSERTION

Data Set: C:\stancil\P-3 Insertion.aqt
Date: 09/03/02 Time: 16:20:53

PROJECT INFORMATION

Company: URS Corporation
Client: MES
Project: 89-00000229.00
Test Location: Stancill Quarry
Test Well: P-3
Test Date: 11/20/01

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

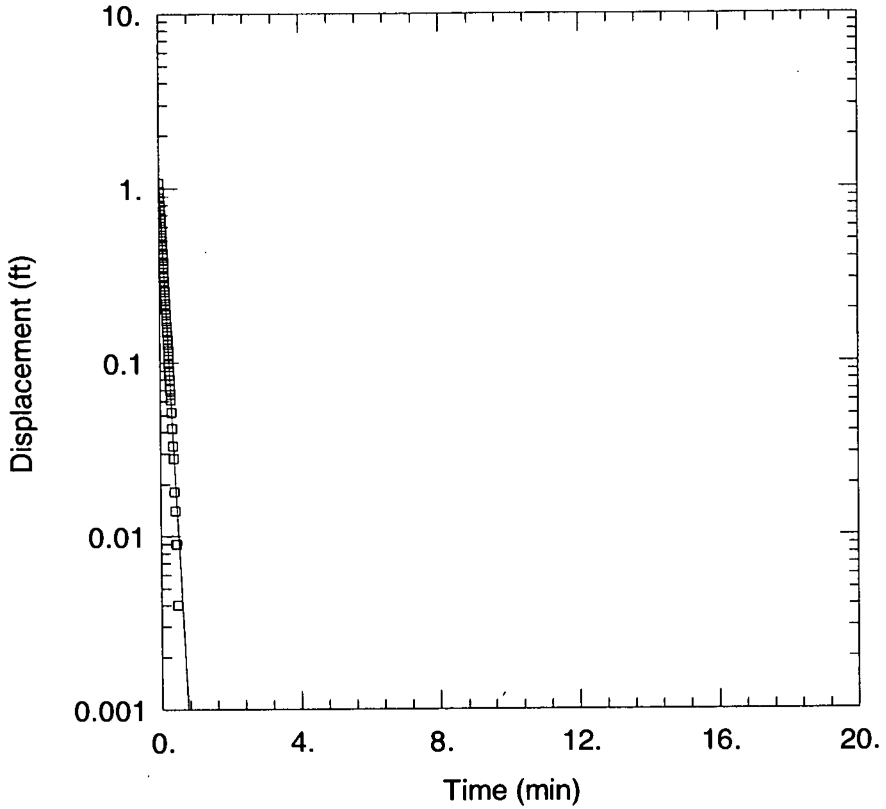
K = 0.002955 cm/sec
y0 = 1.347 ft

AQUIFER DATA

Saturated Thickness: 30. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (P-3)

Initial Displacement: 1.261 ft
Wellbore Radius: 0.25 ft
Screen Length: 10. ft
Gravel Pack Porosity: 0.3
Casing Radius: 0.083 ft
Well Skin Radius: 0.25 ft
Total Well Penetration Depth: 23.63 ft



P-4 WITHDRAWAL

Data Set: C:\stancil\P-4 Withdrawal.aqt
Date: 09/03/02 Time: 16:22:10

PROJECT INFORMATION

Company: URS Corporation
Client: MES
Project: 89-00000229.00
Test Location: Stancill Quarry
Test Well: P-4
Test Date: 11/20/01

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.004017 cm/sec
y0 = 1.212 ft

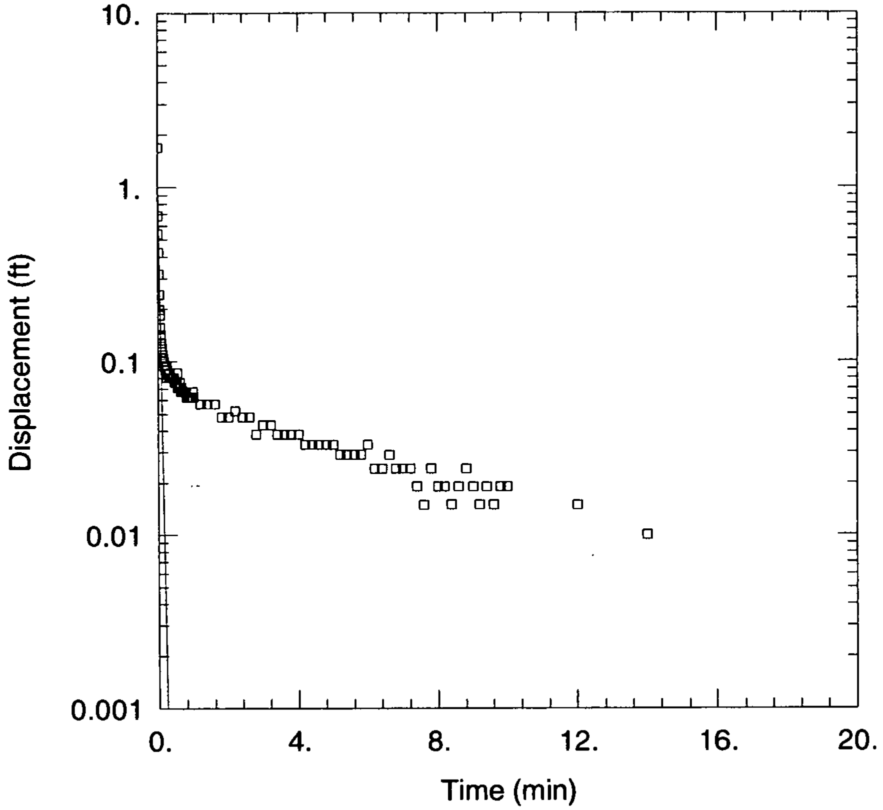
AQUIFER DATA

Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (P-4)

Initial Displacement: 1.072 ft
Wellbore Radius: 0.25 ft
Screen Length: 10. ft
Gravel Pack Porosity: 0.3

Casing Radius: 0.083 ft
Well Skin Radius: 0.25 ft
Total Well Penetration Depth: 9.48 ft



P-5 WITHDRAWAL

Data Set: C:\stancil\P-5 Withdrawal.aqt
Date: 09/03/02 Time: 16:22:47

PROJECT INFORMATION

Company: URS Corporation
Client: MES
Project: 89-00000229.00
Test Location: Stancill Quarry
Test Well: P-5
Test Date: 11/20/01

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.00885 cm/sec
y0 = 1.226 ft

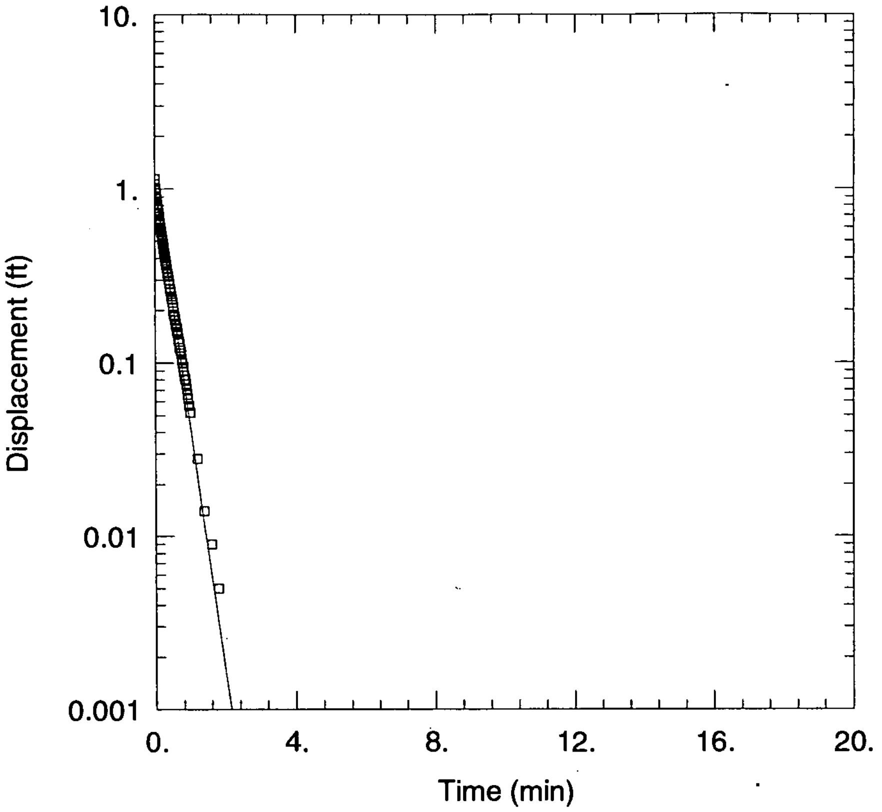
AQUIFER DATA

Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (P-5)

Initial Displacement: 1.685 ft
Wellbore Radius: 0.25 ft
Screen Length: 10. ft
Gravel Pack Porosity: 0.3

Casing Radius: 0.083 ft
Well Skin Radius: 0.25 ft
Total Well Penetration Depth: 3.13 ft



P-6 WITHDRAWAL

Data Set: C:\stancil\P-6 Withdrawal.aqt
Date: 09/03/02 Time: 16:23:19

PROJECT INFORMATION

Company: URS Corporation
Client: MES
Project: 89-00000229.00
Test Location: Stancill Quarry
Test Well: P-6
Test Date: 11/20/01

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

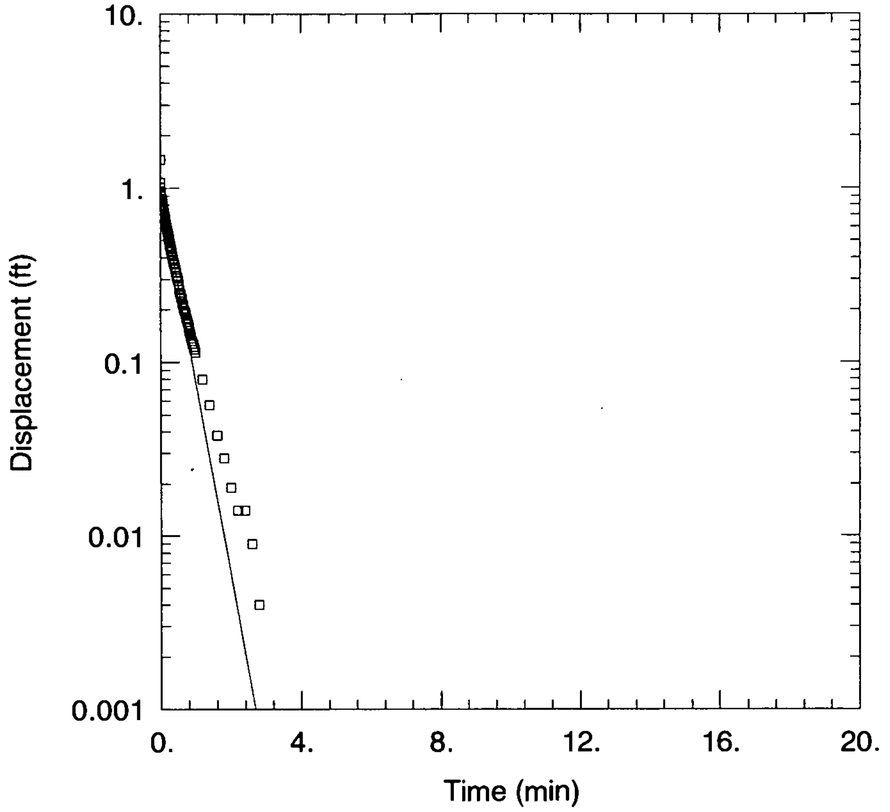
K = 0.001497 cm/sec
y0 = 1.068 ft

AQUIFER DATA

Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (P-6)

Initial Displacement: 1.136 ft
Wellbore Radius: 0.25 ft
Screen Length: 10. ft
Gravel Pack Porosity: 0.3
Casing Radius: 0.083 ft
Well Skin Radius: 0.25 ft
Total Well Penetration Depth: 13.87 ft



P-7 WITHDRAWAL

Data Set: C:\stancil\P-7 Withdrawal.aqt
Date: 09/03/02 Time: 16:23:55

PROJECT INFORMATION

Company: URS Corporation
Client: MES
Project: 89-00000229.00
Test Location: Stancill Quarry
Test Well: P-7
Test Date: 11/20/01

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.001204 cm/sec
y0 = 1.003 ft

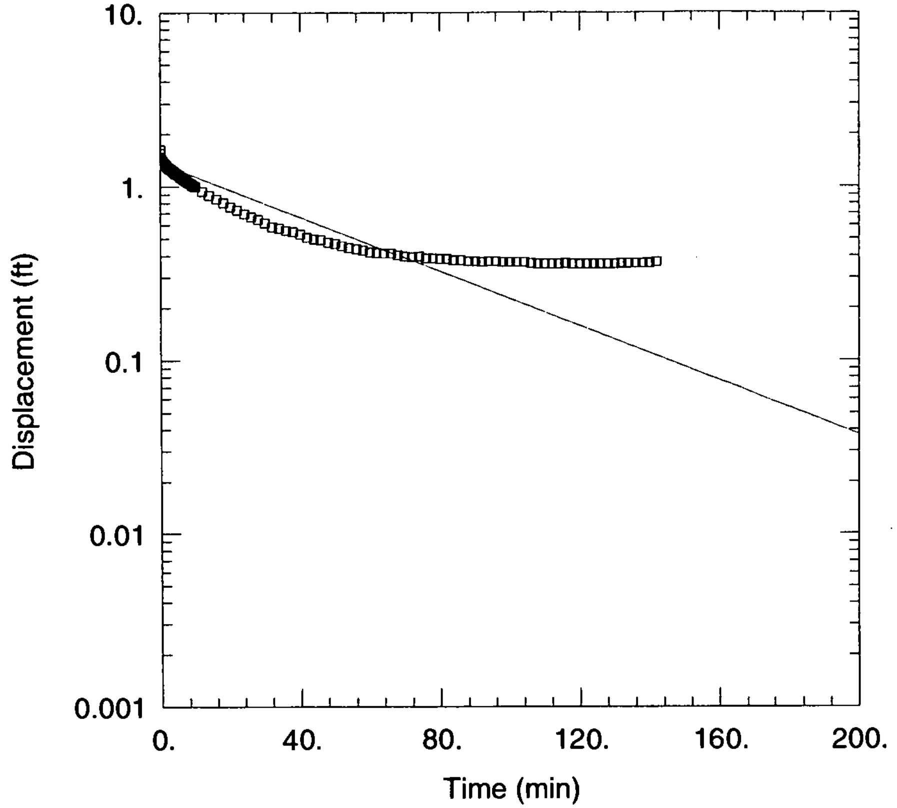
AQUIFER DATA

Saturated Thickness: 20. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (P-7)

Initial Displacement: 1.459 ft
Wellbore Radius: 0.25 ft
Screen Length: 10. ft
Gravel Pack Porosity: 0.3

Casing Radius: 0.083 ft
Well Skin Radius: 0.25 ft
Total Well Penetration Depth: 14.95 ft



P-8 WITHDRAWAL

Data Set: C:\stancil\P-8 Withdrawal.aqt
Date: 09/03/02 Time: 16:24:39

PROJECT INFORMATION

Company: URS Corporation
Client: MES
Project: 89-00000229.00
Test Location: Stancill Quarry
Test Well: P-8
Test Date: 11/20/01

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 9.495E-06 cm/sec
y0 = 1.362 ft

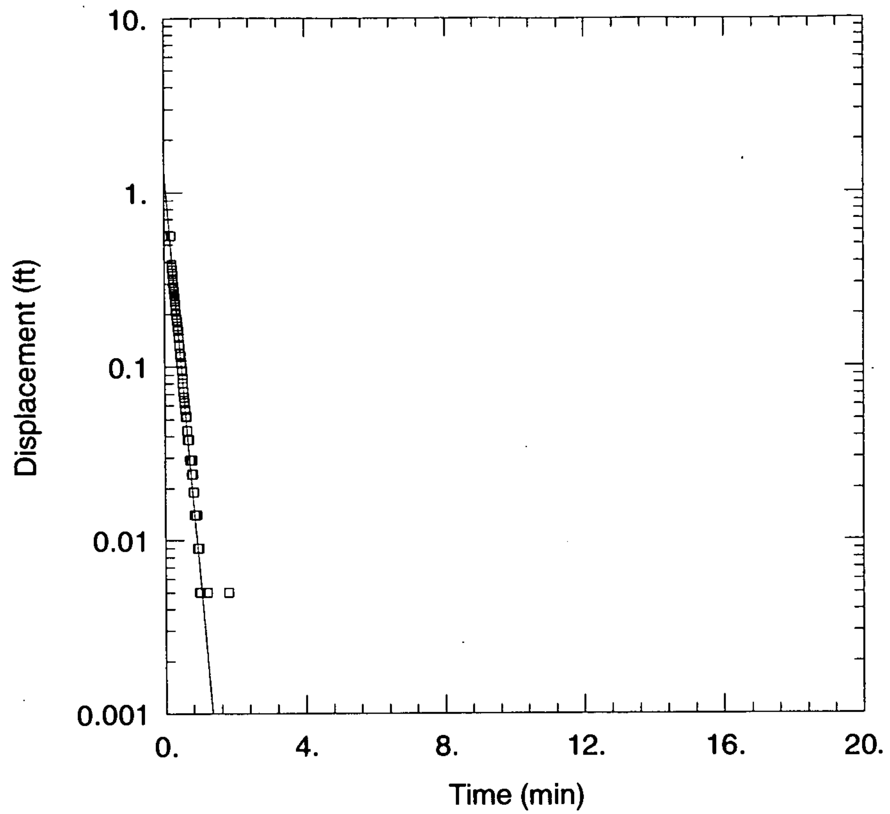
AQUIFER DATA

Saturated Thickness: 40. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (P-8)

Initial Displacement: 1.634 ft
Wellbore Radius: 0.25 ft
Screen Length: 10. ft
Gravel Pack Porosity: 0.3

Casing Radius: 0.083 ft
Well Skin Radius: 0.25 ft
Total Well Penetration Depth: 33.25 ft



P-9 WITHDRAWAL

Data Set: C:\stancil\P-9 Withdrawal.aqt
Date: 09/03/02 Time: 16:25:35

PROJECT INFORMATION

Company: URS Corporation
Client: MES
Project: 89-00000229.00
Test Location: Stancill Quarry
Test Well: P-9
Test Date: 11/20/01

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 0.002767 cm/sec
y0 = 1.332 ft

AQUIFER DATA

Saturated Thickness: 35. ft

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (P-9)

Initial Displacement: 0.564 ft
Wellbore Radius: 0.25 ft
Screen Length: 10. ft
Gravel Pack Porosity: 0.3

Casing Radius: 0.083 ft
Well Skin Radius: 0.25 ft
Total Well Penetration Depth: 27.78 ft

Appendix B

Otton et al. Diagrams (1988, Figures 14 & 15) of Common Chemical Constituents Plus Iron and Manganese in Cecil County Groundwater

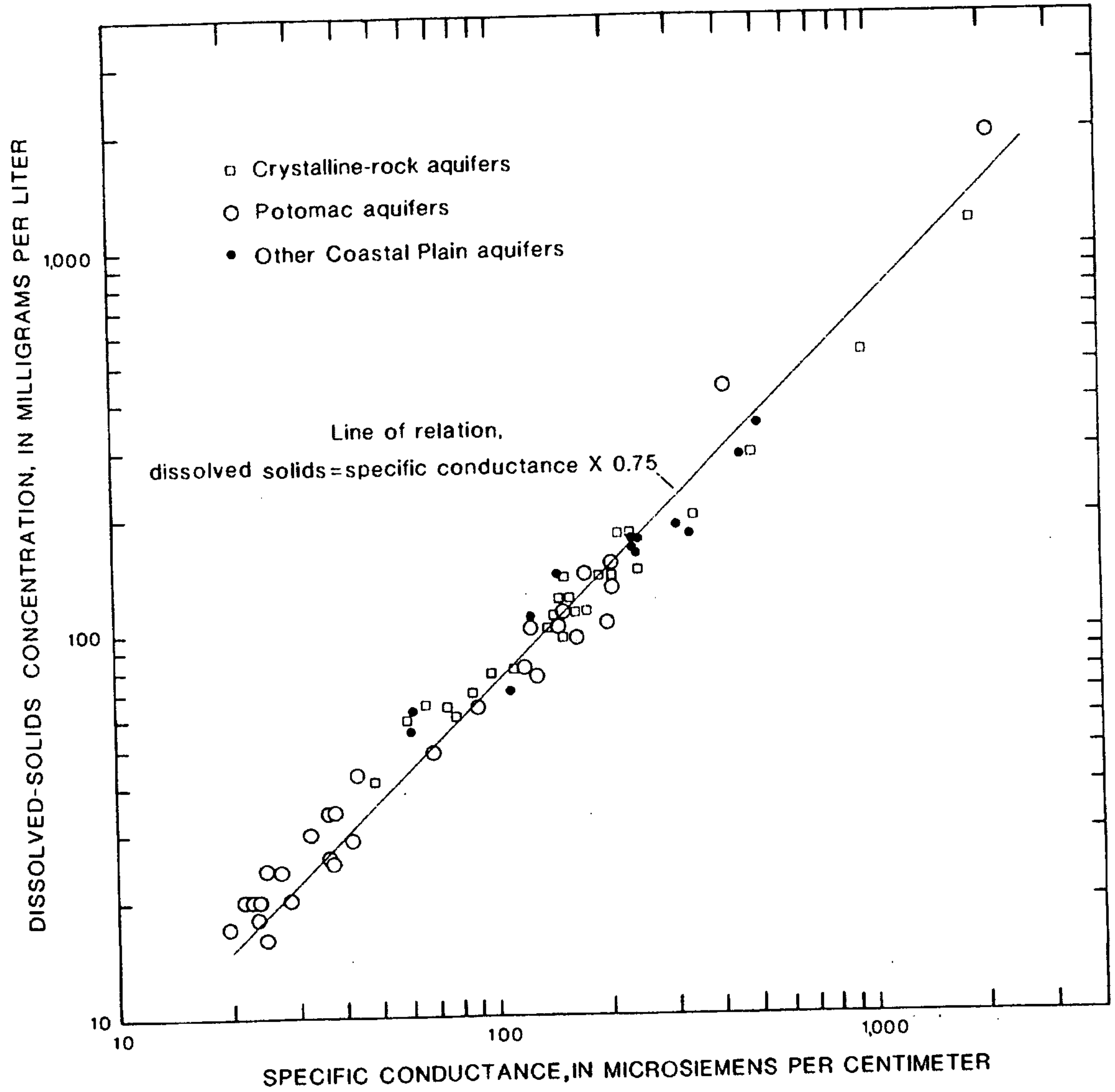


FIGURE 14. Relation of dissolved-solids concentration to specific conductance in ground water in Cecil County, Md.

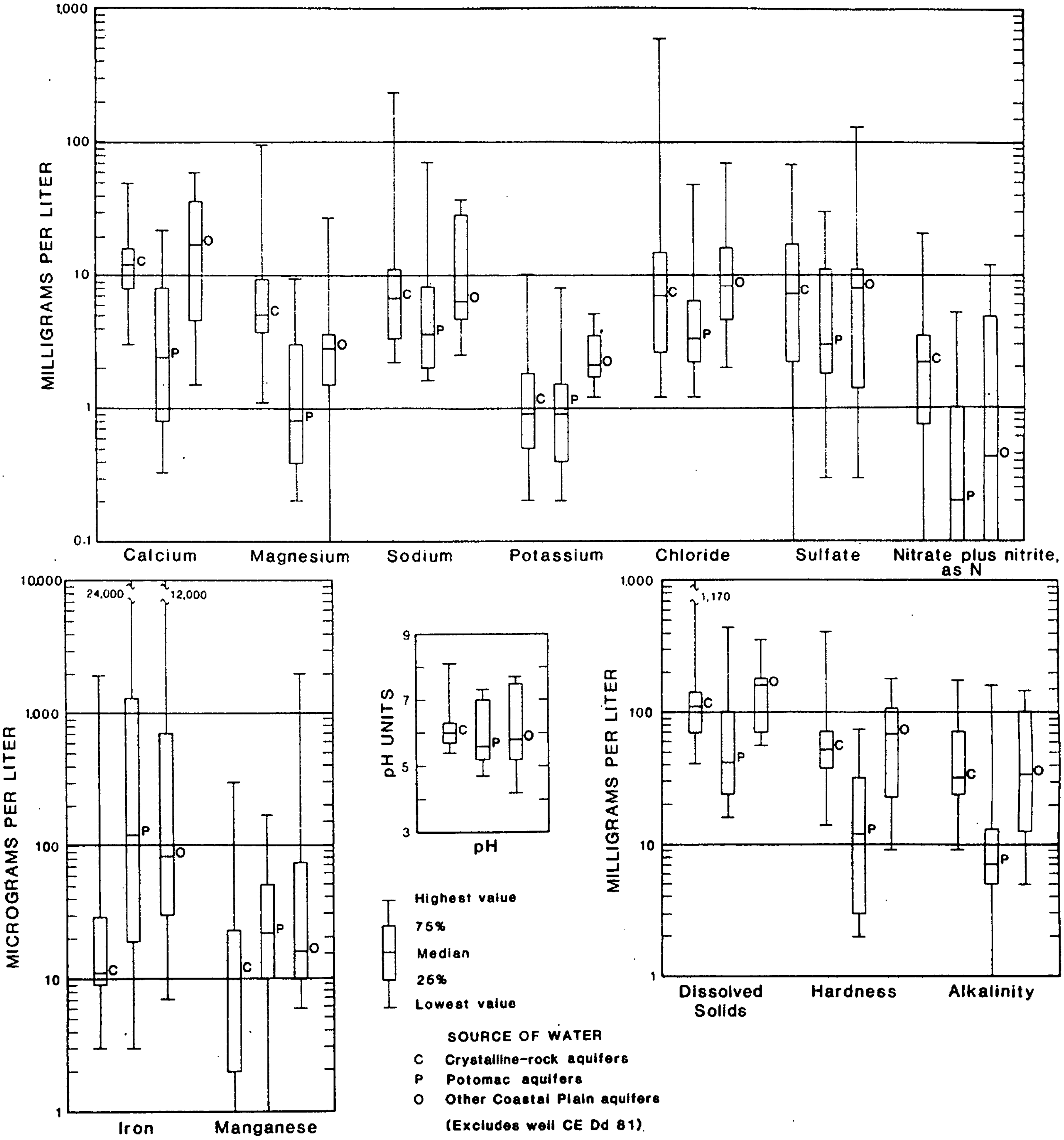


FIGURE 15. Distribution of the concentrations of selected water-quality constituents in ground-water samples.

Appendix C

Chemical Analytical Results from Sampling Piezometers

MARTEL

Sensible Scientific Solutions

Certificate of Analysis

Thursday, November 29, 2001

Prepared expressly for:

KCE Engineering Inc.
3300 North Ridge Road
Suite 360
Ellicott City, Maryland 21043

Attention: Mr. Vir Kathuria
Report for Lab No: 81185.
Samples received by Martel.
P.O. Number: KATHURIA
Project Identification: GW Monitoring, Stancill Quarry,11/06/01.

MARTEL NO. | CLIENT SAMPLE IDENTIFICATION | Sample Date/Time
81185 | 000001 | P-1 | 11/06/2001 10:30

Compound	Test Value	Test Unit	Method	Detection Limit	Analysis Date/Time/Initial
Methane, dissolved	0.200	mg/l	EPA RSK 175	0.0005	11/13/2001 12:00 SUB
Carbon Dioxide	140	mg/l	SM 4500	1	11/07/2001 15:00 BTA
Total Petroleum Hydrocarbons	<2	mg/l	EPA 418.1	2	11/16/2001 11.25 DLJ
Sulfide	<0.1	mg/l	EPA 376.2	0.1	11/12/2001 14:30 BM
Nitrate-Nitrite Nitrogen	0.23	mg/l	EPA 353.1	0.05	11/15/2001 23:51 MDS
Kjeldahl Nitrogen (Total)	<0.5	mg/l	EPA 351.3	0.5	11/09/2001 09:10 TB
Ammonia Nitrogen	<0.2	mg/l	EPA 350.2	0.2	11/08/2001 11:45 TB
Chemical Oxygen Demand	230	mg/l	EPA 410.4	20	11/15/2001 11:30 BM
Phosphorus (total)	0.49	mg/l	EPA 365.2	0.05	11/14/2001 15:21 BM
TOC (Total Organic Carbon)	20	mg/l	EPA 415.1	0.1	11/11/2001 11:00 AK
Sodium	5.8	mg/l	EPA 200.7	0.5	11/14/2001 16:51 DLJ
Potassium	<5.0	mg/l	EPA 200.7	5	11/14/2001 16:51 DLJ
Calcium	5.6	mg/l	EPA 200.7	0.5	11/14/2001 16:51 DLJ
Magnesium	1.3	mg/l	EPA 200.7	0.5	11/14/2001 16:51 DLJ
Iron	~~120~~	~~mg/l~~	~~EPA 200.7~~	0.01	11/14/2001 16:51 DLJ
Manganese	0.26	mg/l	EPA 200.7	0.01	11/14/2001 16:51 DLJ
Arsenic	<0.005	mg/l	EPA 206.2	0.005	11/18/2001 10:42 LB
Cadmium	0.0005	mg/l	EPA 213.2	0.0005	11/14/2001 09:46 LB
Chromium	0.090	mg/l	EPA 218.2	0.005	11/14/2001 11:46 LB
Copper	0.020	mg/l	EPA 220.2	0.005	11/14/2001 11:46 LB
Lead	0.027	mg/l	EPA 239.2	0.005	11/15/2001 07:58 LB
Zinc	0.12	mg/l	EPA 200.7	0.01	11/14/2001 16:51 DLJ
Nickel	0.016	mg/l	EPA 249.2	0.005	11/14/2001 11:46 LB
Selenium	<0.005	mg/l	EPA 270.2	0.005	11/16/2001 09:17 LB
Bicarbonates (as CaCO3)	39	mg/l	EPA 310.1	1	11/12/2001 11:20 TB
Chloride	15	mg/l	EPA 325.2	2	11/12/2001 13:55 BM
Sulfate	17	mg/l	EPA 375.3	5	11/19/2001 14:47 CBS
Nitrate Nitrogen	0.2	mg/l	EPA 353.1	0.05	11/16/2001 23:51 CBS
Nitrite Nitrogen	0.03	mg/l	EPA 353.1	0.02	11/07/2001 14:30 BM
Total Nitrogen	0.23	mg/l	EPA Var	0.05	/ /
Alkalinity, total (as CaCO3)	39	mg/l	EPA 310.1	1	11/12/2001 11:20 TB

MARTEL *Sensible Scientific Solutions*

MARTEL NO. CLIENT SAMPLE IDENTIFICATION Sample Date/Time
81185 000001 P-1 11/06/2001 10:30

Compound	Test Value	Test Unit	Method	Detection Limit	Analysis Date/Time/Initial
Solids (Dissolved)	210	mg/l	EPA 160.1	1	11/09/2001 13:07 TB
Iron (ferrous)	Indeterminate		SM 315B	0.01	11/16/2001 10:00 LB
Iron (Ferric by Calculation)	Indeterminate		SM 3500D	60	11/16/2001 10:00 LB

MARTEL NO. CLIENT SAMPLE IDENTIFICATION Sample Date/Time
81185 000002 P-2 11/08/2001 13:35

Compound	Test Value	Test Unit	Method	Detection Limit	Analysis Date/Time/Initial
Methane, dissolved	0.0011	mg/l	EPA RSK 175	0.0005	11/13/2001 12:00 SUB
Carbon Dioxide	9	mg/l	SM 4500	1	11/07/2001 15:00 BTA
Total Petroleum Hydrocarbons	<2	mg/l	EPA 418.1	2	11/16/2001 11:25 DLJ
Sulfide	<0.1	mg/l	EPA 376.2	0.1	11/12/2001 14:30 BM
Nitrate-Nitrite Nitrogen	0.35	mg/l	EPA 353.1	0.05	11/08/2001 00:05 MDS
Kjeldahl Nitrogen (Total)	<0.5	mg/l	EPA 351.3	0.5	11/09/2001 09:10 TB
Ammonia Nitrogen	<0.2	mg/l	EPA 350.2	0.2	11/08/2001 11:45 TB
Chemical Oxygen Demand	21	mg/l	EPA 410.4	20	11/15/2001 11:30 BM
Phosphorus (total)	0.26	mg/l	EPA 365.2	0.05	11/14/2001 15:21 BM
TOC (Total Organic Carbon)	5.0	mg/l	EPA 415.1	0.1	11/11/2001 11:00 AK
Sodium	13	mg/l	EPA 200.7	0.5	11/14/2001 16:55 DLJ
Potassium	<5.0	mg/l	EPA 200.7	5	11/14/2001 16:55 DLJ
Calcium	8.0	mg/l	EPA 200.7	0.5	11/14/2001 16:56 DLJ
Magnesium	1.9	mg/l	EPA 200.7	0.5	11/14/2001 16:56 DLJ
Iron	5.7	mg/l	EPA 200.7	0.01	11/14/2001 16:55 DLJ
Manganese	0.12	mg/l	EPA 200.7	0.01	11/14/2001 16:55 DLJ
Arsenic	<0.005	mg/l	EPA 206.2	0.005	11/15/2001 10:42 LB
Cadmium	<0.0005	mg/l	EPA 213.2	0.0005	11/14/2001 09:45 LB
Chromium	0.018	mg/l	EPA 218.2	0.005	11/14/2001 11:46 LB
~~Copper~~	~~0.005~~	~~mg/l~~	~~EPA 220.2~~	0.005	~~11/14/2001 11:46 LB~~
Lead	0.007	mg/l	EPA 239.2	0.005	11/15/2001 07:53 LB
Zinc	0.05	mg/l	EPA 200.7	0.01	11/14/2001 16:56 DLJ
Nickel	0.007	mg/l	EPA 249.2	0.005	11/14/2001 11:46 LB
Selenium	<0.005	mg/l	EPA 270.2	0.005	11/16/2001 09:17 LB
Bicarbonates (as CaCO3)	<1	mg/l	EPA 310.1	1	11/12/2001 11:20 TB
Chloride	13	mg/l	EPA 325.2	2	11/12/2001 13:56 BM
Sulfate	16	mg/l	EPA 375.3	5	11/19/2001 16:01 CBS
Nitrate Nitrogen	<0.05	mg/l	EPA 353.1	0.05	11/18/2001 00:05 CBS
Nitrite Nitrogen	0.35	mg/l	EPA 353.1	0.02	11/07/2001 14:30 BM
Total Nitrogen	0.35	mg/l	EPA Var	0.05	/ /
Alkalinity, total (as CaCO3)	<1	mg/l	EPA 310.1	1	11/12/2001 11:20 TB
Solids (Dissolved)	54	mg/l	EPA 160.1	1	11/09/2001 13:07 TB
Iron (ferrous)	Indeterminate		SM 315B	60	11/16/2001 10:00 LB
Iron (Ferric by Calculation)	Indeterminate		SM 3500D	60	11/16/2001 10:00 LB

MARTEL *Sensible Scientific Solutions*

MARTEL NO. CLIENT SAMPLE IDENTIFICATION

81185 000003 P-3

Sample Date/Time
11/06/2001 11:45

Compound	Test Value	Test Unit	Method	Detection Limit	Analysis Date/Time/Initial
Methane, dissolved	0.086	mg/l	EPA RSK 175	0.0005	11/13/2001 12:00 SUB
Carbon Dioxide	24	mg/l	SM 4500	1	11/07/2001 15:00 BTA
Total Petroleum Hydrocarbons	<2	mg/l	EPA 418.1	2	11/16/2001 11:25 DLJ
Sulfide	<0.1	mg/l	EPA 376.2	0.1	11/12/2001 14:30 BM
Nitrate-Nitrite Nitrogen	0.12	mg/l	EPA 353.1	0.05	11/08/2001 00:19 MDS
Kjeldahl Nitrogen (Total)	<0.5	mg/l	EPA 351.3	0.5	11/09/2001 09:10 TB
Ammonia Nitrogen	<0.2	mg/l	EPA 350.2	0.2	11/08/2001 11:45 TB
Chemical Oxygen Demand	<20	mg/l	EPA 410.4	20	11/15/2001 11:30 BM
Phosphorus (total)	0.17	mg/l	EPA 365.2	0.05	11/14/2001 15:21 BM
TOC (Total Organic Carbon)	6.9	mg/l	EPA 415.1	0.1	11/11/2001 11:00 AK
Sodium	7.0	mg/l	EPA 200.7	0.5	11/14/2001 16:59 DLJ
Potassium	<5.0	mg/l	EPA 200.7	5	11/14/2001 16:59 DLJ
Calcium	6.0	mg/l	EPA 200.7	0.5	11/14/2001 16:59 DLJ
Magnesium	2.0	mg/l	EPA 200.7	0.5	11/14/2001 16:59 DLJ
Iron	0.89	mg/l	EPA 200.7	0.01	11/14/2001 16:59 DLJ
Manganese	0.11	mg/l	EPA 200.7	0.01	11/14/2001 16:59 DLJ
Arsenic	<0.005	mg/l	EPA 206.2	0.005	11/15/2001 10:42 LB
Cadmium	<0.0005	mg/l	EPA 213.2	0.0005	11/14/2001 09:45 LB
Chromium	<0.005	mg/l	EPA 218.2	0.005	11/14/2001 11:46 LB
Copper	0.010	mg/l	EPA 220.2	0.005	11/14/2001 11:46 LB
Lead	<0.005	mg/l	EPA 239.2	0.005	11/15/2001 07:53 LB
Zinc	0.03	mg/l	EPA 200.7	0.01	11/14/2001 16:59 DLJ
Nickel	0.008	mg/l	EPA 249.2	0.005	11/14/2001 11:46 LB
Selenium	<0.005	mg/l	EPA 270.2	0.005	11/15/2001 09:17 LB
Bicarbonates (as CaCO3)	18	mg/l	EPA 310.1	1	11/12/2001 11:20 TB
Chloride	14	mg/l	EPA 325.2	2	11/12/2001 13:55 BM
Sulfate	6.7	mg/l	EPA 375.3	5	11/19/2001 16:15 CBS
Nitrate Nitrogen	~~0.1~~	~~mg/l~~	~~EPA 353.1~~	~~0.05~~	11/16/2001 00:19 CBS
Nitrite Nitrogen	0.02	mg/l	EPA 353.1	0.02	11/07/2001 14:30 BM
Total Nitrogen	0.12	mg/l	EPA Var	0.05	/ /
Alkalinity, total (as CaCO3)	18	mg/l	EPA 310.1	1	11/12/2001 11:20 TB
Solids (Dissolved)	64	mg/l	EPA 160.1	1	11/09/2001 13:07 TB
Iron (ferrous)	Indeterminate		SM 315B	60	11/18/2001 10:00 LB
Iron (Ferric by Calculation)	Indeterminate		SM 3500D	60	11/15/2001 10:00 LB

MARTEL NO. CLIENT SAMPLE IDENTIFICATION

81185 000004 P-4

Sample Date/Time
11/06/2001 14:00

Compound	Test Value	Test Unit	Method	Detection Limit	Analysis Date/Time/Initial
Methane, dissolved	0.090	mg/l	EPA RSK 175	0.0005	11/13/2001 12:00 SUB
Carbon Dioxide	8	mg/l	SM 4500	1	11/07/2001 15:00 BTA
Total Petroleum Hydrocarbons	<2	mg/l	EPA 418.1	2	11/16/2001 11:25 DLJ
Sulfide	<0.1	mg/l	EPA 376.2	0.1	11/12/2001 14:30 BM
Nitrate-Nitrite Nitrogen	<0.05	mg/l	EPA 353.1	0.05	11/08/2001 00:33 MDS

MARTEL *Sensible Scientific Solutions*

MARTEL NO. CLIENT SAMPLE IDENTIFICATION Sample Date/Time
81185 000004 P-4 11/06/2001 14:00

Compound	Test Value	Test Unit	Method	Detection Limit	Analysis Date/Time/Initial
Kjeldahl Nitrogen (Total)	<0.5	mg/l	EPA 351.3	0.5	11/09/2001 09:10 TB
Ammonia Nitrogen	<0.2	mg/l	EPA 350.2	0.2	11/08/2001 11:45 TB
Chemical Oxygen Demand	71	mg/l	EPA 410.4	20	11/15/2001 11:30 BM
Phosphorus (total)	0.57	mg/l	EPA 365.2	0.05	11/14/2001 16:21 BM
TOC (Total Organic Carbon)	22	mg/l	EPA 415.1	0.1	11/11/2001 11:00 AK
Sodium	4.9	mg/l	EPA 200.7	0.5	11/14/2001 17:03 DLJ
Potassium	<5.0	mg/l	EPA 200.7	5	11/14/2001 17:03 DLJ
Calcium	5.6	mg/l	EPA 200.7	0.5	11/14/2001 17:03 DLJ
Magnesium	2.3	mg/l	EPA 200.7	0.5	11/14/2001 17:03 DLJ
Iron	7.6	mg/l	EPA 200.7	0.01	11/14/2001 17:03 DLJ
Manganese	0.35	mg/l	EPA 200.7	0.01	11/14/2001 17:03 DLJ
Arsenic	<0.005	mg/l	EPA 206.2	0.005	11/15/2001 10:42 LB
Cadmium	<0.0005	mg/l	EPA 213.2	0.0005	11/14/2001 09:45 LB
Chromium	0.047	mg/l	EPA 218.2	0.005	11/14/2001 11:46 LB
Copper	0.027	mg/l	EPA 220.2	0.005	11/14/2001 11:46 LB
Lead	0.025	mg/l	EPA 239.2	0.005	11/15/2001 07:53 LB
Zinc	0.06	mg/l	EPA 200.7	0.01	11/14/2001 17:03 DLJ
Nickel	0.014	mg/l	EPA 249.2	0.005	11/14/2001 11:46 LB
Selenium	<0.005	mg/l	EPA 270.2	0.005	11/15/2001 09:17 LB
Bicarbonates (as CaCO3)	<1	mg/l	EPA 310.1	1	11/12/2001 11:20 TB
Chloride	10	mg/l	EPA 325.2	2	11/12/2001 13:55 BM
Sulfate	41	mg/l	EPA 375.3	5	11/19/2001 15:28 CBS
Nitrate Nitrogen	<0.05	mg/l	EPA 353.1	0.05	11/16/2001 00:33 CBS
Nitrite Nitrogen	<0.02	mg/l	EPA 353.1	0.02	11/07/2001 14:30 BM
Total Nitrogen	<0.05	mg/l	EPA Var	0.05	/ /
Alkalinity, total (as CaCO3)	<1	mg/l	EPA 310.1	1	11/12/2001 11:20 TB
Solids (Dissolved)	16	mg/l	EPA 160.1	1	11/09/2001 13:07 TB
Iron (ferrous)	Indeterminate		SM 315B	60	11/16/2001 10:00 LB
Iron (Ferric by Calculation)	Indeterminate		SM 3500D	60	11/15/2001 10:00 LB

MARTEL NO. CLIENT SAMPLE IDENTIFICATION Sample Date/Time
81185 000005 P-5 11/08/2001 11:15

Compound	Test Value	Test Unit	Method	Detection Limit	Analysis Date/Time/Initial
Methane, dissolved	0.0063	mg/l	EPA RSK 175	0.0005	11/13/2001 12:00 SUB
Carbon Dioxide	80	mg/l	SM 4500	1	11/07/2001 15:00 BTA
Total Petroleum Hydrocarbons	<2	mg/l	EPA 418.1	2	11/16/2001 11:25 DLJ
Sulfide	<0.1	mg/l	EPA 376.2	0.1	11/12/2001 14:30 BM
Nitrate-Nitrite Nitrogen	<0.05	mg/l	EPA 353.1	0.05	11/08/2001 01:01 MDS
Kjeldahl Nitrogen (Total)	<0.5	mg/l	EPA 351.3	0.5	11/09/2001 09:10 TB
Ammonia Nitrogen	<0.2	mg/l	EPA 350.2	0.2	11/08/2001 11:45 TB
Chemical Oxygen Demand	65	mg/l	EPA 410.4	20	11/15/2001 11:30 BM
Phosphorus (total)	0.65	mg/kg	EPA 365.2	0.05	11/19/2001 16:27 BM
TOC (Total Organic Carbon)	5.9	mg/l	EPA 415.1	0.1	11/11/2001 11:00 AK

MARTEL NO. CLIENT SAMPLE IDENTIFICATION

81185 000005 P-5

Sample Date/Time
11/08/2001 11:15

Compound	Test Value	Test Unit	Method	Detection Limit	Analysis Date/Time/Initial
Sodium	8.0	mg/l	EPA 200.7	0.5	11/14/2001 17:07 DLJ
Potassium	<5.0	mg/l	EPA 200.7	5	11/14/2001 17:07 DLJ
Calcium	9.7	mg/l	EPA 200.7	0.5	11/14/2001 17:07 DLJ
Magnesium	8.3	mg/l	EPA 200.7	0.5	11/14/2001 17:07 DLJ
Iron	11	mg/l	EPA 200.7	0.01	11/14/2001 17:07 DLJ
Manganese	4.2	mg/l	EPA 200.7	0.01	11/14/2001 17:07 DLJ
Arsenic	<0.005	mg/l	EPA 206.2	0.005	11/16/2001 10:42 LB
Cadmium	<0.0005	mg/l	EPA 213.2	0.0005	11/14/2001 09:45 LB
Chromium	0.011	mg/l	EPA 218.2	0.005	11/14/2001 11:46 LB
Copper	0.023	mg/l	EPA 220.2	0.005	11/14/2001 11:46 LB
Lead	0.018	mg/l	EPA 239.2	0.005	11/15/2001 07:53 LB
Zinc	0.05	mg/l	EPA 200.7	0.01	11/14/2001 17:07 DLJ
Nickel	0.019	mg/l	EPA 249.2	0.005	11/14/2001 11:46 LB
Selenium	<0.005	mg/l	EPA 270.2	0.005	11/15/2001 09:17 LB
Bicarbonates (as CaCO3)	32	mg/l	EPA 310.1	1	11/12/2001 11:20 TB
Chloride	13	mg/l	EPA 325.2	2	11/12/2001 13:55 BM
Sulfate	20	mg/l	EPA 375.3	5	11/19/2001 16:11 CBS
Nitrate Nitrogen	<0.05	mg/l	EPA 353.1	0.05	11/18/2001 01:01 CBS
Nitrite Nitrogen	0.03	mg/l	EPA 353.1	0.02	11/07/2001 14:30 BM
Total Nitrogen	<0.05	mg/l	EPA Var	0.05	/ /
Alkalinity, total (as CaCO3)	32	mg/l	EPA 310.1	1	11/12/2001 11:20 TB
Solids (Dissolved)	140	mg/l	EPA 160.1	1	11/09/2001 13:07 TB
Iron (ferrous)	Indeterminate		SM 315B	60	11/15/2001 10:00 LB
Iron (Ferric by Calculation)	Indeterminate		SM 3500D	60	11/15/2001 10:00 LB

MARTEL NO. CLIENT SAMPLE IDENTIFICATION

81185 000005 P-6

Sample Date/Time
11/08/2001 14:30

Compound	Test Value	Test Unit	Method	Detection Limit	Analysis Date/Time/Initial
Methane, dissolved	0.0011	mg/l	EPA RSK 175	0.0005	11/13/2001 12:00 SUB
Carbon Dioxide	16	mg/l	SM 4500	1	11/07/2001 16:00 STA
Total Petroleum Hydrocarbons	<2	mg/l	EPA 418.1	2	11/16/2001 11:25 DLJ
Sulfide	<0.1	mg/l	EPA 376.2	0.1	11/12/2001 14:30 BM
Nitrate-Nitrite Nitrogen	<0.05	mg/l	EPA 353.1	0.05	11/08/2001 01:15 MDS
Kjeldahl Nitrogen (Total)	<0.5	mg/l	EPA 351.3	0.5	11/09/2001 09:10 TB
Ammonia Nitrogen	<0.2	mg/l	EPA 350.2	0.2	11/08/2001 11:45 TB
Chemical Oxygen Demand	49	mg/l	EPA 410.4	20	11/15/2001 11:30 BM
Phosphorus (total)	0.65	mg/l	EPA 365.2	0.05	11/14/2001 15:21 BM
TOC (Total Organic Carbon)	14	mg/l	EPA 415.1	0.1	11/11/2001 11:00 AK
Sodium	3.6	mg/l	EPA 200.7	0.5	11/14/2001 17:10 DLJ
Potassium	<5.0	mg/l	EPA 200.7	5	11/14/2001 17:10 DLJ
Calcium	3.6	mg/l	EPA 200.7	0.5	11/14/2001 17:10 DLJ
Magnesium	2.1	mg/l	EPA 200.7	0.5	11/14/2001 17:10 DLJ
Iron	2.5	mg/l	EPA 200.7	0.01	11/14/2001 17:10 DLJ

MARTEL NO. CLIENT SAMPLE IDENTIFICATION Sample Date/Time
81185 000006 P-5 11/06/2001 14:30

Compound	Test Value	Test Unit	Method	Detection Limit	Analysis Date/Time/Initial
Manganese	0.30	mg/l	EPA 200.7	0.01	11/14/2001 17:10 DLJ
Arsenic	<0.005	mg/l	EPA 206.2	0.005	11/15/2001 10:42 LB
Cadmium	0.0007	mg/l	EPA 213.2	0.0005	11/14/2001 09:45 LB
Chromium	0.035	mg/l	EPA 218.2	0.005	11/14/2001 11:46 LB
Copper	0.016	mg/l	EPA 220.2	0.005	11/14/2001 11:46 LB
Lead	0.012	mg/l	EPA 239.2	0.005	11/15/2001 07:53 LB
Zinc	0.04	mg/l	EPA 200.7	0.01	11/14/2001 17:10 DLJ
Nickel	0.011	mg/l	EPA 249.2	0.005	11/14/2001 11:46 LB
Selenium	<0.005	mg/l	EPA 270.2	0.005	11/15/2001 09:17 LB
Bicarbonates (as CaCO3)	<1	mg/l	EPA 310.1	1	11/12/2001 11:20 TB
Chloride	6	mg/l	EPA 325.2	2	11/12/2001 13:55 BM
Sulfate	20	mg/l	EPA 375.3	5	11/19/2001 16:25 CBS
Nitrate Nitrogen	<0.05	mg/l	EPA 353.1	0.05	11/16/2001 01:15 CBS
Nitrite Nitrogen	<0.02	mg/l	EPA 353.1	0.02	11/07/2001 14:30 BM
Total Nitrogen	<0.05	mg/l	EPA Var	0.05	/ /
Alkalinity, total (as CaCO3)	<1	mg/l	EPA 310.1	1	11/12/2001 11:20 TB
Solids (Dissolved)	50	mg/l	EPA 160.1	1	11/09/2001 13:07 TB
Iron (ferrous)	Indeterminate		SM 315B	60	11/15/2001 10:00 LB
Iron (Ferric by Calculation)	Indeterminate		SM 3500D	60	11/15/2001 10:00 LB

MARTEL NO. CLIENT SAMPLE IDENTIFICATION Sample Date/Time
81185 000007 P-7 11/08/2001 15:00

Compound	Test Value	Test Unit	Method	Detection Limit	Analysis Date/Time/Initial
Methane, dissolved	0.00053	mg/l	EPA RSK 175	0.0005	11/13/2001 12:00 SUB
Carbon Dioxide	20	mg/l	SM 4500	1	11/07/2001 15:00 BTA
Total Petroleum Hydrocarbons	<2	mg/l	EPA 418.1	2	11/16/2001 11:26 DLJ
Sulfide	<0.1	mg/l	EPA 376.2	0.1	11/12/2001 14:30 BM
Nitrate-Nitrite Nitrogen	1.7	mg/l	EPA 353.1	0.05	11/08/2001 01:26 MDS
Kjeldahl Nitrogen (Total)	<0.5	mg/l	EPA 351.3	0.5	11/09/2001 09:10 TB
Ammonia Nitrogen	<0.2	mg/l	EPA 350.2	0.2	11/08/2001 11:45 TB
Chemical Oxygen Demand	38	mg/l	EPA 410.4	20	11/15/2001 11:30 BM
Phosphorus (total)	0.33	mg/l	EPA 365.2	0.05	11/14/2001 16:21 BM
TOC (Total Organic Carbon)	7.2	mg/l	EPA 415.1	0.1	11/11/2001 11:00 AK
Sodium	8.2	mg/l	EPA 200.7	0.5	11/14/2001 17:14 DLJ
Potassium	<5.0	mg/l	EPA 200.7	5	11/14/2001 17:14 DLJ
Calcium	4.8	mg/l	EPA 200.7	0.5	11/14/2001 17:14 DLJ
Magnesium	2.4	mg/l	EPA 200.7	0.5	11/14/2001 17:14 DLJ
Iron	4.5	mg/l	EPA 200.7	0.01	11/14/2001 17:14 DLJ
Manganese	0.09	mg/l	EPA 200.7	0.01	11/14/2001 17:14 DLJ
Arsenic	<0.005	mg/l	EPA 206.2	0.005	11/15/2001 10:42 LB
Cadmium	<0.0005	mg/l	EPA 213.2	0.0005	11/14/2001 09:45 LB
Chromium	0.047	mg/l	EPA 218.2	0.005	11/14/2001 11:46 LB
Copper	0.014	mg/l	EPA 220.2	0.005	11/14/2001 11:46 LB

MARTEL

Sensible Scientific Solutions

MARTEL NO. **CLIENT SAMPLE IDENTIFICATION** Sample Date/Time
81165 000007 P-7 11/06/2001 15:00

Compound	Test Value	Test Unit	Method	Detection Limit	Analysis Date/Time/Initial
Lead	0.012	mg/l	EPA 239.2	0.005	11/15/2001 07:53 LB
Zinc	0.07	mg/l	EPA 200.7	0.01	11/14/2001 17:14 DLJ
Nickel	0.037	mg/l	EPA 249.2	0.005	11/14/2001 11:46 LB
Selenium	<0.005	mg/l	EPA 270.2	0.005	11/15/2001 09:17 LB
Bicarbonates (as CaCO3)	<1	mg/l	EPA 310.1	1	11/12/2001 11:20 TB
Chloride	25	mg/l	EPA 325.2	2	11/12/2001 13:56 BM
Sulfate	9.2	mg/l	EPA 375.3	5	11/19/2001 16:39 CBS
Nitrate Nitrogen	1.7	mg/l	EPA 353.1	0.05	11/16/2001 01:28 CBS
Nitrite Nitrogen	<0.02	mg/l	EPA 353.1	0.02	11/07/2001 14:30 BM
Total Nitrogen	1.7	mg/l	EPA Var	0.05	/ /
Alkalinity, total (as CaCO3)	<1	mg/l	EPA 310.1	1	11/12/2001 11:20 TB
Solids (Dissolved)	69	mg/l	EPA 160.1	1	11/09/2001 13:07 TB
Iron (ferrous)	Indeterminate		SM 315B	60	11/16/2001 10:00 LB
Iron (Ferric by Calculation)	Indeterminate		SM 3500D	60	11/15/2001 10:00 LB

MARTEL NO. **CLIENT SAMPLE IDENTIFICATION** Sample Date/Time
81165 000008 P-8 11/08/2001 16:30

Compound	Test Value	Test Unit	Method	Detection Limit	Analysis Date/Time/Initial
Methane, dissolved	<0.0005	mg/l	EPA RSK 175	0.0005	11/13/2001 12:00 SUB
Carbon Dioxide	14	mg/l	SM 4500	1	11/07/2001 16:00 BTA
Total Petroleum Hydrocarbons	<2	mg/l	EPA 418.1	2	11/16/2001 11:25 DLJ
Sulfide	<0.1	mg/l	EPA 376.2	0.1	11/12/2001 14:30 BM
Nitrate-Nitrite Nitrogen	0.18	mg/l	EPA 353.1	0.05	11/08/2001 01:42 MDS
Kjeldahl Nitrogen (Total)	<0.5	mg/l	EPA 351.3	0.5	11/09/2001 09:10 TB
Ammonia Nitrogen	<0.2	mg/l	EPA 350.2	0.2	11/08/2001 11:45 TB
Chemical Oxygen Demand	21	mg/l	EPA 410.4	20	11/16/2001 11:30 BM
Phosphorus (total)	0.12	mg/l	EPA 365.2	0.05	11/14/2001 15:21 BM
TOC (Total Organic Carbon)	3.3	mg/l	EPA 415.1	0.1	11/11/2001 11:00 AK
Sodium	7.6	mg/l	EPA 200.7	0.5	11/14/2001 17:18 DLJ
Potassium	<5.0	mg/l	EPA 200.7	5	11/14/2001 17:18 DLJ
Calcium	4.3	mg/l	EPA 200.7	0.5	11/14/2001 17:18 DLJ
Magnesium	0.9	mg/l	EPA 200.7	0.5	11/14/2001 17:18 DLJ
Iron	0.27	mg/l	EPA 200.7	0.01	11/14/2001 17:18 DLJ
Manganese	0.07	mg/l	EPA 200.7	0.01	11/14/2001 17:18 DLJ
Arsenic	<0.005	mg/l	EPA 206.2	0.005	11/15/2001 10:42 LB
Cadmium	<0.0005	mg/l	EPA 213.2	0.0005	11/14/2001 09:45 LB
Chromium	<0.005	mg/l	EPA 218.2	0.005	11/14/2001 11:46 LB
Copper	<0.005	mg/l	EPA 220.2	0.005	11/14/2001 11:46 LB
Lead	<0.005	mg/l	EPA 239.2	0.005	11/15/2001 07:53 LB
Zinc	0.03	mg/l	EPA 200.7	0.01	11/14/2001 17:18 DLJ
Nickel	0.007	mg/l	EPA 249.2	0.005	11/14/2001 11:46 LB
Selenium	<0.005	mg/l	EPA 270.2	0.005	11/15/2001 09:17 LB
Bicarbonates (as CaCO3)	4	mg/l	EPA 310.1	1	11/12/2001 11:20 TB

MARTEL *Sensible Scientific Solutions*

MARTEL NO. | CLIENT SAMPLE IDENTIFICATION | Sample Date/Time
81185 000008 P-8 | | 11/06/2001 15:30

Compound	Test Value	Test Unit	Method	Detection Limit	Analysis Date/Time/Initial
Chloride	19	mg/l	EPA 325.2	2	11/12/2001 13:55 BM
Sulfate	6.1	mg/l	EPA 375.3	5	11/19/2001 16:52 CBS
Nitrate Nitrogen	0.1	mg/l	EPA 353.1	0.05	11/16/2001 01:42 CBS
Nitrite Nitrogen	0.06	mg/l	EPA 353.1	0.02	11/07/2001 14:30 BM
Total Nitrogen	0.16	mg/l	EPA Var	0.05	/ /
Alkalinity, total (as CaCO3)	4	mg/l	EPA 310.1	1	11/12/2001 11:20 TB
Solids (Dissolved)	48	mg/l	EPA 160.1	1	11/09/2001 13:07 TB
Iron (ferrous)	Indeterminate		SM 315B	60	11/15/2001 10:00 LB
Iron (Ferric by Calculation)	Indeterminate		SM 3500D	50	11/15/2001 10:00 LB

MARTEL NO. | CLIENT SAMPLE IDENTIFICATION | Sample Date/Time
81185 000009 P-9 | | 11/06/2001 14:45

Compound	Test Value	Test Unit	Method	Detection Limit	Analysis Date/Time/Initial
Methane, dissolved	<0.0005	mg/l	EPA RSK 175	0.0005	11/13/2001 12:00 SUB
Carbon Dioxide	25	mg/l	SM 4500	1	11/07/2001 15:00 BTA
Total Petroleum Hydrocarbons	<2	mg/l	EPA 418.1	2	11/16/2001 11:25 DLJ
Sulfide	<0.1	mg/l	EPA 376.2	0.1	11/12/2001 14:30 BM
Nitrate-Nitrite Nitrogen	0.42	mg/l	EPA 353.1	0.05	11/08/2001 01:56 MDS
Kjeldahl Nitrogen (Total)	<0.5	mg/l	EPA 351.3	0.5	11/09/2001 09:10 TB
Ammonia Nitrogen	<0.2	mg/l	EPA 350.2	0.2	11/08/2001 11:45 TB
Chemical Oxygen Demand	<20	mg/l	EPA 410.4	20	11/15/2001 11:30 BM
Phosphorus (total)	0.09	mg/l	EPA 365.2	0.05	11/14/2001 15:21 BM
TOC (Total Organic Carbon)	1.8	mg/l	EPA 415.1	0.1	11/11/2001 11:00 AK
Sodium	8.5	mg/l	EPA 200.7	0.5	11/14/2001 17:22 DLJ
Potassium	<5.0	mg/l	EPA 200.7	5	11/14/2001 17:22 DLJ
Calcium	2.8	mg/l	EPA 200.7	0.5	11/14/2001 17:22 DLJ
Magnesium	1.6	mg/l	EPA 200.7	0.5	11/14/2001 17:22 DLJ
Iron	0.35	mg/l	EPA 200.7	0.01	11/14/2001 17:22 DLJ
Manganese	0.04	mg/l	EPA 200.7	0.01	11/14/2001 17:22 DLJ
Arsenic	<0.005	mg/l	EPA 206.2	0.005	11/15/2001 10:42 LB
Cadmium	<0.0005	mg/l	EPA 213.2	0.0005	11/14/2001 09:45 LB
Chromium	0.007	mg/l	EPA 218.2	0.005	11/14/2001 11:46 LB
Copper	<0.005	mg/l	EPA 220.2	0.005	11/14/2001 11:40 LB
Lead	<0.005	mg/l	EPA 239.2	0.005	11/16/2001 07:53 LB
Zinc	0.03	mg/l	EPA 200.7	0.01	11/14/2001 17:22 DLJ
Nickel	0.009	mg/l	EPA 249.2	0.005	11/14/2001 11:46 LB
Selenium	<0.005	mg/l	EPA 270.2	0.005	11/15/2001 09:17 LB
Bicarbonates (as CaCO3)	<1	mg/l	EPA 310.1	1	11/12/2001 11:20 TB
Chloride	22	mg/l	EPA 325.2	2	11/12/2001 13:55 BM
Sulfate	11	mg/l	EPA 375.3	5	11/19/2001 17:00 CBS
Nitrate Nitrogen	0.4	mg/l	EPA 353.1	0.05	11/16/2001 01:56 CBS
Nitrite Nitrogen	<0.02	mg/l	EPA 353.1	0.02	11/07/2001 14:30 BM
Total Nitrogen	0.42	mg/l	EPA Var	0.05	/ /

MARTEL *Sensible Scientific Solutions*

MARTEL NO.		CLIENT SAMPLE IDENTIFICATION				Sample Date/Time 11/06/2001 14:45
81186 000009	P-9					
Compound		Test Value	Test Unit	Method	Detection Limit	Analysis Date/Time/Initial
Alkalinity, total (as CaCO3)		<1	mg/l	EPA 310.1	1	11/12/2001 11:20 TB
Solids (Dissolved)		82	mg/l	EPA 160.1	1	11/09/2001 13:07 TB
Iron (ferrous)		Indeterminate		SM 315B	80	11/15/2001 10:00 LB
Iron (Ferric by Calculation)		Indeterminate		SM 3500D	60	11/15/2001 10:00 LB

MARTEL NO.		CLIENT SAMPLE IDENTIFICATION				Sample Date/Time 11/06/2001 08:00
81185 0010TB	Trip Blank					
Compound		Test Value	Test Unit	Method	Detection Limit	Analysis Date/Time/Initial
Methane, dissolved		<0.0005	mg/l	EPA RSK 175	0.0005	11/13/2001 12:00 SUB

All Procedures used are in accordance with the following methods:

"Methods of Chemical Analysis of Water and Wastewater", EPA 600/4-79/020, U.S. EPA, Cincinnati, Revised March 1983. "Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater", U.S. EPA, Appendix A to 40 CFR Part 136, Vol. 49, No. 209, October 26, 1984. "Standard Methods for the Examination of Water and Wastewater", 18th Edition, 1992. **Note: Total Nitrate-Nitrite Nitrogen is the sum of Nitrate and Nitrite analytical results. Total Nitrogen is the sum of Total Nitrate-Nitrite and Kjeldahl Nitrogen analytical results. The ferrous and ferric iron test methods were indeterminate (detection limit of about 60 mg/l) given the relatively low levels of total iron present in the samples.

QC ______

Approved Michael Smith

Date 11/29/01

Date 11/29/01

Martel Laboratories JDS Inc.
1025 Cromwell Bridge Road - Baltimore, Maryland 21286
PH 410-825-7790 FAX 410-821-1054 EMAIL: martel@martellabs.com

KCEENG

CHAIN OF CUSTODY / SAMPLE INFORMATION FORM

81185

Martel Laboratories JDS Inc. • 1025 Cromwell Bridge Road • Baltimore, MD 21286 • (410) 825-7790 • FAX (410) 821-1054

Client Name/Phone/FAX ______

Client Address ______

Invoice Address ______

Sampler ______

Project Name/# Stancill Quarry Groundwaters

Contract/P.O Number ______

Sample Turnaround Time ROUTINE

Station No./ Sample ID	Station Location	Matrix	Container Description/ Preservation Data	Potentially Hazardous?	# of Containers	Date	Time	Analyses Required/Comments
1	P-1	WATER	40 ml VOA/HCL	NO	3	11/6/01	1030	METHANE
			250 ml amber glass/4C		1			CO2
			liter clear glass/H2SO4		1			TPH
			250 ml plastic/ZnAcetate/NaOH		1			S3
			500 ml plastic/H2SO4		1			NO32, TKN, NH3, COD, AP, TOC
			liter plastic/HNO3		1			NA, K, CA, MG, FE, MN, AS2, CD2, CR2, CU2, PB2, ZN2, HG, SE2
			1/2 gallon plastic/NONE		1			HCO3, CL, SO4, NO3, NO2, F, ALK, DS, FEOUS, FERRIC
			(SAME AS SAMPLE 1)		9	11-6	1335	(SAME AS SAMPLE 1)
2	P-2		(SAME AS SAMPLE 1)		9	11-6	1145	(SAME AS SAMPLE 1)
3	P-3		(SAME AS SAMPLE 1)		9	11-6	1400	(SAME AS SAMPLE 1)
4	P-4		(SAME AS SAMPLE 1)		9	11-6	1115	(SAME AS SAMPLE 1)
5	P-5		(SAME AS SAMPLE 1)		9	11-6	1430	(SAME AS SAMPLE 1)
6	P-6		(SAME AS SAMPLE 1)		9	11-6	1500	(SAME AS SAMPLE 1)
7	P-7							

Transferred by: Vii Kaltuno	Received by:	Date 11-6-01	Time 1815
Transferred by:	Received by:	Date	Time
Transferred by:	Received by:	Date	Time

Cooler Receipt Information (LAB USE ONLY)

Sufficient ice? [✓ Yes]/No If No, temp.= ______

Sample containers pres'v'd? [✓ Yes]/No If No, explain

Custody Seal present/intact? Yes/No N/A

Initials: ZSK Date: 11-6-01

g:\mg-share\excel\cockce

CHAIN OF CUSTODY / SAMPLE INFORMATION FORM

8185

Martel Laboratories JDS Inc. • 1025 Cromwell Bridge Road • Baltimore, MD 21286 • (410) 825-7790 • FAX (410) 821-1054

Client Name/Phone/FAX

Client Address

Invoice Address

Sampler

Project Name/# Stancill Quarry Groundwaters

Contract/P.O Number

Sample Turnaround Time ROUTINE

Station No./ Sample ID	Station Location	Matrix	Container Description/ Preservation Notes	Potentially Hazardous?	# of Containers	Date	Time	Analyses Required/Comments
8	P8	WATER	40 ml VOA/HCL	NO	3	11-6	1530	METHANE
			250 ml amber glass/4C		1			CO2
			liter clear glass/H2SO4		1			TPH
			250 ml plastic/ZnAcetate/NaOH		1			S3
			500 ml plastic/H2SO4		1			NO32, TKN, NH3, COD, AP, TOC
			liter plastic/HNO3		1			NA, K, CA, MG, FE, MN, AS2, CD2, CR2, CU2, PB2, ZI NI2, SE2
			1/2 gallon plastic/NONE		1			HCO3, CL, SO4, NO2, NO3, N, ALK, DS, FEOUS, FERRIC
9	P-9		(SAME AS SAMPLE 1)		9	11-6	1445	(SAME AS SAMPLE 1)
10	Trip Blank		(SAME AS SAMPLE 1)		9			(SAME AS SAMPLE 1) Methane
			(SAME AS SAMPLE 1)		9			(SAME AS SAMPLE 1)
			(SAME AS SAMPLE 1)		9			(SAME AS SAMPLE 1)
			(SAME AS SAMPLE 1)		9			(SAME AS SAMPLE 1)
			(SAME AS SAMPLE 1)		9			(SAME AS SAMPLE 1)

Transferred by: Vin Kathuria	Received by:	Date 11-6-01	Time 1815
Transferred by:	Received by:	Date	Time
Transferred by:	Received by:	Date	Time

Cooler Receipt Information (LAB USE ONLY)

Sufficient Ice? - Yes/No If No, temp.= ______

Sample containers present? ; Yes/No If No, explain

Custody Seal present/intact? - Yes/No

Initials: ESS Date: 11/6/01

g:/mg-share/excel/cockos

Appendix D

Chemical Analytical Results from Dredge Sampling of Upper Chesapeake Bay

Table of Chemical Analytical Results of Sediment from 22 Dredge Sites in The Upper Chesapeake Bay

PROJECT NAME, SAMPLING DATE AND SAMPLE LOCATIONS	TKN* MG/KG	TOTAL P* MG/KG	pH UNITS	O&G* MG/KG	TOC* MG/KG	COD* MG/KG	TS* %	ALUMINUM MG/KG	ANTIMONY MG/KG	ARSENIC MG/KG	BARIUM MG/KG	BERYLLIUM MG/KG	CADMIUM MG/KG
OUTER CHANNEL 1985-1999													
AVERAGE	1,456	1,230	8	867	24,635	66,236	39	12,397	5	7	56	1	1
MAXIMUM	5,000	14,917	9	5,842	90,500	390,909	85	29,400	24	33	250	2	5
MINIMUM	40	14	6	1	176	117	18	1,100	0	1	5	0	0
MEDIAN	1,100	785	8	432	22,002	58,981	36	9,804	0	6	50	1	1
Back River Bridge													
	650	700		950	20200		50			3.6	71		3
	430	400		1200	14500		42			0.7	40		3
	310	120		74	7310		45			1	16		3
50' Project, September 1986													
	1100	260	7	78	29000	29000	46			0.5			0.32
	1700	250	6.7	42	33000	69000	43			0.5			0.1
	280	230	8.5	38	3000	3100	79			0.5			0.6
50' Project, September 1986													
	4300	48	8.3	420	58000	110000	21			0.5			0.95
	2700	430	7.8	180	29000	80000	30			0.5			0.63
	2700	220	8	320	39000	100000	26			0.5			0.5
	2500	320	8.1	340	42000	85000	28			0.5			0.57
	2000	240	7.4	48	27000	73000	40			0.5			0.18
	1400	240	7.1	71	21000	86000	42			0.5			0.1
	88	270	7.8	56	28000	97000	32			0.5			0.2
	200	430	8.3	40	38000	84000	28			0.5			0.6
	64	160	8	23	16000	51000	44			0.5			0.38
	4200	920	8.1	40	29000	100000	24			0.5			0.46
	160	310	7.2	40	38000	45000	35			0.5			0.54
	4800	870	8	40	89000	100000	23			0.5			0.48
	2800	470	8	40	38000	80000	34			0.5			0.47
	3300	520	8	40	41000	99000	23			0.5			0.43
	5000	1000	8	40	52000	110000	22			0.5			0.54
	4200	590	8.1	450	35000	110000	22			0.5			0.54
	180	14	7.1	69	1100	4900	74			0.5			0.07
	43	82	8.4	120	11000	11000	65			0.5			0.17
	2800	500	7.9	520	13000	96000	26			0.5			0.27
	1400	190	7.7	320	30000	43000	42			0.5			0.45
	3000	480	8	510	44000	79000	27			0.5			0.44

Table of Chemical Analytical Results of Sediment from 22 Dredge Sites in The Upper Chesapeake Bay

PROJECT NAME, SAMPLING DATE AND SAMPLE LOCATIONS	CHROMIUM MG/KG	COPPER MG/KG	IRON MG/KG	LEAD MG/KG	MANGANESE MG/KG	MERCURY MG/KG	NICKEL MG/KG	SELENIUM MG/KG	SILVER MG/KG	THALLIUM MG/KG	ZINC MG/KG
OUTER CHANNEL 1985-1999											
AVERAGE	50	33	29,365	50	1,967	0	36	3	1	1	197
MAXIMUM	640	240	94,000	464	7,000	2	79	12	8	5	580
MINIMUM	2	1	1,600	2	34	0	2	0	0	0	8
MEDIAN	36	33	32,500	46	1,500	0	36	2	1	1	210
Back River Bridge											
	640	240	14900	280		0.3		0.2	1		
	130	120	8000	120		0.2		0.1	0.39		
	8	12	5400	12		0.04		0.1	0.1		
50' Project, September 1986											
	61	15	94000	15	520	0.05	31				83
	58	17	35000	18	420	0.05	33				81
	34	2.4	7800	1.8	100	0.05	3				12
50' Project, September 1986											
	72	42	30000	52	2100	0.05	48				220
	79	42	32000	70	2000	0.05	44				260
	68	40	32000	54	1800	0.05	48				240
	71	41	31000	51	1500	0.05	42				200
	43	16	37000	17	620	0.05	30				80
	50	14	28000	16	570	0.05	28				65
	61	26	33000	30	810	0.05	38				140
	64	33	25000	41	1400	0.05	37				150
	37	23	17000	29	1100	0.05	25				120
	69	37	28000	52	2800	0.05	41				210
	58	35	32000	45	1100	0.05	45				180
	72	40	36000	54	3600	0.05	48				210
	78	41	37000	55	1500	0.05	50				220
	78	40	35000	50	2800	0.05	48				230
	85	44	43000	54	2000	0.05	51				230
	60	35	28000	44	2600	0.05	40				190
	5.3	2.2	1600	5	60	0.05	2.2				13
	17	7.1	6200	9.7	470	0.05	7.9				40
	72	36	32000	46	2200	0.05	45				180
	45	27	20000	33	960	0.05	28				140
	76	38	32000	52	1200	0.05	45				200

Table of Chemical Analytical Results of Sediment from 22 Dredge Sites in The Upper Chesapeake Bay

PROJECT NAME, SAMPLING DATE AND SAMPLE LOCATIONS	TKN* MG/KG	TOTAL P* MG/KG	pH UNITS	O&G* MG/KG	TOC* MG/KG	COD* MG/KG	TS* %	ALUMINUM MG/KG	ANTIMONY MG/KG	ARSENIC MG/KG	BARIUM MG/KG	BERYLLIUM MG/KG	CADMIUM MG/KG
	1900	250	7.8	390	38000	66000	37			0.5			0.32
	3100	320	8.4	540	35000	84000	28			0.5			0.43
	2700	970	6.7	520	47000	120000	33			0.5			0.36
	3500	692	7.9	700	32000	99000	26			0.5			0.61
	2100	520	7.5	310	28000	97000	42			0.5			0.48
	3300	1100	8.2	760	48000	97000	23			0.5			0.69
	2300	450	8	40	26000	84000	33			0.5			0.78
	2400	300	7.1	40	38000	110000	36			0.5			1
	3100	970	7.2	40	61000	100000	30			0.5			0.8
	3200	610	8.1	40	89000	100000	23			0.5			0.65
	3400	820	8.1	100	38000	120000	22			0.5			1
	4300	1100	8	71	59000	150000	21			0.5			0.76
	2900	25	8	40	29000	140000	23			0.5			0.82
	4300	1300	8	110	53000	140000	22			0.5			0.45
	4900	1100	7.7	60	60000	130000	18			0.5			1.5
	2400	590	7.8	110	41000	120000	32			0.5			1.5
Brewerton/Tolchester, March 1989													
Core # 11	1200	3000	7.7	400	30600		41			10	50		2
Core # 12	1100	2200	7.5	400	39300		41.7			10	50		2
Core # 13	1000	4200	7.8	600	39300		39.1			20	50		1
Core # 14	1100	2000	7.6	500	42300		38.9			20	60		1
Core # 15	1100	3400	8.1	500	36800		37.6			20	60		1
Core # 16	970	3700	7.6	300	34600		34.9			20	60		1
Core # 17	1000	3000	7.4	300	34200		35.1			10	70		1
Core # 18	1400	3800	7.1	700	32500		35.6			10	60		1
Core # 19	1200	3000	7.5	600	36100		37.1			20	60		1
Core # 21	1100	4500	7.3	1400	40600		41.7			10	60		2
Core # 22	1200	2700	7.5	1400	39900		43.4			10	60		1
Core # 24	1200	5000	7.2	1200	43200		43.2			10	60		1
Core # 26	1000	2500	7.6	500	40000		44.5			10	50		5
Grab # 1	790	3300	7.1	400	29900		44.9			10	50		1
Grab # 2	980	1200	7.5	400	27900		33.9			10	50		4
Grab # 3	1000	4800	6.3	400	32700		34.4			20	50		1
Grab # 4	830	2000	7.9	1500	26800		31.6			10	50		1
Grab # 5	780	2900	7.8	900	29400		31.1			10	80		1
Grab # 6	840	3500	7.8	1000	21700		32.5			10	60		1
Grab # 7	1100	4100	7	800	30200		30			20	70		1
Grab # 8	1100	3800	7.8	300	28400		31.1			10	60		1

Table of Chemical Analytical Results of Sediment from 22 Dredge Sites in The Upper Chesapeake Bay

PROJECT NAME, SAMPLING DATE AND SAMPLE LOCATIONS	CHROMIUM MG/KG	COPPER MG/KG	IRON MG/KG	LEAD MG/KG	MANGANESE MG/KG	MERCURY MG/KG	NICKEL MG/KG	SELENIUM MG/KG	SILVER MG/KG	THALLIUM MG/KG	ZINC MG/KG
	60	33	25000	45	860	0.05	37				160
	80	38	30000	50	1100	0.05	44				180
	110	69	47000	90	1800	0.05	68				340
	85	42	35000	58	2500	0.05	46				250
	96	45	38000	71	520	0.05	68				30
	90	43	37000	62	1900	0.05	48				210
	120	43	37000	81	840	0.05	52				330
	110	91	43000	25	1200	0.05	65				320
	130	54	51000	100	2000	0.05	79				350
	160	61	49000	82	1500	0.05	51				250
	180	71	48000	100	2000	0.05	58				33
	220	76	45000	98	3100	0.05	51				310
	150	69	38000	67	1400	0.05	46				240
	240	71	49000	87	2600	0.05	55				300
	390	71	59000	140	4300	0.05	63				410
	360	120	46000	160	520	0.05	52				450
Brewerton/Tolchester, March 1989											
Core # 11	32	30	34800	37		0.1		5	1		172
Core # 12	32	45	37600	55		0.1		5	1		280
Core # 13	40	64	38300	89		0.1		5	1		429
Core # 14	40	63	39100	86		0.1		5	1		406
Core # 15	40	63	39900	84		0.1		5	1		401
Core # 16	44	57	40800	75		0.1		5	1		367
Core # 17	36	52	39000	64		0.1		5	1		336
Core # 18	34	48	37700	63		0.1		5	1		304
Core # 19	39	55	39800	70		0.1		5	1		358
Core # 21	34	52	34800	62		0.1		5	1		324
Core # 22	31	46	35600	56		0.1		5	1		265
Core # 24	32	48	35600	57		0.1		5	1		276
Core # 26	30	45	34100	54		0.1		5	1		256
Grab # 1	39	36	34100	55		0.1		5	1		271
Grab # 2	48	44	33000	64		0.1		5	1		288
Grab # 3	58	56	40300	86		0.1		5	1		398
Grab # 4	42	42	32700	60		0.1		5	1		290
Grab # 5	45	49	40000	66		0.1		5	1		319
Grab # 6	40	45	35800	60		0.1		5	1		303
Grab # 7	40	44	35600	62		0.1		5	1		309
Grab # 8	38	44	34000	57		0.1		5	1		275

Table of Chemical Analytical Results of Sediment from 22 Dredge Sites in The Upper Chesapeake Bay

PROJECT NAME, SAMPLING DATE AND SAMPLE LOCATIONS	TKN* MG/KG	TOTAL P* MG/KG	pH UNITS	O&G* MG/KG	TOC* MG/KG	COD* MG/KG	TS* %	ALUMINUM MG/KG	ANTIMONY MG/KG	ARSENIC MG/KG	BARIUM MG/KG	BERYLLIUM MG/KG	CADMIUM MG/KG
Grab # 9	980	4300	7.6	600	31100		31.3			10	70		1
Grab # 10	1700	4600	7.9	400	27300		28.8			10	60		1
Grab # 20	1200	4500	8.1	400	29700		30.9			10	50		1
Grab # 23	40	4100	6.9	700	40900		41.9			20	50		1
Grab # 25	960	1600	7.9	800	43100		33.3			10	50		1
Craighill Channel, July 1989													
VC-1-TOP	2543	1512		5842	8591	99656	29.1	9107	17	4.5		1.7	1.7
VC-1-MIDDLE	484	833		4301	2366	53763	37.2	7742					
VC-1-BOTTOM	304	179		1038	1038	21467	55.9	4472					
VC-2-TOP	932	932		2564	2564	46620	42.9	8578	12	3.5		1.2	1.2
VC-2-MIDDLE	597	764		2387	2076	50119	41.9	8878					
VC-2-BOTTOM	1072	992		2440	3217	58981	37.3	7641					
VC-3-TOP	1307	235		3183	1323	36851	59.7	3551	8	4.7		0.8	0.8
VC-3-MIDDLE	409	288		3125	1034	38462	41.6	7091					
VC-3-BOTTOM	1133	939		3039	3039	63536	36.2	8011					
VC-4-TOP	966	757		3655	3133	67885	38.3	10653	13	5.0		1.3	1.3
VC-4-MIDDLE	439	537		4634	1756	24390	41	6463					
VC-4-BOTTOM	485	306		3827	1837	20663	39.2	6505					
VC-5-TOP	725	828		2692	2692	35197	48.3	4969	10	2.7		1.0	1.0
VC-5-MIDDLE	1133	1076		3399	4249	56657	35.3	8215					
VC-5-BOTTOM	272	298		440	1192	8549	77.2	1658					
VC-6-TOP	1709	1317		3922	4762	53221	35.7	9804	14	6.2		1.4	1.4
VC-6-MIDDLE	1078	727		3509	2757	32581	39.9	8221					
VC-6-BOTTOM	878	653		2928	2703	33784	44.4	7387					
C-10	609	1445		655	11738	67720	44.3	6208	11	4.7		1.1	1.1
C-11	864	815		741	6667	46914	40.5	9012	12	3.5		1.2	1.2
C-13	418	505		505	2857	21978	45.5	6769	11	4.8		1.1	1.1
C-14	103	164		29	176	117	85.2	1444	6	1.5		0.6	0.6
C-15	665	421		510	5543	66519	45.1	5100	11	5.3		1.1	1.1
C-16	233	202		187	2022	13530	64.3	5365	8	7.8		0.8	0.8
C-17	461	346		202	2305	11816	69.4	8646	7	14.4		0.7	0.7
C-18	593	256		229	1348	9704	74.2	3342	7	6.7		0.7	0.7
C-19	300	240		288	637	9976	83.2	2584	6	3.1		0.6	0.6
C-20	581	839		710	3871	43011	46.5	4946	11	1.1		1.1	1.1
C-23	184	368		1034	2759	27586	43.5	4483	11	4.8		1.1	1.1
C-26	305	266		279	1992	22576	75.3	1700	7	1.2		0.7	0.7
C-27	503	395		354	1905	19048	73.5	2517	7	1.6		0.7	0.7
C-28	700	2045		700	11204	58824	35.7	7703	14	2.0		1.4	1.4
C-29	104	816		454	3175	29478	44.1	6463	11	1.1		1.1	1.1

Table of Chemical Analytical Results of Sediment from 22 Dredge Sites in The Upper Chesapeake Bay

PROJECT NAME, SAMPLING DATE AND SAMPLE LOCATIONS	CHROMIUM MG/KG	COPPER MG/KG	IRON MG/KG	LEAD MG/KG	MANGANESE MG/KG	MERCURY MG/KG	NICKEL MG/KG	SELENIUM MG/KG	SILVER MG/KG	THALLIUM MG/KG	ZINC MG/KG
Grab # 9	39	41	38200	59		0.1		5	1		276
Grab # 10	36	40	34200	58		0.1		5	1		272
Grab # 20	30	39	30600	44		0.1		5	1		228
Grab # 23	30	55	34800	63		0.1		5	1		304
Grab # 25	37	40	32900	44		0.1		5	1		233
Craighill Channel, July 1989											
VC-1-TOP	41.2	17.2	31271	62		0.3	32.6	8.6	3.4	3	337
VC-1-MIDDLE											
VC-1-BOTTOM											
VC-2-TOP	32.6	12.8	8578	55.9		0.2	28.0	5.8	1.2	2	322
VC-2-MIDDLE											
VC-2-BOTTOM											
VC-3-TOP	7.5	10.1	15745	13.4		0.2	8.4	4.2	0.8	2	37
VC-3-MIDDLE											
VC-3-BOTTOM											
VC-4-TOP	26.1	15.7	29765	44.4		0.3	28.7	6.5	1.3	3	196
VC-4-MIDDLE											
VC-4-BOTTOM											
VC-5-TOP	31.1	13.5	16977	33.1		0.2	19.7	5.2	1.0	2	178
VC-5-MIDDLE											
VC-5-BOTTOM											
VC-6-TOP	53.2	23.8	9804	64.4		0.3	36.4	7.0	1.4	3	305
VC-6-MIDDLE											
VC-6-BOTTOM											
C-10	24.8	15.8	19639	36.1		0.2	19.2	5.6	1.1	2	172
C-11	24.7	12.3	24321	29.6		0.2	18.5	6.2	1.2	2	143
C-13	16.5	12.1	27473	17.6		0.2	12.1	5.5	1.1	2	55
C-14	14.1	2.9	5423	1.8		0.1	5.3	0.6	0.6	2	8
C-15	10.0	14.4	28381	17.7		0.2	11.1	5.5	1.1	2	53
C-16	23.3	10.9	26827	10.1		0.1	20.2	0.8	0.8	4	47
C-17	34.6	15.9	24424	13.7		0.1	21.6	0.7	0.7	3	58
C-18	16.2	6.1	13005	4.7		0.1	12.8	0.7	0.7	3	24
C-19	4.8	7.2	6611	7.2		0.1	3.0	3.0	0.6	1	16
C-20	10.8	5.4	17204	21.5		0.2	9.7	5.4	1.1	2	90
C-23	9.2	14.9	15200	17.2		0.2	8.0	5.7	1.1	2	64
C-26	6.6	7.3	6972	3.3		0.1	3.3	0.7	0.7	1	19
C-27	10.9	8.2	7211	10.2		0.1	5.4	3.4	0.7	1	46
C-28	50.4	14.0	28291	58.8		0.3	28.0	7.0	1.4	3	280
C-29	21.5	6.8	20975	27.2		0.2	13.6	5.7	1.1	2	145

Table of Chemical Analytical Results of Sediment from 22 Dredge Sites in The Upper Chesapeake Bay

PROJECT NAME, SAMPLING DATE AND SAMPLE LOCATIONS	TKN* MG/KG	TOTAL P* MG/KG	pH UNITS	O&G* MG/KG	TOC* MG/KG	COD* MG/KG	TS* %	ALUMINUM MG/KG	ANTIMONY MG/KG	ARSENIC MG/KG	BARIUM MG/KG	BERYLLIUM MG/KG	CADMIUM MG/KG
C-31	374	857		747	3956	35165	45.5	3956	11	4.0		1.1	1.1
DT-1	868	1396		528	9434	116981	26.5	14717	19	11.3		1.9	1.9
DT-2	906	2520		1969	16929	118110	25.4	10236	20	5.1		2.0	2.0
DT-3	1619	4333		2810	18095	142857	21	15619	24	9.0		2.4	2.4
DT-4	1318	4318		5000	23636	390909	22	9318	23	3.2		2.3	2.3
DT-5	1639	2418		3648	23770	114754	24.4	10656	20	5.7		2.0	2.0
DT-6	756	756		2493	7843	56022	35.7	6162	14	5.3		1.4	1.4
DT-7	1209	3150		549	16484	124542	27.3	11538	18	6.6		1.8	1.8
DT-8	1131	1651		291	11315	82569	32.7	8410	15	4.0		1.5	1.5
DT-9	1190	3048		929	22305	122677	26.9	12082	19	6.7		1.9	1.9
DT-10	1472	2415		792	18868	124528	26.5	8491	19	3.4		1.9	1.9
Brewerton Eastern Extension													
March 1991													
GRAB SAMPLE 1	910	460	7.5	210	6300		30			3	5		1
GRAB SAMPLE 2	1100	590	7.2	130	11000		26.5			3	10		1
GRAB SAMPLE 3	940	560	7.4	69	10000		26.3			3	10		1
GRAB SAMPLE 4	880	410	7.4	240	8400		26.4			33	17		1
GRAB SAMPLE 5	1200	510	7.7	330	7600		25.8			3	10		1
GRAB SAMPLE 6	870	460	6.9	170	9400		22.2			2	39		1
CORE SAMPLE 1	880	590	7.8	240	6400		37.9			5.2	24		1
CORE SAMPLE 2	890	540	7.7	350	10000		38.2			4.7	69		1
CORE SAMPLE 3	790	270	8.2	200	4700		40.7			2.8	92		1
CORE SAMPLE 4	790	380	6.9	280	7900		43.4			3.3	15		1
CORE SAMPLE 5	690	360	7.9	1	5800		44.4			3	17		1
Tolchester Channel													
March 1991													
GRAB SAMPLE 1	206	104	7.9	72	2310		23.1			1	5		1
GRAB SAMPLE 2	328	208	7.6	97	2312		33.5			1.3	25		1
CORE SAMPLE 1	398	173	7.5	113	3287		33.2			1.6	26		1
CORE SAMPLE 2	150	150	7.3	104	2148		35.8			1.4	18		1
C&D Canal Northern Approach Channel													
March 1991													
GRAB SAMPLE 1	3797	1424	8	823	18671		31.6			9.2			3
GRAB SAMPLE 2	3478	1536	6.8	1188	26087		34.5			10.1			3
GRAB SAMPLE 3	4319	1462	7	432	29568		30.1			9.3			3
GRAB SAMPLE 4	2613	618	7	162	13064		42.1			5.7			2

Table of Chemical Analytical Results of Sediment from 22 Dredge Sites in The Upper Chesapeake Bay

PROJECT NAME, SAMPLING DATE AND SAMPLE LOCATIONS	CHROMIUM MG/KG	COPPER MG/KG	IRON MG/KG	LEAD MG/KG	MANGANESE MG/KG	MERCURY MG/KG	NICKEL MG/KG	SELENIUM MG/KG	SILVER MG/KG	THALLIUM MG/KG	ZINC MG/KG
C-31	16.5	17.6	8050	39.6		0.2	9.9	5.5	1.1	2	132
DT-1	35.8	37.7	31509	52.8		0.4	32.1	9.4	1.9	4	234
DT-2	25.6	19.7	20866	43.3		0.4	19.7	9.8	2.0	4	213
DT-3	38.1	33.3	33571	66.7		0.5	35.7	11.9	2.4	5	286
DT-4	22.7	15.9	19318	34.1		0.5	22.7	11.4	2.3	5	173
DT-5	28.7	24.6	27459	49.2		0.4	26.6	10.2	2.0	4	221
DT-6	11.2	16.8	27031	18.2		0.3	12.6	7.0	1.4	3	53
DT-7	29.3	29.3	28205	51.3		0.4	27.5	9.2	1.8	4	220
DT-8	18.3	15.3	16820	22.9		0.3	15.3	7.6	1.5	3	86
DT-9	33.5	26.0	29368	52.0		0.4	31.6	9.3	1.9	4	223
DT-10	24.5	13.2	21509	45.3		0.4	22.6	9.4	1.9	4	219
Brewerton Eastern Extension											
March 1991											
GRAB SAMPLE 1	14	14	12000	21		0.08		1	1		82
GRAB SAMPLE 2	12	13	8800	13		0.09		1	1		78
GRAB SAMPLE 3	15	14	8700	14		0.08		1	1		82
GRAB SAMPLE 4	9	12	8300	15		0.07		1	1		66
GRAB SAMPLE 5	9.9	12	9100	18		0.05		1	1		67
GRAB SAMPLE 6	8.1	11	8000	13		0.05		1	1		59
CORE SAMPLE 1	21	20	13000	27		0.005		1	1		130
CORE SAMPLE 2	21	20	13000	32		0.06		1	1		120
CORE SAMPLE 3	11	6.9	14000	10		0.05		1	1		36
CORE SAMPLE 4	8.9	16	13000	13		0.04		1	1		60
CORE SAMPLE 5	13	8.5	14000	8		0.06		1	1		43
Tolchester Channel											
March 1991											
GRAB SAMPLE 1	1.9	2.3	1709	2.1		0.014		1	1		12
GRAB SAMPLE 2	4.7	6.4	4020	9.0		0.010		1	1		37
CORE SAMPLE 1	5.0	6.6	3984	11.0		0.027		1	1		33
CORE SAMPLE 2	3.9	5.4	3938	6.4		0.125		1	1		30
C&D Canal Northern Approach Channel											
March 1991											
GRAB SAMPLE 1	31.6	38		212		0.06		3	3		348
GRAB SAMPLE 2	34.8	52.2		464		0.06		3	3		580
GRAB SAMPLE 3	32.2	49.8		133		0.07		3	3		365
GRAB SAMPLE 4	23.5	18.8		71		0.05		2	2		147

Table of Chemical Analytical Results of Sediment from 22 Dredge Sites in The Upper Chesapeake Bay

PROJECT NAME, SAMPLING DATE AND SAMPLE LOCATIONS	TKN* MG/KG	TOTAL P* MG/KG	pH UNITS	O&G* MG/KG	TOC* MG/KG	COD* MG/KG	TS* %	ALUMINUM MG/KG	ANTIMONY MG/KG	ARSENIC MG/KG	BARIUM MG/KG	BERYLLIUM MG/KG	CADMIUM MG/KG
GRAB SAMPLE 5	2735	1766	6.4	712	26496		35.1			8.3			3
GRAB SAMPLE 6	3315	14917	6.7	470	14917		36.2			7.2			3
GRAB SAMPLE 7	2271	1208	6.4	459	18599		41.4			7			2
GRAB SAMPLE 8	1031	1521	6.8	119	7474		38.8			8			3
GRAB SAMPLE 9	1387	535	7.1	136	11436		41.1			2.2			2
GRAB SAMPLE 10	2164	760	6.1	102	21345		34.2			4.1			3
Swan Point Turn													
March 1991													
SPC1	2708	1662	7.2	3:1	5800		32.5			12	234		3.1
SPG1	3824	1849	7.6	1218	8800		23.8			8	46		4.2
SPC2	3165	1867	7.4	1013	9800		31.6			12	111		3.2
SPG2	4314	1848	7.6	1991	11000		21.1			10	47		4.7
SPC3	3788	1780	7.8	720	5400		26.4			12	250		3.8
SPG3	4280	1921	7.7	1179	8200		22.9			13	43		4.4
SPC4	3000	1725	7.2	1425	6600		40			11	138		2.5
Poplar Island, COE 1995													
PI1SED	106	61.4			3280	2680	77.4	2080	0.32	1.3		0.14	0.17
PI2SED	515	147			14400	6010	77.4	4820	0.46	3		0.46	0.46
PI3SED	132	61.8			2500	1340	78.4	1100	0.19	1.5		0.13	0.13
PI4SED	106	61.4			3280	2680	78.8	1290	0.13	0.94		0.13	0.13
PI5SED	515	147			14400	6010	66.1	4110	0.15	2		0.2	0.37
Deep Trough, COE 1995													
DT1SED	1830	843			47500	36700	21.1	21400	0.5	8		1.1	1.5
DT2SED	1370	614			14000	18600	41.9	21100	0.17	13.3		1.1	1.3
DT3SED	2180	632			50700	29000	18.2	19900	0.62	10.9		1.2	1.5
Kent Island Deep, COE 1995													
KI1SED	236	68.6			13600	22100	75.3	1150	0.16	2.1		0.13	0.13
KI2SED	131	661			7250	23900	32.2	16400	0.39	9.7		1.3	1.4
KI3SED	335	92.6			10100	6170	74.1	3100	0.13	2.6		0.29	0.32
Pooles Island, COE 1995													
POL1SED	982	467			36100	88200	39	17800	0.21	9.3		1	1.1
Swan Point Channel, COE 1995													
SWP1SED	2260	1570			90500	13800	24.2	20400	0.38	14.8		1.8	1.3
SWP2SED	2230	1930			44800	91300	23.1	27800	0.32	13.9		1.7	1.9

Table of Chemical Analytical Results of Sediment from 22 Dredge Sites in The Upper Chesapeake Bay

PROJECT NAME, SAMPLING DATE AND SAMPLE LOCATIONS	CHROMIUM MG/KG	COPPER MG/KG	IRON MG/KG	LEAD MG/KG	MANGANESE MG/KG	MERCURY MG/KG	NICKEL MG/KG	SELENIUM MG/KG	SILVER MG/KG	THALLIUM MG/KG	ZINC MG/KG
GRAB SAMPLE 5	26.8	31.3		40		0.2		3	3		160
GRAB SAMPLE 6	27.6	33.1		41		0.06		3	3		177
GRAB SAMPLE 7	29	29		46		0.27		2	2		237
GRAB SAMPLE 8	38.7	28.4		258		0.1		3	3		247
GRAB SAMPLE 9	20.4	11.9		80		0.02		2	2		146
GRAB SAMPLE 10	28.4	17.8		50		0.32		3	3		143
Swan Point Turn											
March 1991											
SPC1	43	55		71		0.28		3.1	3.1		308
SPG1	31.1	39		50		2.1		4.2	4.2		189
SPC2	44.3	51		85		0.16		3.2	3.2		313
SPG2	31.8	42		33		0.33		4.7	4.7		213
SPC3	41.7	53		80		0.15		3.8	3.8		288
SPG3	36.2	52		57		0.35		4.4	4.4		232
SPC4	30	40		35		0.2		2.5	2.5		158
Poplar Island, COE 1995											
PI1SED	3.3	2.1	3620	2.8	65.8	0.06	4.2	0.48	0.41	0.27	22.1
PI2SED	8.3	3.2	7180	7.2	126	0.22	10.9	0.91	1.4	0.88	57
PI3SED	3.2	0.51	3240	1.5	33.8	0.06	2.6	0.25	0.38	0.23	10.4
PI4SED	2.4	0.86	2300	2.1	43.4	0.06	3	0.26	0.4	0.28	15.9
PI5SED	6.8	3	7170	5	132	0.1	8.3	0.68	0.45	0.32	42.2
Deep Trough, COE 1995											
DT1SED	42.2	25	31300	31.1	622	0.3	34.7	0.95	1.4	0.99	166
DT2SED	35.2	10.3	39900	5.7	1550	0.16	28.5	1.5	0.51	0.41	87.6
DT3SED	39.7	25.4	32500	30.5	789	0.35	34.4	1.7	1.3	0.92	183
Kent Island Deep, COE 1995											
KI1SED	4.3	2.1	3700	3	221	0.09	5.8	0.25	0.5	0.23	49.8
KI2SED	39	29.8	33300	39.4	1060	0.24	37.3	1.8	0.87	0.48	219
KI3SED	10.3	3.9	7530	6.9	446	0.07	9.5	0.51	0.4	0.27	87.6
Pooles Island, COE 1995											
POL1SED	26.5	14.6	35100	16.3	1290	0.12	30.6	1	0.64	0.4	94.1
Swan Point Channel, COE 1995											
SWP1SED	47.2	40.1	44300	45.6	3730	0.28	51.5	1.8	7.7	0.81	281
SWP2SED	51.6	39.7	44600	50.5	2840	0.36	50.2	2.5	0.96	0.88	272

Table of Chemical Analytical Results of Sediment from 22 Dredge Sites in The Upper Chesapeake Bay

PROJECT NAME, SAMPLING DATE AND SAMPLE LOCATIONS	TKN* MG/KG	TOTAL P* MG/KG	pH UNITS	O&G* MG/KG	TOC* MG/KG	COD* MG/KG	TS* %	ALUMINUM MG/KG	ANTIMONY MG/KG	ARSENIC MG/KG	BARIUM MG/KG	BERYLLIUM MG/KG	CADMIUM MG/KG
SWP3SED	2550	1290			37000	58500	27.5	21600	0.36	13.6		1.8	1.9
Craighill Entrance, COE 1995													
CRE1SED	855	586			29600	73400	56.8	5190	0.22	4.9		1	0.66
CRE2SED	1190	397			21300	50900	40.6	22100	0.22	9.8		1.5	1.5
CRE3SED	1140	344			17700	50500	40.2	25200	0.21	9.9		1.2	1.7
Craighill Channel, COE 1995													
CR1SED	635	130			10600	25600	61.9	5880	0.11	4.8		0.47	0.58
CR2SED	666	359			13500	76300	62.7	8390	0.2	7.4		0.71	0.89
CR2SEDFD	922	1100			46200	104000	27.7	20000	0.28	15.4		1.5	1.8
CR3SED	1150	344			29000	81200	40.1	16500	0.17	12		1.4	1.5
Craighill Angle, COE 1995													
CRA1SED	2000	1060			42700	52800	30.8	16100	0.26	12.8		1.5	1.7
CRA2SED	1260	1220			47400	133000	24.9	18900	0.39	15.1		1.7	1.9
Craighill Upper Range, COE 1995													
CRU1SED	1490	1120			46500	69100	28.4	12800	0.26	11.4		1.7	1.5
CRU2SED	824	451			8180	40100	44.2	6170	0.23	6.3		0.14	0.64
CRU3SED	1190	437			19900	32600	47.5	17200	0.18	9		1.3	1.4
Cutoff Angle													
CUT1SED	1950	686			41500	81300	25.9	18100	0.3	17.9		1.8	1.7
CUT2SED	2220	1460			38800	81200	22.5	14900	0.3	15.3		1.9	1.7
CUT3SED	1950	1080			33700	53700	32	12000	0.84	15.1		2.1	1.4
Tolchester Channel-Van Veen, COE 1995													
TLC1SED	675	430			56700	91200	46.3	23200	0.15	11.5		2.1	1.1
TLC2SED	1080	328			23600	28300	44	18900	0.14	8.1		1.4	1
TLC2SEDFD	1020	1210			19000	38100	36.7	18800	0.19	9.9		1.3	0.89
TLC3SED	1470	1310			35300	87700	31.1	21300	0.27	13.7		1.8	1.5
Tolchester Channel-Gravity Core, COE 1995													
TLV1SED	444	985			54800	63000	44.7	18500	0.19	14.3		2.4	1.6
TLV2SED	1030	1050			75300	78900	47.3	18700	0.19	15.1		2.2	1.5
TLV3SED	721	983			64500	56400	46.7	17700	0.19	12.7		2	1.7
TLV4SED	854	1370			55200	66900	44.2	21300	0.26	16.5		2.4	2

Table of Chemical Analytical Results of Sediment from 22 Dredge Sites in The Upper Chesapeake Bay

PROJECT NAME, SAMPLING DATE AND SAMPLE LOCATIONS	CHROMIUM MG/KG	COPPER MG/KG	IRON MG/KG	LEAD MG/KG	MANGANESE MG/KG	MERCURY MG/KG	NICKEL MG/KG	SELENIUM MG/KG	SILVER MG/KG	THALLIUM MG/KG	ZINC MG/KG
SWP3SED	46.9	47.2	42200	56.3	2460	0.5	47.5	1.8	0.68	0.74	283
Craighill Entrance, COE 1995											
CRE1SED	16.6	10.6	25600	15.3	1340	0.25	17.1	0.45	0.72	0.47	87.3
CRE2SED	41.9	8.4	45900	17.1	803	0.14	29.6	1.1	1.4	0.4	96.7
CRE3SED	44.2	8.7	39800	17.9	1190	0.12	43.2	1.7	1.3	0.46	104
Craighill Channel, COE 1995											
CR1SED	13.1	2.8	18000	5.8	412	0.06	8.8	0.87	0.86	0.25	37.9
CR2SED	23.4	12.9	19700	17.5	2120	0.17	17.3	1.1	0.55	0.37	103
CR2SEDFD	53	30.7	39400	42.8	5700	0.35	41.5	1.4	0.86	0.58	246
CR3SED	29.5	10.1	40300	17.6	809	0.16	39.4	1.8	1.2	0.43	94.1
Craighill Angle, COE 1995											
CRA1SED	48.5	30.6	37400	44.3	3450	0.32	38.8	1.8	0.79	0.51	242
CRA2SED	58.6	36.6	41600	52.4	3620	0.41	49.2	1.2	0.77	0.68	286
Craighill Upper Range, COE 1995											
CRU1SED	49.3	34.3	41100	53.5	3140	0.37	42.3	1.6	1.5	0.58	273
CRU2SED	29.9	16.8	1840	24.5	1430	0.18	18.5	1.2	0.43	0.28	120
CRU3SED	31.6	7.6	42600	16	1190	0.12	26.5	0.83	1.3	0.43	88
Cutoff Angle											
CUT1SED	66.8	36	42100	64.4	6780	0.44	46.2	1.7	1.5	0.6	317
CUT2SED	66.9	40.4	45200	60.6	2500	0.43	43.8	0.59	1.2	0.65	308
CUT3SED	81.9	42.6	52000	67	5150	0.4	43.1	1.9	0.87	0.43	319
Tolchester Channel-Van Veen, COE 1995											
TLC1SED	27.2	42.4	34500	32	950	0.24	51.6	1.2	0.44	0.39	192
TLC2SED	22.5	26.1	32300	21.5	850	0.12	35.7	0.41	0.43	0.35	118
TLC2SEDFD	24.2	22.8	32000	19.8	713	0.1	32.1	0.38	0.57	0.35	111
TLC3SED	40.8	38.3	38500	43.1	4710	0.25	57.6	1.9	0.82	0.58	249
Tolchester Channel-Gravity Core, COE 1995											
TLV1SED	39.1	59	37500	58.3	2430	0.58	72.2	2.4	0.57	0.4	316
TLV2SED	35.2	56.2	37200	55.8	2060	0.53	70.9	1.6	0.57	0.38	318
TLV3SED	36.6	49.6	35400	51.5	2130	0.42	66.5	1.2	0.5	0.33	307
TLV4SED	42.1	60.3	41900	66.3	2320	0.56	75.6	3	0.62	0.43	365

Table of Chemical Analytical Results of Sediment from 22 Dredge Sites in The Upper Chesapeake Bay

PROJECT NAME, SAMPLING DATE AND SAMPLE LOCATIONS	TKN* MG/KG	TOTAL P* MG/KG	pH UNITS	O&G* MG/KG	TOC* MG/KG	COD* MG/KG	TS* %	ALUMINUM MG/KG	ANTIMONY MG/KG	ARSENIC MG/KG	BARIUM MG/KG	BERYLLIUM MG/KG	CADMIUM MG/KG
TLV5SED	1030	1210			47400	67500	43.8	20000	0.23	13.1		2	2
Brewerton Eastern Extension-Van Veen													
COE 1995													
BE1SED	1860	1430			66900	163000	29	20700	0.41	14.2		2.1	2
BE2SED	815	1010			61500	90200	30.2	24500	0.27	19.6		2.3	2.3
BE3SED	1320	948			53500	39000	27.2	22900	0.22	15.1		2.3	2.3
BE4SED	1570	1110			49000	58000	42.4	21800	0.31	20.3		2.4	2.5
Brewerton Eastern Extension-Gravity Core													
COE 1995													
BEV1SED	930	1050			64200	43800	36.9	23100	0.17	17.4		2.4	2.7
BEV2SED	1330	672			43900	47600	43.4	26700	0.21	14		2.2	2.3
BEV3SED	922	385			26200	33300	45.4	20000	0.22	12.8		1.3	1.7
BEV4SED	1020	644			15400	46700	45.6	22800	0.19	10.4		1.6	1.9
BEV5SED	1120	842			27500	32600	38.9	29400	0.18	13.9		2.1	2.1
BEV6SED	1460	436			28400	36600	39.2	22400	0.21	12.9		1.5	1.7
Blind Splits													
BLINDSPLIT1A(BR1)	1380	1090			55900	86100	33.3	23100	0.46	20.7		1.9	2.6
BLINDSPLIT2A(BR3)	657	807			9710	92000	35.6	22000	0.22	16		1.6	2.3

* Note the following abbreviations:

TKN = Total Kjeldahl Nitrogen

O&G = Oil and Grease

COD = Chemical Oxygen Demand

Total P = Total Phosphorus

TOC = Total Organic Carbon

TS = Total Solids

Table of Chemical Analytical Results of Sediment from 22 Dredge Sites in The Upper Chesapeake Bay

PROJECT NAME, SAMPLING DATE AND SAMPLE LOCATIONS	CHROMIUM MG/KG	COPPER MG/KG	IRON MG/KG	LEAD MG/KG	MANGANESE MG/KG	MERCURY MG/KG	NICKEL MG/KG	SELENIUM MG/KG	SILVER MG/KG	THALLIUM MG/KG	ZINC MG/KG
TLV5SED	38.4	47.8	42200	55.9	2660	0.44	64.1	2.2	0.63	0.38	294
Brewerton Eastern Extension-Van Veen											
COE 1995											
BE1SED	50.2	38.2	41300	54.2	6000	0.5	62.7	1.9	1.2	0.61	305
BE2SED	57.8	45.7	48000	63.2	3910	0.47	65.6	0.95	1	0.57	354
BE3SED	51	43.2	46000	60.5	7000	0.49	76.4	2.4	1.3	0.43	332
BE4SED	75.7	53.4	52300	78.7	6610	0.63	72.1	1.9	1.3	0.59	412
Brewerton Eastern Extension-Gravity Core											
COE 1995											
BEV1SED	52.5	50.7	45500	72.1	4780	0.52	75.5	1.9	1.4	0.39	362
BEV2SED	45.1	39.1	49000	46.3	1890	0.42	60	1	0.64	0.36	242
BEV3SED	35.6	16.7	39900	42.7	1440	0.26	29.4	1.5	0.65	0.36	111
BEV4SED	34.7	23.5	25900	29	2030	0.93	38.8	1	0.57	0.31	123
BEV5SED	42.2	29.8	48900	31.7	2400	0.16	48.9	1.4	0.54	0.49	154
BEV6SED	37.9	11.4	43300	18.4	1360	0.11	33.3	1.7	0.62	0.42	101
Blind Splits											
BLINDSPLIT1A(BR1)	101	58.8	48200	88.1	3380	0.55	51.7	2.1	0.83	0.4	404
BLINDSPLIT2A(BR3)	76.4	43.9	49200	63.1	1970	0.33	38.6	2.2	0.66	0.4	290

APPENDIX D

MODFLOW Report

REPORT

MODFLOW FLOW MODEL REPORT OF THE STANCILL QUARRY SITE, CECIL COUNTY, MARYLAND

Prepared for
Maryland Environmental Service
2011 Commerce Park Drive
Annapolis, MD 21401

September 2002

URS

URS Corporation
200 Orchard Ridge Drive, Suite 101
Gaithersburg, Maryland 20878
89-00000229.00
15294354.00100

TABLE OF CONTENTS

TABLE OF CONTENTS

Tables

Figures

cm/sec	Centimeter per Second
E2CR	Engineering Consultant Construction Remediation, Inc.
ET	Evapotranspiration
ft./day	Feet per Day
ft^2/day	Square Feet per Day
KCE	KCE Engineering, Inc.
in/yr	Inches per Year
K_h	Horizontal Hydraulic Conductivity
K_v	Vertical Hydraulic Conductivity
MES	Maryland Environmental Services
MGS	Maryland Geological Survey
MODFLOW	Modular Three-Dimensional Finite-Difference Ground-Water Flow Model
MODPATH	Particle Tracking Post-Processing Package for MODFLOW
SPT	Standard Penetration Test
URS	URS Corporation, Inc.

URS Corporation, Inc. (URS) developed a model to simulate the flow of groundwater and transport of groundwater constituents at the Stancill Quarry site in Cecil County, Maryland. The Stancill Quarry may be used as a site to place dredge tailings resulting from dredging navigation channels in the upper Chesapeake Bay. Placing dredge tailings at this site may contribute chemical constituents to the groundwater that could be transported in the groundwater.

The objective of the groundwater modeling was to identify the potential affects to groundwater flow and constituent transport within and away from the quarry, as they are associated with the proposed placement of dredge tailings in the quarry. The conceptual hydrogeological model studies and field investigations indicated that groundwater at Stancill Quarry currently flows into the quarry from all sides. The groundwater flows mainly to the west toward surface water bodies after the placement of dredge tailings in the quarry.

The computer programs MODFLOW (a finite-difference numerical groundwater flow modeling code) and MODPATH (a particle tracking package used with MODFLOW) were used for this modeling task. To ensure that the model boundaries included all of the regions that may be potentially affected by the placement of dredge tailings in the Stancill Quarry, the physical model boundaries encompassed the natural drainage basin that encloses the quarry. The physical model boundaries were as follows:

- The northern model boundary, located slightly north of the quarry, is composed of Long Pond and its associated stream channels east and west of the pond;
- The western and southwestern boundaries consist of the tidal portions of Principio Creek and Furnace Bay, which is an arm of the Chesapeake Bay;
- The southern model boundary is the drainage basin divide south of the quarry;
- The eastern model boundary is the drainage basin divide east of Mountain Hill Road.

The model area is nearly rectangular, with dimensions of approximately 3,480 ft. wide by 3,120 ft. long at the widest and longest active points of the model, respectively. Creeks and tidal embayments surround approximately two-thirds of the site.

The water table surface of the surficial aquifer is the upper boundary of the MODFLOW model. The base of the model is within the crystalline rock complex underlying the unconsolidated materials of the surficial aquifer and saprolite. The base of the model is at a point approximately 150 ft. into bedrock. These boundaries are determined from site-specific data, including water surface elevation data from wells and piezometers and lithologic data from well and boring logs. The base of the model was chosen as a surface 150 ft. beneath the bottom of the saprolite, based on other studies in the area (Otton et al., 1988). The thickness of the bedrock is based on data in Otton et al., 1988, which shows that 80% of wells completed in the James Run Formation in Cecil County terminate at depths only slightly greater than the selected value of 150 feet. Although Otton et al. 1988 selected a bedrock thickness of 200 feet for their model, the difference is not considered to be significant and is not expected to impact the results of the model.

The finite difference grid for the model consists of 78 rows and 87 columns at the longest and widest regions of the model area, respectively. Since the available data for the model is distributed throughout the area being modeled, the grids are evenly spaced at 40 ft. by 40 ft. throughout the model area.

The groundwater model of the Stancill Quarry consists of four layers. The top two layers are within the sedimentary units. Layer 1, initially, is mostly within the Quaternary/Tertiary Age deposits in order to calibrate the model to present day conditions. After the model is calibrated, Layer 1 includes the dredge tailings proposed for placement in the quarry. The dredge tailings were added to Layer 1 after the model was calibrated to present day conditions. Layer 2 is mostly within the Cretaceous Age deposits, Layer 3 is mostly within the saprolitic zone, and Layer 4 is mostly within bedrock. In order to increase model efficiency, the model layers identified above were smoothed; therefore, the contacts between layers that were identified in the Conceptual Geologic Interpretation Report (URS, 2002a) and Conceptual Hydrogeologic Interpretation Report (URS, 2002b) could not be followed precisely. Since hydraulic conductivity and other model parameters can be changed for individual cells in the model area, model layers that are approximate to the mapped geologic layers should not significantly influence the model results.

The only other geologic material not accounted for in the model is the dark brown organic silt with low Standard Penetration Test (SPT) counts encountered only in borings E-5 and E-6. Borings E-5 and E-6 were placed on the edge of the dike constructed to keep the upper silt-settling pond intact. It is possible this organic silt was brought in during construction of the dike and are, therefore, introduced sediment. The organic silt may be Cretaceous in age, however, URS interprets the low SPT blow counts as indicating these deposits were not buried deeply and, therefore, not consolidated by the weight of overlying sediment. The low blow counts may be due to the fact that the material was deposited recently to build up the dike.

General head boundary conditions (head-dependent boundary conditions with a flow conductance factor) were used to represent the model boundaries with the coastal water bodies. River reaches (Long Pond and Principio Creek) were modeled using the MODFLOW river package.

The model was calibrated using horizontal and vertical hydraulic conductivity values that were typical for coastal plain deposits. The maximum value of hydraulic conductivity used in the groundwater model of the Stancill Quarry is 25 ft./day, equivalent to a clean sand.

During the calibration process, sensitivity of model results to river boundary conditions, hydraulic conductivity, and recharge were observed. The most sensitive parameter used in the model is the change in Layer 1 horizontal hydraulic conductivity.

Using the computer program MODPATH, the movement of particles in the groundwater flow field was simulated under the scenario of the quarry being filled with dredged tailings. Particles were placed at the highest points in the quarry and the pathlines indicate that constituents will migrate to the west, towards Furnace Bay and Principio Creek.

Given the data available for the site, the model provides a consistent regional representation of the overall groundwater flow in the Stancill Quarry. It can be deduced from the MODPATH simulations that Furnace Bay would receive constituents that are a part of the dredge tailings placed in the quarry.

This report describes the development and use of a hydrogeologic model to simulate the flow of groundwater at the Stancill Quarry located in Cecil County, Maryland (Figure 1). The Stancill Quarry is proposed for use as a site to place dredge tailings resulting from dredging navigation channels in the upper Chesapeake Bay. The modeling was performed under URS Corporation (URS) Contract I.D. No. 02-07-06 with Maryland Environmental Services (MES). The Scope of Work includes preparation of a Groundwater Flow Model Report of the groundwater regime at the Stancill Quarry. This hydrogeologic interpretation is based on review of publicly available data; data collected on-site during this investigation; and discussions with MES, Stancill Quarry representatives, and KCE Engineering, Inc. (KCE). As part of URS' corporate Quality Assurance Program, an Independent Technical Reviewer has reviewed this report.

1.1 OBJECTIVES

The objective of the groundwater flow modeling is to identify the potential impacts to groundwater flow within and away from Stancill quarry, after the proposed placement of dredge tailings in the quarry.

1.2 PREVIOUS REPORTS

Detailed descriptions of the Stancill Quarry history and site characteristics were presented in the November 2000 report by MES entitled, *A Preliminary Assessment of the Feasibility of Using the Stancill's Inc. Property on Furnace Bay in Cecil County as a Dredged Material Containment Area* and in the November 2000 report by Engineering, Consultation, Construction Remediation, Inc. (E2CR) entitled, *Geotechnical Report for Stancill Sand and Gravel Quarry, Cecil County, Maryland.* Two additional reports were written in the process of developing the groundwater model. The first report, *Conceptual Geologic Interpretation for Stancill Quarry, Cecil County, Maryland* (URS, 2002a), provides a detailed evaluation of the geology of the Stancill Quarry. This conceptual geological model was the basis for the conceptual hydrogeologic model presented in the second report, *Conceptual Hydrogeologic Interpretation of the Stancill Quarry Site, Cecil County, Maryland* (URS, 2002b). The groundwater flow model described in this document is based on the conceptual hydrogeologic model.

1.3 ORGANIZATION OF THE REPORT

This report is divided into five sections and includes tables and figures. The figures are provided at the end of the written text. Section 1 presents the contractual authority and basis for the study and report and identifies previous reports on Stancill Quarry referenced in the development of the model. Section 2 presents an overview of the model development. Section 3 summarizes the calibration and sensitivity analysis of the model. Section 4 presents conclusions based on the model results. Section 5 lists the references used during the modeling and documentation effort.

2.1 SOFTWARE SELECTION

One of the tools available for understanding groundwater flow is numerical simulation modeling. A numerical model can represent the hydrogeologic conditions at the Stancill Quarry by incorporating data from numerous available sources. When developing a computer model, simplifying assumptions must be applied to permit practical solution of the inherent mathematical equations and to accommodate the data that are typically available. Since the assumptions and types of data required by each model can vary considerably, selection of the appropriate model is critical to the reliability of the modeling predictions.

Modeling the flow of groundwater and the flowpaths of constituents requires a mathematical system that can model the velocity and direction of groundwater flow. Several computer programs exist to solve these mathematical problems and are accepted by the regulatory agencies. These programs exist in both finite difference and finite element solution methods. In general, the finite difference programs are easier to set up and require shorter computer time to solve. The finite element programs, using the same number of entry points as the finite difference method, provide a more precise physical representation of complex hydrogeologic sites. The output results are comparable for both methods.

The computer programs MODFLOW-96 (a finite-difference numerical groundwater flow modeling code) and MODPATH (a particle tracking package used with MODFLOW) are used for this modeling task (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996). These programs are standard models utilized for this problem and are accepted by the U.S. Army Corps of Engineers, the U.S. Environmental Protection Agency, the U.S. Geologic Survey, and the Maryland Geological Survey. MODFLOW simulates groundwater flow, including conditions of unconfined, semi-confined, and confined aquifers, precipitation recharge, river interaction, and no-flow and fixed-head boundaries; these conditions characterize groundwater flow at Stancill Quarry. MODFLOW was utilized for calculating groundwater head, groundwater flow quantities, and direction of flow at Stancill Quarry. MODPATH can interface with MODFLOW to simulate the flowpaths of constituents and was used to identify potential receptors at Stancill Quarry.

2.2 MODFLOW COMPUTER MODEL SETUP

Hydrogeologic data are available at some points of the modeled domain, such as in proximity to boreholes drilled during investigations of the site. Data was extrapolated from areas where data exist for model input and calibration to other areas of the site. The input data used to set up the MODFLOW computer model are discussed in the following sections.

2.2.1 Horizontal Extent of the Modeled Domain

To ensure that the model boundaries include all regions that may be affected by dredge tailings placed in the Quarry, the physical model boundaries encompass the natural drainage basin that encloses Stancill Quarry. The model area is nearly rectangular with dimensions of approximately 3,480 ft. wide by 3,120 ft. long at the widest and longest points of the "active" model area, respectively. Approximately two-thirds of the site is surrounded by creeks and tidal embayments. The physical model boundaries are as follows (Figure 2):

- The northern model boundary is located slightly north of the quarry and is comprised of Long Pond and its associated stream channels east and west of the pond;
- The western and southwestern boundaries consist of the tidal portions of Principio Creek and Furnace Bay, an arm of the Chesapeake Bay;
- The southern model boundary is the drainage basin divide south of the quarry; and
- The eastern model boundary is the drainage basin divide east of Mountain Hill Road.

2.2.2 Top and Bottom Extent of the Modeled Domain

The water table surface of the surficial aquifer is the upper computational boundary of the MODFLOW model (Figure 3). However, the groundwater table is able to vary in Layer 1 up to the ground surface, which is set at the present day quarry and surrounding topography. The base of the model is represented by the crystalline rock complex underlying the unconsolidated materials of the surficial aquifer and saprolite. The base of the model represents a thickness of approximately 150 ft. of bedrock (Figure 4). These boundaries are determined from site-specific data, including water surface elevation data from wells and piezometers and lithologic data from well and boring logs. The base of the model was chosen as a surface 150 ft. beneath the bottom of the saprolite based on groundwater studies in the area (Otton et al., 1988).

2.2.3 Layer Top and Bottom Elevations

The groundwater model of the Stancill Quarry consists of four layers. Figures 5 and 6 are cross-sections through the quarry showing the four model layers; Figure 2 shows the location of these cross-sections. The top two layers are within the sedimentary units. Layer 1 is mostly within the Quaternary/Tertiary Age deposits and Layer 2 is mostly within the Cretaceous Age deposits. Layer 1 is initially situated mostly within the Quaternary/Tertiary Age deposits to calibrate the model to present day conditions. After the model was calibrated, the dredge tailings proposed for placement in the quarry were added to Layer 1. The dredge tailings are added after the model was calibrated to present day conditions because this material will not exist until some time in the future when the quarry is filled with dredge tailings. The initial condition top surface of Layer 1 cells was obtained by digitizing the present-day quarry topography for the site (KCE Engineering, 2001). The future condition top surface of Layer 1 cells was obtained by digitizing future conditions quarry topography information obtained from MES (2000). Layer 3 is mostly within the saprolitic zone and Layer 4 is mostly within bedrock. To increase model efficiency, the model layers identified above were smoothed, and therefore the contacts between layers that were identified in the Conceptual Geologic Interpretation Report (URS, 2002a) and Conceptual Hydrogeologic Interpretation Report (URS, 2002b) could not be followed precisely. Since hydraulic conductivity and other model parameters can be changed for individual cells in the model area, model layers that are approximate to mapped boundaries should not significantly influence the model results.

2.2.4 Finite Difference Grid Spacing

The finite difference grid for the model consists of 78 rows and 87 columns at the longest and widest regions of the "active" model area, respectively (Figure 7). The grids are evenly spaced at approximately 40 ft. by 40 ft. throughout the model area to provide sufficient spatial resolution for the model area and to optimize the numerical groundwater flow and transport computations. Due to the small scale of the model, cell sizes did not have to vary to accommodate specific areas of interest.

2.2.5 Layer Types

Layer types can be considered unconfined, confined, or a mixture of both. For this model, Layer 1 is modeled as under unconfined conditions. Layers 2 and 3 are modeled as under unconfined/confined conditions; they behave as confined until the water table drops into Layer 2 or 3, at which time they act as unconfined conditions. Layer 4 was modeled under confined conditions.

2.2.6 Boundary Conditions

All layers contain no-flow boundary conditions along the edge of the active region of the model, except parts of Model Layer 4 as described below. This effectively removes the hydraulic connection with Principio Creek and Furnace Bay beyond the model boundary. The base of the model is also set as a no-flow boundary condition and is located approximately 150 ft. into the bedrock layer (Layer 4). General head boundary conditions (head-dependent boundary conditions with a flow conductance factor) are used to represent the model boundaries with the coastal water bodies (Figure 8). These boundaries include Furnace Bay and Principio Creek. All of these general head boundary conditions are in Model Layer 1 The model contains no-flow boundary conditions along the edges and base of the active region of the model.

2.2.7 Interaction with Surface Water Bodies

Long Pond was modeled as variable-head cells with cell top elevations ranging from slightly over 4 ft. in the western portion of the pond to slightly over 4.5 ft. in the eastern portion of the pond. Principio Creek, Furnace Bay, and the southern unnamed tributary were modeled using the MODFLOW RIVER package. Input for the RIVER package includes the stage, or altitude of the water-body surface, the bottom elevation of the water-body, and the conductance of the bottom material. Principio Creek and Furnace Bay were modeled with a stage of -0.32 ft., given as mean tidal water level for the area per Section 8.2 of the Conceptual Hydrogeologic Interpretation Report (URS, 2002b). Principio Creek and Furnace Bay were modeled with a bottom elevation of -3 ft. and conductances ranging from 0.12 to 152 ft^2/day. The elevation of the cells for the southern unnamed stream were set from 3.5 ft. near the mouth to 48 ft. at the headwater, based on the site topographic data (KCE, 2001). Conductances for this reach ranged from 0.99 to 20.57 ft^2/day.

2.2.8 Pumping Well Locations and Pumping Rates

No pumping wells were identified within the model area.

2.2.9 Geologic Boundaries

The vertical geologic contacts identified in previous reports (URS, 2002a and b) could not be followed precisely if model efficiency were to be increased. See the discussion under Subsection 2.2.3 above.

2.2.10 Vertical and Horizontal Hydraulic Conductivities

Starting and calibrated values for vertical and horizontal hydraulic conductivities are presented in Sections 2.4.1 and 3.1, respectively.

2.2.11 Total Recharge to Groundwater

Starting and calibrated values for groundwater recharge are presented in Sections 2.4.2 and 3.2, respectively.

2.3 MODPATH COMPUTER MODEL SETUP

The additional input data used to set up the MODPATH simulations are described below.

2.3.1 Location and Extent of Identified Groundwater Constituents

Locations along the eastern side of the quarry were chosen as starting points for chemical constituents since dredge tailings will contain the constituents to be modeled, and the dredge tailings will be placed throughout the quarry. The points include the highest future elevation in the quarry.

2.3.2 Aquifer Effective Porosity

Conservative aquifer effective porosities of 0.2 (unconsolidated material) were assumed for the proposed dredge tailings based on textbook values for sand (Spitz and Moreno, 1996; Anderson and Woessner, 1992; Freeze and Cherry, 1979).

2.4 MODEL ASSUMPTIONS

The model was developed using the following assumptions:

- Groundwater flow is assumed to be steady state.
- Within a given area, hydraulic conductivity is assumed to be uniform and isotropic in the horizontal plane.
- Vertical hydraulic conductivity is assumed to be one-tenth the horizontal hydraulic conductivity for all geologic units.
- Recharge is assumed to be uniformly distributed over the model domain and to be steady.
- The base of the model is impermeable.
- The groundwater constituents of concern will originate from the dredge tailings to be placed in the quarry. The concentration of these constituents of concern were defined in

Chemical Analytical Results From Dredge Sediment Sampling of Sites in Chesapeake Bay (MES, 2002).

2.5 MODEL PARAMETERS

2.5.1 Hydraulic Conductivity

Site hydrogeologic data were compiled to give an initial estimate of the overall horizontal and vertical hydraulic conductivities. These values are utilized as starting points for assigning hydraulic conductivities to the geologic units in the model. These values are adjusted by geologic unit during the calibration process to allow the modeled head results to reconcile with the observed head values. Each model database number can be adjusted independently of the others, including different hydraulic conductivity values for materials in the various layers. Table 1 below summarizes the initial horizontal hydraulic conductivity values (K_h) and the initial vertical hydraulic conductivity values (K_v) for each geologic unit. This table is a compilation of data predominantly from the interpretation of geologic materials identified in the lithologic logs and slug tests, and from available literature.

Table 1: Initial Estimates of Geologic Unit Hydraulic Conductivity

		Initial Hydraulic Conductivity (ft/d)			
Geologic Unit	Model layer	K_h	K_v	K_h/K_v	Reference
Dredge Tailings Quaternary	1	0.027 to 25.49	0.0027 to 2.549	10	(a)
Present-Day Quarry Quaternary	1	0.027 to 25.49	0.0027 to 2.549	10	Site Slug Tesxts
Mostly Cretaceous	2	0.027 to 25.49	0.0027 to 2.549	10	Site Slug Tesxts
Mostly Saprolite	3	0.283	0.0283	10	Site Slug Tesxts
150 feet into Bedrock	4	0.00283	0.000283	10	Otton et al, 1988

(a) - Vertically averaged values using site slug tests and an assumed conductivity of 2.83 feet/day for silty sand (Spitz and Moreno, 1996; Anderson and Woessner, 1992).

Note that the range in conductivity for the Dredge Tailings Model Layer 1 and Present Day Model Layer 1 are the same, however, the mean or average conductivity is lower for the Dredge Tailings Model Layer 1.

Hydraulic conductivities in Layer 1 were modified based on the thickness of "present-day model Layer 1"and the thickness of "dredge tailings model Layer 1" as these thicknesses changed throughout the quarry. The top of "dredge tailings model Layer 1" is shown in Figure 9 to distinguish it from the "present-day model Layer 1" shown in Figure 2. The approach taken was to combine the dredge tailings layer with the existing Layer 1 and calculate a weighted Kh based on the proportion of each layer that contributes to the new Layer 1 total thickness. This also accounted for the highly variable topographic interface between the present day quarry topography and the introduced dredge tailings.

The Khs used for the present day quarry model Layer 1 (the lower layer) were the contoured values for Layer 1, shown in Figure 10. The Kh used for the dredge tailings (initial) is 2.83 ft./day (10^{-3} cm/s), which is representative of silty sand or the lower end of clean sand (Spitz and Moreno, 1995; Anderson and Woessner, 1992). The weighed average approach discussed above for calculating the new hydraulic conductivities preserves the cell thickness and K values of the present-day quarry model in areas outside of the dredge tailings (because dredge tailings thickness is zero here), and assigns appropriate layer top surfaces based on dredge tailings topography and appropriate Ks to cells within the dredge tailings area. Therefore, Layer 1 cells located in deeply excavated areas (present-day quarry conditions) will have a hydraulic conductivity more proportionally represented by the selected dredge tailings hydraulic conductivity value, whereas cells at areas not presently excavated will reflect the hydraulic conductivity values derived from the slug test analyses.

2.5.2 Water Levels

Water-level data collected at the Stancill Quarry starting in December 2001 showed very little changes in water levels in the surveyed wells (Figure 11). The observed hydraulic gradients remained constant during the fluctuations in water levels. The observed hydraulic gradient changed depending upon location within the quarry: the gradient in the northeastern portion of the quarry is 0.008 ft. per foot to the south-southwest; the gradient in the western portion of the quarry is 0.012 ft. per foot to the east; and the gradient in the southeastern portion of the quarry is 0.029 ft. per foot to the north-northwest.

Groundwater flow patterns are affected by factors such as the distance from natural recharge and discharge points, the location and size of natural recharge zones, changes in lithology, and seasonal fluctuations in precipitation.

2.5.3 Precipitation, Recharge, and Discharge

Groundwater recharge is a factor of precipitation and evaporation (both evapotranspiration [ET] and surface evaporation). Groundwater modeling studies conducted at Aberdeen Proving Ground 10 miles southwest of Stancill Quarry and within similar geologic and hydrogeologic units concluded that precipitation averages 45 inches per year (in/yr) (Whitten, et al, 1997), 52% of which infiltrates groundwater in wooded areas and fields (Rasmussen and Andreason, 1959), and 23% of the total precipitation evaporates from groundwater (Rasmussen and Andreason, 1959). Surface water evaporation is calculated from pan evaporation rates. Pan evaporation averages 40.91 in/yr in this part of Maryland (Whitten, et al, 1997). The adjustment factor or pan coefficient for lakes in the U.S. varies from 0.64 to 0.81 (Bedient and Huber, 1995). The ponds on Stancill Quarry heat up and evaporate water more quickly than the average lake, since the pond water is shallow and is likely warmed while used for processing. Therefore, the higher value of 0.81 is applied to convert to evaporation from the ponds, which results in 33.14 inches of evaporated water per year. Average lake evaporation for this part of the United States is 35 in/yr mean annual lake evaporation, which is based on data collected over the period of 1946 to 1955 (Bedient and Huber, 1995).

ET was withdrawn from each cell in Layer 1 according to the depth below land surface of the simulated water table in that cell. A maximum ET rate of 32.4 in/yr was withdrawn from a cell if the depth to the water table in that cell was at the ground surface and vegetation did not hinder infiltration of rainwater. This rate approximates the lake evaporation for water at or near the ground surface. The maximum ET elevation was the digitized land surface elevation that represents the top of Layer 1. ET was adjusted to 2 ft./day at the southeastern quarry pond to simulate removal of water via ET and by facility pumping. No ET was withdrawn from a cell if the depth to the water table was greater than 6 ft. below the land surface (i.e., ET "extinction depth" of the cell) at all cells except the pond cells. The pond cell extraction depth was adjusted to 10 ft. during calibration. A linear relation is used to calculate ET if the water table depth was between the ground surface and 6 ft. below grade. ET was not used in the dredge-tailing model. In the dredge-tailing model (the future conditions model after the dredge tailings are added to the quarry), recharge is used as a surrogate parameter that implicitly accounts for ET.

2.6 PARTICLE TRACKING

MODPATH uses the flow calculations generated by MODFLOW. It calculates flow velocity vectors within the active model and then traces the path of the particles in the flow field. The flow velocity calculation requires a value for effective porosity. The average effective porosity assumed for the groundwater model for the sedimentary layers is 0.15, a typical value for sedimentary materials (Spitz and Moreno, 1996; Anderson and Woessner, 1992; Freeze and Cherry, 1979). The average porosity's assumed for the groundwater model for the saprolitic and bedrock layers are 0.002 and 0.0002, respectively, also typical values for these materials (Freeze and Cherry, 1979; Otton et al ,1988).

2.7 LIMITATIONS OF THE MODEL

The reliability of the results of the computer model simulations depends upon the reliability and availability of site-specific data. However, even when data are reliable and available, the computer programs operate with inherent limitations. The key limitations for each of these computer programs as it applies to this task are described below.

2.7.1 Limitations of the MODFLOW Computer Program

Limitations of the MODFLOW computer program are as follows:

- The flow of groundwater through unsaturated soil is not modeled. Rather, an estimated rate of water leaving or entering the saturated groundwater is provided. This applies to rivers, wetlands, rainfall infiltration, and ET.
- Groundwater is assumed to flow in a laminar state, parallel to the piezometric surface. The velocity of vertical flows should be at least an order of magnitude smaller (e.g., 10% or less) than the horizontal flows.
- Abrupt, large changes in layer thickness or hydraulic conductivity decrease the accuracy of the modeling results.

2.7.2 Limitations of the MODPATH Computer Program

Limitations of the MODPATH computer program are as follows:

- Particle migration is based upon advective flow with groundwater. Dispersion and diffusion are not accounted for, so the zone of impacted receptors may be larger than indicated. This should not be a significant limitation if the impacted areas of concern involve short particle travel distances in highly conductive materials (as expected at Stancill Quarry) or converging flow fields.

- For all of the computer programs, the models developed can only be considered reliable when the model domain is the same or smaller than the data domain. A model cannot provide a reliable result when it is used to extrapolate predictions beyond the extent of available data.

3.1 CALIBRATION

The initial inputs to the model were based upon field-measured values. To develop a model representative of actual conditions, the model was calibrated by adjusting model input values, using a reasonable range of values based on the field measurements, until modeling output results compare favorably with field observations.

The model was calibrated by varying horizontal and vertical hydraulic conductivities, recharge, ET rates, and riverbed conductances. The groundwater flow model was calibrated to a data set of observations at nine water table piezometers that were measured December 11, 2001 (see Figure 12 for piezometer locations). Figures of groundwater flow for all periods of measurement were presented in the Conceptual Hydrogeologic Interpretation Report (URS, 2002b). The difference in average groundwater surface elevation between the different plots in the Conceptual Hydrogeologic Report is less than 1 ft. As this difference is small, only the December 11, 2001 data set was used for calibration.

As discussed by Anderson and Woessner (1992), the calibration objectives are to minimize the differences between simulated and measured heads. Table 2 compares the simulated versus observed heads at each piezometer location. Figure 13 contains a plot of these values and shows the mean of the head difference in feet (mean error). The head difference is the difference between the observed head and the simulated head. As a general guide, the variance of the head difference should vary less than about 10% of the total head change across the model (Spitz and Moreno, 1996). This quantifies the average error in the calibration but overlooks the distribution of the errors. As Figure 13 demonstrates, the mean error in calibration is 0.53 ft., indicating that the calibrated model only slightly overestimates the observed head. Figure 14 shows the difference between the observed and simulated heads on the base map. Representative plots of the head elevation contours for the present day model Layers 1 and 2 are provided in Figures 15 and 16, respectively.

Table 2: Observed Head Versus Simulated Head at Calibration Points for Present-Day Quarry Model

Piezometer #	Observed Head	Simulated Head	Head Difference*
P-1	7.10	6.83	-0.27
P-2	8.92	7.56	-1.36
P-3	3.28	4.75	+1.47
P-4	-0.24	2.95	-3.19
P-5	13.58	11.01	-2.57
P-6	1.86	5.99	+4.13
P-7	0.91	-0.10	-1.01
P-8	38.78	38.45	-0.33
P-9	2.17	3.74	+1.57

* Head Difference is positive when Simulated Head exceeds Observed Head

3.1.2 Horizontal and Vertical Hydraulic Conductivities

The hydraulic conductivity fields for Layers 1 and 2, which represent the Quaternary/Tertiary and Cretaceous materials, were constructed by contouring the results of the single-well permeability tests (i.e., slug tests) performed at the site. The contoured horizontal conductivity field was assigned to model Layers 1 and 2 cells, and ranged from a low of 0.027 ft./day at P-8 to slightly greater than 25 ft./day at P-5. The distribution of horizontal conductivities used for calibrated model Layer 1 is shown in Figure 17. For these layers, the spatial distribution of hydraulic conductivities was varied in the vicinity of P-8 to provide simulation results in the present-day model that closely matched the groundwater flow field in this area. Hydraulic conductivity values in other areas of the site were not varied during calibration. Vertical hydraulic conductivities were set at 10% of the horizontal hydraulic conductivities assigned to each model cell. Values of horizontal and vertical hydraulic conductivity are similar in the calibrated Stancill Quarry groundwater model to the assumed initial values. Table 3 presents the initial and calibrated hydraulic conductivity values.

Table 3: Initial and Calibrated Hydraulic Conductivity Estimates Used in Groundwater Flow Model

		Initial Hydraulic Conductivity (ft/day)			Calibrated Model Hydraulic Conductivity (ft/day)		
Geologic Unit	Model layer	K_h	K_v	K_h/K_v	K_h	K_v	K_h/K_v
Dredge Tailings/Quaternary	1	0.027 to 25.49	0.0027 to 2.549	10	0.027 to 25.49	0.0027 to 2.549	10
Present-Day Quarry	1	0.027 to 25.49	0.0027 to 2.549	10	0.027 to 25.49	0.0027 to 2.549	10
Mostly Cretaceous	2	0.027 to 25.49	0.0027 to 2.549	10	0.027 to 25.49	0.0027 to 2.549	10
Mostly Saprolite	3	2.83	0.283	10	2.83	0.283	10
150 ft. into Bedrock	4	2.83×10^{-3}	2.83×10^{-4}	10	0.367	0.0367	10

Note that the range in conductivity for the Dredge Tailings Model Layer 1 and Present Day Model Layer 1 are the same, however, the mean or average conductivity is lower for the Dredge Tailings Model Layer 1.

The calibrated values are consistent with the range of values used in the Aberdeen region of the Harford County models by the Maryland Department of the Environment (Drummond, 1999) and Woodward Clyde (1998). A value of just over 25 ft./day is the highest hydraulic conductivity value used in the groundwater model of the Stancill Quarry. Based on URS' experience in modeling coastal plain sediments in other areas of the East Coast, 25 ft./day is an average value among those values occurring with reasonable expectation.

The horizontal hydraulic conductivity of Layer 3 (saprolite material) was set at 2.83 ft./day or 10^{-3} cm/sec, which is the midrange of permeability reported for saprolite in this region (Otton et al., 1988). The horizontal hydraulic conductivity for the bedrock model layer (Layer 4) was initially assigned a value of 0.0023 ft./day to provide a relatively low permeability for this material. It was then adjusted to 0.367 ft/day based on an average transmissivity of 55 ft^2/day for bedrock in the area and a bedrock thickness of 150 ft. Vertical hydraulic conductivities for both Layers 3 and 4 were set at 10% of the horizontal hydraulic conductivity values.

3.1.3 Recharge and Evapotranspiration

Recharge was set at 0.00274 ft/day (12 in/yr) prior to calibration of the present-day quarry model. During calibration, the quarry area was adjusted to 0.0005 ft/day (2.14 in/yr). Recharge at the east settling pond was adjusted to 0 ft./day, because the bottom material is considered to be composed of fine material and likely does not provide for recharge prior to evaporation. Recharge for the west settling pond, however, was adjusted to 0.49 ft./day to account for water pumped to this pond during facility operations, and to simulate higher groundwater levels observed in the area of well P-5. Recharge from the forested southern portion of the model was adjusted to 0.0032 ft/day (14 in/yr). The western edge of the model near P-5 was adjusted to 0.009 ft/day, and the Long Pond area was adjusted to 0.015 ft/day. For the dredge-tailing model, recharge was set at 0.0032 ft./day (14 in/yr) in the southern portion of the model and 0.00274 (12 in/yr) in the remainder of the model domain based on assumed vegetation in the area and ET of 35 in/yr with 45 inches of precipitation.

3.1.4 River Bed Conductance

River conductances for Principio Creek and Furnace Bay were initially set at 0.003 to 0.15 ft^2/day. During calibration, the river conductances were adjusted to 0.12 to 152 ft^2/day. Conductances for the southern unnamed tributary ranged from 0.99 to 20.57 ft^2/day. These values appear to provide a suitable calibration for the model near the surface water bodies, and are within the range of MODFLOW conductances arrived at by Drummond and Bloomquist (1993) for rivers along the western shore of the Chesapeake Bay.

3.2 SENSITIVITY ANALYSIS

The objective of the sensitivity analysis is to quantify the uncertainty of the calibrated model resulting from uncertainty in the values of hydrogeologic properties and other model inputs. Even after the model is calibrated, the values entered to the model may approximate field conditions, but they do not exactly match actual field conditions. The model is insensitive to a wide range of values for some inputs, but is very sensitive to others.

A test for which model parameters are most sensitive to slight changes is important when evaluating modeling output and defining which parameters need to be better quantified, for example, by additional field measurements, if model accuracy must be improved. Determining the sensitive parameters also aides in defining the range in potential error, or the level of accuracy, of the modeled output. The inherent error of those values to which the model is more sensitive receives greater weighting than errors associated with less sensitive values.

During the calibration process, sensitivity of model results to hydraulic conductivity, recharge, ET, and river conductance were observed. The most sensitive parameters used in the model are changes to the Layer 1 horizontal hydraulic conductivity, followed by recharge, Layer 2 horizontal hydraulic conductivity, and ET (Table 4). Because the model areas of concern are distant from most of the river boundary conditions, changes in these boundaries were found to have little effect on the model results.

Table 4: Summary of Sensitivity Analysis

	Layer	Adjustment Multiplier	Calibrated MODFLOW Model Values	Sensitivity Analysis Value or Range of Values	Average Simulated Groundwater Elevation (Arithmetic Mean of All Model Cells in Ft. [MSL])	Change in Average Simulated Groundwater Elevations (Ft.)	Normalized Sensitivity Index (a)	Sensitivity Rank
Calibrated model					9.93			
Sensitivity Runs								
Adjusted Parameter								
Horizontal hydraulic conductivity	1	+10	0.027 to 25.4	0.27 to 254	3.27	-6.66	0.74	9
Horizontal hydraulic conductivity	1	-10	0.027 to 25.4	0.0027 to 2.54	102.41	92.48	102.76	1
Vertical hydraulic conductivity	1	+10	0.0027 to 2.54	0.027 to 25.4	9.83	-0.10	0.01	>10
Vertical hydraulic conductivity	1	-10	0.0027 to 2.54	0.00027 to 0.254	11.11	1.18	1.31	8
Horizontal hydraulic conductivity	2	+10	0.027 to 25.4	0.27 to 254	9.93	0.00	0.00	>10
Horizontal hydraulic conductivity	2	-10	0.027 to 25.4	0.0027 to 2.54	14.99	5.06	5.62	4
Vertical hydraulic conductivity	2	+10	0.0027 to 2.54	0.027 to 25.4	9.54	-0.39	0.04	>10
Vertical hydraulic conductivity	2	-10	0.0027 to 2.54	0.00027 to 0.254	12.07	2.14	2.38	7
Horizontal hydraulic conductivity	3	+10	2.83	28.3	8.97	-0.96	0.11	>10
Horizontal hydraulic conductivity	3	-10	2.83	0.283	10.34	0.41	0.46	10
Vertical hydraulic conductivity	3	+10	0.283	2.83	9.92	-0.01	0.00	>10
Vertical hydraulic conductivity	3	-10	0.283	0.0283	9.92	-0.01	0.01	>10
Horizontal hydraulic conductivity	4	+10	0.00283	0.0283	9.90	-0.03	0.00	>10
Horizontal hydraulic conductivity	4	-10	0.00283	0.000283	9.93	0.00	0.00	>10
Vertical hydraulic conductivity	4	+10	0.000283	0.00283	9.93	0.00	0.00	>10
Vertical hydraulic conductivity	4	-10	0.000283	0.0000283	9.93	0.00	0.00	>10
Recharge	1	1.25	0.00	0.003425 to 0.0225	12.71	2.78	11.12	3
Recharge	1	0.75		0.003162 to 0.0135	6.02	-3.91	15.64	2
Evapotranspiration	1	1.25	0.00724 to 0.4	0.00925 to 0.5	8.87	-1.06	4.24	6
Evapotranspiration	1	0.75	0.00724 to 0.4	0.0056 to 0.3	11.04	1.11	4.44	5
River conductance	1	+10	0.03 to 0.15	0.3 to 1.5	7.25	-2.68	0.30	>10
River conductance	1	-10	0.03 to 0.15	0.003 to 0.015	9.74	-0.19	0.21	>10

(a) Represents average change in groundwater levels per unit change in the indicated sensitivity variable in the first column.

Varying hydraulic conductivity affected the upper layers of the model much more than the lower layers. Likewise, increasing the horizontal conductivity in a layer has a greater effect than increasing the vertical hydraulic conductivity. This observation shows that, in general, a greater amount of water is conveyed horizontally from the recharge areas of the model than is conveyed vertically. However, because groundwater circulates in vertical and horizontal directions, vertical hydraulic conductivity changes affect the ability of the model to convey water. As such, model simulations indicate that vertical hydraulic conductivity values in the calibrated model are approximately one-tenth of the horizontal hydraulic conductivity values.

ET was withdrawn from each cell in Layer 1 according to depth below land surface of the simulated water table in that cell. A maximum ET rate of 32.4 in/yr was withdrawn from a cell if the depth to the water table in that cell was at the ground surface. This rate approximates the lake evaporation for water at or near the ground surface. The maximum ET elevation was the digitized land surface elevation that represents the top of Layer 1. ET was adjusted to 0.4 ft./day at the southeastern quarry pond to simulate removal of water via ET and by facility pumping. No ET was withdrawn from a cell if the depth to the water table was greater than 6 ft. below the land surface (i.e., ET "extinction depth" of the cell). A linear relation is used to calculate ET if the water table depth was between the ground surface and 6 ft. below grade. ET was not used in the dredge-tailing model. In the dredge-tailing model, recharge is used as a surrogate parameter that implicitly accounts for ET.

4.1 DREDGE-TAILINGS MODEL

Upon placing dredge tailings in the quarry, the model exhibited groundwater flow to the west toward Principio Creek and Furnace Bay.

4.2 PARTICLE TRACKING

Constituent migration from different constituent sources was evaluated using MODPATH. Locations along the eastern side of the quarry were chosen as starting points for the constituents since dredge tailings will contain the constituents to be modeled. Furthermore, the dredge tailings will be placed throughout the quarry and groundwater flow in the dredge-tailings model is toward the west. The points include the highest future elevation in the quarry. Figure 18 displays equipotential lines and pathlines in the calibrated future condition model for Layer 1. The pathlines indicate that constituents will migrate to the west, towards Furnace Bay and Principio Creek. Constituent fate and transport will be evaluated using MT3D and will be presented in a separate report.

4.3 MODEL CONCLUSIONS

Given the data available for the site, this model provides a consistent regional representation of the overall groundwater flow in the Stancill Quarry. Constituents from the areas of concern would remain on Stancill Quarry property and eventually discharge to Furnace Bay.

Anderson, M. P. and W. W. Woessner. 1992. *Applied Groundwater Modeling, Simulation of Flow and Advective Transport.* Academic Press, Inc., New York.

Bedient, P.B. and Huber, W.C. 1995. *Hydrology and Floodplain Analysis.* Addison-Wesley, Massachusetts.

Drummond, D. and J.D. Bloomquist. 1993. *Hydrogeology, Water Supply Potential, and Water Quality of the Coastal Plain Aquifers of Harford County, Maryland.* Maryland Geological Survey Report of Investigations No. 58, p. 160, Baltimore, MD.

Drummond, D.D. 1999. *Harford County Modflow Model.* Maryland Geologic Survey. Baltimore, MD.

E2CR. 2000. *Geotechnical Report for Stancill Sand and Gravel Quarry, Cecil County, Maryland.* Engineering, Consultation, Construction, Remediation, Inc. November 2000.

Freeze, R.A. and J.A. Cherry. 1979. *Groundwater.* Prentice-Hall, Inc., Englewood Cliffs, NJ.

Harbaugh, A.W. and M.G. McDonald. 1988. *U.S. Geologic Survey Documentation for MODFLOW-96: An Update to the United States Geologic Survey Modular Finite Difference Ground-Water Flow Model.* U.S. Geologic Survey, Reston, VA.

KCE Engineering. 2001. *Two Foot Contour Map of Stancill Quarry, Maryland.*

McDonald, M.G. and A.W. Harbaugh. 1988. *A Modular Three-Dimensional Finite Difference Ground-Water Flow Model: U.S. Geologic Survey Techniques for Water-Resources Investigations of the United States Geologic Survey.* U.S. Geologic Survey, Reston, VA.

MES. 2000. *A Preliminary Assessment of the Feasibility of Using the Stancill's Inc. Property on Furnace Bay in Cecil County as a Dredged Material Containment Facility.* November 2000.

MES. 2002. *Chemical Analytical Results From Dredge Sediment Sampling of Sites in Chesapeake Bay.*

Otton, E.G., R.E. Willey, R.A. McGregor, G. Achmad, S.N. Hiortdahl, and J.M. Gerhart. 1988. *Water Resources and Estimated Effects of Ground-Water Development, Cecil County, Maryland.* Maryland Geological Survey Bulletin 34.

Personal Communication. 2001, 2002. Discussions between representatives of Maryland Environmental Services (MES), Stancill Quarry, KCE Engineering, Inc. (KCE), and URS Corporation (URS) from August 2001 through June 2002.

Rasmussen, W.C. and G.E. Andreason. 1959. *Hydrologic Budget of the Beaverdam Creek Basin, Maryland: U.S. Geologic Survey Water-Supply Paper 1472.* U.S. Geologic Survey, Reston, VA.

Spitz, K. and J. Moreno. 1996. *A Practical Guide to Groundwater and Solute Transport Modeling.* John Wiley and Sons, Inc. New York.

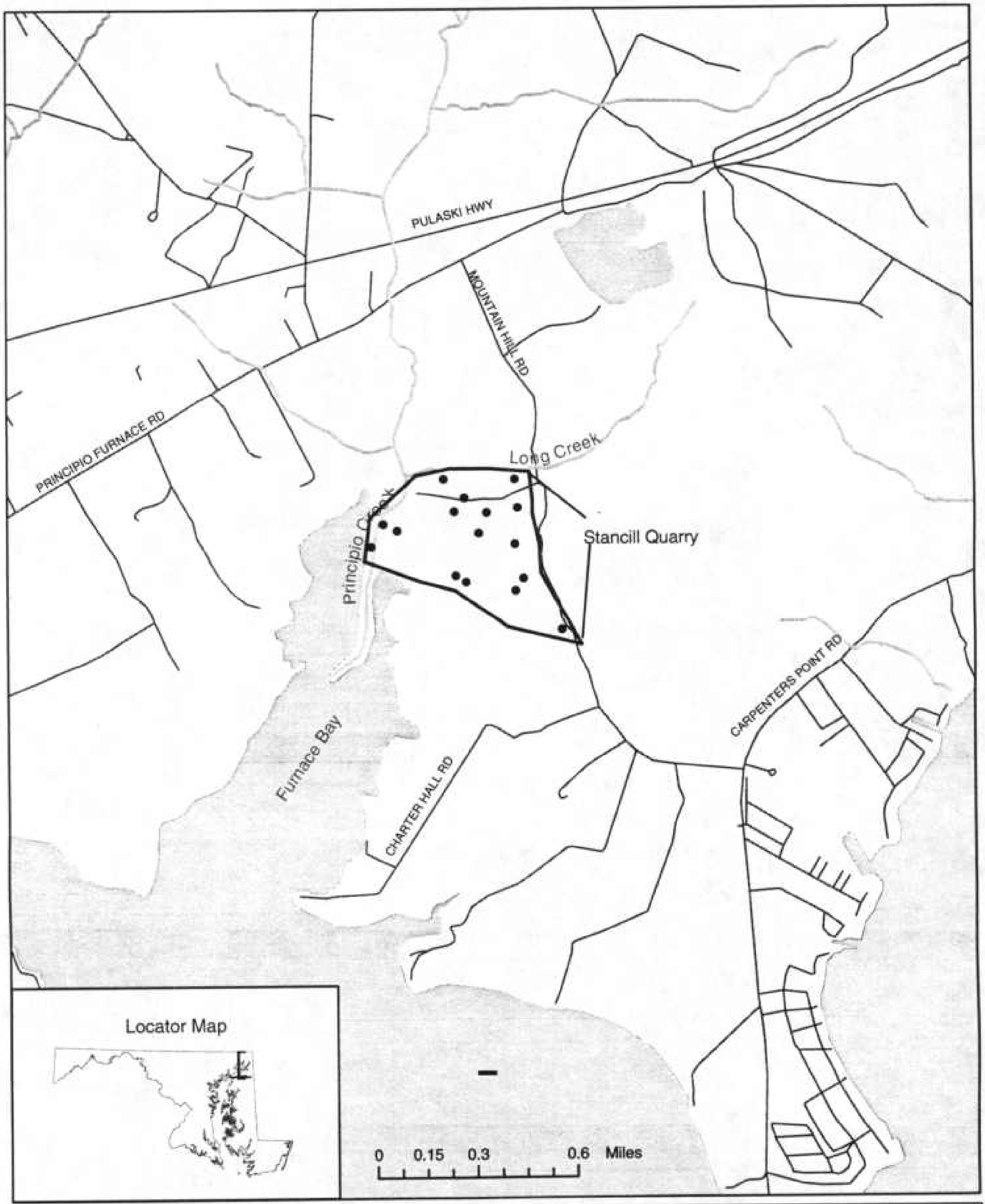
URS. 2002a. *Conceptual Geologic Interpretation for Stancill Quarry, Cecil County, Maryland.* September 2002.

URS. 2002b. *Conceptual Hydrogeologic Interpretation of the Stancill Quarry Site, Cecil County, Maryland.* September 2002.

Woodward Clyde. 1998. *Groundwater Flow Model Report for the Aberdeen Area of Aberdeen Proving Ground, Maryland*. May 1998.

Whitten, C.B., S.M. Swartzel, S.P. Miller, and K. Blough. 1997. *Conceptual Hydrogeologic Model of Aberdeen Proving Ground–Aberdeen Area*. U.S. Army Corps of Engineers, Waterways Experiment Station, Technical Report GL-97-16.

Figures

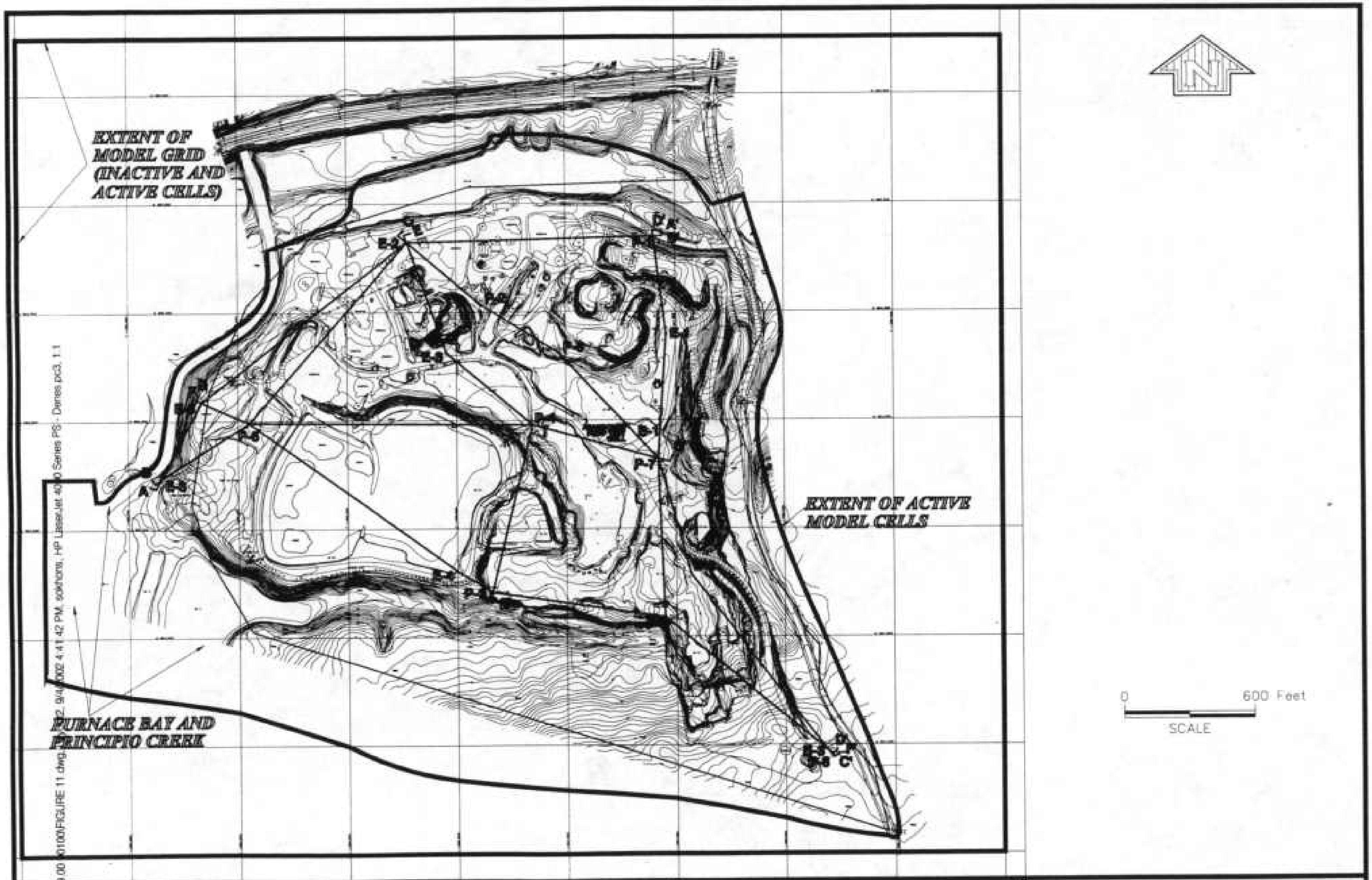


CLIENT: MES			
PROJ: Cecil County			
REVISION NO.		DES BY	
SCALE:	1: 25,000	DR BY	SK
FILE:	G:\8900000229\Projects\locator_map.mxd	CHK BY	JK

TITLE: Site Location - Stancill Quarry,
Cecil County, Maryland

URS

FIGURE:
1



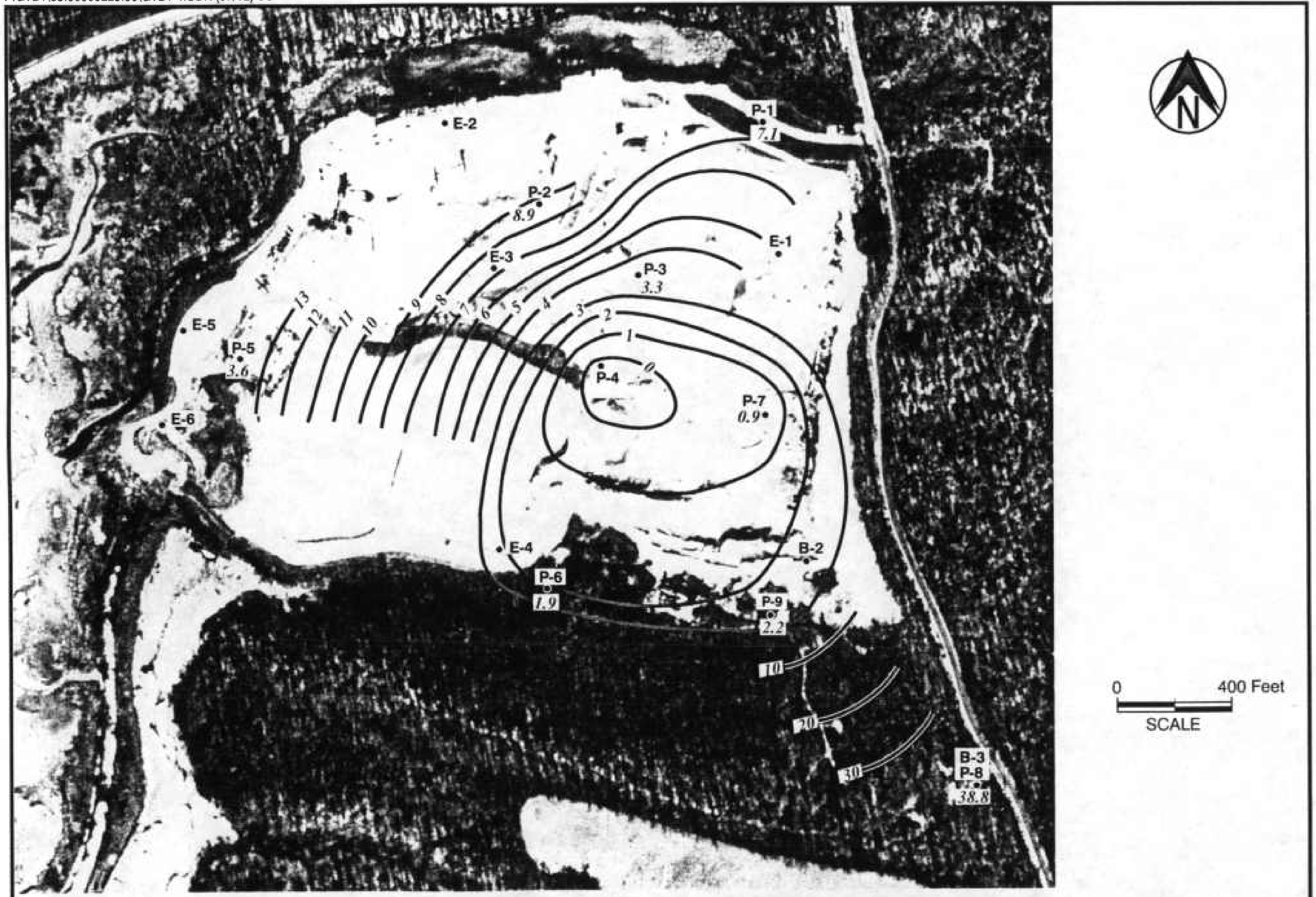
SOURCE: KCE ENGINEERING, INC., 2001

FIGURE 2
PHYSICAL BOUNDARIES OF MODEL

URS

0030B189-000020.00 0100\FIGURE 11.dwg, 9/4/2002 4:41:42 PM, sokhoms, HP LaserJet 4050 Series PS - Dense pc3, 1:1

P:GTB1\89.00000229.00\GTB1 4.CDR (07/02) SS



URS

Figure 3. Groundwater Contour Map For December 11, 2001

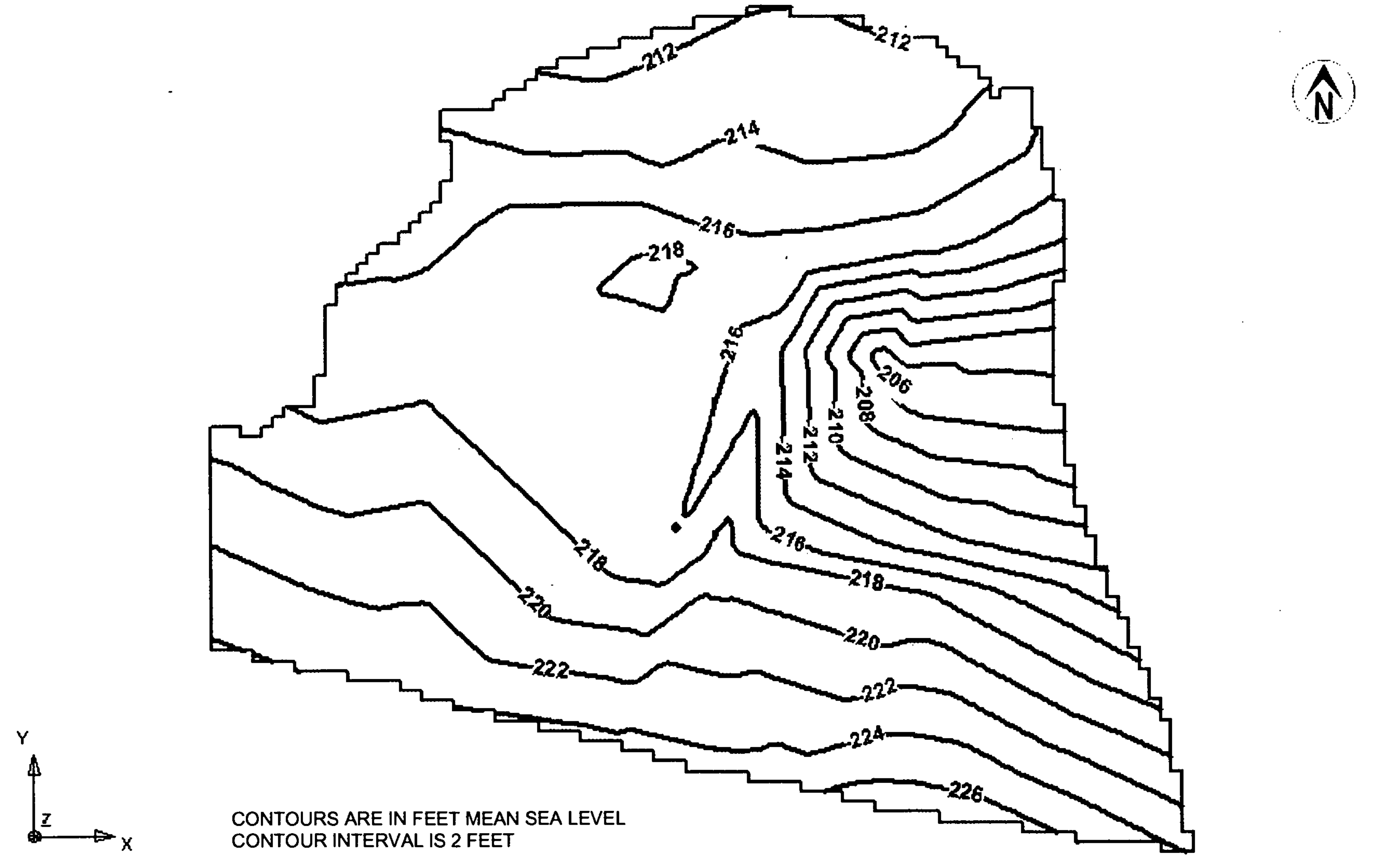
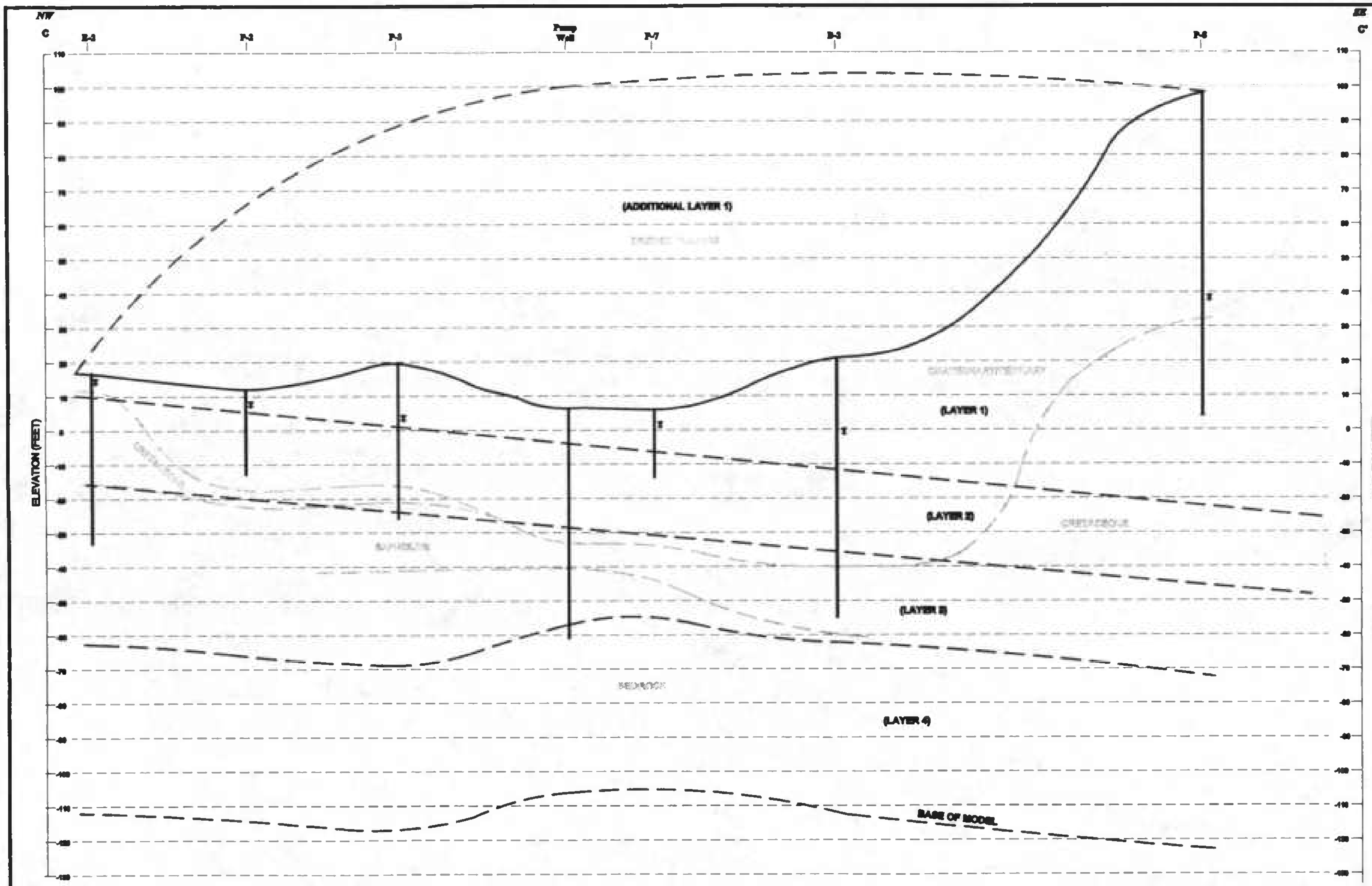


FIGURE 4
Contour Map of Base of Model

URS



Water encountered during drilling or measured in well after development.

— — Model Layer Boundaries

Horizontal scale subject to revision.

URS

FIGURE 5
STANCILL SAND AND GRAVEL QUARRY
CROSS SECTION C-C' SHOWING MODEL LAYERS

P:\Bethesda\15294364 00100-GTB1\98-00000229 00.00100\X-SECT C-C' 1.dwg, Layout1, 9/4/2002 4:38:10 PM, solohons HP LaserJet 5SI_5SI MX PS.pc3, 1:1

P:\Bethesda\15294354 00100-GTB1\99-00000229 00 00100\X-SECT G-G' 1.dwg, Layout1, 9/4/2002 4:39:49 PM, sokhons, HP LaserJet 5SI_5SI MX PS.pc3, 1:1

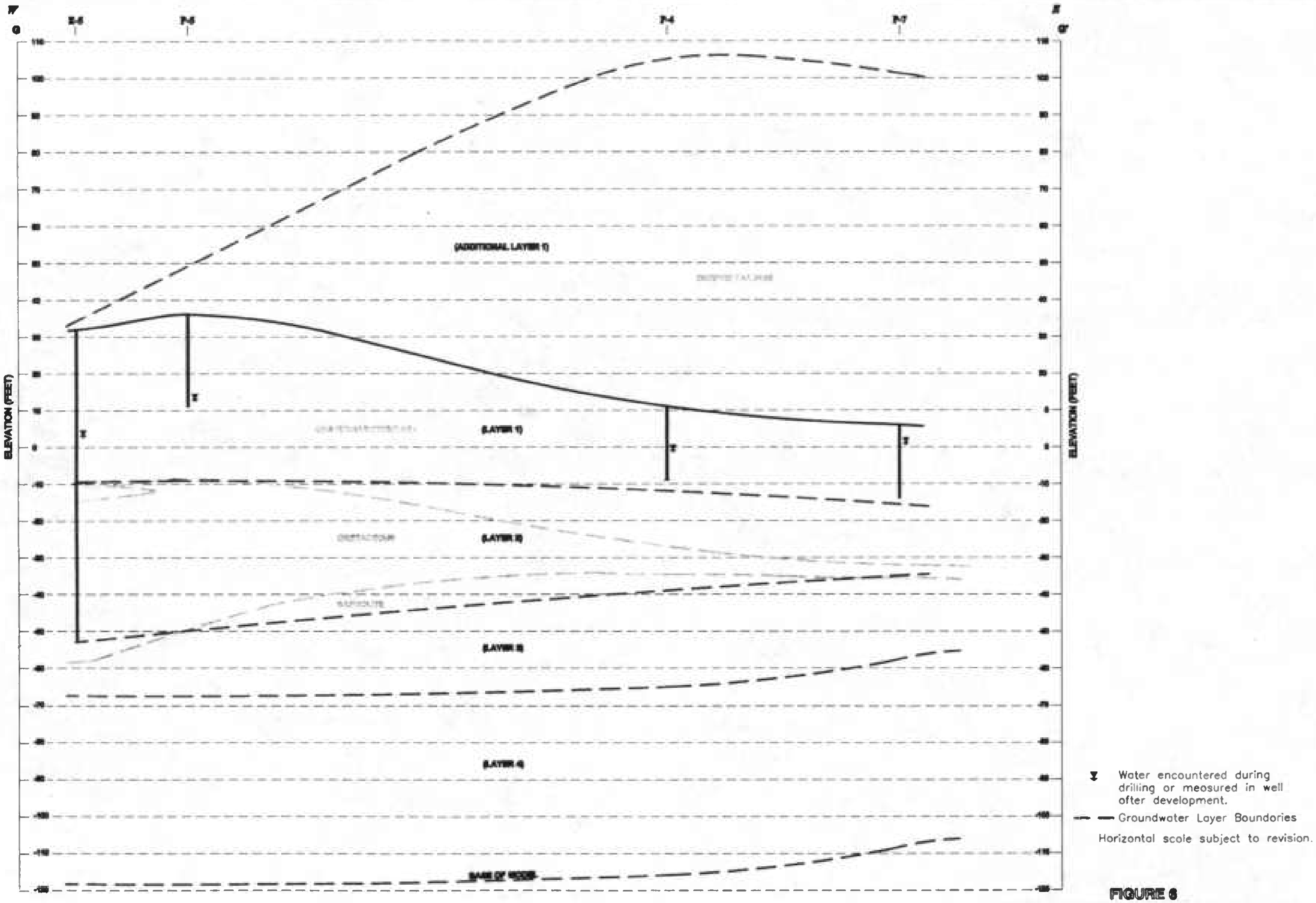


FIGURE 6
STANCILL SAND AND GRAVEL QUARRY
CROSS SECTION G-G' SHOWING MODEL LAYERS

URS

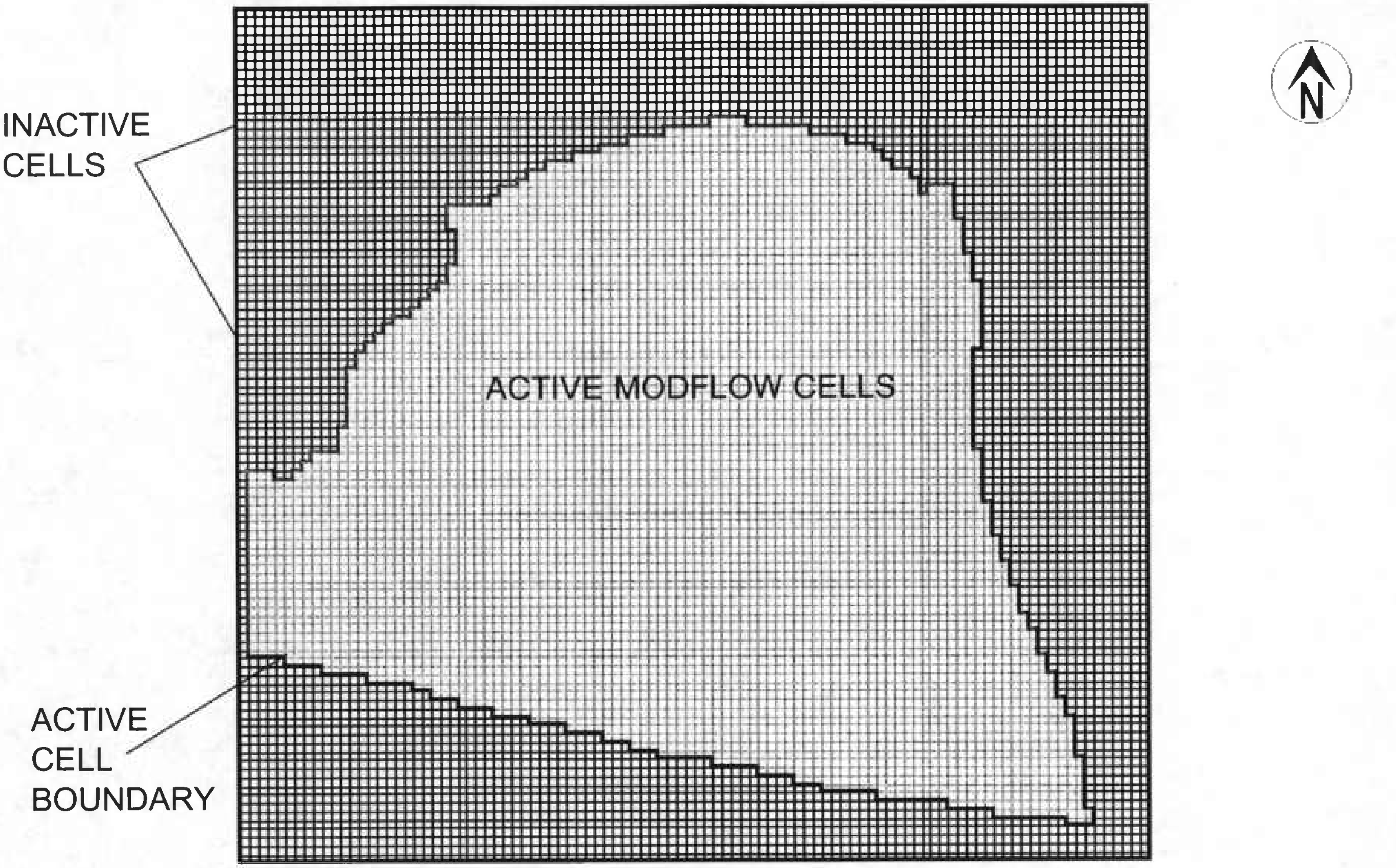


FIGURE 7
Model Grid and Extent Plan View

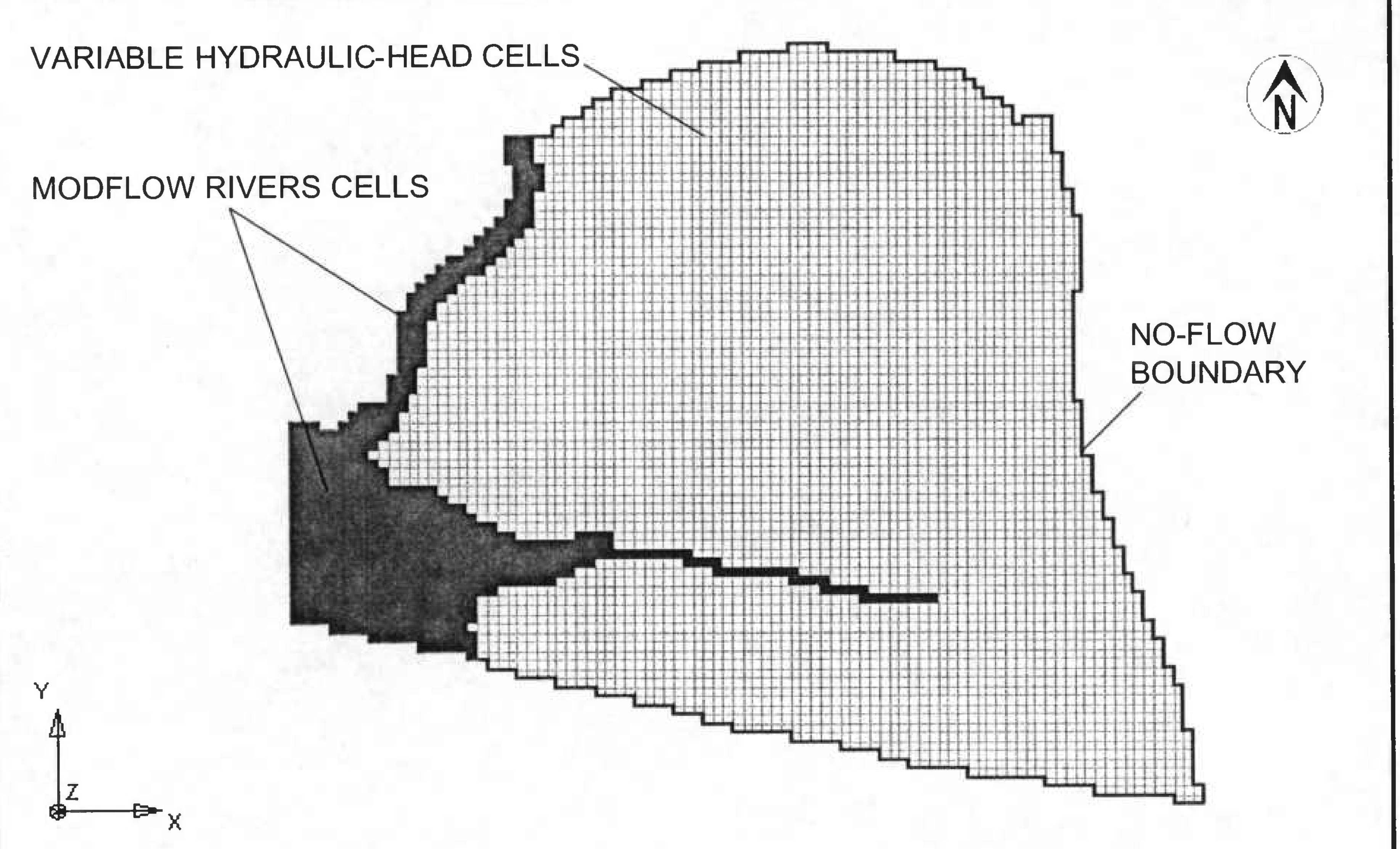


FIGURE 8
Groundwater Model Boundary Conditions in Layer 1

URS

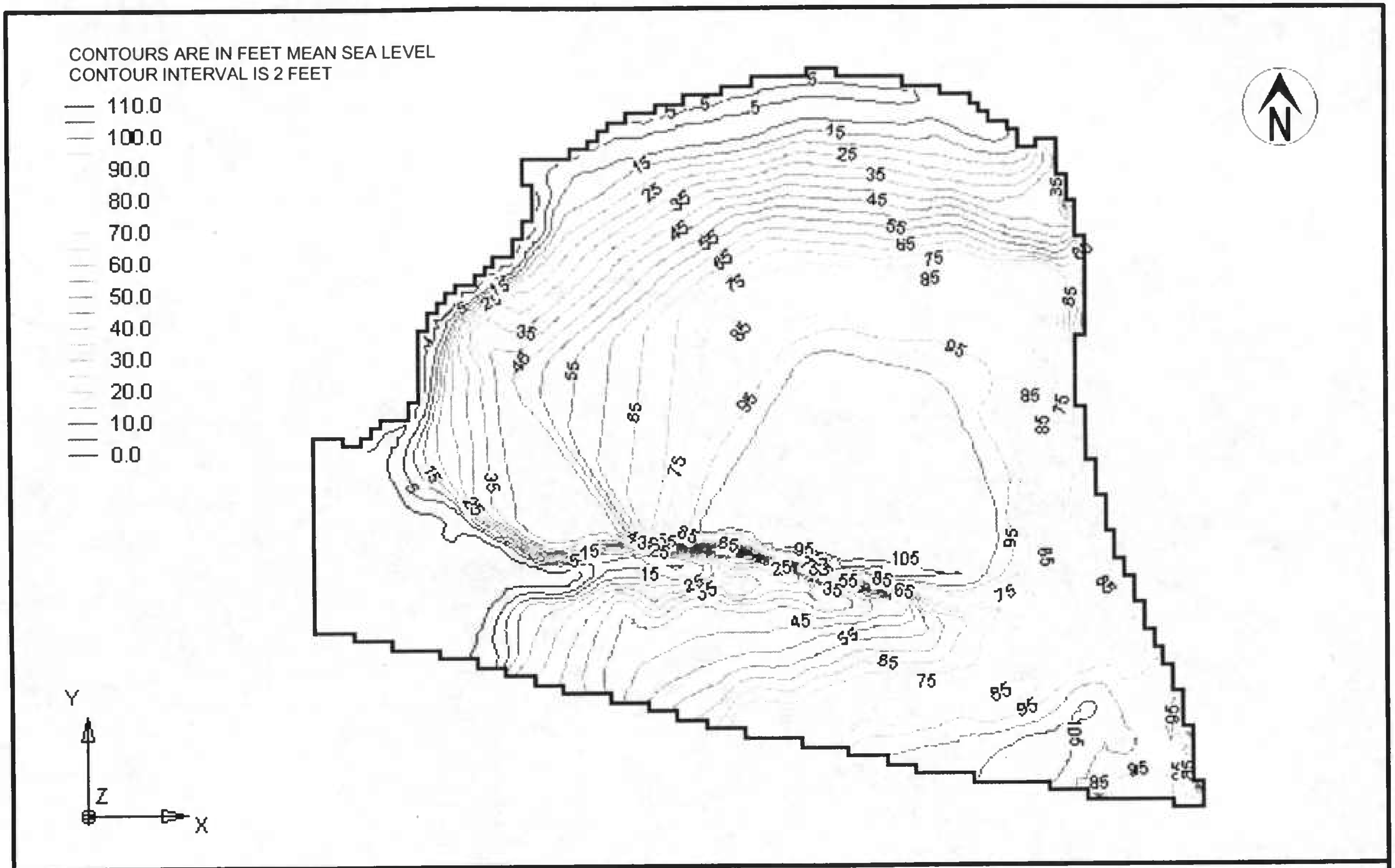
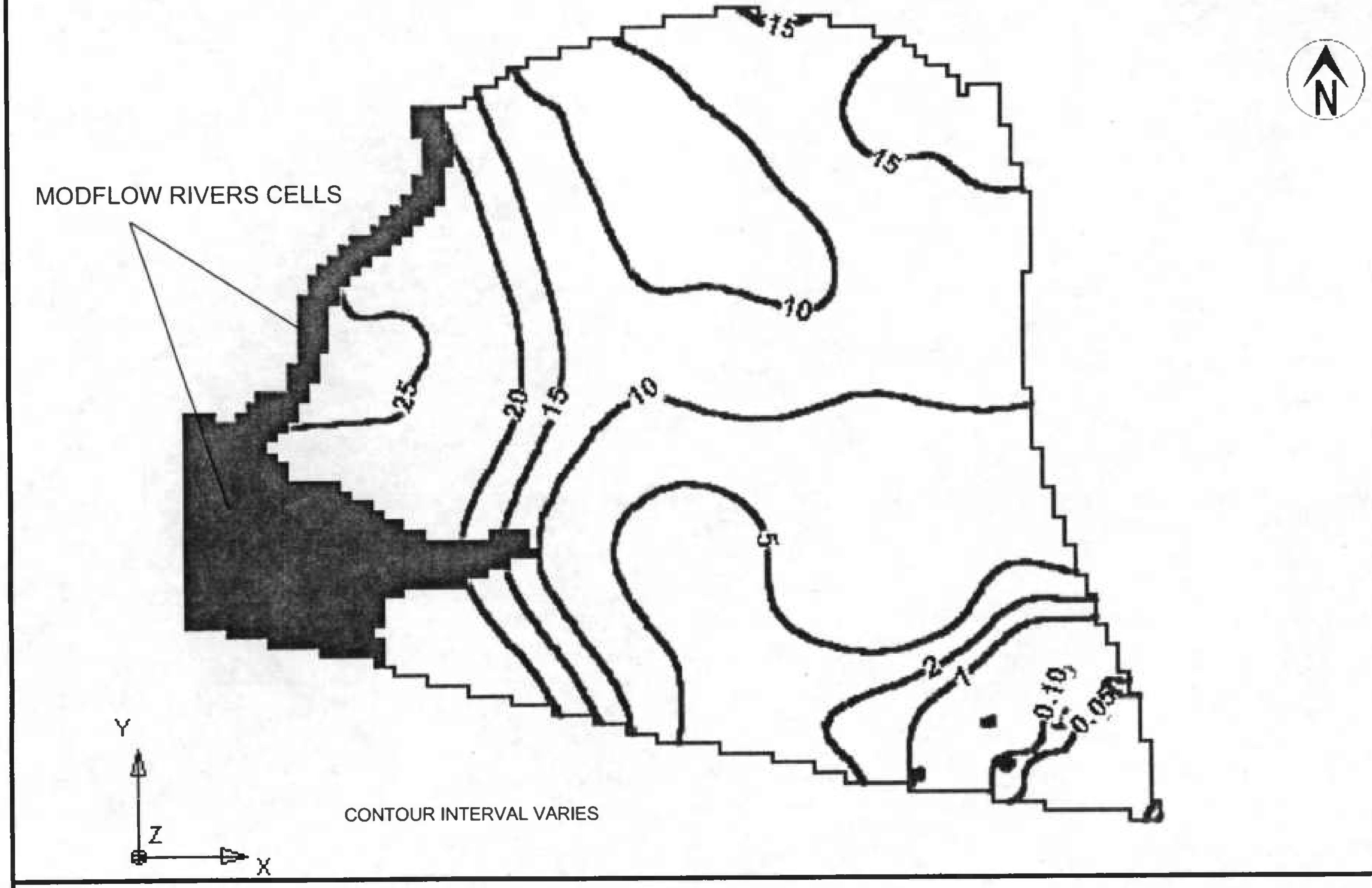


FIGURE 9
Ground Surface in Model Layer 1 After Placement of Dredge Tailings

0 400 FEET
SCALE



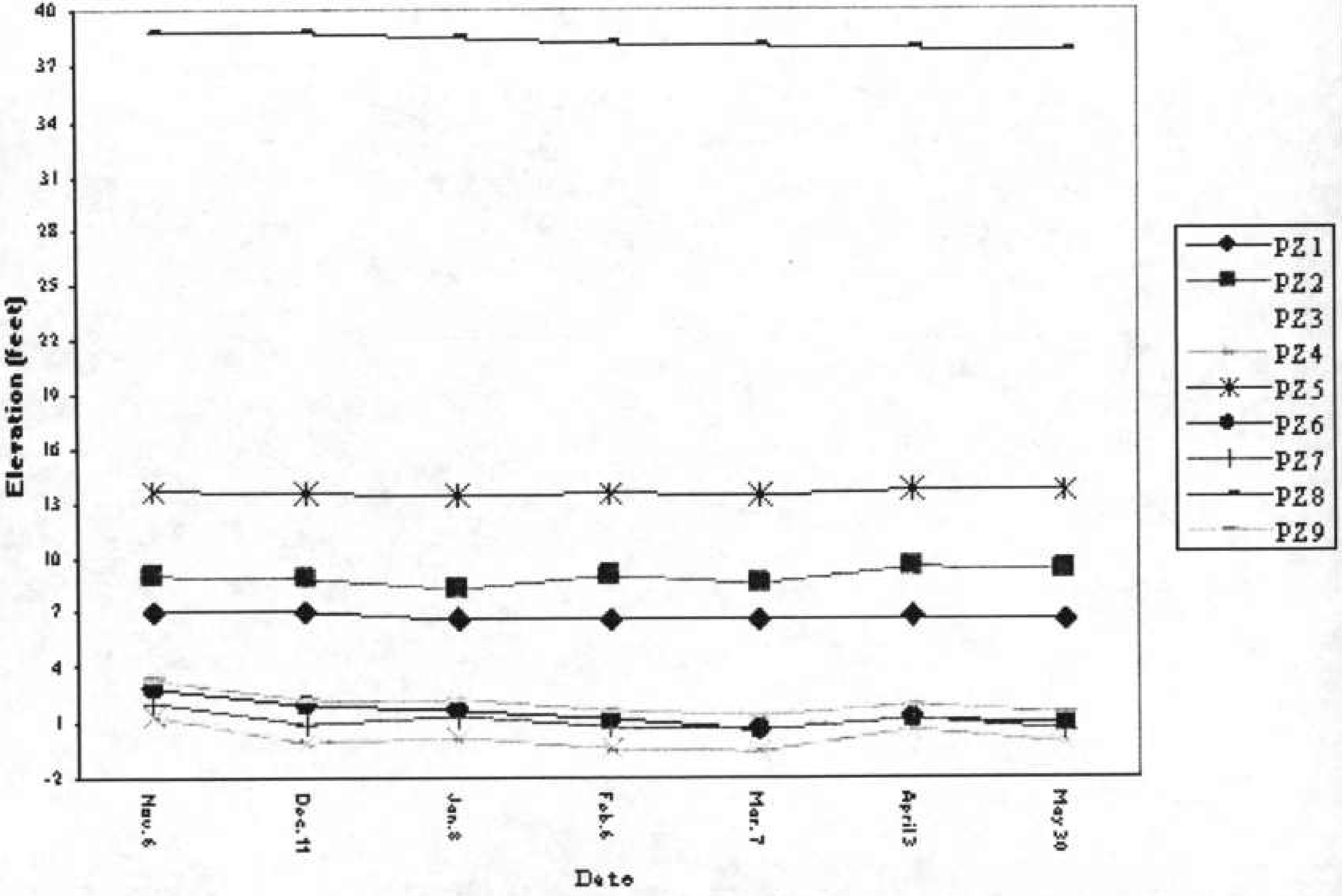
0 400 FEET

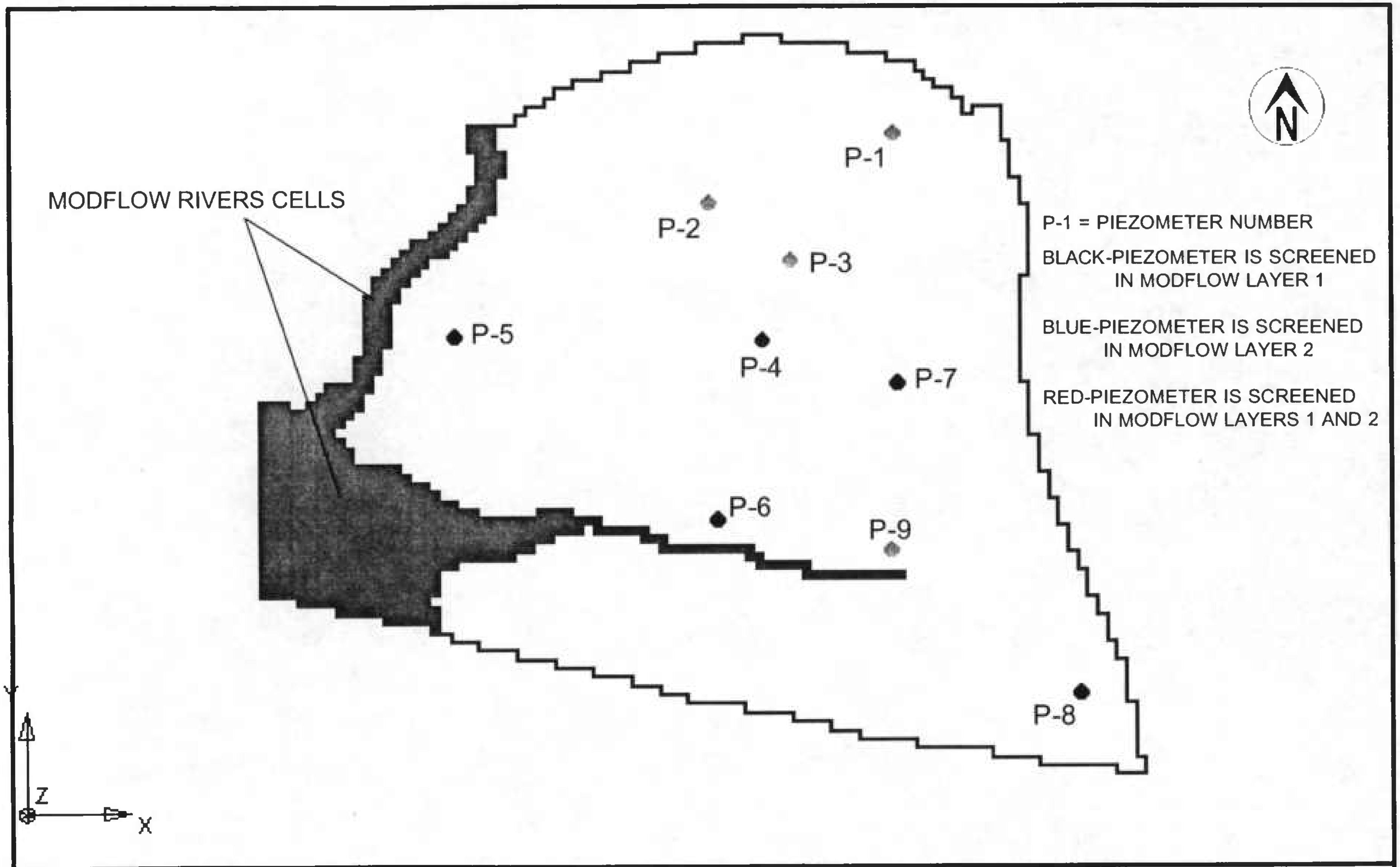
SCALE

FIGURE 10
Contoured Horizontal Hydraulic Conductivity
Values Used for the Present Day Quarry Model Layers 1 and 2

URS

Figure 11: Graph of Monthly Groundwater Level Measurements in Piezometers at Stancill Quarry





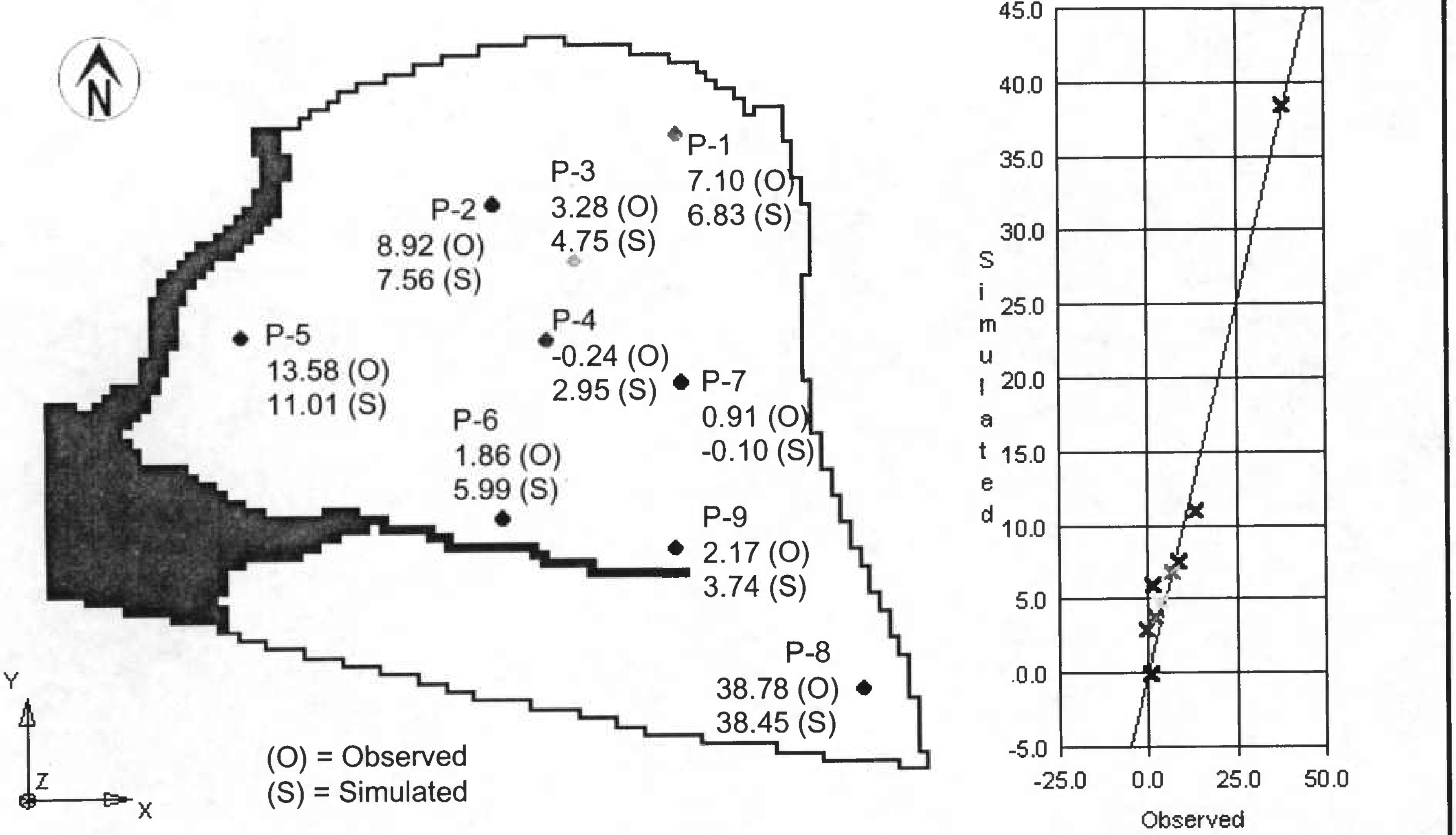
0 400 FEET

SCALE

FIGURE 12

Locations of Piezometers Used in Model Calibration

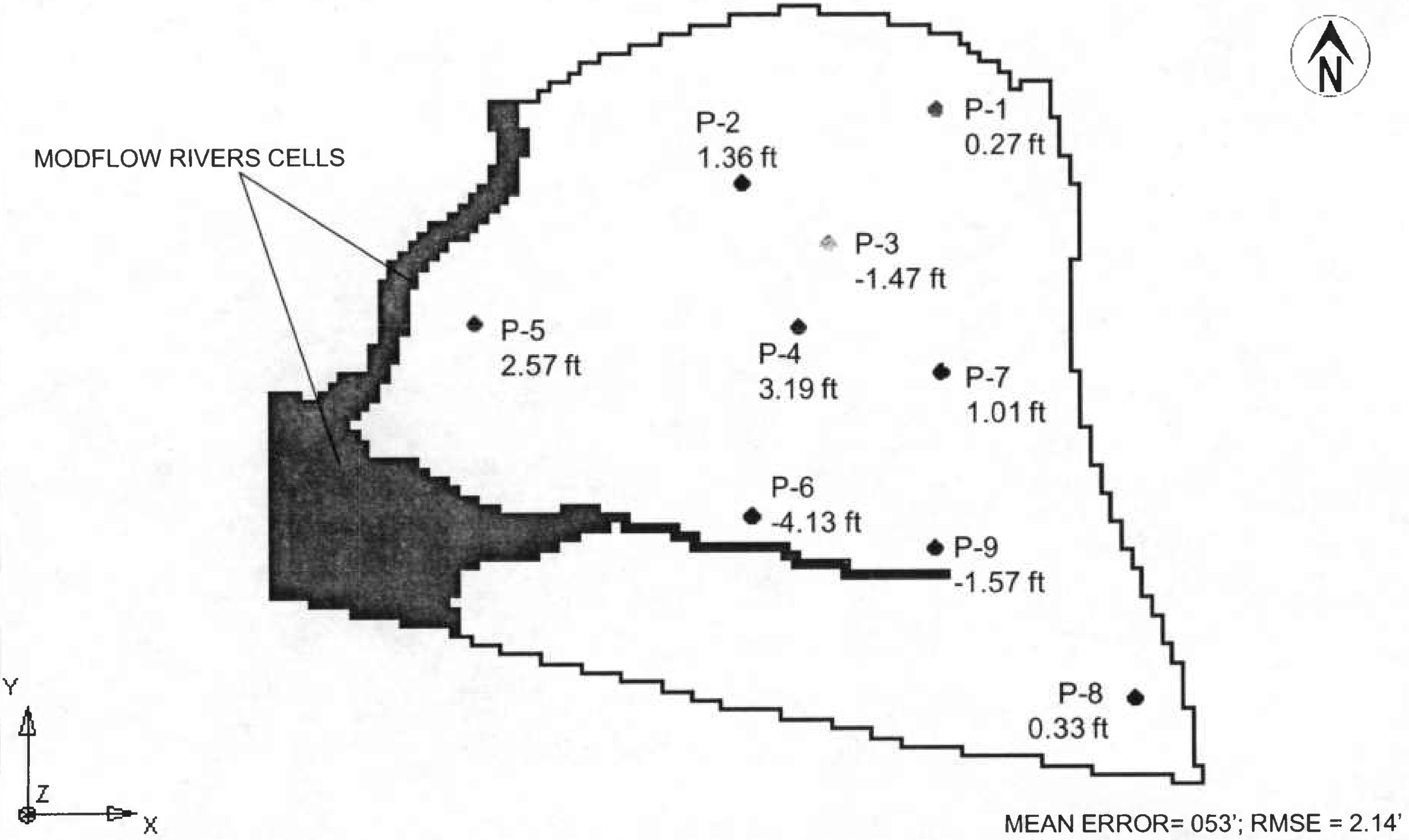
URS



MEAN ERROR= 053'; RMSE = 2.14'

FIGURE13
Simulated Heads Versus Observed Heads for the Calibrated Model

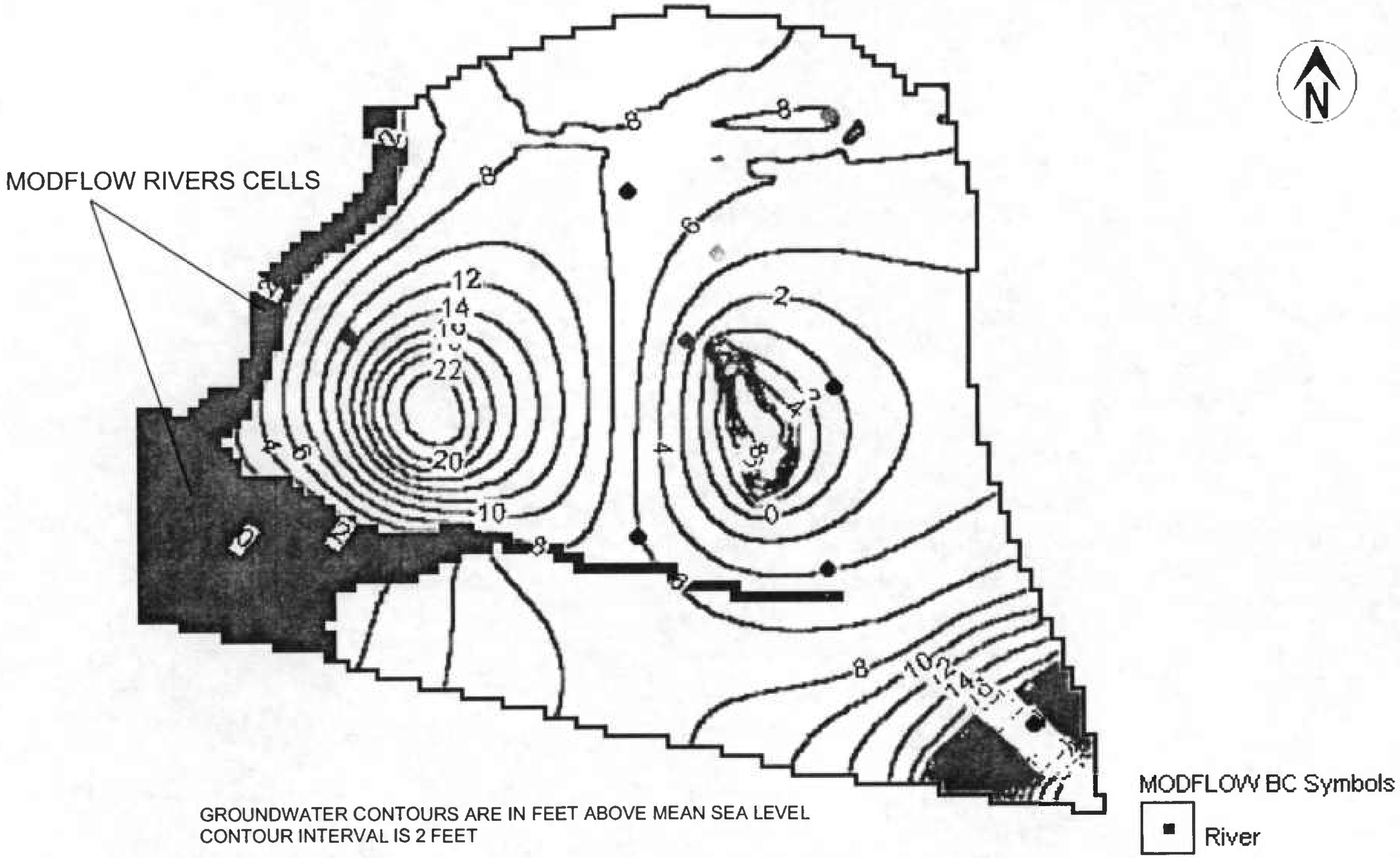
0 400 FEET
SCALE



MEAN ERROR= 053'; RMSE = 2.14'

FIGURE 14
Difference Between Simulated and Observed Model Head Values

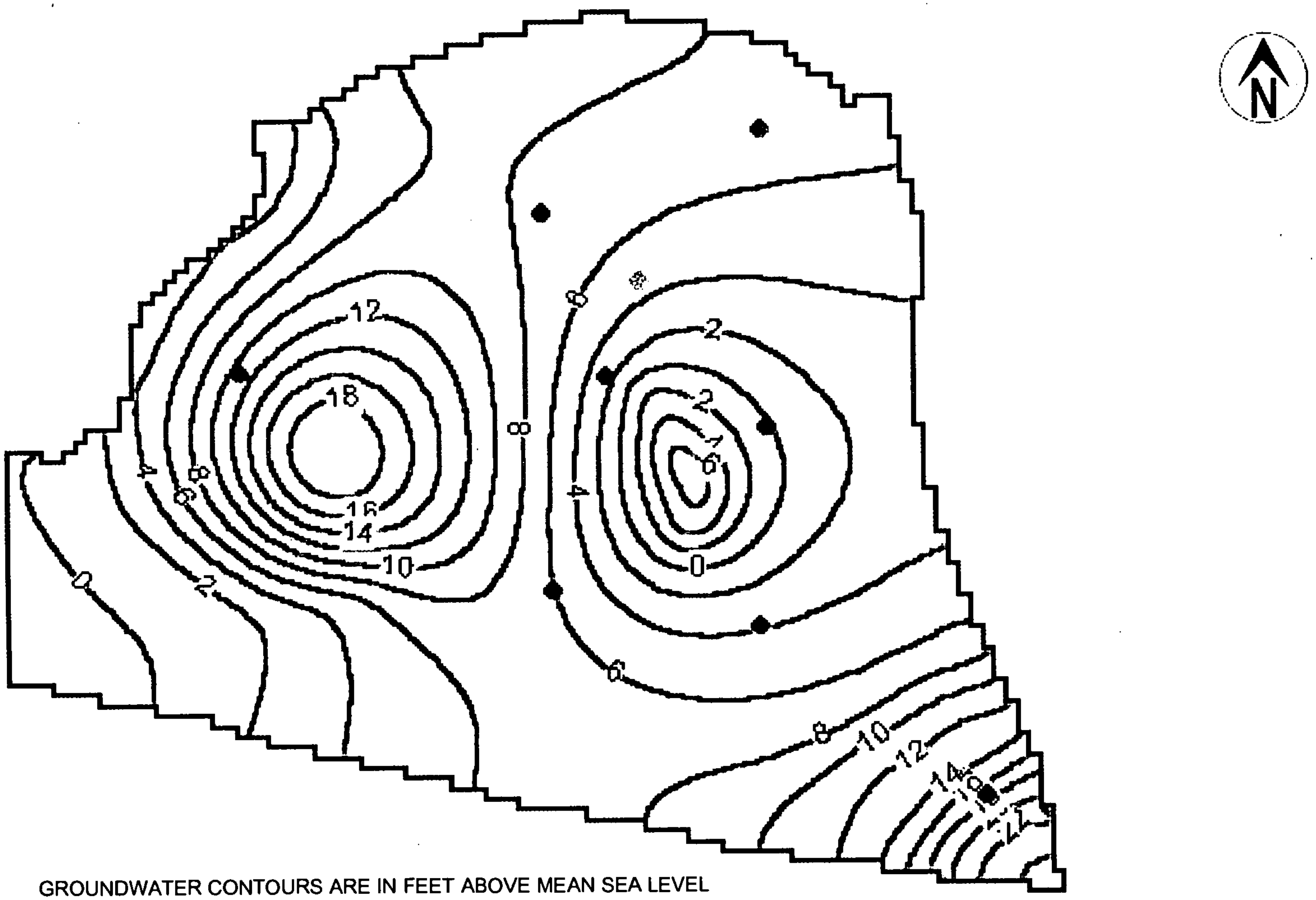
URS



GROUNDWATER CONTOURS ARE IN FEET ABOVE MEAN SEA LEVEL
CONTOUR INTERVAL IS 2 FEET

FIGURE 15
Groundwater Elevation Equipotential Lines
for Layer 1 of Calibrated Model

URS



GROUNDWATER CONTOURS ARE IN FEET ABOVE MEAN SEA LEVEL
CONTOUR INTERVAL IS 2 FEET

FIGURE 16
Groundwater Elevation Equipotential Lines
for Layer 2 of Calibrated Model

0 400 FEET
SCALE

URS

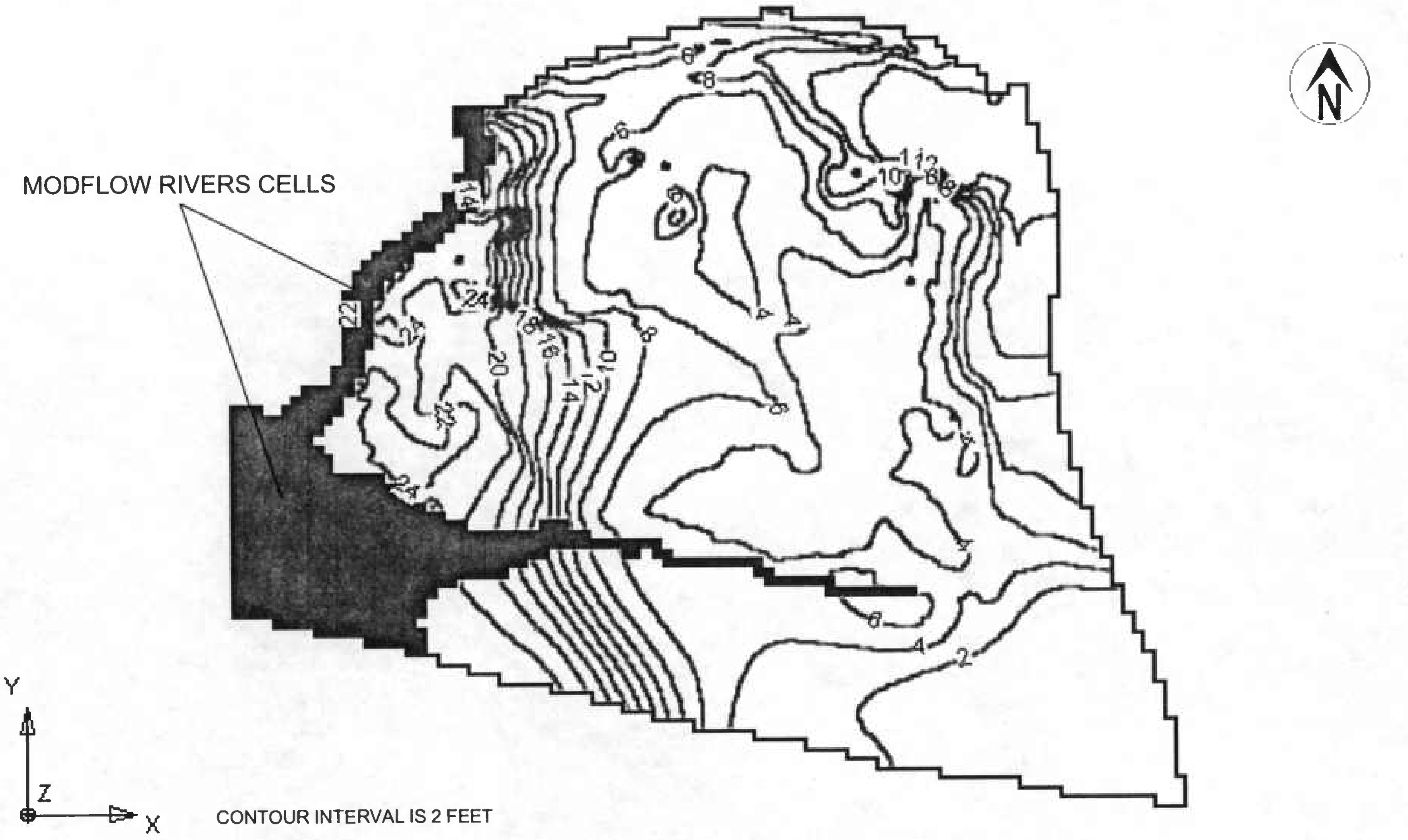
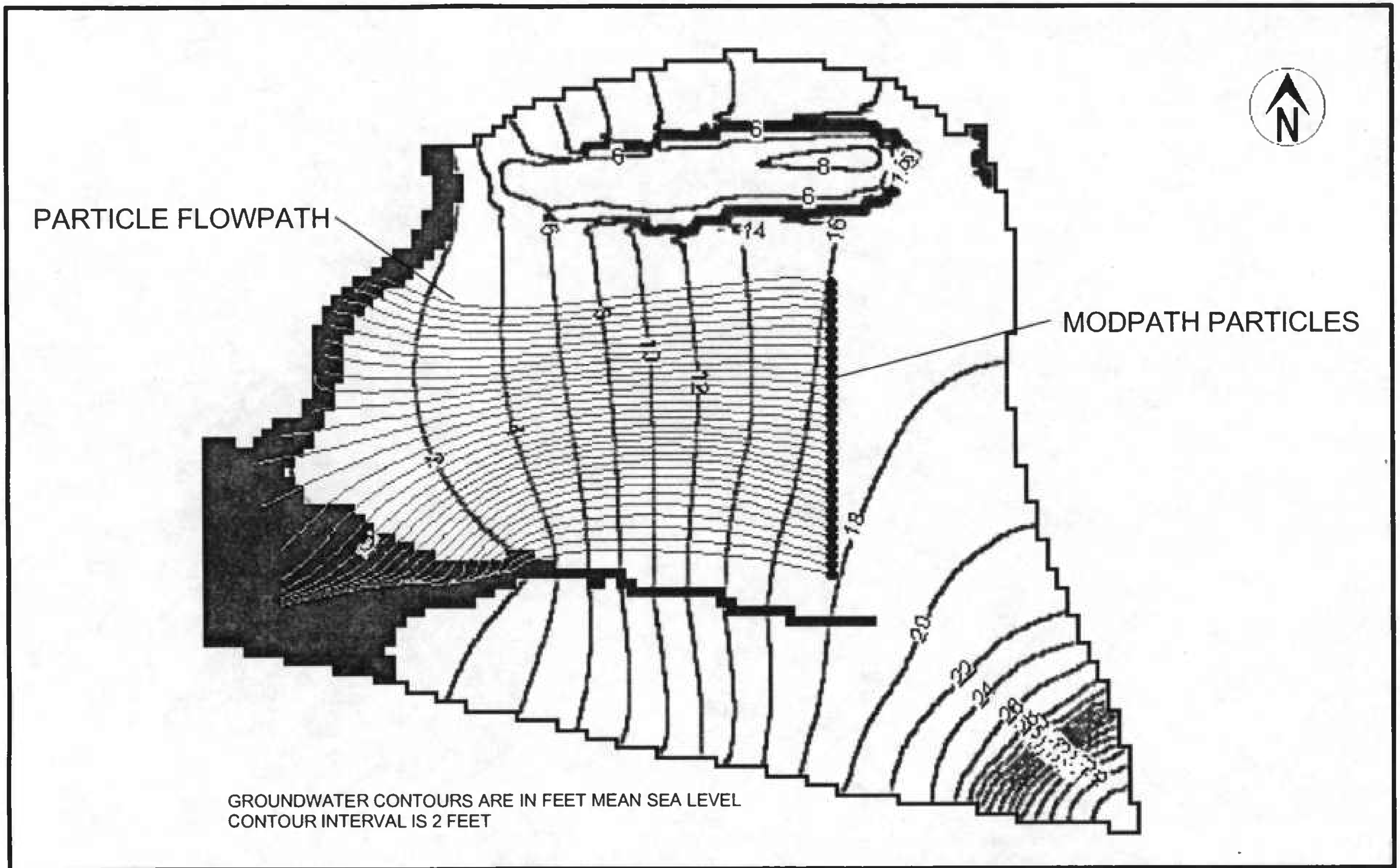


FIGURE 17
Equipotential Lines of Horizontal Conductivities
for Calibrated Model Layer 1

0 400 FEET
SCALE

URS



GROUNDWATER CONTOURS ARE IN FEET MEAN SEA LEVEL
CONTOUR INTERVAL IS 2 FEET

FIGURE 18
Equipotential Lines and Pathlines
in the Calibrated Future Conditions Model for Layer 1

0 400 FEET
SCALE

APPENDIX E

MT3DMS Transport Model Report

REPORT

MT3DMS TRANSPORT MODEL REPORT OF THE STANCILL QUARRY SITE, CECIL COUNTY, MARYLAND

Prepared for
Maryland Environmental Service
2011 Commerce Park Drive
Annapolis, MD 21401

September 2002

URS

URS Corporation
200 Orchard Ridge Drive, Suite 101
Gaithersburg, Maryland 20878
89-00000229.00
15294354.00100

TABLE OF CONTENTS

Table

Figures

TABLE OF CONTENTS

COC	Constituent of Concern
E2CR	Engineering, Consultation, Construction Remediation, Inc.
ft^3	Cubic feet
GMS	Groundwater Modeling System
KCE	KCE Engineering, Inc.
Kd	Adsorption coefficient
Ld	Dispersivity-Longitudinal
MES	Maryland Environmental Service
mg	milligram
mg/L	Milligrams per liter (i.e., parts per million)
MODFLOW	Modular Ground Water Flow Model
MT3D	Modular Three-Dimensional Transport Model
MT3DMS	Modular Three-Dimensional Multispecies Transport Model
SMCL	Secondary Maximum Contaminant Level
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
URS	URS Corporation

URS Corporation (URS) conducted groundwater chemical fate and transport modeling as part of a study of the Stancill Quarry in Cecil County, Maryland to evaluate the potential for constituent transport of chloride, Total Dissolved Solids (TDS), and iron. The Stancill Quarry may be used as a site to place dredge tailings resulting from dredging navigation channels in the upper Chesapeake Bay. Placing dredge tailings at the site may introduce constituents to the groundwater. These constituents are capable of being transported in the groundwater as the groundwater flows toward surface water bodies. The objective of the groundwater modeling was to identify the potential impacts, if any, the placing of dredge tailings in the quarry would have on the groundwater flow and constituent migration within and away from the site. This report presents the construction, calibration, and application of this model to assess potentially introduced constituents to the groundwater system.

The conceptual hydrogeological model studies and field investigations indicate that, prior to the placement of the dredge tailings, groundwater at Stancill Quarry flows into the quarry from all sides; after the placement of dredge tailings, groundwater is anticipated to flow westward to the nearest surface water discharge point in Furnace Bay.

The Conceptual Geologic Interpretation for Stancill Quarry, Cecil County, Maryland report (URS, 2002a) categorized the underlying geology, and the Conceptual Hydrogeologic Interpretation of the Stancill Quarry Site, Cecil County, Maryland (URS, 2002b) report categorized the hydrogeology of the site. The calibrated groundwater flow model was presented in the Groundwater Flow Model Report for Stancill Quarry, Cecil County, Maryland (URS, 2002c).

Chloride, TDS, and iron are believed to be typical of dissolved constituents entering the groundwater from the dredge tailings, which will be placed throughout the quarry. The points of entry for these constituents will therefore be evenly distributed throughout the quarry.

Because of varying aquifer hydraulic properties and the vertical/horizontal extent of the placed constituents, a three-dimensional model was needed to simulate adequately the movement of the constituents. Therefore, a Modular Three-Dimensional Multispecies Transport Model (MT3DMS) was used to simulate site-specific transport and to evaluate the flow of constituents in groundwater.

The transport model shows that constituents will discharge to Furnace Bay. The results of the modeling suggest that an increase of TDS in excess of the Federal and State Secondary Maximum Contaminant Level (SMCL) would likely result from the addition of dredge materials to the Stancill Quarry. However, simulated levels of chloride leaving the site in groundwater or entering Principio Creek and Furnace Bay would be below the SMCL for drinking water. The expected addition of iron to groundwater is negligible compared to the average background concentration presently detected in groundwater at the quarry. Because of the intensity of the Toxicity Characteristic Leaching Procedure (TCLP) leachate tests, the simulated input concentrations are expected to overestimate the amount of iron that will be leached from tailings via incoming precipitation. Furthermore, the results do not take into account the effects of adsorption and chemical precipitation of constituents, which may result in lower levels of constituents than those provided in the simulations.

This document presents the groundwater transport modeling performed for the Stancill Quarry site, Cecil County, Maryland (Figure 1) using information that URS Corporation (URS) gathered in earlier studies of the geology and hydrogeology of the quarry. This report is part of a series that characterizes the geology and hydrogeology of the project area. In this report, we present the details and results of numerical simulations conducted to model subsurface solute-transport of chloride, Total Dissolved Solids (TDS), and iron at the site and describe the solute-transport flow model development and calibration. Figures applicable to this report but contained in the earlier conceptual model reports or the groundwater flow model report are referenced to those documents.

This work was performed under URS Contract I.D. No. 02-07-06 with Maryland Environmental Service (MES). The Scope of Work includes preparation of a Modular Three-Dimensional Transport Model (MT3D) Report. This report is based on modeling results, review of publicly available data, data collected on site during this investigation, and discussions with MES, Stancill Quarry representatives, and information obtained from KCE Engineering, Inc. (KCE). As part of URS' corporate Quality Assurance Program, an independent technical reviewer has reviewed this report.

The Stancill Quarry may be used as a site to place dredge tailings resulting from dredging navigation channels in the upper Chesapeake Bay, and the local hydrogeologic flow regime may be affected by the placement of this additional geologic material in the quarry. This section summarizes the site background, and presents the purpose and objectives of the development of the groundwater transport model and the quality assurance measures taken.

1.1 PURPOSE AND OBJECTIVES

The purpose of the groundwater modeling was to create a tool to evaluate the long-term behavior of chloride, TDS, and iron constituents in groundwater at the Stancill Quarry site. Future concentrations of these constituents were estimated on a worst-case basis to determine the impacts on the local groundwater regime of dredge material placement. The groundwater transport model was used to predict future downgradient concentrations of select constituents and chemical quality of groundwater caused by placement of dredge tailings at the quarry and to determine the impact, if any, of dredge tailing placement on the local groundwater.

1.2 BACKGROUND

Detailed descriptions of the Stancill Quarry history and site characteristics were presented in the November 2000 report by MES entitled, *A Preliminary Assessment of the Feasibility of Using the Stancill's Inc. Property on Furnace Bay in Cecil County as a Dredged Material Containment Area"* and in the November 2000 report by Engineering, Consultation, Construction Remediation, Inc. (E2CR) entitled, *Geotechnical Report for Stancill Sand and Gravel Quarry, Cecil County, Maryland.* Three additional reports were written in the process of developing the groundwater model. The first report entitled, *Conceptual Geologic Interpretation for Stancill Quarry, Cecil County, Maryland* (URS, 2002a) provides a detailed evaluation of the geology of the Stancill Quarry. This conceptual geological model was the basis for the conceptual hydrogeologic model presented in the second report entitled *Conceptual Hydrogeologic Interpretation of the Stancill Quarry Site, Cecil County, Maryland* (URS, 2002b). The conceptual geological and conceptual hydrogeological models were used as the basis for the groundwater flow model presented in *MODFLOW Flow Model Report for Stancill Quarry, Cecil County, Maryland* (URS, 2002c). The groundwater transport model described in this document is based on the conceptual hydrogeologic model.

1.3 ORGANIZATION OF THE REPORT

This report is divided into five sections including tables and figures. The figures are provided at the end of the written text. The first section, the introduction, presents the contractual authority and basis for the study and report, and identifies previous reports written about the site that contain background information about the site. The second section presents an overview of the model development. Section Three summarizes the results of the calibration and sensitivity analysis of the model. Section.Four presents conclusions based on what has been presented. Section Five lists the references cited in this report.

2.1 DATA SOURCES AND DATA QUALITY

Input data for the model include the site's stratigraphy, hydraulic properties and distributions, boundaries, source locations of chloride, TDS, and iron, and the constituents' chemical properties. The source of data consisted primarily of field and laboratory data collected in the upper Chesapeake Bay (MES, 2000) and presented in *Conceptual Hydrogeologic Interpretation of the Stancill Quarry Site, Cecil County, Maryland* (URS, 2002b). Other data sources included site maps and background site information. Data quality is assumed to be adequate for the modeling effort. Where appropriate, parameters used for the solute modeling were taken from previous investigation efforts and site investigation reports. Source concentrations were determined from the results of leachate tests performed on sediment samples considered to be representative of incoming dredge material (MES, 2000). The primary features affecting contaminant transport include time-varying historical sources due to changing operating conditions and time-varying historical sinks.

2.2 SELECTION OF MODEL CODE

Model selection was based on the need to simulate future conditions and to meet the modeling objectives. The objectives were to evaluate the transport of chloride, TDS, and iron in a complex heterogeneous flow system and evaluate potential future migration of these constituents. Technical requirements of the selected model are the ability to simulate numerically the following items:

- Porous media
- Unconfined groundwater flow
- Horizontal and vertical groundwater flow
- Saturated conditions
- Heterogeneous and variably anisotropic hydraulic properties
- Contaminant advection, dispersion, and adsorption
- Space- and time-varying boundary conditions (such as groundwater recharge, discharge, and pumpage)
- Space- and time-varying constituent of concern (COC) sources (point or areal sources and concentrations). The COCs for this modeling effort are chloride, TDS, and iron.

Implementation criteria applied include:

- Is the model available for review in the public domain?
- Is the model readily available and well documented?
- Has the model been verified against analytical solutions or other previously verified models? Are the verification data sets available and well documented?
- Has the model been applied successfully at other similar sites (i.e., has the model been field-tested under conditions similar to those known at this site)?

- Is the model tractable for the modeling team and the computers available for this project?

Based on a review of previous investigations, site data, and project needs, the Modular Three-Dimensional Multispecies Transport Model (MT3DMS) (Zheng and Wang, 1999) was selected to model the transport of the target constituents. MT3DMS is a modular mass transport modeling system that can simulate changes in groundwater concentrations of contaminants while considering advection, dispersion, diffusion, and basic chemical reactions. MT3DMS is unique in that it includes three major classes of transport solution techniques that can be used to evaluate a wide variety of transport conditions, and it has the capability to accommodate add-on reaction packages for modeling general biological and geochemical reactions. It can also be used to model dual-domain advective-diffusive mass transport for both mobile (advective-dominant transport) and immobile (diffusion-dominant transport) domains. It is configured to run in conjunction with the results of the Modular Ground Water Flow Model (MODFLOW) that was used to model groundwater flow (URS, 2002c). The precursor model to this model, MT3D (Zheng, 1990), was documented for the U.S. Environmental Protection Agency by Kerr Environmental Research Laboratory. Both versions of the models are widely accepted for contaminant transport modeling by governmental regulatory agencies and the scientific community.

Data were formatted for input to MT3DMS using the Department of Defense Groundwater Modeling System (GMS) 3.1. GMS is a pre- and post-processor for several model codes, including MODFLOW and MT3DMS. In addition to formatting data for input, GMS was also used to analyze the model results graphically for incorporation into this modeling report.

2.3 MODEL CONSTRUCTION

2.3.1 Model Setup

The solute-transport modeling was initiated using the calibrated MODFLOW groundwater flow model constructed to simulate conditions after placement of the dredge material (URS, 2002c). Model input parameters were selected to provide a worst-case scenario of the potential transport of three dissolved constituents/constituent groups within aquifers below the site. Chloride, TDS, and iron were modeled for their dissolved phases only in the saturated zone. The locations and concentrations of chloride, TDS, and iron were determined based on the proposed placement of the dredge materials and the results of leachate tests conducted on sediment samples considered representative of potential incoming dredge material (MES, 2000).

Table 1 lists the primary aquifer-related and chemical-related variables used for this model effort. A variety of input variables is required for MT3DMS. Because the values and distributions of many of these variables are not known for the site, most were selected using typical values for the COCs. The model was constructed to simulate the primary transport processes of advection and hydrodynamic dispersion. Other transport processes, such as adsorption, speciation, and dissolution/precipitation, were not simulated because of the highly variable and complex nature of these processes, and the lack of site-specific data on which to base assumptions regarding potential future geochemical reactions at the site. Futhermore, chloride is a relatively non-reactive constituent. Therefore, these additional transport mechanisms are not considered to be important for this constituent.

Table 1: MT3DMS Model Input Parameters

Parameter	Value or Range of Values	Value Selected	Units	Primary Source
Model Input Conc.:				
Chloride	Less than 0.39 to 24.8	24.8	mg/L	TCLP Leachate tests of sediment samples (MES, 2002).
TDS	4,204 to 4,441	4,441	mg/L	TCLP Leachate tests of sediment samples (MES, 2002).
Iron	Less than 0.5 to 0.66	0.66	mg/L	TCLP Leachate tests of sediment samples (MES, 2002).
Effective Porosity (unconfined)	0.10 to 0.15	0.15		Achmad (1991); Hughes (1995); Rasmussen and Andreason (1959); Johnston (1976); Chapelle (1985);
Effective Porosity (confined)	0.00005 to 0.005	0.0002		Otton et al. (1988); Drummond and Bloomquist (1993)
Dispersivity-Longitudinal (Ld)	Typically less than 200 (alluvium and sand); 20 feet used by Tenbus and Fleck (2001) for local study	30	ft	Spitz and Moreno (1996); Gelhar, et al., 1992; Tenbus and Fleck (2001)
Dispersivity-Transverse	1% to 10% of Ld	3	ft	Gelhar, et al., (1992); Tenbus and Fleck (2001)
Dispersivity-Vertical	1% to 10% of Ld	0.3	ft	Gelhar, et al., (1992); Tenbus and Fleck (2001)
Diffusion coefficient – Iron	$1.72e^{-4}$ to $2.0e^{-4}$	0	ft^2/day	Spitz and Moreno (1996); Considered negligible
Coefficient of Retardation		0		Assumes no retardation
Adsorption coefficient (Kd)		0	ft^3/mg	Assumes no adsorption
Degradation rate - dissolved		0	day^{-}	Assumes no decay because constituents are inorganic

mg/L = milligrams per liter (parts per million)

2.3.2 Contaminant Sources

The model source inputs were chosen based on the assumption that the quarry would be filled with dredge tailings 34 years in the future, according to the Preliminary Assessment Report (MES, 2000). The groundwater COCs originate from the dredge tailings and are derived from *Chemical Analytical Results From Dredge Sediment Sampling of Sites in Chesapeake Bay* (MES, 2002). Constituent migration from different sources was evaluated for potential impact on downgradient receptors. The area of the quarry fill was chosen as the starting point for the constituents since dredge tailings will contain the constituents to be modeled, and the dredge tailings will be placed throughout the quarry. To be conservative for estimates from present into the future, assuming no hot-spot removal, a continuing source equal to the maximum concentrations observed in leachate test data was used to evaluate the constituent flow patterns and potential for off-site migration. The three constituents were modeled for their dissolved phases only in the saturated zone. The model was constructed to simulate the primary transport processes of advection and hydrodynamic dispersion. Other transport processes, such as adsorption, speciation, and dissolution/precipitation, were not simulated. Chemical decay was not simulated because the constituents are inorganic, and this transport mechanism is, therefore, not applicable.

For the purpose of this model, simulated constituent source inputs were evenly distributed throughout the area of the proposed quarry fill. Initial chloride, TDS, and iron concentrations were set to the highest measured detection reported for leachate tests of sediment samples considered representative of potential quarry fill material (see Table 1). The range of constituent values detected in the tests are summarized in Table 1 above, and are detailed in Table 8 of the hydrogeologic report (URS, 2002b). These values are considered to be conservative because the maximum concentrations were chosen for the tests, and the leachate test concentrations are expected to be greater than those resulting from the impacts of infiltrating precipitation. These higher concentrations are due to the intensity of the TCLP leachate tests used for the study.

2.3.3 Initial Conditions

The initial conditions for the transport simulations consisted of constant-rate source input concentrations of chloride, TDS, and iron in the areas of Layer 1 of the model selected to receive dredge material. Initial solute concentrations (i.e., background) were set to zero (i.e., no detectable concentrations). This provides simulation output free of the complications of background to reflect the impact of the tailings only.

The MT3DMS model selected for analyzing this site has the following assumptions:

- A porous-media model can approximate the flow patterns in the surficial aquifer, saprolite, and bedrock.
- All contaminants are dissolved.
- Density effects are ignored.
- Uniform anisotropy is assumed.
- Dissolved contaminants do not hinder advective groundwater movement.
- Recharge and constituent source input are constant through time.
- Leachate test results provide conservative estimates of future tailing constituent leachate concentrations.

2.3.4 Model Limitations

The model is limited to the simulation of chloride, TDS, and iron. Although conservative estimates were used to simulate the plume, unmapped sources and residual sources, if present, can change the study conclusions. In addition, previously published data provided a range to calibrate within, but site-specific data provide the best estimates. The modeled values that resulted in the best match to anticipated flows, heads, and concentrations were used in evaluating the future conditions.

2.4 MT3DMS MODEL CALIBRATION AND SENSITIVITY ANALYSIS

The purpose of model calibration is to obtain reasonable estimates for uncertain model input data such that model predictions match observed data to the degree possible, given site conditions and the distribution of site chemical data. However, a review of the target constituent data collected for the site does not indicate the presence of a consistent spatial distribution for which to compute and evaluate initial solute transport parameters. For example, initial dispersivity is typically estimated by the approach used by Gelhar et al. (1992) based on the shape of the plume and a travel distance of the constituent from the "source area." Since the constituents will be introduced throughout the excavated areas of the quarry, there is presently no plume, and the source area will cover a majority of the quarry. No site-specific data exist for unconfined and confined effective porosity. Therefore, the parameters were selected based on values obtained in the general transport literature (e.g., Spitz and Moreno, 1996; Gelhar et al., 1992), or local studies (e.g., Otton et al., 1988; Achmad, 1991; Tenbus and Fleck, 2001; etc.). The results are qualified with a discussion of uncertainty based on the sensitivity analysis.

To calibrate the transport model, dispersivity, and effective porosity were varied repeatedly to produce simulated plumes of reasonable shape. The final selected values used in the calibrated model are presented in Table 1. During this calibration process, the effects of dispersivity and effective porosity were noted, and the model values adjusted for additional runs.

The model was considered calibrated when the shape and concentrations of the simulated chloride, TDS, and iron distributions approximated those assumed using engineering judgment. The calibrated transport model was used to predict future concentrations on a worst-case basis to determine impacts to the surrounding groundwater. Model validation runs (comparison of actual conditions in the future to simulated predictions) were not part of this project's scope.

For each transport case run, the model solution behavior was checked for:

- Convergence of flow and transport solutions
- Stability
- Mass balance

The flow runs and the transport runs were typically converged to less than 5% mass error. These solution errors have negligible influence on the predicted results because of the uncertainties in model input data.

3.1 SENSITIVITY ANALYSES

Model sensitivity analysis consisted of varying dispersivity and effective porosity from 2 to 10 from the selected values in Table 1. The parameters were varied to evaluate the impacts of changes to these variables and assess uncertainty in the model.

The results of the sensitivity analysis are demonstrated by the impact on simulated constituent concentrations along a groundwater flow path near Furnace Bay (Figure 2). Source input concentrations and all other variables are held constant with the exception of the varied parameters, dispersivity and effective porosity in this case. Figure 2 shows the location of the observation point (i.e., "observation well") where the simulated concentrations were recorded over the total simulation time (100 years after emplacement of the tailings and achieving constituent equilibrium concentration in Layer 1). Figures 3 through 4 show the concentrations over time at this "observation well" for the varied values of dispersivity and effective porosity.

The results show that downgradient constituent equilibrium concentrations in the transport model are most sensitive to dispersivity. Dispersivity and effective porosity can both vary by several orders of magnitude. However, change by a factor of 3.3 (233? % increase) for dispersivity, for example, only results in slightly more than a 14% increase in the equilibrium concentration of chloride at the observation point.

3.2 FUTURE SIMULATIONS

The results of the MT3D simulations are shown in Figures 5 through 10, and concentration versus time plots for these constituents for model Layers 1 through 4 are shown in Figures 11 through 13. The maps show the concentrations of each constituent within the model area over time. The plots show concentrations over time at the observation well location shown in Figure 2 in model Layers 1, 2, 3 (saprolite), and 4 (bedrock). As shown in Table 1, the input concentrations in the quarry fill area are 24.8 milligrams/liter (mg/L), 4,441 mg/L, and 0.66 mg/L for chloride, TDS, and iron, respectively. The maximum concentrations appear in model Layer 2, with steady-state maximum concentrations of 20.6 mg/L, 3,700 mg/L, and 0.55 mg/L for chloride, TDS, and iron, respectively. Layer 1 concentrations are slightly less than Layer 2, but are similar. Steady-state maximum concentrations appear at the observation well approximately 8 to 20 years after the beginning of the simulation.

A steady-state solute transport model was constructed for the Stancill Quarry project site. Using the groundwater flow solution from a steady-state MODFLOW model, a multispecies transport model was constructed using MT3DMS. For the purpose of this project, three indicator constituents (chloride, TDS, and iron) were simulated.

The results of the modeling suggest that an increase of TDS in groundwater would likely result from the addition of dredge materials to the Stancill Quarry. The simulated concentration of TDS exceeds the SMCL of 500 mg/L. However, the addition of 20.5 mg/L of chloride to an existing average chloride background concentration of 15 mg/L suggests that simulated levels leaving the site in groundwater or entering Principio Creek and Furnace Bay are below the SMCL of 250 mg/L for drinking water. The expected addition of 0.55 mg/L of iron to groundwater is negligible compared to the average background concentration of 17 mg/L presently detected in groundwater. The simulated additional iron input of 0.5 mg/L is only slightly above the SMCL of 0.3 mg/L, and is one-half of the freshwater Ambient Water Quality Criteria for iron of 1 mg/L. Because of the intensity of the TCLP leachate tests, the simulated input concentrations are expected to overestimate the amount that will be leached from tailings via precipitation. Furthermore, the results do not take into account the effects of adsorption and chemical precipitation of iron and TDS, which may result in lower levels of constituents than those provided in the simulations.

REPORT

CONCEPTUAL HYDROGEOLOGIC INTERPRETATION REPORT OF THE STANCILL QUARRY SITE, CECIL COUNTY, MARYLAND

Prepared for
Maryland Environmental Service
2011 Commerce Park Drive
Annapolis, MD 21401

September 2002

URS

URS Corporation
200 Orchard Ridge Drive, Suite 101
Gaithersburg, Maryland 20878
89-00000229.00
15294354.00100

TABLE OF CONTENTS

TABLE OF CONTENTS

Tables

Figures

Appendices

CY	Cubic Yards
gpm	Gallons per Minute
in/yr	Inches per Year
KCE	KCE Engineering, Inc.
K_h	Horizontal Hydraulic Conductivity
K_v	Vertical Hydraulic Conductivity
MCY	Million Cubic Yards
MES	Maryland Environmental Services
MGS	Maryland Geologic Survey
T	Transmissibility
URS	URS Corporation
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geologic Survey
WES	Waterways Experiment Station

The Stancill Quarry, which is located in northeastern Maryland not far from the Delaware and Pennsylvania borders, may be used as a site to place dredge tailings resulting from dredging navigation channels in the upper Chesapeake Bay. Placement of this additional geologic material into the quarry may affect the local hydrogeologic flow regime. The Stancill Quarry is projected to be filled to an elevation of +45 or +90 ft. with dredge tailings most likely consisting of finer grained material, such as fine sands, silts, and clays, and occasional coarser grained sands and gravel. The +90 ft. future condition will be modeled to assume a "worst case" scenario for modeling purposes.

The Stancill Quarry is located about one-half mile from the nearest exposures of crystalline basement rocks along Principio Creek, near Principio Furnace, Maryland. As such, the hydrogeologic regime at the site shares aspects of both the Piedmont and Coastal Plain. The Cretaceous deposits encountered at the Stancill Quarry appear to correspond to the Potomac Group; the lithologic character of the deposits corresponds closely to the description of the middle Potomac confining unit, which is predominantly silt and clay.

Discharge from the groundwater reservoirs in the quarry area is almost entirely a natural discharge. Artificial discharge through pumps is a very small part of the total discharge. Natural discharge takes place through seeps and springs, chiefly along the sides and bottoms of streams. Discharge also may take place through evapotranspiration if the plant roots reach the saturation zone, or if the water table is very near the land surface.

Water-level data were collected from boreholes P-1 through P-9 from November 2001 to April 2002. With the exception of borehole P-5, which showed little change throughout the time period, most of the boreholes showed modest declines. This trend is consistent with severe drought conditions, which prevailed in northern Maryland at the time the measurements were taken. Throughout the current investigation, water-level contours at the Stancill Quarry have consistently shown groundwater flow inward toward the quarry from all directions toward the lowest elevation pond in the quarry floor. However, in October 2000, groundwater levels recorded in temporary wells installed in the quarry showed a groundwater gradient to the south spreading laterally as it moved southward. Well E-6 in the southwestern part of the quarry suggests the possibility of leakance out of the quarry at that point. Based on a slope failure into Principio Creek in the past, it is possible that ponded water may be seeping out of the sides of the pond in that portion of the quarry, or it may be seeping out of the bottom of the settling pond when the settling pond is dredged and the bottom is disturbed. Reportedly, no water is discharged from the quarry to the waters of the state, although an unmeasured amount is believed to leave the quarry with product, suggesting that most direct precipitation on the site is consumed by evaporation and quarry operations.

Recharge to the quarry consists of direct precipitation on the quarry plus groundwater inflow. Discharge from the quarry consists of natural evapotranspiration, water consumed in processing product, water exported with product, and possibly leakage from the higher altitude silt settling pond.

The Stancill Quarry materials from bottom upward consist of (1) crystalline igneous and metamorphic rocks, of great but unknown thickness; (2) residuum of the crystalline rock, weathered in place, termed saprolite; (3) non-marine sediments of early Cretaceous age of the Potomac Group; and (4) unconsolidated non-marine deposits overlying the Potomac Group believed to be of Tertiary/Quaternary age. Conductivity values of these units range from 10^{-4} to

10^{-6} cm/sec. The average value obtained from slug testing piezometers P-1 through P-9 is $3.6X10^{-3}$ cm/sec.

Specific conductance measured in boreholes P-1 through P-9 on November 6, 2001 indicate that the specific conductance of the quarry groundwaters were slightly lower than those of crystalline rock aquifers of Cecil County, but slightly higher than Potomac Group aquifers in the county. The range of pH tested in the field in samples taken November 6, 2001 from boreholes P-1 through P-9 are comparable to those cited by Otton et al. (1988). Laboratory analysis of 32 parameters (including common chemical constituents plus iron and manganese, trace metals, and several miscellaneous parameters) carried out on water samples collected November 6, 2001 from boreholes P-1 through P-9 generally were within the range of samples from crystalline rock aquifers. Notable exceptions were iron and manganese. The iron content of water from borehole P-1 was reported to be 120 mg/L, which is nearly 5 times higher than the highest iron value reported for Cecil County (24 mg/L); the highest manganese content in a sample from borehole P-5 was 4.2 mg/L, compared to about 2 mg/L reported for Cecil County.

This report presents an analysis and interpretation of the hydrogeologic characteristics of the Stancill Quarry and surrounding area. The Stancill Quarry may be used as a site to place dredge tailings resulting from dredging navigation channels in the upper Chesapeake Bay. The work was performed under URS Corporation's (URS) Contract I.D. No. 02-07-06 with Maryland Environmental Services (MES). The Scope of Work included preparation of a Conceptual Hydrogeologic Report to serve as a basis for a numerical predictive model of the groundwater regime at the Stancill Quarry. This interpretation is based on a review of publicly available data, data collected on-site during this investigation, and discussions with MES, Stancill Quarry representatives, and KCE Engineering, Inc. (KCE). As part of URS' corporate Quality Assurance Program, an Independent Technical Reviewer has reviewed this report.

1.1 PURPOSE

This report describes URS' development of a conceptual model to simulate groundwater flow and the transport and fate of groundwater within and surrounding the Stancill Quarry. This conceptual model will be used to create computer models for groundwater flow and constituent transport. The methods to be used to develop these computer models will be described in subsequent reports on the results of the computer modeling.

The purpose of conducting a hydrogeologic investigation, interpreting the hydrogeologic site characteristics, and preparing a hydrogeologic conceptual model of the Stancill Quarry site and surrounding areas is to construct a technical basis for the groundwater flow and transport models. The purpose of this report is to present an interpretation of the hydrogeologic conditions at the Stancill Quarry site to serve as a framework for a predictive numerical model of the groundwater flow regime of the site. The numerical groundwater flow model will be used to characterize the current flow regime, which will be used to predict future heads and flows and chemical quality of groundwater if dredge tailings are placed in the quarry. The hydrogeologic conceptual model, or groundwater flow model, will be incorporated into the future scenario for groundwater migration and used to estimate future downgradient concentrations of select constituents to determine the impacts of dredge tailings placement on the local groundwater regime.

1.2 REPORT ORGANIZATION

The report is divided into eight sections, plus tables and figures. Section 1 presents the contractual authority and basis for the study and report, introduces the reader to the concepts to be presented herein, and provides a summary discussion of previous reports to form the basis for the present interpretation. Section 2 provides an overview of the regional and local hydrogeology. Section 3 discusses the general principles of the occurrence of groundwater and includes a discussion of data used in the study and the processes of data analysis and interpretation. Section 4 describes water-level observations, time trends and implications with respect to groundwater flow, and presents a conceptual water budget for the Stancill Quarry as a foundation for the numerical groundwater flow model. Section 5 discusses the hydrologic properties of the different types of materials encountered at the Stancill Quarry. Section 6 describes groundwater quality in the quarry and provides information on the interstitial water of dredge tailings and how this could affect local groundwater under operating conditions. Section 7 discusses future conditions as the quarry is filled with dredge tailings. Section 8 lists the references and reports cited in this document.

1.3 LOCATION

The Stancill Quarry is located in northeastern Maryland, not far from the Delaware and Pennsylvania borders (Figure 1). The site is located approximately 2 ½ miles east of Perryville in Cecil County. The site is accessed from Mountain Hill Rd. It is surrounded by Long Creek and Amtrak train tracks (former Pennsylvania Railroad tracks) to the north, Mountain Hill Road and a wooded area to the east, a wooded area to the south, and Principio Creek and Furnace Bay to the west. The Chesapeake Bay and Carpenter Point are both south of the site. The Stancill Quarry has been in operation since 1972 for the production of sand, gravel, and clay materials (MES, 2000). The Stancill Quarry property occupies 130 acres on Carpenter Point Neck, of which 100 acres have been excavated. The remaining area is used primarily for processing and storage of product. The site is on the Atlantic Coastal Plain directly east of Principio Creek, near its confluence with Furnace Bay, which is an arm of the Chesapeake Bay. It is estimated that filling the existing quarry to an elevation of 90 ft. would provide storage space for approximately 13.6 million cubic yards (MCY) of tailings, which would provide 34 years of storage space at the anticipated annual rate of 400,000 cubic yards (CY) per year.

Detailed descriptions of the Stancill Quarry, background history, and site characteristics can be found in E2CR (2000), MES (2000), and the Conceptual Geologic Interpretation Report (URS, 2002).

1.4 REVIEW OF AVAILABLE INFORMATION

The Conceptual Geologic Interpretation Report (URS, 2002) presents a current geologic interpretation of the site. Previous hydrogeologic studies especially pertinent to this investigation include reports by Overbeck and Slaughter (1958), Willey et al. (1987), and Otton et al. (1988). In 1958, Overbeck and Slaughter produced the first comprehensive report on groundwater conditions in Cecil County. In 1988, Otton et al. updated and expanded the Cecil County portion of the Overbeck and Slaughter report, based on basic data provided by Willey et al. in 1987.

Information was collected from all available site-specific sources considered pertinent to the development of the conceptual geologic and hydrogeologic models. The data sources are listed in Section 8. The available information sources vary from general well drillers' logs to detailed geologic studies. Consequently, the quality of the available data varies considerably. Table 1 lists the wells, piezometers, and borings drilled at Stancill Quarry for the current investigation as well as for previous investigations.

Additional sources of information for this study include the USGS quadrile maps and water surface elevations measured in monitoring wells to develop an approximation of the surface elevation of the water-table aquifer.

Some distinctions are made when classifying certain data types as actual measurements or observations versus interpretations. The selection of the top of saprolite from the available geologic logs is based upon accepted scientific procedures. The procedures involve some subjectivity, however. Some subjectivity is also inherent in the evaluation of pumping and slug test data to determine hydraulic conductivity, specific yield, and storativity. These data, however, are treated as actual measurements or observations. The estimation of hydrogeologic properties based upon geologic materials from boring log observations is considered interpretive.

Achmad, Grufron, 1991. *Simulated Hydrologic Effects of the Development of the Patapsco Aquifer System in Glenn Burnie, Anne Arundel County, Maryland.* Maryland Geological Survey Report of Investigations No. 54, 90 p.

Chapelle, F.H., 1985. *Hydrogeology, Digital Solute-Transport Simulation, and Geochemistry of the Lower Cretaceous Aquifer System Near Baltimore, Maryland.* Maryland Geological Survey Report of Investigations No. 43, 120 pp.

Drummond, D.D., and J.D. Bloomquist, 1993. *Hydrogeology, Water Supply Potential, and Water Quality of the Coastal Plain Aquifers of Harford County, Maryland.* Maryland Geological Survey Report of Investigations No. 58, 160 pp.

E2CR, 2000. *Geotechnical Report for Stancill Sand and Gravel Quarry, Cecil County, Maryland.* Engineering, Consultation, Construction, Remediation, Inc. November 2000.

Gelhar, L. W., C. Welty, and K. R. Rehfeldt, 1992. *A Critical Review of Data on Field-Scale Dispersion in Aquifers.* Water Resources Research, Vol. 28, No. 7, pp. 1955-1974, July.

Hughes, W.B., 1995. *Ground-Water Flow and the Possible Effects of Remedial Actions at J-Field, Aberdeen Proving Ground, Maryland.* U.S. Geological Survey Water Resources Investigations Report 96-4075, Towson, Maryland, 39 pp.

Johnston, R.H., 1976. *Relation of Ground Water to Surface Water in Four Small Basins of the Delaware Coastal Plain.* Delaware Geological Survey Report of Investigations No. 21, 56 p.

Maryland Environmental Service (MES), 2000. *A Preliminary Assessment of the Feasibility of Using the Stancill's Inc. Property on Furnace Bay in Cecil County as a Dredged Material Containment Facility.* November 2000.

MES, 2002. *Chemical Analytical Results From Dredge Sediment Sampling of Sites in Chesapeake Bay.*

Otton, E.G., Willey, R.E., McGregor, R.A., Achmad, G., Hiortdahl, S.N., and Gerhart, J.M., 1988. *Water Resources and Estimated Effects of Ground-Water Development, Cecil County, Maryland.* Maryland Geological Survey Bulletin 34.

Personal Communications 2001, 2002. Discussions between representatives of MES, Stancill Quarry, KCE Engineering, Inc. (KCE), and URS Corporation (URS) from August 2001 through June 2002.

Rasmussen, W.C., and G.E. Andreasen, 1959. *Hydrologic Budget of the Beaverdam Creek Basin, Maryland.* U.S. Geological Survey Water Supply Paper No. 1472, 106 p.

Spitz, K. and J. Moreno, 1996. *A Practical Guide to Groundwater and Solute Transport Modeling.* John Wiley and Sons, Inc. New York.

Tenbus, F.J., and W.B. Fleck, 2001. *Simulation of Ground-Water Flow and Transport of Chlorinated Hydrocarbons at Graces Quarters, Aberdeen Proving Ground, Maryland.* U.S. Geological Survey Water Resources Investigations Report 01-4106, Baltimore, Maryland, 51 pp.

URS, 2002a. *Conceptual Geologic Interpretation for Stancill Quarry, Cecil County, Maryland.* September 2002.

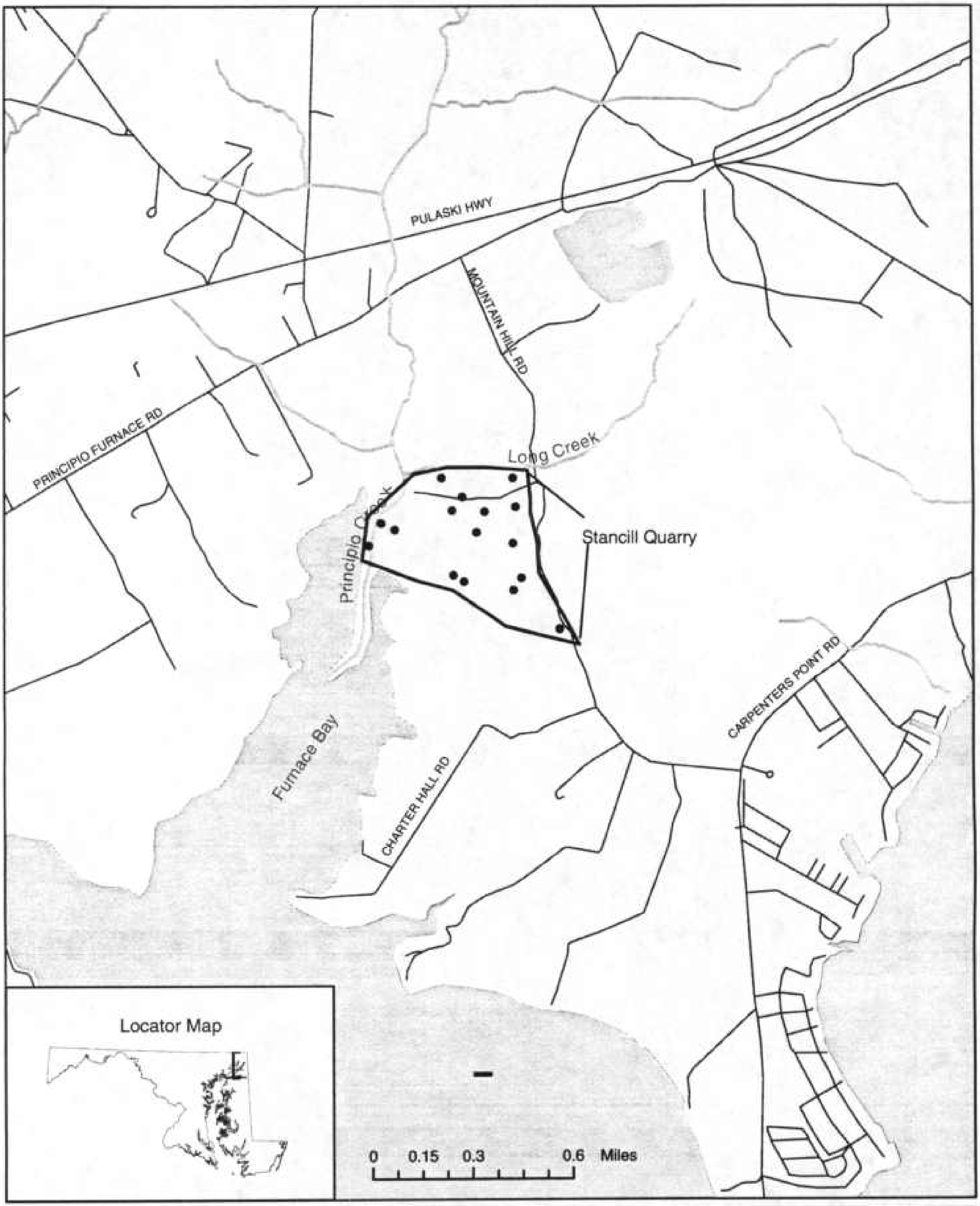
URS, 2002b. *Conceptual Hydrogeologic Interpretation of the Stancill Quarry Site, Cecil County, Maryland.* September 2002.

URS, 2002c. "*MODFLOW Flow Model Report for Stancill Quarry, Cecil County, Maryland.*" September 2002.

Zheng, C., 1990. *MT3D, A Modular Three-Dimensional Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems.* Report prepared for the United States Environmental Protection Agency Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma.

Zheng, C., and P. P. Wang, 1999. *MT3DMS, A Modular Three-Dimensional Multispecies Transport Model.* Documentation and User's Guide, Contract Report No. SERDP-99 prepared by The Hydrogeology Group, University of Alabama for USACE, Washington, D.C., 20314.

Figures



CLIENT: MES				TITLE: Site Location - Stancill Quarry, Cecil County, Maryland	
PROJ: Cecil County				URS	FIGURE: 1
REVISION NO.		DES BY			
SCALE:	1: 25,000	DR BY	SK		
FILE:	G:\8900000229\Projects\locator_map.mxd	CHK BY	JK		

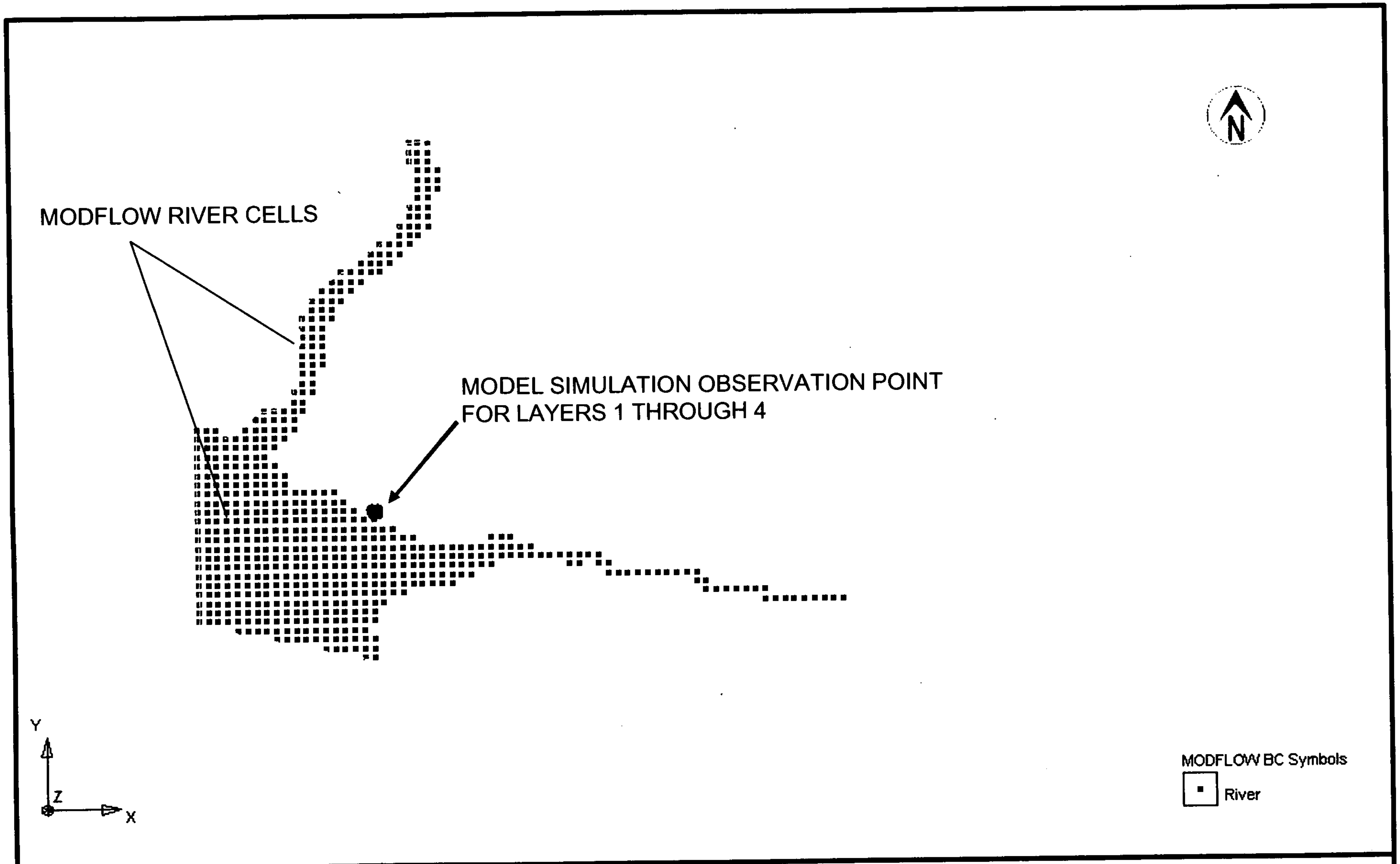
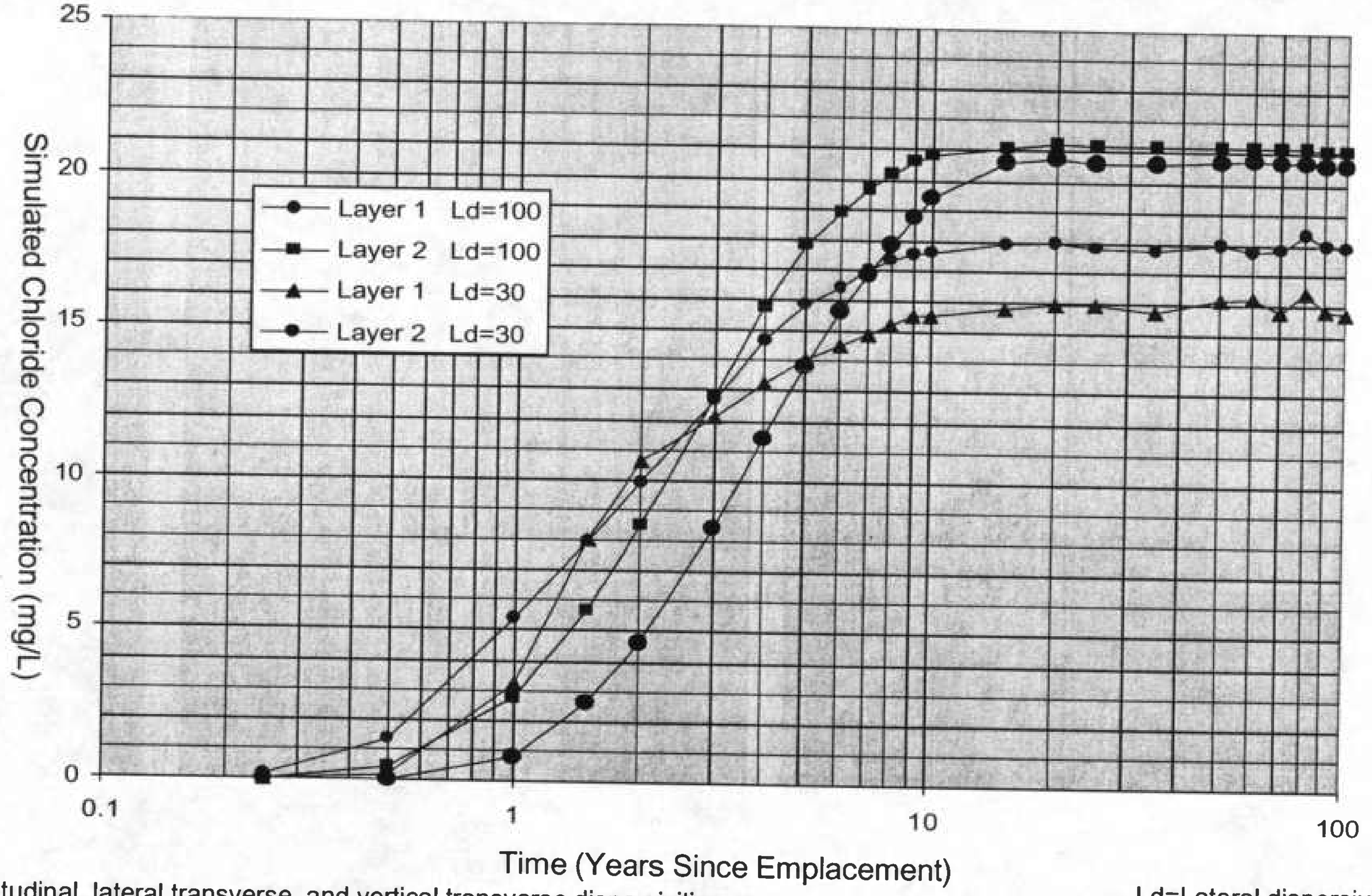


FIGURE 2
Location of Simulated Observation Point
Near Furnace Bay Used for
Sensitivity Analysis and Model Output

0 400 FEET
SCALE

URS



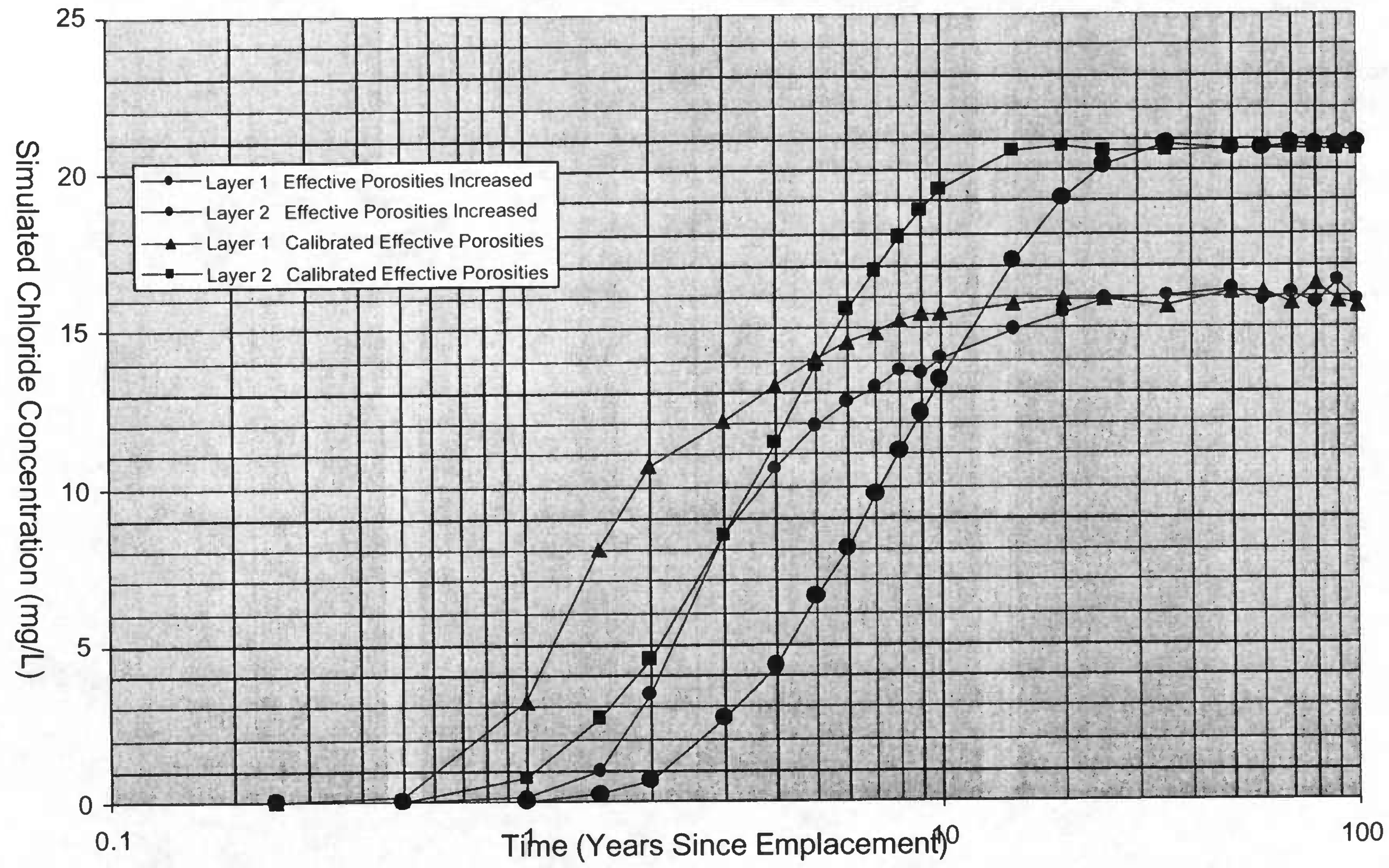
Longitudinal, lateral transverse, and vertical transverse dispersivities were 100, 10, and 1 and 30, 3, and 0.3, respectively, for each simulation.

Ld=Lateral dispersivity

FIGURE 3

Plot of Concentration Versus Time for Chloride for Varied Dispersivities

URS



For plotted sensitivity run, effective porosities for Layers 1 and 2 were varies by 2x and effective porosities for Layers 3 and 4 were varied by 10x.

FIGURE 4

Plot of Concentration Versus Time for Chloride for Varied Effective Porosities

URS

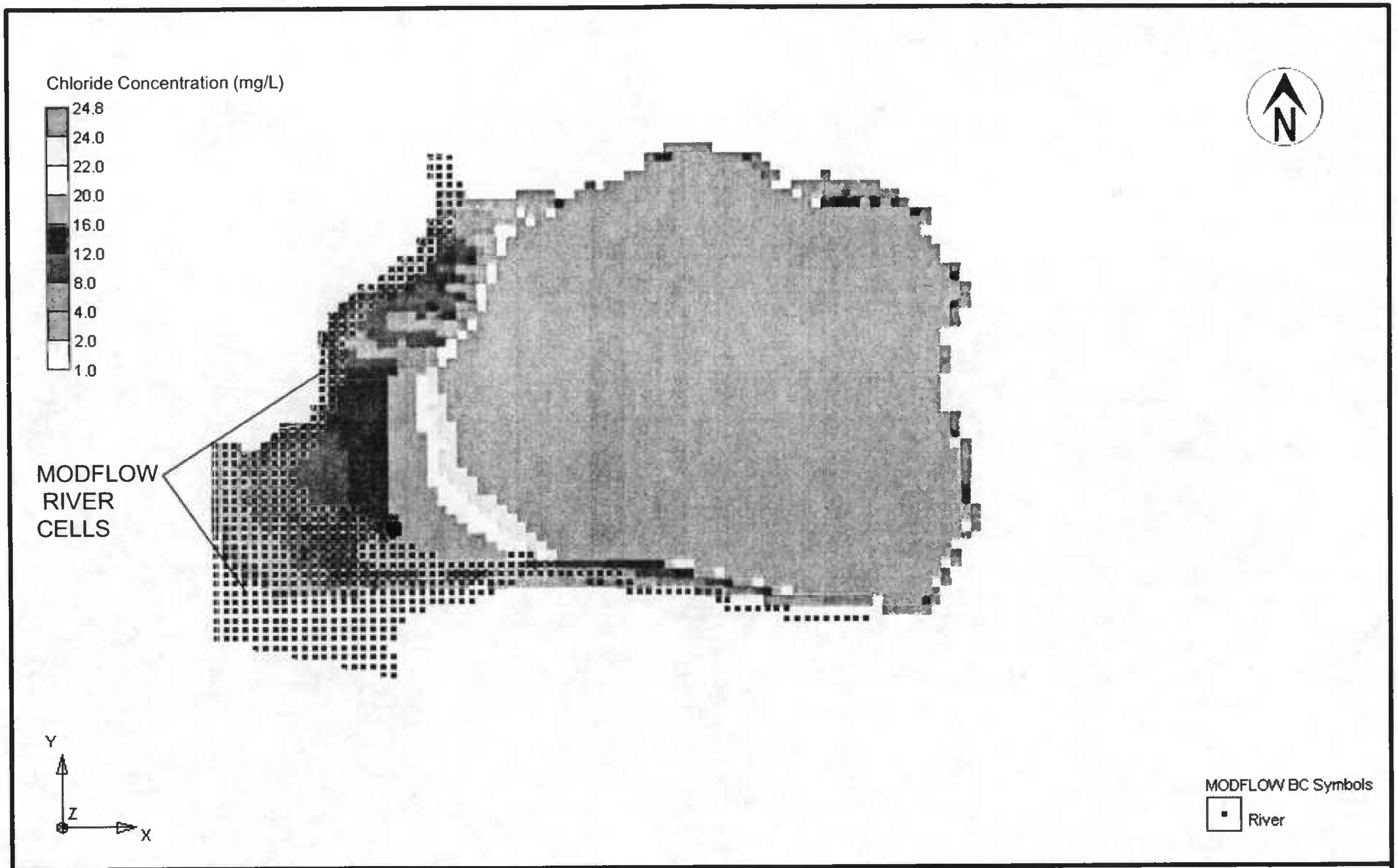


FIGURE 5
Extent of Chloride Constituent in Layer 1
30 Years After Emplacement of Dredge Tailings

URS

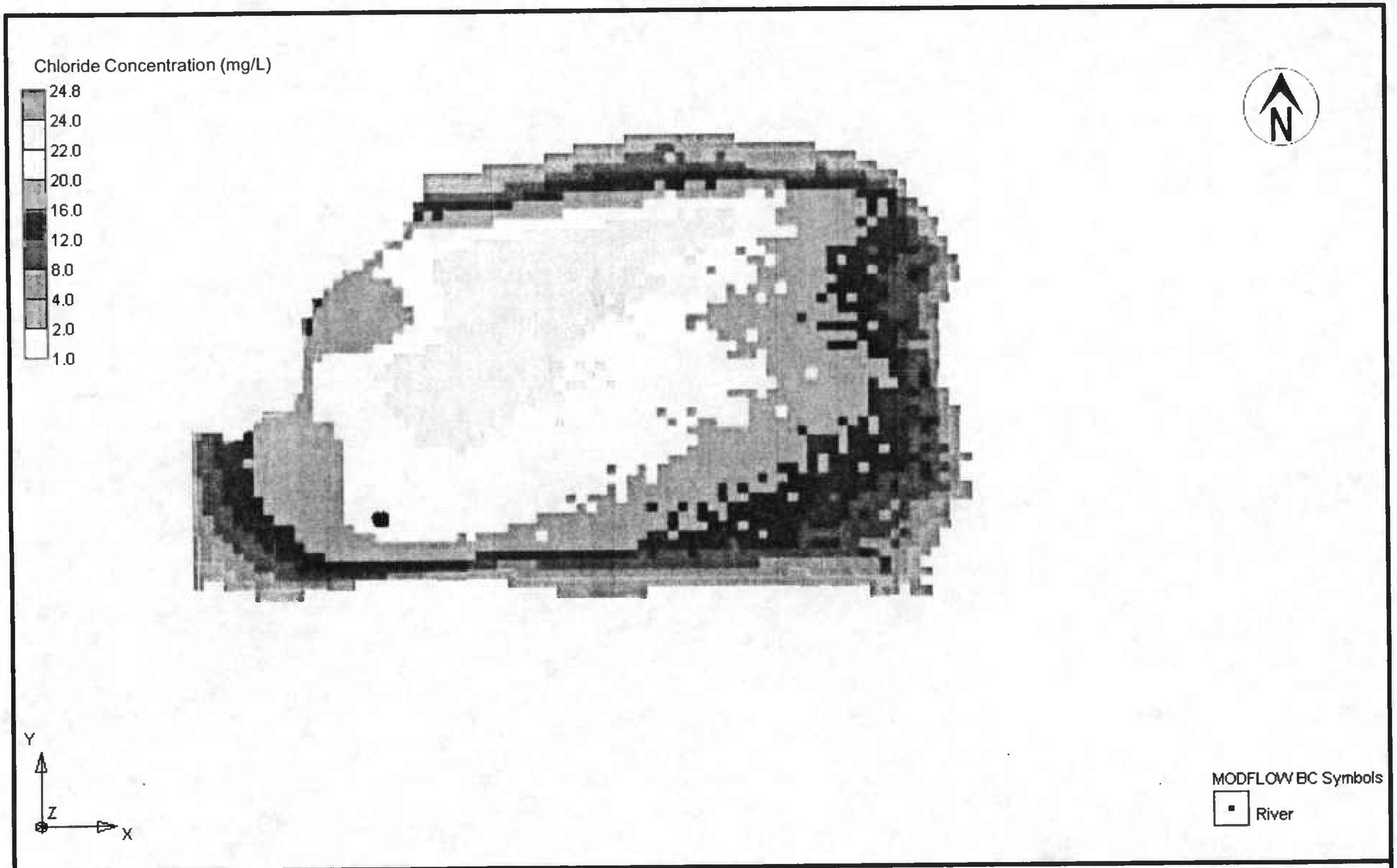


FIGURE 6
Extent of Chloride Constituent in Layer 2
30 Years After Emplacement of Dredge Tailings

0 400 FEET
SCALE

URS

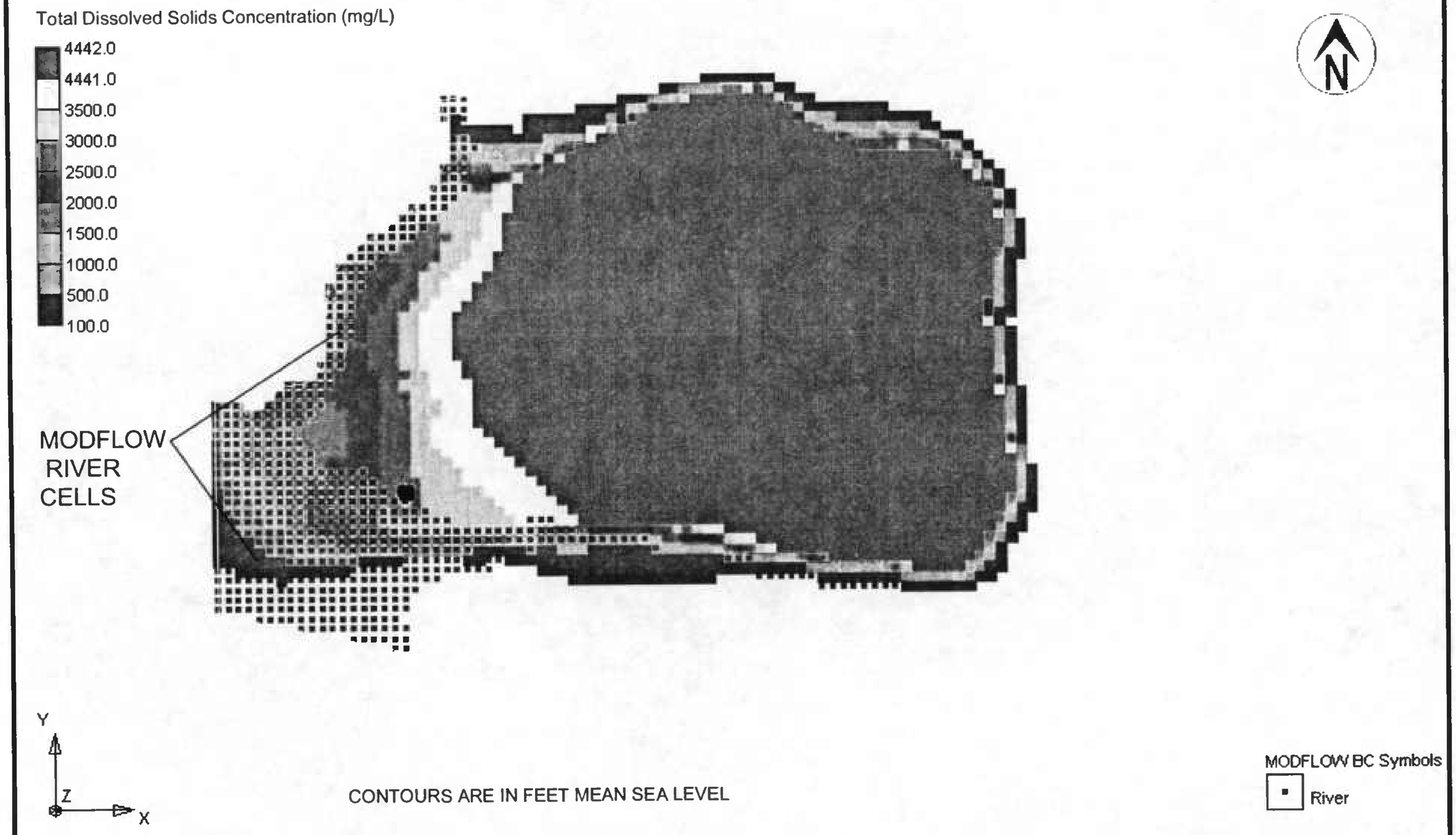


FIGURE 7
Extent of Total Dissolved Solids Constituent in Layer 1
30 Years After Emplacement of Dredge Tailings

0 400 FEET
SCALE

URS

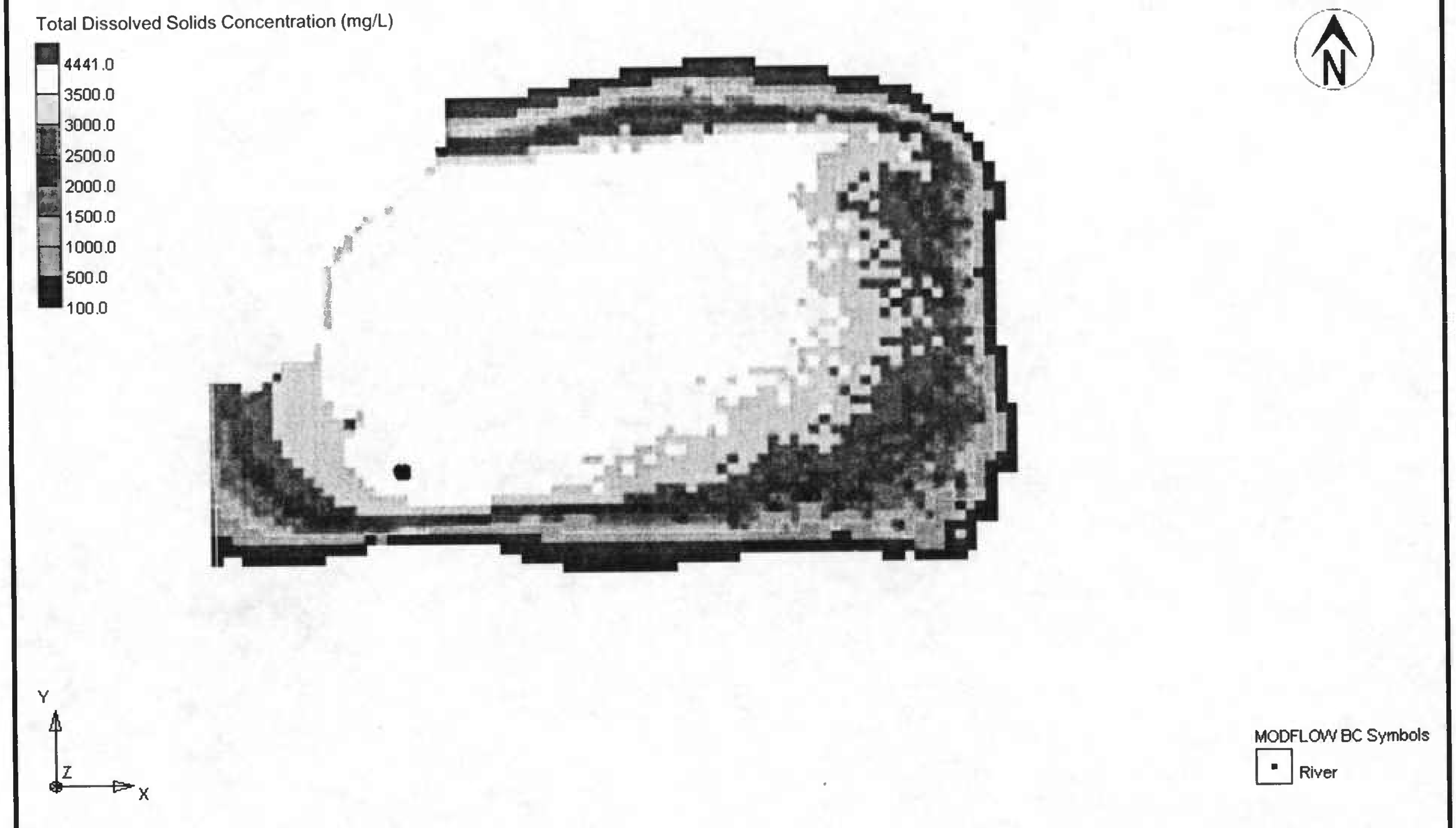


FIGURE 8

Extent of Total Dissolved Solids Constituent in Layer 2
30 Years After Emplacement of Dredge Tailings

0 400 FEET
SCALE

URS

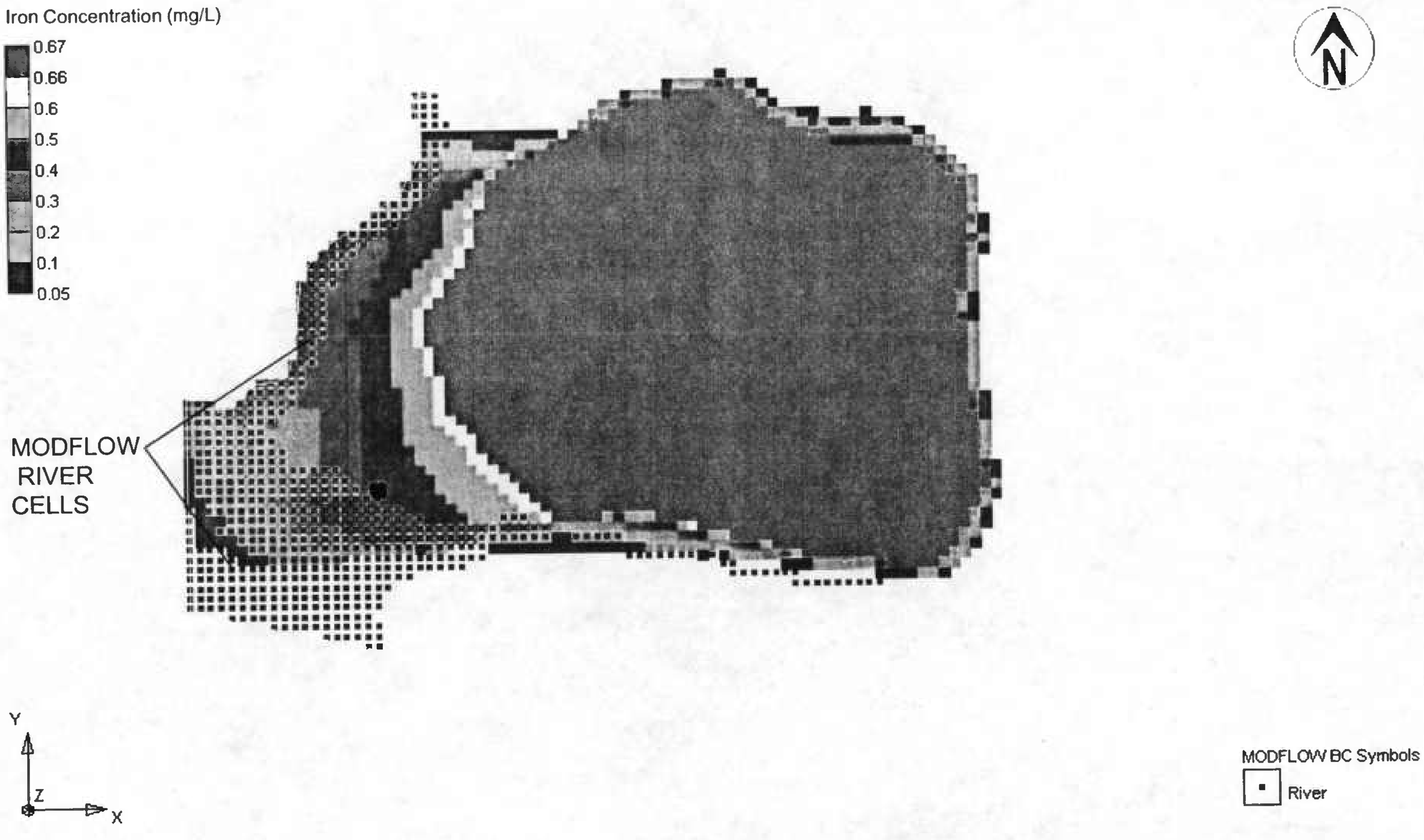


FIGURE 9

Extent of Iron Constituent in Layer 1
30 Years After Emplacement of Dredge Tailings

0 400 FEET
SCALE

URS

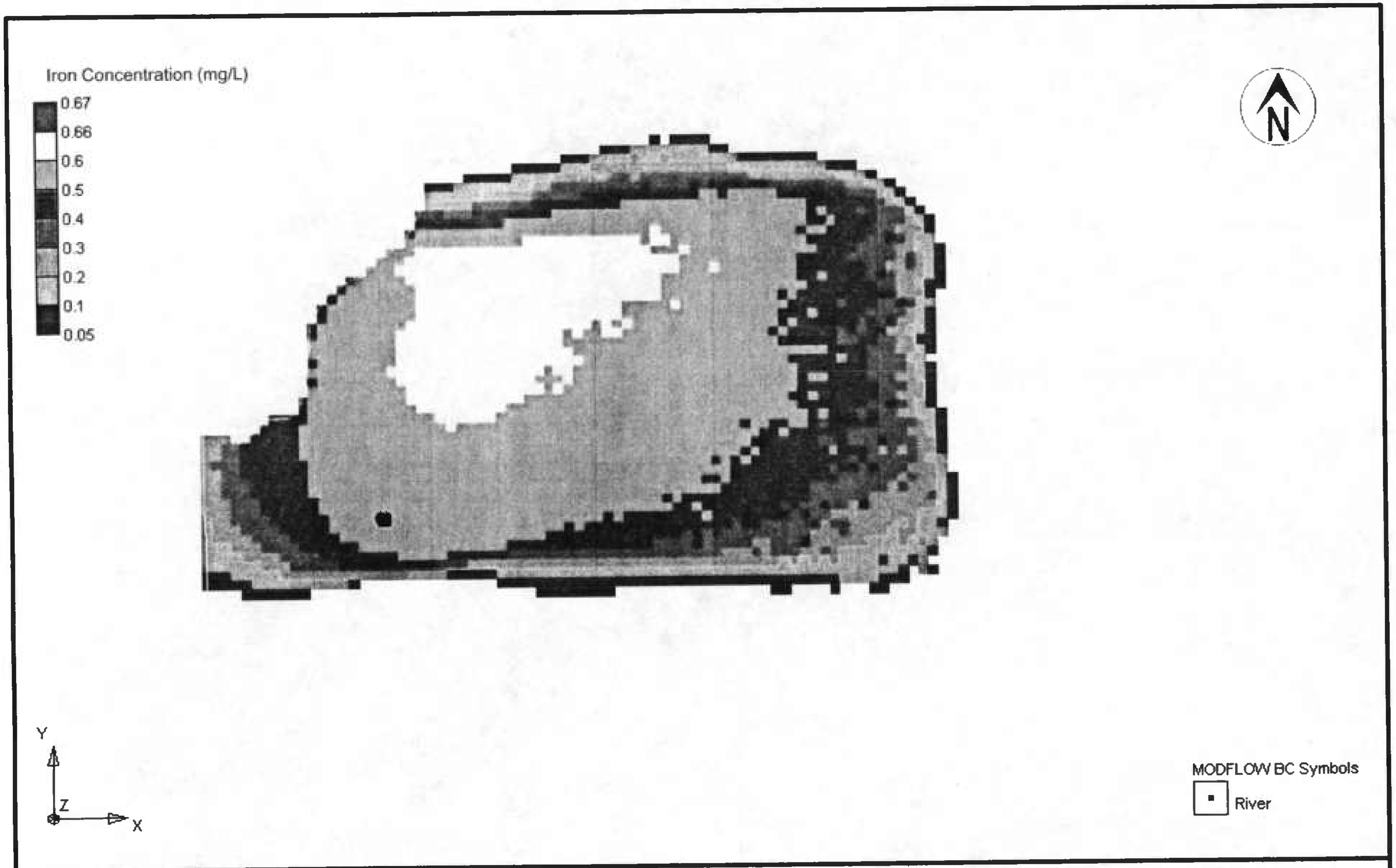
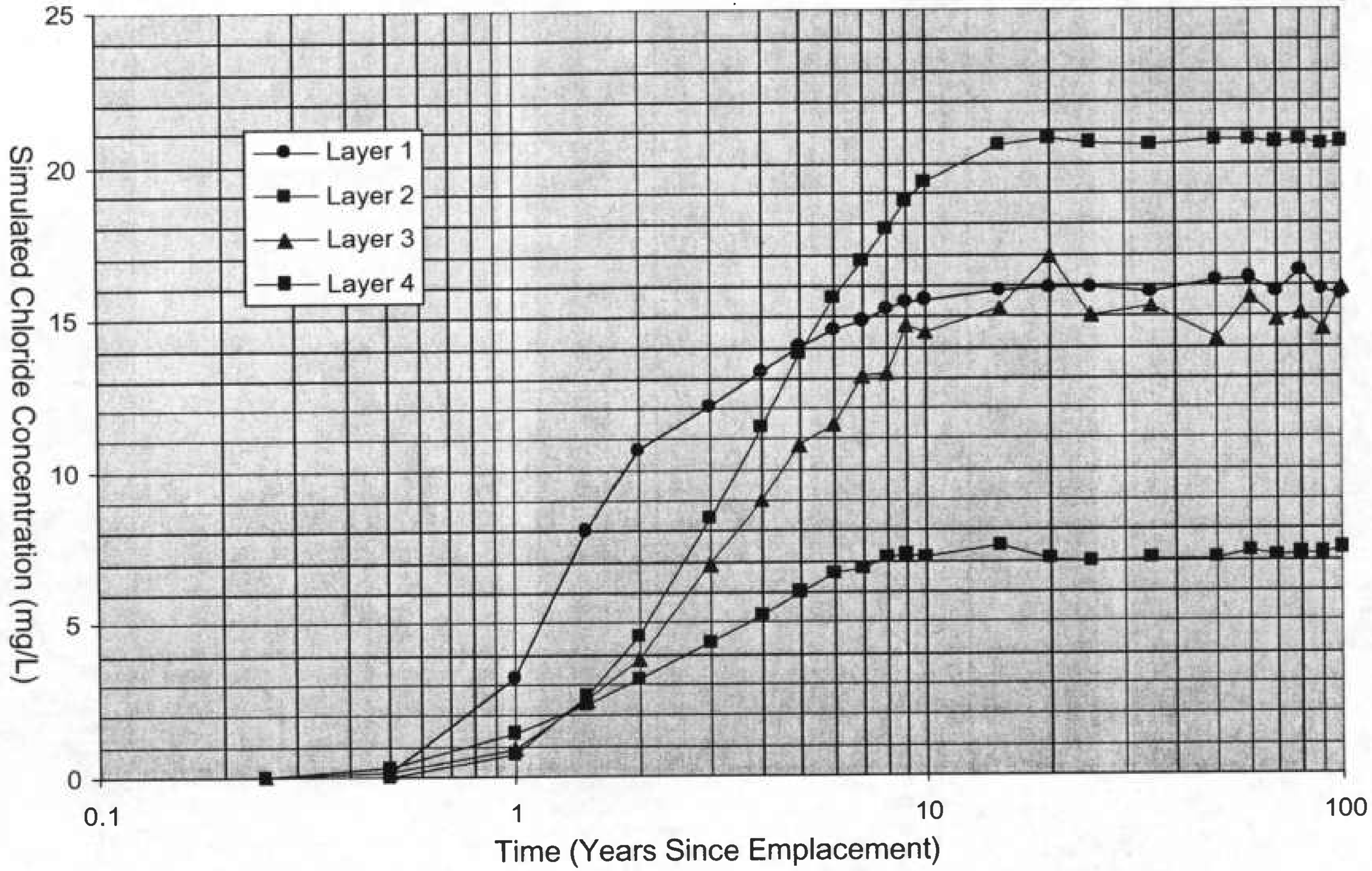


FIGURE 10
Extent of Iron Constituent in Layer 2
30 Years After Emplacement of Dredge Tailings

0 400 FEET
SCALE

URS

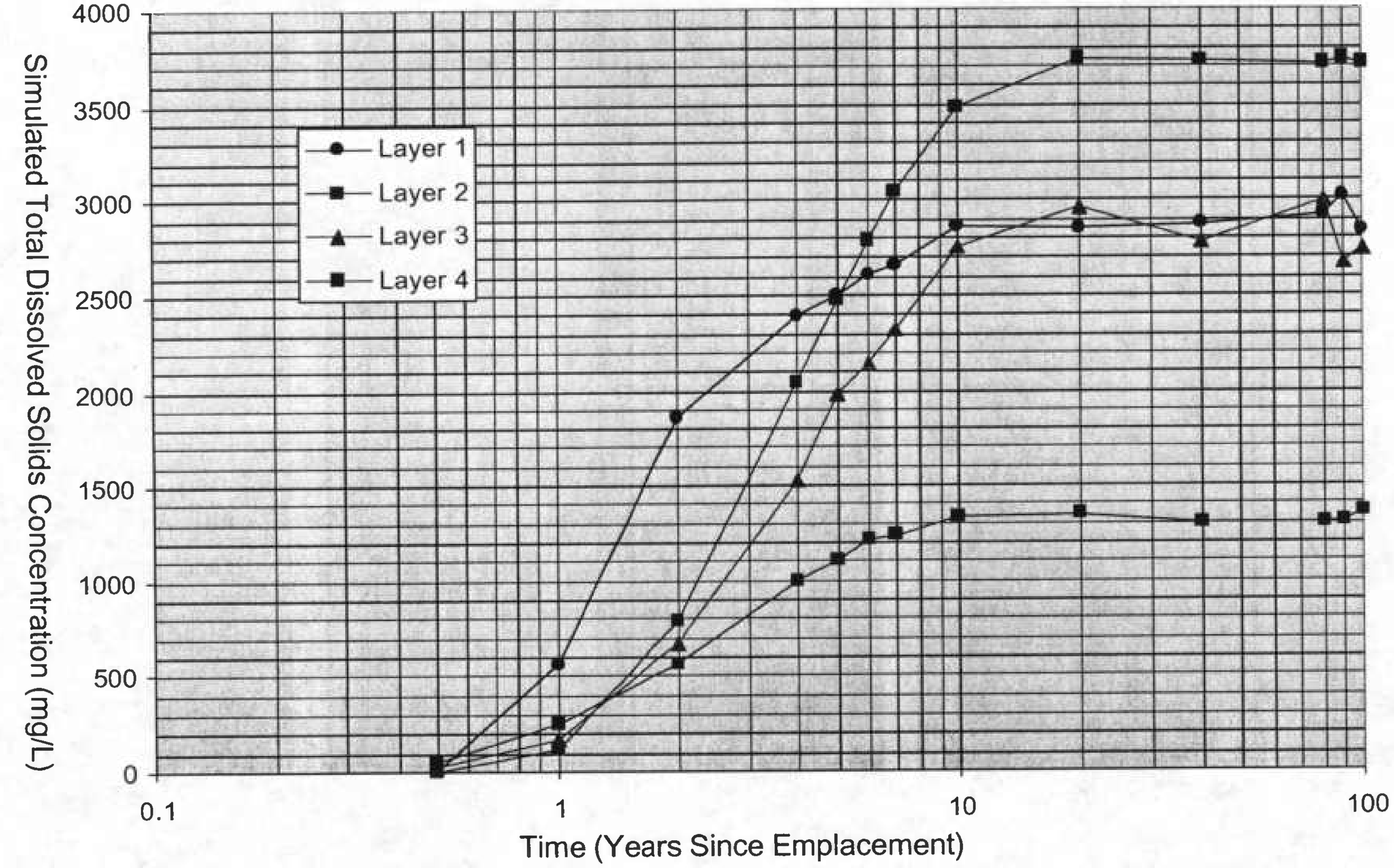


SOURCE INPUT CONCENTRATION IS 24.8 MG/L

FIGURE 11

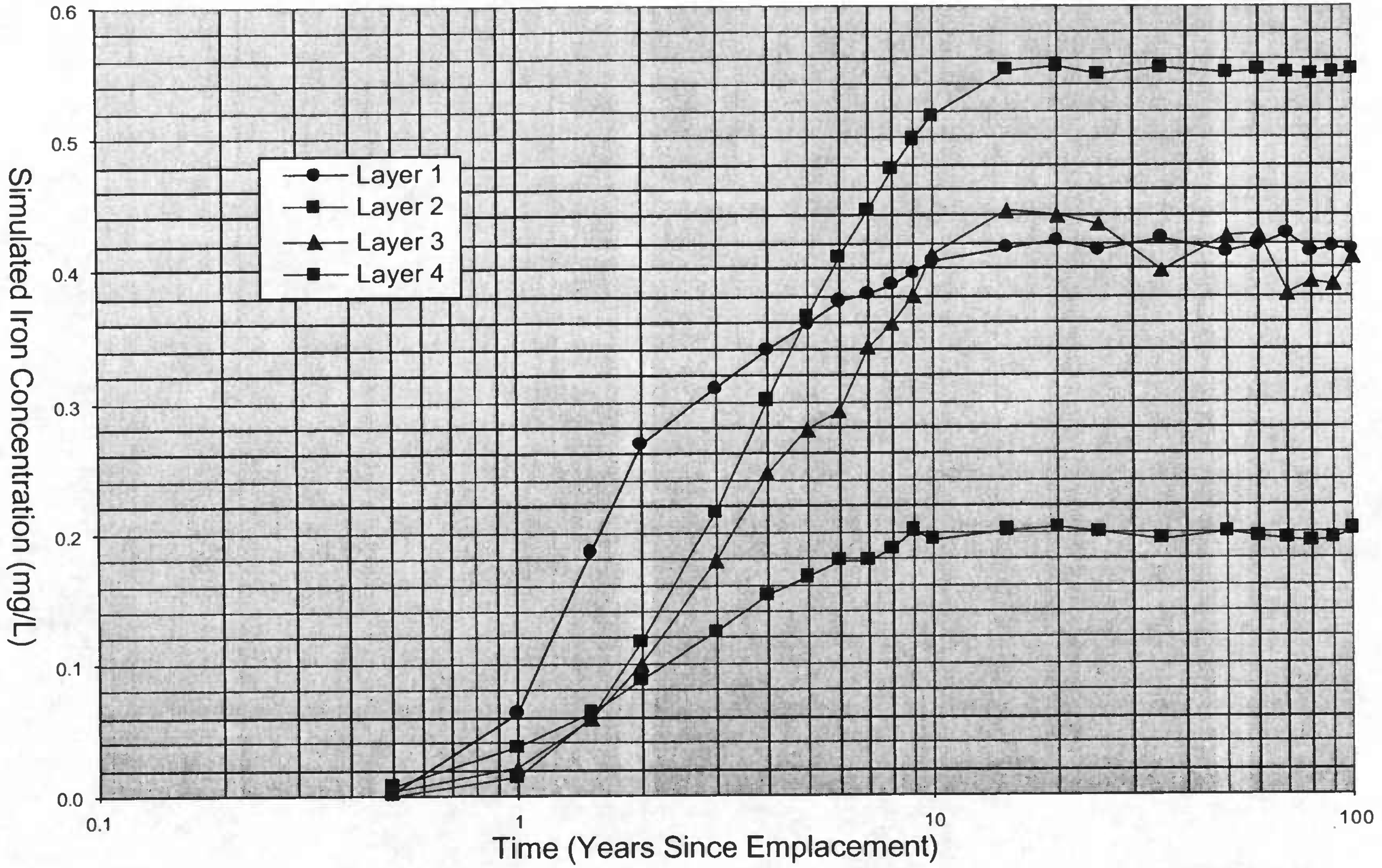
Concentrations Versus Time Plots for Chloride in Layers 1 Through 4

URS



SOURCE INPUT CONCENTRATION IS 4,441 MG/L

FIGURE 12
Concentrations Versus Time Plots for Total Dissolved Solids in Layers 1 Through 4



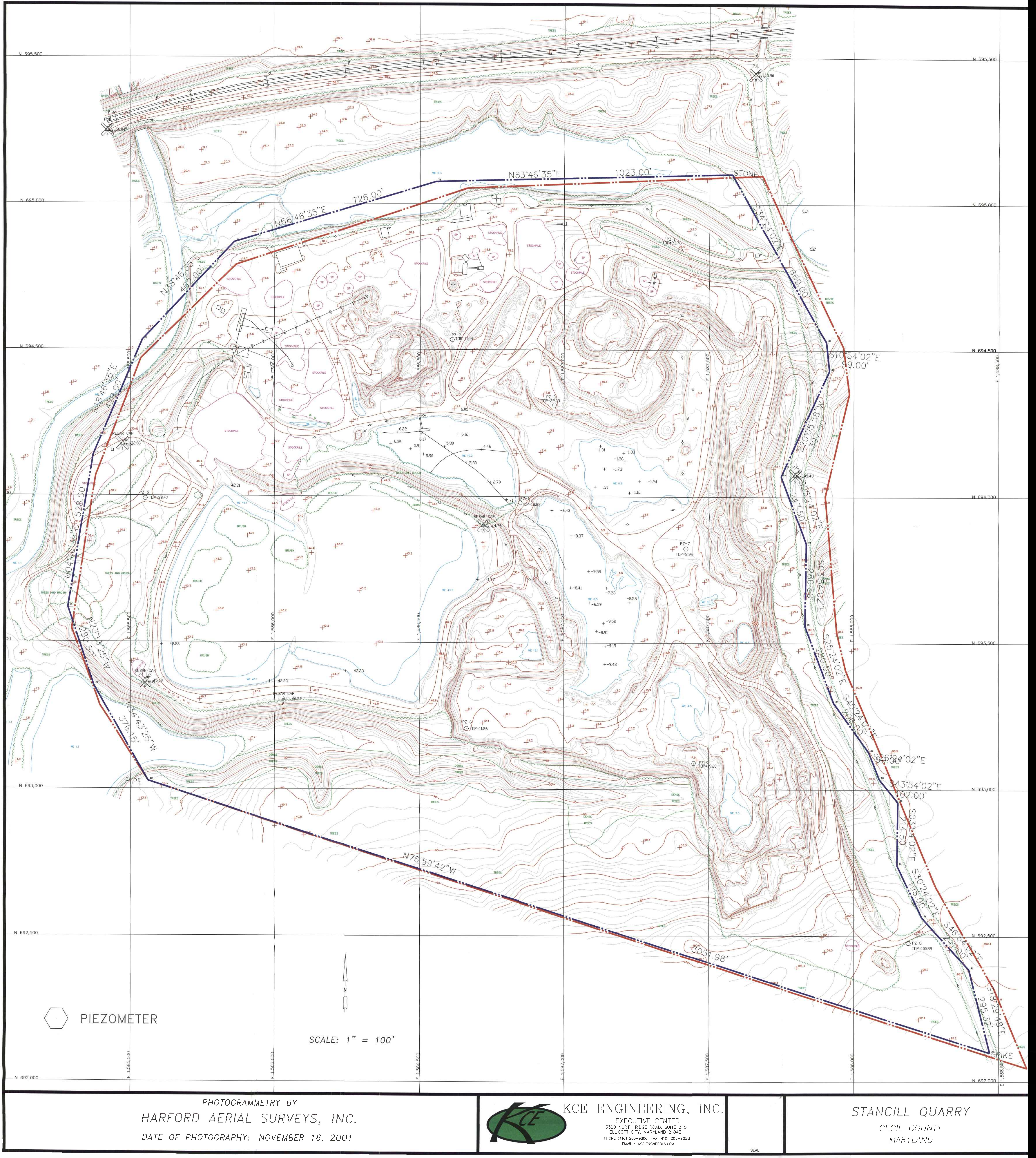
SOURCE INPUT CONCENTRATION IS 0.66 MG/L

FIGURE 13
Concentrations Versus Time Plots
for Iron in Layers 1 Through 4

URS

APPENDIX F

Topographic Map



PIEZOMETER

SCALE: 1" = 100'

PHOTOGRAMMETRY BY
HARFORD AERIAL SURVEYS, INC.
DATE OF PHOTOGRAPHY: NOVEMBER 16, 2001

KCE ENGINEERING, INC.
EXECUTIVE CENTER
3300 NORTH RIDGE ROAD, SUITE 315
ELLICOTT CITY, MARYLAND 21043
PHONE (410) 203-9800 FAX (410) 203-9228
EMAIL : KCE.ENG@EROLS.COM

SEAL

STANCILL QUARRY
CECIL COUNTY
MARYLAND