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DEWATERING WELL ASSESSMENT FOR THE HIGHWAY DRAINAGE SYSTEM AT FOUR SITES IN THE EAST ST. LOUIS AREA, ILLINOIS

(PHASE 2)

by Ellis W. Sanderson, Michael R. Schock, and Robert D. Olson

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CONTENTS

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ABSTRACT

In the East St. Louis vicinity, the Illinois Department of Transportation (IDOT) owns 48 wells that are used to main-tain the elevation of the ground-water table below the highway surface in areas where the highway is depressed below the original land surface. The dewatering systems are located at four sites in the alluvial valley of the Mississippi River in an area known as the American Bottoms. At the dewatering sites the alluvial deposits are about 90-115 feet thick and consist of fine sand, silt, and clay in the upper 10-30 feet underlain by medium to coarse sand about 70-100 feet thick.

The condition and efficiency of a number of the dewatering wells became suspect in 1982 on the basis of data collected and reviewed by IDOT staff. During the past 2 years, a cooperative investigation has been conducted by IDOT and the State Water Survey to more adequately assess the condition of selected individual wells, and to begin an attempt to understand the probable causes of well deterioration. Phase 2 work has established the condition of 12 dewatering wells and initiated a detailed investigation of probable ground-water chemistry changes as the water moves toward a pumping well.

During Phase 1, fourteen wells were field-tested by conducting step tests to determine the response of the wells at various rates of pumping. Most of the tested wells were in relatively good condition. Based upon the analysis of the step-test data, we recommended four wells for treatment and one well for replacement. During Phase 2, twelve additional wells were field-tested with step tests. Most of these wells were in relatively good condition. Based upon well losses of 10 to 29 percent of total drawdown, specific capacities of 33 to 44 gpm/ft of drawdown, and head differences between the wells and their adjacent piezometers of 10 to 13 ft, we recommended four wells for treatment.

The major part of the chemical evaluation for this phase was the collection of samples from the production well (I-70 No. 3) and an array of 12 monitoring wells installed and cased with PVC. Samples were taken after various periods of production well pumping and stagnation. The intent was, first, to obtain an idea of the constituents in the water that might govern chemical reactions that could cause well plugging; and, second, to determine the accuracy and reproducibility of sampling and chemical analysis. This would help determine if it would be possible to infer the location and mechanism of chemical reactions that might be able to cause loss of well capacity (presumably through precipitation).

The monitoring wells were installed in pairs (~30' and ~95' deep) at 2 distances (~6' and ~21') and in 3 directions (north, west, and east) from the production well (No. 3). The monitoring wells were equipped with 2 feet of well screen.

New analytical methods were developed or implemented for several important chemical constituents, including ferrous iron, inorganic carbon, sulfate, nitrate, nitrite, ammonia, silica, and total phosphate. The high level of dissolved iron, and the high amount of silica relative to phosphate, resulted in interference with many of the generally accepted "standard" procedures. Procedural modifications made progress in improving the reliability of the data, but further work is still required in this area.

Some computer analysis of the data in terms of mineral saturation/ precipitation equilibria was begun, and an analysis of the precision of field sampling and the precision and accuracy of the analytical methods was made. Significant conclusions thus far are:

1) There is great variability in chemical composition for major water constituents from monitoring wells on one side of the production well to those on another side. There also is a great difference in chemical composition between the deep monitoring wells and their shallow counterparts.

2) The shallow wells apparently represent a much more oxidizing environment, because they are in or near the saturated/unsaturated zone boundary. This favors ferric iron precipitation and, therefore, plugging of the aquifer material. Iron levels were found to be very low in these wells.

3) Drawdown is so great that samples can be taken only from 2 or 3 of the shallow monitoring wells when the production well has been off. Thus, deeper replacement wells must be added to accurately sample vertical variability of water composition.

4) The flow path of the water to the production well is highly distorted by the other wells in the field.

5) Reliable samples cannot be collected from the high capacity pump curently installed in the production well.

6) The design of the production well (I-70, No. 3) and pump may be a contributor to incrustation, by raising the water pH through degassing of CO_2 and introduction of oxygen, facilitating the precipitation of various carbonates and iron hydroxide.

Recommendations for further study in the report for this recently completed investigation (Phase 2) include suggestions to assess the condition of additional wells and to continue to study the probable chemical reactions causing well deterioration.

INTRODUCTION

Background

The Illinois Department of Transportation (IDOT) operates 48 high capacity water wells at four sites in the East St. Louis area. The wells are used to control and maintain ground-water levels at acceptable elevations to prevent depressed sections of interstate and state highways from becoming inundated by ground water. When the interchange of I-70/55 and I-64 was originally designed, ground-water levels were at lower elevations due to large withdrawals by the area's industry. Due to a combination of water conservation, production cutbacks, and conversion from ground water to river water as a source, ground-water withdrawals by industry have decreased about 50% since 1970, and as a result, ground-water levels in many areas have recovered to early development levels. This exacerbates the Department's need to dewater the areas of depressed highways.

Scope of Study

The Illinois Department of Transportation first installed 12 dewatering wells in 1973, followed by an additional 30 in 1975. By 1977, the initial 12 wells were showing signs of loss of capacity. As a result, all 42 wells in use at that time were chemically treated to restore capacity. Although good results were obtained on most of the wells, routine monitoring by the Department showed that deterioration problems were continuing to develop. Chemical treatment of isolated wells was made by Department personnel as required. In 1982, six more wells were installed. In October 1982, the Department asked the Illinois State Water Survey (ISWS) to begin an investigative study of the dewatering wells to learn more about their condition, to determine efficient monitoring and operating procedures, and to determine suitable methods of rehabilitation. The first phase of the work, begun in. 1983, included an assessment of the condition of 14 selected wells, a review of the Department's monitoring program, a model study to outline efficient operating schemes, recommendations on wells to be treated, and recommendations for chemical treatment procedures. The second phase of the work, begun in 1984, includes an assessment of the condition of 12 selected wells; testing of a non-invasive, portable flow meter; and an initial study of the chemistry of the ground water as it moves toward an operating well.

Future work will measure the effectiveness of rehabilitation by chemical treatment, continue the investigation into the potential causes of well deterioration, and assess the condition of additional wells.

Physical Setting of Study Area

The study area is located in the alluvial valley of the Mississippi River in East St. Louis, Illinois, in an area known as the American Bottoms (see figure 1). The geology of the area consists of alluvial deposits overlying limestone and dolomite of the Mississippian and Pennsylvanian Ages. The alluvium varies in thickness from zero to more than 170 feet, averaging about 120 feet. The region is bounded on the west by the Mississippi River and on the east by upland bluffs. The regional ground-water hydrology of the area is well documented (Bergstrom and Walker, 1956; Schicht, 1965; Collins and Richards, 1986; Ritchey, Schicht, and Weiss, 1984). Ground water generally flows from the bluffs toward the river, except where diverted by pumpage or drainage systems.

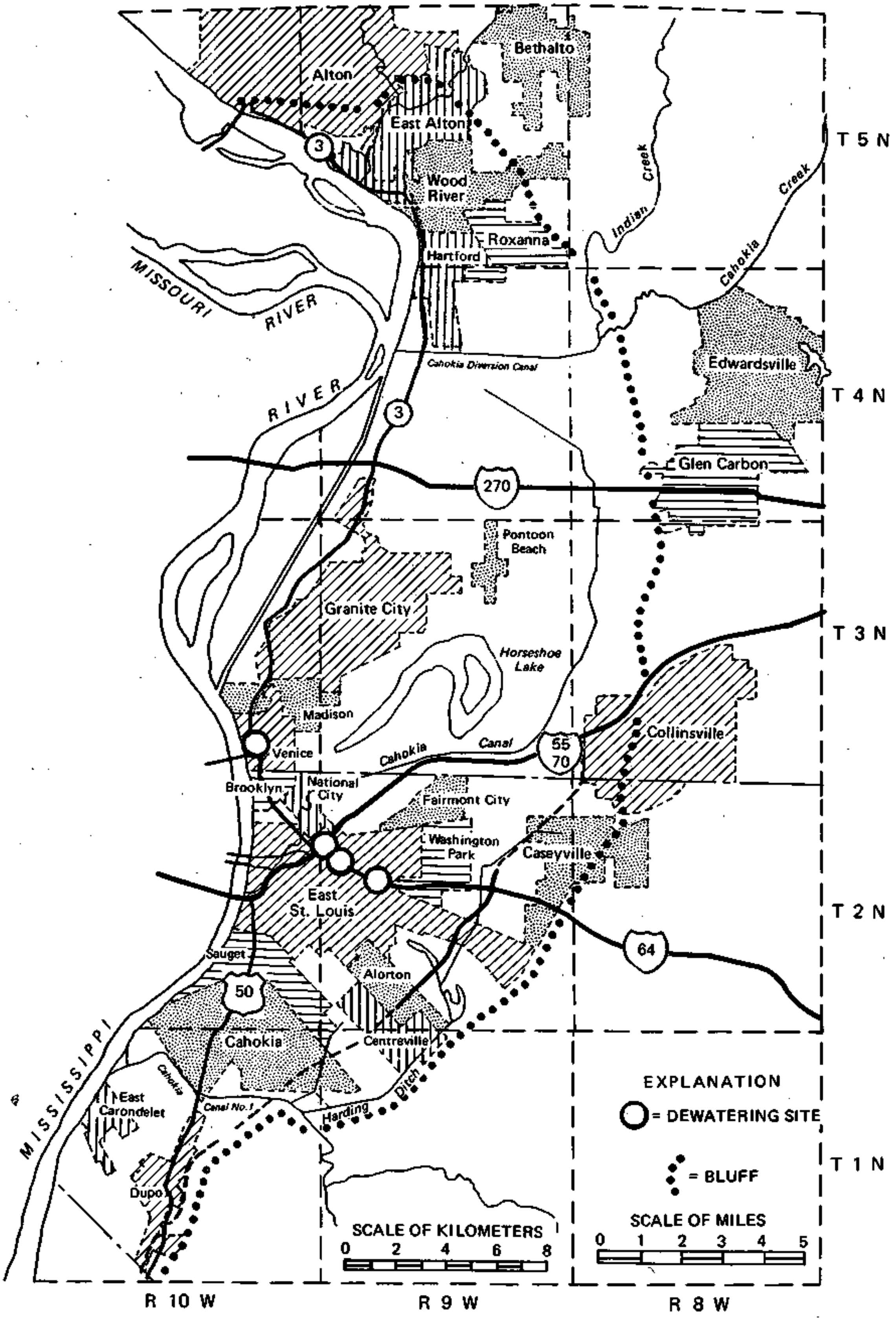

Figure 1. Location of East St. Louis area

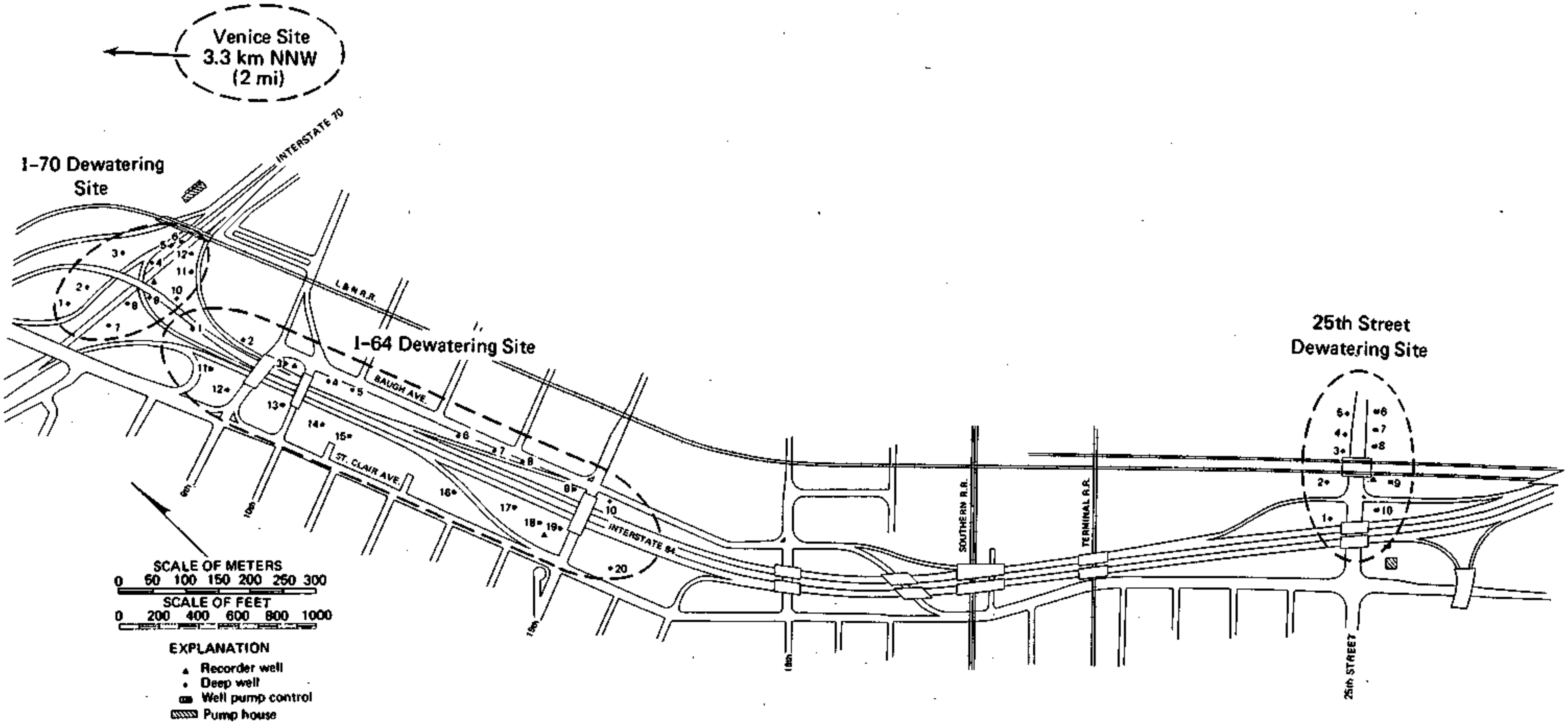

Figure 2. Location of dewatering wells at the I-70 Tri-Level Bridge, I-64, and 25th Street

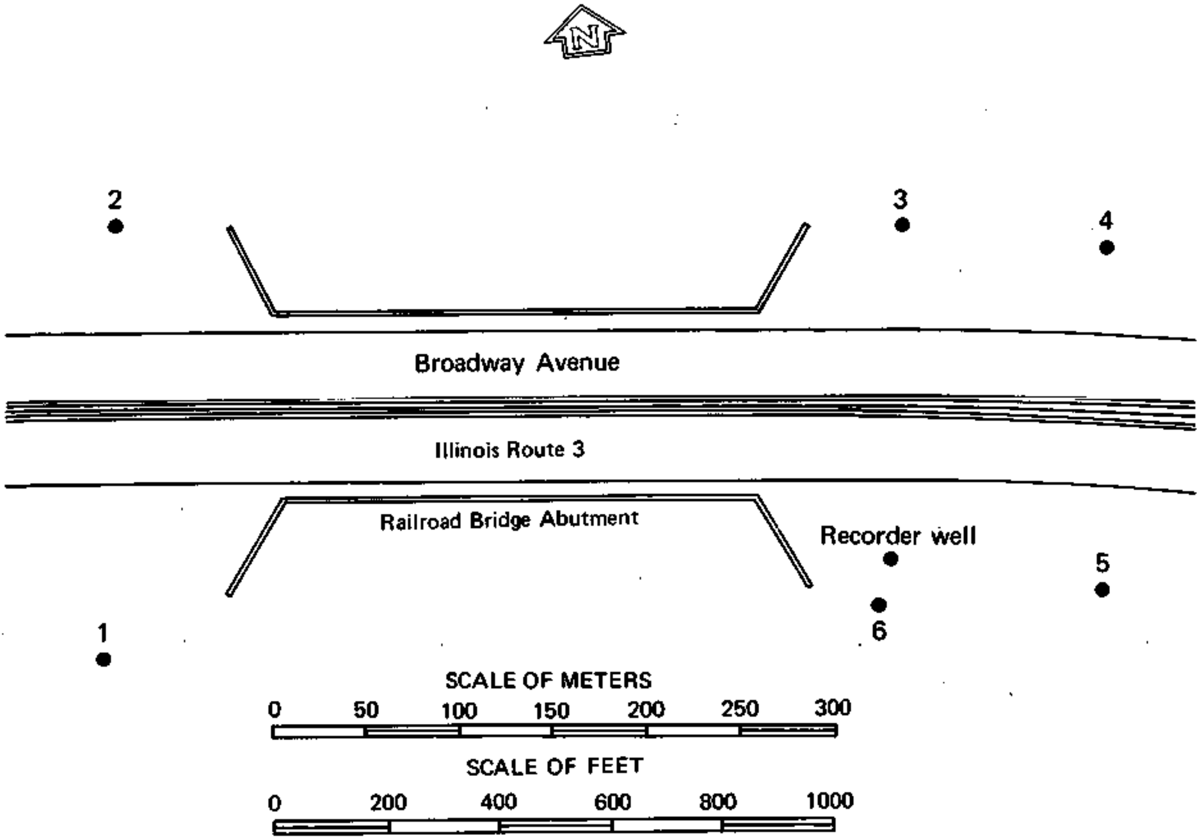

Figure 3. Location of dewatering wells at Venice

Detailed locations of the four dewatering sites operated by IDOT are shown in figures 2 and 3. The geology at these sites is consistent with regionally mapped conditions. The land surface lies at about 410-415 feet above mean sea level (ft msl). The alluvial deposits are about 90-115 ft thick, meaning the bedrock surface lies at approximately 300-320 ft msl. The alluvium becomes progressively coarser with depth. The uppermost 10 to 30 feet consists of extremely fine sand, silt, and clay, underlain by the aquifer which is about 70-100 feet thick. The elevation of the top of the aquifer is about 390-395 ft msl.

Acknowledgments

This phase of the assessment of the condition of the highway dewatering well systems in the American Bottoms was funded by the Illinois Department of Transportation, John D. Kramer, Secretary. Special thanks are due Mr. Navin Rupani, Hydraulic Engineer, District 8, who reviewed and coordinated the investigation. Mr. Robert Nebblesink, Supervisor of District 8's drilling crew, coordinated the construction of the 12 sampling wells used in the chemistry study. The Maintenance Division Pump Crew under the supervision of Mr. Stan Gregowicz provided field support during the conduct of step-drawdown tests on the selected wells. State Water Survey Ground-Water and Aquatic Chemistry Section staff who ably assisted the authors with field data and water sample collection included Robert Kohlhase, Adrian Visocky, Ed Garske,

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HISTORICAL SUMMARY OF DEWATERING DEVELOPMENT

The eastbound lanes of Interstate 70 (I-70) below the Tri-Level Bridge between St. Clair and Bowman Avenues in East St. Louis dip down to elevation 383.5, or approximately 32 feet below natural ground surface. At the time of highway design in 1958 the ground-water levels were near an elevation of 390 or about 6.5 feet above the planned highway (McClelland Engineers, 1971).

Horizontal Drain System

A horizontal French drain system was designed for controlling the ground-water levels along an 800-ft reach of depressed highway. For highway construction, the excavation area was dewatered by pumping from seven wells 100 feet deep and 16 inches in diameter. The wells were equipped with 1800-gpm turbine pumps. The construction dewatering system was designed to maintain the ground-water level at the site near elevation 370.

The French drain system failed shortly after the construction dewatering system was turned off in the fall of 1962. The failure was attributed to the fact that the filter sand around the perforated diagonal drains and collector pipes was too fine for the 1/4-in. holes in the drain pipes. A sieve analysis on the filter sand showed that 98.5% of the filter sand was finer than the 1/4-in. perforations in the drain pipes. As a result, when the construction dewatering system was turned off and ground-water levels rose above the drains, filter sand migrated through the holes into the drain pipes. After the filter sand migrated into the drain, the very fine "sugar" sand used as the pavement foundation was free to move downward to the drains, resulting in development of potholes above the drains. Further migration of sand into the French drainage system was halted by operating the construction dewatering system to lower the ground-water table. Since it was very likely that the foundation sands had piped from beneath the pavement, the diagonal drains beneath the pavement were cement grouted to prevent any future loss of support beneath the pavement (McClelland Engineers, 1971).

Horizontal and Vertical Well Drainage System

A new drainage system was designed and installed in early 1963. It consisted of 20 vertical wells and 10-inch- to 12-inch-diameter horizontal drain pipes. The 20 wells (10 wells on each side of the highway) were spaced about 75 feet apart. They were 6 inches in diameter, about 50 feet deep, and equipped with 32 feet of stainless steel well screen (Doerr) with 0.010-inch slots. The horizontal drains were sized for a flow of about 1 gpm per foot of drain, were perforated with 3/8-in.-diameter holes on 3-inch centers, and were surrounded with 6 inches of gravel and sand filter. A total of six 2-inch-diameter piezometers were installed for ground-water level measurements.

Tests immediately after the installation indicated that the new system was performing satisfactorily with a discharge of about 1200 to 2000 gpm compared to a computed design flow of 4500 gpm. Ground-water levels were lowered to elevation 375.5±, about 2 feet below the design ground-water elevation of 377.5, or about 8 feet below the top of the concrete pavement.

The system performed efficiently until March 1965, when a gradual rise in ground-water levels was detected. By July 1967 a rise of 1 foot had occurred, and from July 1967 to April 1969 an additional 4-foot rise was observed. No additional rise was observed between August 1969 and August 1970.

Visual inspection during the late 1960's revealed some sinking of the asphalt shoulders and areas around the storm drainage inlets. Several breaks and/or blockages of the horizontal transite drain pipes were noted on both sides of the pavement, and a break in the steel tee in Well 17 was also observed. Depressions in the earth slopes immediately adjacent to the curb and gutter section were noticed. Loss of foundation sands through the transite pipe breaks appeared to be the cause of these depressions. One manhole had settled a total of 15 inches. The attempt to correct this condition was suspended with the detection of a shift in the bottom of this manhole.

A thorough field investigation was begun to correct the damages to the underground system or to replace it if necessary. During the cleaning process of the collector pipes (using a hydrojet at the rate of 100 gpm under a pressure of about 800 psi), a significant amount of scale was removed from inside the mild steel pipes, indicating serious corrosion. Nearly all transite drain pipes also showed signs of stress. Some drains were broken and filled with sand. Attempts to clean or restore the drain pipes were abandoned in favor of a complete replacement of the system.

The field investigation also showed that the tees in the manholes, the collector pipes, and the aluminum rods on the check valves were badly corroded. Sinks, potholes, and general settlement of the shoulders indicated a distressed condition requiring immediate attention. Television inspection of the vertical wells showed no damage to the stainless steel well screens.

Excessive corrosion of the mild steel tees, well risers, and collector pipes was one of the major causes or contributors to the overall failure of the drainage system. The investigations concluded that the corrosion was caused primarily by galvanic action between the stainless steel (cathode) and mild steel (anode) components of the drainage system, with anaerobic bacteria and carbonic acid attack from the carbon dioxide (CO_2) dissolved in the well water. Galvanic action was magnified by the lack of oxygen and the high chloride contents. A chemical analysis showed the extremely corrosive quality of the ground water as evidenced by:

- Extremely high concentration of dissolved carbon dioxide, 160 to 240 ppm
- Complete lack of oxygen, 0 ppm
- High chloride, 54 to 128 ppm; sulfates, 294 to 515 ppm; and iron concentration, 13 ppm
- Biological activity

The field investigators recommended that 304 stainless steel pipes should be used throughout any replacement system in order to withstand the possibility of severe corrosion caused by the chemical contents of ground water and to prevent galvanic action between different metals (McClelland Engineers, 1971).

Individual Deep Well Systems

Experience during highway construction in 1961-1962 and during the 1963 drainage system replacement showed that individual deep wells were effective in temporarily maintaining ground-water levels at desired elevations. This alternative as a permanent system, therefore, was given further study. A 1972 consultant's report (Layne-Western, 1972) showed that water levels at the I-70 Tri-Level Bridge site could be maintained at desired elevations with 10 deep wells equipped with 600 gpm pumps. An additional two wells were included to permit well rotation and maintenance. These 12 wells were constructed in 1973 and the new system placed in service in April 1974. The wells are 16-inch gravel-packed (42-in. borehole) wells averaging about 96 feet deep and are equipped with 60 feet of Layne stainless steel well screen. The pumps are 600-gpm capacity with 6-inch-diameter stainless steel (flanged coupling) column pipe.

A recorder well was included in the well dewatering system to monitor ground-water levels near the critical elevation of the highway. The well is 8 inches in diameter and is constructed of stainless steel casing and screen. A Leupold-Stevens Type F recorder is in use. Additionally, 2-inch-diameter piezometers with 3-ft-long screens were placed about 5 feet from each dewatering well to depths corresponding to the upper third point of each dewatering well screen. The purpose of these piezometers is to provide information on ground-water levels and to monitor the performance of individual wells by measuring water level differences between the wells and the piezometers.

The western terminal of Interstate 64 joins Interstate 70 at the Tri-Level Bridge site. A 2200-foot stretch of this highway also is depressed below original land surface as it approaches the Tri-Level Bridge site. To maintain ground-water levels along I-64, a series of 20 wells was added to the dewatering system. The wells were built in 1975 and are essentially identical to the ones constructed for the Tri-Level Bridge site.

About 6200 feet southeast of the Tri-Level Bridge, at the East St. Louis 25th Street interchange with I-64, the street was designed to pass below the highway and adjacent railroad tracks. As a result, the 25th Street pavement would be about 3.5 feet below ground-water levels. Ten wells were installed at this site to control ground-water levels. These wells also are identical in design to the I-70 wells. The pumps installed in the wells along I-64 and at 25th Street have nominal pumping capacities of 600 gpm. Two 8-inch observation wells, located near each end of the I-64 depressed section, are used to monitor ground-water levels. An 8-inch observation well also is installed near the critical location at the 25th Street underpass. As at the I-70 wells, each dewatering well for I-64 and 25th Street has a piezometer located approximately 5 feet away for monitoring performance of each individual installation.

Approximately 2-1/4 miles north of the I-70 Tri-Level Bridge, Illinois Highway 3 passes beneath the N and W, ICG, and Conrail railroad tracks. When the highway was constructed, ground-water levels were controlled with a horizontal drain system placed 3 feet below the pavement. Problems with the pavement and drainage system were noted in May 1979, and were attributed to the above normal ground-water levels resulting from 3 to 4 months of continuous flood stage in the Mississippi River (about 2000 ft west). Subsequent investigation showed deterioration of the drainage system, and the consultants recommended installation of six wells to control ground-water levels at the site (Johnson, Depp, and Quisenberry, 1980). The wells were installed in 1982 and are 16 inches in diameter with 50 feet of well screen. They range in depth from 78 to 89 feet below grade and are equipped with submersible turbine pumps with nominal capacities of 600 gpm. One recorder well for the site and piezometers at each dewatering well were constructed to monitor system performance.

Thus at present, the highway dewatering operation in the American Bottoms consists of 48 individual dewatering wells fully penetrating the water-bearing sand and gravel aquifer. The wells are distributed at four sites as follows:

I-70 (Tri-Level Bridge) - 12 wells
I-64 - 20 wells
25th Street - 10 wells
Venice (Route 3) - 6 wells

As shown in figure 4, the wells are of similar construction, with 16-inch-diameter stainless steel casing and screen, and 6-inch-diameter stainless steel column pipe. Each well is equipped with a 600-gpm submersible pump with bronze impellers, bowls, and jacket motors. The early experience with severe corrosion problems showed that corrosion-resistant materials are required to maximize service life. A total of five 8-inch recorder wells are available to monitor ground-water elevations near critical locations at the four sites. Each of the 48 wells has a 2-inch-diameter piezometer for monitoring individual well performance.

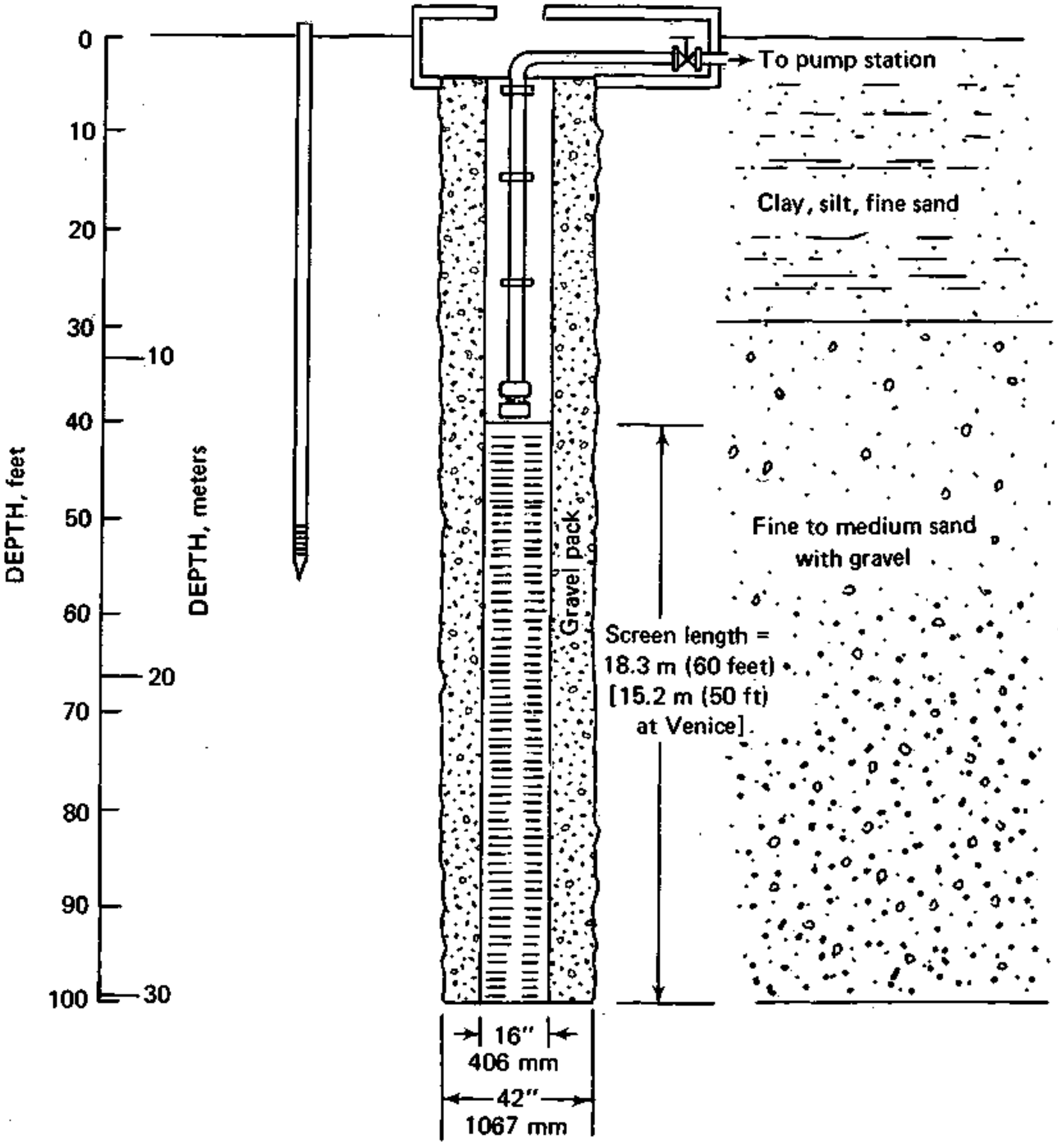

Figure 4. Typical features of a dewatering well

Usually, about one-third of the wells are in operation simultaneously. Total purapage was estimated to be about 10.8 million gallons per day in 1984.

DEWATERING SYSTEM MONITORING

When originally constructed, the well installations at I-70, I-64, and 25th Street included pitot tube type flow rate meters. Reportedly, a combination of corrosion and chemical deposition caused premature failure of these devices. Flow rates are now occasionally checked with a temporarily inserted pitot tube meter, but erratic results are reported by the field crew. The six new installations at Venice include a venturi tube coupled to a bellows type differential pressure indicator to measure the flow rate. Flow measurements from the venturi tube are reported to be accurate to within ±1% of full pipe flow rate and the differential pressure indicators to within ±0.75% of the deflection. The bronze-lined venturi tubes will probably remain unaffected over time by the quality of water pumped from these wells; however, the water comes in direct contact with the bellows in the differential pressure indicators via two 1/4-inch water lines from the venturi tubes. The same corrosion and chemical deposition affecting the pitot tubes could, over time, cause obstructions in the water lines and/or water chambers or direct failure of the bellows. Annual withdrawals currently are calculated on the basis of pumping time and estimated or measured pumping rates.

Operational records show that wells are pumped for periods of about two to nine months and then left off for longer periods while another set of wells is operated. Since 1977, the percentage of days operated has ranged from 23 to 45%, averaging 38%, at I-70; from 13 to 36%, averaging 21%, at I-64; and from 12 to 47%, averaging 30%, at 25th Street. No standard sequence of pumping rotation is followed because of maintenance and rehabilitation requirements. Bar charts showing the periods of operation are prepared by the Department for monitoring the accumulated hours of operation.

Water levels in the piezometer adjacent to each dewatering well are measured every 2-4 weeks. The pumping water level in each operating well also is measured. These water level data are reviewed by IDOT supervisors to monitor ground-water levels in relation to the pavement elevation and to assess the condition of individual dewatering wells. Water level differences of 3 to 5 feet between the pumping wells and the adjacent piezometers usually are considered normal by the Department. Greater differences are interpreted to indicate that well deterioration is occurring. Piezometer water levels also are superposed on drawings of longitudinal sections of the highway for visual comparison. This technique suggests probable errors in field measurements when the water level elevation for a given piezometer is not consistent with water levels in adjacent piezometers.

Finally, each dewatering well site includes an observation well equipped with a Leupold-Stevens water level recorder. The recorder charts are changed monthly and are intended to provide a continuous record of water levels near the critical location at each dewatering site.

INVESTIGATIVE METHODS AND PROCEDURES

Well Loss

When a well is pumped, water is removed from the aquifer surrounding the well, and the water levels are lowered. The distance that the water level is lowered, whether within the well or in the surrounding aquifer, is referred to as drawdown, which under ideal conditions is a function of pumpage, time, and the aquifer's hydraulic properties. However, other geohydrologic and hydraulic factors also can affect the observed drawdown, especially within the pumped well. Aquifer boundaries, changes in aquifer thickness or hydraulic properties, interference from nearby wells, partial-penetration conditions, and well losses all can affect observed drawdowns. Well losses usually are associated only with the pumped well and are the only non-ideal condition addressed in this report.

Well losses are related to pumping rate and ideally are not a function of time. These losses are associated with changes in flow velocity in the immediate vicinity of the well, resistance to flow through the well screen, and changes in flow path and velocity inside the well. Velocities may become sufficiently large that a change from laminar to turbulent flow may occur. Under these conditions the well-loss component of drawdown can become significant and can increase in a nonlinear manner with increases in pumping rate. Well losses often reflect a deterioration in the condition of a well, especially if they are observed to increase with time.

Thus, even under near-ideal conditions, the observed drawdown (s_o) in a pumping well is made up of two components: the formation loss(es), resulting from laminar (and sometimes turbulent) flow head loss within the aquifer, and well loss (s_w), resulting from the turbulent flow of water into and inside the well, as shown in equation 1.

$$s_o = s + s_w \tag{1}$$

Jacob (1947) expresses these components as being proportional to pumping rate (Q) in the following manner:

$$s_o = BQ + CQ^2 \tag{2}$$

where B is the formation loss constant at the well-aquifer interface per unit discharge and C is the well loss constant. Rorabaugh (1953) suggested that the well loss component be expressed as CQ^n, where n is a constant greater than 1. He thus expressed the drawdown as

$$s_o = BQ + CQ^n \tag{3}$$

In order to evaluate the well loss component of the total drawdown, one must know the well loss coefficient (if using equation 2) or both the coefficient and the exponent (if using equation 3). This analysis requires a controlled pumping test, called a step drawdown test, in which total drawdown is systematically measured while pumping rates are varied in a stepwise manner.

Methodology for Determining Well Loss

If Jacob's equation is used to express drawdown, then the coefficients B and C must be determined. A graphical procedure can be employed after first modifying equation 2 as

$$s_o/Q = B + CQ$$

After this modification, a plot of s_o/Q versus Q can be prepared on arithmetic graph paper from data collected during a step drawdown test. The slope of a line fitted to these data is equal to C, while the y-intercept is equal to B, as shown in figure 5. If the data do not fall on a straight line but, instead, curve concavely upward, then Rorabaugh's method usually is suggested. The curvature of the plotted data indicates that the 2nd order relationship between Q and s_o is not valid.

If Rorabaugh's equation is used, then the coefficients B and C as well as the exponent n must be determined. In order to facilitate a graphical procedure, equation 3 is rearranged as

$$(s_o/Q) - B = CQ^{n-1} \tag{5}$$

Taking logs of both sides of the equation leads to

$$\log [(s_o/Q) - B] = \log C + (n - 1) \log Q \tag{6}$$

A plot of $(s_o/Q) - B$ versus Q can be made on logarithmic graph paper from step test data. Values of B are tested until the data fall on a straight line (figure 6). The slope of the line equals n - 1, from which n can be found. The value of C is determined from the y-intercept at Q = 1. In the example shown, the graphical procedure is facilitated if Q is plotted as cubic feet per second and $(s_o/Q) - B$ is plotted as seconds per foot squared. It is also convenient (although not mandatory) to use these same units in the Jacob method.

Step Test Procedure

The primary objective of a step drawdown test (or step test) is determination of the well loss coefficient (and exponent, if Rorabaugh's method is used). With this information, the well loss portion of drawdown for any pumping rate of interest can be estimated. During the test the well is pumped successively at a number of selected pumping rates. Equally spaced pumping rates are selected to facilitate the data analysis. Each pumping period at a given rate is called a step, and all steps are of equal time duration. Generally the pumping rates increase from step to step, but the test also can be conducted by decreasing pumping rates.

During each step pumpage is held constant. Water level measurements are made every minute for the first six minutes, every two minutes for the next ten minutes, and then every four to five minutes thereafter until the end of the step. In this investigation, water levels were measured for 30 minutes per step. At the end of each 30-minute interval, the pumping rate was immediately changed, the water level measurements reverted to the 1-minute frequency again, and so on-until a wide range of pumping rates within the capacity of the pump was tested.

Schematically, the time-water level relationship resembles that shown for a five-step test in figure 7. Drawdowns for each step (shown as Δs_i) are measured as the distance between the extrapolated water levels from the previous step and the final water level of the current step. For step 1 the nonpumping water level trend prior to the start of the test is extrapolated, and Δs_1 is measured from this datum. All data extrapolations should be performed on semilog graph paper for the most accurate results. For the purpose of plotting s_o/Q versus Q or $(s_o/Q) - B$ versus Q, values of observed drawdown s_o are equal to the sum of Δs_i for the step of interest. Thus, for step 3, $s_o = \Delta s_1 + \Delta S_2 + \Delta S_3$.

Piezometers

Piezometers--small diameter wells with a short length of screen--are used to measure water levels at a point in space within an aquifer and are often used in clustered sets to measure variations in water levels (head) with depth. In the case of turbulent loss studies piezometers can be employed to measure head losses across a well screen or across a gravel pack or well bore.

All 48 of the IDOT dewatering wells have piezometers drilled approximately 5 feet from the center line of each well and finished at a depth corresponding to approximately the upper third point of the screen in the pumping well. An indication of well losses in a pumped well can be found in such an arrangement by comparing the difference in head between water levels in the well and those in the adjacent piezometer over a sufficiently large range of pumping rates. If turbulent losses exist within that range, the difference in heads should be nonlinear with increasing pumping rate. It can also sometimes be useful to simply plot depth to water (or- drawdown) in the piezometer versus pumping rate. If turbulence extends outward from the well to the piezometer, then this relationship will also be nonlinear. Additionally, the piezometers can be used as mechanisms to continually monitor head differences between the wells and the piezometers to detect deterioration at any well. This has been IDOT's primary use of data from the piezometers.

FIELD RESULTS

Well Selection

The 12 wells selected for testing were determined by examining graphs of the monitoring data collected by IDOT. Those installations showing the greatest water level differences between the operating well and piezometer were judged most likely to have deteriorated, thus requiring verification of their condition. The wells selected for testing in 1984 were:

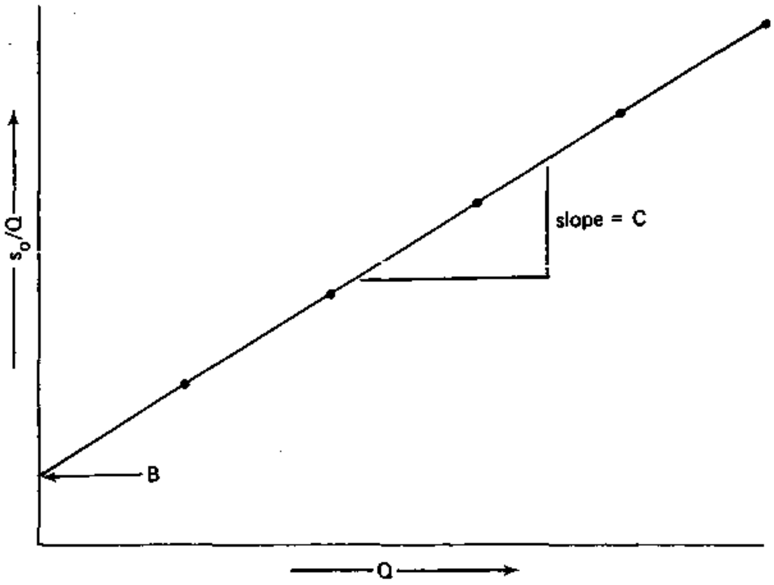

Figure 5. Graphical solution of Jacob's equation for well loss coefficient, C

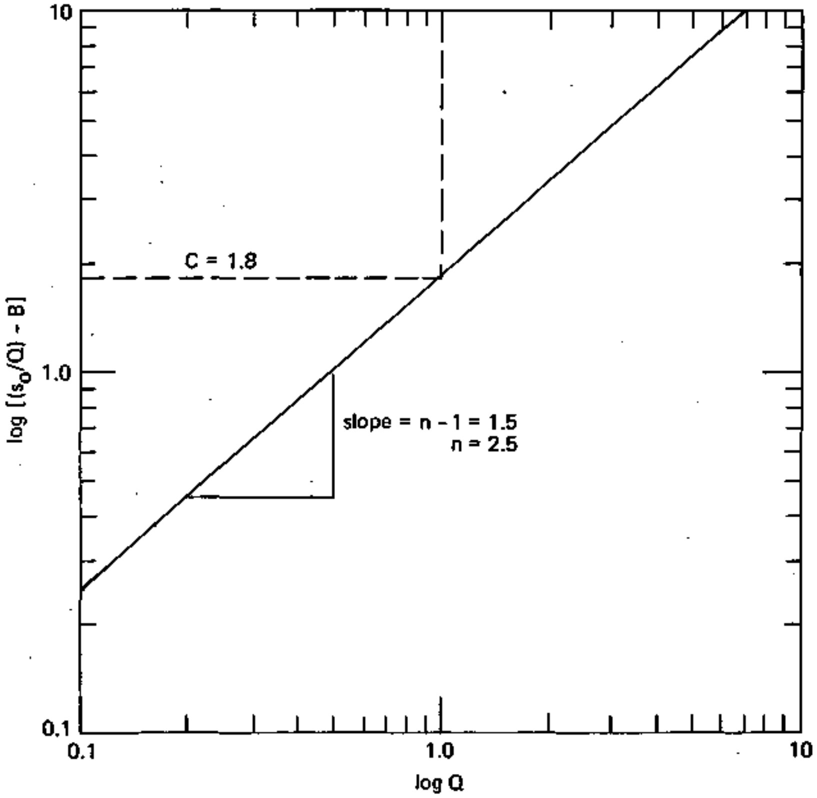

Figure 6. Graphical solution of Rorabaugh's equation for well loss coefficient (C) and exponent (n)

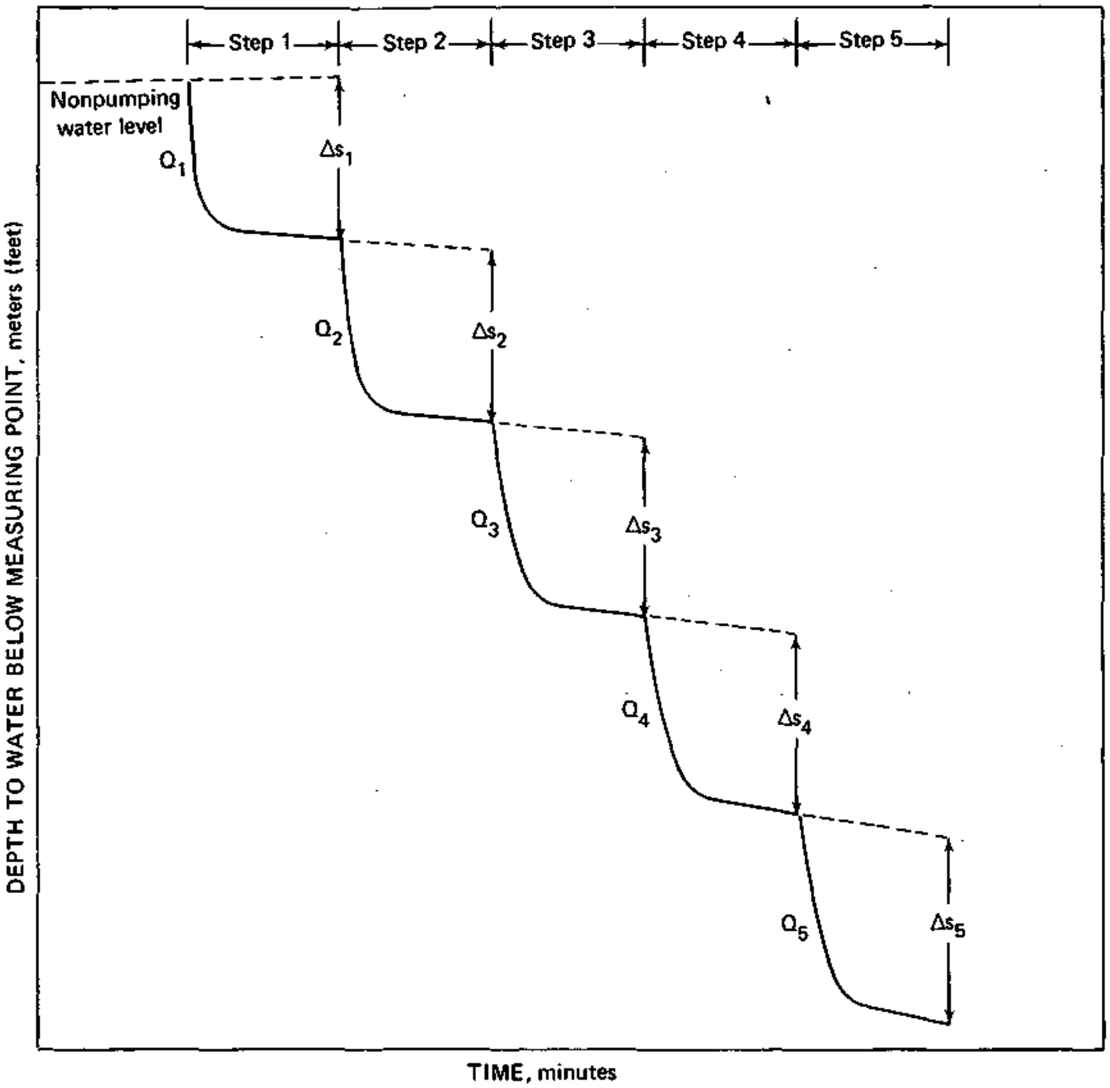

Figure 7. Time-water level relationship during a five-step drawdown test

I-70	No. 1 No. 4 No. 5 No. 8 No. 9 No. 10 No. 11
I-64	No. 3 No. 10 No. 11 No. 13
25th Street	No. 6

Field Testing Procedure

Field work was conducted by Water Survey staff with the assistance of the IDOT Maintenance Division Pump Crew under the general supervision of Stan Gregowicz. The IDOT Pump Crew made all necessary discharge pipe modifications and provided special piping adapters. This allowed the water from the pumped wells to be discharged through a flexible hose and orifice tube provided by the Water Survey. Discharge water from the orifice tube was directed to nearby storm water drains.

Orifice tubes are considered standard equipment for measuring flow rates. The orifice plate used to measure the range of flow rates was calibrated in the University of Illinois Hydraulics Lab under discharge conditions similar to those expected in the field. The rating curve developed from the calibration procedure is shown in figure 8.

Prior to the start of each test, the nonpumping water levels in the well and the piezometer were measured with a steel tape. Standard electric droplines were used to determine depths to water during the step tests.

The objective of each step test on the selected wells was to control the flow rate at increments of 50 gpm and to include as many steps as possible at 300 gpm or greater for each well. In addition, since routine monitoring by IDOT personnel is based upon the difference in water levels between the operating well and the piezometer, water level declines (drawdowns) during the step tests were observed in both the pumped well and the piezometer. This routine provided data for comparison with the historical monitoring data available from IDOT.

The 12 well tests were conducted during the period of June 26 through August 16, 1984. Each of these tests was started at a pumping rate of 300 gpm and increased in increments of 50 gpm until full pump capacity was reached. The water level and pumping rate measurements collected during each of the step tests are included in Appendix A. Near the end of each step

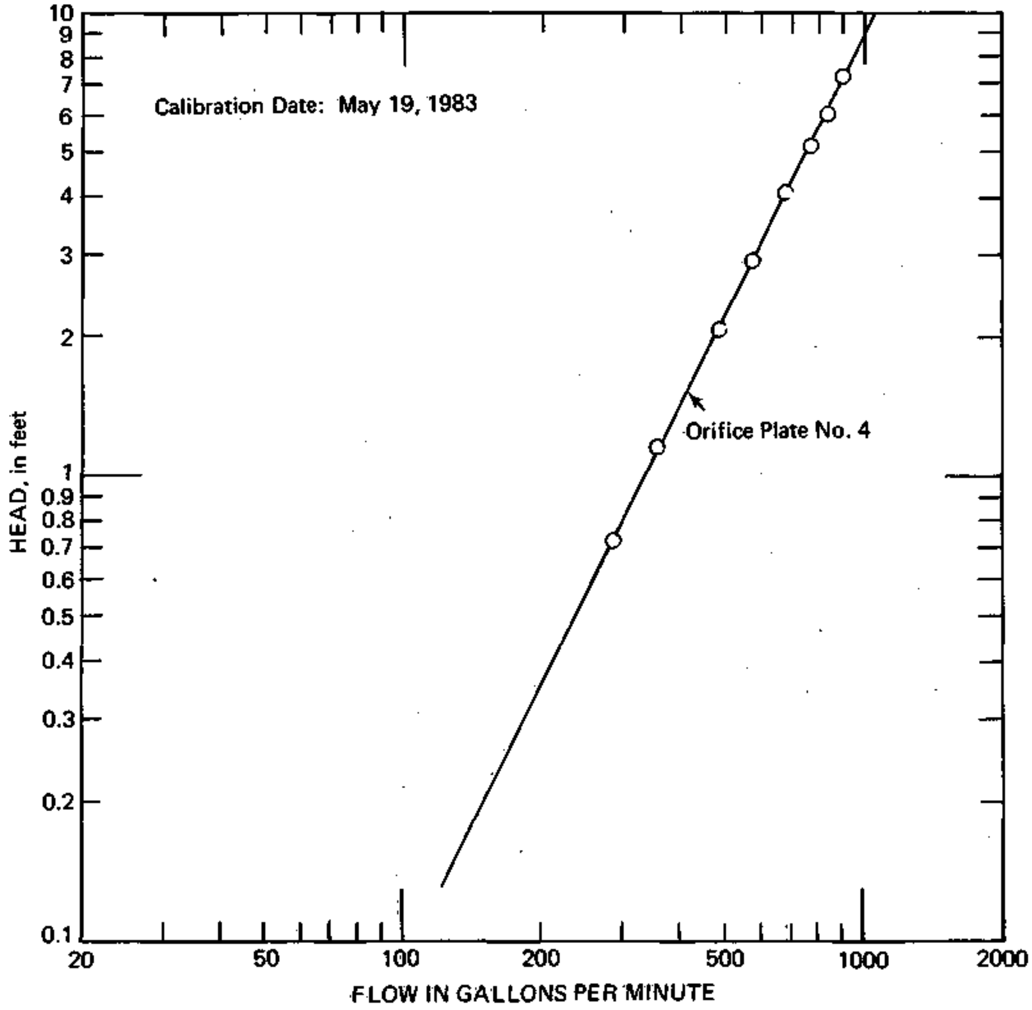

Figure 8. Rating curve for ISWS 8-inch orifice tube with plate No. 4

test, a water sample was collected for chemical analysis. The results of the analyses are presented in Appendix B.

Results of Step Tests

Data from each of the step tests were analyzed using the Jacob method (the exponent of Q for the well loss component of drawdown is 2). To illustrate this technique in detail, an example follows wherein data from the July 10, 1984, test of I-70 Well No. 5 are analyzed.

Pumping at Well No. 5 commenced at 12:05 p.m. at an initial rate of 300 gpm. During each succeeding 30-minute step, pumpage was increased by 50 gpm so that steps 2 through 9 had discharge rates of 350, 400, 450, 500, 550, 600, 650, and 700 gpm, respectively. A water sample was collected during the 9th step at 4:21 p.m., and the test was concluded at 4:35 p.m.

Data from the pumped well are shown in a plot of s/Q versus Q (figure 9). To facilitate the procedure, the discharge rate was plotted in units of cubic feet per second. As described earlier, the two components of drawdown can be determined by solving for the coefficients B and C, where B is the aquifer loss coefficient and C is the well loss coefficient. From the analysis, the coefficients B and C were determined to be 4.28 sec/ft^2 and 0.50 sec^2/ft^5, respectively. Applying these coefficients to equation 2 at a discharge rate of 600 gpm (1.337 cfs), for example, we have

$$s = BQ + CQ^2 \tag{7}$$

$$\begin{aligned} s &= 4.28(1.337) + 0.50(1.337)^2 \\ &= 5.72 + 0.89 \\ &= 6.61 \text{ feet} \end{aligned}$$

The total drawdown of 6.61 feet compares favorably with the observed drawdown, which was 6.53 feet, suggesting a good correlation between theoretical and observed results.

The analysis indicates that at 600 gpm the portion of drawdown caused by turbulent well losses at the well screen and inside the well was 0.89 feet or 13.6% of total drawdown, which is moderately low. Another indication that the well is in good hydraulic condition is the specific capacity. At 600 gpm the observed specific capacity was 91.9 gpm/ft, which compares favorably with values obtained at other sites and which also compares well with the theoretical specific capacity for the I-70 area (estimated from hydraulic properties in the area).

Figure 10 shows water level differences (Ah) between I-70 Well No. 5 and its nearby piezometer during the test. The relationship appears to be linear, suggesting that turbulent losses in the vicinity of the well are small. This was corroborated by a plot of drawdowns at the piezometer versus pumpage, which showed a linear relationship.

The results of analyses performed on data gathered during the step-drawdown testing of 12 IDOT wells in 1984 are summarized in table 1. As seen in the table, well losses in most cases were a relatively small portion of

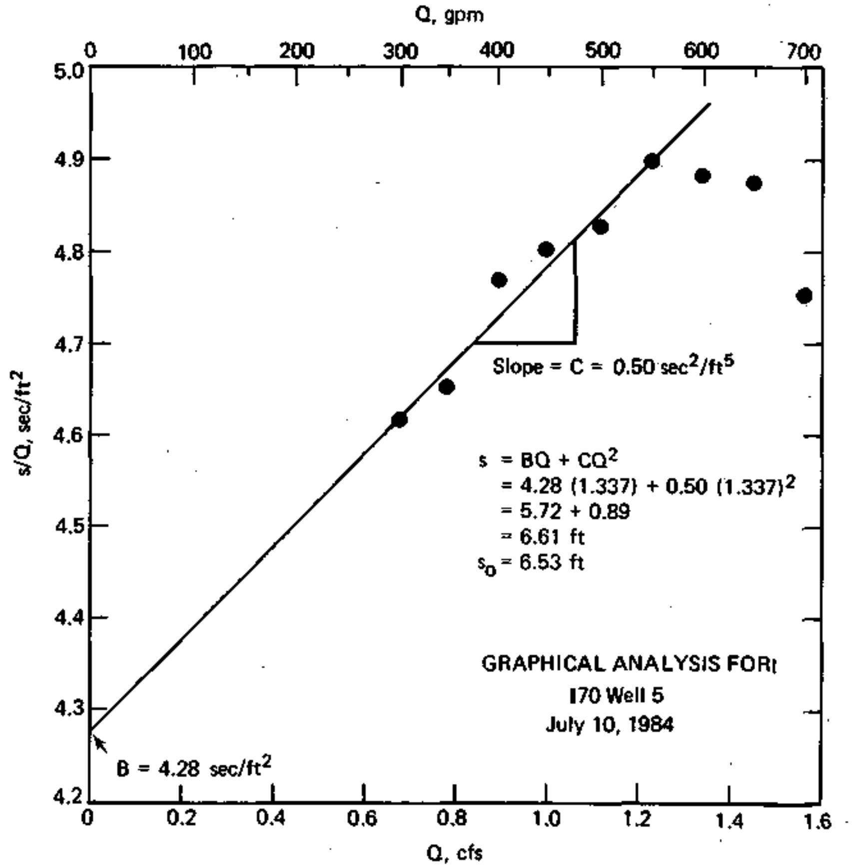

Figure 9. Graphical analysis for I-70 Well No. 5

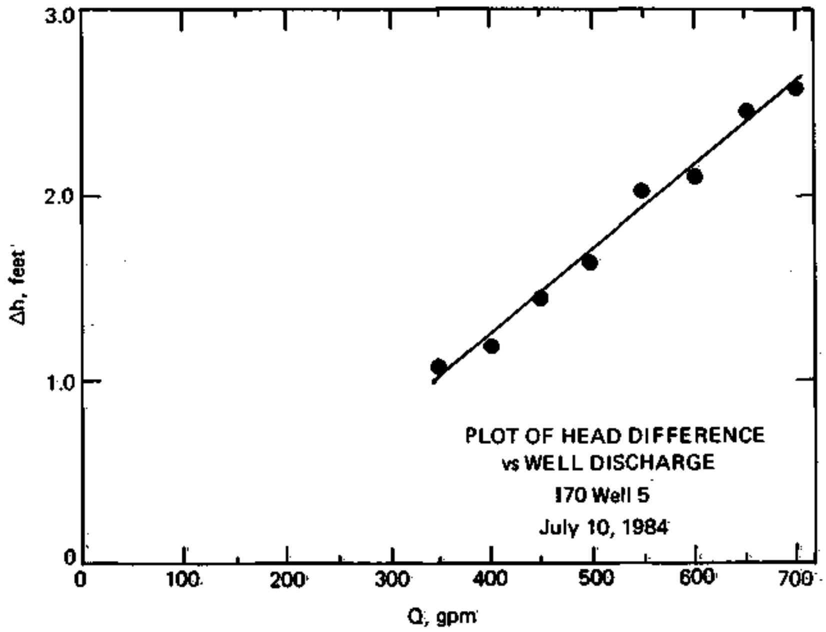

Figure 10. Plot of head difference vs. discharge, I-70 Well No. 5

Table 1. Results of Step Tests on IDOT Wells, 1984

Well	Date of test	Well loss @ 600 gpm (feet)	Drawdown @ 600 gpm (feet)	Well loss portion (%)	Specific capacity (gpm/ft)	Δh* @ 600 gpm (feet)	Remarks
I-70							
No. 1	8/15/84	**	18.1 est.	**	33.1 est.	12.8 est.	Q_{max} = 328 gpm
No. 4	8/16/84	.07	9.33	0.8	64.3	--	Piezometer plugged
No. 5	7/10/84	.89	6.53	13.6	91.9	2.11	Q_{max} = 740 gpm
No. 8	8/1/84	2.68	13.54	19.8	44.3	9.94	Q_{max} = 625 gpm
No. 9	6/28/84	**	9.46	**	63.4	5.94	Q_{max} = 630 gpm
No. 10	7/11/84	4.47 est.	15.49 est.	28.9	38.7 est.	--	Piezometer plugged, Q_{max} = 480 gpm
No. 11	8/2/84	1.58 est.	15.41 est.	10.2	38.9 est.	13.45 est.	Q_{max} = 555 gpm
I-64							
No. 3	6/26/84	.52	10.73 est.	4.8	55.9 est.	--	Piezometer partially plugged, Q_{max} = 525 gpm
No. 10	7/11/84	**	7.46	**	80.4	2.73	Q_{max} = 605 gpm
No. 11	8/14/84	**	7.22 est.	**	83.1 est.	3.2 est.	Q_{max} = 520 gpm
No. 13	7/12/84	**	6.44	**	93.2	2.65	Q_{max} = 600 gpm
25th Street							
No. 6	6/27/84	.14	9.44	1.5	63.6	--	Piezometer plugged, Q_{max} = 775 gpm

* Head difference between pumped well and adjacent piezometer

** Graphical analysis indicated laminar flow conditions and possible well development, making a well-loss determination impossible the total drawdowns at 600 gpm. The 600 gpm discharge rate was selected as a standard, since it is the design rate for the IDOT wells. Well losses were high in Wells No. 8 and 10 along I-70, reaching 19.8 and 28.9 percent of the total drawdown at 600 gpm. The next highest percentage was 13.1% for Well No. 5 at I-70. However, note that Well No. 5 has the second highest specific capacity of the group tested. All of the other wells had calculated well losses of 10% or less, the smallest well loss being 0.07 foot for I-70 Well No. 4. Data from five wells indicated conditions resembling development at the screen which does not allow calculation of well loss. We suspect this response may be due to the well having not been in use for an extended period of time before the step-tests. At this time, it is assumed that well losses in these wells is generally low except for I-70 Well No. 1 where the specific capacity of 33.1 gpm/ft and a Ah of 12.8 feet suggests significant well deterioration. In addition, discharge piping showed mineral incrustation about 1 inch thick inside the pipe. Ferrous carbonate was the principal compound forming the incrustation.

Specific capacity values also were calculated for a 600 gpm pumping rate and ranged from 33.1 gpm/ft at I-70 Well No. 1 to 93.2 gpm/ft at I-64 Well No. 13. The overall average specific capacity was 62.6 gpm/ft. Based on the 26 tests that have now been conducted during Phase 1 and 2, the highest group average of 98.9 gpm/ft was seen at 25th Street. Averages for the other well groups were 90.1, 78.3, and 62.3 gpm/ft for Venice, I-64, and I-70, respectively. The I-70 average without the value from Well No. 12 (a new well) and Well No. 5 was only 48.5 gpm/ft. The averages are based on samples of various sizes, but can be used for general comparative purposes.

Since head differences between water levels in the wells and in their adjacent piezometers (Ah) form the basis for current monitoring practices by IDOT, these values also were determined during the step tests and are included in table 1. Values ranged from 2.1 to 13.5 feet at 600 gpm and averaged 6.6 feet. In general, Ah values varied inversely with specific capacity. The relationship between Ah and well loss might be expected to be linear; however, the relationship is not a strong one. Part of the reason for this is that the distribution of the Ah values is skewed toward the lower end of their range of values. Another possibility is that the Ah value includes some laminar losses between the well and the piezometer. It is very difficult to assess laminar well losses, however, because of the need to separate them from laminar formation losses.

Evaluation of Groundwater Quality

Twelve wells were sampled for analysis by the State Water Survey analytical laboratory. The analytical results are reported in Appendix C. Analytical methods conform to procedures presented in the 16th Edition of Standard Methods for the Examination of Water and Wastewater (1985). Samples were preserved with acid for determining iron, calcium, and magnesium concentrations. The sample temperature was determined at each well site, and pH was determined in the laboratory immediately after transit of samples.

The range of concentrations and anticipated influence of each parameter is presented in table 2.

Table 2. Ranges of Concentration and Potential Influence of Common Dissolved Constituents

Parameter	Concentration, mg/1 Min.	 Max.	Potential influence
Iron (Fe)	9.2	20.0	Major - incrustative
Calcium (Ca)	132	277	Major - incrustative
Magnesium (Mg)	37.2	74.1	Minor - incrustative
Sodium (Na)	14.2	222	Neutral
Strontium (Sr)	0.7	1.2	Minor - incrustative
Silica (SiO_2)	29.8	35.2	Minor - incrustative
Nitrate (NO_3)	<0.3	3.7	Neutral
Chloride (Cl)	24	390	Moderate - corrosive
Sulfate (SO_4)	169	636	Major - corrosive
Alkalinity (as $CaOC_3$)	334	480	Major - incrustative
Hardness (as $CaCO_3$)	486	998	Major - incrustative
Total Dissolved Solids	663	1148	Major - corrosive
PH	7.0	7.2	Major - incrustative

Although the ground-water samples vary in water chemistry, generally the ground water can be described as highly mineralized, very hard, and very alkaline, with unusually high soluble iron concentrations. The water quality is consistent with samples previously analyzed and reported for wells in the nearby area.

Evaluation of Flow Rate Meters

The Phase 1 report (Sanderson et al., 1984) recommended the testing and procurement of a portable, non-invasive (dry transducer) ultrasonic type flowmeter device for use on the 48 dewatering wells, as part of the Phase 2 project. This section summarizes the findings of the efforts directed, so far, towards this particular goal.

Availability of portable, non-invasive ultrasonic flowmeters (PNUF) is very limited. To date, only two meter manufacturers (Controlotron and Polysonics) have been found which make such a meter designed to work under the conditions found at the IDOT dewatering wells. Since our investigation began over a year ago as part of the Phase 1 project, the ultrasonic technology has continued to advance. As a result, it is reasonable to expect more devices of this type will be available in the near future from other manufacturers. The technology for these devices is rather recent (less than 15 years) and portable type devices were not available until only the last several years.

In light of the newness of the PNUF, early efforts were directed towards borrowing or obtaining a demonstration of the units, for operation under actual field conditions, to monitor performance and accuracy. Results of the testing will be used to either select a particular unit for purchase or reject them both.

It became evident as negotiations proceeded that only Polysonics and their St. Louis area distributor (Sun Day Corporation) were willing to work under the above arrangement. While testing both manufacturers' devices would be ideal, the Polysonics meter appeared on paper to offer more options and flexibility in use for less cost as well as operational ease. Therefore, arrangements were made with Sun Day to test their model DHT-P meter on August 2 and 16, 1984. On these dates, the SWS conducted step tests on I-70 Wells No. 11 and 4, respectively.

During the step tests, flow rate measurements by the DHT-P were collected for comparison against the SWS 8-inch diameter orifice tube for flow rates ranging from 310 to 650 gpm through both 6- and 8-inch diameter pipe. The calibration of the orifice tube had recently been tested in the U of I Hydraulics Laboratory and found to be accurate within ±2% of the total flow. As a further check, the DHT-P was taken to the Venice dewatering well site on August 16 to compare flow rate measurements with the installed venturi tubes. Results of the testing are summarized in table 3.

A different DHT-P meter was used on each of the test days. The unit used on August 2 had been utilized as a rental and demo unit for an unspecified period of time by the distributor but was reportedly recalibrated for our test. A brand new, previously unused unit was employed for the testing on August 16. In all cases, with the exception of one questionable measurement, the DHT-P indicated flow readings on the high side. Furthermore, measurements averaged about 4 to 6% high when the instrument was used on the 6-inch I.D. (inside diameter) schedule 40 pipe (adapter and 2-foot long nipple) and about 11 to 17% high when used on the 8-inch I.D. lightweight steel approach pipe for the orifice tube (see figure 11). Measurements obtained from the DHT-P appeared to fluctuate more when the older instrument was used.

Polysonics specifies that the DHT-P is accurate to within ±5.0% of full scale. When the DHT-P is used on the 6-inch standard weight pipe, the measurements appear close to this specified error. Although the data is not totally conclusive, the error seen appears to be constant (about 30 to 50 gpm) (see figure 12). Since the meter actually measures water velocity in the pipe and the velocity is used in equation 8 to compute the flow rate, recalibration of the DHT-P for the 6-inch diameter discharge pipe should be possible.

$$GPM = (ID)^2 \times V \times 2.45 \tag{8}$$

where:

GPM = flow in gallons per minute
ID = discharge pipe inside diameter in inches
V = velocity of water through the pipe in feet per minute (fpm) as measured directly with DHT-P
2.45 is a dimensionless constant

Table 3. Flowmeter Field Test Results (flow rates in gpm)

Instrument Tested: Polysonics Portable, Non-intrusive Ultrasonic Flowmeter
Model DHT-P

Calibration Instrument: SWS 8-inch diameter orifice tube (plate no. 4)

		DHT-P					
		6-inch pipe			8-inch pipe		
Test date	Orifice tube Q	Q	ΔQ	%	Q	ΔQ	%
8/2/84	310				328-360	18-50	5.8-16.1
	350	308(?)	-42	-12	392-407	42-57	12-16.3
	400	441	41	10.3	447-470	47-70	11.8-17.5
	450	460-480	10-30	2.2-6.7	478	28	6.2
8/10/84	450	478	28	6			
	500	522-532	22-32	4-6			
	550	585	35	6			
	600	630	30	5			
	650	700-720	50-70	8-11	724-744	74-94	11-14

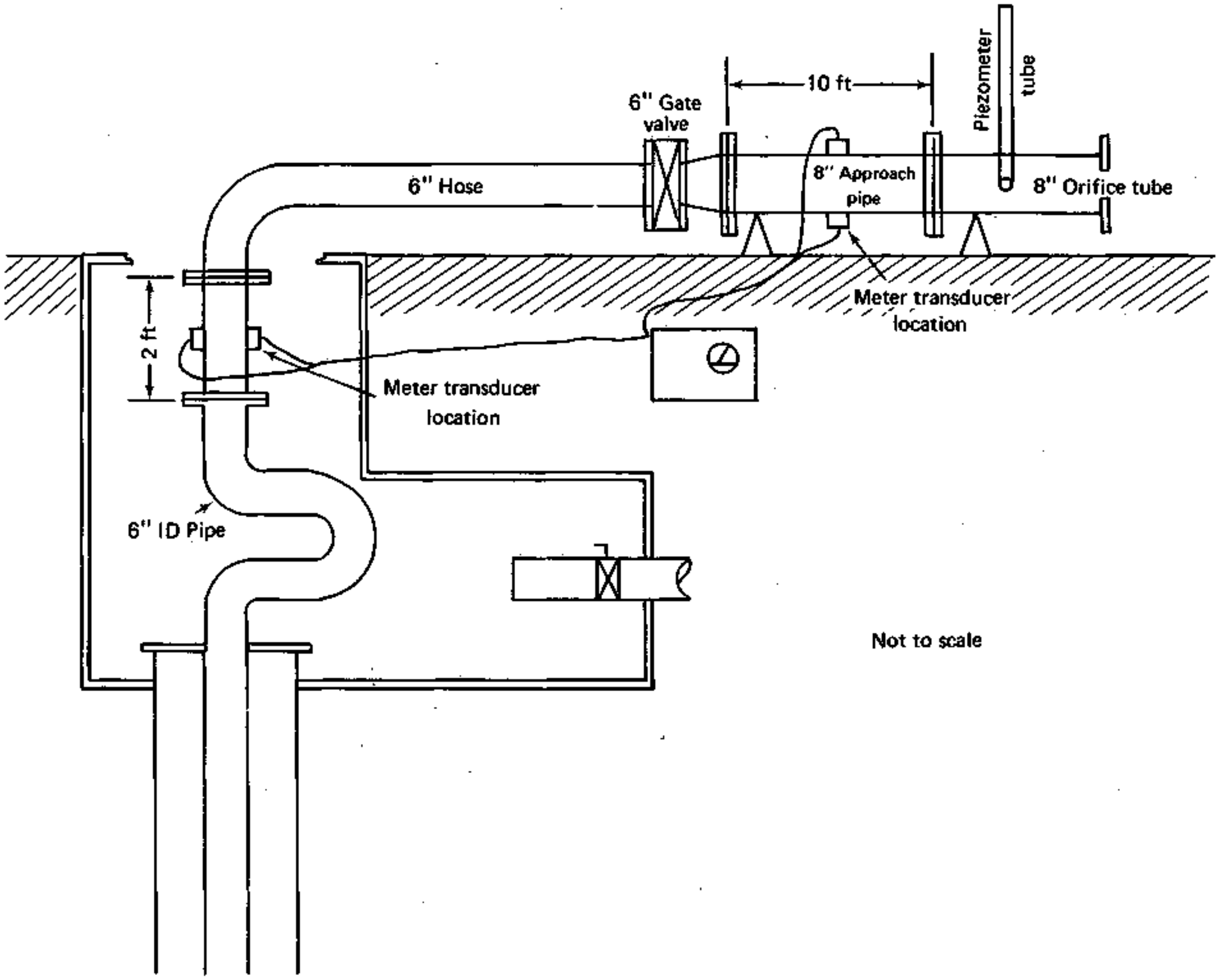

Figure 11. Typical arrangement for flowmeter tests

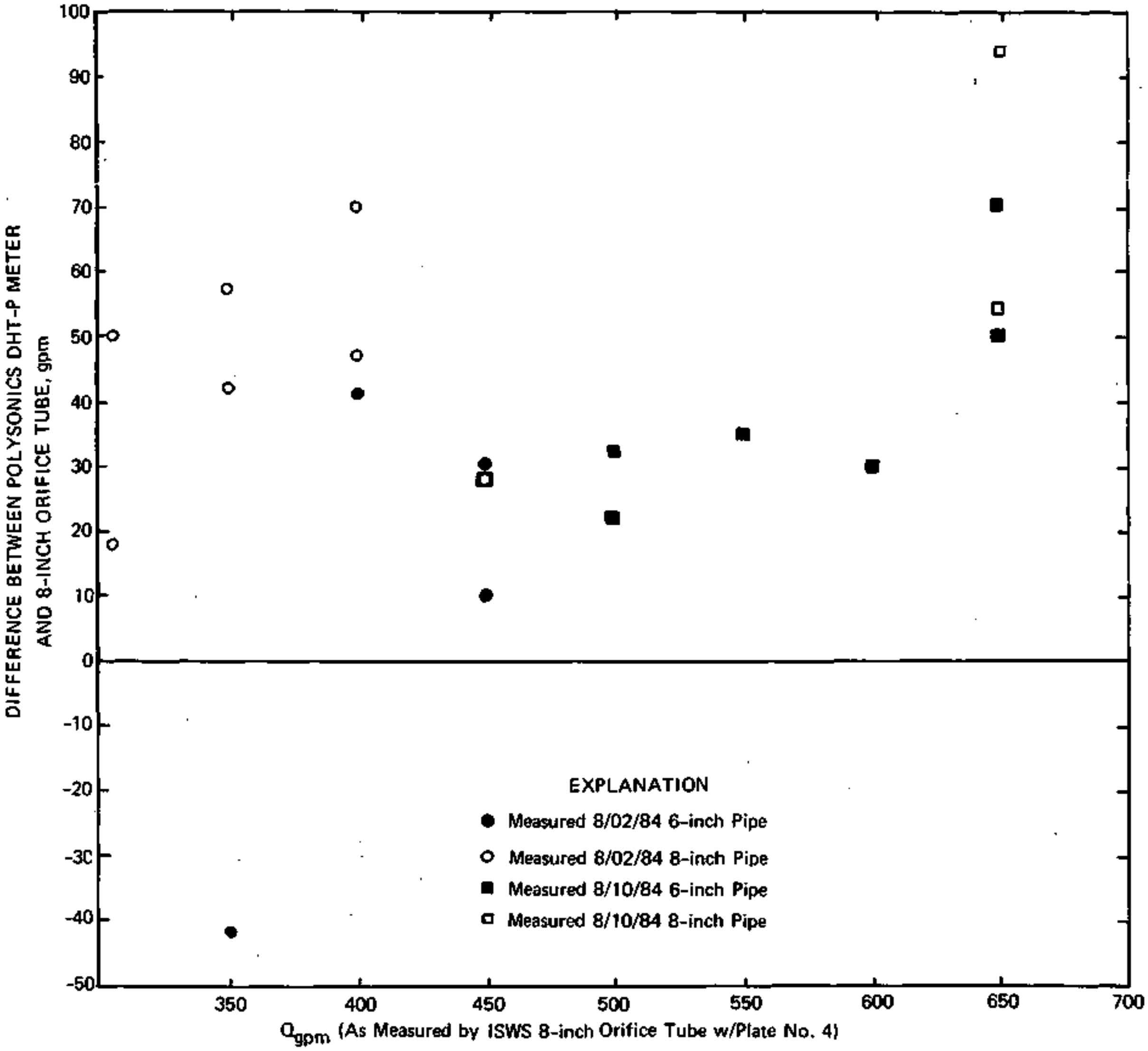

Figure 12. Flow accuracy of Polysonics DHT-P Portable Ultrasonic Flowmeter

The reason for 2 to 3 times more error when the DHT-P is used on the 8-inch lightweight approach pipe is probably inherent in the physical operation of the meter and its incompatibility with the pipe material or construction. However, recalibration would also be a possibility in this case.

It is interesting to note that the DHT-P meter was compared to measurements from only one venturi tube at the Venice dewatering wells. This was due in part to one or two of the wells not currently pumping but also to two of the venturi tubes not functioning properly. At Venice Well No. 3 the DHT-P agreed to within a few gpm of the flow reading obtained with the venturi tube.

It is evident from our tests that the DHT-P flowmeter could be utilized to obtain reasonable estimates of the flow rates from the 48 dewatering wells. Initially, the meter would need to be calibrated perhaps for groups of dewatering wells having similar plumbing arrangements. A problem which has been noticed during the course of our step tests which would not be overcome easily is the buildup of deposits on the inside of the discharge pipes. A thick deposit buildup will severely affect the accuracy of the flow rate measurements. As can be seen from equation 8, any error in the I.D. measurement of the pipe will be squared.

For example, the velocity of flow through the 6-inch discharge pipe for the 600 gpm flow rate is 6.80 fpm. If this velocity had been measured on this same pipe with an 1/8-inch thick deposit or an overall reduction in the pipe diameter to 5.75 inches, the actual flow rate would be 551 gpm. In other words, the 600 gpm flow rate as determined from the measured velocity would be 8.9% above the actual flow rate of 551 gpm. Deposits 1/8-inch thick have been common in the discharge pipes, and, in some cases, the deposit buildups are much thicker. There is no easy solution to this problem; the only apparent solution being the periodic physical disconnection of the plumbing to check on the thickness of the deposits.

Finally, the DHT-P is a relatively delicate instrument and correct placement of the portable transducers on the discharge pipe, as well as a good understanding of the operational principles of the instrument, is critical for obtaining accurate measurements. To help assure reliability, satisfactory performance, and longevity of the instrument, we recommend that one and certainly no more than two technicians operate and maintain the DHT-P. Past observations of the pump maintenance crew handling other equipment suggests similar care given to the DHT-P would result in unsatisfactory reliability, performance, and premature failure of the instrument.

GROUND WATER CHEMISTRY INVESTIGATION

Background

Water chemistry and step-test data results in Phase 1 suggested that the ground water at the dewatering sites has a significant potential for deposition of minerals on the aquifer and gravel pack material which would induce deterioration in dewatering well performance. This part of the investigation is using careful sampling techniques, precise and accurate research analyses, and computerized geochemical models to determine the chemical mechanism causing the deterioration. From a knowledge of the mechanism, appropriate hydrologic and/or chemical control strategies could be suggested. Field sampling plus analysis of unstable chemical constituents is being performed. Twelve monitoring wells with PVC casings were built at I-70 Well No. 3. They are located in a 3-direction pattern around the well.

Construction of Sampling Wells

The array of monitoring wells at I-70 Well No. 3 was constructed during the period July to August. As shown in figure 13, the array consists of twelve wells at six locations. The six locations are divided into 3 directions from I-70 Well No. 3 - approximately east, west, and north - with each location including a shallow and a deep monitoring well. The first pair of wells is located as close to the production well as site conditions permit; about 5 (deep) and 7 (shallow) feet in the east and north directions and about 7 and 9 feet in the west direction. The second, or outer, pair of wells are located at distances of about 20 (deep) and 22 (shallow) feet from the production well.

The monitoring wells were constructed with the use of a hollow-stem drilling rig operated by IDOT District No. 8. For each monitoring well the hole was augered to the desired depth, the hollow stem washed clean to the bottom, and a 2-inch diameter PVC casing with a 2-foot length of screen inserted to the bottom of the hole. The augers were then pulled from the hole. The sandy formation materials collapsed around the casing to near the water table elevation, usually about 25 to 30 feet below land surface. A bentonite plug 1 1/2 to 2 feet long was then formed by using 50 pounds of bentonite pellets. The remainder of the hole was filled with drill cuttings and a lockable well protector placed at the top.

Split spoon samples were taken at 4 of the locations for later physical examination.

Flow Path and Rate Study

In order to determine the length of time it takes water to pass from the outer monitoring wells to the inner ones, a brief tracer study was conducted. Travel time is an important consideration when attempting to evaluate the possibility of precipitation or dissolution reactions of minerals occurring in the saturated zone along the path of flow in the study area. Too rapid a flow rate would indicate insufficient time for equilibration with the aquifer material; hence, the chemical composition of the water entering the dewatering well would represent characteristics acquired outside of the monitoring area. Additionally, a successful chemical monitoring effort requires that the samples reflect water that is actually along flow paths leading into dewatering well I-70 No. 3.

For the tracer study, the dye Rhodamine WT was used. A 100 ppm solution was prepared by mixing the liquid dye with pumped water in a steel drum. Using a peristaltic pump, 17 gallons of the 100 ppm solution were injected into the bottom of the easternmost deep monitoring well (Well No. 11, see

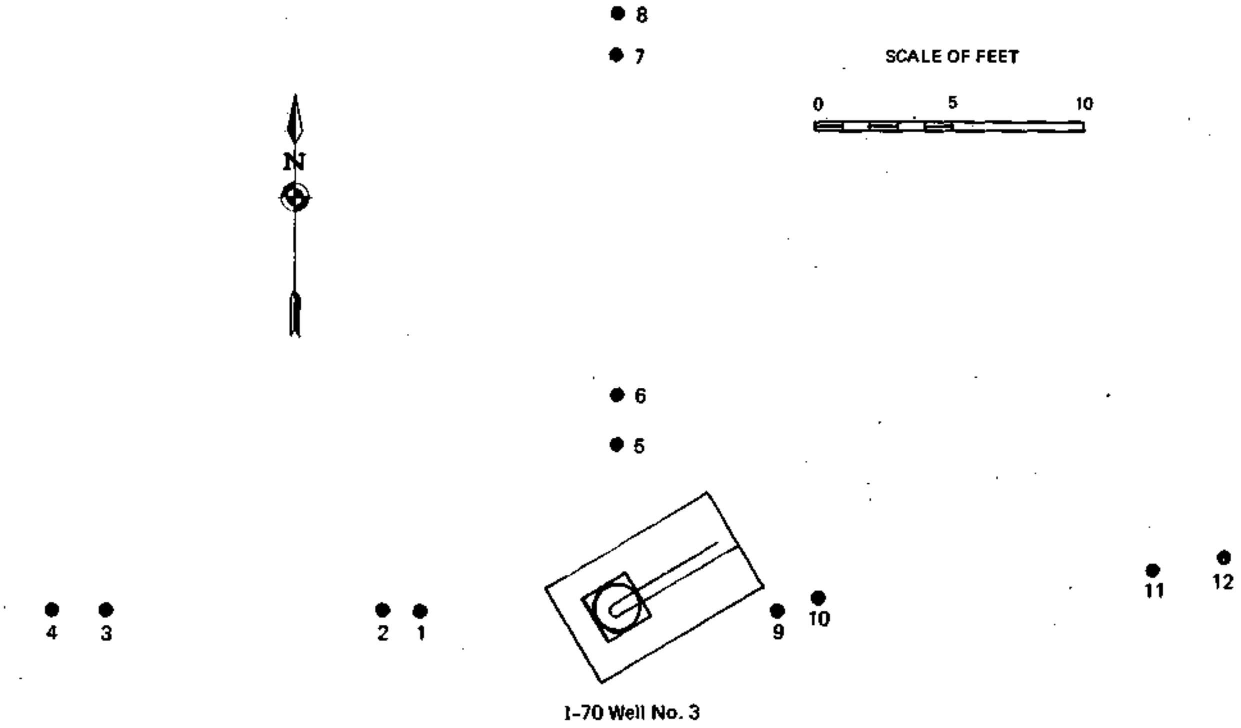

Figure 13. Locations of monitoring wells at I-70 Well No. 3

figure 13) in a period of 20 minutes. Timing began when the peristaltic pump was shut off.

Sampling was initiated in Monitoring Well No. 9 one hour later. Samples were obtained using a QED Model 3013 controller and driver, and a QED Well Wizard(R) T-1101 pump, equipped with a Teflon(R) bladder.

The pump line was run through the flow-through cell of a Turner Model 111 fluorometer, to monitor Rhodamine concentration. No attempt was made at calibrated quantitative measurement; only the relative concentration indicating the passage of the tracer slug was sought. After 1 hour, a second pump was operated to withdraw standing water containing Rhodamine from the injection well. This action would both prevent excessive tailing of the tracer peak, and would limit the amount of Rhodamine contaminating the aquifer material.

The same general procedure was followed for the north (Wells 7 and 5) and west sides (Wells 3 and 1) on the next two days. In these runs, 200 ppm solutions of dye were used. On the north side, visual inspection of samples taken every 5 minutes in polyethylene bottles was used, because the dye concentration exceeded the capacity of the fluorometer. The time periods found are summarized in table 4.

Table 4. Observed Travel Times from Outer to Inner Deep Monitoring Wells

Outer well	Inner Well	Distance (ft)	Direction	Time (min)
11	9	18	E-W	235 ± 30
7	5	14	N-S	220 ± 30
3	1	13.5	W-E	210 ± 30

The low fluorescence readings found for the peaks on the east and west sides indicate that the flow net about production dewatering Well I-70 No. 3 (henceforth referred to as the "production well") is extremely distorted by the other dewatering wells in the system. The flow is diverted to the south of the production well, so a smaller amount of the dye was observed. Because the innermost deep wells are within 5 feet of the depth of the production well, and a high concentration was found for the north-south flow path, vertical dispersion was not considered to be a plausible explanation for the low dye amounts found for the west-to-east and east-to-west flow paths.

Chemistry Sampling and Analysis Techniques

Samples for chemical analysis were taken from the monitoring wells by the following procedure. QED Model 3013 pump controllers were used, and either P-1101 or T-1101 QED Well Wizard(R) bladder pumps. Because the bladders were all Teflon(R), and all constituents of interest (except NV0C) were inorganic, PVC and Teflon(R) pump casings were considered interchangeable. Nitrogen gas was used for bladder operation, and samples were drawn through a 110-ft length of 3/8-in. 0D P-5000 tubing. The pump was found to operate effectively when there was a minimum of 2 to 2.5 ft of water above the pump to provide sufficient head to force water into the evacuated bladders.

A valving system was set up to allow the simultaneous operation of up to three pumps and sequential sampling. Sample water was pumped directly from the well to a Plexiglas(R) flow-through cell containing two platinum combination Eh electrodes, a glass combination pH electrode, a conductivity cell, and a temperature sensing and compensation probe for the pH meter. The sampling cell and associated waters, and the calibration procedures are described in some detail elsewhere (Garske and Schock, 1985).

When stable readings of pH, Eh, SPC (specific conductance), and temperature were obtained, indicating water freshly obtained from the aquifer was being sampled by the pump, the readings were noted. Then, the sample flow was diverted around the cell via a valve and was sent through a "filtration tree." This tree was an apparatus constructed from polyethylene tubing, Y-connectors, Teflon(R) valves, and three 47-mm diameter plastic in-line membrane filter holders, allowing either unfiltered or filtered (0.4 µm Nuclepore(R) polycarbonate) samples to be taken for analysis. The filtrations were performed without atmospheric contact or pressurization changes (which could bias the sample chemical measurements) through the use of this filtration assembly, and the sample stream could be immediately diverted to an unused filter as one became clogged. This technique assured that the samples were taken in a reasonable length of time, and that the maximum particle size transmitted would be reasonably consistent from sample to sample.

Unfiltered samples were used for dissolved oxygen analyses, and other special samples. Filtered samples were used for all other constituents taken back to the laboratory, plus total alkalinity. Bottles were rinsed with sample water before collections were begun. Table 5 summarizes the types of samples generally taken, their method of preservation, and the constituents measured in each. The preservatives were added immediately upon collection.

The sampling cell and filtration "tree" could not be used for samples taken from the production well. Samples were taken using a hose fastened to a faucet. No pH, Eh, or SPC measurements were attempted because representative samples could not be obtained.

Table 6 summarizes the dates on which samples were collected, and the wells involved. Monitoring wells 2 and 4 were unusable because of construction problems. The outermost shallow monitoring wells on the north and east sides never had enough water in them to enable samples to be extracted. When the production well was operating, a sample was first taken from the outer monitoring well on a given side. Then, the samples were taken from the inner pair of monitoring wells on the same side after waiting for the length of time indicated in table 4 for the water flow. This protocol was an attempt to obtain samples from approximately the same parcel of water as it moved through the subsurface.

The sampling trip of November 6, 1984, was a reconnaissance mission to determine the approximate levels of constituents likely to be encountered, and what potential interferences to the analytical chemical methods might be

Table 5. Preservation Methods and Analytical Determinations Performed

Size	Container*	Preservation+	Analytes
-	Flow-through cell	isolation from air	pH, Eh, SPC, temperature
-	glass	determined immediately	Total Alkalinity, Dissolved Oxygen
1000 ml	LPE	none	NO_2, NO_3, SO_4, SiO_2, Cl^-, Ortho-PO_4, S^{2-}, PO_4 (total)
500 ml	Opaque LPE	0.2% 6N HC1, no air contact	Fe(II)
250 ml	LPE	0.1% Conc. HNO_3	Ca,Mg,Na,K,Fe,Sr
125 ml	glass, amber	0.16% Conc. H_2SO_4	NH3-N, PO_4 (total) in last set
25 ml	glass	no air contact	NVOC
25 ml	plastic syringe	no air contact	Dissolved or Total Inorganic C

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* LPE = linear polyethylene

\+ All samples returned to the laboratory were refrigerated during transport, and were stored in a refrigerator in the dark. Preservation concentrations are those in the bottle after mixing with the sample.

Table 6. Sample Collection Record

Date	Dewatering Well	Monitoring Well									
	#3	1	3	5	6	7	8	9	10	11	12
PRODUCTION WELL ON											
11/6/84	X	X	X	X	I	X	I	X	I	X	I
11/26/84	X	X	X								
11/27/84	X			X	I	X	I				
11/28/84	X							X	I	X	I
12/11/84	X	X	X					X	X	X	I
12/12/84	X			X	X	X	I				
12/18/84	X							X	I	X	I
12/18 PRODUCTION WELL TURNED OFF											
1/7/85	X			X	X	X	I				
1/8/85	X							X	X	X	I
1/9/85	X	X	X								
1/9 PRODUCTION WELL TURNED ON											
1/14/85	X							X	I	X	I
1/15/85	X			X	I	X	I				
1/16/85	X	X	X								

Notes

X = sample collected
I = insufficient water in well for sample

present. The sampling trips starting on November 26, December 11, and December 18 reflected continuously pumping conditions.

On December 18, I-70 Well No. 3 was shut off and was left off until January 7, 1985. The hiatus in pumping was an attempt to observe changes that might be apparent in the monitoring wells that could be attributed to possible "recovery" of the production well during off periods. Behavior indicating such a possibility had been previously observed from the routine monitoring data (Ah values) collected by IDOT.

On the sampling trip of November 26, 27, and 28, 1984, both filtered and unfiltered samples were taken for Ca, Mg, Na, Fe, Fe(II), and Sr to check for the presence of undissolved particles that could indicate active precipitation going on in the aquifer.

At the start of sampling on January 7, 8, and 9, 1985, sampling pumps were placed in the usable monitoring wells on a given side. First, these wells were pumped to clear stagnant water from inside the casings. Then, the production well was started, and the monitoring well sampling procedure was initiated after 15 to 30 minutes. The production well was shut off immediately following the last sample of January 7 and 8, but was left on after the samples were collected on January 9.

Samples were collected again on January 14, 15, and 16 to see if the chemical constituents resumed the concentrations they had before the production well was shut down.

Samples were normally taken early in the morning. As the samples were taken, they were refrigerated by putting them under ice in a cooler. When the last sample for the day was collected, they were immediately driven to the laboratory in Champaign for analysis of volatile or perishable constituents: inorganic carbon, ferrous iron, sulfide, nitrate, nitrite, ammonia, and orthophosphate. The other analyses were performed within two weeks as part of the normal laboratory analytical schedules.

In the field, all alkalinity titrations were performed in duplicate or triplicate. Also, because multiple aliquots could not be taken from the same container, all DIC (dissolved inorganic carbon), TIC (total inorganic carbon), and NVOC (non-volatile organic carbon) samples were taken in triplicate.

On the November 26, 1984, sampling date, all samples to be returned to the laboratory for analysis were taken in triplicate in order to determine if there was sampling inconsistency or bias. An examination of this data indicated that, with the exception of orthophosphate, virtually all variability could be attributable to the variance of the analytical methods themselves. Thus, replicate samples need not be taken during each sampling session. The orthophosphate variability could have been the result of a random contamination and is not considered to be indicative of normal sampling variation, particularly in light of the other results.

Table 7 is a summary of the analytical method precision obtained using pooled replicate analysis data for samples and quality control standards. Most of the samples obtained were analyzed in duplicate or triplicate. In

Table 7. Precision of Most Analytical Methods Used in This Project, Based on Pooled Data from Multiple Replicate Analyses

Constituent	Method*	Standard Deviation (mg/1)
Ca	PT	2.5
Ca	AAS	1.3
Mg	PT	2.85
Mg	AAS	0.2
Na	AAS	1.0
K	AAS	0.22
Sr	AAS	0.13
Fe(total)	AAS	0.99
Fe(II)	PT	0.08
DIC/TIC(as C)	CT	0.44
Total Alk (as $CaCC_3$)	PT	3.9
SiO_2	S(A)	0.2
Cl^-	PT	0.11
SO_4	S(A)	11.6
NH_3-N (as NH_4)	S	0.10
Ortho-PO_4	S	0.04
Total-PO_4	S	0.01
NO_2-N, (NO_2+NO_3)-N	S(A)	most below detection limit
S^{2-}	S	below detection limit

* methods: PT = potentiometric titration; CT = coulometric titration;
AAS = atomic absorption spectrophotometry;
S = Spectrophotometric, either manual or automated (A)

general, the precision obtained in this project for the analytical methods exceeds that normally expected (Standard Methods, 1985; USEPA, 1979; Skougstad et al., 1978). Therefore, small changes in the concentrations of most parameters can readily be detected. The relatively poor precision of the usually reliable titrimetric calcium and magnesium procedures is caused by the large amount of iron found in the samples. The atomic absorption method will be employed in the future studies.

Precision is not the whole story, however, and serious interferences were found for several of the methods that will need more work. Particularly troublesome is the positive interference caused by silica in the standard procedures for orthophosphate and total phosphate analyses when the ratio of silica to phosphate is high. Some progress was made using a high acid-to-molybdate ratio (Downes, 1978; Stauffer, 1983), but the interference has not been entirely overcome. An attempt will be made to automate the procedure and try other means to reduce the problem while maintaining necessary sensitivity.

Ferrous iron was found to suppress the indicated concentration of silica in the standard automated colorimetric procedure. This interference has not been successfully overcome. There were some problems with poor recoveries of spikes in the ammonia procedure, which has been corrected by procedural modifications. The reproducibility of the NVOC analyses was often poor. This was apparently related to long sample holding times (up to 3 months) caused by instrumental breakdowns, which allowed time for the precipitation of colloids of iron and organic material after iron oxidation. Sample preservation techniques will be explored in the future, and the recent acquisition of a new organic carbon analysis instrument will enable a much more rapid turnaround of samples.

The dissolved oxygen analyses were originally performed by the Azide Modification of the Winkler method (Standard Methods, 1985). The samples were generally below the detection limit of the field procedure used, so the analyses were performed using an Orion model 97-08 dissolved oxygen electrode, and all reported data were acquired with this instrument. Two problems were encountered with this analysis. First, it is extremely difficult to obtain a sample in a BOD bottle without atmospheric contamination. This is particularly a problem when bladder pumps are used because samples are taken in pulses and the sample bottles take several pulses to fill to overflowing. The second problem was the heating or cooling of the sample during measurement. A flow-through cell has subsequently been designed to accommodate the D.O. electrode in a similar fashion to that devised for the Eh and pH electrodes which would eliminate several of the problems encountered in this phase. An attempt will also be made in the future to attach a submersible temperature probe to the bladder pump to get a more accurate reading of the in situ temperature. During sampling, heating or cooling of the sample was found to take place during its transit through the 110-ft polyethylene sample line from the pump to the measurement flow cell. The amount of temperature change depended upon the air and ground temperatures and the flow rate of the pump.

Data Storage and Evaluation

Analytical data from the project was entered by project personnel into a data base in the Aquatic Chemistry Section DEC PRO 350 microcomputer. Simple statistical summaries, manipulations, sorting, and plotting is available using the RS/1 software package. A quality control data base was also set up to monitor the precision and accuracy of the analytical effort.

To verify the analytical data, ion balance computations were performed using a version of the WATEQFC geochemical modeling program (Runnells and Lindberg, 1981). Attempts were made to use the program on the State Water Survey VAX 11/750 computer, but hardware limitations prevented it. A second data base was then created on the University of Illinois CDC Cyber 175 computer in order for the data checks to be completed. Several monitoring well samples from December 11, 1984, did not have accurate pH data because of a meter malfunction. Also, production well samples had to have pH values estimated because accurate samples could not be obtained. Of the samples for which pH data was available or estimated (42), the highest ion balance error found was only ±4.9%. A total of 74% had ion balance errors of less than ±2%.

An additional check was performed by comparing the actual analyzed dissolved inorganic carbon concentration to the computed value. This comparison can indicate the possible importance of organic acids or bases in the water, or erroneous pH or alkalinity data in concentration regions where ion balance checks are not sensitive. Of the 29 monitoring well samples for which there were analyzed DIC values, the average percent difference between the computed and analyzed concentrations was 2.2%. One sample was deleted because there was a 59% difference, indicating that there probably was an alkalinity error, particularly in comparison to pH and alkalinity trends in the wells. The computed versus analyzed DIC comparison indicates generally good agreement and internal consistency of the related variables in the data set.

An attempt will be made to use the PHREEQUE geochemical model (Parkhurst et al., 1980) to compute the missing pH values from the monitoring wells, by "synthesizing" water to observed concentrations for other sampling periods using a series of hypothetical mineral assemblages. If other, similar, monitoring well waters can be reproduced, then the computed pH values will probably be very reliable.

The WATEQFC computer model was used to compute saturation indices for a large number of natural minerals, some of which could be important controls on the water chemistry and potential of debilitating deposition. The saturation index for mineral x is defined as (Freeze and Cherry, 1979; Runnells and Lindberg, 1981):

$$SI_x = \log (Q/K_{eq}) \qquad (9)$$

where Q is the reaction quotient and K_{eq} is the equilibrium constant for the solubility reaction. In this form, SI = 0 reflects equilibrium conditions, SI > 0 indicates a tendency to precipitate a solid, and SI < 0 indicates a tendency to dissolve a solid. The accuracy of prediction depends not only on the accuracy of the analytical determinations, but also somewhat on the accuracy of the equilibrium constant (K_{eq}) for the reaction of interest. Frequently, the latter problem is more significant than the former, when natural systems are involved. This approach also does not take into account the reaction rates (which are usually not known precisely), and kinetic barriers such as ionic poisoning of surficial crystal growth sites.

The computed data is currently being analyzed to determine if differences with respect to monitoring well or with respect to time are truly significant or if they might be attributable to artifacts arising from normal analytical error (the precision of the determinations). A critical evaluation is also being initiated to assess the reliability of the solubility equilibrium constants incorporated into the computer programs for the solids that appear to be most likely of some significance in governing the water chemistry based on these chemical measurements.

Summary of Chemical Observations

Figures 14 through 23 illustrate the variation found for several constituents of interest around dewatering Well I-70 No. 3. As can be seen, the chemical quality of the water is variable around the production well, and large differences from side to side are common. The shallow monitoring wells for which water could be collected (6 and 10) tend to show more similarity in composition than the deeper wells. The similarity in trends in the constituents from the deep wells from a given side, the fact that they differ greatly from their associated shallow well, and the frequent similarity in behavior between the two shallow wells suggests that the chemical/flow environment of the shallow wells is considerably different from that of the deep wells. The differences are particularly striking for calcium, silica, ferrous iron, total phosphate, magnesium (not shown), and dissolved inorganic carbon.

Although samples were taken from the I-70 Well No. 3 when monitoring wells from each side were sampled, the water chemistry variations in the monitoring wells are so large that little useful information can be obtained from the production well. This is the result of the fact that the production well quality represents an "integrated" sample of waters from all directions and different depths. The individual component qualities are virtually infinite in number and are undifferentiable (for practical purposes) given the design of the sampling network. Quality changes from the location of the innermost monitoring wells through the gravel pack and production well screen are also not monitorable because of the changes induced in sample water chemistry (pH, total carbonate content, etc.) by the production well pump itself.

The computed parameters also show interesting trends in the monitoring wells. Though the data analysis is far from complete, some strong relationships are suggested. Figures 24 through 27 show the trends in the computed saturation indices for silica gel (an amorphus silica phase generally representative of nonequilibrium silica-rich sedimentary environments), siderite (ferrous carbonate, $FeCO_3$), Calcite ($CaCO_3$, rhombohedral crystalline form), and dolomite [$CaMg(CO_3)_2$].

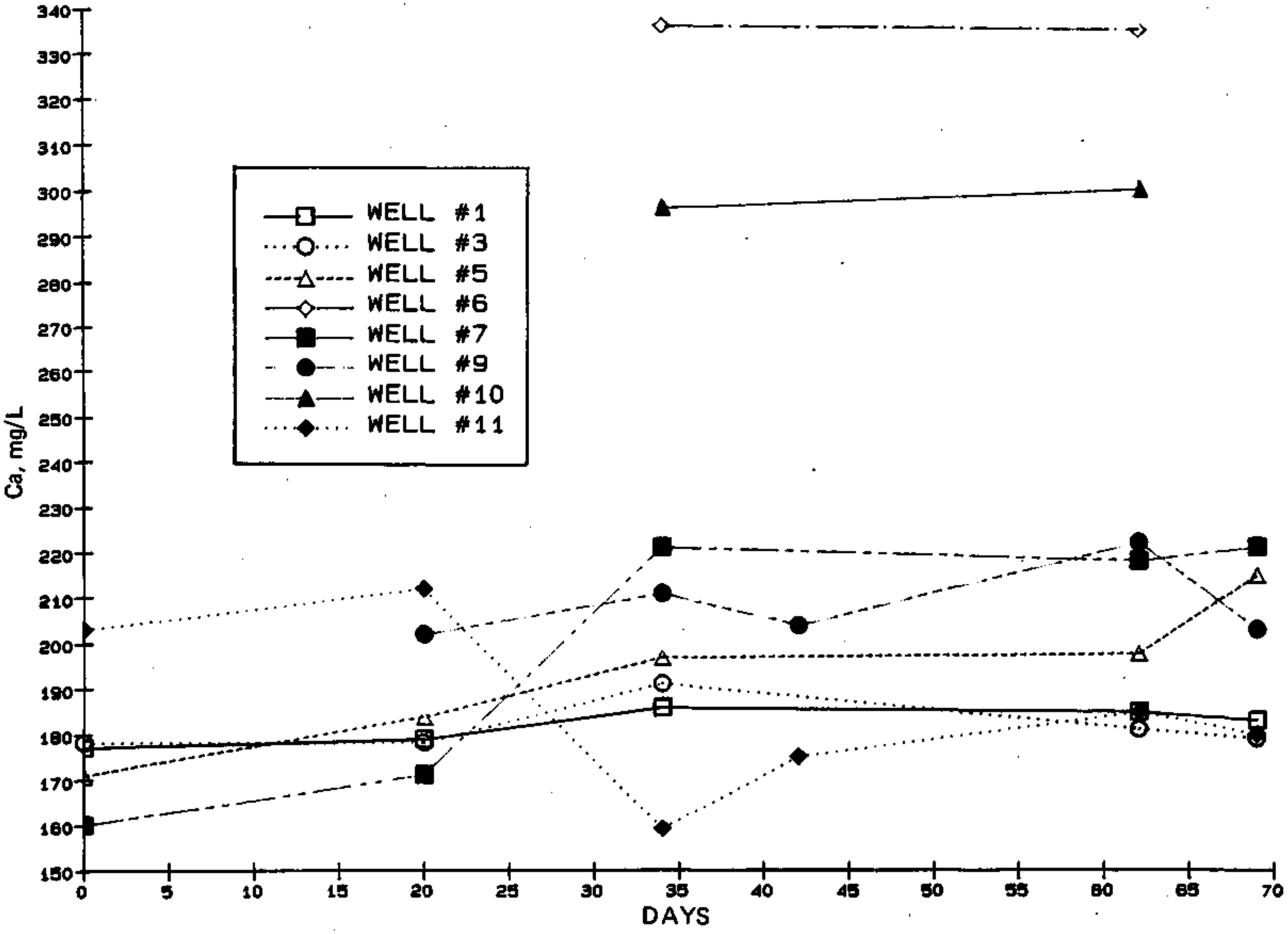

Figure 14. Plot of dissolved calcium concentrations in the monitoring wells around I-70 Well No. 3
(Refer to figure 13 for well locations)
The elapsed days count from November 6, 1984.

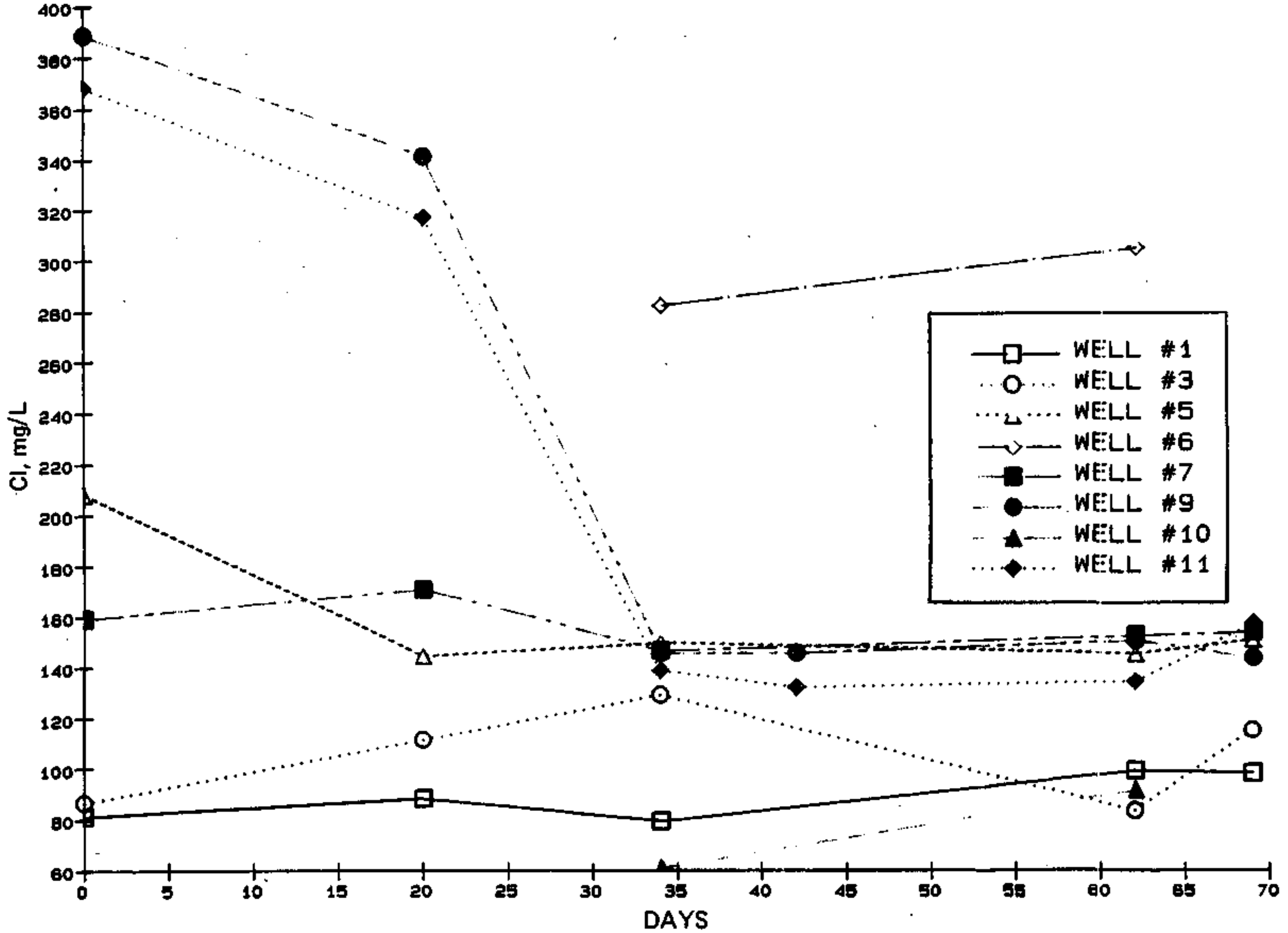

Figure 15. Plot of dissolved chloride concentrations in the monitoring wells around I-70 Well No. 3
(Refer to figure 13 for well locations)
The elapsed days count from November 6, 1984.

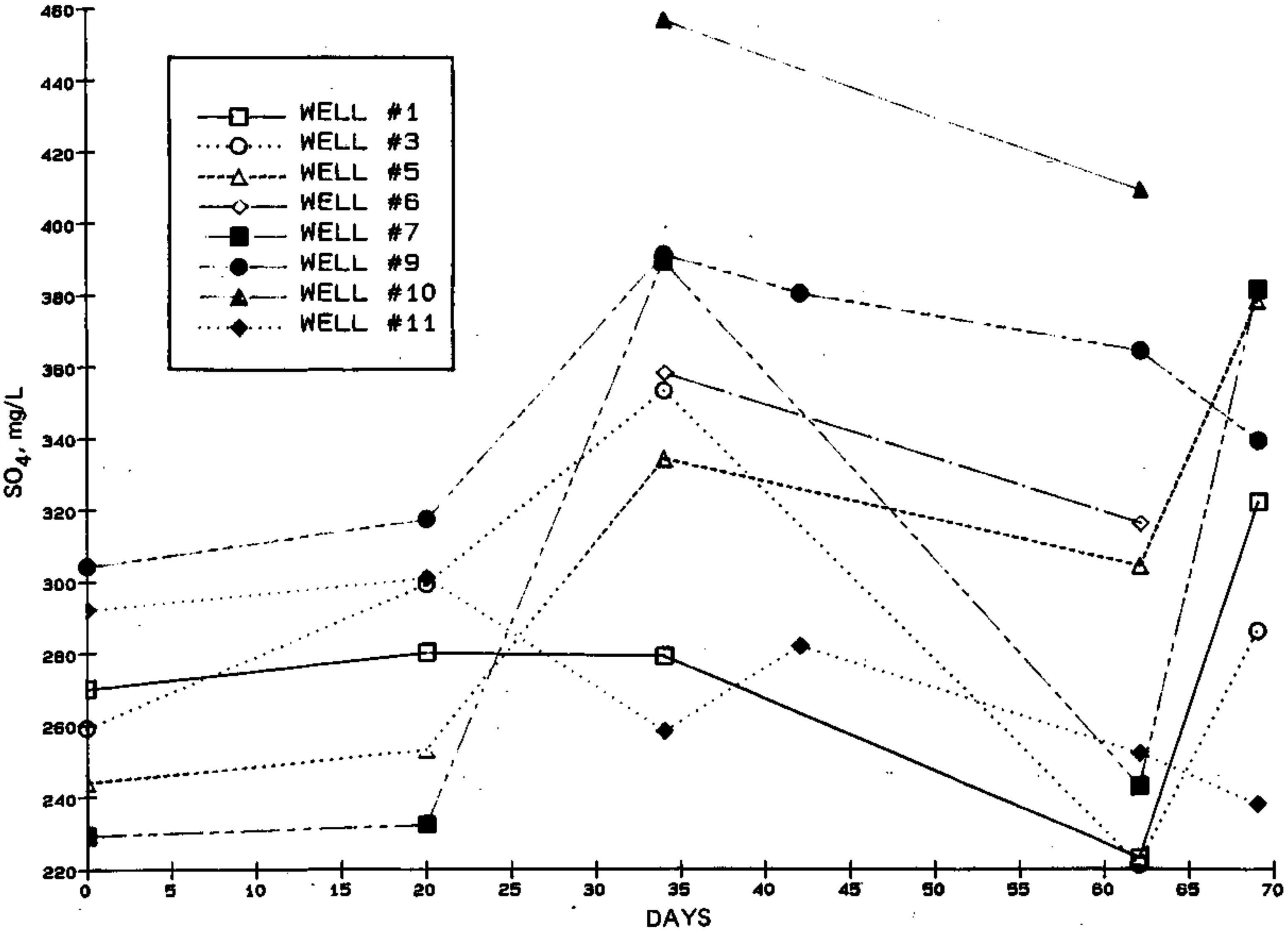

Figure 16. Plot of dissolved sulfate concentrations in the
monitoring wells around I-70 Well No. 3
(Refer to figure 13 for well locations)
The elapsed days count from November 6, 1984.

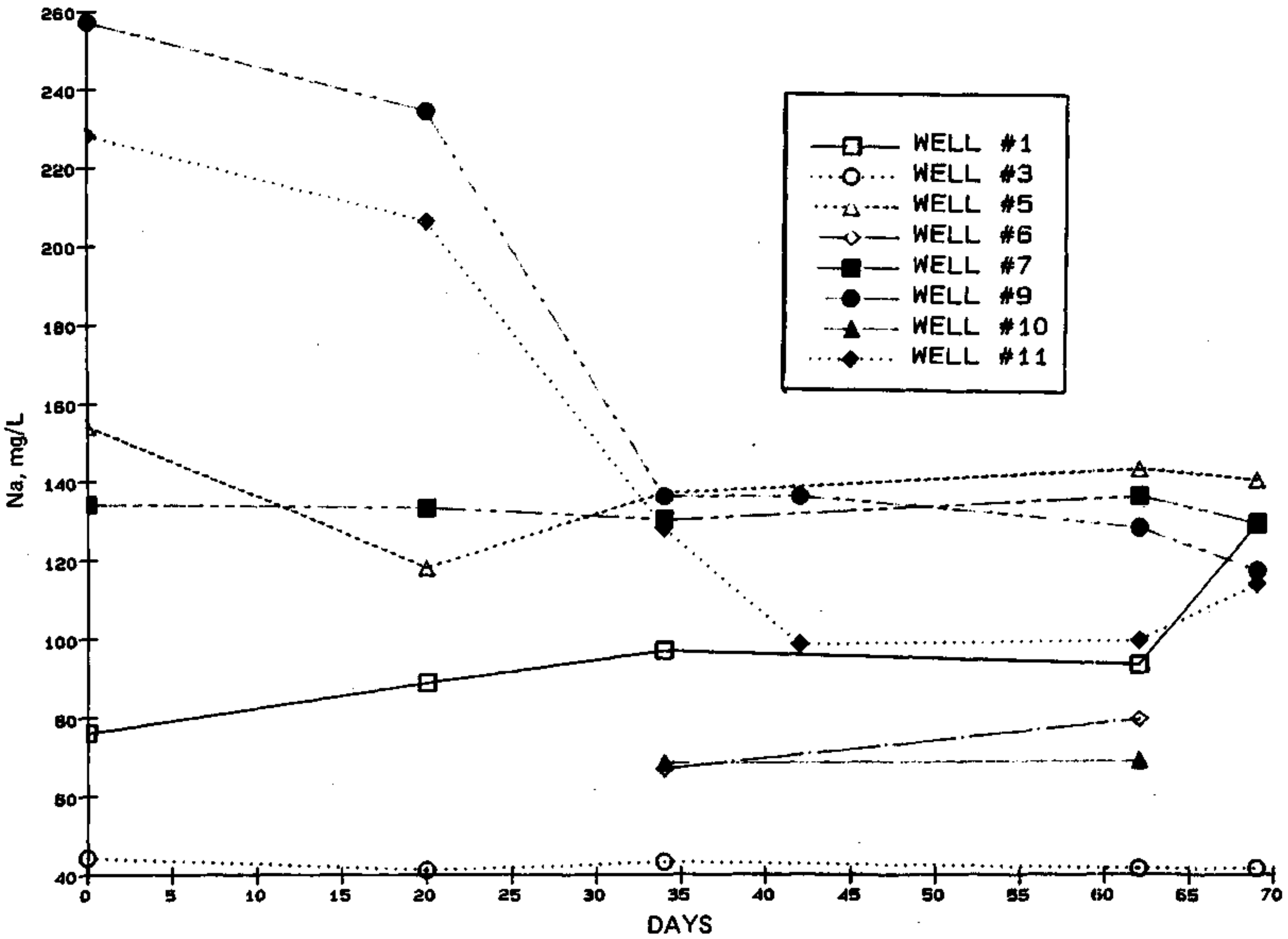

Figure 17. Plot of dissolved sodium concentrations in the monitoring wells around I-70 Well No. 3 (Refer to figure 13 for well locations) The elapsed days count from November 6, 1984.

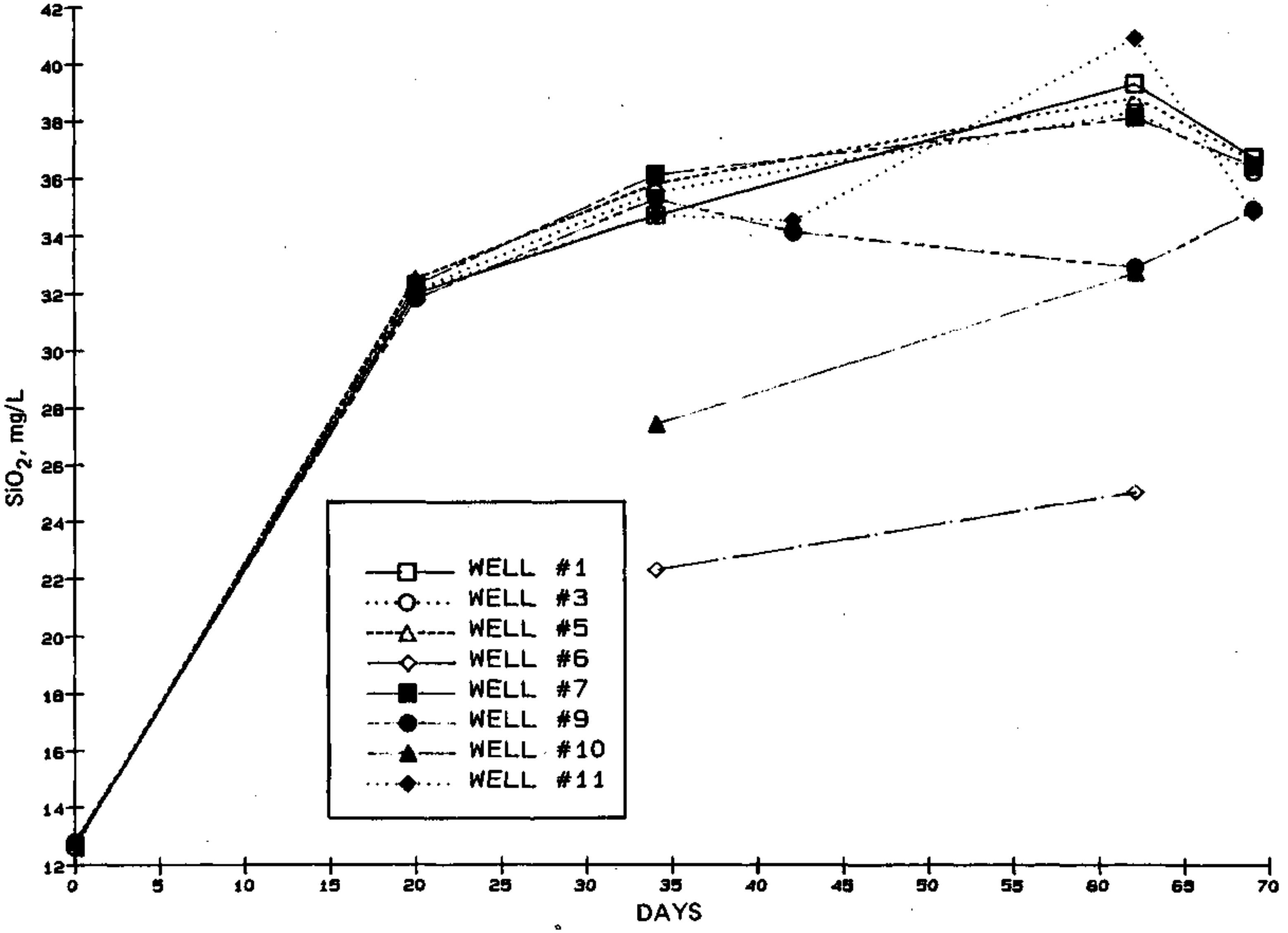

Figure 18. Plot of dissolved silica concentrations in the monitoring wells around I-70 Well No. 3
(Refer to figure 13 for well locations)
The elapsed days count from November 6, 1984.

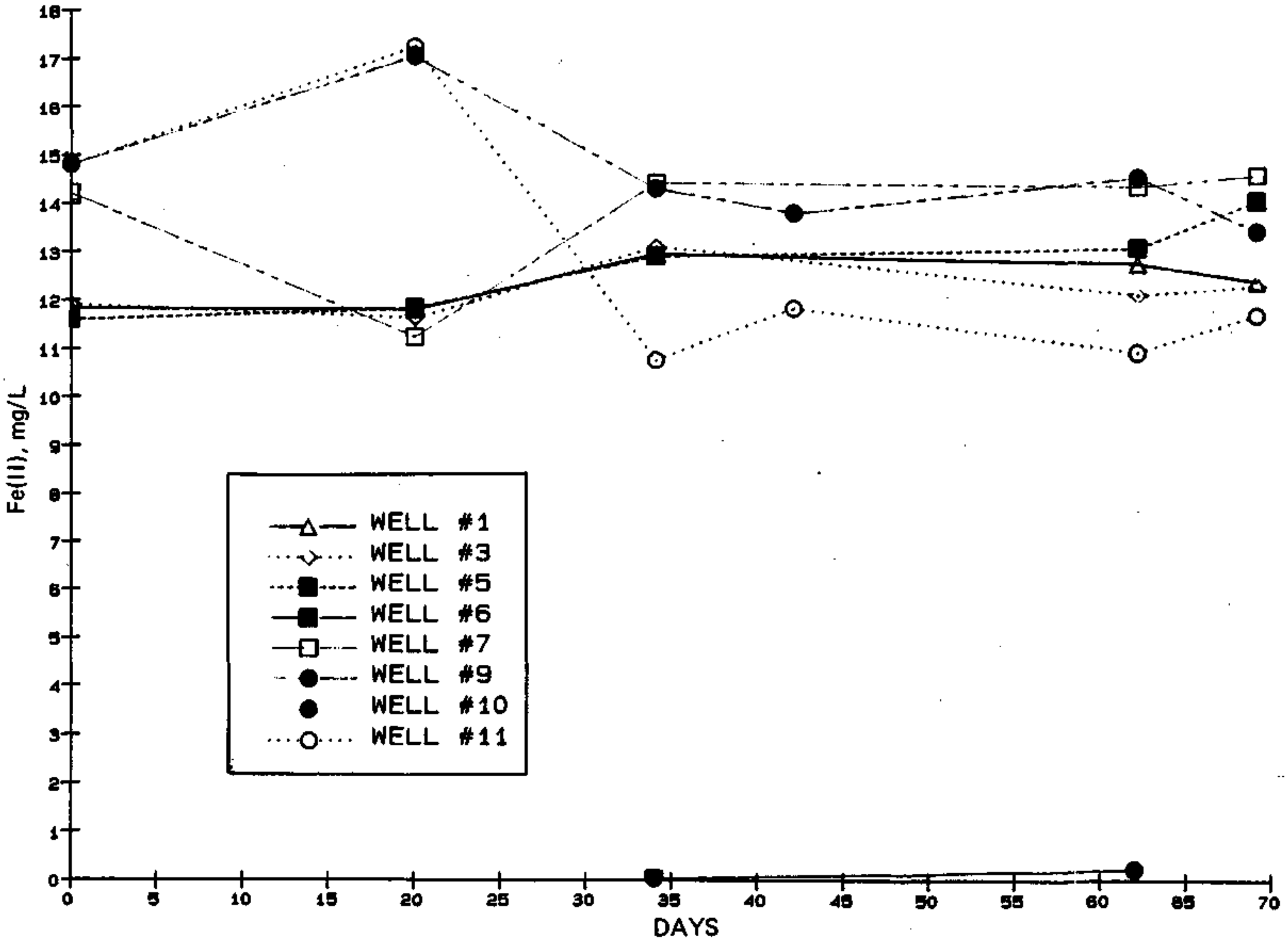

Figure 19. Plot of dissolved ferrous iron concentrations in the monitoring wells around I-70 Well No. 3 (Refer to figure 13 for well locations) The elapsed days count from November 6, 1984.

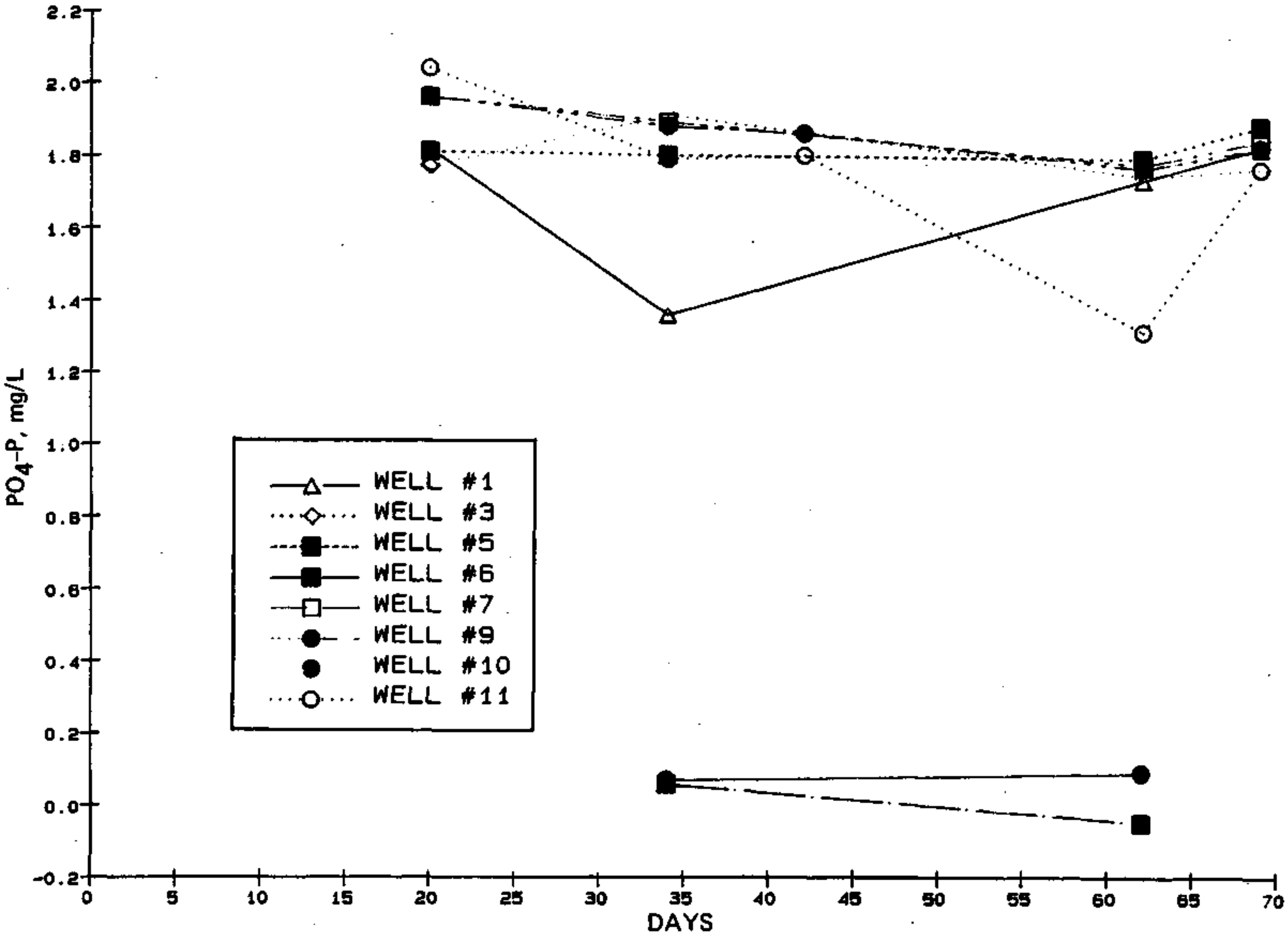

Figure 20. Plot of dissolved total phosphate concentrations in the monitoring wells around I-70 Well No. 3 (Refer to figure 13 for well locations) The elapsed days count from November 6, 1984.

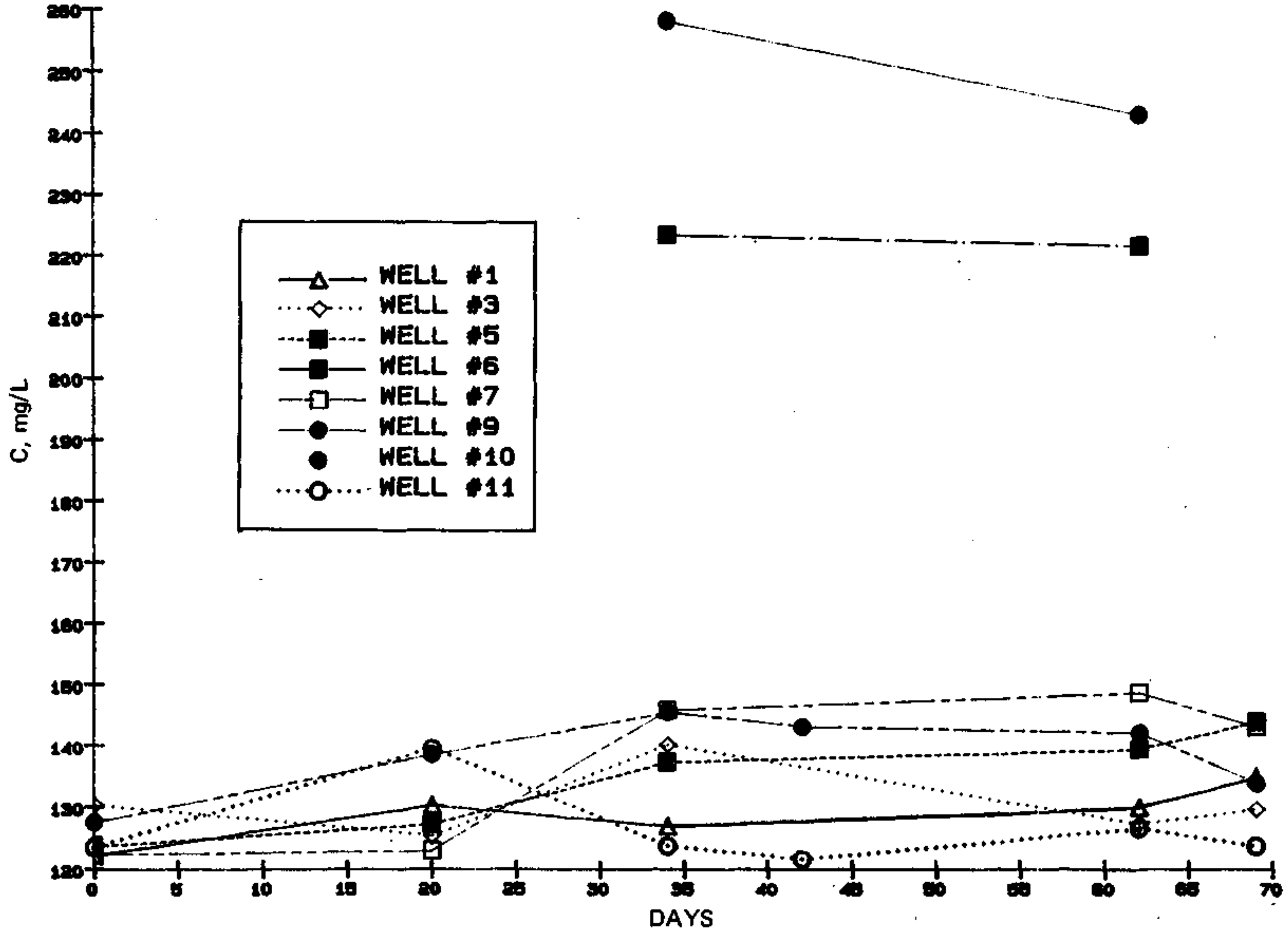

Figure 21. Plot of dissolved inorganic carbon concentrations in the monitoring wells around I-70 Well No. 3 (Refer to figure 13 for well locations) The elapsed days count from November 6, 1984.

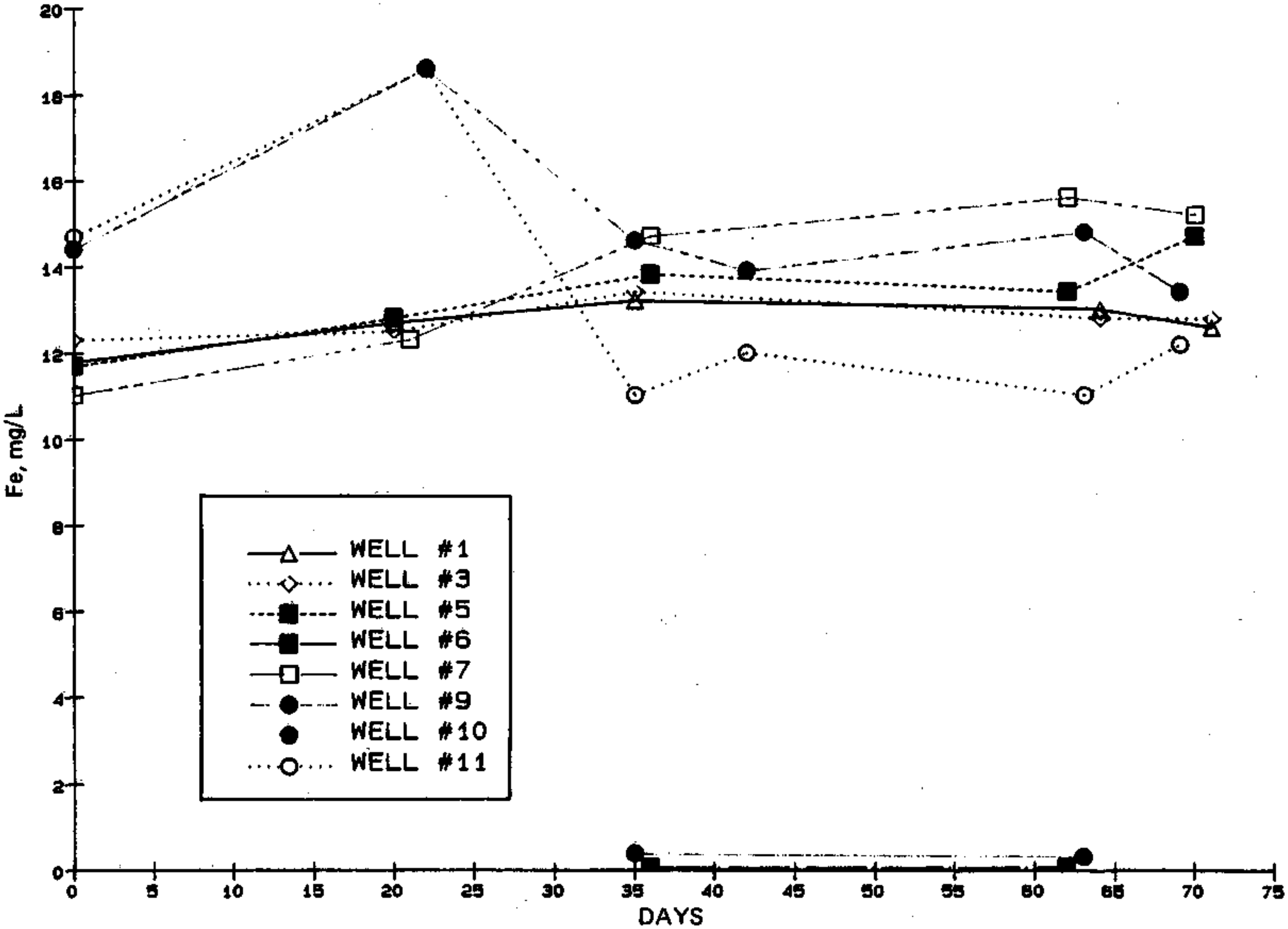

Figure 22. Plot of dissolved total iron concentrations in the monitoring wells around I-70 Well No. 3 (Refer to figure 13 for well locations) The elapsed days count from November 6, 1984.

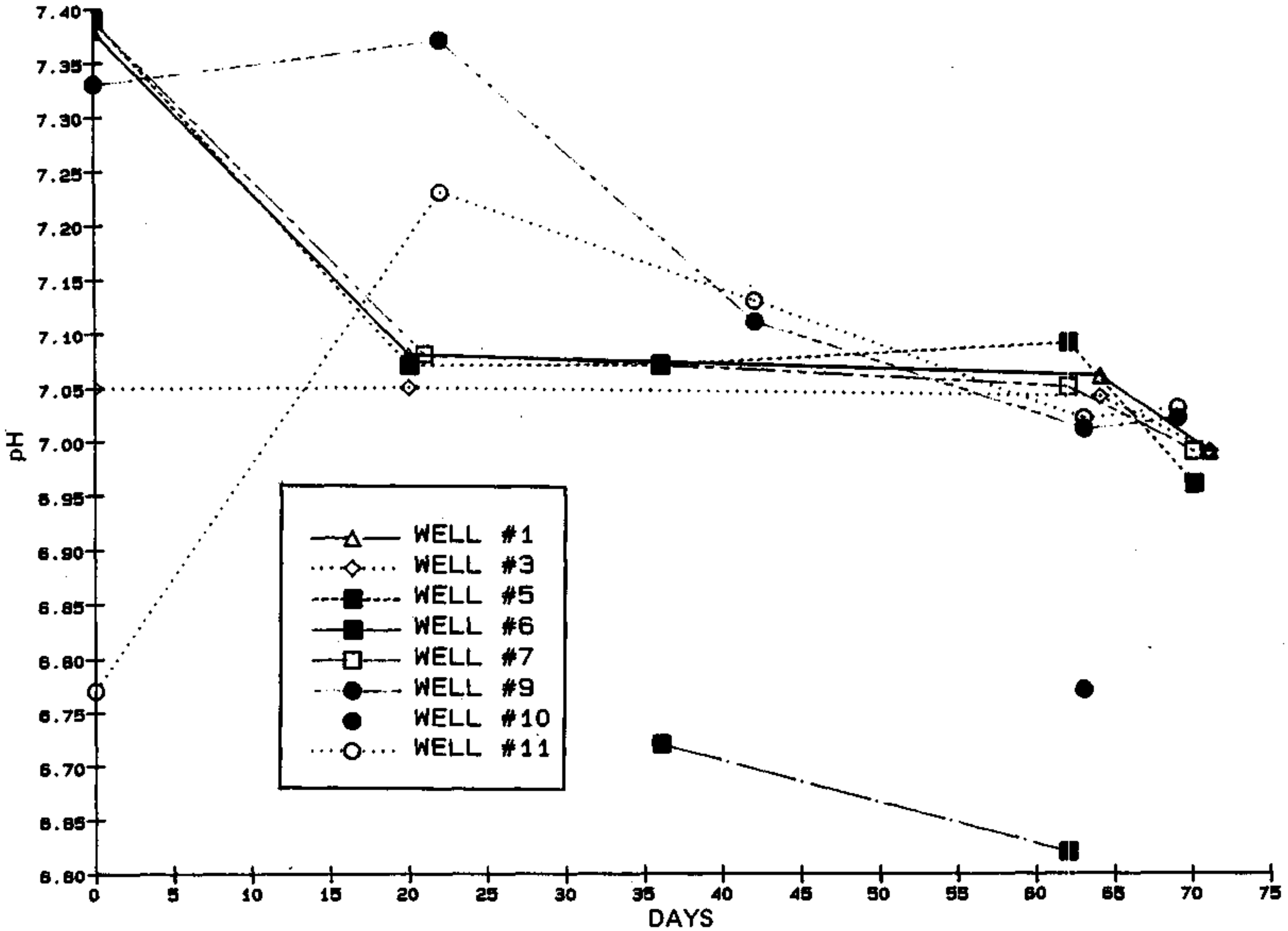

Figure 23. Plot of pH in the monitoring wells around I-70 Well No. 3
(Refer to figure 13 for well locations)
The elapsed days count from November 6, 1984.

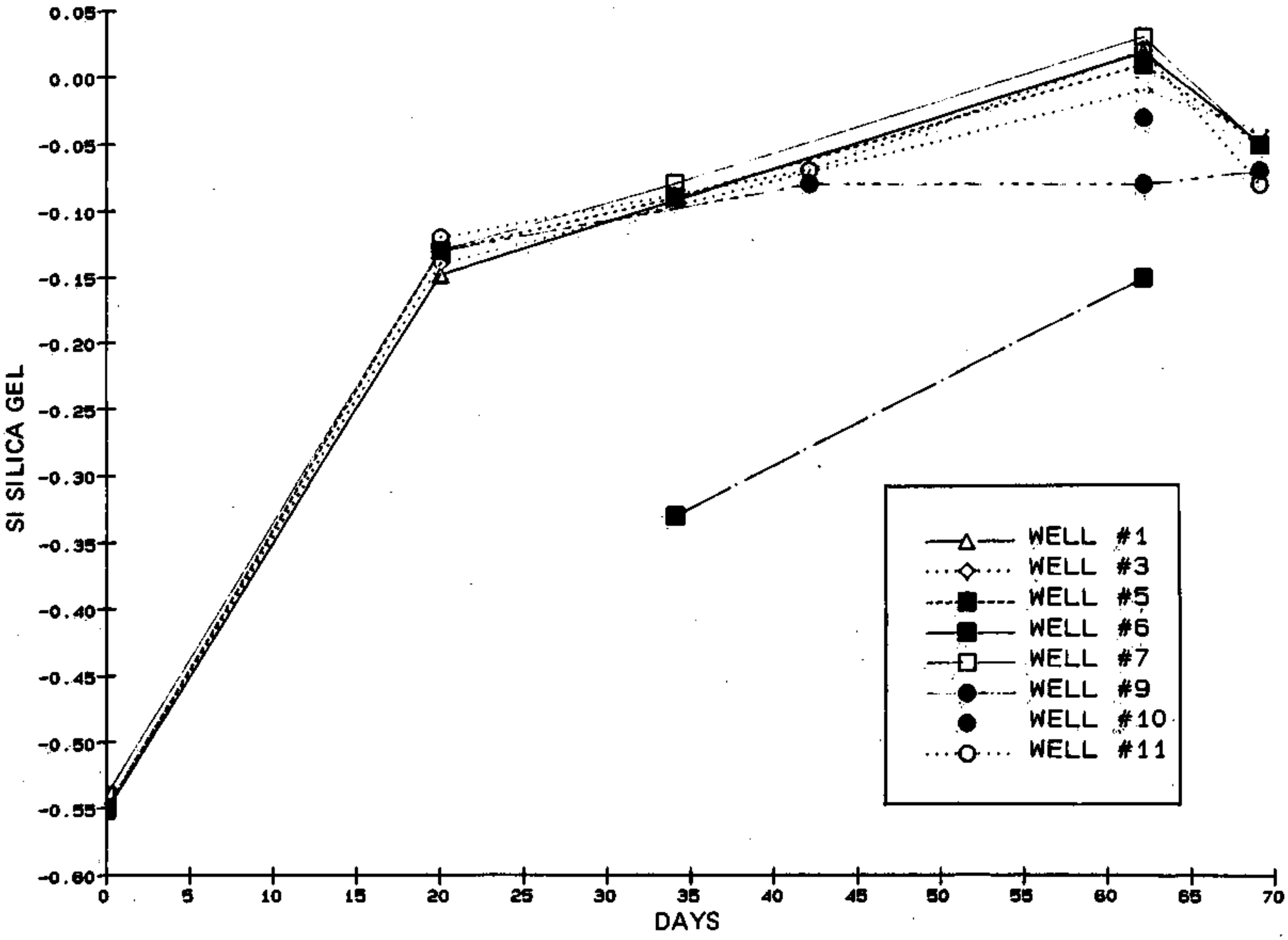

Figure 24. Plot of the Saturation Index for amorphous silica in the monitoring wells around I-70 Well No. 3 (Refer to figure 13 for well locations) The elapsed days count from November 6, 1984.

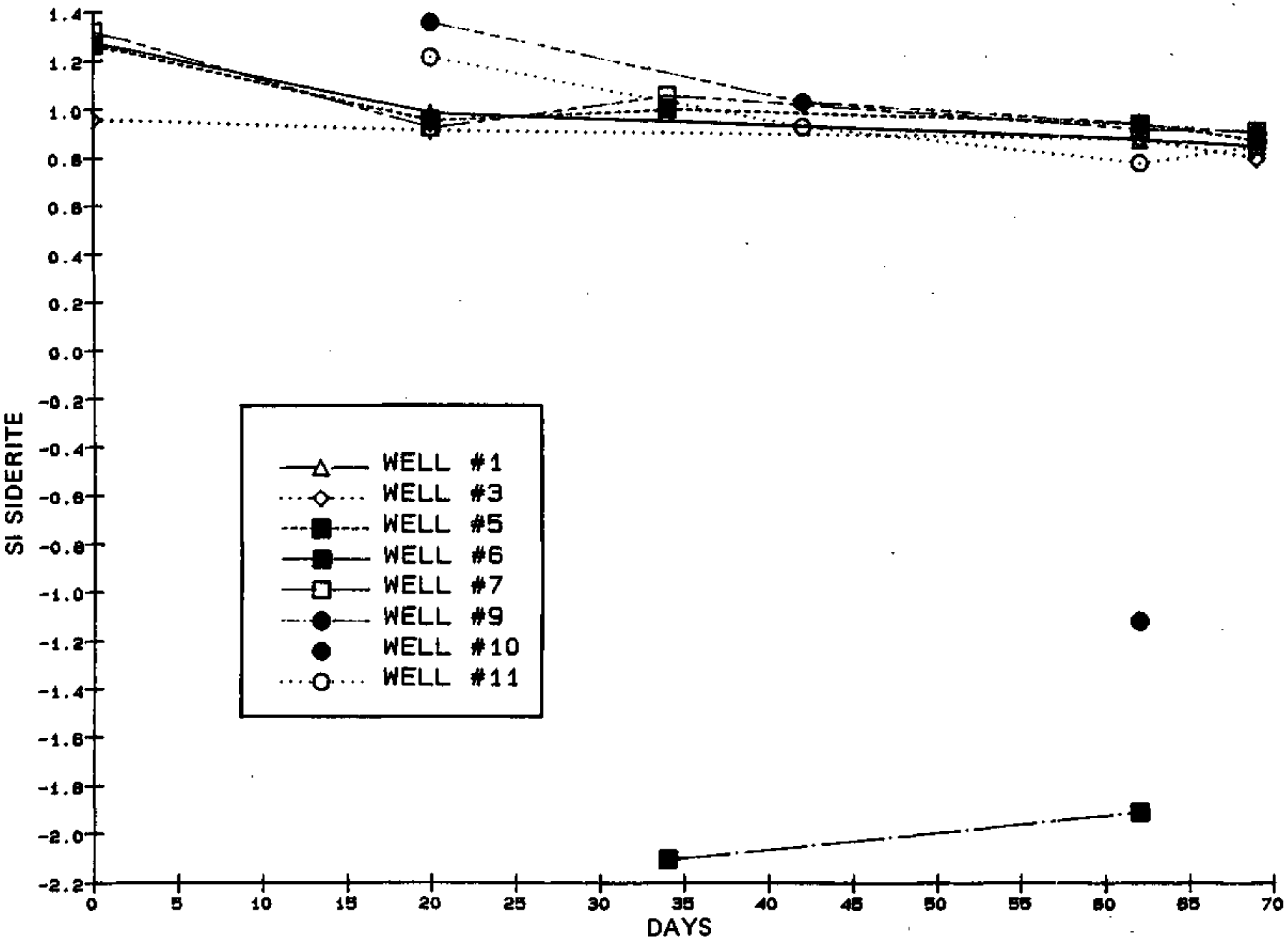

Figure 25. Plot of the Saturation Index for ferrous carbonate (siderite) showing the probable control of iron concentration by this mineral or an impure form. The well locations are given in figure 13. The elapsed days count from November 6, 1984.

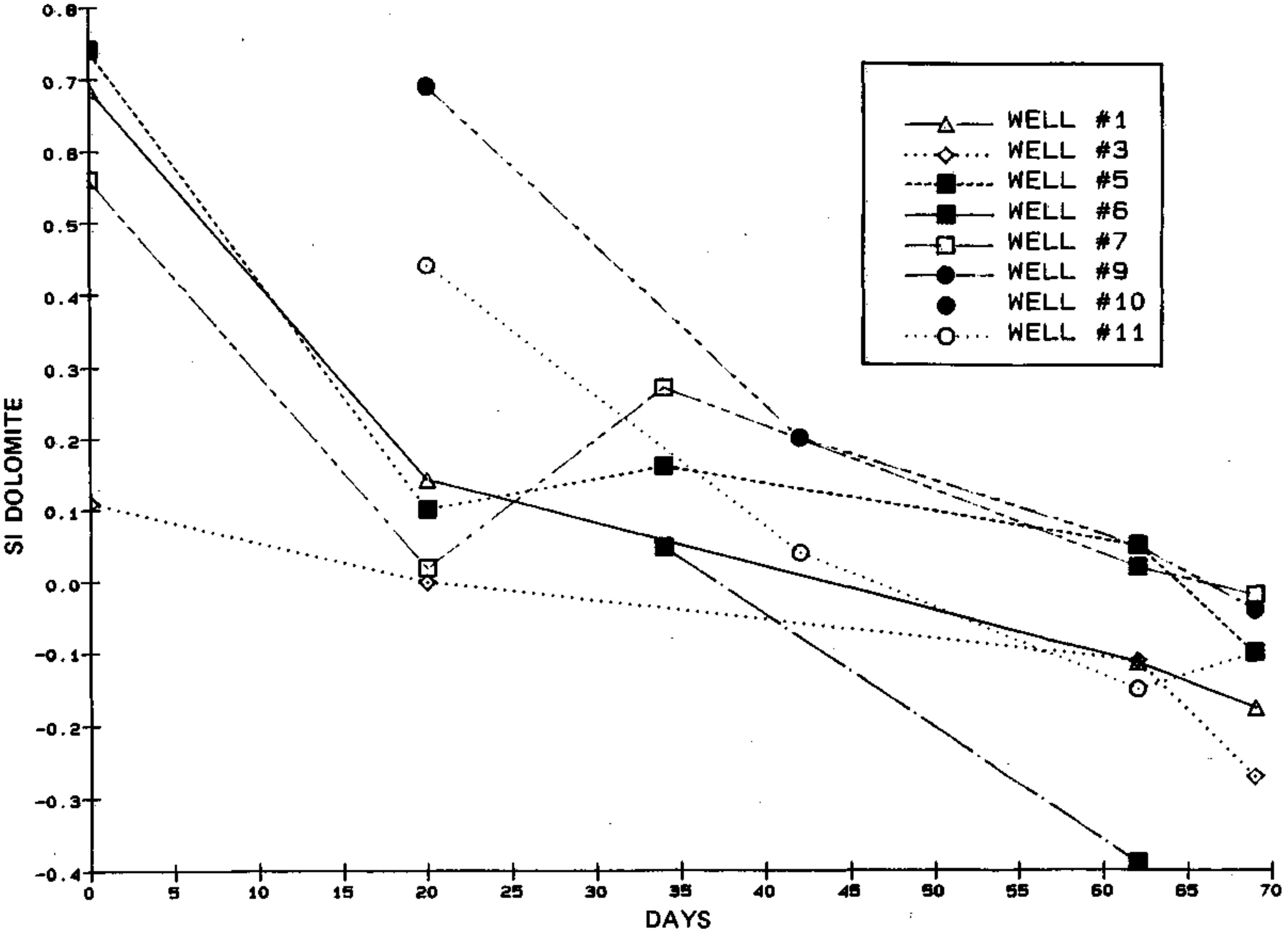

Figure 26. Plot of the Saturation Index for calcium-magnesium carbonate (dolomite) for the monitoring wells around I-70 Well No. 3 (see figure 13 for well locations) The elapsed days count from November 6, 1984.

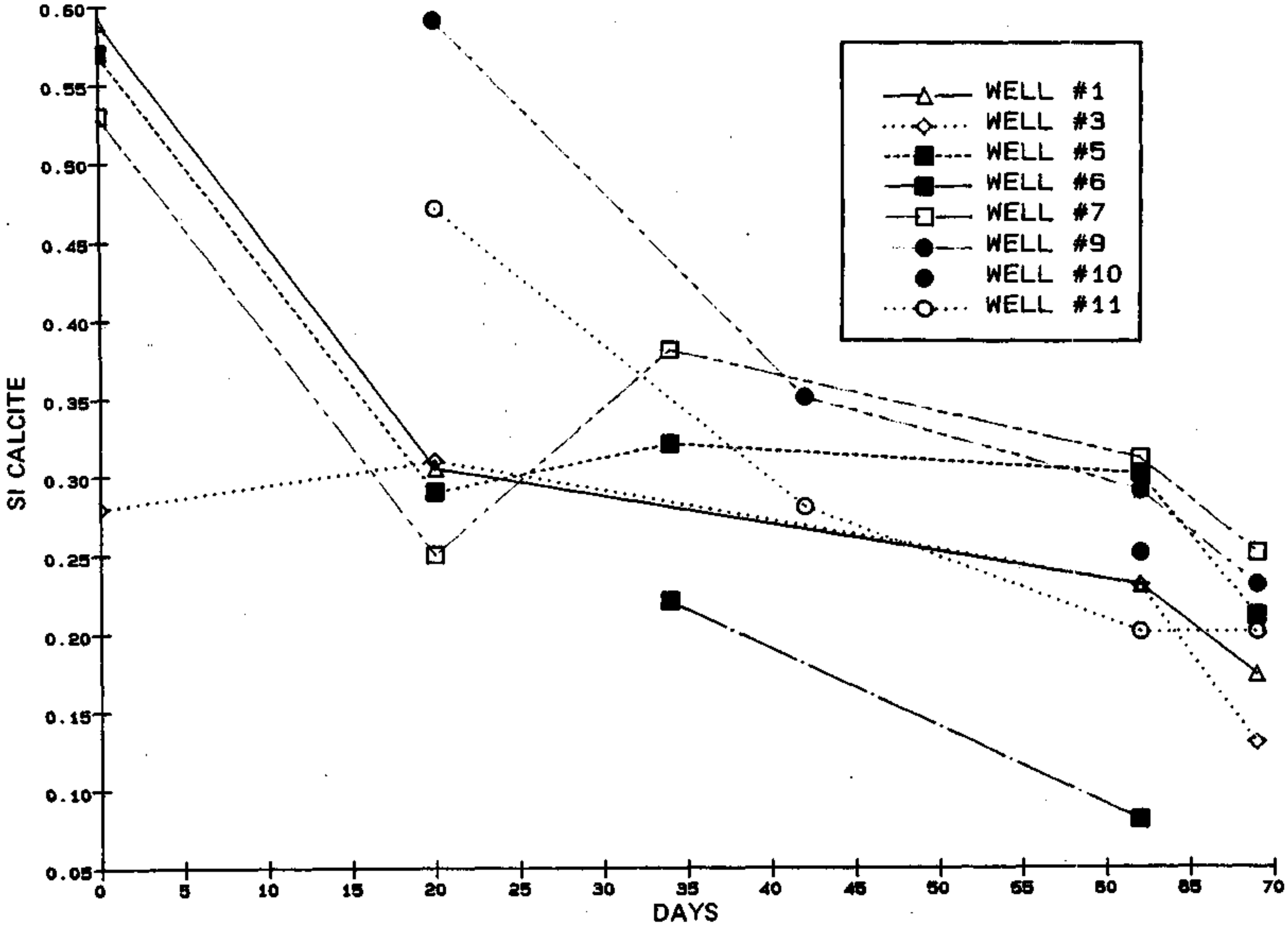

Figure 27. Plot of the Saturation index for calcium carbonate (calcite)
for the monitoring wells around I-70 Well No. 3
(see figure 13 for well locations)
The elapsed days count from November 6, 1984.

The saturation index data for silica gel indicates that there is available silica in the subsurface and that it places an upper limit on the concentration found in solution.

The siderite saturation state (SI_{SID}) in the deep monitoring wells is very consistent, which very strongly implies control of the iron concentration by dissolution/deposition of that mineral. The siderite saturation state is much lower in the more oxidizing conditions (more ferric iron relative to ferrous) of the shallow monitoring wells, where precipitation of very insoluble ferric hydroxide forms (lepidocrocite, amorphous forms, etc.) probably greatly reduces the iron concentration. Theoretically, SI_{SID} should be zero, and the observed data are consistently displaced above it. Plausible reasons for this could be 1) errors in the $FeCO_3(s)$ solubility constant; 2) solid solution substitution of another cation for ferrous iron, resulting in a more soluble mineral phase; or 3) the existence of unaccounted for ferrous iron complexes in solution, probably with silica or dissolved organic species. In any event, the apparent equilibrium with siderite would mean that changes induced by the dewatering well pump system - such as degassing of carbon dioxide with the resulting pH increase, pH changes caused by pressure drops, or any oxygenation - would provide a large potential for iron deposition.

The SI data for dolomite shows an approach to saturation equilibrium from oversaturation during the course of the field study. Whether this indicates actual precipitation or changes in chemistry related to recharge phenomena is not known. The saturation index data for calcite also indicates considerable oversaturation and the potential for deposition. The equilibrium constant for the solubility of pure calcite (as well as that for another more soluble crystal form, aragonite) is very good; therefore, a disequilibrium situation is indicated. Carbonate mineral saturation state interpretations are made very difficult from the potential of minerals such as calcite and dolomite to dissolve incongruently (to dissolve or precipitate independently of each other), and by the fact that in a dynamic non-equilibrium flow system the observed saturation states are very sensitive o the order and sequence of aquifer mineral materials and environments through which they pass (Freeze and Cherry, 1979; Palmer and Cherry, 1984). Calcite oversaturation can also be generated by rapid dissolution of trace amounts of gypsum, which is conceivable considering the sulfate concentrations in the area.

An examination of the filtered versus unfiltered data taken on November 26, 27, and 28, 1984, revealed that there was no significant difference (95% probability level) between the two types of samples. Thus, those constituents were probably in the dissolved state. There does seem to be a possibility that some particulate inorganic carbon might be present, when all of the very precise TIC and DIC analyses done throughout the project are considered. The particulate carbonate carbon would have to be associated with some metal, probably Ca, Mg, or Fe(II). However, the unfiltered metal samples were only taken on those three days, because the precision of their analysis, although fairly good, was just not adequate to indicate that they had the potential to generate data with a significance commensurate with the added effort involved.

CONCLUSIONS AND RECOMMENDATIONS

Condition of Wells

The detailed step tests have provided data that allow a comparison of the condition of the wells. As presented earlier in the field results, the data show that I-70 Well No. 5 and I-64 Well Nos. 10, 11, and 13 are all in good condition. The 30-minute specific capacities of these 4 wells on the dates of testing were all greater than 80 gallons per minute per foot of drawdown. The differences in water levels between the wells and piezometers were less than 3.2 feet (estimated at I-64 Well No. 11 because of the pumping rate adjustment to 600 gpm). Because of laminar flow conditions, a well loss (0.89 feet) could only be determined at I-70 Well No. 5 in this group of wells. While the well loss portion of the drawdown for this well in comparison with other wells in good condition is relatively high (13.6%), the other factors suggest its condition warrants only continued monitoring in the next year.

The I-70 Well Nos. 4 and 9, I-64 Well No. 3, and 25th Street Well No. 6 are all in moderately good condition. They have specific capacities of about 55 to 64 gpm/ft and drawdown due to well loss between 0.07 (the lowest calculated for any of the wells) and 0.52 feet, although laminar flow prohibited this calculation for I-70 Well No. 9. Due to plugged piezometers the water level difference between the wells and piezometers could be determined only for I-70 Well No. 9 (5.94 feet). Since I-64 Well No. 3 and 25th Street Well No. 6 are not in strategic locations and other wells at I-70 are in poorer condition than I-70 Well Nos. 4 and 9, rehabilitation work on any of these wells is not recommended at this time. However, their performance should be closely monitored.

Results of the step tests on I-70 Well Nos. 1, 8, 10, and 11 indicate they are all in poor condition. The specific capacities for these wells range from about 33 to 44 gpm/ft and the projected water level difference at the well discharge rate of 600 gpm was about 12.8 and 13.5 feet for I-70 Well Nos. 1 and 11. The differences at I-70 Well Nos. 8 and 10 could not be determined due to plugged piezometers. The drawdown due to well losses ranged from about 1.6 to 4.5 feet (greatest of the 12 wells tested in this phase of work) which accounts for 10 to 29% of the total drawdown. Well loss could not be determined on I-70 Well No. 1 because of laminar flow conditions. Because of their poor condition and strategic location in regard to the deep pumping cone, we recommend rehabilitation work on all 4 of these wells.

Flowmeters

Field testing of a portable, non-invasive ultrasonic flowmeter, PNUF, reveals that, in most cases, a relatively accurate indication of well pumping rates can be obtained in a timely fashion with this type of device. However, operational procedures and conditions inherent to effective use of this device and the delicate nature of certain components of the device warrant dedication of the instrument to one or two trained operators. We recommend purchase of a PNUF only if it is to be operated under this condition. A field demonstration of the device can be arranged for interested IDOT staff as part of the Phase 3 well evaluation tests, if desired.

Ground Water Chemistry

The tracer study indicated that the water flow path about the I-70 Well No. 3 was highly distorted and not as expected. The water levels and the flow paths were highly sensitive to the operation of the other wells in the field. The water levels in the shallow monitoring wells were much lower than expected. These factors, coupled with the inhomogeneity of the water quality about the production well, make it impossible to conduct sampling with pumping and flow conditions as controllable as was originally intended.

The inhomogeneity of the water quality may reflect both vertical and lateral differences in aquifer material composition and in chemical environment. The distortion of the flow paths suggests that the most efficient and effective data collection would be obtained by concentrating on the one direction (N-S) that is most direct, and adding more wells to cover the indicated vertical variability.

Some sensitivity to recharge volume might be indicated in the chemical data; thus, a study that would give a better indication of possible seasonal effects seems to be warranted.

Most of the analytical methods developed and applied to this study had precision and accuracy exceeding that normally expected from standard procedures; therefore, not much additional delineation of trends is possible by improvements in analytical procedures and taking replicate field samples. Several procedures do need additional effort to overcome certain interferences that remain unresolved.

The early computer modeling results provide an indication that some potentially important chemical relationships involving deposition potential can be defined. Following expansion of the SWS VAX computer system floating-point computation capability, a wider variety of geochemical models can be brought to bear on the problem. This can be coupled to further critical evaluation of literature on the solubility of potentially important minerals.

The chemical differences between the deep and shallow monitoring wells indicate that there could be considerable potential for incrustation in the upper part of the saturated zone at the saturated/unsaturated zone interface because of iron oxidation resulting from aeration. Whether or not the low iron concentrations in the zone represent post-deposition conditions, or a lack of mobilization of available iron as takes place under more reducing conditions at greater depths, can not be determined at present. The water analyses and modeling do indicate that there is a great potential for deposition of a variety of carbonate minerals, with only subtle changes in pH or redox conditions. These changes could conceivably be induced by the production well pump itself. If the deposition occurs away from the production well, the elucidation of probable deposition reactions would give a good clue as to the most appropriate rehabilitation techniques, and whether or not the problem will keep recurring.

Reliable samples could not be obtained from the production well for many constituents critical to the geochemical modeling. Further work is necessary to devise a representative sampling system, and to attempt to isolate what chemical changes in the water might be induced by the pump, and how that would relate to the depositional tendency of the water as estimated by the samples from the closest monitoring wells.

Well Rehabilitation

The ground water chemistry study, while not conclusive, verifies that the water is very unstable and that there is a great potential for deposition of a variety of carbonate minerals including calcite and siderite. Interpretation of the step test data suggests that because of the linear relationships of Ah versus well discharge, the chemical deposition is probably taking place within five feet of the well. A likely location is at the aquifer-gravel pack interface. The amount of incrustation and its relationship to well operation schedules cannot be determined from the investigation conducted thus far. It is hoped that the well rehabilitation work scheduled to begin in Phase 3 will allow conclusions to be drawn about the proper quantities and sequence of chemical treatments to assure maximum and lasting restoration of well capacity.

It is suggested that the four wells recommended for rehabilitation work in this phase be treated at the same time, by the same contractor, as three of the wells recommended for rehabilitation work from Phase 1. Documentation of the procedures during the field work, followed by controlled step tests, is recommended to begin proper assessment of the rehabilitation techniques employed. Close monitoring of these wells with time will also be important to learn how long the restored capacity is maintained.

Rehabilitation work on other wells is not recommended until step tests have been conducted and analyzed to confirm their present condition. Depending upon the results of the rehabilitation work on the first seven wells, similar procedures may be recommended or other contractors may be utilized to demonstrate their rehabilitation techniques. Careful investigation and documentation of the various treatment methods together with post-treatment monitoring will result in a treatment technique known to provide good results under most conditions. This information will be invaluable in maintaining the dewatering system.

Future Investigations

A program of continued investigation of the condition of additional dewatering wells is recommended. Comparison of the water level differences recorded during the controlled step tests with the historical water level differences reported during routine monitoring indicates that other wells may also need rehabilitation. However, a blanket inference of that need based on present data is not warranted. Based on this comparison, step tests are recommended to properly assess the condition of the following wells:

I-70 Well No.:
6

I-64 Well Nos.:
2, 4, 12

25th Street Well Nos.:
3, 10

A total of 26 dewatering wells have been step-tested as part of Phases 1 and 2. Most of the remaining untested wells are located in less strategic positions in regard to the deepest part of the pumping cone with the exception of I-70 Well No. 6. The remaining untested wells can be considered for future testing in the next one or two summers until all 48 dewatering wells have been step-tested once. Any of the previously tested and/or rehabilitated dewatering wells suspected of developing a deterioration problem can easily be retested as part of this program. Consideration should also be given to step-testing any replacement dewatering well(s) constructed. Such testing will help evaluate the effectiveness of the contractor's development of the well and the "as new" condition of the well for future reference.

BIBLIOGRAPHY

Arceneaux, W. 1974. Operation and maintenance of wells. Journal, American Water Works Association, March.

Bergstrom, R.E., and T.R. Walker. 1956. Ground-water geology of the East St. Louis area, Illinois. Illinois State Geological Survey Report of Investigation 191.

Collins, M.A., and S. Richards. 1986. Groundwater levels and pumpage in the East St. Louis area, 1978-1980. Illinois State Water Survey Circular 165.

Cowan, J.C., and D.J. Weintritt. 1976. Water-formed scale deposits. Gulf Publishing Company.

Downes, M.T. 1978. An automated determination of low reactive phosphorus concentrations in natural waters in the presence of arsenic, silicon, and mercuric chloride. Water Research, 12:743.

Emmons, J.T. 1979. Groundwater levels and pumpage in the East St. Louis area, Illinois, 1972-1977. Illinois State Water Survey Circular 134.

Freese, R.A., and J.A. Cherry. 1979. Groundwater. Prentice-Hall, Englewood Cliffs, N.J., 604 pp.

Garske, E.E., and M.R. Schock. 1986. An inexpensive flow-through cell and measurement device for monitoring selected ground water chemical parameters. Ground Water Monitoring Review, Summer.

Jacob, C.E. 1947. Drawdown tests to determine effective radius of artesian well. Transactions American Society of Civil Engineers, v. 72.

John Mathes and Associates, Inc. 1981. Venice subway FAUS Report 8807 Section 27T, Madison County, Illinois, Job No. P-98-041-79. Consultant's report to the Division of Highways.

Johnson, Depp, and Quisenberry. 1980. Venice subway dewatering. Consultant's report to the Division of Highways.

Larson, T.E. 1955. Report on loss of carrying capacity of water mains. Journal, American Water Works Association, November.

Larson, T.E., and A. M. Buswell. 1942. Calcium carbonate saturation index and alkalinity interpretations. Journal, American Water Works Association, November.

Layne-Western Company, Inc. 1972. Ground water drainage system F.A.I. Route 70 Tri-level location, East St. Louis, Illinois. Consultant's report to the Division of Highways.

McClelland Engineers, Inc. 1971. Highway I-70 drainage system at Tri-Level Bridge, East St. Louis, Illinois. Consultant's report to the Division of Highways.

Merrill, D.T., and R.L. Sanks. 1977. Corrosion control by deposition of $CaCO_3$ films, Part 2. Journal, American Water Works Association, December.

Mogg, J.L. 1973. Corrosion and incrustation guidelines for water wells. Water Well Journal, March.

Moss, R., Jr. 1966. Evaluation of materials for water well casings and screens. Proceedings, National Association of Corrosion Engineers Western Region Meeting, October.

Palmer, C.D., and J.A. Cherry. 1984/1985. Geochemical evolution of groundwater in sequences of sedimentary rocks. Journal Hydrol., 75:27.

Parkhurst, D.L., et.al. 1980. PHREEQUE - A computer program for geochemical calculations. U.S. Geological Survey, WRI 80-96, 210 pp.

Ritchey, J.D., R.J. Schicht, and L.S. Weiss. 1984. Groundwater level analysis by computer modeling--American Bottoms groundwater study. Illinois State Water Survey Contract Report 352A-E.

Rorabaugh, M.I. 1953. Graphical and theoretical analysis of step drawdown test of artesian well. Proceedings American Society of Civil Engineers, v. 79, Separate No. 362.

Runnells, D.D., and R.D. Lindberg. 1981. Hydrogeochemical exploration for uranium ore deposits: use of the computer model WATEQFC. Journal of Geochemical Exploration, vol. 15, no. 37.

Rupani, N. 1976. Highway I-55 & 70 and I-64 deep drainage system at Tri-Level Bridge in East St. Louis, Illinois. Division of Highways file report.

Ryznar, J.W. 1944. A new index for determining amount of calcium carbonate scale formed by a water. Journal, American Water Works Association, April.

Sanderson, E.W., A.P. Visocky, M.A. Collins, R.D. Olson, and C.H. Neff. 1984. Dewatering well assessment for the highway drainage system at four sites in the East St. Louis area, Illinois (Phase 1). State Water Survey Contract Report 341.

Saner, J.L. 1976. Corrosion study of East St. Louis dewatering wells. Bureau of Materials and Physical Research Report.

Schicht, R.J. 1965. Ground-water development in the East St. Louis area, Illinois. Illinois State Water Survey Report of Investigation 51.

Skougstad, M.W. et al. 1978. Methods for analysis of inorganic substances in water and fluvial sediments. U.S. Geological Survey Open-File Report 78-679, 1005 pp.

Standard methods for the examination of water and wastewater. 1985. 16th Edition, APHA-AWWA-WPCF, 1268 pp.

Stauffer, R.E. 1983. Determination of arsenic and phosphorous compounds in ground water with reduced molybdenum blue. Analytical Chemistry, 55:1205-1210.

Theis, C.V. 1935. The relation between the lowering of piezometric surface and the rate and duration of discharge of a well using ground-water storage. Transactions, American Geophysical Union 16th Annual Meeting, pt. 2.

U.S. Environmental Protection Agency. 1979. Methods for chemical analysis of water and wastes, EPA 600/4-79-020, 460 pp.

Walton, W.C. 1962. Selected analytical methods for well and aquifer evaluation. Illinois State Water Survey Bulletin 49.

A NOTE CONCERNING APPENDICES A, B, AND C

Three appendices to this report have been compiled. Appendix A provides the water level and pumping rate measurements collected during each of the step tests; Appendix B gives the results of chemical analyses on water samples collected near the end of each step test; and Appendix C provides the chemical analyses of samples collected from the monitoring wells at I-70 Well No. 3.

These three appendices have been printed under separate cover as Illinois State Water Survey Contract Report 424A. A limited number of copies is available and may be obtained by writing to the Illinois State Water Survey, Ground-Water Section, 2204 Griffith Drive, Champaign, Illinois 61820, or by calling (217) 333-8888.