PERSPECTIVE ON GROUNDWATER FLOW AT SHEFFIELD

PREFACE

This report is a summary of the NRC staff understanding of groundwater flow at the Sheffield Illinois low-level radioactive waste disposal site. The report is for internal distribution and use only. It is expected that the information herein will be amended in the future as new data and analyses refine and increase our understanding of the site's behavior.

PERSPECTIVE ON GROUNDWATER FLOW AT SHEFFIELD

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Working Draft, 14 June 1985

INTRODUCTION

This report is a summary of the NRC staff understanding of groundwater flow at the Sheffield, Illinois low-level radioactive waste (LLW) disposal site. This understanding is based on a recently expired contract with the U.S. Geological Survey (USGS), meetings with USGS, Illinois State Geological Survey (ISGS), and Illinois Department of Nuclear Safety (IDNS) staff, available literature, and other sources.

Disposal at the site (see location map Figure 1) was authorized in 1967 and the last disposal took place in 1978. Disposal was in 21 shallow land burial trenches on the 20 acre site (Figure 2). Approximately 3 million cubic feet of wastes containing about 60,000 curies byproduct, 55 kilograms of special nuclear, and 600,000 pounds of source material were buried (Dragonette et al. 1979). In addition to operating the LLW facility, U.S. Ecology operates a closed hazardous waste landfill adjacent to the north-west corner of the site. Unlicensed disposal of industrial wastes took place outside the northern boundary of the site. Groundwater beneath these disposal locations is partially connected to the LLW site groundwater flow system.

Low concentrations of tritium have been found in wells onsite and offsite to the east. In particular, concentrations significantly above background, but below Maximum Permissible Concentration (MPC) limits, are found in a series of wells extending from the northeast corner of the site towards a strip mine lake about 500 feet from the site boundary. Figure 3 is a water table surface

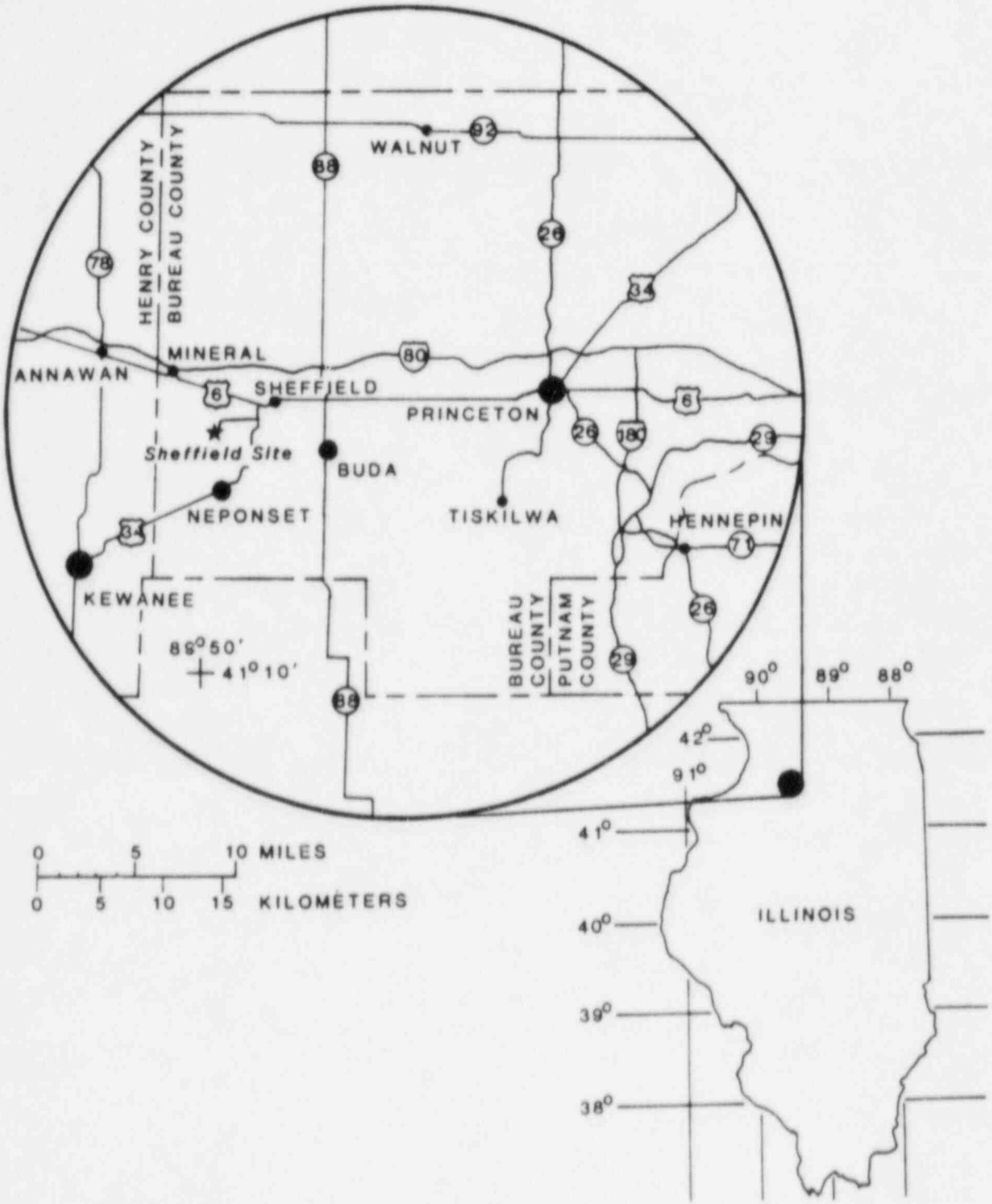


Figure 1.--Location of Sheffield low-level radioactive-waste disposal site.

(from Foster et al., 1984b)

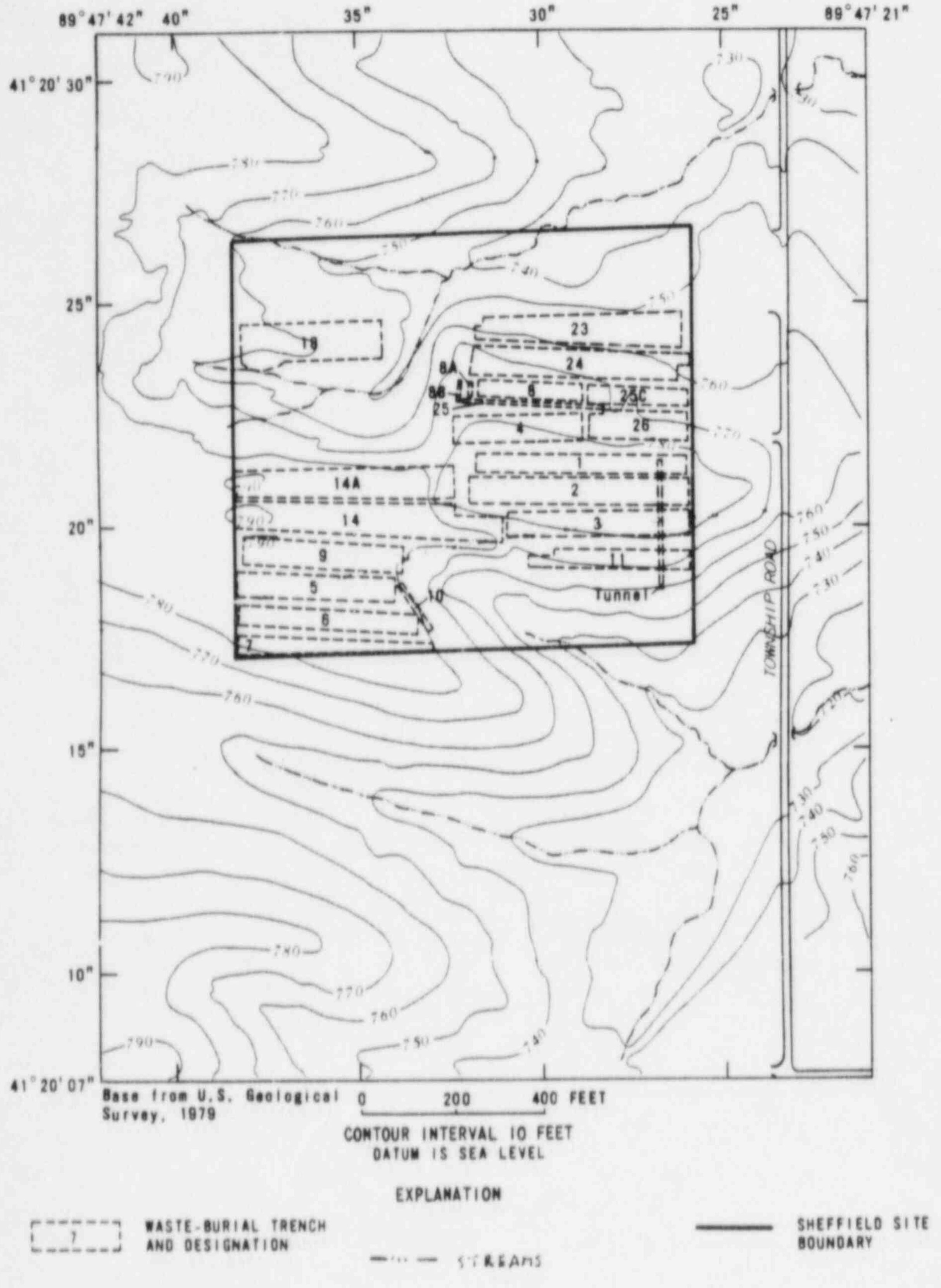


Figure 2.-- Waste-burial trenches, intermittent streams, and topography at Sheffield site.

(from Foster et al. 1984a)

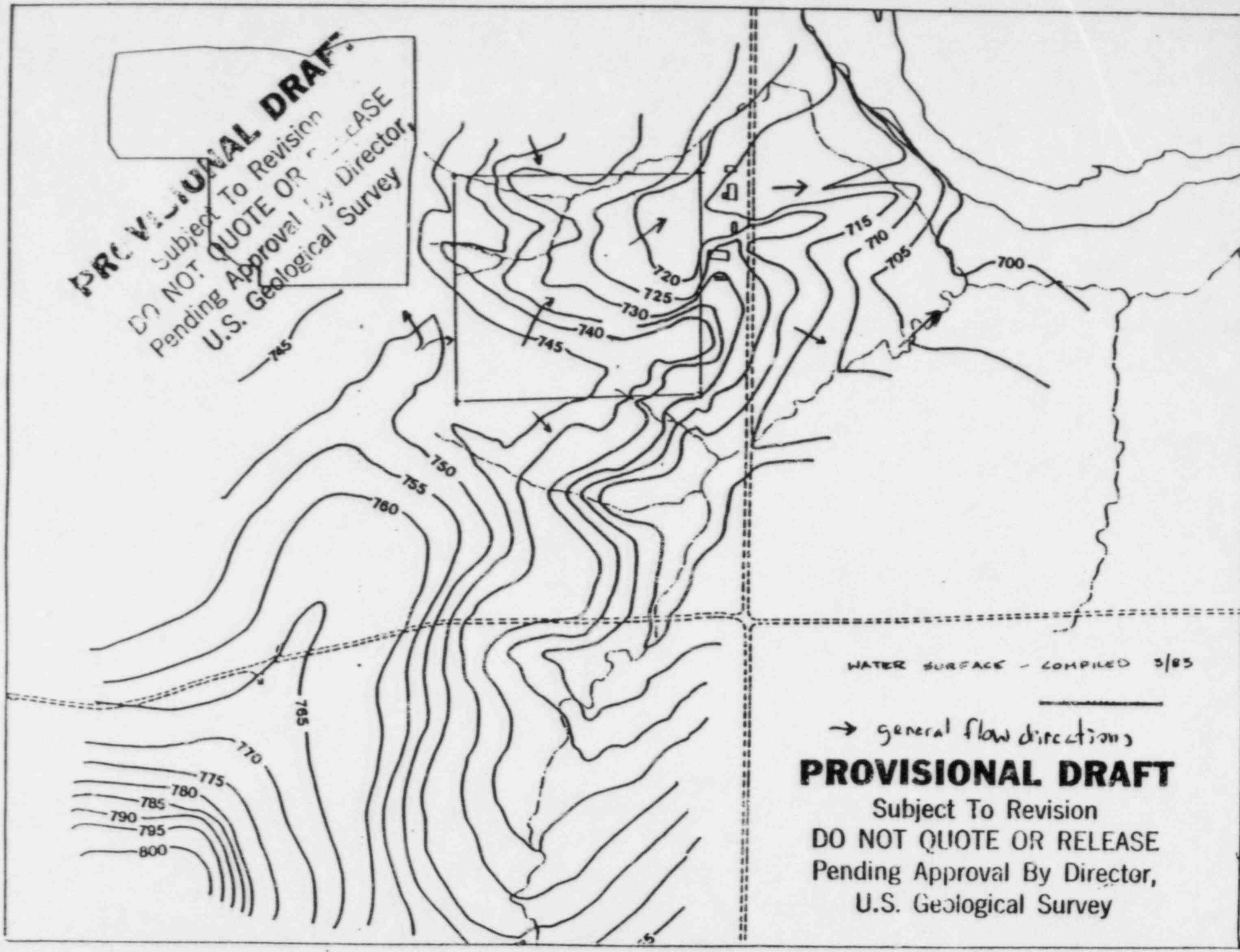


Figure 3. March '83 Water Table (ft MSL)

contour map compiled in March 1983 showing the general direction of groundwater flow from the site to the east towards the strip mine lake.

HYDROGEOLOGIC SETTING

The hydrogeology of the site has been investigated by the USGS. Foster and Erickson (1980) and Foster and others (1984a) describe the hydrogeology of the site area. Foster and others (1984b) describe the hydrogeologic setting of the area immediately east of the site. Much of the data on which these interpretations are based are presented by Foster and others (1984c). The geology of the site has been investigated using remote geophysics (ISGS, e.g. Larson et al. 1983) and boreholes (USGS). Figure 4 shows the location of cross-sections of the area east of the site based on USGS boreholes. Figures 5 - 8 are representative of the glacial geology of the site.

Groundwater is under water table (unconfined) conditions in the glacial and recent alluvial materials at the site. These units overlie shale bedrock which is weathered in the upper portion. The water table is generally more than 30 ft. below land surface and 5 ft. below trench bottoms, except at trench 18 (NRC 1981). The geologic units which control groundwater flow are described below, from bedrock up to surficial materials.

Bedrock in the site area is a shale of the Carbondale Formation of the Desmoinesian Series. The topography of this weathered shale is similar, though not identical, to the land surface topography. This formation is believed to isolate the shallow groundwater system from deeper aquifers (Foster et al. 1984a). However, NECO (1979a) reports an average hydraulic conductivity of 2.1 x 10^{-5} cm/sec from borehole tests in the weathered shale. This value is higher than values from tests in the tills (below). Also, coal seams exist in this unit; these seams have been mined locally. These seams are typically permeable and may form an alternative flow path for water that seeps through the overlying shale (K. Cartwright, ISGS, personal communication, January 1984). Figures 9 and 10 are bedrock topography maps for the area east of the site, and for the site proper, respectively.

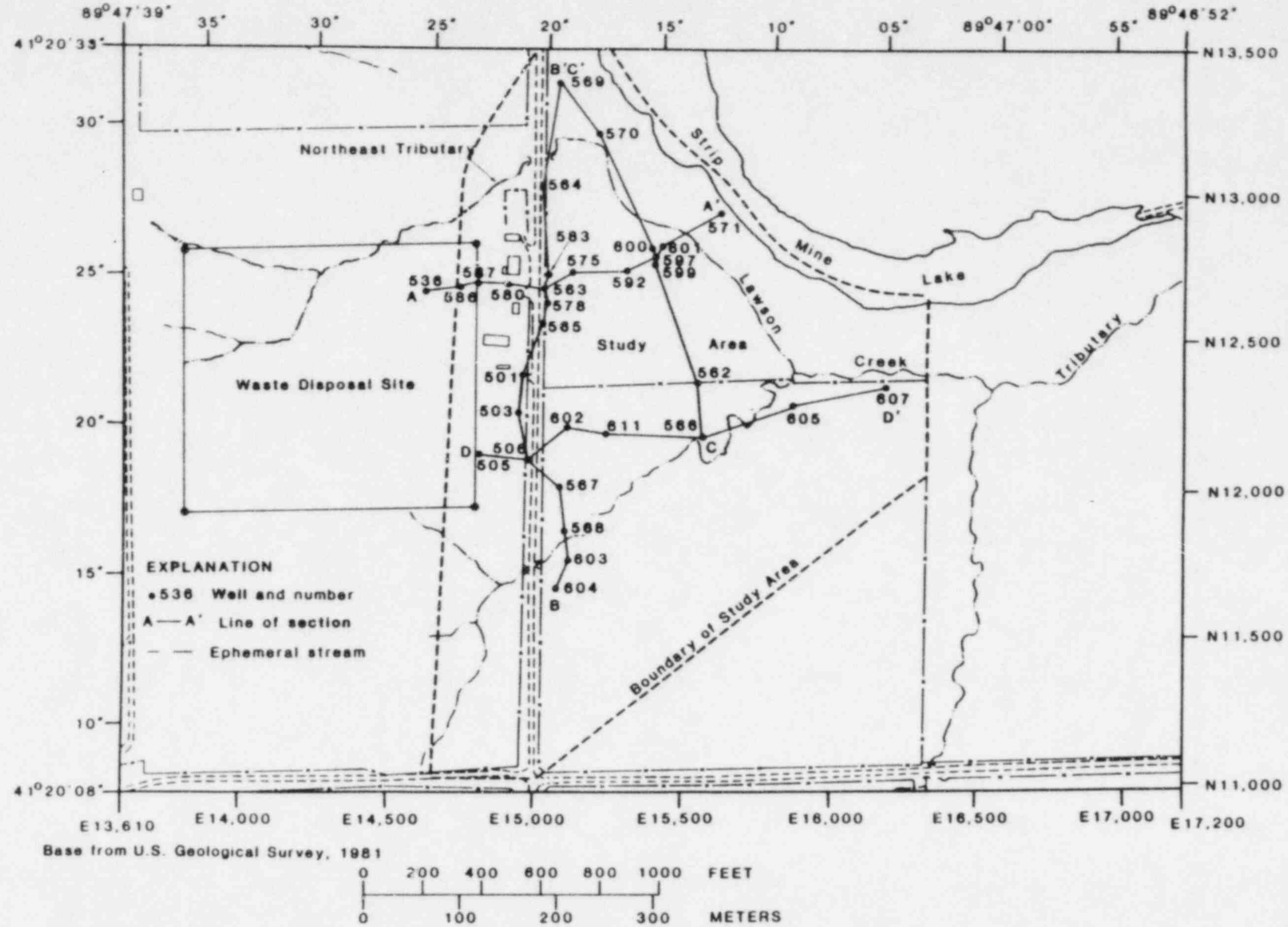
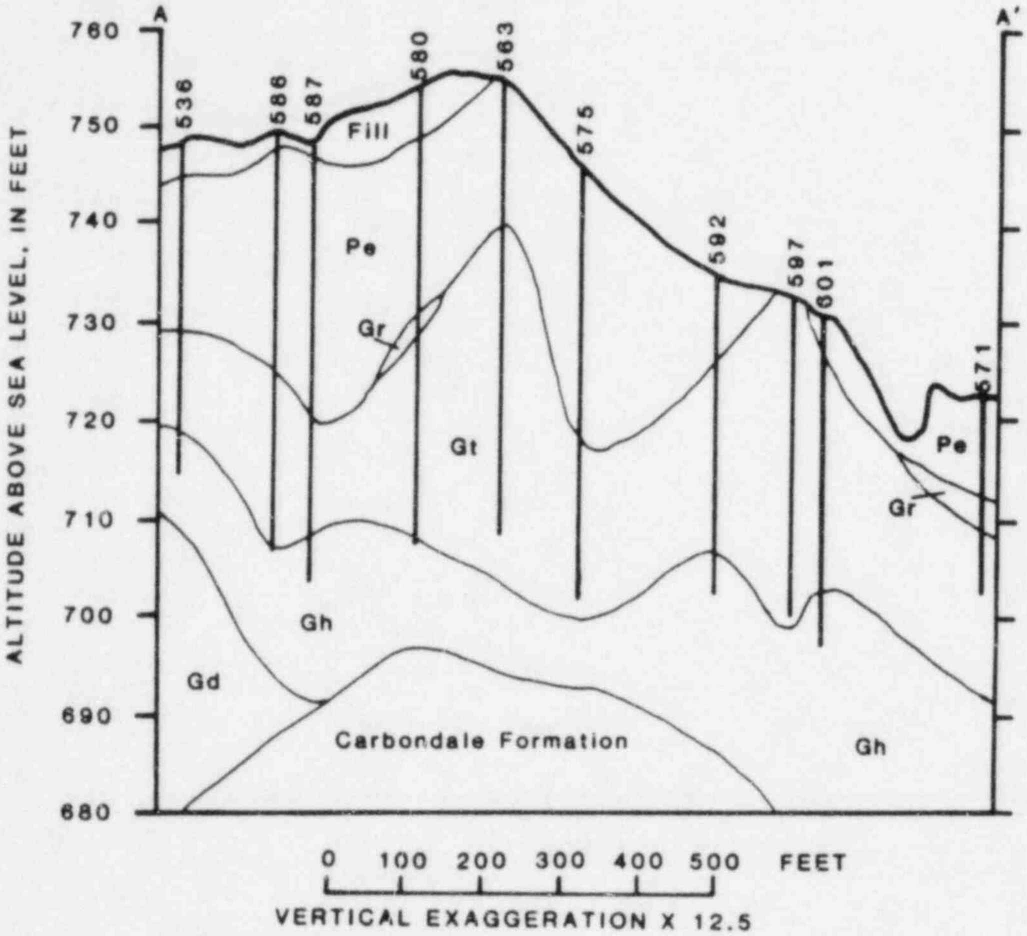


Figure 4.--Waste-disposal site, study area, drainage, and lines of section.
(from Foster et al. 1984b)



EXPLANATION

Pe - Peoria Loess

Gr - Glasford Formation, Radnor Till Member

Gt - Glasford Formation, Toulon Member

Gh - Glasford Formation, Hulick Till Member

Gd - Glasford Formation, Duncan Mills Member

Figure 5.--Geologic section A-A'.
(from Foster et al 1984b)

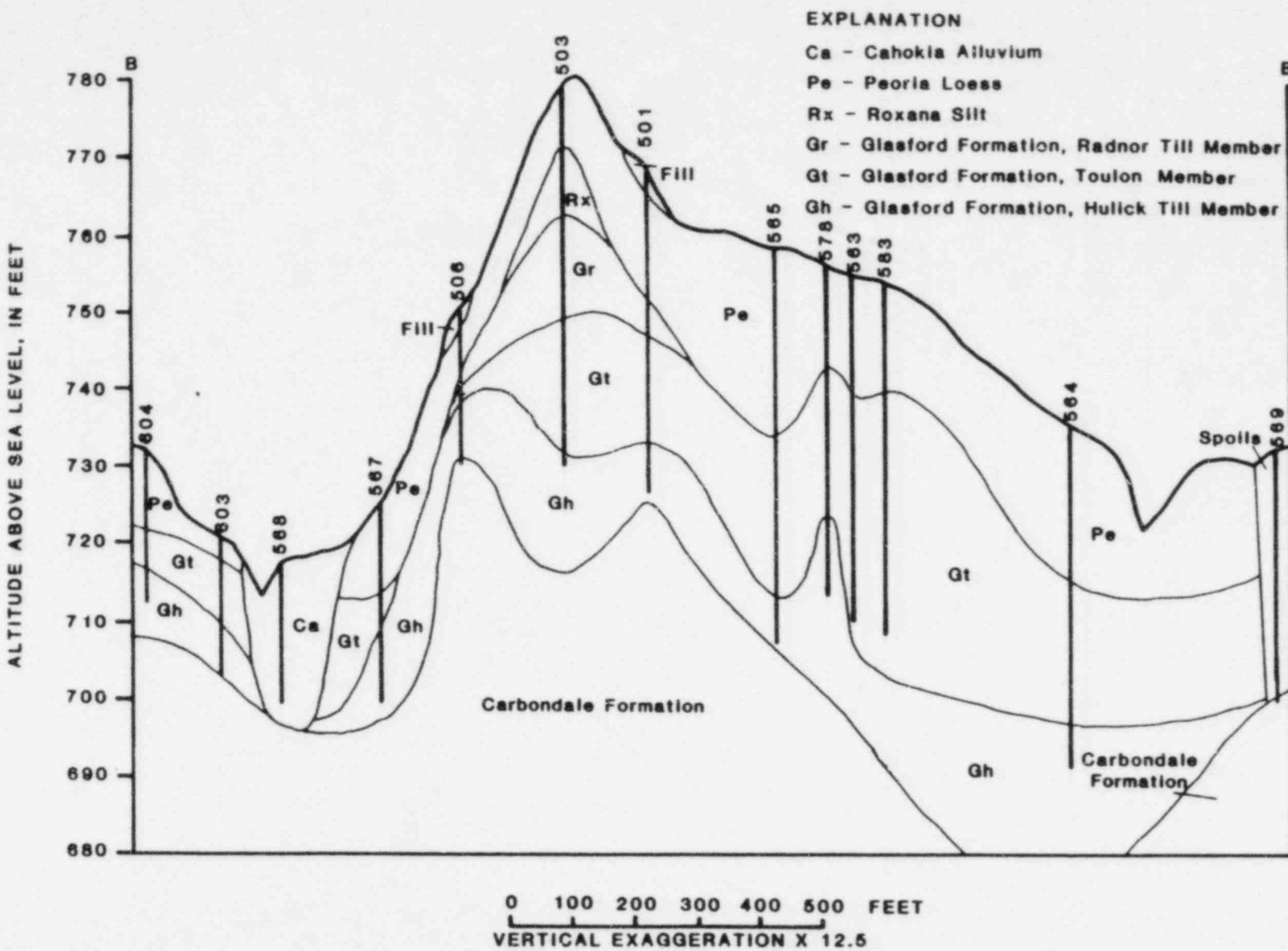
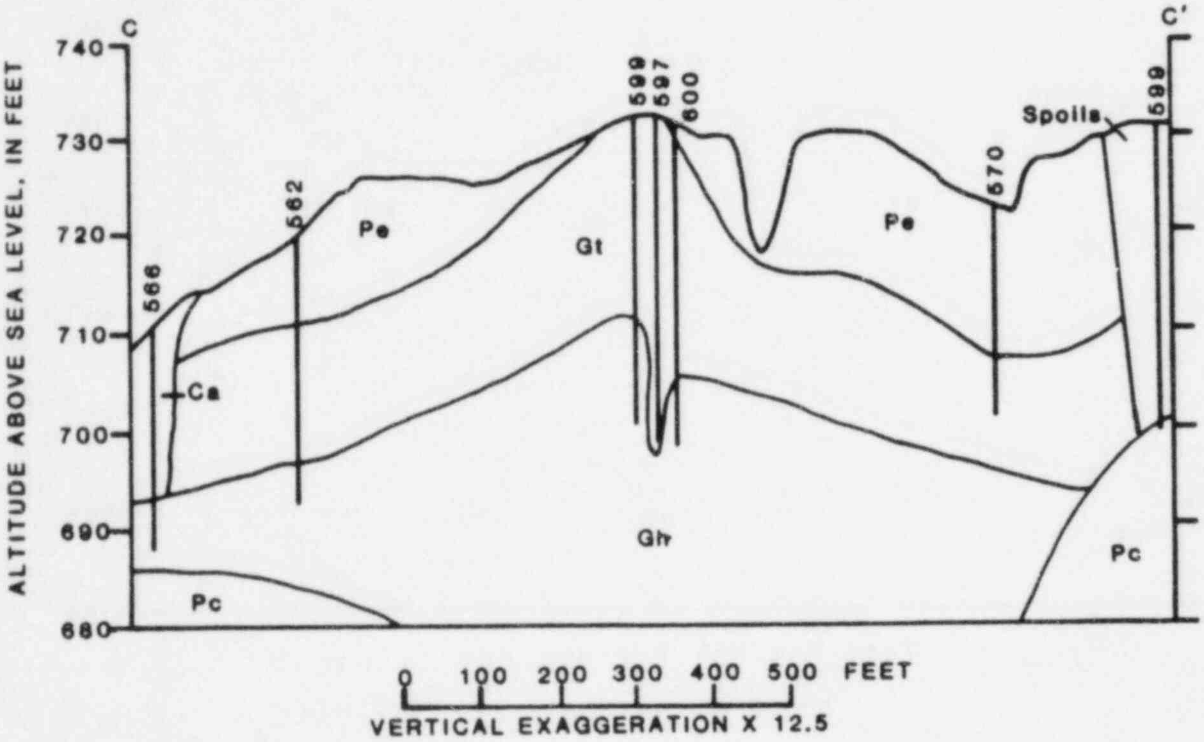


Figure 5'.--Geologic section B-B'.
(from Foster et al. 1984b)



EXPLANATION

Ca - Cahokia Alluvium

Pe - Peoria Loess

Gt - Glasford Formation, Toulon Member

Gh - Glasford Formation, Hulick Till Member

Pc - Carbondale Formation

Figure 7.--Geologic section C-C'.
(from Foster et al. 1984b)

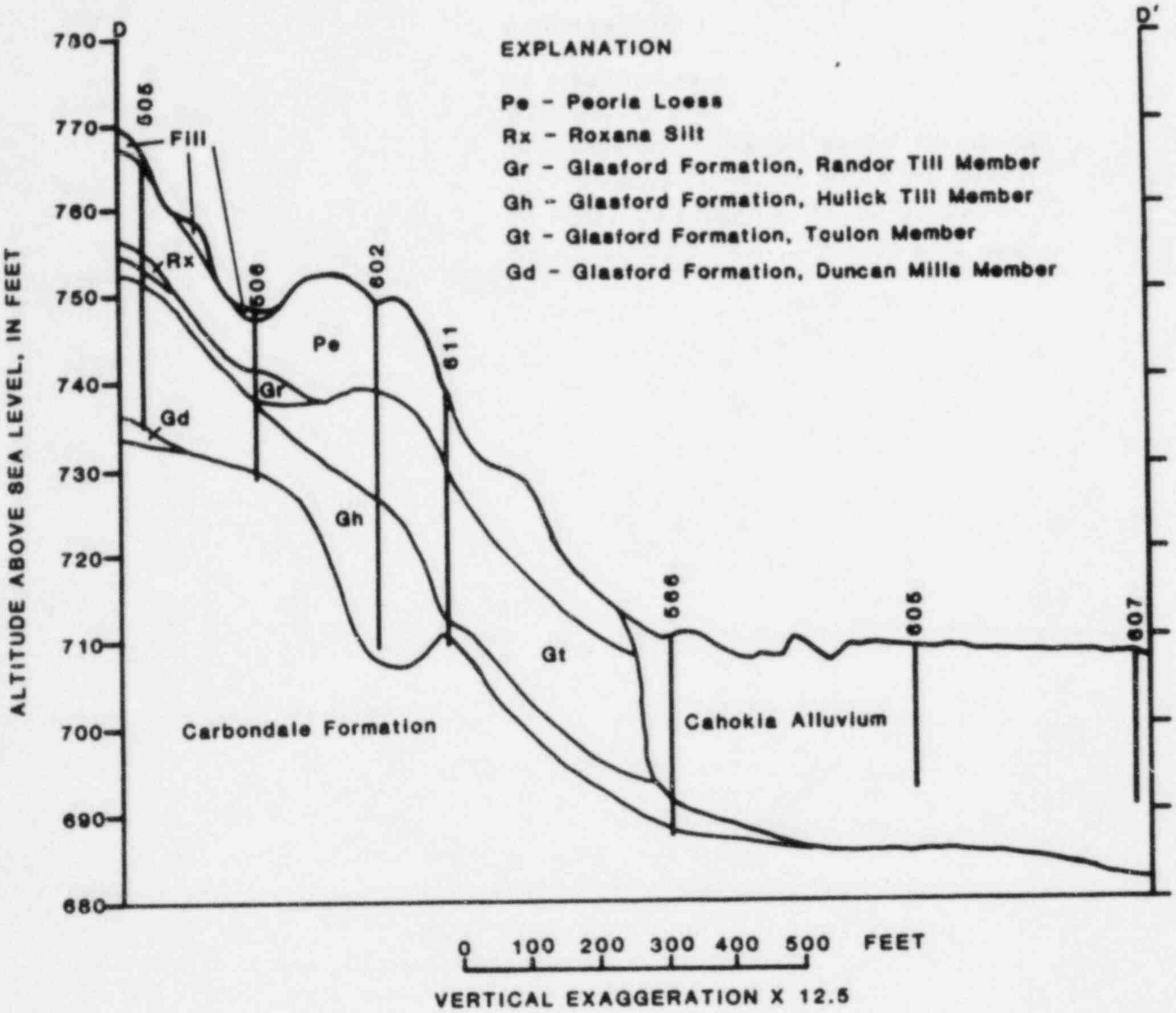


Figure 8.--Geologic section D-D'.
(from Foster et al. 1984b)

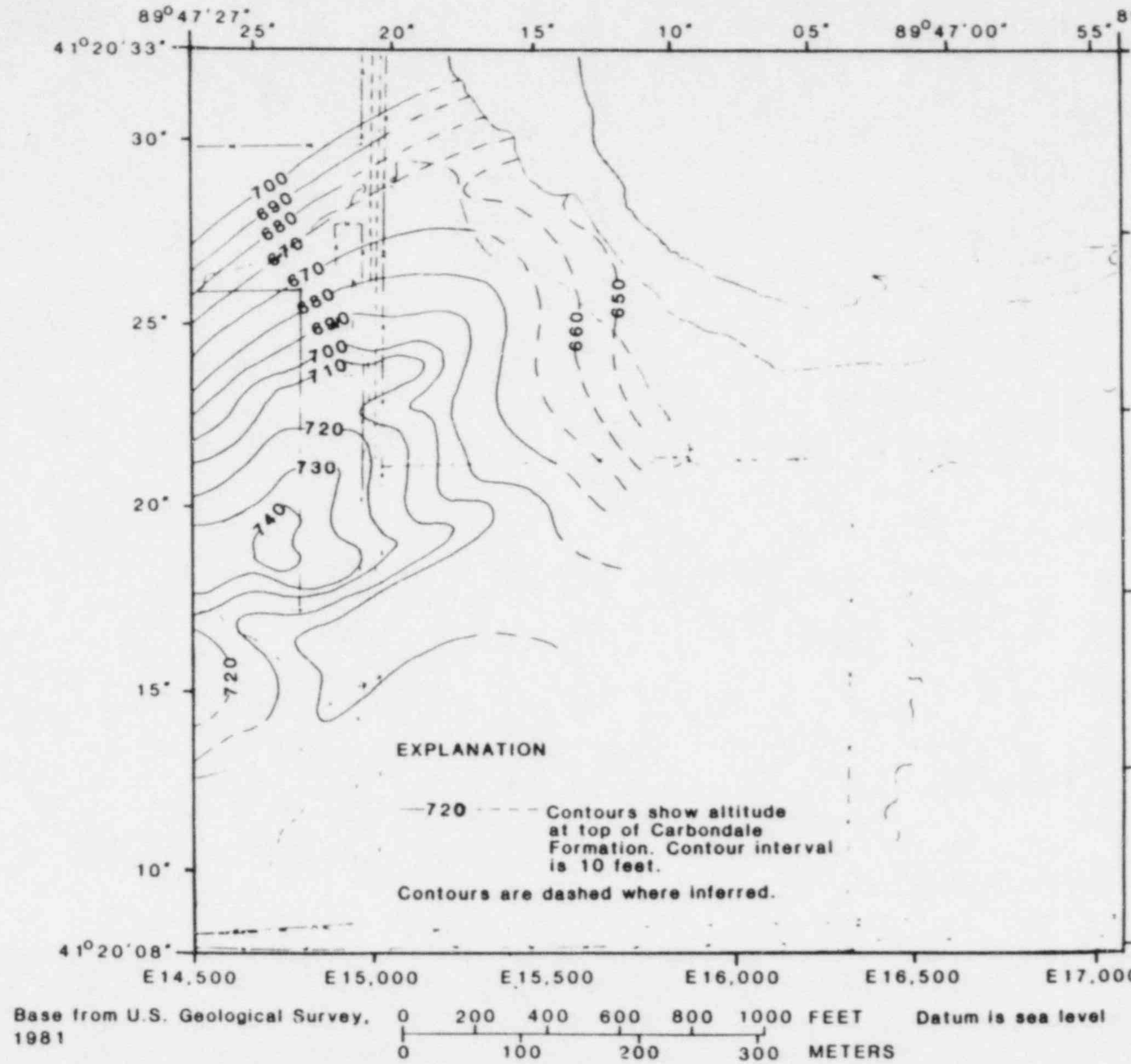
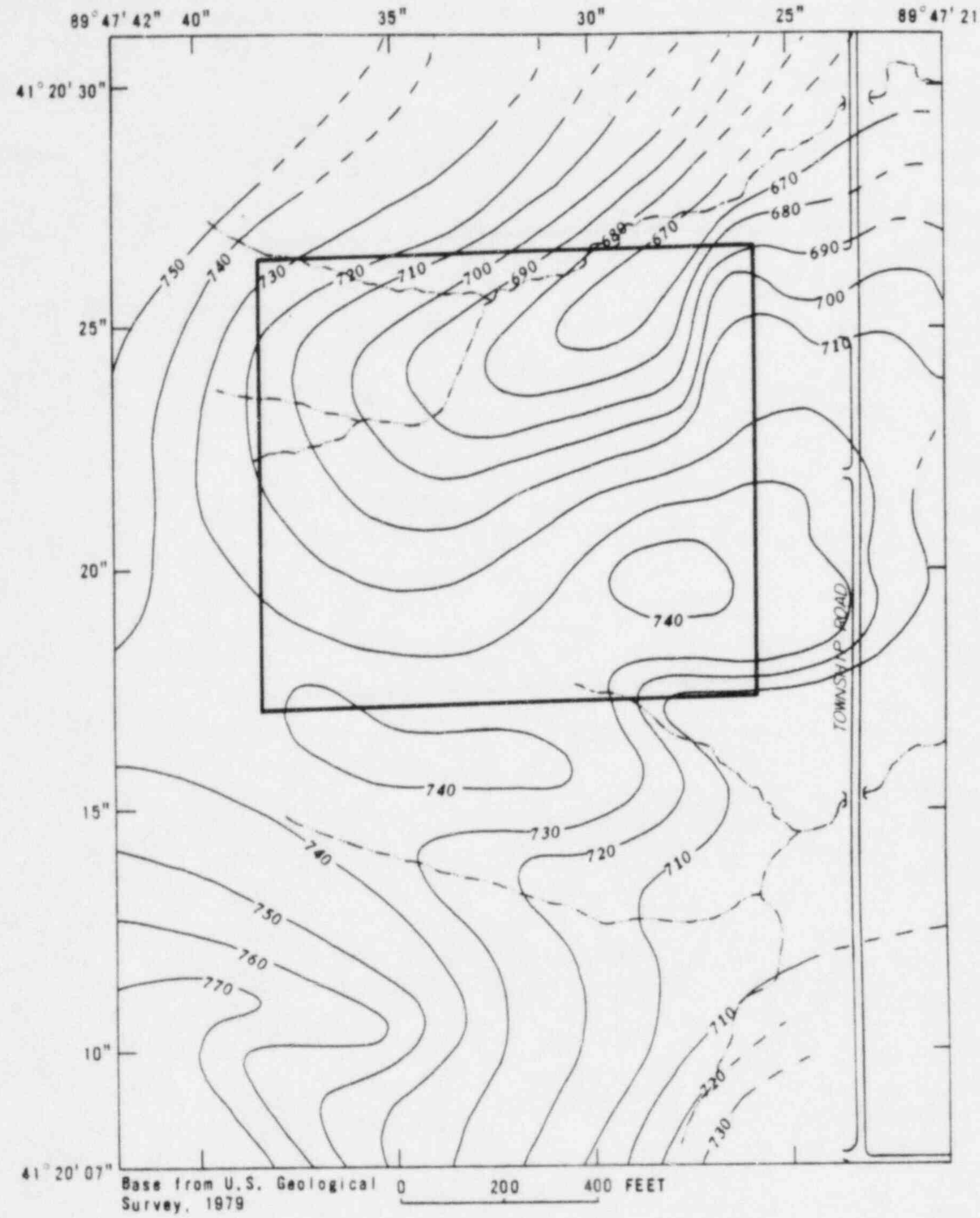


Figure .--Altitude of top of Carbondale Formation.
(from Foster et al. 1984b)



EXPLANATION

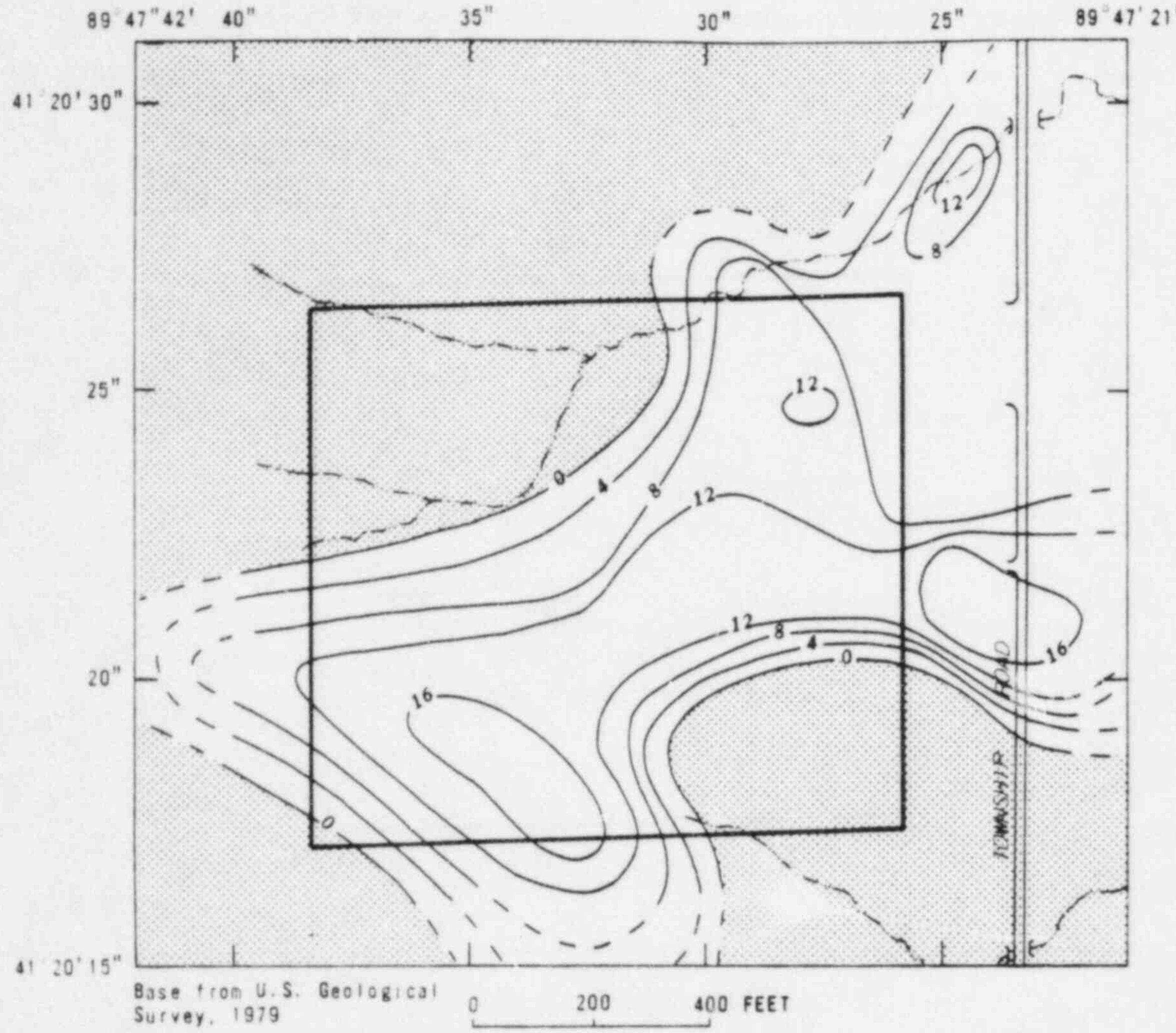
—— 720 — — BEDROCK CONTOUR -- Shows altitude of top of Pennsylvanian shale. Dashed where inferred. Contour interval 10 feet. Datum is sea level

Figure 10.-- Bedrock topography of Sheffield site.
(from Foster et al. 1984a)

Most of the geologic materials overlying bedrock are from glaciation. The Hulick Till lies unconformably on the bedrock and is composed of sand-silt-clay with some gravel layers. In the absence of gravel layers, the hydraulic conductivity of this member is relatively low. The licensee report that insitu variable head tests resulted in an average hydraulic conductivity of 2.9 x 10^{-6} cm/sec for site tills (Hulick and Radnor) (NECO 1979a). This till does not overlay bedrock in all locations and is on occasion seperated from bedrock by other members of the Glasford Formation, of which the Hulick is a member (see Figures 5 and 8).

The Toulon Member of the Glasford Formation consists of sand, silty-sand, and sand and gravel, and is the most permeable hydrogeologic unit at the site. Borehole tests indicate hydraulic conductivities as high as 10^{-3} cm/sec (NECO 1979a). Over much of the site, the bottom of the Toulon consists of a thin silt overlying the Hulick Till. In some areas (e.g. wells 578, 580, and 592) sands of the Toulon rest directly on the till. On the northeast corner of the site, a very narrow shallow depression in the till is filled by a pebbly-sand unit of the Toulon Member (see Figure 7). The extent and thickness of this unit is shown in Figures 11 and 12 for the site and area east of the site, respectively. The pebbly-sand unit is not present at the northwest and southeast corners of the site. The hydraulic conductivity of this unit is very high relative to other units at the site. Results of a natural gradient tracer test in the pebbly-sand unit indicate groundwater velocity of about 6.9 ft/day (2,500 ft/year) (Garklavs and Toler, 1985).

The high flow anomaly in the pebbly-sand unit is also indicated by geothermic measurements on the east side of the site (Larson et al. 1983). Similar studies on the other boundaries of the site indicate the possibility of a minor flow path off the north-east corner of the site (Heigold and Larson, 1984). The existence of this pathway is not supported by available hydrologic and concentration data. No other significant pathways are indicated by the geophysics investigations (Heigold and Larson 1984).



EXPLANATION

AREAL EXTENT OF PEBBLY-SAND UNIT

4 LINE OF EQUAL THICKNESS OF PEBBLY-SAND UNIT -- Toulon Member of Glasford Formation. Dashed where inferred. Interval 4 feet

Figure 11.-- Thickness of pebbly-sand unit of Toulon Member of Glasford Formation. (From Foster et al. 1984a)

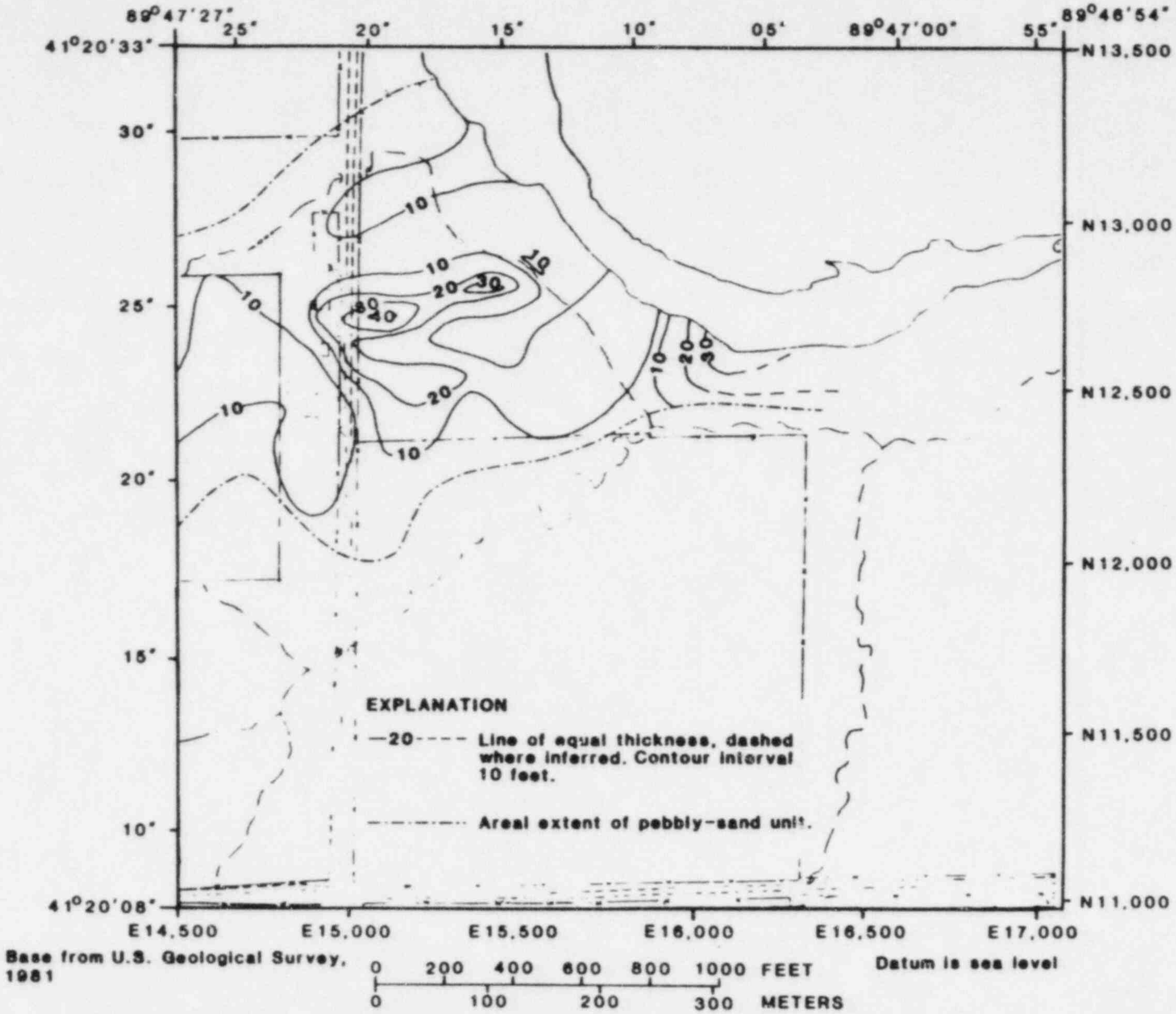


Figure 12.--Areal extent and thickness of pebbly-sand unit of Toulon Member of Glasford Formation.

(from Foster et al. 1984b)

The Radnor Till Member of the Glasford Formation occurs near the strip mine lake and the southern portion of the site. This till consists of clayey silt with intermingled coarse materials. The Peoria Loess, silt and clayey-silt, covers the entire site outside of eroded stream channels. The LLW disposal trenches are constructed in the loess unit. The Cahokia Alluvium occurs beneath a tributary to Lawson Creek in wells 605 and 607 to the south of the site (see Figure 8). This recent alluvium is clayey silty-sand of high permeability and acts as a groundwater drain for the southeast corner of the site.

Of the average annual precipitation of 36 inches, an average of 1 to 3 inches is estimated to recharge local groundwater. Most recharge occurs in the early spring when precipitation is high and plant evapotranspiration and surface evaporation are low. In addition, spring snowmelt may contribute a significant portion of annual recharge, depending on climatic conditions.

FLOW MODELING

The modeling described below is currently being expanded by the USGS to include a larger area, incorporating the southeast and southwest areas of the site. Dames & Moore (1979) developed a water balance model of the site and used a streamline model to predict radionuclide concentrations at the site boundary. In a cooperative agreement, Johnson and Grant (1980) applied 2 simple transport models to the site. Neither of these efforts included the pebbly-sand unit which (it was subsequently discovered) is the primary pathway for groundwater from the site.

Groundwater flow at the site is conceptualized by the USGS as single layer unconfined horizontal flow in the porous glacial materials. A computer program developed by R.L. Cooley (USGS, Denver) and employing the finite element method is used to solve the groundwater flow equations. Only steady-state flow is simulated. Based on the geologic setting and groundwater flow patterns, the site has been modeled as three seperate basins. The boundaries between these basins are groundwater divides (no flow boundaries) in relatively low

conductivity materials. Since these seperate areas are composed of similar geologic media, and are in reality hydraulically connected, the boundaries, material properties, and recharge values used must be consistent from basin to basin. The discussion below is limited to the two basins (1 and 2) which include all groundwater flow from the site except a minor flux to the southwest (Figure 13).

Basin 1

Basin 1 includes most of the site and all areas in which the high permeability sand unit (Toulon Member) is saturated. The model grid consists of about 700 nodes and 660 elements. No flow groundwater divide boundaries are assumed on the north, west, and south boundaries. Along the east boundary, at the strip mine lake, the piezometric head is fixed at the lake level.

The hydraulic conductivities of the aquifer have been determined through calibration of the steady state model. Since no measurements of flux are available, these calibrated values are directly related to the recharge assumed for the model. The best match between observed and simulated piezometric heads has been obtained by dividing basin 1 into six zones with different hydraulic conductivities and recharge values. Saturated aquifer thickness, which is multiplied by conductivity to yield transmissivity, has been specified at every node from field data. Saturated thickness was not adjusted during model calibration. Table 1 lists the best calibrated values for the zones shown in Figure 14. Zones 1, 4, and 5 correspond to areas where the sand unit does not exist or is unsaturated. The sand is exposed at the surface in zones 2, 3, and 6 and hence recharge values are much higher. In addition, zone 3 represents a topographic low which acts as a surface drainage basin for a significant portion of the site. Zone 6 is the saturated area of the very high conductivity pebbly-sand unit of the Toulon Member.

The major conduit for groundwater from the site is the pebbly-sand unit to the northeast corner of the site (zone 6). Simulated velocities in this zone of up to 2000 ft/yr agree with observations from a tracer test performed by the

Attachment I - showing approximate model and zone boundaries

- · - Model boundaries

- - - - Zone boundaries

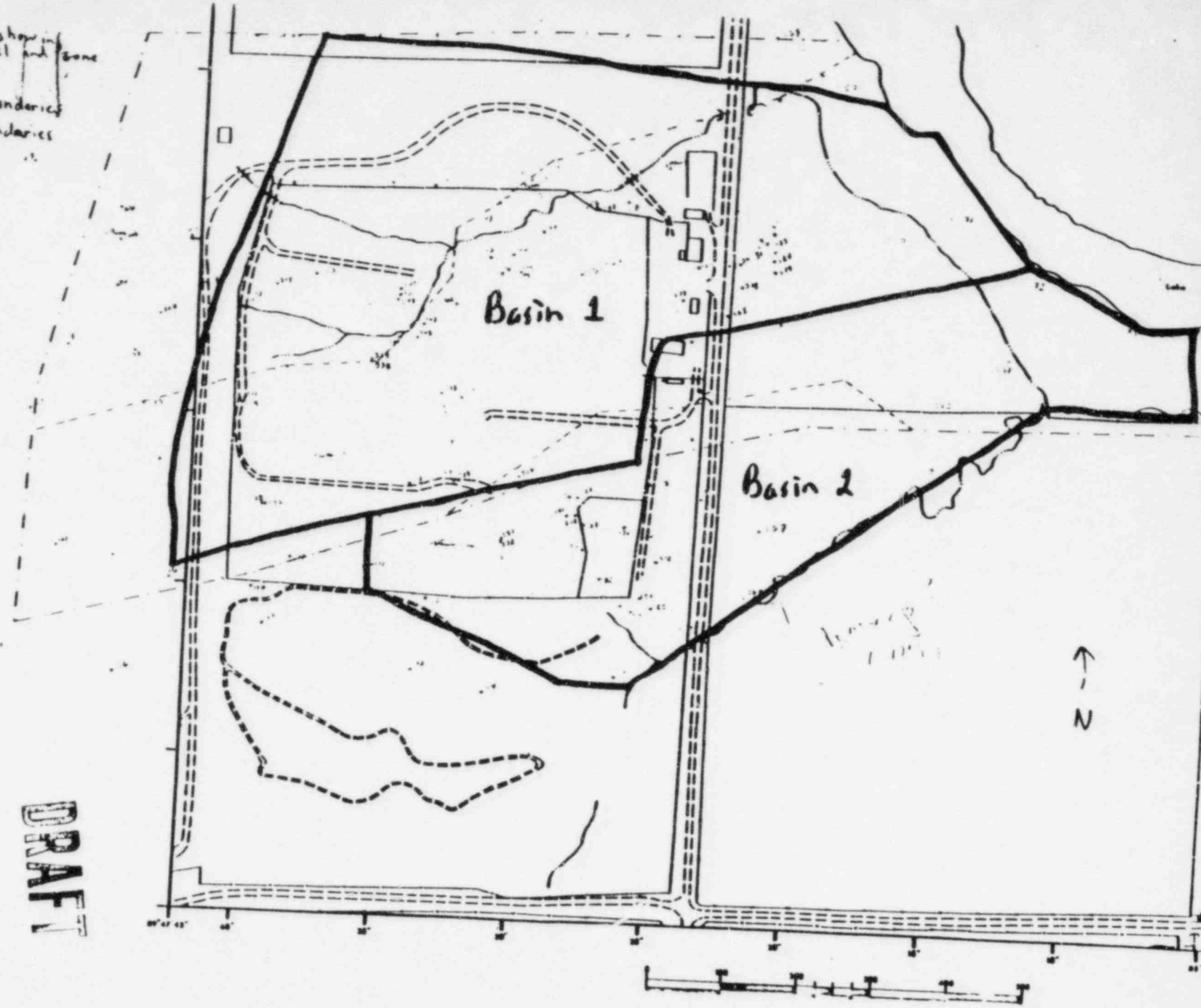


Fig ~~14~~ 13 Model Basins

TABLE 1

Calibrated Parameters for Basin 1 of the USGS groundwater flow model

Zone	Hydraulic Conductivity (ft/sec)	Recharge (in/yr)
1	1.5 E-6	1.0
2	1.4 E-4	5.3
3	1.4 E-4	26.5
4	5.0 E-5	1.0
5	2.0 E-5	1.0
6	1.4 E-3	5.3

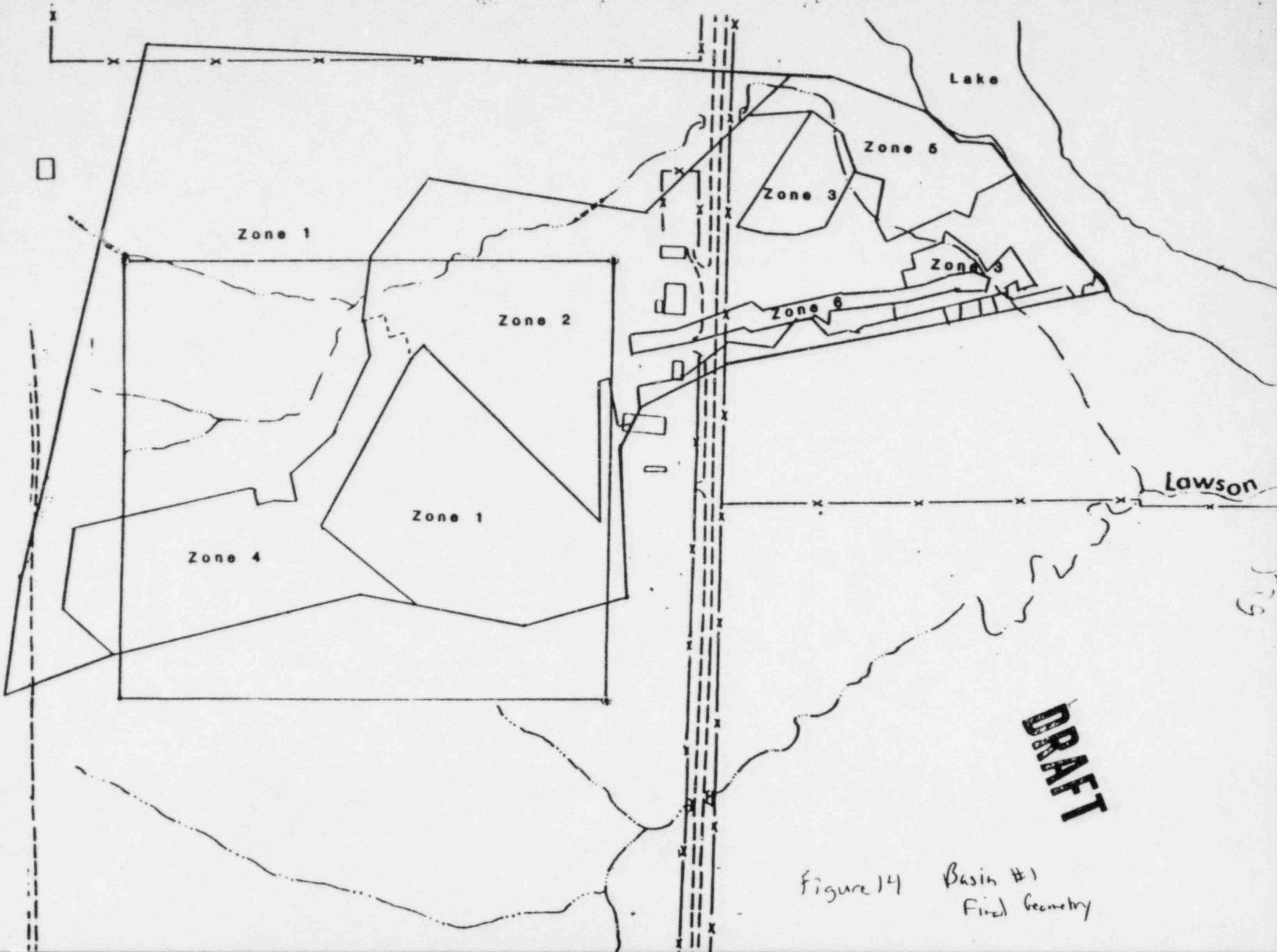


Figure 14 Basin #1 Final Geometry

USGS in the pebbly sand channel (Garklavs and Toler 1985). Approximately 70 percent of the flow leaving the site occurs in this extremely narrow subsurface channel. Although this zone does not extend comletely to the strip mine lake, all flow from this channel, and the entire basin, discharges to the lake.

Basin 2

Basin 2 represents the southeast portion of the site and the area from the site south to the stream bed (see Figure 13). A channel of thick alluvial sand deposits beneath the stream bed acts as a drain for groundwater leaving the site to the southeast. This boundary condition is approximated as a fixed head boundary which assumes that the stream is flowing (at steady state) and that that flux leaves the groundwater system. If the stream is not flowing, the flux which is computed to leave the system actually flows northeast in the channel to the strip mine lake, where it discharges along with all other groundwater from the site. In any case, this approximation has little effect of computation of flow from the site since the conductivity of the alluvium channel is much higher than that of the tills. As in Basin 1, the lake is modeled as a fixed head boundary, and all other basin borders represent no flow groundwater divide boundaries.

This basin has been divided into 3 zones for calibration of the model (Figure 15). Zone 1 represents the channel of sand beneath the stream and has a hydraulic conductivity and recharge similar (identical?) to that for Basin 1 zone 2. Zone 2 of Basin 2 represents areas in which the sand is unsaturated and corresponds to Basin 1 zone 5. Finally, zone 3 of Basin 2 is composed of low conductivity till and has a hydraulic conductivity and recharge similar to that for Basin 1 zone 1.

Flow from the site to the southeast accounts for less than one third of the total flow from the site. Groundwater velocities in the till, where the sand is not saturated, are very low. Groundwater that does seep through the tills discharges into the buried stream channel which acts as a drain for the entire southeast portion of the site. This channel also drains areas to the

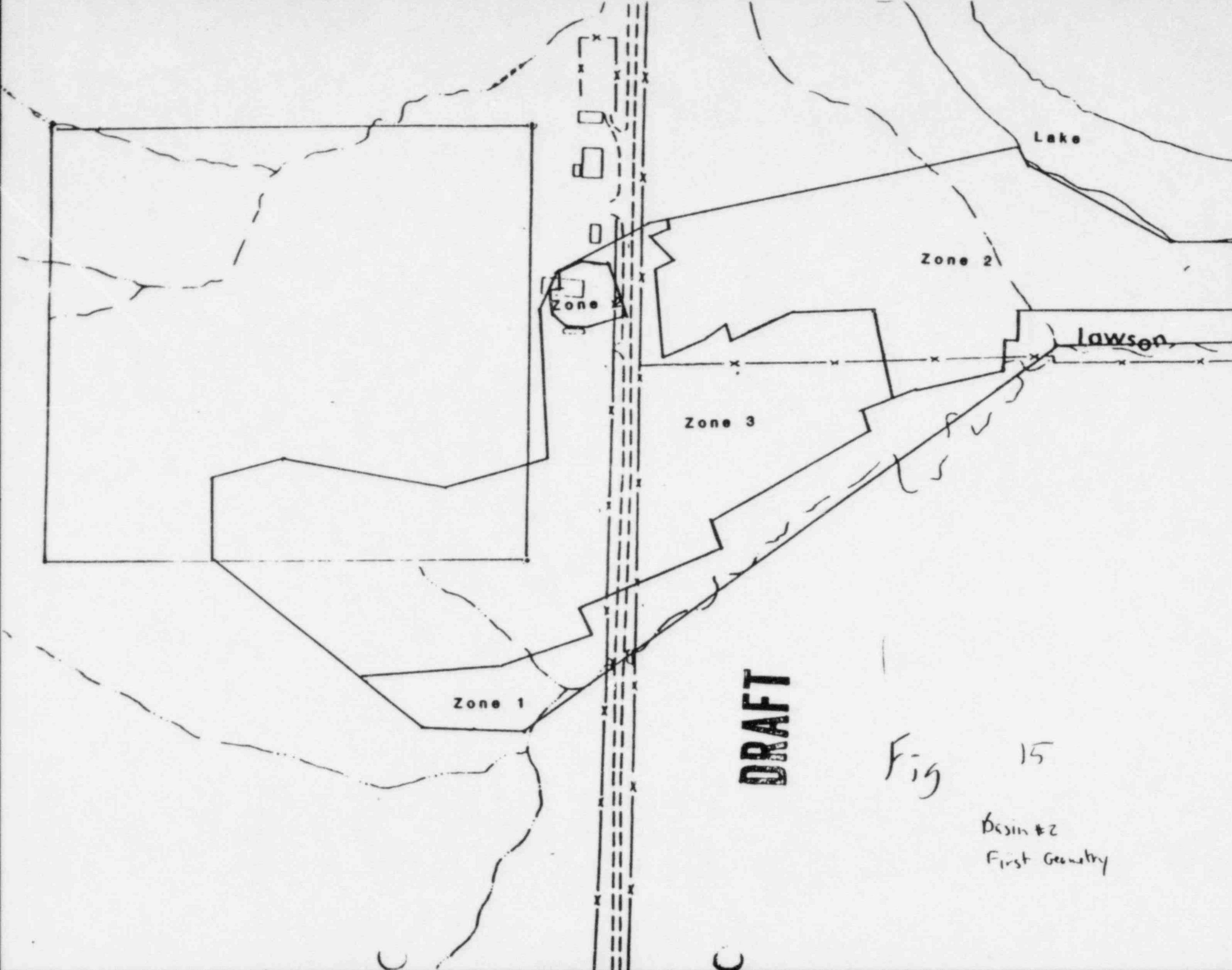


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Fig 15

Basin #2
First Geometry

south of the stream (see Figure 3) and thus no groundwater movement occurs from one side of the stream to the other.

SOLUTE TRANSPORT

Tritium has migrated from the disposal units at Sheffield. Figure 16 indicates wells with relatively high activities of tritium. The two locations with highest activities are the pebbly sand unit draining the site (wells 563 and 575) and well 523 next to Trench 11. The latter is screened in the low-conductivity till and does not appear to represent a significant release because the groundwater flow rate is very low. However, concentrations at this location are continuing to increase and may eventually be of a regulatory concern. The tritium plume in the pebbly-sand unit towards the strip mine lake is confined to a width of 30-50 ft which is slightly larger than the width of the unit itself (Garklavs and Toler 1985). Since this unit drains the area, tritium within the unit is carried downgradient and is not released to adjacent areas. The occurence of tritium offsite only in this pebbly-sand unit supports the hypothesis of the unit acting as a subsurface drain.

Other constituents are also being released from the disposal units. Sampling by the ORNL under contract to the NRC indicated increased concentrations of several indicators and organic chemicals in wells at Sheffield. These wells included the wells identified above with high tritium levels. Although none of these concentrations are high enough to be of a health concern, they do indicate release from the trenches. These releases appear, on the basis of available information, to follow the same pattern as tritium releases except that adjacent disposal activities may be a source for chemical constituents in the north half of the site.

UNCERTAINTY

There are at least three processes or levels of detail which have not been investigated in detail. These are: flow in the bedrock, or units within or below the Carbondale shale; lateral unsaturated flow in the tills and clays;

SHEFFIELD WELL SITES

BLOW UP OF SITE
STATUS AS OF JULY 1983

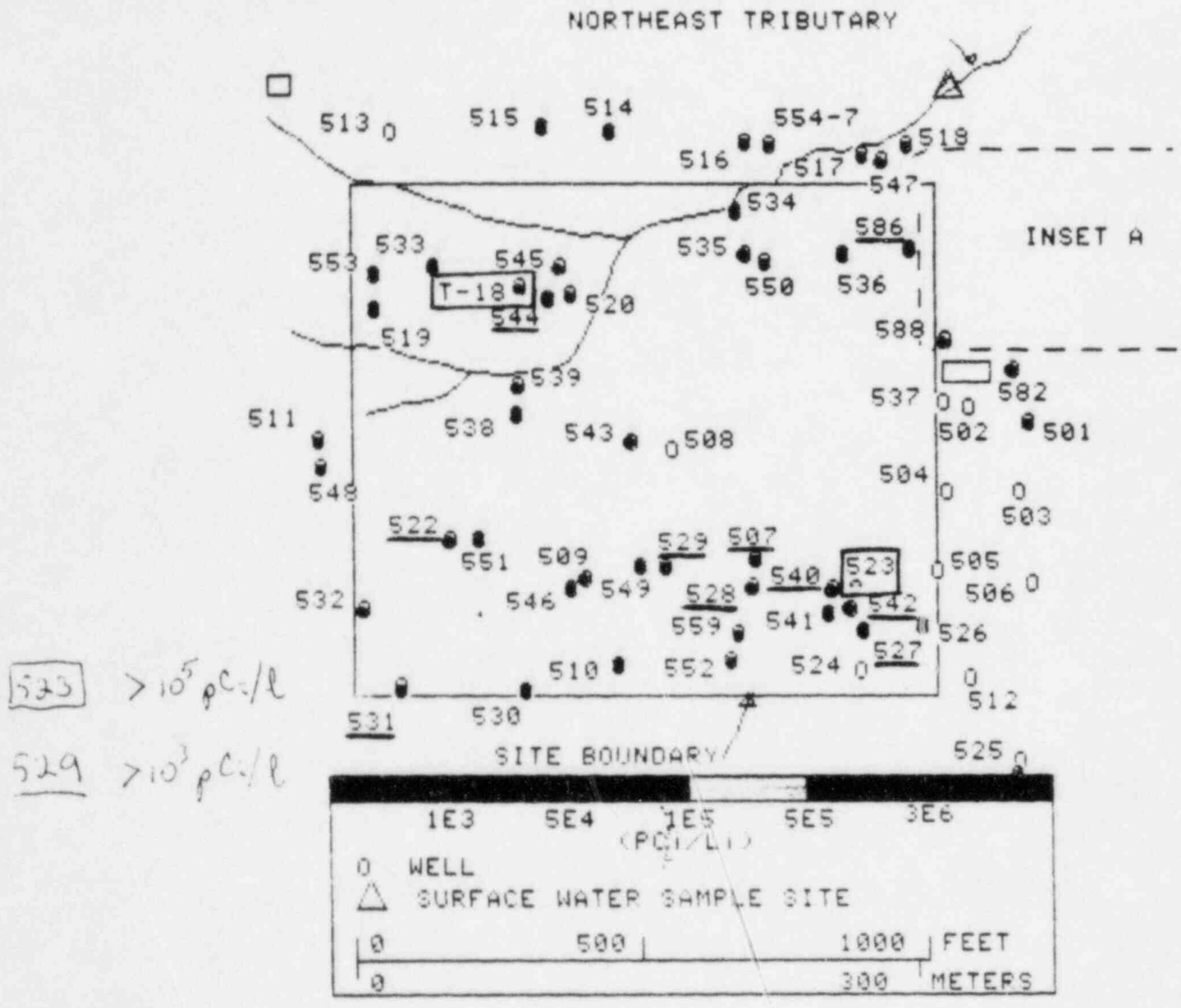


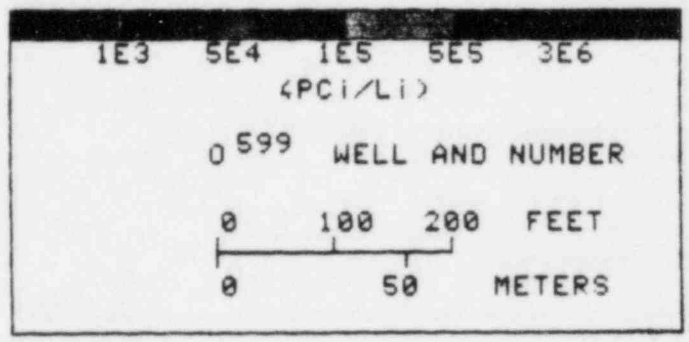
Figure 16a. Tritium levels in USGS wells onsite (from K Hamel, IDNS, personal communication, 1984)

SHEFFIELD WELL SITES

INSET A
STATUS AS OF JULY 1983

[563] > 5 x 10^4 pCi/l

583 > 10^3 pCi/l



INSET A

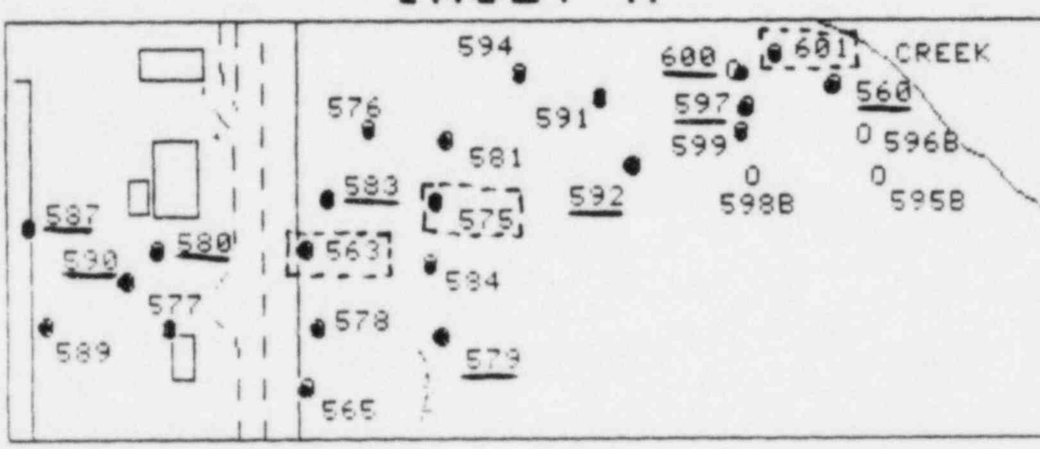


Figure 16b. Tritium levels in USGS wells in offsite plume.
(from M. Hamel, IDNS, personal communication, 1984)

SHEFFIELD WELL SITES

and, alternative stratigraphies in the glacial materials. These processes do not appear significant in terms of groundwater flow, based on available data and the success in modeling the site as a single layer water table aquifer. However, they may important when investigating solute transport. With regard to alternative stratigraphies, past experience indicates that each new borehole will yield some alteration in our conceptualization of the system. Fortunately, the site investigation has advanced to a stage at which those additional changes would have little effect, if any, on our assessment of the site as a LLW disposal site.

SUMMARY

The groundwater flow system at the Sheffield LLW disposal site has been investigated by the USGS, ISGS, and the licensee. These investigations have included over 150 boreholes, most of which have been developed as monitoring wells, and resistivity and temperature surveys. The USGS has modeled the site as a single layer water table aquifer using a steady state finite element model. Approximately 70 percent of the groundwater leaving the site does so through a very narrow pebbly-sand channel which extends from the northeast corner of the site towards a strip mine lake. All groundwater discharging from the site eventually flows into this lake through the pebbly-sand, through a buried stream bed to the south of the site, or through other, lower conductivity units.

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