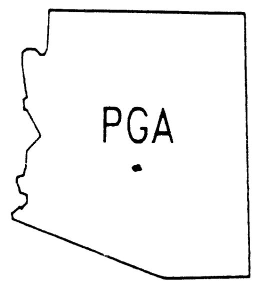
ARIZONA DEPARTMENT OF WATER RESOURCES

# PHOENIX-GOODYEAR AIRPORT GROUNDWATER FLOW AND CONTAMINANT TRANSPORT MODEL

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HYDROLOGY DIVISION

MODELING REPORT NO. 5

ARIZONA DEPARTMENT OF WATER RESOURCES

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# Phoenix-Goodyear Airport
# Goodyear, Arizona

## Groundwater Flow and Contaminant Transport Model

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**Phoenix-Goodyear Airport Contaminant**

**Transport Modeling Report**

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## I. Executive Summary

Groundwater contamination, specifically trichloroethylene and other volatile organic compounds, was found in the vicinity of the Cities of Goodyear and Avondale and the Phoenix-Goodyear Airport Site was placed on the National Priorities List in 1983. In 1984, the Arizona Department of Water Resources entered into a Cooperative Agreement with the U.S. Environmental Protection Agency to develop and operate a computer model of the geohydrologic system for the Phoenix-Goodyear Airport area as part of the overall Remedial Investigation/ Feasibility Study. This model is used to evaluate the Remedial Alternatives for the Endangerment Assessment portion of the Feasibility Study. It was not used for source identification or verification.

A detailed groundwater investigation to support the modeling study was undertaken. The information presented in this report is the result of that effort. Given the limitations of the available data, the groundwater flow modeling results achieved a reasonable match between simulated and observed parameters. A detailed sensitivity analysis was conducted to determine the geohydrologic parameters considered to impact the flow and transport model results. The results of the sensitivity analysis illustrated that order of magnitude changes in parameters such as horizontal hydraulic conductivity of sub-unit A and storage terms had little or no effect on the flow model predictions. Also brought out by the sensitivity analysis was that those parameters that significantly affected the flow model results (i.e., horizontal hydraulic conductivity) were factors known with more certainty based on field data.

The modeling feasibility study was conducted under three different Base Cases of future water use. Base Case 1 is very conservative and assumes continued agricultural pumpage and the addition of all the City of Goodyear's proposed wells under its water masterplan but does not include the Section 16 Operable Unit Feasibility Study. The Section 16 Operable Unit was designed by ICF Technology, Incorporated for Goodyear Tire and Rubber Corporation to remediate the contamination in Sub-unit A of the Upper Alluvial Unit Aquifer at the Phoenix-Goodyear Airport. Base Case 2 assumes continued agricultural recharge and pumpage, and includes the Section 16 Operable Unit. Base Case 3, probably the most realistic scenario, phases in the City of Goodyear's proposed wells and phases out agriculture and related pumpage and recharge in accordance with the City of Goodyear's urbanization projections. This Base Case also includes the Section 16 Operable Unit.

The results from the groundwater extraction alternatives for each Base Case are presented in Table 1. An accelerated reduction of contamination to meet Applicable or Relevant and Appropriate Requirements (ARAR's; Alternative 4) showed the greatest percent reduction in contamination, ranging from 81 to 83 percent for Base Cases 2 and 3, respectively. This was accomplished by pumping 3600 acre-feet (ac-ft) of groundwater per year from three additional remediation wells. However, a reduction of contamination to meet ARAR's (Alternative 3) resulted in a 75 percent reduction in contamination for both Base Case 2 and 3 by the addition of one remediation well pumping 1200 ac-ft of groundwater per year (see Table 1).

| TABLE 1<br>COMPARISON OF GROUNDWATER EXTRACTION ALTERNATIVES FOR BASE CASES 1, 2 AND 3 | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Alternatives** | **Initial Mass of Solute in Groundwater for all Sub-units (Gallons TCE)** | **Remaining Mass of Solute After 21 Year Projection Run (Gallons TCE)** | | | **Percent Reduction in Contamination** | | |
| | | ***Base Case 1*** | ***Base Case 2*** | ***Base Case 3*** | ***Base Case 1*** | ***Base Case 2*** | ***Base Case 3*** |
| Alternative 1<br>No Action Alternative | 1280 | 1065 | 325 | 309 | 18% | 75% | 76% |
| Alternative 2 *<br>Containment of Groundwater | | | | | | | |
| Alternative 3<br>Reduction of Contamination to meet ARAR's | 1280 | 1070 | 315 | 316 | 17% | 75% | 75% |
| Alternative 4<br>Accelerated Reduction of Contamination to meet ARAR's | 1280 | 896 | 247 | 220 | 30% | 81% | 83% |
| Alternative 5<br>Reduction of Contamination to Exceed ARAR's | 1280 | 896 | 288 | 275 | 23% | 77% | 78% |
| Alternative 6<br>Accelerated Reduction of Contamination to Exceed ARAR's | 1280 | 1022 | 283 | 306 | 20% | 78% | 76% |

* Alternative 2 not run at this time.

## II. Introduction

### Background

In 1981 the Arizona Department of Environmental Quality (ADEQ; formerly the Arizona Department of Health Services) sampled groundwater wells in the vicinity of the Cities of Avondale and Goodyear and the Phoenix-Goodyear Airport (the Airport). Results of this sampling even indicated that groundwater in this area was contaminated with chromium and volātile organic compounds (VOCs) such as trichloroethylene (TCE) that exceeded the state's drinking water guidelines. As a result, the Phoenix-Goodyear Airport site was placed on the National Priorities List (NPL) in 1983 and a Remedial Investigation (RI) was initiated.

The Phoenix-Goodyear Airport (PGA) site is located approximately 20 miles west of downtown Phoenix and encompasses an area of approximately 35 square miles. Figure 1 shows the overall site location. This area includes the Cities of Avondale and Goodyear and the Phoenix-Goodyear Airport. It is characterized by agricultural lands which at this time depend on groundwater as their main source of water for irrigation. Wells also supply the only source of drinking water to the entire population within the study area. This population is currently at 17,500 for the cities of Avondale and Goodyear combined (Valley National Bank, 1987), and is expected to grow substantially within the next few years.

Throughout the Remedial Investigation, the U.S. Navy, Goodyear Aerospace Corporation (GAC) and Unidynamics Phoenix, Incorporated (UPI) have been identified as potentially responsible Parties (PRPs). Groundwater contamination encompasses an area of approximately one square mile located in the vicinity of the Loral Corporation (formerly GAC) and the airport facilities. TCE concentrations in this area range from below the EPA action limit of 5 parts per billion (ppb) to approximately 7500 ppb (December 1986 sampling event). Groundwater contamination also exists in the vicinity of the UPI facility, which is located approximately three-quarters of a mile north of the Loral facility (refer to Figure 1). TCE concentrations in this area range from the 1 ppb detection limit to 180,000 ppb (June 1987 sampling event) and the contaminated zone encompasses an area of approximately one-half square mile.

The disposal of waste products at these facilities occurred from the late 1940's until the late 1970's. Disposal practices documented in the Source Verification/Field Investigation Report by Ecology and Environment (E&E, 1986) indicate that discarded solvents containing many chemical compounds were used by GAC, UPI and the U.S. Navy. Common waste disposal practices for solvents at that time included disposal to on-site dry wells, sewer systems, sludge drying beds and, as in the case of the Navy, directly onto the land surface during de-greasing and paint-stripping of aircraft. Possible contaminant source areas for GAC and the airport have been identified as mentioned above during the Operable Unit Investigation of Section 16 at PGA ($CH^2M$-Hill, 1987). Contaminant source areas at the UPI facility have been identified as four on-site dry wells (E&E, 1986). The contamination to date is found in the Upper Alluvial Unit only and does not affect the Middle Fine-Grained or Lower Conglomerate Units. Therefore, only the contaminated Upper Alluvial Unit is addressed with the model.

As part of the Remedial Investigation/Feasibility Study (RI/FS) the Arizona Department of Water Resources (ADWR) entered into a Cooperative Agreement (CA) with the EPA in 1984 to conduct groundwater modeling studies for both the Phoenix-Goodyear Airport (PGA) and Indian Bend Wash (IBW) superfund sites. This report presents the results of the PGA groundwater flow and contaminant transport modeling and also provides the data gathered through all modeling efforts by ADWR for this site.

## Authorization

The Arizona Department of Water Resources (ADWR) entered into a Cooperative Agreement (CA; contract No. V-009383-01) with the EPA to develop and operate a computer model of the geohydrologic systems and data base management system for the Indian Bend Wash (IBW) and Phoenix-Goodyear Airport (PGA: formerly Phoenix-Litchfield Airport) areas as part of the overall Remedial Investigation/Feasibility Study (RI/FS). Funding for these model studies has been provided for under this grant since October 10, 1984. The PGA model study was completed in June of 1989 and any subsequent funds were provided to the IBW model study for completion. In addition to this grant, much of the modeling study at the PGA site has been funded at the ADWR's own expense.

## Purpose

The purpose of the contaminant transport modeling and data base management is to support the efforts of the EPA and its contractors in their Phoenix-Goodyear Airport Remedial Investigation/Feasibility Studies of groundwater contamination. It is also a way of compiling and organizing hydrogeologic and contaminant data at the site. The overall goal of the PGA modeling study is to accurately define the hydrologic system that exists in this area and to evaluate alternative Remedial Actions (RA's) that will allow containment and cleanup of contaminated groundwater.

## Scope of Work

The original scope of work for the PGA modeling study encompassed the following:

- Operate and maintain a computerized data base for modeling data.

- Develop and operate computerized numerical models of the groundwater systems of the PGA study area.

- Simulate groundwater flow regimes and movement of selected contaminants in response to stresses that occur in the groundwater systems.

- Calibrate models using historic data and use to determine probable source of contaminants.

- Simulate future response of contaminants in groundwater to a variety of Remedial Alternatives (RA's).

- Identify data deficiencies and possible locations for Phase II monitor wells.

- Confirm nature, extent and severity of contamination in study area and test information collected by EPA and participating PRP's on potential sources and amounts of contaminant disposed of.

The use of the model to determine the probable source of contaminants was infeasible due to the dearth of historic data regarding disposal practices and quantities of solvents disposed.

## Organization

The remainder of this report is arranged in the following order:

- Chapter III discusses the hydrogeologic framework, including the regional setting, geohydrologic units, and groundwater conditions;

- Chapter IV discusses the modeling approach, site-specific data, and groundwater flow and contaminant transport modeling assumptions;

- Chapter V provides the results of the groundwater flow and contaminant transport calibration and an analysis of the accuracy of the parameters used;

- Chapter VI includes the Groundwater Modeling Feasibility Study and provides an analysis of Groundwater Extraction Alternatives 1 through 6 (as provided by the EPA);

- Chapter VII provides conclusions and recommendations as a result of this study;

- Chapter VIII provides the references, figures and appendices to the report.

The appendices include the results of the regional two-dimensional groundwater flow modeling at the PGA site, the three-dimensional groundwater flow model calibration history, and sensitivity analysis.

## Acknowledgments

There are many hydrologists who contributed greatly to the data collection and modeling efforts that culminated in the final report. Cam Williams essentially initiated the project and without her thorough and detailed research efforts much of the historical and geologic information would not have been known. Mike Darr and Wayne Cooley were involved in additional data collection, analysis, and the modeling effort itself at one time or another in their

careers at the ADWR. Wayne Cooley essentially conducted and authored the sensitivity analysis section contained in the report and appendix. Without the efforts of these people the modeling work and subsequent report would not have been a reality.

## III. Hydrogeologic Framework

### Regional Setting

The Phoenix-Goodyear Airport (PGA) site is located approximately twenty miles west of Phoenix in the West Salt River Valley, a broad alluvial basin located in the Basin and Range physiographic province. The area of study is bounded on the south by the Sierra Estrella Mountains and on the west by Cotton Lane (see Figure 1). To the north is the City of Litchfield Park and to the east is the Agua Fria River. The confluence of the Gila and Salt Rivers lies about two miles east of the study area. The Gila River flows perennially from east to west at the southern end of the study area. This is due to effluent releases from the 23rd and 91st Avenue Waste Water Treatment Plants. The Agua Fria River flows only in response to flood events in conjunction with releases from upstream dams. Land surface elevations range from less than 900 feet at the Gila River to over 1,000 feet above sea level near Litchfield Park.

In this arid region precipitation averages less than 10 inches per year (National Oceanic and Atmospheric Administration, 1986). Extensive agriculture in the PGA area is possible through a network of private wells and groundwater-supplied canals. The Cities of Avondale and Goodyear lie in the center of the PGA area (Figure 1). The communities have a combined population of 17,500 (Valley National Bank, 1987) and host the Unidynamics Phoenix, Inc. (UPI) and Goodyear Aerospace Corporation (GAC) industrial facilities, which have been named as PRPs. The Goodyear Aerospace Facility was sold to the Loral Corporation, however, GAC retains liability for contaminated soils and groundwater at the site. The PGA (the Airport) is located just west and southwest of Goodyear and Avondale.

### Hydrogeologic Units

The hydrogeologic units in the PGA area are, in descending order: the Upper Alluvial Unit (UAU), the Middle Fine-Grained Unit (MFU), the Lower Conglomerate Unit (LCU), and the Basement Complex. The UAU, MFU, and LCU are alluvial basin-fill units of middle-to-late Tertiary age (Eberly and Stanley, 1978). The Basement Complex is composed mainly of Precambrian-age crystalline rocks (schist and gneiss) and forms the floor and margins of the West Salt River Valley Basin.

#### Upper Alluvial Unit (UAU)

The UAU contains the highest observed concentrations of trichloroethylene (TCE) and chromium in the study area, and is thus the unit of most concern. The UAU is composed of predominantly coarse sediments consisting of gravel and sand deposited by the through-flowing Gila River system in the last 3.3 million years (Laney and Hahn, 1986). Fine-grained sediments also occur in the UAU. The UAU is transitional with the underlying MFU, and a transition zone of interbedded clay and coarse material reaches a thickness of 100 feet toward the basin center. UAU thickness ranges from over 400 feet near the basin center to less than 200 feet on the basin margin. In general, the UAU is coarsest near the Gila and Agua Fria Rivers, and contains more fine-grained sediments towards the basin center. The unit is unconsolidated and the average horizontal hydraulic conductivity is approximately 750 gpd/ft$^2$ (gallons per day/foot squared; ADWR, 1987). Vertical hydraulic conductivity is estimated to be about one-tenth to one-fifth of horizontal hydraulic conductivity (Bouwer, 1978). The UAU is the watertable aquifer in the PGA area, and many wells withdraw groundwater from this unit.

As a result of the ongoing remedial investigation, the UAU has been divided into three sub-units, labeled A, B, and C from top to bottom. Geologic cross-sections through the UAU were prepared from correlation of geophysical and driller's logs. A location map for these cross-sections is provided in Figure 2 and the cross-sections are illustrated in Figures 3a through 3c. Sharp contacts which probably represent erosional surfaces at the base of the coarser A and C sub-units were the primary horizons correlated. Coarse and fine facies were also correlated. Data provided in Table 2 are the basis of the maps' construction. A structure contour map and related isopach map for each sub-unit is presented in Figures 4a through 4g. Table 2 lists the data points for these maps and cross-sections. Refer to Figure 2 for the orientation of these maps.

Sub-unit A comprises mostly coarse grained sediments. Two zones are generally recognizable in geophysical logs of sub-unit A: A finer upper zone and a coarser lower zone. Data values used to construct the isopach and structure maps in Figures 4b and 4e were chosen at the base of the deeper coarse zone, usually 100 to 150 feet below land surface. In contrast to the other UAU sub-units, sub-unit A is thickest (over 150 feet) at the basin margin near the Sierra Estrella Mountains and Gila River in the south PGA area. Sub-unit A is thinnest (less than 100 feet) near the GAC and PGA facilities, several miles from the basin margin. The average horizontal hydraulic conductivity is estimated at 550 gpd/ft$^2$ (ADWR, 1988), and assumed to be isotropic throughout the study area. Vertical hydraulic conductivity is estimated to be about one-fifth to one-tenth of the horizontal value (Bouwer, 1978). Specific yield is estimated at 10%.

Sub-unit B is composed of fine grained silts and clays with an average horizontal hydraulic conductivity of 150 gpd/ft$^2$ (ADWR, 1988). Vertical hydraulic conductivity is estimated to be one-hundredth or less (Freeze and Cherry, 1979) of the horizontal value. Specific yield is estimated at 5% and storage coefficient is estimated at .0005. Data values used to construct the isopach and structure maps in Figures 4c and 4f were chosen at the coarse zone that defines that contact between sub-units B and C. The sub-unit is thickest (to 100 feet) in the basin center and thins to less than 50 feet at the basin margin. Near the Sierra Estrella Mountains and the Gila River in the south PGA area, sub-unit B becomes quite coarse. In this area sub-unit B cannot be distinguished and the UAU section is uniformly coarse-grained. The hydraulic conductivity of sediments in this area are estimated at 350 gpd/ft$^2$ (ADWR, 1988).

Sub-unit C comprises up to 150 feet of very coarse-grained materials with an average horizontal hydraulic conductivity of 1025 gpd/ft$^2$ and ranges from 1,000 to 5,000 gpd/ft$^2$. These values are based on analysis of aquifer test data and are assumed to be isotropic throughout the model domain. Vertical hydraulic conductivity is estimated at one-fifth to one-tenth of the

| *Table 2* <br> *Data Base for UAU Sub-Unit Structural-Stratigraphic Map Suite* | | | | |
|---|---|---|---|---|
| **Well Location Number(s)** | **Log Type*** | **Elevation Base of Sub-unit A** | **Elevation Base of Sub-unit B** | **Elevation Base of Sub-unit C** |
| B-1-2 25BBC2 | D | NP** | NP | 675 |
| B-1-2 25DBA1, DBA2 | D | NP | NP | 705 |
| B-1-2 24BDC1, BDC2 | D,D | NP | NP | 675 |
| B-1-2 24BBB | D | 740 | NP | NP |
| B-1-2 24BAC | D | 720 | ?*** | 625 |
| B-1-1 19CCB | D | NP | NP | ? |
| B-1-2 24ABC | D | 725 | 710 | 655 |
| B-1-2 24AA1, AA2 | D,D | ? | ? | 650 |
| B-1-1 29DDA2 | D | NP | NP | 695 |
| B-1-1 19BBA | D | 775 | 705 | 645 |
| B-1-1 20CBC | D | 810 | ? | 635 |
| B-1-1 28BCA | D | 790 | 765 | 705 |
| B-1-1 20BBB1, BBB2 | D,D | 825 | 695 | 640 |
| B-1-1 18BDC | D | 865 | 815 | ? |
| B-1-1 28BBA | D | 800 | 765 | 680 |
| 20 EMW-23 | G | 827 | 756 | 650 |
| B-1-1 20ADD | D | 830 | 780 | ? |
| B-1-1 18BAA | D | 870 | 815 | 710 |
| 20 EMW-24 | G | 829 | 739 | 619 |
| B-1-1 17BCB | D | 855 | 785 | 685 |
| B-1-1 8CCC | D | 855 | ? | 685 |
| B-1-1 7CAA1, CAA2 | D,D | 865 | ? | 715 |
| B-1-1 21ABA | D | ? | 815 | 660 |

| ***Table 2*** ***Data Base for UAU Sub-Unit Structural-Stratigraphic Map Suite*** | | | | |
|---|---|---|---|---|
| **Well Location Number(s)** | **Log Type*** | **Elevation Base of Sub-unit A** | **Elevation Base of Sub-unit B** | **Elevation Base of Sub-unit C** |
| B-1-1 20AAA | D | ? | 815 | ? |
| 16 EMW-18 | G | 844 | 824 | 657 |
| 16 EMW-19 | G | 851 | 802 | 669 |
| B-1-1 17AAD1, AAD2 | D,D | 865 | 790 | 645 |
| B-1-1 16DBD | D | 850 | ? | 660 |
| 16 EMW-20 | G | 840 | 790 | 665 |
| B-1-1 8BBA | D | 850 | 765 | 675 |
| 16 EMW-1 | G | 843 | 780 | 659 |
| 16 EMW-21 | G | 841 | 794 | 658 |
| 16 GMW-1 | G | 869 | 791 | 653 |
| B-1-1 5DCB1, DCB2, DCB3 | D,D,D | 845 | ? | 640 |
| B-1-1 15DCA | D | 860 | 780 | 660 |
| B-1-1 15BAD | D | 840 | 790 | 650 |
| 9 UMW-1 | D | 820 | 758 | 640 |
| 9 UMW-6 | G | 830 | 787 | 622 |
| B-1-1 10DDB | D | 815 | 725 | 590 |
| B-1-1 10BDB | D | 825 | 720 | 615 |
| B-1-1 10AA1, AA2 | D,D | ? | ? | 625 |
| B-1-1 4AAB | D | 820 | 785 | 640 |
| B-1-1 3DAC | D | 805 | 715 | ? |
| B-1-1 33BDD1, BDD2 | D,D | 800 | ? | ? |

*Log Types:
D - Driller's Log
G - Geophysical Log

NP** = Contact Not Present
?*** = Contact Not Distinguishable

horizontal hydraulic conductivity (Bouwer, 1978). Specific yield is estimated at 20% and storage coefficient is estimated at 0.001. The majority of wells within the PGA study area are perforated in sub-unit C. The sub-unit is highly transmissive and yields most of the water to wells completed in the UAU. Two coarse zones can be distinguished in sub-unit C with use of geophysical logs - a lower, sharp-based zone that fines upward and an upper zone that coarsens upward. Data values used to construct the isopach and structure maps in Figures 4d and 4g were chosen at the distinct base of the lower coarse zone, usually at 250 to 350 feet below land surface. Sub-unit C is thickest (up to 150 feet) in the center of the model area, and thins to less than 50 feet near the Sierra Estrella Mountains. The cross sections (Figures 3a through 3c) illustrate the relationships of sub-units A, B, and C within the UAU throughout the model area.

**Middle Fine-Grained Unit (MFU)**

The Middle Fine-Grained Unit (or MFU) consists partially of silt-size particles. A brown sticky clay is also commonly described in driller's logs of the MFU. Sand and gravel stringers do occur, especially at the top and bottom of this unit, where transitional contacts occur with the coarser overlying UAU and underlying LCU. Typically, the MFU is weakly cemented by calcite. It is over 1,000 feet thick in the basin center and thins to zero thickness at the basin margin. Wells drilled in the southwest part of the PGA area near the Sierra Estrella Mountains penetrated MFU sections less than 50 feet thick, or did not penetrate any fine-grained materials representative of the MFU. Therefore, the MFU is considered to "pinch out" in this area. Horizontal hydraulic conductivity of the MFU over most of the study area is estimated at 45 gpd/ft$^2$ (Montgomery and Associates, 1986) and is assumed to be isotropic. However, due to its thickness the transmissivity values can be high. Many wells in the study area draw appreciable amounts of groundwater from the MFU. The vertical hydraulic conductivity of the MFU is not known with certainty but has been estimated to range between .002 ft/day to .004 ft/day for the Middle Alluvial Unit that occurs in the East Salt River Valley (Montgomery and Associates, 1987).

**Lower Conglomerate Unit (LCU)**

The Lower Conglomerate Unit (or LCU) consists of coarse gravel, boulders, and sand along the margins of the West Salt River Valley basin. The LCU becomes finer-grained towards the center of the basin near Luke Air Force Base. The LCU also becomes thicker towards the basin center, reaching a maximum thickness of over 10,000 feet. The LCU thins to a feather edge along the basin margin, such as along the Gila River bed at the base of the Sierra Estrella Mountains in the south part of the PGA area. The LCU has been cemented by calcite to various degrees, which reduces its ability to store and transmit groundwater. Horizontal hydraulic conductivity is assumed to be isotropic and to average about 170 gpd/ft$^2$ (Montgomery and Associates, 1986). Due to its great thickness and coarse-grained makeup, the LCU is an important aquifer. Several production wells in the PGA study area draw water from the LCU.

### Basement Complex

The basement complex comprises mainly Precambrian schist and granites overlain by the Tertiary-age Red Unit (Laney and Hahn, 1986). Locally Tertiary volcanic rocks may also be present as part of the basement complex. In the PGA area the Red Unit is not considered to be an important aquifer but rather part of the Basement Complex. These rocks form the floor and margins of the West Salt River Valley basin, and create a nearly impermeable barrier to groundwater flow (Ross, 1978).

## Groundwater Conditions

The three main hydrogeologic units described above (UAU, MFU, and LCU) can be characterized as three distinct aquifers each with unique physical and hydraulic properties. These aquifers occur within the PGA study area in the West Salt River Valley. The importance and significance of these aquifers are discussed below in descending order beginning with the Upper Alluvial Unit aquifer.

### Upper Alluvial Unit Aquifer

Sub-unit A of the UAU is under unconfined or water-table conditions. Recharge, including effluent, canal losses and irrigation returns directly impacts the quantity and quality of the groundwater in sub-unit A. Groundwater flow is generally to the west in the PGA area, paralleling surface topography along the course of the Gila River. Southwesterly and north-westerly components of flow are apparent from detailed water level data in sub-unit A. The net result is a groundwater divide through the middle of the model area. Groundwater flow directions diverge slightly on either side of this divide (see Figures 5a and 5b). Many wells in the PGA area tap sub-unit A of the UAU.

Sub-units B and C are assumed to behave in a hydrologically similar manner. Figures 6a and 6b are water level maps for sub-units B and C. The fine-grained sub-unit B serves as an aquitard to separate the coarse sub-unit A from the coarse sub-unit C. Water table elevations in the PGA area are sufficiently high to fully saturate sub-units B and C. These two UAU sub-units are under semi-confined conditions. Data indicate that under quiescent, or winter-time conditions when pumpage is minimal, heads in sub-units B and C are approximately five feet lower than heads in sub-unit A, as shown in the hydrographs in Figures 7a through 7c. The groundwater flow direction in sub-units B and C is generally due west.

UAU water levels, gradients and flow directions have changed drastically during the past forty years, as shown in Figures 8a through 8f. Water levels declined prior to the mid-1960's due to increased agricultural pumpage. Consequently the UAU was largely dewatered and agricultural users were forced to deepen their wells and withdraw water from the underlying MFU and LCU. In the early 1960's large pumping centers apparently were numerous, and groundwater flow directions and hydraulic gradients were erratic and often in contrast to the present system, as shown in Figure 8b. In the mid-1960's the UAU began to accumulate water in storage due to recharge from overlying agricultural land and from Gila River recharge, as increasing amounts of effluent discharged from the 23rd and 91st Avenue Wastewater Treatment Plants began to maintain more consistent flow in the previously ephemeral Gila River. Several important flood and recharge events in the Gila River channel also occurred in 1965, 1968, and 1973, along with controlled upstream releases during those same years. UAU groundwater levels in the PGA area began to rise and are still rising today.

The net result on the UAU due to increased Gila River flows downstream from its confluence with the Salt River has been waterlogging, in which water levels in the aquifer approximate that of the land surface at the river level (Montgomery and Associates, 1986). Since the mid-1960's the waterlogging situation has progressed upstream from Gillespie Dam to the confluence of the Salt and Gila Rivers. This upstream progression of waterlogging is paralleled by a general upstream progression through time of dense phreatophyte growth along the Gila River channel punctuated by streambed denudation from flood events (Graf and Smith, 1976). In addition, groundwater salinated from irrigation deep percolation became diluted with lower-salinity effluent recharged into the system, thereby beneficially affecting the water quality. At present UAU water levels are currently rising at one to two feet per year in the PGA area as a whole (ADWR, 1988).

Since the early 1970's to the present, groundwater flow patterns have shown the same trend of generally westward flow (refer to Figures 8c through 8f). This indicates a stabilization of the geohydrologic system with respect to effluent flow in the perennial Gila River, and a probably direct hydraulic connection between flow in the Gila River channel and the adjacent UAU aquifer. It is then reasonable to assume that negligible recharge to an already fully saturated groundwater system has occurred due to effluent flow in the Gila River channel since the mid-1970's (Halpenny, personal communication, 1987), although effluent must certainly be lost due to evapotranspiration by abundant phreatophyte growth. Gila River flood flows after the mid-1970's are also considered to contribute negligible recharge to the adjacent aquifer.

### Middle Fine-Grained Unit and Lower Conglomerate Unit Aquifers

The MFU and LCU have not been studied in great detail. Both aquifers appear to be under confined conditions. This assumption is supported by regional water level data and sparse aquifer tests throughout the West Salt River Valley. Precise groundwater flow directions in these units are not known with certainty, but they are generally from the basin margins toward a pumping center in the middle of the West Salt River Valley Basin (Reeter and Remick, 1986). Towards the basin center, heads in the LCU are lowest in elevation, heads in the MFU are intermediate, and heads in the UAU are the highest in elevation. Sparse data indicate that under equilibrium conditions the head difference between the MFU and UAU is from 5 to 15 feet in the vicinity of Litchfield Park and Luke Air Force Base, near the basin center. At the basin margin, little lithologic contrast exists between the MFU and UAU, and it is therefore assumed that little head difference exists in this area.

## Water Budget

A conceptual water budget is presented in Table 3. Components of the water budget comprise inflows, outflows, and change in storage. Values listed are in acre-feet per year and represent the average yearly amount of water attributed to the respective component for the model simulation period (1978 to 1987). A detailed water budget for the regional PGA study area that includes the area bounded on the north by Litchfield Park, on the west by Cotton Lane, on the south by the Sierra Estrella Mountains and on the east by 115th Avenue is given in Appendix A. The water budget in Table 3 was derived for the contaminant transport model domain. All of the water budgets were derived for the UAU only and do not account for any budget components in the MFU or LCU. This is because there are no known sources of contaminant in either of these units to date and the MFU serves as a hydraulic barrier to flow of groundwater from the UAU.

Inflows to the UAU within the PGA model domain comprise groundwater underflow and recharge. Underflow occurs from the east and accounts for approximately one-half of all the inflow to the hydrologic system within the model domain. Approximately 18,000 ac-ft/yr of water is supplied to the model domain by groundwater inflow. This figure is based on flow net analysis and previous three-dimensional groundwater flow modeling for the PGA site, (see Appendix A).

The majority of recharge is attributed to agriculture irrigation deep percolation and canal losses, with lesser amounts estimated from miscellaneous industrial wastewater sources and municipal recharge. Recharge sources specified within the model domain are shown in Figure 9. Approximately 9,600 ac-ft of recharge can be attributed to agricultural irrigation, with only 200 and 300 ac-ft of recharge attributed to golf course and municipal irrigation, respectively. The average rates for each recharge component are listed in Table 4, however, these rates may vary throughout the model domain.

Recharge due to flood flows from the Gila River can be attributed to bank storage and is considered to be negligible for the model time period from 1978 to the present. Effluent flow within the stream channel has made the Gila River a perennial stream within the PGA area, with low flow stages of one to three feet. Any recharge from the 23rd and 91st Avenue Wastewater Treatment Plants is considered to be negligible for the model time period from 1978 to 1987. A hydrologic connection is assumed to exist between the effluent flows and the groundwater in the vicinity of the Gila River. Thus, there is essentially no recharge due to effluent flows from the confluence of the Salt and Gila Rivers, just outside of the PGA study area, to Gillespie Dam (Halpenny, personal communication, 1987).

Other recharge within the model domain can be attributed to the Buckeye Irrigation Company (BIC) canal and miscellaneous sources that include agricultural-tailwater sumps, reservoirs and sewage disposal pits. Recharge from the BIC canal accounts for approximately 6,100 ac-ft/yr. Direct recharge from precipitation is considered negligible in the model area.

*Table 3*
*Conceptual Water Budget of the UAU for the PGA*
*Contaminant Transport Model Domain*

| Component | Acre-Feet/Year |
|---|---|
| I. Inflows | 18,000 |
| A. Groundwater Inflow* | |
| (Range 15,900-22,200) | |
| B. Recharge (Total) | 18,400 |
| 1. Irrigation | |
| a. Agricultural | 9,600 |
| (Range 9,600-42,400) | |
| b. Municipal | 300 |
| (No range) | |
| c. Golf Course | 200 |
| (No range) | |
| 2. Surface Water | |
| Gila River | 0 |
| (Range 0-46,500) | |
| 3. Effluent | |
| 23rd & 91st Avenue WWTP's | 0 |
| 4. Canals | |
| BIC | 6,100 |
| (Range 3,400-7,600) | |
| 5. Miscellaneous | 2,200 |
| (Range 2,200-14,700) | |
| **Total Inflows** | **36,400** |
| II. Outflows | |
| A. Groundwater Outflow* | 10,000 |
| (Range 8,000-11,500) | |
| B. Groundwater Discharge | |
| 1. Pumpage | 23,400 |
| 2. Phreatophytes along Gila River | 500 |
| **Total Outflows** | **33,900** |
| III. Change in Storage | |
| Inflow - Outflow | +2,500 |
| Calculated Change in Storage | +11,300 |
| **Residual** | **8,800** |

* Groundwater inflow and outflow values were derived from previous three-dimensional groundwater flow modeling at the PGA site.

*Table 4*
*PGA Model Area Recharge Rates*

| Source | Rate |
|---|---|
| 1. Agriculture | 1.39 feet/year (average-rate varied within model) |
| 2. Municipal (Includes: industrial, residential, business, and golf course) | 0.34 feet/year |
| 3. Gila River | 0.00 |
| 4. Agua Fria River | 0.91 feet/day |
| 5. Effluent from: (23rd Ave. and 91st Ave. WWTP's) | 0.00 |
| 6. BIC canal | 1.08 feet/day |
| 7. Sumps, ponds, sewage disposal pits | 0.04 feet/day (average-rate varied within model) |

This is mainly because annual precipitation is very small (about 10 inches per year) and sporadic, and typically occurs as isolated events of less than 0.1 inches per day.

Outflows from the UAU within the PGA model domain comprise groundwater pumpage, evapotranspiration from phreatophyte growth along the Gila River, and groundwater outflow to the north and west. Groundwater outflow accounts for approximately a third, or 10,000 ac-ft/yr of water out of the model domain. Groundwater pumpage and evapotranspiration by phreatophytes account for the balance of 33,900 ac-ft of total outflows. Discharge from wells of approximately 23,400 ac-ft is the major component of outflow within the model domain. Evaporation of groundwater from the water table is considered negligible because depth to water in most of the study area is greater than 20 feet except in the vicinity of the Gila River where phreatophyte growth accounts for approximately 500 ac-ft of overall discharge within the model domain (ADWR file data, 1988).

Water budget inflows minus outflows (the change in storage) yields a positive value. This is confirmed by groundwater levels which are currently rising at one to two feet per year over the PGA area. A complete water budget for the PGA groundwater flow and contaminant transport model domain appears in Table 3.

## IV. Technical Analysis

### Modeling Approach

A phased approach was employed to conduct the modeling study for the PGA RI/FS. This approach consisted of extensive data collection and analysis, development of a regional two-dimensional groundwater flow model, an interim three-dimensional site-specific groundwater flow model and finally a three-dimensional groundwater flow and contaminant transport model. The flow chart presented in Figure 10 illustrates this phased approach by ADWR.

The two-dimensional groundwater flow model was initiated as a preliminary investigatory tool of the site and was constructed with the best available data at that time. This model was completed in June 1987 and provided the basis for the site-specific models. The U.S. Geological Survey Modular Three-Dimensional Finite Difference Groundwater Flow code (MODFLOW; McDonald and Harbaugh, 1984) was used to construct the two-dimensional flow model and also the interim three-dimensional site-specific flow model. Appendix A presents the regional modeling calibration results as presented to the PGA Modeling Sub-Committee in July 1987.

The interim three-dimensional site-specific groundwater flow model was constructed to facilitate the transition between the U.S. Geological Survey MODFLOW computer code and the proprietary Dames and Moore TARGET (Transient Analyzer of Reacting Groundwater and Effluent Transport) code (Dames & Moore, 1985). The interim three-dimensional site-specific model using the U.S. Geological Survey code was used to set boundary conditions and expedite the execution run times for the TARGET model.

The results of the groundwater flow and contaminant transport model using the TARGET code are presented in this report. A discussion of the site-specific data used in this model is provided in the following pages. Figure 10 illustrates the phased modeling approach by ADWR as well as the calibration process for both the flow and transport portions of the model. Unless specifically noted otherwise, the use of the term "model" hereafter, will refer to the three-dimensional groundwater flow and contaminant transport model developed using the TARGET code.

### Site Specific Hydrologic Parameters

There has been an extensive amount of site-specific data collected throughout the history of this project. Much of this information has been provided by ADWR, ADEQ, the EPA and its contractors and the PRP's and their contractors. This information has been analyzed and provides the basis for the modeling effort. The information provided in this section of the report relates to the site-specific flow and contaminant transport models.

The site-specific model domain encompasses an area of approximately 20 square miles and includes the Phoenix-Goodyear Airport, the Loral facility and the Unidynamics facility. The model domain was based on the extent of contamination as derived from historical water quality sampling data, ending with the December 1986 sampling event. A fairly fine model grid (200 by 200 feet) was constructed in the vicinity of these facilities as shown in Figures 11a through 11c. These areas include the most concentrated TCE contamination. In areas of low level or no contamination the grid size has been expanded to 1,000 by 1,000 feet. Additional factors considered in the design and construction of this grid included the ratio of longitudinal dispersivity to cell size and the groundwater flow directions in sub-unit A (the most contaminated sub-unit in extent and concentration). Assuming longitudinal dispersivity, values are on the order of 100 to 200 feet for TCE in alluvial sediments (Mercer & Faust, 1981), and the Peclet number (Pe) ranges from 1 to 10, which is adequate for this model. The regional groundwater flow direction is to the west as shown in the most recent water level contour map in Figure 8f. However, in sub-unit A there are major flow components to the southwest and the northwest. These have been present over time as illustrated in the suite of water level contour maps (Figures 8c through 8f). Therefore, the grid was oriented 45° west of N to account for the diverging flow directions in sub-unit A.

Boundary conditions for the model are illustrated in Figure 12. Specified flux boundaries were chosen as the best approach to defining a relatively small area in a broad alluvial basin where there are no specific hydrologic or geologic boundary conditions. In the southwest portion of the model domain however, the Sierra Estrella Mountains provide a hydrogeologic boundary that is represented by no-flow cells.

There are three major water budget components of the hydrologic system that greatly impact any modeling effort at the site. These include: (1) groundwater inflow and outflow, (2) groundwater recharge from agriculture, canals and miscellaneous sources and, (3) groundwater discharge due to pumpage from municipal, industrial and agricultural production wells.

Groundwater inflow and outflow values are listed in Table 3. These estimates are based on flow net analysis for the UAU at the model boundaries and results from prior three-dimensional groundwater flow modeling of the PGA site.

Recharge to the groundwater from all sources is shown in Figure 9. This figure illustrates the areal distribution and respective volumes that are attributed to the various recharge sources within the model domain. Irrigation deep percolation has the greatest impact on the system and accounts for approximately 9,600 ac-ft of water per year. Recharge rates for the respective sources are listed in Table 4. An average recharge rate of 1.39 feet per year has been derived for agricultural irrigation. BIC canal recharge is 6,100 ac-ft/yr at an average rate of 1.08 feet per day (refer to Table 3). Miscellaneous recharge sources, including sumps, ponds and sewage disposal pits, contribute approximately 2,200 ac-ft/yr, at an average rate of 0.04 feet per day.

The last major water budget component is groundwater discharge due to pumpage. Table 5 lists all of the pumpage within the model domain for the time period of 1978 to 1985. Groundwater pumpage attributed to the UAU sub-unit aquifers is graphically represented in

**Table 5**
**PGA Model Area Pumpage Data from 1978 to 1985**
**(Total Pumpage per Well in Acre-Feet/Year)**

| Well Location | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 |
|---|---|---|---|---|---|---|---|---|
| (B-1-1)4AAB | 115 | 96 | 96 | 96 | 96 | 96 | 77 | 62 |
| (B-1-1)4CAA | 564 | 836 | 846 | 815 | 880 | 873 | 866 | 506 |
| (B-1-1)7CDD | 1394 | 1535 | 1473 | 1648 | 1248 | 1248 | 1248 | 1248 |
| (B-1-1)8BBA | 1429 | 1429 | 1381 | 156 | 1618 | 2132 | 1795 | 1444 |
| (B-1-1)9ABA2 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| (B-1-1)10BDA | 347 | 210 | 310 | 308 | 179 | 125 | 80 | 69 |
| (B-1-1)10BDB | 198 | 123 | 213 | 197 | 146 | 137 | 151 | 166 |
| (B-1-1)10CBD | 157 | 157 | 157 | 157 | 157 | 157 | 217 | 93 |
| (B-1-1)10CCD | 58 | 98 | 37 | 232 | 168 | 152 | 145 | 139 |
| (B-1-1)15CBB | 600 | 529 | 861 | 934 | 479 | 328 | 176 | 3 |
| (B-1-1)16AAB | 305 | 305 | 305 | 305 | 305 | 305 | 305 | 305 |
| (B-1-1)16AAC | 266 | 266 | 266 | 266 | 266 | 266 | 266 | 266 |
| (B-1-1)16ACD2 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| (B-1-1)17AAD1 | 1174 | 1279 | 1415 | 1509 | 1016 | 836 | 0 | 0 |
| (B-1-1)17AAD2 | 0 | 0 | 0 | 0 | 0 | 0 | 921 | 1142 |
| (B-1-1)17BCB | 1044 | 1023 | 996 | 1232 | 939 | 728 | 929 | 951 |
| (B-1-1)18BDC | 889 | 1176 | 871 | 622 | 336 | 220 | 103 | 32 |
| (B-1-1)18DDB | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| (B-1-1)19BBA | 545 | 748 | 810 | 830 | 554 | 294 | 507 | 482 |
| (B-1-1)19CBA | 383 | 522 | 479 | 582 | 195 | 195 | 195 | 195 |
| (B-1-1)19CDD | 1021 | 21 | 316 | 393 | 103 | 335 | 477 | 477 |
| (B-1-1)20ADD | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| (B-1-1)20BBB1 | 648 | 560 | 1138 | 717 | 614 | 592 | 769 | 762 |
| (B-1-1)20CBA1 | 110 | 110 | 110 | 110 | 110 | 110 | 136 | 84 |
| (B-1-1)20CBA2 | 98 | 98 | 98 | 98 | 98 | 98 | 137 | 58 |
| (B-1-1)20DDA | 98 | 46 | 112 | 87 | 33 | 15 | 94 | 2 |
| (B-1-1)21ABA | 2041 | 1461 | 1585 | 1388 | 1353 | 1219 | 1084 | 1228 |
| (B-1-1)21CBA | 794 | 618 | 766 | 828 | 635 | 868 | 692 | 692 |
| (B-1-1)22BAB | 401 | 405 | 189 | 273 | 209 | 86 | 37 | 37 |
| (B-1-1)28BBA | 495 | 428 | 490 | 465 | 450 | 467 | 530 | 524 |
| (B-1-1)28BCA | 199 | 126 | 188 | 163 | 148 | 165 | 225 | 225 |

**Table 5**
**PGA Model Area Pumpage Data from 1978 to 1985**
**(Total Pumpage per Well in Acre-Feet/Year)**

| *Well Location* | *1978* | *1979* | *1980* | *1981* | *1982* | *1983* | *1984* | *1985* |
|---|---|---|---|---|---|---|---|---|
| (B-1-1)29CAD | 1065 | 180 | 157 | 1262 | 890 | 528 | 2124 | 1124 |
| (B-1-1)29CBB | 1877 | 938 | 0 | 154 | 1428 | 978 | 2315 | 1624 |
| (B-1-1)29DDA2 | 1352 | 340 | 261 | 1167 | 1068 | 479 | 2029 | 1726 |
| (B-1-1)30CBA | 999 | 200 | 411 | 1787 | 1201 | 1038 | 3034 | 1748 |
| (B-1-1)30DDB | 841 | 183 | 352 | 1741 | 1020 | 1381 | 1931 | 1377 |
| (B-1-2)13DBD | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| (B-1-2)13DCD | 285 | 392 | 520 | 422 | 520 | 346 | 171 | 103 |
| (B-1-2)24ABC | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 |
| (B-1-2)24ABD | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| (B-1-2)24ACB | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| (B-1-2)24ACC | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| (B-1-2)24BAA | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| (B-1-2)24BAB | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| (B-1-2)24BDC2 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| (B-1-2)24DAA | 680 | 680 | 680 | 680 | 680 | 680 | 810 | 549 |
| (B-1-2)25DBA2 | 713 | 1205 | 1150 | 1029 | 856 | 1096 | 1337 | 1136 |
| *TOTALS* | *23996.4* | *19381.6* | *20551.3* | *25649.8* | *21152.1* | *19550.4* | *27764.2* | *22710.5* |

Figure 13. Annual groundwater withdrawals within the model domain for the years 1978 to 1985 were from 19,000 to 28,000 ac-ft annually. Groundwater withdrawals have averaged around 23,000 ac-ft/yr for the model simulation period (refer to Figure 13).

Aquifer parameter data for the contaminant transport model are presented in Table 6. The majority of the parameters were determined by field data collected during the RI/FS process however, some of the data in this table is assumed or referenced in the literature.

***Table 6***
***Aquifer Parameter Data for 3-D Contaminant Transport Model***

| | Upper Alluvial Unit | | | Middle Fine-Grained Unit |
|---|---|---|---|---|
| *Parameter* | *A* | *B* | *C* | |
| Horizontal ($Gpd/Ft^2$) | 550[a,b] | 150[a,b,c] 250[b,c] 350[b,c] | 1025[a,b] | 45[b,c,e] 170[c,e] |
| Hydraulic Conductivity (Ft/Da) | 74 | 20, 34, 48 | 137 | 6, 22 |
| X-Y Anisotrophy | 1[d] | 1[d] | 1[d] | 1[d] |
| Vertical ($Gpd/Ft^2$) | 5, 5[e] | 1.3[e] | 5.0[e] | .08[e] |
| Hydraulic Conductivity (Ft/Da) | .74[d] | .01[d] | .01[d] | .005[d] |
| Storativity | .002[a] | .0005[d,e] | .005[a] | .002[e] |
| Specific Yield | .10[a,b] | .05[a,b] | .20[a,b] | .02[b] |
| Porosity | .35[b,e] | .40[b,e] | .35[b,e] | .30[b,e] |
| Dry Bulk Density (1b./CuFt) | 2.6[e] | 2.6[e] | 2.6[e] | 2.6[e] |
| Longitudinal Dispersivity (Ft) | 100[e] | 100[e] | 100[e] | 100[e] |
| Transverse Horizontal Dispersivity (Ft) | 10[e] | 10[e] | 10[e] | 10[e] |
| Transverse Vertical Dispersivity (Ft) | 1[e] | 1[e] | 1[e] | 1[e] |
| Absorption Distribution (m/g) Coefficient | 0.0[e] | 0.0[e] | 0.0[e] | 0.0[e] |
| Specific Gravity (TCE) | 1.46[e] | 1.46[e] | 1.46[e] | 1.46[e] |
| Viscosity (CP) (TCE) | 0.58[e] | 0.58[e] | 0.58[e] | 0.58[e] |
| Background (TCE), (ppb) | 0.0[d] | 0.0[d] | 0.0[d] | 0.0[d] |

a Based on aquifer test and pump test data
b Based on data from ADWR Driller's Log Program
c Values change with facies from stratigraphic analysis
d Assumed
e Based on Literature Review

## Groundwater Flow Modeling Assumptions

The following groundwater flow modeling assumptions were made in order to simplify the groundwater system or to simplify problems where data uncertainties exist. Many of these assumptions are the same for this model as for the regional two-dimensional groundwater flow model that is reported in Appendix A. However, through the modeling process prior assumptions have been revised to reflect the current level of information known about the site. The major groundwater flow modeling assumptions are listed below.

- **Available groundwater level data adequately represent the flow system within the model domain. Water table and potentiometric surface distributions reflect the stresses (natural and artificial) imposed on the hydrologic system by pumpage, recharge and fluxes along the boundaries of the model domain.** The historic water level maps (Figures 8a through 8f) are the basic data available to which the model was calibrated. Map accuracy becomes better with time as more data have been collected in recent years. In addition to water table and potentiometric surface distributions for the respective sub-units A, B, and C of the UAU, hydrographs illustrated in Figures 7a through 7c provide relative head distributions between the sub-units. This information, along with the conceptual water budget (which provides the magnitude of stresses in or out of the system), was used as the basis for calibrating the model.

- **Static water level measurements taken during the winter months are representative of the site when the hydrologic system is considered to be the most quiescent.** Changes in the system during this period of time are assumed to be a direct result of the hydrologic system's long-term adjustment to regional influences and not to transient influences such as local pumpage. Pumpage is a major stress on the hydrologic system and winter water levels are assumed to be reflective of the system after influence from short-term heavy pumpage during summer months has had a chance to dissipate. The effects of regional pumpage during summer months can be seen in hydrographs of wells completed in all three sub-units as at monitor well cluster sites EMW 1, 2, and 3, GMW 1, 2, and 3, and UMW 2, 5 and 6. Figures 7a through 7c illustrate the seasonal fluctuation of water levels attributed to summer pumpage. These hydrographs show that the greatest change in water levels occur during the heaviest pumping of the summer months. During the winter months water levels in all sub-units recover to a state that reflects the previous non-pumping winter season.

- **There is no leakage of water from the UAU to the MFU.** Overall water budget calculations for the regional model indicated that less than 5% of outflow is attributable to leakage between these two units. Therefore a no flow boundary was chosen as an appropriate boundary condition for the base of the model domain.

- **The Gila River within the model boundaries is in direct hydraulic connection with the UAU aquifer during the model simulation period.** UAU water level maps for the years 1977, 1984, and 1985 (illustrated in Figures 8d through 8f, respectively) suggest an interconnection between the Gila River and the UAU groundwater system. It is apparent from close inspection of this information that some type of connection exists. Montgomery and Associates (1986) state that near the Salt and Gila Rivers the water level in the UAU is presently near or at land surface. Stream-aquifer interactions in terms of gaining or losing stream reaches are unknown within the model domain. Therefore, the river is assumed to be neither gaining nor losing, but rather in equilibrium, so that the river does not contribute nor gain water to or from the groundwater system.

- **Wells perforating multiple sub-units of the UAU are withdrawing water from each sub-unit of the UAU. The amount of water that each sub-unit contributes is dependent on the permeability and saturated perforated thickness of that sub-unit as compared to the permeability of the overall saturated thickness of the sub-unit(s) the well is perforated in.** The precise proportion and distribution of water flowing into perforations in wells in this area are unknown. Therefore, the amount of water each sub-unit and the MFU contributes to the well was calculated using the following formulae:

$$Q_n = \frac{Kn*bn}{T_t} * Q_t * 100 \qquad (1)$$

And:

$$Q_t = Q_1 + Q_2 + Q_3 ... + Q_n \qquad (2)$$

$$T = K_1b_1 + K_2b_2 + K_3b_3 + ... + K_nb_n \qquad (3)$$

Where:

$Q_n$ = percentage of total well pumpage contributed by sub-unit n
$K_n$ = permeability of sub-unit n
$b_n$ = saturated perforated thickness of sub-unit n
$T_t$ = total transmissivity of saturated perforated sub-units
$Q_t$ = total pumpage from well

Although equation (1) ignores well loses and the effects of partial penetration, due to the complexity and extent of the well field within the study area and the lack of any other data, this type of limiting and simplifying assumption was necessary.

- **Evaporation of groundwater from the water table is considered negligible. In the Gila River floodplain where phreatophyte growth is extensive, vegetative use of water is assumed to include any evaporation loss.** This is due to the fact that the depth to water in most of the study area is greater than 20 feet; therefore this assumption is appropriate.

- **Recharge from precipitation is considered negligible in the model area.** Depth to water considerations preclude effective recharge by direct precipitation. High intensity, low depth precipitation events are more likely to contribute to flash floods rather than recharge the groundwater. This is because soil moisture that occurs close to the land surface would tend to evaporate, thereby decreasing the relative conductivity and inhibiting flow through the unsaturated zone. In addition, annual precipitation averages less than 10 inches at the site, and is generally of less than 0.1 inch per event, while annual open-water evaporation averages more than 6 feet.

## Transport Modeling Assumptions

The major transport modeling assumptions used in the TARGET model analysis are listed below. These assumptions serve two purposes: (1) to simplify the problems where data uncertainties exist, and (2) to facilitate the Feasibility Study which addresses the remediation of contamination.

- **TCE is soluble and can be treated as a solute for the purpose of transport calculations at the concentrations observed in the groundwater.** The solubility limit of TCE is 1,100,000 parts per billion (ppb) at 25°C (Nyer, 1985). The concentrations observed in the groundwater at the PGA site range from non-detect to greater than 100,000 ppb. Although the overall solubility of a mixture of solvents decreases, it is assumed for the purposes of the contaminant transport modeling that TCE is a single solvent.

- **No free-phase TCE is present at any of the facilities concerned, according to field data.** No free-phase TCE has been found in either the saturated nor unsaturated zones to date.

- **Adsorption of TCE onto the aquifer material may be neglected.** The retardation of contaminant due to the adsorptive properties of the aquifer material is not known with great certainty at the PGA site. However, laboratory tests were conducted on field samples of similar soil types as those found at PGA. The results of the Motorola 52nd Street adsorption and solubility studies as presented in the RI/FS documents (Dames & Moore, 1987) indicated very little if any TCE absorbed onto the soil matrix.

- **The longitudinal and transverse dispersivity values are assumed to be 100 and 10 feet, respectively, due to a lack of definite source information from which to simulate plume generation.** The values for longitudinal and transverse dispersion, normally considered unknowns during transport calculations, are usually determined during the calibration of the transport model. However, it was not possible to calibrate to a known plume given the lack of historic source information and distribution in the groundwater system. The values chosen are reported in Anderson (1979) and are representative of the soil types found at the PGA site.

- **Solvent sources in the unsaturated zone may be neglected for the purposes of modeling TCE transport and migration.** This includes attenuation, dilution and dispersion of contaminant in the unsaturated zone. This assumption was made on the basis of (1) no continuous source of TCE found in the unsaturated zone throughout the Remedial Investigation ($CH_2M$ Hill, 1988b) and (2) the future cleanup of contamination in the unsaturated zone by the responsible party as dictated by the EPA. This will eliminate future sources, if any, at the PGA site.

- **Biodegradation of TCE may be neglected for the purposes of transport modeling at this site.** It is not known with certainty if the solvents Trans-DCE and DCE were used at the facilities in question, therefore it is assumed that these are the by-products of TCE biodegradation. Trans-DCE and DCE are found in low concentrations ranging from <1 to 791 ppb ($CH_2M$ Hill, 1988b) for wells at the airport and Loral facility. Monitor well data from the Unidynamics facility indicate concentrations of <1 to 10,000 ppb ($CH_2M$ Hill, 1988b) of Trans-DCE and DCE. Degradation products were not incorporated into this analysis because TCE was chosen as the indicator parameter. This assumption was made in order to simplify the problem.

- **The 1986 and 1987 field sampling events accurately define the extent and concentration of TCE contamination at this site for the purpose of evaluating the remedial alternatives.** These field sampling events represent the most comprehensive contaminant data available. It includes data for all three sub-units. Therefore, the remedial alternatives are based on the best available data to date.

- **The concentration of contamination at any given point in the calculation domain extends the full thickness of the sub-unit.** For example, if a sample from a monitor well in the upper or lower sub-unit C aquifer finds 100 ppb TCE concentration, then it is assumed this concentration of TCE exists throughout the entire thickness of sub-unit C aquifer at that point. This assumption is necessary due to the lack of depth-specific sampling data. This is a conservative assumption that probably leads to estimation of more contamination than is actually present.

## V. Results

The results of the groundwater flow and contaminant transport model are presented in the following three sections of this chapter. The first two sections present the calibration results in the form of a table and discussion for both the groundwater flow and contaminant transport portions of the model, respectively. The third section consists of a parameter evaluation in the form of a sensitivity analysis and discussion that includes both the groundwater flow and contaminant transport portions of the model.

### Groundwater Flow Modeling Results

Inherent in a discussion of groundwater flow and contaminant transport modeling is an evaluation of the model's usefulness as an investigative tool. It is important to understand the objectives of the modeling and the limitations of the observed data that are used to calibrate the model. Confidence in modeling results is based on the accuracy of the observed field data, limitations of the model code used and evaluation of the predicted results.

At the Phoenix-Goodyear Airport Superfund site the majority of geohydrologic data are concentrated near the source locations at all three facilities: the Phoenix-Goodyear Airport, the Loral (formerly Goodyear Aerospace Corporation) Facility and the Unidynamics Facility. Beyond these facilities' boundaries the data available become more scarce and less reliable, and analysis becomes more interpretive. This is especially true for hydraulic head, aquifer parameter, and geophysical information. The extent of contamination, however, especially in sub-units B/C, extends two or three miles past the closest probable source location. This area of contamination was taken into consideration in the model design. The groundwater flow and contaminant transport models include the best data available for areas of the domain removed from the vicinity of the PRP's, however data are not at the level of detail exemplified at the three facilities.

Model calibration was achieved by a comparison of observed versus calculated hydraulic heads and gradients, and a comparison of hand-calculated versus model generated mass balance and water budget components. The UAU aquifer was evaluated in a transient state over a 9 year time period from 1978 to 1987. The results are presented throughout this text as a comparison between the observed and model-generated data for the years 1985 through 1987, inclusive. This is due to a definite lack of data prior to 1985. The last three years of the simulation period were chosen due to the available field data.

The groundwater flow model calibration history is presented in Appendix B. The parameters used in the final model run are presented in Table 6. Production Run 40 (JOBID 620) was chosen as the basis for the contaminant transport model and the remedial alternatives.

The results for Production Run 40 are presented in Figures 14a through 15e. Head values from February and August were used to compare between the observed and calculated heads in the figures. The simulation was conducted in six month time periods to reflect the seasonal variation in pumpage that occurs within the PGA study area. The month of February and the months of July through September were chosen to be the most representative months of the winter and summer seasons, respectively. This is due to the fact that the system is stressed the most in August and the least in February. It is important to note that as the Remedial Investigation has progressed more data have become available. This is reflected in the increasing amounts of observed (field) data shown on Figures 14a through 15e.

The six month time periods represent pumping or non-pumping seasons and not exact points in time. Table 7 illustrates the model date, time in days, pumping or non-pumping time period, and the sampling event used to conduct the comparison. This methodology was used for model layers 8 and 4 which are representative of sub-units A and B/C, respectively.

***Table 7***
***Model Time Periods and Sampling Events Use for Water Level Comparisons***

| *Actual Date* | *Model Simulation Time in Days* | *Status* | *Observed Data* |
|---|---|---|---|
| August 1985 | 2557 | Pumping | September 1985 |
| February 1986 | 2739 | Non-Pumping | February 1986 |
| August 1986 | 2922 | Pumping | August 1986 |
| February 1987 | 3104 | Non-Pumping | February 1987 |
| August 1987 | 3287 | Pumping | July 1987 |

**Sub-Unit A**

The model results for Sub-unit A are presented in Figures 14a through 14e. Sub-unit A is represented by model layer 8 (refer to Figures 11b and 11c). Flow directions are consistent with recent historic trends (see Figures 5a and 5b) and present, observed water levels. The flow lines diverge between the facilities, flowing northwesterly near the UPI facility and flowing due west with a southwesterly component in the vicinity of the Loral and Airport facilities. Predicted hydraulic gradients range from 5.8 feet/mile near the Airport to 12.7 feet/mile at the western margin of the model domain. Observed hydraulic gradients for sub-unit A near the airport and Loral facilities are reported to average 10.6 feet/mile (.002 feet/feet) ($CH_2M$ Hill, 1988b). Table 8 lists the predicted hydraulic gradients near the Loral and Airport facilities, the Unidynamics facility, and the western model domain for both sub-units A and C. The average groundwater flow velocities for sub-unit A can be calculated based on the hydraulic conductivity, average hydraulic gradient, and the porosity. The velocity of groundwater movement in sub-unit A in the vicinity of the Loral and Airport facilities is predicted at approximately 230 feet/year, which agrees well with the 200 feet/year estimate reported in the RI/FS documents by $CH_2M$ Hill (1988b). In the vicinity of UPI the predicted velocity of groundwater movement is approximately

330 feet/year and near the western model boundary groundwater is predicted to move at approximately 400 feet/year.

Observed water levels are illustrated as data points instead of contour intervals because (1) it is very tenuous to interpolate site-specific data from the Loral Airport, and Unidynamics facilities to areas a mile or two away, (2) depth-specific data are not available off-site of PRP facilities, and (3) contours represent a subjective interpretation of the few observed data points. The predicted water levels near the Loral and Airport facilities are within 3 to 10 feet of the observed (see Figures 14a through 14e). At the Unidynamics facility the predicted water levels are within 1 to 5 feet of the observed water levels. Model predicted results are lower than observed due to boundary conditions, that is, the specified flux boundaries and the inability of any model to address this type of boundary with complete accuracy.

## Sub-Unit B/C

The model results for sub-unit B/C are presented in Figures 15a through 15e. Sub-units B and C are represented by model layers 2 through 6 (refer to Figures 11b and 11c). The flow direction is to the west in sub-unit B/C and is consistent with historic trends. Predicted hydraulic gradients range from an average of 14.8 feet/mile to 16.9 feet/mile in the vicinity of the PRP's to 9.0 feet/mile in the western model domain. The average hydraulic gradient is reported to be approximately 10.6 feet/mile ($CH_2M$ Hill, 1988b). Table 8 lists the predicted hydraulic gradients near the Loral and Airport facilities, the Unidynamics facility and the western model domain for sub-unit C.

***Table 8***
***Predicted Hydraulic Gradients (Feet/Mile) in the Vicinity of the Loral and Unidynamics Facilities, and the Western Model Domain for Sub-units A and B/C***

| *Figure* | *Loral Facility* | *Unidynamics Facility* | *Western Model Domain* |
|---|---|---|---|
| **SUB-UNIT A** | | | |
| Summer 1985 | 7.9 | 10.6 | 11.6 |
| Winter 1986 | 7.4 | 9.5 | 11.6 |
| Summer 1986 | 5.8 | 9.0 | 12.1 |
| Winter 1987 | 6.9 | 10.6 | 11.6 |
| Summer 1987 | 6.3 | 9.0 | 12.7 |
| | **$\bar{x}$ = 6.9** | **$\bar{x}$ = 9.7** | **$\bar{x}$ = 11.9** |

| Table 8<br>Predicted Hydraulic Gradients (Feet/Mile) in the Vicinity of the Loral and Unidynamics Facilities, and the Western Model Domain for Sub-units A and B/C | | | |
|---|---|---|---|
| *Figure* | *Loral Facility* | *Unidynamics Facility* | *Western Model Domain* |
| **SUB-UNIT C** | | | |
| Summer 1985 | 15.8 | 14.8 | 7.4 |
| Winter 1986 | 15.3 | 18.5 | 7.4 |
| Summer 1986 | 15.3 | 17.4 | 9.0 |
| Winter 1987 | 14.8 | 16.9 | 9.5 |
| Summer 1987 | 13.7 | 16.4 | 11.6 |
| | $\bar{x}$ = 15.0 | $\bar{x}$ = 16.8 | $\bar{x}$ = 9.0 |

The average groundwater flow velocity for sub-unit C in the vicinity of the Loral and Airport facilities is 560 feet/year as predicted by the model. $CH_2M$ Hill (1988b) reported a value of 490 feet/year in the Preliminary Draft RI Report for PGA. Predicted groundwater flow velocities increase to approximately 640 feet/year in the vicinity of UPI and decrease to approximately 340 feet/year near the western model boundary.

Observed water level data for sub-units B and C are sparse at best. This is reflected in Figures 15a through 15e, which illustrate the predicted heads for sub-unit C as compared to observed values. It was not until 1987 with the installation of additional cluster well sites on the airport property that additional unit-specific water level data were available for sub-unit C. Differences between observed versus predicted water levels range from 0 to 14 feet (see Figures 15a through 15e).

A conceptual (hand-calculated) water budget for the contaminant transport model is presented in Table 3. Model results are presented as total inflow or outflow rates for comparative purposes. Average predicted inflows (1978 to 1987) are 34,000 ac-ft/yr, as compared to a hand-calculated value of 37,000 ac-ft/yr. Average predicted outflow (1978 to 1987) rates in ac-ft/yr are 20,000 ac-ft/yr, as compared to a hand-calculated value of 34,000 ac-ft/yr. The model has also predicted a positive change in storage of 12,000 ac-ft/yr as compared to a calculated value of 11,000 ac-ft/yr. This agrees with a rise in water levels which has been seen historically.

The model behaves well over the simulation period and reproduces the flow directions, gradients, and hydraulic heads as observed by field data, especially for sub-unit A. Total mass imbalance is approximately 1% or less (see Appendix B), which is acceptable. Therefore, confidence can be placed in the model's predictive capabilities. A thorough sensitivity analysis has been performed on the groundwater flow model and the results are discussed under the parameter evaluation section of this report.

A disparity was noted between pumpage rates used in the model calibration versus pumpage rates used in the projection scenarios. Correcting the pumpage rates used in the calibration runs had a minimal effect on the outcome of the projection runs. The change in the overall removal of contaminants for the alternatives was about one percent which can be considered insignificant. The flow directions, hydraulic gradients and groundwater velocities remain virtually unchanged for both the calibration and projection runs. This is probably due to the fact that the change in head was uniform over the model. Therefore the integrity and predictive capabilities of the model remain intact. Appendix D contains a thorough explanation and analysis of this problem.

## Contaminant Transport Modeling Discussion

The approach to contaminant transport modeling at the Phoenix-Goodyear Airport site has been influenced by many factors. These include:

- Poor historic records of disposal practices, volumes and composition of solvents disposed of, rates at which these solvents were disposed of, and source locations where these solvents were released.
- Areal extent of groundwater contamination as defined by the December 1985/1986 sampling event (see Figures 16a and 16b).
- Extent of known vertical contamination in each sub-unit A, B, or C.
- The assumption that the MFU is not contaminated based on the available data to date.

The lack of historic records of disposal practices, combined with a very dynamic hydrologic system from the late 1940's to the late 1970's, and lack of study-wide geohydrologic data has not allowed the application of the model to source tracing or to replicate the contaminant migration from the time of disposal. Therefore, since the "classic" calibration and verification procedures were not allowed by data constraints, the extent of contamination in December 1986 was delineated and input into the model as an initial condition of the projection runs in order to evaluate various remediation alternatives. Figures 16a and 16b illustrate the initial contaminant distribution as it was discretized and used as a basis for the projection runs.

## Sensitivity Analysis

The purpose of incorporating a sensitivity analysis section in this report is to determine if the model results are easily disturbed by the uncertainty in the model parameters. This was accomplished by determining the confidence in the model values used for each parameter based on the available field data. Table 9 presents the results of the groundwater flow model parameters tested. Although Table 9 is qualitative, it is meant to present the results of the sensitivity analysis in terms easily interpreted. Appendix C, however, provides a detailed quantitative discussion of the sensitivity analysis.

The final model run (Production Run 40) that utilized the model parameters listed in Table 6 was used to conduct the sensitivity analysis on the groundwater flow portion of the model. In order to expedite the sensitivity analysis and minimize run times each sensitivity run was conducted for the last half (1983 to 1987) of the total simulation time period from 1978 to 1987. Therefore, model parameters were tested under a 4 year period from 1983 to 1987. The parameters were varied from one-half the model input value as reported in Table 9 to 1370 times the model input value to determine how strong the model results are in relation to the uncertainties that exist in the model parameters.

The sensitivity analysis for this model concentrated most on evaluating the ranges of parameters that were most uncertain. In many of these cases, an order of magnitude change in the parameter values was used to be conservative. In addition, parameters that reflected high confidence levels but were critical to the model results were changed during the sensitivity analysis to evaluate the effect of variability in those parameters. The relative level of confidence placed in each parameter was determined by the amount and quality of the available data for that parameter. Table 9 provides a summary of the confidence placed in all the parameters evaluated and provides a concise synopsis of the relative sensitivity of the model to varying these parameters. The parameters evaluated are discussed below in order of the confidence levels placed in them.

Parameters of relatively 'poor' confidence (uncertain parameters) are as follows:

- **Vertical Hydraulic Conductivity (sub-units A, B and C).** No field or lab measurements were made of this parameter. The values selected for use in the model were derived from literature. Final vertical conductivity values were derived through the model calibration process.

- **Storage Coefficient (sub-unit A and B).** Although several single well pump tests were performed on sub-units A and B, storativity calculated based on drawdown data from the pumped well are generally not reliable Driscoll (1986), Fetter (1988).

- **Porosity (sub-units A, B, and C).** No field measurements were made of porosity in sub-units A, B, or C. However, several resistivity logs were reviewed and an attempt to back-calculate porosity from the Archie saturation equation (Archie, 1942) was made. To make such a calculation, the resistivity of water (Rw) was converted from published reports of specific conductance of water produced in the area. Also, the formation resistivity factor (F) had to be approximated from the

**Table 9**
**Summary of Sensitivity Analysis**

| *Parameter Evaluated* * | *Confidence Model Value* | *Model Value* | *Sensitivity Value* | *Very Sensitive* | *Moderately Sensitive* | *Not Very Sensitive* | *Relative Change in Head* ** |
|---|---|---|---|---|---|---|---|
| HCXY A | Fair | 74 Ft/Day | 148 Ft/Day (2* Base Case) | x | x | | 5-10 |
| HCXY A | Fair | 18.5 Ft/Day | 37 Ft/Day (.5* Base Case) | X | X | | 5-10 |
| HCXY B | Fair | 20, 34, 48 Ft/Day | 40, 68, 96 Ft/Day (2* Base Case) | | | X | <5 |
| HCXY B | Fair | 20, 34, 48 Ft/Day | 10, 17, 24 (.5* Base Case) | | X | X | <5 |
| HCXY C | Good | 137 Ft/Day | 273 Ft/Day (2* Base Case) | X | X | | 5-10 |
| HCXY C | Good | 137 Ft/Day | 68 Ft/Day (.5* Base Case) | X | | | |
| HCZ A | Poor | .74 Ft/Day | .074 Ft/Day (.1* Base Case) | | | X | <5 |
| HCZ A | Poor | .74 Ft/Day | 7.4 Ft/Day (10* Base Case) | | | X | <5 |
| HCZ B | Poor | .01 Ft/Day | .001 Ft/Day (.1* Base Case) | | X | | 5-10 |
| HCZ B | Poor | .01 Ft/Day | 2, 3, 4, 4.8 (200*-480 Base Case) | | | X | <5 |
| HCZ C | Poor | .01 Ft/Day | .001 Ft/Day (.1* Base Case) | | X | | 5-10 |
| HCZ C | Poor | .01 Ft/Day | 13.7 Ft/Day (1370* Base Case) | | | X | <5 |
| STY A | Poor | .10 | (.20) (2* Base Case) | | X | X | <5 |
| STY A | Poor | .10 | .05 (.5* Base Case) | | | X | <5 |
| STC B | Poor | .0005 | .005 (10* Base Case) | | | X | <5 |
| STC B | Poor | .0005 | .00005 (.1* Base Case) | | | X | <5 |
| STC C | Good | .005 | .00005 (.01* Base Case) | X | X | | <10 |
| STC C | Good | .005 | .05 (10* Base Case) | | X | X | 5-10 |
| POR A | Poor | .35 | .05 (.143* Base Case) | | | X | <5 |
| POR A | Poor | .35 | .50 (1.43* Base Case) | | X | X | <5 |
| POR B | Poor | .40 | .05 (.125* Base Case) | | | X | <5 |
| POR B | Poor | .40 | .50 (1.25* Base Case) | | | X | <5 |
| POR C | Poor | .35 | .05 (.143* Base Case) | | | X | <5 |
| POR C | Poor | .35 | .50 (1.43* Base Case) | | X | X | <5 |

* Explanation of Codes

** Please refer to Appendix C for a quantitative discussion of the sensitivity analysis results.

HCXY = Horizontal Hydraulic Conductivity
HCZ = Vertical Hydraulic Conductivity
STC = Storativity
STY = Specific Yield
POR = Porosity

A = UAU Sub-unit A
B = UAU Sub-unit B
C = UAU Sub-unit C

Humble and Archie formulas (Winsauer, 1952 and Archie, 1942, respectively) for clastics. The values calculated were excessively high and unacceptable. The confidence placed on the porosity values used in the model for all three sub-units is poor.

Parameters of relatively 'Fair' confidence are as follows:

- **Horizontal Hydraulic Conductivity (sub-units A and B).** Several single well pump tests were run in both sub-units A and B. Sub-unit A demonstrated four tests that only a fair level of confidence could be placed on because the discharge rates were relatively low (5-100 gpm), the duration of the tests was less than three days (Driscoll, 1986), and there was always the possibility of interference from the surrounding production wells. The hydraulic conductivities calculated from the sub-unit A pump test analyses ranged from 43 to 101 ft/da. Eight acceptable single well pump tests were run on sub-unit B. These tests were also of less than three days in duration and pumping from 5 - 100 gpm. Calculated hydraulic conductivities ranged from 1 to 335 ft/da. Therefore, the confidence in the data for sub-unit B is considered fair.

Relatively 'High' confidence can be placed in the following parameters:

- **Horizontal Hydraulic Conductivity (sub-unit C).** The Loral No. 4 Aquifer Test (pumping at 1510 gpm for 3 days) supplied good results for the model. Although cyclic interference occurred with two nearby wells, acceptable corrections were made and reasonable values were derived. The calculated horizontal hydraulic conductivities from wells ranged from 126 to 175 ft/da. Of all the parameters evaluated these data reflect the highest confidence level.

- **Storativity (sub-unit C).** Four observation wells in the Loral No. 4 Aquifer Test displayed good storativity values ranging from .018 to .020 (storage coefficients ranging from .00015 to .00017). Multiplying these coefficients times an average sub-unit C thickness of 120 feet yielded the storativity values. Storativity for sub-unit C reflects a relatively high level of confidence.

The model is very sensitive to changes in the horizontal hydraulic conductivity values used for sub-units A and C as noted in Table 9. However, the level of confidence in the sub-unit A values is fair and in the sub-unit C values is "good." Therefore, although the model is sensitive to these parameters, the level of confidence in the values used is greater because the available field data to support these parameters is good. Conversely, the model is not very sensitive to most of the parameters that have little or no confidence in the value used. For a complete detailed analysis of each sensitivity run refer to Appendix C.

The contaminant transport parameters, specifically longitudinal and transverse dispersivity and adsorption were not evaluated in this sensitivity analysis. This is because it would be a purely academic exercise due to the dearth of historic contaminant data.

## VI. Groundwater Modeling Feasibility Study

The Groundwater Modeling Feasibility Study is based on projecting hydrologic conditions into the future and observing the predicted plume at the end of the projection period. In a classical approach to contaminant transport modeling the current (1986) contamination would be reproduced by starting the model simulation at the time contaminants were introduced into the aquifer, thereby recreating the plume over time. However, due to the limited historic knowledge of source areas, quantities and rates at which solvents were disposed of, and of the pre-existing hydrogeologic system, this type of historical plume re-creation was not possible. Therefore, the contamination was delineated based on available field data from the 1986 sampling event. The sub-unit A plume was derived from the available data represented in the draft RI/FS document ($CH_2M$ Hill, 1988b). The sub-unit B/C plume was taken directly from Figure 3-20 of the Preliminary Draft RI Report Phoenix-Goodyear Airport RI/FS ($CH_2M$ Hill, 1988b). The initial contaminant distribution map for sub-units A and B/C are shown in Figures 16a and 16b. This discretization of contaminant concentration was used as a basis to conduct the projections from 1987 into the future. The initial mass of solute in the groundwater for all sub-units is estimated at 1,280 gallons or approximately 15,000 lbs. of TCE. Approximately 900 gallons of TCE has been calculated to occur in sub-unit A.

This section of the report discusses and presents the modeling results for the six Ground Water Extraction Alternatives received from $CH_2M$ Hill (1988a) for the PGA Feasibility Study. These alternatives were evaluated for each of three different Base Cases (1, 2, and 3). Figure 17 presents a diagram which illustrates what each Base Case consists of and how they are related to the groundwater extraction alternatives. Base Case 1 assumes the full implementation of the City of Goodyear's proposed wells through the year 2008 and the continuation of agricultural pumpage at 1985 levels. The Section 16 Operable Unit Feasibility Study (OUFS) is not incorporated in this base case. Base Case 2 assumes that pumpage and recharge remain constant at 1985 rates and the Section 16 OUFS is incorporated into the model projection. Base Case 3 phases in the City of Goodyear's projection wells as per the City's Water Master Plan (Cleveland, 1988), and phases out agricultural pumpage and recharge where urbanization is projected to occur. This base case incorporates the Section 16 OUFS.

Table 10 provides a summary of the results from all three base cases for the No Action Alternative (Alternative No. 1). It is apparent from Table 10 that the incorporation of the Section 16 OUFS remediation plan has a major impact on the base case results. Both Base Cases 2 and 3 resulted in a 75% or more reduction in groundwater contamination after 21 years. This is compared to Base Case 1 which resulted in only an 18% reduction in groundwater contamination for the same period of time. The predicted concentrations of TCE remaining in groundwater adjacent to selected municipal wells are given in Table 11 for all alternatives for each base case.

| Table 10<br>Results of the No Action Alternative (Alternative No. 1) for Base Cases 1, 2, and 3 | | | |
|---|---|---|---|
| *Base Case* | *Description* | *% Reduction in Contaminant* | *Contaminant Remaining after 21 Years (Gals/Lbs)* |
| 1 | Continued agricultural pumpage at 1985 levels in addition to full implementation of City of Goodyear's proposed wells. Section 16 Operable Unit not incorporated. | 18 | 1056/12862 |
| 2 | Pumpage and recharge assumed to remain constant at 1985 rates over projected run. Section 16 Operable Unit incorporated. | 75 | 325/3959 |
| 3 | Phase in City of Goodyear's projected production wells per the City of Goodyear's Water Masterplan. Phase out agricultural pumpage and recharge. Section 16 Operable Unit incorporated. | 76 | 309/3764 |

The ending results for 1987 from the three-dimensional groundwater flow modeling are the basis for evaluating the effectiveness of the six selected alternatives in controlling groundwater contamination at the site. These alternatives were run for a 21 year time period from 1987 to the year 2008. The alternatives include the Goodyear Aerospace Corporation (GAC) and Department of Defense (DOD) plume, but not the UPI plume. Each of the six alternatives are described and evaluated separately for each of the three base cases.

***Table 11***
***Predicted Concentration of TCE Remaining in Groundwater Adjacent to Selected Municipal Wells (in ppb) After 21 Years***

| *Well Name* | *Base Case 1* | *Base Case 2* | *Base Case 3* |
|---|---|---|---|
| **Alternative 1** | | | |
| City of Avondale School District | 0.0 | 0.0 | 0.0 |
| City of Goodyear No. 1 | 1.0 | 1.0 | 1.0 |
| City of Goodyear No. 3 | 0.0 | 0.0 | 0.0 |
| City of Goodyear No. 8 | <1.0 | 1.0 | 1.0 |
| City of Goodyear No. 11 | **10.4** | 3.6 | 1.1 |
| City of Goodyear PW* 1 | 0.0 | **NA | 0.0 |
| City of Goodyear PW 2 | <1.0 | NA | <1.0 |
| City of Goodyear PW 3 | 1.7 | NA | <1.0 |
| City of Goodyear PW 4 | <1.0 | NA | <1.0 |
| City of Goodyear PW 5 | <1.0 | NA | <1.0 |
| City of Goodyear PW 6 | 3.4 | NA | 1.9 |
| City of Goodyear PW 7 | <1.0 | NA | <1.0 |
| **Alternative 3** | | | |
| City of Avondale School District | 0.0 | 0.0 | *** |
| City of Goodyear No. 1 | <1.0 | <1.0 | *** |
| City of Goodyear No. 3 | 0.0 | 0.0 | *** |
| City of Goodyear No. 8 | <1.0 | <1.0 | *** |
| City of Goodyear No. 11 | **9.7** | 4.6 | *** |
| City of Goodyear PW 1 | 0.0 | NA | *** |
| City of Goodyear PW 2 | <1.0 | NA | *** |
| City of Goodyear PW 3 | 1.5 | NA | *** |
| City of Goodyear PW 4 | <1.0 | NA | *** |
| City of Goodyear PW 5 | <1.0 | NA | *** |
| City of Goodyear PW 6 | 4.6 | NA | *** |
| City of Goodyear PW 7 | <1.0 | NA | ** |

| *Table 11*<br>*Predicted Concentration of TCE Remaining in Groundwater Adjacent to Selected Municipal Wells (in ppb) After 21 Years* | | | |
|---|---|---|---|
| *Well Name* | *Base Case 1* | *Base Case 2* | *Base Case 3* |
| **Alternative 4** | | | |
| City of Avondale School Dist. | 0.0 | 0.0 | 0.0 |
| City of Goodyear No. 1 | <1.0 | <1.0 | <1.0 |
| City of Goodyear No. 3 | 0.0 | 0.0 | 0.0 |
| City of Goodyear No. 8 | <1.0 | <1.0 | <1.0 |
| City of Goodyear No. 11 | **5.2** | 2.3 | 4.8 |
| City of Goodyear PW 1 | 0.0 | NA | 0.0 |
| City of Goodyear PW 2 | <1.0 | NA | <1.0 |
| City of Goodyear PW 3 | <1.0 | NA | <1.0 |
| City of Goodyear PW 4 | <1.0 | NA | <1.0 |
| City of Goodyear PW 5 | <1.0 | NA | <1.0 |
| City of Goodyear PW 6 | 3.6 | NA | 1.5 |
| City of Goodyear PW 7 | <1.0 | NA | <1.0 |
| **Alternative 5** | | | |
| City of Avondale School District | 0.0 | 0.0 | 0.0 |
| City of Goodyear No. 1 | <1.0 | <1.0 | <1.0 |
| City of Goodyear No. 3 | 0.0 | 0.0 | 0.0 |
| City of Goodyear No. 8 | <1.0 | <1.0 | <1.0 |
| City of Goodyear No. 11 | **5.6** | 2.7 | 5.8 |
| City of Goodyear PW 1 | 0.0 | NA | 0.0 |
| City of Goodyear PW 2 | <1.0 | NA | <1.0 |
| City of Goodyear PW 3 | <1.0 | NA | <1.0 |
| City of Goodyear PW 4 | <1.0 | NA | <1.0 |
| City of Goodyear PW 5 | <1.0 | NA | <1.0 |
| City of Goodyear PW 6 | **5.3** | NA | 1.8 |
| City of Goodyear PW 7 | 1.6 | NA | 1.5 |

| Table 11<br>Predicted Concentration of TCE Remaining in Groundwater Adjacent to Selected Municipal Wells (in ppb) After 21 Years | | | |
|---|---|---|---|
| *Well Name* | *Base Case 1* | *Base Case 2* | *Base Case 3* |
| **Alternative 6** | | | |
| City of Avondale School District | 0.0 | 0.0 | 0.0 |
| City of Goodyear No. 1 | <1.0 | <1.0 | <1.0 |
| City of Goodyear No. 3 | 0.0 | 0.0 | 0.0 |
| City of Goodyear No. 8 | <1.0 | <1.0 | <1.0 |
| City of Goodyear No. 11 | 3.1 | 1.2 | 2.8 |
| City of Goodyear PW 1 | 0.0 | NA | 0.0 |
| City of Goodyear PW 2 | <1.0 | NA | <1.0 |
| City of Goodyear PW 3 | <1.0 | NA | <1.0 |
| City of Goodyear PW 4 | <1.0 | NA | <1.0 |
| City of Goodyear PW 5 | <1.0 | NA | <1.0 |
| City of Goodyear PW 6 | 1.1 | NA | 2.1 |
| City of Goodyear PW 7 | 1.0 | NA | <1.0 |

* PW = Projection well
** NA = Not applicable to this base case
*** Data not available
5.0 Numbers in bold are above the 5ppb action level

## Base Case 1

The alternatives are based on the ending model run discussed in the groundwater flow modeling results sections. Pumpage and recharge rates are assumed to remain at 1985 values for the projection period except the projected pumpage for the City of Goodyear which will increase. Each of the alternatives incorporate the city's projected pumpage. Figure 18 shows the city's proposed well locations and projected rates for each well are provided in Table 12. Total projected pumpage from the City of Goodyear's wells is approximately 21,000 ac-ft/yr. In addition, the city's current wells that are within the model domain are also included in Figure 18 and Table 12. Unlike Base Cases 2 or 3, Base Case 1 does not specifically address the contamination in sub-unit A; the Section 16 Operable Unit is not incorporated. Alternatives 1 through 6 for Base Case 1 are discussed in detail below and summarized in Table 13.

| Table 12<br>Current and Projected Pumpage Rates for the City of Goodyear's Wells | |
|---|---|
| *Well Name* | *Pumpage Rate (ac-ft/yr)* |
| City of Goodyear No.1 | 484 |
| City of Goodyear No. 3 | 726 |
| City of Goodyear No. 11 | 3,000 |
| City of Goodyear PW* 1 | 784 |
| City of Goodyear PW 2 | 1,792 |
| City of Goodyear PW 3 | 3,025 |
| City of Goodyear PW 4 | 3,025 |
| City of Goodyear PW 5 | 2,128 |
| City of Goodyear PW 6 | 3,025 |
| City of Goodyear PW 7 | 3,025 |
| **Total** | **21,014** |

* PW = Projection well

**Alternative 1**

The first alternative is the No Action Alternative. For Base Case 1, the no action alternative incorporates the projected pumpage for the City of Goodyear. This alternative proposes only the continued use of existing wells to extract and contain contaminated groundwaters. In this sense, this is not a true "no action" scenario because future development is taken into account. The current and proposed well field for the City of Goodyear (Cleveland, 1988) is shown in Figure 18. Current and projected pumpage rates for the City of Goodyear's wells are presented in Table 12. These rates are used in the 21 year projection.

Throughout the 21 year projection the flow direction is predicted steadily to the west and southwest in all sub-units, with a northwesterly component in sub-unit A in the eastern portion of the model domain. Hydraulic gradients are approximately 10.6 feet/mile in the center of the model domain and steepen closer to the western model boundary (see Figure 19a). The approximate model dewatered line of sub-unit A near the western boundary is due to a combination of (1) a groundwater flux out of the model domain, (2) City of Goodyear's projected pumpage for 21 years, and (3) the relatively small saturated thickness of the UAU in this area.

The remaining mass of solute after the 21 year No Action alternative is 1,060 gallons of TCE as compared to 1,280 initially. This is an 18% reduction in contaminant due to removal by existing wells and the projected City of Goodyear pumping only. There are no wells specifically constructed for remedial action included in this alternative. Table 13, Results of Groundwater Extraction Alternatives for Base Case 1, lists the results of each of the alternatives and compares their relative effectiveness in removing TCE contamination. Figures 19a through 19d illustrate the projected hydraulic heads and TCE contamination concentrations for sub-units A and B/C, respectively, at the end of the 21 year No Action alternative.

***Table 13***
***Results of Groundwater Extraction Alternatives for Base Case 1***

| *Alternatives* | *Additional Pumpage Due to Remediation Wells (Ac-Ft/Yr)* | *Initial Mass of Water for all Sub-units (Gallons TCE)* | *Remaining Mass 21 Year Projection Run (Gallons TCE)* | *Percent Reduction in Contamination* |
|---|---|---|---|---|
| Alternative 1<br>No Action Alternative | --- | 1,280 | 1,065 | 18% |
| Alternative 2<br>Containment of Groundwater | Not run at this time | | | |
| Alternative 3<br>Reduction of Contamination to Meet ARAR's | 1,200 | 1,280 | 1,070 | 17% |
| Alternative 4<br>Accelerated Reduction of Contamination to Meet ARAR's | 3,600 | 1,280 | 896 | 30% |
| Alternative 5<br>Reduction of Contamination to Exceed ARAR's | 4,800 | 1,280 | 986 | 23% |
| Alternative 6<br>Accelerated Reduction of Contamination to Exceed ARAR's | 10,800 | 1,280 | 1,022 | 20% |

## Alternative 2

The second alternative is for containment of the groundwater using a slurry wall installed to a depth of 350 feet below land surface and surrounding the source areas within portions of Sections 9 and 16. In order to properly assess the effects of a slurry wall as an effective remedial alternative, the model would have to be discretized to a smaller cell size to physically represent the slurry wall. This alternative will probably not be run using this model and it is not discussed under either Base Case 2 or 3.

### Alternative 3

The third alternative, reduction of contamination to meet the Applicable Relevant and Appropriate Requirements (ARAR's), resulted in a 17% reduction in groundwater contamination after 21 years (see Table 13). This alternative proposes a single additional well to be installed toward the downgradient end of the plume in sub-unit B/C, near the southwest corner of Sarival and Lower Buckeye Roads as shown in Figure 20. Projected hydraulic heads and TCE concentrations for sub-units A and B/C are shown in Figures 21a through 21d, respectively. The impact of further reduction of contamination due to the installation of one additional well at the trailing edge of the plume is minimal as compared to the no action alternative, Alternative 1. This is probably due to the fact that the remedial action well is located farthest from the areas with the highest initial TCE concentrations (see Figure 20).

### Alternative 4

The fourth alternative, accelerated reduction of contamination to meet ARAR's, suggests that a 30% reduction in contamination is possible by locating three remediation wells through the plume. Figure 22 shows that the three remediation wells proposed in Alternative 4 are located near the source of the plume, in the middle and near the end of the plume. The projected TCE concentrations and hydraulic heads for sub-units A and B/C are shown in Figures 23a through 23d. The remaining mass of TCE in the groundwater after the 21 year projection run for Alternative 4 is 896 gallons. Of the five alternatives evaluated for Base Case 1, this alternative has the greatest impact on reducing the extent of contamination in sub-unit B/C.

### Alternative 5

The fifth alternative, reduction of Contamination to exceed ARAR's, resulted in a 23% reduction of contamination. Figure 24 illustrates the well placement design for Alternative 5. Three wells are proposed to be placed at the edge of the plume between Cotton Lane and Sarival Road, north and south of Lower Buckeye Road. An additional well is proposed nearer the source. Projected hydraulic heads and TCE concentrations are shown in Figures 25a through 25d for sub-units A and B/C, respectively.

### Alternative 6

The model projection of Alternative 6, accelerated reduction of contamination to exceed ARAR's, exhibits problems at the western flux boundary. This is due to extensive future pumpage (21,000 ac-ft/yr) as proposed by the City of Goodyear, combined with nine additional remediation wells pumping at 750 gpm in the same vicinity as the City's proposed wells (see Figure 26). The projection run for this alternative indicated that the UAU aquifer becomes dewatered in an area of approximately 2 square miles in the western portion of the model domain as a cumulative result of this pumpage after 21 years. The results of Alternative 6 were included in Table 13 for comparative purposes.

## Base Case 2

This Base Case assumes that pumpage and recharge remain constant at 1985 rates for the projection period and incorporates the Section 16 remediation as presented by ICF Technology Incorporated (ICF) in their report entitled: "Final Draft Design and Specifications PGA Operable Unit Treatment Plant" dated January, 1989. ICF's remedial design (including both recharge and discharge wells) is presented in Figure 27. The incorporation of ICF's remedial design has a great impact on the results of both Base Cases 2 and 3. The flow directions, gradients and heads in sub-unit A are greatly affected by the Section 16 OU in the vicinity of the airport. Also, as shown in Table 14, groundwater cleanup has been greatly accelerated due to the inclusion of the remedial design. This is not surprising, however, because of the extensive contamination in sub-unit A which Base Case 1 does not address. Table 14 presents the results of each alternative for Base Case 2. These alternatives are discussed below.

**Table 14**
**Results of Groundwater Extraction Alternatives for Base Case 2**

| *Alternatives* | *Additional Pumpage Due to Remediation Wells (Ac-Ft/Yr)* | *Initial Mass of Solute in Groundwater for all Sub-units (Gallons TCE)* | *Remaining Mass of Solute After 21 Year Projection Run (Gallons TCE)* | *Percent Reduction in Contamination* |
|---|---|---|---|---|
| Alternative 1<br>No Action Alternative | --- | 1280 | 325 | 75% |
| Alternative 2 *<br>Containment of Groundwater | | | | |
| Alternative 3<br>Reduction of Contamination to Meet ARAR's | 1,200 | 1,280 | 315 | 75% |
| Alternative 4<br>Accelerated Reduction of Contamination to Meet ARAR's | 3,600 | 1,280 | 247 | 81% |
| Alternative 5<br>Reduction of Contamination to Exceed ARAR's | 4,800 | 1,280 | 288 | 77% |
| Alternative 6<br>Accelerated Reduction of Contamination to Exceed ARAR's | 10,800 | 1,280 | 283 | 78% |

* Alternative 2 not run at this time.

### Alternative 1

This is the No Action alternative for Base Case 2. This alternative proposes only the continued use of existing wells to extract and contain contaminated groundwaters. Unlike Base Case 1, this alternative includes the Section 16 Operable Unit remediation wells. The flow direction in sub-unit A is dominated by the Operable Unit remedial design (see Figure 18a). The effect it has on containing the contamination can be seen by comparing Tables 13 and 14 (Base Case 1, Alternative 1 to Base Case 2, Alternative 1).

The results of this alternative are presented in Figures 28a through 28d. These figures illustrate the projected hydraulic heads and TCE contamination concentrations for sub-units A and B/C after 21 years.

The remaining mass of solute after the 21 year No Action alternative is 325 gallons of TCE as compared to 1,280 initially. This is a 75% reduction in contaminant due to removal by existing wells and the OUFS remedial design. There are no wells specifically constructed for remedial action included in this Alternative. For comparative purposes the results of all the alternatives for Base Case 2 are presented in Table 14.

**Alternative 3**

Alternative 3, the reduction of contamination to meet ARAR's also resulted in a 75% reduction in groundwater contamination after 21 years (see Table 14). Figure 20 shows the location of the additional well to be installed if this alternative were implemented. Projected hydraulic heads and TCE concentrations for sub-units A and C are shown in Figures 29a through 29d, respectively. The remaining mass of TCE in the groundwater is 315 gallons after the 21 year projection run for Alternative 3 which is a 75% reduction in contaminant. As in Base Case 1, the impact of further reducing contamination by installing one additional well at the trailing edge of the plume is minimal as compared to the No Action alternative, (Alternative 1). Again, this is probably due to the fact that the remedial action well is located farthest from the areas with the highest initial TCE concentrations.

**Alternative 4**

An accelerated reduction of contamination to meet ARAR's, this alternative resulted in an 81% reduction of groundwater contamination by locating three remediation wells throughout the plume (see Figure 22). The projected hydraulic heads and TCE concentrations for sub-units A and C are shown in Figures 30a through 30d. The remaining mass of TCE in the groundwater is 247 gallons after the 21 year projection run for Alternative 4, a reduction of 81% of the contaminants. Of the five alternatives evaluated for Base Case 2, this alternative has the greatest impact on reducing the extent of contamination in sub-unit C.

**Alternative 5**

The reduction of contamination to exceed ARAR's, Alternative 5 suggests that a 77% reduction in contamination is possible. The well placement design for Alternative 5 is presented in Figure 24. Projected hydraulic heads and TCE concentrations are shown in Figures 31a through 31d for sub-units A and B/C, respectively. The remaining mass of TCE in the groundwater is 228 gallons after the 21 year projection run for Base Case 2, Alternative 5.

## Alternative 6

The accelerated reduction of contamination to exceed ARAR's, Alternative 6, also exhibits problems at the western flux boundary as seen in Base Case 1. This is due to the nine additional remediation wells pumping at 750 gpm located in the western portion of the model domain proposed by this alternative. These wells pump an additional 10,800 ac-ft/yr of water from this area. This alternative resulted in a 78% reduction in TCE contamination (see Table 14). The remaining mass of TCE in the groundwater is 783 gallons after the 21 year projection run for this alternative.

## Base Case 3

Base Case 3 projects the effects of urbanization of land within the PGA study area. For this Base Case, the City of Goodyear's Water Master Plan was incorporated by phasing in the additional city wells. An average of each planning area was taken for the time when the city's wells were phased in as shown in Figure 32. The respective pumpage and recharge rates for agriculture were then omitted in these areas at the same time. This Base Case provided very similar results to Base Case 2. Each Alternative for Base Case 3 is discussed in detail below and presented in Table 15.

***Table 15***
***Results of Groundwater Extraction Alternatives For Base Case 3***

| *Alternatives* | *Additional Pumpage Due to Remediation Wells (Ac-Ft/Yr)* | *Initial Mass of Solute in Groundwater for All Sub-units (Gallons TCE)* | *Remaining Mass of Solute After 21 Year Projection Run (Gallons TCE)* | *Percent Reduction in Contamination* |
|---|---|---|---|---|
| Alternative 1<br>No Action Alternative | --- | 1,280 | 309 | 76% |
| Alternative 2 *<br>Containment of Groundwater | | | | |
| Alternative 3<br>Reduction of Contamination to Meet ARAR's | 1,200 | 1,280 | 316 | 75% |
| Alternative 4<br>Accelerated Reduction of Contamination to Meet ARAR's | 3,600 | 1,280 | 220 | 83% |
| Alternative 5<br>Reduction of Contamination to Exceed ARAR's | 4,800 | 1,280 | 275 | 78% |
| Alternative 6<br>Accelerated Reduction of Contamination to Exceed ARAR's | 10,800 | 1,280 | 306 | 76% |

*Alternative 2 not run at this time.

**Alternative 1**

Alternative 1, the No Action Alternative, resulted in a 76% reduction of TCE contamination after 21 years for Base Case 3, the best percent reduction in contamination out of all three Base Cases for this alternative. The remaining mass of solute after 21 years is approximately 309 gallons of TCE as compared to 1,280 initially. Table 15, Results of Groundwater Extraction Alternatives, lists the results of each of the alternatives for Base Case 3 and compares their relative effectiveness in removing TCE contamination. Figures 33a through 33d illustrate the projected hydraulic heads and TCE concentrations for sub-units A and B/C, respectively, at the end of the 21 year No Action alternative.

**Alternative 3**

Alternative 3, which proposes a reduction of contamination to meet ARAR's, resulted in a 75% reduction in groundwater contamination after 21 years (see Table 15). Figure 20 shows the additional remedial well that is proposed to be installed with this alternative. The remaining mass of TCE in the groundwater is 316 gallons after the 21 year projection run for this alternative. Figures 34a through 34d illustrate the projected hydraulic heads and projected TCE concentrations for sub-units A and B/C, respectively.

**Alternative 4**

Alternative 4, accelerated reduction of contaminant to meet ARAR's, resulted in an 83% reduction in TCE contamination. Out of all the alternatives for each Base Case, this produced the best results. Figure 22 shows the remediation well placement design. The remaining mass of TCE in the groundwater after 21 years is approximately 220 gallons for this alternative. Figures 35a through 35d illustrate the projected hydraulic heads and TCE concentrations for sub-units A and B/C, respectively.

**Alternative 5**

Alternative 5, reduction of contamination to exceed ARAR's, suggests that a 78% reduction in TCE contamination is possible. Figure 24 shows the remediation well design. The remaining mass of TCE in the groundwater is 275 gallons after the 21 year projection run for this alternative. Figures 36a through 36d illustrate the projected hydraulic heads and TCE concentrations after 21 years for sub-units A and B/C, respectively.

**Alternative 6**

Alternative 6, accelerated reduction of contamination to exceed ARAR's, resulted in a 76% reduction in TCE contamination. Figure 26 illustrates the remediation well design. The remaining mass of TCE in the groundwater is 306 gallons after the 21 year projection run for this alternative. This run was again included for comparative purposes, however, excessive drawdowns again occurred at the western model domain, as discussed under Base Case 2, Alternative 6.

## VII. Conclusions and Recommendations

### Conclusions

The results of the groundwater flow model calibration provided a basis from which to project TCE contamination into the future and evaluate various remediation alternatives under different Base Cases. The results of the groundwater flow sensitivity analysis indicated that the model is most sensitive to changes in hydraulic conductivity, however, this parameter is known with relative certainty, therefore, a higher level of confidence can be placed in the parameter itself. For the most part, the sensitivity analysis indicated that model results were the most sensitive to changes in parameters with higher confidence levels, and less sensitive to uncertainty in parameters of lower confidence. Therefore, acceptable confidence can be put into the groundwater flow model calibration results thereby providing a base for the contaminant transport model feasibility study.

The results from the six groundwater extraction alternatives for each Base Case of the groundwater modeling feasibility study are summarized in Table 16. It is apparent from comparing these results that the inclusion of the Section 16 Operable Unit remedial design in Base Cases 2 and 3 greatly reduces the amount of contamination at the PGA site. Base Case 1 does not specifically address the contamination in sub-unit A and has resulted in a 30 percent reduction in contamination at best. The Section 16 Operable Unit design will be incorporated into the final design, therefore, it is more appropriate to compare the results of Base Case 2 and 3 rather than either with Base Case 1.

The results of the alternatives for Base Cases 2 and 3 indicate that an accelerated reduction of contamination to meet ARAR's (Alternative 4) achieved the highest percent of contamination removed after 21 years (see Table 1). However, this result was achieved by the additional pumpage of 3,600 ac-ft/yr from the three remediation wells. A reduction of contamination to meet ARAR's (Alternative 3) achieved similar results with the addition of only one remediation well pumping 1,200 ac-ft of groundwater per year. Alternative 3 when compared with the No Action alternative (Alternative 1) achieved very similar results without any additional pumpage from new remedial wells other than those installed as part of the Section 16 Operable Unit remediation plan (see Table 16).

The reduction of contamination to exceed ARAR's (Alternative 5) or an accelerated reduction of contamination to exceed ARAR's (Alternative 6) achieved better results than the No Action alternative (Alternative 1) and the reduction of contamination to meet ARAR's (Alternative 4). However, Alternatives 5 and 6 called for the addition of 4,800 and 10,800 ac-ft/yr of groundwater pumpage, respectively.

*Table 16*

***Comparison of Groundwater Extraction Alternatives for Base Cases 1, 2 and 3***

| *Alternatives* | *Additional Pumpage Due to Remediation Wells (Ac-Ft/Yr)* | *Initial Mass of Solute in Groundwater for All Sub-units (Gallons TCE)* | *Remaining Mass of Solute After 21 Year Projection Run (Gallons TCE)* | | | *Percent Reduction in Contamination* | | |
|---|---|---|---|---|---|---|---|---|
| | | | **Base Case 1** | **Base Case 2** | **Base Case 3** | **Base Case 1** | **Base Case 2** | **Base Case 3** |
| Alternative 1<br>No Action Alternative | | 1,280 | 1,065 | 325 | 309 | 18% | 75% | 76% |
| Alternative 2 *<br>Containment of Groundwater | | | | | | | | |
| Alternative 3<br>Reduction of Contamination to Meet ARAR's | 1,200 | 1,280 | 1,070 | 315 | 316 | 17% | 75% | 75% |
| Alternative 4<br>Accelerated Reduction of Contamination to Meet ARAR's | 3,600 | 1,280 | 896 | 247 | 220 | 30% | 81% | 83% |
| Alternative 5<br>Reduction of Contamination to Exceed ARAR's | 4,800 | 1,280 | 986 | 288 | 275 | 23% | 77% | 78% |
| Alternative 6<br>Accelerated Reduction of Contamination to Exceed ARAR's | 10,800 | 1,280 | 1,022 | 283 | 306 | 20% | 78% | 76% |

* Alternative 2 not run at this time.

## Recommendations

The ability of the model to replicate the geohydrologic system within the PGA study area is adequate at this time to provide a relative evaluation of the various groundwater remediation alternatives. Further modeling work would entail fine-tuning and refining the model to explore additional RA scenarios, and to address data limitations and deficiencies. The recommendations are as follows:

1) Update model to the present by including pumpage data, water level data and the incorporation of new urban and industrial development.

2) Concentrate on alternatives that impact the plume centrally rather than at the leading edge. Most of the groundwater remediation alternatives located wells far from the assumed source(s) of contamination and the impact of these remediation designs was minimal, as shown in the groundwater modeling feasibility section of the report.

3) Future projection runs should include assessment of the Unidynamics site and also the joint assessment of all contaminant sites. This may, however, require refinement of boundary conditions in the north-east portion of the model domain. It may be important to determine the joint impacts of the remedial designs from all sites due to the possibility of one interfering with another and with the City of Goodyear water master-plan (in process).

4) Further assess regional impacts of the geohydrologic system in this area. This would include incorporating proposed groundwater recharge sites in the Agua Fria River east of the Cities of Avondale and Goodyear, water logging problems along the Gila River and their effect on the western portion of the model domain, and the pumping center commonly referred to as the Luke Sink of the model domain.

5) Explore scenarios of possible MFU contamination.

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# Figures

# LOCATION MAP OF STUDY AREA

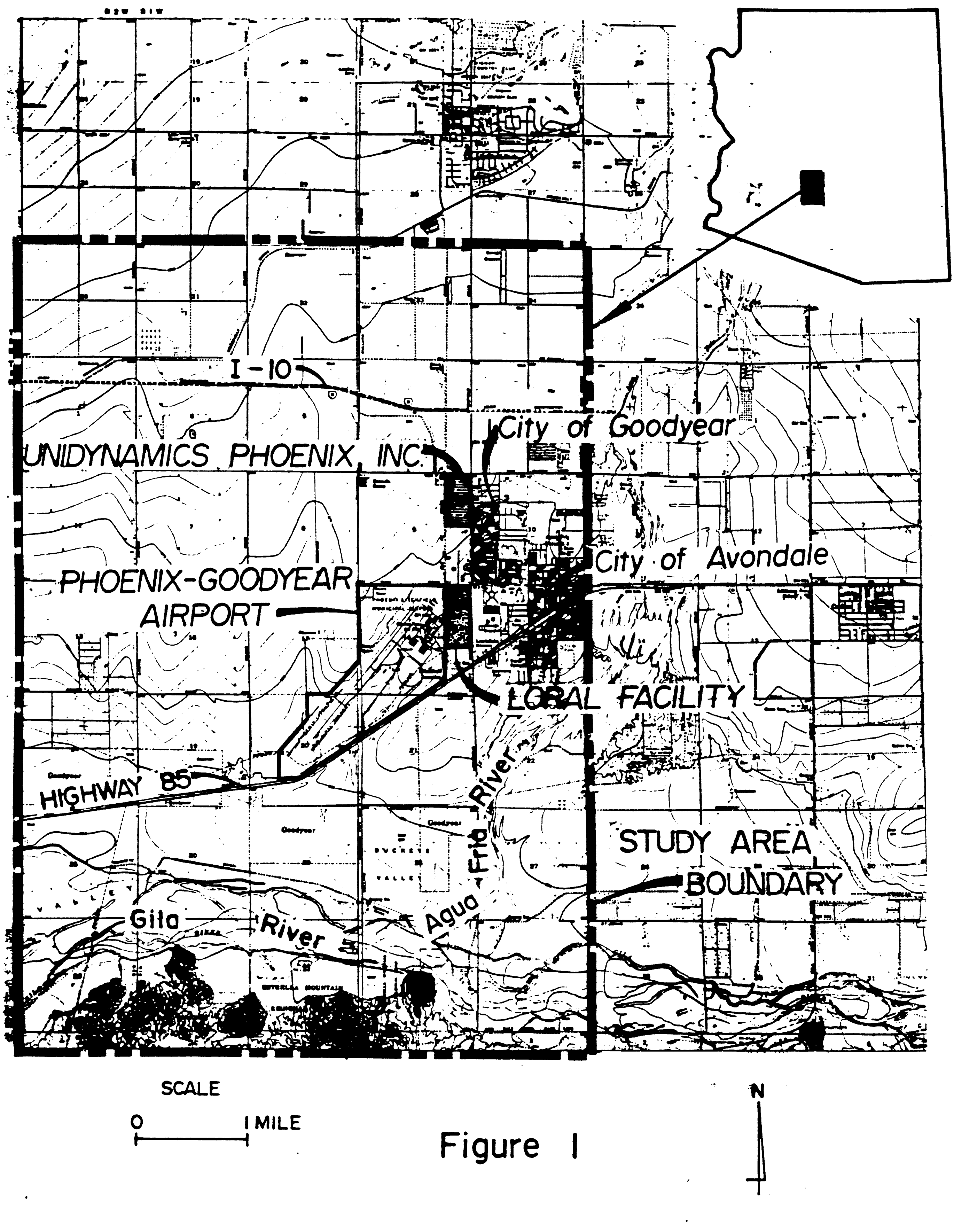



Figure 1

# LOCATION MAP FOR GEOLOGIC CROSS-SECTIONS

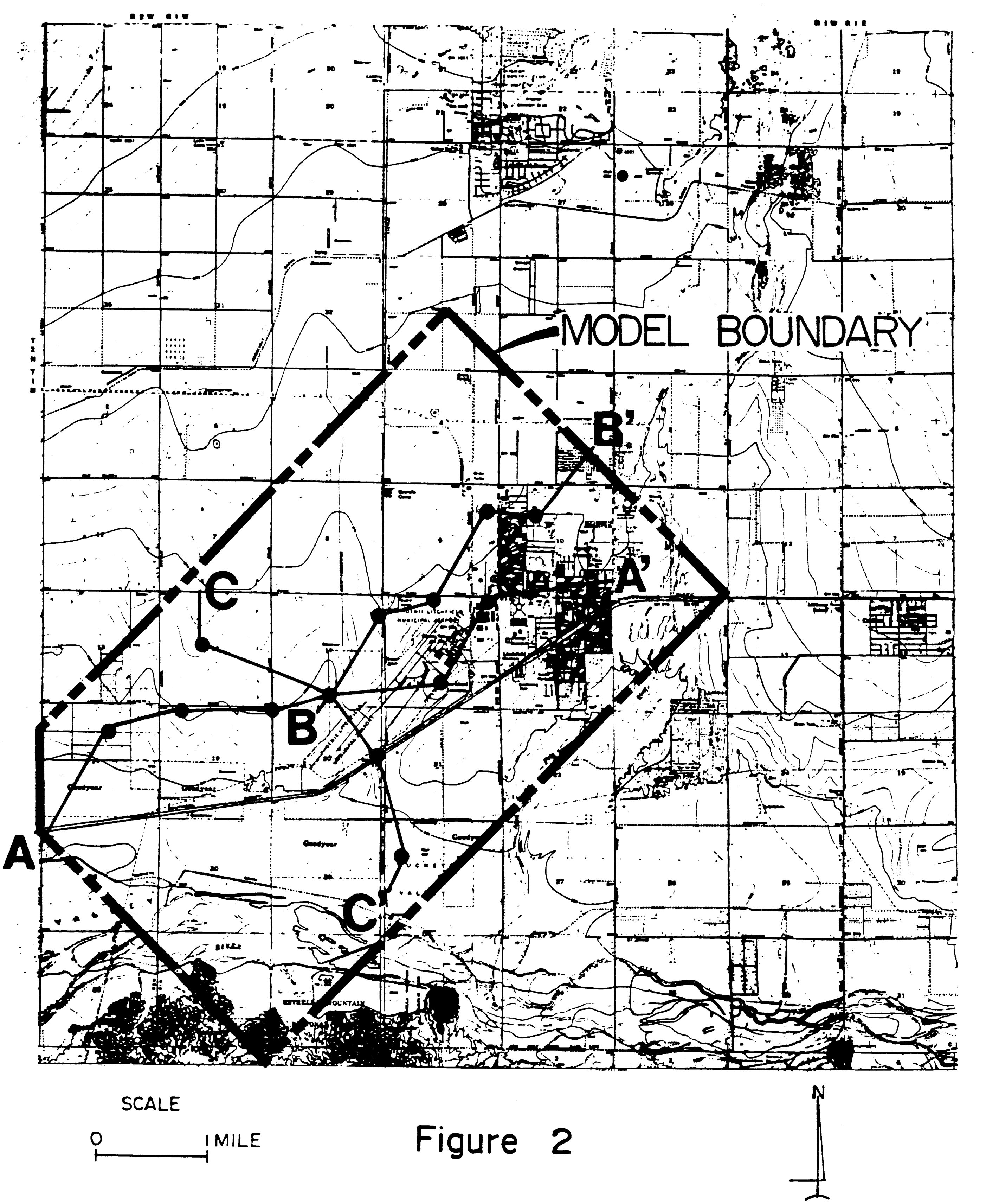



Figure 2

# GEOLOGIC CROSS-SECTION THROUGHOUT MODEL AREA

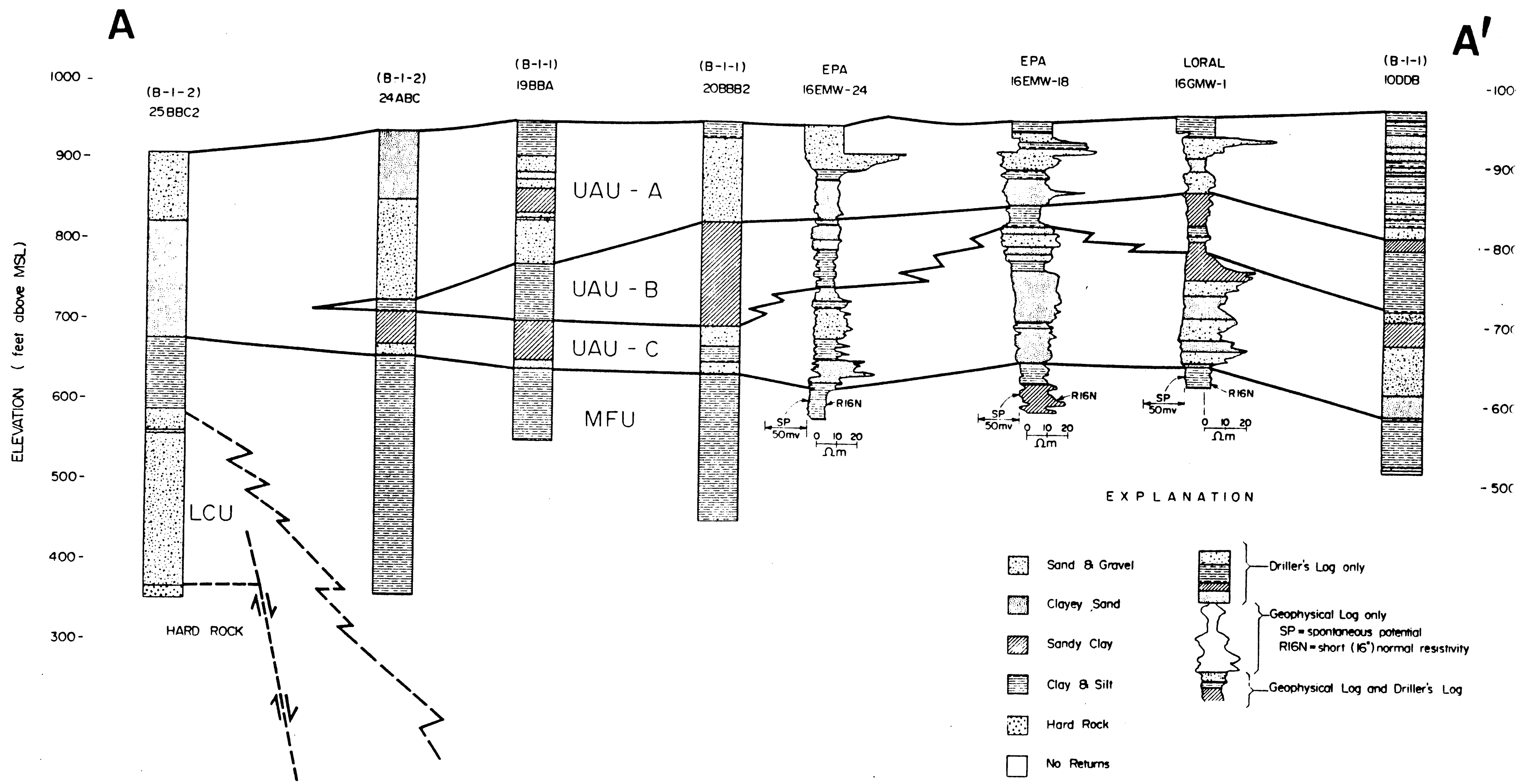



Figure 3a

# GEOLOGIC CROSS-SECTION THROUGHOUT MODEL AREA

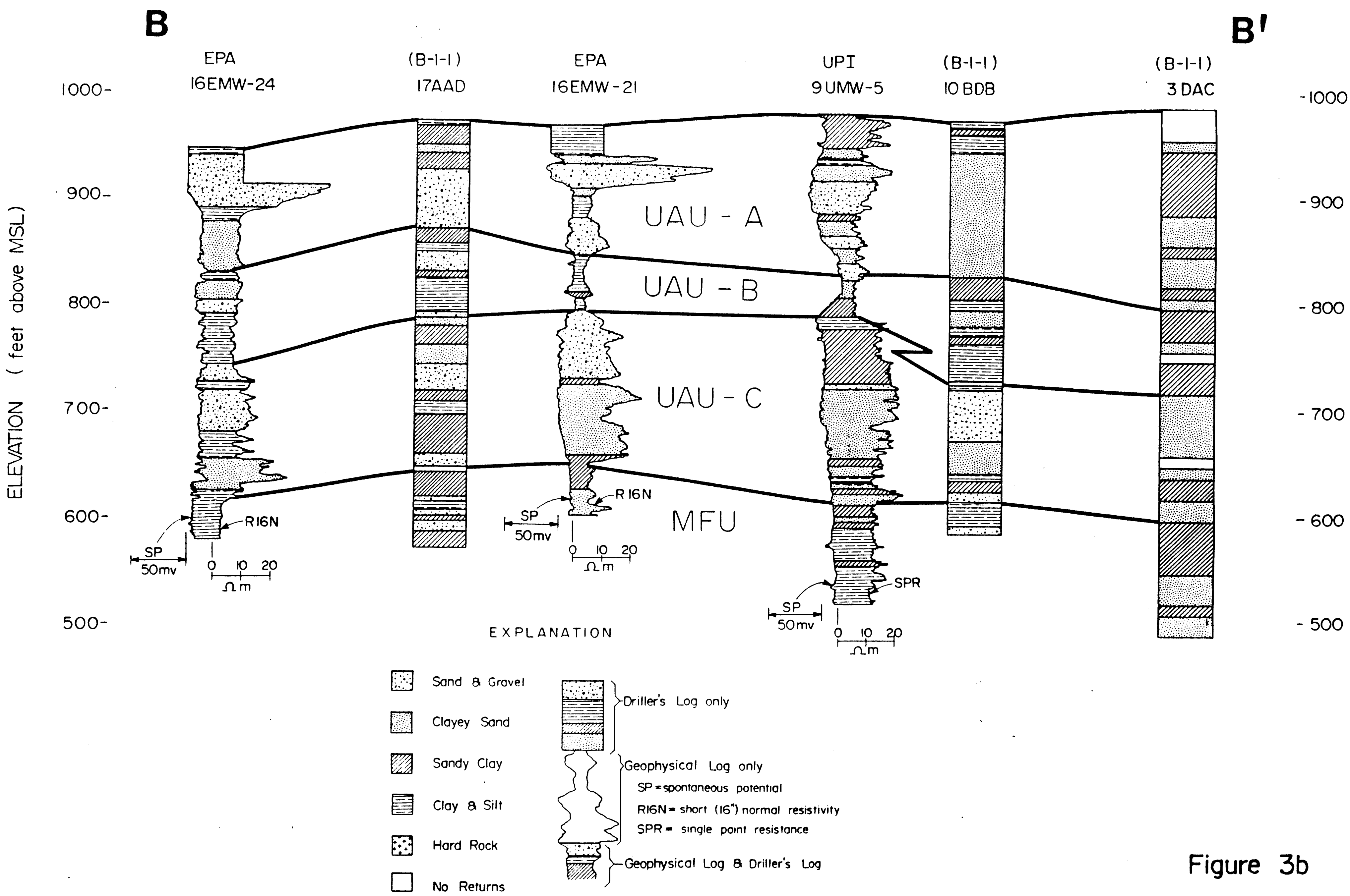



Figure 3b

# GEOLOGIC CROSS-SECTION THROUGHOUT MODEL AREA

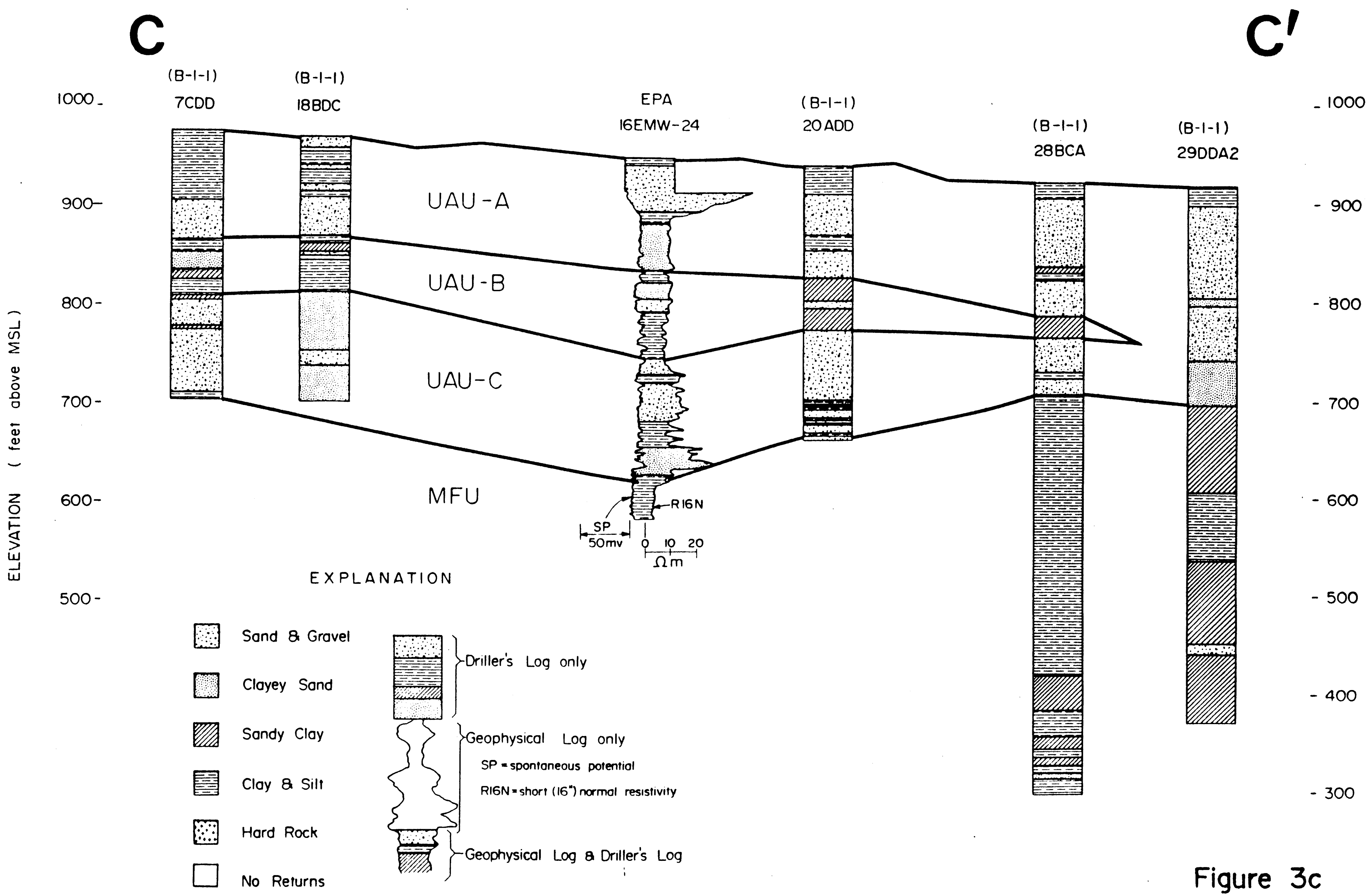
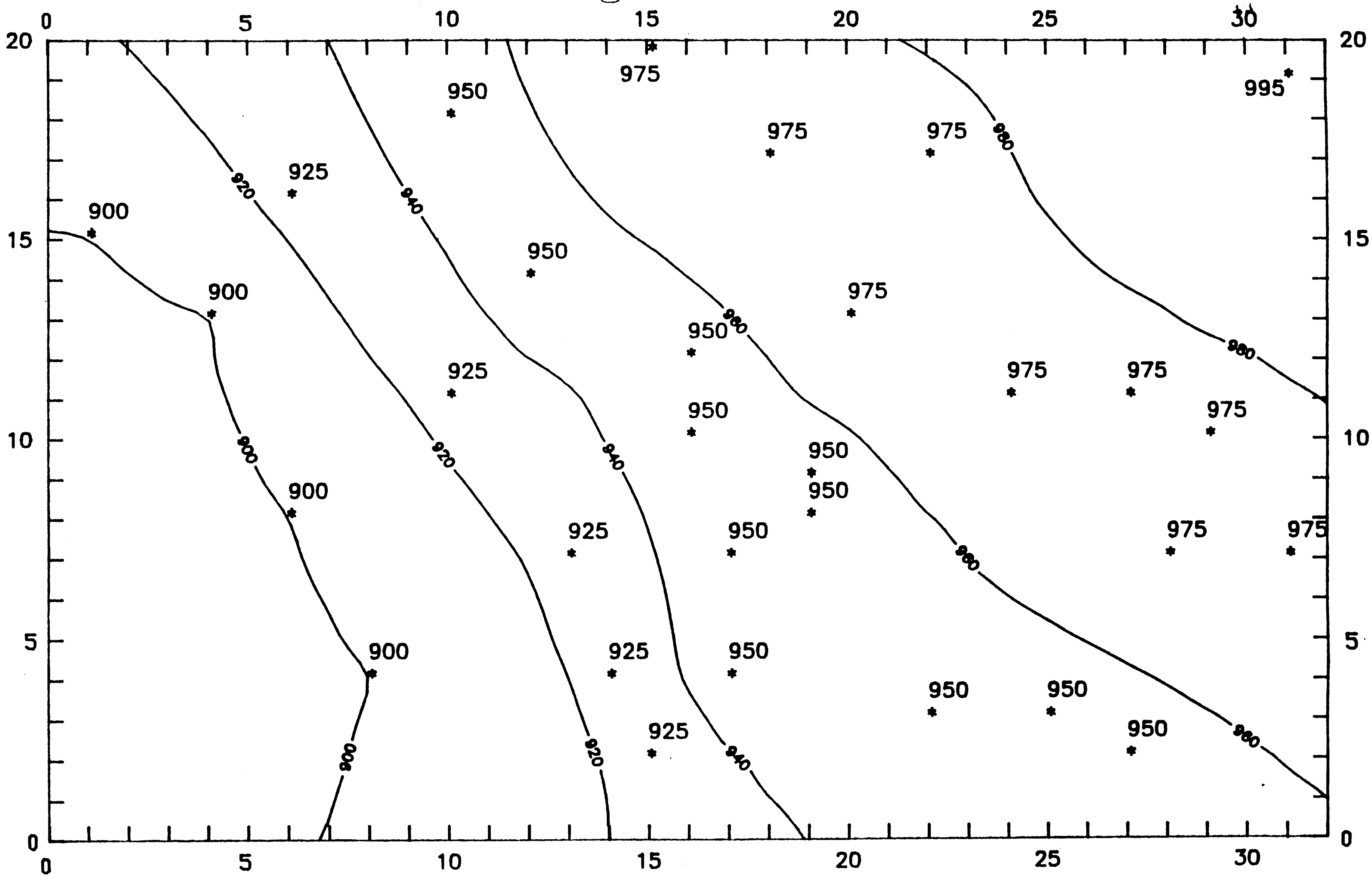



Figure 3c

Figure 4a



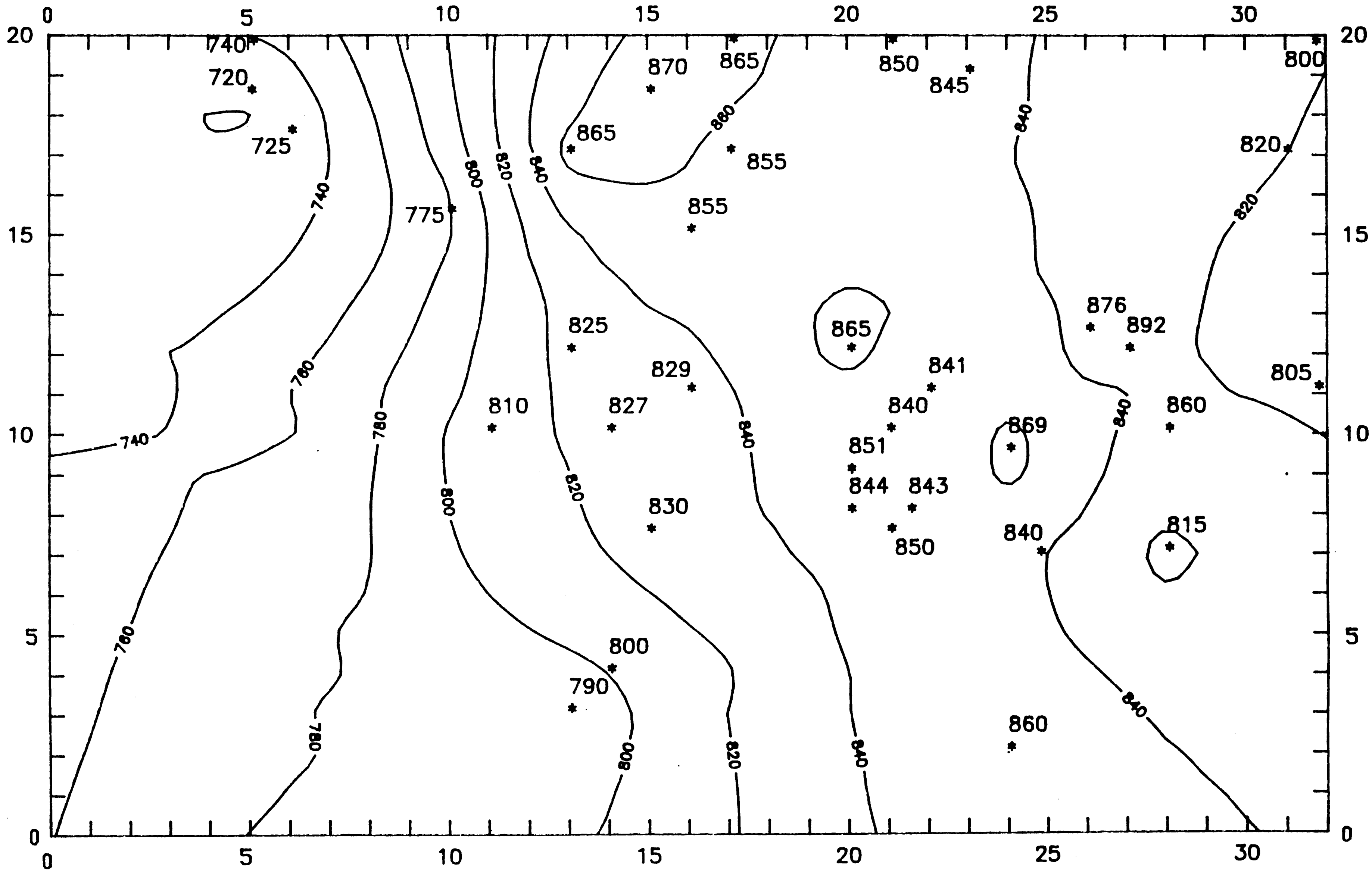

# GENERALIZED TOPOGRAPHY IN THE MODEL DOMAIN

* 790 Data point, in feet above mean sea level

0 1 2
Scale in Miles

Northeast

Figure 4b




ELEVATION OF BASE OF SUBUNIT 'A'

790 * Data point, in feet above mean sea level

0 1 2
Scale in Miles

→ Northeast

Figure 4c

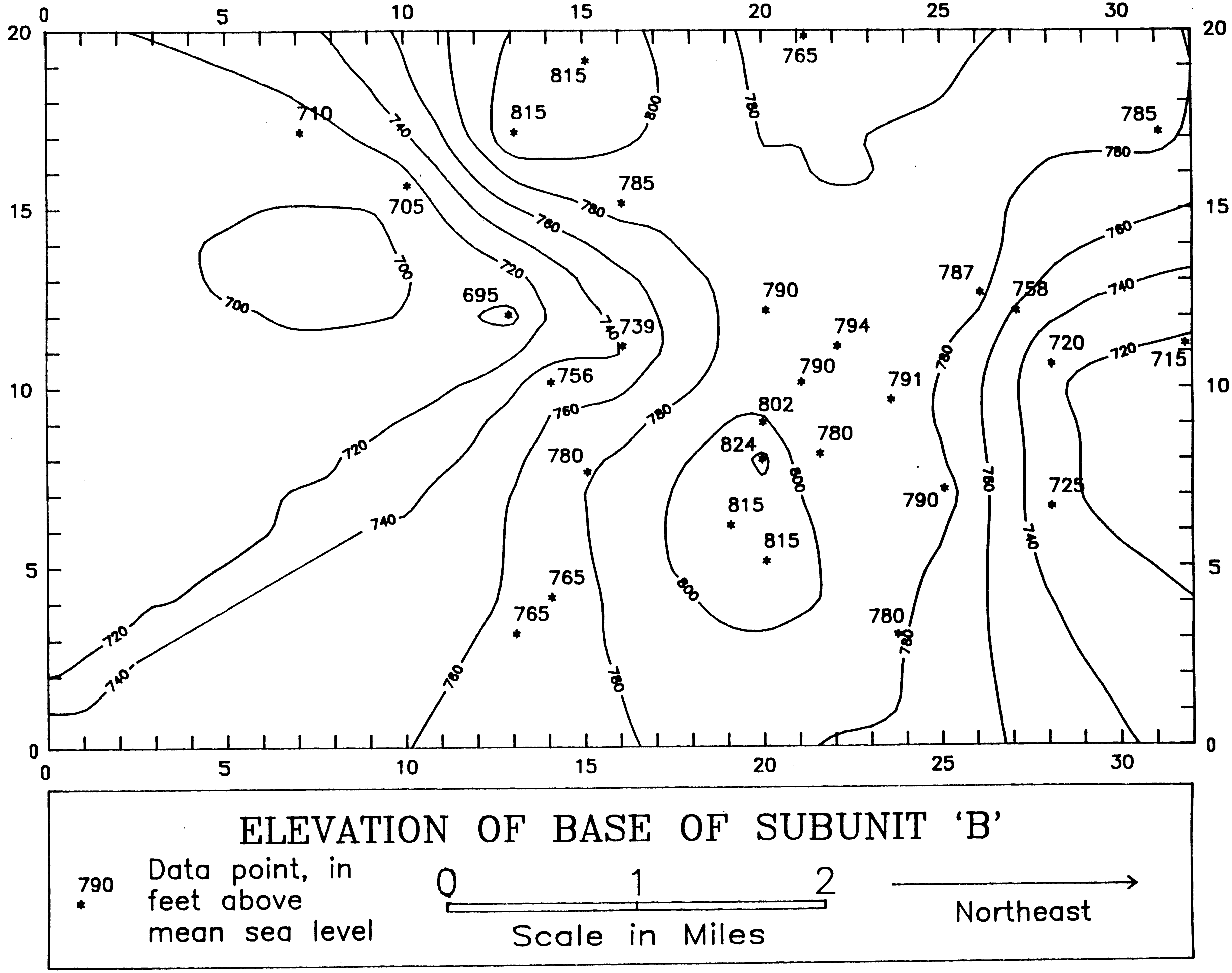

ELEVATION OF BASE OF SUBUNIT 'B'
790 * Data point, in feet above mean sea level
0 1 2
Scale in Miles
Northeast

Figure 4d

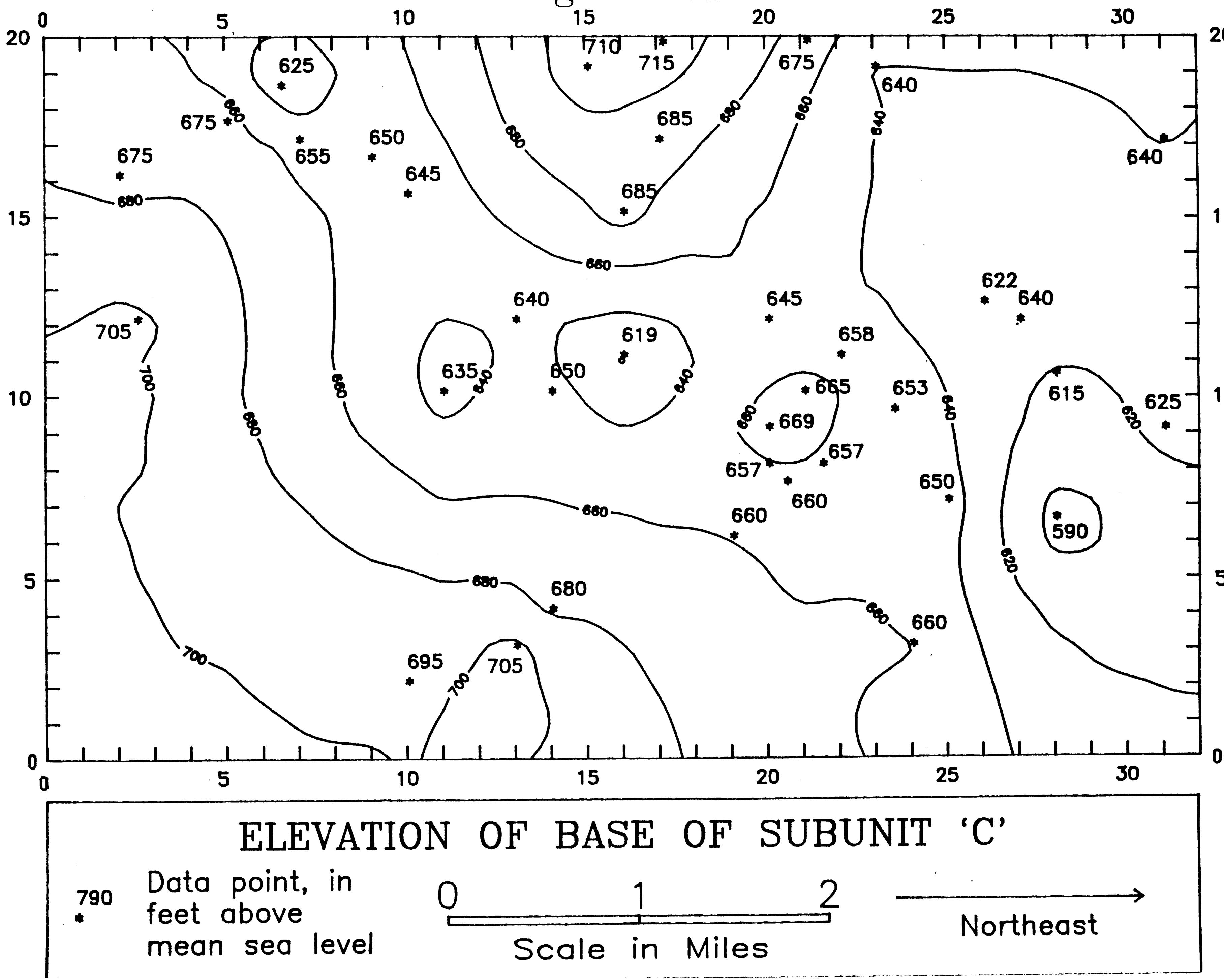
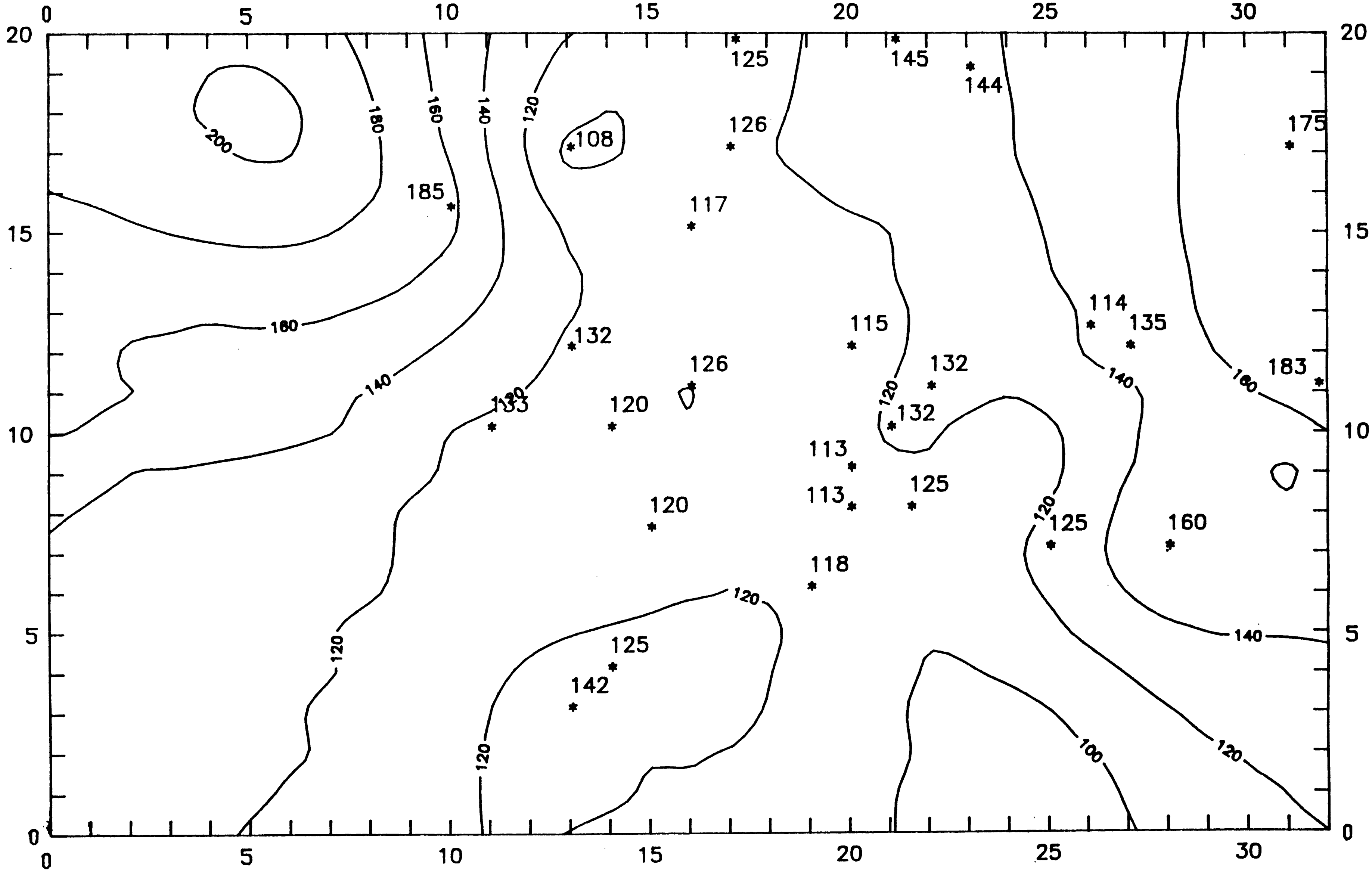

ELEVATION OF BASE OF SUBUNIT 'C'
790 Data point, in feet above mean sea level
0 1 2
Scale in Miles
Northeast

Figure 4e



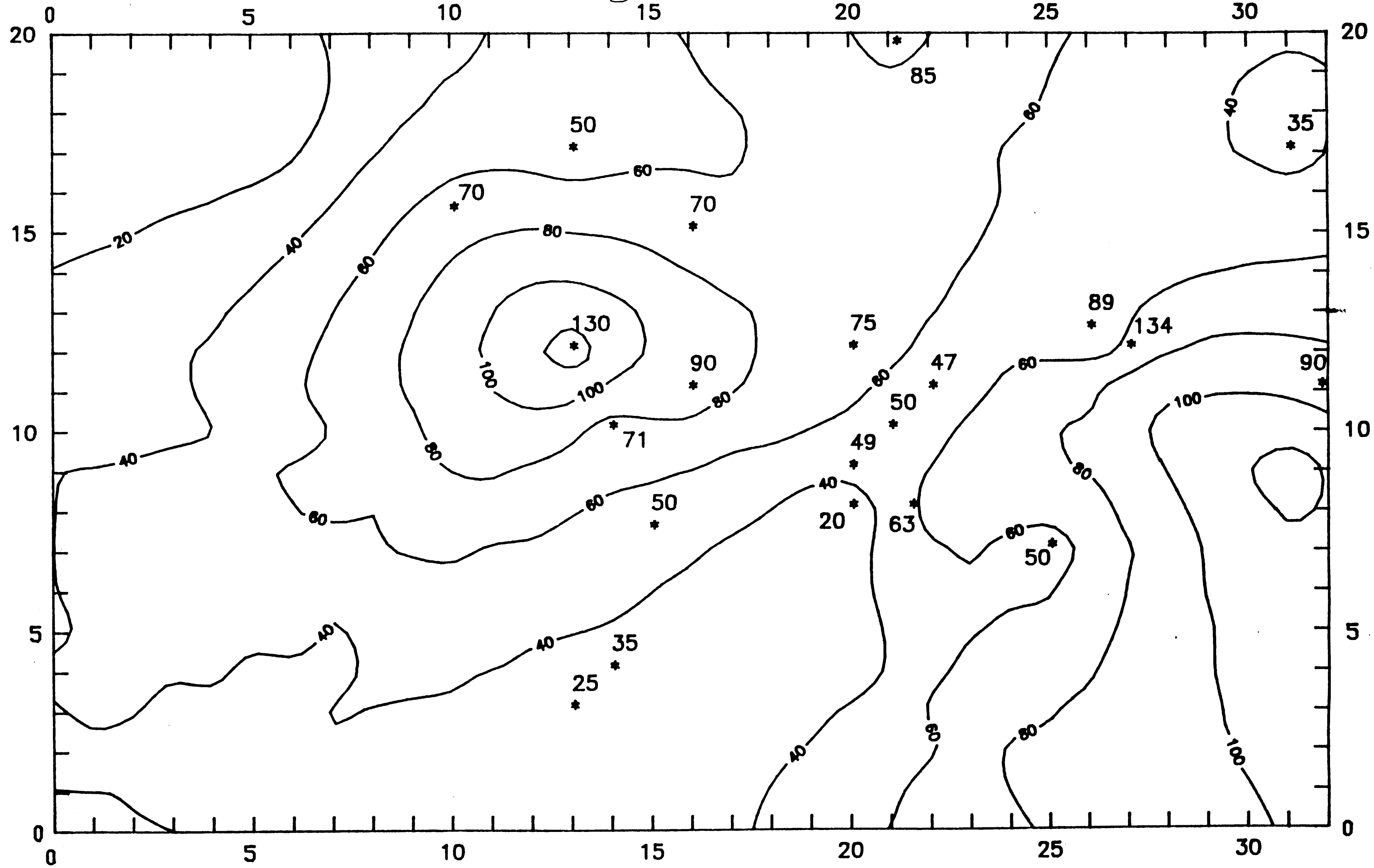

ISOPACH MAP OF UAU SUBUNIT 'A'

* 25 Data point, value in feet

0 1 2 Scale in Miles

→ Northeast

Figure 4f




ISOPACH MAP OF UAU SUBUNIT 'B'

* 25 Data point, value in feet

0 1 2
Scale in Miles

→ Northeast

Figure 4g

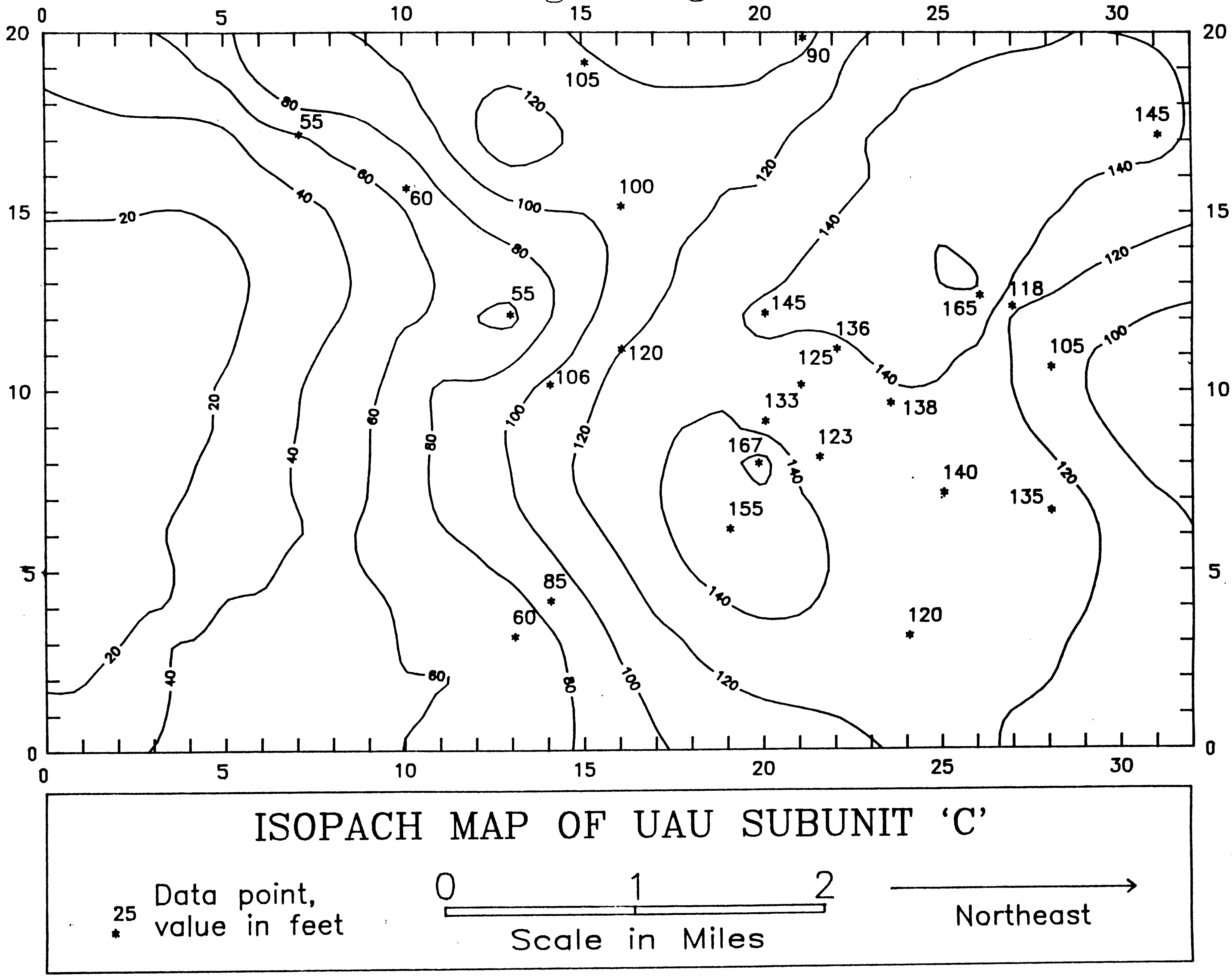
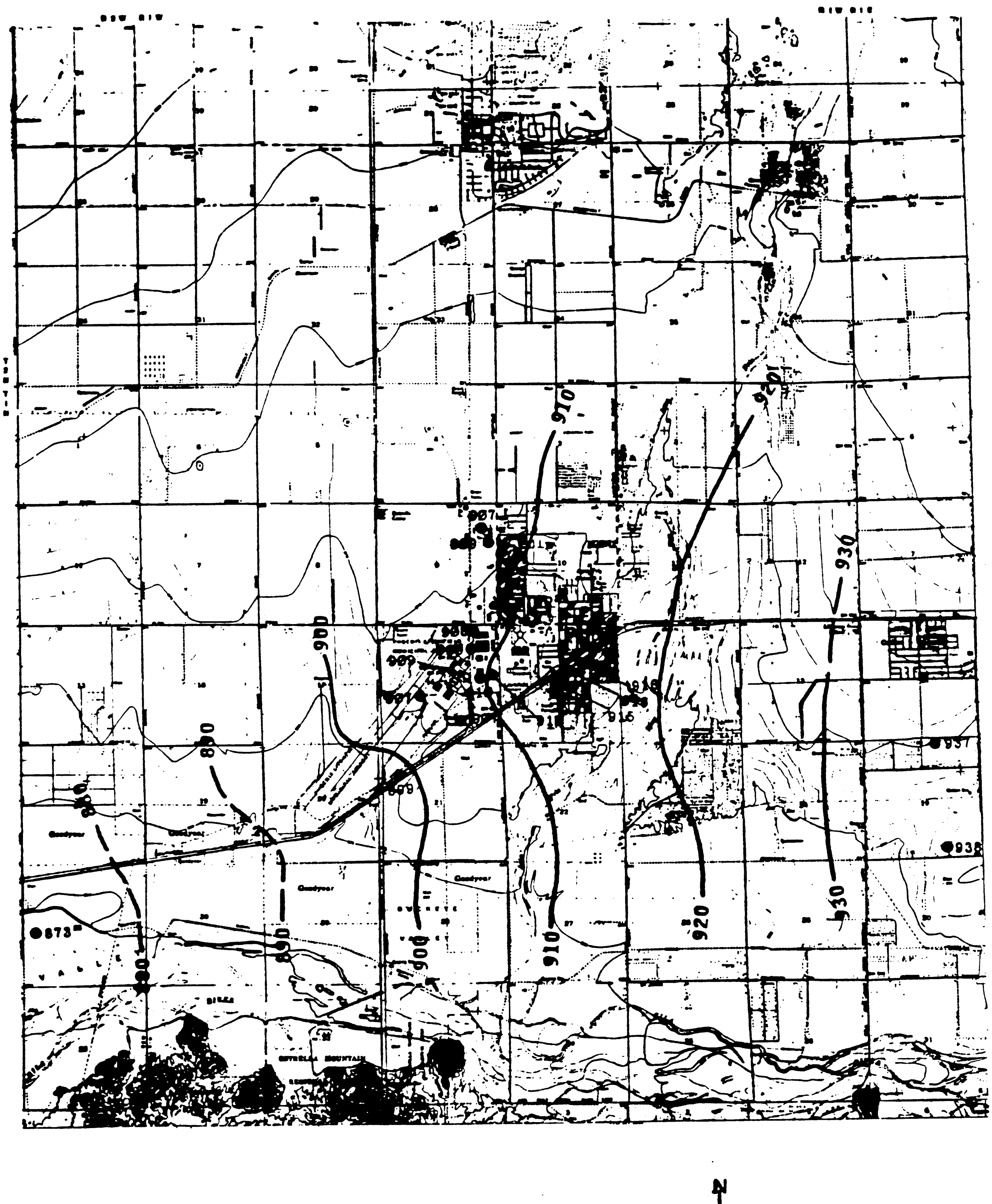

ISOPACH MAP OF UAU SUBUNIT 'C'
Data point, value in feet
0 1 2
Scale in Miles
Northeast

Figure 5a

**1984 Sub-unit A Water Level Contour Map**




Explanation:

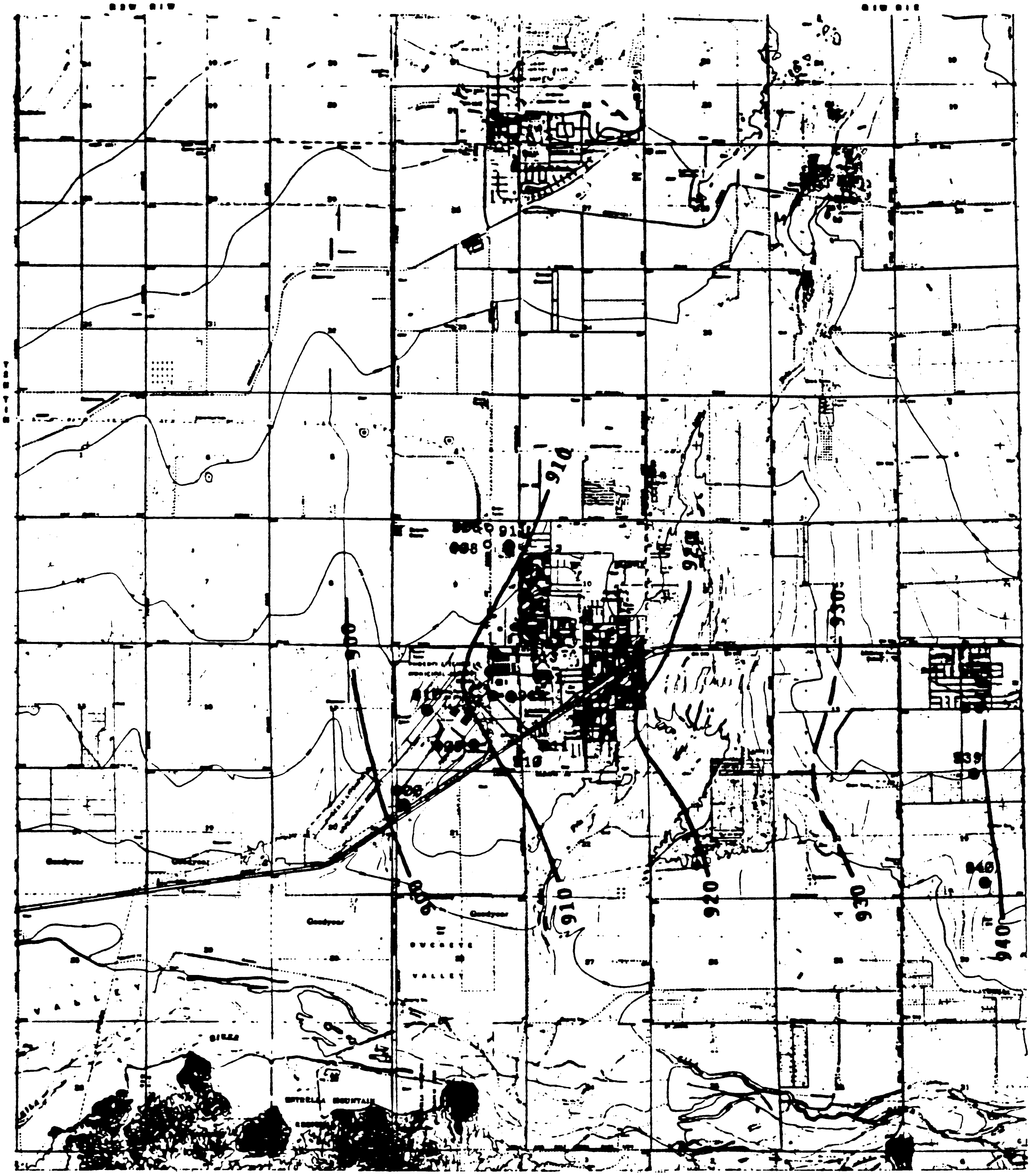
- Single water level measurement
- Averaged water level measurements from surrounding wells

SCALE

0 1 MILE

Figure 5b

1985 Sub-unit A Water Level Contour Map




Explanation:

- • Single water level measurement
- • Averaged water level measurements from surrounding wells

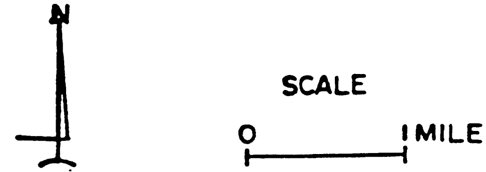
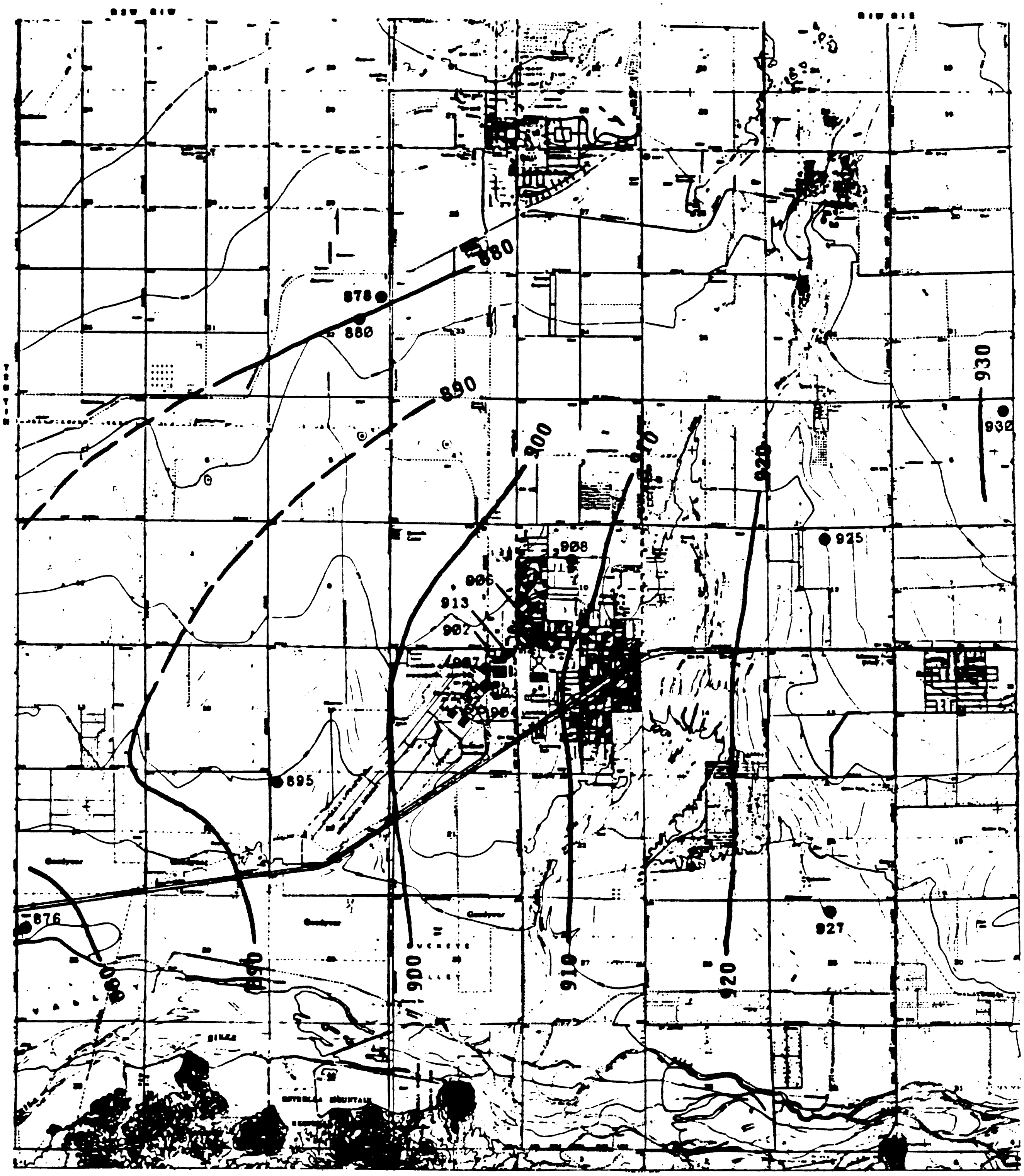


Figure 6a

1984 Sub-unit B/C Water Level Contour Map




Explanation:

• Single water level measurement

• Averaged water level measurements from surrounding wells

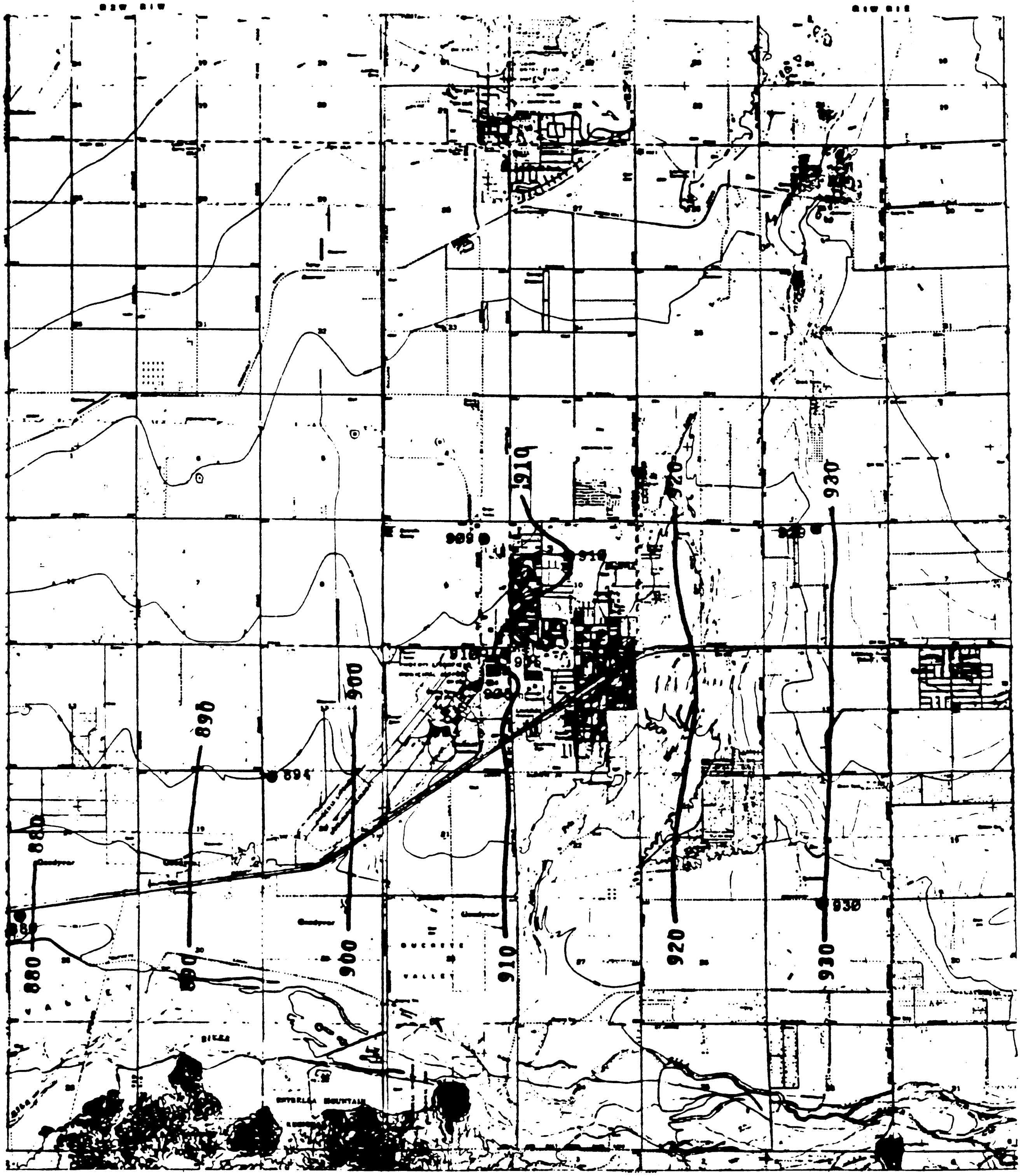
N

SCALE

0 1 MILE

## Figure 6b

## 1985 Sub-unit B/C Water Level Contour Map




Explanation:

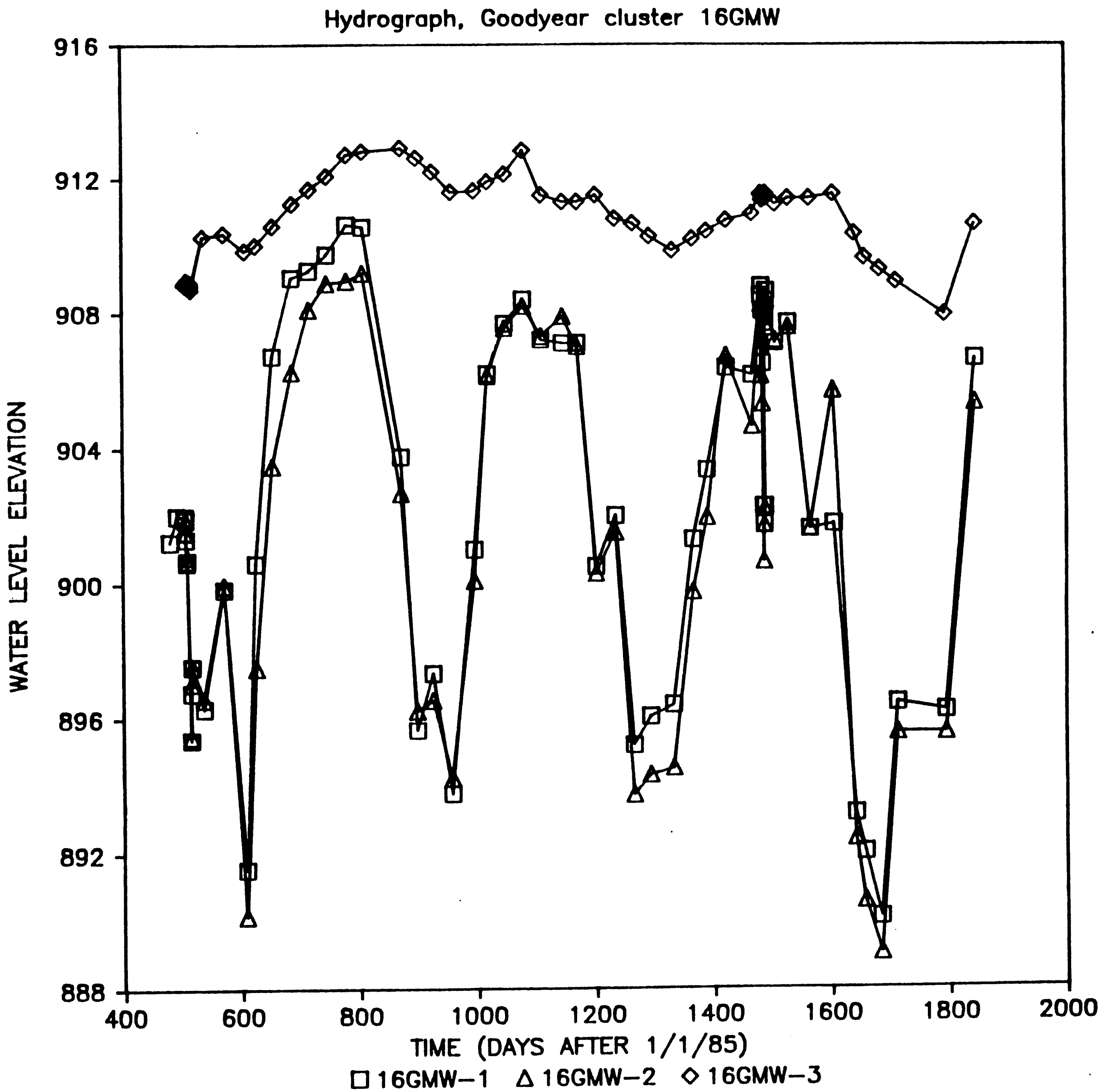
• Single water level measurement

• Averaged water level measurements from surrounding wells

N

SCALE

0 1 MILE



Hydrograph, Goodyear cluster 16GMW
WATER LEVEL ELEVATION
916
912
908
904
900
896
892
888
400
600
800
1000
1200
1400
1600
1800
2000
TIME (DAYS AFTER 1/1/85)
□ 16GMW-1 △ 16GMW-2 ◇ 16GMW-3


Figure 7a

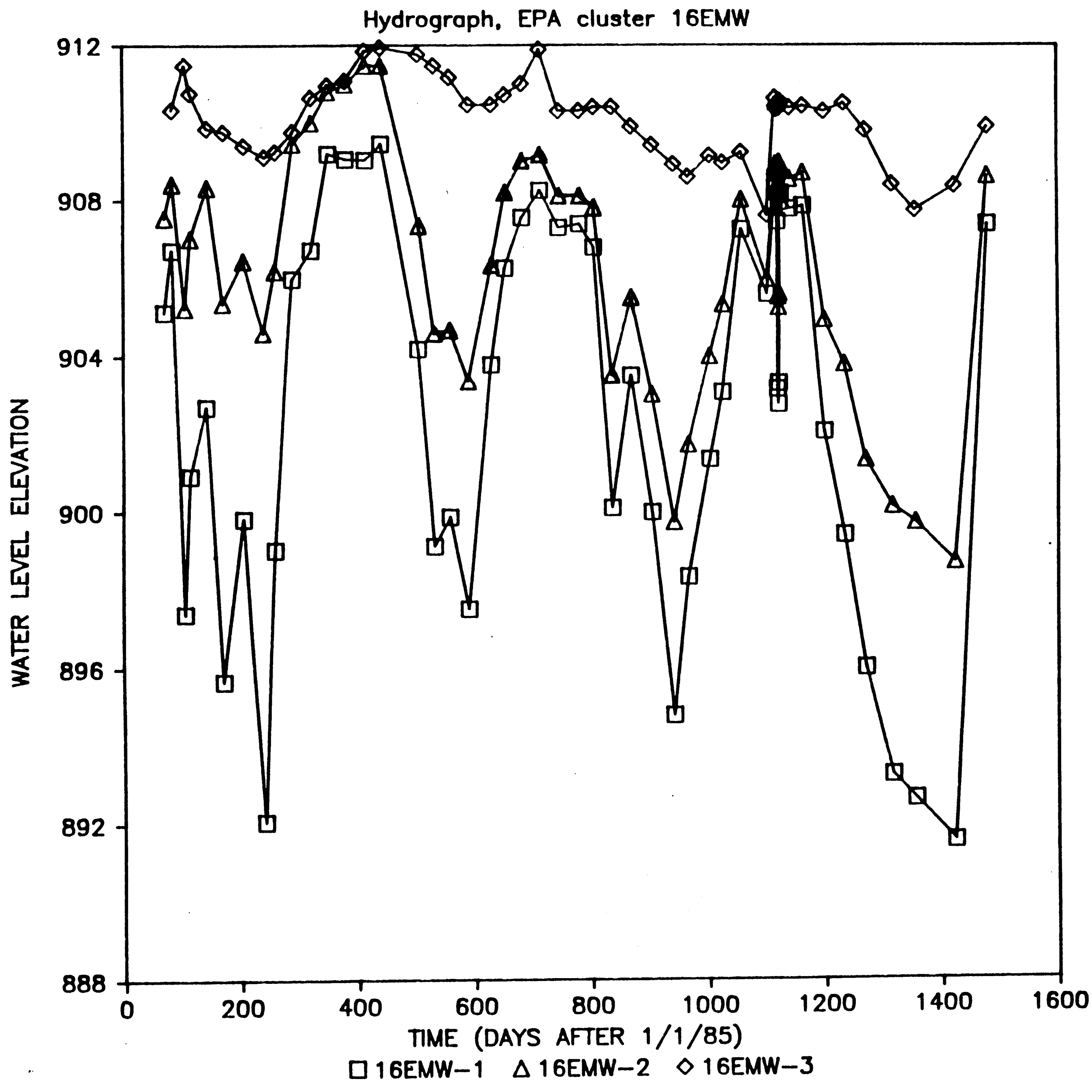
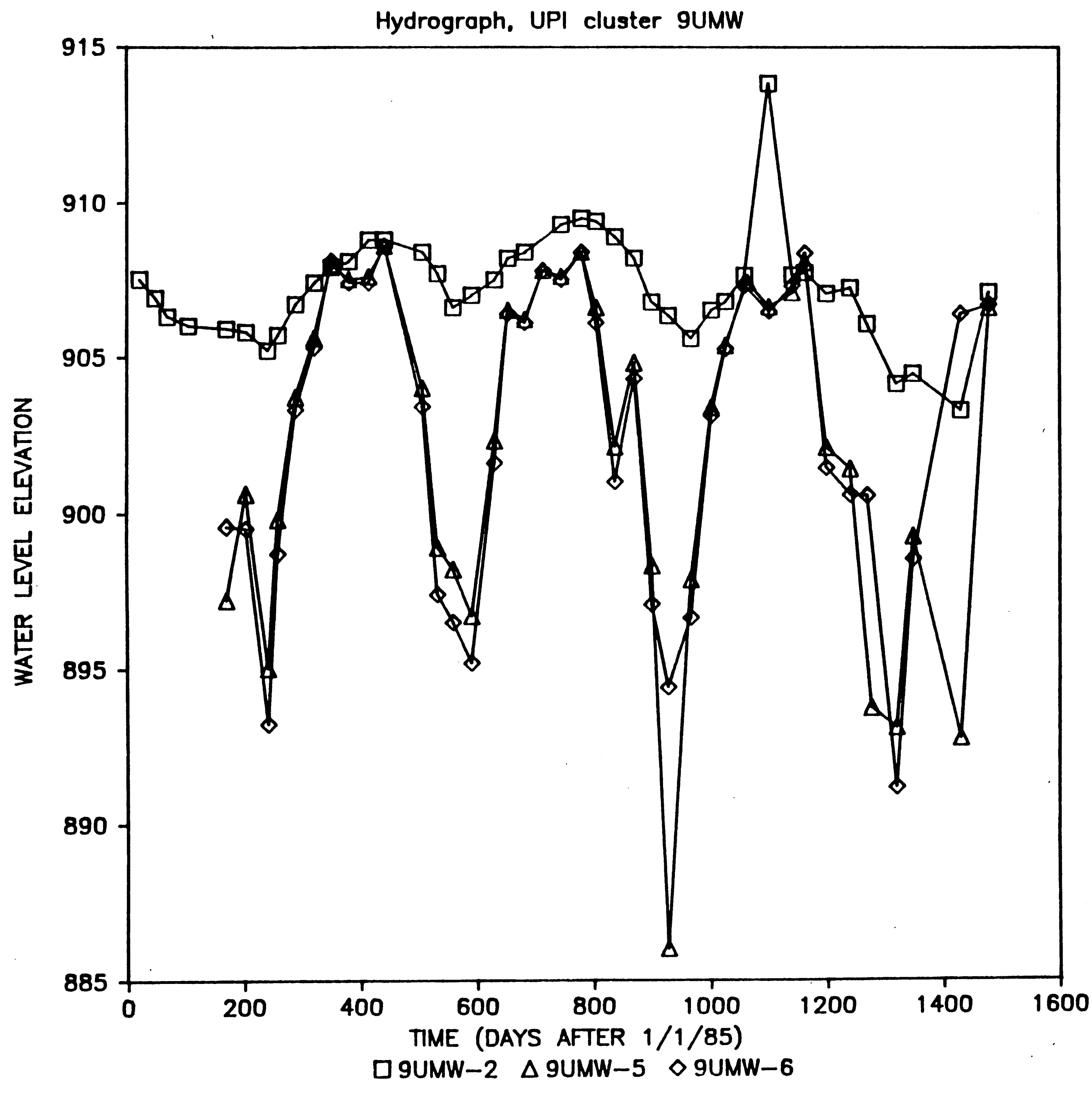

Hydrograph, EPA cluster 16EMW
912
908
904
900
896
892
888
WATER LEVEL ELEVATION
0
200
400
600
800
1000
1200
1400
1600
TIME (DAYS AFTER 1/1/85)
□ 16EMW-1 △ 16EMW-2 ◇ 16EMW-3

Figure 7b

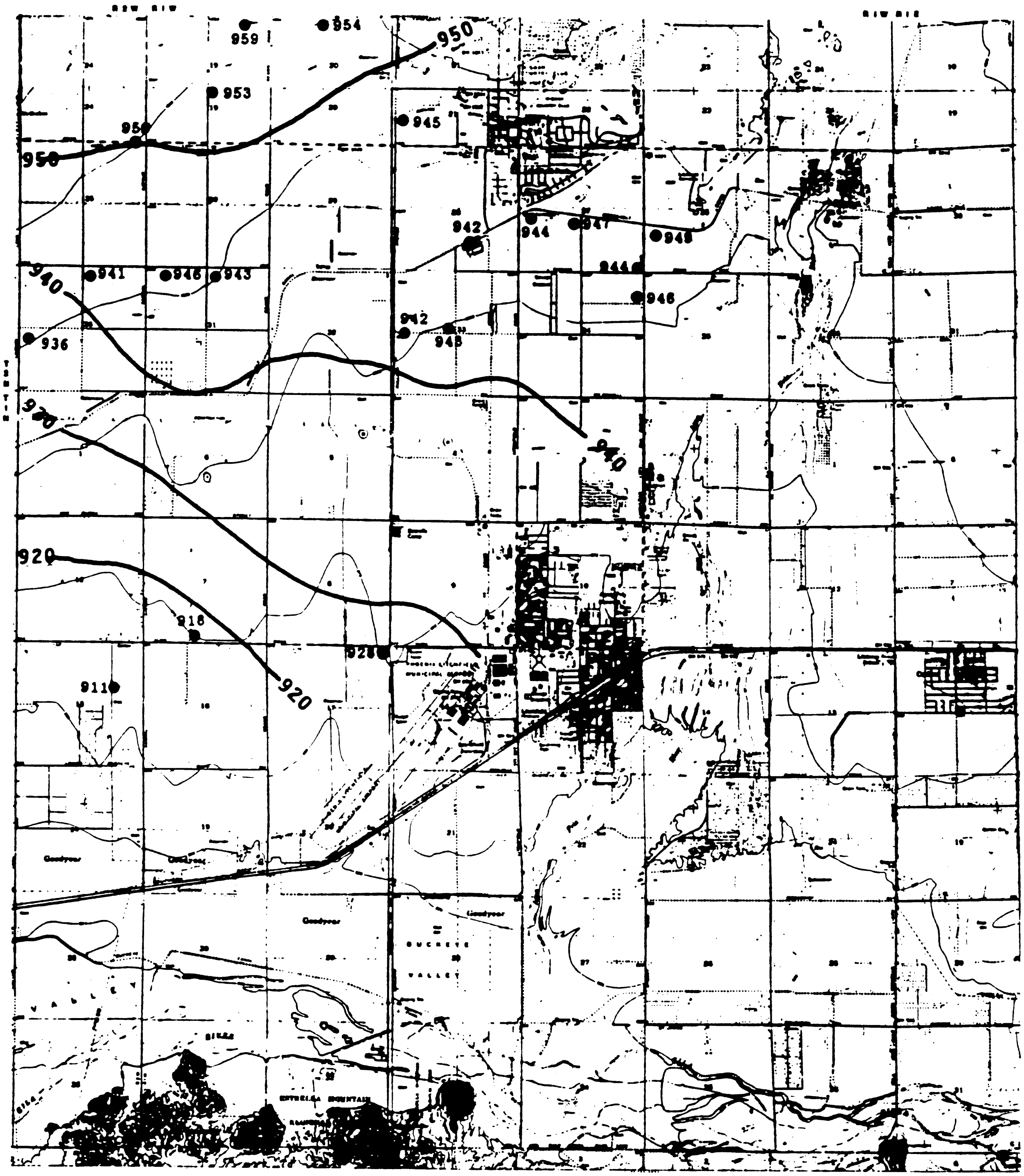


Hydrograph, UPI cluster 9UMW
915
910
905
900
895
890
885
WATER LEVEL ELEVATION
0
200
400
600
800
1000
1200
1400
1600
TIME (DAYS AFTER 1/1/85)
□ 9UMW-2 △ 9UMW-5 ◇ 9UMW-6


Figure 7c

Figure 8a

1945 UAU Water Level Contour Map




Explanation:

- Single water level measurement
- Averaged water level measurements from surrounding wells

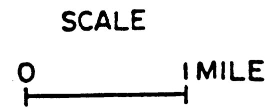
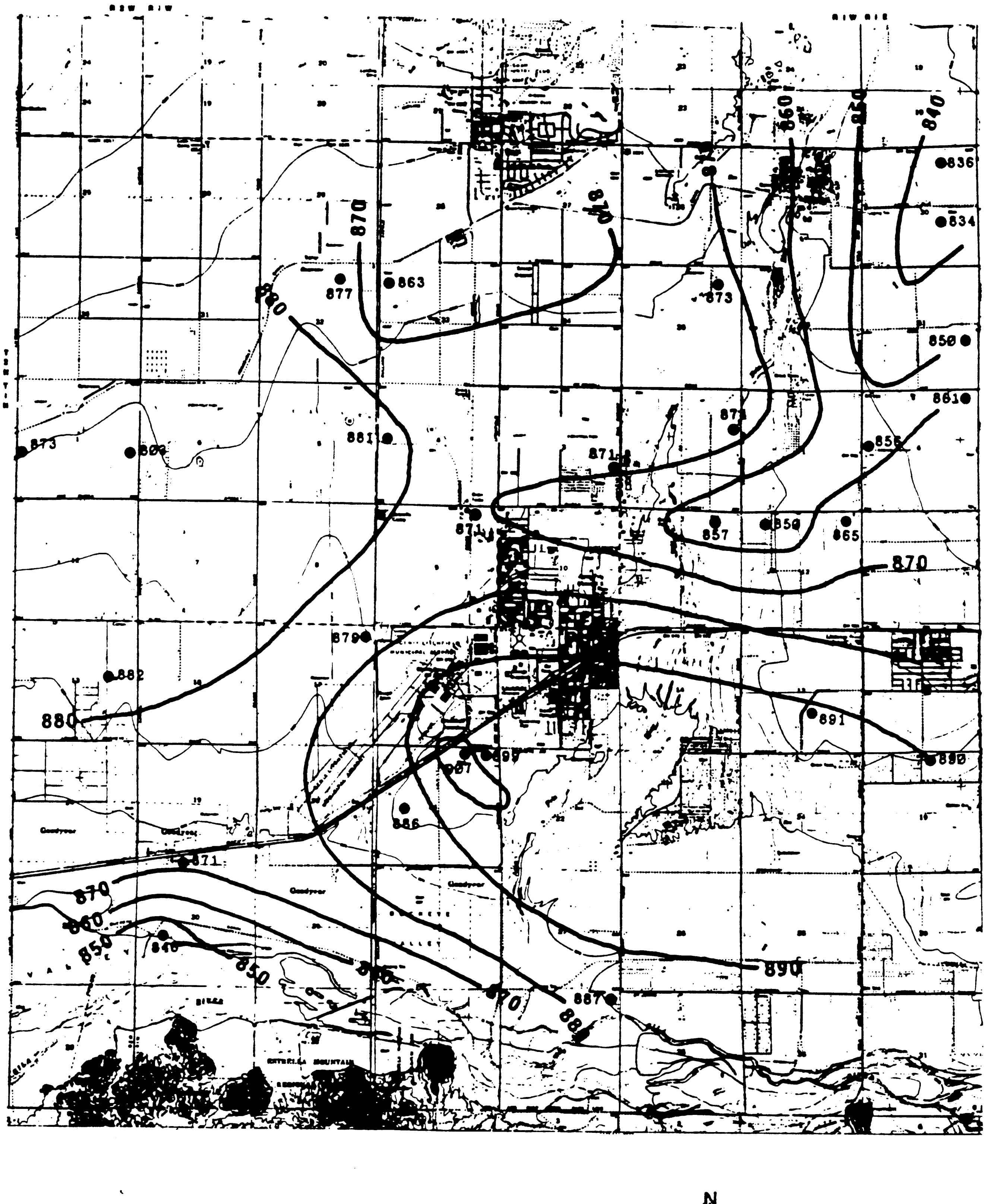



Figure 8b

1962 UAU Water Level Contour Map




Explanation:

● Single water level measurement

• Averaged water level measurements from surrounding wells

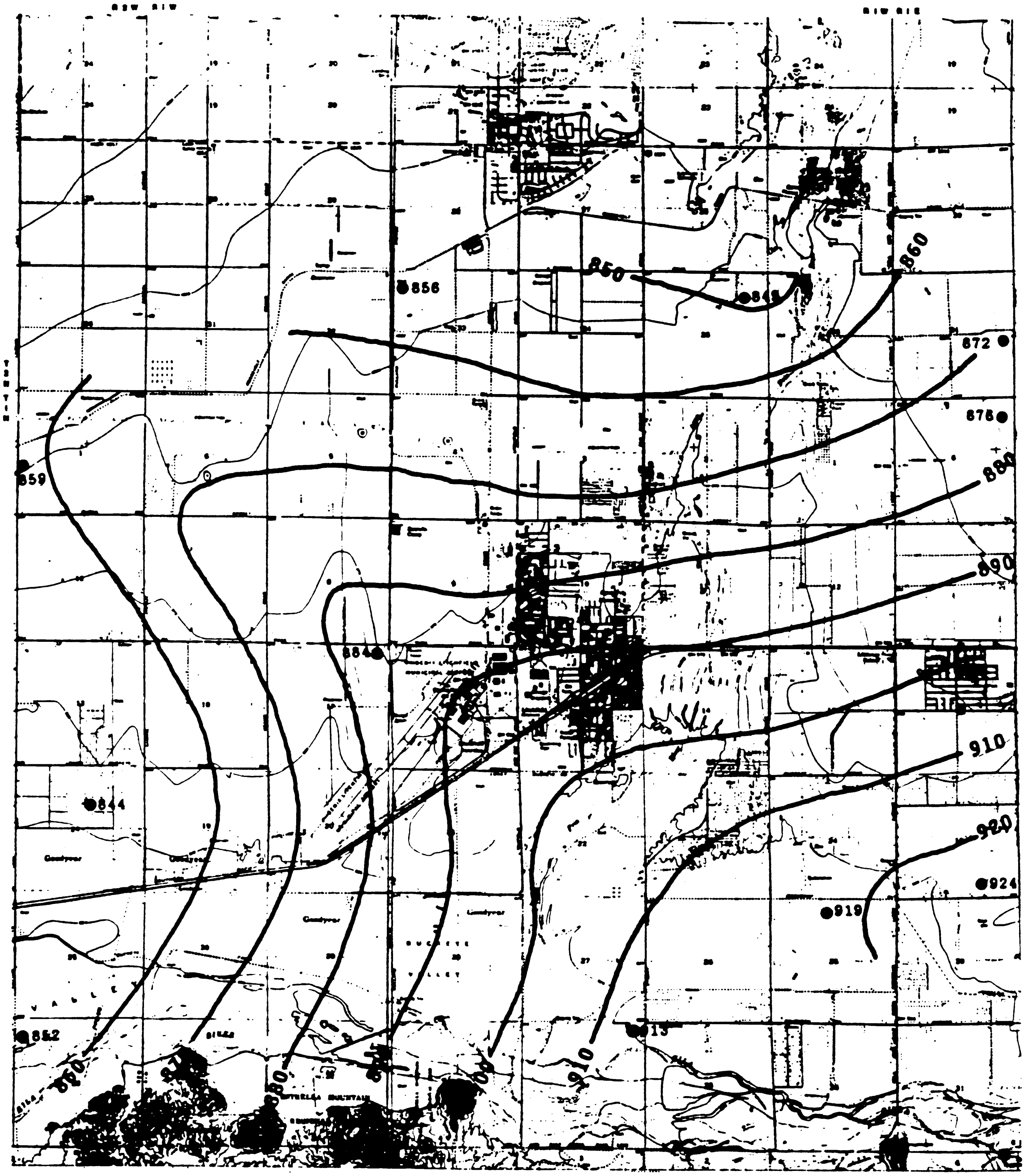
N

SCALE

0 — 1 MILE

Figure 8c

1972 UAU Water Level Contour Map




Explanation:

• Single water level measurement

• Averaged water level measurements from surrounding wells

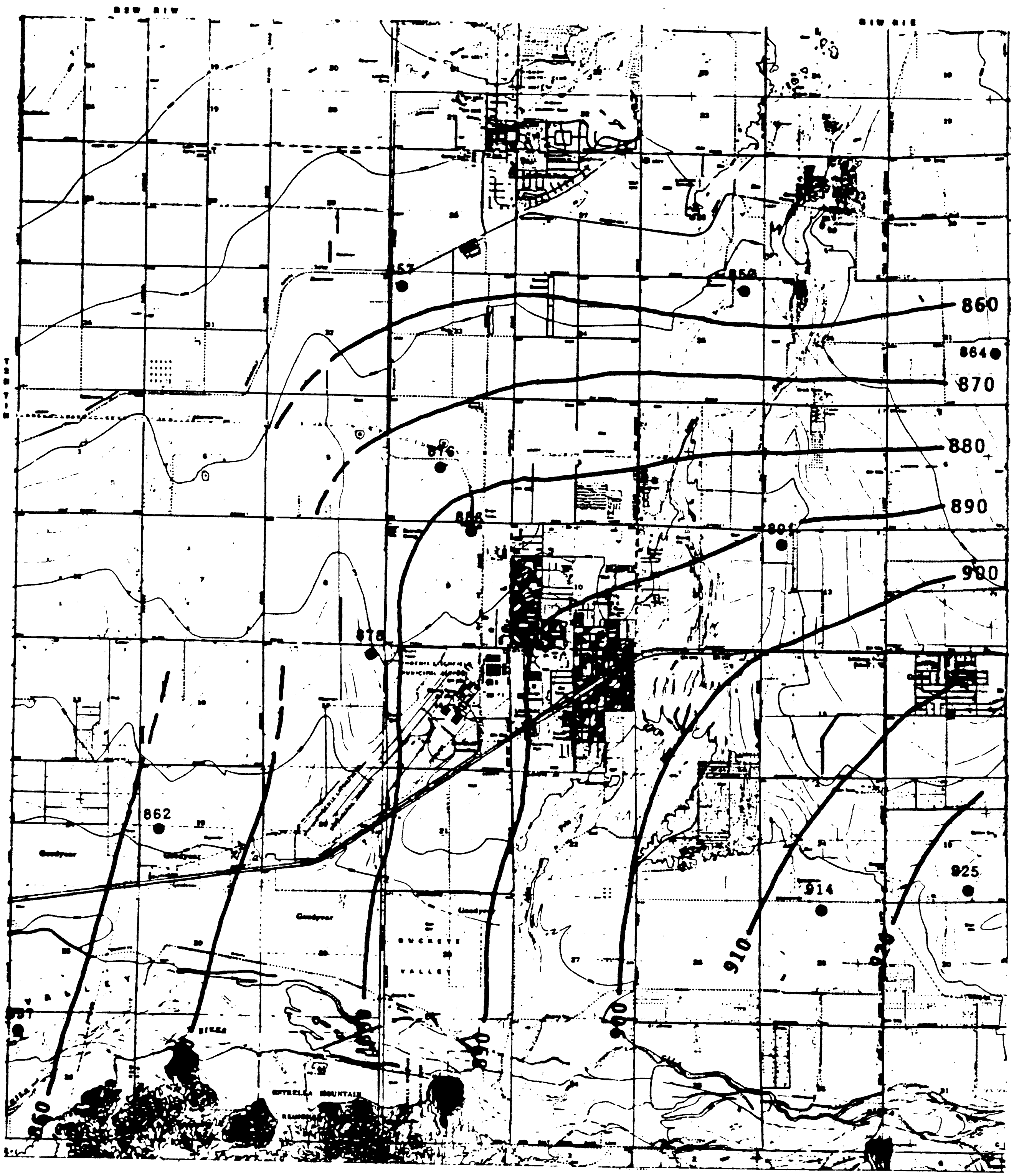
N

SCALE

0 1 MILE

Figure 8d

1977 UAU Water Level contour Map




Explanation:

- Single water level measurement
- Averaged water level measurements from surrounding wells

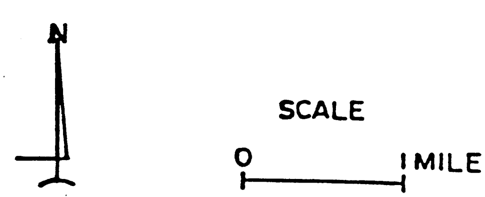
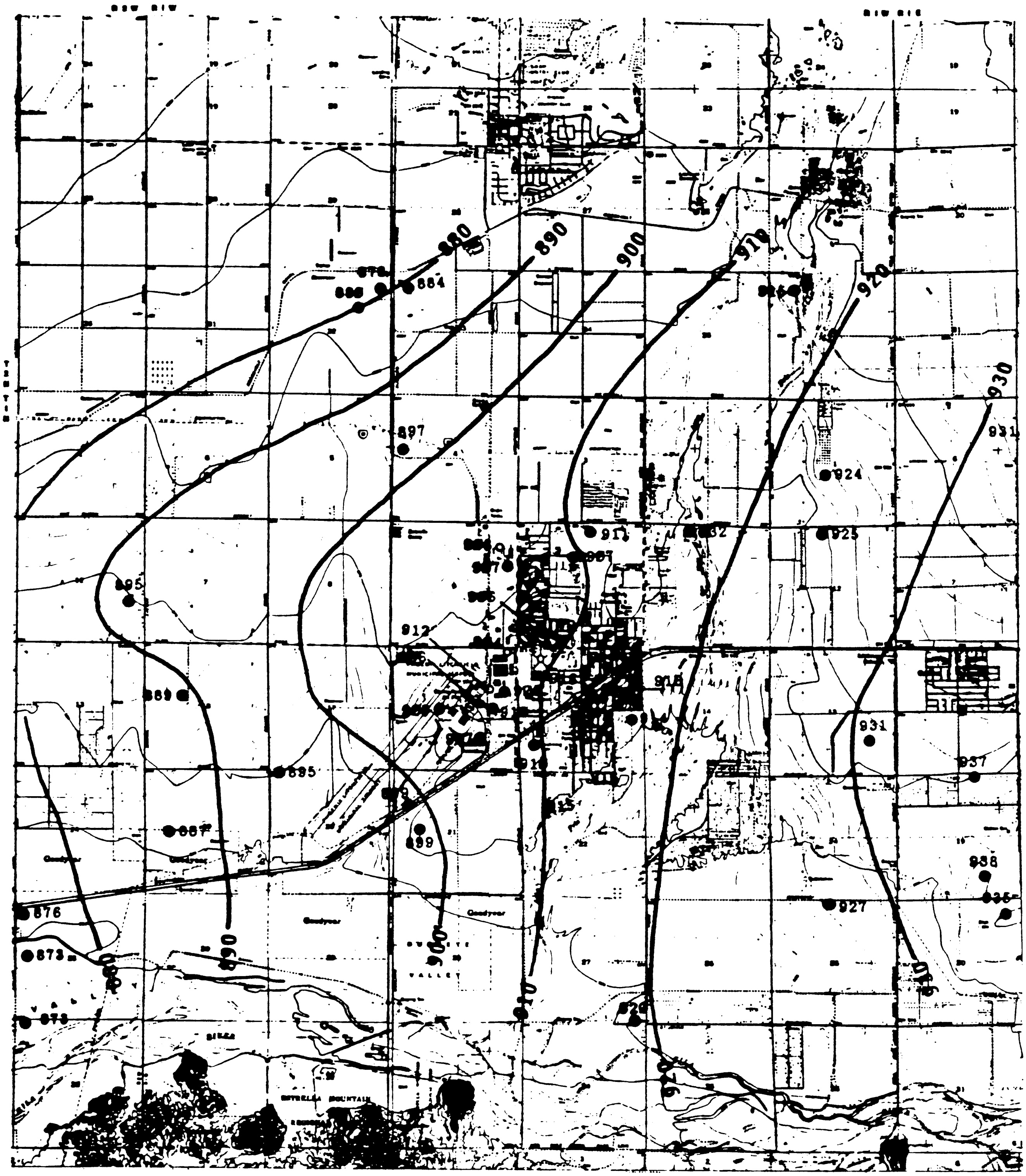


Figure 8e

1984 UAU Water Level Contour Map





SCALE

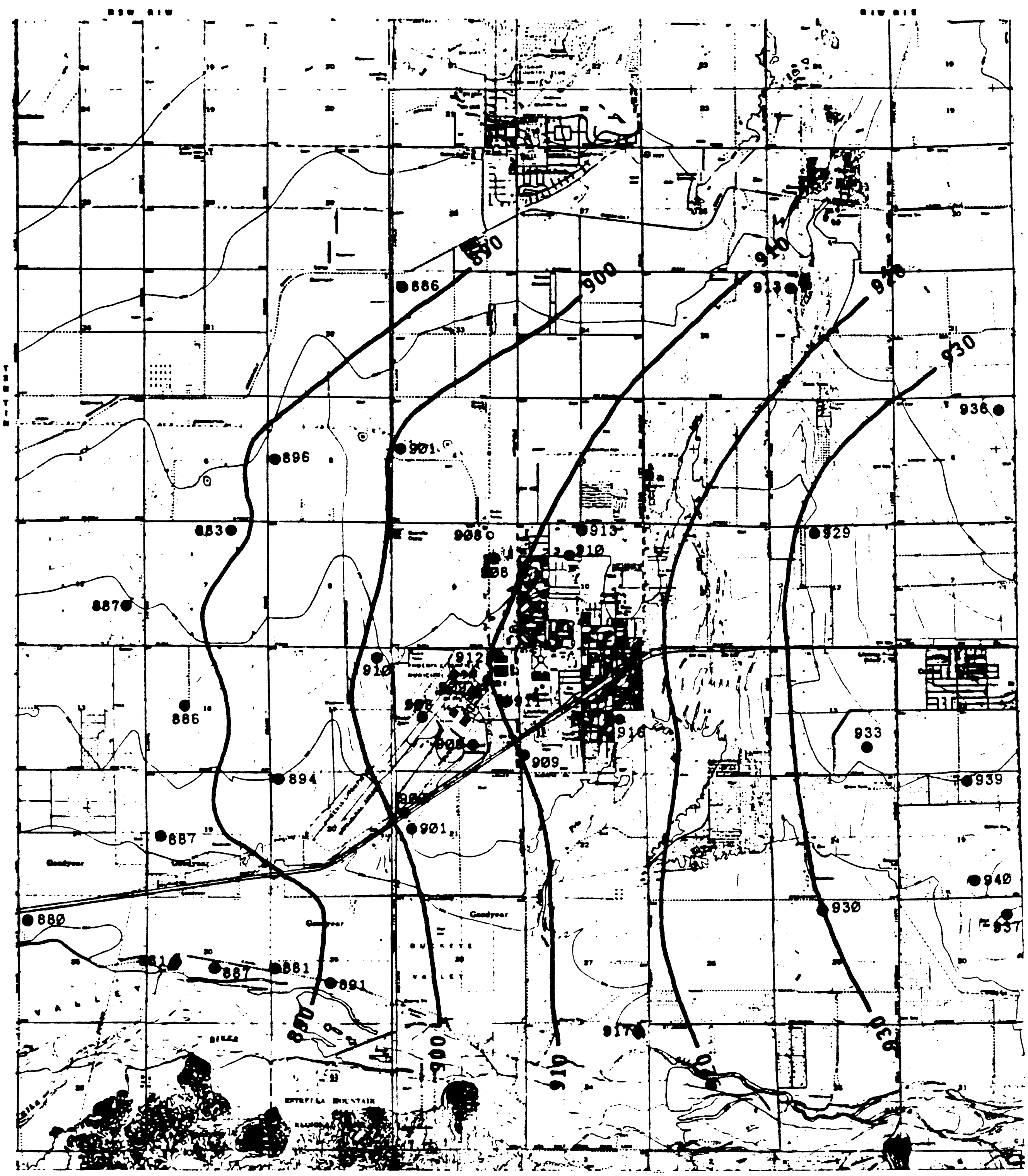
0 1 MILE

Explanation:

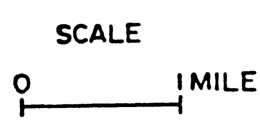
- Single water level measurement
- Averaged water level measurements from surrounding wells

Figure 8f

1985 UAU Water Level Contour Map



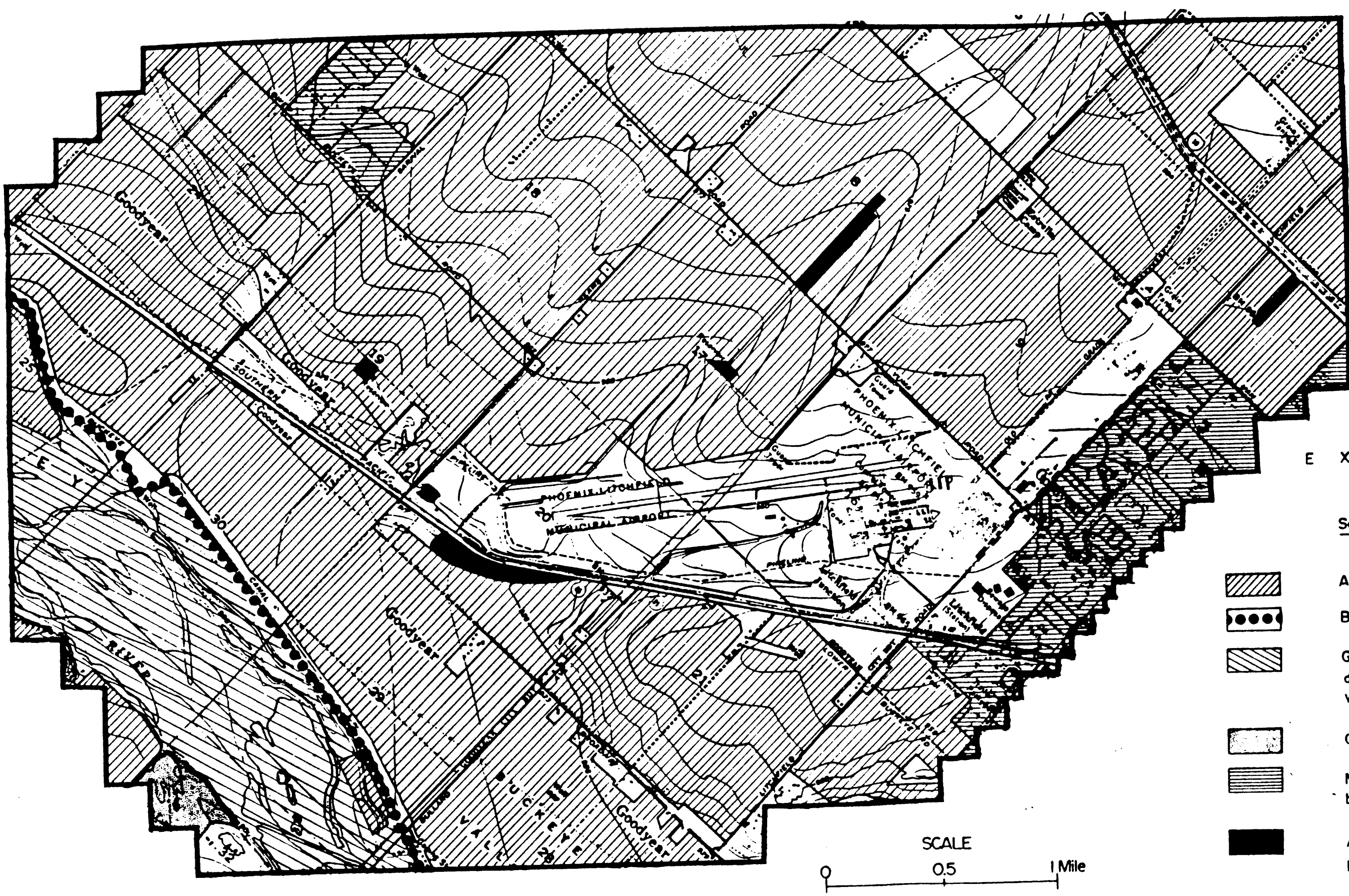


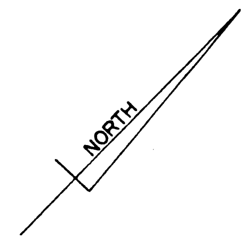



Explanation:

- Single water level measurement
- Averaged water level measurements from surrounding wells

# MAP SHOWING LOCATION OF RECHARGE SOURCES WITHIN THE MODEL DOMAIN




E X P L A N A T I O N

| Sources of Recharge | Acre Feet / Year |
|---|---|
| Agriculture | 9600 |
| Buckeye Irrigation Company Canal | 6100 |
| Gila River Floodplain inqluding effluent discharge from 23rd. an 91st. Ave Waste Water Treatment Plants | 0 |
| Golf Course, Sierra Estrella | 200 |
| Municipal (includes industrial, residential, businesses and public parks) | 300 |
| Ag-tailwater sumps, sewage disposal pits, ponds and reservoirs | 2200 |

Figure 9

Figure 10

OVERVIEW OF MODELING PROCESS BY ADWR
FOR THE
PHOENIX-GOODYEAR SUPERFUND SITE

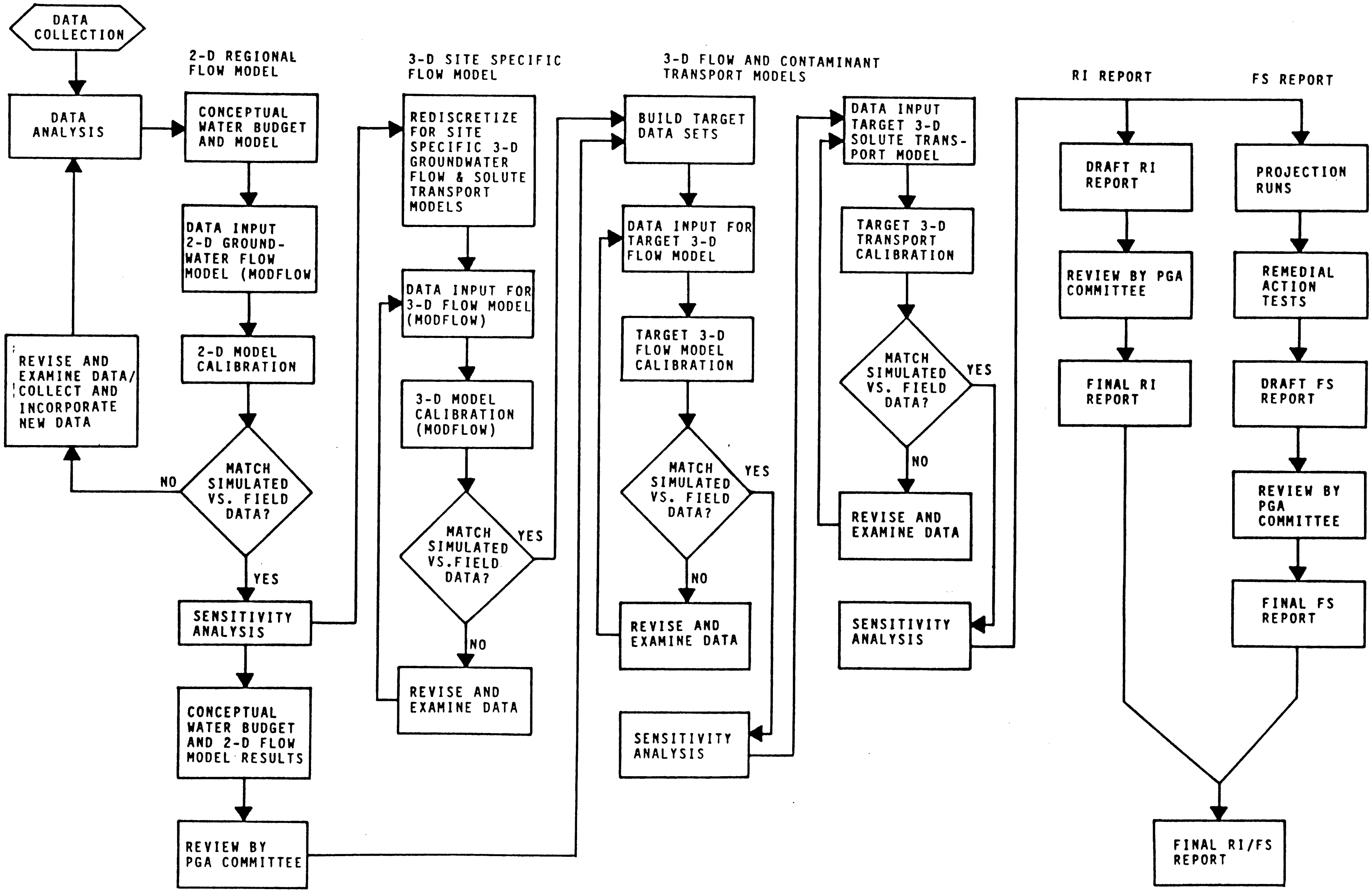


Figure 11a

Contaminant Transport Model Grid Design in the Horizontal Plane

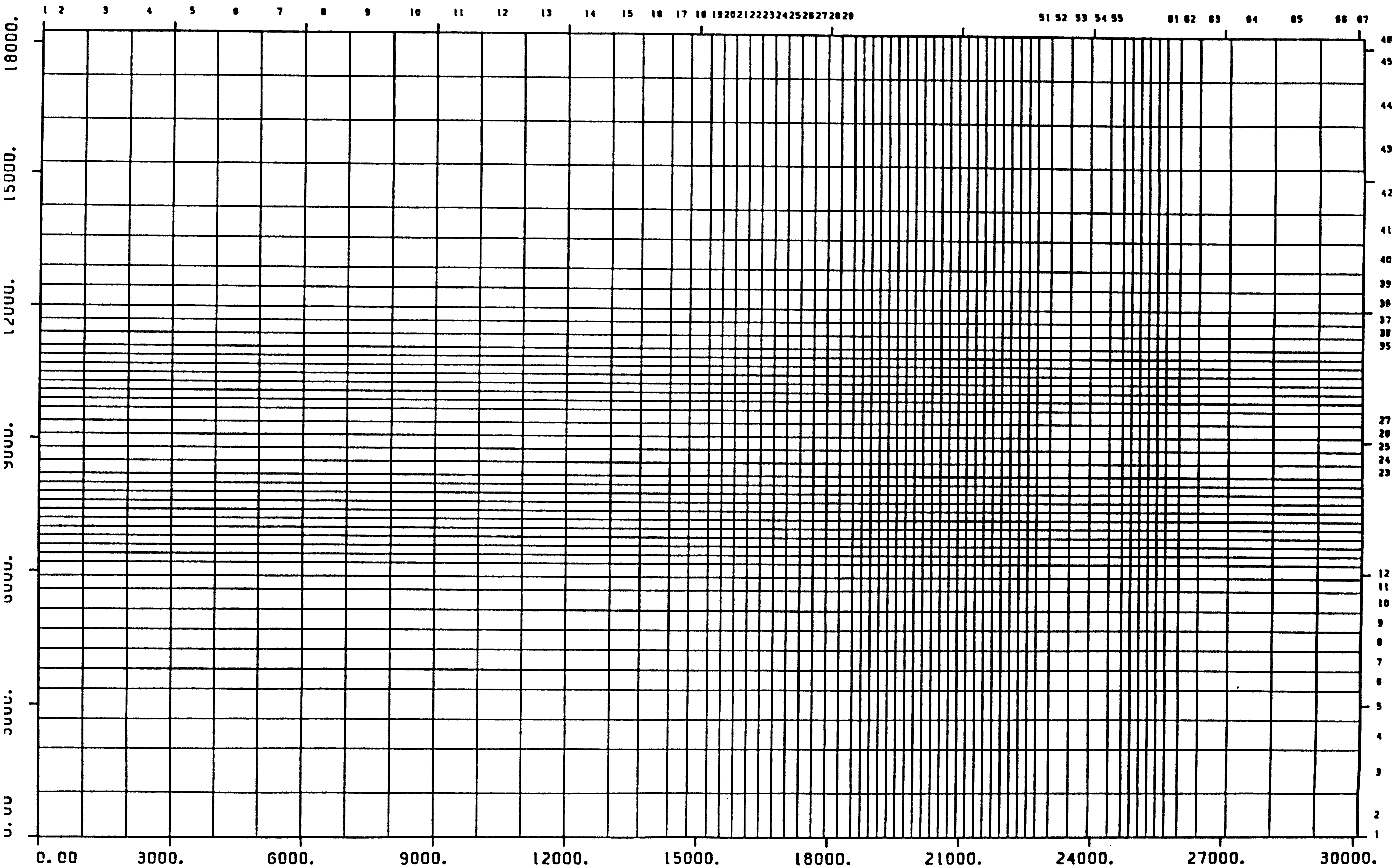


Figure 11b

Contaminant Transport Model Grid Design
in the Northwest-Southeast Vertical Plane

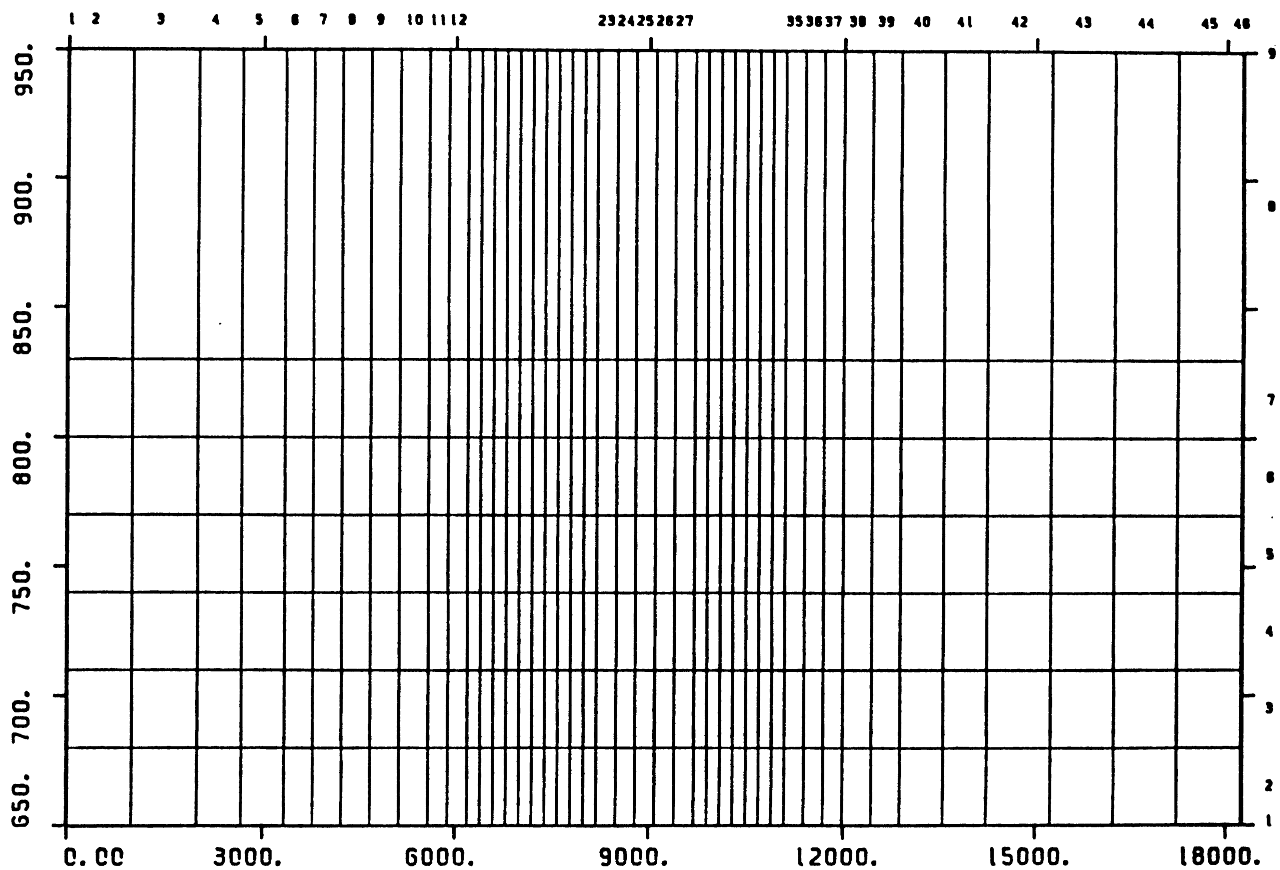


Figure 11c

Contaminant Transport Model Grid Design
in the Southwest-Northeast Vertical Plane

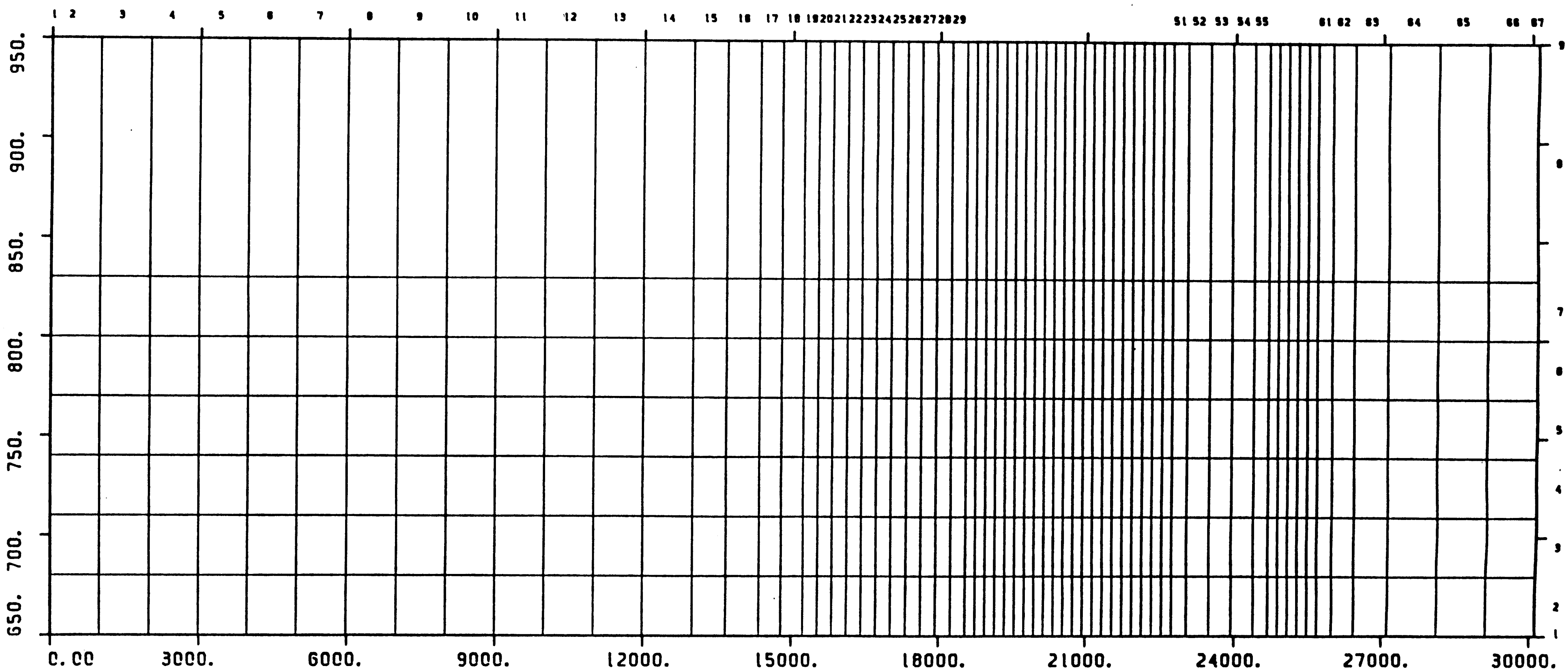


Figure 12

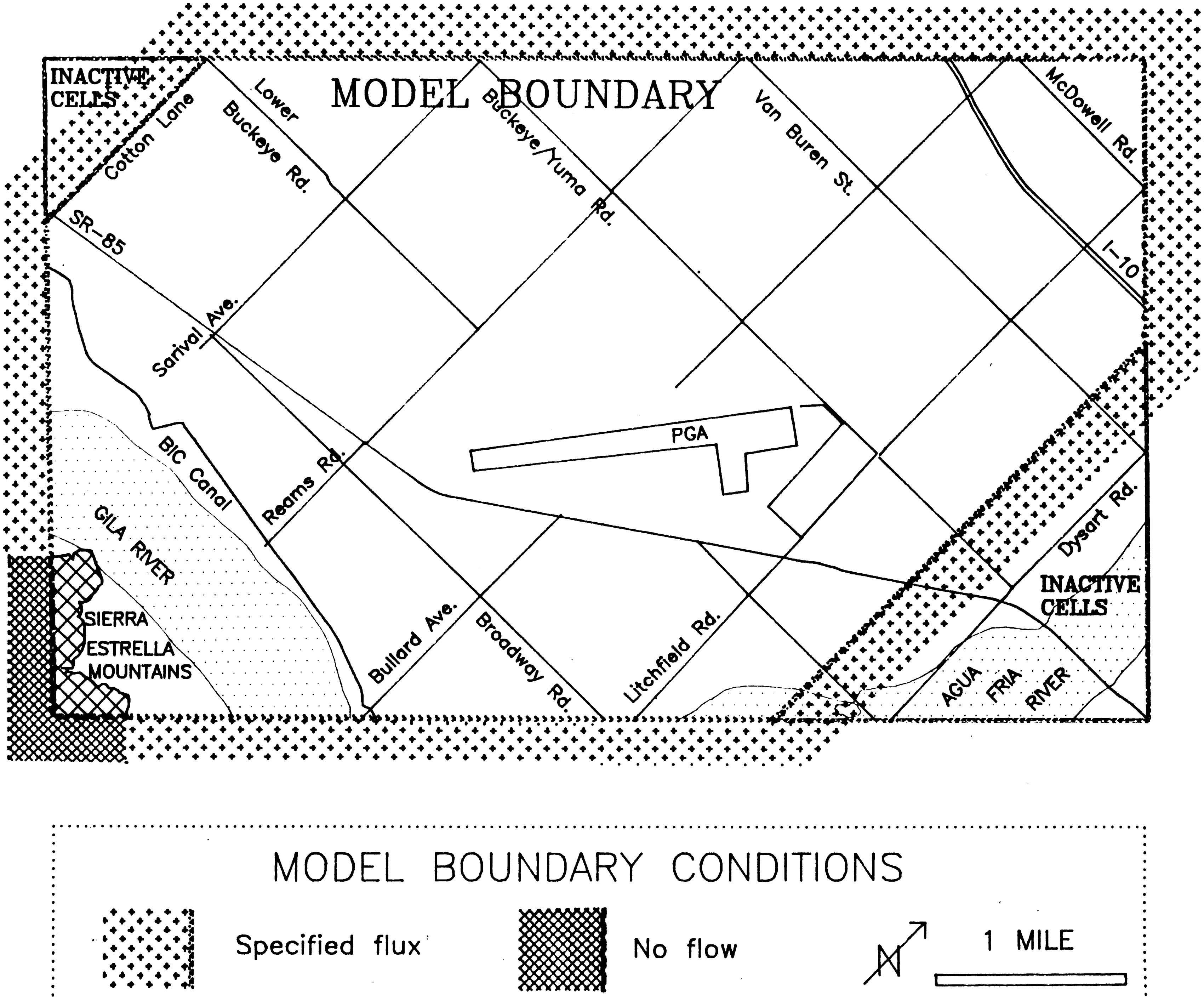

MODEL BOUNDARY
INACTIVE CELLS
Cotton Lane
Lower Buckeye Rd.
Buckeye/Yuma Rd.
Van Buren St.
McDowell Rd.
I-10
SR-85
Sarival Ave.
BIC Canal
Reams Rd.
PGA
GILA RIVER
SIERRA ESTRELLA MOUNTAINS
Bullard Ave.
Broadway Rd.
Litchfield Rd.
Dysart Rd.
INACTIVE CELLS
AGUA FRIA RIVER
MODEL BOUNDARY CONDITIONS
Specified flux
No flow
N
1 MILE

Figure 13

TOTAL PUMPAGE VALUES IN THE
3D CONTAMINANT TRANSPORT MODEL

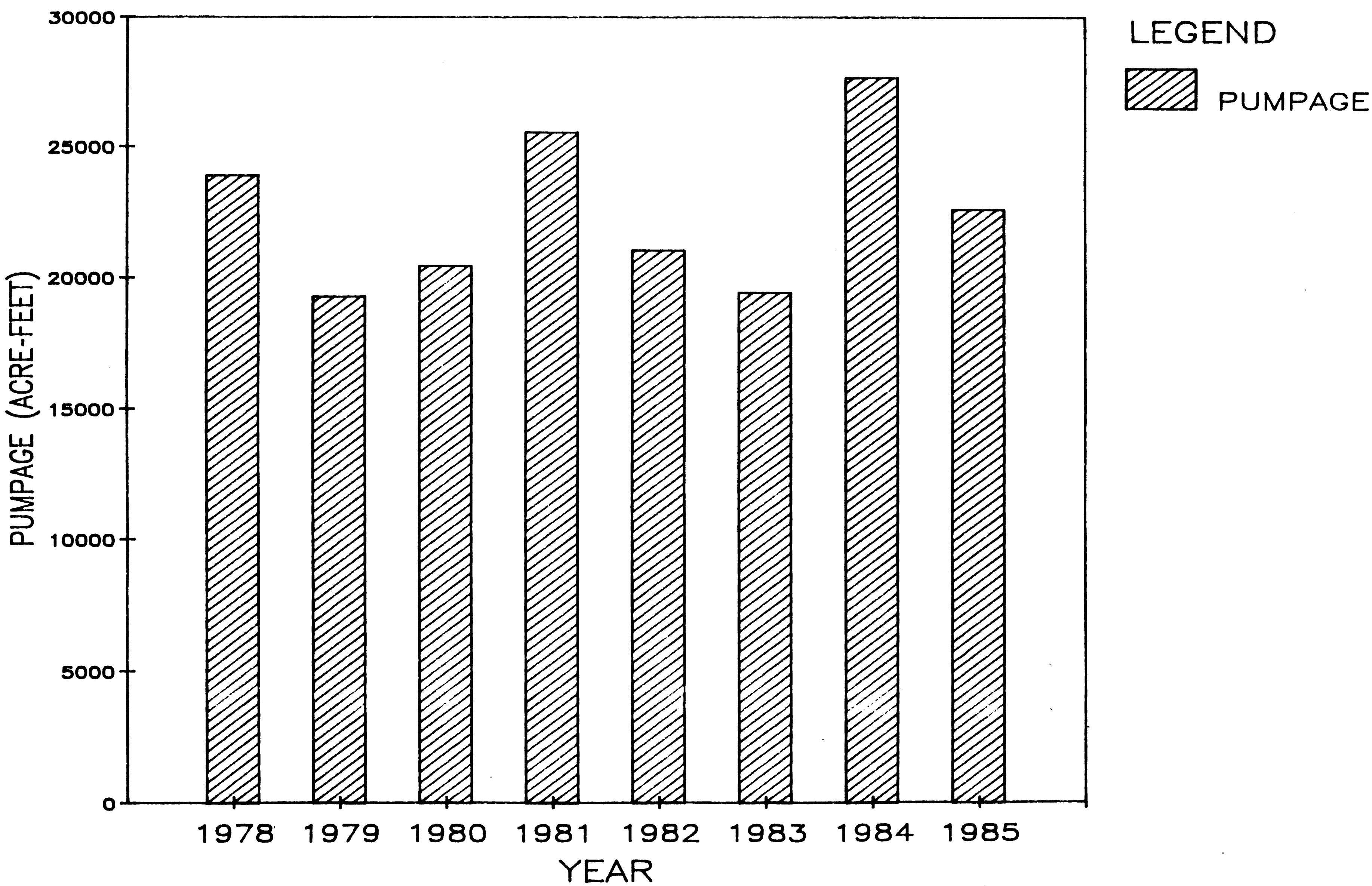
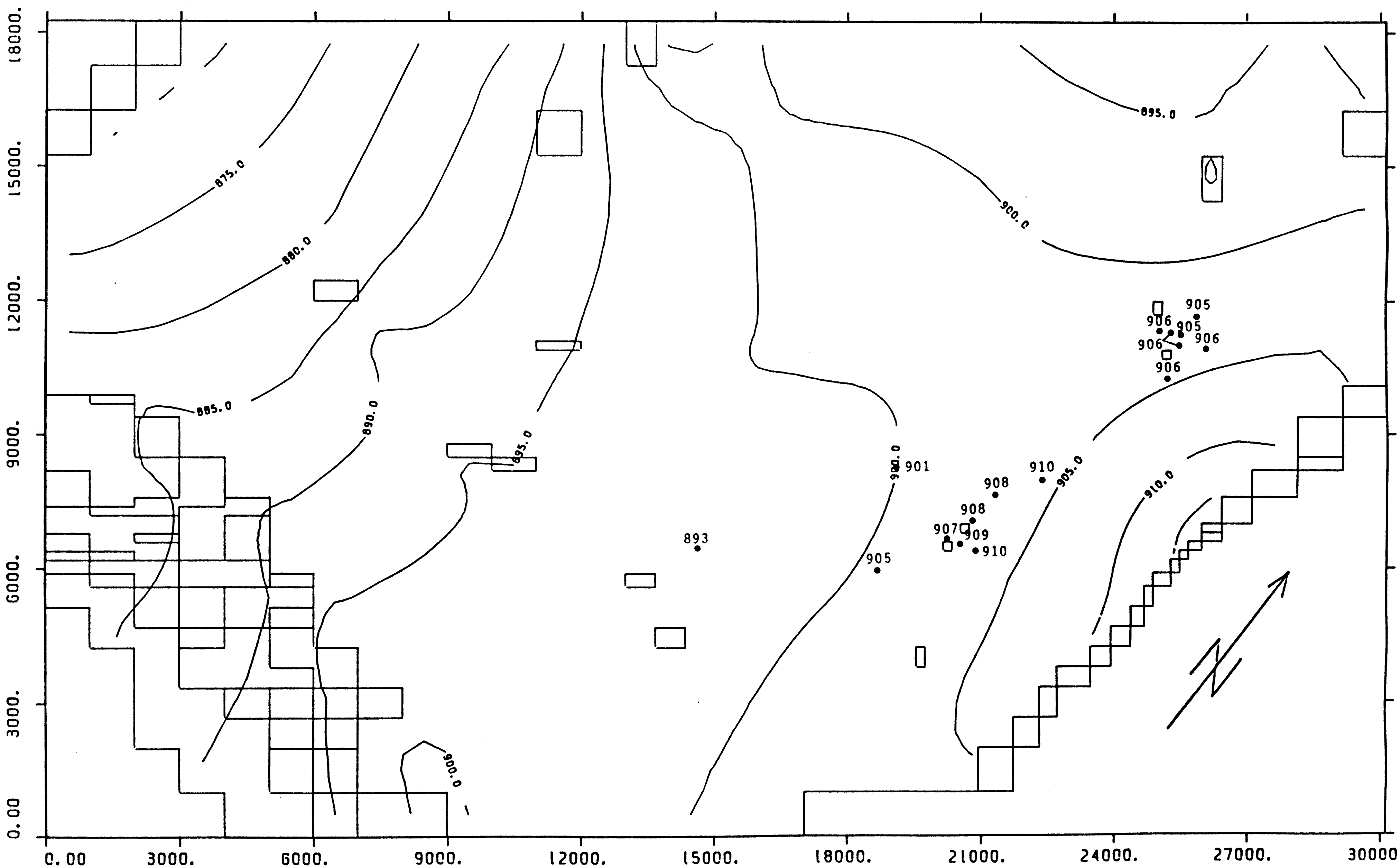


Figure 14a

Calculated Versus Observed Hydraulic Heads for Sub-Unit A, Summer 1985




Explanation:

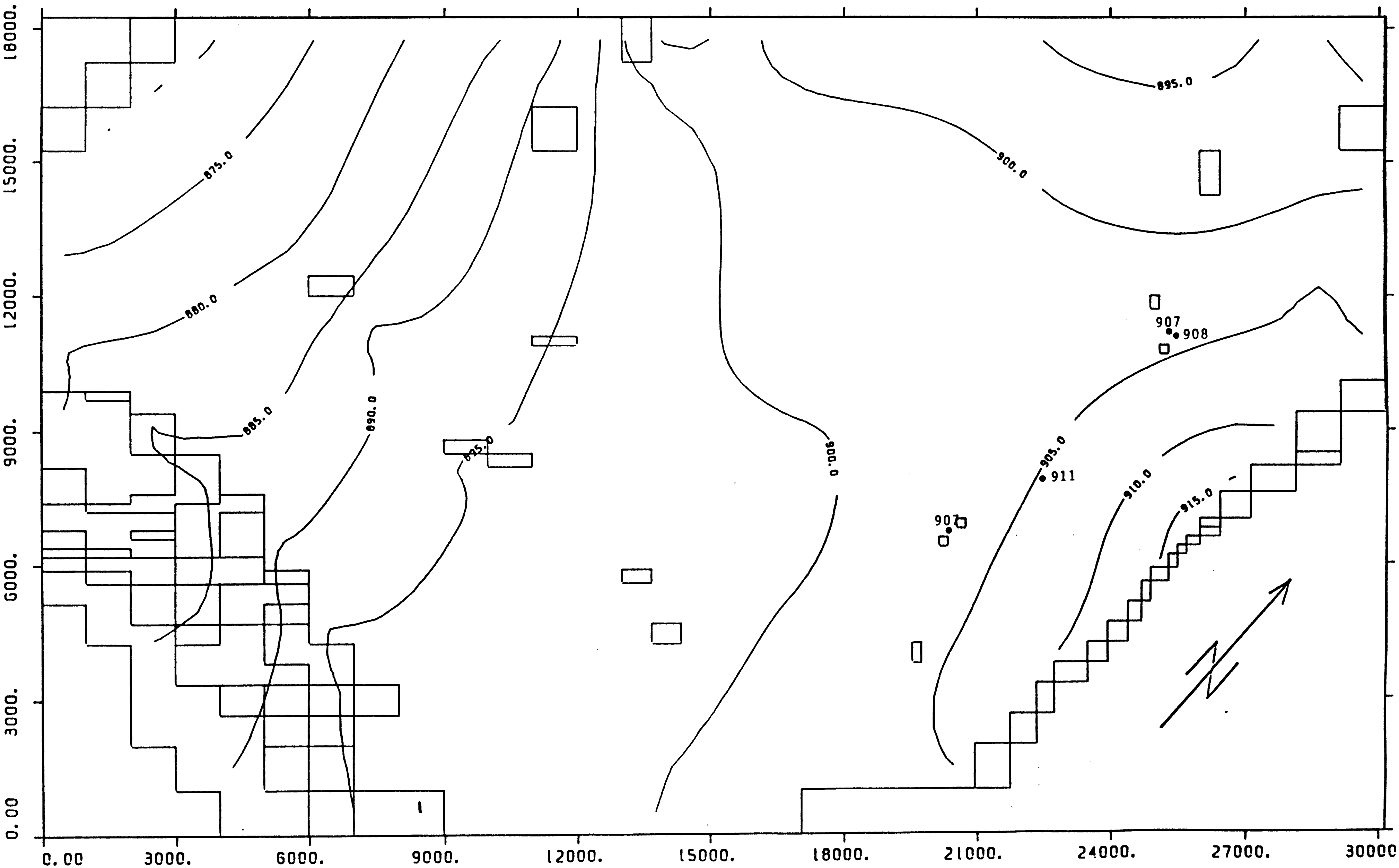
• Field Data-Water Level Elevation Feet Above Mean Sea Level

—900- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 14b

Calculated Versus Observed Hydraulic Heads for Sub-Unit A, Winter 1986




Explanation:

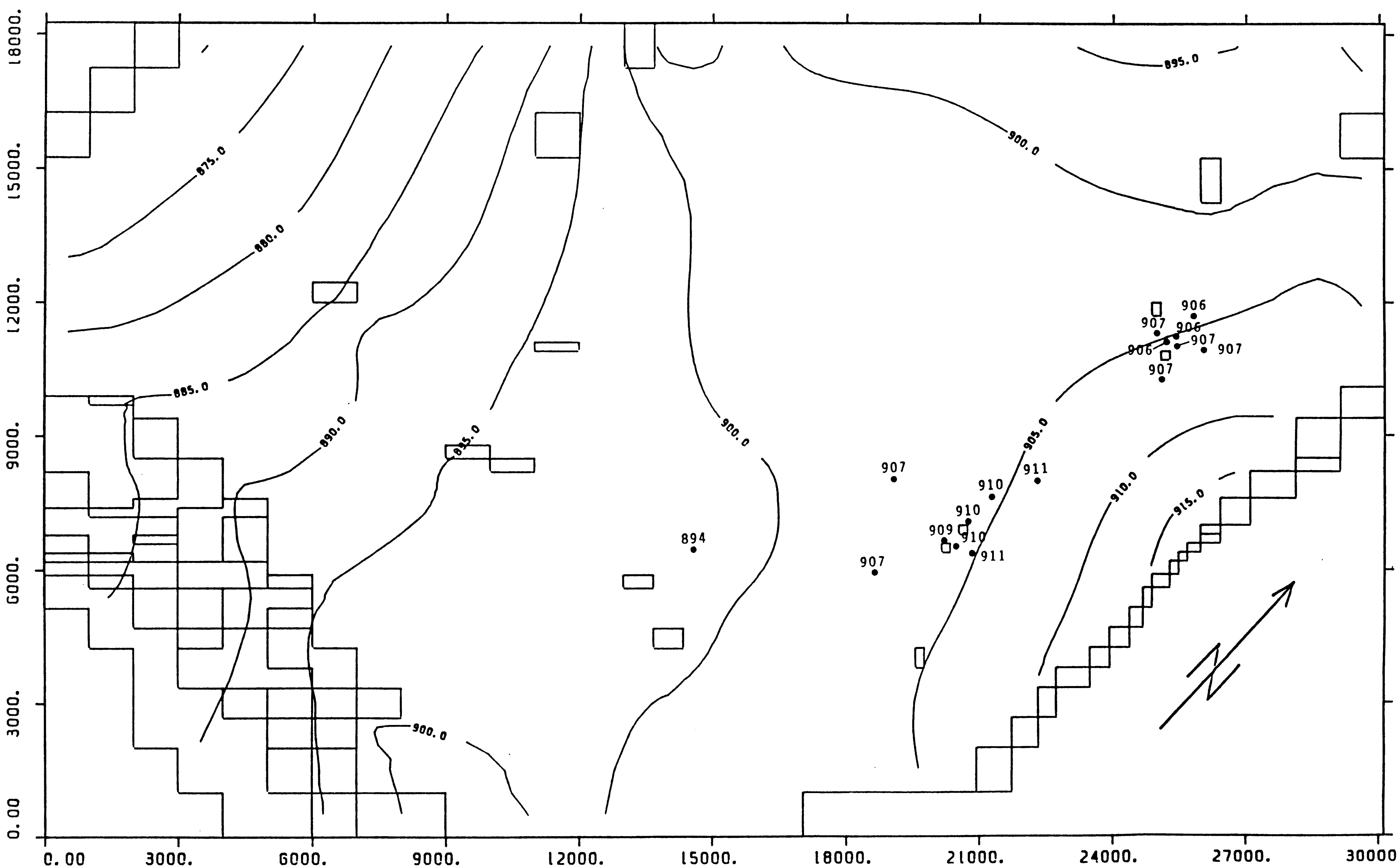
• Field Data-Water Level Elevation Feet Above Mean Sea Level

——900- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 14c

Calculated Versus Observed Hydraulic Heads for Sub-Unit A, Summer 1986




Explanation:

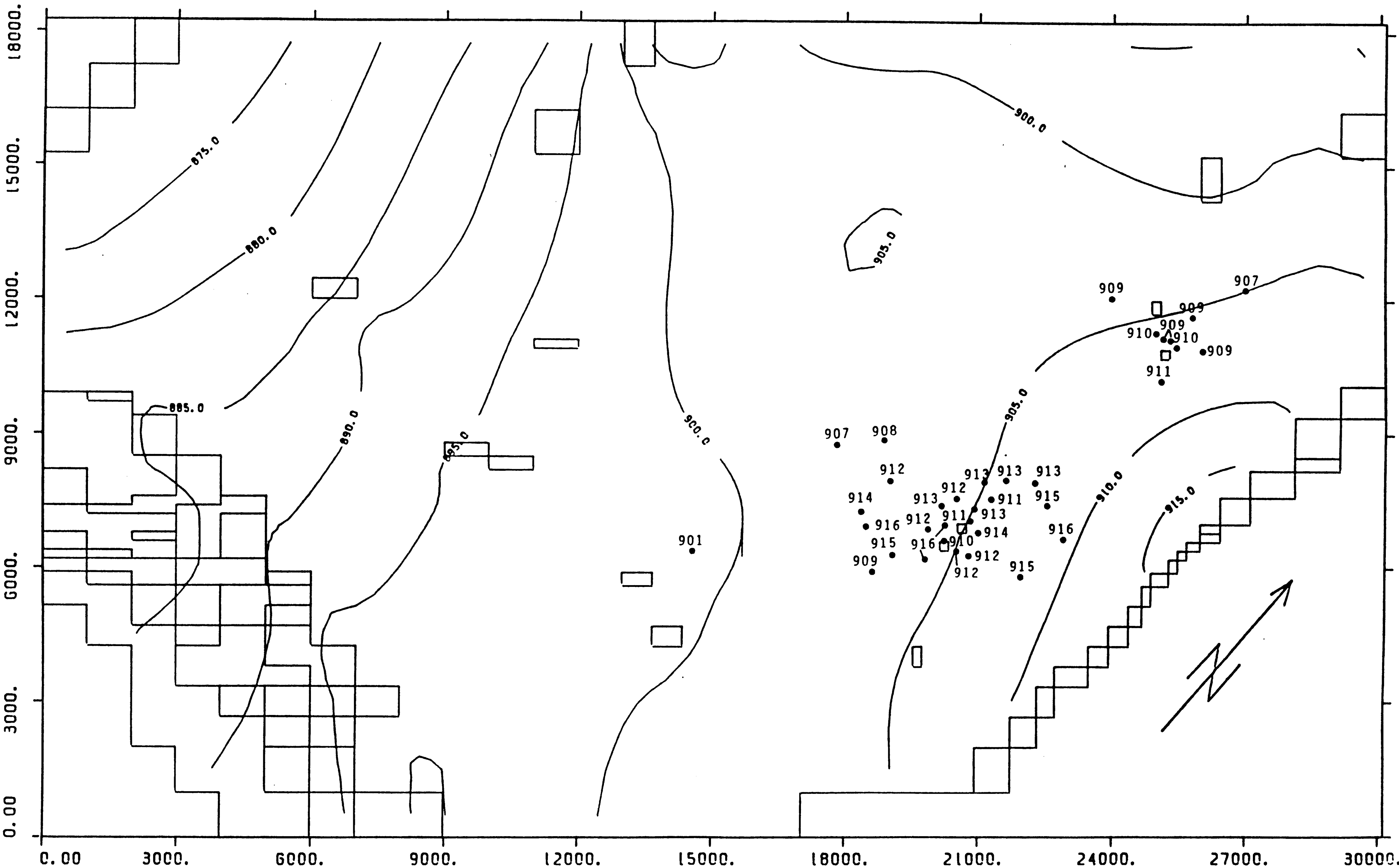
• Field Data-Water Level Elevation Feet Above Mean Sea Level

—900- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 14d

Calculated Versus Observed Hydraulic Heads for Sub-Unit A, Winter 1987




Explanation:

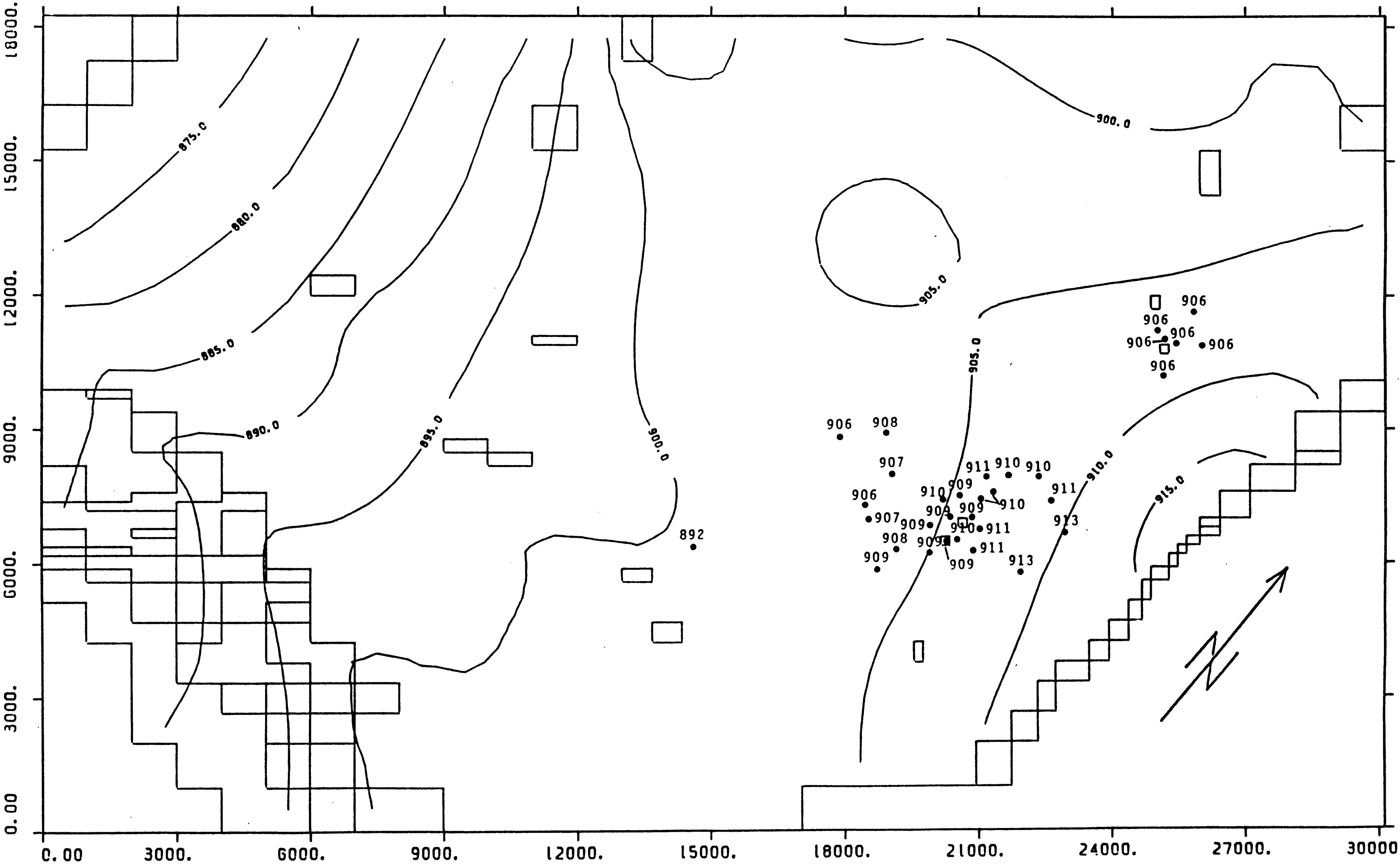
• Field Data-Water Level Elevation Feet Above Mean Sea Level

—900- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 14e

Calculated Versus Observed Hydraulic Heads for Sub-Unit A, Summer 1987




Explanation:

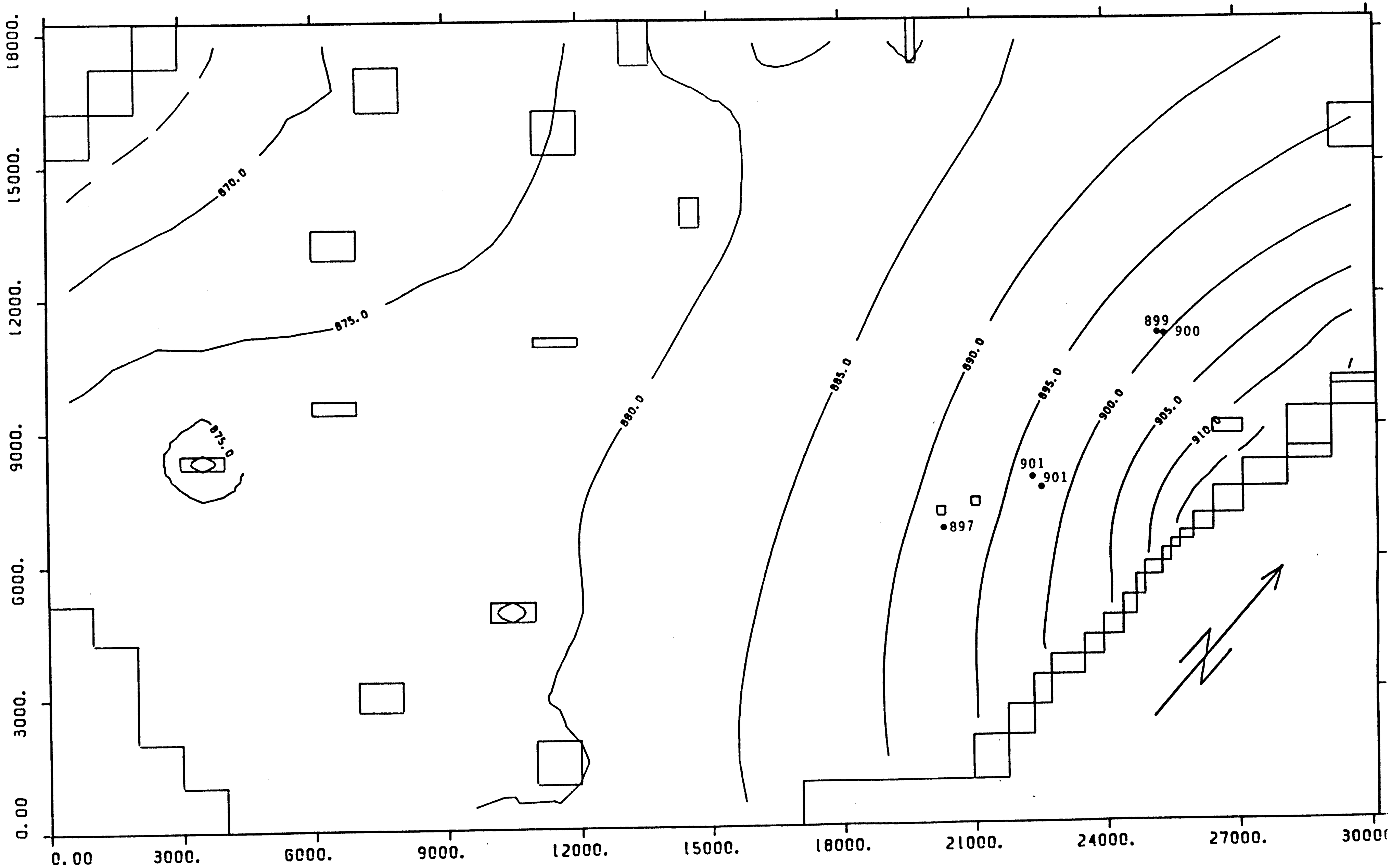
• Field Data-Water Level Elevation Feet Above Mean Sea Level

—900- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 15a

Calculated Versus Observed Hydraulic Heads for Sub-Unit B/C, Summer 1985




Explanation:

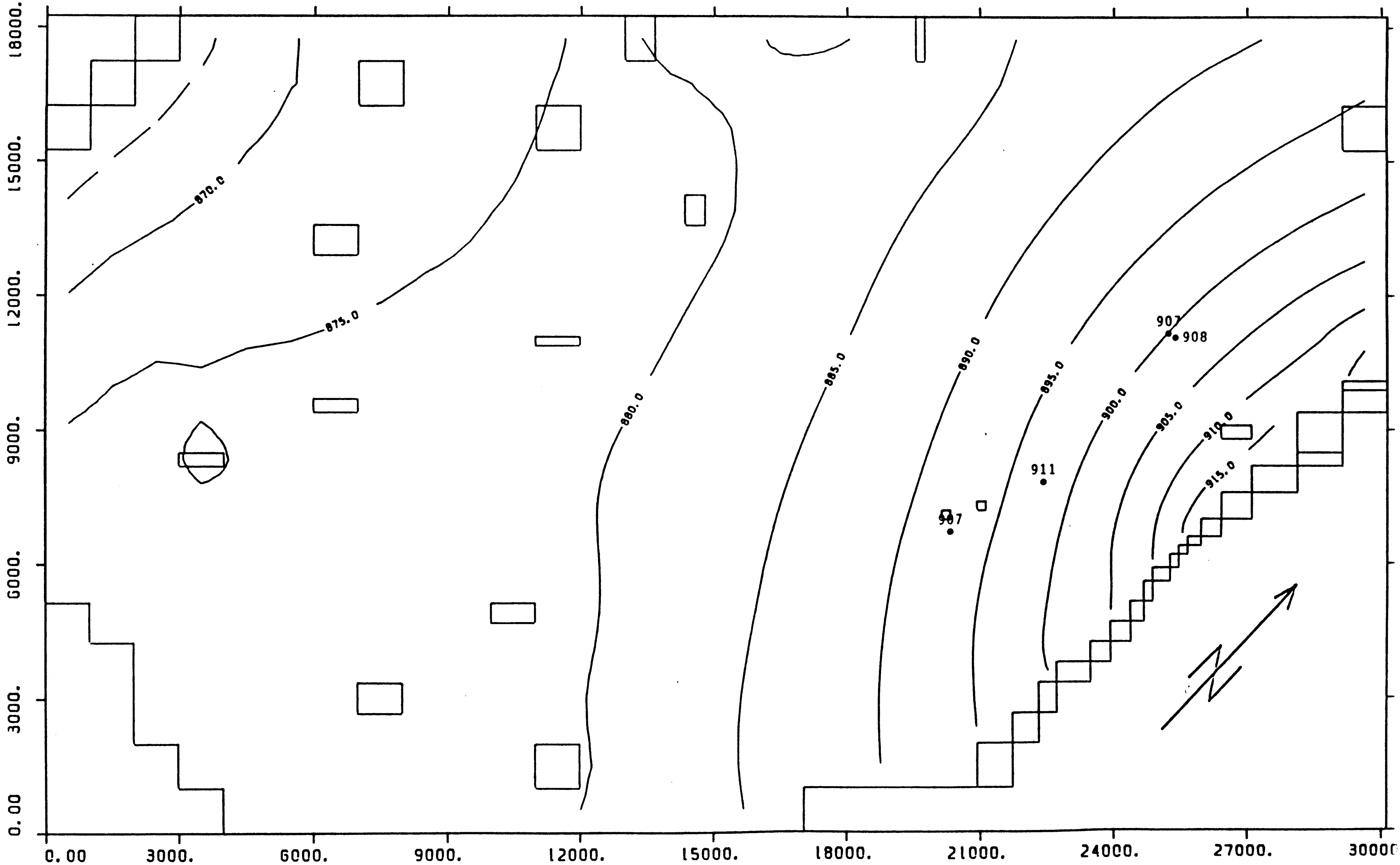
• Field Data-Water Level Elevation Feet Above Mean Sea Level

—900- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 15b

Calculated Versus Observed Hydraulic Heads for Sub-Unit B/C, Winter 1986




Explanation:

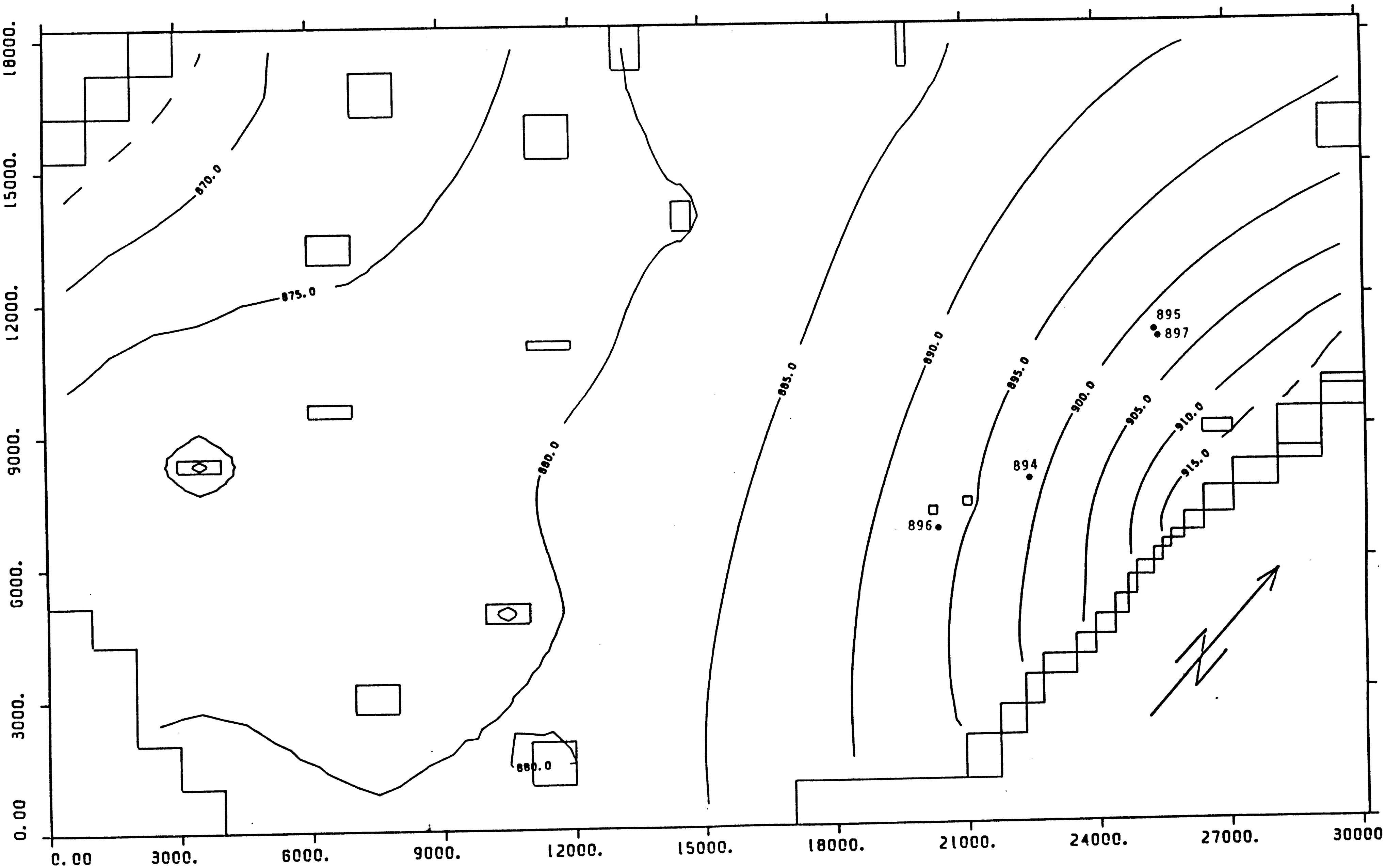
- Field Data-Water Level Elevation Feet Above Mean Sea Level

—900- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 15c

Calculated Versus Observed Hydraulic Heads for Sub-Unit B/C, Summer 1986




Explanation:

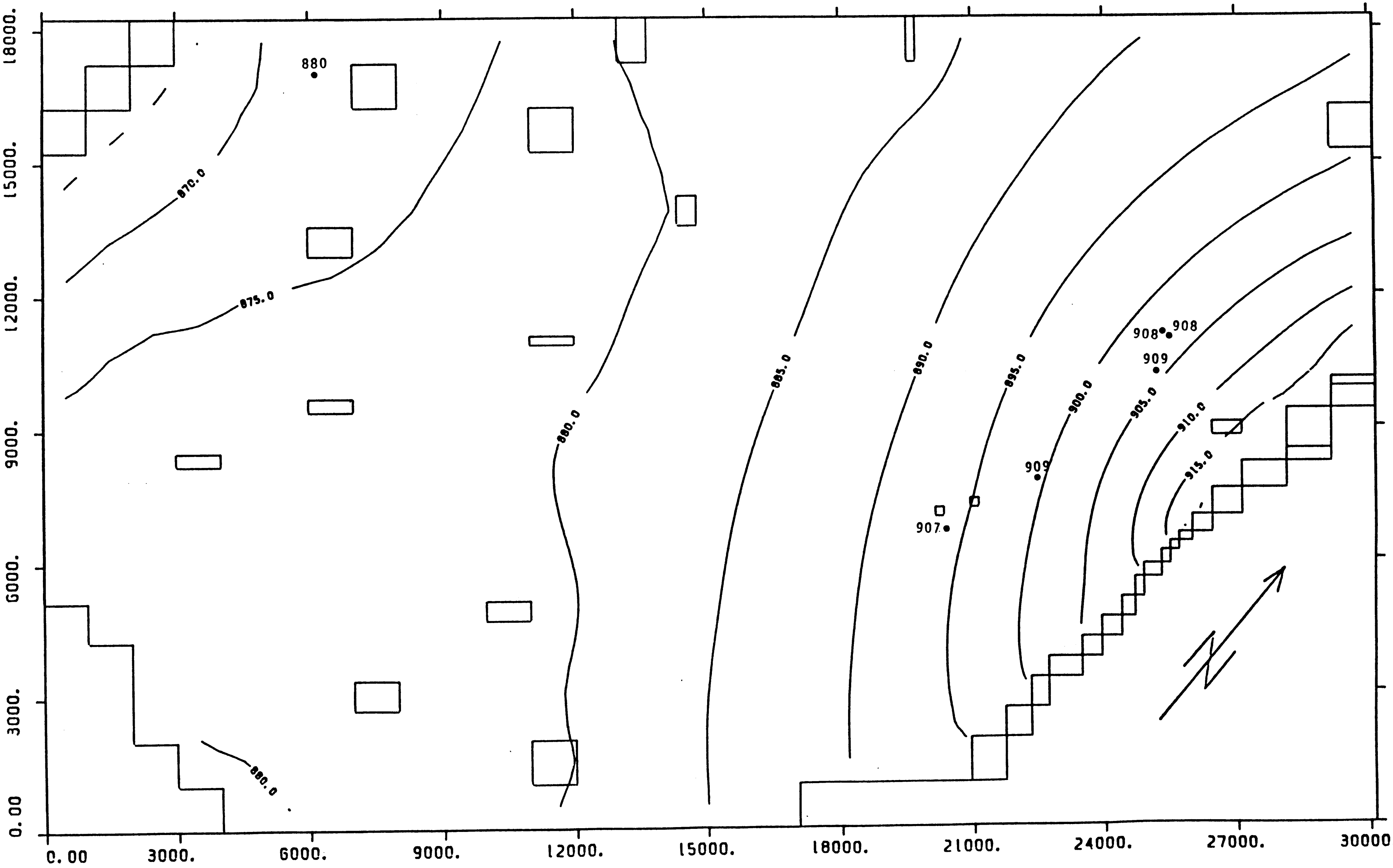
• Field Data-Water Level Elevation Feet Above Mean Sea Level

—900- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 15d

Calculated Versus Observed Hydraulic Heads for Sub-Unit B/C, Winter 1987




Explanation:

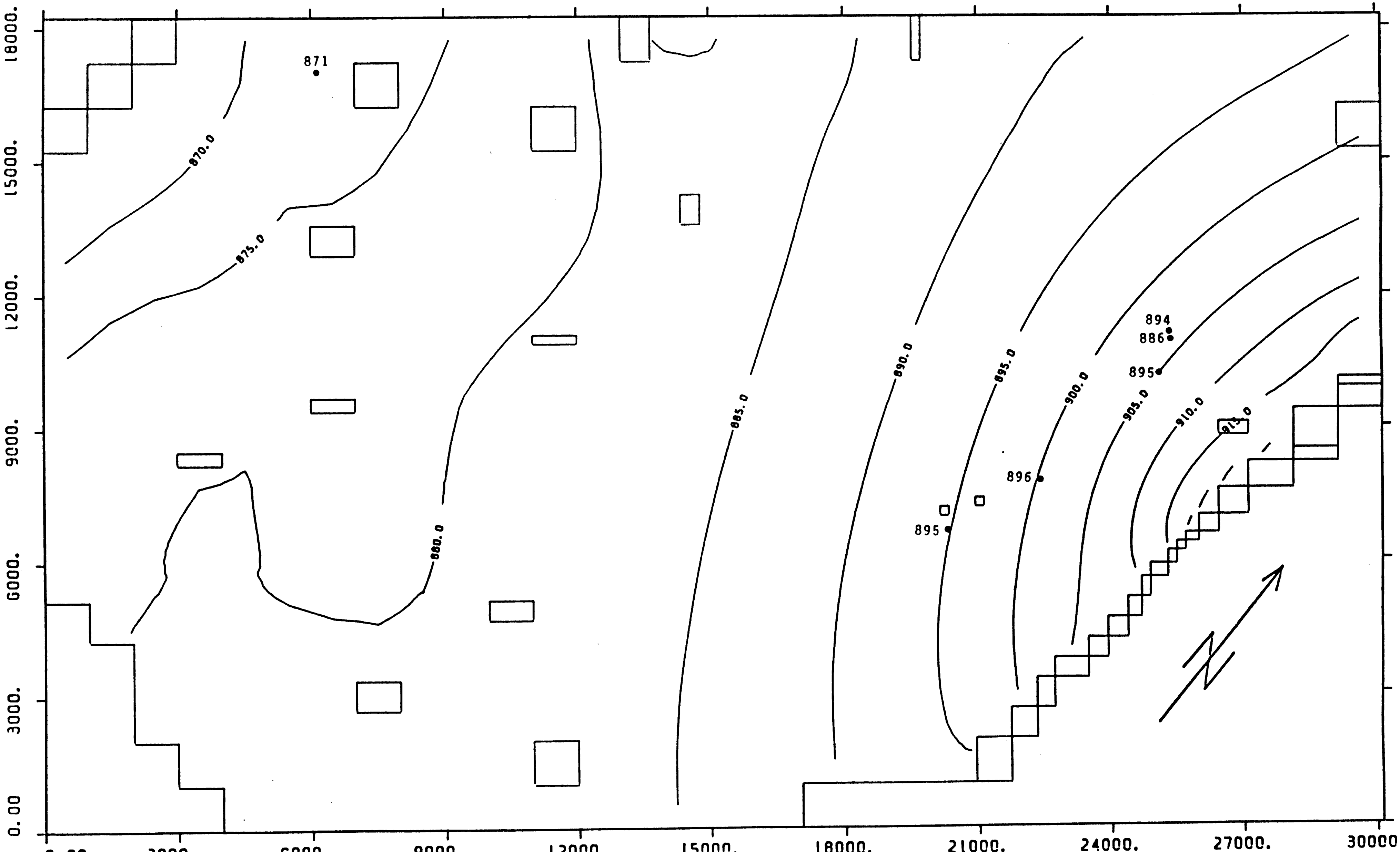
• Field Data-Water Level Elevation Feet Above Mean Sea Level

—900- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 15e

Calculated Versus Observed Hydraulic Heads for Sub-Unit B/C, Summer 1987



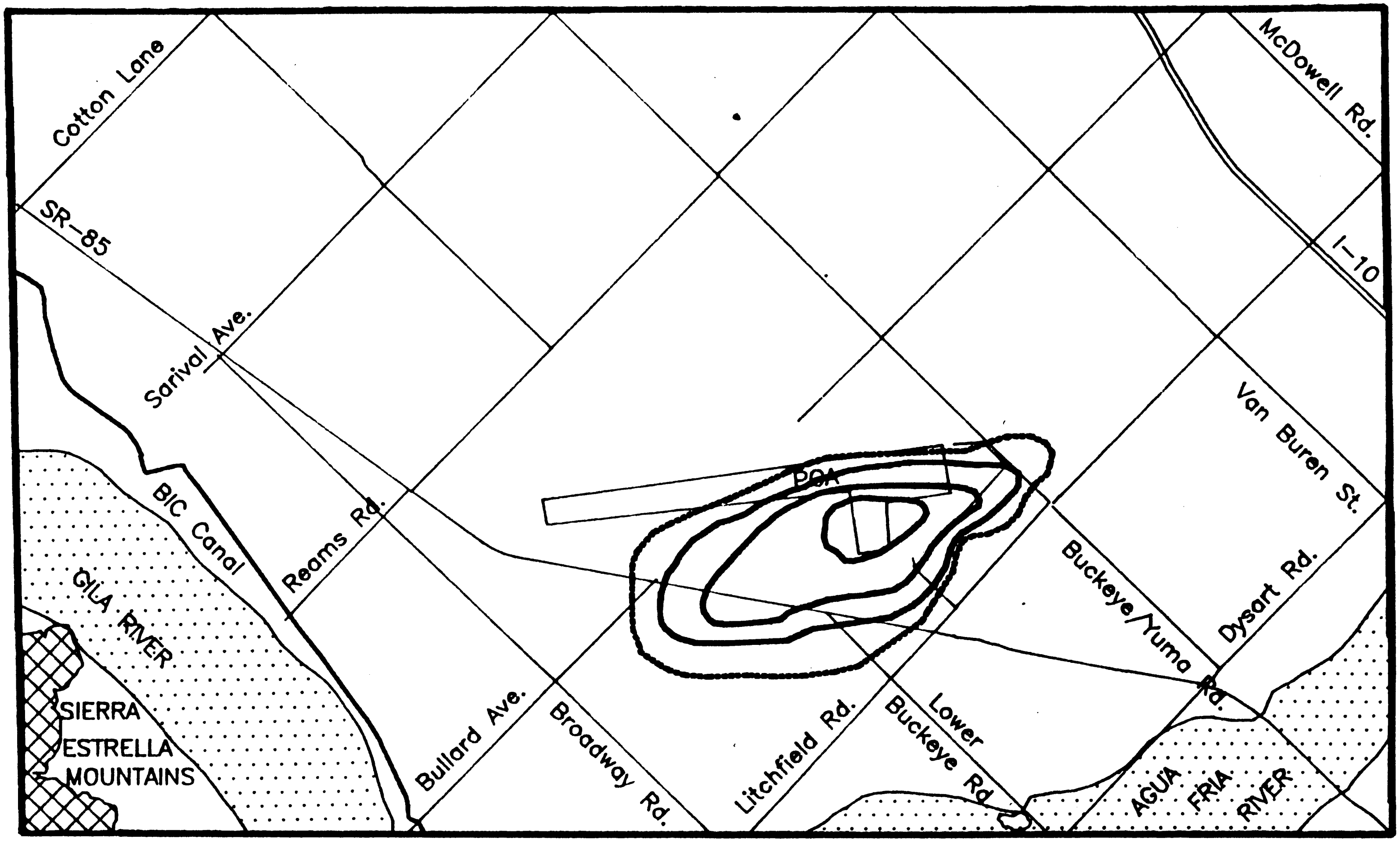

Explanation:

• Field Data-Water Level Elevation Feet Above Mean Sea Level

—900- Predicted Hydraulic Head

Scale 1" = 3000'

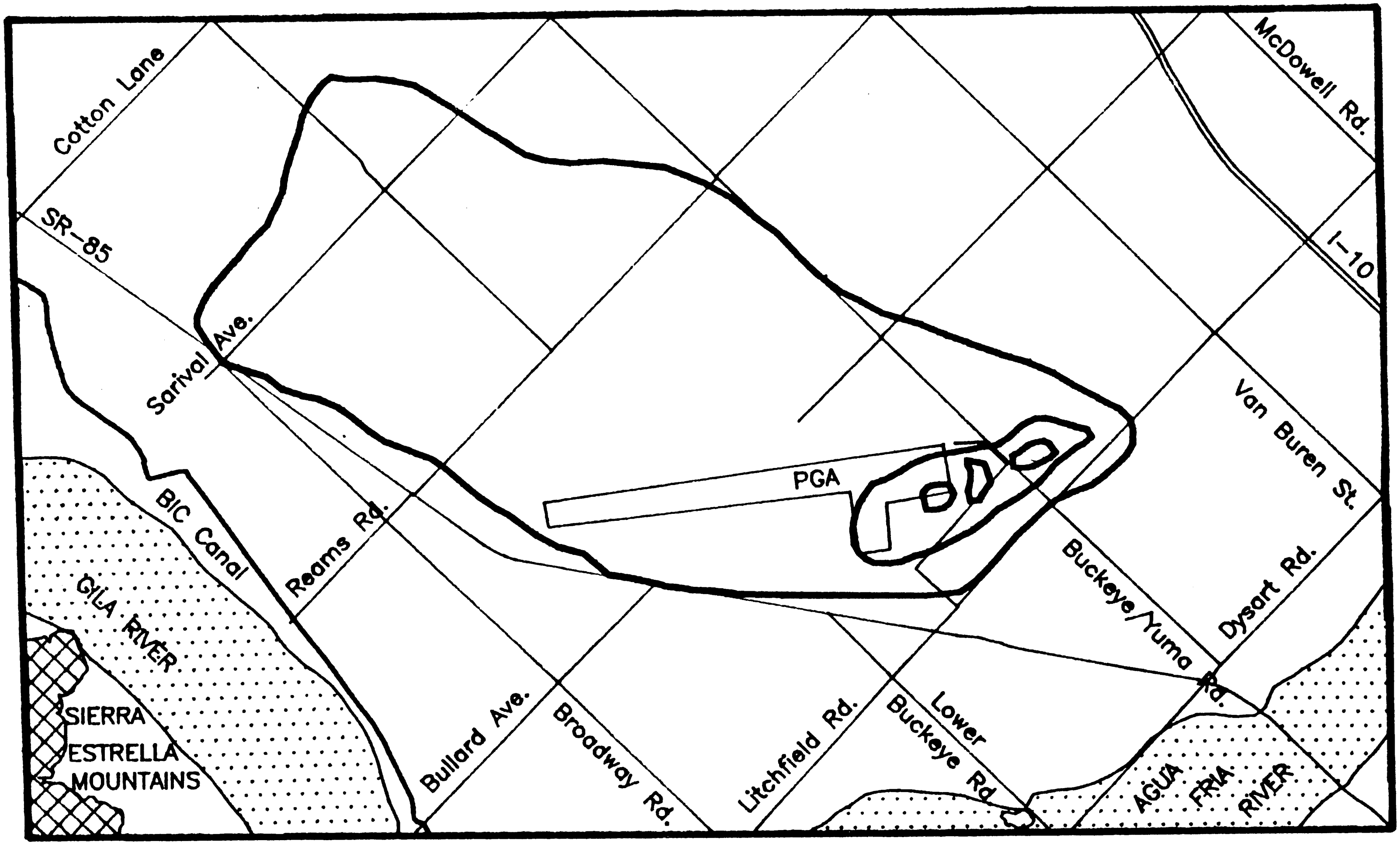
# Figure 16a




APPROXIMATE INITIAL CONTAMINANT DISTRIBUTION
SUBUNIT A

CONTOUR VALUES ARE
1, 10, 100, AND 1000 PARTS PER BILLION

Figure 16b




APPROXIMATE INITIAL CONTAMINANT DISTRIBUTION
SUBUNIT B/C

CONTOUR VALUES ARE
1, 10, AND 100 PARTS PER BILLION

# Figure 17

# Flow Chart of the Groundwater Modeling Feasibility Study

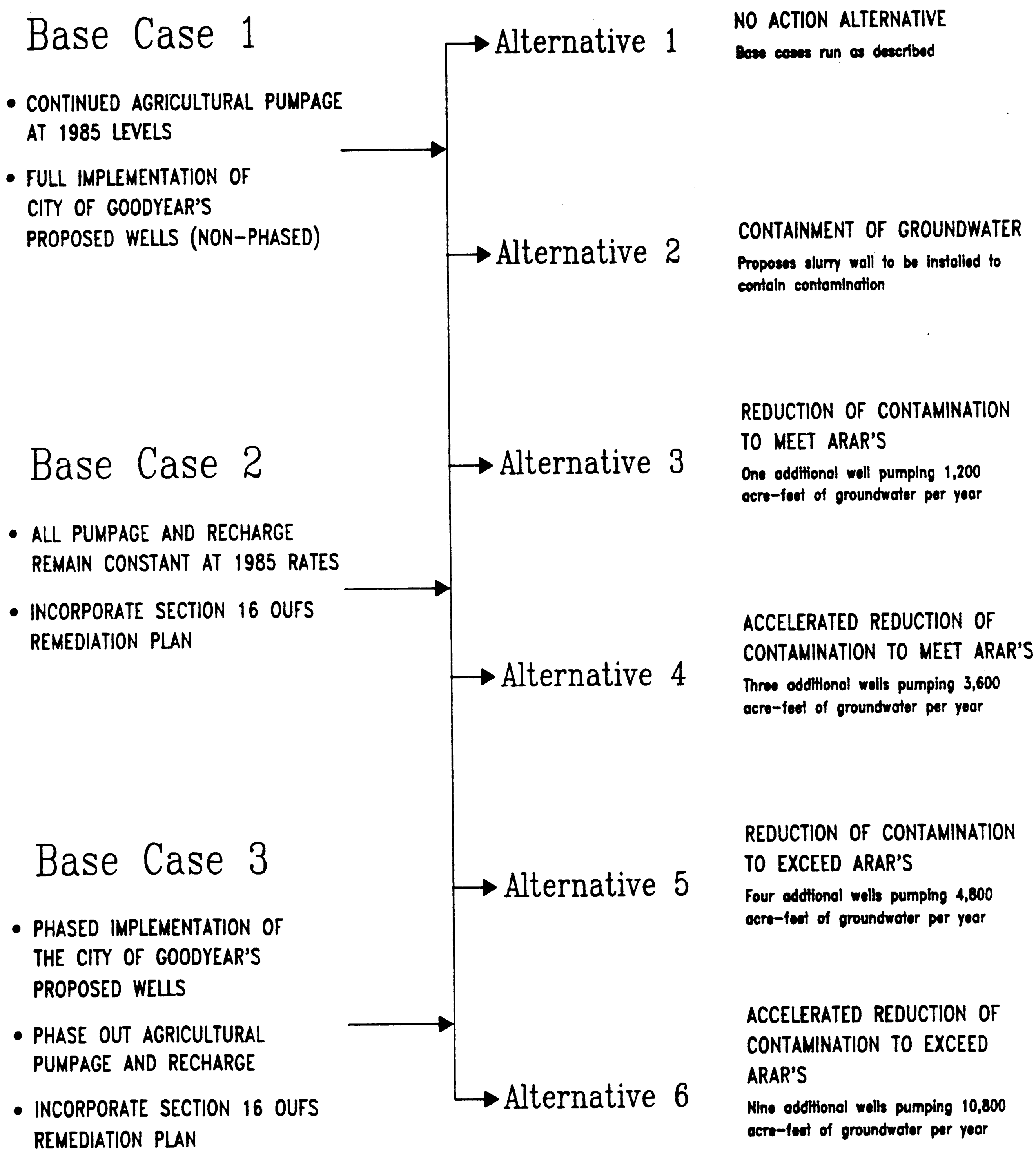
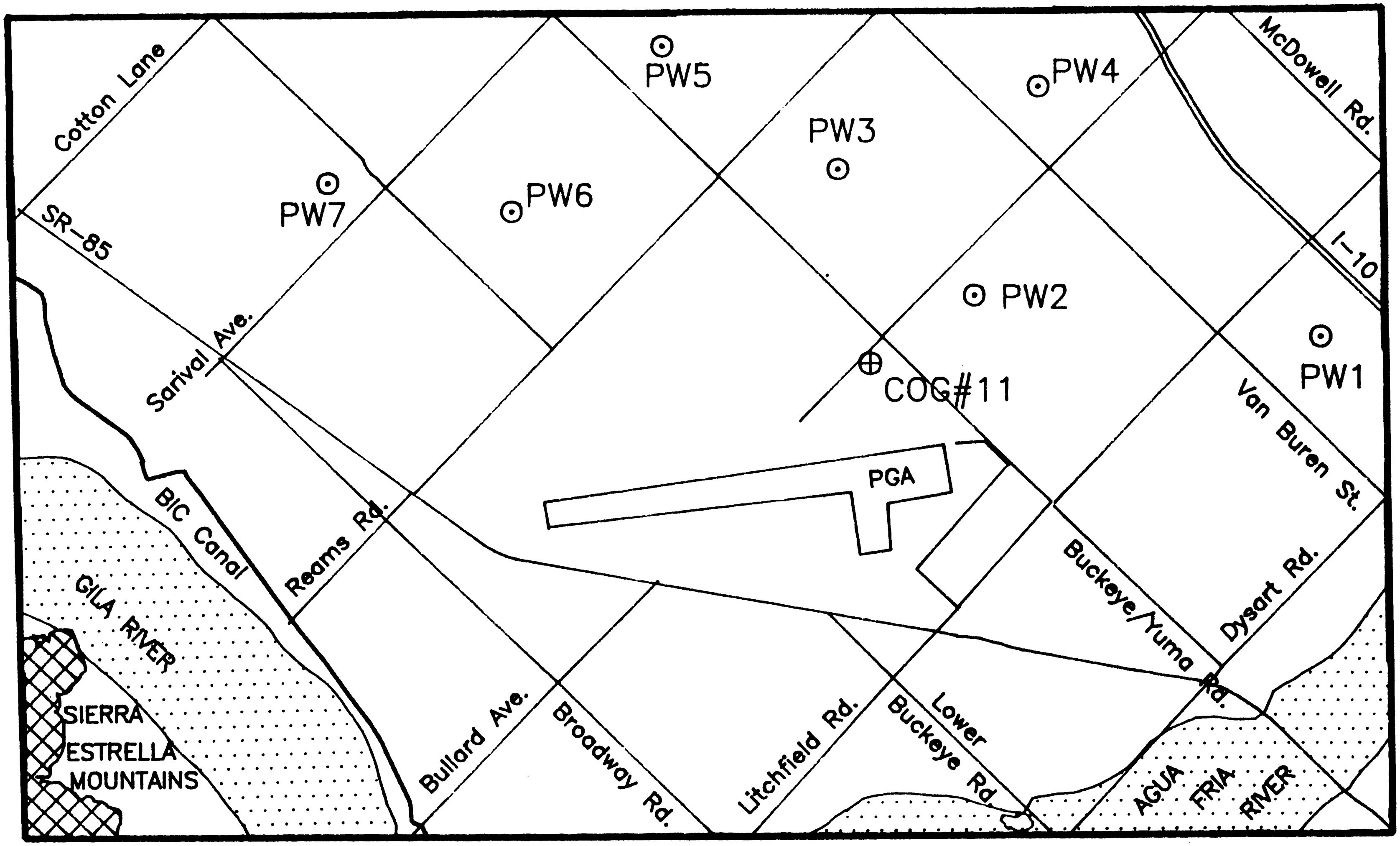


Figure 18



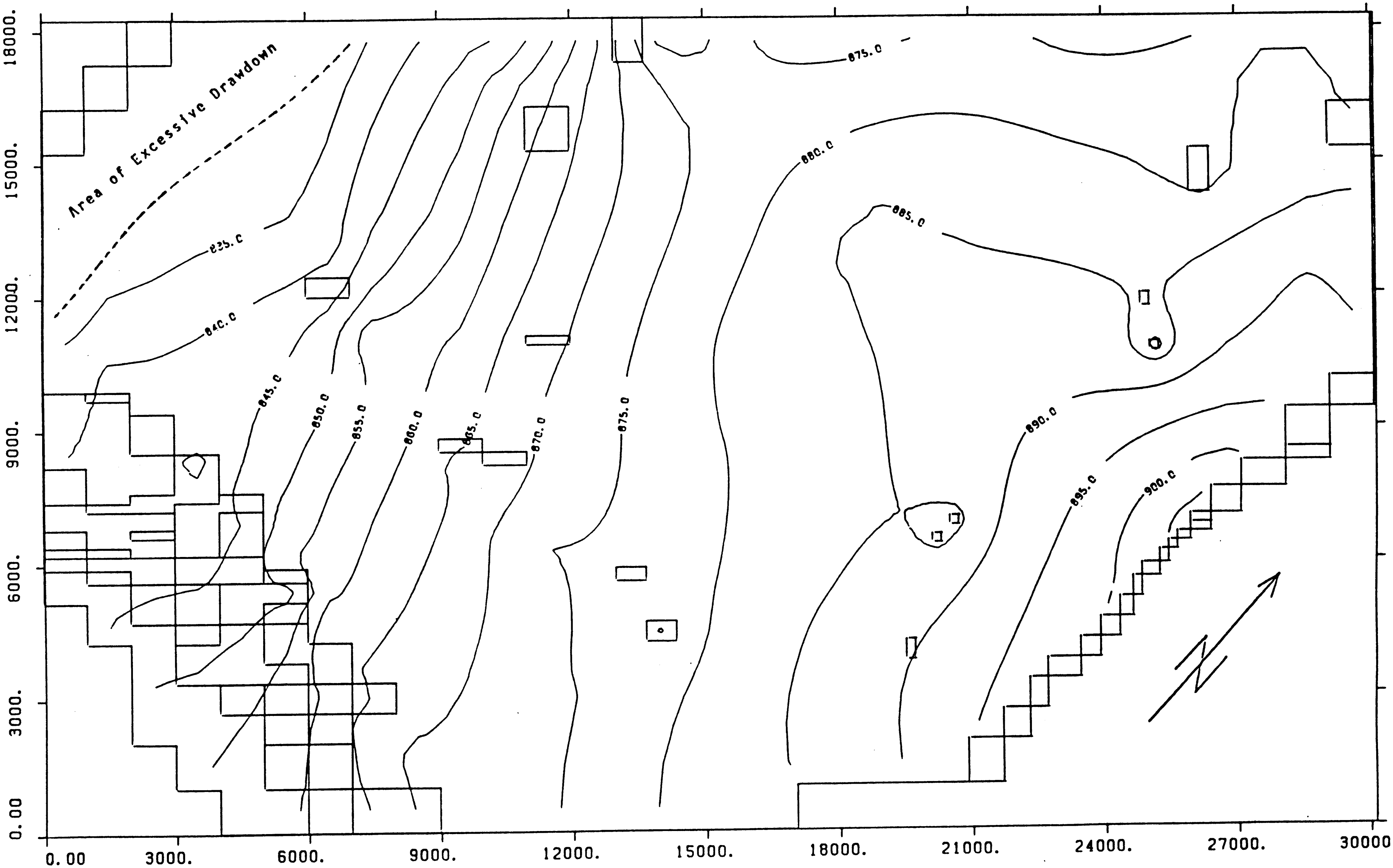

CITY OF GOODYEAR CURRENT AND PROPOSED WELL LOCATIONS WITHIN MODEL DOMAIN FOR WELLS WITHDRAWING UAU WATER

⊙ PROPOSED ⊕ EXISTING

N

1 MILE

Figure 19a
Base Case 1, No Action Alternative Projected Water Level
for Year 2008, Sub-Unit A

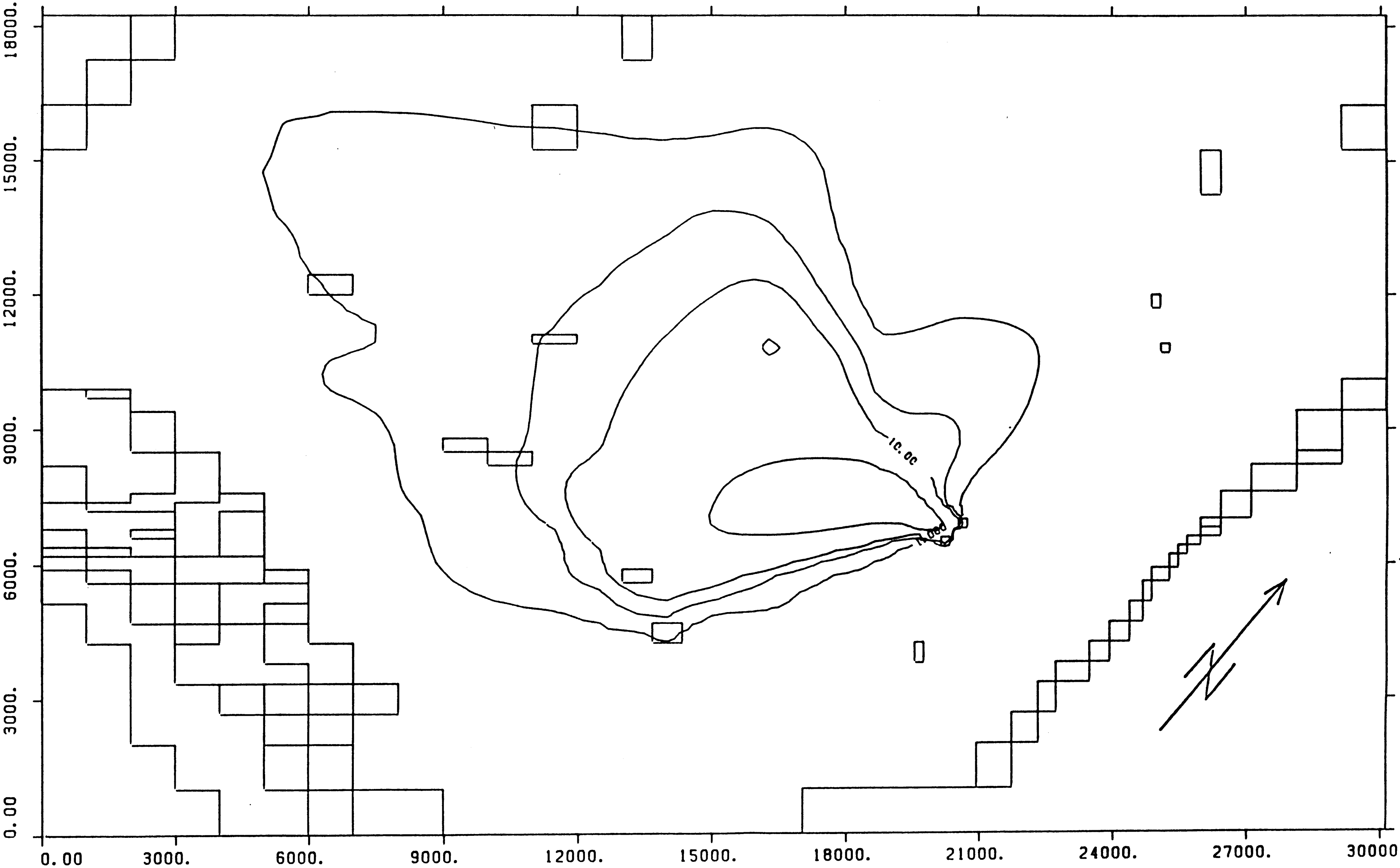



Explanation:

—900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 19b
Base Case 1, No Action Alternative Projected Contaminant for Year 2008, Sub-Unit A

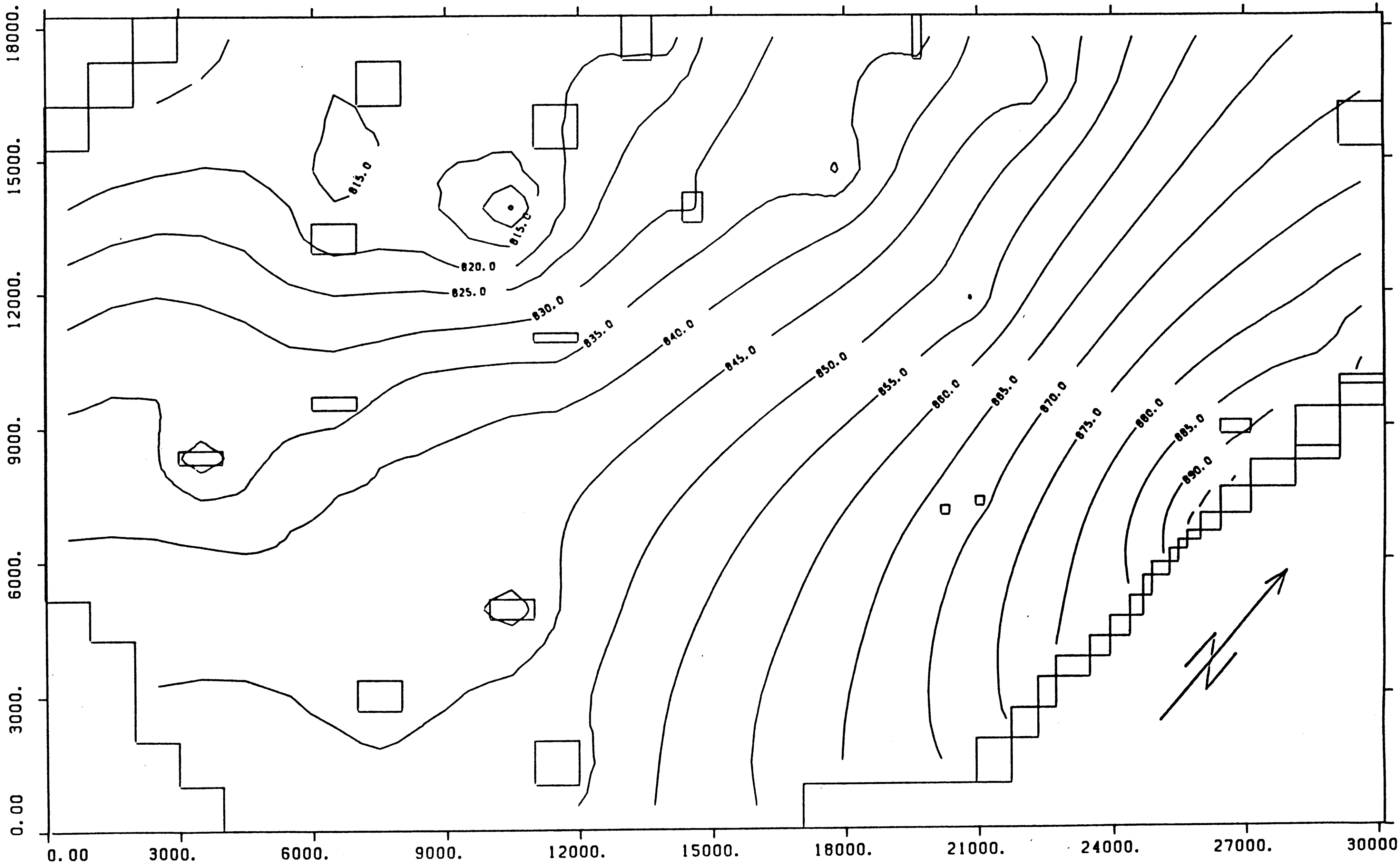



Explanation:

Predicted TCE Concentrations - Contour Values 1.5.10 and 100ppb.

Scale 1" = 3000'

Figure 19c
Base Case 1, No Action Alternative Projected Water Level
for Year 2008, Sub-Unit B/C

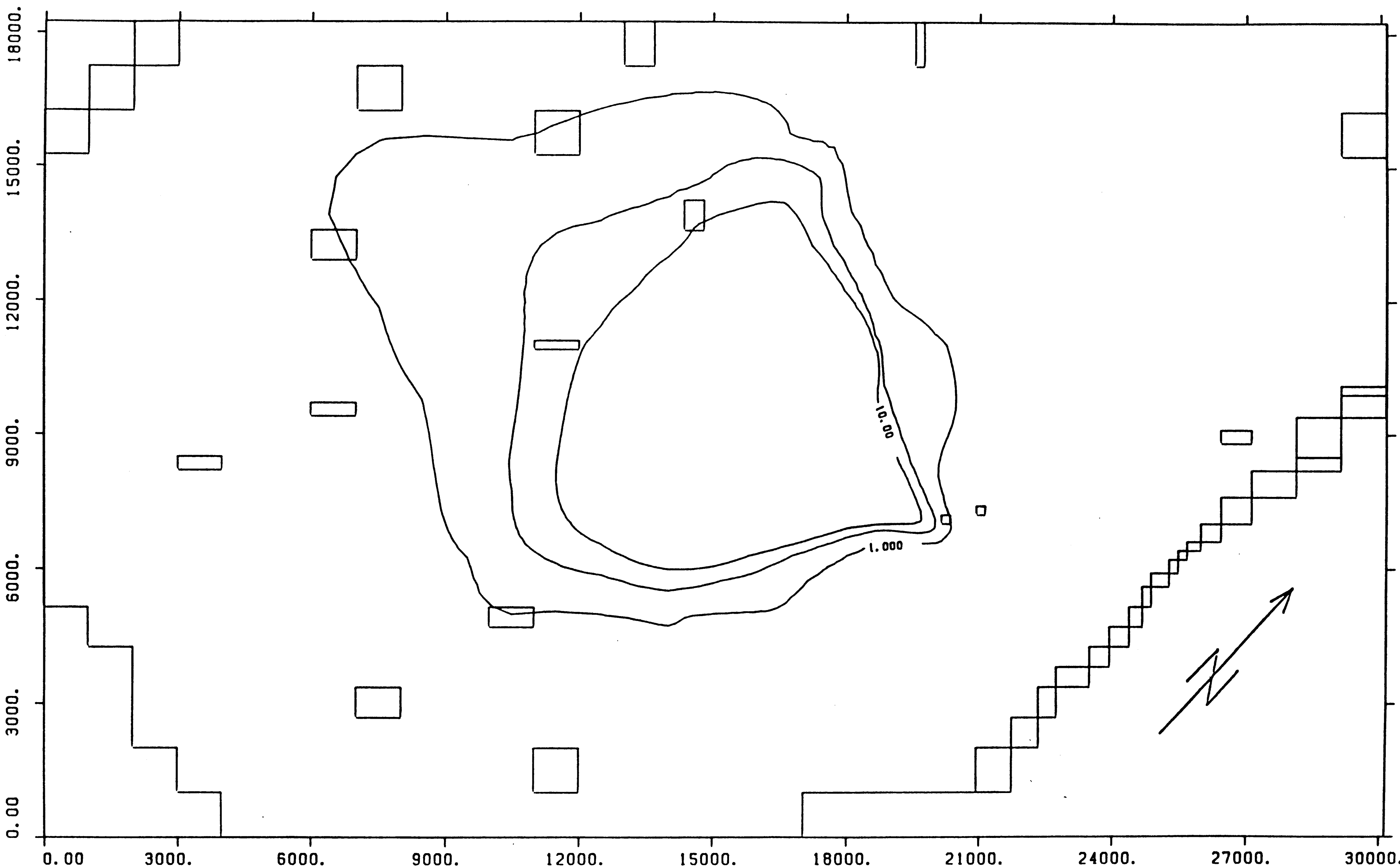



Scale 1" = 3000'

Explanation:

000.0- Predicted Hydraulic Head

Figure 19d
Base Case 1, No Action Alternative Projected Contaminant
for Year 2008, Sub-Unit B/C




Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Scale 1" = 3000'

Figure 20

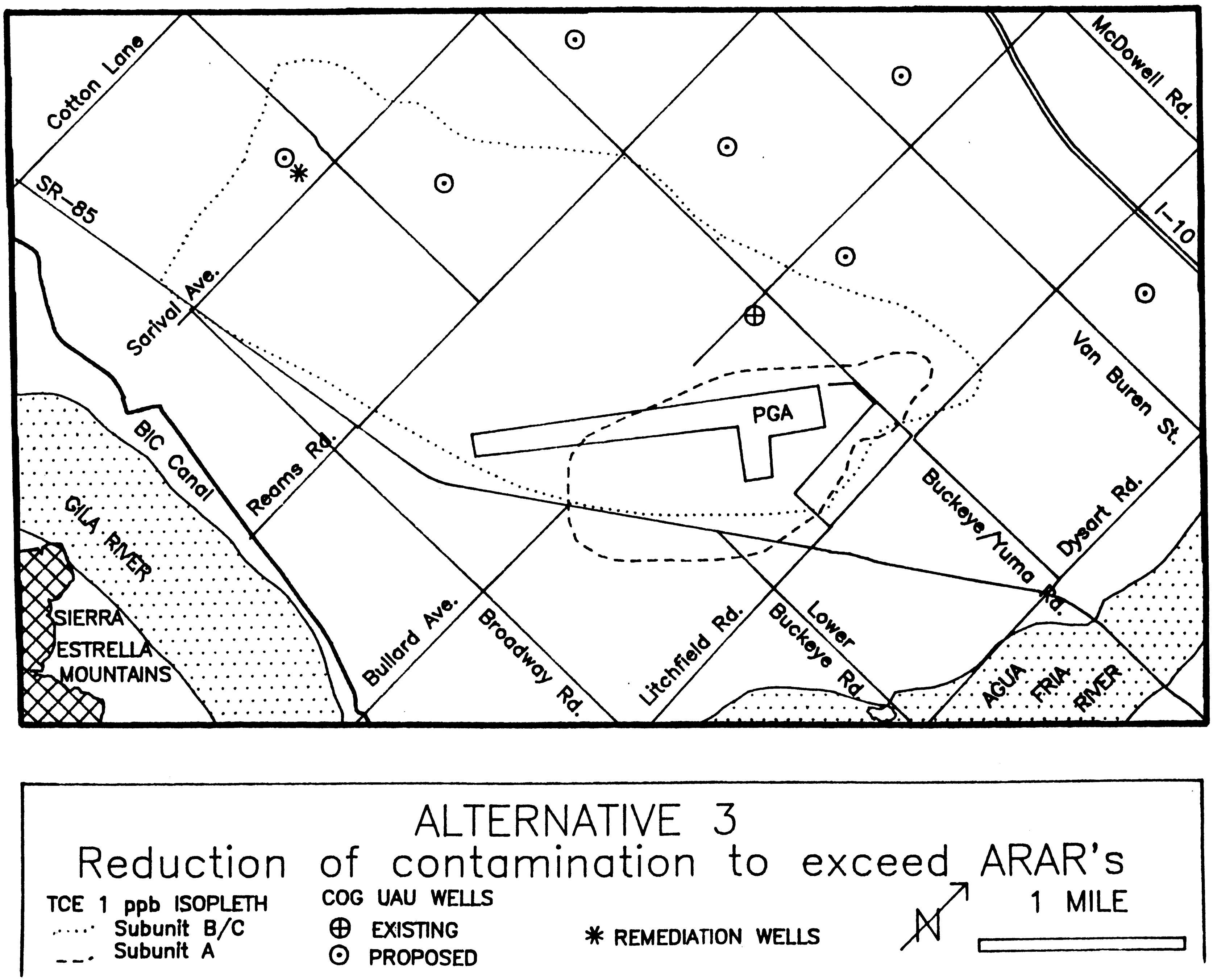
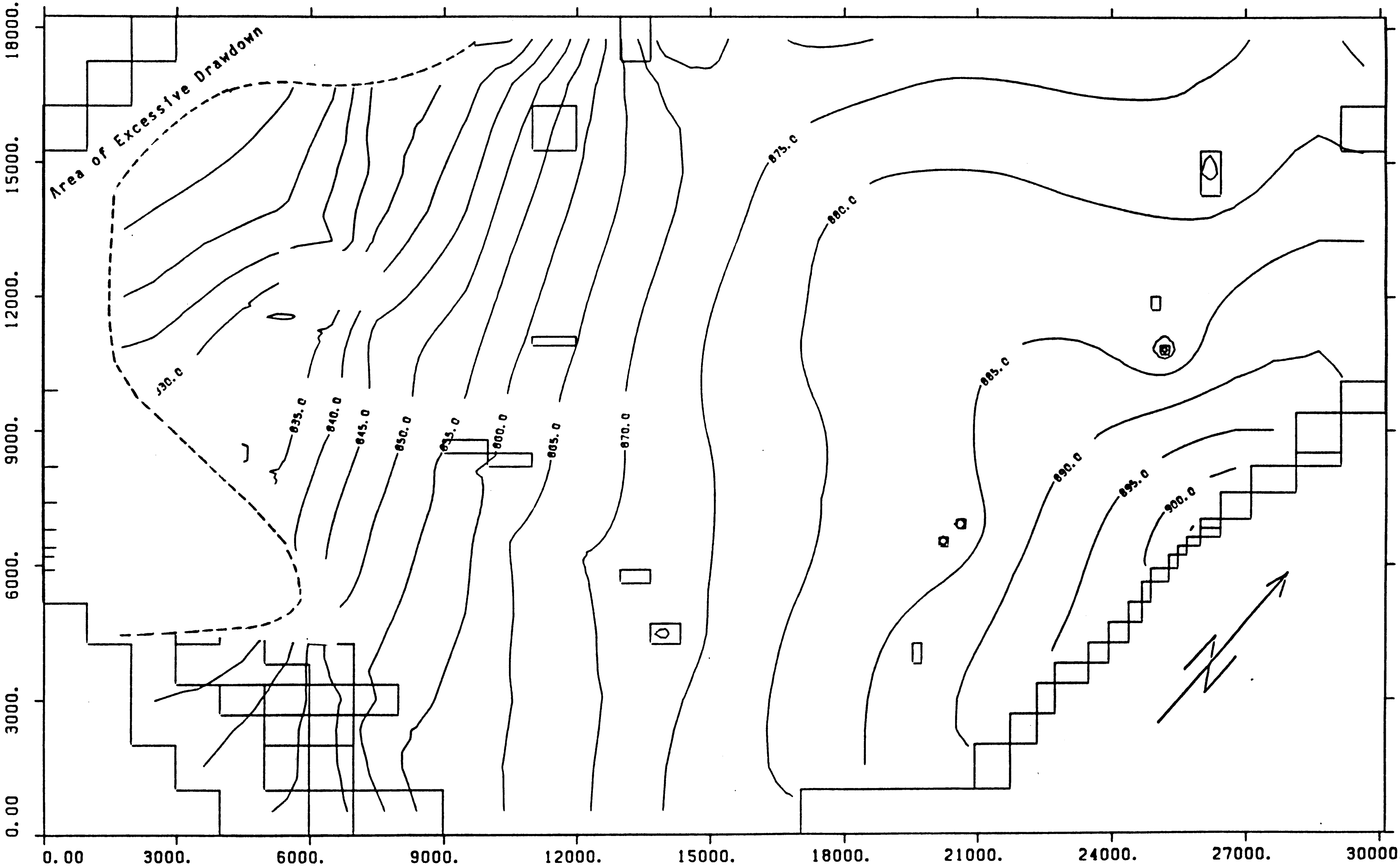

Cotton Lane
SR-85
Sarival Ave.
BIC Canal
Reams Rd.
GILA RIVER
SIERRA
ESTRELLA
MOUNTAINS
Bullard Ave.
Broadway Rd.
Litchfield Rd.
Lower
Buckeye Rd.
PGA
Buckeye/Yuma Rd.
Dysart Rd.
Van Buren St.
I-10
McDowell Rd.
AGUA
FRIA
RIVER
ALTERNATIVE 3
Reduction of contamination to exceed ARAR's
TCE 1 ppb ISOPLETH
Subunit B/C
Subunit A
COG UAU WELLS
EXISTING
PROPOSED
REMEDIATION WELLS
N
1 MILE

Figure 21a
Base Case 1, Alternative 3, Projected Water Level
for Year 2008, Sub-Unit A

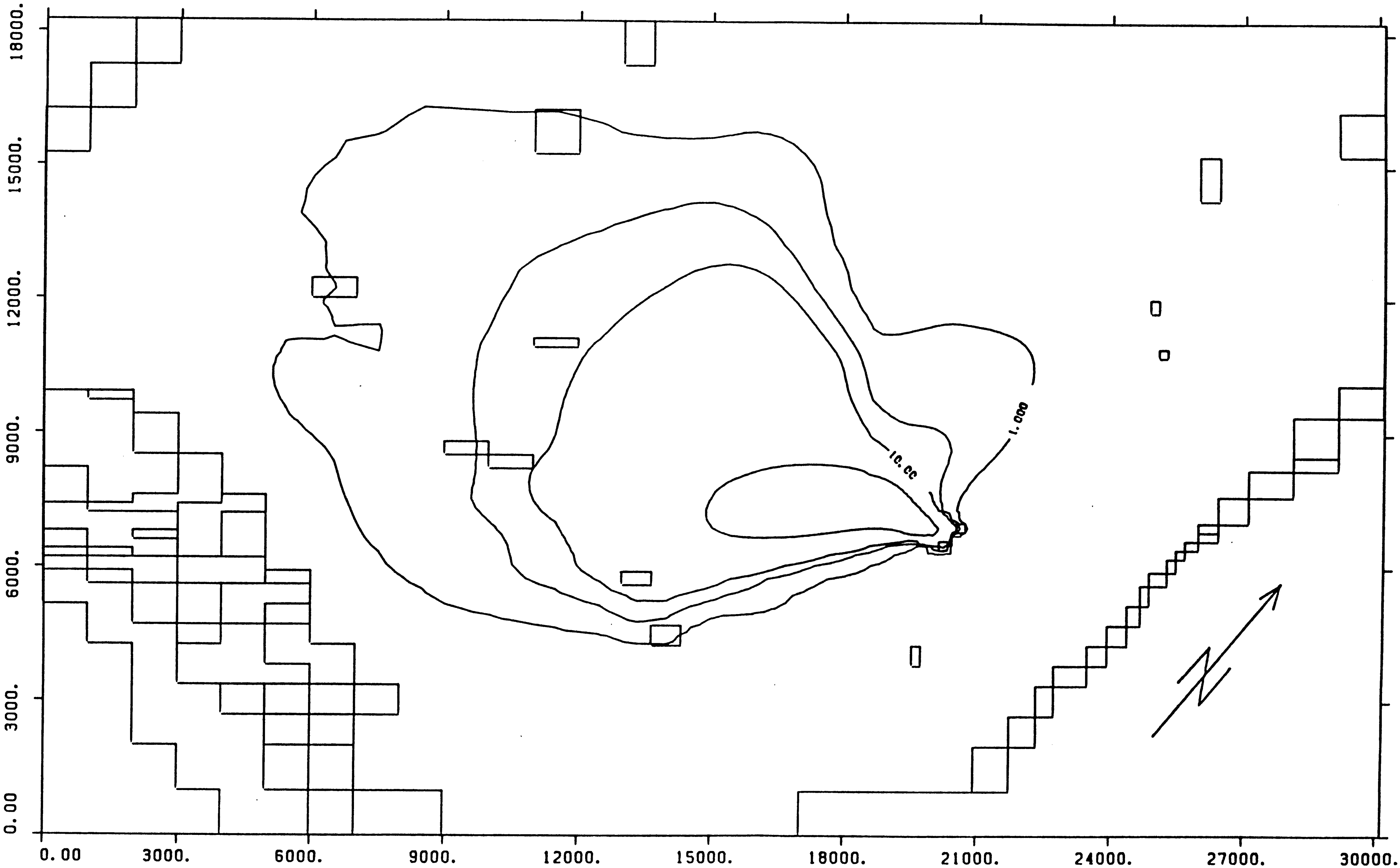



Explanation:

—900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 21b
Base Case 1, Alternative 3, Projected Contaminant for Year 2008, Sub-Unit A

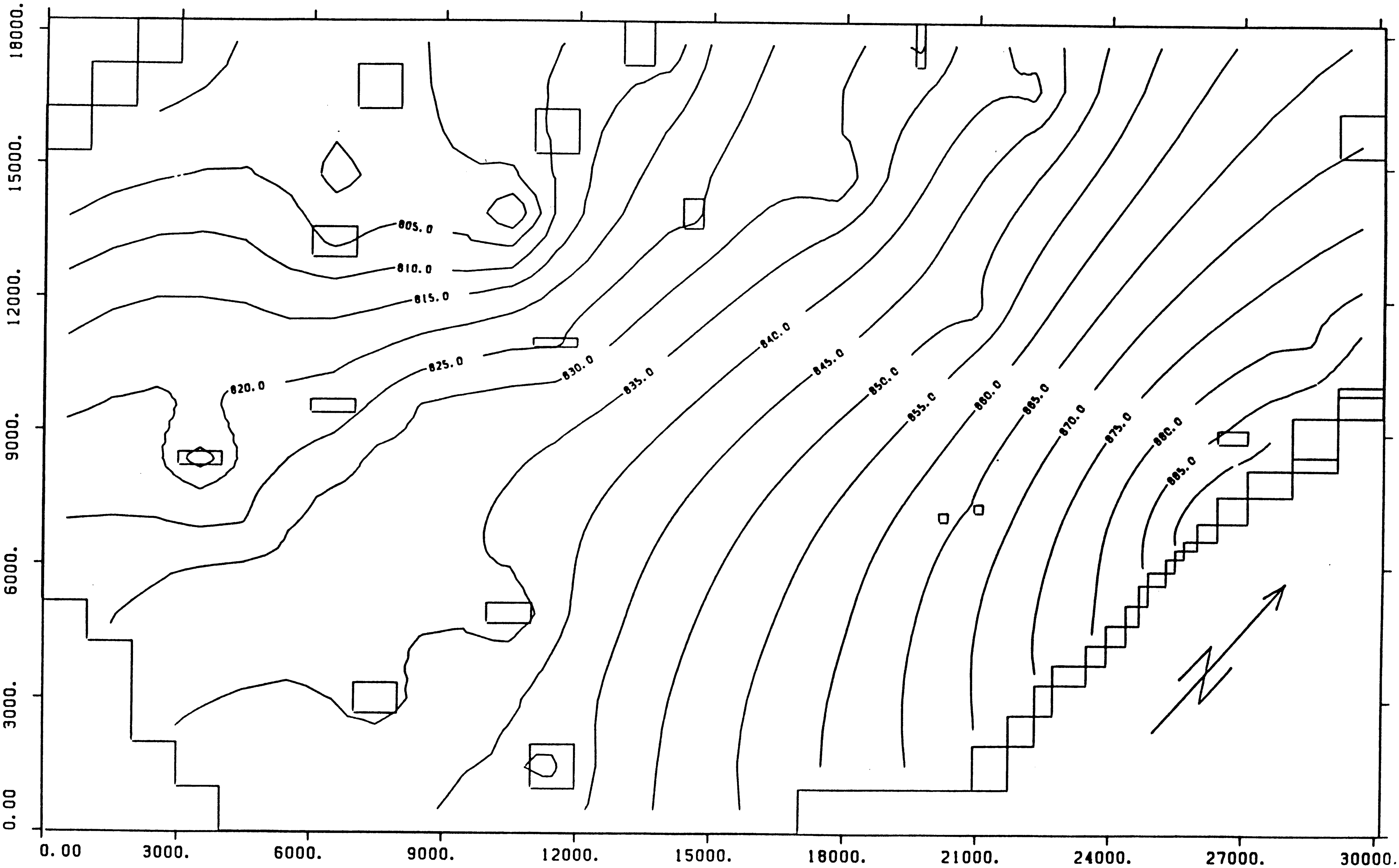



Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Scale 1" = 3000'

Figure 21c
Base Case 1, Alternative 3, Projected Water Level
for Year 2008, Sub-Unit B/C

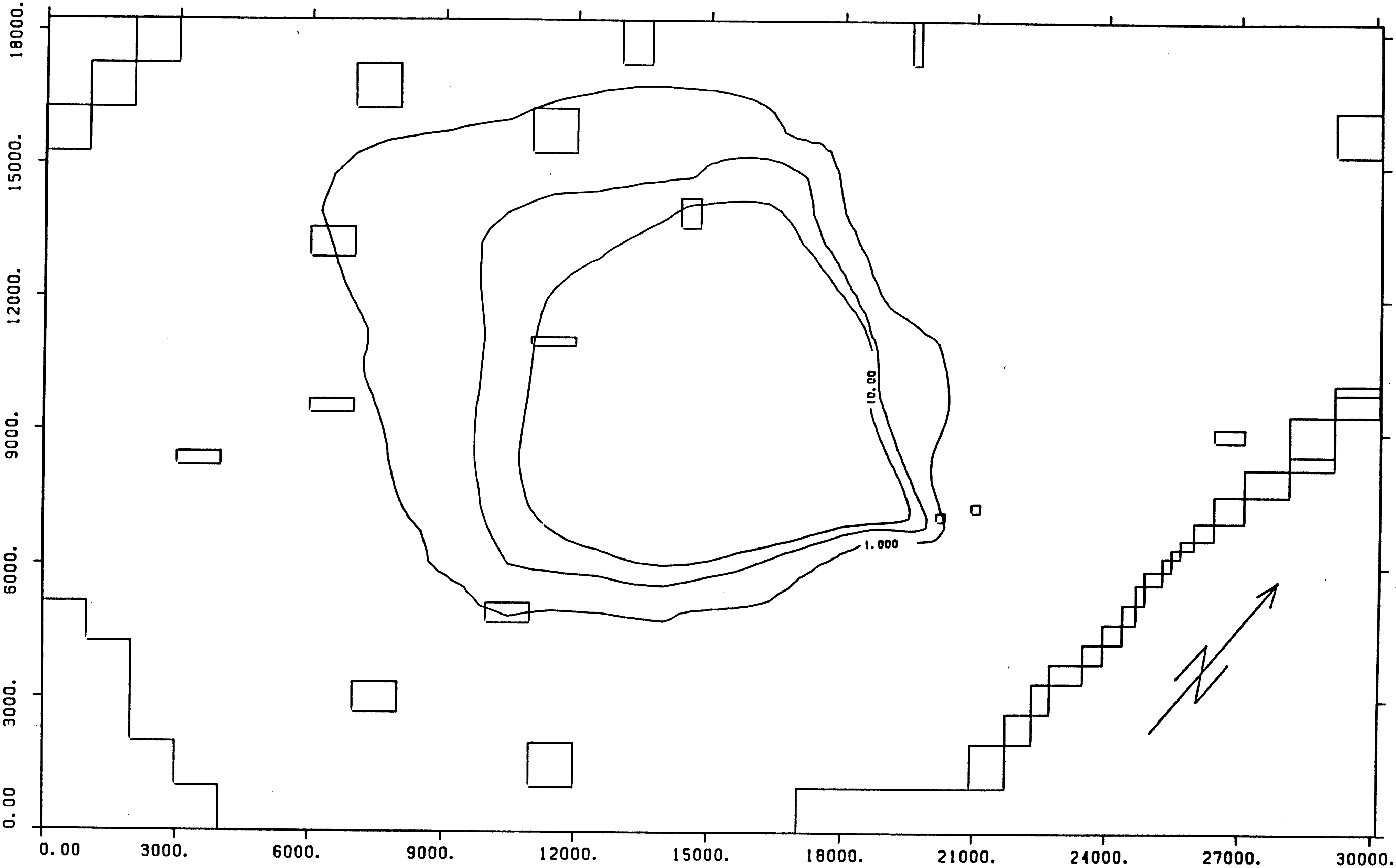



Explanation:

—900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 21d
Base Case 1, Alternative 3, Projected Contaminant
for Year 2008, Sub-Unit B/C

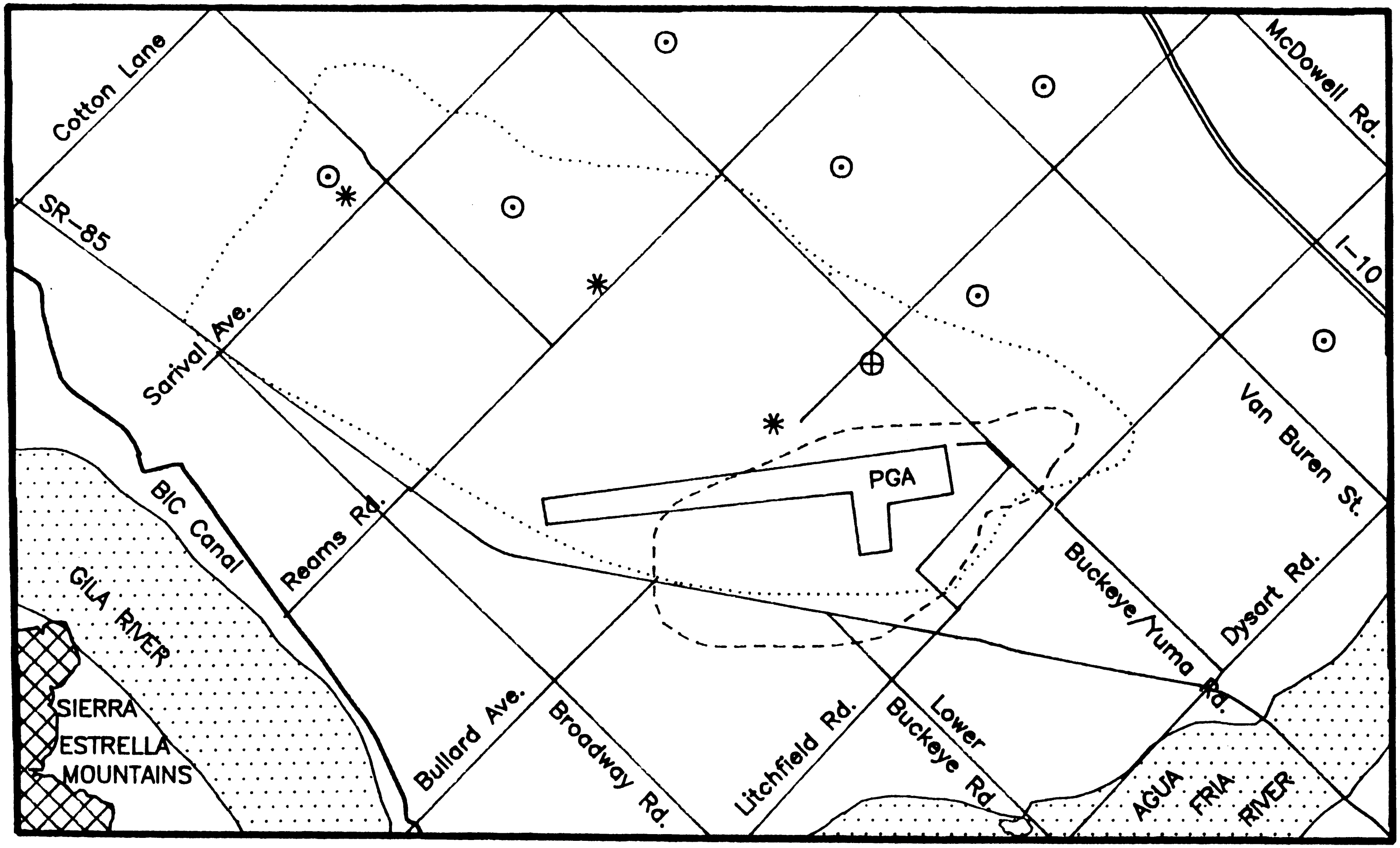



Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Scale 1" = 3000'

Figure 22




ALTERNATIVE 4

Accelerated reduction of contamination to meet ARAR's

TCE 1 ppb ISOPLETH
Subunit B/C
Subunit A

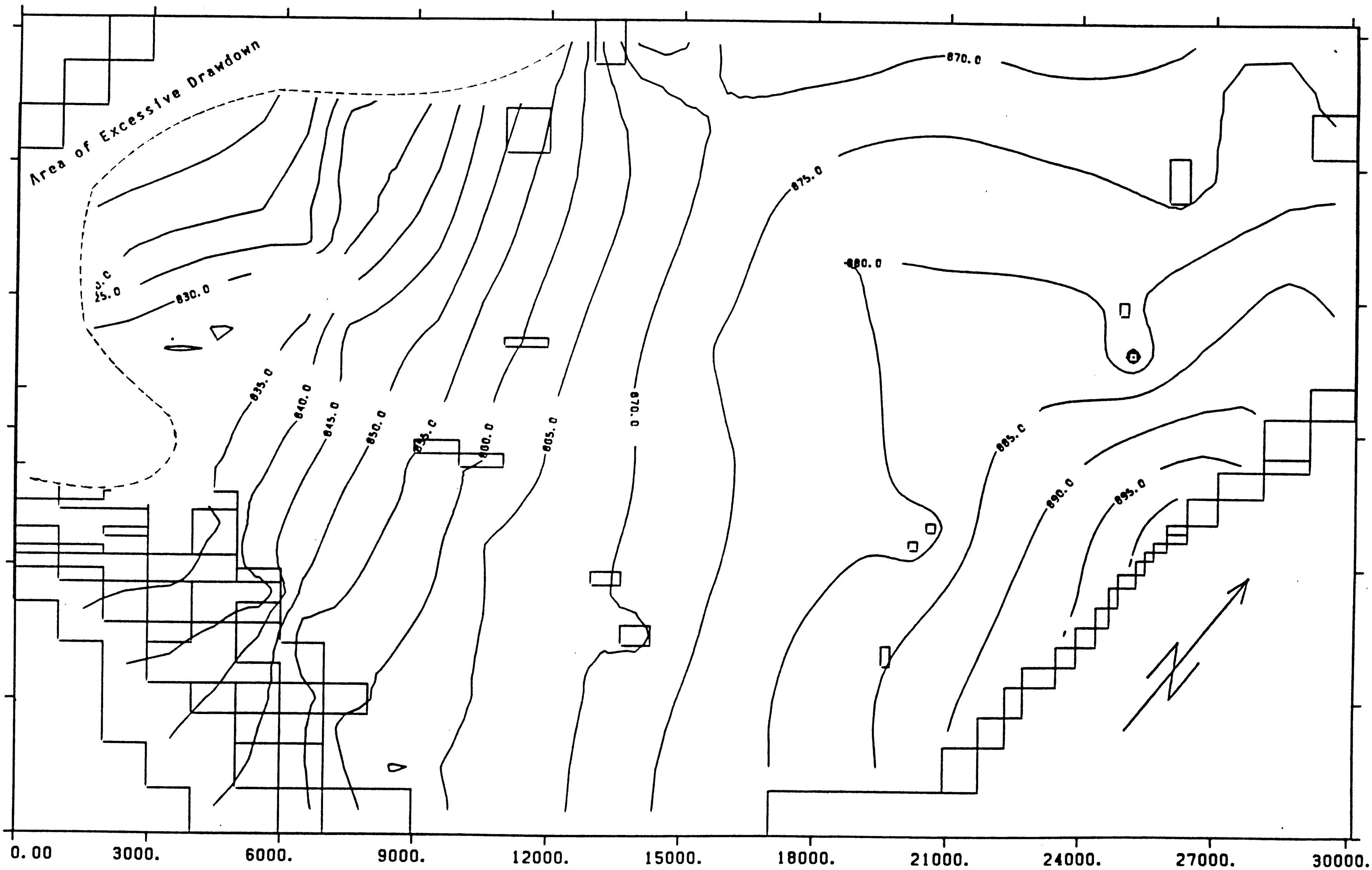
COG UAU WELLS
EXISTING
PROPOSED

REMEDIATION WELLS

N

1 MILE

Figure 23a
Base Case 1, Alternative 4, Projected Water Level
for Year 2008, Sub-Unit A



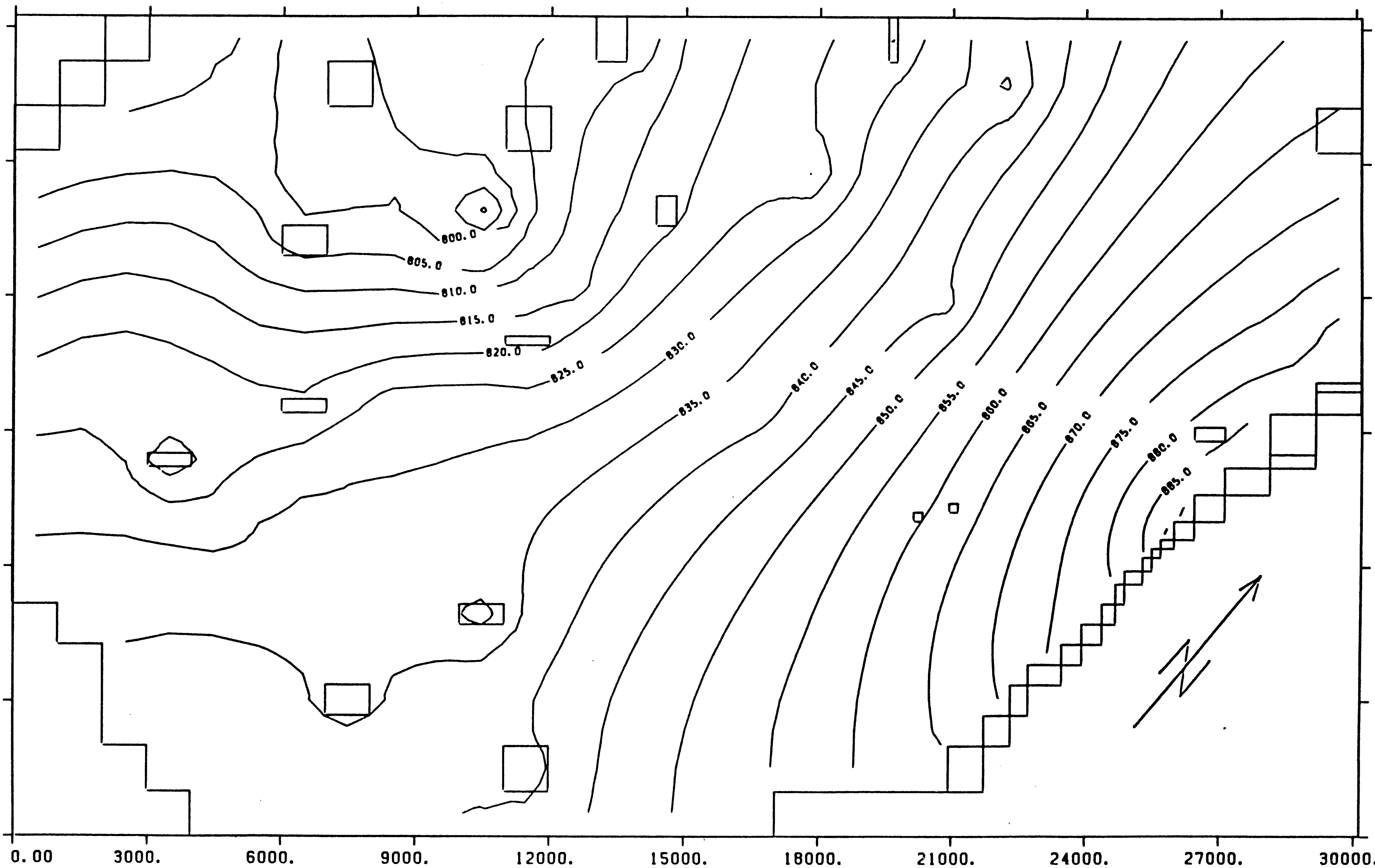

Explanation:

—900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 23c

Base Case 1, Alternative 4, Projected Water Level
for Year 2008, Sub-Unit B/C

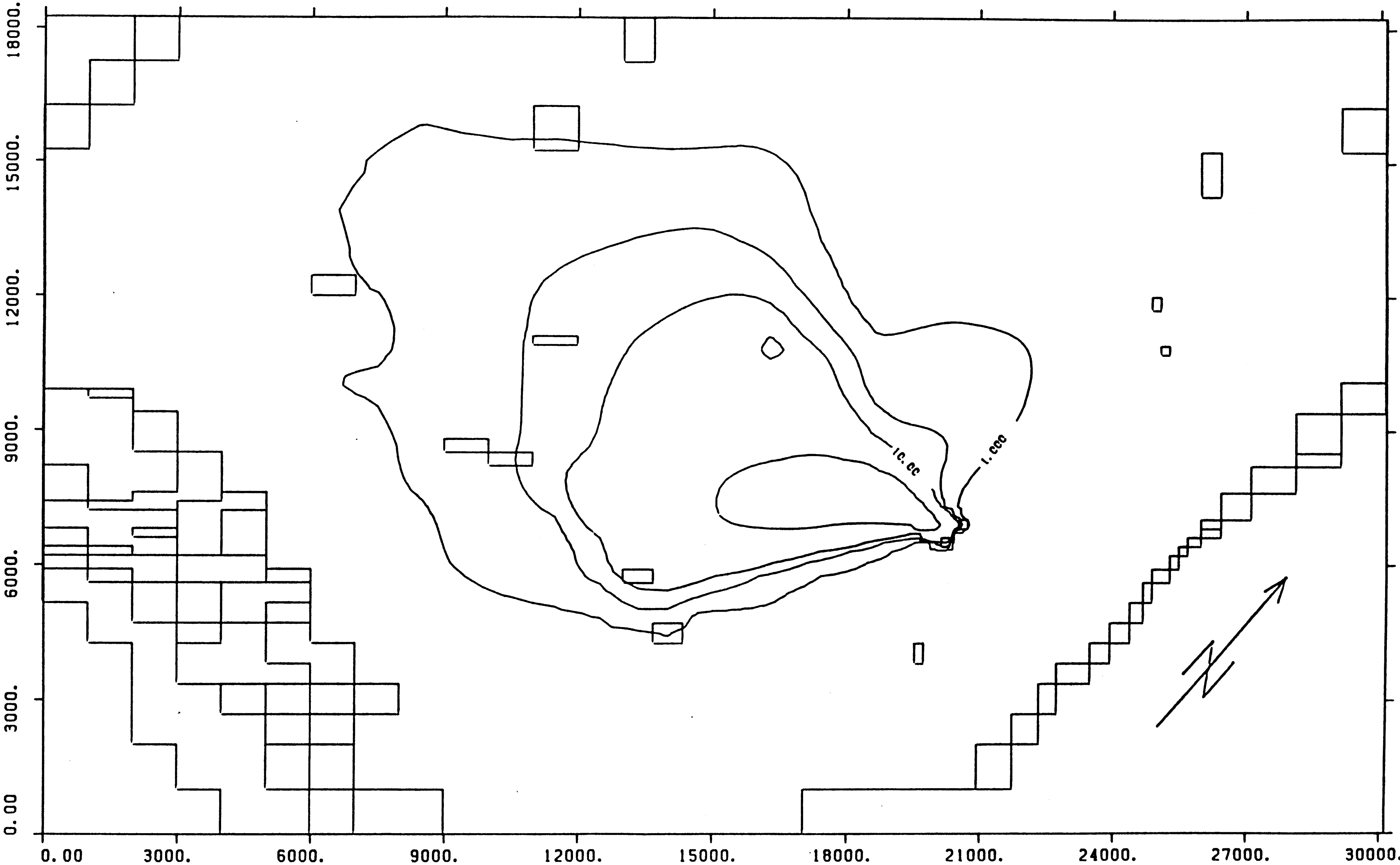



Explanation:

—900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Base Case 1, Alternative 4, Projected Contaminant
for Year 2008, Sub-Unit A

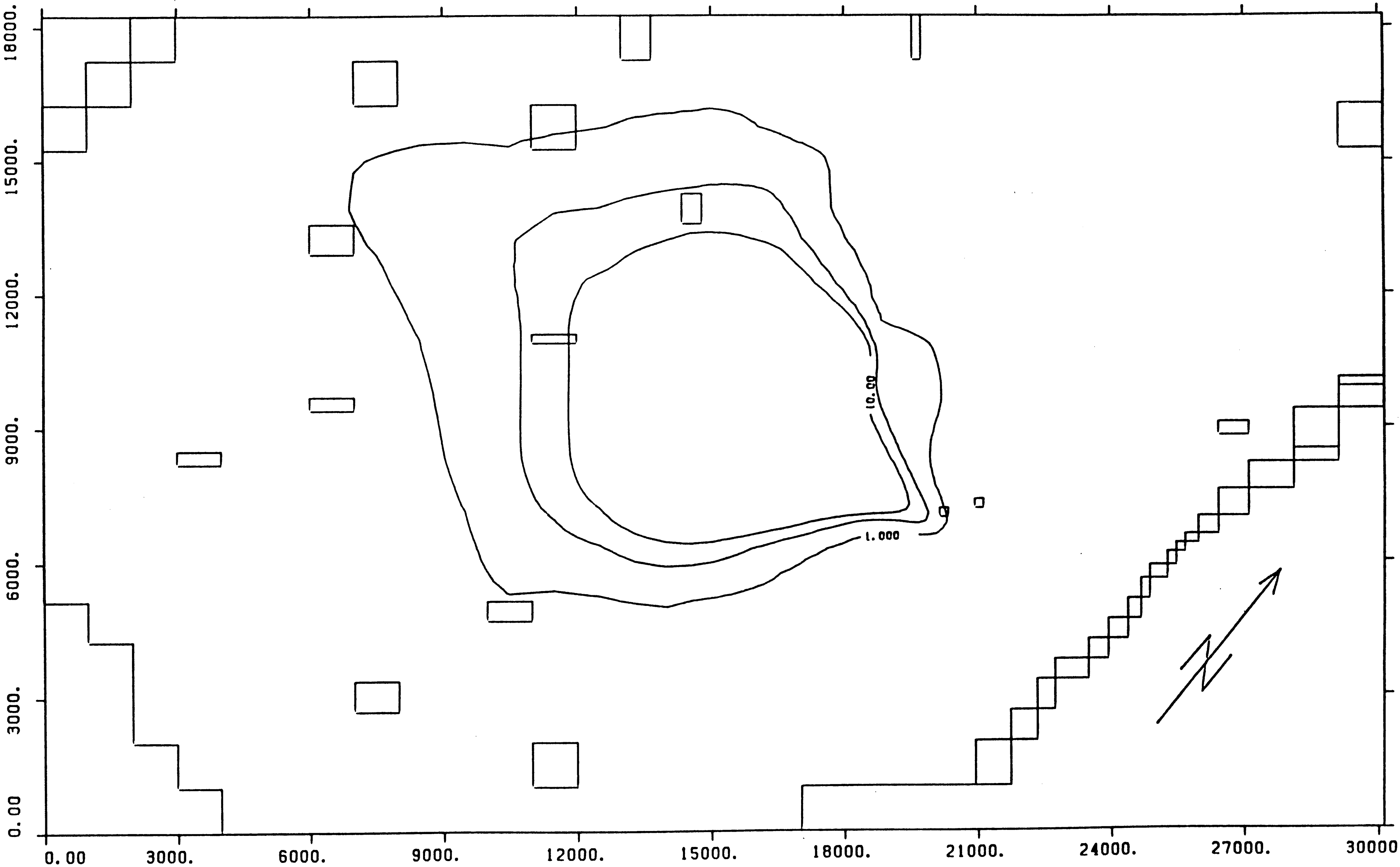



Scale 1" = 3000'

Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Figure 23d
Base Case 1, Alternative 4, Projected Contaminant
for Year 2008, Sub-Unit B/C




Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Scale 1" = 3000'

Figure 24

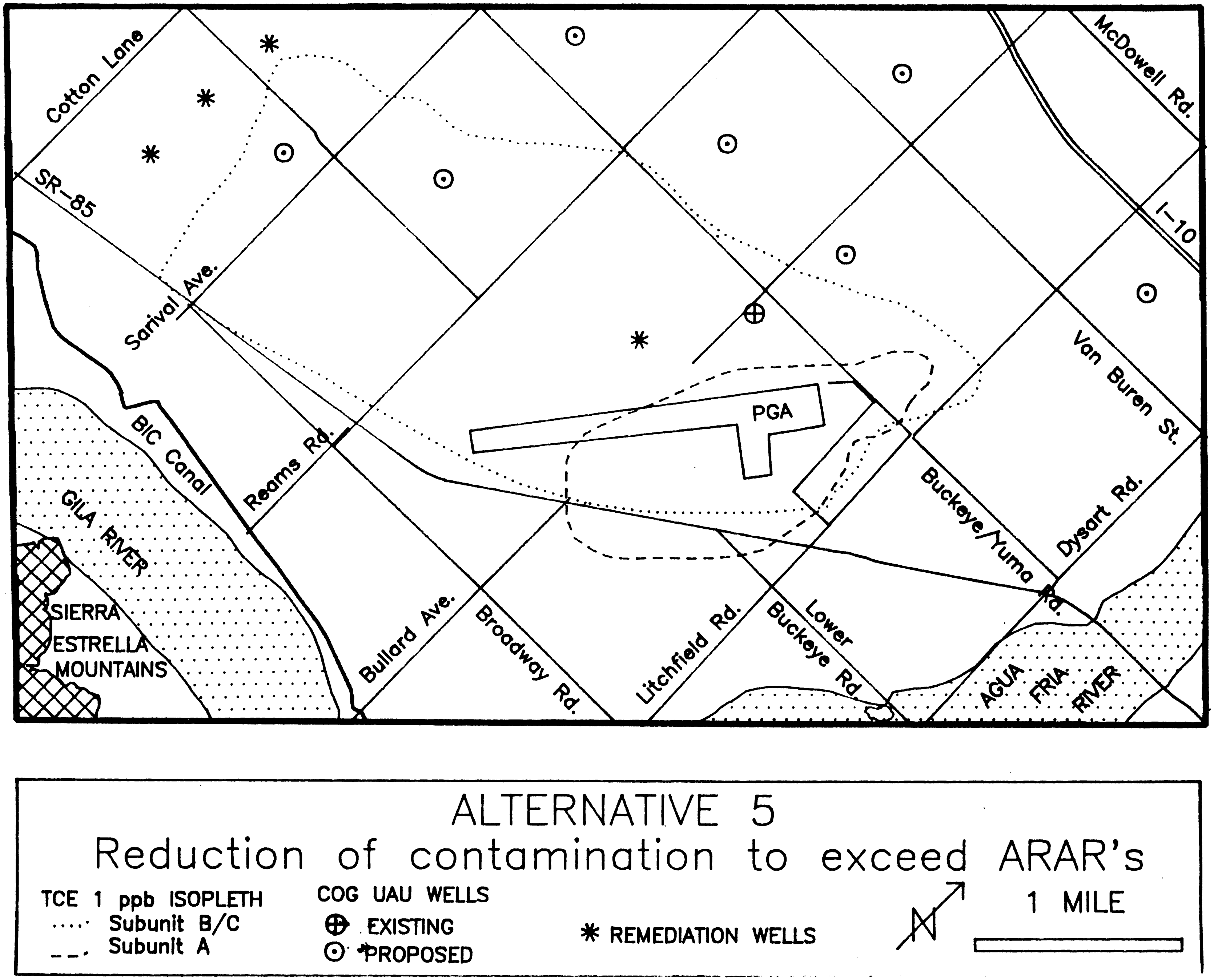
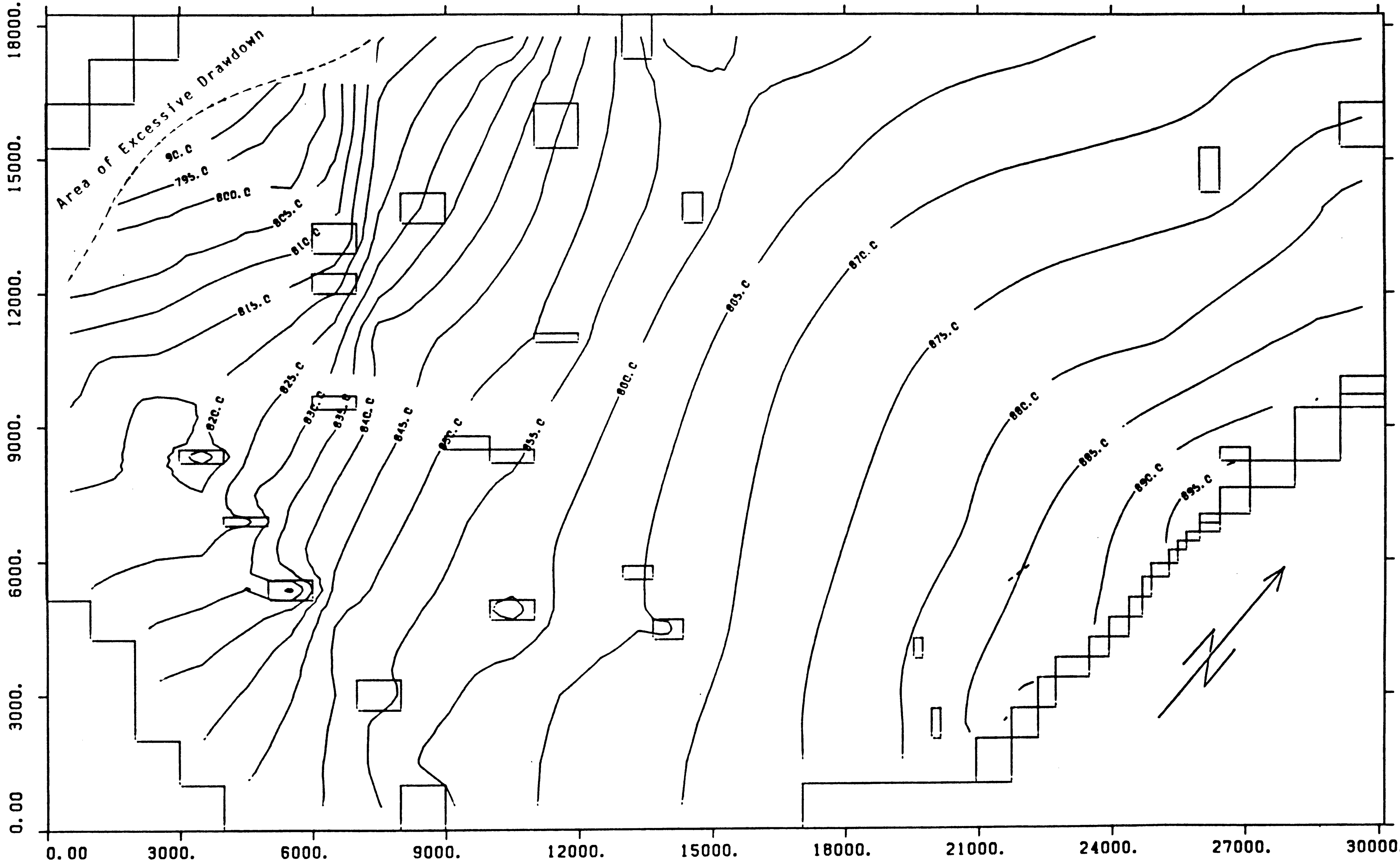

Cotton Lane
SR-85
Sarival Ave.
BIC Canal
GILA RIVER
SIERRA
ESTRELLA
MOUNTAINS
Reams Rd.
Bullard Ave.
Broadway Rd.
Litchfield Rd.
Lower
Buckeye Rd.
PGA
Buckeye/Yuma Rd.
Dysart Rd.
Van Buren St.
I-10
McDowell Rd.
AGUA
FRIA
RIVER
ALTERNATIVE 5
Reduction of contamination to exceed ARAR's
TCE 1 ppb ISOPLETH
Subunit B/C
Subunit A
COG UAU WELLS
EXISTING
PROPOSED
REMEDIATION WELLS
1 MILE

Figure 25a
Base Case 1, Alternative 5, Projected Water Level
for Year 2008, Sub-Unit A

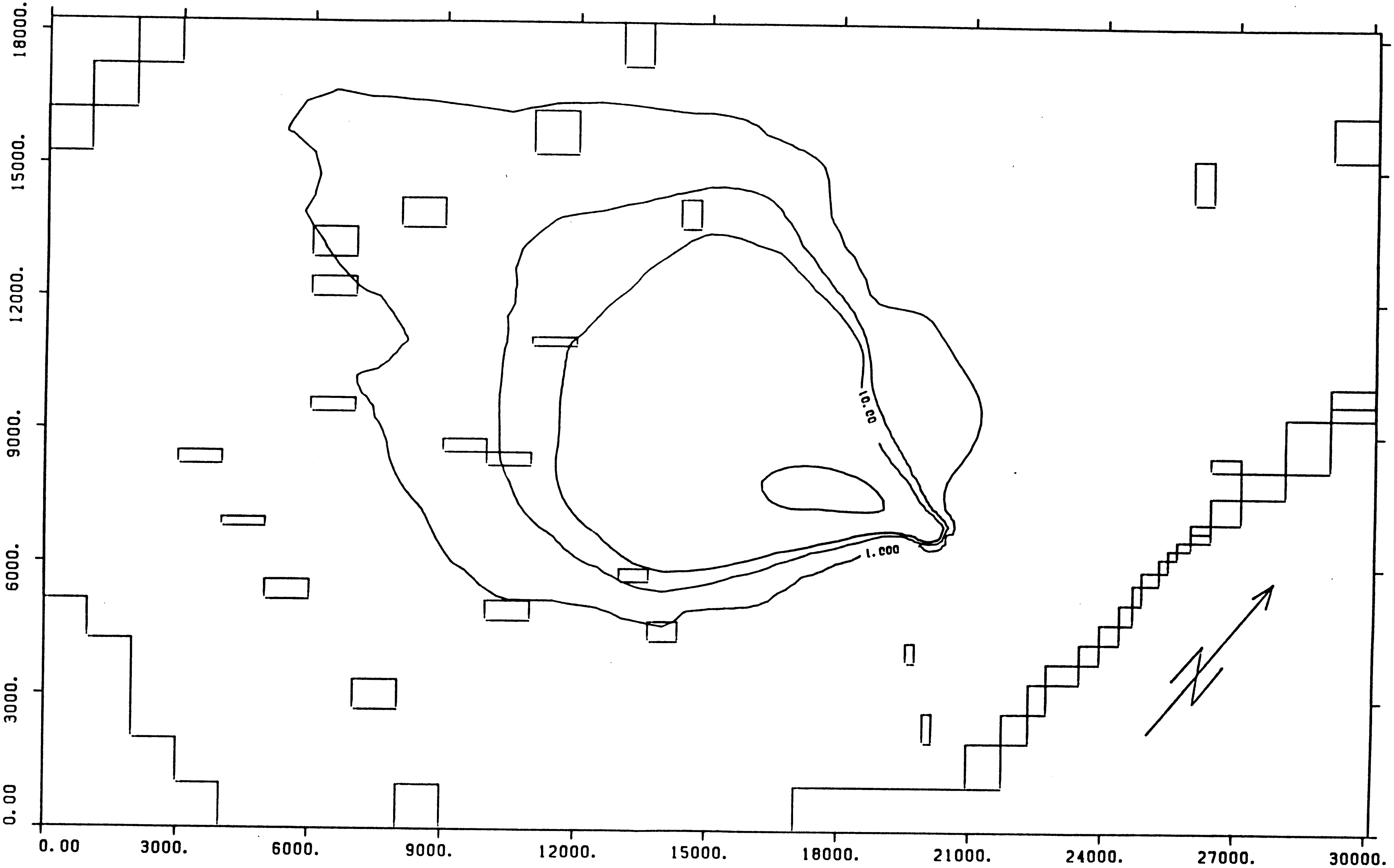



Explanation:

—900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 25b
Base Case 1, Alternative 5, Projected Contaminant
for Year 2008, Sub-Unit A



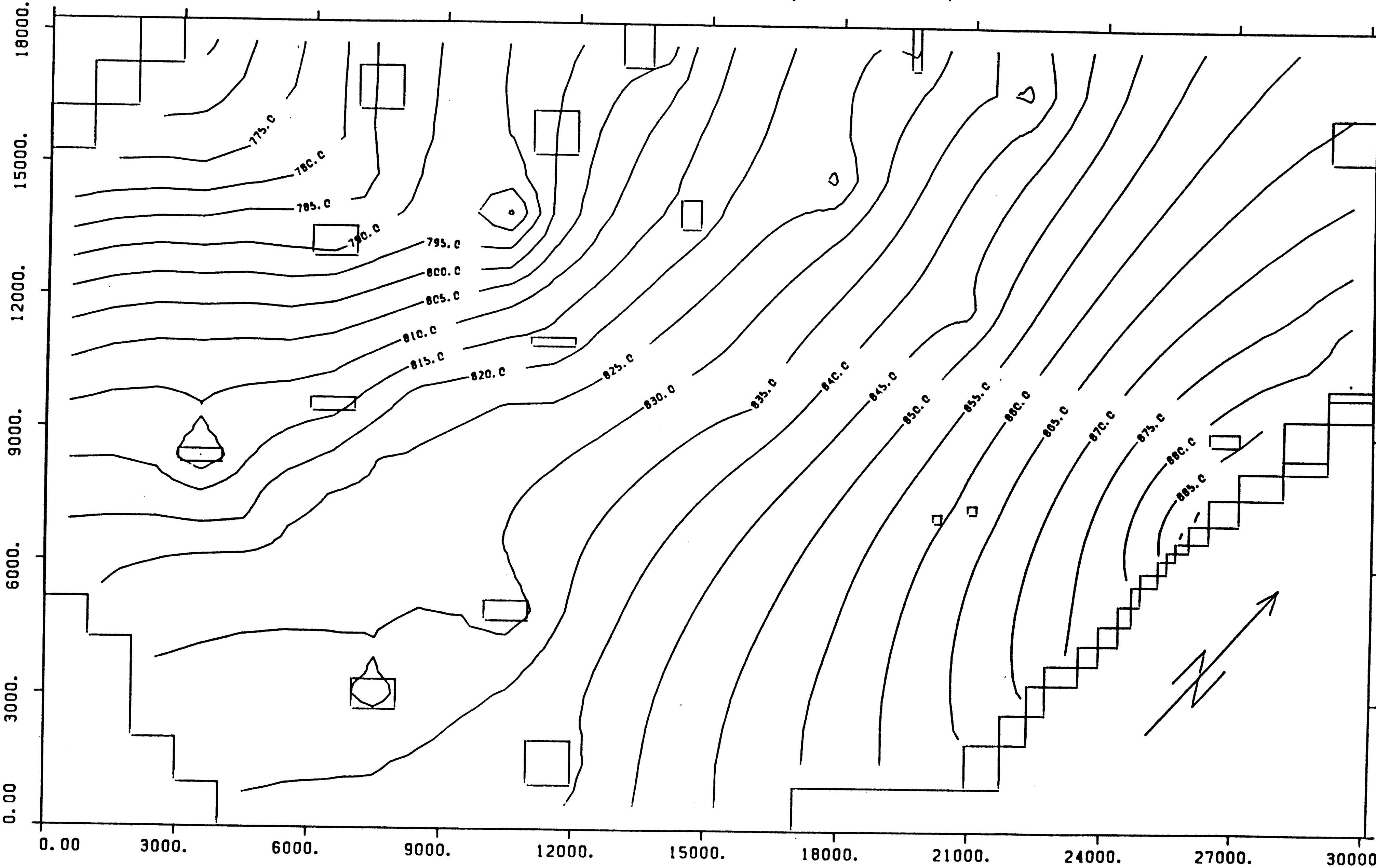

Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Scale 1" = 3000'

Figure 25c

Base Case 1, Alternative 5, Projected Water Level for Year 2008, Sub-Unit B/C

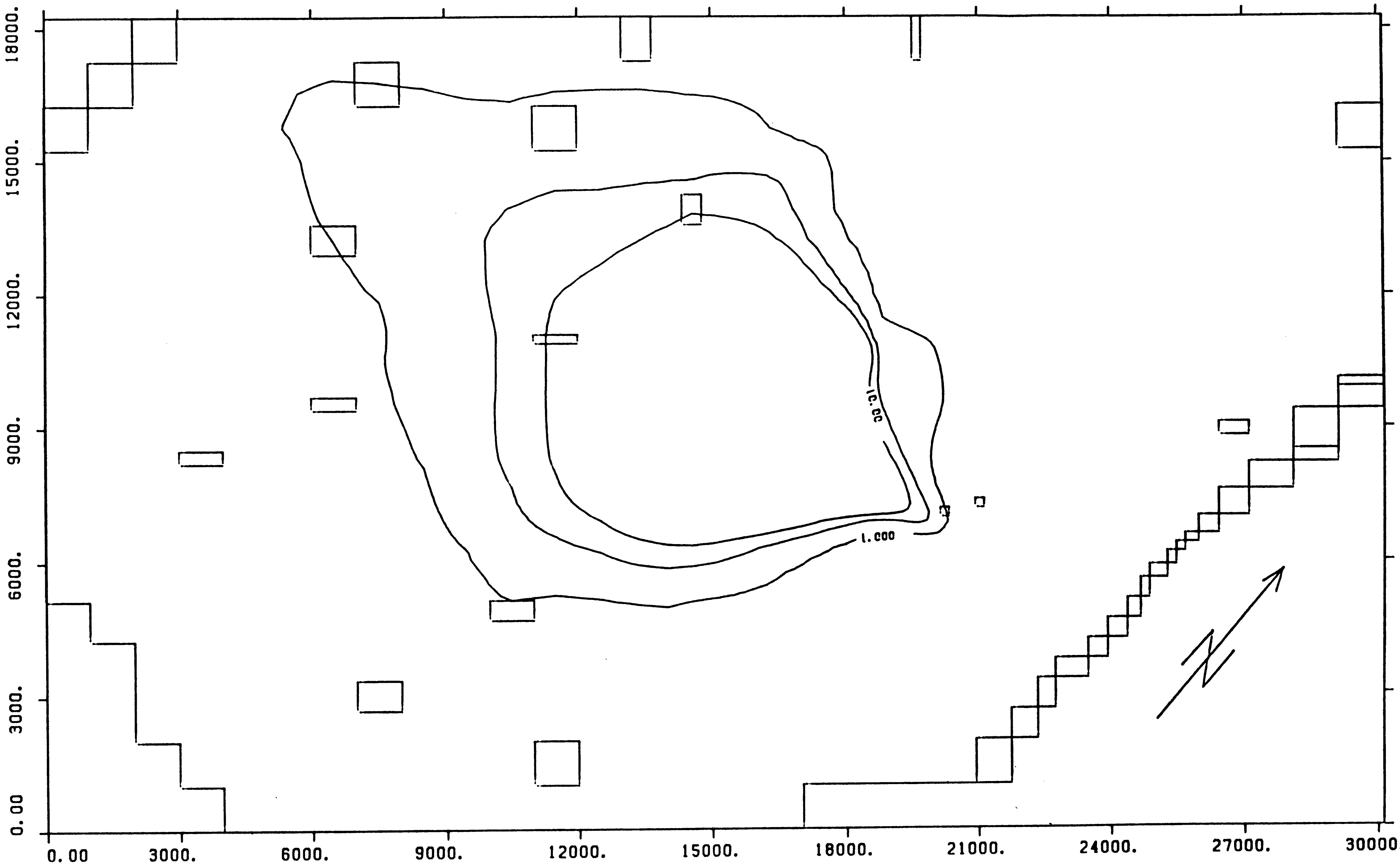



Explanation:

—900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 25d
Base Case 1, Alternative 5, Projected Contaminant
for Year 2008, Sub-Unit B/C

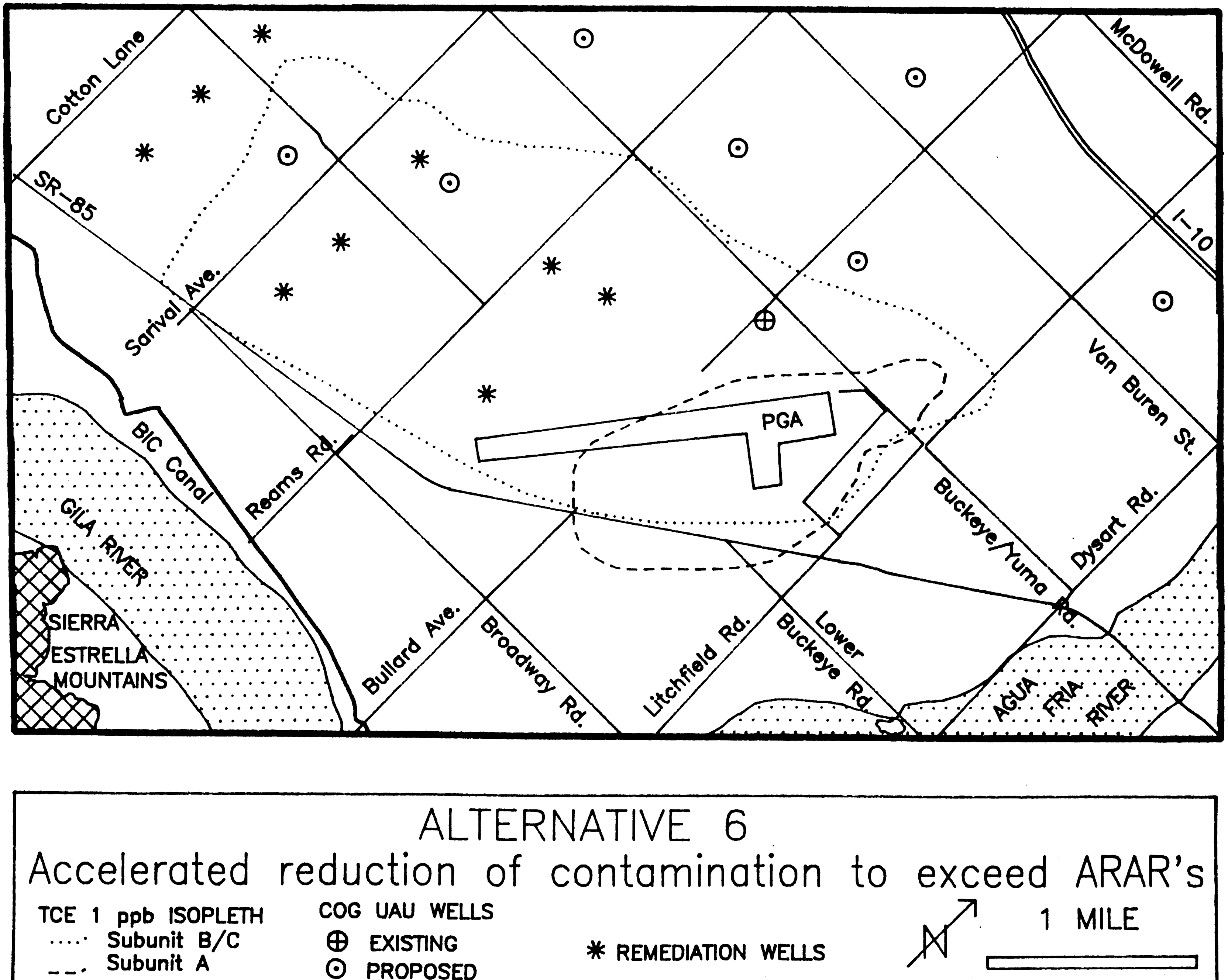



Scale 1" = 3000'

Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Figure 26




ALTERNATIVE 6

Accelerated reduction of contamination to exceed ARAR's

Figure 27

**NOTE:**

COORDINATE SYSTEM SHOWN IS GRID
BASED ON ARIZONA STATE PLANE
COORDINATE SYSTEM.

Remedial Design Site Plan for
Section 16 Operable Unit

Source: ICF Technology Incorporated for
Goodyear Aerospace Corporation

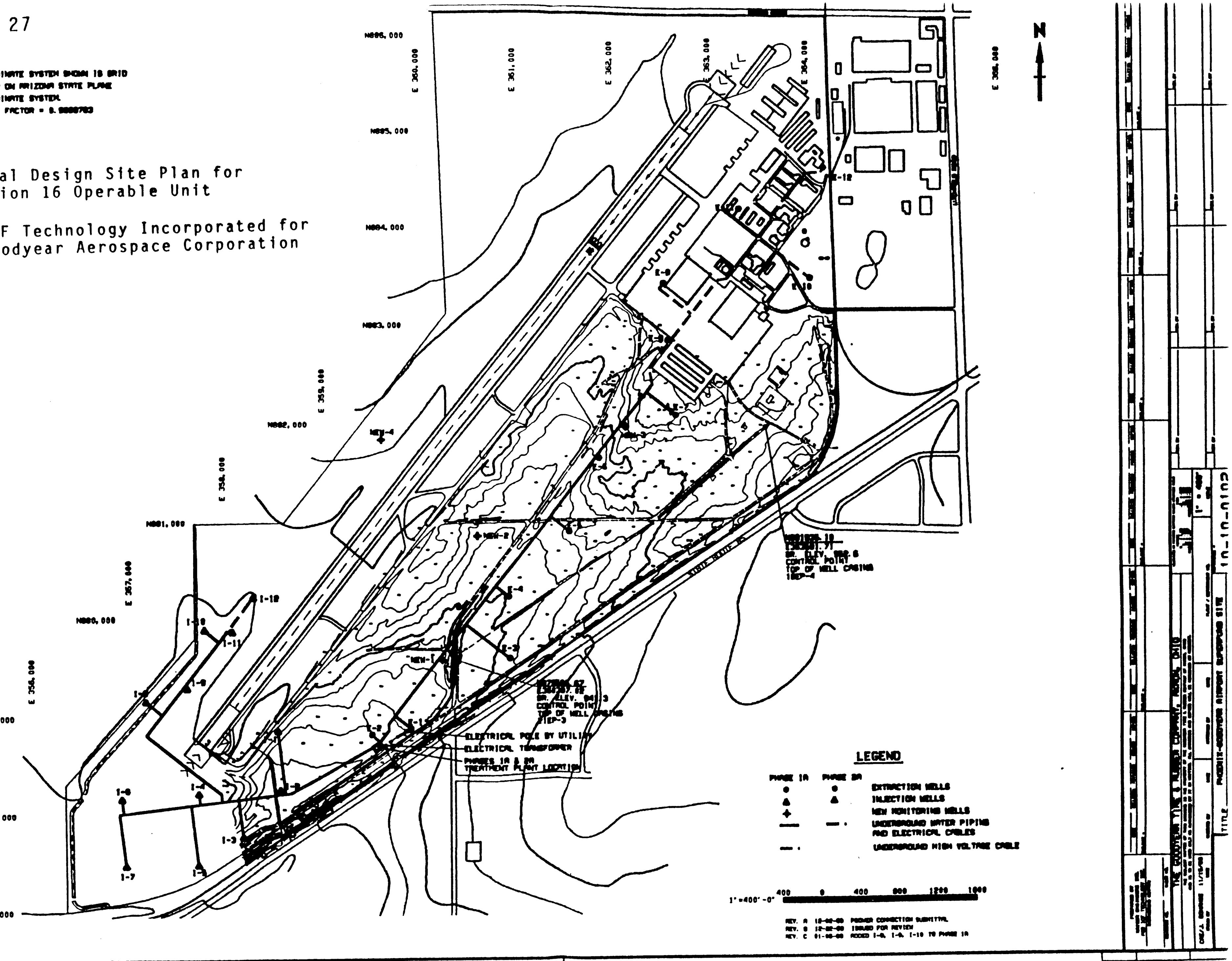
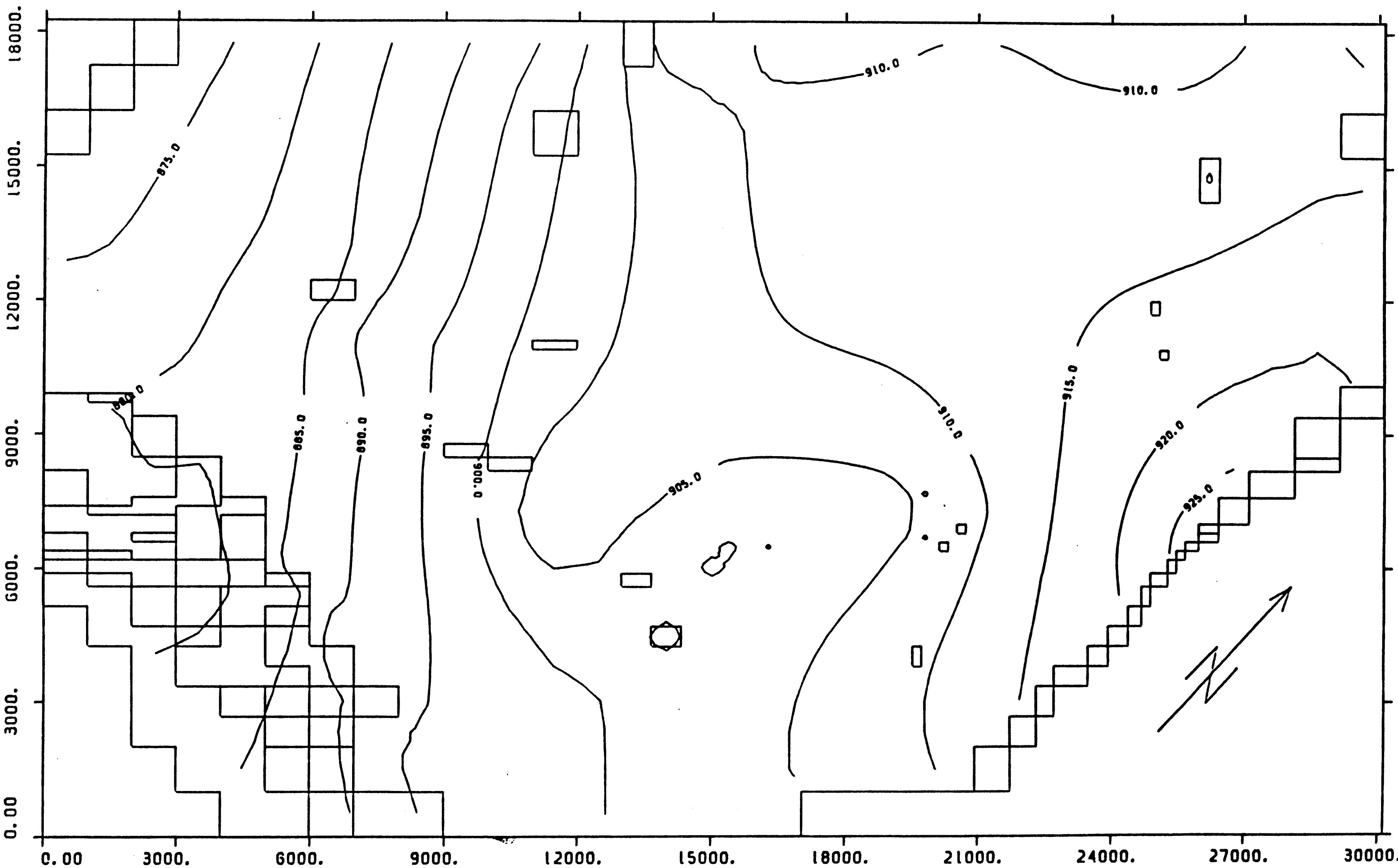


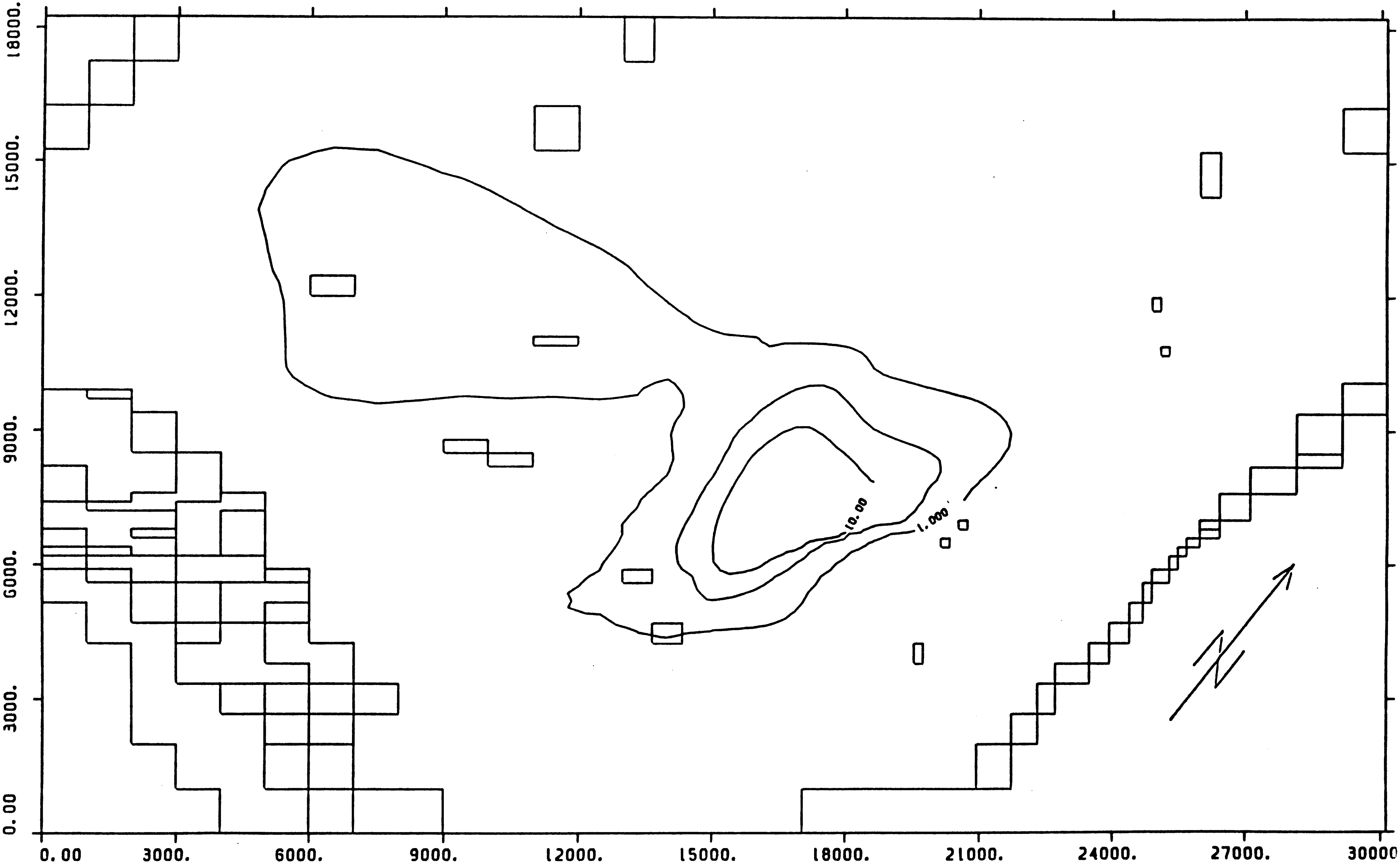
Figure 28a
Base Case 2, No Action Alternative Projected Water Level
for Year 2008, Sub-Unit A




Explanation:
—900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 28b
Base Case 2, No Action Alternative Projected Contaminant
for Year 2008, Sub-Unit A

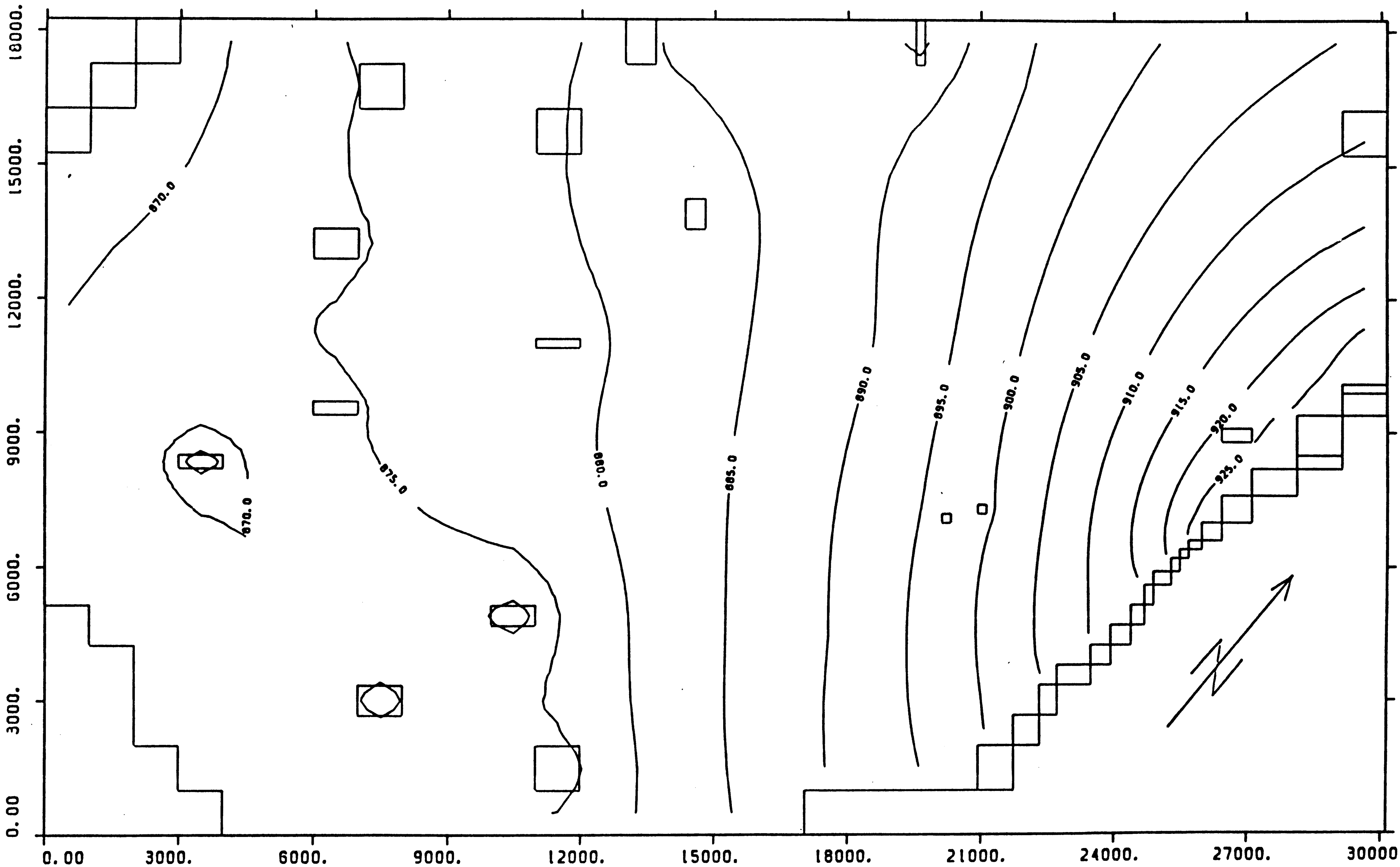



Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Scale 1" = 3000'

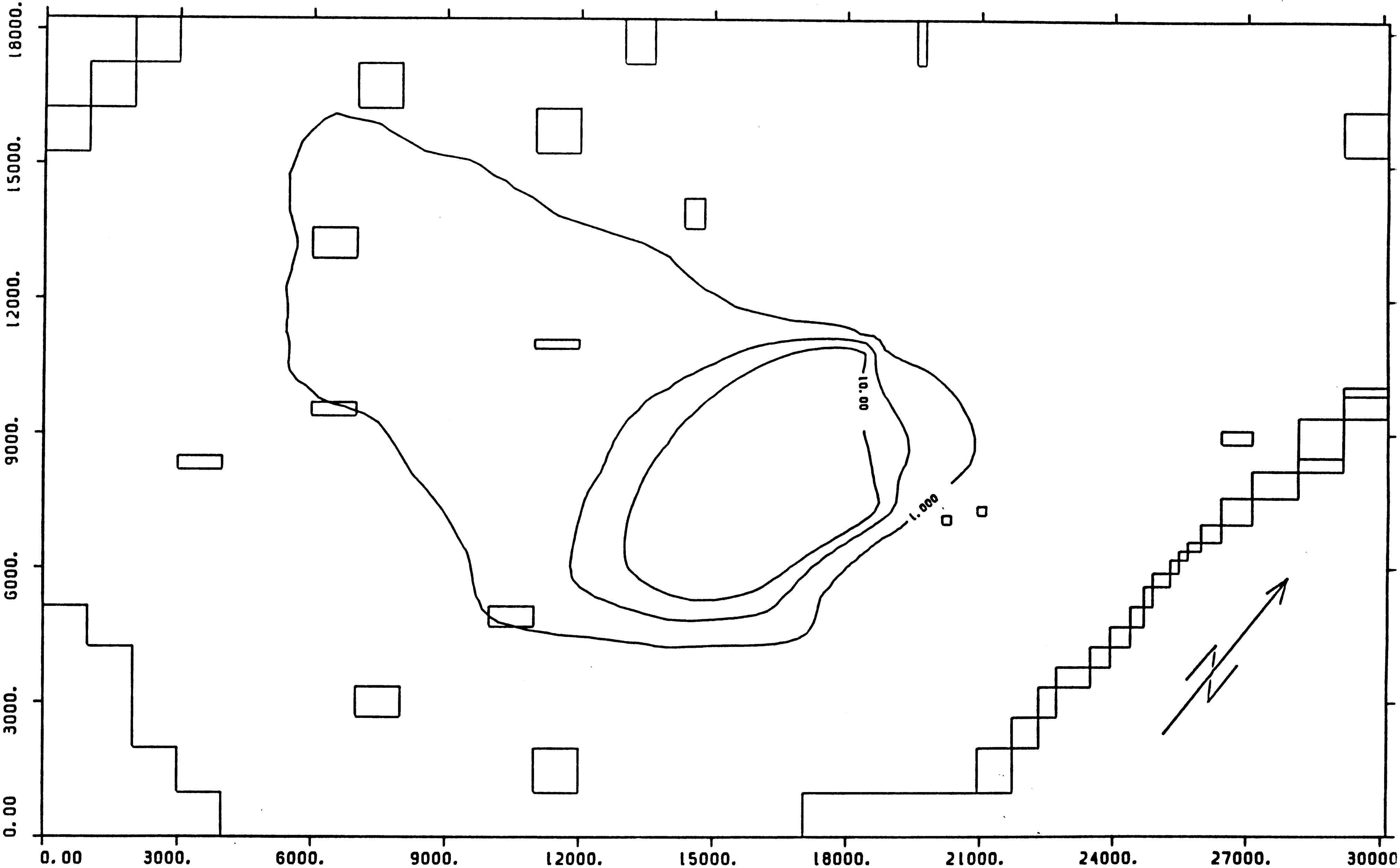
Figure 28c
Base Case 2, No Action Alternative Projected Water Level for Year 2008, Sub-Unit B/C




Explanation:
—900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 28d
Base Case 2, No Action Alternative Projected Contaminant for Year 2008, Sub-Unit B/C

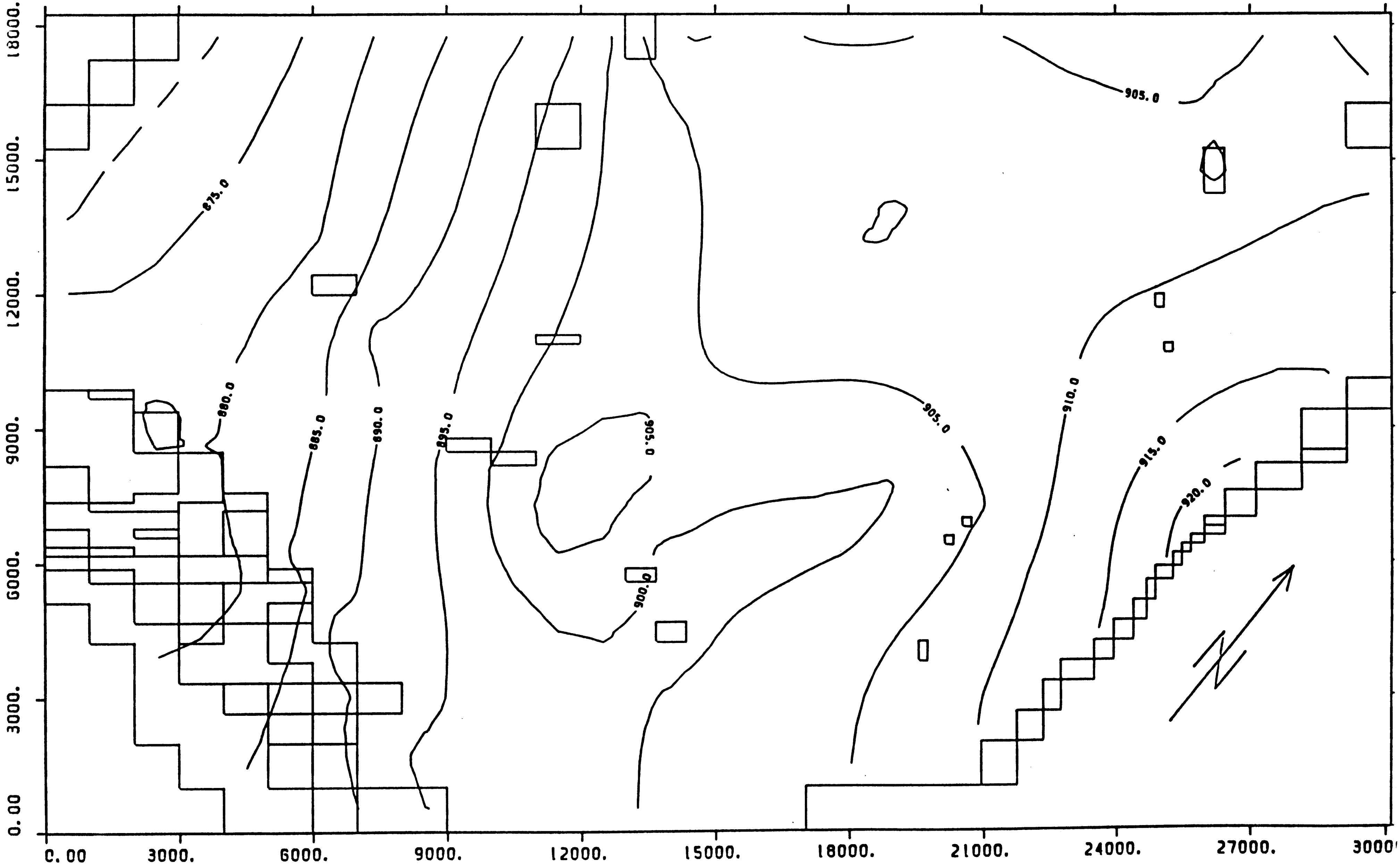



Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Scale 1" = 3000'

Figure 29a
Base Case 2, Alternative 3, Projected Water Level
for Year 2008, Sub-Unit A

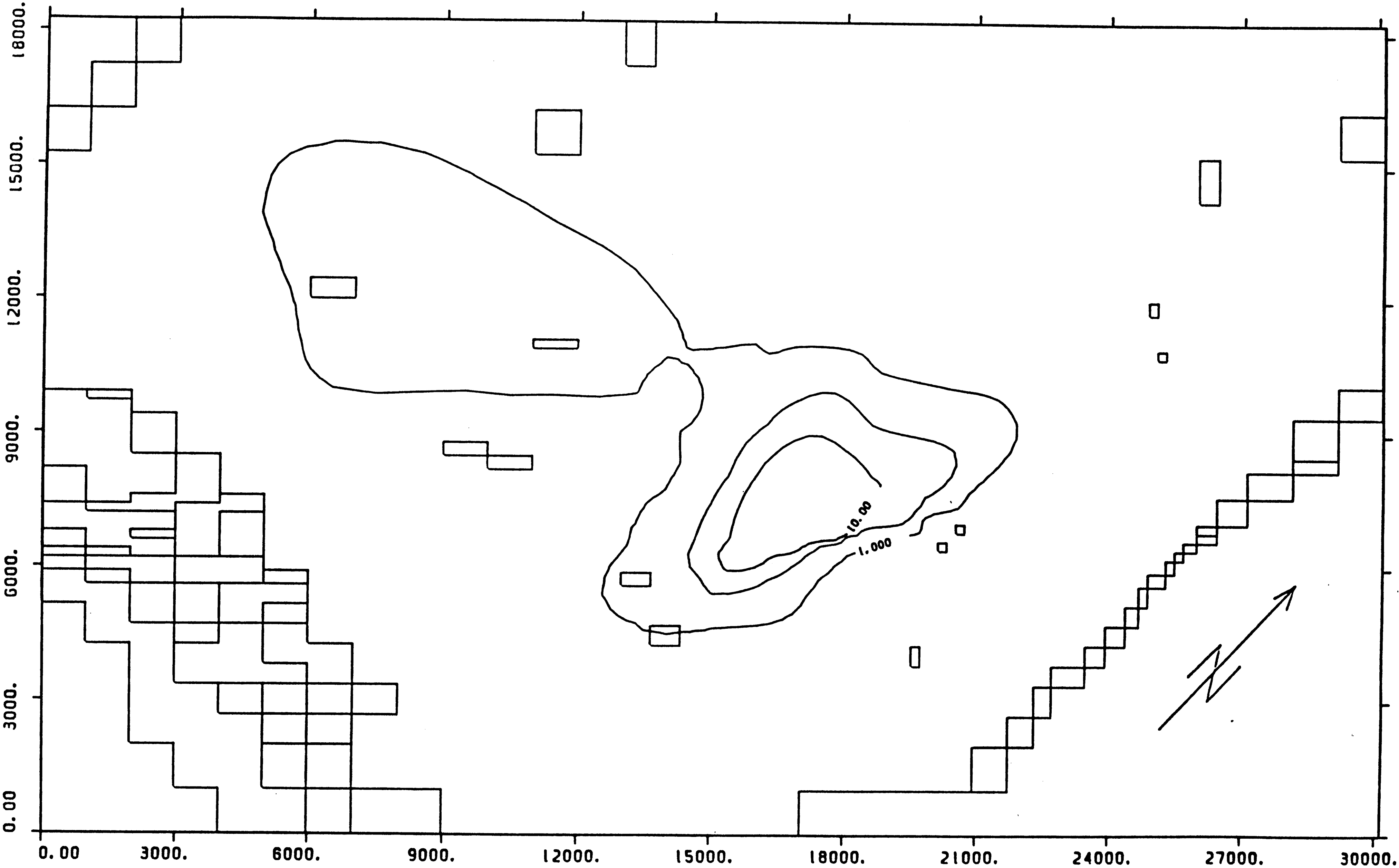



Explanation:

——900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 29b
Base Case 2, Alternative 3, Projected Contaminant
for Year 2008, Sub-Unit A

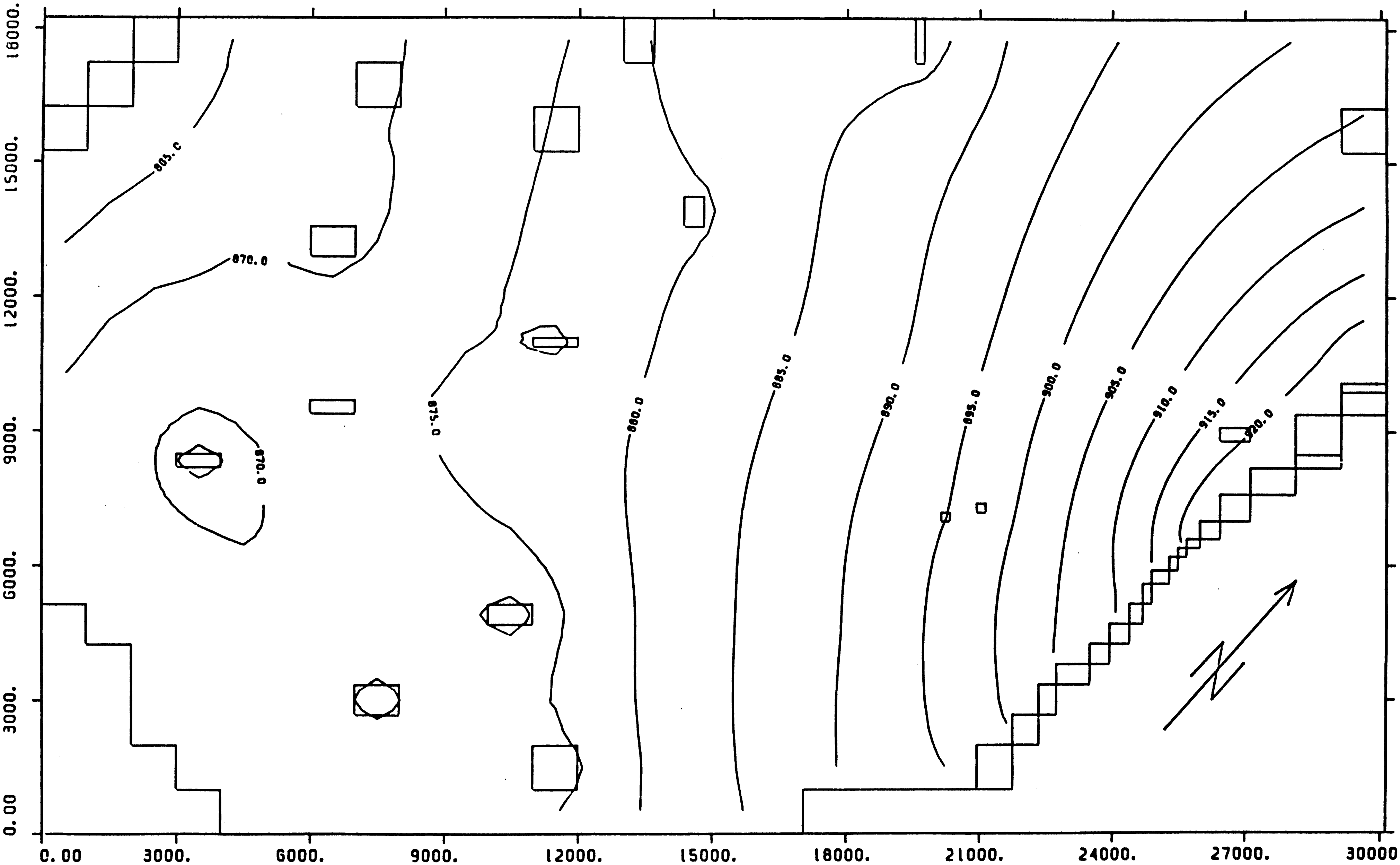



Scale 1" = 3000'

Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Figure 29c
Base Case 2, Alternative 3, Projected Water Level
for Year 2008, Sub-Unit B/C

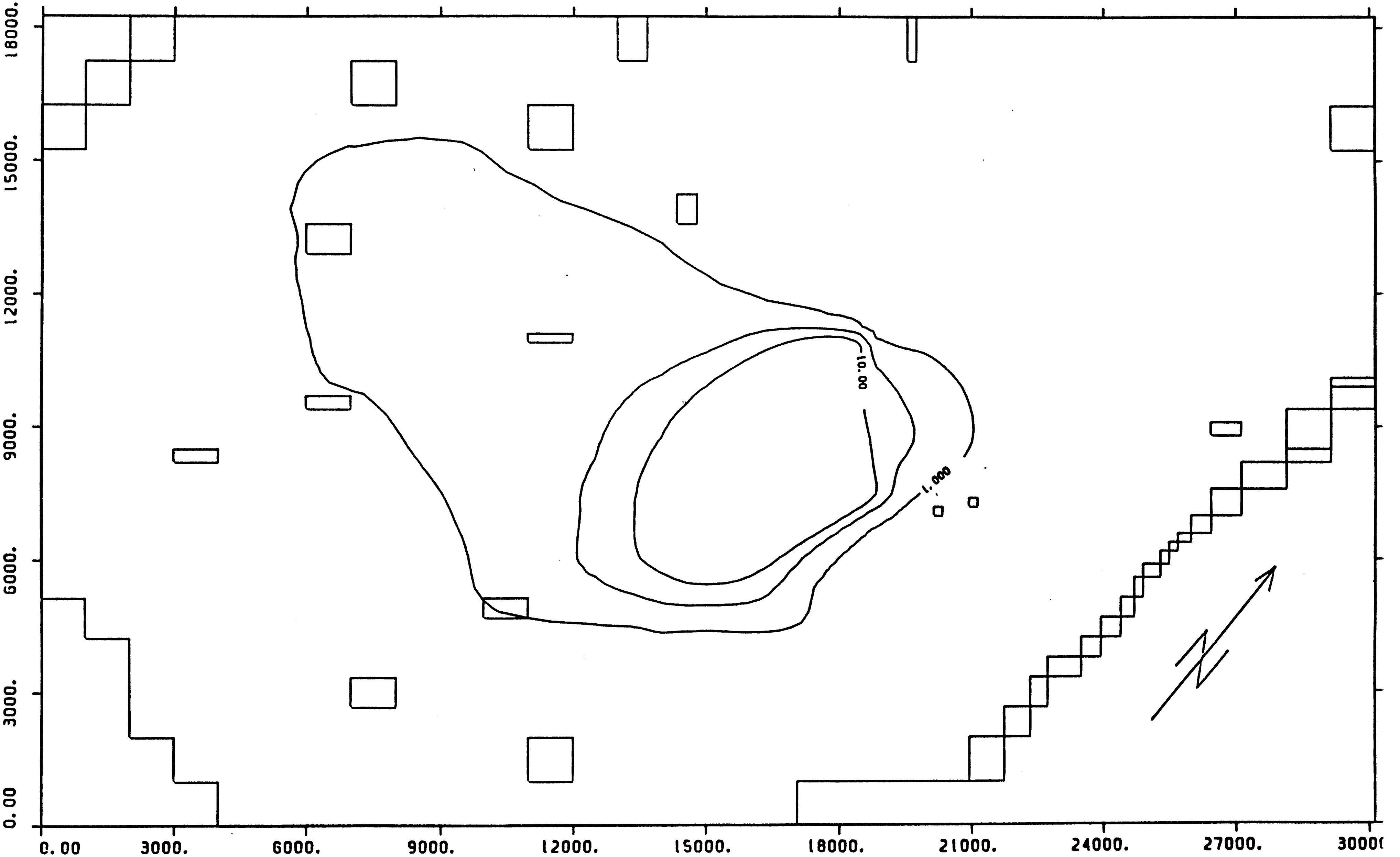



Explanation:

———900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 29d
Base Case 2, Alternative 3, Projected Contaminant
for Year 2008, Sub-Unit B/C

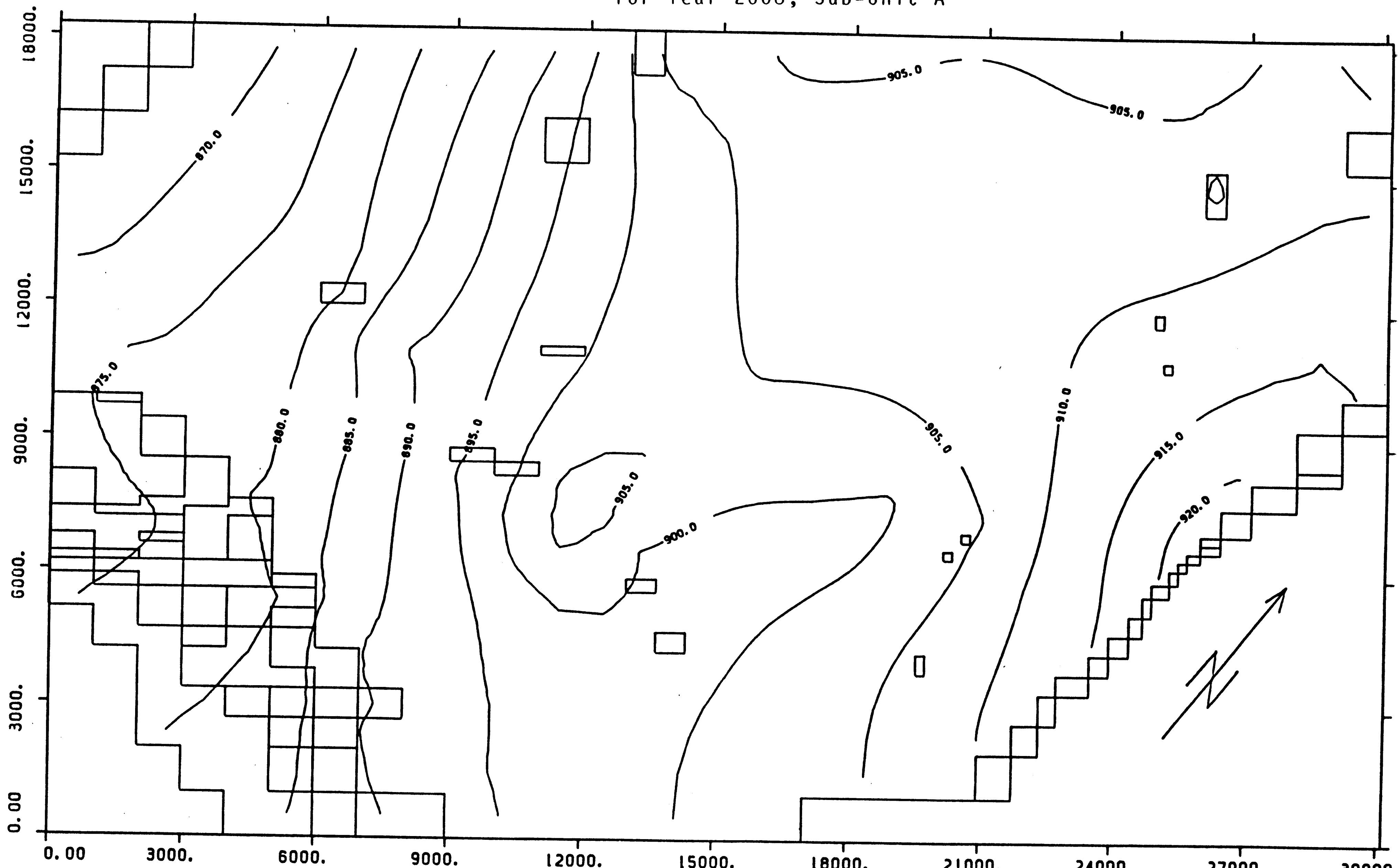



Scale 1" = 3000'

Explanation:

Predicted TCE Concentrations - Cortour Values 1.5,10 and 100ppb.

Figure 30a
Base Case 2, Alternative 4, Projected Water Level
for Year 2008, Sub-Unit A



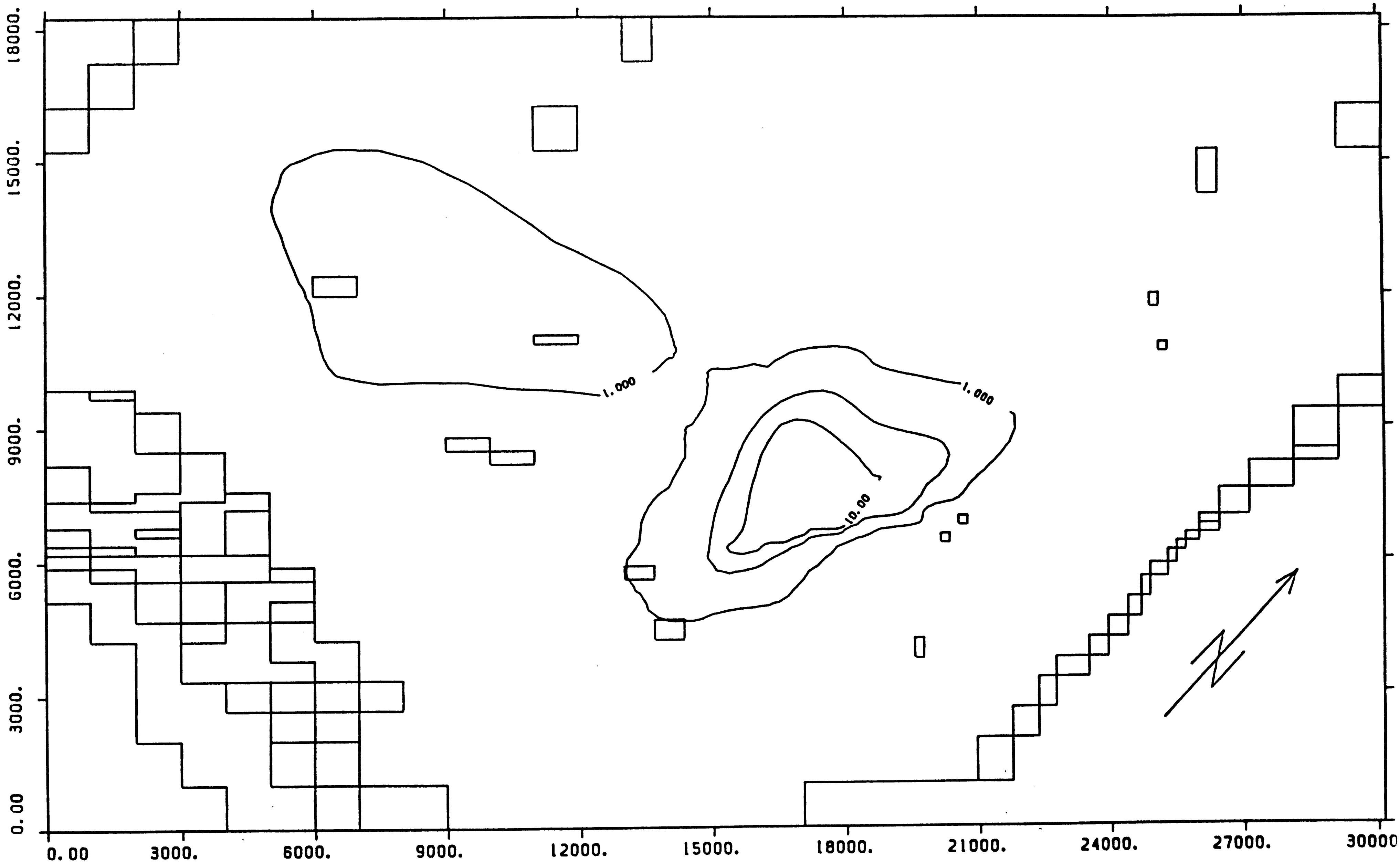

Explanation:

——900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 30b

Base Case 2, Alternative 4, Projected Contaminant for Year 2008, Sub-Unit A

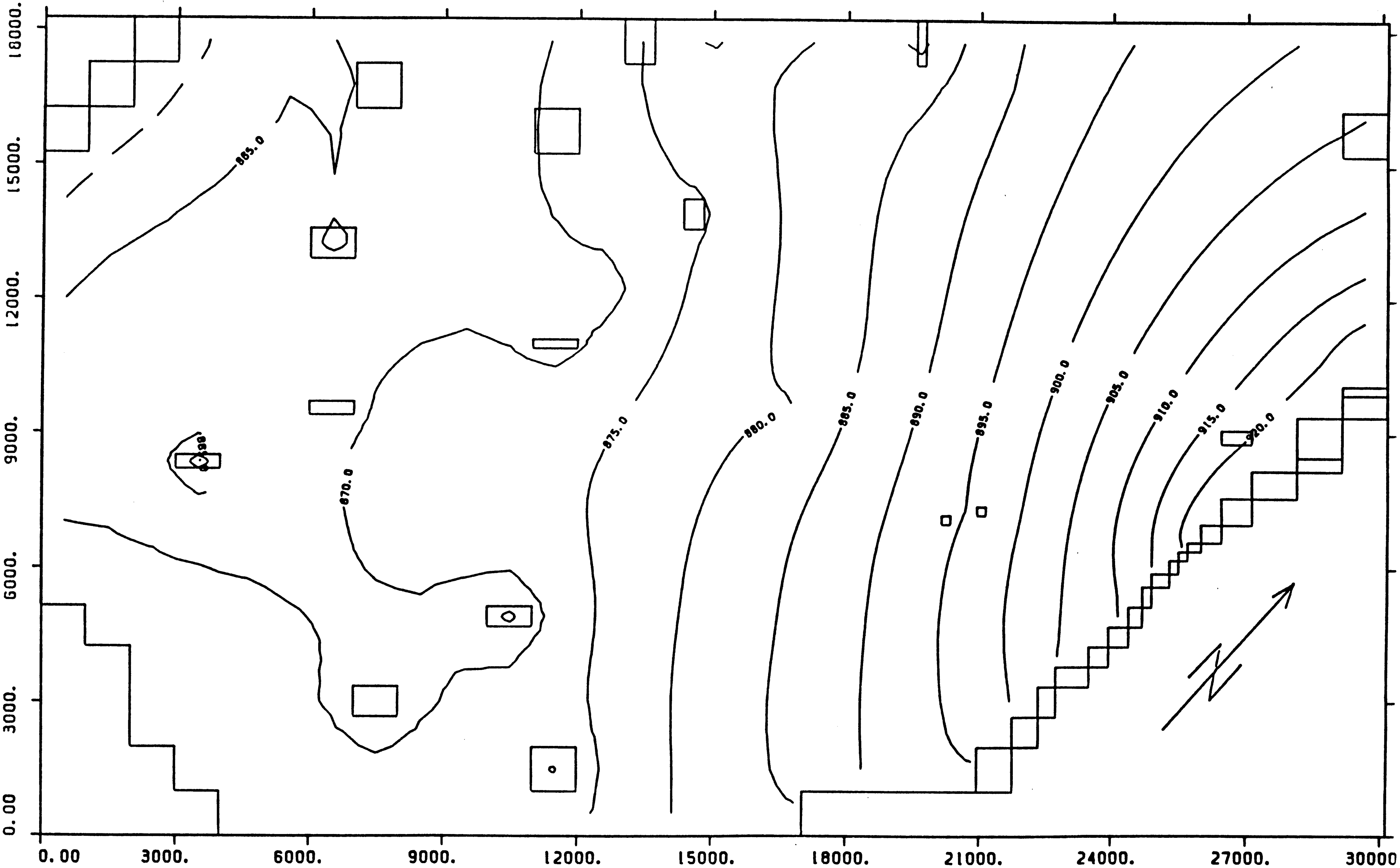



Scale 1" = 3000'

Explanation:
Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Figure 30c

Base Case 2, Alternative 4, Projected Water Level for Year 2008, Sub-Unit B/C

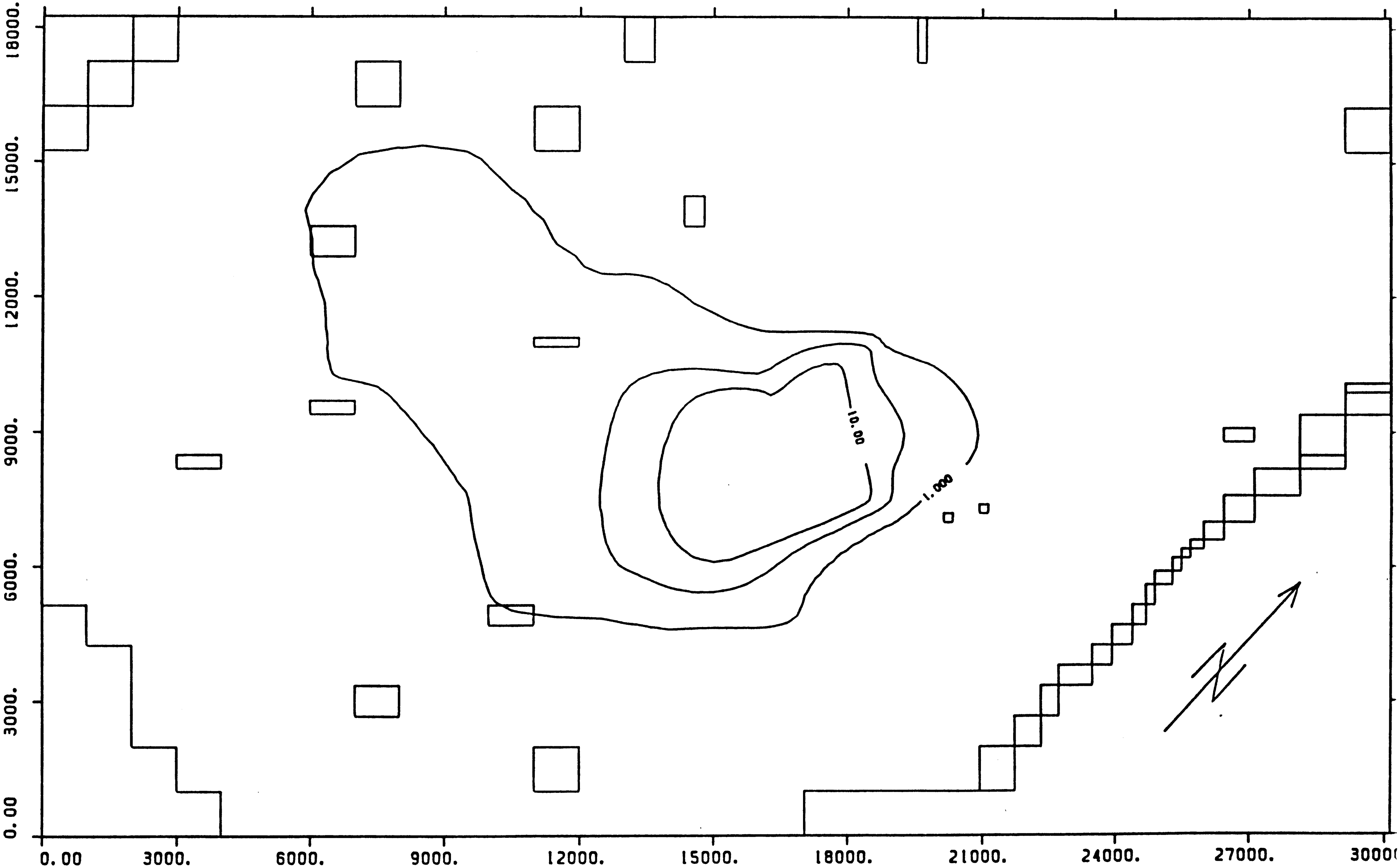



Explanation:

——900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 30d
Base Case 2, Alternative 4, Projected Contaminant for Year 2008, Sub-Unit B/C

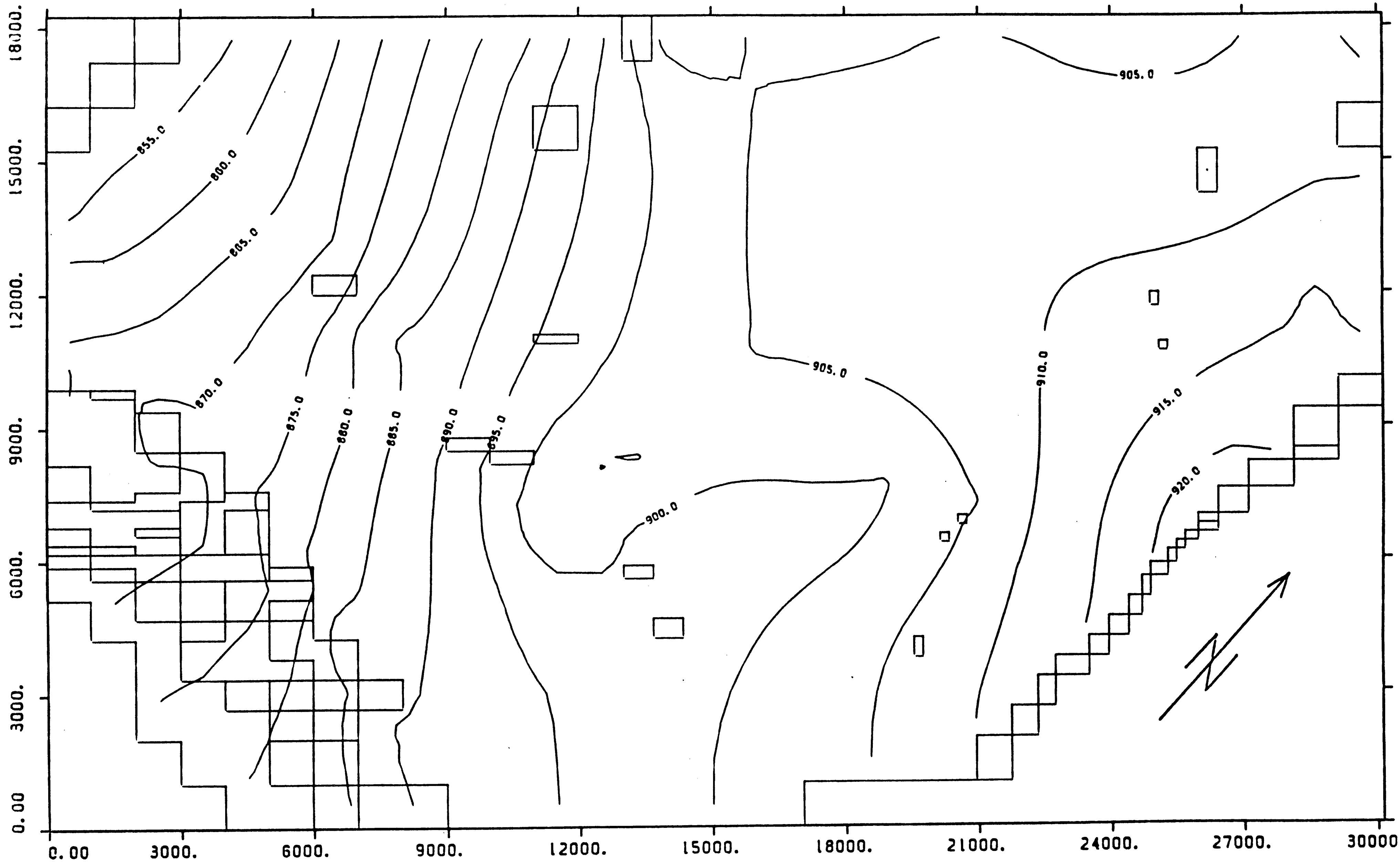



Scale 1" = 3000'

Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Figure 31a
Base Case 2, Alternative 5, Projected Water Level
for Year 2008, Sub-Unit A

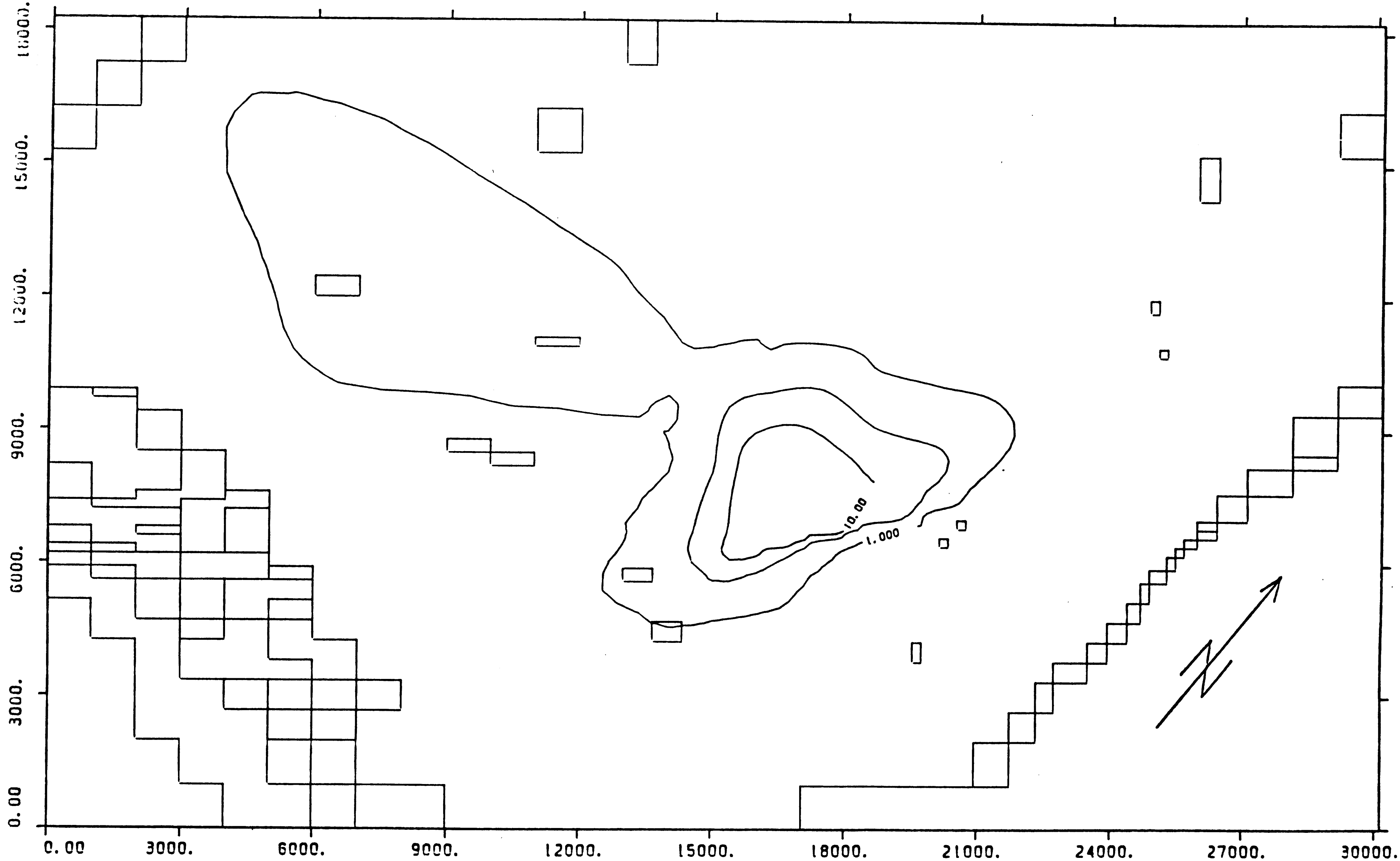



Scale 1" = 3000'

Explanation:
——900.0- Predicted Hydraulic Head

Figure 31b

Base Case 2, Alternative 5, Projected Contaminant for Year 2008, Sub-Unit A

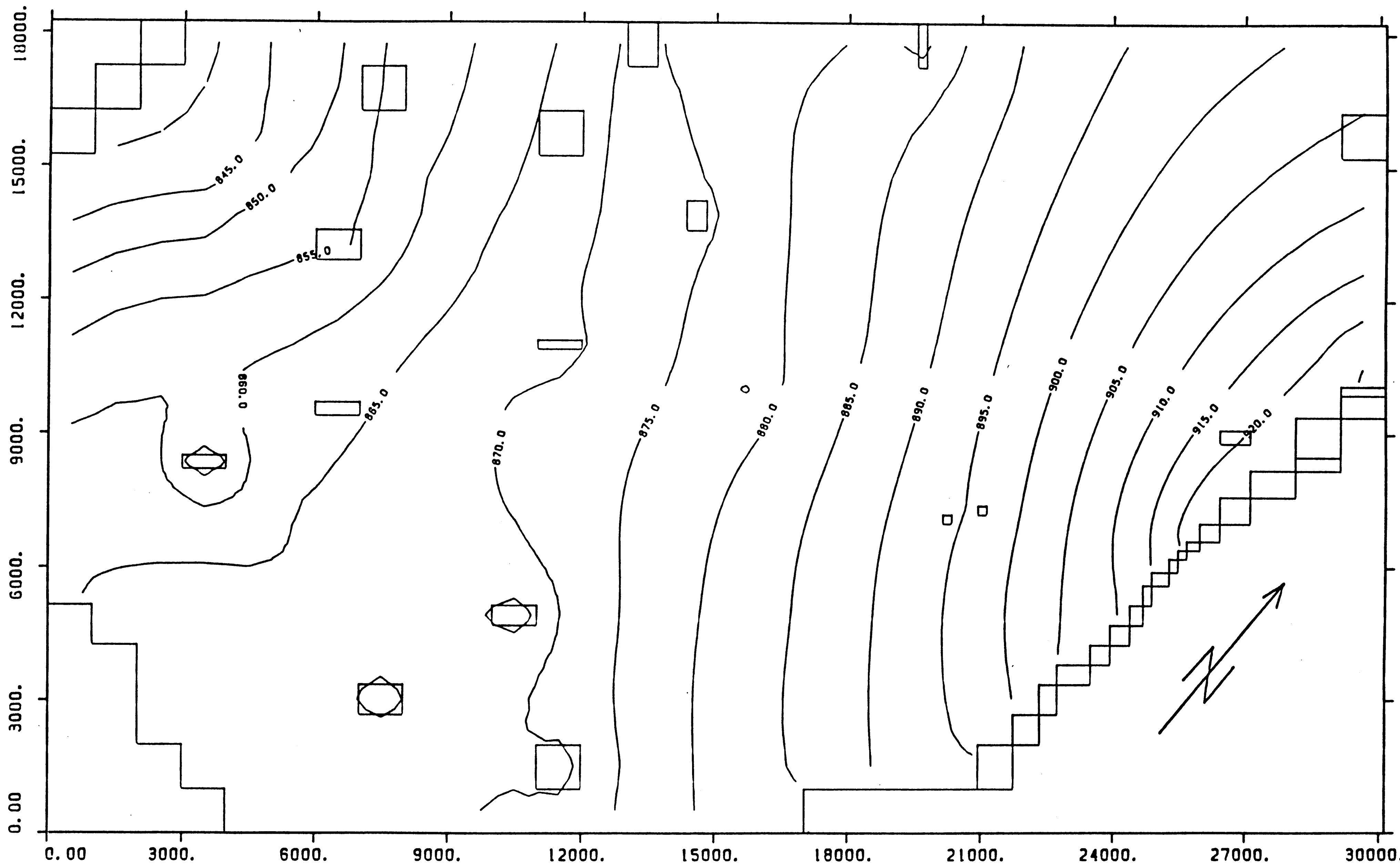



Scale 1" = 3000'

Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Figure 31c
Base Case 2, Alternative 5, Projected Water Level
for Year 2008, Sub-Unit B/C

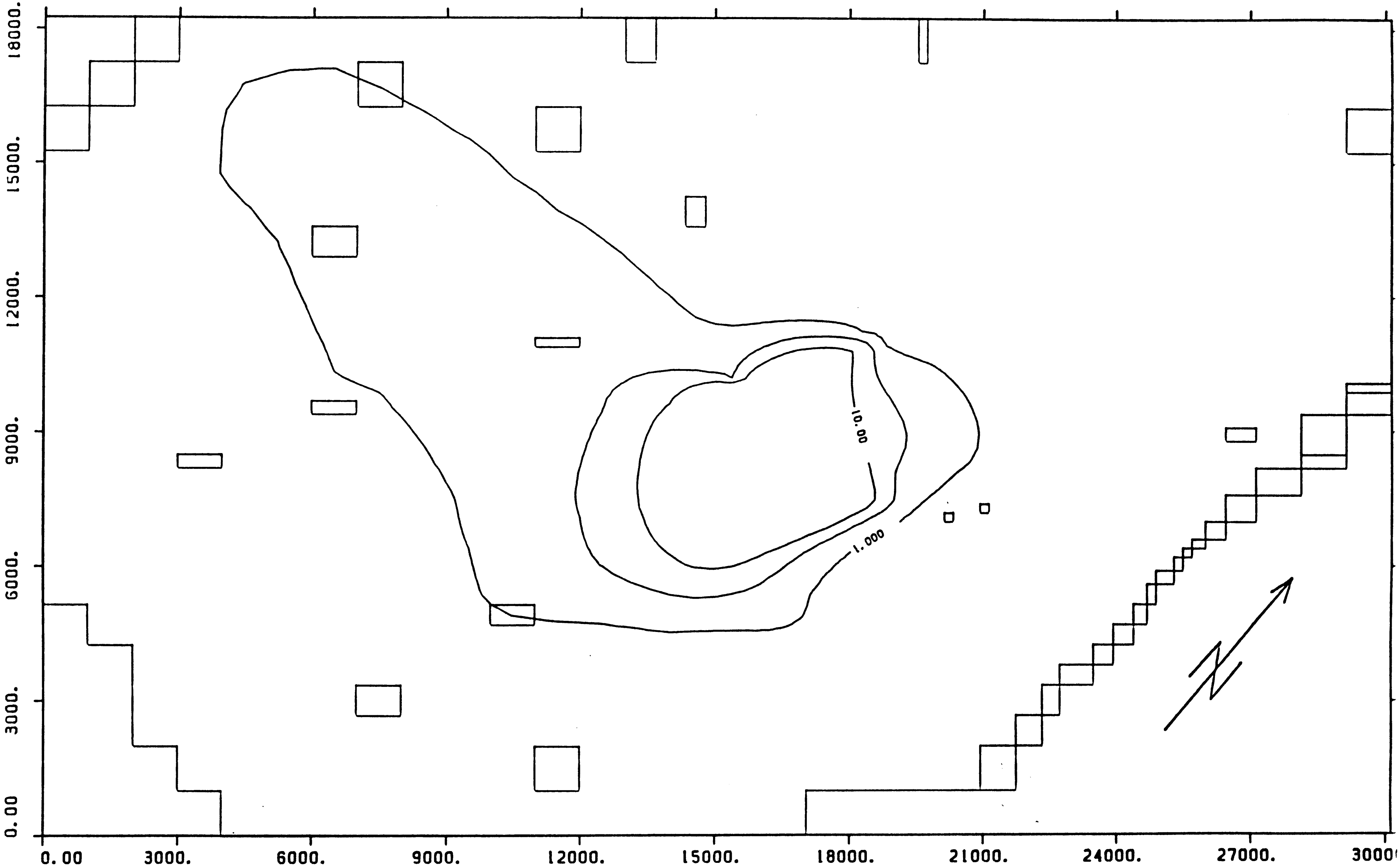



Explanation:

——900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 31d
Base Case 2, Alternative 5, Projected Contaminant
for Year 2008, Sub-Unit B/C

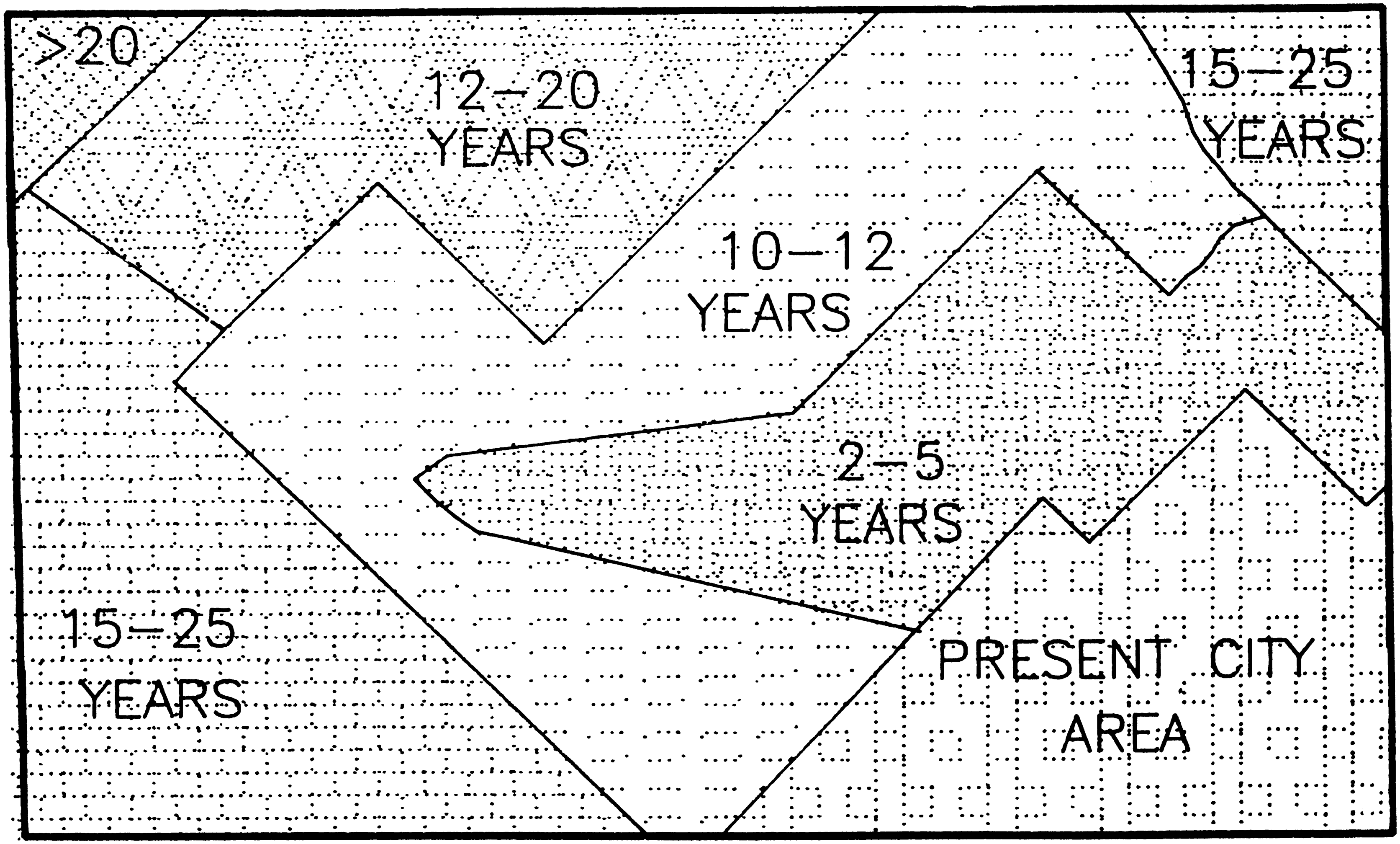



Scale 1" = 3000'

Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Figure 32

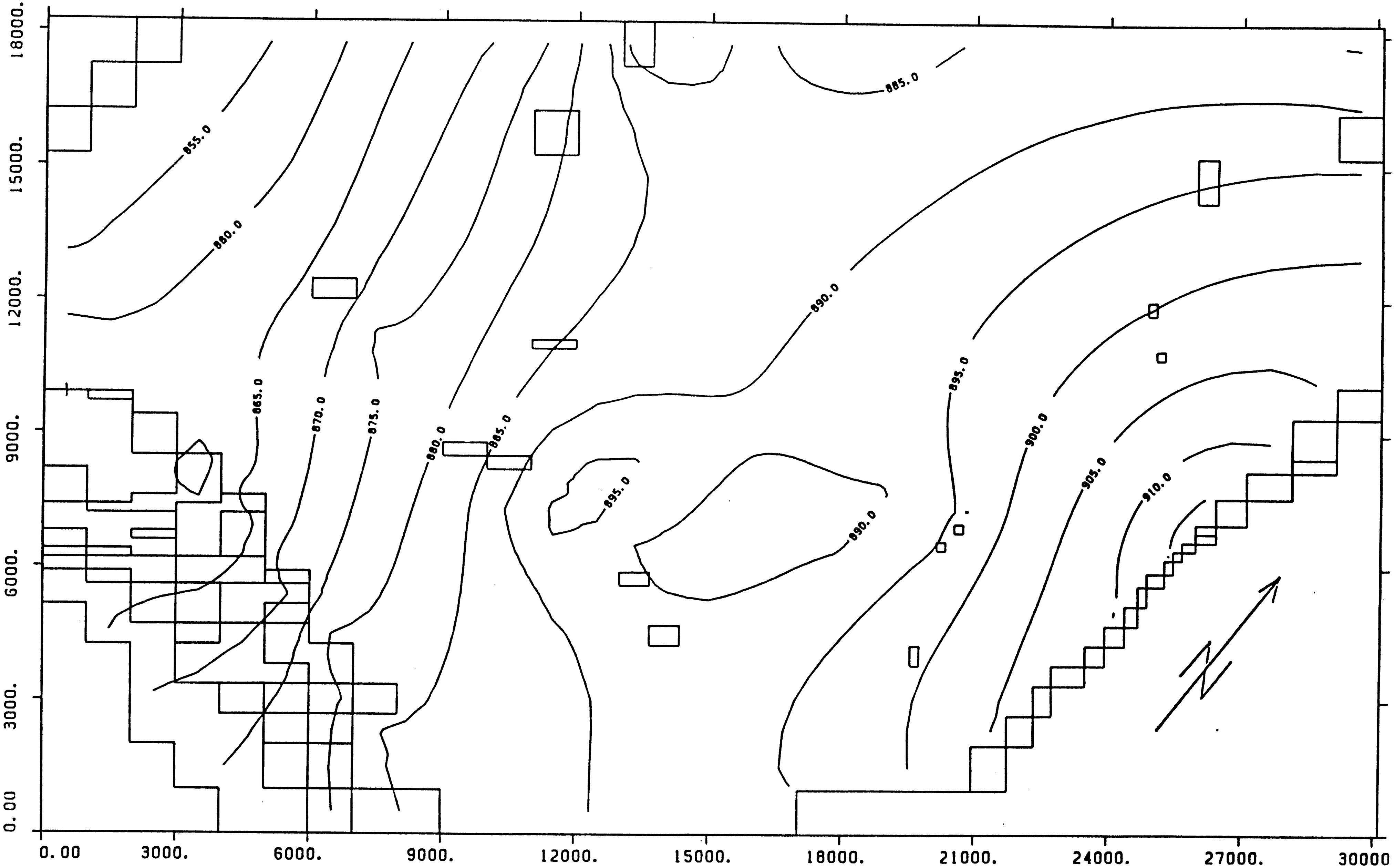



ESTIMATED GROWTH OF CITY OF GOODYEAR

Estimated years to development
is posted within planning areas.

N 1 MILE

Figure 33a
Base Case 3, No Action Alternative Projected Water Level
for Year 2008, Sub-Unit A



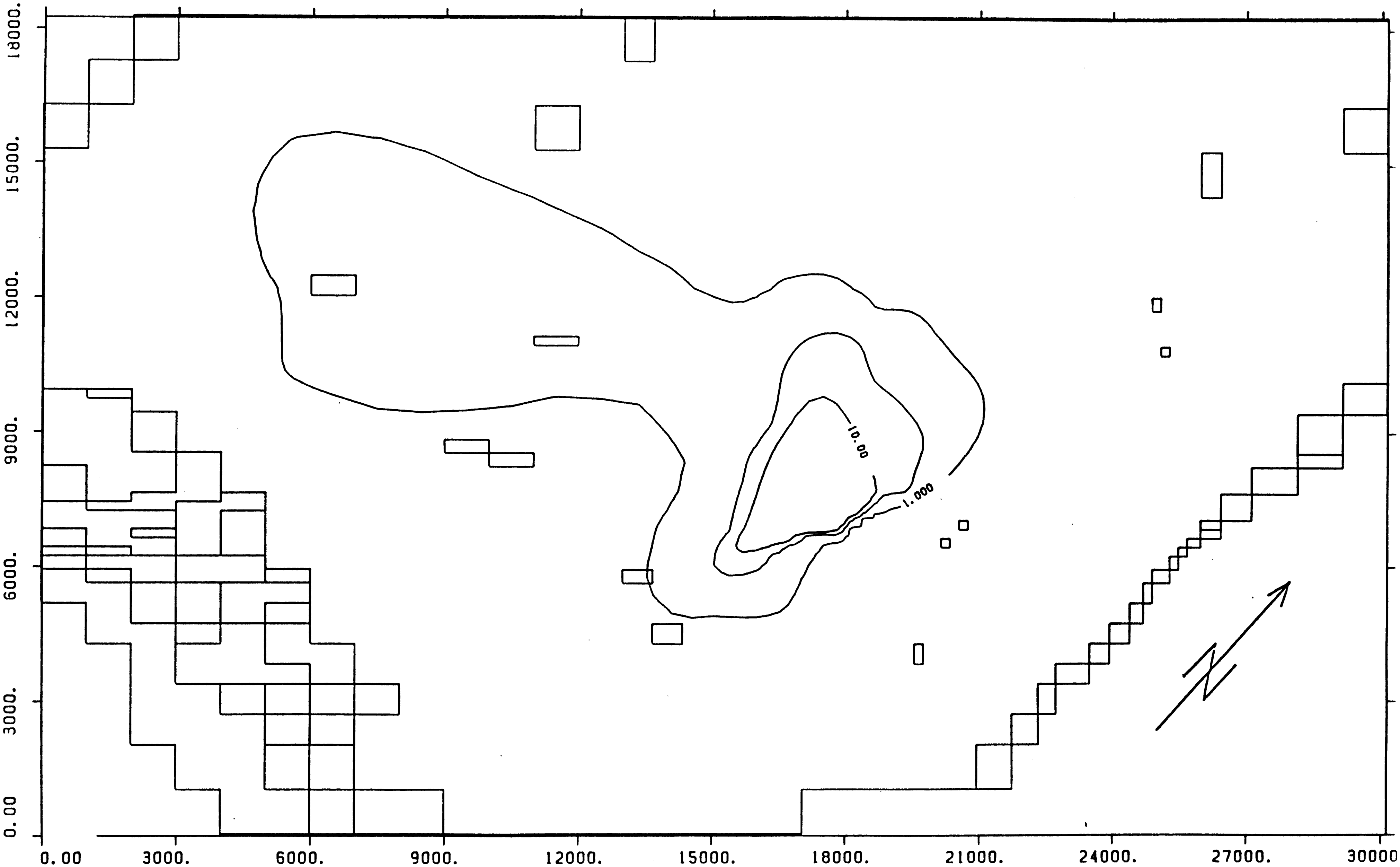

Scale 1" = 3000'

Explanation:

——900.0- Predicted Hydraulic Head

Figure 33b

Base Case 3, No Action Alternative Projected Contaminant for Year 2008, Sub-Unit A



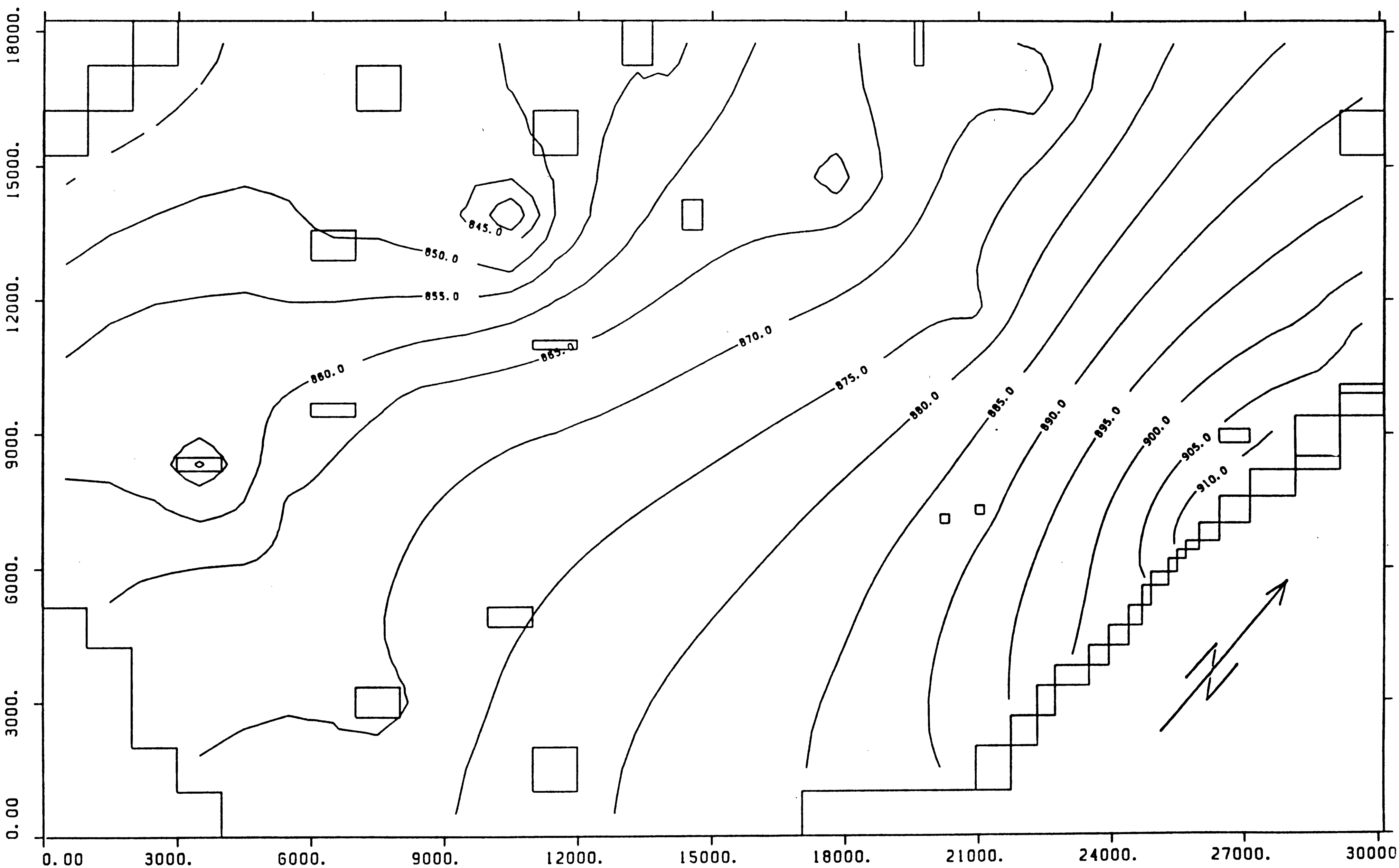

Scale 1" = 3000'

Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Figure 33c

Base Case 3, No Action Alternative Projected Water Level for Year 2008, Sub-Unit B/C

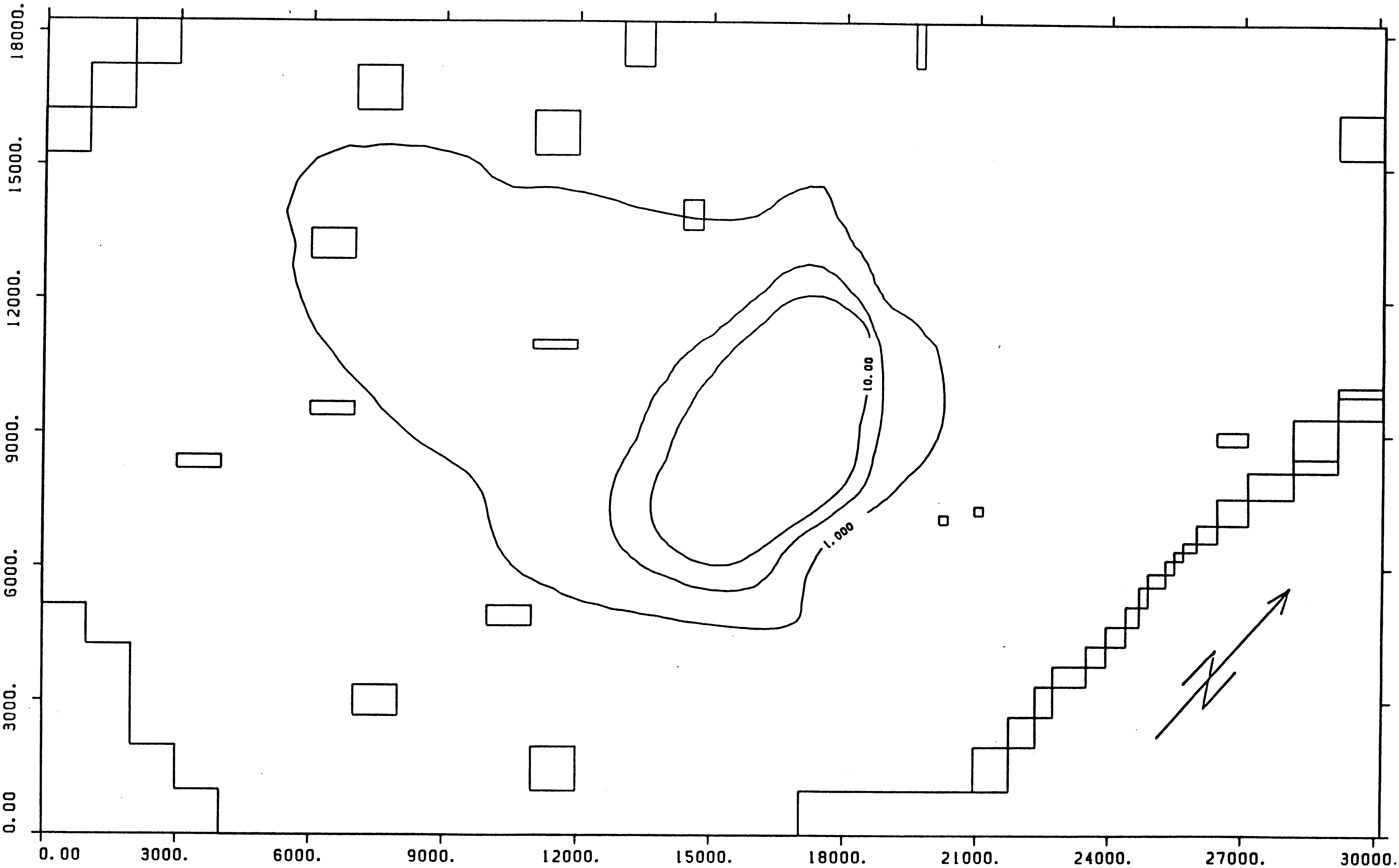



Explanation:

—900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 33d
Base Case 3, No Action Alternative Projected Contaminant
for Year 2008, Sub-Unit B/C

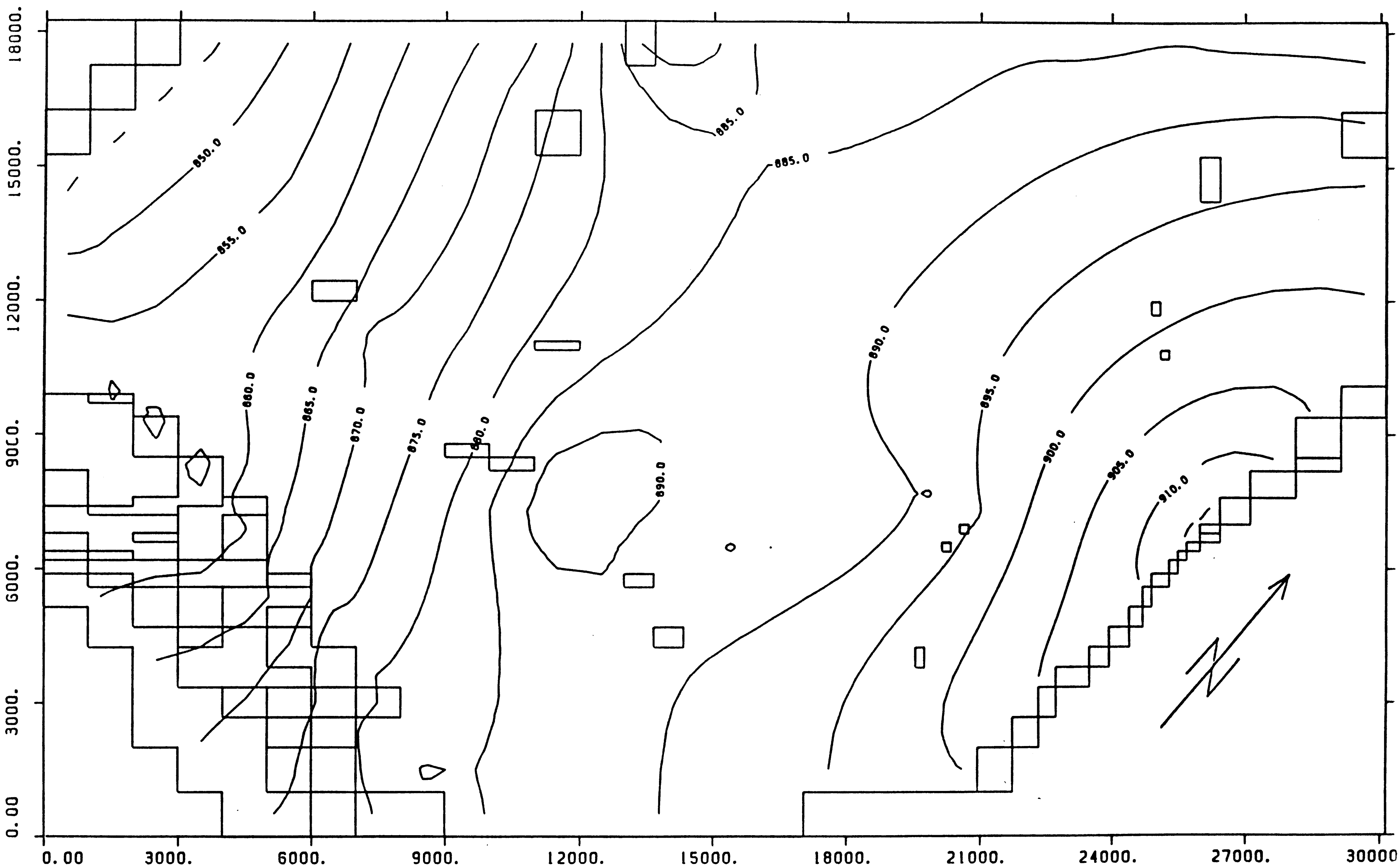



Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Scale 1" = 3000'

Figure 34a
Base Case 3, Alternative 3, Projected Water Level
for Year 2008, Sub-Unit A



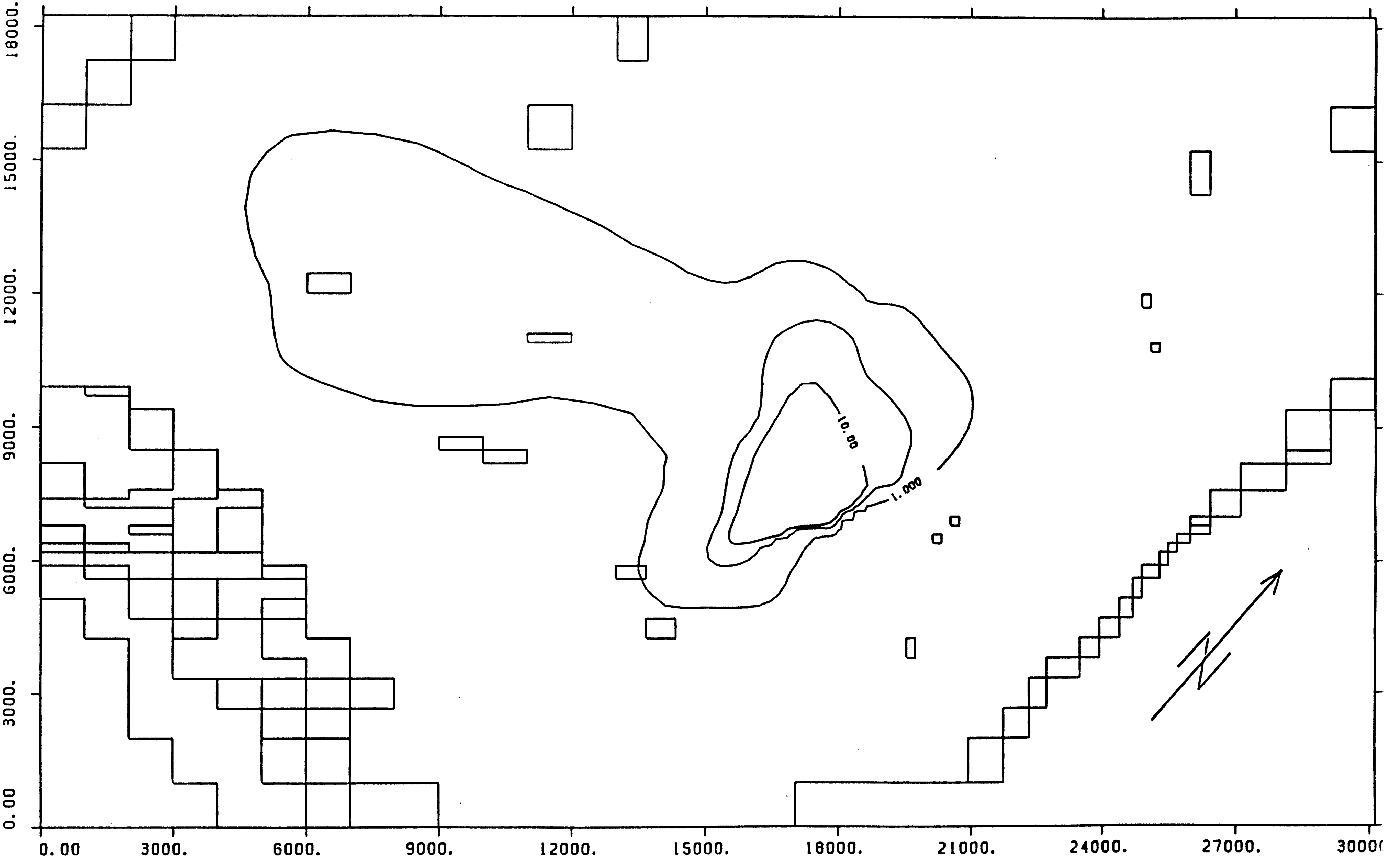

Explanation:

——900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 34b

Base Case 3, Alternative 3, Projected Contaminant for Year 2008, Sub-Unit A



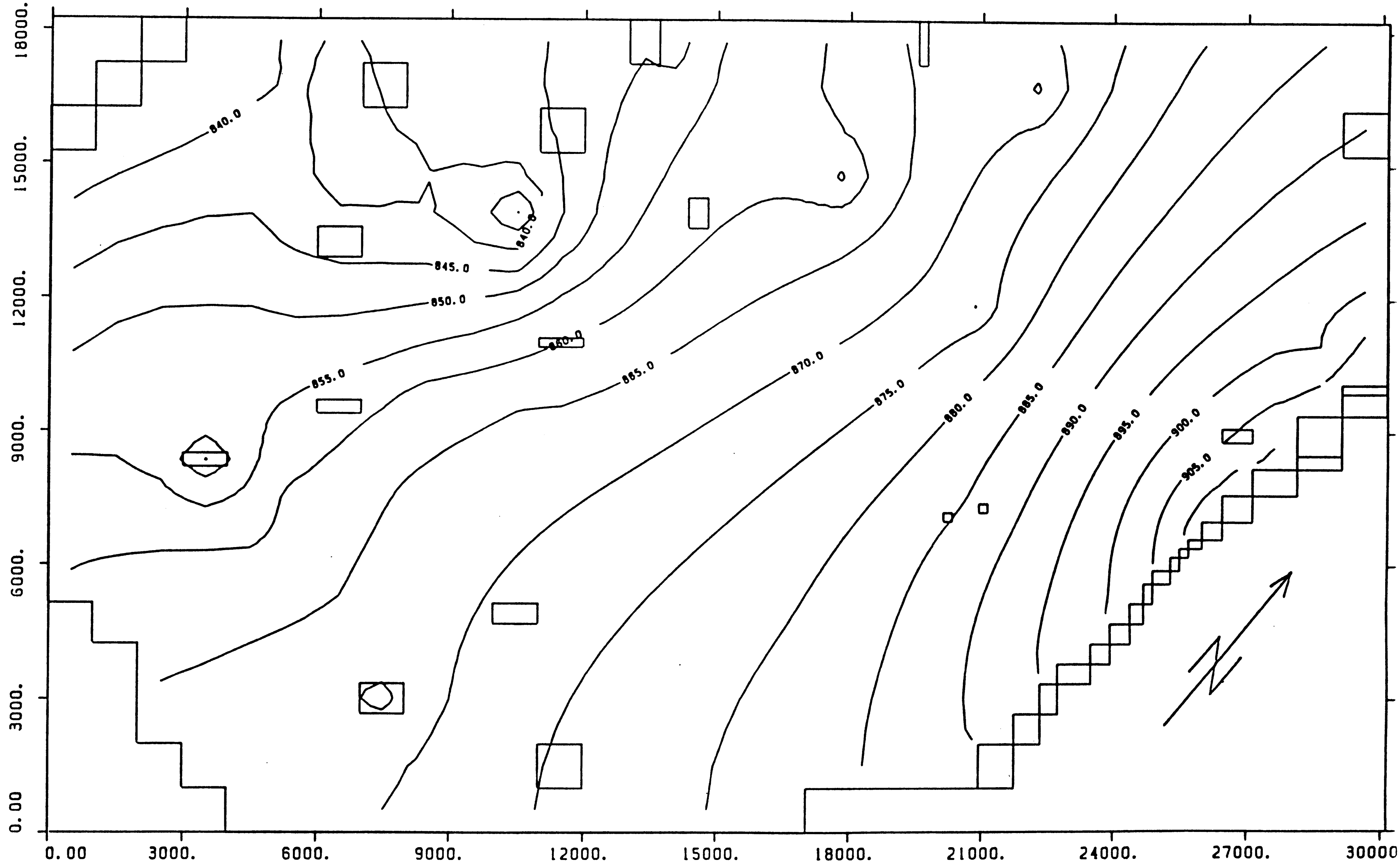

Scale 1" = 3000'

Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Figure 34c

Base Case 3, Alternative 3, Projected Water Level for Year 2008, Sub-Unit B/C

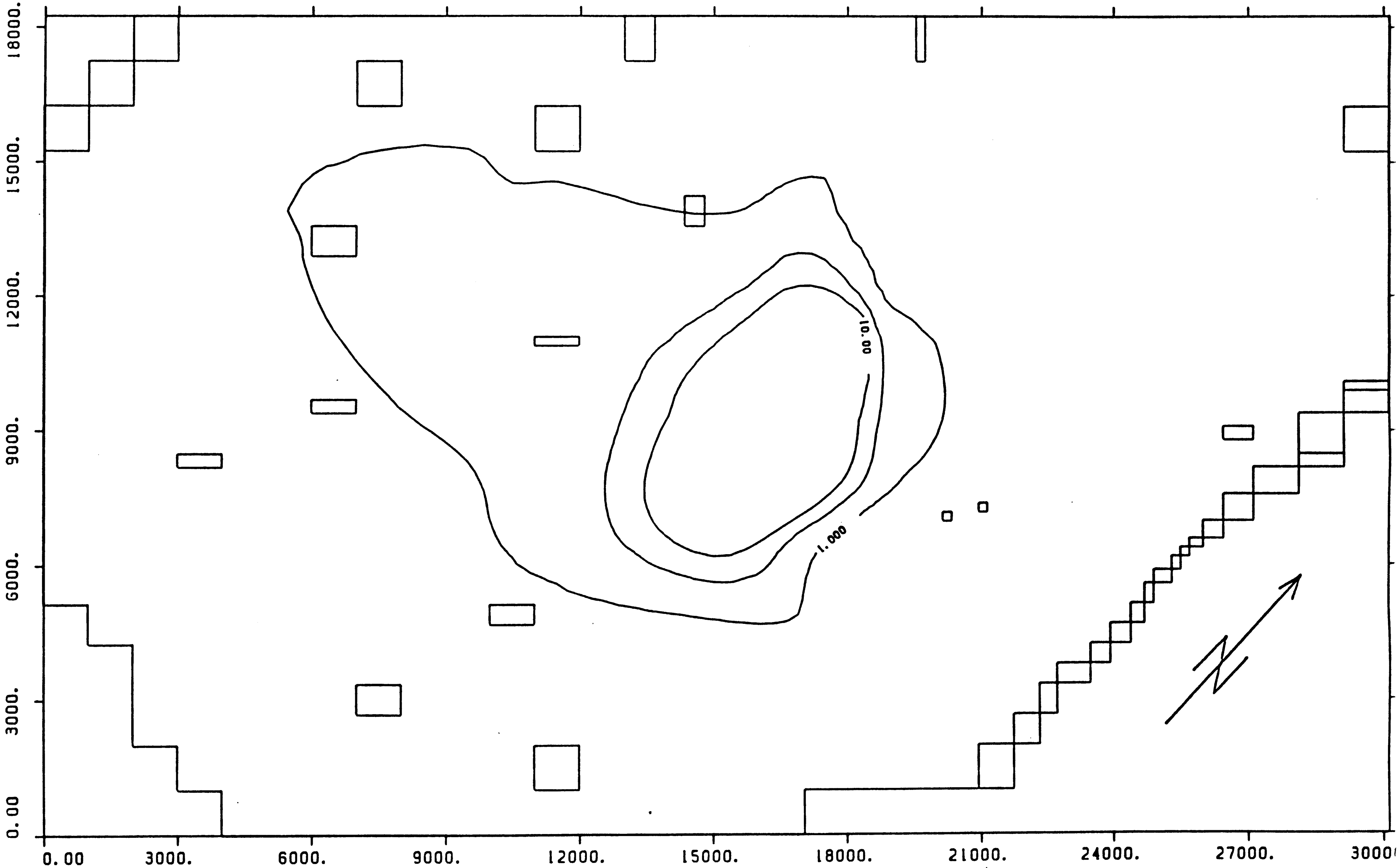



Explanation:

——900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 34d
Base Case 3, Alternative 3, Projected Contaminant
for Year 2008, Sub-Unit B/C



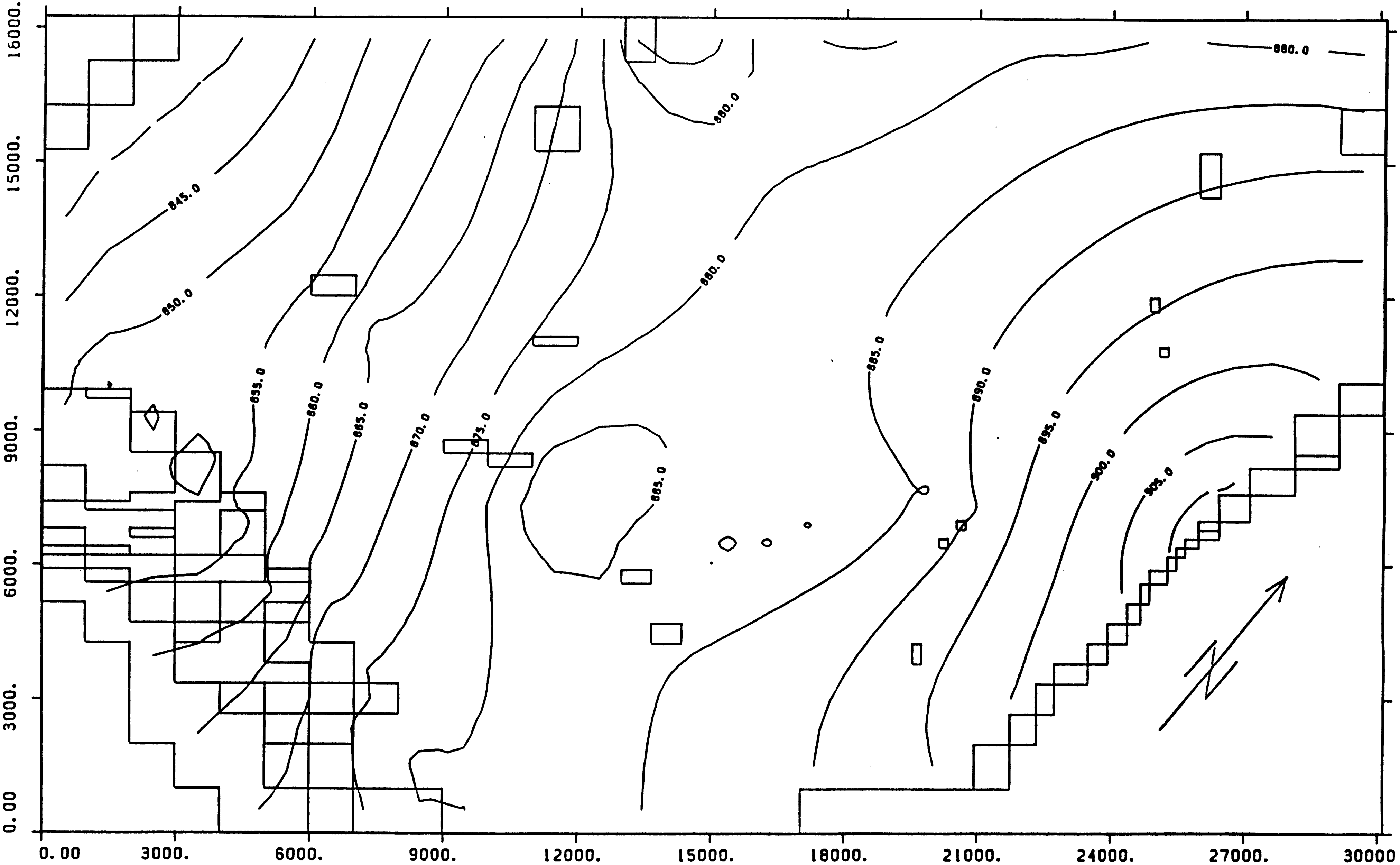

Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Scale 1" = 3000'

Figure 35a

Base Case 3, Alternative 4, Projected Water Level for Year 2008, Sub-Unit A

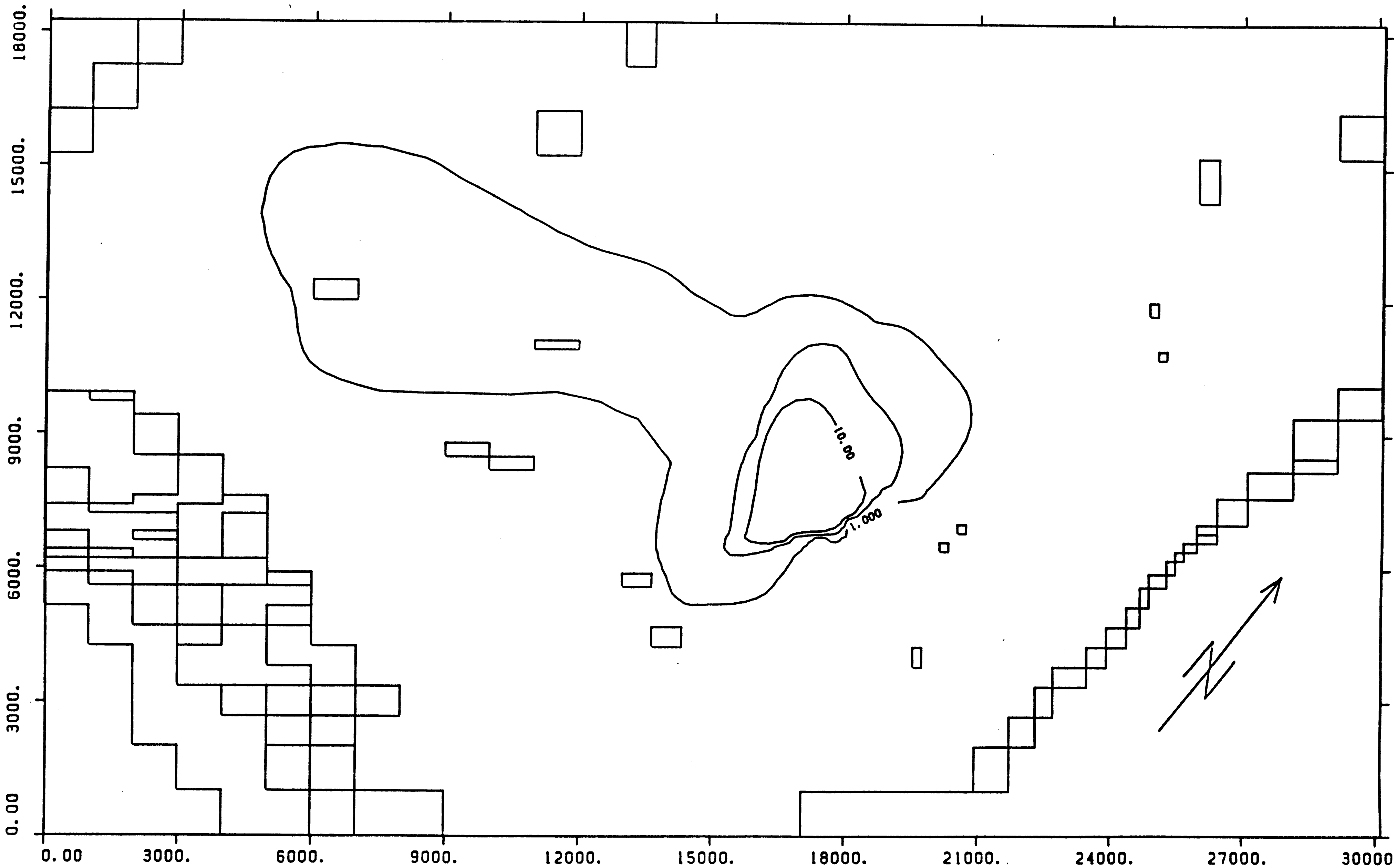



Explanation:

—900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 35b
Base Case 3, Alternative 4, Projected Contaminant
for Year 2008, Sub-Unit A

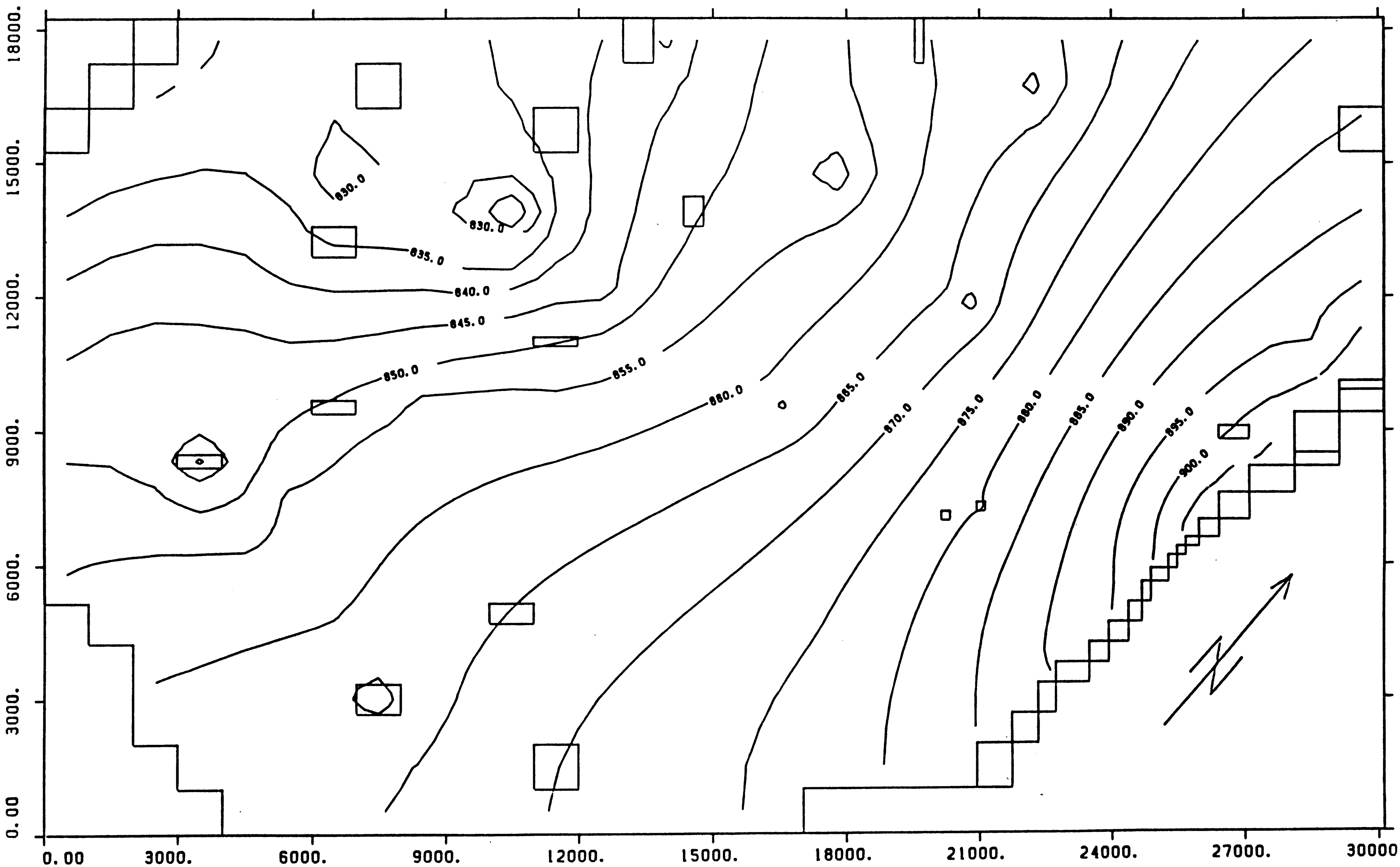



Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Scale 1" = 3000'

Figure 35c
Base Case 3, Alternative 4, Projected Water Level
for Year 2008, Sub-Unit B/C

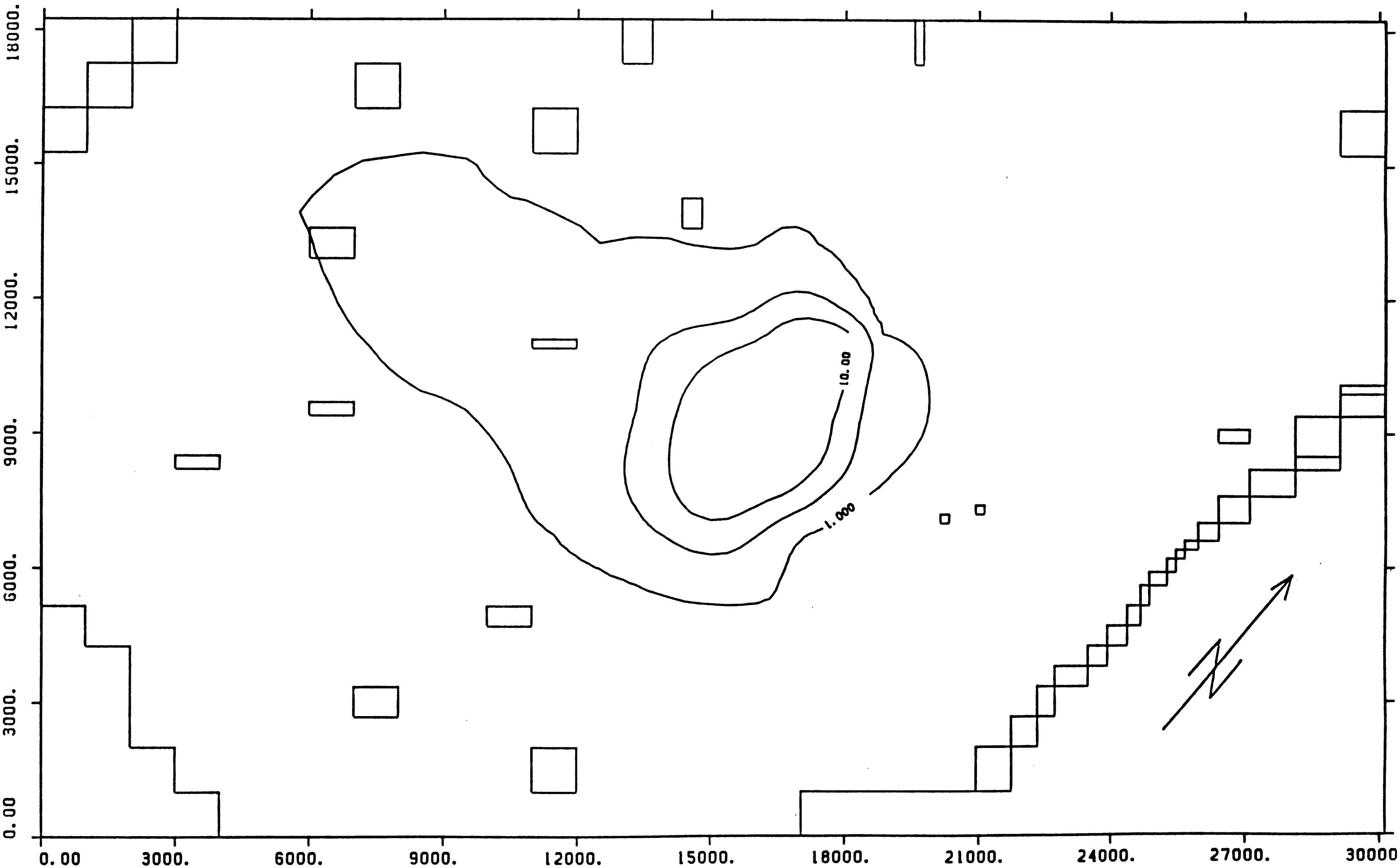



Scale 1" = 3000'

Explanation:

—900.0- Predicted Hydraulic Head

Figure 35d
Base Case 3, Alternative 4, Projected Contaminant
for Year 2008, Sub-Unit B/C

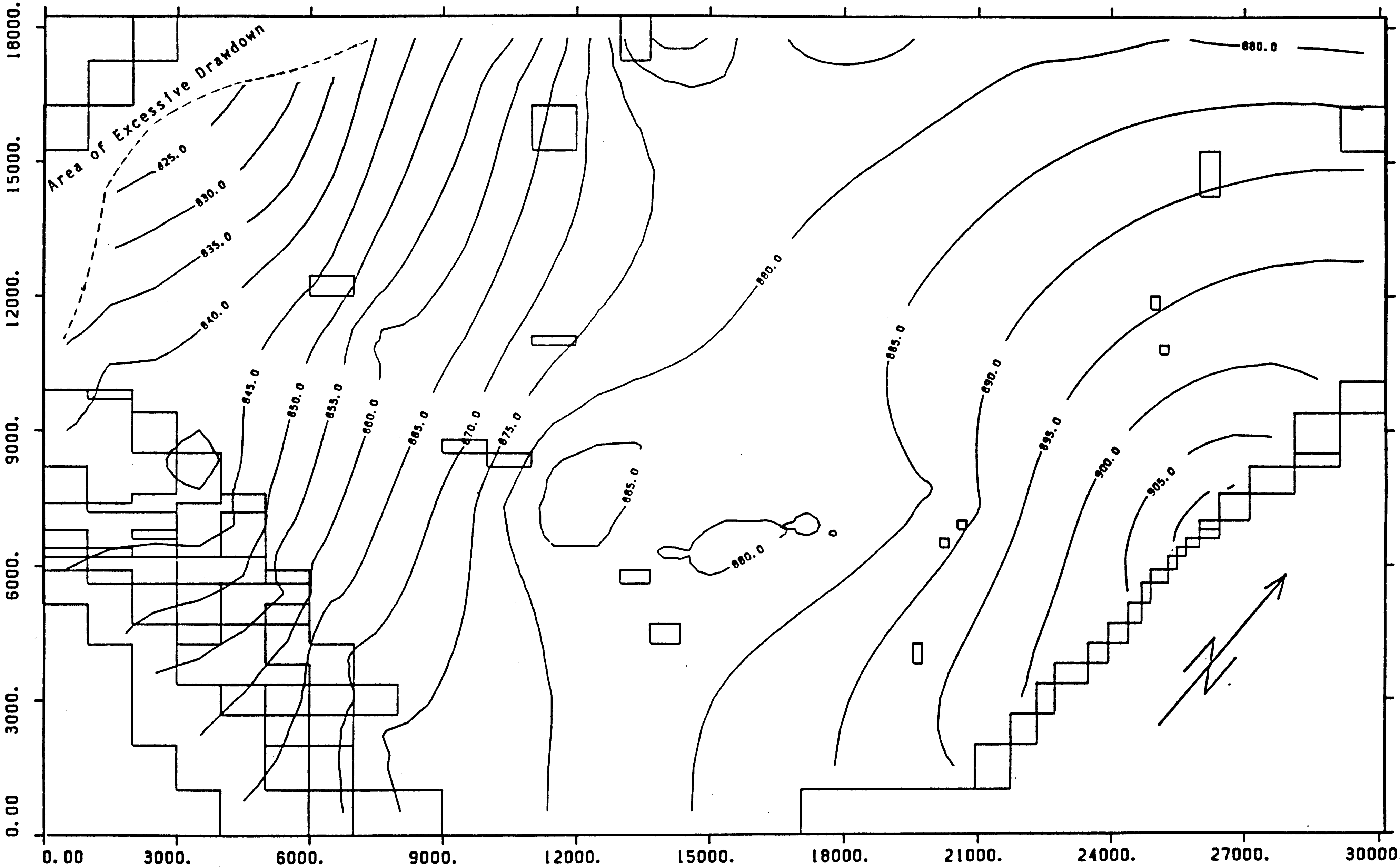



Scale 1" = 3000'

Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Figure 36a
Base Case 3, Alternative 5, Projected Water Level
for Year 2008, Sub-unit A

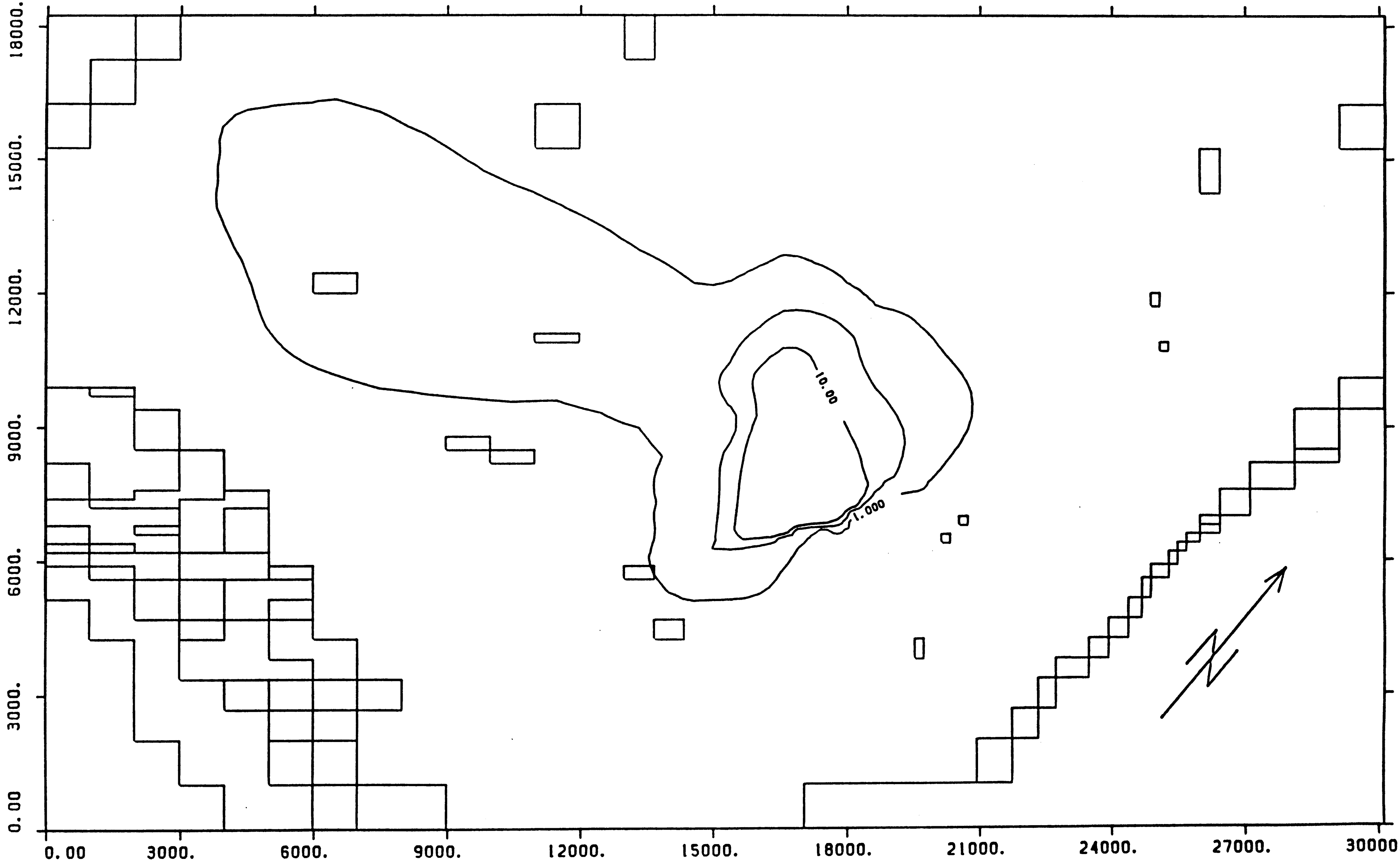



Explanation:
—900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 36b

Base Case 3, Alternative 5, Projected Contaminant for Year 2008, Sub-Unit A



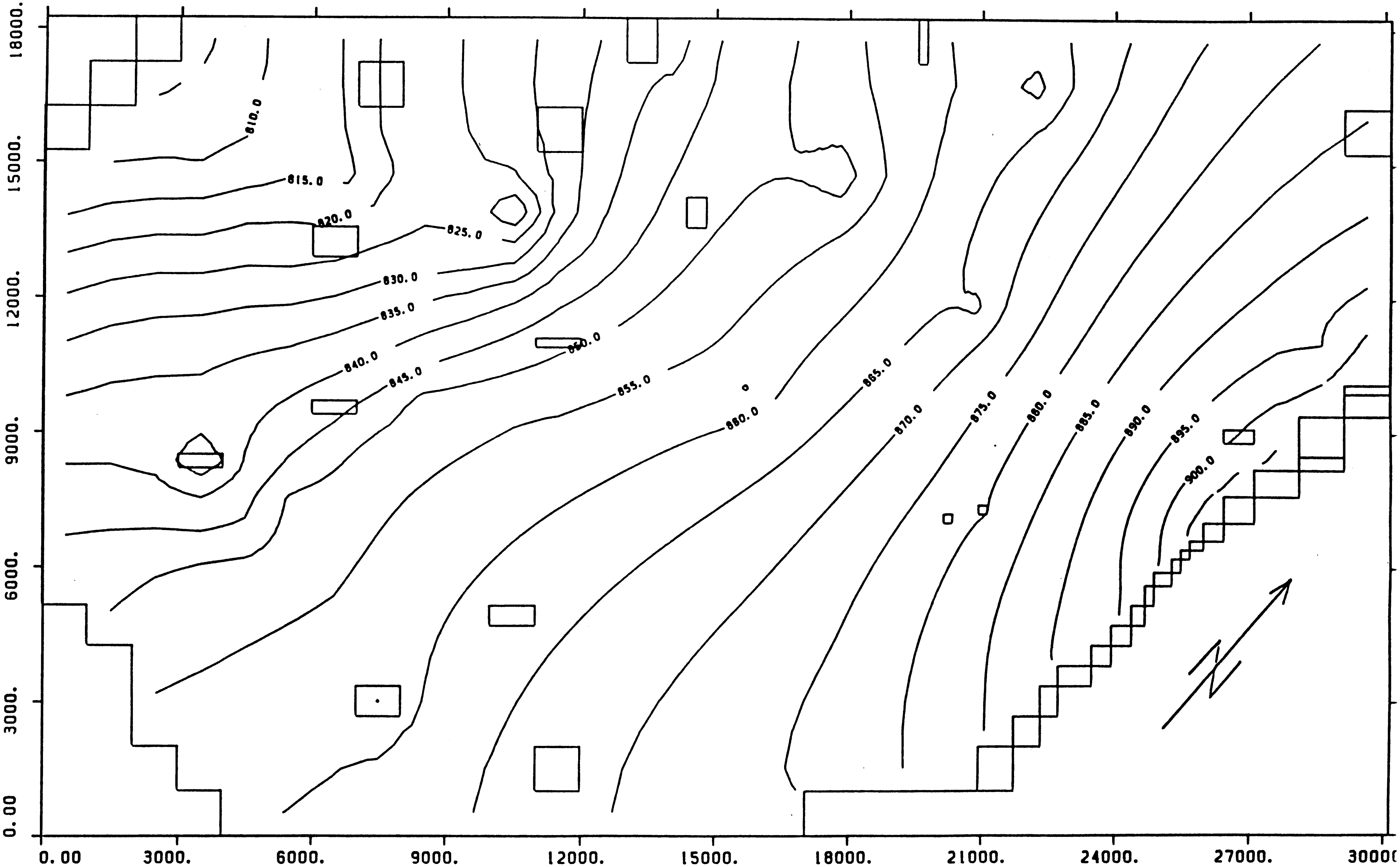

Scale 1" = 3000'

Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

Figure 36c

Base Case 3, Alternative 5, Projected Water Level for Year 2008, Sub-Unit B/C

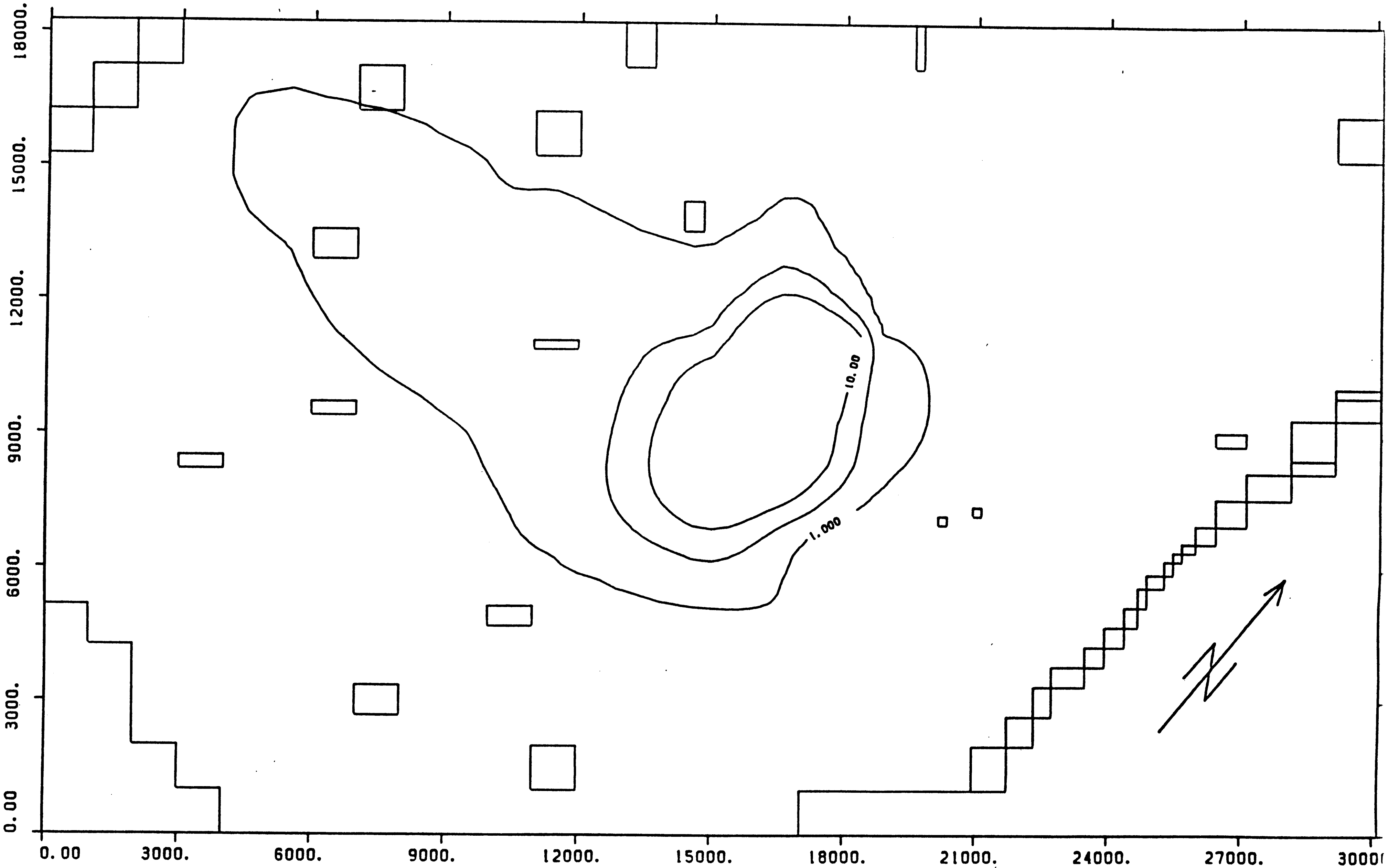



Explanation:

——900.0- Predicted Hydraulic Head

Scale 1" = 3000'

Figure 36d
Base Case 3, Alternative 5, Projected Contaminant
for Year 2008, Sub-Unit B/C




Scale 1" = 3000'

Explanation:

Predicted TCE Concentrations - Contour Values 1,5,10 and 100ppb.

# Appendix A:

Regional Two-Dimensional Groundwater Flow Modeling at the Phoenix-Goodyear Airport Site

**DEPARTMENT OF WATER RESOURCES**

**HYDROLOGY DIVISION**

**M E M O R A N D U M**

**TO:** PGA Modeling Sub-Committee Members

**FROM:** Greg Bushner

**DATE:** July 7, 1987

**SUBJECT:** Distribution of the Results of the Regional Two-Dimensional Groundwater Flow Modeling at the Phoenix-Goodyear Airport Superfund Site

Enclosed for your review and comment are the results of the 2-dimensional groundwater flow modeling at the PGA site. This phase of modeling has been ongoing for approximately a year and should facilitate the next phase of modeling which will include a more site-specific approach to the contamination problem at the PGA site. Comments concerning the enclosed memo would be appreciated by Friday, July 24, 1987. These comments will be applied to the 3-dimensional groundwater flow and contaminant transport models. Major comments concerning the 2-dimensional model results can be discussed at the Modeling Sub-Committee Meeting on July 16, 1987.

# MEMORANDUM

**TO:** PGA Modeling Sub-Committee Members

**FROM:** Greg Bushner and Mike Darr

**DATE:** July 7, 1987

**SUBJECT:** REGIONAL PGA TWO-DIMENSIONAL GROUNDWATER FLOW MODEL

This memo presents the results of the regional 2-dimensional groundwater flow model. Construction, calibration, and sensitivity analysis are covered, and the foundation is laid for the next phase of modeling at the PGA site. The memo is organized to include a discussion of purpose, scope, modeling approach, groundwater flow system assumptions, calibration results, sensitivity analysis, and conclusions. We are presenting the results of our work in this format to facilitate and expedite the review and comment process by the committee. However, this memo is a summary and will therefore not reflect the degree of detail to be found in the modeling report for the PGA RI/FS. Comments received concerning the 2-dimensional model will be considered and applied to the construction and calibration/verification process of the site-specific 3-dimensional groundwater flow and contaminant transport models.

## PURPOSE

The major goal of the 2-dimensional groundwater flow model was to define the boundary conditions for the site-specific 3-dimensional groundwater flow and contaminant transport models. In addition to the achievement of this goal a better understanding of the hydrologic system in the study area was attained. The calibration of the 2-dimensional model will facilitate the construction, calibration and verification of the 3-dimensional models.

## SCOPE

The scope of work for the 2-dimensional regional groundwater flow model covers the following tasks:

* Collect and analyze pertinent hydrologic data for the site including: well inventory, geologic log analysis, cross-section construction and analysis, facies map construction, water level map construction, aquifer parameter estimation, and pumpage, recharge and leakage estimates.

* Develop and maintain a data-base for the above data.

* Define the geohydrologic system within the study area.

* Define the boundary conditions for next phase of modeling.

* Conduct groundwater flow model calibration and perform sensitivity analysis.

* Prepare conclusions as a result of this model development.

## MODELING APPROACH

Inherent in a discussion of an approach to groundwater modeling of the PGA site is the basic characterization of the hydrologic system as it is today and more importantly how the system has behaved historically. The presentation at the May 20, 1987 Modeling Subcommittee meeting gave our basic understanding of the historic hydrologic system and the availability of data for the model. A short synopsis of that presentation is given below.

Historic hydrologic conditions are illustrated in figures 1 through 7. These water level maps were constructed for the years with the most available water level data from wells completed only in the Upper Alluvial Unit (UAU). They illustrate the availability of water level data and how the system has behaved historically.

UAU water levels, gradients and flow directions have changed drastically during the past forty years. Water levels declined prior to the mid-1960s due to increased agricultural pumpage, as is apparent by a comparison of the 1945 and 1962 water level maps (figures 1 and 2). As a consequence, the UAU was largely dewatered and agricultural users were forced to deepen their wells and withdraw water from the underlying Middle Fine-grained Unit and Lower Conglomerate Unit (MFU and LCU, respectively). During the mid-1960s there were many changes in the hydrologic system as shown in the 1962 water level map (figure 2). Pumping centers apparently were numerous and large, and groundwater flow directions and hydraulic gradients were erratic and often different than the present system. Also during this time the UAU began to accumulate water in storage from recharge from overlying agricultural land and from effluent discharged from the 23rd and 91st Avenue Waste Water Treatment Plants to the Salt River above the confluence with the Gila River. Effluent discharge increased steadily from the early 1960s to the present as shown in figure 8. Water levels in the UAU began to rise in the mid-1960s and currently they are rising 1 to 2 feet per year. Since at least the early 1970s to the present, the hydrologic system has shown the same trends, as illustrated by a comparison of figures 3 through 7.

One of the most important considerations in deciding how to approach the hydrologic situation at this site is the availability of historic data. Prior to the 1960s, data are sparse; however, after that time more data have become available. At the present time, much of the information needed is known about the site, although only for the last few years.

Because of poor data and a major change in the hydrologic system, modeling of the site prior to the mid-1960s is not feasible. It was not until the mid to late 1970s that enough information became available to develop a reasonably detailed water budget. For these reasons the modeling approach has been to concentrate on the years with the most available data, from 1978 to the present. Calibration of the 2-dimensional groundwater flow model is to 1985 hydrologic conditions because of the available 1985 water level map. The 3-dimensional models will be calibrated to 1986 field data.

## GROUNDWATER FLOW SYSTEM ASSUMPTIONS

A discussion of the conceptual groundwater flow system is necessary in order to make the appropriate assumptions to model the system. The conceptual system is discussed below, followed by the major groundwater flow system assumptions.

A conceptual representation of the hydrologic system within the model area is presented to figure 9. This figure illustrates all of the major items that impact the hydrologic system within the model area. The southern model boundary is considered to be a no-flow hard rock boundary formed by the Sierra Estrella Mountains. The northern, eastern, and western boundaries are considered to be specified flux boundaries. The generalized flow direction after the mid-1960s is from west to east with minor components of northwesterly and southwesterly flow.

Groundwater recharge due to agriculture, canal leakage, gravel pits, agricultural tailwater sumps, sewage disposal pits, and the Agua Fria River are the major items contributing water to the system, in addition to groundwater inflow through the eastern boundary. Groundwater pumpage from wells perforated in the UAU and from composite wells (perforated both in the UAU and MFU) are major items extracting water from the system. Groundwater also leaves the model area as outflow through the northern and western boundaries.

Other major features that impact the hydrologic system include the Gila River and effluent discharged into the Salt River from the 23rd and 91st Avenue Wastewater Treatment Plants. Effluent flow has made the Gila River a perennial stream in the model area. Gila River low-flow stages are approximately one to three feet in the model area. It is assumed that from the mid-1970s to the present the UAU has been in hydraulic connection with the (effluent) flow in the Gila River channel.

Another important aspect of the hydrologic system in this area is the connection between the UAU and MFU aquifers. It is assumed that the UAU is vertically leaking some amount of water into the MFU. A second layer has been added to the model to simulate this connection. The amount of water contributing to this leakage has not been quantified at this time. Modeling efforts for the 2-dimensional regional groundwater flow model have focused on the UAU aquifer, and not on the MFU.

The important groundwater flow related assumptions relevant to the modeling are listed below:

* **Available water level data adequately represent the system.** The historic water level maps (figures 1 through 7) are the basic tools used in modeling this area. These maps are based on the best available data. Their accuracy becomes better as more data have been collected in recent years (see figures 6 and 7).

* **Static water level measurements taken during the winter months are representative of the site when the hydrologic system is considered to be the most quiescent.** Changes in the system during this period of time are assumed to be a direct result of the hydrologic system's adjustment to major influences and not to manmade influences such as local pumpage. All model simulations are calibrated to winter water levels (October through March).

* **The UAU is "leaking" water into the MFU.** This assumption is necessary because the base of the UAU cannot be a no-flow boundary. Therefore some type of hydraulic connection between the UAU and MFU is simulated in the model.

* **The Gila River within the model boundaries is in direct hydraulic connection with the UAU aquifer.** It is not known whether this reach of the Gila River is a losing or gaining stream. However, for the purpose of this model this reach is assumed to be neither gaining nor losing, but rather in equilibrium, so that the stream does not contribute water to the system in the sense of surface water recharge.

* **Composite wells (wells perforated in both the UAU and MFU) are withdrawing a certain amount of water from the UAU based on the permeability and saturated perforated thickness of the UAU as compared to the saturated perforated thickness and permeability of other layers open to the well.** Composite wells do extract water from the UAU, but the precise proportion is unknown. Therefore, this simplifying assumption is necessary.

* **Evaporation of groundwater from the water table is considered negligible.** This is due to the fact that the depth to water in most of the study area is greater than 20 feet, therefore this assumption is appropriate.

* **Recharge from precipitation is considered negligible in the model area.** This is because depth to water considerations preclude effective recharge by direct precipitation. Also, annual precipitation averages about 6 inches at the site, while annual open-water evaporation averages more than 6 feet.

These assumptions were made on the basis of what was felt appropriate and although the majority of these assumptions cannot be quantified the behavior of the system based on these assumptions can be scrutinized through the sensitivity analysis that follows the calibration results. This will help in defining a set of useful parameters, thereby providing a basis from which to work in the next phase of modeling.

## CALIBRATION RESULTS

The results of the regional 2-dimensional groundwater flow model calibration are presented in Table 1, entitled: Model Calibration. Table 1 contains the majority of model runs presented in chronological order. Modifications, results and comments made for each run are listed as well as the recommendations for the next run. A brief discussion of the model calibration results is provided below.

Model runs 1 through 4 consisted of initial water budget parameter estimates for the period 1978-1982. These runs were made with the available data at that time in order to begin the modeling process. Water budget and aquifer parameter estimates were refined as the model was being built and as new data became available. In model runs 1 through 4, ending heads were far too high and the groundwater flow direction was to the north-northwest instead of to the west. Undesirable results were due in part to the lack of data on aquifer parameters and recharge estimates. Therefore, aquifer parameters were revised using the Drillers Log Program. The results were presented to the modeling subcommittee at the February 4, 1987 meeting and in the memorandum to the Modeling Subcommittee dated March 11, 1987. A revised conceptual water budget was also presented to the modeling subcommittee in the memo dated March 11, 1987.

Many parameters were changed in model runs 5 through 7. These runs consisted of changing water budget and aquifer parameters to agree with the memos sent to the Modeling Subcommittee March 11, 1987. These revisions were based on the results from the initial model runs. Model run 5 was presented to the Modeling Subcommittee at the meeting of March 18, 1987. Ending heads for 1982 from model run 5 were contoured and compared with sparse field data. This comparison showed a good match in the northern model area; however, the heads in the southern model area were still too high by approximately 30 feet in the southeast. The overall flow direction in this model run was to the northwest, instead of the westerly flow direction indicated by field data. In model run 7 effluent recharge and BIC Canal recharge were halved because ending heads were too high as discussed above. The results from model run 7 showed that the ending heads dropped approximately 10 to 15 feet in the southern model area. Therefore this type of approach was thought necessary to calibrate the model.

Model runs 8, 9, and 10 experimented with keeping the river cells at a constant head. This resulted in the desired effect of reducing water levels along the river; however, it produced other undesirable effects such as altering the flow direction, exaggerating pumping centers in the northwest and bowing of contour lines upgradient more than one mile in the southwest.

Model run 11 consisted of adjusting model parameters to allow leakage downward to the MFU. These adjustments had virtually no effect on ending heads in the UAU, but MFU ending heads dropped slightly instead of being equal to UAU heads. Field data indicate that MFU heads are about 10 feet lower than UAU heads.

Model runs 12 and 13 consisted of breaking the water budget period into three stress periods, simulating times in which a stress or stresses on the system remained "constant." These stress periods coincided with periods of high, low, and moderate yearly flow in the Gila River during the water budget period from 1978 to 1982. Total surface water recharge was also approximately halved in order to lower ending heads in the southern part of the model area. Ending heads for these runs rose in the west and dropped in the east, and results from these runs compared fairly well with field data. However, the eastern area showed a northwest (instead of west) flow direction and cones of depression from pumping centers were still far too large in the northwest.

It was felt at this time nothing more was to be gained from adjusting parameters for the water budget period (1978-198) because 1982 field data were quite poor. Therefore, the model simulation period was extended in time to the present when field data are more complete. Seven stress periods were simulated during the time period from 1978 to 1986. The last 4 stress periods (4 through 7) cover the years 1983 through 1986. Model run 14 includes these additional stress periods and sets boundary conditions for them. Comparison of this run with 1985 field data showed an overall flow direction to the northwest instead of to the west, and ending heads were about 10 feet too high in general.

At this point the system was reconceptualized to reflect the hydraulic interconnection of effluent streamflow and the adjacent UAU aquifer. This idea was based mainly on water balance studies by Halpenny and others (1974 and 1975). These studies showed that the effluent in the Gila River channel had waterlogged the adjacent aquifer by the mid-1970s, so that virtually no effluent could infiltrate. A decision was made not to assign recharge to cells where surface water and effluent flow were present, but rather to model the perennial Gila River as a stream with a stage from 1 to 3 feet for the periods 1978-1982 and 1983-1986, respectively. To further aid in lowering ending heads and to build a more complete data set, composite pumpage was taken into account by calculating proportions of composite pumpage from the UAU. Proportioning of UAU pumpage from composite wells was achieved by considering saturated perforated thickness in the UAU as compared to total perforated thickness, and by considering the permeability differences between the UAU and the other hydrogeologic units open to well.

Model run 15 is the result of deleting all effluent and surface water recharge, using the "river package" of the numerical model and revising recharge for the SRP canal based on a field inspection of the canal. This run showed a much better match with 1985 field data and groundwater flow direction changed to a generally westward direction. In the western area ending heads were still too high by approximately 5 to 10 feet. Model run 16 included pumpage attributable to the UAU from composite wells. This resulted in a good match with 1985 field data, and ending heads dropped approximately 10 feet in the west thereby sufficiently calibrating the model. Model runs 17 through 20 include minor revisions to the model necessary to attain the best match with 1985 field data. Figure 10 illustrates the results of the final, calibrated run. Figure 11 compares 1985 model-simulated heads with field data, and it can be seen that the contour lines match to within 5 feet of each other.

A revised conceptual water budget for the period 1978-1982 which includes all changes made in the calibration process appears in Table 2. A mass-balance water budget generated by the numerical model is also included in Table 3. The greatest disagreement between the conceptual and model-simulated water budgets involves groundwater inflow and outflow across the specified-flux boundaries. This is mostly due to a change in groundwater flow direction from

1978 to 1982 from northeasterly to westerly (compare figures 3 through 7). The change in flow directions produced less outflow across the northern boundary than was estimated in the conceptual water budget.

## SENSITIVITY ANALYSIS

Individual model parameters were varied in a sensitivity analysis to determine their effects on 1985 ending heads and to define a range of reasonable values. Changes in model parameters which do not alter 1985 UAU ending heads by more than 5 feet are considered to be within a range of reasonable values. Sensitivity runs were compared to the calibrated 2-dimensional regional groundwater flow model 1985 ending head map (figure 10). Details of the sensitivity analysis are presented in Table 3. In summary, the model is most sensitive to variations in UAU hydraulic conductivity, storage coefficient, specified flux across model boundaries, and recharge.

The UAU aquifer parameters of hydraulic conductivity and storage coefficient are input into the calibrated model as a heterogeneous array of values ranging from 250 to 1500 gpd/sqft and from .06 to .21, respectively. The average values of hydraulic conductivity and storage coefficient in the UAU were determined by the Drillers Log Program to be 762 gpd/sqft and .15, respectively. These values may be increased or decreased by 25% without significantly altering model results.

Sensitivity runs were also made using homogeneous values of hydraulic conductivity. Results show that the average hydraulic conductivity value of 762 gpd/sqft may be varied by from -0% to +40% without significantly altering model results. This suggests that the average value of 762 gpd/sqft may be rather low in terms of model sensitivity.

Values in the entire recharge array can be increased or decreased up to 50% of the total input values without significant alterations to model results. The model is more sensitive, however, to variations in recharge from individual sources within the overall recharge package, most importantly canal, surface water, effluent, and agricultural recharge. For example, recharge from the BIC Canal, located in the southwestern part of the model area, was halved in model run 17 (see Table 1). Ending heads in 1985 dropped by about 5 feet in the southwest model area as a result. The effect of SRP Canal recharge is also pronounced in the southeast part of the model area, as illustrated by model runs 7 and 13 (see Table 1). The model is also sensitive to recharge from effluent and surface water sources, as shown in model runs 1, 2, and 15. Agricultural recharge covers most of the PLA area, so its effects on model results are probably illustrated by the plus or minus 50% value discussed in the first part of this paragraph.

Variations in boundary conditions strongly influence model results in those cells near to the specified flux boundaries. These effects extend into the model area from the boundary a distance of 3 or 4 cells, while the interior of the model area is usually not affected greatly.

Model-simulated 1985 ending heads are not sensitive to variations in aquifer parameters in the MFU (layer 2). In general, minimal interconnections of the UAU and MFU is assumed in the model input, because layer 2 (MFU) aquifer parameters can be varied several orders of magnitude without significantly altering layer 1 ending heads.

## CONCLUSIONS

The following conclusions can be summarized at this time:

* Table 2 (Water Budgets) illustrates water budget values that provide the best matc h between predicted and observed water levels. This table includes the range of reasonable values used and the mass-balance water budget generated by the model.

* The northern, eastern, and western boundary conditions have been defined as specified flux. The 2-dimensional regional groundwater flow model served its purpose by quantifying hydrologic conditions for input into the smaller, more site-specific 3 dimensional models. This includes new boundary conditions and all other previously specified parameters.

# Figures

Figure 1
1945 UAU WATER LEVEL CONTOUR MAP FROM FIELD DATA

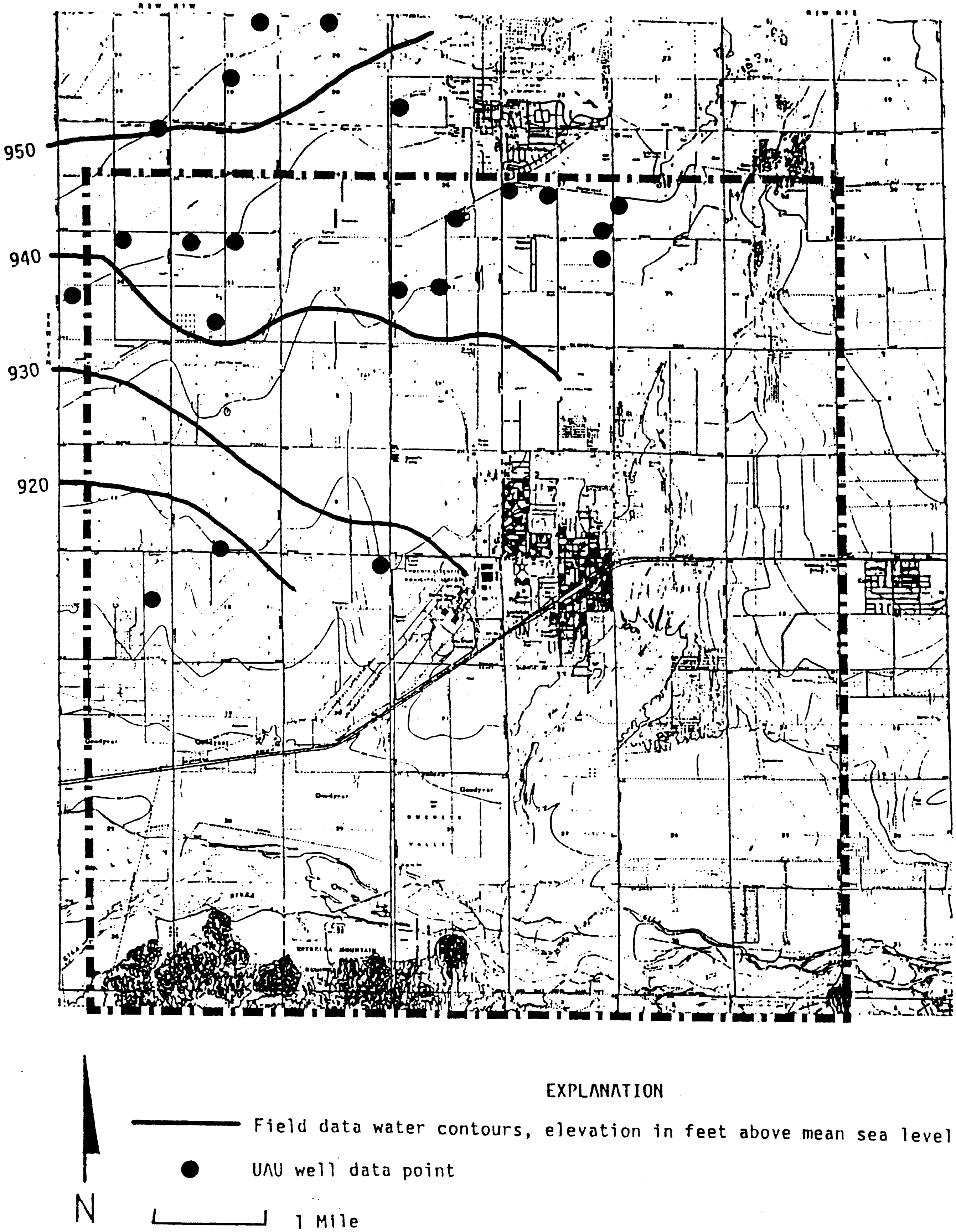
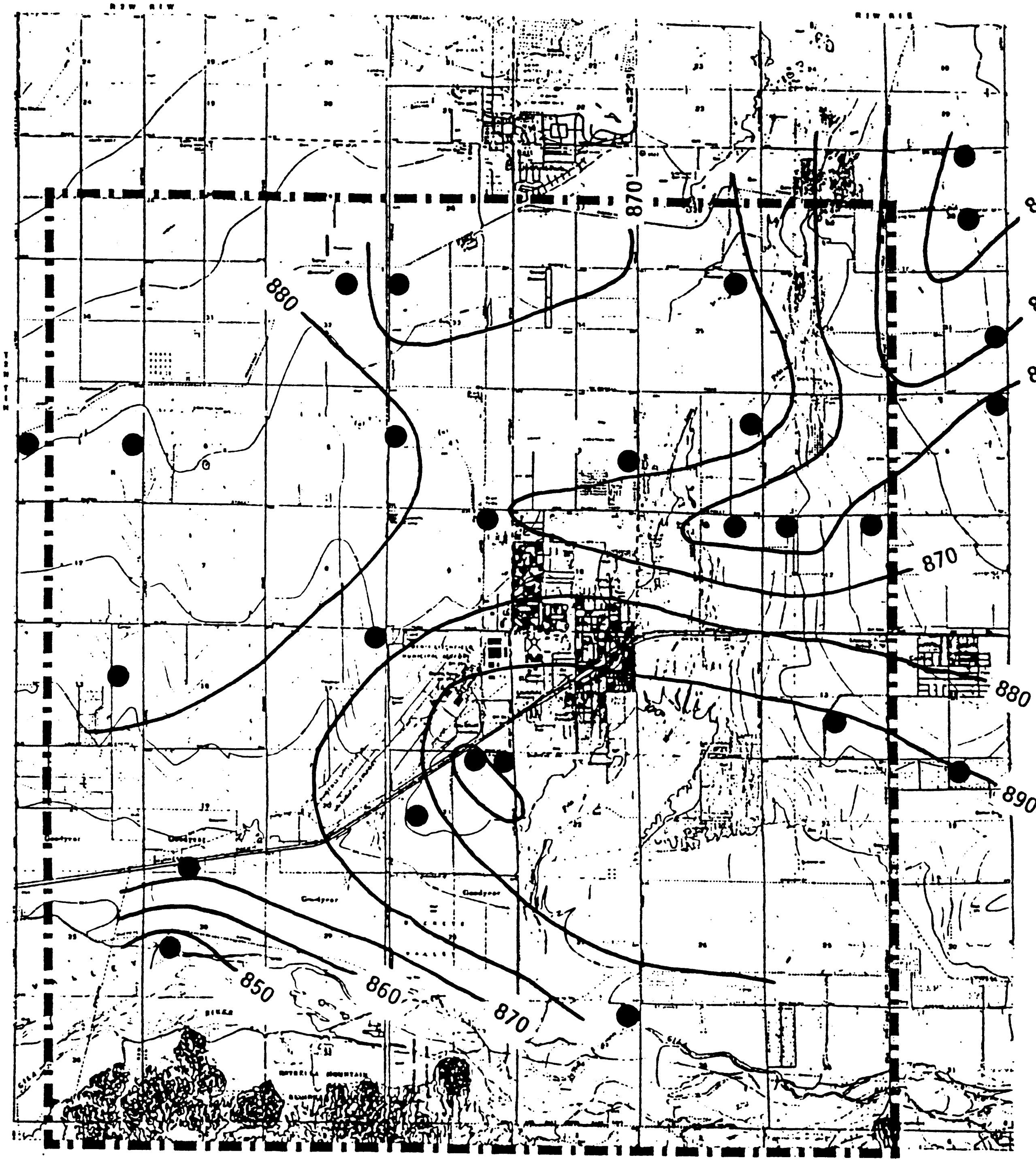


Figure 2

1962 UAU WATER LEVEL CONTOUR MAP FROM FIELD DATA




EXPLANATION

Field data water contours, elevation in feet above mean sea level

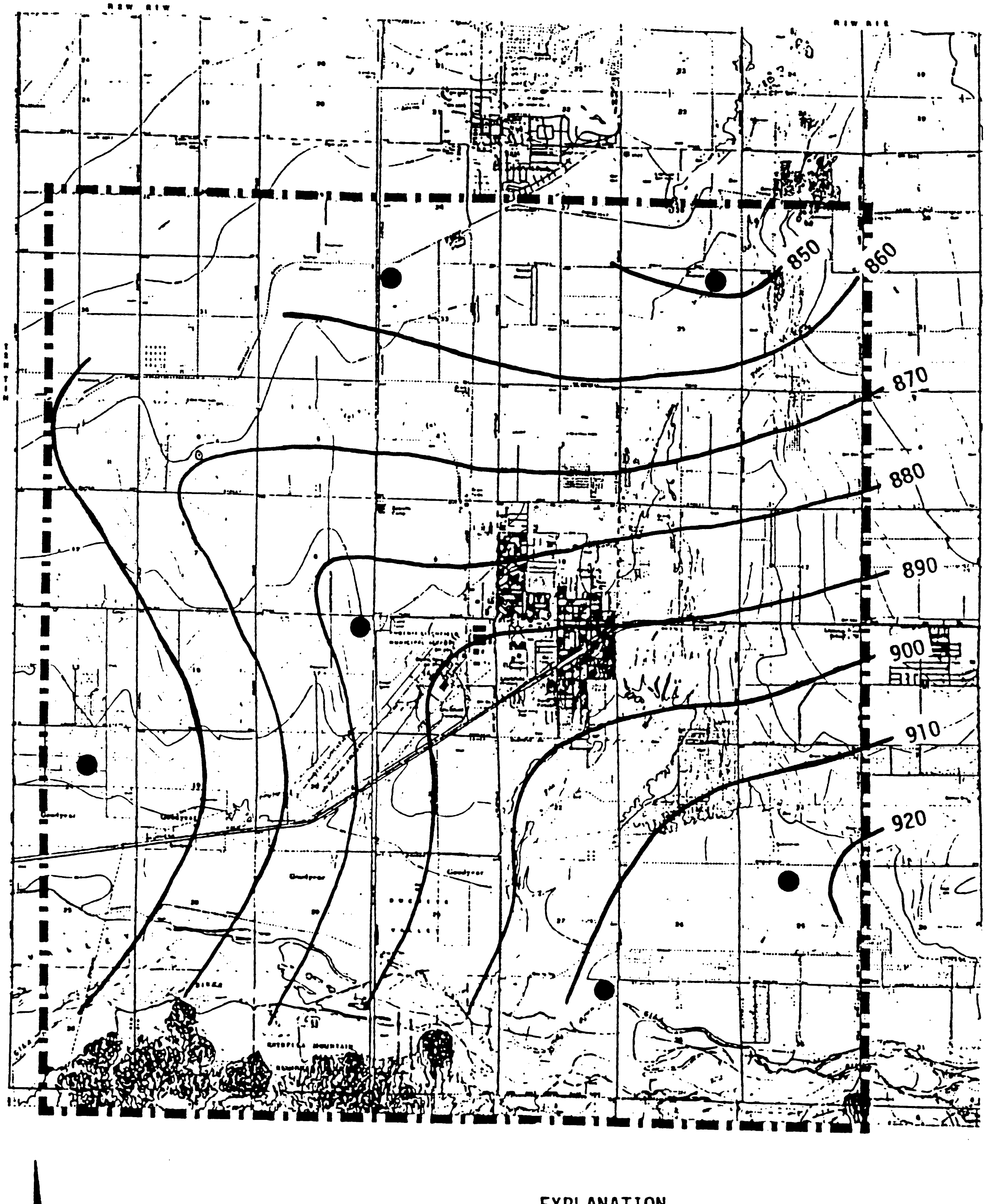
UAU well data point

N

1 Mile

Figure 3

1972 UAU WATER LEVEL CONTOUR MAP FROM FIELD DATA




N

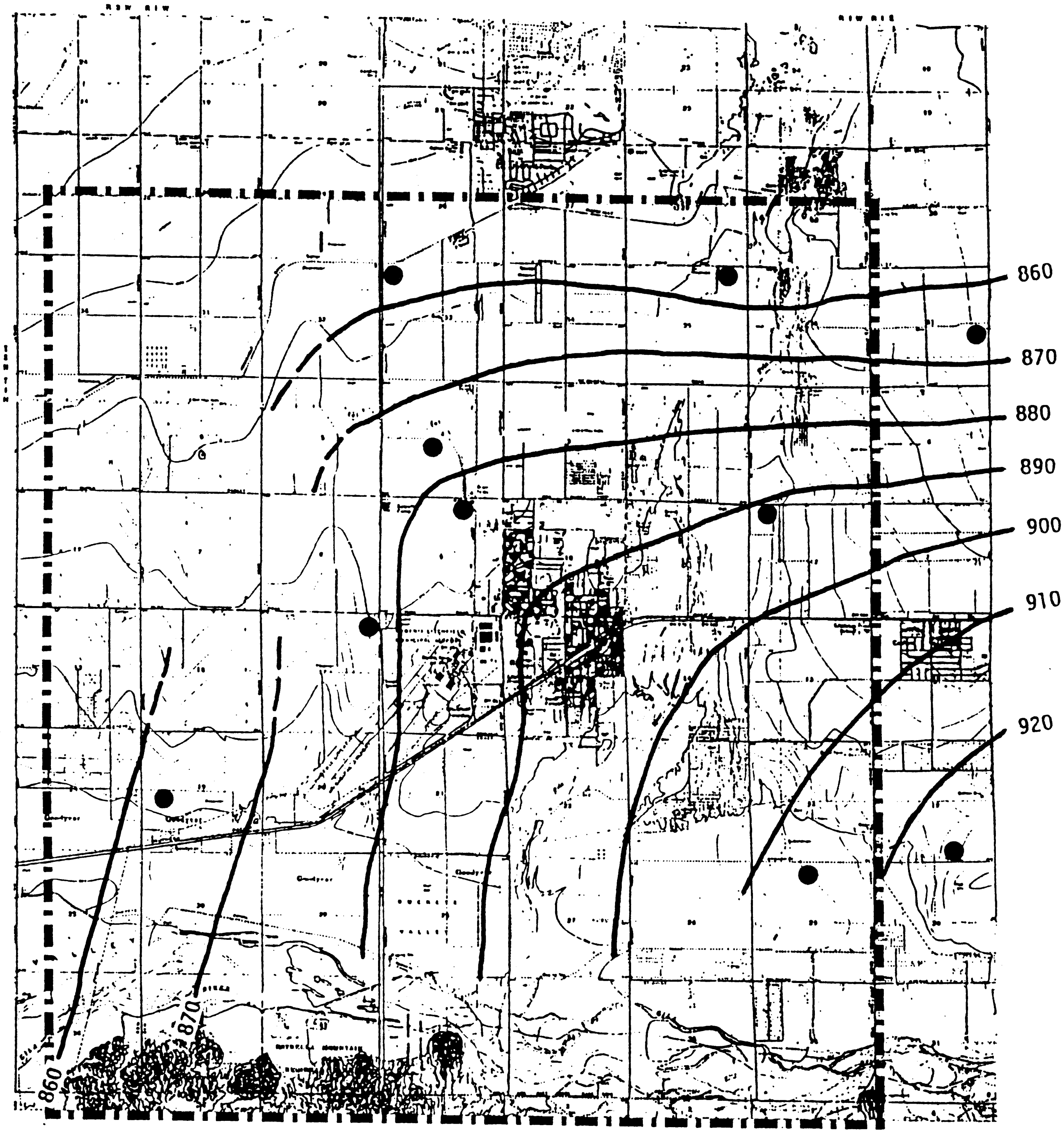
EXPLANATION

Field data water contours, elevation in feet above mean sea level

UAU well data point

1 Mile

Figure 4
1977 UAU WATER LEVEL CONTOUR MAP FROM FIELD DATA




EXPLANATION

Field data water contours, elevation in feet above mean sea level

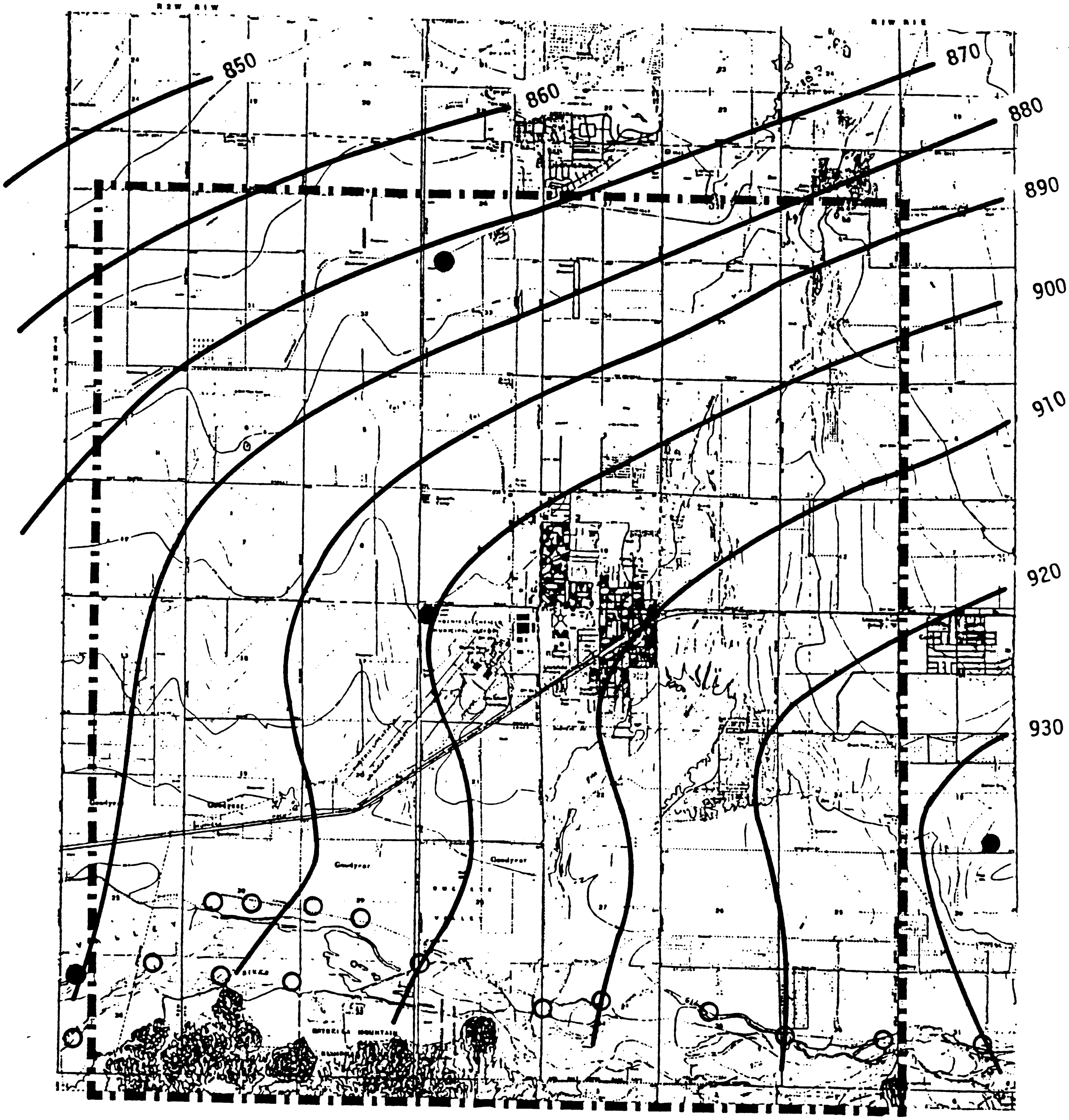
UAU well data point

N

1 Mile

Figure 5

1982 UAU WATER LEVEL CONTOUR MAP FROM FIELD DATA




EXPLANATION

Field data water contours, elevation in feet above mean sea level

River bed elevation used as data point

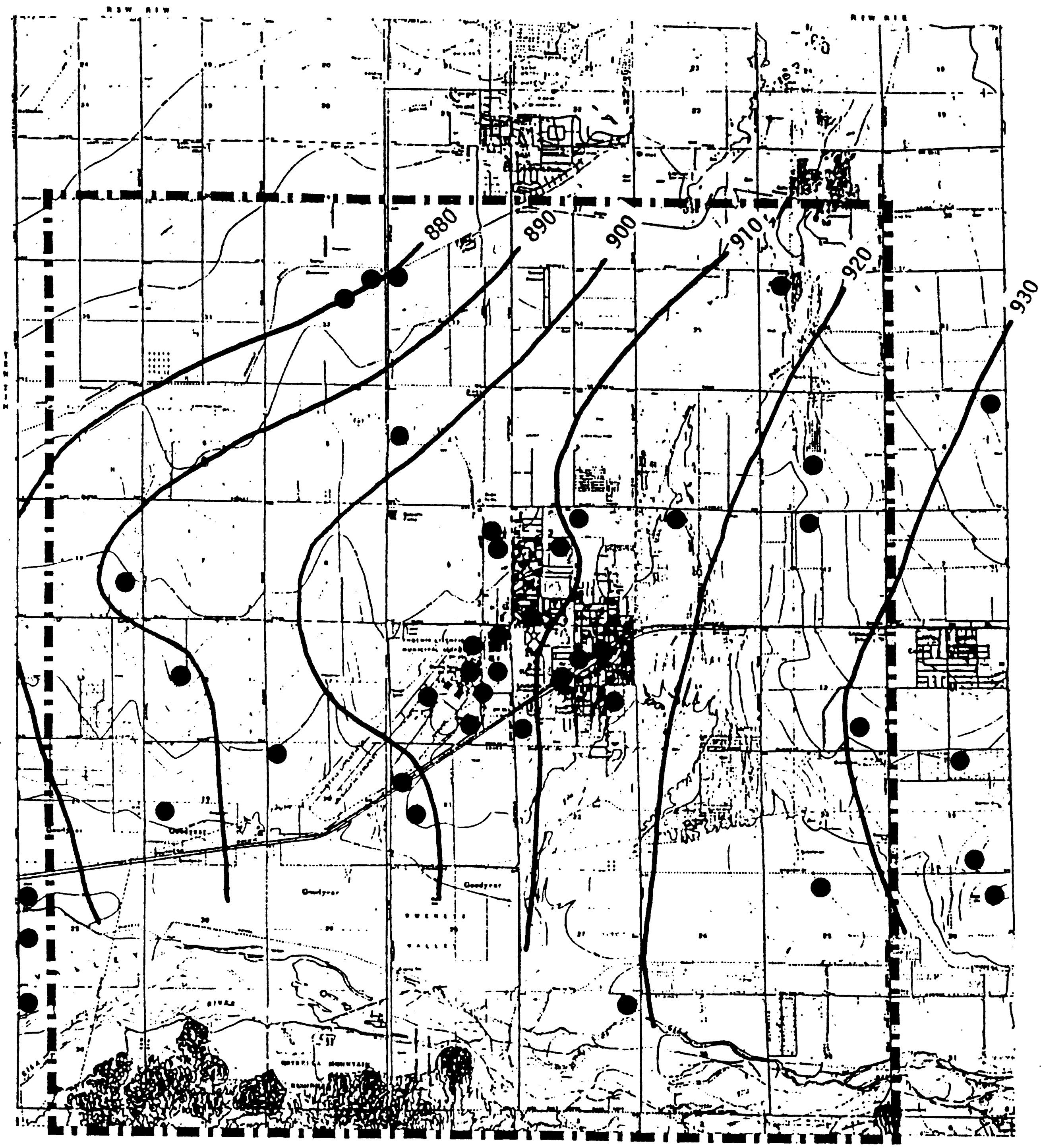
UAU well data point

N

1 Mile

Figure 6

1984 UAU WATER LEVEL CONTOUR MAP FROM FIELD DATA




N

EXPLANATION

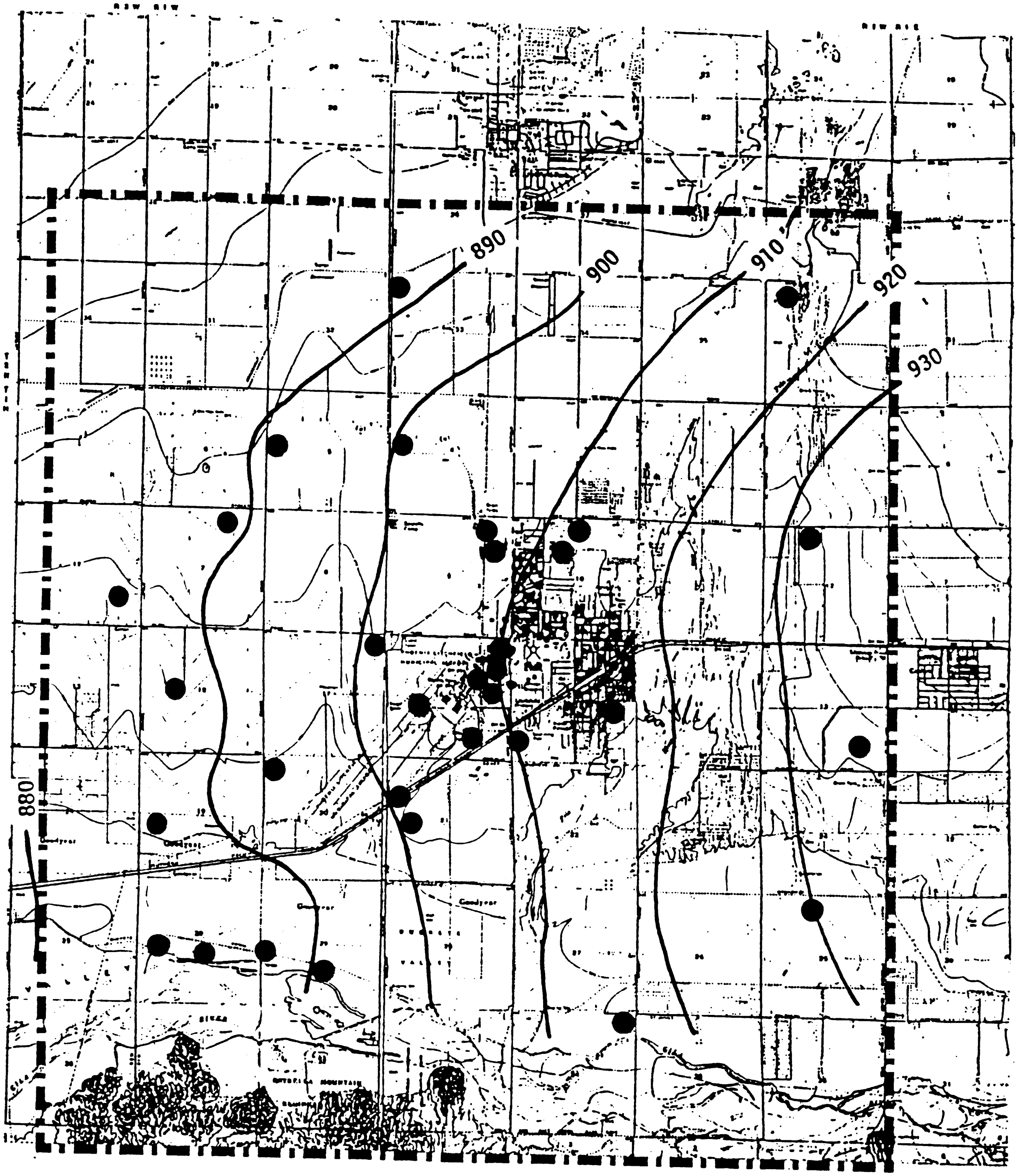
Field data water contours, elevation in feet above mean sea level

UAU well data point

1 Mile

Figure 7

1985 UAU WATER LEVEL CONTOUR MAP FROM FIELD DATA




EXPLANATION

Field data water contours, elevation in feet above mean sea level

UAU well data point

N

1 Mile

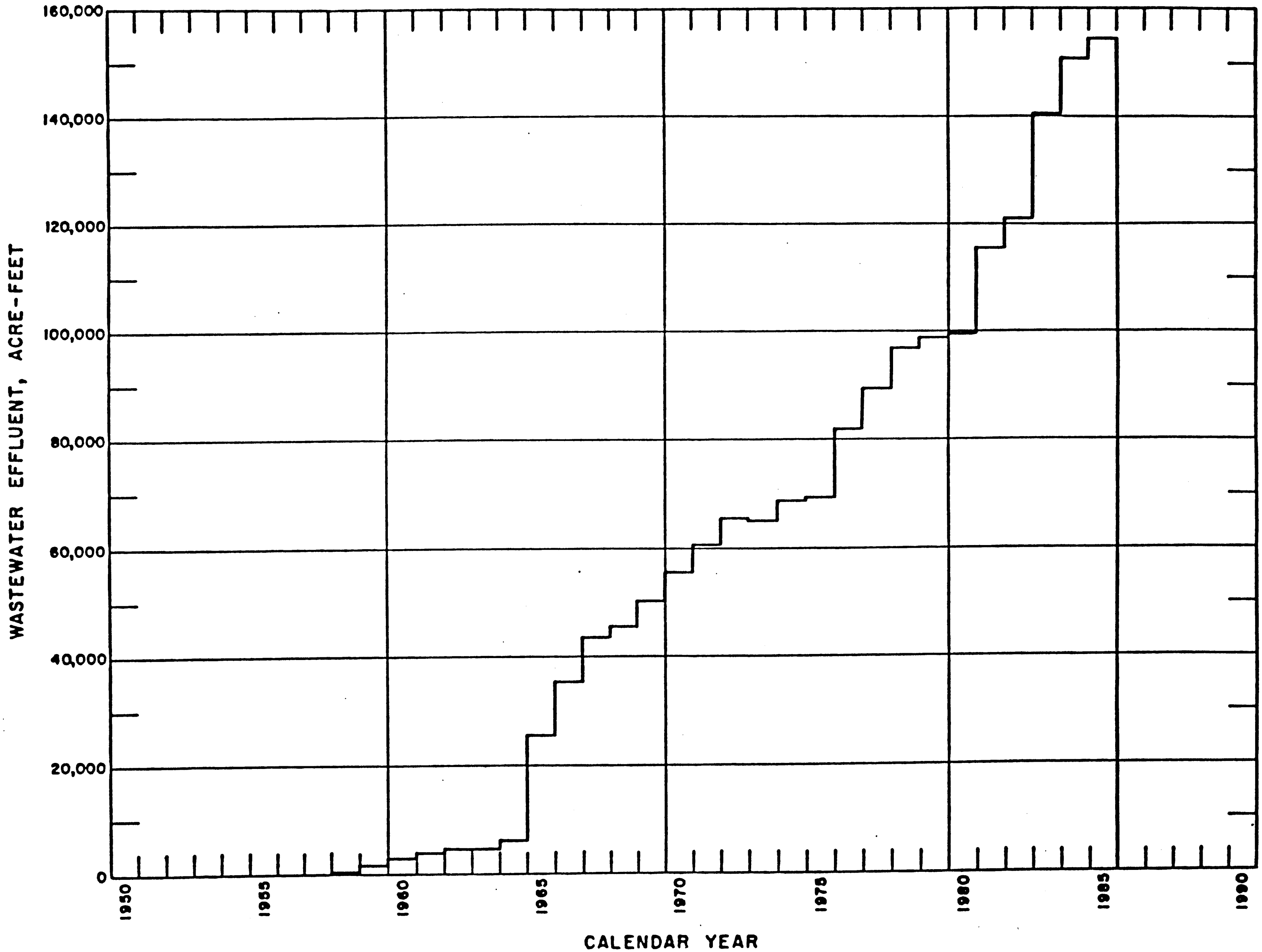



Figure 8: Hydrograph of effluent discharged to Salt River from 91st Avenue Wastewater Treatment Plant. (Source: Montgomery and Associates, 1986: Study of Waterlogging Problems in the West Salt River and Hassayampa Sub-Basins of the Phoenix Active Management Area, Task IA: Evaluation of Past Hydrogeologic Conditions. Preliminary

Figure 9: Schematic showing major components of conceptual water budget in the Phoenix-Goodyear Airport area. Note that agricultural recharge, vertical leakage, groundwater pumpage, and miscellaneous recharge extend over most of study area.

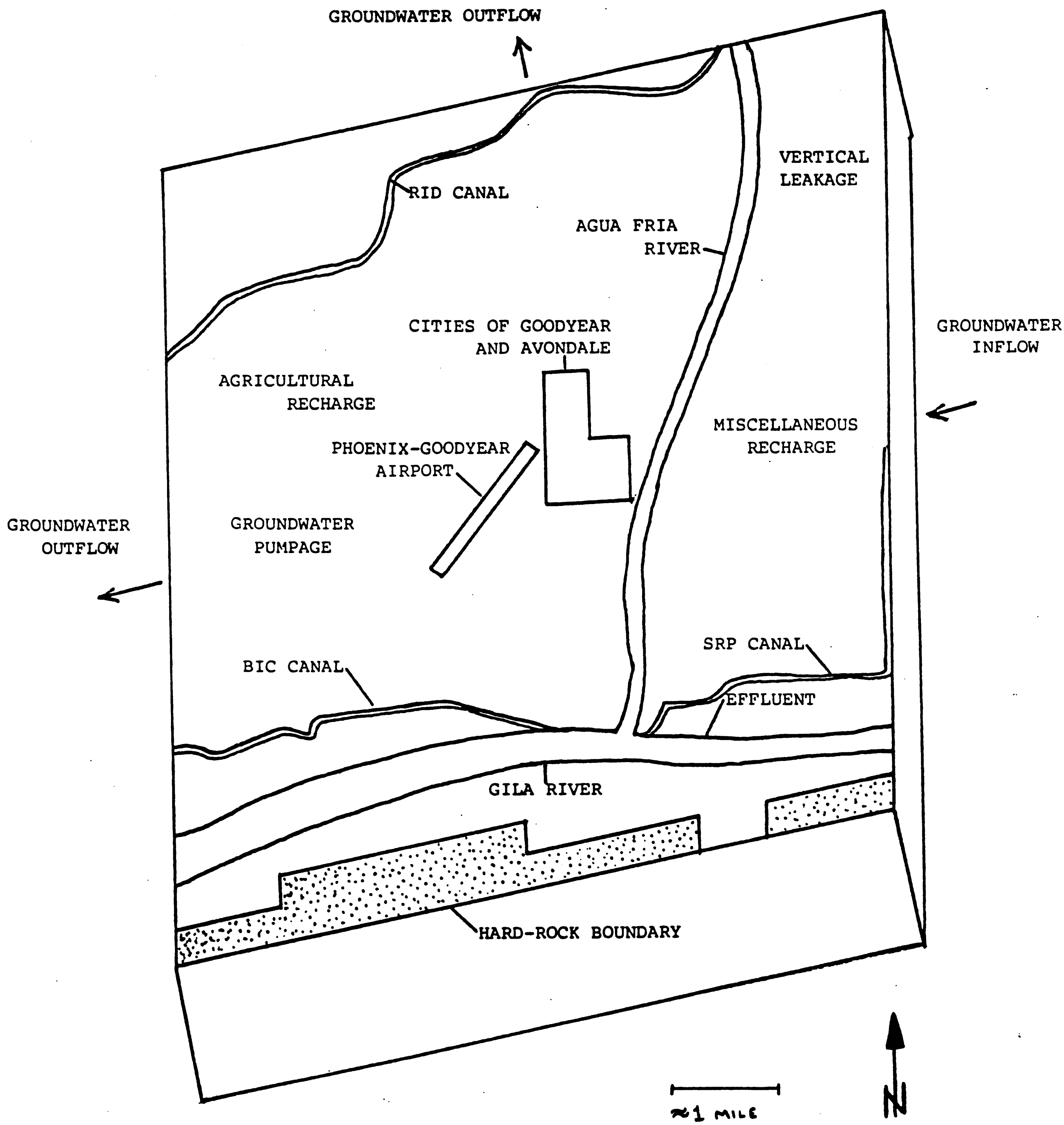
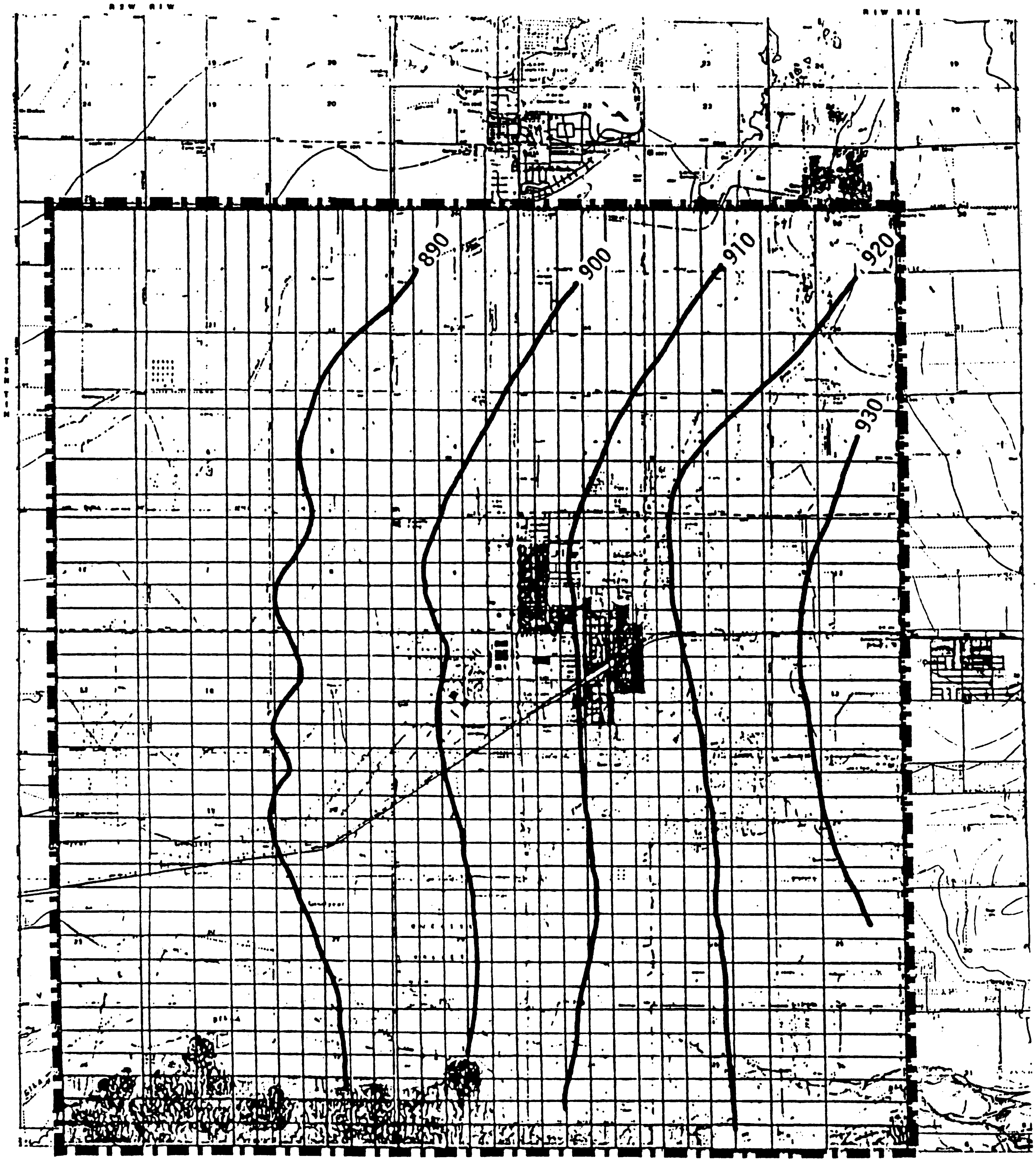


Figure 10
1985 MODEL - SIMULATED WATER LEVEL CONTOUR MAP



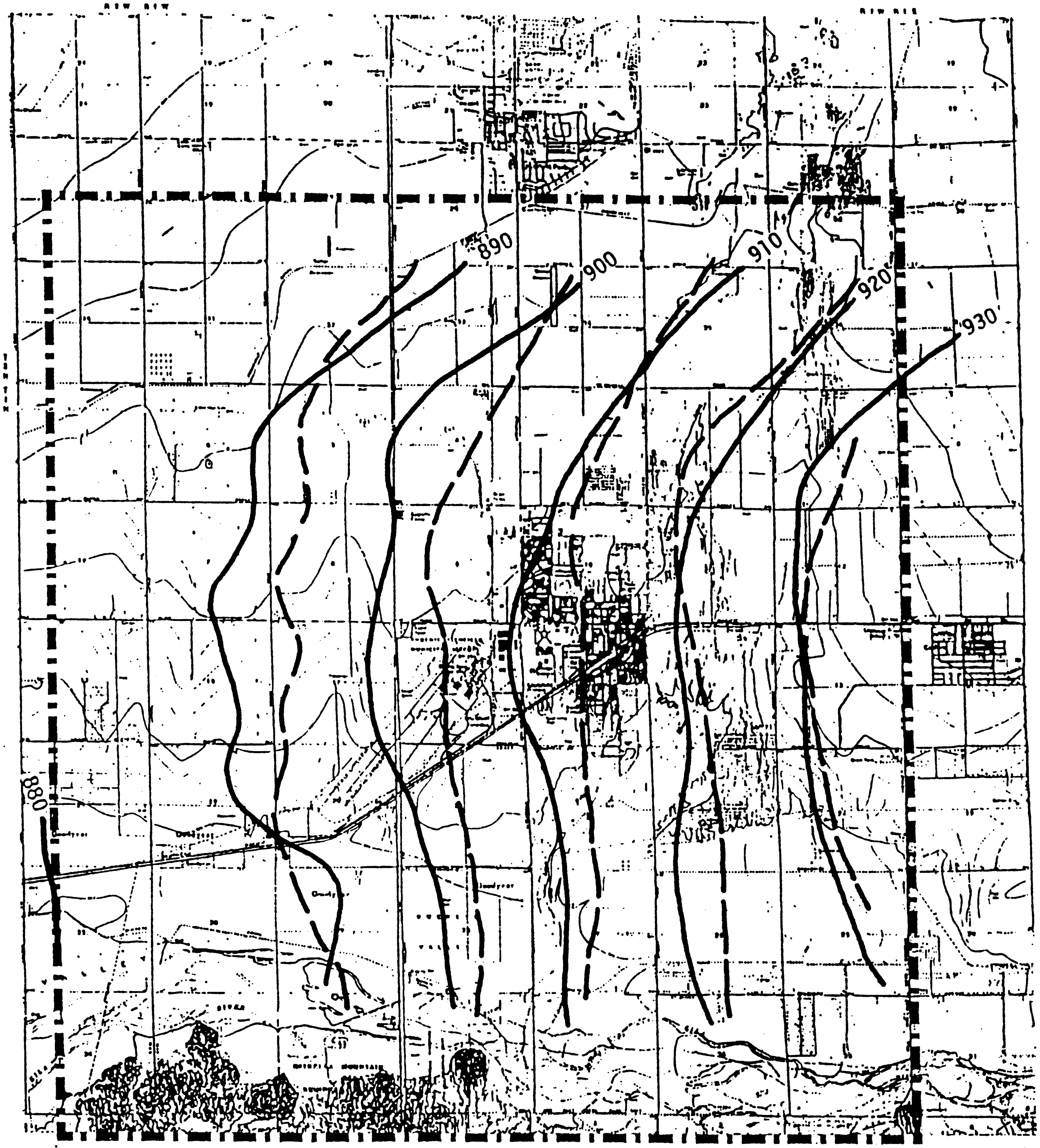

EXPLANATION

Water level contours, elevation in feet above mean sea level

N

1 Mile

Figure 11
COMPARISON OF MODEL SIMULATED VS. FIELD DERIVED 1985 HEADS
FOR THE PERIOD 1978 - 1985




EXPLANATION

Model - simulated water level contours, elevation in feet above mean sea level

Field data water contours, elevation in feet above mean sea level

N

1 Mile

# Tables

TABLE 1
MODEL CALIBRATION

| MODEL RUN | MODIFICATIONS FROM PRIOR RUN | RESULTS AND COMMENTS | RECOMMENDATIONS |
|---|---|---|---|
| #1 9/11/86 | • Initial Model Run - used initial water budget parameters as presented at the May 21, 1986 modeling sub-committee meeting.<br>• Initial heads from 1978 composite (UAU-MFU) water level maps.<br>• Uniform values of storage coefficient, .15, and hydraulic conductivity, 75 gpd/$ft^2$ for model area. | • Many pumping center anomalies throughout model area.<br>• Poor match with 1982 field data; heads approximately 150 feet too high.<br>• General flow direction to north, not west as it should be. | • Adjust recharge and pumpage.<br>• Refine aquifer parameters. |
| #2 9/23/86 | • Input starting heads based on 1978 UAU Water Levels only.<br>• Halved initial water budget estimate of Gila River recharge. | • Same as above except 1982 ending water levels dropped approximately 100 feet near the Gila River. | Same as above |
| #3 9/23/86 | • Same as above except using 1978 UAU-MFU composite water levels for starting head values. | • Approximately a ten foot ending head drop overall as compared with model run number 2. | Same as above. |
| #4 11/4/86 | • Selected 1978 UAU water levels only for starting heads.<br>• Revised Pumpage estimates to include data reported in the Registery of Grandfathered Rights Reports.<br>• Refined estimates of hydraulic conductivity to range from 670 gpd/$ft^2$ to 2800 gpd/$ft^2$ throughout model area, as presented at the 11-5-86 modeling sub-committee meeting. | • Better match with 1982 field data.<br>• Flow direction to the northwest.<br>• Heads still too high in northwest; however, pumpage centers not apparent due to higher hydraulic conductivity values. | Further revise aquifer parameters and recharge estimates. |

TABLE 1 CONT'D
MODEL CALIBRATION

| MODEL RUN | MODIFICATIONS FROM PRIOR RUN | RESULTS AND COMMENTS | RECOMMENDATIONS |
|---|---|---|---|
| #5 3/17/87 | • Adjusted hydraulic conductivity values to range from 250 $gpd/ft^2$ to 1250 $gpd/ft^2$.<br>• Storage coefficient values adjusted; range from .02 to .21.<br>• Added second layer to simulate MFU; same starting heads used for layer 1.<br>• Adjusted recharge values to agree with memo dated March 11, 1987 entitled: Summary of PGA (PLA) Conceptual Water Budget.<br>• Adjusted specified boundary conditions to the 1982 UAU water level maps. | • Good match with 1982 field data for northern part of model area, however, up to 30 feet higher in southeast.<br>• Flow direction overall to the northwest.<br>• Pumping centers too large. | • Change aquifer parameters to match with memo dated March 11, 1987 entitled: Summary of PGA (PLA) Aquifer Parameters.<br>• Optimize time steps.<br>• Cut recharge in southern model area. |
| #6 4/1/87 | • Adjusted storage coefficient values to range from .09 to .21.<br>• Decreased beginning heads for layer 2 by 10 feet.<br>• Changed time steps from 1 to 5 for the five-year (1978 to 1982) simulation. | Same as above. | • Revise recharge estimates. |
| #7 4/1/87 | • Halved effluent recharge from 83,800 ac-ft to 41,900 ac-ft, and halved BIC canal recharge from 67,900 to 33,950 ac-ft. | • Ending water levels drop to 10 to 15 feet in southeast.<br>• Flow direction west to northwest in western part of model area.<br>• Pumping centers dominant in northwest. | • Further adjust recharge and pumpage estimates.<br>• Implement idea of constant heads at the river. |
| #8 4/1/87 | • Kept heads constant in river cells.<br>• Halved effluent again to a total of 20,900 ac-ft. | • Heads drop near river 10-15 feet.<br>• Good match with 1982 field data in eastern model area.<br>• Pumping centers in northwest exaggerated.<br>• Flow direction west except in the east where it is to the north-northwest. | • Alter boundary conditions to correct for flow direction problem in the northeast part of model area.<br>• Compare with constant head cells off. |

TABLE 1 CONT'D
MODEL CALIBRATION

| MODEL RUN | MODIFICATIONS FROM PRIOR RUN | RESULTS AND COMMENTS | RECOMMENDATIONS |
|---|---|---|---|
| #9 4/3/87 | • No constant head cells in river.<br>• Altered boundary conditions.<br>• Smoothed hydraulic conductivity values; i.e. interpolated between data points instead of "blocks" in specified areas. | • Ending heads drop in northwest due to increase in K-values.<br>• Flow direction to northwest. | • Compare with constant head cells on. |
| #10 4/6/87 | • Same as model run #9 except included constant heads cells along river. | • Flow direction changed to west.<br>• Problems along river: approximately 10 foot drop in heads, contours bow up-stream over one mile.<br>• Pumping centers in northwest exaggerated. | • Abandon use of constant head cells; however, keep "idea" of constant heads along river.<br>• Increase vertical leakage from UAU to MFU. |
| #11 4/9/87 | • Adjusted aquifer parameters for layer 2.<br>(1) Storage coefficient values 0.025.<br>(2) For vertical conductance: over most of area, used value of 4.4E-10, corresponding to a UAU thickness of 350 ft. and MFU vertical conductivity (Kz) of 0.1 gpf/$ft^2$. In south and east, used value of 5.0E-9, corresponding to UAU thickness of 300 ft. and MFU Kz of 1.0 gpd/$ft^2$. In extreme south, used of value 3.0E-8, corres-ponding to UAU thickness of 250 ft. and MFU Kz of 33 gpd/$ft^2$.<br>(3) Transmissivity values of .0108 ft/second (45 gpd/ft).<br>• Used specified flux for boundary conditions for layer 2. | • Heads drop 3-5 feet by river due to increase in aquifer parameter values for layer 2 near river.<br>• Can compare this run with model run #9. virtually no change. | • Abandon specified flux boundary for layer 2.<br>• Break into 3 stress periods. |

TABLE 1 CONT'D
MODEL CALIBRATION

| MODEL RUN | MODIFICATIONS FROM PRIOR RUN | RESULTS AND COMMENTS | RECOMMENDATIONS |
|---|---|---|---|
| #12 4/14/87 | • Distribute surface water recharge in stress periods 1, 2, and 3 at 25%, 100%, and 0% of value presented in March 11, 1987 water budget memo (67,200 ac-ft per 5 years); total surface water recharge thus reduced to 30,200 ac-ft per 5 years. | • General flow direction to west.<br>• 1982 ending heads too high in southeast. | • Adjust effluent recharge down to lower heads in southeast.<br>• Revise boundary conditions to account for different specified flux during different stress periods. |
| #13 4/15/87 | • Cut effluent recharge by half again from 20,900 to 10,000 ac-ft, and doubled BIC canal recharge from 33,950 to 67,900 ac-ft.<br>• Used 1978 values for boundary heads and horizontal conductance in GHB package for first 2 stress periods. | • Heads rose in west, dropped in east.<br>• Good match with 1982 field data, except eastern area shows northwest flow direction instead of west flow direction.<br>• Problem present with pumping center in northwest area. | • Model sufficiently calibrated to 1982 given limitations of field data.<br>• Extend model to present when better field data exists. |
| #14 4/23/87 | • Added stress periods 4 through 7 for years 1983 through 1986; used 2 time steps per year.<br>• Used 1985 water level map for boundary heads in GHB package for stress periods 4 through 7. | • Poor match with 1985 field data: overall, heads about 10 feet too high, flow direction to northwest. | • **RECONCEPTUALIZE SYSTEM:** assign no recharge from effluent or surface water and use "river" package instead.<br>• Perform field inspection on canals. |
| #15 5/11/87 | • Install "river" package.<br>• Return all recharge values to those in memo dated 3/11/87, except delete effluent and surface water recharge.<br>• Revise SRP canal recharge as per field inspection to be 25,600 ac-ft per 5 years. | • Good match with 1985 field data, except in western area where heads about 5 to 10 feet too high.<br>• Flow direction to west, as it should be. | • Add estimated composite pumpage to lower overall heads. |

TABLE 1 CONT'D
MODEL CALIBRATION

| MODEL RUN | MODIFICATIONS FROM PRIOR RUN | RESULTS AND COMMENTS | RECOMMENDATIONS |
|---|---|---|---|
| #16 5/15/87 | • Added composite pumpage (from calculated UAU portion).<br>• Restored canal recharge in two "river" cells; revised recharge in miscellaneous recharge in 3 cells located in gravel pits on Agua Fria River. | • Heads dropped about 10 feet in west area.<br>• Better match with 1985 field data.<br>• Slight problems with pumping centers in northwest area; heads about 5 to 10 feet too high in southwest area and 5 feet too low in central area. | • Adjust BIC canal recharge: decrease as per field inspection to lower heads in southwest area. |
| #17 5/22/87 | • Adjusted BIC canal recharge to 25,700 (from 67,900) ac-ft based on field measurement of wetted perimeter and infiltration rate of 0.8534 ft/day. | • Heads dropped about 5 feet in southwest area.<br>• Very good match with 1985 field data: southwest flow direction in southwest area, overall flow direction due west. | • Adjust GHB package to agree with revised 1985 water level contour map. |
| #18 5/27/87 | • Input head values and horizontal conductance values measured from revised 1985 water level contour map. | • Heads dropped about 5 feet in northern area; 880 foot contour appeared in southwest area.<br>• Better match with 1985 field data along northern and western boundaries; still about 5 feet too high in northwest. | • Revise composite pumpage to agree with new data.<br>• Adjust GHB package to lower heads in northwest area.<br>• Impose limits on K-values based on ranges reported in memo of 3-11-87. |
| #19 6/10/87 | • Revised composite pumpage based on new data.<br>• Adjusted boundary heads in GHB package along west third of north boundary.<br>• Set maximum and maximum K-values of 250 to 1500 $ft^2$ and altered K-values exceeding the above limits (about 20% of all K-values). | • Heads rose 2 to 5 feet in in center area.<br>• Pumping cones decreased in extent.<br>• Southwest flow direction in southwest; heads dropped 5 feet in northwest.<br>• Excellent match with 1985 field data; model appears to be sufficiently calibrated. | • Verify model input to assure calibration. |

TABLE 1 CONT'D
MODEL CALIBRATION

| MODEL RUN | MODIFICATIONS FROM PRIOR RUN | RESULTS AND COMMENTS | RECOMMENDATIONS |
|---|---|---|---|
| #20 6/23/87 | • Verify pumpage; minor alterations made to some values.<br>• Verify recharge values; BIC canal recharge value restored to original estimate (27,000 ac-ft) of 6-19-86.<br>• Verify all other model input. | • Only slight effects. | • 2-D regional groundwater flow model appears to be sufficiently calibrated to allow development of the site-specific 3-D groundwater flow and contaminant transport models. |

## TABLE 2: WATER BUDGETS, 1978 - 1982

| CATEGORIES | CONCEPTUAL WATER BUDGET VALUE* | MODEL-PREDICTED VALUE* |
|---|---|---|
| I. INFLOWS | | |
| A. GROUNDWATER INFLOW | 45,600 | 121,900 |
| (Range 45,600 - 55,000) | | |
| B. RECHARGE(total) | 249,900 | 249,900 |
| 1. IRRIGATION | | |
| a. Agricultural | 110,600 | 110,600 |
| (Range 110,600 - 274,500) | | |
| b. Municipal | 1,600 | 1,600 |
| (No range) | | |
| c. Golf course | 1,100 | 1,100 |
| (No range) | | |
| 2. SURFACE WATER | | |
| a. Gila River | 0 | 0 |
| (Range 0 - 232,300) | | |
| b. Agua Fria River | 4,500 | 4,500 |
| (No range) | | |
| 3. EFFLUENT | | |
| a. 23rd & 91st Avenue WWTP's | 0 | 200 |
| (Range 0 - 83,800) | | |
| b. Goodyear and Avondale | 3,400 | 3,400 |
| (Range 3,400 - 8,100) | | |
| 4. CANALS | | |
| a. RID | 29,000 | 29,000 |
| (Range 7,100 - 38,000) | | |
| b. BIC | 27,000 | 27,000 |
| (Range 17,000 - 67,900) | | |
| c. SRP | 16,900 | 16,900 |
| (Range 16,900 - 27,000) | | |
| 5. INDUSTRIAL WASTEWATERS | 1,200 | 1,200 |
| (No range) | | |
| 6. MISCELLANEOUS | 54,600 | 54,600 |
| (Range 41,600 - 104,000) | | |
| TOTAL INFLOWS | 295,500 | 372,000 |
| II. OUTFLOWS | | |
| A. GROUNDWATER OUTFLOW | 110,800 | 63,400 |
| (Range 18,000 - 110,800) | | |
| B. GROUNDWATER PUMPAGE, UAU AND COMPOSITE | 270,000 | 270,000 |
| (No range) | | |
| D. VERTICAL LEAKAGE | 0 | unquantified |
| (Range 0 - 114,900) | | |
| TOTAL OUTFLOWS | 380,800 | 333,400 |
| III. CHANGE IN STORAGE | | |
| INFLOW - OUTFLOW | -85,300 | +38,600 |
| CALCULATED CHANGE IN STORAGE | +56,500 | -38,400 |
| RESIDUAL | -28,800 | +200 |

* Values are in acre-feet per five years; ranges of values refer to previous estimations reported in prior conceptual water budgets.

TABLE 3
SENSITIVITY ANALYSIS

| PARAMETER | CALIBRATED MODEL VALUES | REASONABLE RANGE OF VALUES (No more than 5 ft. change in layer 1 ending heads) | COMMENTS |
|---|---|---|---|
| "Slice-successive over-relaxation" (SSOR) Package (method of solving the finite difference equations) | Used for comparison: 50 for maximum number of iterations, .01 ft. for closure criterion from the "Strongly Implicit Procedure" (SIP) Package | No stricter closure criterion than 0.1 ft. maximum head differences between iterations; no less than 100 iterations to closure. | The strongly implicit procedure (SIP) produces similar ending heads as SSOR, but takes less iterations and computer time to converge. |
| "River" Package Parameters | Used riverbed conductivity of 1000 gpd/$ft^2$ with 1 ft. stage for 1978-1982 and 5 ft. stage for 1983-1986. | 1. Hydraulic Conductivity of Riverbed: at least 500-2000 gpd/$ft^2$ (double or half model input values)<br>2. River Stage: 0 ft. to at least 5 ft. (dry to well over known low-flow stage). | Conductivity of riverbed material and stage of river have no effect on ending heads within the range of values explored.<br>Non-use of the River Package also does not affect ending heads as long as the stage does not exceed 5 ft. |
| "General Head Boundary" (GHB) Package Parameters | Used boundary heads measured from 1978, 1982, and 1985 water level contour maps for stress periods 1-2, 3, and 4-7, respectively. Used horizontal conductance values determined at cell boundaries from HY1 array and from water level contour maps from each year. | See Table 1 | The model is very sensitive to specified boundary heads and horizontal conductances. Effect of GHB parameters extends to at least 2 or 3 cells away from specified flux boundary toward interior of model area. |

TABLE 3 CONT'D
SENSITIVITY ANALYSIS

| PARAMETER | CALIBRATED MODEL VALUES | REASONABLE RANGE OF VALUES (No more than 5 ft. change in layer 1 ending heads) | COMMENTS |
|---|---|---|---|
| Hydraulic Conductivity of Layer 1 (HY1) | Used heterogeneous array ranging from 250 to 1500 $gpd/ft^2$ derived from Driller's Log Program analyses. (Average value is 762 $gpd/ft^2$.) Values as reported in memo to modeling sub-committee dated 3/11/87, except values interpolated between data points for discrete cell K-values, and maximum and minimum limits of 1500 and 250 $gpd/ft^2$ imposed. | 1. Heterogeneous: ±25% (188 to 1875 $gpd/ft^2$) of range (250 to 1500 $gpd/ft^2$).<br><br>2. Homogeneous: -0% to +65% (750 to 1250 $gpd/ft^2$) of average value (762 $gpd/ft^2$) | Heterogeneous HY1 values may change ±25% from input distributions without significantly raising or lowering UAU ending heads. Sensitivity analysis of homogeneous HY1 arrays suggests that the average of 762 $gpd/ft^2$ may be on the lower end of the range of reasonable values. |
| Storage Factor of Layer 1 (SF1) | Used heterogeneous array (ranging from .06 to .21) derived from driller's log program analysis, as reported in memo to modeling sub-committee dated 3/11/87. | .05 to .25 (±20% of model input values) | Model is not very sensitive to application of varying storage factors; within .05 to .25 the ending heads rise or drop about 5 ft. or less, respectively. |

## TABLE 3 CONT'D
## SENSITIVITY ANALYSIS

| PARAMETER | CALIBRATED MODEL VALUES | REASONABLE RANGE OF VALUES (No more than 5 ft. change in layer 1 ending heads) | COMMENTS |
|---|---|---|---|
| Vertical Hydraulic Conductivity divided by thickness (VCONT) | Over most of area, used value of 4.4E-10, corresponding to a UAU thickness of 350 ft. and MFU vertical conductivity ($K_z$) of 0.1 gpd/ft$^2$. In south and east, used value of 5.0E-9, corresponding to UAU thickness of 300 ft. and MFU $K_z$ of 1.0 gpd/ft$^2$. In extreme south, used value of 3.0E-8, corresponding to UAU thickness of 250 ft. and MFU $K_z$ of 33 gpd/ft$^2$. | 7 orders of magnitude greater to 3 orders of magnitude less than model input values. | Model insensitive to variations in VCONT. At high VCONT values, UAU-MFU interconnection exists and heads become equal; at low VCONT values, no leakage occurs. Sensitivity analysis suggests that the model input values are on the lower end of the range of reasonable values. |
| Storage Factor for Layer 2 (SF2) | .025 over most of area; .15 in southernmost cells. | Heterogeneous: .07 to .60 in southernmost area, and less than .01 to .10 in most of area (+200% to -50% of model input value). Homogeneous: less than 1% to at least 15%. | Model fairly insensitive to increase in SF2, but fairly sensitive to decrease in SF2 suggesting that model input values are on the lower end of the range of reasonable values. Sensitivity analysis of homogeneous SF2 values suggests that the model input values span the range of reasonable values. |
| Transmissivity of Layer 2 (TRAN2) | Uniform Value of 0.0108 ft/sec (45 gpd/ft). | One half of an order of magnitude greater and at least 4 orders of magnitude less. | Model fairly insensitive. Model input values are on the higher end of the range of reasonable values. |

TABLE 3 CONT'D
SENSITIVITY ANALYSIS

| PARAMETER | CALIBRATED MODEL VALUES | REASONABLE RANGE OF VALUES (No more than 5 ft. change in layer 1 ending heads) | COMMENTS |
|---|---|---|---|
| Recharge | Heterogeneous array, as in Table 2 of this memo. | ±25% of sum total of values in recharge array. | Model sensitive to recharge values. At ±25% of recharge values, heads rise/drop only 1 to 2 ft.; at ±50%, heads rise/drop 2 to 5 ft. Model is far more sensitive to variations in recharge from individual sources (i.e. canals, agriculture, surface water) in recharge array; effects of several are apparent in Table 1 (see text). |

## Appendix B:

Three-Dimensional Groundwater Flow Model Calibration History

## THREE-DIMENSIONAL GROUNDWATER FLOW MODEL CALIBRATION HISTORY

| Date & Job I.D. | Reason for Performing Calculation | Modifications to Data Set | Assumptions Summary | Results & Comments Flow & Solute Mass Imbalance: Convergence Behavior | Recommended Next Step |
|---|---|---|---|---|---|
| 1/24/88<br>Prod. Run 1<br>JOBID 1540 | Initiate production runs for the purpose of calibrating the flow portion of the transport model | *Initial Aquifer Parameter Input Data (see tables below) | - Evapotranspiration significant in vicinity of river.<br><br>- Gila River is an expression of the groundwater table within the model domain. | Flow direction generally correct, however, simulated heads much lower than observed heads by end of simulation. Prior runs indicate mass imbalance approximately 1-2% and convergence behavior satisfactory. | Revise method of deriving boundary flux rate. |

| KL1 (ft/dy) | KL2 (ft/dy) | Kv (ft/dy) | n (%) | Sc (1) | Sy (%) |
|---|---|---|---|---|---|
| 74.0 | 74.0 | 0.74 | 0.15 | .002 | .10 |
| 34.0 | 34.0 | 0.17 | 0.10 | .0005 | .05 |
| 20.0 | 20.0 | 0.17 | 0.10 | .0005 | .05 |
| 48.0 | 48.0 | 0.17 | 0.10 | .0005 | .05 |
| 137.0 | 137.0 | 0.67 | 0.25 | .005 | .20 |
| 6.0 | 6.0 | .005 | 0.15 | .002 | .02 |
| 22.0 | 22.0 | .005 | 0.15 | .002 | .02 |

| Kd (1/ft) | D1 (ft/dy) | Dt (ft/dy) |
|---|---|---|
| 0.0 | 100 | 10 |
| 0.0 | 100 | 10 |
| 0.0 | 100 | 10 |
| 0.0 | 100 | 10 |
| 0.0 | 100 | 10 |
| 0.0 | 100 | 10 |
| 0.0 | 100 | 10 |
| 10.0 | 100 | 10 |
| Not Applicable | Not Applicable | Not Applicable |

*Data listed as presented in the following order:

(1) Upper Alluvial Unit - sub-unit A
(2) Upper Alluvial Unit - sub-unit B
(3) Upper Alluvial Unit - sub-unit B
(4) Upper Alluvial Unit - sub-unit B
(5) Upper Alluvial Unit - sub-unit C
(6) Middle Fine Grained Unit
(7) Middle Fine Grained Unit

Explanation of Symbols:

KL1: Horizontal hydraulic conductivity along x-axis
KL2: Horizontal hydraulic conductivity along y-axis
Kv: Vertical hydraulic conductivity
n: Porosity
Sc: Specific Storativity
Sy: Specific Yield
Kd: Absorption distribution coefficient
D1: Longitudinal dispersivity
Dt: Transverse dispersivity

## THREE-DIMENSIONAL GROUNDWATER FLOW MODEL CALIBRATION HISTORY

| Date & Job I.D. | Reason for Performing Calculation | Modifications to Data Set | Assumptions Summary | Results & Comments Flow & Solute Mass Imbalance: Convergence Behavior | Recommended Next Step |
|---|---|---|---|---|---|
| 2/20/88 Prod. Run 2 JOBID 1147 | Adjust boundary flux rates to simulate more groundwater inflow. | Refine boundary flux rates based on 3D modflow model. Change flux rates in QINF array. | Increased flux rates more in line with observed data. | Flow direction toward Gila River to the southwest as compared to a more westerly direction observed. Heads approximately 30 feet too low over model domain. Mass imbalance approximately 1-2%. | Re-analyze boundary flux rates. |
| 2/23/88 Prod. Run 3 JOBID 1406 | To check effects of increasing boundary flux rates. | Revise boundary flux rates to reflect more flow in and out of model domain. Change flux rates in QINF array. | Same as above. | Power surge - program amended. Probably very little change from previous run. Mass imbalance approximately 1-2%. | Review input data and boundary flux rates. |
| 2/25/88 Prod. Run 4 JOBID 1572 | Correct flags to set inflow boundary. | Revise boundary designations in CFLAG array to simulate inflow and outflow boundary conditions properly. | Same as above. | Flow direction more consistently toward the west. Heads still approximately 30 feet too high, however inflow and outflow boundaries correctly simulated and heads initially rose with the appearance of an 895 contour in the eastern portion of the domain. Mass imbalance approximately 1-2%; total error over approximately 2000 cells. | Conduct steady state analysis of boundary flux conditions and then revise accordingly. In addition, experiment with tolerance criteria and number of iterations performed to minimize run time and maximize solution convergence behavior. |
| 3/01/88 Prod. Run 5 JOBID 88 | Steady state run to check the effect of boundary flux rates. | ISTUN = 1 | Effects of flux rates will be exaggerated over a long period of time. | NR | N/A |
| 3/03/88 Prod. Run 6 JOBID 203 | Same as above. | Second IPRINT VARIABLE changed to -999. | The effects of changing noted parameters will be exaggerated under steady state conditions. | Mass imbalance = 11% change in storage 1.6E+9. | Explore varying parameters under steady state conditions. |
| 3/03/88 | NOTE: System down from 3/15/88 to 4/15/88 due to move of ADWR Management Information Systems Division to new building. | | | | |

## THREE-DIMENSIONAL GROUNDWATER FLOW MODEL CALIBRATION HISTORY

| Date & Job I.D. | Reason for Performing Calculation | Modifications to Data Set | Assumptions Summary | Results & Comments Flow & Solute Mass Imbalance: Convergence Behavior | Recommended Next Step |
|---|---|---|---|---|---|
| 4/18/88<br>Prod. Run 7<br>JOBID 1636 | To check effects of changing storage and porosity values. | STY = .05 for NMAT = 1 & 5<br>POR = .08 ALL NMAT<br>NITERS - psi = 50<br>ISTUN = 1 | Same as Prod. Run 6<br>JOBID 203 | Change in storage = 1.172E+9. 3% mass imbalance.<br><br>Run Time = 1 hour 59 minutes. Heads increased on Eastern boundary by 1-2 feet. | Same as above. |
| 4/19/88<br>Prod. Run 8<br>JOBID 1787 | To check effects of boundary flux rates and increased porosity values. | POR = .35 .40 .40 .40 .35 .30 .30<br>STY = .15 .05 .05 .05 .20 .02 .02 for all NMAT values (values from EPA memo dated 3/22/88) | Same as above. | Results very similar to prior run. CPU time = 86 minutes 25 seconds. | Same as above. |
| 4/19/88<br>Prod. Run 9<br>JOBID 1873 | To check effects of boundary flux rates except decreased storage values. | STY = .01 for all NMAT<br>I-TYP location 22,20,8 | Same as above. | No real change in water levels 4% mass imbalance.<br>CPU time - 85 minutes 41 seconds | It appears that changing these parameters has little effect on system therefore will increase flux rates next. |
| 4/20/88<br>Prod. Run 10<br>JOBID 1888 | To check effects of doubling infiltration rates at inflow boundaries. No changes made at outflow boundaries. | 1-STY = .10 .05 .05 .05 .20 .02 .02 for all NMAT; Niters-PSI-10 respective QNIF VALUES; .044, .138, .270, .356, .286, .450, .250, 1.512, 1.164, 1.154, .932, 2.124. | Assumes more flux across inflow boundaries than exiting system. | 30% mass imbalance. Mass error over 1000 cells change in storage +1.567+9.<br><br>CPU time = 18 minutes 23 seconds Mass imbalance too high, cannot use this run. Heads increased at Eastern boundary by 5 feet. | Change inflow infiltration rates back to original values - not doubled and re-run job; need to run job for more iterations so it will coverge on tolerance. |
| 4/20/88<br>Prod. Run 11A<br>JOBID 1983 | Use This steady state as basis for transient run. | Changed QINF values from prior runback to original values. | N/A | 3% mass imbalance mass error over 1600 cells.<br><br>CPU time = 18 minutes 15 seconds Heads still too low, not much change from initial runs. | Execute transient simulation for period 1978 to 1985. |
| 4/20/88<br>Prod. Run 11B<br>JOBID 2066 | Transient run based on previous steady state run. | ISTUN = 2<br>ISTART = 1<br>DTMAX = 500.0<br>STIME (NST) = 2922.0<br>PTIME (NPT) = 2922.0 | N/A | 4% mass imbalance.<br><br>CPU time = 157 minutes<br>Water levels still too low; no significant change. | Change storage parameters to see if can effect rise in water levels. |

## THREE-DIMENSIONAL GROUNDWATER FLOW MODEL CALIBRATION HISTORY

| Date & Job I.D. | Reason for Performing Calculation | Modifications to Data Set | Assumptions Summary | Results & Comments Flow & Solute Mass Imbalance; Convergence Behavior | Recommended Next Step |
|---|---|---|---|---|---|
| 4/21/88<br>Prod. Run 12<br>JOBID 2143 | Same as above. | STY = .01 for all NMAT | N/A<br><br>Storage is critical parameter to head change. | 5% mass imbalance.<br><br>CPU time = 156 minutes<br>Essentially no change from previous runs; no rise in water levels. | Simulate inflow boundary on all sides. |
| 4/21/88<br>Prod. Run 13<br>JOBID 2220 | Steady state run to check effects of total inflow boundary. | STY values equal those used in Prod. 10 JOBID 1888 on 4/20/88; all NIF rates for boundaries are positive. | Regional rise in water levels not accurately simulated by outflow boundary. | 43% mass imbalance. Mass imbalance indicates this is not a valid approach.<br><br>CPU time = 18 minutes | Explore changes in conductivity values. |
| 4/26/88<br>Prod. Run 14<br>JOBID 2625 | Steady state run to check effects of unsaturated conductivity value. | KRMIN = 1.0 for all NMAT. NIF rates for boundaries same as in Prod. Run 12 JOBID 2143 on 4/21/88. | N/A | 3% mass imbalance.<br><br>CPU time = 18 minutes.<br>No significant change from prior runs. | Same as above. |
| 4/29/88<br>Prod. Run 15<br>JOBID 3100 | Steady state run to check effects of increasing hydraulic conductivity values. | HCX = 500.0 ft/day<br>HCY = 500.0 ft/day<br>HCZ = 1.0 ft/day | N/A | Converged on 10 iter, 19% mass imbalance<br>IN:INF 4,543E+6<br>OUT:WELLS = 2,621E+6<br>INV = 1.061E+?<br><br>Change in S = 3.005E+8<br>No rise in heads as compared to initial conditions; H-TYP decrease approximately 3 ft. for entire simulation time. Error over 1600 cells. | Check model convergence behavior. Look at effects on interior cells. |

## THREE-DIMENSIONAL GROUNDWATER FLOW MODEL CALIBRATION HISTORY

| Date & Job I.D. | Reason for Performing Calculation | Modifications to Data Set | Assumptions Summary | Results & Comments Flow & Solute Mass Imbalance: Convergence Behavior | Recommended Next Step |
|---|---|---|---|---|---|
| 5/02/88<br>Prod. Run 16<br>JOBID 70 | High number of iterations to allow model to converge on tolerance; will use as a check to see if cells in the interior of the calculation domain are affected. | NITERS - PSI = 500 STIME (NSTI) = 365.0 PTIME (NPTI) = 365.0 uses data set as in JOBID 203, Prod. Run 6 on 3/3/88. PDR values same as those in JOBID 1787 Prod. Run 8 on 4/19/88. | N/A | Stopped iter = 500 H-TYP lowest @ iter = 14 from there-6.684E+) H-TYP increased to 1.685E+0 on iter = 500 very slowly. SUMD term did not change from iter = 84 to iter. 3% mass imbalance.<br><br>Heads risen overall by approximately 5 ft appearance of 900 contour intervals in SE as compared with original input data. | Same as above. |
| 5/13/88<br>Prod. Run 17<br>JOBID 1140 | Results of running well converged model for initial conditions; use as baseline for future runs and see if converges on tolerance. | POR values same as in run Prod. Run 8 JOBID 1787 on 4/19/88 H-TYP locations = 22,20,8. | N/A | Converged on tolerance, <1% mass imbalance. PROD data set. | Change tolerance to 1E+5 and resubmit. |
| 5/14/88<br>Prod. Run 18<br>JOBID 232 | To check effects of increasing all infiltration rate values by a third. | NIF = +30%<br>QPUMP = -10%<br>STIME (INST) = 2922.0<br>PTIME (NPTI) = 2922.0 | Increasing recharge values by a third is well within the limits of the parameter and more recharge is necessary to recharge system. | 10 iter, S = 3.985E+10/ IN:<br>INF = 4,753+6, OUT: WELLS - 2,621E+6<br>INF =1.061e+6 change in S = 1.269E+9<br>29% mass imbalance, error over 1000 cells.<br><br>Water level in H-TYP cell decreasing heads overtime very similar to input data. | N/A |
| 5/27/88<br>Prod. Run 19<br>JOBID 2554 | Transient run to see effects of using constant heads for initial conditions in ss run. | QINF + 10%, QPUMP - 10%<br>ISTUN = 2 everything else same. | Same assumption as above. | Appearance of 900 foot contour interval on Southeast boundary however flow direction not good and heads still too low. | Use an upward leakage factor from bottom of calculation domain. |

**THREE-DIMENSIONAL GROUNDWATER FLOW MODEL CALIBRATION HISTORY**

| Date & Job I.D. | Reason for Performing Calculation | Modifications to Data Set | Assumptions Summary | Results & Comments Flow & Solute Mass Imbalance: Convergence Behavior | Recommended Next Step |
|---|---|---|---|---|---|
| 6/01/88<br>Prod. Run 20<br>JOBID 124 | Try and simulate underflow from sub-unit C to effect rising water table. | Correction to CFLAG array s to m for boundary layer 3 and 1 cell in layer 8<br>L58 = .0005 ft/day<br>ISTART = 1. | Water flowing from lower units infiltrating upper units affecting rising water table. | Mass imbalance 1%, monotonicaly converging on tolerance of 1.0E+5. Infiltration contributed by leakance equals approximately 12,000 ft/day or 16% of total infiltration.<br><br>Water levels rose 5 ft; flow direction still erroneous, in some cases perpendicular to what it should be. | Increase leakage rate from bottom cells. |
| 6/02/88<br>Prod. Run 21<br>JOBID 213 | Simulate more underflow into layer 3 this run very similar to JOBID 124, Prod. Run 20 on 6/1/88. | Change L58 = .002 ft/day rate quadrupled from Run 20 ISTART = 1 same as run 20. | Rising water levels within UAU within study area can be attributed to regional stresses and be simulated as model domain. | 1% mass imbalance mass error over 3100 cells approximately 29% or 20,000 ft/day of leakance can be attributed to flux from the bottom of the domain. Appearance of 915 foot contour interval near Southeast boundary, flow direction better near East boundary, however, no place else. | Re-submit same run using initial conditions specified within the data set. |
| 6/07/88<br>Prod. Run 22<br>JOBID 544 | Perform calculations as in JOBID 213 Prod. Run 21 on 6/2/88. See recommendations for that job. | See above; this job uses initial conditions specified within the data set as opposed to a restart file. | The conditions specified within the data set are sufficient to initiate the calculations and adequately represent the initial conditions at the site. | Mass imbalance 1% or less for each switch time. Convergence good.<br><br>Very slow rise in water levels over simulation period. Water levels still too low by 15 ft. Flow direction in center of domain satisfactory; however, it is not anywhere else. | Run same data set and adjust leakance value L58 to .002 as in JOBID 213 Prod. Run 21. |

## THREE-DIMENSIONAL GROUNDWATER FLOW MODEL CALIBRATION HISTORY

| Date & Job I.D. | Reason for Performing Calculation | Modifications to Data Set | Assumptions Summary | Results & Comments Flow & Solute Mass Imbalance: Convergence Behavior | Recommended Next Step |
|---|---|---|---|---|---|
| 6/08/88<br>Prod. Run 23<br>JOBID 718 | To compare effects of increasing bottom boundary with JOBID 544 Prod. Run 22 on 6/7/88. | L58 = .002 ft/day. | Same as above. | 1% mass imbalance error over 3400 cells change in storage +6711E+7.<br><br>Appearance of 910' contour interval near southeast border. Heads rose approximately 10 feet over model domain, however, flow directions same as in JOB Prod. Run 22. Discard bottom flux as a boundary condition. | Double conductivity values to see if this will allow more water into the system instead of a flux boundary as a bottom boundary condition. |
| 6/09/88<br>Prod. Run 24<br>JOBID 908 | Check to see what effects of increasing conductivity values would have on the ending heads. | NMAT / HCX / HCY<br>1 / 134 / 134<br>2 / 48 / 48<br>3 / 48 / 48<br>4 / 48 / 48<br>5 / 361 / 361<br>6 / 22 / 22<br>7 / 22 / 22<br>L58=0.0 | Higher conductivity values are more representative of the hydrologic system in this area. | Mass imbalance 2%. Error over 3300 cells. Change in storage +2.749E+06. Converged on tolerance - good.<br><br>Compared to Prod. Run 25 JOBID 2018, heads are considerably higher - 5 feet higher overall, however, flow direction looks the same as the previous runs. Contours are being controlled by southeastern boundary fluxes. | Delete boundary fluxes to the southwest and change conductivity values back to what they were originally in order to compare with this run. |
| 6/21/88<br>Prod. Run 25<br>JOBID 2018 | Zero out flux across southeast boundary, and set all hydraulic conductivity values back to their original values (see next column). | NMAT / HCX / HCY<br>1 / 74 / 74<br>2 / 74 / 74<br>3 / 20 / 20<br>4 / 48 / 48<br>5 / 137 / 137<br>6 / 6 / 6<br>7 / 22 / 22 | The flux boundary condition for the southeast boundary does not adequately represent the system as defined by the ending heads: therefore this boundary will be changed to no flow to correspond with the observed data. | 1% mass imbalance convergency very good.<br><br>Flow direction excellent, however, 15 feet too low in the western portion to 20 feet too low in the eastern portion of the model domain. | Incorporate seasonal pumpage into model. |
| | | Changed all S's for rows 1 and 2 of layers 2 through 8 to X's (no-flow) in the C-Flag arrays. | | | |

## THREE-DIMENSIONAL GROUNDWATER FLOW MODEL CALIBRATION HISTORY

| Date & Job I.D. | Reason for Performing Calculation | Modifications to Data Set | Assumptions Summary | Results & Comments Flow & Solute Mass Imbalance; Convergence Behavior | Recommended Next Step |
|---|---|---|---|---|---|
| 6/22/88<br>Prod. Run 26<br>JOBID 2167 | To check effects of seasonal pumpage. | Add 9 additional s-times break up original 8 into 17; simulate 6 months pump on and 6 months pump off. | Seasonal pumpage is more reflective of the stresses actually affecting the hydrologic system in this area. | Pumping mass imbalance <1%, non-pumping mass imbalance <2%, convergence good for both.<br><br>Flow direction excellent, however, heads approximately 15 feet too low gradients are OK. | Increase boundary flux rate to incorporate more inflow to the system. |
| 6/24/88<br>Prod. Run 27<br>JOBID 2490 | To check effects of doubling inflow rates. | Pump same as in JOBID 2167, Prod. Run 26. Inflow boundary rates doubled for each S-time. | Underflow representing regional trends in the hydrologic gradient have a much greater impact on heads within model domain than was previously simulated. | Convergence and mass imbalance same as above.<br><br>Flow direction very similar to Prod. Run 26; head differences between layers 8 and 4 only 2' maximum, however, this may be a result of the layer chosen to plot out. Best run to date. | Change horizontal hydraulic conductivity values as a small sensitivity test. |
| 7/04/88<br>Prod. Run 28<br>JOBID 158 | To compare effect of increasing K-values only. | Same as above except decreased inflow boundary flux rates. | Same as above. | Mass imbalance 1.3% error over ~3000 cells good convergence. Simulated heads approximately 5' lower than observed. 895' contour contradictory to 900 and 890 observed contours. Sub-unit C (Layer 4) heads ~3-4' lower than sub-unit A. Same comments as above not much change. | Higher K values look promising therefore, revise dataset per the Loral No. 4 aquifer test. |
| 7/13/88<br>Prod. Run 30<br>JOBID 1397 | To use K-values from Loral 4 aquifer test; vertical K-values will not change. | Changed NMAT array to respective values to correspond with revised K's for layers A&C. Added NMAT=9 NMAT=8 sub-unit A K-value of 40 ft/day NMAT=9 sub-unit C K-value of 200 ft/day. Same boundary flux rates as in JOBID 159 Prod. Run 29 on 7/4/88. | K-values derived from Loral No. 4 aquifer test adequately represent the system. | Good convergence non-pumping mass imbalance ~2%, pumping mass imbalance <1%.<br><br>Divergent flow direction seen in 890 foot contour interval, however, ending heads still ~10-15 feet too low. | Revise model to emulate hydrologic system better. |

| THREE-DIMENSIONAL GROUNDWATER FLOW MODEL CALIBRATION HISTORY | | | | | |
|---|---|---|---|---|---|
| Date & Job I.D. | Reason for Performing Calculation | Modifications to Data Set | Assumptions Summary | Results & Comments Flow & Solute Mass Imbalance: Convergence Behavior | Recommended Next Step |
| 7/14/88<br>Prod. Run 31<br>JOBID 1549 | Refine boundary conditions to reproduce hydrologic gradients and flow regime to behave more like observed. | Change SE boundary by river to essentially no flow and modified eastern boundary to simulate more southwesterly flow. | Changes to boundary conditions are appropriate to replicate hydrologic system. | Pumping mass imbalance <1%; non-pumping mass imbalance ~2% error over ~1000 cells.<br><br>Pumping time-steps take water from storage and during non-pumping timesteps water is put into storage. Flow direction along Gila River are much better behaved. Heads are still too low same as in Prod. Run 30. | Still lacking enough water to effect water level rises as seen in sub-unit A over time. Therefore, need to introduce more water into the system. |
| 7/18/88<br>Prod. Run 32<br>JOBID 1894 | To refine inflow boundary conditions for sub-unit "A" represented by layers 8-5. | Double rates for locations 61-65 in NIF array. These rates will correspond to boundary cells that represent flux across sub-unit A. | Same as above. | Mass imbalance for all timesteps ~2%.<br><br>Gradient and flow direction are good, however, heads approximately 7-10' too low in vicinity of UPI and 10-15' too low in vicinity of Loran and the Airport. This run was presented to Project Committee at 7/88 meeting. | Further refine boundary conditions. |
| 7/28/88<br>Prod. Run 33<br>JOBID 3248 | Re-run JOBID 2490 Prod. Run 27, dated 6/24/88. This is the closest match between simulated and observed values to date. | HCX and HCY values same as in Prod. Run 31 JOBID 1549 on 7/14/88 along with inflow boundary conditions for southwest boundary where it is set at no-flow. | Same as in Prod. Run 27 JOBID 2490. | Mass imbalance 1.5% for all timesteps; error over 1500 cells.<br><br>Results same as in Prod. Run 33. Best match to date. | Check vertical hydraulic conductivity values. |
| 8/01/88<br>Prod. Run 34<br>JOBID 153 | To see what effects changing vertical conductivity values will have on pumping effects on sub-units B/C. | Change HCZ values for sub-unit B & C decrease to .01 ft/day. | Less vertical connection between layers - assume sub-unit B behaves more like true confining unit. | Mass imbalance ~1% for all timesteps; error over ~1500 cells. Positive change in storage for each timestep. Good convergence.<br><br>Good match with field data in vicinity of GAC however, 5-7 feet too high in area of UPI. | Increase vertical K's to set limits. |

**THREE-DIMENSIONAL GROUNDWATER FLOW MODEL CALIBRATION HISTORY**

| Date & Job I.D. | Reason for Performing Calculation | Modifications to Data Set | Assumptions Summary | Results & Comments Flow & Solute Mass Imbalance: Convergence Behavior | Recommended Next Step |
|---|---|---|---|---|---|
| 8/09/88<br>Prod. Run 35<br>JOBID 1368 | To give upper boundary on the vertical conductivity effects. | Change HCZ values for sub-unit B/C increase to .1 ft/day. | N/A | Mass imbalance ~1% per all timesteps. Good convergence.<br><br>Results are very similar to Prod. Run 33. Good match of field data with simulated in vicinity of UPI, but heads too low near GAC.<br>Results indicate vertical K's should be somewhere between .1 and .01 ft/day. | Decrease flux across southwest boundary to better simulate divergent equipotential lines. |
| 8/10/88<br>Prod. Run 36<br>JOBID 1543 | Reduce flux across southeast boundary to better simulate divergent gradients. | Change boundaries to no-flow for layers 7 and 8 at boundary cell locations 20-35. | N/A | Mass imbalance ~1% for all timesteps. Good convergence.<br><br>Contours near southeast boundary show diverging equipotential lines. | Check effects of localized pumping. Are hydrographs at cluster sites representative of regional or local trends. Also amount of flux across eastern boundary of sub-unit C probably dampens pumpage effects near that boundary. |
| 8/11/88<br>Prod. Run 37<br>JOBID 1649 | Half flux across southeastern boundary in sub-unit C. | Halved flux boundaries for values in locations 61-64, 66, 67, 71, 72, and 74 in the NIF array. | Less inflow to C sub-unit | Mass imbalance pumping timesteps <1%: for non-pumping timesteps <2% error over 500 cells. Good convergence.<br><br>Mass in storage is negative for pumping time-step and positive for non-pumping time-step. Ending heads ~15 to 20 feet too low. | Boundary flux rates too low - this is not a solution to the problem. Will use vertical conductivities to decrease flow into sub-unit C. |
| 8/15/88<br>Prod. Run 18<br>JOBID 1877 | Revise dataset per previous 4 runs. | Revise pumping and recharge data arrays to be original values.<br><br>Change boundary flux rates to what they were before Prod. Run 37. | N/A | Mass imbalance >8% unacceptable. Good convergence.<br><br>Ending heads too high by 13 to 15' in eastern portion of model domain. | Revise dataset per best runs to date, i.e., Prod. Runs 27 and 34. |

| THREE-DIMENSIONAL GROUNDWATER FLOW MODEL CALIBRATION HISTORY | | | | | |
|---|---|---|---|---|---|
| Date & Job I.D. | Reason for Performing Calculation | Modifications to Data Set | Assumptions Summary | Results & Comments Flow & Solute Mass Imbalance: Convergence Behavior | Recommended Next Step |
| 8/29/88 Prod. Run 39 JOBID 3812 | Basis of scenarios. | STC for sub-C = 5.0E-3<br><br>Change flux rates (out) to correspond with rates in Prod. Runs 27 and 34. | N/A | Mass imbalance <1% pumping timesteps <5% non-pumping timesteps. Ending heads too low 10-12' in eastern portion of model domain. | Pick best runs to date and use for remedial alternatives. |
| 9/01/88 Prod. Run 40 JOBID 1620 | Basis for remedial alternatives. | Same as Prod. Run 34 - Best match with field data to date. | N/A | N/A | N/A |

# APPENDIX C:

## Three-Dimensional Groundwater Flow Model Sensitivity Analysis

| THREE-DIMENSIONAL GROUNDWATER FLOW MODEL SENSITIVITY ANALYSIS | | | | | |
|---|---|---|---|---|---|
| *Date Job ID/Data Set Name* | *Parameters Evaluated* | *Base Case Parameter Value* | *Sensitivity Parameter Value* | *Comments* | *Mass Error/ Mass Inflow (%)* |
| 1/04/89<br>Job ID 0193<br>PORC4 | Porosity<br>Sub-unit "C" | .35 | .50<br>(1.43x Base Case) | Increasing the porosity in sub-unit "C" had a moderate effect upon the model, sub-unit "A" heads rose from 1' in the western boundary and central position and 2' in the eastern boundary. Heads in sub-unit "C" rose from 2' in the western boundary to 4' in the central portion and eastern boundary | 1.9 |
| 1/04/89<br>Job ID 0296<br>HCZA3 | Vertical (Z)<br>Hydraulic<br>Conductivity<br>Sub-unit "A" | .74<br>(.1x Base Case) | .074<br>(.1x Base Case) | Decreasing the Vertical Hydraulic Conductivity of sub-unit "A" one order of magnitude had a negligible effect on sub-unit "A" heads by only increasing them in the central portion 1/4'. Heads in sub-unit "C" decreased 2' in the western boundary and remained the same in other portions of the model. The model displays very little sensitivity to vertical hydraulic conductivity in sub-unit "A." | 1.9 |
| 1/05/89<br>Job ID 0395<br>HCZA4 | Vertical (Z)<br>Hydraulic<br>Conductivity<br>Sub-unit "A" | .74 Ft/Da | 7.4 Ft/Da<br>(10x Base Case) | Increasing the vertical hydraulic conductivity of sub-unit "A" an order of magnitude increased the heads in sub-unit "A" 2' in the eastern boundary of the model, 1-2' in the central portion, and .5' in the western boundary. Sub-unit "C" heads rose 2' in the western boundary and 4' in the central and eastern portions of the model. The model reflects results that are fairly insensitive to an order of magnitude increase in vertical hydraulic conductivity in sub-unit "A." | 1.9 |
| 1/06/89<br>Job ID 0778<br>HCZC3=.001 | Vertical (Z)<br>Hydraulic<br>Conductivity<br>Sub-unit "C" | .01 Ft/Da | .001 Ft/Da<br>(.1x Base Case) | Decreasing the vertical conductivity of sub-unit "C" an order of magnitude resulted in heads rising in sub-unit "C." At the western boundary (NW corner of model domain) the heads rose 4-6' with the orientation of the equipotential lines rotating from westerly to south-westerly, some mounding occurred in the NE ¼ of the western ½ of the model domain. In the eastern part of the model flow fields were similar to the base case but heads were from 4-8' higher. Sub-unit "A" reflected a rise in heads of 4' in the west, 4-6' in the central portion and 6' in the eastern portion. The model displays moderate sensitivity to lowering the vertical hydraulic conductivity. | 1.9 |
| 1/06/89<br>Job ID 0779<br>HCZC4=13.7 | Vertical (Z)<br>Hydraulic<br>Conductivity<br>Sub-unit "C" | .01 Ft/Da | 13.7 Ft/Da<br>(1370x Base Case) | Increasing the vertical conductivity of sub-unit "C" in general causes the heads to fall a foot in the west, rise 2-3' in the central area and remain the same in the eastern portion of the model. When vewing the vertical sections the most dramatic effect is that there is no longer any vertical gradient in sub-unit "C." The water fluxing into the model from the eastern boundary is equally distributed vertically with no downward or upward gradients. This results in the lower portions of sub-unit "C" reflecting greater heads and the heads of sub-unit "A" being 2' lower in the west, 4' lower in the center and 1' lower in the eastern boundary of the model. The models sensitivity to a dramatic change (Base x1370) is minute. | 1.9 |

| THREE-DIMENSIONAL GROUNDWATER FLOW MODEL SENSITIVITY ANALYSIS | | | | | |
|---|---|---|---|---|---|
| **Date Job ID/Data Set Name** | **Parameters Evaluated** | **Base Case Parameter Value** | **Sensitivity Parameter Value** | **Comments** | **Mass Error/ Mass Inflow (%)** |
| 12/09/88 Job ID 1538 STYA1 | Specific yield Sub-unit "A" | .10 | .05 (.5x Base Case) | Halving the specific yield caused sub-unit "A" heads to rise 1-2'. Such a change would be expected. A 1' drop in heads was observed in sub-unit "C" in the central portion and western part of the model. The model does not reflect extreme sensitivity to halving the specific yield in sub-unit "A" and running the changed parameter for 4 years. | 1.6 |
| 12/12/88 Job ID 1898 STCC1 | Storativity Sub-unit "C" | .005 | .00005 (.01x Base Case) | Reducing the storativity of sub-unit "C" by 100 times dramatically affected the heads in sub-unit "C." Heads rose in the eastern boundary 26-28', a rise in the central portion of 22-24' was detected and a rise of 8' to the west. Considering that the specified flux is supplying more water from the eastern boundary than leaving the western boundary the difference in heads (east vs west) seems reasonable. Sub-unit "A" also reflected the reduced storage of the total system - heads rose 6-8'. The model demonstrates that use of storativity of .00005 for sub-unit "C" is unacceptable. | 4.3 |
| 12/13/88 Job ID 2090 STCC2 | Storativity Sub-unit "C" | .005 | .05 (10x Base Case) | Increasing the storativity one order of magnitude lowered the heads 4-6' in sub-unit "C" and 0-4' in sub-unit "A" reflecting the lower acceptable range of storativity to be .05. It also demonstrates that changing the storativity parameter a whole order of magnitude did not dramatically affect the model. | 1.4 |
| 12/23/88 Job ID 3358 PORC3 | Porosity Sub-unit "C" | .35 | .05 (.143x Base Case) | Decreasing the porosity of sub-unit "C" resulted in an expected rise in water levels. Water levels in sub-unit "C" rose 3-5'. Water levels in sub-unit "A" rose 1-2'. The effect of reducing porosity by a seventh was minimal. | 1.9 |
| 12/23/88 Job ID 3357 HCXYB2 | X-Y Horizontal Hydraulic Conductivity Sub-unit "B" | 20, 34, 48 Ft/Da | 40, 68, 96 Ft/Da (2x Base Case) | Doubling the hydraulic conductivity of sub-unit "A" had little affect on the model. Sub-unit "C" virtually remained the same. The heads in sub-unit "A" dropped 1' in the eastern boundary, remained the same in the central portion and rose 1' in the western portion of the model. The model is fairly insensitive to doubling the Horizontal Hydraulic Conductivity from 20, 34 and 48 Ft/Da to 40, 68 and 96 Ft/Da. | 1.6 |
| 12/27/88 Job ID 3637 HCXYB1 | X-Y Horizontal Hydraulic Conductivity Sub-unit "B" | 20, 34, 48 Ft/Da | 10, 17, 24, Ft/Da (.5x Base Case) | Halving the horizontal hydraulic conductivity of sub-unit "B" resulted in 1-2' rise in sub-unit "C." Sub-unit "A" heads rose from 5' in the eastern boundary to 1' in the western boundary. The model reflected a moderate sensitivity to reducing sub-unit "B" hydraulic conductivity by a factor of 2. | 1.8 |
| 12/27/88 Job ID 3705 PORA3 | Porosity Sub-unit "A" | .35 | .05 (.143x Base Case) | Decreasing the porosity of sub-unit "A" to .05 from .35 did not dramatically affect the heads in units "A" or "C." Sub-unit "A" reflected changes from a drop of 1' in the eastern boundary to a rise of 1' in the west. Sub-unit "C" demonstrated heads rising from .5-1'. | 1.9 |

| THREE-DIMENSIONAL GROUNDWATER FLOW MODEL SENSITIVITY ANALYSIS | | | | | |
|---|---|---|---|---|---|
| *Date Job ID/Data Set Name* | *Parameters Evaluated* | *Base Case Parameter Value* | *Sensitivity Parameter Value* | *Comments* | *Mass Error/ Mass Inflow (%)* |
| 11/15/88<br>Job ID 1826<br>Prod. 3A | N/A<br>Base Case | N/A<br>Base Case | N/A<br>Base Case | Base Case | 1.9 |
| 11/21/88<br>Job ID 3352<br>HCXYA2 | X-Y<br>Hydraulic<br>Conductivity<br>Sub-unit "A" | 74 Ft/Da | 148 Ft/Da<br>(2x Base Case) | Doubling the hydraulic conductivity of sub-unit "A" most dramatically affects the boundaries in the east and west where the greatest volumes of water are entering model (east) and leaving the model (west). Subsequently, the gradient is flattened in sub-unit "A." Heads fall 6-8' in the east and rise 8-10' in the west. Sub-unit "C" also reflects a rise in heads of 2-4' in the east and a 4-6' rise in the west. The model shows a marked response to doubling the hydraulic conductivity in sub-unit "A." | 1.9 |
| 11/30/88<br>Job ID 0037<br>HCXYA1 | X-Y<br>Hydraulic<br>Conductivity<br>Sub-unit "A" | 74 Ft/Da | 37 Ft/Da<br>(.5x Base Case) | Sub-unit "A" reflects the greatest changes hear specified flux boundaries. When the hydraulic conductivity of sub-unit "A" is halved, the gradient is steepended, the heads fall from 6-8' in the west and rise 8-10' in the east, whereas the heads only rise 1-2' in the center of the model. Very little effect is detected in sub-unit "C", the western boundary is 3-4' lower than the base case. The model is very sensitive to halving the hydraulic conductivity in sub-unit "A." | 1.7 |
| 12/02/99<br>Job ID 0330<br>HCXYC2 | X-Y<br>Hydraulic<br>Conductivity<br>Sub-unit "C" | 137 Ft/Da | 274 Ft/Da<br>(2x Base Case) | The same effect is seen as demonstrated in earlier run #3352 (HCXYA2) when the conductivity was raised in the "A" sub-unit. In this run sub-unit "C" hydraulic gradient is flattened due to the increased conductivities. The heads in sub-unit "C" in the east are 6-8' lower and in the west 8-10' higher, and are the same in the central portion of the model. Sub-unit "A" reflects an overall rise of 2-4'. The model is sensitive to horizontal hydraulic conductivity. | 2.0 |
| 12/06/88<br>Job ID 0859<br>STYA2 | Specific yield<br>Sub-unit "A" | .10 | .20<br>(2x Base Case) | A 1' drop in the heads occurred in most areas of sub-unit "A" when its specific yield was doubled. Heads rose 3-5' in sub-unit "C." The model is moderately sensitive to a change in specific yield. | 1.7 |
| 12/09/88<br>Job ID 1472<br>HCXYC1 | X-Y<br>Hydraulic<br>Conductivity<br>Sub-unit "C" | 137 Ft/Da | 68 Ft/Da<br>(.5x Base Case) | Halving the hydraulic conductivity in sub-unit "C" propagated the expected results of steeping the hydraulic gradient in sub-unit "C." A 22-24' rise in water levels in the east was observed, a 4' rise in the central portion and a 0-2' rise in the western boundary. Sub-unit "A" reflected a 2-4' rise in the east and center with the heads being the same in the western boundary. Again it was demonstrated that the model is very sensitive to changes in horizontal conductivities in sub-unit "C." | 1.3 |

## Appendix D:

Memorandum Regarding Pumpage Rates Used to Calibrate the PGA Groundwater Flow and Contaminant Transport Model

ARIZONA
DEPARTMENT
OF WATER
RESOURCES

Rose Mofford, Governor
N. W. Plummer
Director

15 South 15th Avenue
Phoenix, Arizona 85007

**MEMORANDUM**

**TO:** PGA Project Committee

**FROM:** Greg Bushner GB

**DATE:** May 10, 1989

**SUBJECT:** Pumpage rates used to calibrate the PGA groundwater flow and contaminant transport model


Summary

The PGA groundwater flow and contaminant transport models were used to determine the effectiveness of various remedial alternatives as developed by the EPA as part of the Endangerment Assesment for the PGA Superfund site. These alternatives were evaluated under different groundwater management scenarios. The contaminant transport model results as reported in Appendix V of the PGA RI/FS report illustate how effective the remedial alternatives were in removing the contaminants for each of the groundwater management scenarios.

A disparity was noted between pumpage rates used in the model calibration versus pumpage rates used in the projection scenarios. Correcting the pumpage rates used in the calibration runs had a minimal effect on the outcome of the projection runs. The change in the overall removal of contaminants for the alternatives was about one percent and can be considered insignificant for the purposes stated above. The flow directions, hydraulic gradients and groundwater velocities remain virtually unchanged for both the calibration and projection runs. This is probably due to the fact that the change in head was uniform over the model domain, so hydraulic gradients, flow directions, and velocities remained virtually unchanged. Therefore the integrity and predictive capabilities of the model remain intact.

**Problem:**

In order to simulate the effects of seasonal pumpage as shown in hydrographs from monitor well clusters at the Phoenix-Goodyear Airport Superfund site, 6 month stress periods were incorporated in the model to represent non-pumping and pumping seasons during the model calibration process. When this was done the rates used to represent groundwater pumpage from wells remained the same as when yearly stress periods were used. In effect this meant that the wells were pumping only half the volume of water actually withdrawn. The projection runs, however, were not divided into 6 month stress periods due to the long execution times (24 to 48 hours). The projection runs, therefore, used rates that simulated the total volume of water actually withdrawn from the pumping wells within a year's time.

**Solution:**

The solution to this problem consisted of a sensitivity test to determine the effects of using the corrected (doubled) rates in the final data set used in the calibration runs. The results from the calibration run were used as a basis to evaluate the projection runs (Base Cases 1,2, & 3). The results from the data set for both the calibration and projection runs that included the doubled pumpage rates will be referred to as the test case. For the projection run, Base Case 2 (Alternative 3), most likely the preferred alternative, was used to evaluate the test case. This solution was derived to assess the effects of the doubled pumpage rates on the final calibration run and on a projection run in order to determine if it would be necessary to reevaluate the percent contaminant removed in all three Base Cases and the respective alternatives.

**Analysis:**

Base Case

Sub-Unit A: Ending heads were plotted for each stress period from a seasonal equivalent of August 1986 to August 1987 (the same time period as presented in the PGA RI/FS report Appendix V). The gradients and flow directions are essentially the same, i.e. flow directions are to the west-southwest overall and to the northwest in the vicinity of the UPI facility. Mass imbalance error improved somewhat due to the additional pumpage to balance the inflows to the model. Figures 1 through 5 illustrate the comparison between the final calibration run, observed data, and the test case for sub-unit A. Heads were lowered over the model domain and ranged from 5 to 12 feet lower than the observed data in the vicinities of the PRP facilities.

Sub-Unit B/C: The ending heads from sub-unit B/C were lowered over the model domain and ranged from 5 to 10 feet lower than the final calibration run. Figures 6 through 10 illustrate the comparison between the calibration run, observed data, and the test case for sub-unit B/C. Very little seasonal variation can be seen in the predicted (both calibration and test cases) as compared to the observed data. Therefore in the pumping stress period heads agree with the observed data within approximately 1 to 2 feet. However, during the non-pumping season predicted heads are 10-13 feet lower than observed. This is one of the overall limitations of this model.

## Projection Run

A run was made from the test case (pumpage doubled) ending heads to ascertain the effects on a projection run. This run uses the ending heads from the double pumpage calibration run as starting heads for the projection run for 21 years into the future (see figures 11 through 14). The projection run is based on Base Case 2, Alternative 3 (most likely the preferred alternative). The largest difference in the projected contaminant distribution is a change in the 1 ppb isopleth in sub-unit A; however, the predicted percent TCE removed differed by only 1%. Projected TCE concentrations are essentially the same for sub-unit B/C contamination (refer to figures 13 and 14). The results indicate that the overall heads were lowered for the test case by 10 feet for sub-unit A and approximately 7 feet for sub-unit B/C over the model domain as a whole. All other parameters including flow directions, gradients and groundwater flow velocities remain virtually the same (refer to figures 11 and 12).

## Conclusions:

From this several conclusions can be made:

1. Doubling the pumpage doès not have a great effect on the groundwater flow directions, gradients or velocities (outside the direct vicinity of the pumping wells). It also improves the overall mass imbalance error of the model. The water budget is more balanced.

2. The effect of doubling the pumpage resulted in lowering heads from 5-10 feet depending on the location within the model domain. This in effect worsens the calibration match between observed and predicted data by 5-7 feet. (See figures 1 through 10).

3. The pumpage effects do not negatively or positively impact the seasonal variation in heads as the calibrated model is insensitive to these seasonal variations.

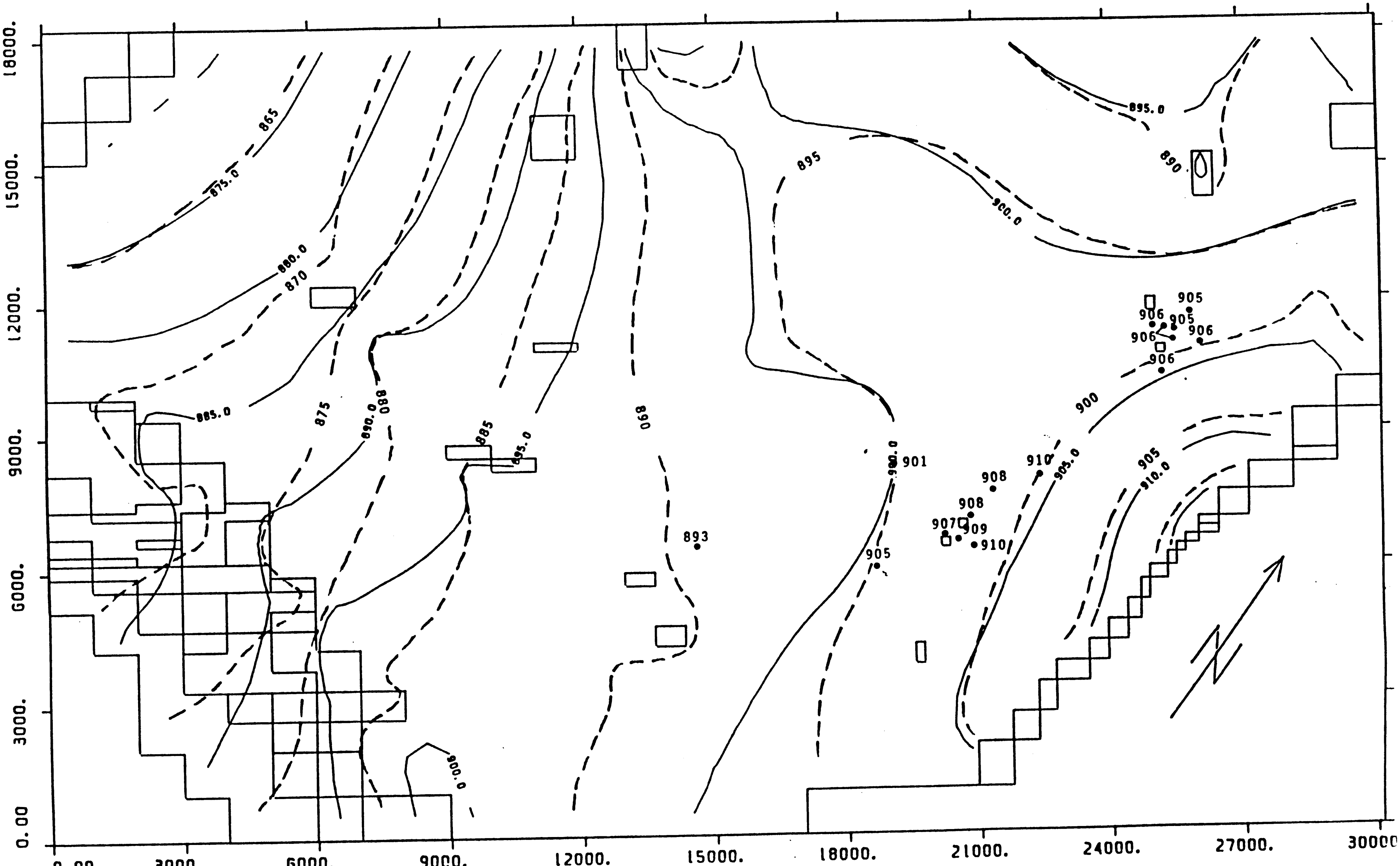
4. The projection run based on the test case indicates that doubling the pumpage essentially lowers the heads within the model domain by approximately 10 feet by 2008.

5. The effects on the contamination are minimal and results in a 76% reduction in contamination as compared with a 75% reduction as stated in the PGA RI/FS report Appendix V (pumpage halved). This is probably due to the fact that the change in head was uniform over the model domain and therefore hydraulic gradients and flow directions were virtually unchanged in the vicinity of the plume as pumpage was doubled or halved.

**Recommendations:**

The contaminant transport portion of the model is insensitive to drastic changes in pumpage from the existing wells within the model domain. The projection runs remain valid and should be kept as presented in the PGA RI/FS report Appendix V. The calibration section of the report should state this problem and the information in this memo should be included in the final PGA RI/FS report Appendix V.

Figure 1



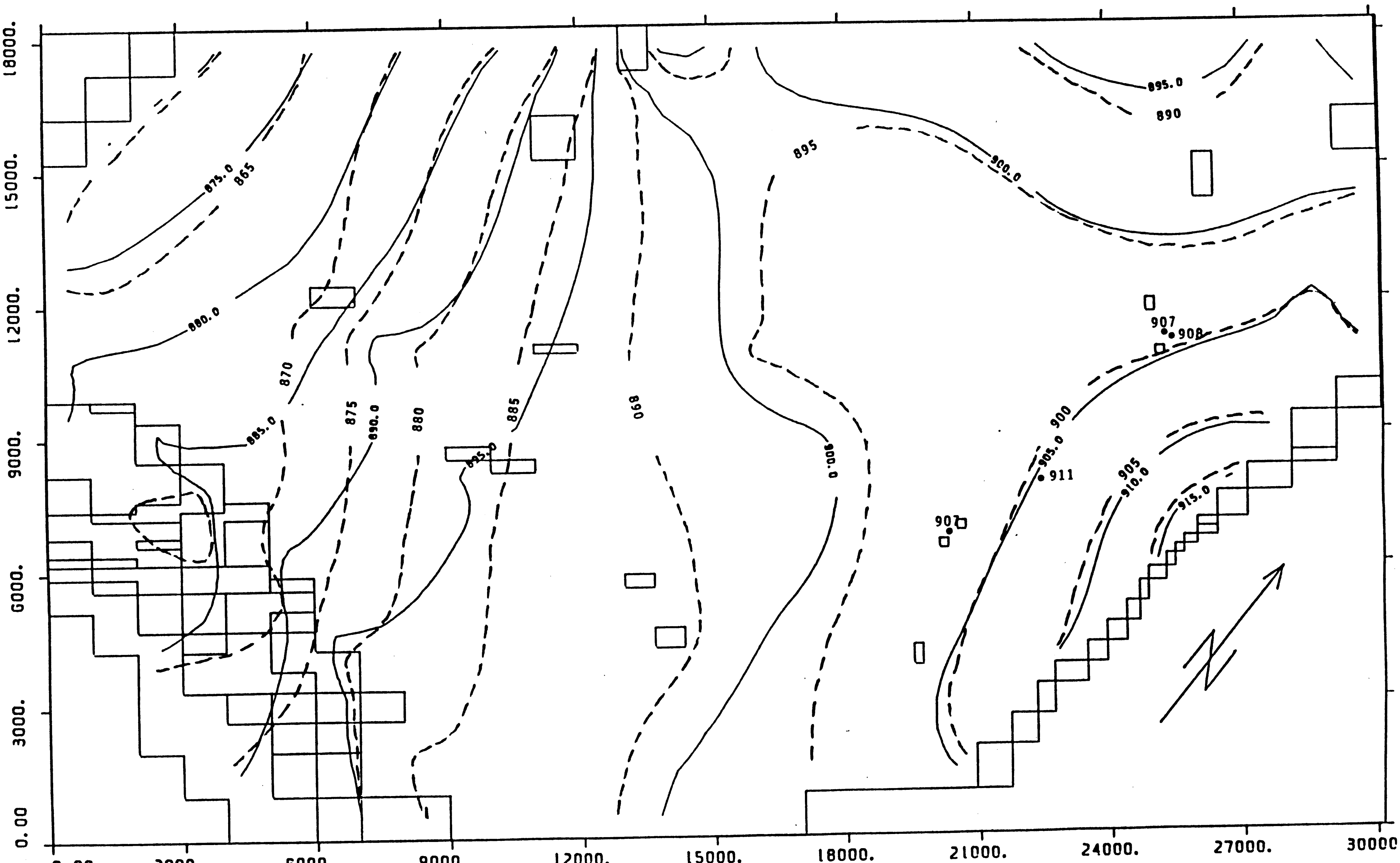

Scale 1" = 3000'

Explanation:

• Field Data-Water Level Elevation Feet Above Mean Sea Level

—900- Predicted Hydraulic Head ---900 - Test Case Predicted Hydraulic Head

Figure 2



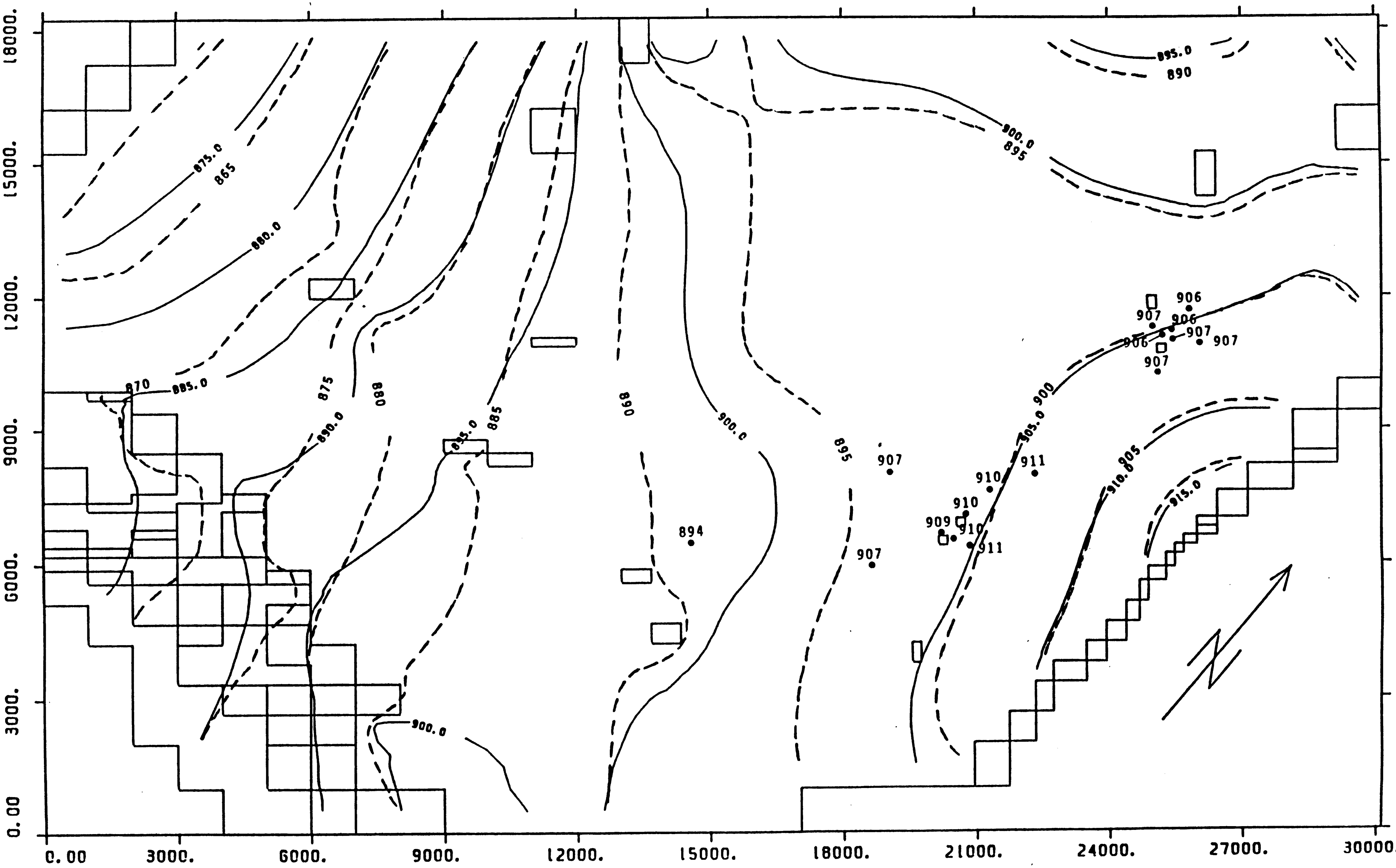

Scale 1" = 3000'

Explanation:

• Field Data-Water Level Elevation Feet Above Mean Sea Level

900 - Predicted Hydraulic Head ——900 - Test Case Predicted Hydraulic Head

Figure 3

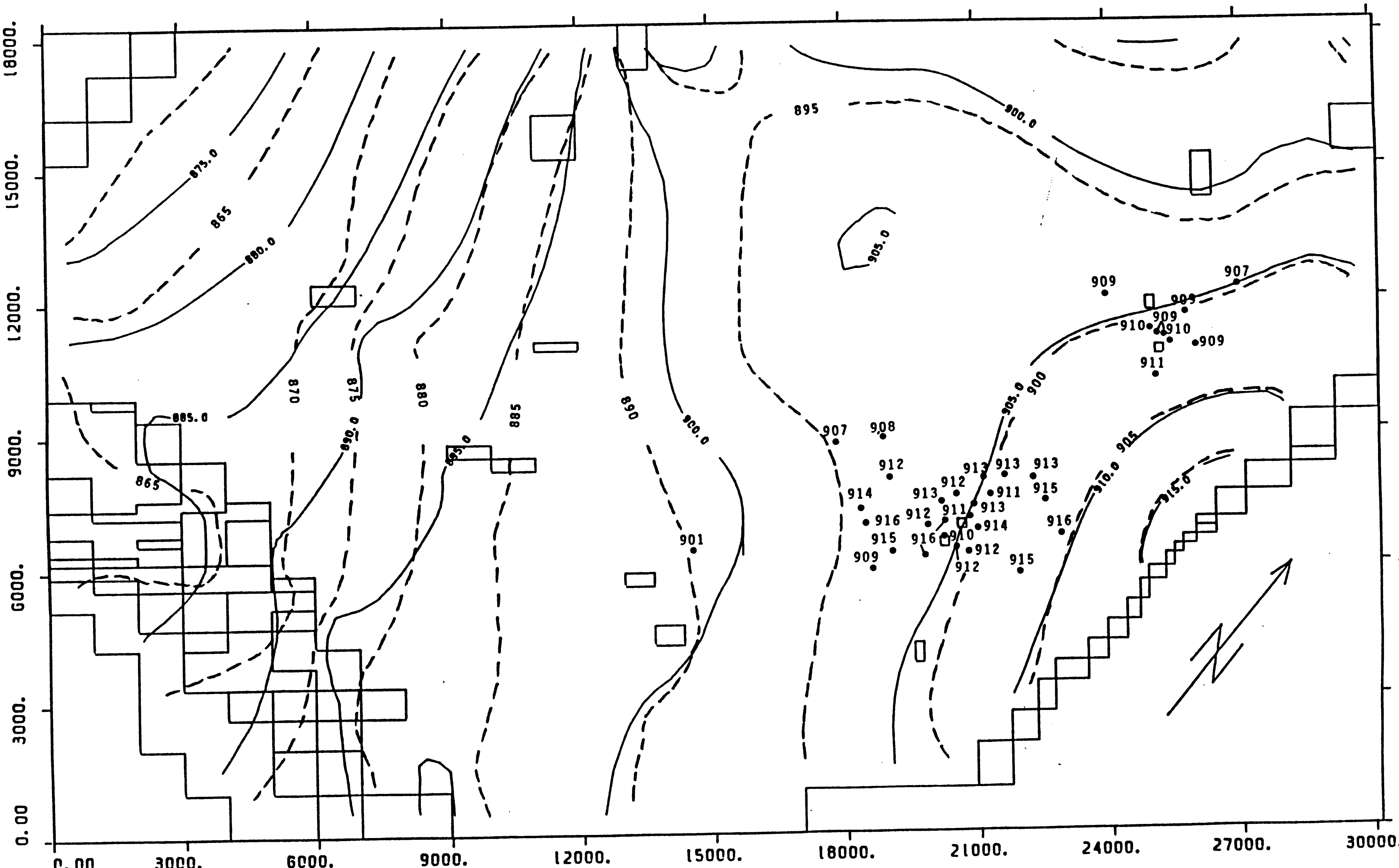



Explanation:

• Field Data-Water Level Elevation Feet Above Mean Sea Level

900– Predicted Hydraulic Head ---900 - Test Case Predicted Hydraulic Head

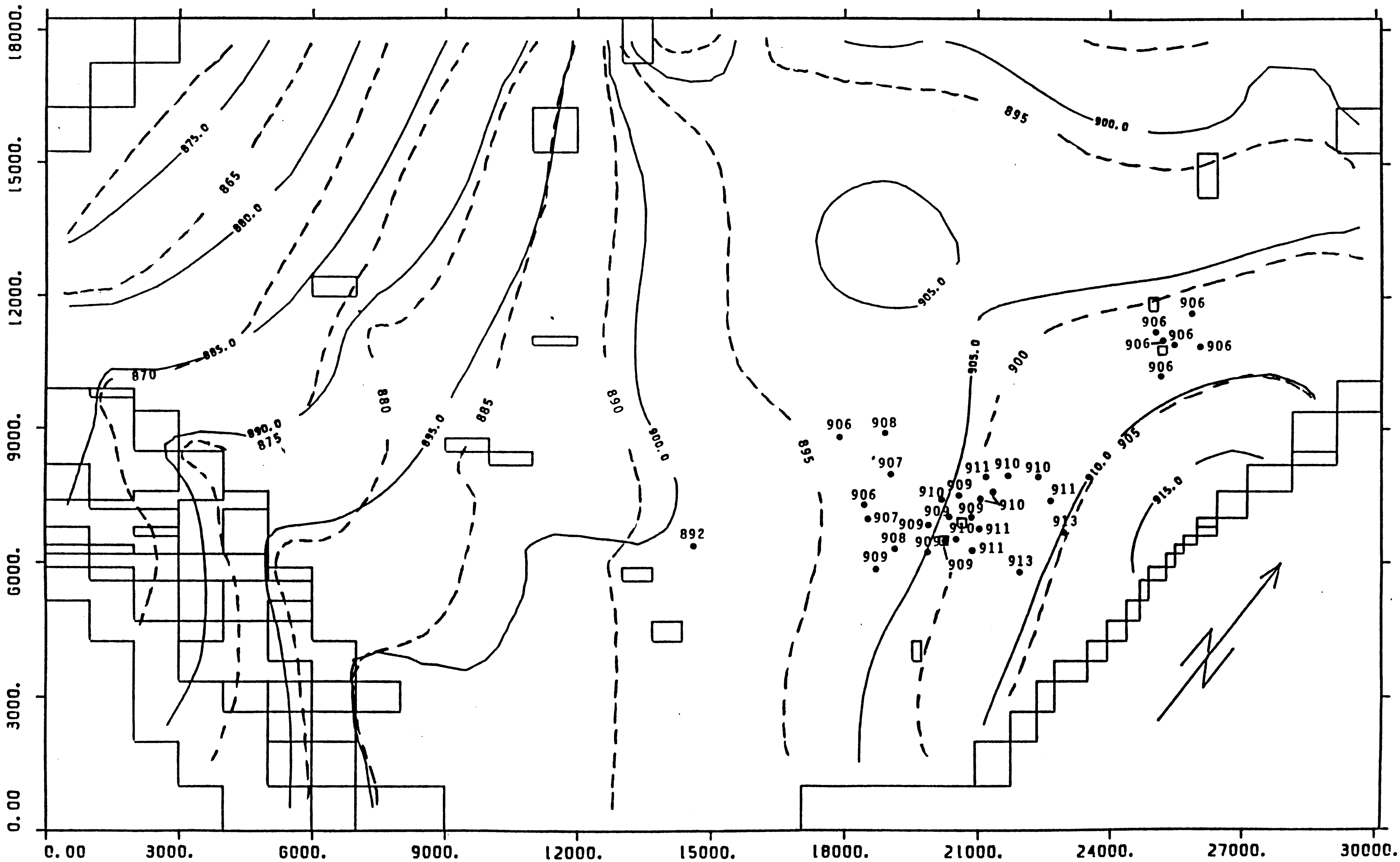
Figure 4




Explanation:

• Field Data-Water Level Elevation Feet Above Mean Sea Level

Figure 5



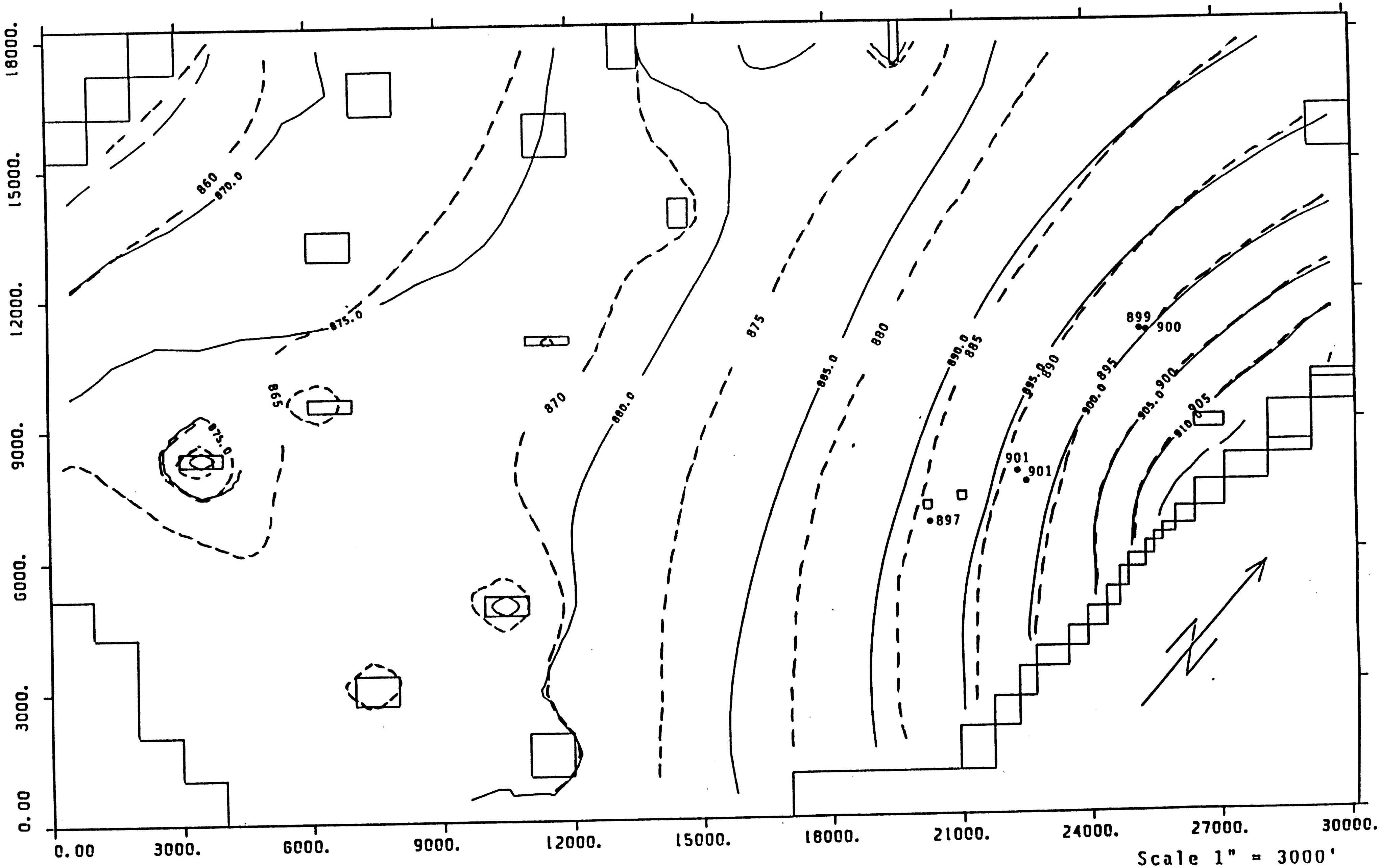

Scale 1" = 3000'

Explanation:

• Field Data-Water Level Elevation Feet Above Mean Sea Level

—900— Predicted Hydraulic Head ---900 - Test Case Predicted Hydraulic Head

Figure 6

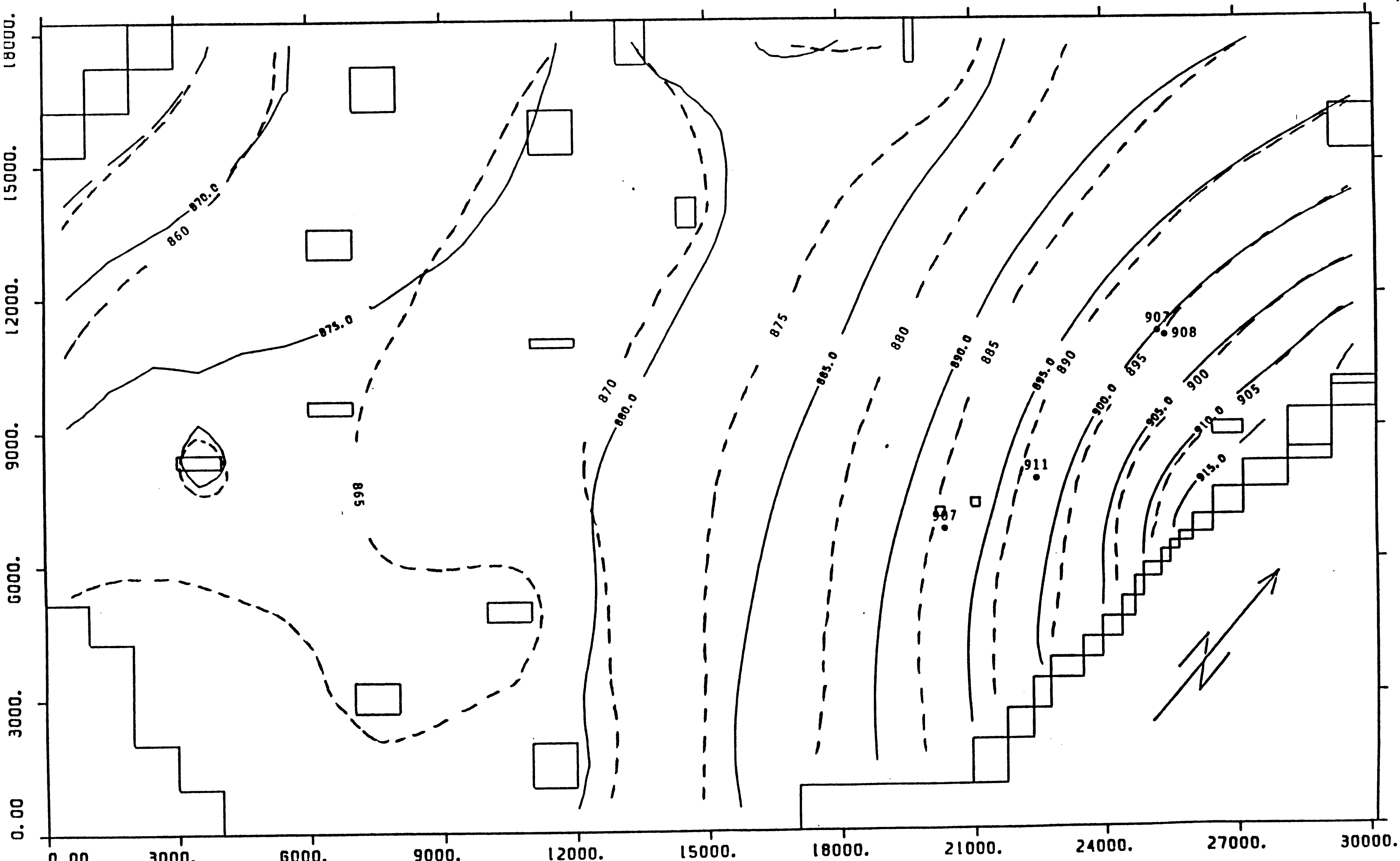



Explanation:

• Field Data-Water Level Elevation Feet Above Mean Sea Level

-900- Predicted Hydraulic Head ---900 - Test Case Predicted Hydraulic Head

Figure 7

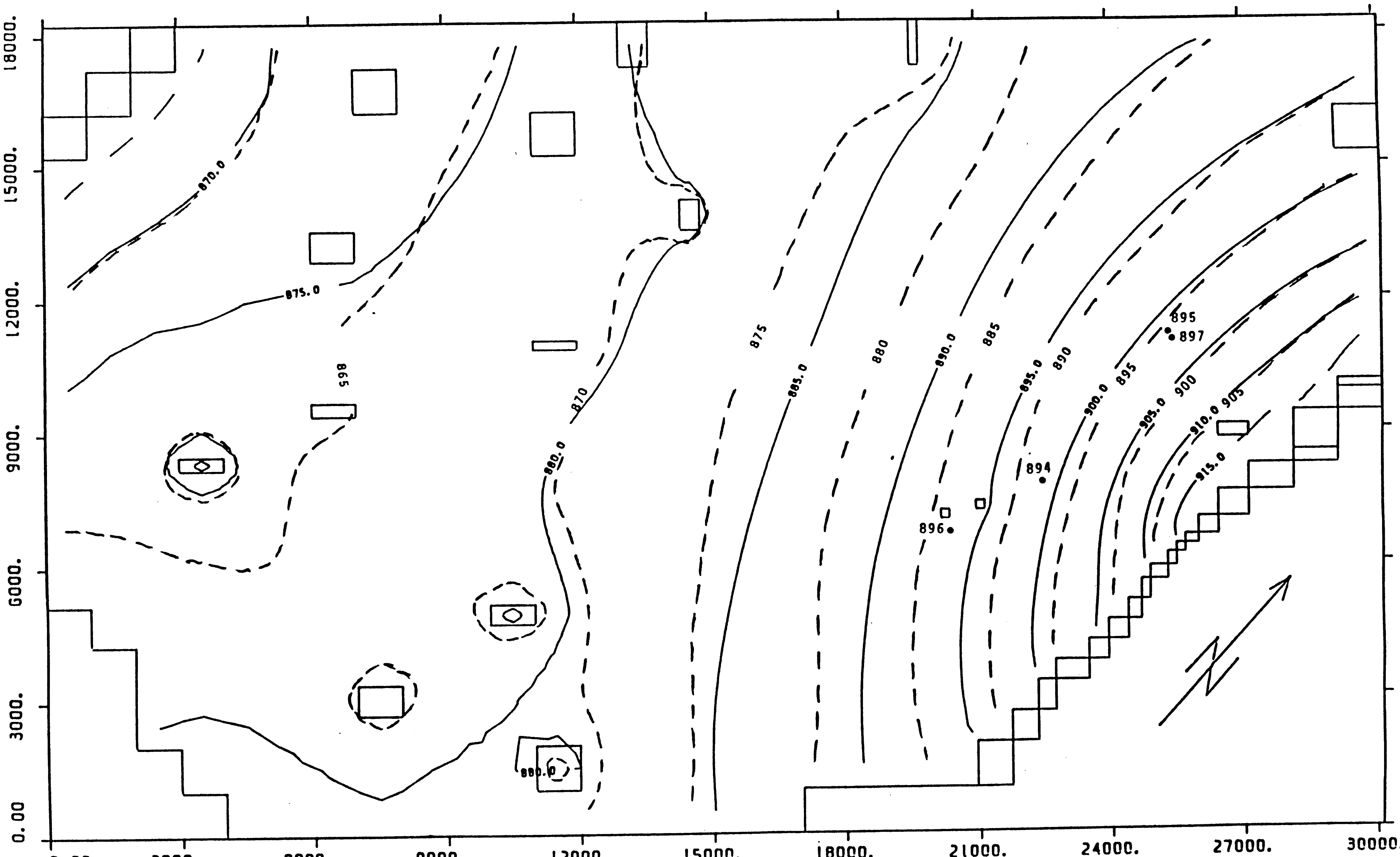



**Explanation:**

• Field Data-Water Level Elevation Feet Above Mean Sea Level

— Predicted Hydraulic Head — 900 - Test Case Predicted Hydraulic Head

Figure 8



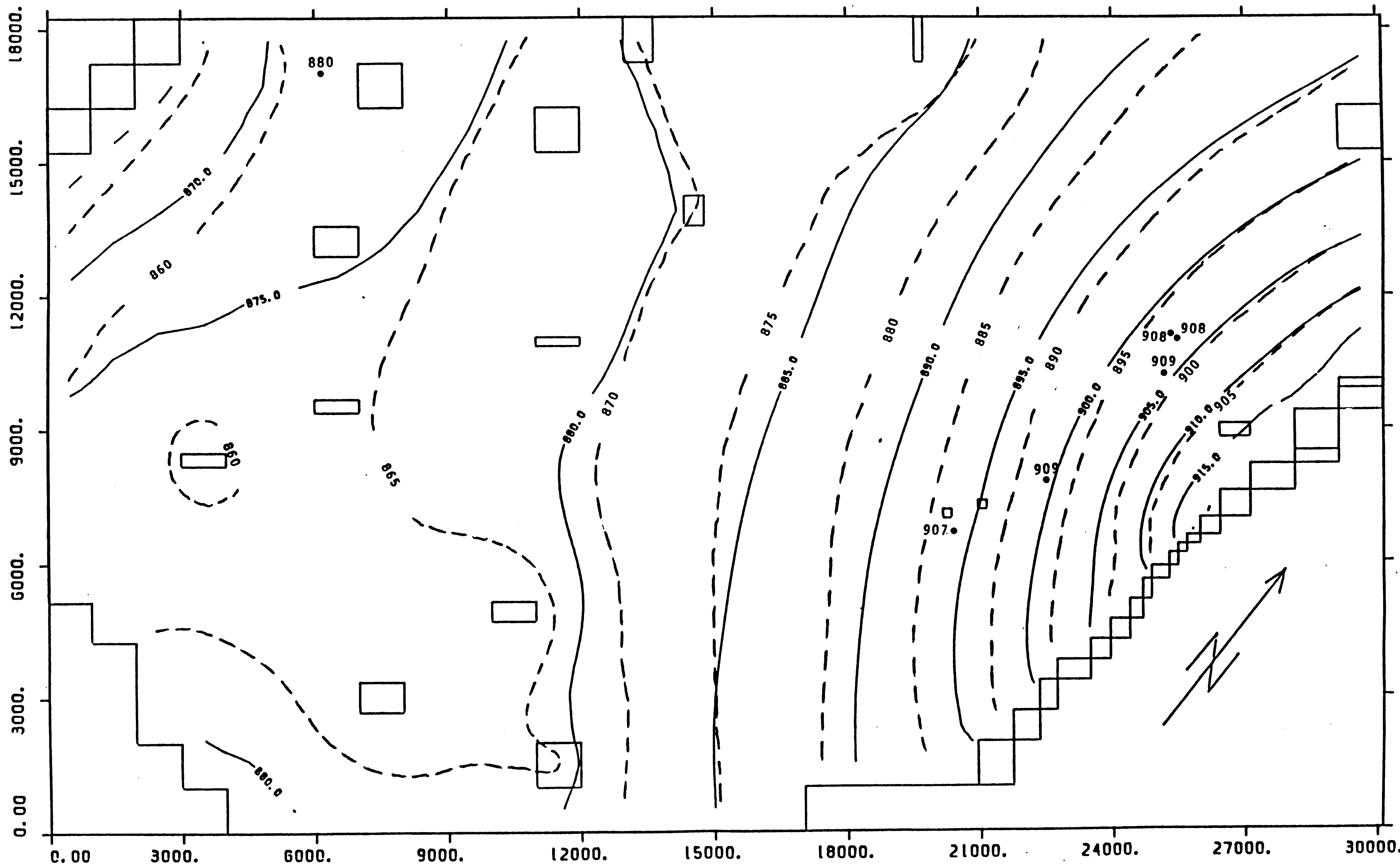

Scale 1" = 3000'

Explanation:

• Field Data-Water Level Elevation Feet Above Mean Sea Level

—900— Predicted Hydraulic Head   ---900 - Test Case Predicted Hydraulic Head

Figure 9

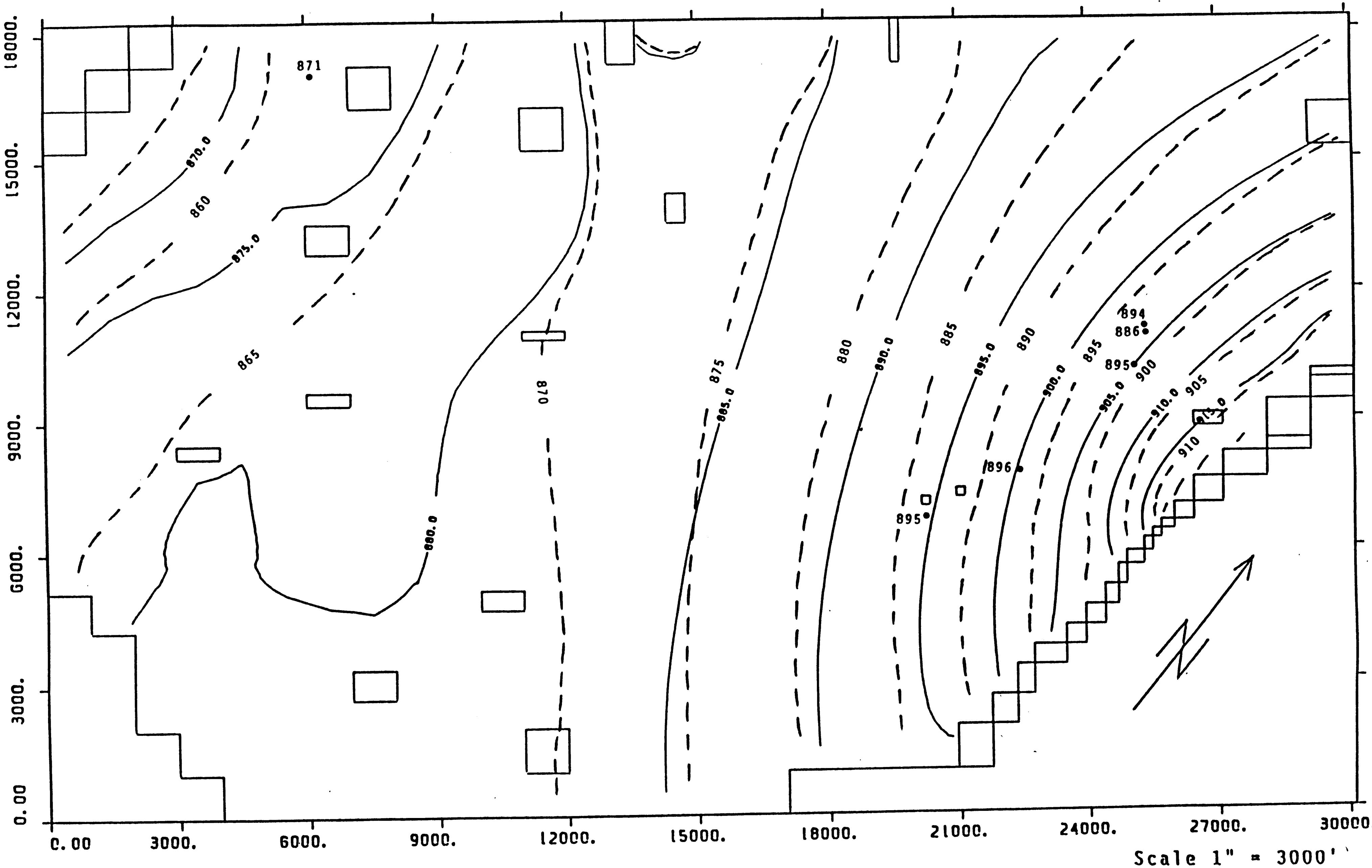



Explanation:

• Field Data-Water Level Elevation Feet Above Mean Sea Level

—900— Predicted Hydraulic Head ---900 - Test Case Predicted Hydraulic Head

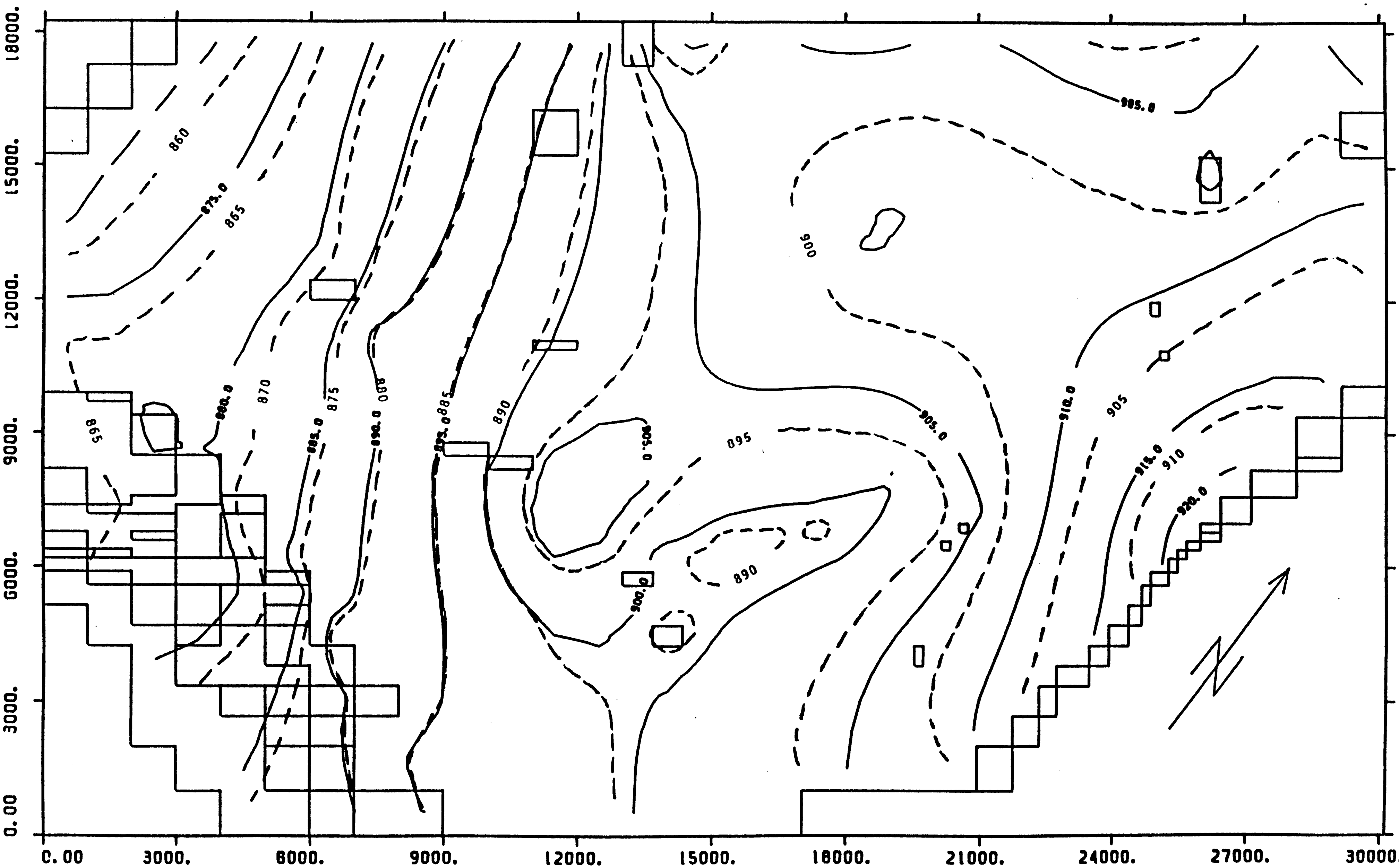
Figure 10




Explanation:

• Field Data-Water Level Elevation Feet Above Mean Sea Level

Figure 11



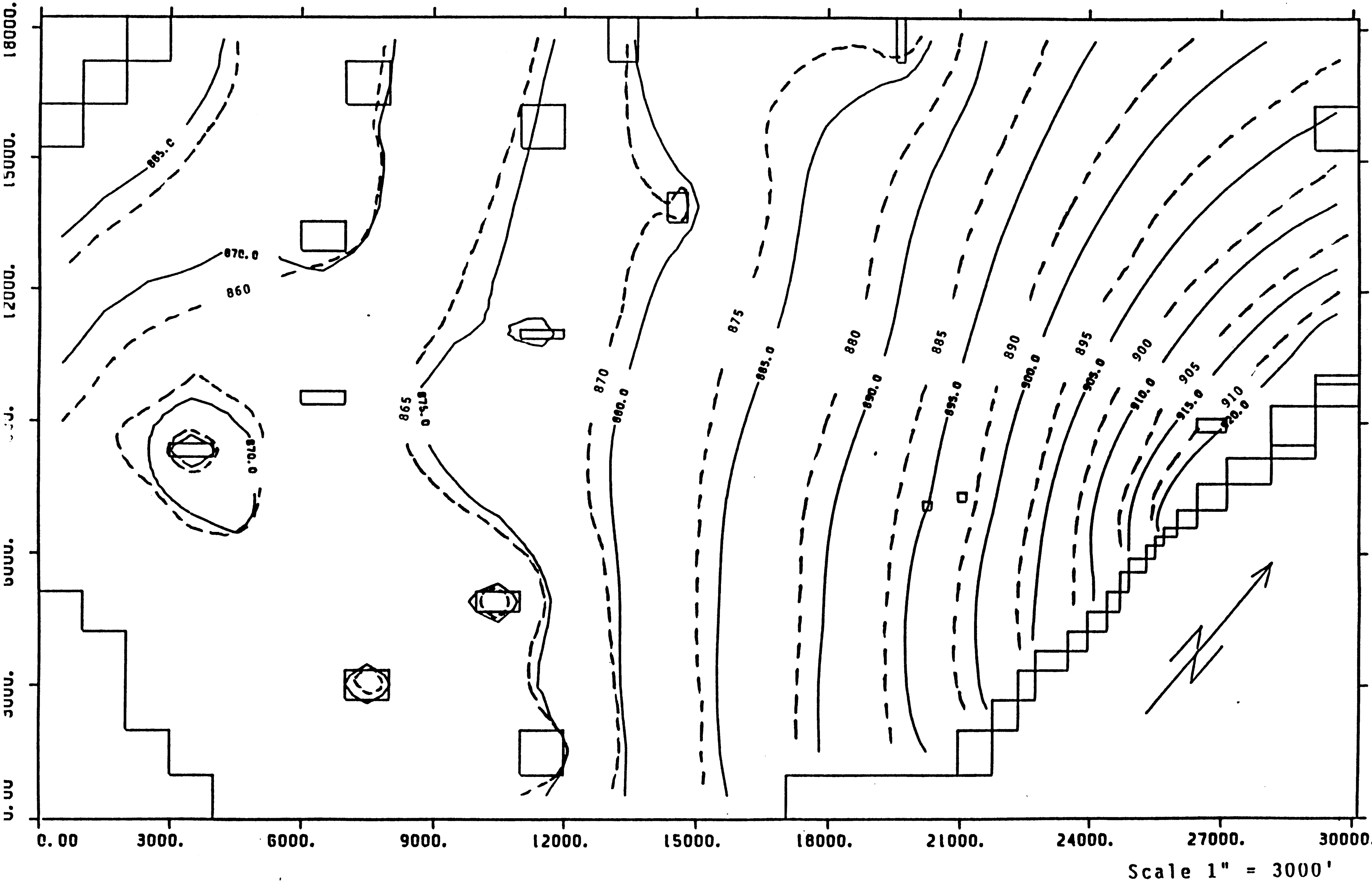

Scale 1" = 3000'

**Explanation:**

• Field Data-Water Level Elevation Feet Above Mean Sea Level

—900- Predicted Hydraulic Head ---900 - Test Case Predicted Hydraulic Head

Figure 12

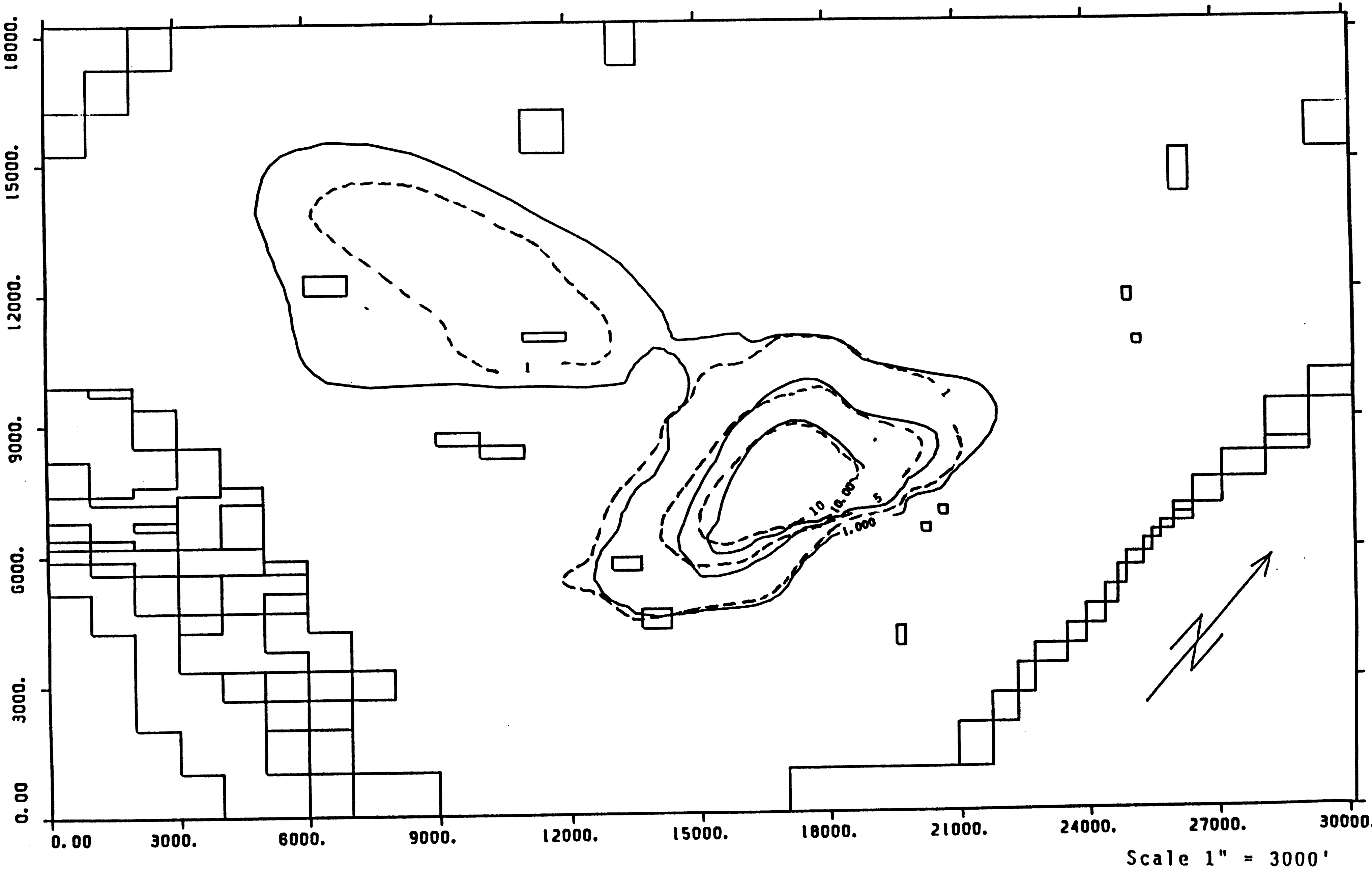



Explanation:

• Field Data-Water Level Elevation Feet Above Mean Sea Level

—900— Predicted Hydraulic Head  ---900 - Test Case Predicted Hydraulic Head

Figure 13

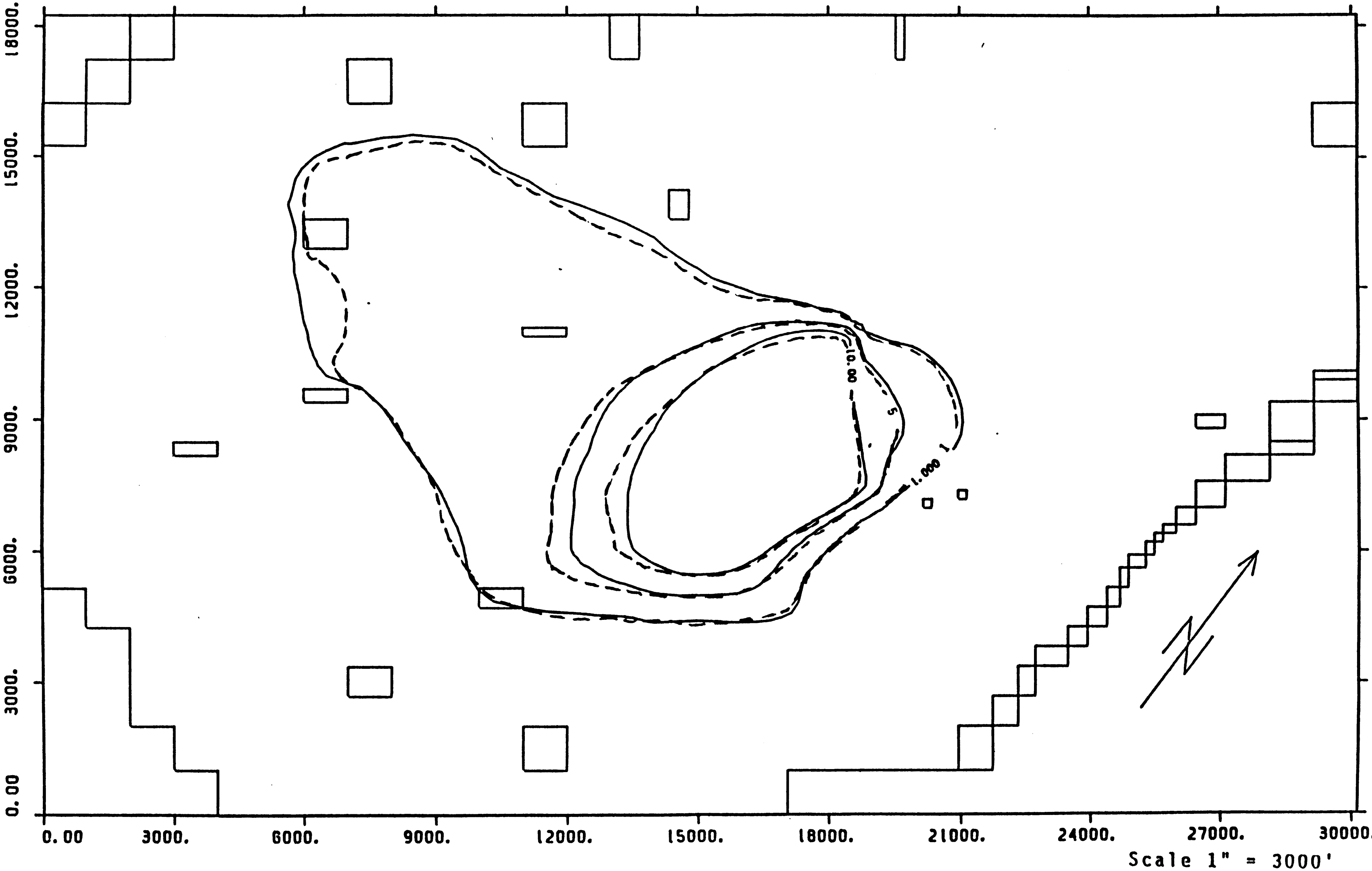



Explanation:

—— Predicted TCE Concentrations - contour Values 1,5,10 and 100ppb.

– – – Test Case Predicted TCE Concentrations

Figure 14




Explanation:

—— Predicted TCE Concentrations - contour Values 1,5,10 and 100ppb.

– – – Test Case Predicted TCE Concentrations