GROUND-WATER CONDITIONS IN THE KINGSTON AREA, LUZERNE COUNTY, PENNSYLVANIA, AND THEIR EFFECT ON BASEMENT FLOODING

By

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Prepared by the U.S. Geological Survey in cooperation with
the Pennsylvania Department of Environmental Resources,
Bureau of Resources Management, and the Susquehanna River Basin Commission

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CONVERSION FACTORS

Factors for converting English units to metric units are shown to four significant figures. However, in the text the metric equivalents are shown only to the number of significant figures consistent with the values for the English units.

English	*Multiply by*	*Metric*
ft^3/s (cubic feet per second)	2.832×10^{-2}	m^3/s (cubic meters per second)
ft (feet)	3.048×10^{-1}	m (meters)
in (inches)	25.40	mm (millimeters)
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.590	km^2 (square kilometers)

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ABSTRACT

Ground water underlying the Kingston area occurs in one very complex reservoir that consists of two essential parts--a shallow system and a deep system. The shallow system is composed of the unconsolidated deposits in the buried valley. The deep system is composed of bedrock, including anthracite coal, some of which has been removed by mining.

Ground-water levels in the shallow system are affected by fluctuations in the stage of the Susquehanna River as far as 1 mile (1.609 kilometres) from the river. At greater distances, ground-water levels are controlled by local stream losses and ground-water conditions outside the study area. Ground-water levels in the deep system are also affected by fluctuations in the stage of the Susquehanna River. Significant vertical movement of ground water is probably occurring between the shallow and deep systems.

Areas of potential basement flooding by ground water are delineated on a depth-to-water map of the shallow system. Eight major problem areas are widely scattered throughout the study area. Although potential for basement flooding decreases as water levels decline seasonally, shallow ground-water levels in parts of the study area fluctuate so little that basement flooding can be a year-round problem.

The low relief of the study area and its proximity to the Susquehanna River favor a naturally high water level in the shallow system. In addition, two other factors probably contribute significantly to the basement flooding in all areas: recovery of water levels in the deep ground-water system following the cessation of deep mining and associated pumping, and land subsidence.

The following nonpumping methods of lowering the high water level in problem areas were evaluated: (1) gravity drainage wells, (2) gravity overflow wells (relief wells), (3) sealing of Toby Creek, and (4) a drainage ditch deep enough to intercept ground water moving into the study area from upgradient sources.

INTRODUCTION

Purpose and Scope of this Investigation

Early in 1973, the U.S. Geological Survey began a study of the Kingston area in cooperation with the Pennsylvania Department of Environmental Resources, Bureau of Resources Management, and the Susquehanna River Basin Commission. The purpose was to determine the source and movement of ground water and the seasonal fluctuation of ground-water levels in order to delineate areas in and adjacent to Kingston, Pennsylvania, where basement flooding occurs, and to determine the severity of the flooding. In addition, factors that control the subsurface routing of water were to be examined, so that nonpumping methods to alleviate basement flooding could be evaluated.

Statement of Problem

This study was begun because of numerous complaints of basement flooding by residents of the Kingston area. The basement flooding investigated during this study is that resulting from rising ground-water levels. Many basements were flooded by surface water from Tropical Storm Agnes in 1972, but this type of flooding is not herein considered.

Methods of Investigation

Information on ground-water levels was needed to determine the relationship between the ground-water systems and the basement-flooding problem. Approximately 20 observation wells had been established in the study area during previous investigations. Some of these wells were completed in the upper 30 ft (9.14 m) of the unconsolidated deposits, and others were completed in mined-out coal seams in the underlying bedrock. This network was supplemented by approximately 40 new shallow observation wells.

Sixteen water-level recorders were installed in selected wells at various times to provide concurrent records of water-level fluctuation in shallow and deep parts of the ground-water system. The remaining observation wells were measured at intervals that ranged from weekly to monthly. Three recorders were installed in basements to correlate water levels in basements with changes in ground-water levels.

Eleven surface-water measuring points on Toby Creek, Bowmans Creek, Bowmans Pond, and the Susquehanna River were established and measured periodically. The record of continuous water-level recorders in operation at two of these stations was utilized to investigate the relationship between surface water and the ground water.

Elevations of all ground-water and surface-water measuring points were surveyed using the bench mark in the Public Square, Wilkes-Barre, as the base. This benchmark, located in an area under which no mining occurred, is generally considered to be the only reliable benchmark in the Wyoming Valley.

A continuous recording precipitation station was established in Kingston, so that the relationship between local precipitation and water-level rises could be studied.

Acknowledgements

Many people extended unusual cooperation or made available considerable data to the author. I wish to cite the following in this regard: Gomer Gealy, Pennsylvania Department of Environmental Resources; Paul Sachs of the Kingston Borough Authority; John Burke of Smith Miller and Associates; Gene Heath of Pennsylvania Gas and Water Company; personnel of U.S. Bureau of Mines, Wilkes-Barre; Paul Koval, Pennsylvania Department of Environmental Resources; and Anthony DeAngelo and Carl Gottschall, Pennsylvania Department of Transportation.

The author wishes to acknowledge initial project planning and implementation of the data collection network by O. B. Lloyd, Jr., U.S. Geological Survey, and J. P. Stephenson formerly with the Geological Survey. J. R. Hollowell of the Susquehanna River Basin Commission, and O. B. Lloyd, Jr., supplied technical advice and assistance during various phases of the project. G. D. Bennett, of the Geological Survey rendered technical assistance on the quantitative hydrology, including drainage-ditch and drainage-well discharge systems. L. D. Carswell, of the Survey, assisted the author in the operation of an electrical analog model simulation of drainage-ditch operation.

LOCATION OF STUDY AREA

The location of the study area, with respect to local and regional geomorphic features, is shown in figure 1. Of particular note are the

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Figure 1.--(Caption on next page) belongs near here.

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following features, which will be discussed later in the report: (1) unconsolidated buried valley deposits, (2) the drainage divide above the study area, and (3) surface-water drainage systems.

Figure 1.--Location map of the study area in north-central Wyoming Valley, Luzerne County, showing generalized geomorphic features.

Location

The Kingston area is located in the north-central part of the Wyoming Valley, Luzerne County (Fig. 1). For the purpose of this study, the Kingston area is the approximate 6 mi^2 (16 km^2) area bounded on the south by the Susquehanna River and including all or part of the following communities: Kingston, Luzerne, Swoyersville, Edwardsville, Forty-Fort, Pringle, and Wilkes-Barre. Plate 1 shows the study area in detail.

Precipitation

Long-term precipitation (1886-1972) averages 39.97 in (1,015 mm) annually, as measured at a non-recording precipitation station in Wilkes-Barre (U.S. Department of Commerce, 1973).

In order to determine the relationship between average precipitation and precipitation during the main period of study (June 1973 through May 1974), monthly totals for the main period of study were compared with long-term monthly-average figures through 1972 at the Wilkes-Barre station (Fig. 2). Total precipitation during this 12-month period amounted to

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Figure 2.--(Caption on next page) belongs near here.

43.10 (1,095 mm) or only 7.8 percent above average. However, monthly totals during the study period deviated significantly from the historical average.

Figure 2.--Comparison of precipitation during study period with long-term monthly-average precipitation at Wilkes-Barre station.

Population and Urban Redevelopment

The population of the study area was estimated to be 37,000, based on 1970 population figures (U.S. Department of Commerce, 1971). The population of the boroughs that make up most of the Kingston area is as follows: Kingston - 18,325; Swoyersville - 6,786; Forty-Fort - 6,114; Luzerne - 3,100; and Edwardsville - 2,800. Population figures were adjusted for Luzerne and Swoyersville because large residential areas of these communities are outside the study area. Much redevelopment is going on presently in the study area. Redevelopment activities during the period of this study included renovation of sections of old sanitary- and storm-drainage facilities and installation of new sanitary-drainage facilities in some areas.

Mining History

The main industry in the Wyoming Valley was anthracite mining before the early 1950's. Anthracite mining began here in the early 1800's and reached a peak in the early 1900's. Coal was mined by underground and surface methods. Deep mining of anthracite under the study area ceased in the late 1950's or early 1960's, owing partly to the Knox Mine Disaster. On January 22, 1959, the Susquehanna River broke through the mine workings of the Knox Coal Company approximately 2 1/2 mi (4 km) northeast of the study area. Before the 40 ft (12.1 m) diameter breach was "sealed" with railroad cars and dirt, water poured into the mine workings at a rate estimated to be more than 30,000 ft^3/s (850 m^3/s) (P. Gupta, oral communication, 1975). The Knox and adjacent mines were flooded. Many never reopened and other mines not directly flooded ceased operations shortly thereafter.

The U.S. Bureau of Mines (1963) reports that deep mining of anthracite coal in the Wyoming Valley was accomplished by the room and pillar method. Vertical shafts provided access to the underground mines. Mining generally proceeded in three stages. During the first stage, coal was extracted from intersecting tunnels driven along the coal bed. This combination of tunnels and coal pillars formed a grid pattern. During the second stage, additional coal was mined either from the sides of pillars or by tunneling through pillars. During the third stage, also popularly referred to as "robbing", essentially all remaining coal pillars were mined. As a result of mining, the overlying rocks in many mines collapsed, which caused the overlying land surface to subside in some places. Mined-out coal seams were backfilled locally with refuse or gob to prevent or decrease land subsidence. The degree to which underground mining progressed under part of the study area is shown in Figure 3 by a geologic section indicated in plate 1.

Figure 3.--(Caption on next page) belongs near here.

Barrier pillars are bodies of unmined coal in each coal seam along company property lines. The effectiveness of barrier pillars, originally designed to function as underground dams between adjacent mines, has in some places been seriously diminished as a result of man-made breaches including mining. Also, many barrier pillars were inadvertently weakened after the mines were allowed to fill with water. Hollowell (1971, p. 34-35) states that wetting of previously dry surfaces and the buildup of several hundred feet of hydrostatic head cause minor weaknesses in the barrier pillars to become pronounced.

Figure 3.--Geologic section of an area in Kingston showing undifferentiated surficial deposits, bedrock structure, and the extent of mining in underlying coal seams. (Courtesy of U.S. Bureau of Mines)

Surface mining (strip mining) of coal in the outcrop areas has been an increasingly significant part of total anthracite mining since about 1940. Some surface mining of coal occurred upslope from the project area, but in 1974 there were no active operations.

Topography and Drainage

The study area is part of the regional topographic feature known as Wyoming Valley, which occupies the southwestern half of the northern anthracite field. The Wyoming Valley resembles a crescent-shaped dish in outline. An inner lowland is surrounded by bedrock that forms the steep slopes and rim of the valley.

The study area lies on the broad, flat alluvial flood plain of the Susquehanna River. Excluding man-made features such as the flood levees, the topography of the study area has low relief and slopes irregularly toward the Susquehanna River. (See pl 1.) The land surface becomes steep on the flanks of the valley wall along most of the Western project boundary. Topographic relief for most of the study area is approximately 20-25-ft (6-8 m).

Surface drainage for the study area is to the Susquehanna River via Toby Creek and Abrahams Creek along most of its course within the study area. Toby Creek flows in a subsurface tunnel; most surface drainage does not enter the creek naturally but is first routed through storm drains. Abrahams Creek and its tributaries probably transport very little runoff into the Susquehanna River, because the creek is intermittent and has a discontinuous and poorly graded channel. (See pl 1.) Some surface drainage does not reach these creeks at all, as it collects in low spots and infiltrates to the ground-water reservoir. The area where natural surface drainage to Toby Creek and Abrahams Creek cannot occur is designated as the drainage basin of the study area in figure 1.

The subsurface tunnel through which Toby Creek flows is but one example of the considerable change that the surface-water drainage system has undergone since the late 1800's. The surface-water drainage in the study area, as it existed in the late 1800's (Second Geological Survey of Pennsylvania, 1884), is shown on Plate 1. It may not have been entirely natural at that time, but the contrast with the present drainage system is striking. To account for these changes in the study area, either the land surface or hydrology has changed considerably from 1884 to 1974. The "old" surface-water drainage system does not have any effect on basement flooding except possibly in Luzerne.

Geology

The rocks of the study area consist of unconsolidated surficial deposits overlying bedrock containing anthracite coal seams that have been partly or wholly removed by mining. This relationship is shown in figure 3 for the section indicated in plate 1.

The surficial material is composed of glacial, alluvial, and alluvial fan deposits. Glacially derived deposits of clay, silt, sand, gravel, cobbles, and boulders and mixtures of these underlie most of the study area. These deposits fill an ancient valley overdeepened during Pleistocene glaciation by the plucking and gouging action of the ice and the associated erosive action of streams flowing beneath the ice on the underlying bedrock (Itter, 1938). This overdeepened valley and associated sediments is referred to as the Buried Valley of the Susquehanna River. The bedrock surface that forms the bottom of the buried valley is irregular. In the study area, the thickness of the buried valley deposits ranges from 20 ft (6.1 m) to 220 ft (67 m), and the average thickness is about 120 ft (36 m). The thickness of these deposits generally decreases to the northwest and southeast.

Post-glacial alluvial and alluvial fan deposits of silt, sand, and gravel occur in and adjacent to stream channels of the Susquehanna River, Toby Creek, and Abrahams Creek. An alluvial fan deposit with subtle topographic expression is present under Luzerne.

The sediments in the buried valley were deposited in many different environments; consequently, the character and thickness of the deposits may differ significantly from place to place within a short distance. Sand and gravel at the surface is underlain by clay and silt, which is underlain by sand, gravel, and boulders. Appendix D shows the character and thickness of the deposits from selected subsurface logs whose locations are shown on plate 5.

The Llewellyn Formation of Pennsylvanian age underlies the unconsolidated deposits in the Wyoming Valley and the slopes of the bordering mountains. It contains interbedded layers of variable thickness that are composed of quartz granule and pebble conglomerate, fine-to-coarse grained sandstone, siltstone, claystone, shale, carbonaceous shale, and anthracite coal (U.S. Geological Survey, 1963). These rocks have been folded and faulted (fig. 3) and are part of the major northeast-trending structural downwarp within which the Wyoming Valley lies.

On the hillsides beyond the study area, the top part of the bedrock probably consists of a weathered and well-fractured regolith such as commonly occurs in other areas (Ott, Barker, and Growitz, 1973). This regolith is overlain locally by glacial deposits and coal-refuse material (Hollowell, 1971, plate 1). The regolith is probably absent beneath the buried valley deposits as a result of intense glacial erosion.

GROUND-WATER HYDROLOGY

General Features

Ground water is the subsurface water within the zone of saturation--the zone in which all the interconnected pores, crevices, and voids are filled with water under pressure greater than atmospheric. Ground water accrues from precipitation that infiltrates the earth's surface and reaches the zone of saturation.

Ground water moves continuously from points of intake or recharge to points of discharge. This movement is always in the direction in which head, or water level, decreases. In isotropic materials - those in which the hydraulic properties are the same in any direction - the ground water movement occurs in the direction of most rapid decrease in head. Because ground water generally moves from hilltops to valleys, surface water bodies such as streams serve as major outlets for ground-water discharge. Approximately 60 to 70 percent of annual streamflow in the Commonwealth of Pennsylvania comes from ground-water discharge (Becher, 1971). The rate of ground-water movement is a function of the hydraulic gradient and the hydraulic conductivity of the material through which the water is moving. Hydraulic conductivity refers to the ability of a rock or sediment to transmit water and depends upon the size and degree of interconnection of openings within that rock or sediment.

Ground-water flow normally has both a lateral and vertical component. Throughout most of the study area, the lateral component of ground-water flow is much greater than the vertical, so that ground-water movement seems to be largely lateral. Nevertheless, the general pattern is circulation from upland areas downward into the valleys, followed by upward discharge through the valley sediments into the streams. This shows that vertical flow is a significant part of the flow system.

The ground-water reservoir underlying the Wyoming Valley consists of bedrock (including coal-mine voids) and the overlying unconsolidated deposits. It functions as one very complex interconnected system. The Kingston area is part of this system. For this report, this complex reservoir has been generalized and its functions separated into two parts--a shallow system and a deep system. Water levels used in the evaluation are measurements of conditions in the upper part of the shallow system and the upper to intermediate part of the deep system. Intermediate parts of these two systems are assumed to have intermediate water levels. This is probably a valid assumption except for local anomalies.

The shallow system consists of the unconsolidated sediments in the buried valley. Ground water occurs in and moves through intergranular openings between sediment particles, mostly under water-table conditions.

The deep ground-water system, popularly referred to as the mine-water or "mine-pool" system, consists of the bedrock beneath the unconsolidated deposits. Ground water moves through secondary openings such as natural fractures and faults, fractures resulting from roof rock collapse, and the large, interconnected conduits created during the mining of anthracite coal. The water in this deep system is under artesian pressure in the study area and the "roof rock" or bedrock overlying the top mined coal acts as a leaky confining layer.

In this report, the ground-water surface is synonymus with ground-water level or potentiometric surface. Two potentiometric surfaces are described in this report - one for the shallow system and one for the deep system. The potentiometric surface is defined by Lohman and others (1972, p. 11) as follows:

> "The potentiometric surface...is a surface which represents the static head. As related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells. Where the head varies appreciably with depth in the aquifer, a potentiometric surface is meaningful only if it describes the static head along a particular specified surface or stratum in that aquifer. More than one potentiometric surface is then required to describe the distribution of head. The water table is a particular potentiometric surface".

Regional head relationships and directions of ground-water movement in the shallow and deep systems are shown diagramatically by the geohydrologic section of figure 4. The potentiometric surfaces of both systems slope

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Figure 4.--(Caption on next page) belongs near here.

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toward the Susquehanna River and indicate that ultimately ground-water discharge is to the river. Under the coal outcrop area the potentiometric surface in the shallow system is higher than the potentiometric surface in the deep system. This relationship was inferred from an examination of subsurface logs and associated water-level data supplied by the Pennsylvania Department of Transportation for borings in Courtdale, Pa. (a nearby community in a similar geologic setting). These relationships suggest that some ground water is being lost to the deep system in these upslope areas, and some ground water is moving down the potentiometric gradient of the shallow system into the study area.

Potential movement of ground water between the shallow and deep systems is governed by water-level relationships between the two systems. Considering the vertical component of ground-water flow in Figure 4, the regional recharge area is depicted as that area where the potentiometric surface of the shallow system stands at higher elevations than that of the deep system. Here the vertical direction of ground-water movement is downward. In the regional discharge area, the potentiometric surface of the deep system stands higher than that of the shallow system, and the vertical component of ground-water flow is upward.

Figure 4.--Diagrammatic section through the west half of the Wyoming Valley showing water-level relationships and directions of ground-water movement in the shallow and deep ground-water systems.

Shallow Ground-Water System

Plate 2 shows the configuration of the potentiometric surface in the shallow ground-water system on April 30 and May 1, 1974. This configuration is similar to that shown on a map of an earlier period, in October 1973, (Growitz, 1973). Some surface-water elevations were used in the construction of the shallow potentiometric contour map in Plate 2 because of the control of ground-water discharge, (and to a small extent ground-water recharge) by surface water.

Plate 2 shows that in the Luzerne area, the potentiometric contours are relatively evenly spaced and define a lobate body. This ground-water feature is probably caused by the presence of the underlying alluvial fan deposit described by Itter (1938) and surface-water losses from Toby Creek. A ground-water trough is present in the Vaughn Street area of Luzerne. This may indicate an area where significant downward movement of ground water from the shallow to the deep system is occurring.

In western Kingston, the ground-water gradient decreases abruptly between the 530 and 525 ft potentiometric contours to 0.00086 ft/ft (0.00026 m/m), whereas the gradient under Luzerne is 0.015 ft/ft (0.0046 m/m). The lower gradient probably results from a combination of increased hydraulic conductivity of the sediments and reduced flow through the shallow system owing to increased discharge to the deep ground-water system. Between the 525 and 520 ft and the 520 and 515 ft potentiometric contours, the gradient increases to 0.0020 ft/ft (0.00061 m/m) and 0.0086 ft/ft (0.0026 m/m), respectively. The increased gradient probably is due to increased flow in the shallow system due to upward movement of ground water from the deep to the shallow system. This is discussed in more detail under the section "Vertical movement of ground water".

Recharge to the shallow ground-water system in the study area is by (1) infiltration of local precipitation and surface runoff from nearby areas, (2) shallow subsurface flow into the study area, (3) downward flow from losing streams and leaky subsurface drains, and (4) upward flow from the deep ground-water system. Infiltration of local precipitation occurs over the entire surface of the study area except for paved or covered surfaces.

Water can enter the study area from upslope sources as either ground water or surface water. The upslope area is very steep with no well-defined major surface-water drainage (fig. 4). Part of the precipitation on this area probably moves down the steep slope as runoff and infiltrates to the shallow ground-water system within the study area. Part of this same precipitation can reach the study area by first infiltrating to the shallow potentiometric surface in the regolith of the bedrock (fig. 4).

Surface-water losses resulting in recharge to the shallow ground-water system probably occur in Luzerne where ground-water contours indicate a recharge mound under or near Toby Creek. In addition, old subsurface storm- and sanitary drain facilities may be leaking and locally adding water to the shallow system in Kingston and Luzerne. Faulty drain pipes are now being repaired in Kingston as part of the redevelopment program. In the area of Buckingham Avenue and Walnut Street, Luzerne, the author observed two terra cotta drainage pipes carrying water approximately 8 feet below land surface. These were uncovered during recent sanitary sewer construction. It was not possible to determine if these were old storm drain lines, or a late 1800's attempt to enclose part of the old Toby Creek Drainage system shown in plate 1.

Recharge to the shallow system from the deep system is possible where the potentiometric surface in the deep system is higher than in the shallow system. These areas generally lie in the eastern half of the study area. Ground water probably moves vertically through the leaky confining material of the bedrock system and around or through the fine-grained silt or clay prevalent in the lower part of the buried-valley deposits. In many places the bedrock confining material has been extensively fractured above areas of mine-roof collapse. Upward propagation of the fractures probably occurs and increases the permeability of the overlying fine-grained deposits. Although these are preferred areas of upward ground-water movement, areas containing unaltered fine-grained deposits can also transmit water.

Natural discharge of ground water from the shallow system is principally to the Susquehanna River and, perhaps, to the lower reaches of Toby Creek. Because the potentiometric surface is close to land surface in many parts of the project area, evaporation and transpiration of ground water by plants may occur, but it is not considered significant because of the minor amount of vegetation in this urban area. Discharge of ground water from the shallow to the deep system by vertical movement is possible where the potentiometric surface in the shallow system is higher than in the deep system. These areas generally lie in the western half of the study area.

Deep Ground-Water System

Data from deep observation wells drilled by the Commonwealth of Pennsylvania to monitor water levels in selected mines were used to construct the generalized regional potentiometric map shown in Figure 5. The actual flow path of the ground water in the deep system may be rather circuitous along

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Figure 5.--(Caption on next page) belongs near here.

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preferred directions, but flow is generally from the higher elevations to lower elevations - crossing the potentiometric contours at right angles. The contour configurations indicate that significant quantities of ground water from the northern and northeastern part of the area (fig. 5) must move through the study area. The average hydraulic gradient of the deep potentiometric surface under the Kingston study area (plate 5) is 0.00070 ft/ft (0.00021 m/m). This gradient is much less than that associated with any part of the shallow ground-water system.

Figure 5.--Generalized potentiometric contour map of water levels in the deep ground-water system in part of the Wyoming Valley, for the period April 26-30, 1974.

Known discharges from the deep system are shown in figure 5. The discharge structures include: (1) a vertical mine shaft in the Nottingham-Buttonwood mine complex and (2) relief wells (gravity overflow wells drilled into a mine void). Ground water is discharged to the surface through these structures under natural artesian pressure. Within the closed 525-ft potentiometric contour there is only one relief structure. However, significant quantities of ground water from the deep system may be discharged through the unconsolidated sediments to the Susquehanna River which is coincident with the center of the water level depression. Hollowell (1971, p. 41) shows an area adjacent to the river, on Lance Colliery property, that is a probable area of "mine water seepage and overflow".

Within the study area, ground water can move into or out of the deep system depending on local vertical-head relationships as discussed earlier. The potential for recharge from the shallow system exists in the western half of the study area, and the potential for discharge exists in the eastern half of the study area. In addition, Hollowell (1971, p. 41) states that considerable discharge of ground water from the deep system may occur through boreholes that were drilled into the mines to alleviate surface drainage problems and to dispose of sewage in the past.

Water-Level Fluctuations

Surface-water and ground-water levels in the study area change continuously in response to recharge and discharge. Differences in the hydrologic properties of the ground-water reservoir within the study area and the proximity to recharge or discharge sources result in differential water-level fluctuations. This, in turn, causes changes in the configuration of the potentiometric surface at different times. Ground-water and surface-water fluctuations for the main period of data collection in the study are presented in Appendix B, and the ground-water data are summarized in table 1. (See pl. 1 for location of observation wells.) Water-level hydrographs are shown in figure 6.

Table 1.--Summary of ground-water fluctuations.

	Number of wells	Ground-water-level fluctuations, in feet, May 1973-May 1974		
		Minimum	Maximum	Average
Shallow ground-water system	35	1.10	>7.35	3.58
Deep ground-water system	7	5.10	11.40	7.44
All wells, western half of study area	27	1.10	11.40	3.76
All wells, eastern half of study area	15	3.46	7.22	5.07

Table 1 indicates that the average range of water-level fluctuation is greater in the deep ground-water system than in the shallow ground-water system. Additionally, the average ranges in water-level fluctuations in both the shallow and deep ground-water systems are generally least in the western half of the study area and are greatest in the eastern half, adjacent to the Susquehanna River.

Ground-Water - Surface-Water Relationships

Effects of Local Streams on Ground-Water Levels

Most streams receive ground-water discharge during much of the year. However, some streams or reaches of streams may recharge the ground-water reservoir continuously. The water table contour map (pl. 2) shows a ground-water mound under Toby Creek in the northwestern part of the study area. This mound suggests that Toby Creek is losing water to the shallow ground-water system in that area, and this is further substantiated by other information. First, it is common for streams, such as Toby Creek, that flow down a steep bedrock slope to lose water as they enter a relatively flat area composed of unconsolidated deposits. Second, early in the study it was noted that ground-water levels in observation wells Lu-342 and Lu-344 apparently were affected by fluctuations in the stage of Toby Creek. These well locations are approximately 25-ft (8 m) from the creek. A controlled release of water to Toby Creek from Huntsville Reservoir, simulating selective recharge to Toby Creek, was made on October 10, 1973, with the cooperation of personnel from Pennsylvania Gas and Water Company. Water levels were monitored and some of these data are presented below.

Table 2.--Relationship between water levels in Toby Creek and two nearby observation wells before and after controlled surface-water release.

	Surface-water station 01537000	Observation well Lu-344	Surface-water station located 225-feet upstream from surface-water station No.3[a/]	Observation well Lu-342
Elevation of water surface, in feet, above mean sea level				
Before surface-water release	574.64	572.98	592.13	591.20
After surface-water release	575.76	573.06	593.06	591.26
Amount of rise in water level, in feet	.92	.08	.92	.06
Ground-water level rise, as percent of surface-water level rise		7.6		6.5

a/ Relationship between surface-water elevation at station No. 3 and 01537000 was used to estimate surface-water elevation adjacent to Lu-342.

The data in table 2 show ground-water levels were lower than nearby surface-water levels. After the surface water release, ground-water levels rose but were still lower than surface water levels. Examination of continuous hydrographs of Lu-344, and Lu-342, and 01537000 for October 9-11, 1973, showed ground-water level fluctuations were not as responsive as Toby Creek fluctuations and the ground-water peaks lagged about 8 hours behind the surface-water peak. The lag time may be explained by poor hydraulic connection between the stream bed and shallow ground-water system. The ground-water response to the rise in Toby Creek's stage was not instantaneous, so it is highly unlikely that an aquifer loading effect is responsible for the ground-water rises. Further, recharge to the shallow ground-water system from antecedent precipitation seems improbable. (The last significant rainfall prior to the experiment occurred on October 5, 1973.) Rather, ground-water levels appear to have risen in response to an increased transfer of water from Toby Creek to the shallow ground-water system.

Stream discharge measurements were made at selected points along Toby Creek under several different conditions of flow to determine the amount of surface water being lost. Results of these seepage runs are presented in table 3.

The data in table 3 are not conclusive, but, despite anomalies (which may be caused by the inherent error in the discharge measurements), they indicate an overall loss between the uppermost and lowermost stations in each seepage run. Stream losses, averaging approximately 10 percent, occur either between stations 2 and 01537000 or 2 and 4. This 10 percent figure was derived in the following way:

Reach of Toby Creek from station	Percentage of flow lost 6-20-73	6-27-73	10-10-73	5-30-74	Average percent loss
2 to 01537000	13	6	+3	20	9
2 to 4	10	10	12		11

Upstream from station 2, Toby Creek apparently is receiving ground-water flow. Data in table 3 indicate an increase in discharge from station 1 to station 2.

The average flow of Toby Creek from August 1941 to September 1973 (U.S. Geological Survey, 1973) was approximately 3.8 million ft^3/d (cubic feet per day) or 0.11 million m^3/d (cubic meters per day). A 10 percent loss of flow averages 0.38 million ft^3/d (0.011 million m^3/d). Such losses are significant and will be discussed further under the section entitled "Evaluation of nonpumping methods to lower ground-water levels".

Table 3.--Discharge data for Toby Creek at selected points.

Surface water station	Date of discharge measurement Flows are in cubic feet per second 6-20-73	6-27-73	10-10-73	5-30-74	Remarks
1	--	--	--	24.2	Approximately 5,200 feet upstream of station 01537000.
2	16.8	22.2	111.0[a]	26.4	Approximately 3,000 feet upstream of station 01537000.
01537000	14.7	20.8	114.0	21.0[b]	U.S. Geological Survey gaging station no. 01537000. See plate 1 for location.
4	15.1	19.9	97.6[a]	--	Approximately 3,000 feet downstream of station 01537000. See plate 1 for location.

a/ Stage changed slightly during measurement.

b/ Flow estimate from stage-discharge relationship established for this station.

The relationship between water levels in the shallow ground-water system and local streams on April 30-May 1, 1974, are shown by hydrologic cross sections in plate 2. Section B-B' shows that the ground-water mound sloping away from Toby Creek in both directions is controlled by water losses from the creek in this area.

Section C-C' shows that Toby Creek is losing water in this area. However, this water is diverted by the local ground-water trough (previously discussed under the section, "Shallow ground-water system"), whose approximate center is along Vaughn Street. Northeast of Walnut Street the water table slopes toward Slocum Street at a considerable depth below land surface. However, under Slocum Street, because of the rapid decline of land surface elevation, the water is only a few feet below land surface.

Section D-D' shows relationships in the eastern part of Luzerne and Swoyersville. The water elevation of Toby Creek at the mouth of the flood basin is about 20 feet higher than the ground-water elevation in nearby Lu-364, but no evidence of a ground-water mound exists. This suggests significant surface-water losses are not occurring in this area. The ground-water surface slopes away in both directions in the vicinity of Charles Street. A large surface sump approximately 400 ft (122 m) southwest of Lu-354 collects overland storm runoff, which is pumped to Toby Creek in an enclosed pipe. Check valves were installed near the bottom of the sump to allow ground water to enter the sump. Continuous water-level records from Lu-354 suggests the ground water at this point is lowered as much as 0.3 ft (0.09 m) during sustained pumpage from the sump. The water level slopes toward Swoyersville and is within a few feet of land surface just west of Slocum Street.

The relationship between Bowmans Pond, Bowmans Creek and observation well Lu-331 in this Slocum Street area is important because Bowmans Pond apparently receives overland runoff from a Luzerne Borough storm sewer. At high water levels, Bowmans Pond overflows into Bowmans Creek. Bowmans Creek also receives storm water from upslope sources. This storm water flows toward Lu-332, where it is pumped over the Erie-Lackawanna Railroad tracks. Downslope from here the stormwater flows into a subsurface pipe near Mercer Avenue, which is connected to the subsurface tunnel of Toby Creek. Water levels in Lu-331 and the two "Bowman" surface-water stations were so similar throughout the study period as to suggest, that during rainless periods, water in Bowmans Pond and Bowmans Creek reflect the local ground-water level. During and following precipitation, water elevations in Bowmans Creek and Bowmans Pond are generally higher than the water level in Lu-331. Surface water is probably lost to the shallow ground-water system from Bowmans Pond and Bowmans Creek and from storm runoff that collects in the surface depression between Bowmans Creek and Slocum Street during and following precipitation.

Effects of the Susquehnna River on Ground-Water Levels

In the study area, all local surface-water systems and ground-water systems discharge into the Susquehanna River. Accordingly, their base level is controlled by the river. Figure 6 shows precipitation recorded at the U.S. Geological Survey's Kingston station and hydrographs of surface and

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Figure 6.--(Caption on next page) belongs near here.

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ground-water level fluctuations for a concurrent period of time.

Figure 6.--Hydrographs of ground-water and surface-water levels in Kingston and Luzerne and daily precipitation for Kingston.

Hydrographs for Toby Creek at Luzerne and Susquehanna River at Wilkes-Barre (fig. 6) are very dissimilar. Toby Creek at Luzerne, which has a drainage area of 32.4 mi^2 (83.9 km^2), responds quickly to local precipitation. The Susquehanna River at Wilkes-Barre has a drainage area of 9,960 mi^2 (25,796 km^2). Thus, surface water flows longer distances than in the Toby Creek area and there is an appreciable lag time between local precipitation and related peaks in the river stage. Also, closely spaced precipitation events cause coalescing peaks more often on the Susquehanna River than on Toby Creek. The hydrograph of the Susquehanna River shows a prominent seasonal trend not readily apparent in the hydrograph of Toby Creek. The water level for the Susquehanna River generally declined from about April, 1973, to the end of October, 1973, at which time it began to rise. This seasonal rise continued into April, 1974.

Both shallow and deep ground-water levels in some observations wells in figure 6 show significant effects of both seasonal trends and individual peaks in the stage of the Susquehanna River. Hydrographs of water levels in observations wells Lu-320, Lu-333, Lu-336, and Lu-337 show the same seasonal decline and rise referred to above for the Susquehanna River. The hydrograph of Lu-313 is similar to that of Toby Creek at Luzerne and neither hydrograph shows a significant seasonal trend, suggesting that these water levels are not strongly affected by the Susquehanna River.

Individual peaks in some ground-water hydrographs appear to correlate strongly with peaks in the Susquehanna River. Hydrographs of all wells in Figure 6 except Lu-313 show grossly similar peaks, which correspond to major peaks in the Susquehanna River.

The effect of the Susquehanna River on both shallow and deep ground-water levels decreases with increasing distance (generally reflected by higher water-level elevations) from the river. This is in agreement with a mathematical evaluation of changes in ground-water heads, ground-water flow, and bank storage caused by flood waves in rivers outlined by Cooper and Rorabaugh (1963). A qualitative explanation of the effect follows. As the stage of the Susquehanna River rises faster and to a higher elevation than nearby ground-water levels some surface water moves into the ground-water reservoir as bank storage. This forms a natural "water dam" that will retard or prevent ground-water discharge. The ground water starts to back up within the system and the water-level response diminishes in amplitude as the distance from the river increases. The hydrographs of Lu-337 and Lu-333 (shallow and deep system respectively), more than 1 mile (1.6 km) from the Susquehanna River, show more subtle effects than the hydrographs of Lu-336 and Lu-320 (shallow and deep system respectively). At even more distant points, for example Lu-313, there is no observable effect on water levels from short-term fluctuations in the Susquehanna River.

Figure 6 also shows water-level fluctuations in two basements in the study area. The floor of basement-A is about 7 feet below ground surface and the floor of basement-B is about 8 feet below ground surface. The gross features of basement hydrographs are very similar to hydrographs of nearby observation wells, even though the water level in basement-B appears to show the effects of pumping during construction of nearby sanitary sewers in Luzerne. These relationships suggest that basement flooding is significantly affected by rises in ground-water levels.

DELINEATION OF AREAS AFFECTED BY BASEMENT FLOODING

Figure 6 shows that ground-water levels are generally lowest in early fall and highest in the spring. For the data-gathering period of this study (1 year), the highest shallow ground-water levels in general were reached in mid-April 1974. Local basement flooding by ground water should be the most severe during this time. A map showing depth to water in the shallow system and relative severity of basement flooding was constructed from measurements obtained during April 30-May 1, 1974 (pl. 3).

Depths to water were determined from plate 2 by subtracting ground-water elevations from land-surface elevations. These calculated values were then contoured to produce the depth-to-water map shown on Plate 3. The intervals between the depth-to-water contours were assigned a relative potential for basement flooding. For example, the area where the shallow ground-water level is from 0 to 5 ft (1.5 m) below land surface has the greatest potential for basement flooding and is colored red. Conversely, the area where the shallow ground-water level is more than 15 feet (4.6 meters) below land surface has the least potential for basement flooding and is colored green. It should be emphasized that the map is a generalization. Also, because of continuous ground-water-level fluctuations, the map is only representative of conditions during the April 30-May 1, 1974 period. Plate 3 is a slight modification of an earlier, preliminary map (Growitz, 1974).

Problem areas are defined as those areas in which the depth to water is 10 feet or less, and inspection of plate 3 reveals that many parts of the study area are included in this category. In four relatively large areas of Kingston water levels are within 10 ft (3.05 m) of the land surface. Ground water is also within 10 ft (3.05 m) of the land surface in the upper and lower sections of Luzerne, the Slocum Street area of Swoyersville, and parts of northwestern Swoyersville.

The Greatest-Potential and High-Potential zones will contract as water levels decline from the seasonal high and eventually disappear during times of low water-level conditions. However, some areas have year-round problems because ground-water levels fluctuate only a few feet throughout the year, according to water-level data collected during this study. Areas that fall within this category include Luzerne and Slocum Street in Swoyersville.

PROBABLE CAUSES OF BASEMENT FLOODING

The high ground-water level in the shallow system and associated basement flooding by ground water are attributed primarily to three factors that are common to all problem areas. These are 1. the recovery of deep ground-water levels, 2. land subsidence, and 3. [the characteristics of the geologic [illegible]] geomorphic setting.

Discussion on p. 48 includes geologic aspects as well. RL

Recovery of Deep Ground-Water Levels

Many deep coal mines were operating underneath and adjacent to the Kingston area up to the late 1950's. In order to operate, water had to be pumped continuously from the mines. Pumping lowered water levels throughout the deep ground-water system and created a regional discharge area in which the hydrologic systems above (shallow ground water and surface water) contributed water to the pumps operating below. This caused a lowering of water levels in the shallow ground-water system throughout the area. However, it is highly unlikely that the shallow ground-water system was ever completely dewatered.

Most building development in the study area occurred during the period of mining and associated pumping. When the mines closed deep-mine pumping ceased, and water levels in the deep ground-water system started to rise. Figure 7 shows the recovery of ground-water levels in the deep system, as measured at six mines within the study area for different periods. For all practical purposes the deep water levels recovered completely by 1965. Once the deep system was full, water levels could recover in the shallow system. Complaints of basement flooding in Kingston were recorded as early as 1967 (Hollowell, 1971, p. 42).

Figure 7.--(Caption on next page) belongs near here.

Figure 7.--Recovery of water levels within the deep ground-water system.

Land Subsidence

Land subsidence is a contributing factor and locally may be the most important factor causing basement flooding, for one or more of the following reasons:

1. Subsidence lowers the land surface elevation, bringing it closer to the water table.

2. Subsidence alters natural surface grades and creates local depressions on the land surface that collect and hold storm runoff. Infiltration of this water to the shallow ground-water system raises water levels and may cause local flooding problems.

3. Subsidence can destroy the grade or even cause breaks in subsurface storm and sanitary drainage facilities.

4. Subsidence can damage building foundations permitting easy ingress of local precipitation.

5. Subsidence can increase vertical permeability of rock and unconsolidated deposits, permitting large quantities of ground water to move through the affected vertical section.

General areas considered to be affected by subsidence are shown in plate 4. These areas have been defined primarily from depression contours noted on the topographic base map. Calculations of the amount of subsidence for 130 points, shown on plate 4, have been compiled in appendix C and are based on land-surface surveys dating back to 1919.

The amount of maximum subsidence was calculated in the following manner. Available maps (proposed sewer lines or topographic surveys) that listed street elevations were examined. The old elevations were adjusted to make them compatible with the present base (bench mark in the Public Square, Wilkes-Barre) by using correction factors for local coal-company benchmarks (U.S. Bureau of Mines, 1963, Table 3). These corrected elevations were then compared with elevations on the present topographic base map, and maximum subsidence (the difference between the lowest and the highest elevation for all years for which data were available) was calculated. Less than 10 percent of the calculated changes in elevations are increases. The increases suggest inconsistencies in the accuracy of surveys of some elevations or may indicate that some areas were filled to raise or restore the original grade. The compiled data in general are accurate, although some values probably are in error. Data from appendix C are summarized in table 4.

Data in appendix C and the summary in table 4 both indicate that appreciable subsidence has occurred in the study area. Generally, the greater the land subsidence the more significant its contribution to the problem of basement flooding. Data in appendix C for "bench mark" points A-H shown on plate 4 suggest that locally the land surface has continued to subside in recent years.

Table 4.--Average maximum land subsidence calculated for areas in Luzerne, Swoyersville, Forty-Fort, and Kingston.

Area	Number of points at which subsidence was calculated	Years for which historical elevations were available	Average maximum subsidence calculated for entire area, in feet	Average maximum subsidence calculated for those elevation points that fall within the 10-foot depth-to-water contour on Plate 4, in feet
Luzerne	17	1919, 1933, 1950, 1973	5.2	6.1
Swoyersville	59	1928, 1939, 1973	4.2	5.4
Forty-Fort	15	1919, 1973	3.7	---
Kingston	44	1929, 1937, 1958-60, 1973	2.8	5.3

Geomorphic Setting

Under natural conditions, without mining or land subsidence, the geomorphology of the study area is conducive to the existence of a high potentiometric surface in the shallow ground-water system. The study area is adjacent to a major river and lies within a broad flood plain composed of unconsolidated deposits. Such an area is highly susceptible to ground-water flooding.

ESTIMATES OF HYDRAULIC CONDUCTIVITY AND GROUND-WATER DISCHARGE

The quantity of ground water moving through the unconsolidated deposits must be known in order to evaluate methods to dewater these deposits. Ground-water discharge may be expressed by the relationship Q = TIW (Ferris, and others, 1962) where Q equals the discharge of ground water in cubic feet per day (cubic meters per day), T is the transmissivity expressed in square feet per day (square meters per day), I is the hydraulic gradient, which is defined as the difference in hydraulic head or water level between two points divided by the flow distance between them expressed in feet per foot (meters per meter), and W is the width, in feet (meters), of the cross section through which the discharge occurs.

Transmissivity is determined by K x m. K is the hydraulic conductivity and is the amount of water in feet (meters) per day that can be transmitted through a cross section area of one square foot (meter) under a unit hydraulic gradient. The saturated thickness, in feet (meters), or the aquifer thickness below the water table is expressed by m. Accurate hydraulic conductivity data are important in calculations of ground-water flow. The present study did not allow collection of accurate field hydraulic conductivity data; however, reasonable estimates of hydraulic conductivity can be made from data on subsurface lithology.

Subsurface lithologic data for the shallow ground-water system for a large part of the study area are compiled in a report by Hollowell (1971). Additional subsurface data were obtained from the Pennsylvania Department of Highways (written communication, 1973). Most of these lithologic descriptions are general, but they are considered adequate for determining internally consistent hydraulic conductivity and relative estimates of ground-water flow. Most significant are the trends of these ground-water flows and any large differences between flows. Hydraulic conductivity data for points shown on plate 5 are given in appendix D. At individual sites throughout the study area, hydraulic conductivity of the unconsolidated deposits ranges from 30 to 550 ft (8.5 to 167 m) per day and averages 140 ft (41.8 m) per day.

Lateral Movement of Ground Water

The quantity of ground water moving through these deposits must be known in order to evaluate methods to dewater the unconsolidated deposits. Lateral ground-water flow (Q) across the 540-ft (164.5 m) potentiometric-contour line of the shallow system was calculated by the equation Q = TIW; where T is the average transmissivity calculated from the subsurface logs near the 540-ft shallow-system potentiometric contour; I is the average hydraulic gradient between the 535 and 545-ft shallow-system potentiometric contours; and W is the distance F-G-H-I-J. The ground-water discharge, Q, moving through the shallow system at the 540-ft contour (line F-G-H-I-J on Plate 5), was calculated to be approximately 1.8 million ft^3/d (0.050 million m^3/d). A breakdown of this discharge by sections follows: section F-G, 0.40 million ft^3/d (0.011 million m^3/d); section G-H, 0.52 million ft^3/d (0.015 million m^3/d); and section H-I-J, 0.84 million ft^3/d (0.024 million m^3/d).

Only 0.75 million cubic feet per day (0.021 million cubic meters per day), or 42 percent of the 1.8 million ft^3/d (0.050 million m^3/d) can be accounted for by a general hydrologic budget analysis which follows. Inspection of 7.5 minute topographic maps indicated a "drainage area" of about three-square miles (7.8 square kilometres) between the 540-ft shallow-system potentiometric contour and the upslope drainage divide. Assuming 50 percent of all precipitation on this area infiltrates the shallow ground-water system (the probable maximum), then 0.37 million ft^3/d (0.011 million m^3/d) can contribute to the flow calculated along F-G-H-I-J. Losses from Toby Creek to the shallow ground-water system were estimated at 0.38 million cubic feet per day (0.011 million cubic meters per day).

Based on land area, approximately 20 percent of the 0.37 million cubic feet per day results from precipitation on the western part of the study area, and 80 percent results from precipitation upslope from the study area. This indicates significant amounts of ground water are being contributed from outside the study area, as suggested under the discussion of "Ground-water hydrology, general features".

The difference between the accountable and the calculated ground-water flow probably is due to inaccuracies in the hydraulic conductivity data and suggests that these values should be reduced by at least 57 percent. However, because of the uncertainties involved with using subsurface lithologic data from two sources, no attempt was made to adjust the hydraulic conductivity data. Rather it should be recognized that the values of hydraulic conductivity and ground-water flow are merely estimates.

Vertical Movement of Ground Water

Present ground-water levels are probably similar to those that existed prior to mining. The hydrologic system has been changed by deep mining only to the extent that it has resulted in more inter-connected storage for ground water in the deep system and also has created better vertical connection between the shallow and deep ground-water systems. Possible methods for alleviating basement flooding by ground water can be evaluated by determining the head relationship between the shallow and deep ground-water system as well as by determining whether or not ground water is moving vertically between these systems.

Plate 5 shows the relationship in the study area between ground-water levels in the shallow and deep systems for the period April 30-May 1, 1974. The hydrologic cross section, E-P-E', shows that a potential exists for downward vertical movement of ground water from the shallow to the deep system between point E and point P. From point P to point E' the potential is for ground water to move upward from the deep system to the shallow system.

Estimates of ground-water discharge through the unconsolidated deposits along section E-P-E' (approximately coincident with a ground-water flow line) are shown in table 5. Average transmissivities for the unconsolidated sediments between adjacent pairs of shallow potentiometric contours were calculated from appendix D. These transmissivity values were used together with the head gradients for each interval to calculate the lateral ground water flow through a vertical strip 1 foot wide extending through the unconsolidated sediments in each interval.

Table 5.--Estimates of ground-water discharge through the unconsolidated deposits along a hydrologic cross section through Kingston and part of Luzerne.

Contour interval	Average saturated thickness, m, in feet	Average hydraulic conductivity, K, in feet per day	Average transmissivity T, in square feet per day	Width, W, (assumed one foot)	Hydraulic gradient, I, in feet per foot	Ground water flow, Q, through middle of flow line section, in cubic feet per day
545-540	110 2/	70 1/	7,700	1	.017	130
540-535	105 2/	70 1/	7,400	1	.016	120
535-530	100 2/	70 1/	7,000	1	.013	90
530-525	90	30	12,000	1	.00086	10
525-520	70	20	8,400	1	.0020	20
520-515	40	340	14,000	1	.0086	120

1/ Average of four logs in Luzerne

2/ Determined by subtracting top of rock elevation (U.S. Geological Survey, 1963) from water-level elevation in middle of flow segment.

Significant flow of ground water between the shallow and deep system may be occurring in specific areas, but small amounts of vertical flow are probably occurring throughout most of the area. The data in Table 5 indicate that the amount of ground-water moving through the shallow system decreases consistently between the 545-540-ft contour lines and the 530-525-ft contour lines; a zone where downward leakage into the deep system can occur because of the existing head relationships. Little change in ground-water flow is apparent between the 530-525-ft contour lines and the 525-520-ft contour lines. There are only small differences in head between the two systems in this zone. There is a significant increase in ground-water flow through the last pair of contour lines, and there is also greater potential for upward flow based on the differences in head. The calculated changes in ground-water flow suggests relatively significant quantities of ground water are transferred between the two systems.

Review of ground-water quality data from observation wells in Kingston (Appendix A) seems to support the hypothesis that significant upward flow is occurring. Specific conductances (an approximation of dissolved solids) are generally much higher in ground water from the deep system than from the shallow system. Specific conductances of ground water from observation wells Lu-335, 336, and 357 (in areas where the potential for upward vertical flow exists) are anomalously high.

The vertical hydraulic conductivity was calculated to be 0.65 feet (0.20 meters) per day. This calculation was based on available data associated with the 525-520-ft and 520-515-ft shallow potentiometric contour lines in table 5. The vertical hydraulic conductivity, K_v, in feet (meters) per day is equal to

$$\frac{Q_v}{(\Delta L)\ (W)\ \left(\frac{h_{DGW} - h_{SGW}}{m}\right)}$$

where Q_v is the increase in ground-water discharge between the 525-520-ft and 520-515-ft contours, in cubic feet (cubic meters) per day; ΔL is the distance along the cross section from the midpoint of the 525-520-ft to the midpoint of the 520-515-ft contour in feet (meters); W is the assumed 1-foot width of discharge; h_{DGW} is the ground-water elevation in the deep system at the point where the cross section intersects the 520-ft shallow potentiometric contour; h_{SGW} is the ground-water elevation in the shallow system at the 520-ft shallow potentiometric contour; and m was taken to be the average saturated thickness of the unconsolidated deposits associated with the 525-520-ft contours.

Anisotropy

The anisotropy of a ground-water reservoir may be expressed as $\frac{K_x}{K_z}$ where K_x is the average lateral hydraulic conductivity; and K_z is the average vertical hydraulic conductivity. Assuming the vertical hydraulic conductivity determined above is representative of the study area, then the lateral hydraulic conductivity is approximately 200 times greater than the vertical hydraulic conductivity.

EVALUATION OF NONPUMPING METHODS TO LOWER GROUND-WATER LEVELS

Partial relief from basement flooding may occur in areas where sanitary sewer systems have been installed or renovated. Water that formerly recharged the shallow ground-water reservoir from on-lot disposal systems will be transported out of the area once the sanitary sewers are operative. Partial relief is also possible where sanitary sewer excavation extends into the zone of water-level fluctuation. Where such sewer pipe is placed in a clean gravel bed, ground water may flow into and along the pipe because of its high hydraulic conductivity.

Any surface water that can be prevented from infiltrating the ground represents an amount of water that the ground-water system need not handle, thereby reducing the potential for basement flooding from this source. Storm runoff efficiently routed through the area to avoid large depressions in the land surface, would go far in reducing such infiltration. In addition, inspecting surface drainage or subsurface storm-drain facilities and correcting leaks or improper grades would help prevent basement flooding.

It was pointed out previously in this report that quantitative estimates of ground-water flow are general and relative rather than specific and absolute. These estimates are not precise enough to be used in a cost-benefit analyses. Consequently, the effects of various dewatering methods that will be discussed should be regarded as approximations representing idealized conditions. Further, it is stressed that the methods evaluated in this report constitute only a few of the possible means of lowering ground-water levels and alleviating basement flooding.

Because of the vertical connection between the shallow and deep ground-water systems, dewatering part of the shallow system may also cause lower ground-water levels in the deep system; conversely, dewatering part of the deep system may cause lower ground-water levels in the shallow system. In addition, as ground water is withdrawn locally from one area, ground water from the surrounding areas will attempt to adjust to this local stress by moving toward the area of withdrawal. This generally will result in the actual drawdown being less than the calculated drawdown for any of the nonpumping methods given in this report. The most practical way of evaluating both interaction and adjustment to a state of equilibrium would be by model simulation of the study area.

Methods to alleviate the basement flooding problem by techniques that do not involve pumping can be approached in either of two ways: 1) lowering water levels in a problem area by removing ground water from that specific area through drain wells and relief wells; or 2) lowering water levels in problem areas by removing ground water from upgradient areas, either by lining Toby Creek, to prevent infiltration, or by using a subsurface drainage ditch. The maximum amount of water-level lowering that can be achieved by any nonpumping method will be controlled by the elevation of the Susquehanna River, the base-level control for all hydrologic systems in the study area.

Removal of Ground Water from Problem Areas

A line of "equal head" is shown on Plate 5. This line represents the place where the ground-water elevation in the shallow system is the same as that in the deep system. Problem areas in Luzerne and Swoyersville lie to the west of this line of equal head. These are areas where ground-water levels in the shallow system are higher than those in the deep system. A possible nonpumping method to relieve basement flooding in these areas would be to transfer ground water (in greater quantities than is now occurring naturally) to the deep system via gravity drainage wells. However, a drainage system may result in the formation of additional "acid-mine drainage" and, therefore, may be in violation of the Clean Streams Act of Pennsylvania (J. Demchalk, oral communication, 1975).

A drainage well, as the term is used here, is simply a well connecting the unconsolidated deposits and a mine void in the underlying bedrock system. In response to the difference in head between the unconsolidated deposits and the deep system, water will discharge downward through a well of this type, draining the unconsolidated deposits. The overall success of any drainage well system probably will depend upon the availability of a suitable site for the construction of a gravity overflow well or relief well. The purpose of a gravity overflow well is to discharge water introduced from up-gradient drainage wells.

The hypothetical drainage wells, whose performance in Luzerne and Swoyersville is evaluated below, had the following design characteristics. They are completed in a mine void of the deep ground-water system. A well screen is installed through the entire saturated interval of unconsolidated deposits. The limiting factor controlling drawdown in these drainage wells is the static head of the deep ground-water system, and it is assumed that this head will not increase as a result of the water transfer. The following discussion will consider a line of 2-ft (0.61-m) diameter drainage wells arbitrarily spaced on 1,000-ft (304.8 m) centers. A 2,000-ft (609.6 m) radius of influence is assumed for each well. It is assumed that there is no change in head with depth in the unconsolidated deposits, and therefore ground water will flow from the entire screened interval. With these restrictions, the ground-water discharge into any drain well can be estimated by a modification of the Thiem equation (Lohman, 1972, p. 12) expressed as:

$$Q = \frac{2\pi \times K \times L \times (h_{SGW} - h_{DGW})}{2.3 \log_{10} \frac{r_e}{r_w}} \text{ where,}$$

Q is the discharge of ground water from the shallow system into the drain well, in cubic feet (cubic meters) per day;

K is the average hydraulic conductivity in a problem area, in feet (meters) per day;

L is the average saturated thickness of the unconsolidated deposits in a problem area, in feet (meters);

h_{SGW} is the original ground-water elevation in the shallow system in an area;

h_{DGW} is the average ground-water elevation in the deep system in a problem area;

r_e is the radius of influence of the drain well, in feet (meters), a radius beyond which drawdown in the unconsolidated deposits due to the operation of the drain well is assumed to be negligible; the head at r_e is, thus, assumed to remain equal to h_{SGW} throughout the operation; and

r_w is the radius of the drain well, in feet (meters).

Once Q is obtained, the drawdown of water level in the shallow system at any distance from the drain well can be estimated using the Thiem equation for drawdown, expressed as:

$$S_w - S_1 = \frac{2.3Q}{2\pi KL} \log \frac{r1}{r_w} \quad \text{where}$$

S_1 is the drawdown of the ground water in the shallow system at any distance, r, in feet (meters);

S_w is the drawdown in the drain well, which is assumed equal to the difference between the static shallow water level and the deep water level, in feet (meters);

Q, K, and L are as defined above;

r_1 is the distance, ~~in feet,~~ between the drain well and the point at which drawdown is measured, in feet (meters); and

r_w is as defined previously.

Drawdowns obtained from the above equation were used to construct theoretical sections of the potentiometric surface in the shallow system under assumed equilibrium conditions of drainage for the three major problem areas in Swoyersville and Luzerne.

The procedure of calculation outlined above is not completely consistent, as discharge is calculated assuming a radius of influence of 2,000 feet (609.6 meters) in the initial step, and a drainage well spacing of 1,000 feet (304.8 meters) in the later steps. Interference between drainage wells cannot manifest itself here as additional drawdown within the drainage wells, because the wells are assumed to operate at a constant water level, equal to that of the deep ground-water system. Thus, interference can appear only as a decrease in flow into each drainage well, causing the actual flow to be less than that calculated assuming the undisturbed radius of influence of 2,000 feet (609.6 meters). However, this effect may be partially offset by the fact that the area of influence of each well can extend itself in an elongate pattern, at right angles to the line of wells, rather than remaining circular as assumed in the equations. In any case, in view of the uncertainties in the data and the numerous arbitrary assumptions that were made in the calculations, and because the exercise was intended to yield only rough estimates, no attempt was made to correct the drainage well discharges for interference effects. In constructing the diagrams of figure 8, however, water-level interference in the areas between drain wells was taken into account by adding the drawdowns from adjacent wells.

Hydrologic sections for lines H-I-J, N-N', G-H, M-M', K-K', and L-L' (see pl. 5) are shown in figure 8. Maximum drawdown occurs at the drainage well site and decreases with increasing distance from the drainage well. Sections in figure 8 oriented perpendicular to the flow direction show that

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Figure 8.--(Caption on next page) belongs near here.

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the average drawdown could be as much as 4.5 feet (1.37 meters) under the Slocum Street-Swoyersville area, and as much as 10-feet (3.05 meters) under the major problem area in Luzerne. Drawdowns of those magnitudes would result in local relief from basement flooding by ground water in these areas. In addition, drainage wells would function somewhat as ground-water interceptors, resulting in decreased amounts of ground-water flow and lower ground-water levels in the shallow system at all points downgradient from the wells.

Drainage wells would transfer a significant amount of ground water from the shallow to the deep system. The five drainage wells in northwest Swoyersville would transfer approximately 0.44 million cubic feet (0.013 million cubic meters) per day of ground water; the three drain wells near Slocum Street, Swoyersville would transfer approximately 0.55 million cubic feet (0.016 million cubic meters) per day; and the Luzerne drain well would transfer approximately 0.20 million cubic feet (0.0057 million cubic meters) per day to the deep system. Relief wells (gravity overflow wells) near the Susquehanna River probably would be necessary to prevent local head build up in the vicinity of any drainage well. Such relief wells would be completed in a mine void and cased through the unconsolidated deposits. Relief wells would discharge water from the deep system directly to the surface, where it could be diverted to the river.

Figure 8.--Theoretical configuration of shallow potentiometric surface in parts of Swoyersville and Luzerne showing drawdown effects of hypothetical gravity-drainage wells.

Passage not copied from marked-up page. R.L.

Gravity-drainage wells would not be practical for the problem area in Kingston, because water levels in the deep ground-water system are generally higher than those in the shallow system. However, if upslope drainage wells are used in Luzerne and Swoyersville, significant quantities of ground water would be intercepted, resulting in some relief from basement flooding in Kingston. Relief wells drilled into the deep ground-water system to provide artesian discharge to the surface and then to the river, would be another possible means for lowering ground-water levels in this area. Such wells would reduce the upward flow to the unconsolidated aquifer from the deep system and would result in a corresponding decrease in head in the unconsolidated aquifer. The number of relief wells installed would be a function of the kind and combination of solutions that are implemented and also the hydrologic properties of the deep bedrock ground-water system. Unfortunately, no data on the hydrologic properties of the bedrock are available; therefore, no quantitative estimates of the effectiveness of relief wells can be made at this time. However, it is possible to discuss some hydrologic aspects of the deep ground-water system that are significant.

R.L. Relief wells ~~will~~ would be most effective if they are close to the area where a lower water level is desired in the deep system. This conclusion is based on the small changes in the water level that have occurred since the recent completion of the Plains area relief well (table 6).

Table 6.--Comparison of water-level data from deep ground-water system showing effect of February, 1974, relief-borehole installation in the Plains area.

Date of measurement	Water level elevation, in feet above mean sea level: Henry Shaft	Water level elevation, in feet above mean sea level: Lu-340	Amount of water-level difference between Henry Shaft and Lu-340, in feet
1973			
Jan. 22 - 30[1]	536.91	534.16	2.75
Feb. 18 - 28[1]	535.51	532.25	3.26
Mar. 19 - 28[1]	536.41	532.20	4.21
Apr. 17 - 25[1]	538.91	534.30	4.61
May 21 - 25[1]	536.71	534.02	2.69
June 18 - 27[1]	535.01	531.95	3.06
July 25 - Aug. 2[1]	534.71	531.29	3.42
Aug. 27 - 30[1]	532.61	529.61	3.00
Sept. 24 - 28[1]	533.91	528.86	5.05
Oct. 4	532.51	528.16	4.35
Oct. 18	532.02	527.76	4.26
Dec. 5	531.46	527.15	4.31
1974			
Jan. 3	539.51	533.90	5.61
Feb. 5	538.71	535.16	3.55
Feb. 15	533.40[1]	532.21	1.19
Mar. 5	533.91	532.71	1.20
Apr. 4	535.04	536.82	-1.78
May 1	533.90	534.42	-.52
May 30	532.31	531.56	.75
June 5 - 7[1]	532.01	531.36	.65
June 25 - 28[1]	531.41	529.86	1.55
July 25 - Aug. 6[1]	531.01	528.41	2.60
Aug. 27 - 30[1]	530.21	527.56	2.65
Sept. 25 - 30[1]	531.21	528.96	2.25
Oct. 25 - 30[1]	531.01	528.76	2.25
Nov. 25 - 29	531.21	529.16	2.05

1/ Data supplied by Pennsylvania Department of Environmental Resources.

The relief well was installed by the Commonwealth in early February, 1974, and is 6,600 feet (2,012 meters) southeast of Lu-340 and 2,800 feet (853 meters) north of the Henry Shaft measuring point(Plate 5). Data in Table 6 show that from January 1973 through February 5, 1974, the water-level elevation at Henry Shaft was an average of 3.9 feet (1.19 meters) higher than the water-level elevation in Lu-340. From June 25-28, 1974, through November 1974, the average difference was 2.2 feet (0.67 meters). Examination of the continuous water-level record at Lu-340 for the period June 1973 through May 30, 1974, showed no visible effect on the water level in this well as a result of the installation of the relief well; therefore, the difference in water levels at Lu-340 and the Henry Shaft (following an initial significant drop and, presumably, adjustment to a later equilibrium) is now 1.7 feet (0.52 meters) less (the difference between 3.9 and 2.2 feet) than before installation of the relief well. Although no data are available, water-level decline is probably greater at the relief well site; conversely, at some distance, between 2,800 and 6,600 feet (853 and 2,012 meters) from the relief well, there is no measurable drawdown from the relief well.

Removal of Ground Water from Sites Upgradient from Problem Areas

Systems designed to prevent ground water in the shallow system from reaching a problem area, or surface water (storm runoff or stream losses) from infiltrating the shallow system, can ~~produce~~ be lower ground-water levels under that problem area. One solution might be the sealing of the Toby Creek channel with impervious material, to prevent stream water from entering the shallow ground-water system. Some of the ground water moving through the F-G-H section at the 540-foot shallow potentiometric contour (Plate 5) probably originates from Toby Creek and contributes to the high ground-water level and associated basement flooding along Slocum Street in Swoyersville, as well as in Luzerne.

Assuming that the water losses from Toby Creek are equally distributed along the F-G-H section (an undeterminable amount of the losses probably moves outside the study area, west of point F), then eliminating surface-water losses from the creek could decrease the ground-water flow through the F-G-H section by

$$\frac{0.38 \text{ million ft}^3/\text{d} \quad (0.011 \text{ m}^3/\text{d}) \quad \text{(estimated loss from Toby Creek)}}{0.92 \text{ million ft}^3/\text{d} \quad (0.026 \text{ m}^3/\text{d}) \quad \text{(calculated ground-water discharge through F-G-H)}}$$

or about 40 percent. Any decrease in ground-water flow theoretically would result in a similar decrease in hydraulic gradient downgradient from where the losses were occurring. The theoretical amount of lowering in the potentiometric surface would be greatest in the Luzerne area and would decrease in a downgradient direction as shown in table 7. The results in table 7 were calculated assuming that the percent of the regional flow circulating downward through the deep system would be unchanged due to the lining of the creek, and this is undoubtedly an oversimplification.

Table 7.--Estimates of water-level lowering in shallow ground-water system after theoretical elimination of surface-water losses from Toby Creek.

Present water-level elevation (plate 5)	Theoretical water-level elevation in areas affected by losses from Toby Creek, after elimination of losses	Amount of theoretical water-level lowering, (in feet)
590	562	28
580	556	24
570	550	20
560	544	16
550	538	12
540	532	8
530	526	4
Susquehanna River	---	0

Another method that may lower the shallow ground-water level significantly is the excavation of a ditch from land surface to some depth below the water table. This type of dewatering system, located to intercept ground water moving into the study area, was evaluated by an electric-analog model using techniques described by Karplus (1958) and similar to those used by Bennett and Giusti (1971).

The analog model (fig. 9) simulates geohydrologic conditions along section O-N-N'-O' in plate 5. A complete discussion of figure 9 and of the model, including its restrictions, is presented in Appendix E.

Figure 9.--Essential features of Teledeltos analog model along section O-N-N'-O'.

The theoretical reduction in flow from the hypothetical ditch and resulting amount of water-level lowering are shown in Table 8. The data indicate the water level in the approximate middle of the northwest Swoyersville problem area could be lowered by as much as 3.5 feet (1.07 meters) by use of the drainage ditch. This amount of lowering would reduce the potential for basement flooding.

The most effective location for the ditch would be approximately coincident with the 545-foot shallow potentiometric contour, which is upgradient from the problem area in Swoyersville. Before constructing a subsurface drainage ditch, the amount of overland runoff that moves into the study area from upslope sources and infiltrates the shallow ground-water system would have to be determined. Surface diversion ditches could be constructed to intercept any significant quantities of overland runoff entering the area. Some lowering of ground-water levels would result.

The drainage ditch method may have application along the southwestern boundary of the study area in Edwardsville. However, adequate geologic and hydrologic data are not available to permit an evaluation of the effects of ditching in that area.

Table 8.--Estimates of the quantity of ground water that can be intercepted by a theoretical drainage ditch in the shallow ground-water system, expressed as the percentage of total ground-water flow and resulting ground-water level lowering.

	Ditch excavation, in feet below water level	Approximate total depth of ditch from land surface to below water level, in feet	Elevation of static water level at drainage ditch site from Plate 5, in feet above mean sea level	Elevation of static water level at drainage ditch site from Teledeltos analog model, in feet above mean sea level	Elevation of water level in bottom of drainage ditch, in feet above mean sea level	Theoretical percentage of incoming ground water that can be intercepted by drainage ditch	Amount of water-level lowering, in feet, determined from the model as the difference between the static water level and water level after ditch installation at the sites of following shallow potentiometric contour			
							Contour sites			
DRAINAGE DITCH at site N (Plate 5)	0	5	545	551.8	--	--	540	535	530	525
	5	10			546.8	7.0	1.1	.9	.5	.4
	10	15			551.2	13.0	2.9	2.2	1.7	1.1
	15	20			536.8	20.0	3.5	3.0	2.3	1.7

SUMMARY

The potential for basement flooding based on depth-to-water measurements is shown on plate 3. The map delineates present problem areas and can be used with local building and zoning regulations in the planning of new basement construction in selected areas, thereby preventing additional structures from being flooded by ground water.

The alternative nonpumping methods of providing relief from basement flooding summarized below should not be construed necessarily as solutions but rather as possible approaches to alleviating the problem. Evaluation of the alternative methods indicates that each is hydrologically feasible and could result in local relief from basement flooding, but it is emphasized that amounts of calculated water-level decline are estimates made from approximate data under idealized situations. Additional detailed hydrologic data are necessary to refine these estimates. A single solution or combination of solutions ~~can~~ could be implemented depending on the specific objectives.

The following nonpumping methods or structures for lowering the high-water level and providing relief from basement flooding by ground water were evaluated in this report: 1) lining of Toby Creek, 2) a drainage ditch, 3) gravity drainage wells, and 4) relief wells. All of these have the following effects in common: The decrease in shallow ground-water-level gradients ~~will~~ would be proportional to the decrease in ground-water flow produced by dewatering; the maximum declines in ground-water levels produced by any of the dewatering methods would occur at the dewatering site; and declines would be progressively less downgradient.

Lining of Toby Creek to prevent surface water from recharging the shallow ground water in Luzerne could reduce the ground-water flow through eastern Luzerne and Slocum Street, Swoyersville, by ~~up to~~ as much as 40 percent. A drainage ditch in northwestern Swoyersville could reduce ground-water flow by ~~up to~~ as much as 20 percent. Drainage wells in Luzerne and along Slocum Street, Swoyersville, and northwestern Swoyersville could provide local relief and also may reduce ground-water levels in Kingston.

Relief wells or gravity overflow wells could be used to achieve several objectives. Water transferred to the deep ground-water system by drainage wells could be discharged through relief wells. Also, use of relief wells could result in lower gradients in the shallow ground-water system by decreasing the amount of upward flow from the deep system.

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APPENDIX A

RECORD OF WELLS AND FIELD WATER QUALITY DATA

Well Number	Well completed in	Depth, in feet below land surface	Casing diameter, in inches	Description of measuring point	Elevation of measuring point, in feet above mean sea level	Field temperature, in degrees C	Field specific conductance, in micromhos at 25°C	Date of Sampling	Remarks
Lu-259	Upper part of unconsolidated deposits (shallow ground-water system)	23	8	Top of casing, 4.0 ft below land surface	531.87	12	330	3-15-73	--
Lu-313	Upper part of unconsolidated deposits (shallow ground-water system)	16	7	Base of recorder shelter, 3.2 feet above land surface	567.83	19	550	9-12-73	Pennsylvania Department of Environmental Resources' well
Lu-314	Upper part of unconsolidated deposits (shallow ground-water system)	19	7	Base of recorder shelter, 2.0 ft above land surface	537.03	--	--	--	Pennsylvania Department of Environmental Resources' well
Lu-315	Upper part of unconsolidated deposits (shallow ground-water system)	15	7	Base of recorder shelter, 1.7 ft above land surface	578.95	11.0 16.5	380 240	4-18-74 9-12-73	Pennsylvania Department of Environmental Resources' well
Lu-316	Upper part of unconsolidated deposits (shallow ground-water system)	19	7	Base of recorder shelter, 3.0 ft above land surface	556.48	12 16	280 220	4-18-74 9-12-73	Pennsylvania Department of Environmental Resources' well

Appendix A.--Record of Wells and Field Water Quality Data--(Continued)

Well Number	Well completed in	Depth, in feet below land surface	Casing diameter, in inches	Description of measuring point	Elevation of measuring point, in feet above mean sea level	Field temperature, in degrees C	Field specific conductance, in micromhos at 25°C	Date of Sampling	Remarks
Lu-318	Upper part of unconsolidated deposits (shallow ground-water system)	22	8	Rim of well pit at land surface	529.95	15	100	10-09-74	Pennsylvania Department of Environmental Resources' borehole number 23
Lu-320	Bedrock (deep ground-water system)	363	8	Rim of well pit at land surface	533.95	15	8,000	3-08-73	Pennsylvania Department of Environmental Resources' borehole number 42. Cased down to 110 feet. (Sampled at 300 feet, results approximate)
Lu-322	Upper part of unconsolidated deposits (shallow ground-water system)	34	6	Rim of well pit at land surface	551.41	12 14	350 170	4-16-74 9-12-73	Pennsylvania Department of Environmental Resources' borehole number 26
Lu-324	Bedrock (deep ground-water system)	212	8	Rim of well pit at land surface	534.73	14	1,400	2-15-74	Pennsylvania Department of Environmental Resources' borehole number 39. Cased to 64 feet. (Sampled at 200 feet, results approximate)

Appendix A.--Record of Wells and Field Water Quality Data--(Continued)

Well Number	Well completed in	Depth, in feet below land surface	Casing diameter, in inches	Description of measuring point	Elevation of measuring point, in feet above mean sea level	Field temperature, in degrees C	Field specific conductance, in micromhos at 25°C	Date of Sampling	Remarks
Lu-325	Bedrock (deep ground-water system)	256	8		542.47	13	350	3-18-74	Pennsylvania Department of Environmental Resources' borehole number 41. Cased to 150 feet. (Sampled at 240 feet, results approximate)
Lu-326	Upper part of unconsolidated deposits (shallow ground-water system)	15	2	Top of casing, 1.8 ft above land surface	544.62	--	--	--	Pennsylvania Department of Environmental Resources, Well Number OW-1
Lu-327	Upper part of unconsolidated deposits (shallow ground-water system)	15	2	Top of casing, 1.3 ft above land surface	543.82	--	--	--	Pennsylvania Department of Environmental Resources, Well Number OW-2
Lu-328	Upper part of unconsolidated deposits (shallow ground-water system)	15	2	Top of casing, 1.5 ft above land surface	544.93	--	--	--	Pennsylvania Department of Environmental Resources, Well Number OW-3

Appendix A.--Record of Wells and Field Water Quality Data--(Continued)

Well Number	Well completed in	Depth, in feet below land surface	Casing diameter, in inches	Description of measuring point	Elevation of measuring point, in feet above mean sea level	Field temperature, in degrees C	Field specific conductance, in micromhos at 25°C	Date of Sampling	Remarks
Lu-329	Upper part of unconsolidated deposits (shallow ground-water system)	15	2	Top of casing, 0.3 ft above land surface	548.14	--	--	--	Pennsylvania Department of Environmental Resources, Well Number OW-4
Lu-330	Upper part of unconsolidated deposits (shallow ground-water system)	15	2	Top of casing, 1.0 ft above land surface	542.01	--	--	--	Pennsylvania Department of Environmental Resources, Well Number OW-5
Lu-331	Upper part of unconsolidated deposits (shallow ground-water system)	15	2	Top of casing, 0.5 ft above land surface	541.31	--	--	--	Pennsylvania Department of Environmental Resources, Well Number OW-6
Lu-332	Upper part of unconsolidated deposits (shallow ground-water system)	40	2	Top of casing, 3.0 ft above land surface	549.50	--	--	--	Pennsylvania Department of Environmental Resources, Well Number OW-7

Appendix A.--Record of Wells and Field Water Quality Data--(Continued)

Well Number	Well completed in	Depth, in feet below land surface	Casing diameter, in inches	Description of measuring point	Elevation of measuring point, in feet above mean sea level	Field temperature, in degrees C	Field specific conductance, in micromhos at 25°C	Date of Sampling	Remarks
Lu-333	Bedrock (deep ground-water system)	98	8	Down-slope rim of well pit at land surface	563.87	15	760	7-12-74	Pennsylvania Department of Environmental Resources' borehole number 40. Cased to 21 feet. (Sampled at 80 feet, results approximate)
Lu-334	Bedrock (deep ground-water system)	148	5	Top of casing at land surface	577.08	--	--	--	--
Lu-335	Upper part of unconsolidated deposits (shallow ground-water system)	35	6	Base of recorder shelter, 3.0 ft above land surface	550.26	14	570	3-19-74	Pumped sample
Lu-336	Upper part of unconsolidated deposits (shallow ground-water system)	36	6	Base of recorder shelter, 2.4 ft above land surface	541.26	13.5	2,200	4-16-74	Pumped sample. H_2S odor

Appendix A.--Record of Wells and Field Water Quality Data--(Continued)

Well Number	Well completed in	Depth, in feet below land surface	Casing diameter, in inches	Description of measuring point	Elevation of measuring point, in feet above mean sea level	Field temperature, in degrees C	Field specific conductance, in micromhos at 25°C	Date of Sampling	Remarks
Lu-337	Upper part of unconsolidated deposits (shallow ground-water system)	25	6	Base of recorder shelter, 2.5 ft above land surface	541.33	12	300	4-16-74	Pumped sample
Lu-338	Upper part of unconsolidated deposits (shallow ground-water system)	25	6	Base of recorder shelter, 3.1 ft above land surface	537.46	11.5	300	4-16-74	Pumped sample
Lu-339	Bedrock (deep ground-water system)	165	6	Rim of well pit at land surface	578.88	--	--	--	Pennsylvania Department of Environmental Resources' borehole number 43
Lu-340	Bedrock (deep ground-water system)	--	8	Base of recorder shelter, 2.9 ft above land surface	553.97	--	--	--	Pennsylvania Department of Environmental Resources' borehole number 44. (Mine air shaft converted into observation well)
Lu-341	Upper part of unconsolidated deposits (shallow ground-water system)	18	7	Base of recorder shelter, 2.0 ft above land surface	601.27	16.5	295	9-12-73	Pennsylvania Department of Environmental Resources' well

Appendix A.--Record of Wells and Field Water Quality Data--(Continued)

Well Number	Well completed in	Depth, in feet below land surface	Casing diameter, in inches	Description of measuring point	Elevation of measuring point, in feet above mean sea level	Field temperature, in degrees C	Field specific conductance, in micromhos at 25°C	Date of Sampling	Remarks
Lu-342	Upper part of unconsolidated deposits (shallow ground-water system)	16	7	Top of casing, 2.5 ft above land surface	608.07	15	200	9-12-73	Pennsylvania Department of Environmental Resources' well
Lu-343	Upper part of unconsolidated deposits (shallow ground-water system)	16	7	Top of casing, 1.5 ft above land surface	580.27	19.5	620	9-12-73	Pennsylvania Department of Environmental Resources' well
Lu-344	Upper part of unconsolidated deposits (shallow ground-water system)	17	7	Top of casing, 1.5 ft above land surface	586.85	--	--	--	Pennsylvania Department of Environmental Resources' well, well destroyed November, 1973
Lu-345	Upper part of unconsolidated deposits (shallow ground-water system)	24	7	Top of casing, 1.8 ft above land surface	579.21	19.5	205	9-12-73	Pennsylvania Department of Environmental Resources' well

Appendix A.--Record of Wells and Field Water Quality Data--(Continued)

Well Number	Well completed in	Depth, in feet below land surface	Casing diameter, in inches	Description of measuring point	Elevation of measuring point, in feet above mean sea level	Field temperature, in degrees C	Field specific conductance, in micromhos at 25°C	Date of Sampling	Remarks
Lu-347	Upper part of unconsolidated deposits (shallow ground-water system)	26	1	Top of casing at land surface	551.35	--	--	--	--
Lu-348	Upper part of unconsolidated deposits (shallow ground-water system)	13	1	Top of casing at land surface	543.63	--	--	--	--
Lu-349	Upper part of unconsolidated deposits (shallow ground-water system)	13	1	Top of casing at land surface	539.08	--	--	--	--
Lu-350	Upper part of unconsolidated deposits (shallow ground-water system)	28	1	Top of casing at land surface	551.02	--	--	--	--

Appendix A.--Record of Wells and Field Water Quality Data--(Continued)

Well Number	Well completed in	Depth, in feet below land surface	Casing diameter, in inches	Description of measuring point	Elevation of measuring point, in feet above mean sea level	Field temperature, in degrees C	Field specific conductance, in micromhos at 25°C	Date of Sampling	Remarks
Lu-351	Upper part of unconsolidated deposits (shallow ground-water system)	17	1	Top of casing at land surface	543.44	--	--	--	--
Lu-352	Upper part of unconsolidated deposits (shallow ground-water system)	14	1	Top of casing at land surface	552.44	--	--	--	--
Lu-353	Upper part of unconsolidated deposits (shallow ground-water system)	23	1	Top of casing at land surface	550.93	--	--	--	--
Lu-354	Upper part of unconsolidated deposits (shallow ground-water system)	14	7	Top of casing, 2.5 ft above land surface	549.56	18	490	9-12-73	Pennsylvania Department of Environmental Resources' well

Appendix A.--Record of Wells and Field Water Quality Data--(Continued)

Well Number	Well completed in	Depth, in feet below land surface	Casing diameter, in inches	Description of measuring point	Elevation of measuring point, in feet above mean sea level	Field temperature, in degrees C	Field specific conductance, in micromhos at 25°C	Date of Sampling	Remarks
Lu-355	Upper part of unconsolidated deposits (shallow ground-water system)	43	1	Top of casing at land surface	547.04	14	220	10-09-74	--
Lu-356	Upper part of unconsolidated deposits (shallow ground-water system)	33	1	Top of casing, 0.7 ft above land surface	544.20	14	140	10-09-74	--
Lu-357	Upper part of unconsolidated deposits (shallow ground-water system)	31	1	Top of casing, 1.7 ft above land surface	536.38	14	700	10-09-74	--
Lu-358	Upper part of unconsolidated deposits (shallow ground-water system)	24	1	Top of casing, 0.7 ft above land surface	539.34	--	--	--	--
Lu-359	Upper part of unconsolidated deposits (shallow ground-water system)	30	6	Base of recorder shelter, 3.2 ft above land surface	544.86	--	--	--	--

Appendix A.--Record of Wells and Field Water Quality Data--(Continued)

Well Number	Well completed in	Depth, in feet below land surface	Casing diameter, in inches	Description of measuring point	Elevation of measuring point, in feet above mean sea level	Field temperature, in degrees C	Field specific conductance, in micromhos at 25°C	Date of Sampling	Remarks
Lu-362	Upper part of unconsolidated deposits (shallow ground-water system)	22	1	Top of casing, 0.5 ft above land surface	532.50	14	430	10-09-74	--
Lu-363	Upper part of unconsolidated deposits (shallow ground-water system)	22	1	Top of casing, 0.5 ft above land surface	530.54	--	--	--	--
Lu-364	Upper part of unconsolidated deposits (shallow ground-water system)	20	1	Top of casing, 1.0 ft above land surface	544.10	--	--	--	--
B-7	Upper part of unconsolidated deposits (shallow ground-water system)	48	2			--	--	--	Smith Miller & Associates' well

Appendix A.--Record of Wells and Field Water Quality Data--(Continued)

Well Number	Well completed in	Depth, in feet below land surface	Casing diameter, in inches	Description of measuring point	Elevation of measuring point, in feet above mean sea level	Field temperature, in degrees C	Field specific conductance, in micromhos at 25°C	Date of Sampling	Remarks
B-9	Upper part of unconsolidated deposits (shallow ground-water system)	45	2			--	--	--	Smith Miller & Associates' well
B-10	Upper part of unconsolidated deposits (shallow ground-water system)	48	2			--	--	--	Smith Miller & Associates' well
B-14	Upper part of unconsolidated deposits (shallow ground-water system)	21	2			--	--	--	Smith Miller & Associates' well
B-16	Upper part of unconsolidated deposits (shallow ground-water system)	43	2			--	--	--	Smith Miller & Associates' well
B-17	Upper part of unconsolidated deposits (shallow ground-water system)	48	2			--	--	--	Smith Miller & Associates' well

Appendix A.--Record of Wells and Field Water Quality Data--(Continued)

Well Number	Well completed in	Depth, in feet below land surface	Casing diameter, in inches	Description of measuring point	Elevation of measuring point, in feet above mean sea level	Field temperature, in degrees C	Field specific conductance, in micromhos at 25°C	Date of Sampling	Remarks
B-18	Upper part of unconsolidated deposits (shallow ground-water system)	48	2			--	--	--	Smith Miller & Associates' well
B-20	Upper part of unconsolidated deposits (shallow ground-water system)	53	2			--	--	--	Smith Miller & Associates' well
B-29	Upper part of unconsolidated deposits (shallow ground-water system)	26	2			--	--	--	Smith Miller & Associates' well
B-32	Upper part of unconsolidated deposits (shallow ground-water system)	41	2			--	--	--	Smith Miller & Associates' well

Appendix A.--Record of Wells and Field Water Quality Data--(Continued)

Well Number	Well completed in	Depth, in feet below land surface	Casing diameter, in inches	Description of measuring point	Elevation of measuring point, in feet above mean sea level	Field temperature, in degrees C	Field specific conductance, in micromhos at 25°C	Date of Sampling	Remarks
B-33	Upper part of unconsolidated deposits (shallow ground-water system)	33	2			--	--	--	Smith Miller & Associates' well
B-34	Upper part of unconsolidated deposits (shallow ground-water system)	33	2			--	--	--	Smith Miller & Associates' well
B-43	Upper part of unconsolidated deposits (shallow ground-water system)	47	2			--	--	--	Smith Miller & Associates' well

APPENDIX B WATER-LEVEL DATA

Water-level data,
May, 1973 through May, 1974,
except where indicated

Station Name and Number or Observation Well Number	Frequency of Measurements	Maximum Elevation	Minimum Elevation	Range in fluctuation in feet	Remarks
		Surface Water			
by Creek at zerne-01537000	Continuous	576.72	574.77	1.95	Upstream regulation by Water Company
squehanna River Wilkes-Barre-536500	Continuous	530.01	511.73	18.28	--
wmans Pond tation No. 5)	Weekly or monthly	540.00	538.70	1.30	--
wmans Creek tation No.6)	Weekly or monthly	537.89	537.05	.84	--
		Ground Water--Shallow System			
Lu-259	Weekly or monthly	525.64	521.59	4.05	Some water-levels may be affected by pumping
Lu-313	Continuous	555.84	554.29	1.55	--
Lu-314	Continuous	526.59	522.21	4.38	--
Lu-315	Continuous	574.09	572.03	2.06	Some water-levels affected by pumping during sewer construction
Lu-316	Continuous	545.66	542.42	3.24	--
Lu-318	Weekly or monthly	521.87	517.31	4.56	--
Lu-322	Weekly or monthly	528.77	524.05	4.72	--
Lu-326	Weekly or monthly	539.12	<535.62	>3.50	--
Lu-327	Weekly or monthly	541.22	540.08	1.14	--
Lu-328	Weekly or monthly	541.33	539.98	1.35	--
Lu-329	Weekly or monthly	540.89	539.01	1.83	--
Lu-330	Weekly or monthly	537.65	536.43	1.22	--
Lu-331	Weekly or monthly	539.38	537.03	2.35	--
Lu-332	Weekly or monthly	530.87	529.56	1.31	--
Lu-335	Continuous	527.92	522.31	5.61	--
Lu-336	Continuous	525.44	519.58	5.86	--
Lu-337	Continuous	527.35	522.18	5.17	--
Lu-338	Continuous	522.56	516.49	6.07	--
Lu-341	Continuous	592.03	590.03	2.0	Water-level measurements began in June, 1973. Some water-levels may be affected by pumping.
Lu-342	Weekly or continuous	592.08	590.98	1.1	Water-level measurements began in June, 1973.
Lu-343	Weekly or monthly	570.69	567.67	3.02	Water-level measurements began in June, 1973. Some water-levels affected by pumping during sewer construction.

Station Name and Number or Observation Well Number	Frequency of Measurements	Water-level data, May, 1973 through May, 1974 except where indicated: Maximum Elevation	Minimum Elevation	Range in fluctuation in feet	Remarks
Lu-345	Weekly or continuous	553.66	552.14	1.52	Water-level measurements began in June, 1973.
Lu-347	Weekly or monthly	536.25	531.60	4.65	Water-level measurements began in June, 1973.
Lu-348	Weekly or monthly	537.71	531.63	6.08	Water-level measurements began in June, 1973.
Lu-349	Weekly or monthly	530.96	528.79	2.17	Water-level measurements began in June, 1973.
Lu-350	Weekly or monthly	533.13	529.22	3.91	Water-level measurements began in June, 1973.
Lu-351	Weekly or monthly	533.79	529.97	3.82	Water-level measurements began in June, 1973.
Lu-352	Weekly or monthly	545.46	544.24	1.22	Water-level measurements began in June, 1973.
Lu-353	Weekly or monthly	535.28	<527.93	>7.35	Water-level measurements began in June, 1973.
Lu-354	Weekly or continuous	539.41	536.99	2.42	Water-level measurements began in June, 1973. Water-levels appear to be affected by drainage sump operation.
Lu-355	Weekly or monthly	521.41	517.20	4.21	Water-level measurements began in July, 1973.
Lu-356	Weekly or monthly	525.83	522.37	3.46	Water-level measurements began in July, 1973.
Lu-357	Weekly or monthly	523.44	519.25	4.19	Water-level measurements began in July, 1973.
Lu-358	Weekly or monthly	528.55	523.30	5.25	Water-level measurements began in July, 1973.
Lu-359	Continuous	533.22	527.04	6.18	Water-level measurements began in July, 1973.
Lu-362	Intermittent	--	--	--	Water-level measurements began in August, 1973.
Lu-363	Intermittent	--	--	--	Water-level measurements began in August, 1973.
Lu-364	Intermittent	--	--	--	Water-level measurements began April 15, 1974.
Basement A	Continuous	526.44	525.19	1.25	Much lost record. Basement floor at elevation 525.19.
Basement B	Continuous	569.34	567.98	1.36	Sump in basement floor at elevation 567.98.
Basement C	Weekly or monthly	536.72	534.32	2.15	Basement floor at elavation 534.16
		Ground Water--Deep System			
Lu-320	Weekly or Continuous	528.15	520.94	7.21	Well completed in mined-out void in Dorrance-Pettibone Colliery.
Lu-324	Weekly or monthly	525.23	520.13	5.10	Well completed in mined-out void in Woodward Colliery.
Lu-325	Weekly or monthly	529.35	524.07	5.28	Well completed in mined-out void in East Boston Colliery.
Lu-333	Continuous	531.30	523.67	7.63	Well completed in mined-out void in Kingston Colliery.
Lu-334	Weekly or monthly	530.48	524.43	6.05	Well completed in mined-out void in Black Diamond Colliery.
Lu-339	Weekly or monthly	535.03	525.69	9.34	Well completed in mined-out void in Harry E-Forty Fort Colliery.
Lu-340	Continuous	538.17	526.77	11.40	Well completed in mined-out void in Maltby-Westmoreland Colliery.

APPENDIX C.--COMPARISON OF ELEVATIONS OF OLD SURVEYS AND 1973 ELEVATIONS

LUZERNE BOROUGH

Map Point	Survey Date: Elevation of Land Surface in feet above mean sea level				Maximum Subsidence Calculated, (in feet)
	1919[a]	1933[b]	1950[c]	1973[d]	
1	--	606.05	--	603.	3.0
2	582.94	579.78	579.11	577.	5.9
3	--	576.22	575.31	576.[e]	.9
4	587.14	579.05	577.21	579.[e]	9.9
5	586.54	585.16	581.71	584.	4.8
6	585.04	579.47	578.61	579.[e]	6.4
7	583.34	577.62	576.91	578.	6.4
8	582.04	575.87	575.31	576.5	6.7
9	--	593.17	594.21	595.5	+2.3
10	593.24	587.58	586.91	589.[e]	6.3
11	590.94	587.84	586.01	587.5	4.9
12	582.24	580.97	579.61	579.	3.2
13	561.14	557.15	555.81	557.	5.3
14	550.54	547.70	546.51	547.	4.0
15	562.24	560.73	559.41	559.5[e]	2.8
16	551.44	548.06	--	547.	4.4
17	608.54	596.60	594.91	595.	13.6

SWOYERSVILLE BOROUGH

Map Point	Survey Date			Maximum Subsidence Calculated, (in feet)
	1928[f]	1939[g]	1973	
18	594.2	592.09	592.	2.2
19	591.7	591.6	589.92[h]	1.8
20	549.5	547.84	544.[e]	5.5
21	--	546.36	541.5	4.9
22	--	550.2	544.5	5.7
23	553.9	553.48	555.5	+2.0
24	554.3	554.06	554.	.3
25	551.8	551.7	553.5	+1.8
26	556.2	551.54	549.5	6.7
27	555.9	552.5	551.5	4.4
28	554.2	--	548.	6.2
29	553.6	--	546.	7.6
30	553.9	--	549.	4.9
31	554.75	554.28	549.	5.8
32	554.3	--	551.	3.3
33	554.8	--	544.5	10.3
34	554.2	--	549.5	4.7
35	554.4	553.21	549.5	4.9
36	581.7	--	579.5	2.2
37	555.9	--	552.	3.9
38	554.8	--	552.	2.8
39	555.	553.49	552.	3.0
40	551.2	--	543.5	7.7
41	556.	--	547.	8.0
42	553.7	--	542.5	11.2
43	551.2	549.27	543.5	7.7
44	552.2	--	543.5	8.7
45	549.5	549.12	544.	5.5
46	553.7	--	547.	6.7
47	554.1	--	546.	8.1
48	553.7	--	551.	2.7
49	573.7	--	569.	4.7
50	552.11	--	546.	6.1
51	569.7	--	567.	2.7
52	549.9	--	548.	1.9
53	549.1	--	548.	1.1
54	552.9	--	552.	.9
55	554.	--	552.	2.0
56	552.8	--	551.5	1.3
57	557.4	--	552.	5.4
58	554.3	--	554.	.3
59	556.2	--	556.	.2
60	554.7	--	556.5	+1.8
61	588.7	578.94	577.5	11.2

Appendix C.--Comparison of Elevations of Old Surveys and 1973 Elevations-Continued

FORTY FORT BOROUGH

Map Point	Survey Date 1919 i/	1973	Maximum Subsidence Calculated, (in feet)
62	555.6	552.	3.6
63	555.2	547.	8.2
64	549.5	544.5	5.0
65	551.3	551.	.3
66	551.8	540.5	11.3
67	551.9	549.	2.9
68	560.1	547.	13.1
69	553.1	550.5	2.6
70	558.6	557.	1.6
71	558.2	557.	1.2
72	558.7	558.	.7
73	558.5	556.	2.5
74	555.51	556.	+.5
75	559.9	559.	.9
76	549.0	547.5	1.5

KINGSTON BOROUGH

Map Point	Survey Date 1929 j/	1937 k/	1959-60 l/	1973	Maximum Subsidence Calculated, (in feet)
77	--	544.36	--	543.5	.9
78	--	545.	--	542.5	2.5
79	543.77	545.36	--	541.	4.4
80	537.37	535.86	--	536.5	1.5
81	536.57	536.36	--	537.5	+1.1
82	543.17	542.36	--	543.	.8
83	544.17	543.36	--	541.5	2.7
84	--	541.86	--	539.5	2.4
85	--	537.36	--	531.	6.4
86	537.36	533.36	--	527.5	9.9
87	537.57	533.36	--	528.	9.6
88	536.40	532.36	--	529.5	6.9
89	536.07	535.86	--	536.	+.2
90	535.97	535.86	--	537.	+1.1
91	535.77	535.86	535.97	536.	+.2
92	546.57	542.86	--	542.	4.6
93	538.97	537.36	536.11	535.5	3.5
94	542.17	540.86	--	541.	1.3
95	--	538.56	--	536.	2.6
96	536.97	534.36	531.15	531.5	5.8
97	538.77	539.86	536.28	536.5	3.6
98	--	539.36	536.05	536.	3.4
99	538.17	541.36	--	538.5	3.2
100	542.37	541.86	--	541.	1.4
101	543.17	542.36	--	542.5	.7
102	544.17	543.36	--	543.	1.2
103	539.17	539.36	--	536.5	2.9
104	537.67	536.86	--	533.5	4.2
105	--	542.36	539.44	540.5	2.9
106	544.45	545.36	--	543.	2.4
107	541.17	--	--	538.5	2.7
108	542.17	--	--	534.5	7.7
109	540.17	540.36	--	532.	8.4
110	541.28	541.36	--	538.	3.4
111	549.47	550.36	548.62	549.	1.7
112	--	543.36	--	544.	+.6
113	--	550.36	--	548.	2.4
114	--	550.36	549.90	549.	1.4
115	541.53	540.86	--	541.	.6
116	--	543.36	--	543.	.3
117	542.67	543.36	--	543.	.4
118	542.42	542.86	--	542.	.9
119	--	548.86	--	549.3	+.4
120	550.17	551.36	--	551.	1.4

Appendix C.--Comparison of Elevations of Old Surveys and 1973 Elevations-Continued

"BENCH MARKS" IN STUDY AREA

Map Point	Well identification number used in this study	Borough	Survey Date 1967m/	1973n/	Maximum Subsidence Calculated, (in feet)
A	Lu-324	Kingston	534.76	534.73	.03
B	Lu-318	Kingston	530.00	529.95	.05
C	Lu-320	Kingston	534.13	533.95	.18
D	Lu-325	Kingston	542.65	542.42	.23
E	Lu-322	Kingston	551.67	551.41	.26
F	Lu-333	Kingston	564.69	564.55	.14
G	Lu-339	Swoyersville	579.37	578.88	.49
H	——	Forty Fort	556.15	556.12	.03

a/ Elevations from map prepared by Boyle and Howe Jr., Borough Engineers. Correction factor of 6.14 feet (difference between Black Diamond Colliery base and present map base) was added to original elevations.

b/ Elevations from map prepared by John E. Guido, Borough Engineer. Correction factor of 6.14 feet was added to original elevations.

c/ Elevations from map prepared by Robert N. Bierly. Statement on map says to add 446.51 to original elevations to make them compatible with Geological Survey Datum.

d/ Elevations from map supplied by Susquehanna River Basin Commission. Base is bench mark in Public Square, Wilkes-Barre.

e/ Elevation was extrapolated between 5-foot contours.

f/ Name of map preparer not available. A statement by Mr. Halsey dated 4-12-28 visible on map. Correction factor of 6.7 feet (difference between Harry E. Colliery base and present map base) was added to original elevations.

g/ Elevations from map prepared by John J. Reilly, Borough Engineer. Correction factor of 6.7 feet was added to original elevations.

h/ Elevation determined in 1974.

i/ Elevations from map prepared by Alexander Potter, Consulting Engineer. Correction factor of 6.7 feet was added to original elevations.

j/ Elevations from map prepared by F. C. Wintermute, Engineer. Correction factor of 5.17 feet (difference between Glen Alden Corporation base and present map base) was added to original elevations.

k/ Elevations from map prepared by Robert L. Williams, Borough Engineer. Elevations extrapolated from 1-foot contours.

l/ No credits available for these elevations.

m/ Elevation points are brass plates set in concrete that are adjacent to boreholes drilled under Project 46. Brass plate date is stamped 1971. (After checking original survey notes, it was discovered that the base line from bench mark in Wilkes-Barre square was established in 1967).

n/ Brass plates re-surveyed in 1973.

APPENDIX D

HYDROLOGIC PROPERTIES OF UNCONSOLIDATED DEPOSITS

~~Coefficient of~~ hydraulic conductivity, in feet per day,
Modified from Lohman (1972, Table 17)
for following sediments ~~description~~:

Not called coefficient RL.

RL.

Boulders - 1000
Gravel - 950
Gravel and sand - 350
Sand, gravel, and boulders - 280
Sand and gravel - 270
Clay and gravel - 80
Clay and gravel with sand - 67
Sand - 50
Silty sand and gravel - 27
Silty sand, some gravel - 20
Silty clayey sand, some gravel - 18
Silty sandy clay and gravel - 16
Clayey sand, some gravel - 15
Clayey silt, some gravel - 14
Silty sand - 13
Sand and clay - 10
Clay and sand - 4
Silt - 2
Silt and clay - 1.6
Silty clay - 1.3
Clay - 1

Appendix D.--Hydrologic properties of unconsolidated deposits.--Continued

KINGSTON AREA
Descriptions From Hollowell, (1971)

Log number (see Plate 5 for location)	Description from water level in shallow ground-water system to top of rock and feet of saturated thickness	Hydraulic conductivity estimate at logsite, in feet per day	Transmissivity estimate at logsite, in square feet per day
103	Gravel - 10		
	Clay - 6		
	Sand & Gravel - 7	410	9,400
125	Sand & gravel - 11		
	Clay - 53		
	Sand - 2	50	3,300
1161	Gravel - 12		
	Sand & gravel - 17	550	16,000
1688	Sand & gravel - 18		
	Sand - 143	70	11,000
1730	Sand & gravel - 15		
	Sand - 124	70	10,000
1826	Gravel - 9		
	Clay - 24		
	Sand & gravel - 8	260	11,000
1835	Sand & gravel - 14		
	Sand & clay - 58		
	Sand & gravel - 4	60	4,600
1848	Gravel - 2		
	Sand & gravel - 13		
	Clay - 49		
	Gravel - 19	280	23,000

Appendix D.--Hydrologic properties of unconsolidated deposits.--Continued

Log number (see Plate 5 for location)	Description from water level in shallow ground-water system to top of rock and feet of saturated thickness	Hydraulic conductivity estimate at ~~logsite~~ wellsite, in feet per day	Transmissivity estimate at ~~logsite~~ wellsite, in square feet per day
1862	Gravel - 16 Clay & sand - 38 Sand - 2	280	16,000
5004	Gravel - 8 Sand & clay - 72 Clay - 6	90	7,700
5009	Sand & gravel - 18 Clay - 63 Sand - 3	60	5,000
5027	Gravel - 11 Gravel & sand - 10 Clay & sand - 79	140	14,000
5069	Gravel - 14 Clay - 60 Sand - 13	190	17,000
5137	Clay - 11 Gravel - 15 Clay - 55	180	15,000
5142	Clay - 9 Gravel - 10 Clay - 24 Sand - 10 Sand & gravel - 19	210	15,000
5151	Clay - 14 Sand & gravel - 4 Clay - 24	30	1,300
5154	Clay - 11 Gravel - 8 Clay - 41 Sand & gravel - 7	140	9,400

Appendix D.--Hydrologic properties of unconsolidated deposits.--Continued

Log number (see Plate 5 for location)	Description from water level in shallow ground-water system to top of rock and feet of saturated thickness	Hydraulic conductivity estimate at ~~logsite,~~ well site, in feet per day	Transmissivity estimate at ~~logsite,~~ well site, in square feet per day
5155	Clay - 23 Gravel - 10 Clay - 45	100	7,800
5168	Sand & gravel - 24 Clay - 35	110	6,500
5200	Sand & gravel - 25 Clay - 58 Sand & gravel - 3	90	7,700
5313	Sand & gravel - 17 Clay - 40 Sand & gravel - 6	100	6,300
5538	Sand & gravel - 15 Clay - 7 Sand - 6	160	4,500
7172	Sand & gravel - 15 Clay - 58 Sand - 19	50	4,600
7183	Gravel - 20 Clay - 43 Sand - 23 Sand & gravel - 10	240	23,000
7314	Sand & gravel - 10 Clay - 55 Sand - 19	50	4,200
7326	Gravel - 10 Clay - 59 Sand & gravel - 11	70	5,600
7348	Gravel - 14 Clay - 69 Sand - 6	160	14,000

Appendix D.--Hydrologic properties of unconsolidated deposits.--Continued

Log number (see Plate 5 for location)	Description from water level in shallow ground-water system to top of rock and feet of saturated thickness	Hydraulic conductivity estimate at ~~[logsite]~~ well site, in feet per day	Transmissivity estimate at ~~[logsite]~~ well site, in square feet per day
7578	Sand & gravel - 15 Clay - 58	60	4,400
8696	Sand & gravel - 13 Clay - 50 Sand & gravel - 5	70	4,800
8712	Sand & gravel - 12 Clay - 45 Sand & gravel - 2	70	4,100
8743	Sand & gravel - 21 Clay - 53 Sand & gravel - 8	90	7,400

Appendix D.--Hydrologic properties of unconsolidated deposits.--Continued

SWOYERSVILLE - Northeast Area
Descriptions From Hollowell, (1971)

Log number (see Plate 5 for location)	Description from water level in shallow ground-water system to top of rock and feet of saturated thickness	Hydraulic conductivity estimate at [~~logsite,~~] wellsite, in feet per day	Transmissivity estimate at [~~logsite,~~] wellsite, in square feet per day
39	Gravel - 20		
	Clay - 80		
	Sand - 68	130	22,000
350	Gravel - 25		
	Sand - 124		
	Gravel - 12	350	56,000
359	Gravel - 30		
	Sand - 101		
	Gravel - 6		
	Sand & gravel - 2	290	40,000
380	Sand & gravel - 28		
	Clay - 90	70	8,300
381	Sand & gravel - 28		
	Clay - 68		
	Sand - 2		
	Gravel - 1		
	Sand - 5	90	9,400
513	Sand & gravel - 10		
	Sand - 118		
	Gravel - 3	60	7,900
523	Sand & gravel - 20		
	Clay & sand - 84		
	Sand & gravel - 48	120	18,000
527	Sand & gravel - 10		
	Clay - 90		
	Sand & gravel - 30	80	10,000
6865	Sand & gravel - 25		
	Sand - 30		
	Clay - 40		
	Sand & clay - 23	70	8,300
8175	Sand & gravel - 16		
	Clay & sand - 47		
	Sand - 14	70	5,400

Appendix D.--Hydrologic properties of unconsolidated deposits.--Continued

SWOYERSVILLE - Northwest Area
Descriptions From Hollowell, (1971)

Log number (see Plate 5 for location)	Description from water level in shallow ground-water system to top of rock and feet of saturated thickness	Hydraulic conductivity estimate at ~~logsite~~ well site, in feet per day	Transmissivity estimate at ~~logsite~~ well site in square feet per day
8180	Sand & gravel - 21		
	Clay & sand - 34		
	Sand - 40		
	Gravel - 12	180	19,000
9206	Sand & gravel - 6		
	Sand & silt - 19		
	Sand - 8		
	Sand & silt - 46		
	Sand - 24		
	Sand & gravel - 10	60	6,700

Appendix D.--Hydrologic properties of unconsolidated deposits.--Continued

SWOYERSVILLE - Slocum Street Area
Descriptions From Hollowell, (1971)

Log number (see Plate 5 for location)	Description from water level in shallow ground-water system to top of rock and feet of saturated thickness	Hydraulic conductivity estimate at [~~logsite~~] well site, in feet per day	Transmissivity estimate at [~~logsite~~,] well site, in square feet per day
131	Sand - 38		
	Gravel - 3		
	Sand - 97		
	Sand & gravel - 2		
	Sand - 9		
	Sand & gravel - 1	70	11,000
164	Sand - 31		
	Sand & gravel - 29	150	9,000
168	Sand - 2		
	Clay - 6		
	Sand - 48		
	Gravel - 12		
	Sand - 7		
	Gravel & sand - 46	280	34,000
205	Gravel - 33		
	Sand - 33		
	Clay - 124	170	32,000
233	Gravel - 12		
	Sand - 120		
	Clay - 26		
	Sand - 30		
	Gravel - 8	130	25,000
284	Gravel - 21		
	Sand - 174		
	Gravel - 8	180	36,000
450	Sand & gravel - 12		
	Sand & clay - 128		
	Gravel - 6	70	10,000

Appendix D.--Hydrologic properties of unconsolidated deposits.--Continued

LUZERNE
Description From Pennsylvania
Department of Transportation

Log number (see Plate 5 for location)	Description from water level in shallow ground-water system to top of rock and feet of saturated thickness	Hydraulic conductivity estimate at ~~logsite,~~ well site, in feet per day	Transmissivity estimate at ~~logsite,~~ well site in square feet per day
H-24	Sand & gravel - 1.8 Clayey silt, some gravel - 4.2 Silty sand - 5.8 Silty sand, (trace gravel - 6.3 Silty sand & gravel, (occasional boulder)- 4.3 Silty sand & gravel - 10.5 Silty clayey sand & gravel - 10.7 Silty clayey sand & gravel, (occasional boulder)-7.0	30	1,800
H-25	Silty sand & gravel - 4 Silty clay - 3.5 Silty sand - 9.0 Silty sand & gravel - 31.5 Silty sandy clay & gravel - 4 Boulders - 4.5	100	5,700
T-1	Clayey sand, some gravel - 2.4 Silty sand, some gravel - 4.8 Clayey sand with gravel - 7.8 Sand, (trace clay)-3.6 Sand & gravel, (trace clay)- 16 Silty sand - 3.5 Clayey sand, some gravel - 4	130	5,500
T-2	Silty sand & gravel - 6.7 Silty clayey sand, some gravel - 12.8 Silty sand & gravel - 12.7 Clay & gravel with sand - 11.8	35	1,500

APPENDIX E

Discussion of Electric Analog Simulation

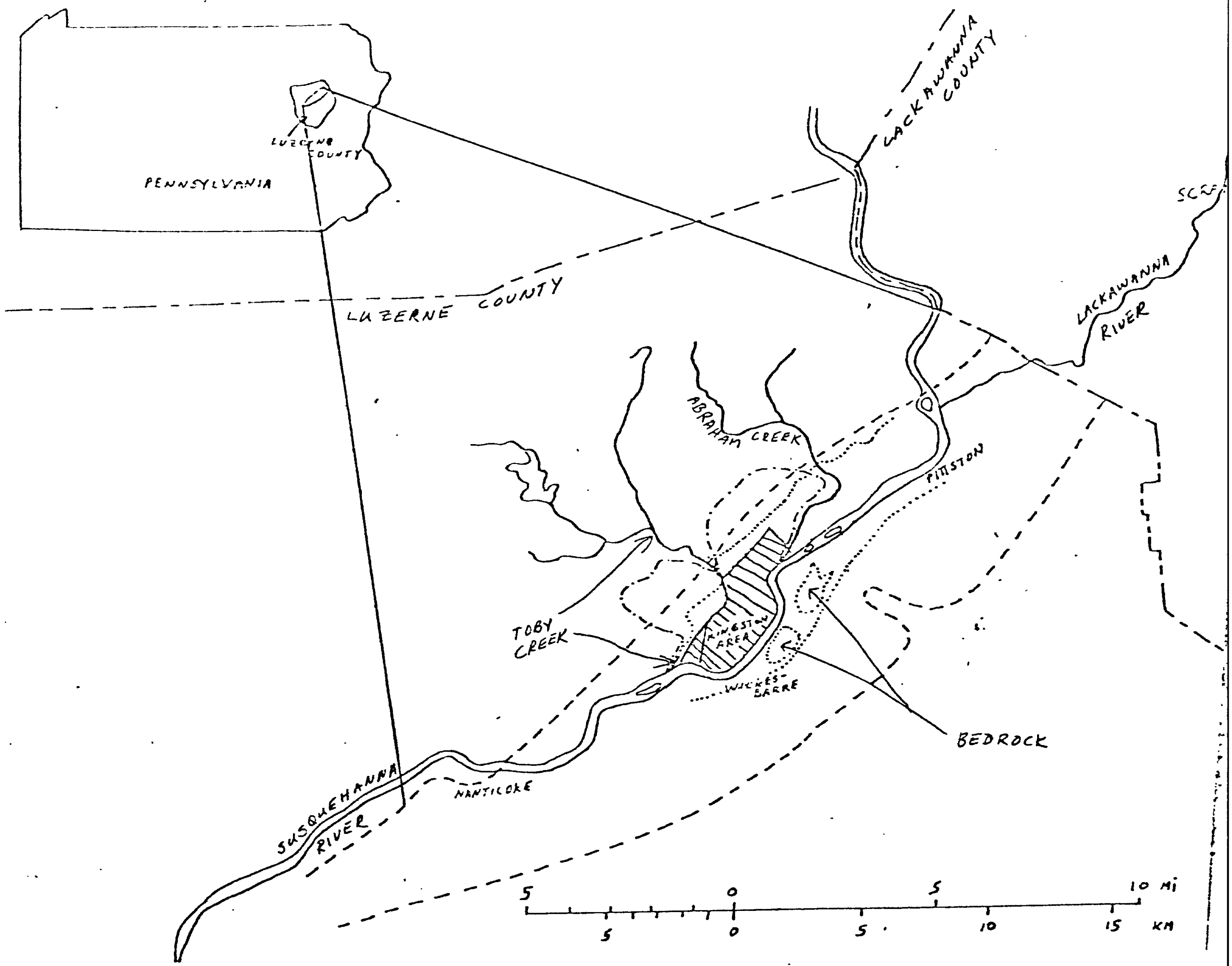
The analog model in figure 9 simulates geohydrologic conditions along section O-N-N'-O' in plate 5 and was constructed from Teledeltos conducting paper. The top edge of the paper was cut to approximate the water level in the shallow system as determined from water-level contours in plate 5. The gradient outside the study area was estimated from the topography on a 7.5 minute map. Three contact points were used in the model, each coated with silver printed-circuit paint. The painted contact at O is the point of electrical input to the model, and through it current is introduced, simulating ground water moving into the study area. The contact at O' represents output to the Susquehanna River. The output N represents the location of a theoretical drainage ditch approximately 25-feet wide at the bottom that extends into the shallow ground-water system. The vertical strips of Teledeltos paper beneath the unconsolidated deposits represent a vertical connection between the shallow and deep systems, and the strip of conductive paint at the bottom represents the potentiometric surface of the deep system.

The thickness of the model was determined initially as the approximate thickness of the unconsolidated deposits. Anisotropy of the aquifer was simulated by distortion of the vertical scale of the model, following the relations given by Muskat (1946), $\frac{\overline{Z}}{\overline{X}} = \sqrt{K_L/K_V}$ where $\overline{Z}$ and $\overline{X}$ are the dimensions of a rectangular segment of the model, representing a square segment of the aquifer; K_L is the average lateral hydraulic conductivity of the unconsolidated deposits; and K_V is the average vertical hydraulic conductivity between the top of the deep system and the water level in the shallow system.

Voltage measurements in the model represent water levels in the field, and currents measured in the model are analogous to the fluid discharge through the aquifer. In the model analysis, the unconsolidated aquifer was assumed to have a uniform, though anisotropic, hydraulic conductivity, and steady-state conditions were assumed. Results were recorded as percentage of total flow and as percentage of total potential difference. Using this method of operation, it was not necessary to specify a particular value of hydraulic conductivity in designing the experiments.

Two model simulations were run. The first simulation was essentially a calibration run without using the drainage ditch. Measured potentials were made to agree as closely as possible with observed water levels by modifying slightly the thickness of the unconsolidated deposits. In the second simulation, the drainage ditch was connected in the model. The water level within the ditch was assumed to be at the bottom different water levels, that is different depths of ditch, were simulated by varying the electrical potential at N.

The model results are only as reliable as the input data that were used, and are based on the assumption that the shallow ground-water surface can be maintained at the bottom of the ditch (by an adequate subsurface and surface grade to carry this water to the Susquehanna River). The Teledeltos analog model simulates water level conditions only along the section O-N-N'-O', or at one point along the hypothetical drainage ditch. The analysis is based on the assumption there is no flow normal to the analog model section.



EXPLANATION

All boundaries approximate
— — —County boundary
▧ Study area
—.—. Drainage area above study area
- - - Outcrop of lowermost mined Coal (Lateral limits of mining)
..... Lateral limits of buried valley deposits

Figure 1. Location map of study area in north-central Wyoming Valley, Luzerne County, showing generalized geomorphic features.

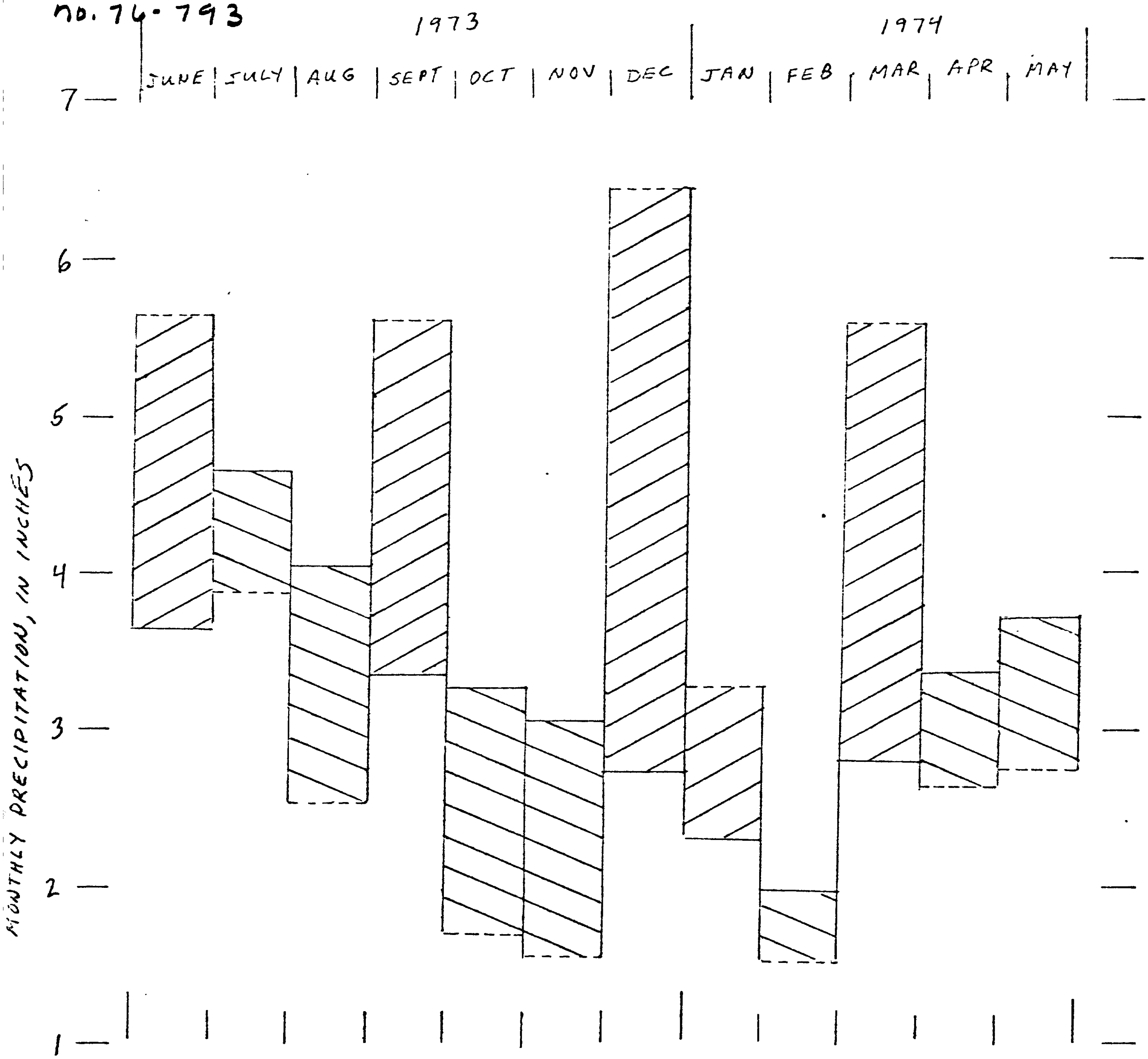


Figure 2. Comparison of precipitation during study period with long-term monthly-average precipitation at Wilkes-Barre station

EXPLANATION

—— Long-term average-monthly precipitation at Wilkes-Barre, 1886-197[illegible]

- - - Total monthly precipitatation at Wilkes-Barre, June 1973-May 197[illegible]

Above average precipitation

Below average precipitation

EXPLANATION

Diagram not to scale

↓ Arrows indicate direction of ground-water movement

Potentiometric surface in shallow system

Inferred potentiometric surface in shallow system

Potentiometric surface in deep system

Inferred potentiometric surface in deep system

Top of bedrock

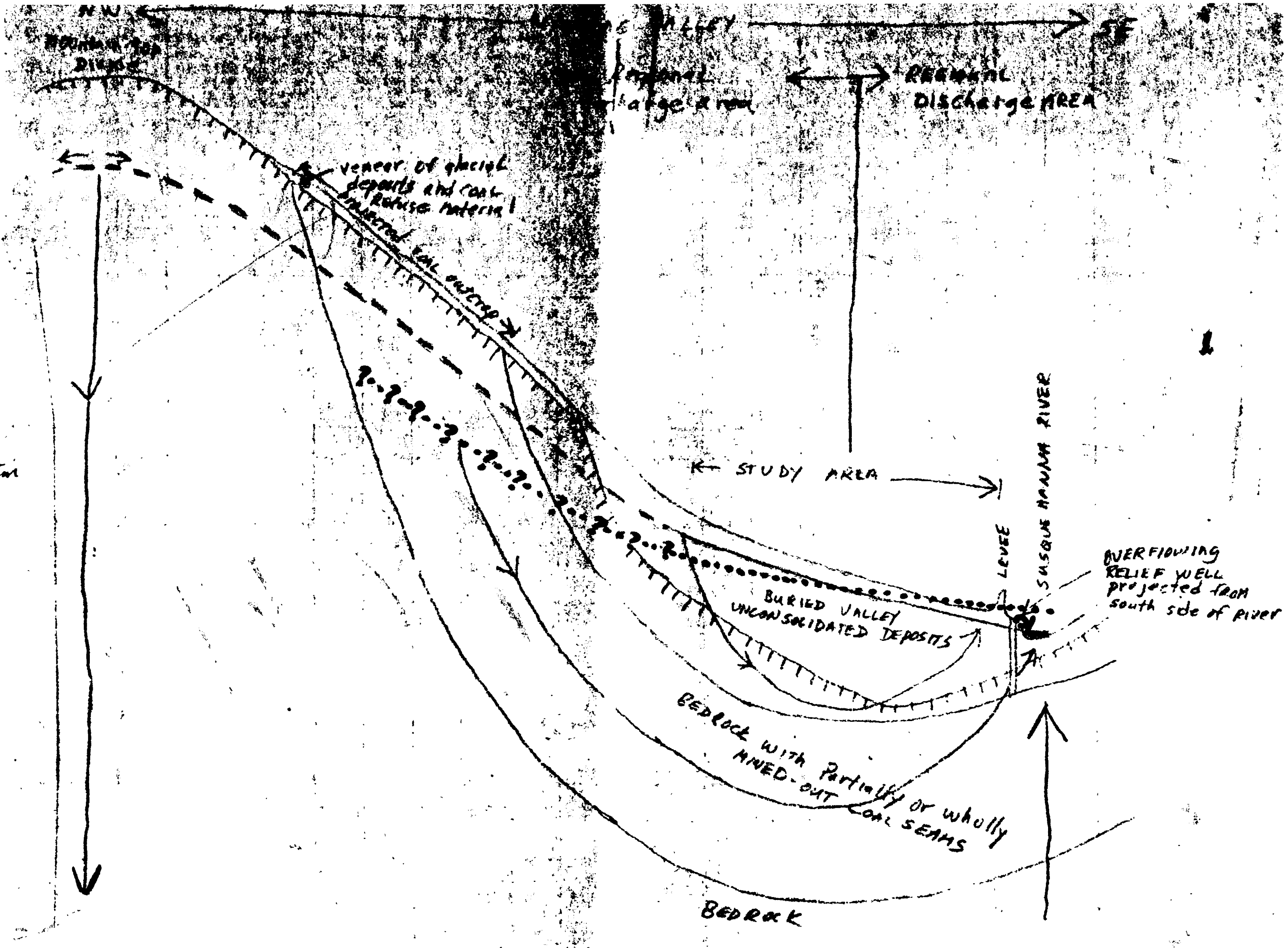


Figure 4. Diagrammatic section through the west half of the Wyoming Valley showing water-level relationships and the directions of ground-water [illegible] within the shallow and deep [illegible].

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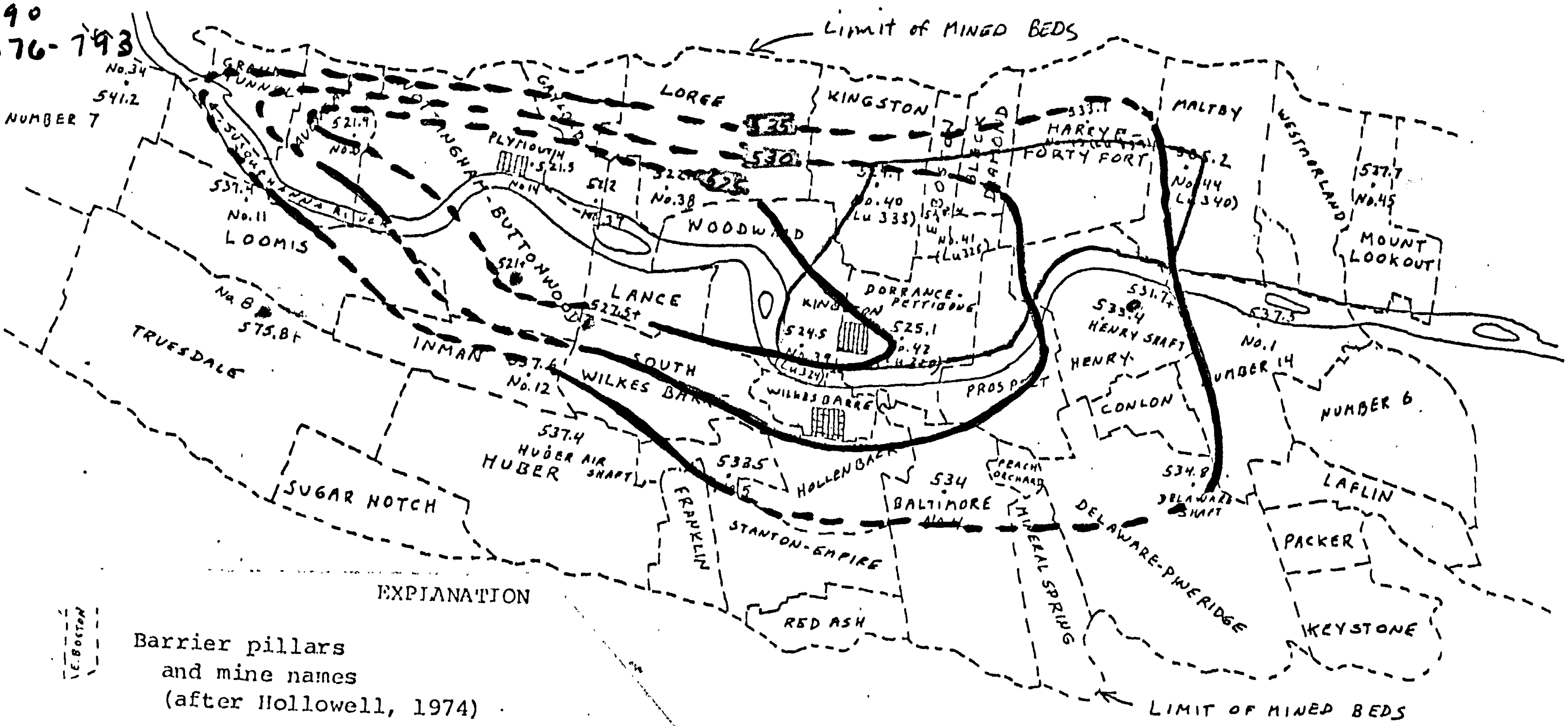

EXPLANATION

Barrier pillars and mine names (after Hollowell, 1974)

530 Potentiometric contour line, dashed where inferred. Contour interval - 5 feet

527.5+ [redacted], with minimum potentiometric elevation (elevation is of overflow point of relief structure)

535.2 No.44 (Lu 340) Location of observation well. Upper number is elevation of ground-water level; lower number is identification number or name. Data supplied by Pennsylvania Department of Environmental Resources. Lu number in parenthesis is identification number used in this report.

Present study area

Figure 5. Generalized potentiometric-contour map of the deep ground-water system in part of the Wyoming Valley, for the period April 26-30, 1974.

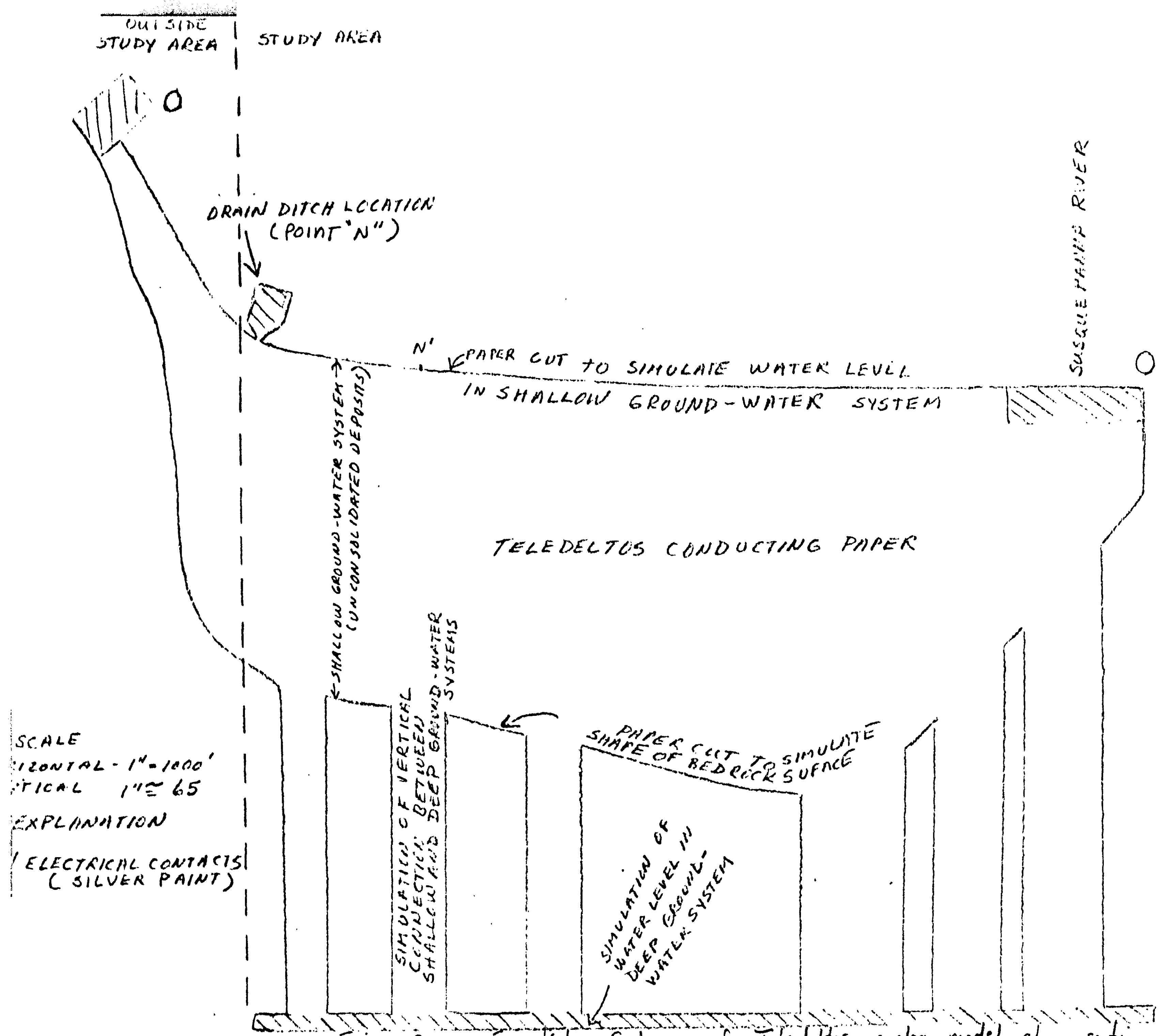

Figure 9 Essential features of Teledeltos analog model along section O-N-N'-O

FIGURE 9 ESSENTIAL FEATURES OF TELEDELTOS ANALOG MODEL ALONG SECTION O-N-N'-O