R-39

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Woodward-Clyde Consultants

April 8, 1986
83C2236-8

#67

E.I. duPont de Nemours & Co., Inc.
26th Street & Buffalo Avenue
Niagara Falls, New York 14302

Attention: Mr. Steve Crawley

Re: Numerical Simulation of
Bedrock Water-Bearing Zones
Niagara Plant Site

Gentlemen:

Woodward-Clyde Consultants is pleased to submit this report on the numerical modeling of the bedrock water-bearing zones at the Niagara Plant. The objective of this study was to estimate the magnitude of groundwater withdrawal required to create a hydraulic barrier to prevent offsite contaminant migration in the east plant water-bearing fracture zones. The simulated groundwater response indicates that a total pumping rate of approximately 800 gpm would be required to achieve this remedial objective. Model design and simulated results are presented and discussed herein.

We appreciate the opportunity to be of service to DuPont on this project, and we welcome any comments or questions.

Sincerely,

WOODWARD-CLYDE CONSULTANTS

Kelly R. McIntosh
Hydrologist

Mark N. Gallagher
Project Manager

KRM/MNG/mm/8B

cc: Richard Gentilucci
Frank Waller

NUMERICAL SIMULATION OF
BEDROCK WATER-BEARING ZONES
NIAGARA PLANT SITE

Submitted to:

E.I. DUPONT DE NEMOURS & CO., INC.

Niagara Falls, New York

Prepared by:

WOODWARD-CLYDE CONSULTANTS

Plymouth Meeting, Pennsylvania

EXECUTIVE SUMMARY

As part of the ongoing Niagara Plant remediation studies, Woodward-Clyde Consultants (WCC) has developed a computer model of the bedrock water-bearing zones. The purpose of the model is to estimate the pumpage necessary to create a hydraulic barrier to offsite flow in the east plant. The bedrock was modeled using a three-dimensional finite difference groundwater flow model. The fractured bedrock flow system was simulated by assuming that the fractured rock would respond as an equivalent porous media and could, therefore, be subdivided into five layers (A-, B-, CD-, D-, and F-zones). Each layer was discretely represented as a 91 x 46 finite difference grid, bounded by the Niagara River, the PASNY conduits, Falls Street, and Carborundum Road.

The model was calibrated by approximating the present hydraulic head distribution utilizing transmissivities calculated from the results of single-well permeability tests. The model was considered calibrated when a reasonable representation of the observed hydraulic distribution was obtained.

The east plant bedrock remediation was modeled by simulating four pumping wells on 350-foot centers along DuPont Road for each water-bearing zone. The site was modeled usign 16 pumping wells because of model constraints. We do not anticipate installing a single pumping well in each fracture zone for remediation. Installing a single well open to all fractures would be expected to be as effective. Pumping rates were varied in each well until an acceptable hydraulic barrier was created. The estimated pump rate required to create an effective hydarulic barrier in the east plant was approximately 800 gpm.

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INTRODUCTION

E.I. duPont de Nemours & Co., Inc. is in the process of implementing a remedial program to mitigate groundwater contamination at the Niagara Plant. The overburden (A-zone) groundwater remedial alternatives were previously modeled and evaluated by Woodward-Clyde Consultants (WCC) (report for "Hydraulic Comparisons of Tile Drain Versus Pumping Well Remedial Alternatives, Niagara Plant Site," dated December 2, 1985). The currently operating bedrock groundwater remediation involves the utilization of the Olin Corporation's two production wells located outside of the northwest corner of the site, separated by approximately 10 feet. The production wells, considered in this study as a single withdrawal point, are 24 inches in diameter, cased from the ground surface to below the B-zone, and open from the CD- through F-zones of the Lockport Formation. The site geology was characterized and the primary water-bearing zones of the Lockport Formation were described in WCC's report dated December 1, 1984, entitled "Geohydrologic Investigations, Niagara Plant," Volume 1.

The effectiveness of the Olin production wells with respect to bedrock groundwater remediation is the subject of a concurrent report titled "The Hydraulic Impact of the Olin Production Wells at the Niagara Plant." Among the conclusions in this report is that the current pumping hydraulically controls most of the west plant bedrock groundwater area, but does not significantly impact the east plant. The scope of this groundwater modeling study is limited to the east plant bedrock remediation, with the objective being to estimate the rate of groundwater withdrawal required to create a hydraulic barrier to offsite flow east of Gill Creek.

NUMERICAL MODELING

Groundwater flow in fractured rock can be simulated using fractured flow models. The development of these models has been the topic of research recently, however, they have not be demonstrated as useful for practical application. In addition, fractured media flow models are "data intensive" with respect to the transmission properties of the fractures. The parameters required for such a model are seldom available and the collection costs are prohibitive. Given the data requirements and the unproven nature of fractured flow model-generated results, WCC concluded that the use of a fractured flow model is not appropriate for the Niagara Plant simulations. The system was therefore simulated using a three-dimensional finite difference groundwater flow model (McDonald and Harbaugh 1984). This approach requires the assumption that the fractured media responds as an equivalent porous media. This method, termed the continuum method, has been successfully applied to fractured flow problems (Mercer and Faust 1981).

MODEL DESCRIPTION

The McDonald and Harbaugh model, entitled "A Modular Three-Dimensional Finite Difference Groundwater Flow Model" (MODULAR), was developed by the U.S.G.S. and is programmed in modular form for ease of modification to particular problems. The model contains features for handling water sources and boundary conditions for both two- and three-dimensional flow situations. Groundwater flow is simulated by applying a block-centered finite difference approach with a choice of two solution techniques: strongly implicit procedure (SIP) or slice-successive overrelaxation (SSOR).

A water-bearing zone within the system can be simulated as confined, unconfined, or a combination of both. The model allows for confined water-bearing zones to become unconfined during the simulation, providing options regarding the calculation of storage coefficient and transmissivity once the aquifer becomes unconfined. The major source/sink options include wells, drains, rivers, recharge, and evapotranspiration, which can be characterized as constant or variable during simulation.

The model output consists of hydraulic head, drawdown, and node-by-node water fluxes for the various source/sink options. Post-processors have been developed by WCC to extract the appropriate output and construct equipotential contour maps of hydraulic head and/or drawdowns, as well as cumulative discharge across defined boundaries within the aquifer system.

MODEL DESIGN

The Niagara Plant groundwater flow regime was simulated as a five-layer system. The top layer (Layer 1) corresponds to the overburden (A-zone), and Layers 2 through 5 correspond to the water-bearing fracture zones (B-, CD-, D-, and F-zones). The study domain (Plate 1) was bounded by the Niagara River to the south, the PASNY aqueducts to the east, Falls Street to the north, and Carborundum Road to the west. Each layer was discretely represented as a 91 x 46 finite difference grid. The grid spacing was constant, with node dimensions of 50 x 50 feet, within the area bounded by the PASNY conduits, the Niagara River, Buffalo Avenue, and the western plant boundary. Node spacing increased north of Buffalo Avenue and west of the plant boundary to maximum dimensions of 250 x 250 feet.

The model boundaries were simulated as specified (or constant) head boundaries, which would be either constant sources or sinks, depending on the direction of groundwater flow. Groundwater elevation data generated by the plant site monitoring program indicate that the PASNY conduits and Olin production wells act as groundwater sinks, while the Niagara River, south of the plant, acts as a groundwater source (in the bedrock zones). Groundwater elevations at the model boundaries were based on extrapolation of the plant site groundwater contours and hydraulic gradients. Gill Creek was modeled using the river package, which simulates leakage into or out of a streambed, based on the hydraulic gradient between the stream surface and the water table. Plates 2 through 6 show the finite difference grid and boundary conditions for each layer.

CALIBRATION

The model was calibrated by approximating the present hydraulic head distribution reflected by the groundwater elevations measured in the field (Plates 7 through 10). The results of single-well permeability (slug) tests were used to indicate the range of expected hydraulic conductivities and transmissivities. Existing conditions at the Niagara Plant are impacted by the west plant remedial program, which utilizes the Olin production wells. Therefore, the calibrated model incorporates the current west plant remediation. The model was considered calibrated when a reasonable representation of the observed hydraulic head distribution was obtained.

Within each layer, homogeneity and isotropy were assumed with respect to hydraulic conductivity. Implicit in this assumption is that the east plant and west plant respond similarly to stress; therefore, the transmissivities required to simulate the observed drawdowns near the Olin wells were assumed to be representative of all nodes within the same layer. The implications of this assumption will be discussed in a later section.

Several parameters can be manipulated during the calibration procedures, including transmissivity, hydraulic conductivity, vertical conductance, and hydraulic head at the constant head boundary nodes. The parameters manipulated to achieve calibration of the plant site model were primarily transmissivity, vertical conductance, and hydraulic head at the constant head boundaries. The simulations were carried out at steady state to represent equilibrium conditions.

Transmissivities incorporated into the calibrated model were kept within the ranges indicated by the slug test results. Simulation of the observed drawdowns at the Olin production wells at a pumping rate of approximately 800 gpm (1985 monthly average pumping rate) required a transmissivity of approximately three times the slug test values. A probable explanation of this apparent inconsistency is the existence of a more direct connection between the Olin production wells and the Niagara River due to heterogeneity and anisotropy than can be simulated assuming homogeneous and isotropic conditions. If the higher transmissivities were incorporated into the model, it is likely that overestimation of the required remedial pumping rates in the east plant would result. To reduce the likelihood of overestimating the east plant pumping rate, the transmissivities indicated by the slug test results were used. At these lower transmissivities, a pumping rate of 435 gpm at the Olin production wells was required to approximate the observed hydraulic head distributions. Table 1 presents the input parameters which produced the closest approximation of the observed head distribution in the calibration simulations. Plates 11 through 14 present the hydraulic head contours generated by the calibrated model.

SIMULATION OF EAST PLANT REMEDIATION

The proposed east plant hydraulic barrier was modeled by simulating a line of pumping wells along DuPont Road. The wells were located within the grid, as shown on Plate 15, with each location representing four wells (i.e., one per water-bearing fracture zone). Because of model constraints, the pumping wells were simulated on 350-foot centers with four wells per layer. These wells would be as effective as a single well open to all water-bearing zones. Pumping rates were varied in each well, and the resulting hydraulic barrier was evaluated with respect to the degree of hydraulic containment of the east plant.

CONCLUSIONS

Plates 16 through 19 show the bedrock hydraulic head contours resulting from pumping the east plant wells at a rate sufficient to create a hydraulic barrier to offsite groundwater flow. The corresponding pumping rates are listed in Table 2. The total simulated pumping rate was approximately 800 gpm.

Based on the results of the October 1984 pump tests, WCC has estimated that a pumping rate of 500 gpm at the Olin production wells is sufficient to hydraulically control offsite groundwater flow in the west plant bedrock fracture zones ("Pump Test Program," final report, June 1985). Based on the assumption that the east and west plant groundwater regimes respond similarly to stress, and since the east and west plant areas are approximately the same size, it would be expected that the total required east plant pumping should be approximately equal to that estimated for the west plant, or 500 gpm. The results of this study indicate a higher total pumping rate is required to create a hydraulic barrier in the east plant. The simulations indicate that this higher rate is required due to hydraulic influence of the groundwater sink associated with the PASNY aqueducts. This groundwater sink causes steeper offsite hydraulic gradients in the east plant and, therefore, greater groundwater withdrawal rates are required for gradient reversal near the plant boundary.

REFERENCES

McDonald, M.G. and Harbaugh, A.W. (1984) A Modular Three Dimensional Finite Difference Groundwater Flow Model. U.S. Geological Survey: Open-File Report 83-875.

Mercer, J.W. and Faust, C.R. (1981) Groundwater Modeling, National Water Well Association.

Tables

TABLE 1
INPUT PARAMETERS USED IN THE CALIBRATED MODEL
NIAGARA PLANT
E.I. DUPONT DE NEMOURS & CO., INC.

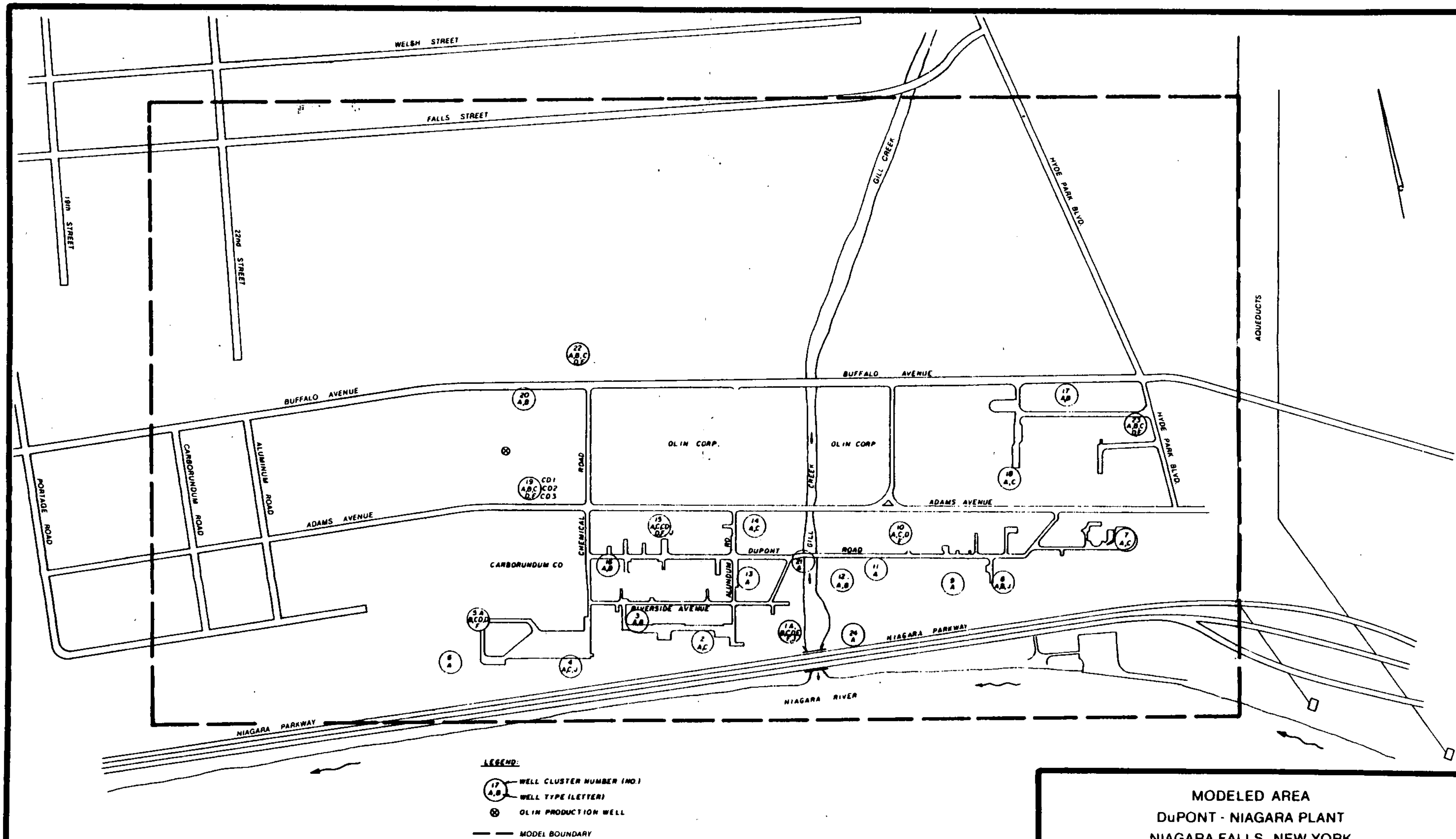
Parameter	Value
Recharge	15 inches/year
Hydraulic Conductivity-Layer 1	3.9×10^{-4} ft/sec
Transmissivity-Layer 2	5×10^{-3} ft/sec
Transmissivity-Layer 3	1.0×10^{-2} ft/sec
Transmissivity-Layer 4	1.0×10^{-3} ft/sec
Transmissivity-Layer 5	1.0×10^{-3} ft/sec
Vertical Conductance-Layer 1	2×10^{-8} sec^{-1}
Vertical Conductance-Layer 2	1.0×10^{-7} sec^{-1}
Vertical Conductance-Layer 3	1.0×10^{-7} sec^{-1}
Vertical Conductance-Layer 4	2×10^{-8} sec^{-1}

TABLE 2
ESTIMATED PUMPING RATES
NIAGARA PLANT REMEDIATION
NIAGARA FALLS, NEW YORK

Layer	Well Number(1)	Estimated Pumping Rate
2 (B-zone)	1	30
	2	22
	3	22
	4	30
3 (CD-zone)	1	150
	2	100
	3	100
	4	150
4 (D-zone)	1	30
	2	22
	3	22
	4	30
5 (F-zone)	1	30
	2	22
	3	22
	4	30
Total Bedrock Pumping Rate		812

(1) Within each layer, the pumping wells are sequentially numbered, with number 1 being the closest well to Gill Creek.

Plates

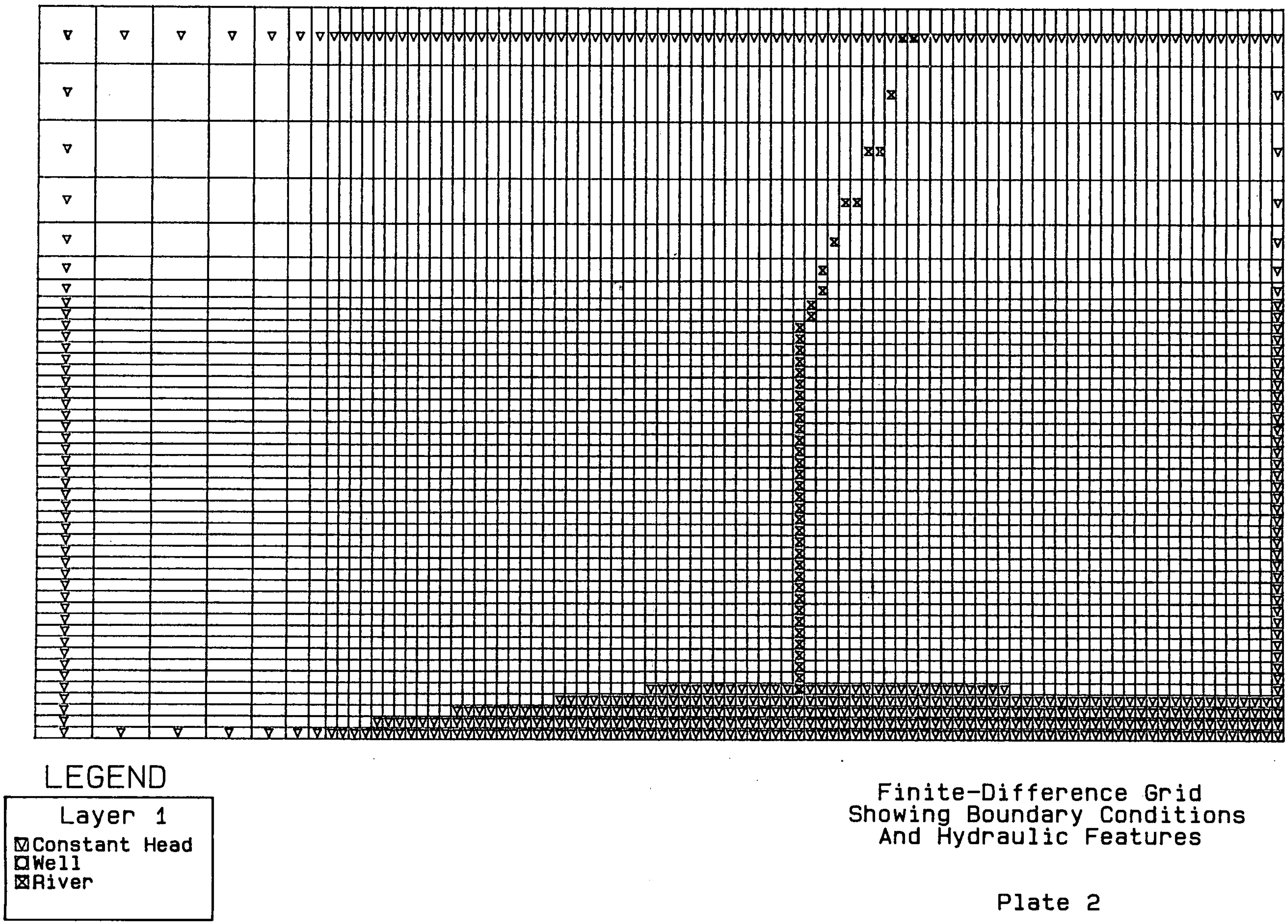


MODELED AREA
DuPONT - NIAGARA PLANT
NIAGARA FALLS, NEW YORK

WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIROMENTAL SCIENTISTS

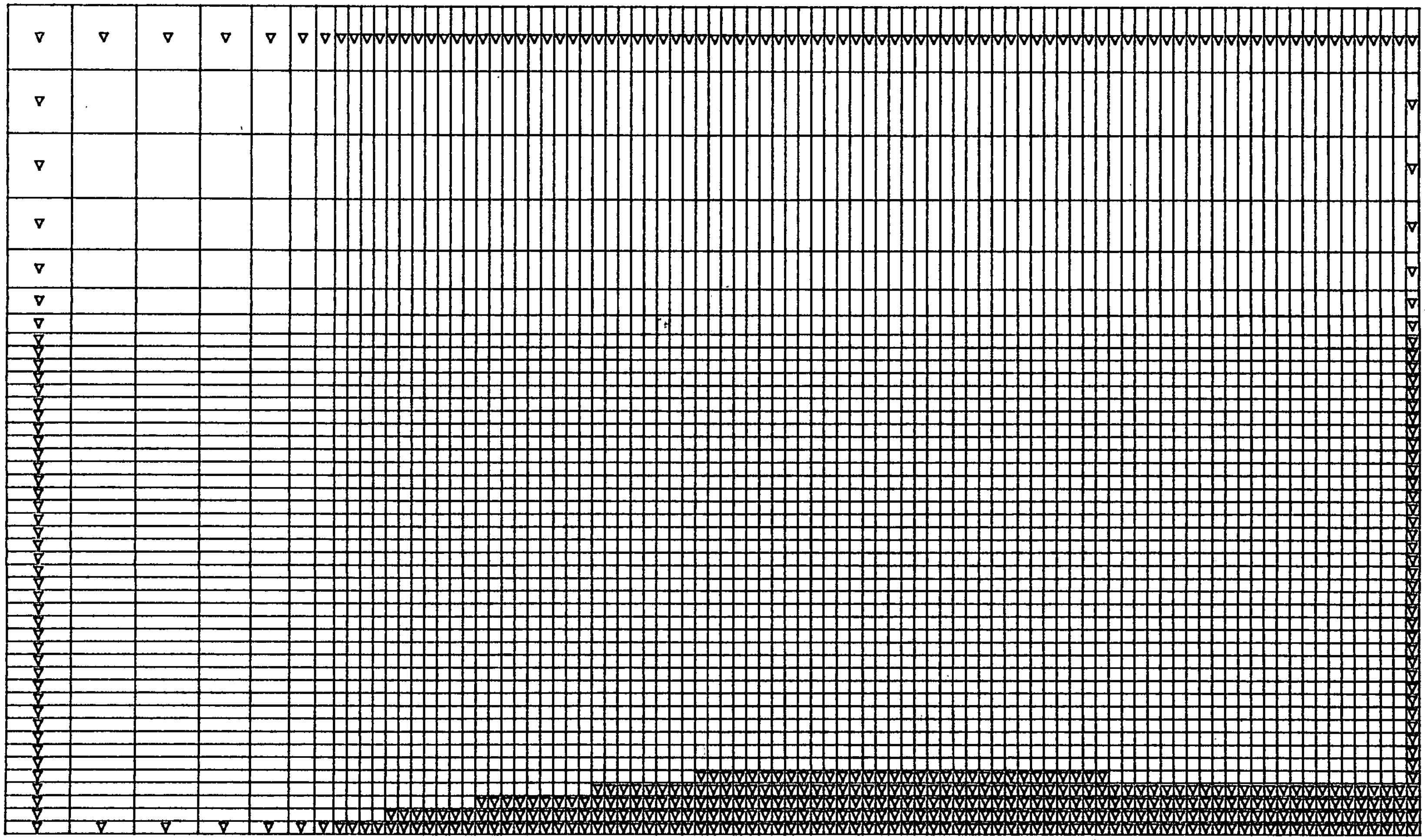
Drawn By: D.B.	SCALE IN FEET	Date: 3/7/86
Checked: K.R.M.	0 500	Job: 83C2236-8

PLATE 1



Finite-Difference Grid
Showing Boundary Conditions
And Hydraulic Features

Plate 2

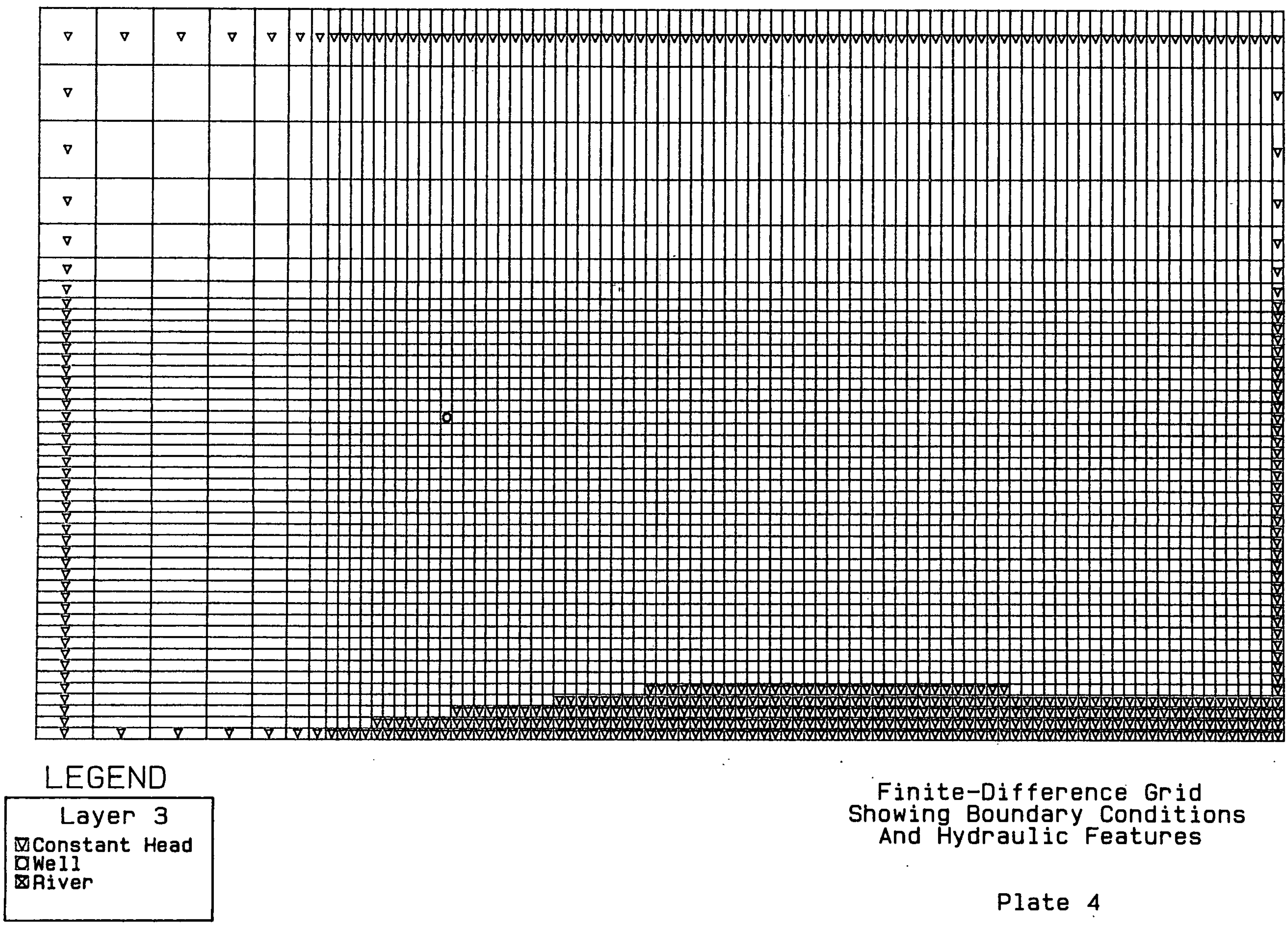


LEGEND

Layer 2
☑Constant Head
☐Well
☒River

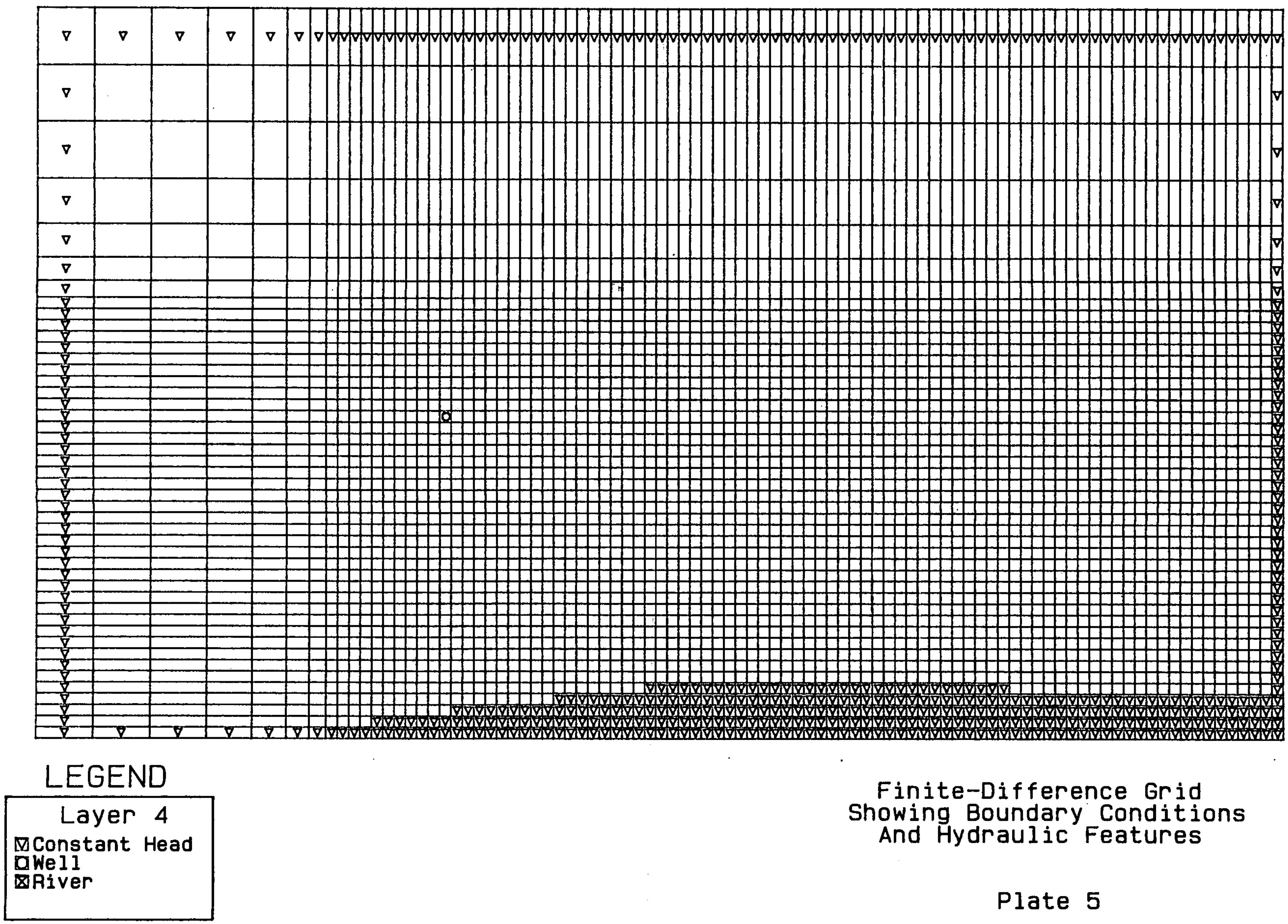
Finite-Difference Grid
Showing Boundary Conditions
And Hydraulic Features

Plate 3



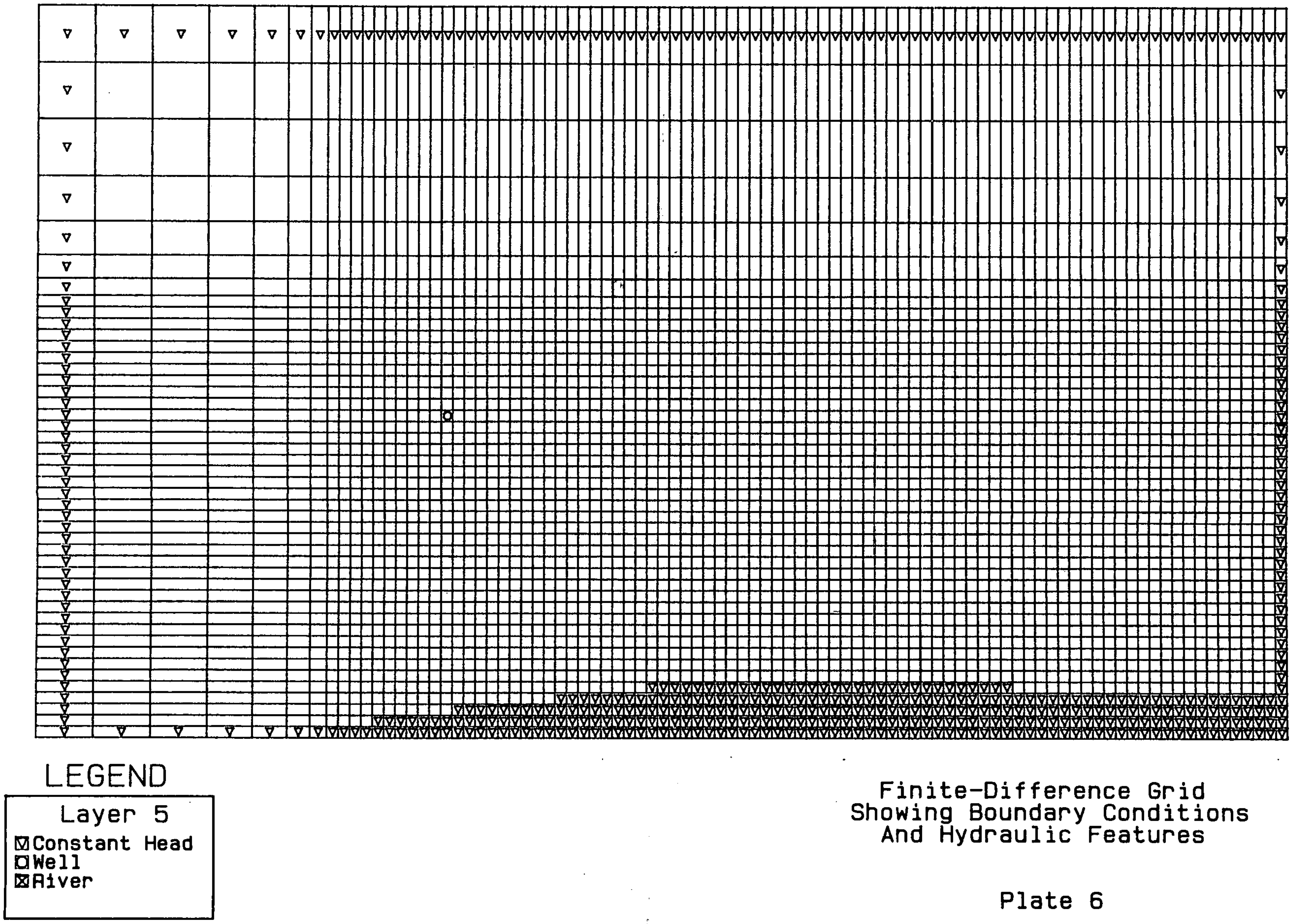
Finite-Difference Grid
Showing Boundary Conditions
And Hydraulic Features

Plate 4



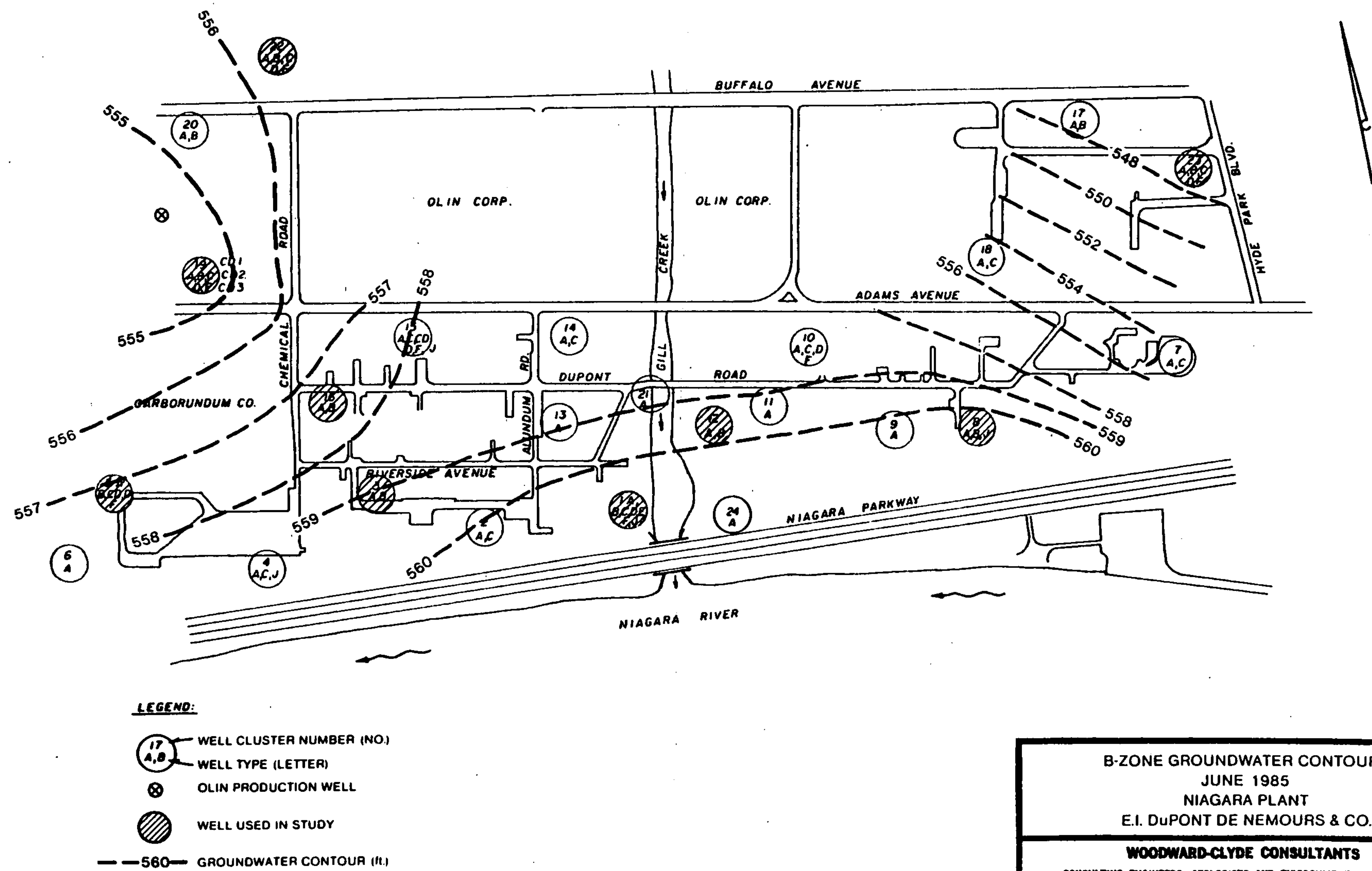
Finite-Difference Grid
Showing Boundary Conditions
And Hydraulic Features

Plate 5



Finite-Difference Grid
Showing Boundary Conditions
And Hydraulic Features

Plate 6



B-ZONE GROUNDWATER CONTOURS
JUNE 1985
NIAGARA PLANT
E.I. DuPONT DE NEMOURS & CO.

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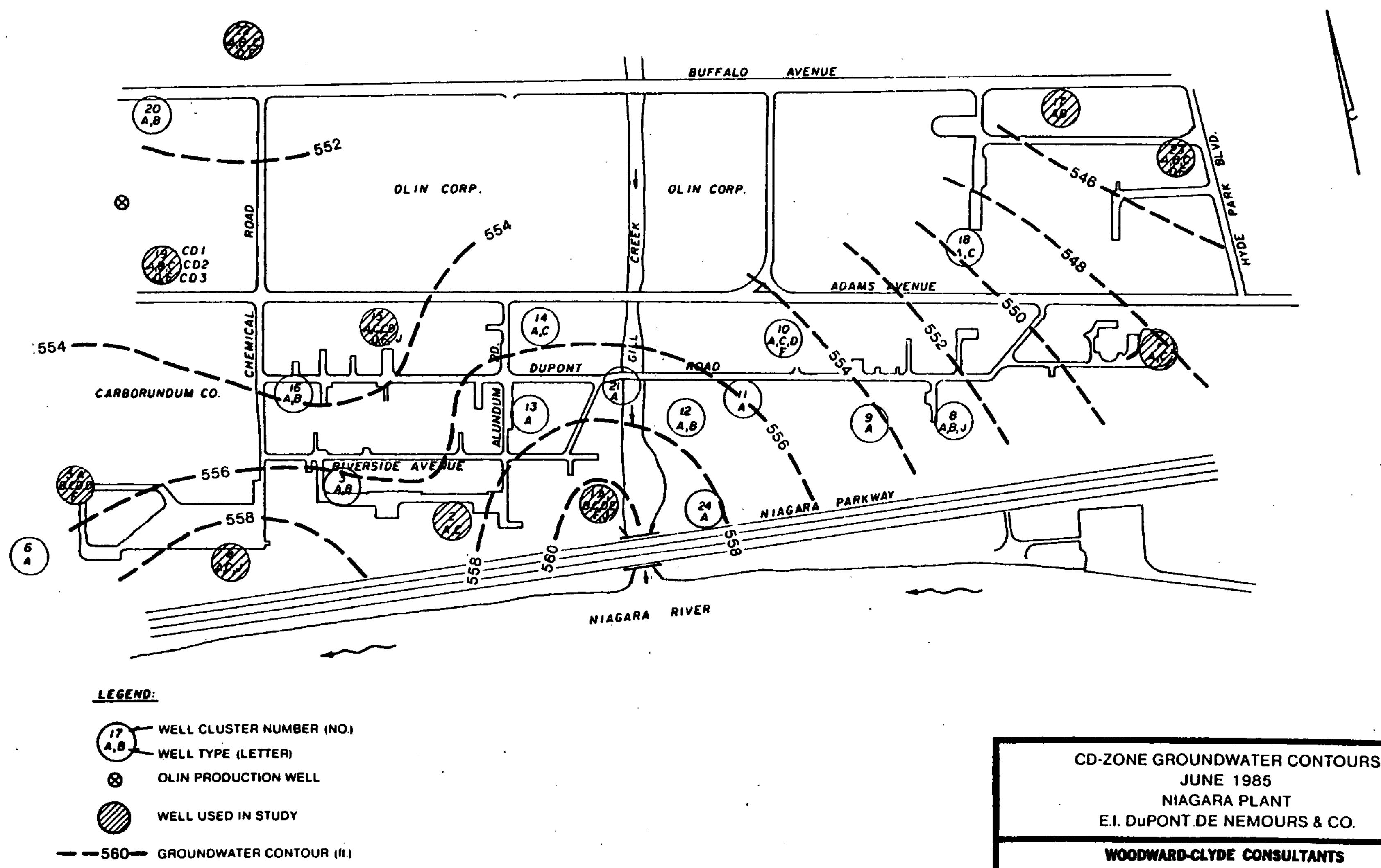
DRAWN BY: T.P.	SCALE in FEET		DATE: 3/26/86
CHECKED: M.N.G.	0 300		JOB: 83C2236-8

PLATE 7



CD-ZONE GROUNDWATER CONTOURS
JUNE 1985
NIAGARA PLANT
E.I. DuPONT DE NEMOURS & CO.

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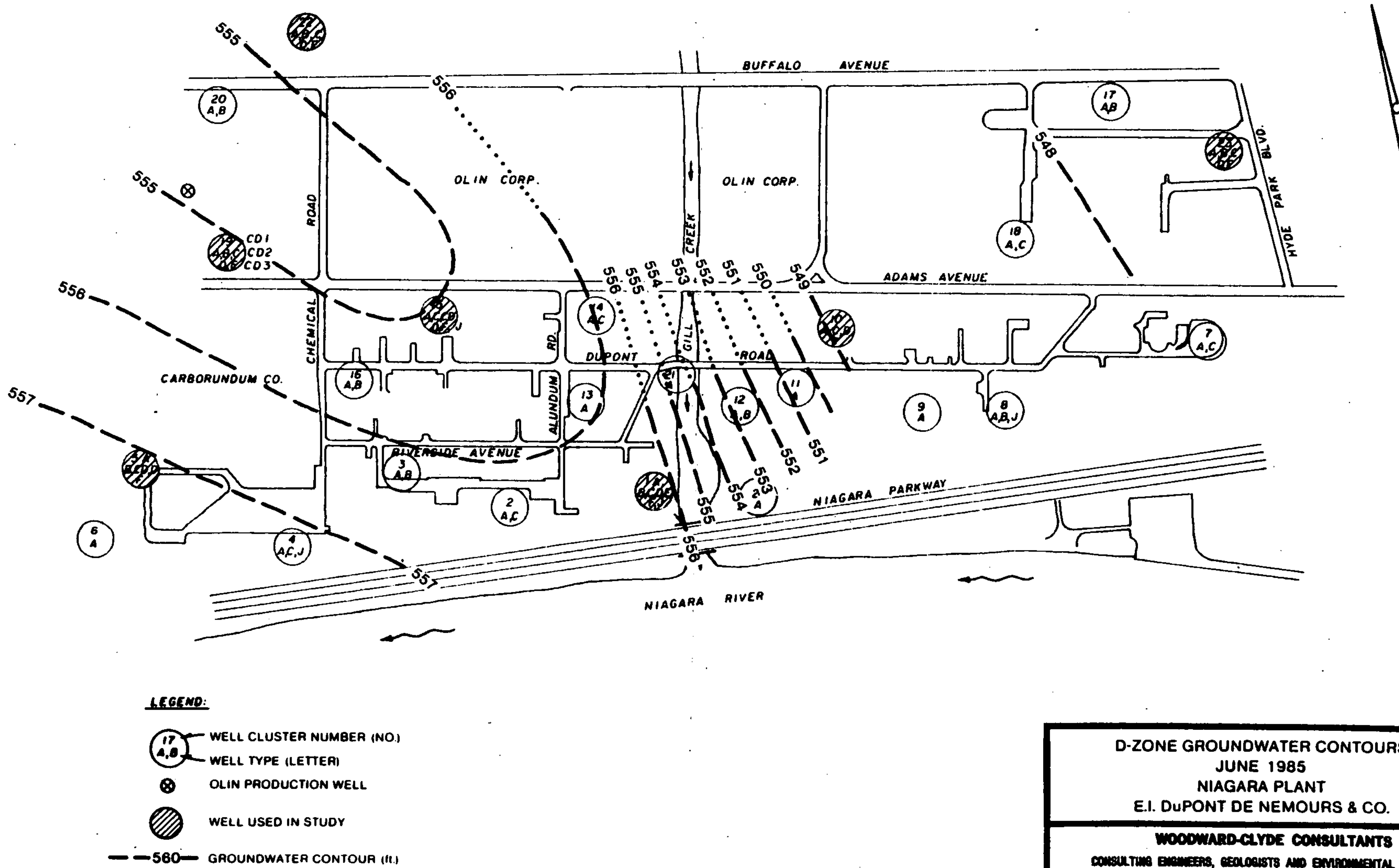
PLATE 8



D-ZONE GROUNDWATER CONTOURS
JUNE 1985
NIAGARA PLANT
E.I. DuPONT DE NEMOURS & CO.

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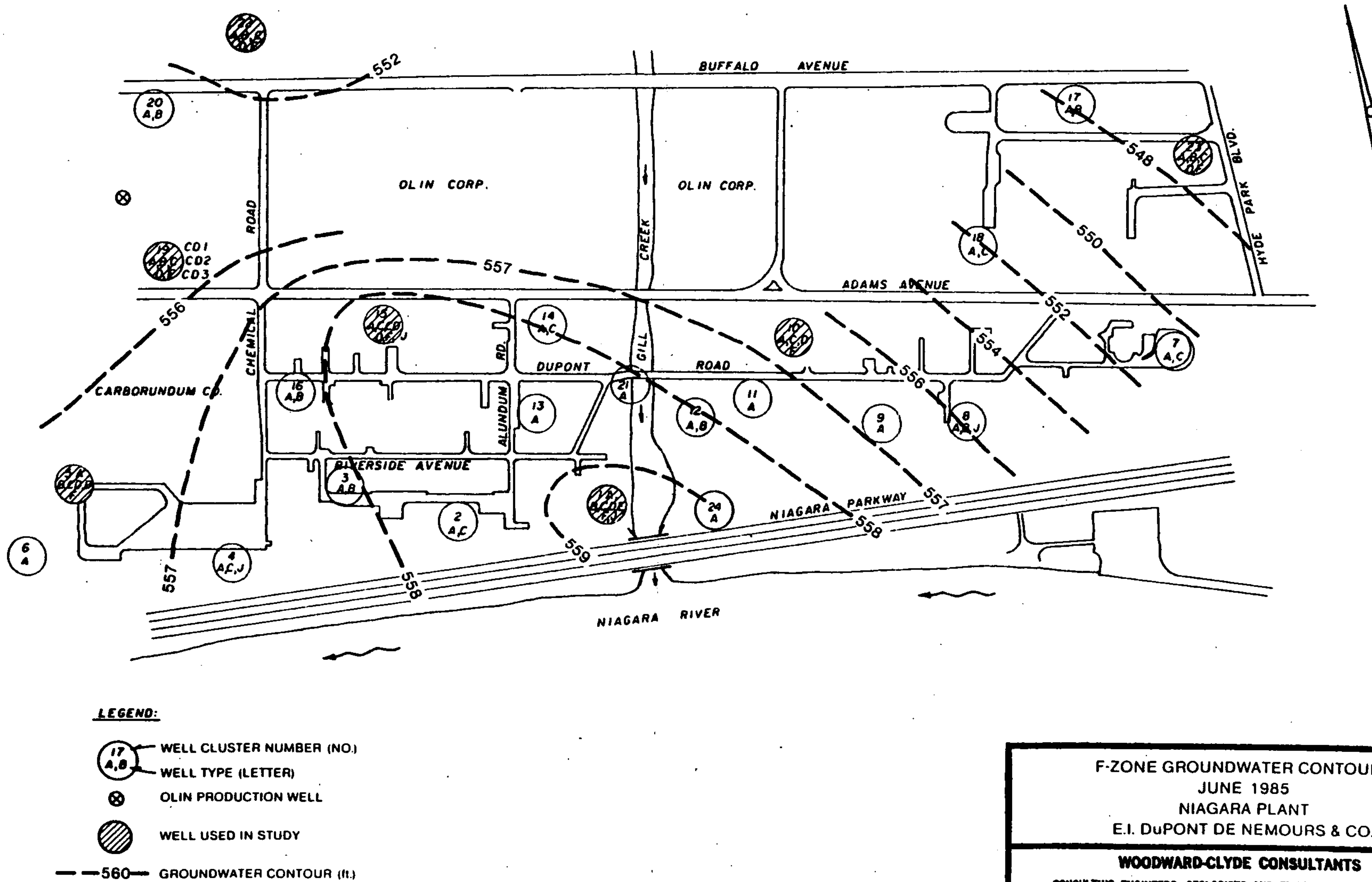
PLATE 9



F-ZONE GROUNDWATER CONTOURS
JUNE 1985
NIAGARA PLANT
E.I. DuPONT DE NEMOURS & CO.

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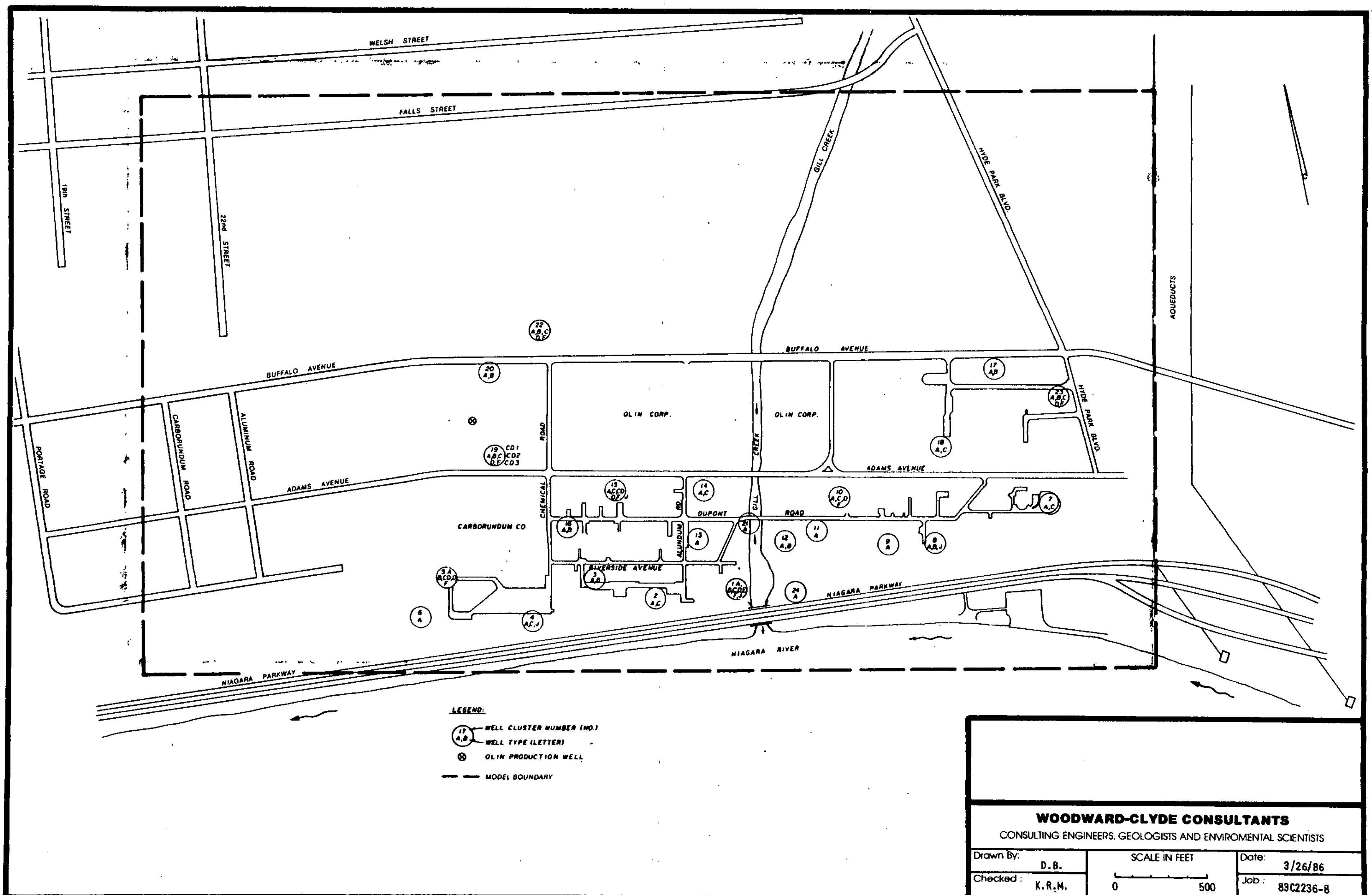
PLATE 10



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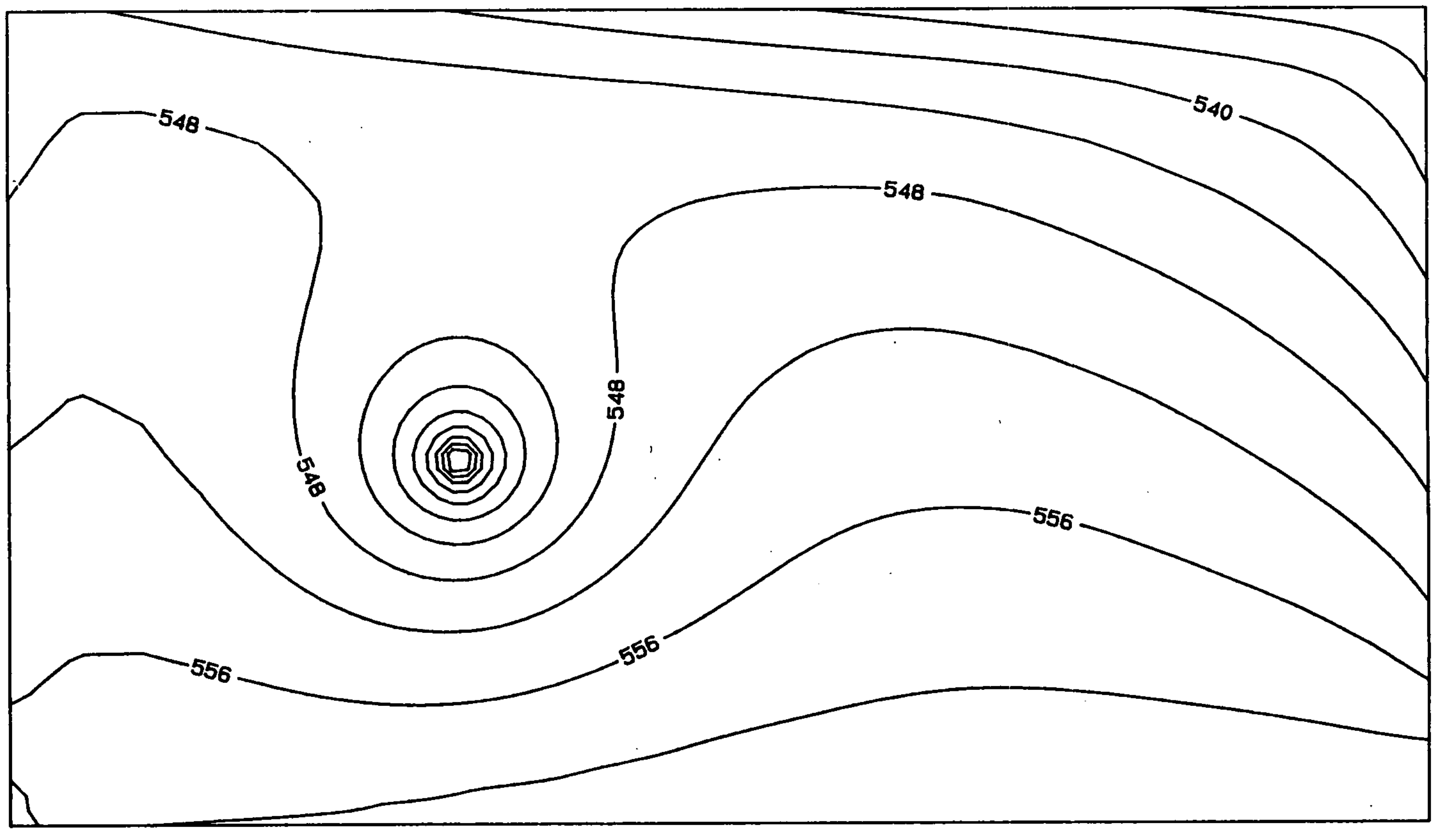
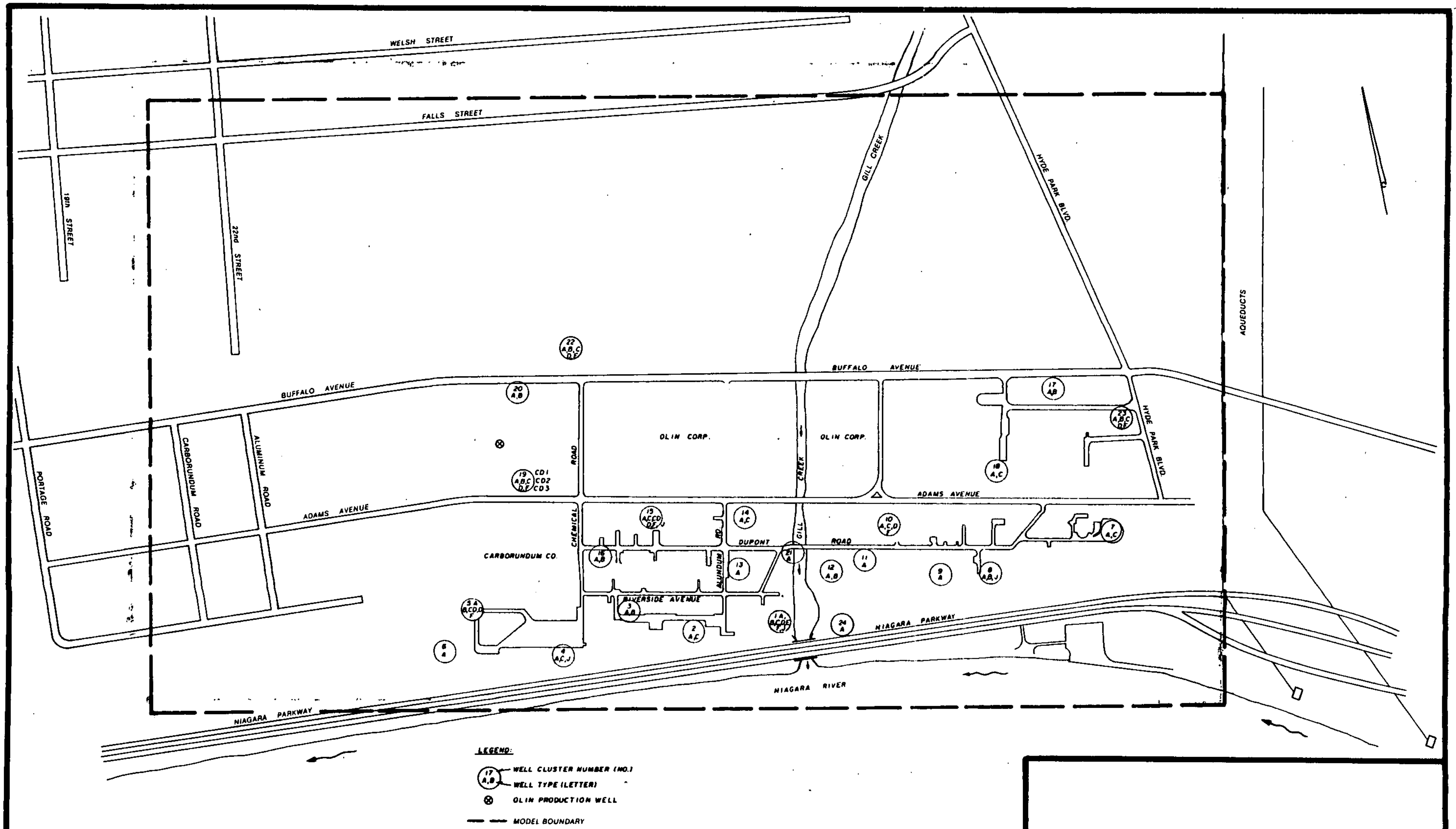


SIMULATED HYDRAULIC HEAD CONTOURS
CD-ZONE: CALIBRATION
DuPONT - NIAGARA PLANT
NIAGARA FALLS, NEW YORK

PLATE 12



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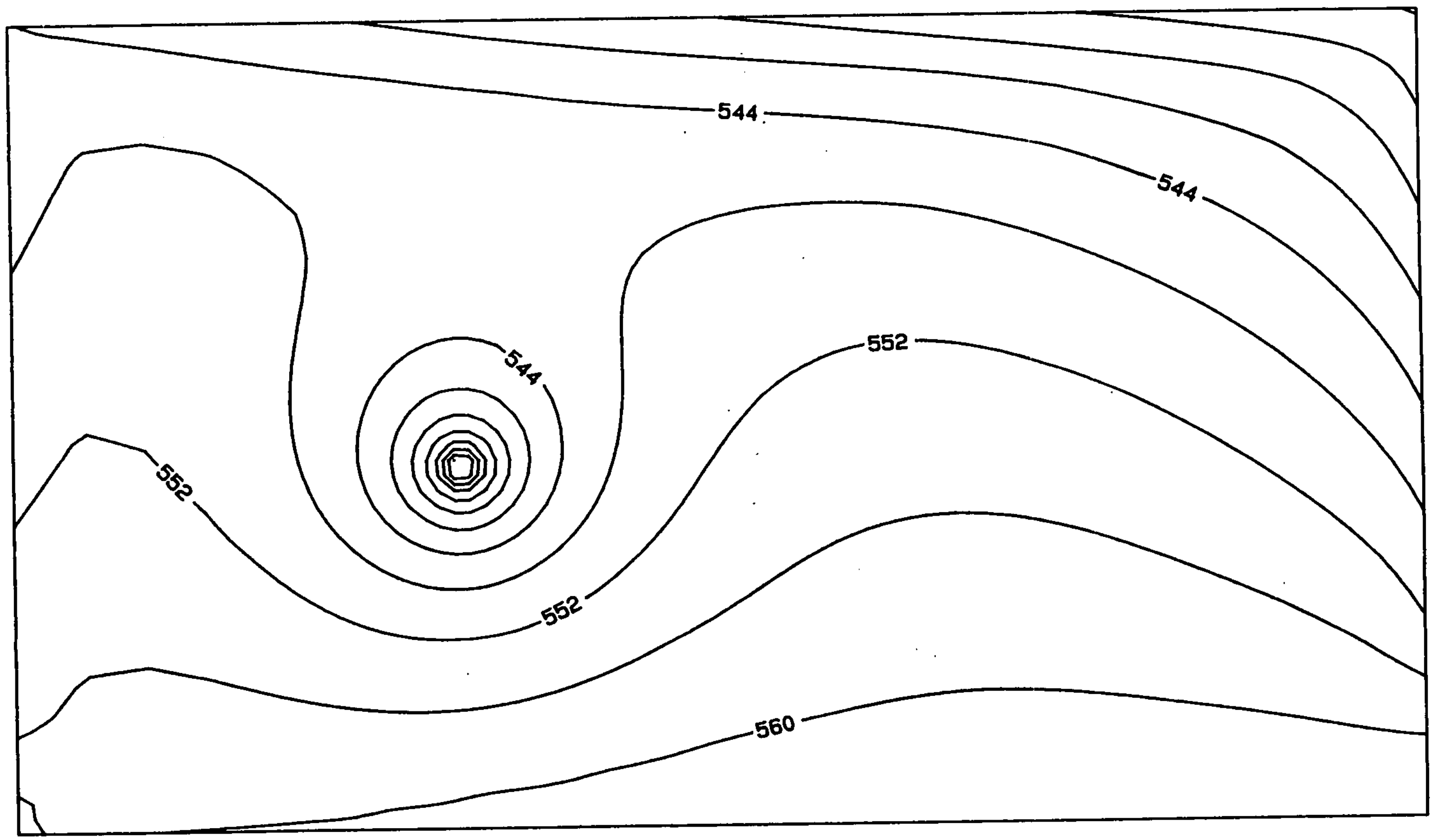
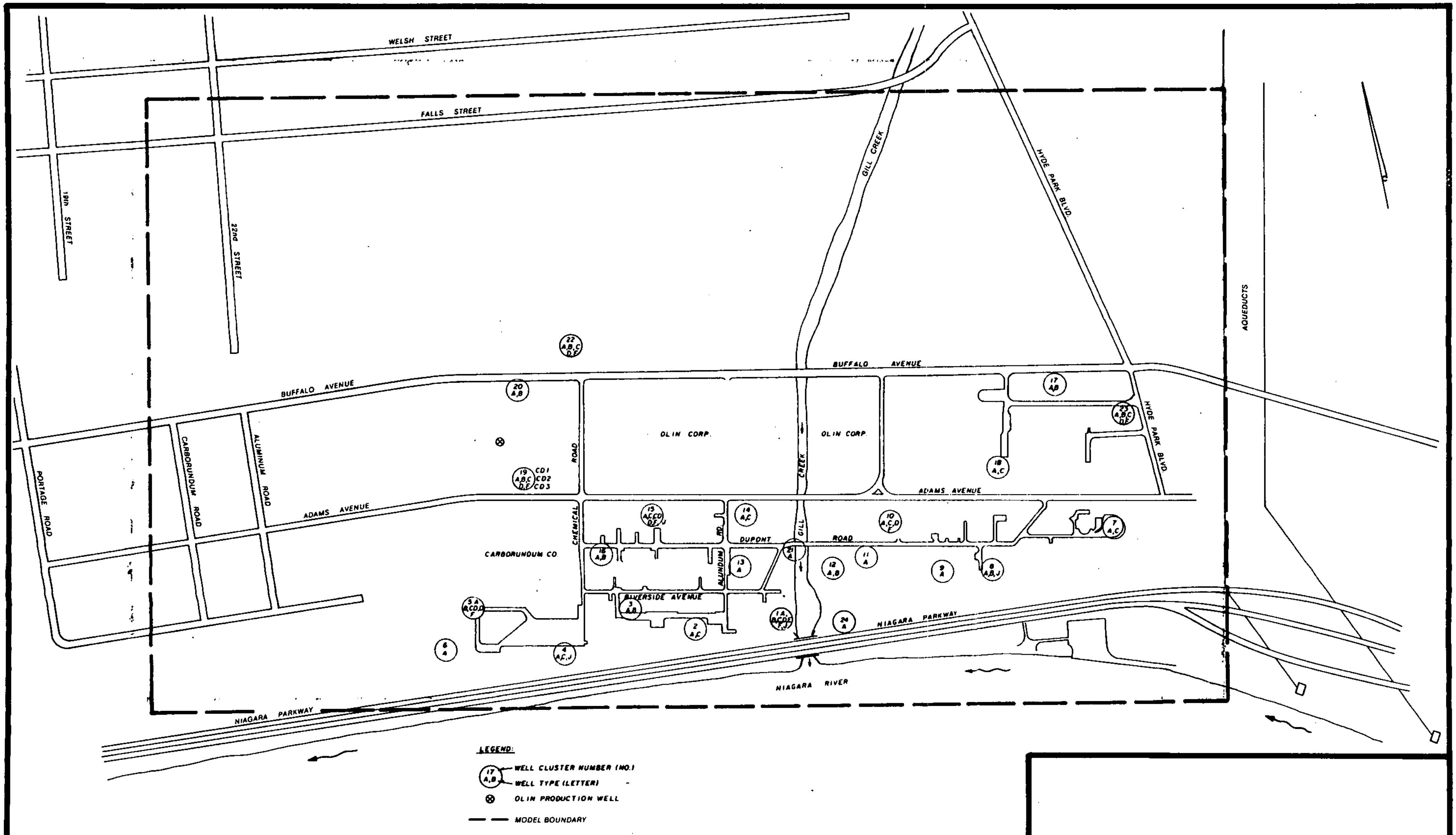


SIMULATED HYDRAULIC HEAD CONTOURS
D-ZONE: CALIBRATION
DuPONT - NIAGARA PLANT
NIAGARA FALLS, NEW YORK

PLATE 13



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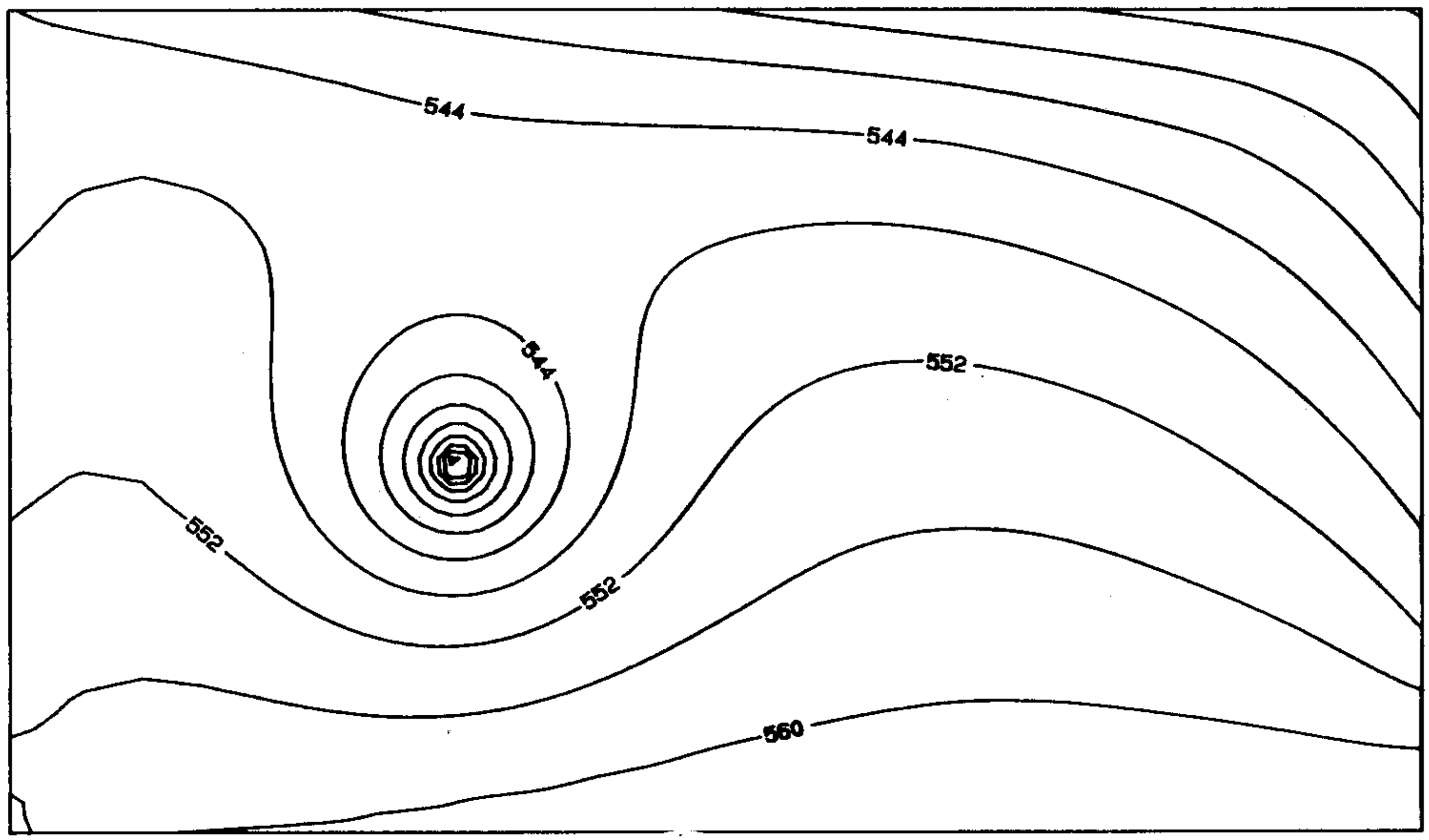
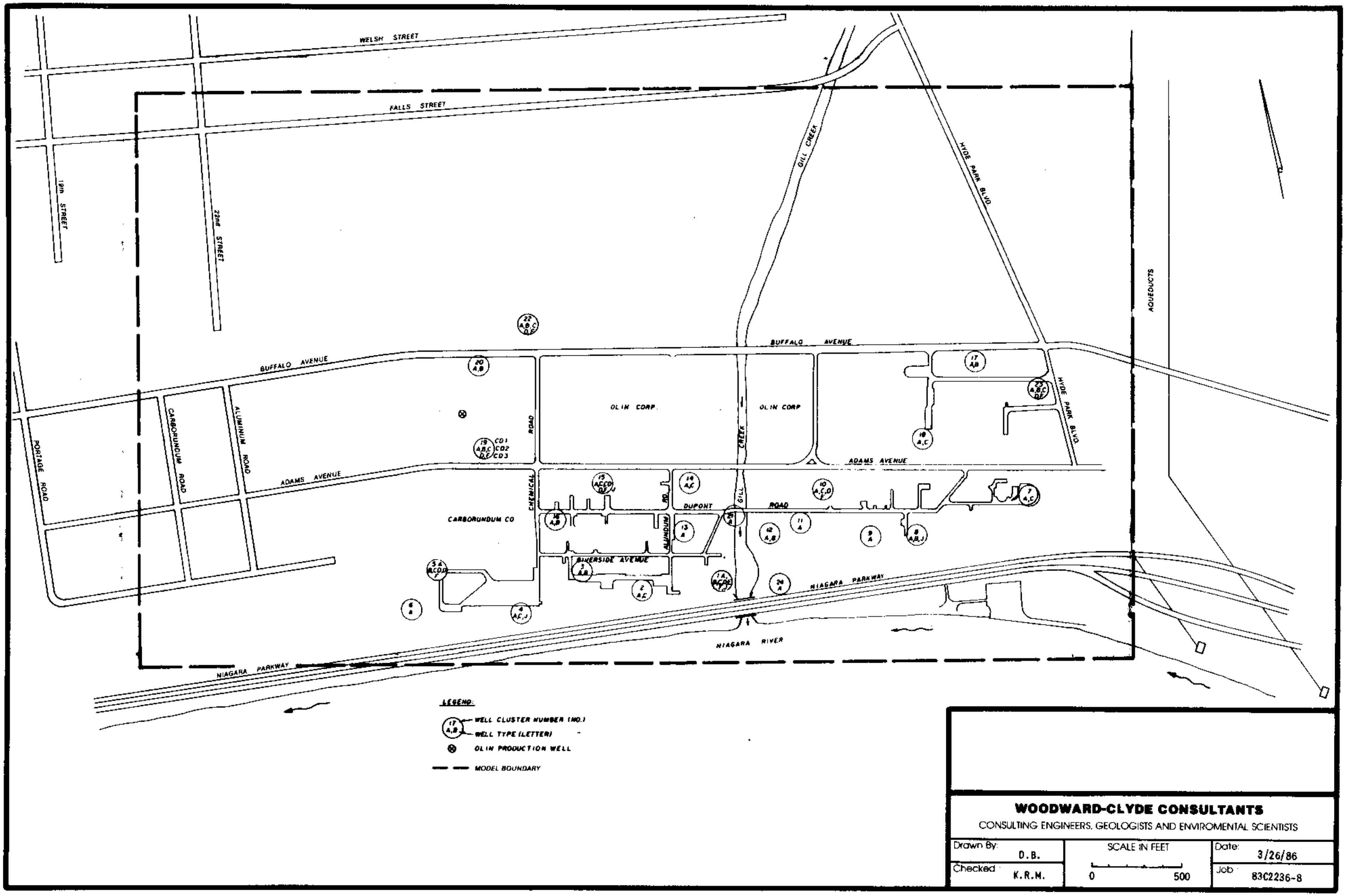


SIMULATED HYDRAULIC HEAD CONTOURS
F-ZONE: CALIBRATION
DuPONT - NIAGARA PLANT
NIAGARA FALLS, NEW YORK

PLATE 14


WELSH STREET
FALLS STREET
19th STREET
22nd STREET
GILL CREEK
HYDE PARK BLVD.
AQUEDUCTS
BUFFALO AVENUE
PORTAGE ROAD
CARBORUNDUM ROAD
ALUMINUM ROAD
ADAMS AVENUE
OLIN CORP.
OLIN CORP
CHEMICAL ROAD
DUPONT ROAD
RIVERSIDE AVENUE
CARBORUNDUM CO
NIAGARA PARKWAY
NIAGARA RIVER
LEGEND:
WELL CLUSTER NUMBER (NO.)
WELL TYPE (LETTER)
OLIN PRODUCTION WELL
MODEL BOUNDARY
WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIROMENTAL SCIENTISTS
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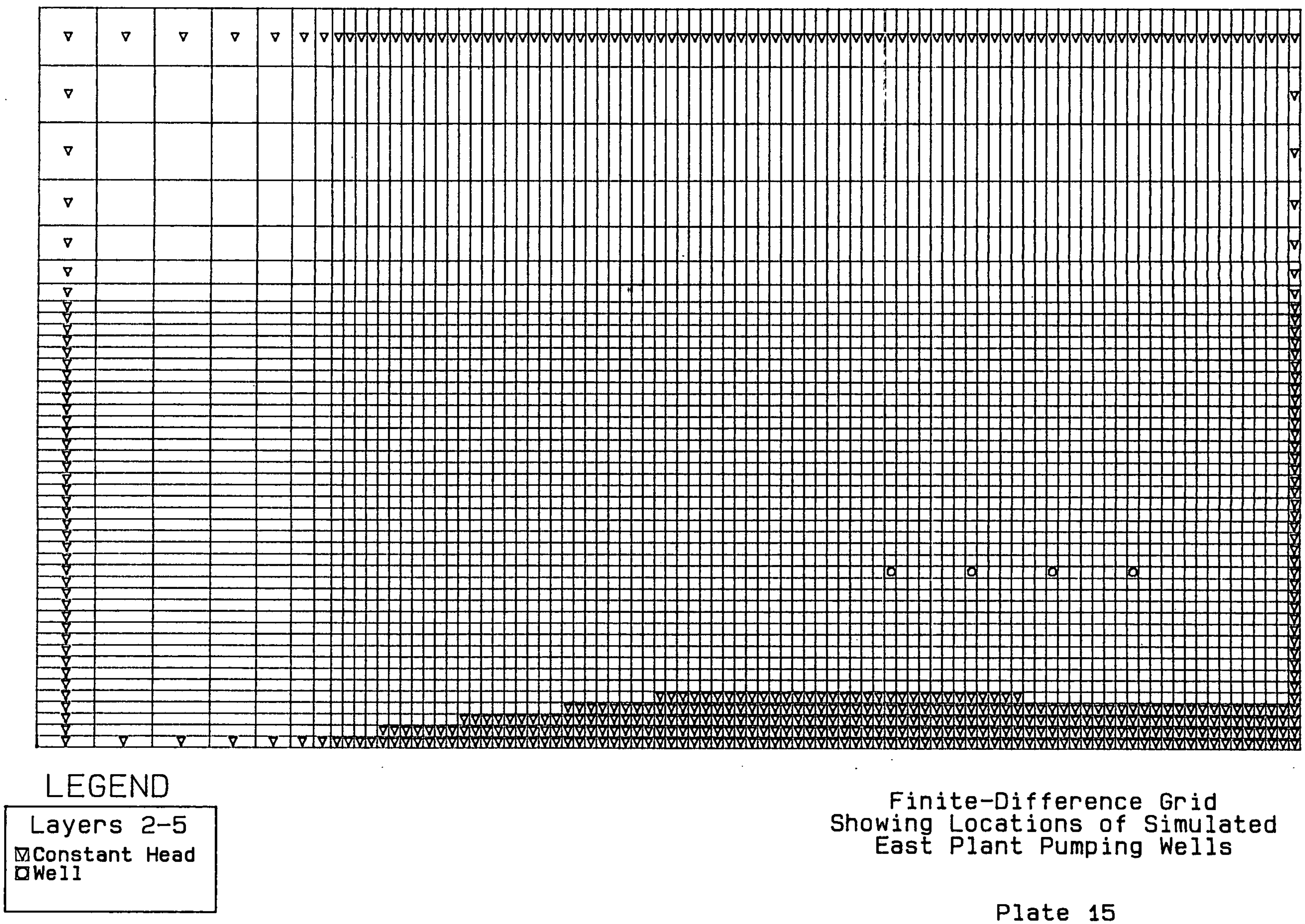
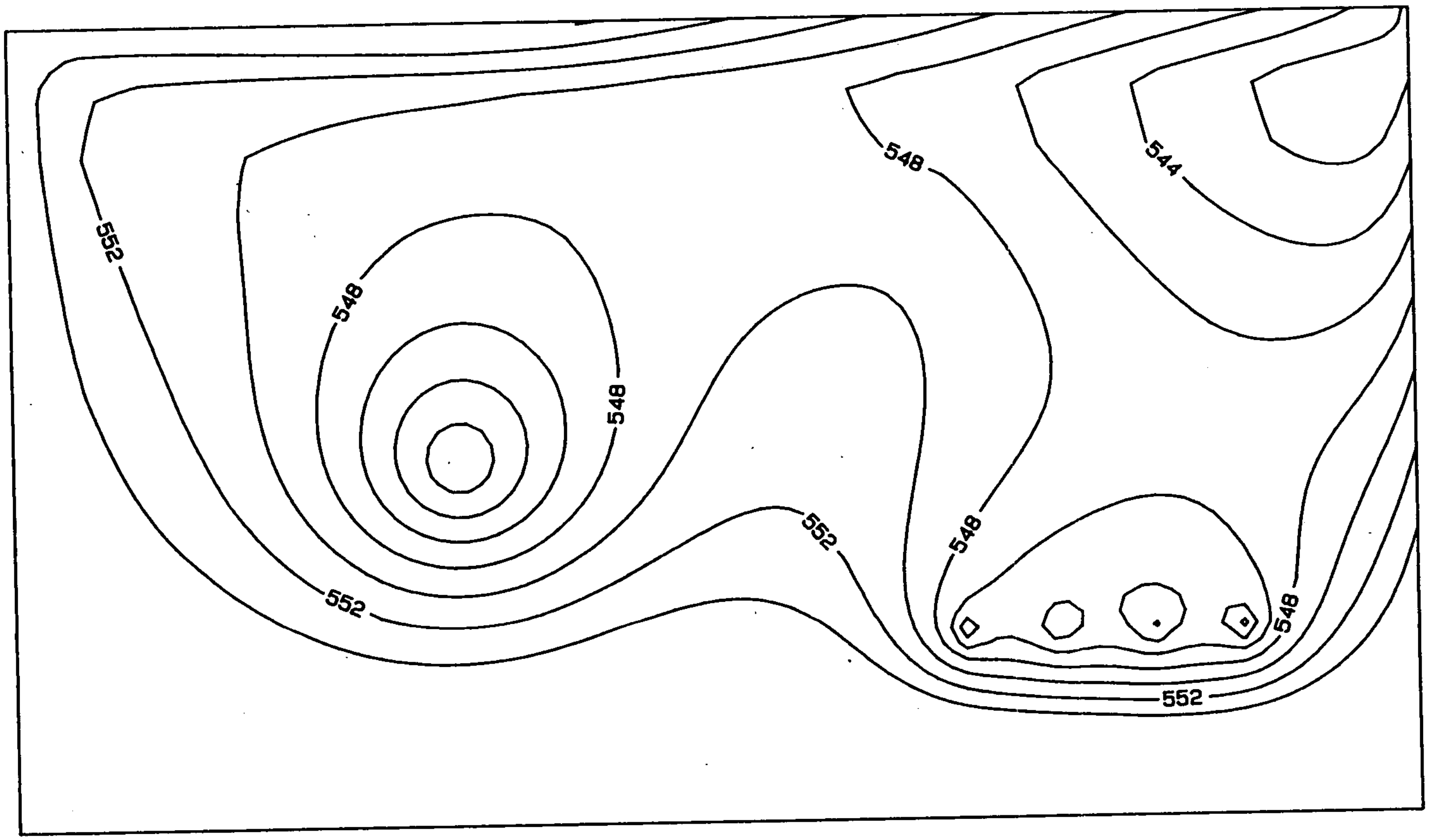


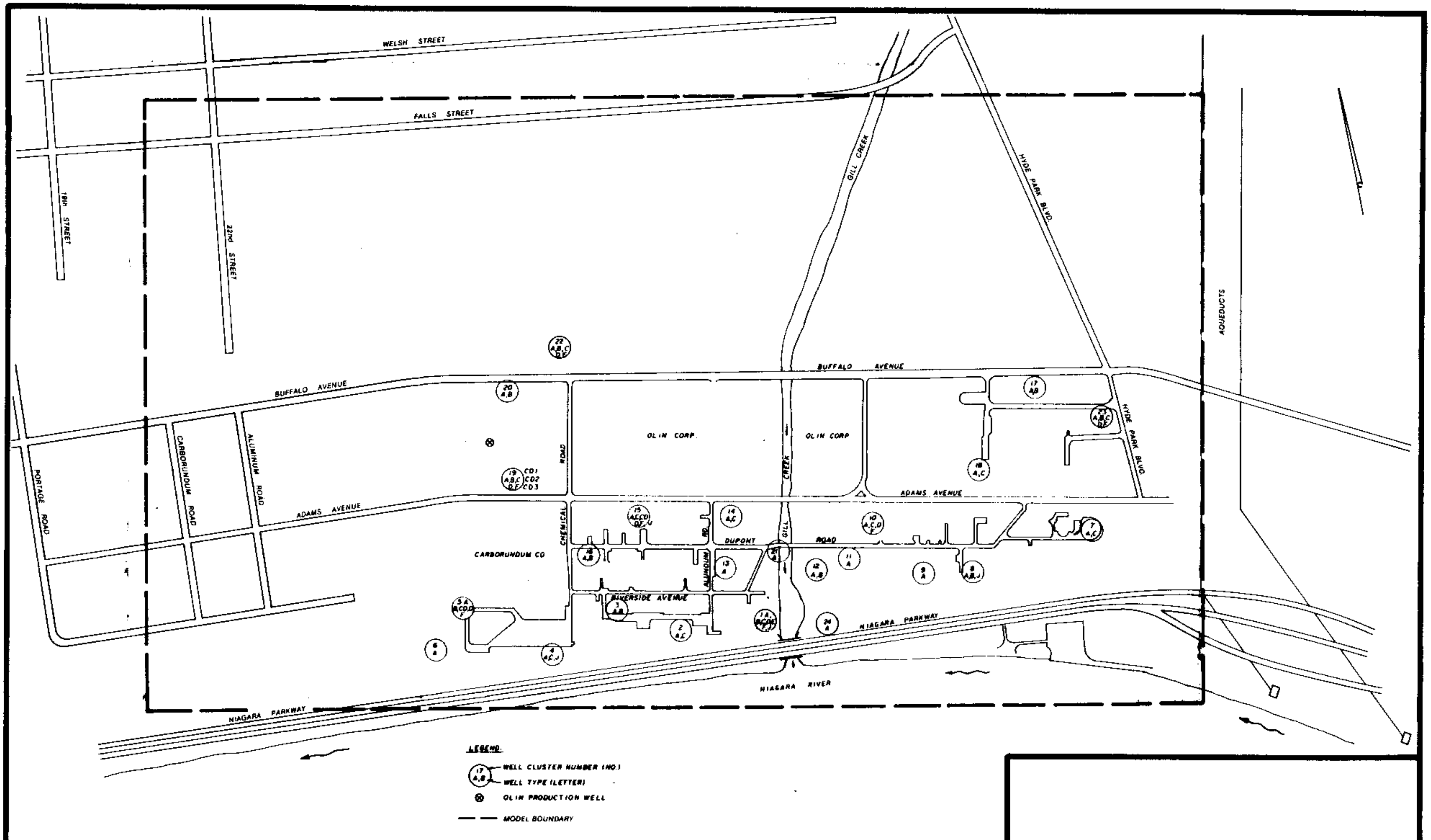
Finite-Difference Grid
Showing Locations of Simulated
East Plant Pumping Wells

Plate 15



SIMULATED HYDRAULIC HEAD CONTOURS
B-ZONE: REMEDIATION
DuPONT - NIAGARA PLANT
NIAGARA FALLS, NEW YORK

PLATE 16



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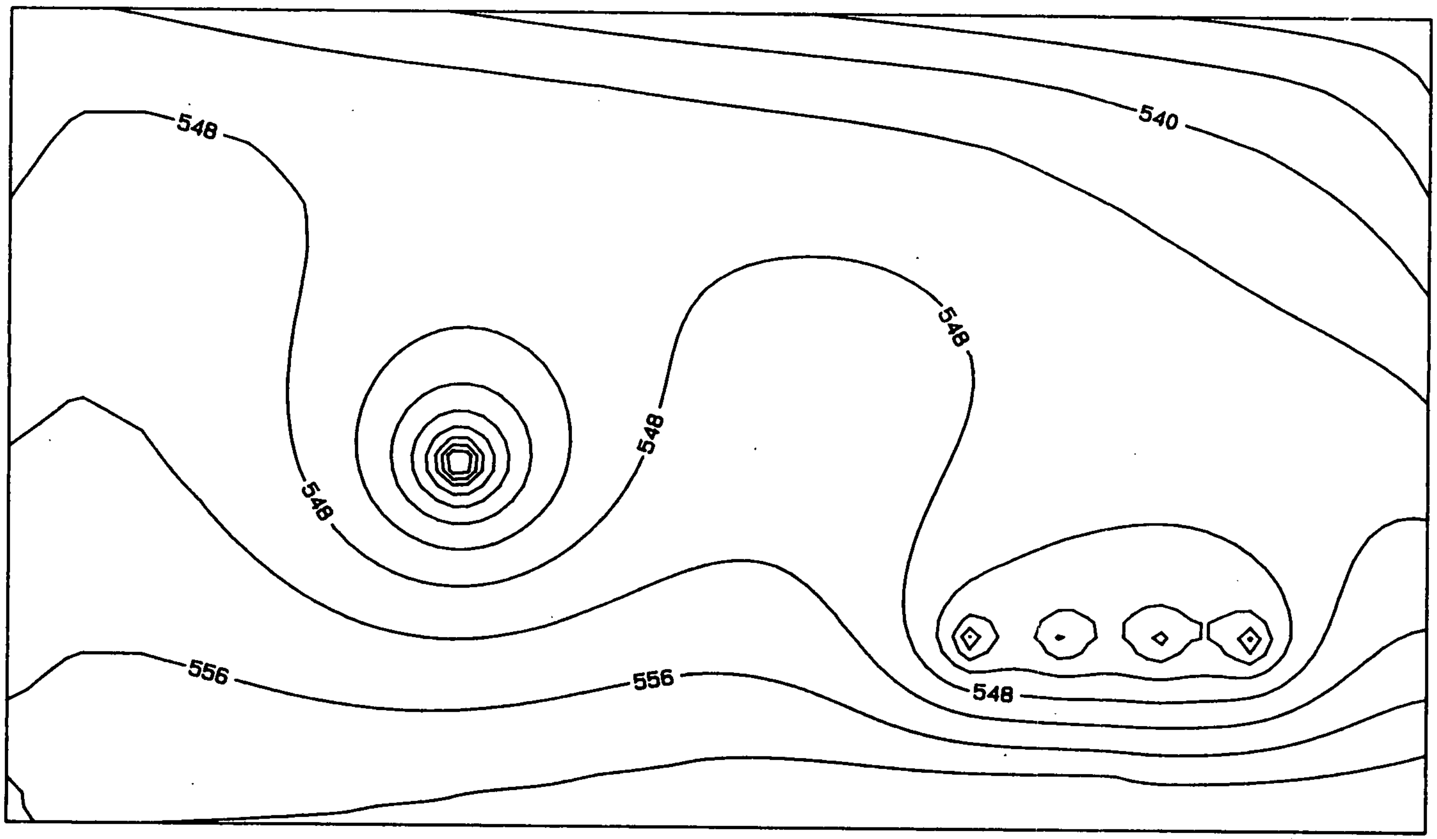
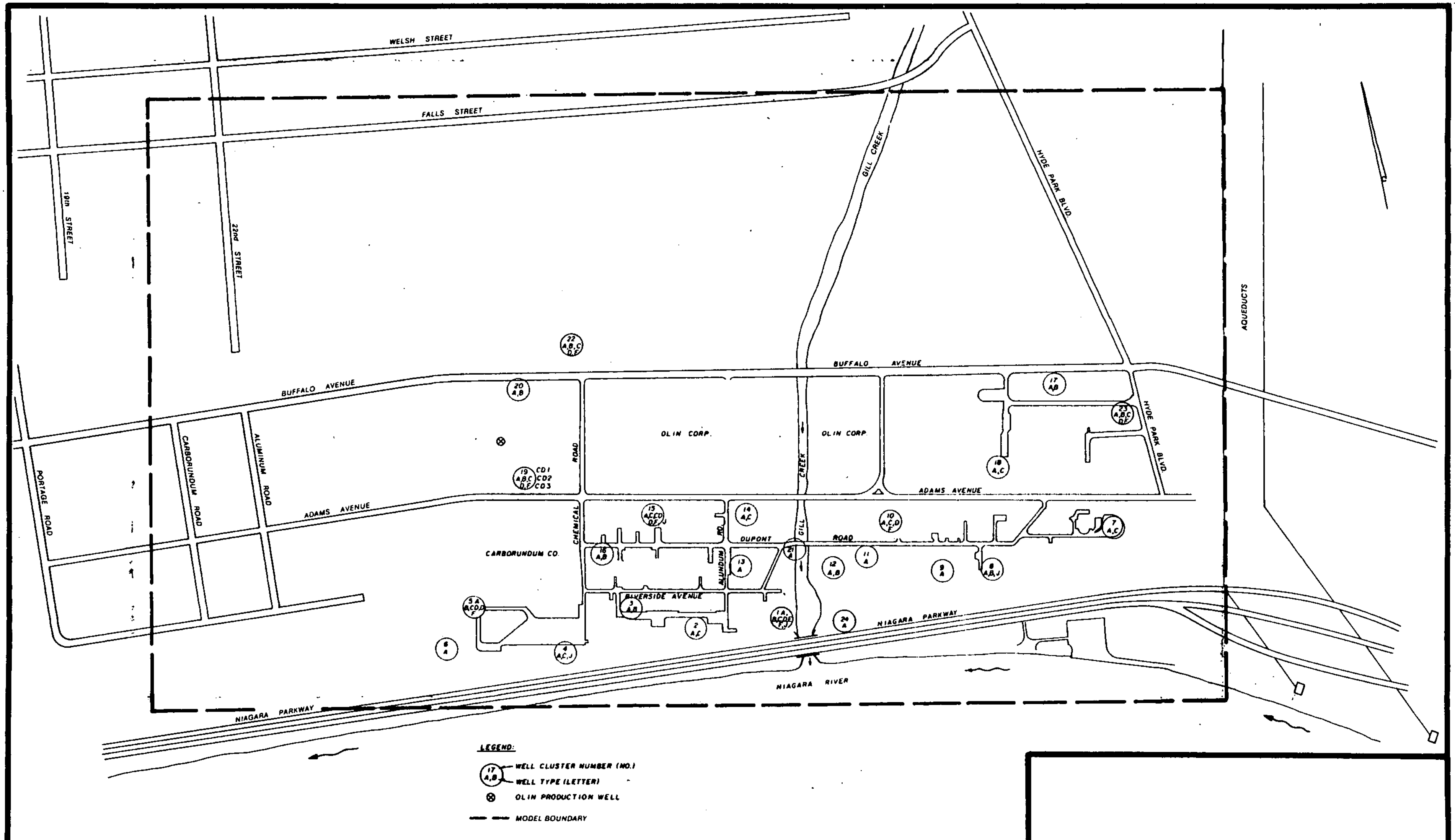


SIMULATED HYDRAULIC HEAD CONTOURS
CD-ZONE: REMEDIATION
DuPONT - NIAGARA PLANT
NIAGARA FALLS, NEW YORK

PLATE 17



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CONSULTING ENGINEERS, GEOLOGISTS AND ENVIROMENTAL SCIENTISTS

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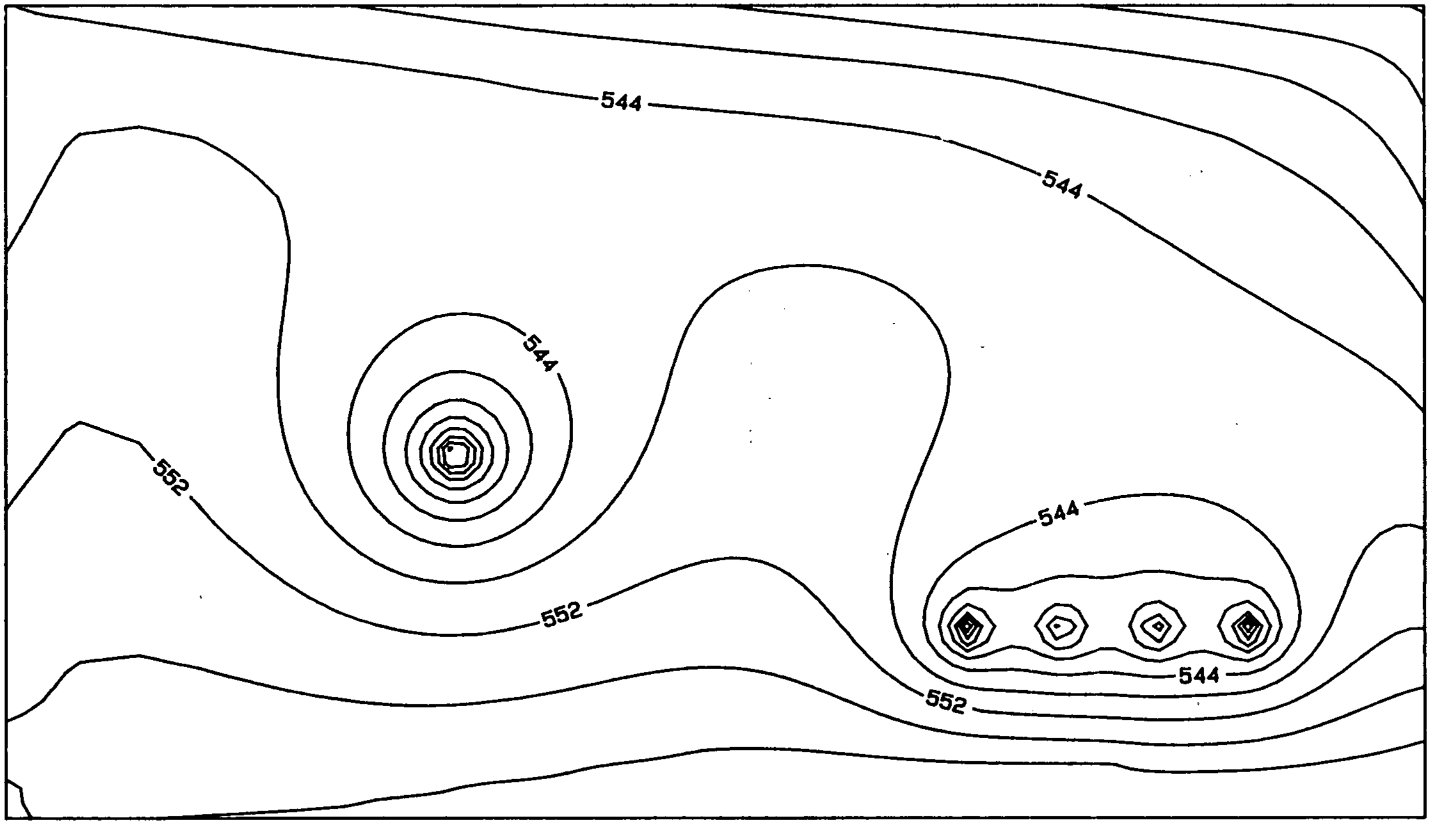
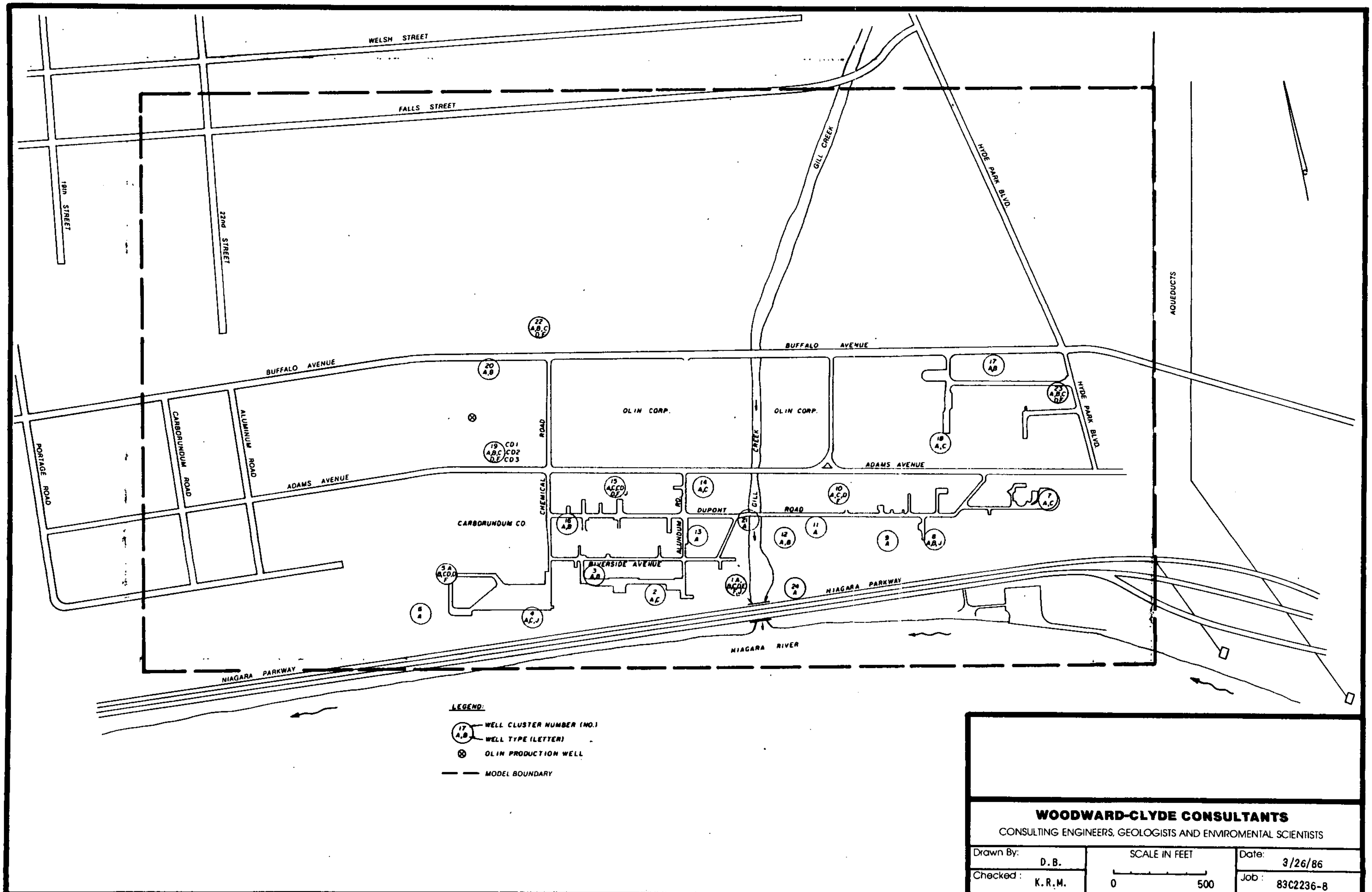


SIMULATED HYDRAULIC HEAD CONTOURS
D-ZONE: REMEDIATION
DuPONT - NIAGARA PLANT
NIAGARA FALLS, NEW YORK

PLATE 18



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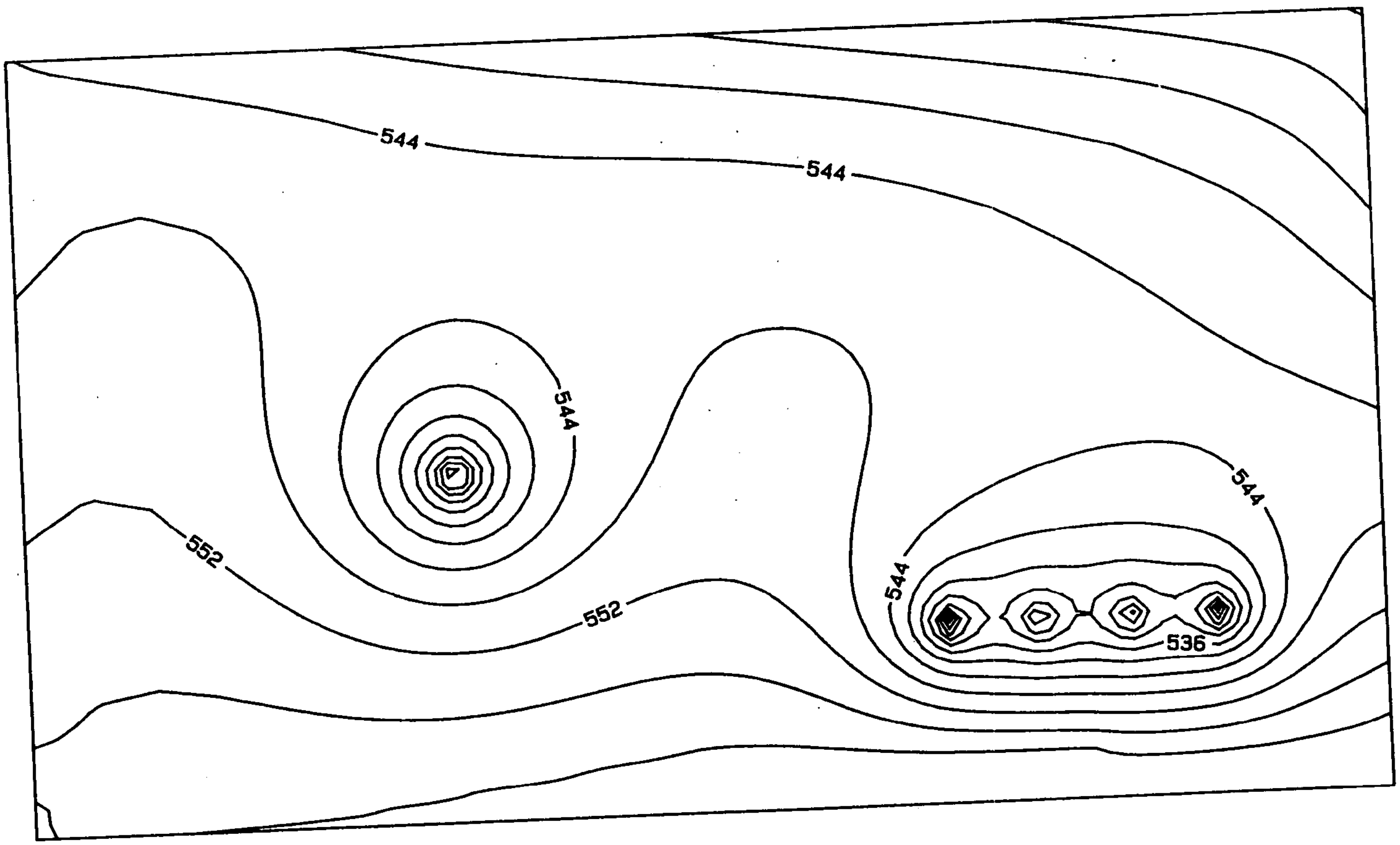
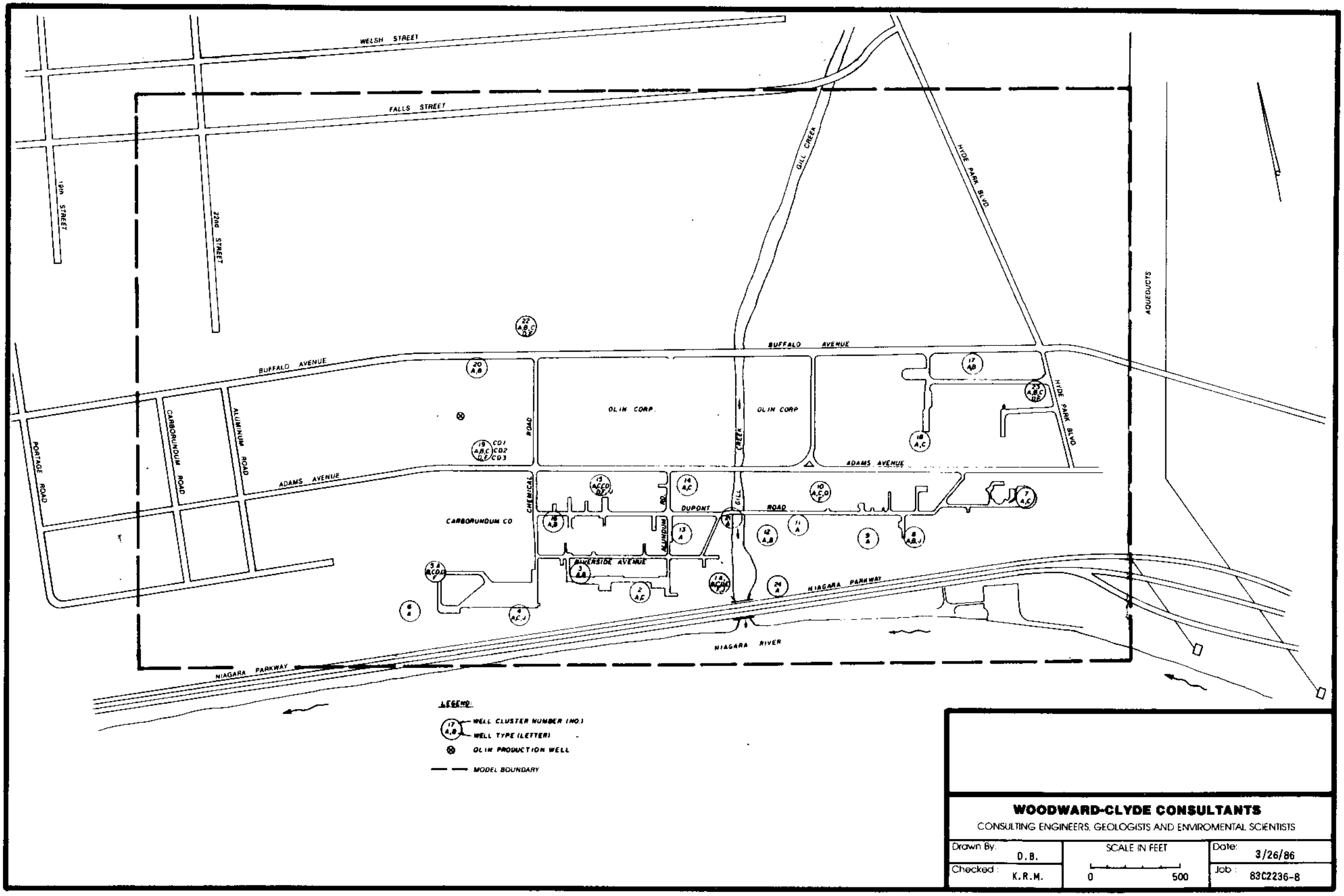


SIMULATED HYDRAULIC HEAD CONTOURS
F-ZONE: REMEDIATION
DuPONT - NIAGARA PLANT
NIAGARA FALLS, NEW YORK

PLATE 19


WELSH STREET
FALLS STREET
19th STREET
22nd STREET
GILL CREEK
HYDE PARK BLVD.
AQUEDUCTS
BUFFALO AVENUE
ADAMS AVENUE
OLIN CORP.
OLIN CORP
CARBORUNDUM CO
CHEMICAL ROAD
DUPONT ROAD
RIVERSIDE AVENUE
ALUMINUM ROAD
CARBORUNDUM ROAD
PORTAGE ROAD
NIAGARA PARKWAY
NIAGARA RIVER
LEGEND:
WELL CLUSTER NUMBER (NO.)
WELL TYPE (LETTER)
OLIN PRODUCTION WELL
MODEL BOUNDARY
WOODWARD-CLYDE CONSULTANTS
CONSULTING ENGINEERS, GEOLOGISTS AND ENVIROMENTAL SCIENTISTS
Drawn By: D.B.
Checked: K.R.M.
SCALE IN FEET
0 500
Date: 3/26/86
Job: 83C2236-8

#67