Report. HW. 712004. 1994-02-24. Groundwater_ Path_ Analysis. PDF

United States Department of the Interior

GEOLOGICAL SURVEY
Water Resources Division
903 Hanshaw Road
Ithaca, New York 14850
607-266-0217

February 24, 1994

Mr. Mark Granger
United States Environmental Protection Agency
Region 2
Jacob J. Javits Federal Building
New York, New York 10278

Dear Mr. Granger

Enclosed are results of a particle-tracking analyses for the Rosen Superfund site in Cortland, New York. Included in the report are; a brief background on the hydrogeology of the Cortland aquifer system, rather extensive section on documentation of the computer ground-water model, and lastly a description (with illustrations) of ground-water path lines originating from both the upper and lower aquifers at the Rosen site. Model simulations and particle-tracking analyses were done for high-, average-, and low-recharge conditions for both the upper and lower aquifer. Several illustrations are presented for each scenario (black and white of entire aquifer and zoom version; and color of entire aquifer and zoom versions). I've included a clear transparency of a base map at same scale of the "zoom" particle-tracking illustrations so that you can overlay it over the zoom versions to orient yourself with the social-geographic features of the study area. If you have any questions please feel free to call me at (607) 266-0217.

Sincerely,

Todd S. Miller

GROUND-WATER PATH LINES FROM THE ROSEN SUPERFUND SITE IN CORTLAND, NEW YORK

By
Todd S. Miller

INTRODUCTION

The Rosen Superfund site is in the southeast part of the Otter Creek-Dry Creek aquifer in Cortland, New York (fig. 1). The aquifer is one of the most productive in New York and has been designated as a "Primary Aquifer" by the New York State Department of Environmental Conservation, and as a "Sole Source Aquifer" by the U.S. Environmental Protection Agency. A hydrogeologic investigation of the Rosen Superfund site by Blasland and Bouck Engineers (1992) found several volatile and semi-volatile organic compounds (VOCs and SVOCs) in ground water in concentrations that exceeded U.S. Environmental Protection Agency's(USEPA) Maximum Contaminant Levels (MCLs). 1,1,1-Trichloroethane and 1,2-dichloroethane concentrations exceeded the MCLs in off-site wells, as well as in on-site wells. Federal and local government agencies needed to know the path of contaminants that are migrating from the site in order to plan remediation practices.

For a hydrogeologic study conducted during 1989-93 by the USGS, in cooperation with Cortland County, three computer ground-water models (MODFLOW) were constructed and a particle-tracking computer program, MODPATH, was used in conjunction with the numerical computer ground-water models, to determine the advective-phase path of chemicals migrating from sources of contamination and to estimate the contributing areas to public-water-supply wells. These models and particle-tracking program were applied to the Rosen site to determine the path of the advective phase contaminants that may be migrating in ground water from the the site.

HYDROGEOLOGY OF THE CORTLAND AQUIFER SYSTEM

The Cortland aquifer system is part of a large regional aquifer system, which includes most major valleys in the Tioughnioga River Basin. The Cortland aquifer system is defined in this investigation as the Otter Creek-Dry Creek Valley and parts of adjacent West Branch, East Branch, and Tioughnioga River Valleys (fig. 1). The aquifers in the valley-fill deposits of the Otter Creek-Dry Creek valley consist of sand and gravel layers. The aquifer system consists of a 40-to-80-ft thick unconfined aquifer (upper aquifer) that overlies a 1-to-150-ft thick confining layer which, in turn, overlies a 0-to-150-ft thick confined aquifer (lower aquifer). The upper aquifer consists of poorly sorted clay, silt, sand, and gravel of kame moraine deposits in the west part of the study area and well-sorted outwash sand and gravel that extends from the moraine to the east part of the study area. Glaciolacustrine fine sand, silt, and clay form the confining layer in the valley except where it is absent in many places along the edges of the valley. The lower aquifer consists of fair-to-poorly sorted silt, sand, and gravel. Although the confining unit impedes ground-water movement between the upper and lower aquifers in the middle of the valley, there is hydraulic continuity between the upper and lower aquifers where the confining layer is absent in many places along the valley walls such as at the Rosen Superfund site in the southeast part of the study area (fig. 2).

The top of the unconfined upper aquifer is the water table in the kame and outwash material. The sides of the upper aquifer have abrupt lateral contacts along till-covered bedrock hillsides. The bottom of the upper aquifer is the top of the lacustrine confining unit except where it is absent in many places along the sides of the valley, in which case, the approximate elevation of the top of the confining unit that was nearby was used for an arbitrary bottom to the upper aquifer. The bottom of the upper aquifer (also the top of the lacustrine unit) is flat to gently sloping. Saturated thickness of the unconfined upper aquifer, the depth from the water table to the top of the glaciolacustrine confining unit, was typically as much as 80-ft thick in the west part and then it thins to the northeast where it is about 40-ft thick at the Tioughnioga River. Saturated thickness that thins from southwest to the northeast results in a long, wedge-shaped aquifer with relatively smooth sloping top and bottom surfaces.

The top of the lower aquifer is the bottom of the lacustrine confining layer; the bottom of the lower aquifer is the smooth walls and floor of the U-shaped till/bedrock valley. The shape of the bottom of the lower aquifer conforms to that of the valley which is symmetrical in most places, but is asymmetrical in some reaches of the valley. The top of the lower aquifer has an undulating surface reflecting the buried hummocky kames and/or beaded-shaped glaciofluvial deltas that comprise the deposits that form the confined aquifer. The saturated thickness of the lower aquifer is the distance from the bottom of the glaciolacustrine sediments to the top of the till/bedrock valley; saturated thickness ranges from 1 to 150 feet. The lower aquifer was found everywhere in the study area, except in the west part, where geologic logs of several wells indicate that lacustrine deposits extend to the bedrock valley floor.

Glaciolacustrine sediments, consisting of interbedded fine sand, silt, and clay, form a relatively impermeable confining layer that separates the unconfined (upper) from the confined (lower) aquifers except in some places along the valley walls (fig. 2) where the confining unit pinches out and the upper and lower aquifers are connected. The glaciolacustrine sediments roughly form a wedge-shaped lens when viewed in a geologic section perpendicular to the axis of the valley. The confining unit is as much as 155 ft thick in the middle of the valley in the central and north parts of the study area; the confining unit thins from the middle of the valley towards the valley walls where it pinches out. The confining unit is typically 60-140 ft thick in the central and east parts of the study area. The depth to the confining layer from land surface is typically 100 to 130 ft in the west part; 55-85 ft in the central part; and 35-65 ft in the east part of the study area. The confining layer extends beyond the study area in all the valleys.

SIMULATION OF GROUND-WATER FLOW

In order to simulate the range of flow conditions that occur in the aquifer system and because the amount of recharge varies both seasonally and annually in the Otter Creek-Dry Creek aquifer, which results in significant differences in flow conditions, three steady-state models were developed to simulate average annual high-, average-, and low-recharge conditions. Ideally, transient-flow models are better than steady-state models to simulate the seasonal variations of recharge, but as of the time of this study the particle-tracking program, which is critical to the goals of this study, works only with steady-state flow models. Dave Pollock of the Water-Resources Division, USGS is working on transient-flow model version of the particle-tracking program that will be available in 1994.

Description and Design of Numerical Models and Input Parameters

Three quasi-three-dimensional, digital ground-water flow models were constructed and calibrated to compute hydraulic head (hereafter referred to as head) in the glacial aquifer system in

Cortland. The models were developed using the computer program described by McDonald and Harbaugh (1988). The numerical model is based on block-centered, finite-difference equations that describe the physics of water flowing through unconsolidated deposits. The differential equation relates water levels to the geometry of the aquifer, to recharge, to hydraulic properties such as hydraulic conductivity and storage coefficient, and to stresses such as pumpage. Water levels are calculated only at discrete points, the center of a cell block, each which represents a part of the aquifer system. All characteristics of the system, including geometry of the aquifer, hydraulic properties, and stresses, are defined by values specified at the center of the cell block. The process of representing a continuous system with a limited number of discrete points is called discretization.

In the finite-difference method, the discrete points are located along rows and columns, and each point is associated with a cell. The finite-difference grid forms a "checkerboard" of cells. "Active" cells represent the aquifer and are assigned values describing geometry of the aquifer, hydraulic properties, and recharge and discharge rates to the cell; "inactive" cells are outside the aquifer or simulated area and are ignored in the simulations. Three finite-difference grids were used to represent the three-layered Otter Creek-Dry Creek aquifer system.

The design of the numerical model is based and was built on the conceptualized model of the aquifer system as previously discussed in the glacial geology and hydrology sections in this report. The conceptual model of the aquifer system is an upper unconfined aquifer that is underlain by a confining layer (lacustrine fine-grained deposit), which in turn is underlain by the lower aquifer that is confined except in some places along the valley walls (fig. 2). The valley-fill aquifer system is simulated as a quasi-three-dimensional flow system with three layers (fig. 2). In this model, the upper aquifer is divided in half to form layers 1 and 2 for greater vertical resolution and so that flow paths and particles used in the particle-tracking program could flow beneath streams that are weak sinks. Layer three is the lower aquifer. In this approach to vertical discretization, the confining unit, a fine-grained lacustrine layer, is represented by the vertical conductance between layers 2 and 3. Heads in the confining unit are not calculated.

Available geohydrologic data of the aquifer system were used to identify geometrical and hydraulic properties such as altitudes of aquifer surfaces and stream channels; and hydraulic conductivities. In areas with little or no data, the model inputs were estimated and then adjusted during calibration of the model within reasonable limits so that simulated water levels and flows matched measured values.

Grid

A rectangular finite-difference grid with 66 rows and 119 columns was superimposed on a map of the Otter Creek-Dry Creek valley to discretize the geohydrologic conditions of the conceptual model. A grid with uniform-sized cells, 300 x 300 ft, were used because public-water supply wells, streams, and sources of contamination are scattered throughout the study area and a uniform-sized grid simulates more accurately the regional geohydrologic conditions than a grid with variable-sized cells which increases detail in areas of special interest in the finely-spaced cell areas at the expense of not accurately representing the areal extent of the unconsolidated deposits and streams in the coarsely-spaced cell areas.

Aquifer Geometry

Geologic sections that were drawn for every second row of the model, for a total of 33 sections, were used to determine the geometry of the aquifer system. The surface elevations of the bottom of layer 1, and top and bottom of layers 2 and 3 were picked off from the geologic sections and entered as arrays into the block-centered-flow (bcf) package. The model calculates the elevation of the top of layer 1, which is the water table. Elevation data of aquifer geometry for intervening rows of the model that had no geologic sections were derived from cells in those rows that had a well log and from interpolation of elevation data from the rows with geologic sections. The bottom of layer 1 is either the till/bedrock surface along the valley walls and where there are no underlying layers or approximately half the thickness of the upper aquifer where it is underlain by layer 2. The top of layer 2 (also bottom of layer 1) is also half the thickness of the upper aquifer; the bottom of layer 2 is the top surface of the lacustrine confining unit. The top of layer 3 is the bottom of the confining unit or bottom of layer 2 where the confining unit is absent; the bottom of layer 3 is the till/bedrock surface in the valley.

Hydraulic Conductivities

The horizontal hydraulic conductivity values used for layers 1 and 2 ranged from 1 to 1,200 ft/d. The horizontal hydraulic conductivity of the upper aquifer (layers 1 and 2) were measured during 7 aquifer tests which used large pumping wells such as the public-water supply and industrial wells. In addition, several hydraulic conductivity measurements (slug tests) were made by Blasland and Bouck Engineers in test wells at the Rosen Superfund site.

There is little information on the origin of the sediments and hydraulic properties of layer 3. Values of hydraulic conductivity of layer 3 were estimated to range typically from 10 to 150 ft/d based on two aquifer tests in the west part of the study area and 6 slug tests at the Rosen Superfund site; from several brief qualitative analyses of the water-producing capacity of wells; and of the distribution in grain size of sediments collected in layer 3 during test drilling.

Low to moderately low values of hydraulic conductivity, 10 to 100 ft/d, reflect the poorly-to-moderately-sorted silty sand and gravels that comprise kame deposits at crest of the Valley Heads moraine and silty gravel outwash in some places along the valley walls throughout the study area, such as the Rosen Superfund Site.

Moderately-high values of hydraulic conductivity, 100 to 300 ft/d, reflect areas where moderately-sorted, alluvial inwash comprised of silty sand and gravel from local upland tributaries and from slope erosion mixed with well sorted outwash sand and gravel; this zone is well developed where large tributaries flow onto the aquifer and weakly developed where small tributaries flow onto the aquifer and where there is slope erosion along the valley walls.

High values of hydraulic conductivity, 300 to 1,200 ft/d, in the upper aquifer reflect well-sorted sand and gravel outwash that was deposited in the central parts of the valleys by fast-flowing meltwaters that flowed northeast from the Valley Heads moraine. The outwash in the central parts of the valleys are comprised of coarse-grained sediments whose grain sizes gradually decrease to the northeast as distance from the terminus of Valley Heads ice increases. Meltwaters deposited bouldery, cobble gravel with little or no fine-grained sediments in the proximal reaches in front of the Valley Heads ice in the west part of the study area which was the source of coarse material and where the stream gradient was relatively steep and flow was fast. Then fine-to-medium sand and gravel was deposited in distal reaches of the valleys in the east part of the study area where the gradient of stream channels decreased and cobbles and boulders were mechanically worn to smaller clasts as they were transported greater distances from the ice front. Values of hydraulic conductivity were gradually decreased to the northeast to reflect the decreasing grain size of the outwash deposits as distance from the moraine increased.

Horizontal hydraulic conductivity was estimated to be 10 times the vertical hydraulic conductivity of the aquifers throughout the modelled area, so that the anisotropy is 10:1. Vertical hydraulic conductivity tends to be less than horizontal hydraulic conductivity in stratified drift because, at a small scale, the stratified drift is composed of many layers of sediment some of which are plate shaped and they tend to settle horizontally. The platy sediments that settle horizontally impede the flow of ground water more than they impede horizontal flow.

Streams

The Streamflow-Routing Package developed by Prudic (1989) was the program used to simulate the interaction between the water-table aquifer and the streams and springs in the study area. Streams in the program are divided into segments and reaches. Each reach corresponds to individual cells in the grid used to simulate ground-water flow. A segment consists of a group of reaches connected in downstream order. Streams in the modelled study area are represented by 427 reaches and 52 segments.

Leakage is subtracted or added to the amount of streamflow in each reach (either into or out of the ground-water flow model depending on the head difference between the stream and aquifer and a conductance term) and the difference is incorporated into the ground-water flow model. Recharge to the aquifer ceases when all the streamflow in upstream reaches has leaked into the aquifer and the stream is dry. A stream can flow again in downstream reaches if the head in the aquifer is above the elevation of the streambed.

Boundary Conditions

Several types of boundary conditions were specified in the digital model to represent the simulated aquifer system. Natural aquifer boundaries are preferred and were used where possible, but because the aquifer system extends many miles beyond the study area in several of the adjoining valleys, arbitrary boundaries were used to limit the modelled area to manageable size. The arbitrary boundaries were located far from the areas of interest, such as municipal well fields and sources of chemical contamination, as to have little effect on model results. "Flux" boundaries refer to those boundaries where a volume of water per unit of time crosses a unit cross-sectional area such as recharge from precipitation over the aquifer.

A no-flow boundary was used for the bottom of the lower aquifer (layer 3) where the sand and gravel aquifer overlies till and/or shale along the bottom of the valley. Till and shale have low hydraulic conductivities and any flux that crosses that boundary would be very small and negligible compared to the relatively large amounts of flow through the aquifers.

No-flow or streamline arbitrary boundaries were used for the upper aquifer (layers 1 and 2) in the West and East Branches of the Tioughnioga River valleys, and in the Tioughnioga River valley. A streamline is a curve that is tangent to the direction of ground-water flow; thus no-flow components exist perpendicular to a streamline and no flow crosses a streamline. The streams in the West and East Branches of the Tioughnioga River valleys, and in the Tioughnioga River valley, where the arbitrary boundaries were drawn, abut against the sides of the valleys; these streams are the discharge areas for the upper aquifer in those reaches and therefore influence the direction of ground-water flow-- ground-water flows roughly from the valley wall without the stream to the side that has the stream. This flow path, from one side of the valley to the other, was chosen as the arbitrary streamline boundary, and was located far from pumping wells and chemical plumes, so that they wouldn't significantly affect model results.

A free-surface recharge boundary was used for the top of the upper aquifer (layer 1), defined by the water table, which is represented in the model as a moving surface where recharge from precipitation was applied uniformly. The water table may rise or fall depending on the overall balances of stresses in the aquifer system, such as pumping wells, recharge, and gain or loss of water from streams that flow over the aquifer.

A specified-flux boundary was used for the contact between sand and gravel the till/bedrock valley walls. Recharge wells along the valley walls were used to simulate the flux (seepage) of surface runoff and ground water from bordering unchannelized uplands into the upper aquifer (layer 1). The amount of flux was determined by the size of the drainage area of the upland that bordered the modelled area. Drainage areas of unchannelized uplands were delineated on maps and their size measured by a digitizer. The drainage area was divided by the number of bordering cells in the model, then the divided areas were multiplied by the recharge rate for the three conditions that were modelled- high-, average-, and low- recharge conditions.

A specified-flux boundary was used to simulate ground-water flow into and out of the confined aquifer (layer 3) in all the major stream valleys (Fall Creek valley, West and East Branches if the Tioughnioga River valleys, Tioughnioga River valley). Ground water flows out of the modeled area through layer 3 in the Fall Creek and Tioughnioga River valleys; and ground water flows into the modeled area through layer 3 in the West and East Branches of the Tioughnioga River valleys.

A specified-flux boundary was also used to simulate ground-water movement through the lacustrine confining layer between the upper aquifer (layer 2) and the confined aquifer (layer 3). Heads in the confining layer were not calculated, instead resistance to flow in the confining unit is included in the conductance equations between layers 2 and 3. This approach of simulating flow through a confining layer is called the “quasi-three-dimensional approach”.

Model Calibration For the Rosen Site

To determine whether the computer ground-water models reasonably represent water levels and hence flow path lines from the Rosen Superfund site, simulated heads from the average-recharge computer model were compared to the closest period that water-level measurements were made at the Rosen site by Blasland and Bouck, Engineers (fig. 9). The computer model was calibrated using synoptic water-level measurements made by USGS throughout the aquifer during May 28 through June 4, 1991. Water levels that were measured three weeks earlier at the Rosen site (May 10, 1991) by Blasland and Bouck, Engineers was the closest in time of measurements made at the site. Although the two periods are not exactly coincident they are reasonably close and can be used to generally assess whether the heads generated by the model are reasonably close to those water levels measured in the field. and if the distribution or pattern of water-levels are similar then path lines will be also. The simulated heads and measured water levels match reasonably well (fig. 9). Measured and simulated heads are all within two feet of each other, which is considered a good calibration.

GROUND-WATER PATH LINES FROM THE ROSEN SUPERFUND SITE

Particle tracking has been used in “advective” models to generate path lines and thereby provide a simple means of evaluating the advective transport characteristics of ground-water systems. Advective models cannot be used to compute solute concentrations in ground water because they do not account for the effect of mixing by dispersion. However, advective models represent a valuable intermediate step between ground-water flow models and advective-dispersion solute transport models. Due to dispersion, contaminant plumes will typically be more extensive than that indicated by an advective model.

The computer program MODPATH (Pollock,1989) is a three-dimensional particle tracking post-processing program designed for use with output from steady-state flow simulations obtained using MODFLOW, the USGS modular three-dimensional finite-difference ground-water flow model (McDonald and Harbaugh, 1988). MODPATH-PLOT generates graphical output using results from MODPATH.

Path Lines in Unconfined Outwash Aquifer during High-, Average-, and Low-Recharge Conditions

Particles were put on top of the water table (top face of cell in layer 1, upper aquifer) in each of the 11 cells within the Rosen site and then, the particle-tracking program was run in forward mode to determine the path of ground water migrating from the site. The path lines of ground water in the upper aquifer during high-, average-, and low-recharge conditions are shown in figures3a-c, 5a-d, and 7a-d Ground water flows from the Rosen Site to the middle of the aquifer and then discharges into the Tioughnioga River, a distance of about 1 mile from origin to discharge area. Path lines shift from a northerly route during high-recharge conditions to more progressively southerly routes during average- and low-recharge conditions. The amount that path lines move to the north depends on the amount of recharge from seepage of upland unchannelized and channelized runoff along the south valley wall in the vicinity of the Rosen site; the more recharge to the aquifer from the south valley wall, the more path lines move to the north. This cause-and-effect condition of recharge from the south valley wall is the most important factor in controlling path lines. There is little or no recharge from the north valley wall countering the influence from the south because the Tioughnioga River is against the valley wall and therefore upland runoff flows directly into the river and does not enter or recharge the aquifer.

aquifer (where the confining layer is not present along the south valley wall) and which would also be where a NAPL may potentially sink from a surface spill to the bottom of the lower aquifer. On the Rosen site, particles were not placed in cells of the lower aquifer where it is confined by lacustrine deposits because there is probably little or no significant movement of contaminants from the upper aquifer through the confining layer of low permeability and to the lower aquifer.

Path lines in the lower aquifer (layer 3) do not extend as far north as those in the upper aquifer (figs. 4a-c, 6a-d, and 8a-d). Path lines in the lower aquifer trend northeast from the Rosen site and then bend to the southeast where they either or both exit the modelled area as underflow in the lower aquifer through the Tioughnioga River Valley (toward Bloggett Mills) as shown in the high- and average-conditions (figs. 4a-c and 6a-d) or they rise into the upper aquifer along the valley wall about 3,000 ft southeast of the Rosen site and discharge into the Tioughnioga River near the southeast end of the modelled area as show in low-recharge conditions (figs. 8a-d). More detailed hydrogeologic data would be needed in the area where path lines rise up into the upper aquifer along the valley wall to determine which or if both conditions occur. If the contaminants follow the path to the Tioughnioga River (scenario shown in figs. 8a-d), there are no drinking-water supplies would be threatened, and the VOCs that discharge into the Tioughnioga River would readily volatilize once they discharge into the river. However, if ground water in the lower aquifer is contaminated and it moves as underflow towards Bloggett Mills, then the individual home wells in Bloggett Mills may be contaminated. Wells in Bloggett Mills would have to inventoried in order to determine whether they tap the upper or lower aquifer.

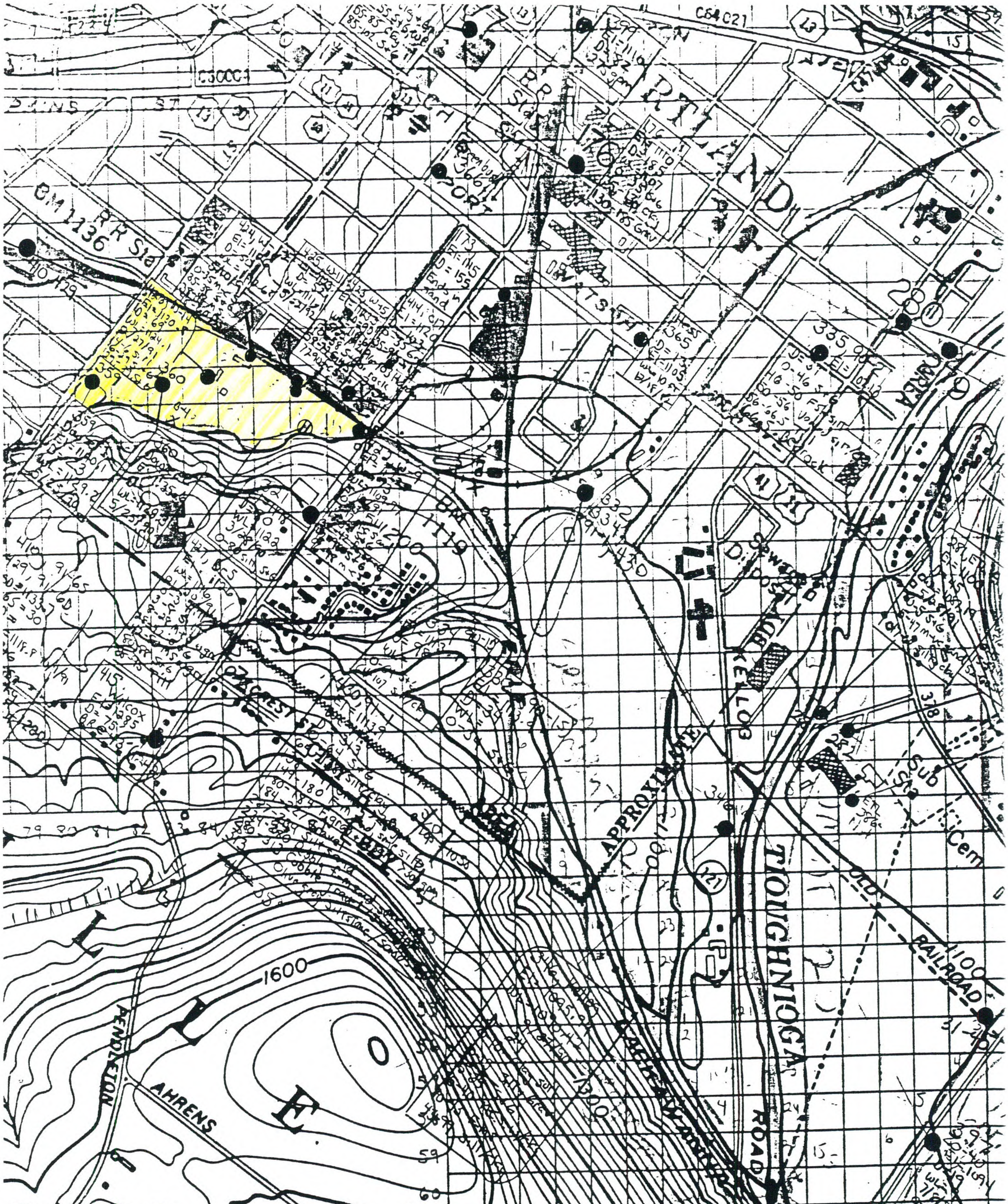
Time-of-travel ranges from 30 to 35 years for ground water to move from the Rosen site to either the discharge area in the Tioughnioga River or to exit the modelled area as underflow through layer 3 in the Tioughnioga River valley.

When path lines are in their most southerly course during low-recharge condition, most path lines end in the Tioughnioga River, but the southernmost path line showed ground water discharging to a pumping well owned by ETL Testing Laboratories (figs 7a-d). TCA is one of the contaminants found in ground water in the ETL well, but more detailed study would be needed to determine whether the TCA found in the ETL well comes from the Rosen site, from the ETL site itself, or from both.

Path lines for all three simulated conditions pass through the cell which contains well 90-1S, an USGS test well installed in the unconfined aquifer and that was sampled in the fall of 1991, and which had TCA, 1,1-DCA, and trans-DCE concentrations of 107.5, 25, and 28.9 µg/L, respectively. A well south of the path lines (Kellogg Road well) had less VOCs (TCA and 1,1-DCA concentrations of 13.8 1nd 5.2 µg/L, respectively) than well 90-1S. VOCs found in much lower concentrations in the Kellogg Road well than in well 90-1S may indicate the dispersive phase of contaminants rather than advective phase. It is not yet conclusive how much of the contaminants found in well 90-1S and in the Kellogg Road well originate from the Rosen site because there are other potential sources of these contamiants between the wells and Rosen site. Time-of-travel for ground water to move from the Rosen site to the Tioughnioga River ranges from 3 years during high-recharge conditions to 4 years during low-recharge conditions.

Path Lines in Lower Aquifer During High-, Average-, and Low-Recharge Conditions

Particles were put on the bottom face of the lower aquifer to simulate the advective path line of a Non-Aqueous Phase Liquid (NAPL) that can sink to the bottom of the lower aquifer and then release a dissolved phase contaminant to ground water (It has not been determined whether a NAPL is present at the Rosen site therefore, this scenario may be hypothetetical). Particles were placed in 7 cells in the lower aquifer where the cells were in hydraulic connection to the upper



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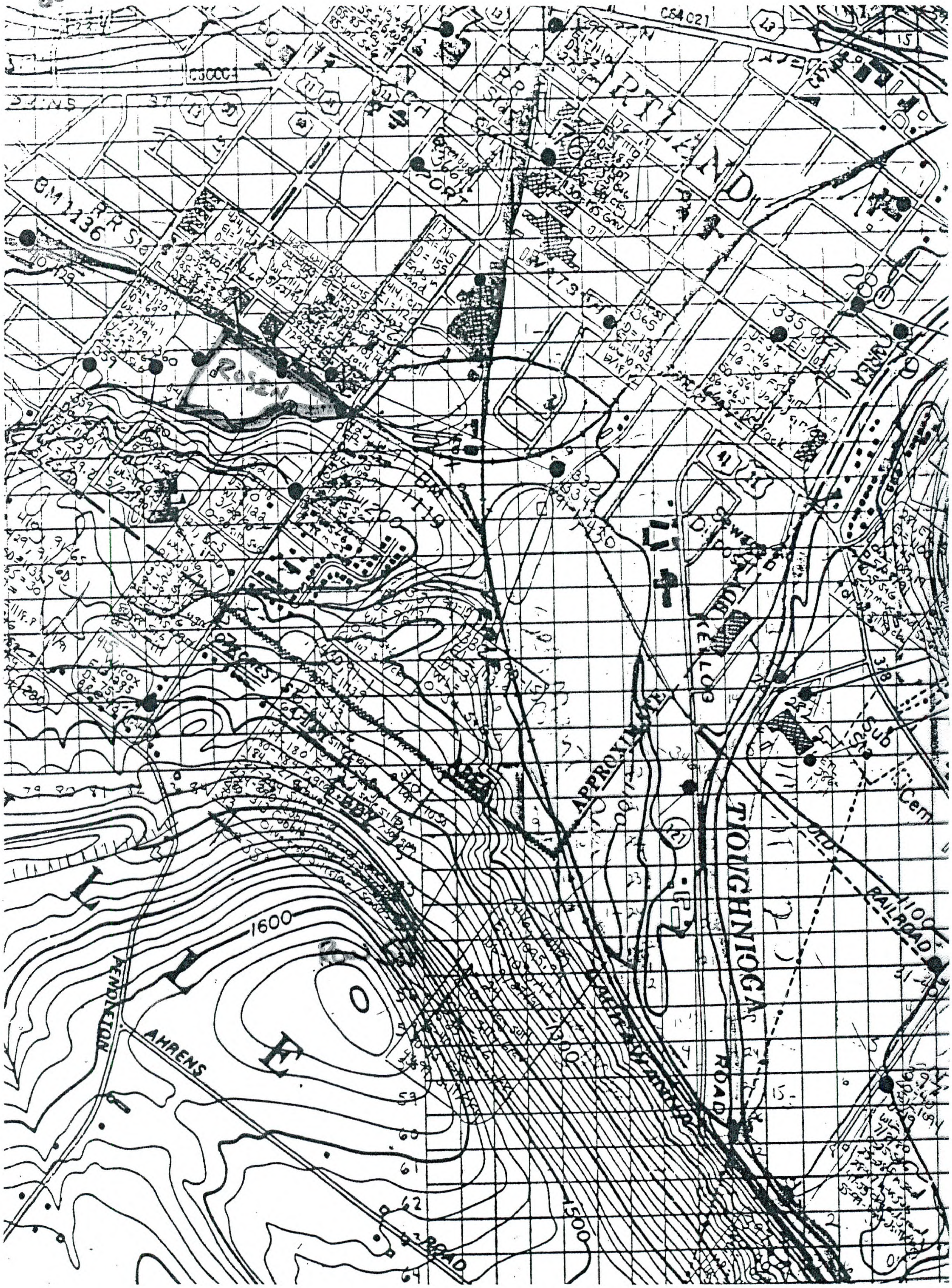
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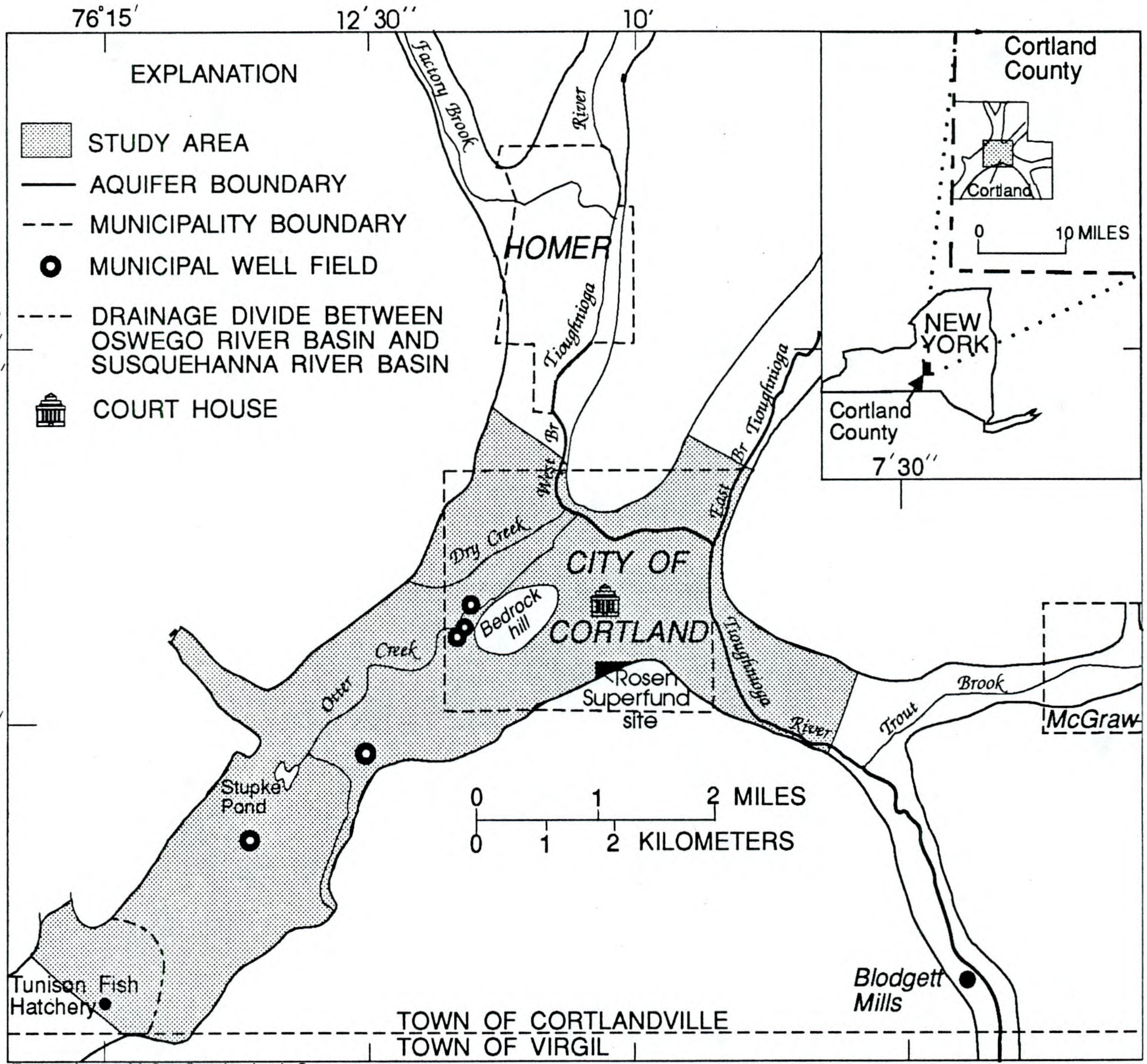
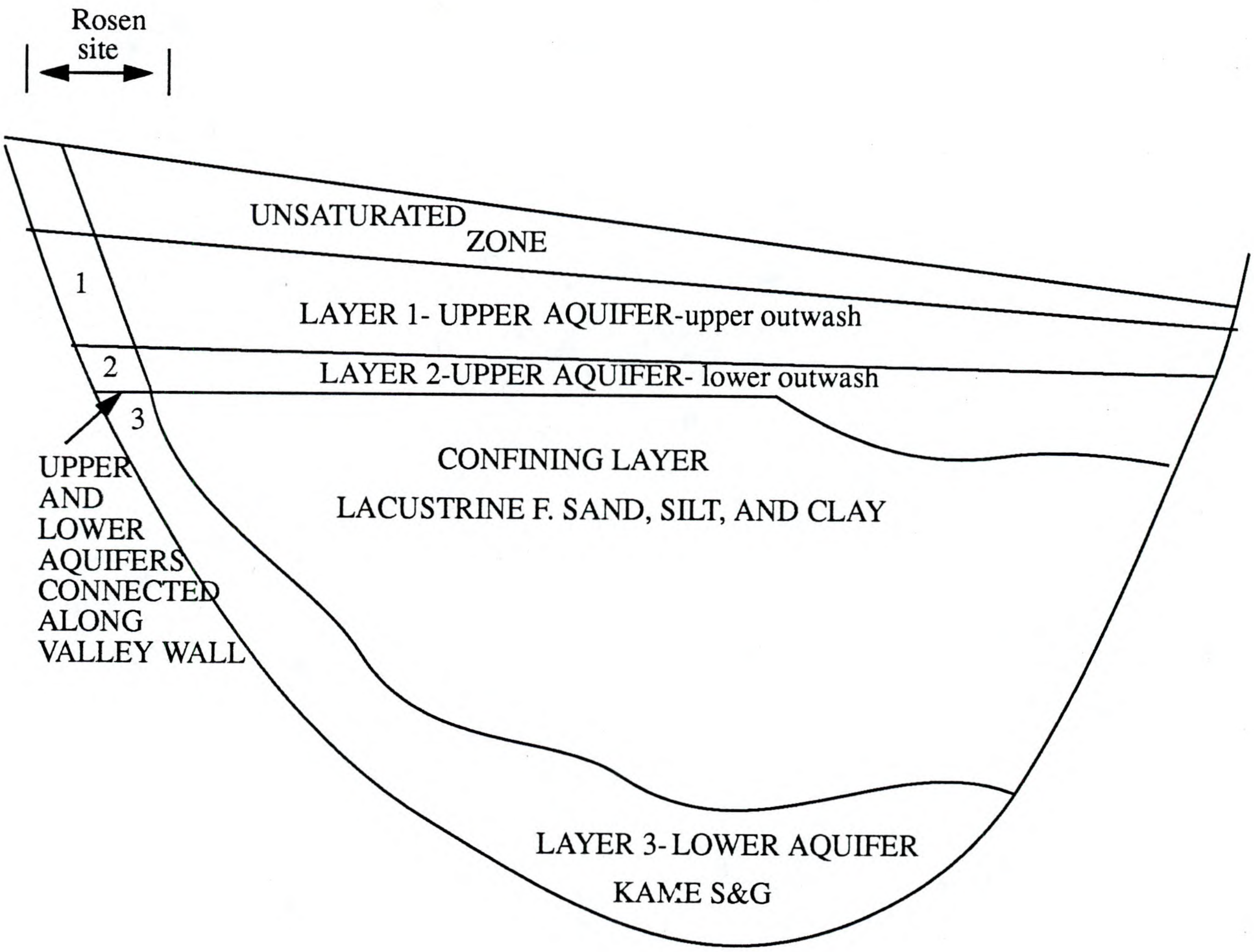


Base from U.S. Geological Survey 1:62,500 series: Cortland (1903) and Groton (1903)

Figure 1. -- Location of study area

QUASI 3-D MODEL OF CORTLAND AQUIFER SYSTEM

CELL DIMENSION=300X300 FT



Not to scale

Figure 2.-- Conceptual model of the Cortland aquifer system.

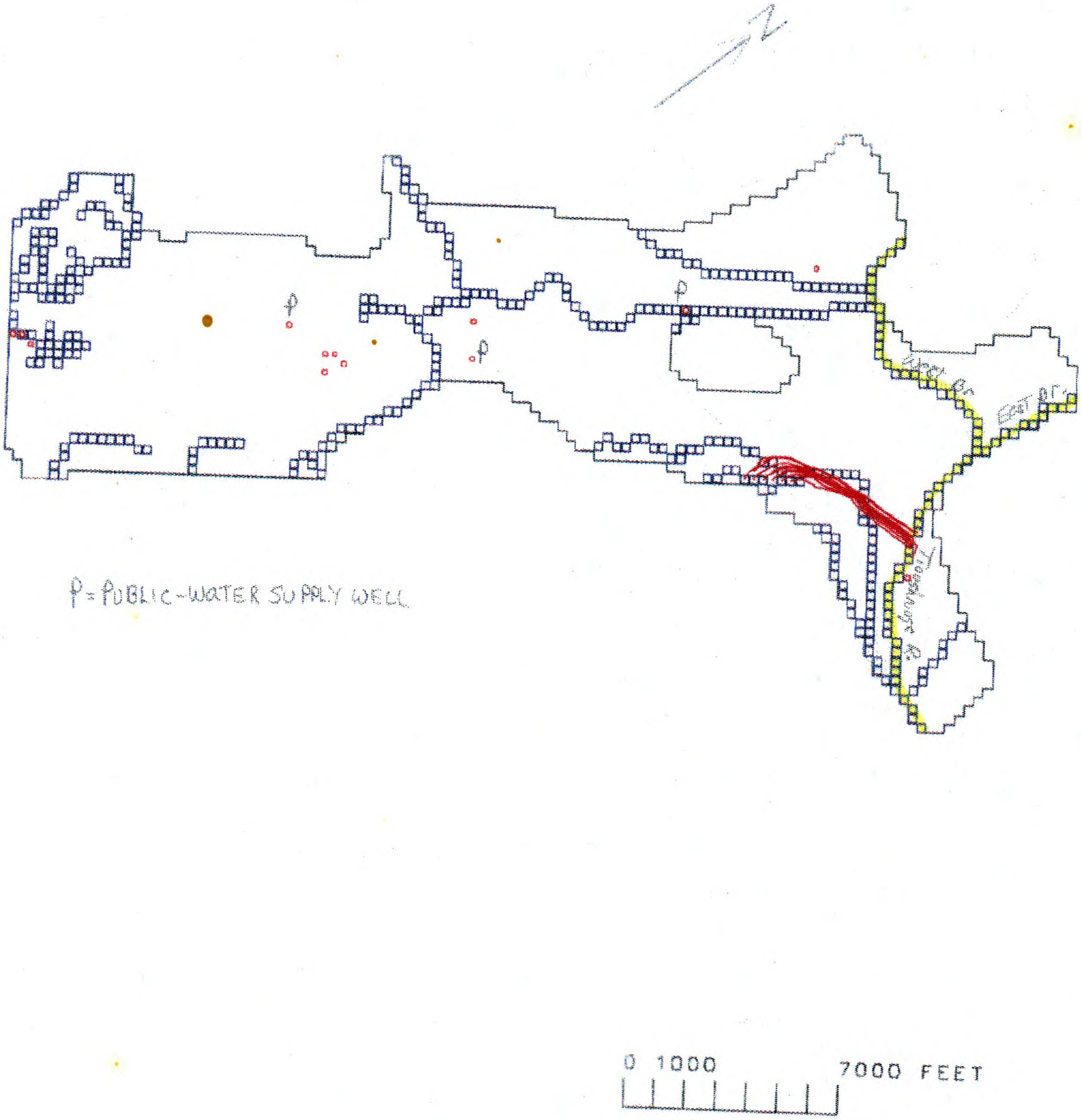


Figure 3b. - color - high-recharge conditions, upper aquifer

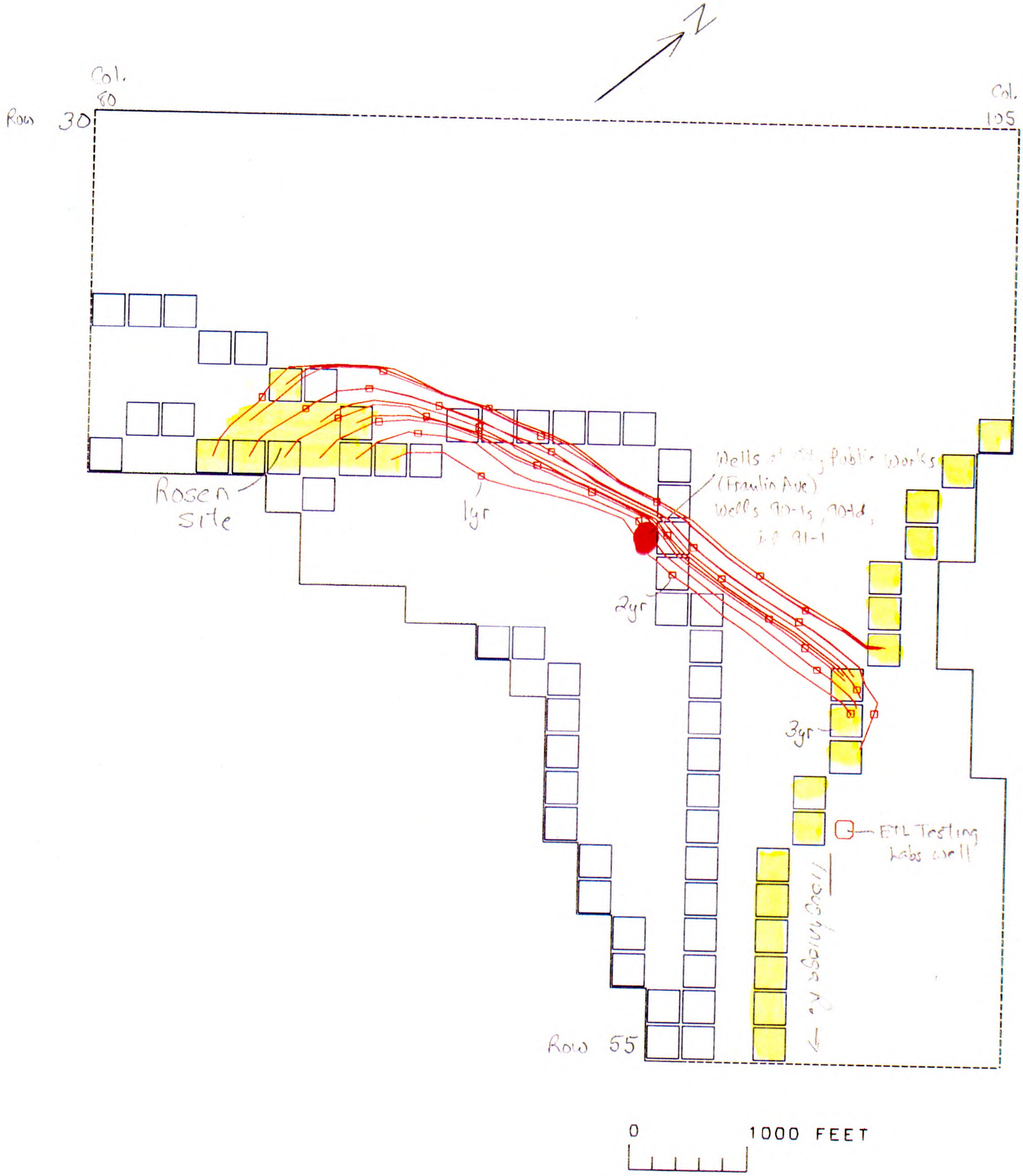
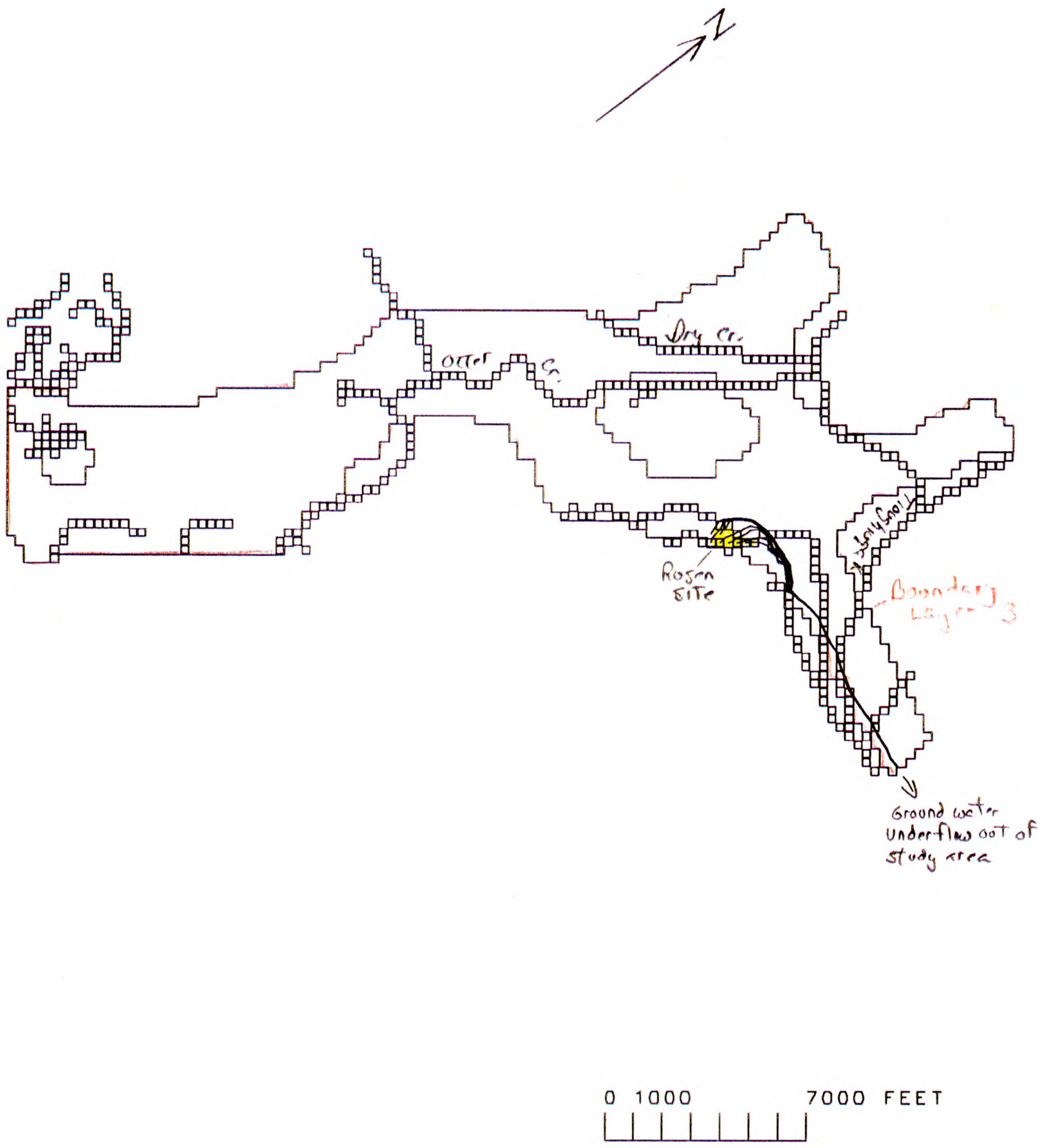


Figure 3c. — Color, zoom, high recharge conditions, upper aquifer



Pathlines from Rosen site (Lower confined aquifer)- high-recharge conditions

Figure 4a.--

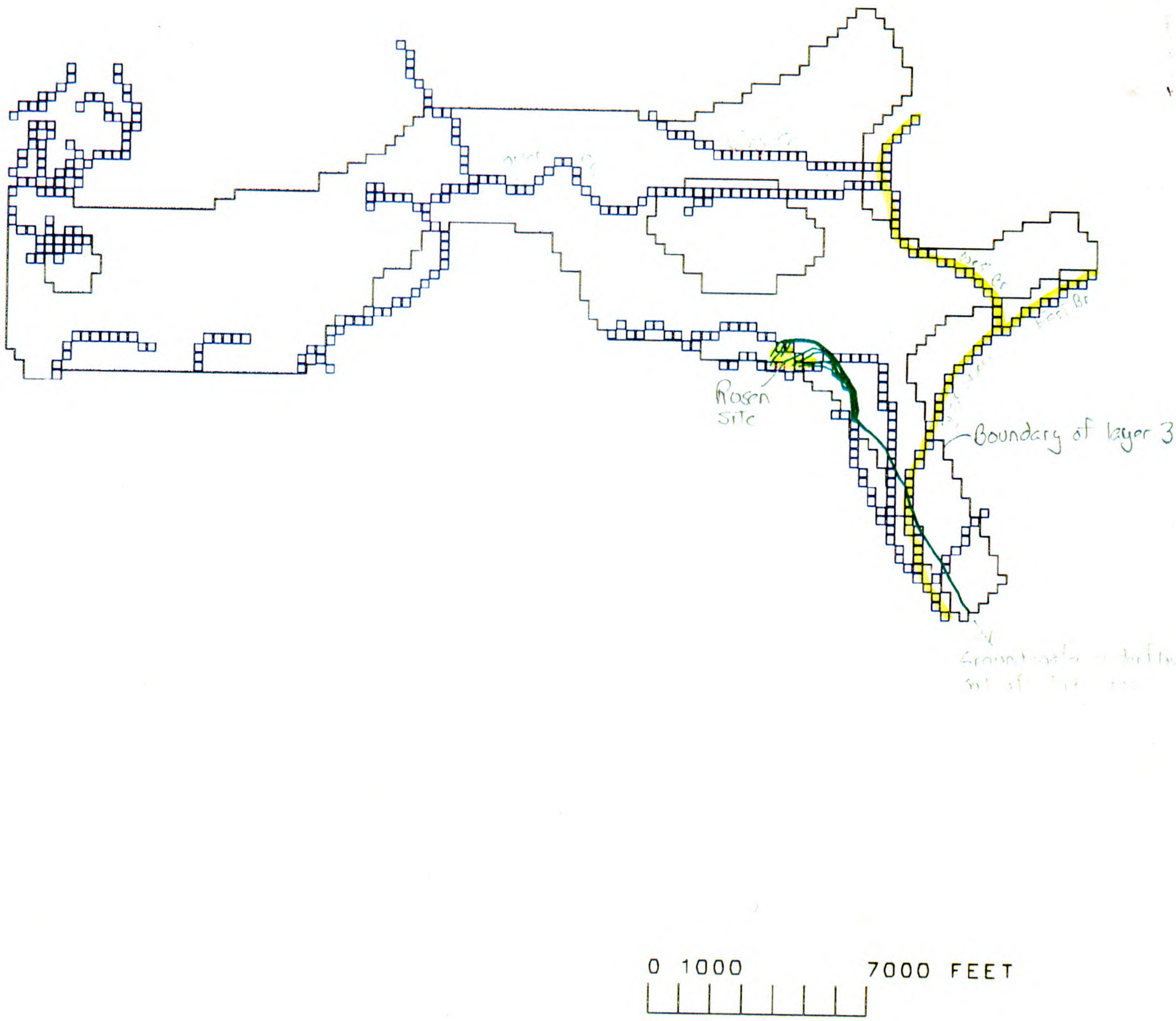


Figure 4b. -

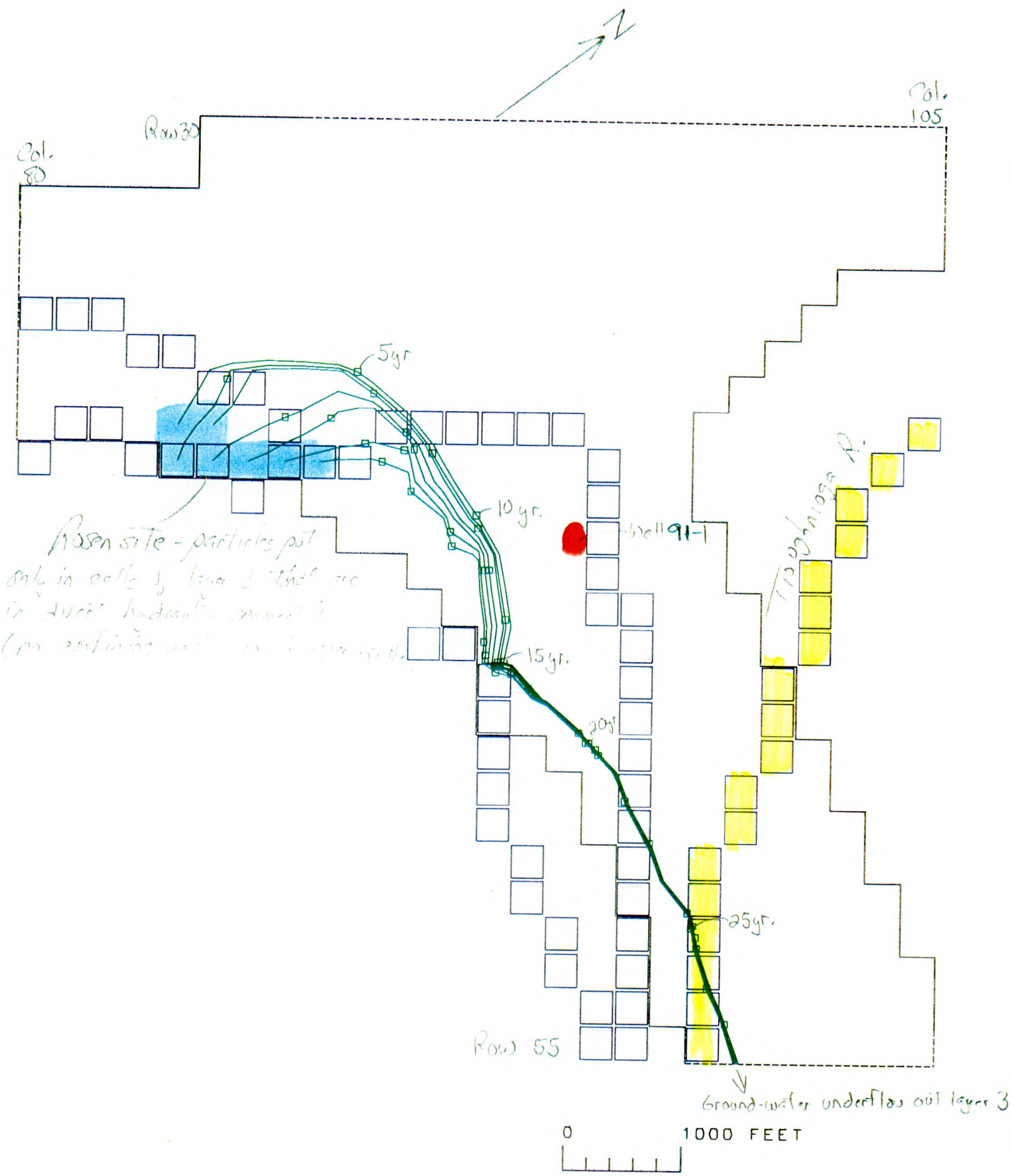


Figure 4c. - Lower aquifer, high-recharge conditions, color, zoom

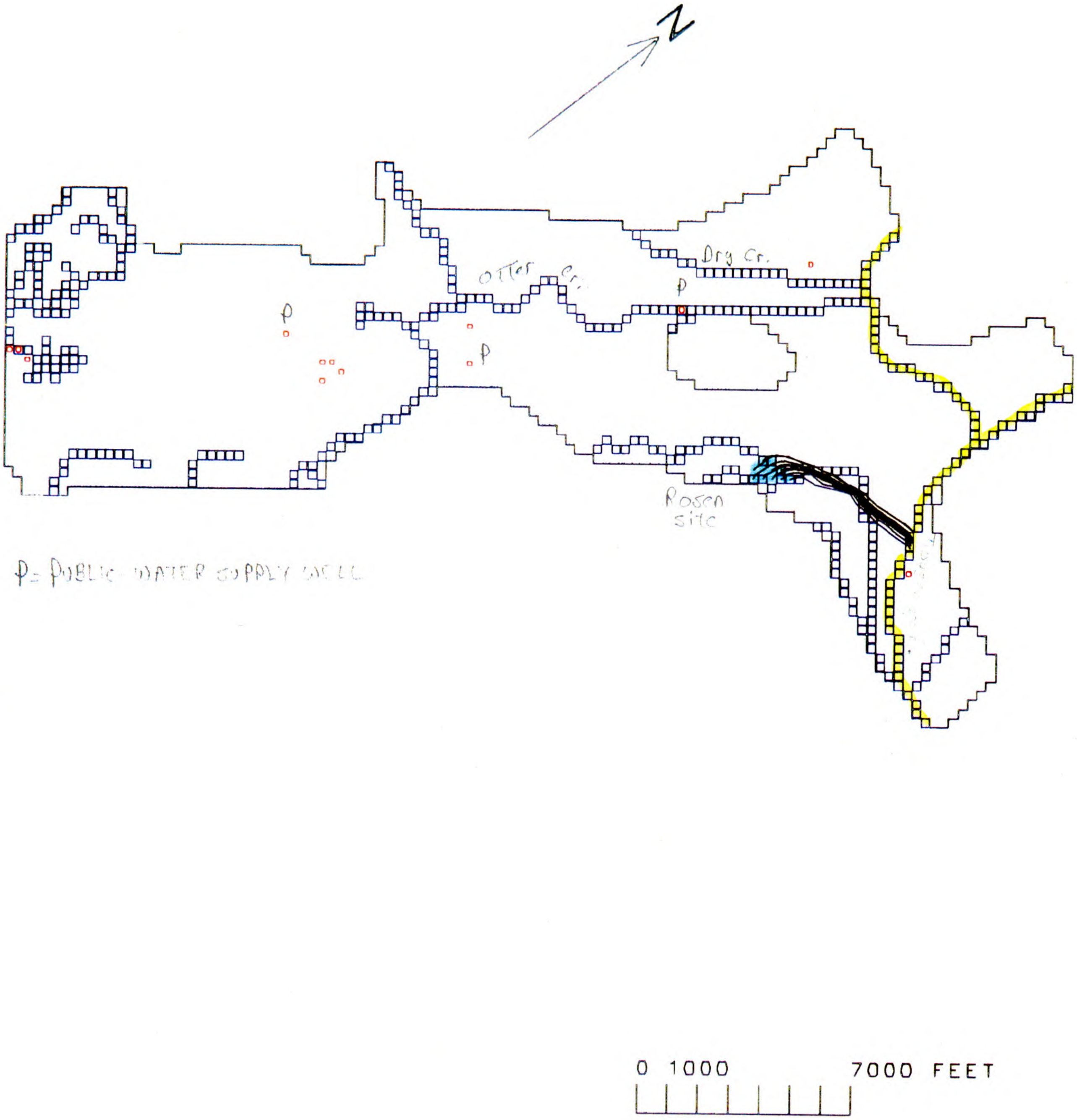


Figure 5b. - Path lines from Rosen site in upper aquifer during average-recharge conditions, color, entire aquifer

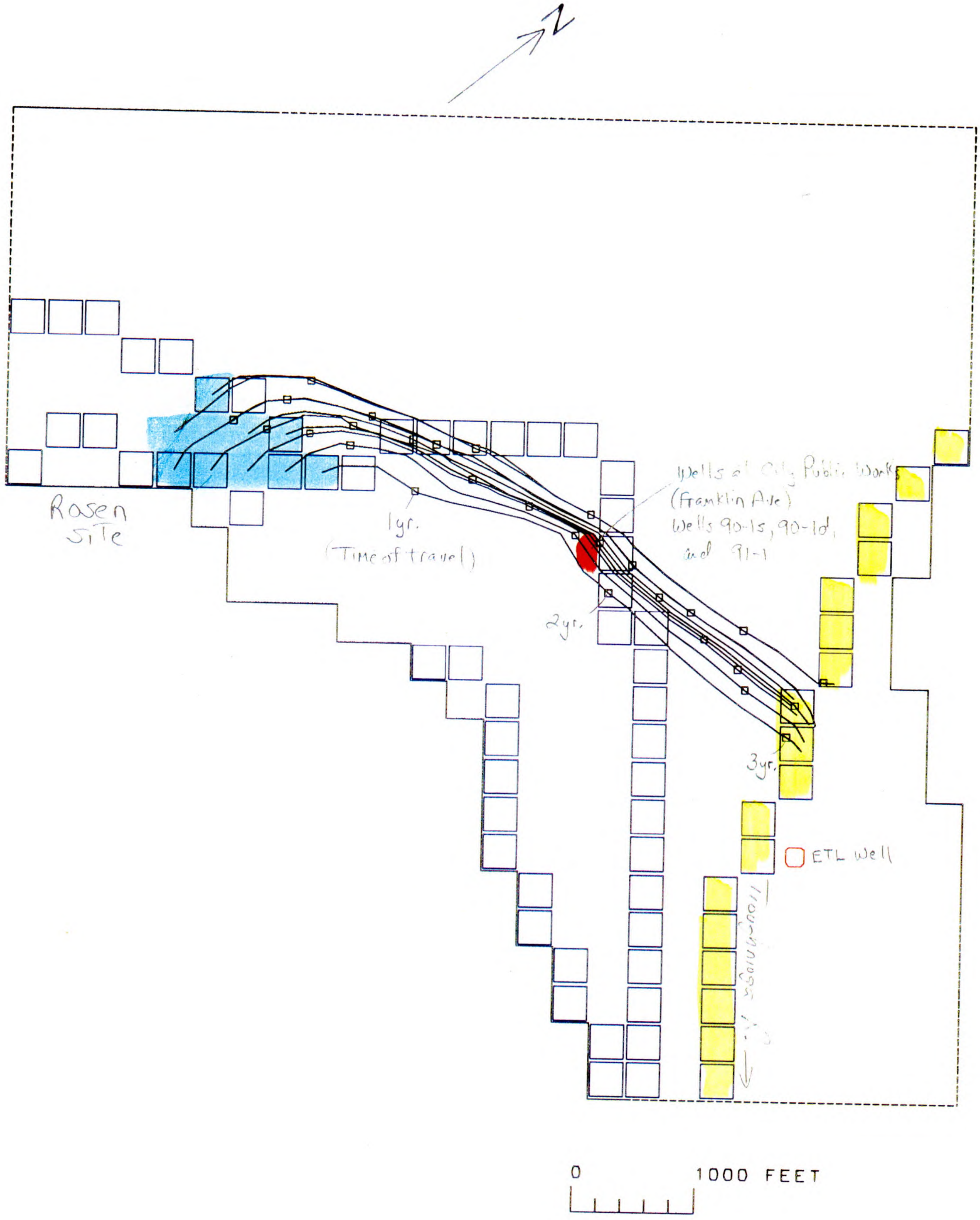


Figure 5d. - Color, zoom, Upper aquifer, average recharge conditions

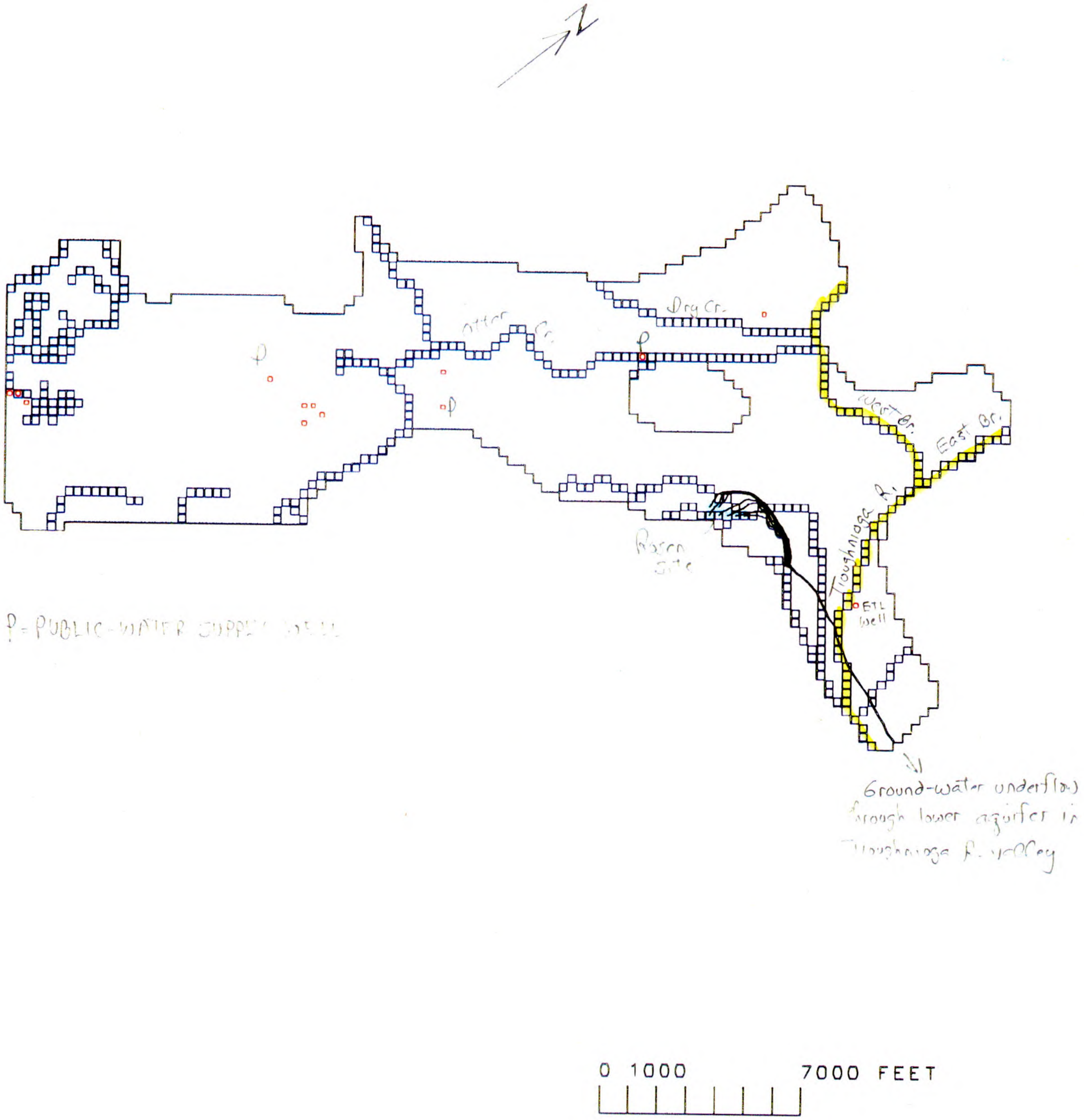


Figure 6c.— color, [illegible], lower aquifer, average conditions

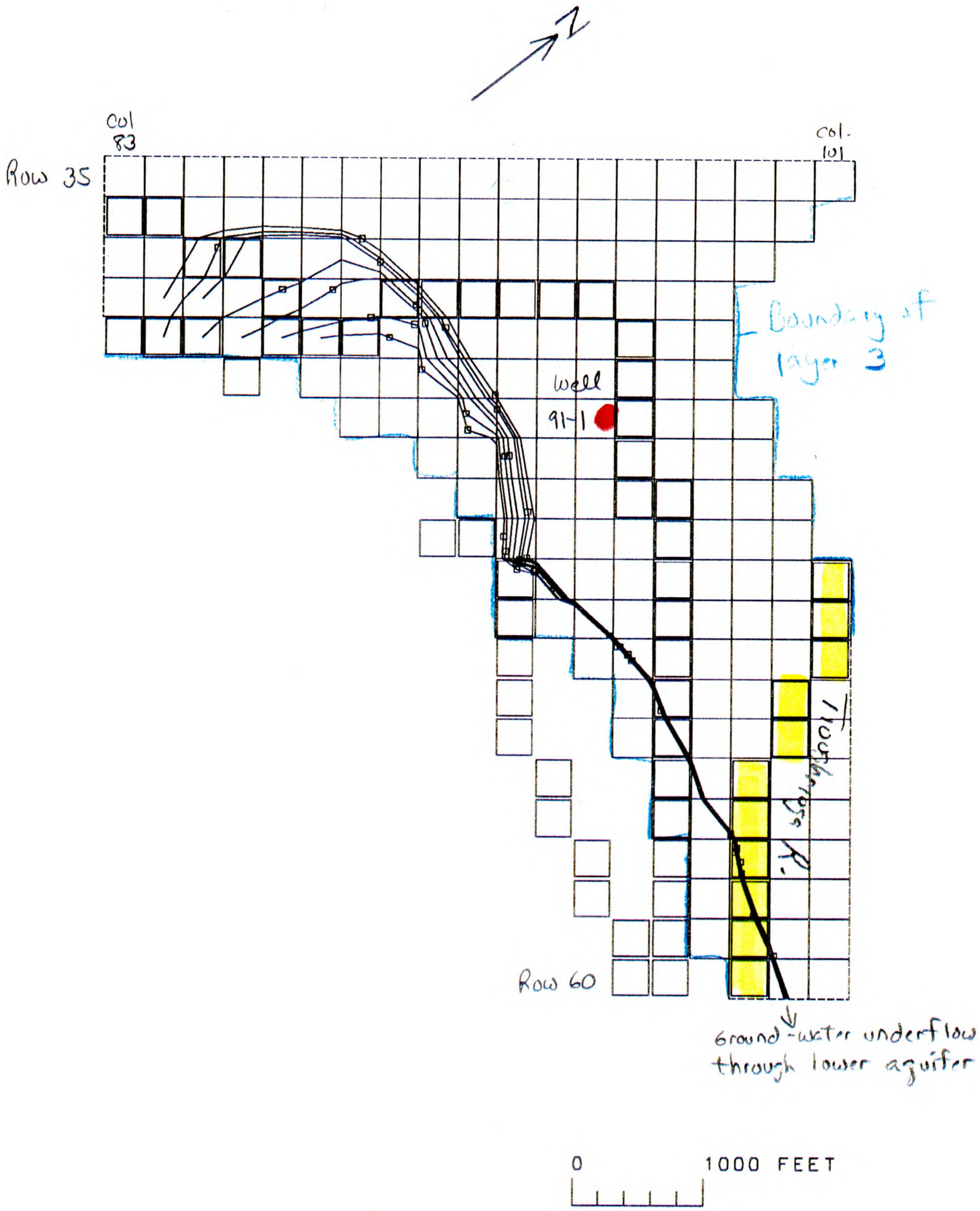


Figure 6c. - B+W, zoom, lower aquifer, average conditions

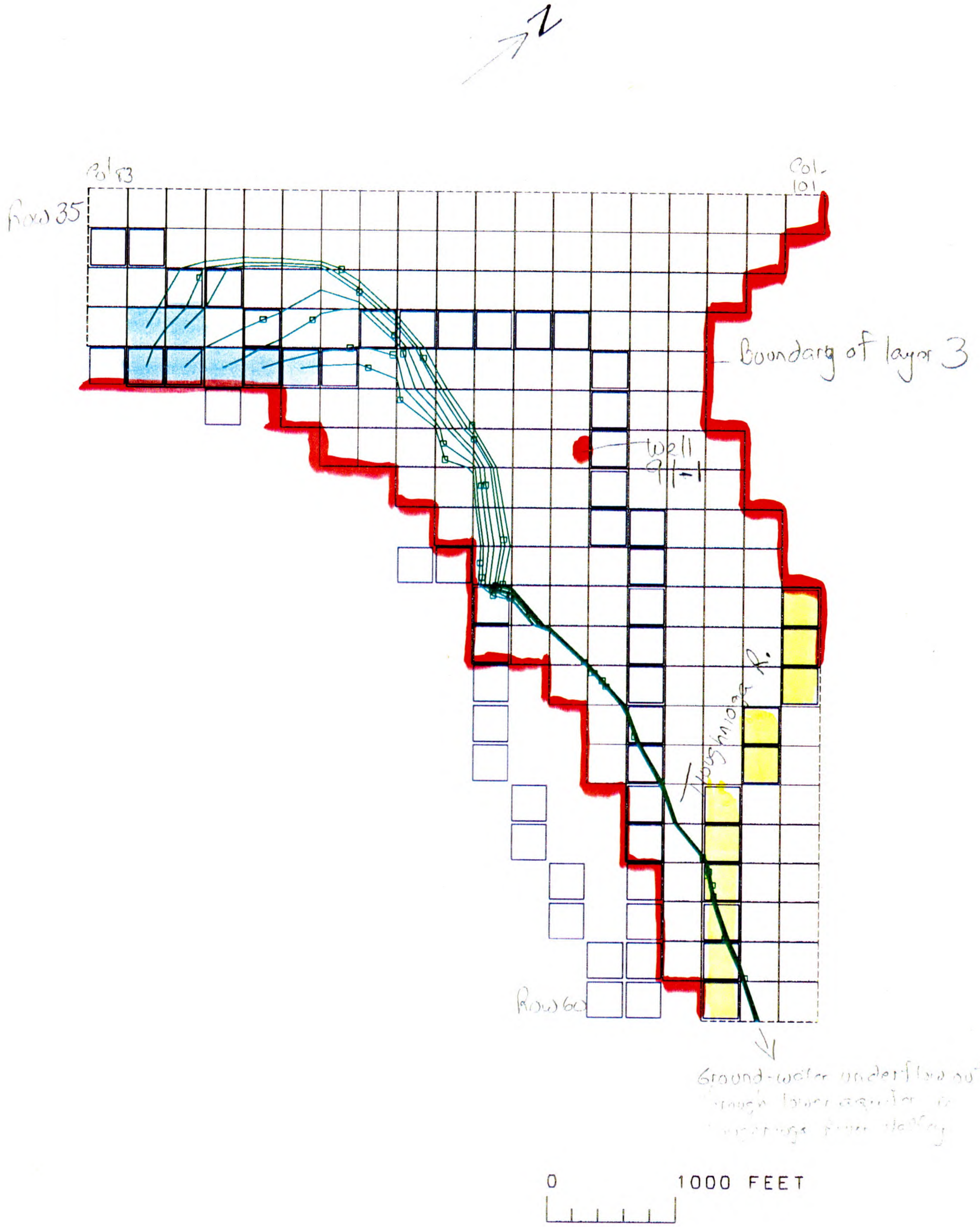


Figure 6d. - Color, zoom, lower aquifer, average conditions

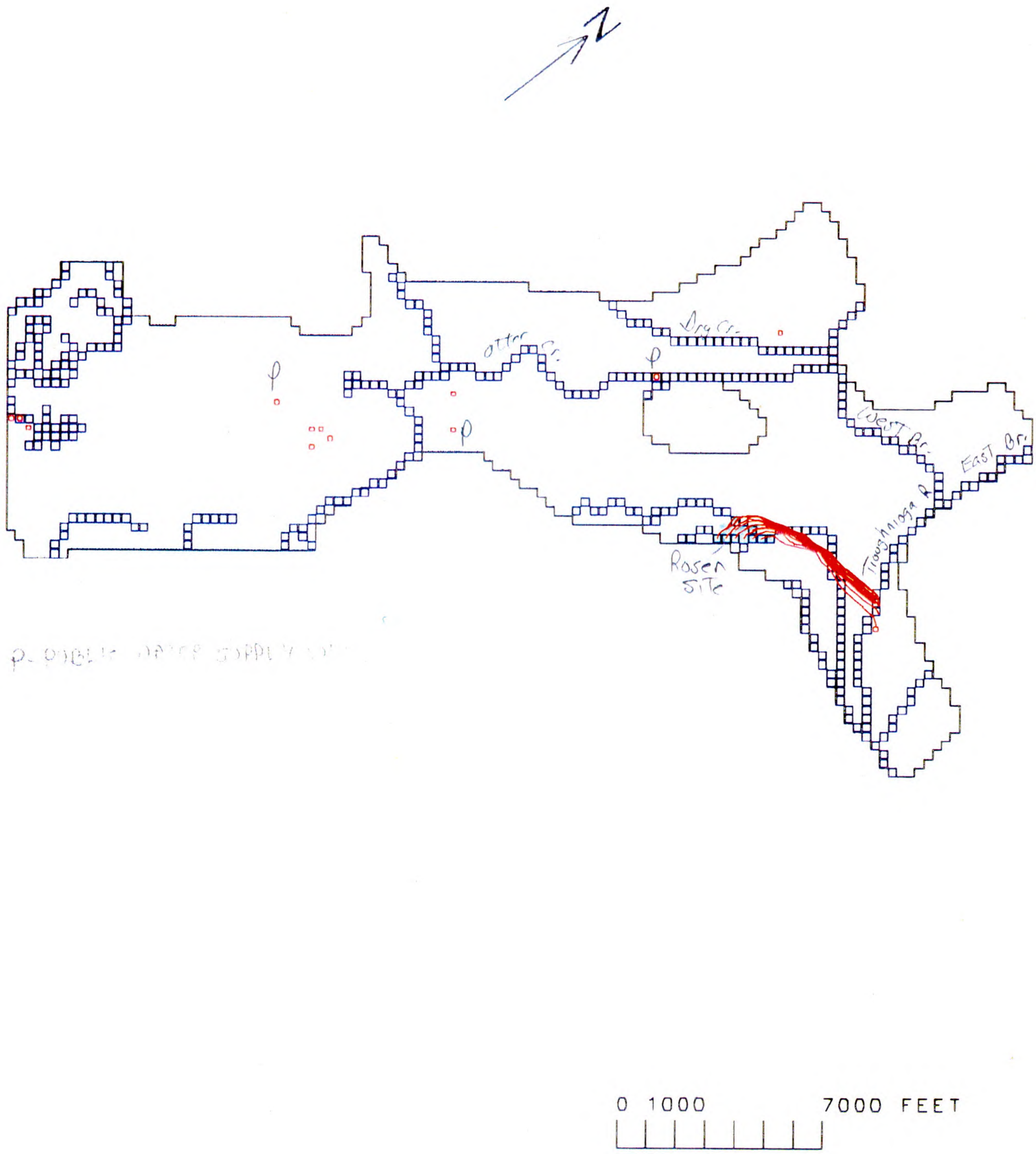
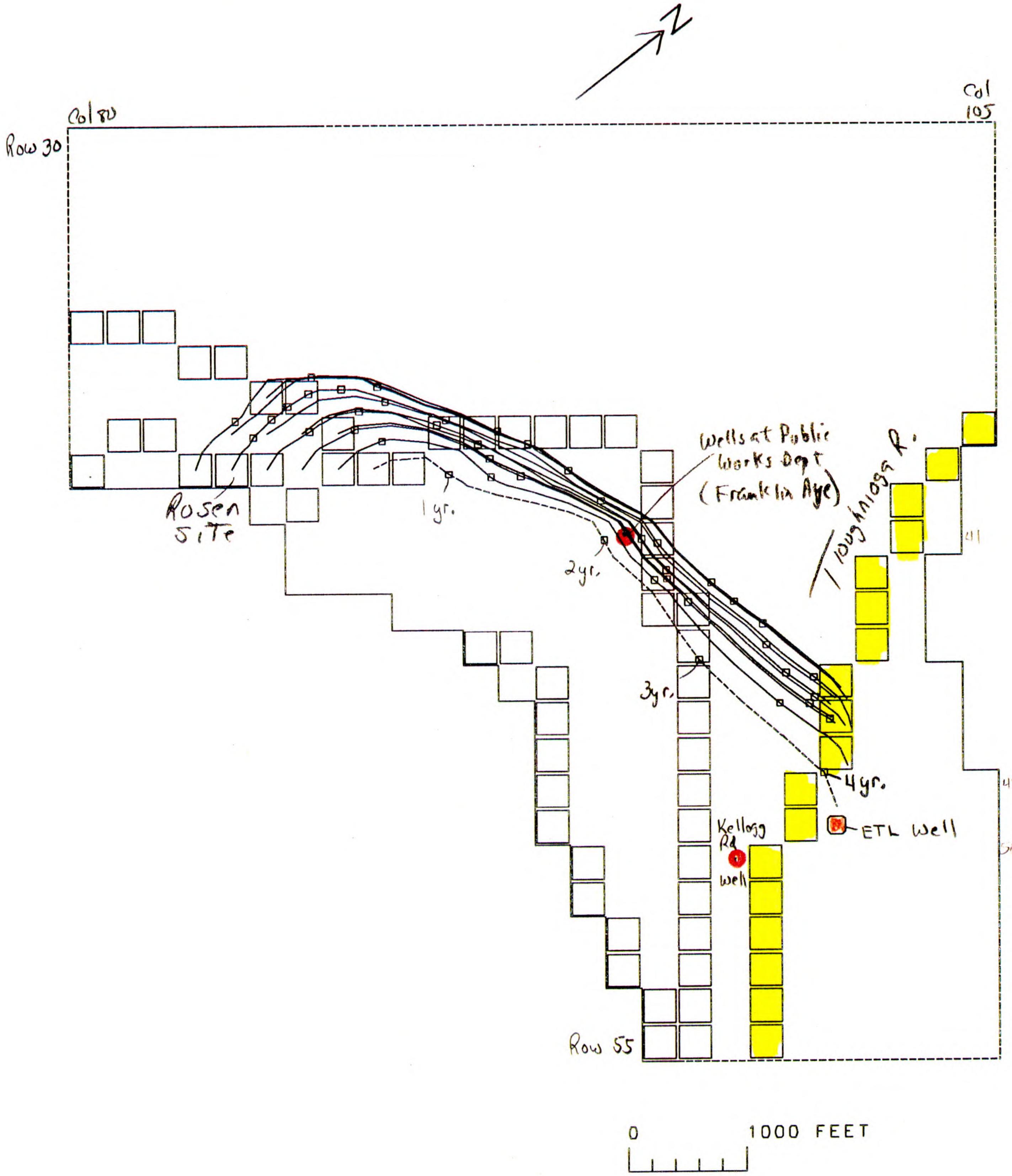


Figure 7b. – [illegible] aquifer, upper aquifer, low-recharge conditions



Pathlines from Rosen site (upper unconfined aquifer) low-recharge conditions

Figure 7c. - B&W, zoom

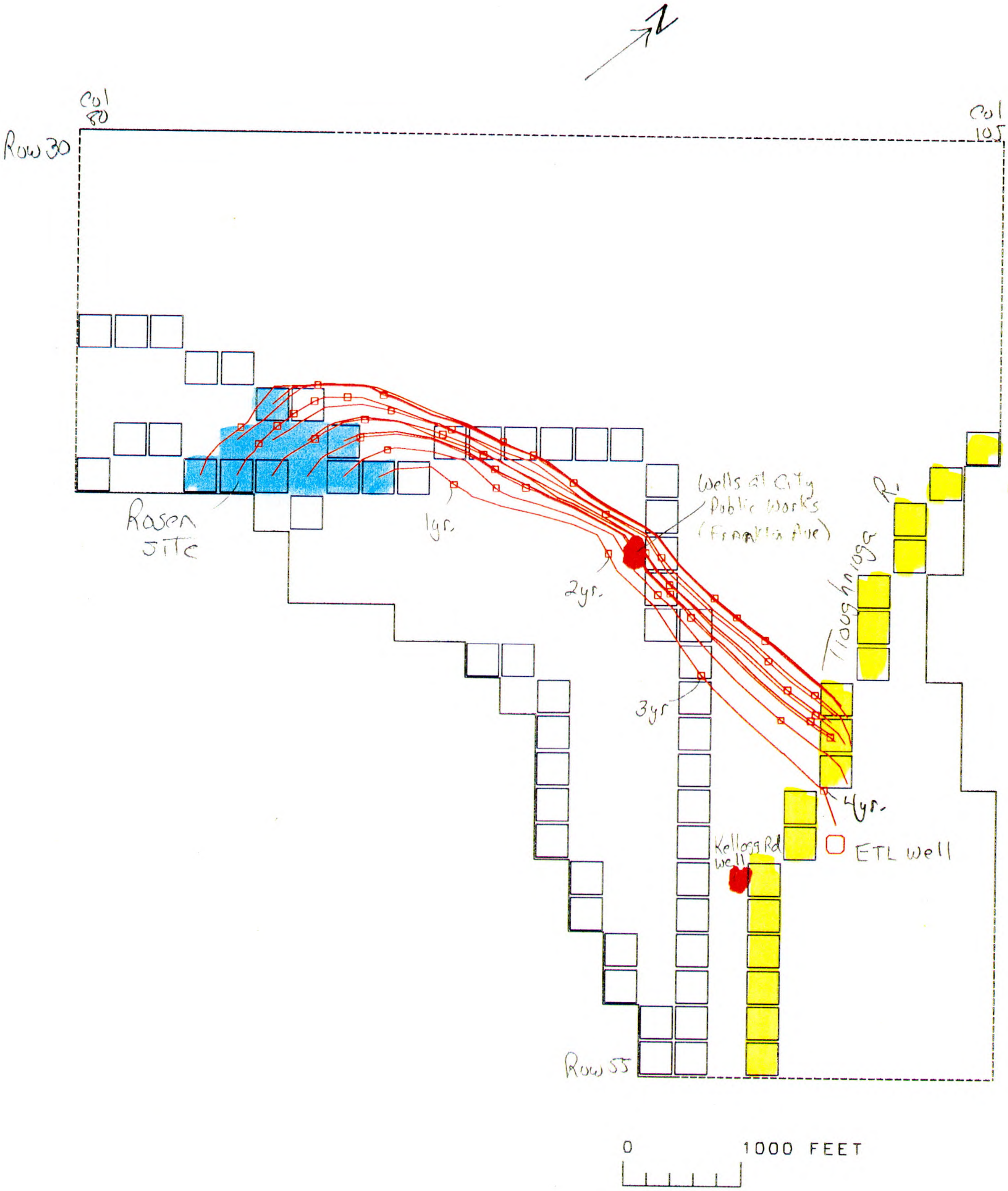


Figure 7d. - Color, zoom, upper aquifer, low-recharge conditions

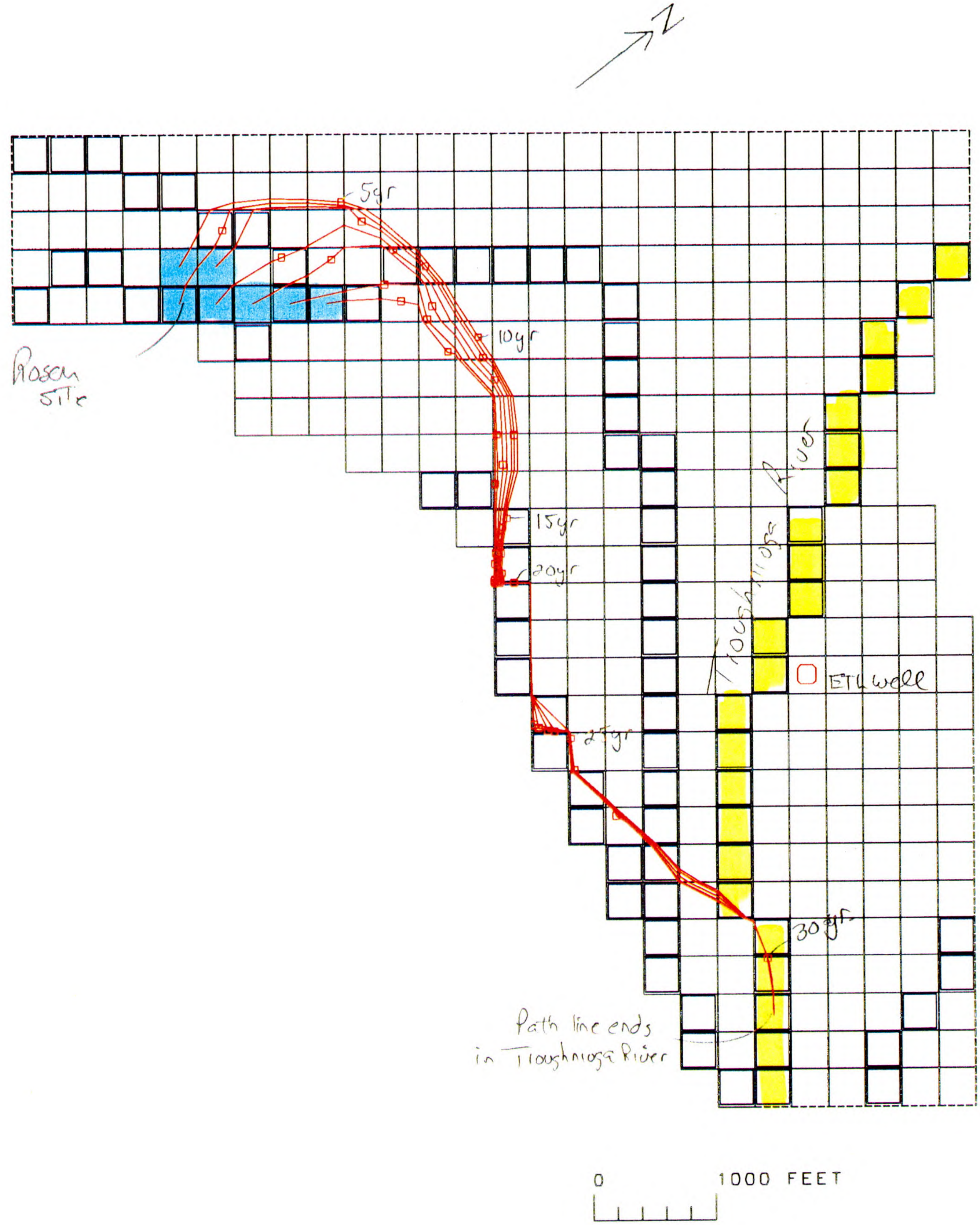


Fig 8d.- Color, zoom, lower aquifer, low-recharge conditions, Time step = 5yr.

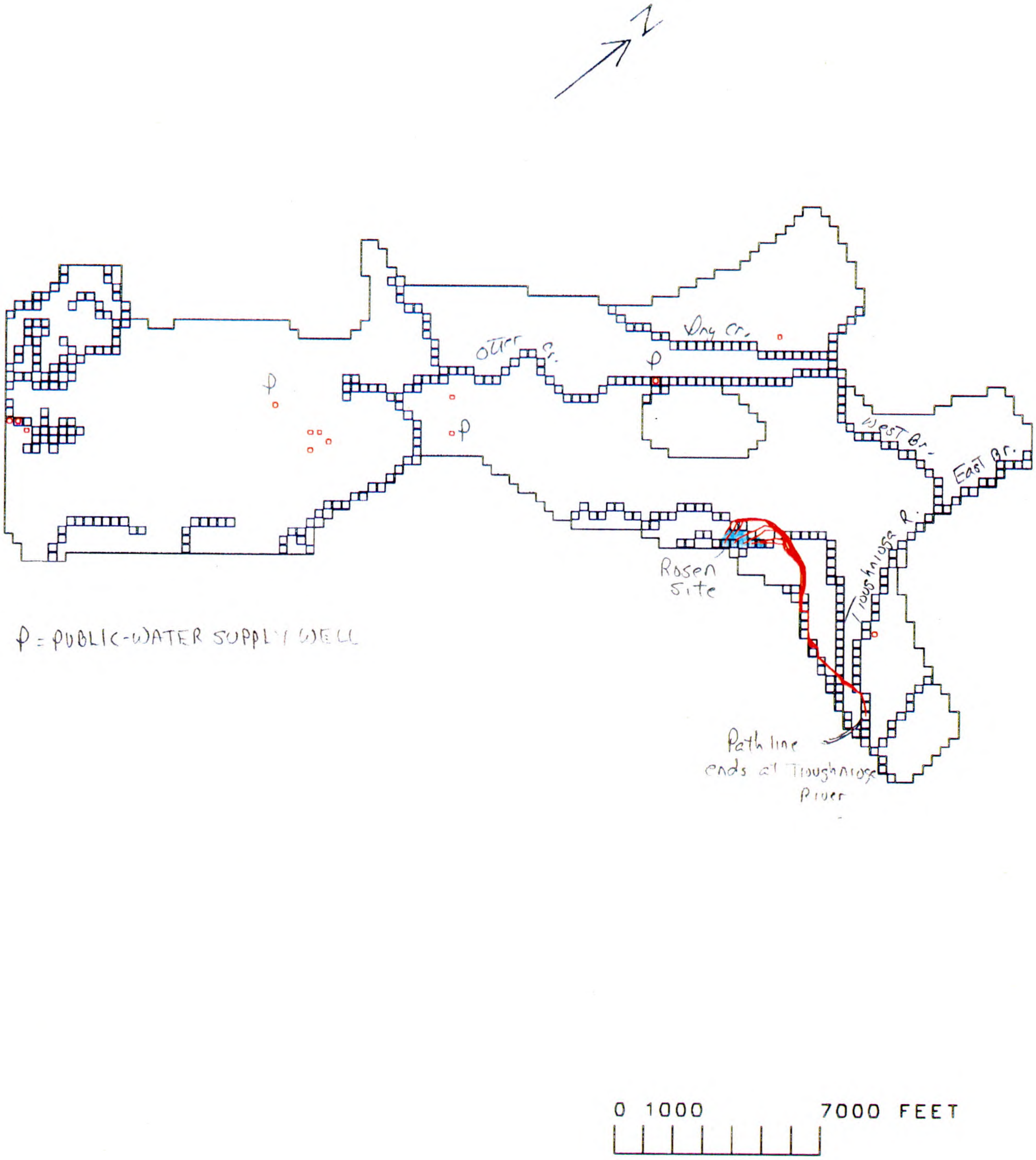
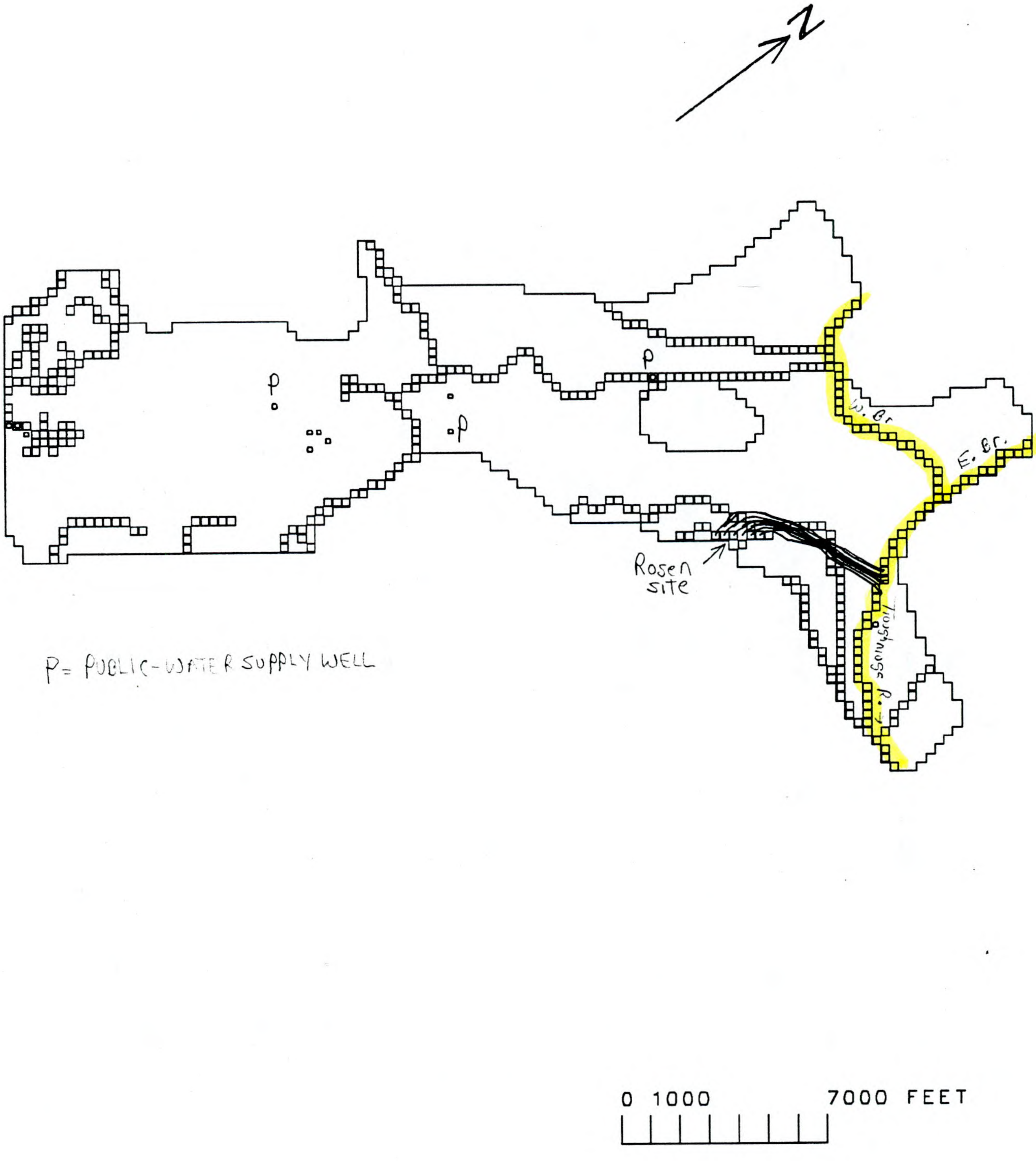
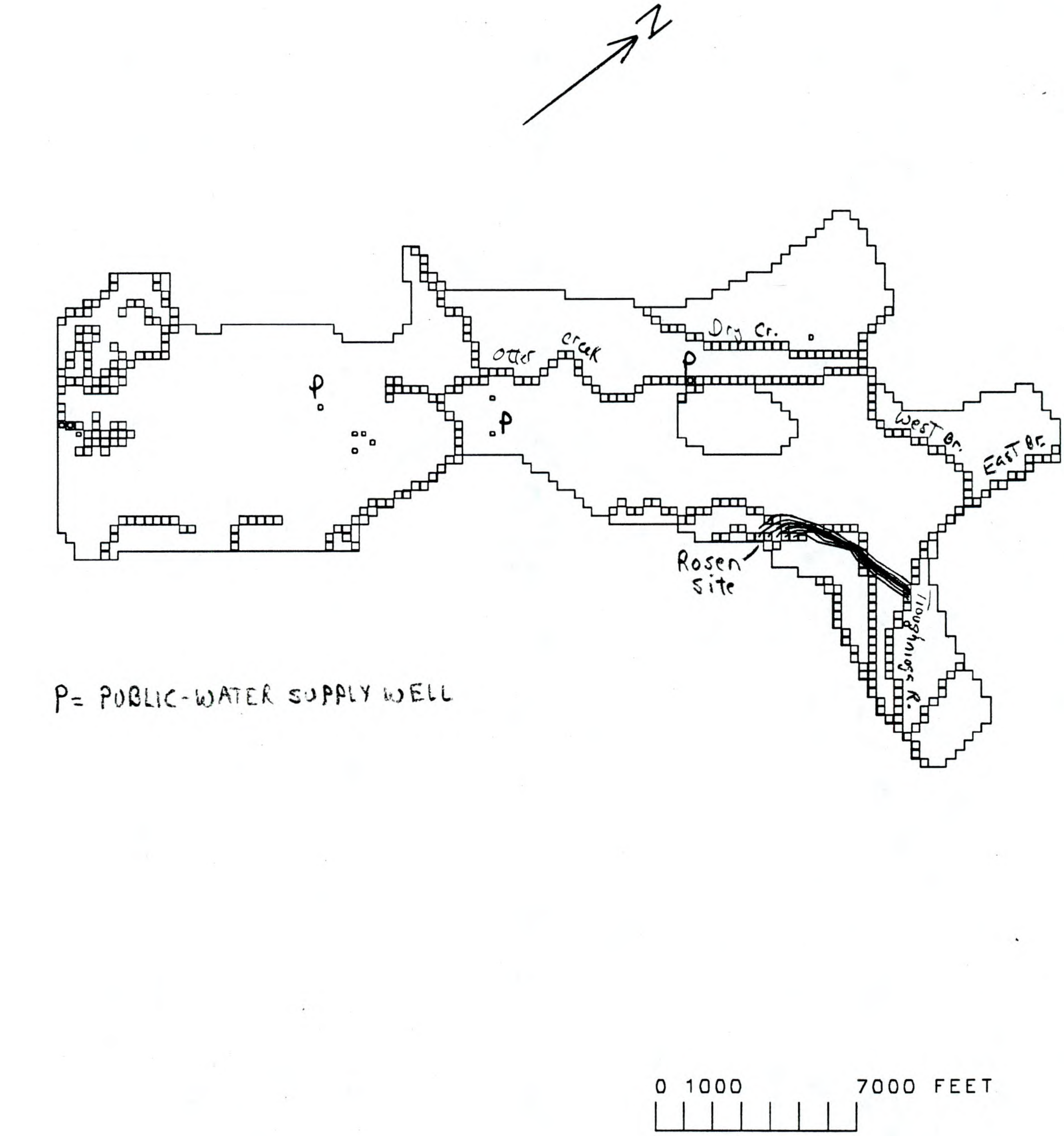


Figure 8b. - Color, entire aquifer, lower aquifer, Low-recharge conditions



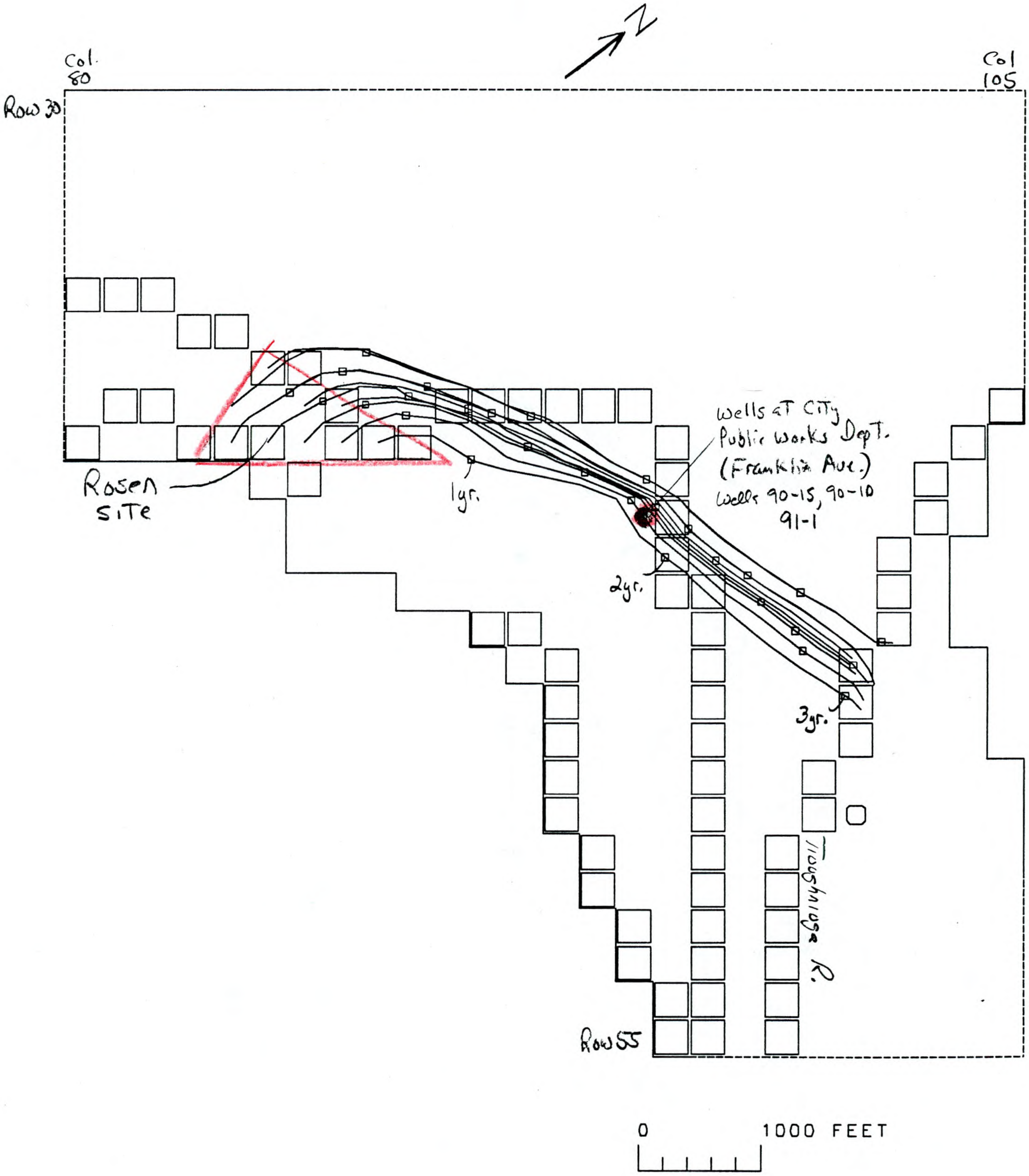
Pathlines from Rosen site (unconfined aquifer)– high-recharge condition

Figure 3a. – B&W



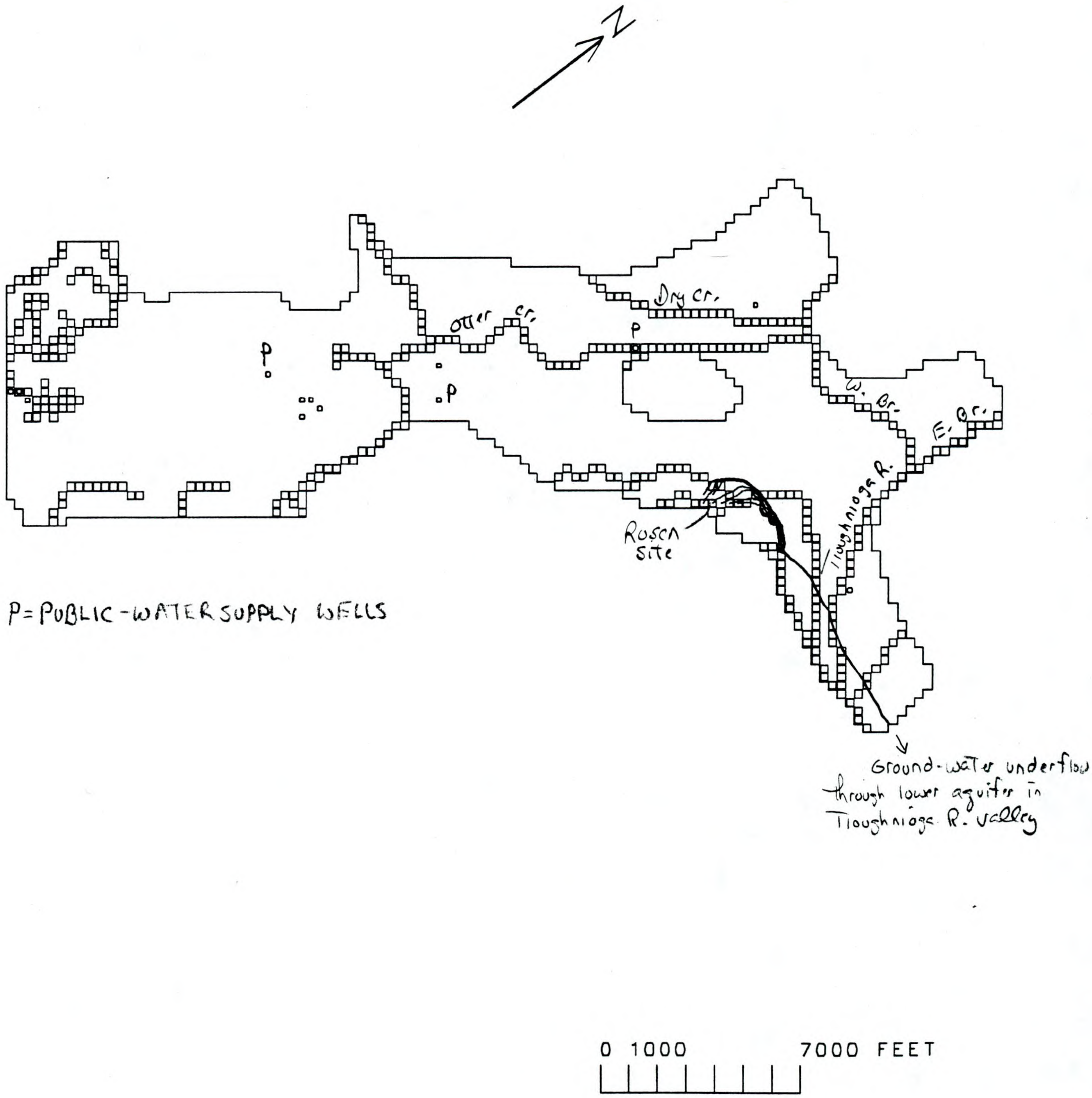
Pathlines from Rosen site (Upper unconfined aquifer)- average-recharge condit

Figure 5a.- Upper aquifer, B+W, entire aquifer



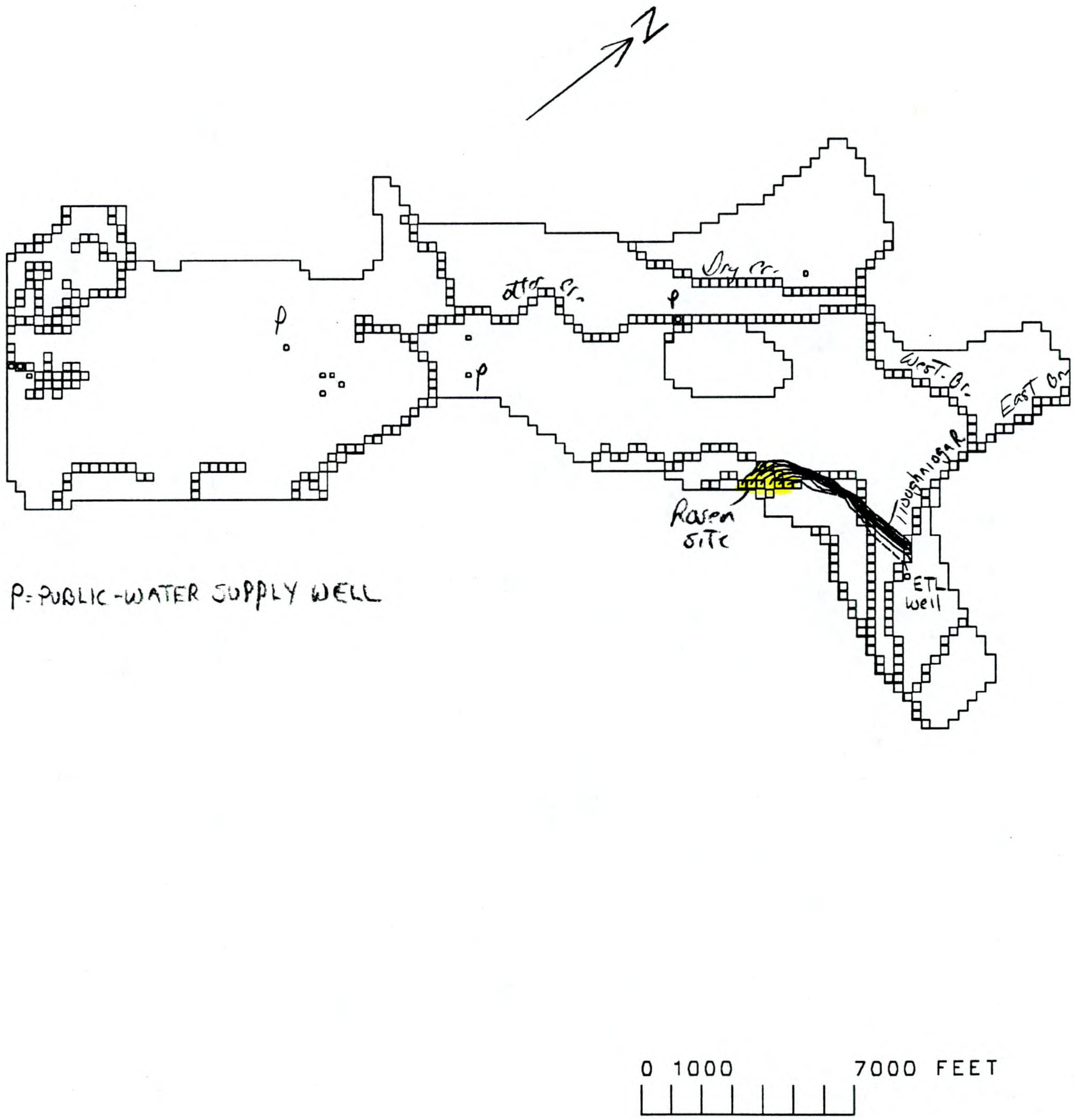
Pathlines from Rosen site (unconfined aquifer)- average-recharge condit

Figure 5c. B+W, zoom, upper aquifer



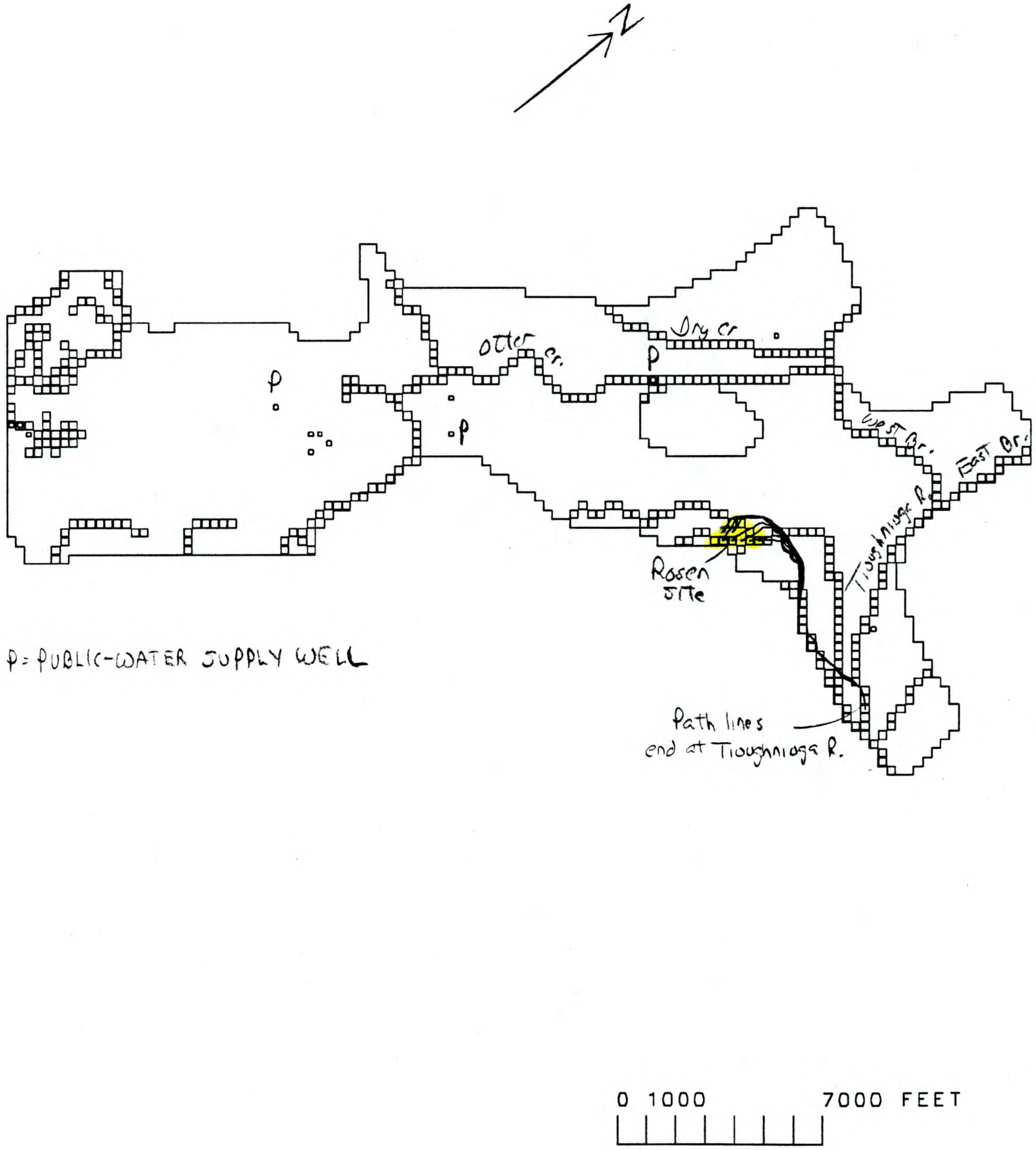
Pathlines from Rosen site (Lower confined aquifer)- Average conditions

Figure 6a. - L&W, entire aquifer



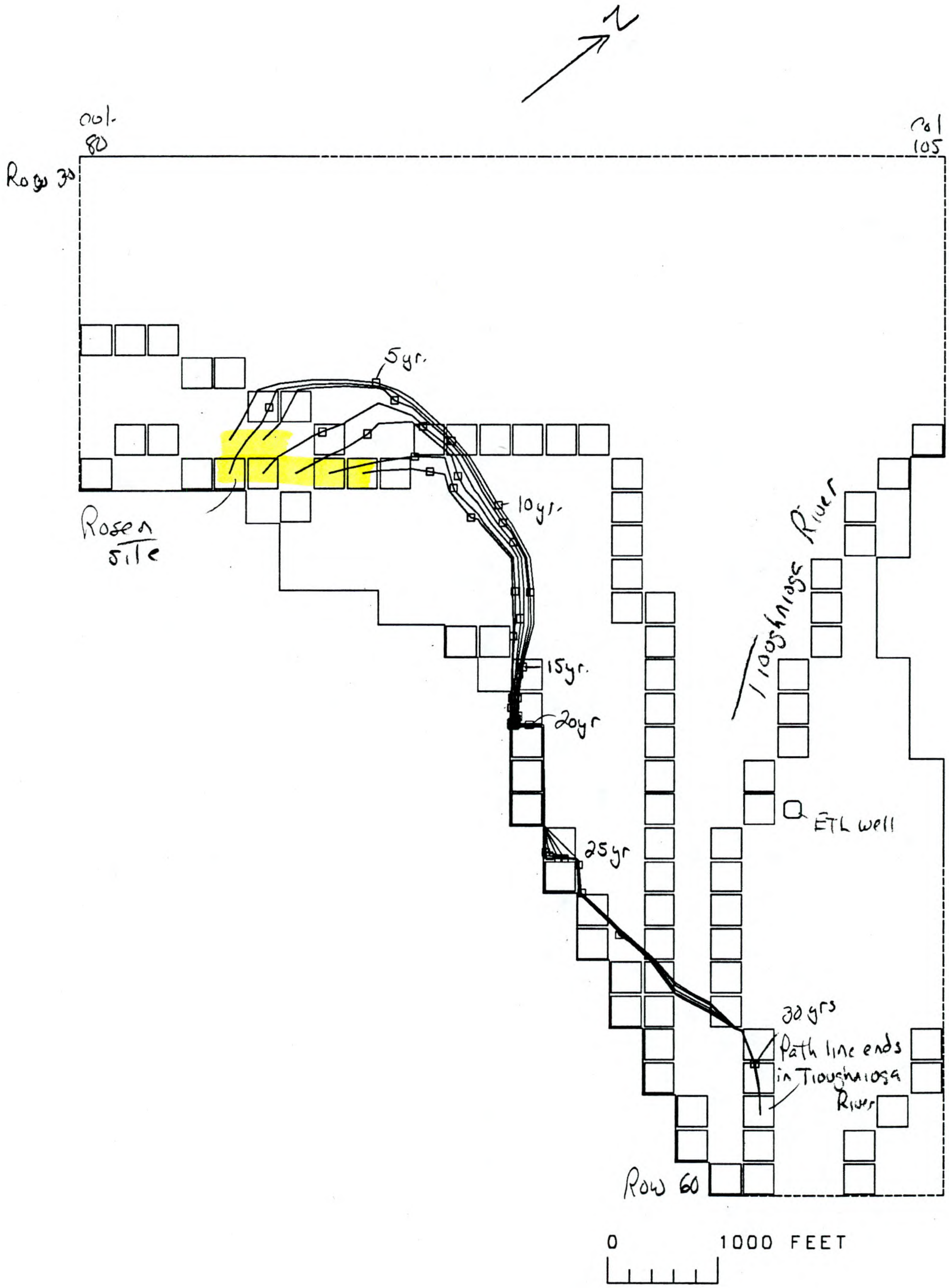
Pathlines from Rosen site (upper aquifer) low-recharge conditions

Figure 7a.- B&W, entire aquifer



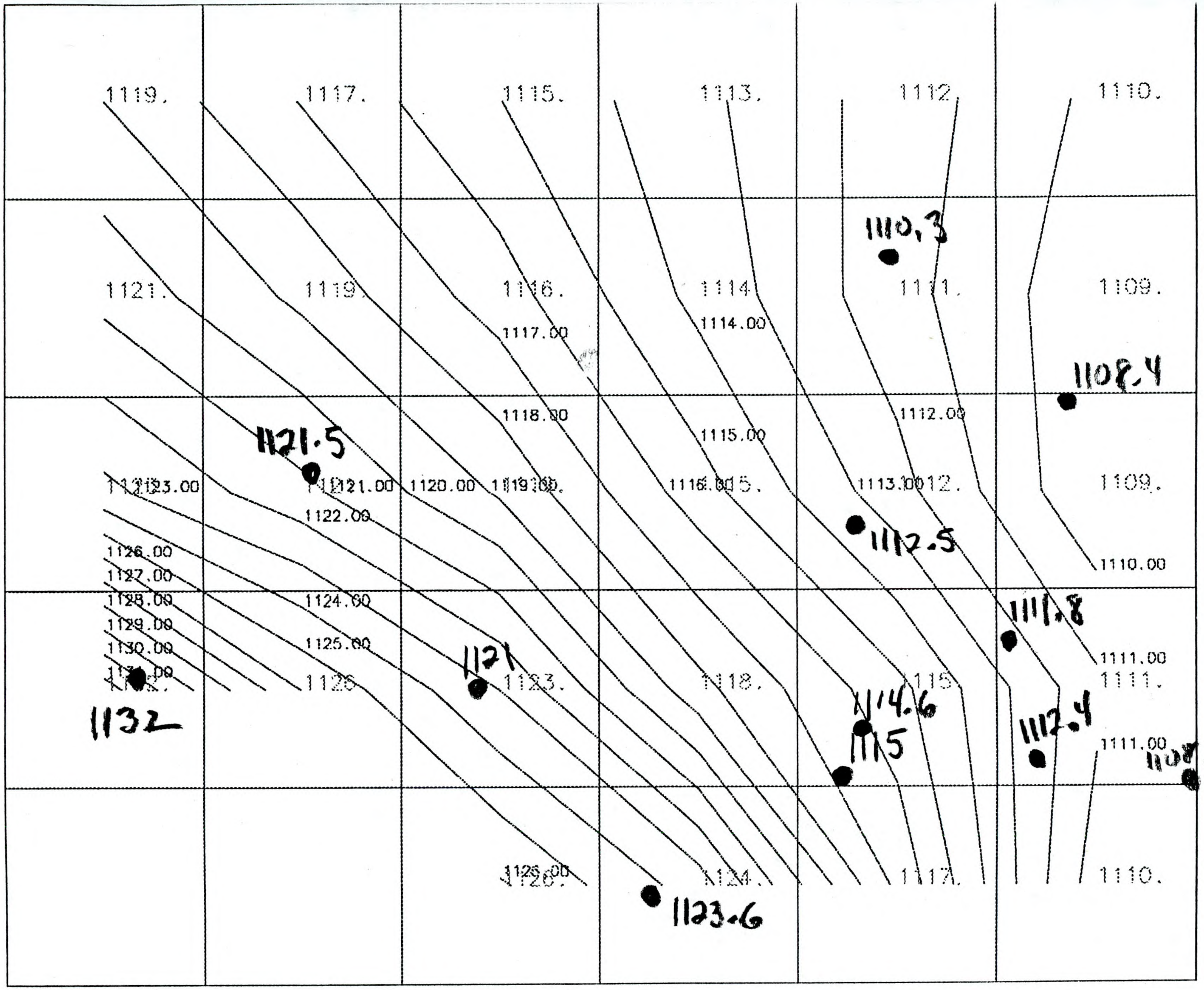
Pathlines from Rosen site (Lower confined aquifer) low-recharge conditions

Figure 8a. — B+W, entire aquifer



Lower
Pathlines from Rosen site (confined aquifer) low-recharge conditions

Figure 8c. - B&W, zoom, lower aquifer, Low-recharge conditions, Time step = 5 yr.



● 1132 = WELL LOCATION AND ELEVATION OF WATER LEVEL MEASURED by BLASLAND AND BOUCK on MAY 10, 1991