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Dewatering Well Assessment for the Highway Drainage System at Four Sites in the East St. Louis Area, Illinois

(FY00 - Phase 17)

by

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Prepared for the
Illinois Department of Transportation
Division of Highways

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Illinois State Water Survey
Groundwater Section
Champaign, Illinois

A Division of the Illinois Department of Natural Resources

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

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Abstract

In the East St. Louis vicinity, the Illinois Department of Transportation Division of Highways (IDOT) owns 56 high-capacity wells that are used to maintain the elevation of the groundwater table below the highway surface in areas in which the highways were constructed below the original land surface. The dewatering systems are located at five sites in the alluvial valley of the Mississippi River in an area known as the American Bottoms. The alluvial deposits at the dewatering sites are about 90 to 115 feet thick and consist of fine sand, silt, and clay in the upper 10 to 30 feet, underlain by about 70 to 100 feet of medium to coarse sand.

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. Since 1983, IDOT and the Illinois State Water Survey have conducted a cooperative investigation to more adequately assess the operation and condition of the wells, to attempt to understand the probable causes of well deterioration, and to evaluate rehabilitation procedures used on the wells.

Work scheduled for FY 00 (Phase 17) included conducting 18 condition-assessment and posttreatment step tests, monitoring of the chemical treatment of 11 wells, and observing and documenting the construction of 2 new (replacement) dewatering wells. Of the 18 step tests conducted, 11 were post-chemical-treatment step tests, 5 were routine condition assessment step tests on existing wells, and 2 were condition assessments on newly constructed wells.

The results of the five condition assessment step tests indicated specific capacities ranging from 25.1 to 65.2 gallons per minute per foot (gpm/ft), corresponding to very poor to fair well conditions, respectively. It was recommended that all five wells be chemically treated in FY01.

Posttreatment step tests were used to help document the rehabilitation of 11 dewatering wells during FY 00 (Phase 17): I-70 Wells 2A and 8A; 25th Street Wells 2, 3, 4, 5, 7, 8, and 9; and Missouri Avenue Wells 2 and 3. Chemical treatments used to restore the capacity of these seven wells were moderately successful. There was a wide range of improvement in specific capacity per well, ranging from 2 percent to 503 percent improvement, and averaging 124 percent based on specific-capacity data from pre- and posttreatment step tests.

A sand pumpage investigation, which was conducted during 15 of the 18 step tests during FY 00, revealed that 25th Street Wells 2, 3, and 4 were pumping sand. These conditions may pose a threat to the long-term operation of these wells, especially 25th Street Well 4. Smaller amounts of sand were found following the step test for 25th Street Wells 2 and 3.

Introduction

Background

The Illinois Department of Transportation (IDOT) Division of Highways operates 56 high-capacity water wells at five sites in the East St. Louis area. The wells are used to control and maintain groundwater levels at acceptable elevations to prevent depressed sections of interstate and state highways from becoming inundated by groundwater. When the interchange of Interstates I-55/I-70 and I-64 was originally designed, groundwater levels were at lower elevations because of large withdrawals by area industries. Due to a combination of water conservation, production cutbacks, and conversion from groundwater to river water as a source, industrial groundwater withdrawals have decreased at least 50 percent since 1970 (Schicht and Buck, 1995). As a result, groundwater levels in many areas have recovered to early development levels, which exacerbates IDOT's need to keep groundwater levels below the areas of depressed highways.

In October 1982, IDOT asked the Illinois State Water Survey (ISWS) to begin an investigative study to learn more about the condition of the dewatering wells, to determine efficient monitoring and operating procedures, to determine suitable methods of well rehabilitation, and to document well rehabilitation procedures and outcomes.

Previous Reports

Several ISWS publications document the dewatering well assessment activities since the ISWS has been involved. Phases 1-12, which document project activities corresponding to fiscal years (FYs) 1984-1995, respectively, are contained in the reports listed below. Sanderson and Olson (1999) provide a brief (approximately one paragraph) description of the scope of work for each of these phases on previous years' studies. A historical summary of dewatering development, including discussion of earlier dewatering systems that failed, also is provided.

Listing of Previous Years Dewatering Well Assessment Reports by Year

Phase 1 - Sanderson et al., 1984
Phase 2 - Sanderson et al., 1987
Phase 3 - Olson et al., 1990
Phase 4 - Wilson et al., 1990
Phase 5 - Wilson et al., 1991
Phase 6 - Olson et al., 1992
Phase 7 - Sanderson et al., 1993
Phase 8 - Sanderson and Olson, 1993
Phase 9 - Olson and Sanderson, 1997
Phase 10 - Sanderson and Olson, 1998
Phase 11 - Sanderson and Olson, 1999
Phase 12 - Olson and Sanderson, 2000
Phase 16 - Anliker and Olson, 2000

Scope of Report

The scope of this report is to present a summary of the field activities, the data collected, and an analysis of these data for the FY 00 phase of this ongoing study.

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 (Figure 1). The geology of the area consists of alluvial deposits overlying limestone and dolomite of the Mississippian and Pennsylvanian Age. 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 groundwater hydrology of the area is well documented (Bergstrom and Walker, 1956; Schicht, 1965; Collins and Richards, 1986; Ritchey et al., 1984a-e; Kohlhase, 1987; Schicht and Buck, 1995). Except where it is diverted by pumpage or drainage systems, groundwater generally flows from the bluffs toward the river.

Detailed location maps of the five dewatering sites operated by IDOT are shown in Figures 2-4. The geology at these sites is consistent with regionally mapped conditions. The land surface lies at about 410 to 415 feet above mean sea level (ft-msl). Alluvial deposits are about 90 to 115 feet thick, which corresponds to a bedrock surface at approximately 300 to 320 ft-msl. The alluvium becomes progressively coarser with depth. The uppermost 10 to 30 feet of the alluvium consists of extremely fine sand, silt, and clay, underlain by the aquifer, which is about 70 to 100 feet thick. The elevation of the top of the aquifer is about 390 to 395 ft-msl.

Individual Well Systems

I-70 System

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

A recorder well, 8 inches in diameter and constructed of stainless steel casing and screen, was included in the well dewatering system to monitor groundwater levels near the critical (i.e., lowest) elevation of the highway. A Leupold-Stevens Type F recorder is in use. Additionally, 2-inch-diameter piezometers with 3-foot-long screens were placed about 5 feet from each

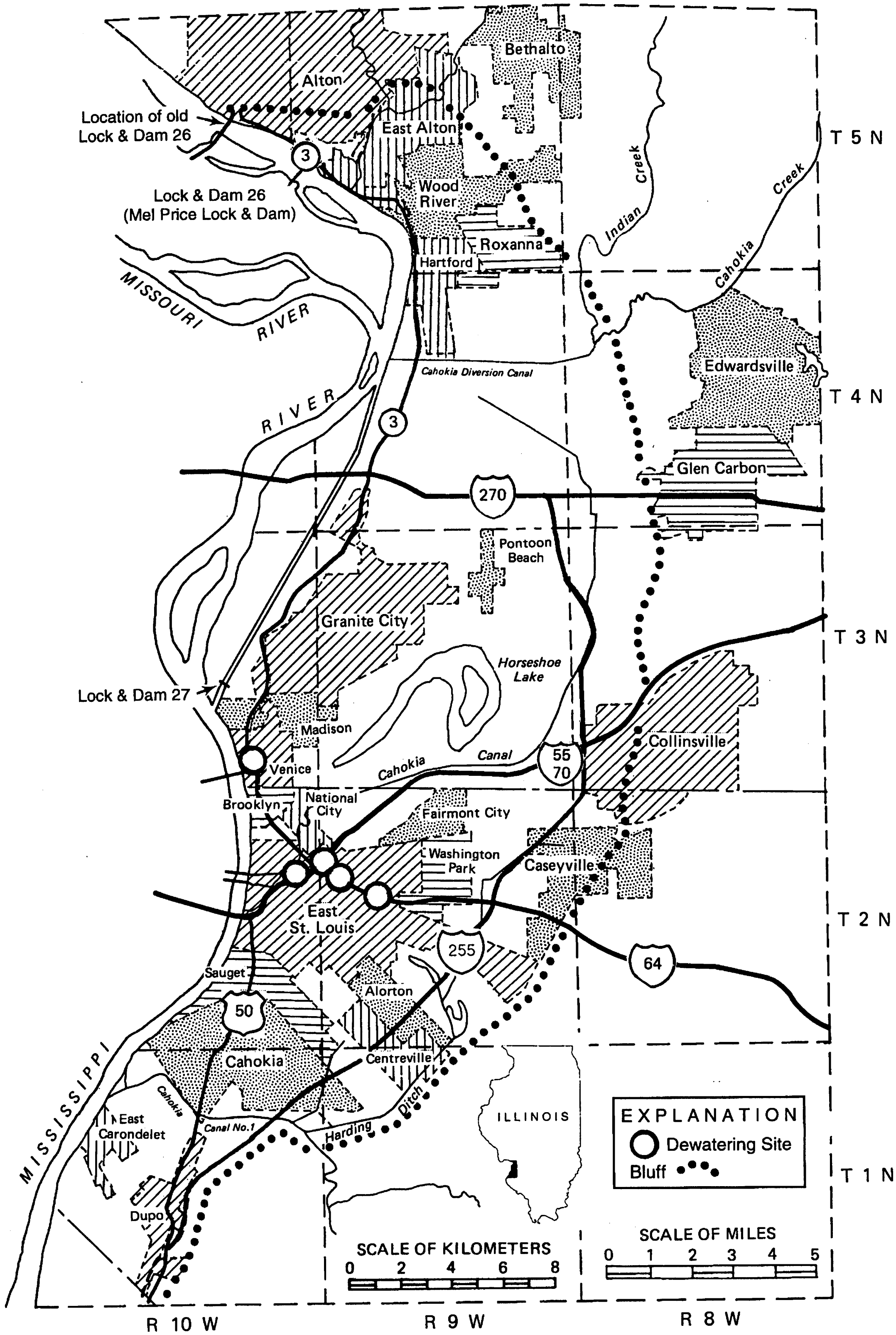

Figure 1. Location of the East St. Louis area

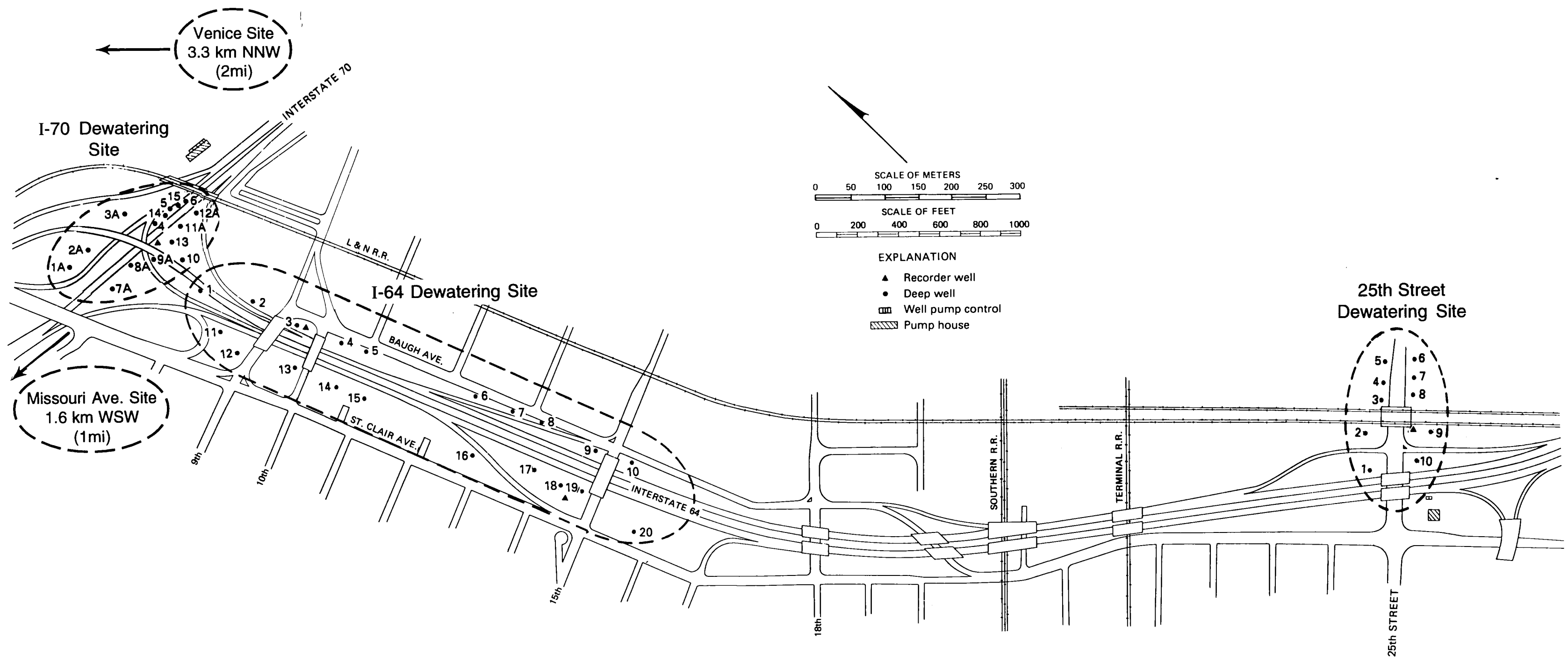

Figure 2. Locations of dewatering wells at the I-70 Tri-Level Bridge, I-64, and 25th Street

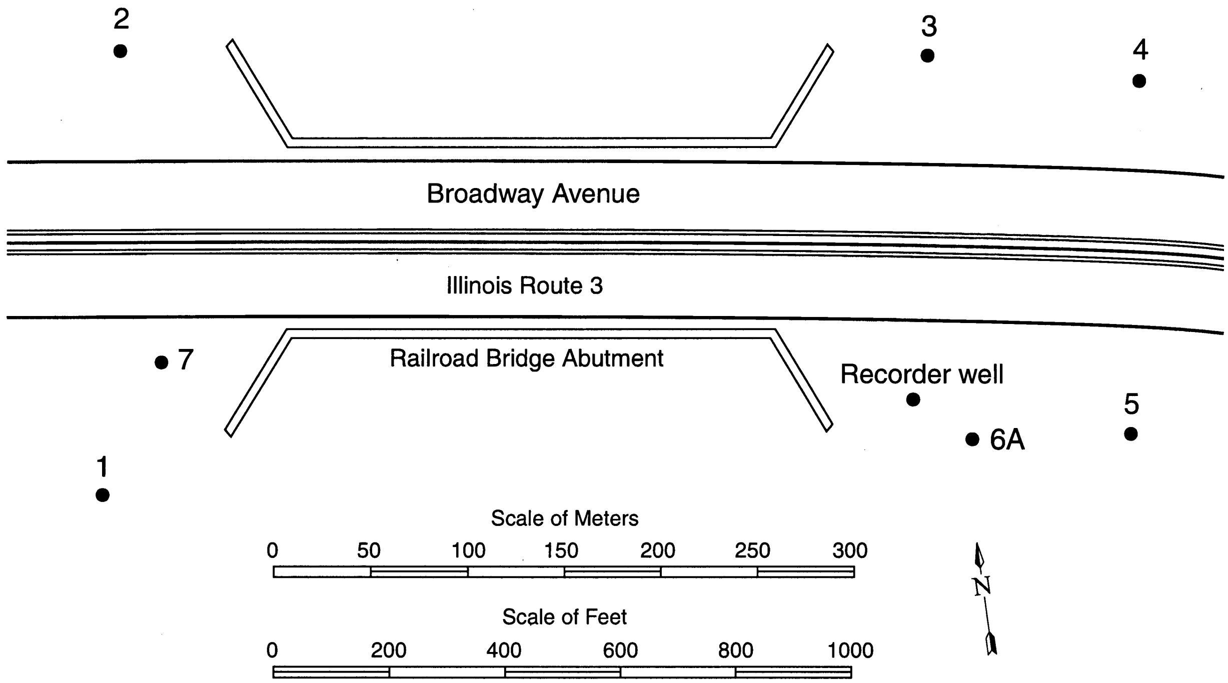

Figure 3. Locations of dewatering wells at the Venice Subway (Illinois Route 3)

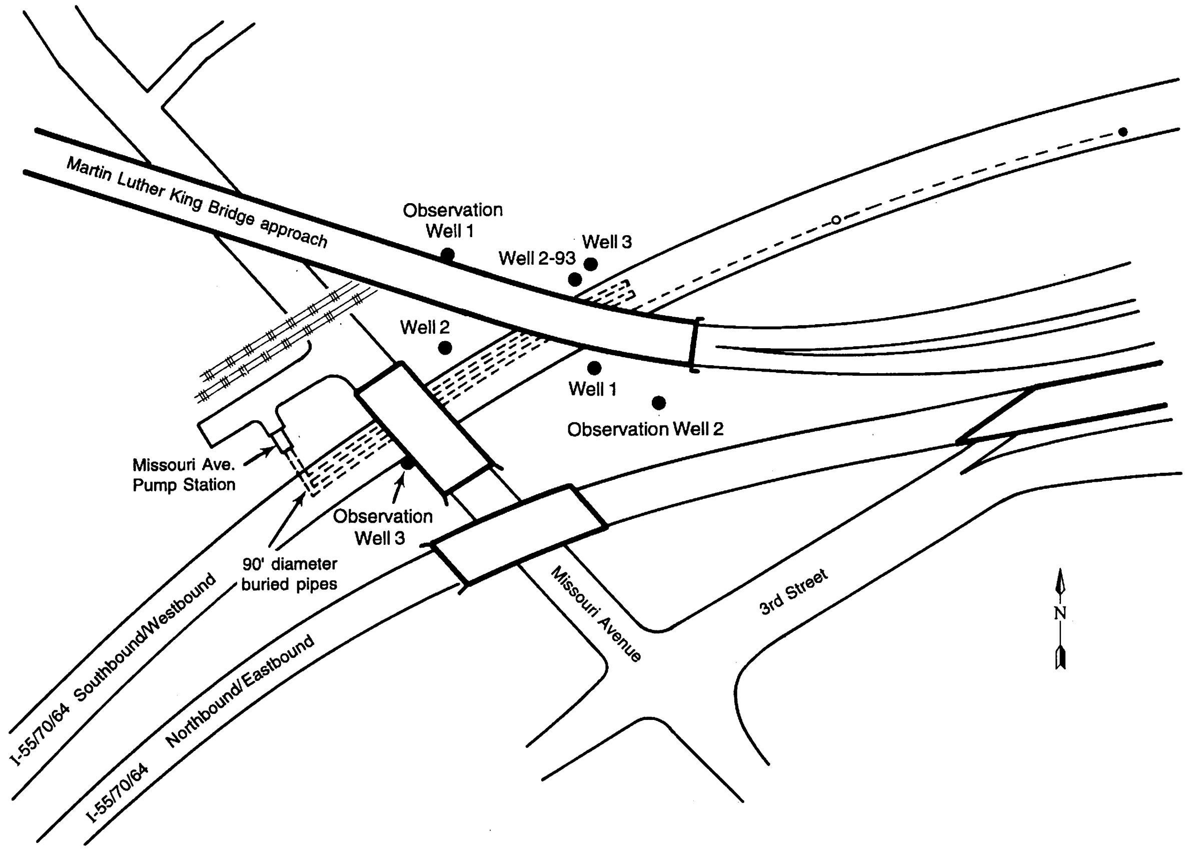

Figure 4. Locations of dewatering wells at Missouri Avenue

dewatering well to depths corresponding to the upper third point of each dewatering well screen. These piezometers provide information on groundwater levels and monitor the performance of individual wells by measuring water-level differences between the wells and the piezometers.

In the late 1970s, the exit ramp from the I-64 westbound lanes onto the I-55/I-70 northbound lanes was relocated, necessitating the abandonment of I-70 Well 12. Replacement Well 12A then was constructed at a nearby location using components similar to those in the original wells. The well screen in I-70 Well 7 reportedly failed in the 1970s, and an attempt was made to rehabilitate the well by inserting a new screen inside the old screen. The well's pumping capacity remained unsatisfactory following this modification, so the well was used only on an emergency basis until it was replaced in 1986. The replacement well (Well 7A) was constructed using components similar to those used in the original wells, with the exception of a continuous-slot well screen designed on the basis of the sieve data from the nearest original test boring (Wilson et al., 1990).

In late 1986, loss of gravel pack was discovered at I-70 Well 9, and subsequent investigation revealed pumpage of fine sand, apparently from the upper 5 to 10 feet of well screen. In 1987, sand pumpage also was discovered at I-70 Wells 2 and 8 and at Venice Well 6. Replacement wells were constructed in spring 1989 for I-70 Well 8 (now Well 8A) and I-70 Well 9 (now Well 9A). Continuous-slot well screens also were used in these wells as in I-70 Well 7A (Olson et al., 1992).

In 1990 (FY 91), two more wells were added at the I-70 site to provide greater flexibility in operation, maintenance, treatment, and repair of the other wells at the site. These wells (I-70 Wells 13 and 14) were located on either side of the eastbound lanes of I-55/I-70 near the lowest point of the highway. The wells were similar in construction to the replacement wells (Wells 7A, 8A, and 9A) drilled in 1987 and 1989.

In 1991 and 1992 (FY 92), four replacement wells and one new well were added to the I-70 site. Because of various sand pumpage, settlement, and potential operational problems, replacement wells were constructed for Wells 1, 2, 3, and 11 (new Wells 1A, 2A, 3A, and 11A). The new well (Well 15) was placed between Wells 5 and 6. The wells were similar in construction to the new wells drilled in 1987, 1989, and 1990.

I-64 System

The western terminal of I-64 joins I-70 at the Tri-Level Bridge site. A 2,200-foot stretch of this highway also is constructed below the original land surface as it approaches the Tri-Level Bridge site. To maintain groundwater levels along I-64, a series of 20 wells was added to the dewatering system (I-64 site). The wells were built in 1975 and are essentially identical to the original wells constructed for the Tri-Level Bridge site.

25th Street System

About 6,200 feet southeast of the Tri-Level Bridge, at the interchange with I-64, 25th Street in East St. Louis was designed to pass below the interstate highway and adjacent railroad tracks. As a result, the 25th Street pavement is about 3.5 feet below groundwater levels. Ten wells were installed in 1975 to control groundwater levels at the 25th Street site. These wells are identical in design to the original I-70 wells. Pumps installed in the wells along I-64 and at 25th Street have a nominal pumping capacity of 600 gpm. Two 8-inch-diameter observation wells, located near each end of the depressed section of I-64, are used to monitor groundwater levels. An 8-inch-diameter observation well also was 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 to monitor performance at the installation.

Venice System

Approximately 2¼ miles north of the I-70 Tri-Level Bridge, Illinois Highway 3 passes beneath the Norfolk and Western, Illinois Central Gulf, and Conrail railroad tracks. When the highway was constructed, groundwater 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 groundwater levels resulting from 3 to 4 months of continuous flood stage in the Mississippi River (about 2,000 feet west). Subsequent investigation showed deterioration of the drainage system, and the consultants recommended installation of six wells to control groundwater levels at the site (Johnson, Depp, and Quisenberry, 1980). The wells were installed in 1982. They are 16 inches in diameter with 50 feet of well screen, 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.

Problems were encountered with Venice Well 6 after chemical treatment in FY 88 (Phase 5). The well pumped sand formation and gravel-pack particles, indicating a possible split or weld failure of the well screen or well casing. Replacement Well 6A was drilled, and a new Well 7 was added at the Venice site in FY 91 (Phase 8). District highway staff considered the additional well desirable because of operational problems maintaining appropriate groundwater levels in 1984 when the Mississippi River was at high stages for several months. The wells are similar in construction to the original wells at this site.

Missouri Avenue System

During the spring and summer of 1993, the Mississippi River was at flood elevations for an extended period. Just east of the Martin Luther King Bridge near downtown East St. Louis beneath the southbound/westbound lanes of I-55/I-64/I-70, two large-diameter, stormwater detention structures were found to be subject to failure due to excessive infiltration of groundwater and piping of foundation material into the structures. The IDOT engineers contracted, on an emergency basis, for the construction of four high-capacity dewatering wells to draw down the high groundwater levels at the stormwater structures to help minimize the chance for their failure. Three wells are now equipped with 1,200- to 1,500-gpm well pumps and are in regular use. The fourth well (Well 2-93) is capped and remains available as an alternate for nearby Well 3.

Summary

The highway dewatering operation in the American Bottoms consists of 56 individual dewatering wells finished in the water-bearing sand-and-gravel aquifer. Usually, about one-third of the wells operate simultaneously. The wells are distributed at five sites as follows:

I-70 (Tri-Level Bridge)	-	15 wells
I-64	-	20 wells
25th Street	-	10 wells
Venice (Route 3)	-	7 wells
Missouri Avenue	-	4 wells

The wells are of similar construction, generally with 16-inch-diameter stainless steel casings and screens (Figure 5). The IDOT's early experience with severe corrosion problems showed that corrosion-resistant materials are required to maximize service life. Except for the Missouri Avenue site, each well is equipped with a 600-gpm submersible pump with bronze impellers, bowls, jacket motors, and a 6-inch-diameter stainless steel column pipe. Five 8-inch-diameter recorder wells are available to monitor groundwater elevations near critical locations at these four sites. Most of the 56 wells have a 2-inch-diameter piezometer nearby to help monitor individual well performance. The wells at Missouri Avenue are equipped with 1,200- to 1,500-gpm pumps with Niresist© impellers and bowls, stainless steel jacket motors, and 6- to 8-inch-diameter stainless steel column pipes. One 2-inch-diameter piezometer is measured periodically to monitor groundwater elevations at the site.

Acknowledgments

This phase of the assessment of the condition of the highway dewatering well systems in the American Bottoms was funded by IDOT, Kirk Brown, Secretary. Barry Roberts, Pump Technician, District 8, reviewed and coordinated the investigation. He and maintenance personnel provided field support during step-drawdown tests on the selected wells.

Analytical work by the ISWS Analytical Chemistry and Technology Unit was performed under the direction of Kent Smothers, with Brian Kaiser, Lauren Sievers, and Daniel Webb performing the lab analyses. Eva Kingston edited the manuscript, Linda Hascall prepared the illustrations, and Pamela Lovett provided word processing support. Steve Burch and Ken Hlinka reviewed the manuscript for technical content.

Any opinions, findings, and conclusions or recommendations expressed in this report are those of the authors and do not necessarily reflect those of the sponsor or the Illinois State Water Survey.

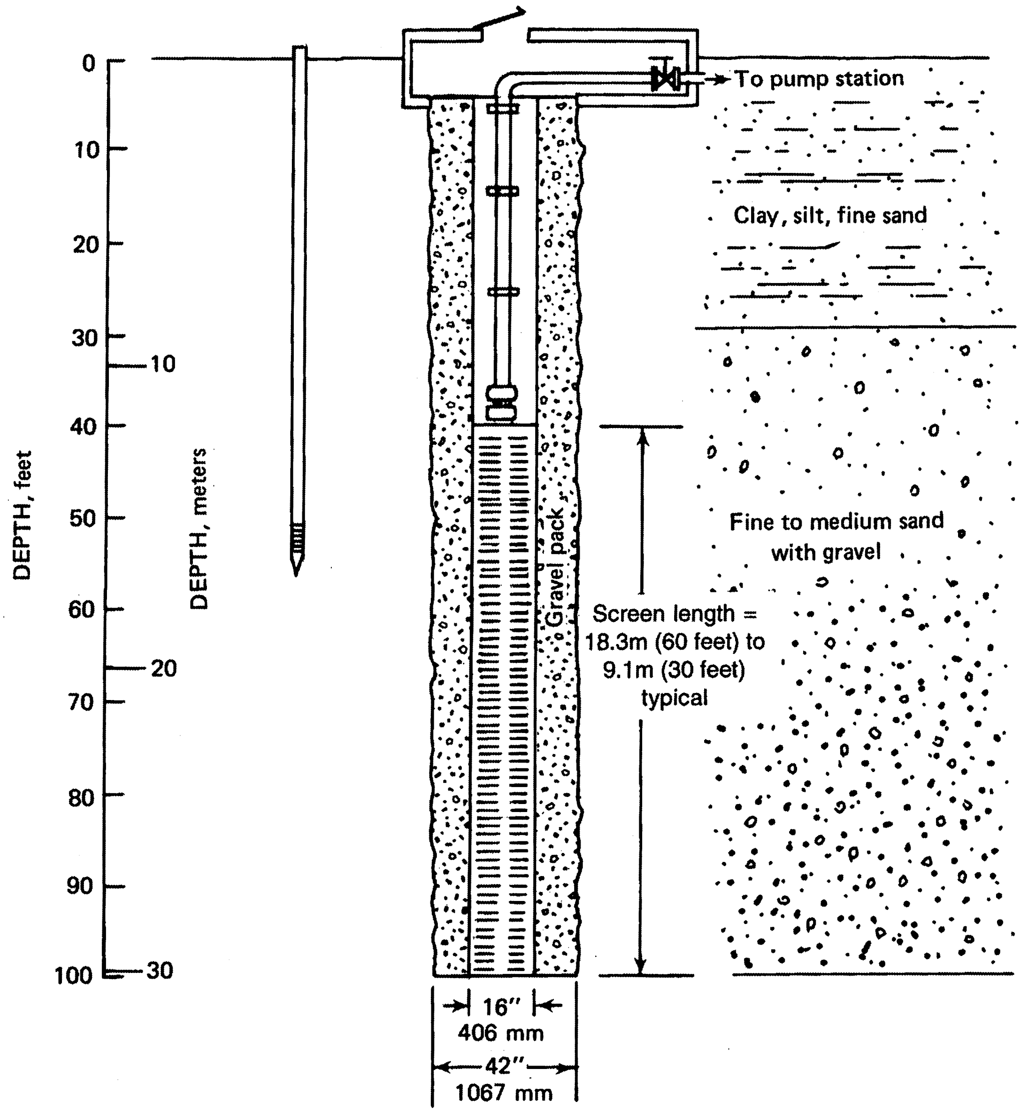

Figure 5. Typical features of a dewatering well

Dewatering System Monitoring

When originally constructed, the wells at I-70, I-64, and 25th Street included pitot-tube flow-rate meters. A combination of corrosion and chemical deposition caused premature failure of these devices. Flow rates were occasionally checked with a pitot-tube meter temporarily inserted, but the field crew reported erratic results. The six installations at Venice in 1982 included a venturi tube coupled to a bellows-type differential pressure indicator to measure the flow rate. However, the water quality and environment in the well pits also had adverse impacts on the operation of these instruments. Accurate flow measurements became impossible within a few years, and the field crew reported at least one direct failure of the venturi tube. These meters were subsequently disconnected.

As part of the scope of work in FY 85-FY 87 (Phases 2-4), a noninvasive, portable ultrasonic flowmeter was tested, calibrated, and used to check flow rates for specific capacity calculations of 21 dewatering wells. Although this meter was found to be limited in some cases, it was turned over to IDOT for use in their routine monitoring program.

Operational records have shown that wells are pumped for periods of about two to nine months, then idled for longer periods while another set of wells is operated. No standard sequence of pumping rotation is followed because of maintenance and rehabilitation requirements. Annual withdrawals currently are calculated on the basis of pumping time and estimated pumping rates.

Until November 1989, IDOT highway maintenance personnel periodically measured water levels at each dewatering well to monitor the overall performance of the dewatering system. Due to internal reorganization of the highway maintenance staff in District 8, ISWS staff began monitoring groundwater levels at the dewatering sites at the end of February 1990. Until the mid-1990s, water levels were measured every two months in each dewatering well and in the adjacent piezometer of each pumping well. After this time, the frequency of the water-level measurements was reduced to a quarterly basis. Data collected during FY 00 (Phase 17) have been tabulated and are listed in Appendix A.

Each dewatering well site (except Missouri Avenue) also includes at least one observation well (two at the I-64 site) equipped with a Leupold-Stevens Type F water-level recorder. Recorder charts are changed monthly and provide a continuous record of water levels near the critical location at each dewatering site. Because of the District 8 reorganization, the ISWS also assumed responsibility for the monthly servicing of the recorders beginning at the end of November 1989.

Each time measurements are collected, the ISWS forwards IDOT a report of the groundwater level data, including any recommendations for the operation of the dewatering wells. This information is used to compare groundwater elevations to pavement elevations and evaluate if any adjustments in pumpage are necessary. The data also are useful for assessing the condition of individual dewatering wells. Water-level differences of 3 to 5 feet between the pumping wells and the adjacent piezometers are considered normal by IDOT. Greater differences are interpreted to indicate that well deterioration is occurring.

Step-Test Investigative Methods and Procedures

Well Loss

When a well is pumped, water is removed from storage within the aquifer, causing water levels to decline over time in the vicinity of the well. This effect, referred to as drawdown, is most pronounced at the pumped well and gradually diminishes at increasing distances away from the well. Drawdown is the distance that the water level declines from its nonpumping stage. Under ideal conditions, drawdown is a function of pumping rate, time, and the aquifer's hydraulic properties. Aquifer boundaries, spatial variation in aquifer thickness or hydraulic properties, interference from nearby wells, and partial-penetration conditions all can affect observed drawdowns at both pumping and observation wells. However, well loss or additional drawdown inside the pumped well due to turbulent flow of water into and inside the well is a measure of the hydraulic efficiency of the pumping well only, reflecting the unique flow geometry of the borehole, well screen, and pump placement.

Because of well loss, the observed drawdown in a pumped well is usually greater than that in the aquifer formation outside the borehole. In addition to considerations of flow geometry, as noted above, the amount of well loss also can depend on the materials used (screen openings, gravel-pack size distribution, drilling fluids, etc.) and the care taken in constructing and developing the well. Some well loss is natural because of the physical blocking of the aquifer interstices caused by the well screen and the disturbance of aquifer material around the borehole during construction. However, an improperly designed well and/or ineffective well construction and development techniques can result in excessive well losses. In addition, well losses often reflect a deterioration in the condition of an existing well, especially if well losses increase over time.

Specific capacity, the quotient of pumping rate divided by the drawdown observed after a given time period, is often used in the field as an indicator of well performance. However, specific capacity combined with an analysis of well loss provides a more complete picture of the condition of the well that allows for normalization and comparison at various pumping rates.

Well loss is a function of pumping rate but, theoretically, not of time. It is 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, all of which cause the flow to change from laminar to turbulent. Head losses under turbulent conditions are nonlinear; that is, drawdowns increase more rapidly with increases in pumping rate than under laminar conditions, as discussed below.

Although it is possible to have turbulent flow within the aquifer and laminar flow within a pumping well, under near-ideal conditions the observed drawdown (s_o) in a pumping well is made up of two components: the formation loss (s_a), resulting from laminar 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.

$$s_o = s_a + s_w \qquad (1)$$

Jacob (1947) devised a technique for separating well losses from formation losses, assuming that all formation losses are laminar and all well losses are turbulent. These components of theoretical drawdown, s, in the pumped well are then expressed as being proportional to pumping rate, Q, in the following manner:

$$s = BQ + CQ^2 \qquad (2)$$

where B is the formation-loss coefficient per unit discharge, and C is the well-loss coefficient. For convenience, s is expressed in feet and Q in cubic feet per second (ft^3/sec). Thus, the well loss coefficient C has units sec^2/ft^5.

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:

$$s = BQ + CQ^n \qquad (3)$$

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). These analyses require a controlled pumping test, called a step drawdown test (described below), 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 (Bierschenk, 1964) can be used after first modifying Equation 2 as:

$$s/Q = B + CQ \qquad (4)$$

Substituting the observed drawdown, s_o, for s, 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, and the y-intercept is equal to B, as shown in Figure 6. If the data do not fall within a straight line but curve concavely upward, the curvature of the plotted data indicates that the second-order relationship between Q and s_o is invalid, and that the Rorabaugh method of analysis usually is appropriate.

Occasionally the data plot of s_o/Q versus Q may yield a straight-line fit with essentially zero slope or with a negative slope, or the data may be too scattered to allow a reasonable fit to

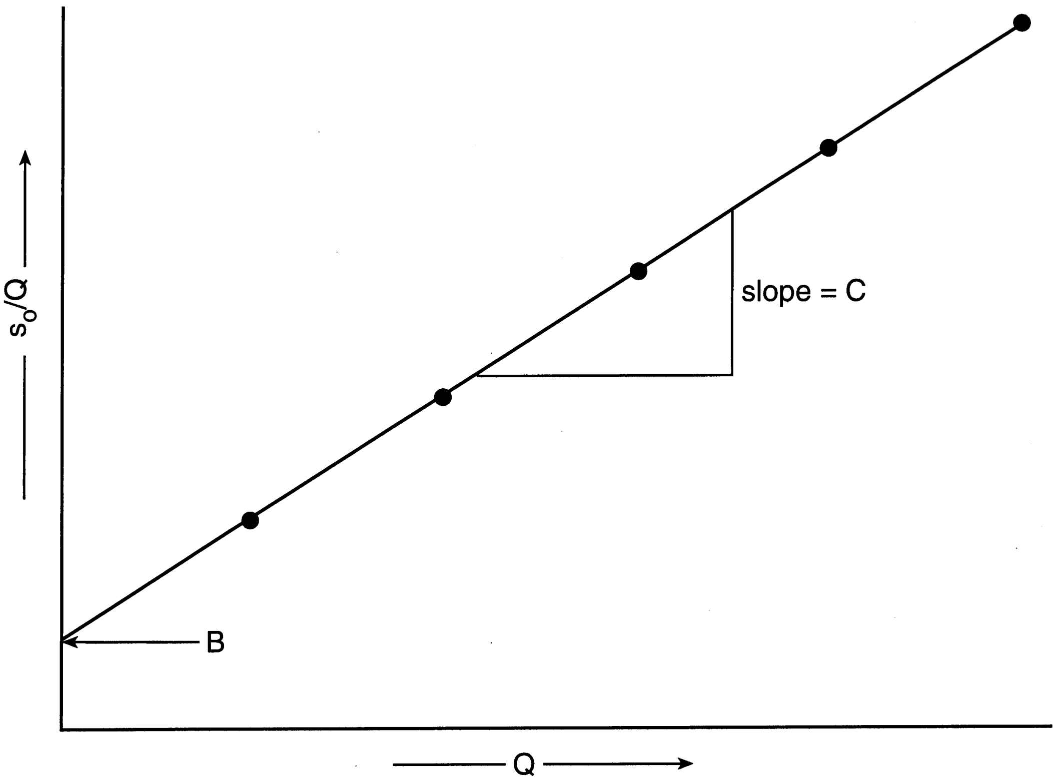

Figure 6. Graphical solution of Jacob's equation for well loss coefficient, C

be made at all. In these instances, the well-loss parameters are immeasurable. Possible explanations for this are: 1) turbulent well loss was negligible for the range of pumping rates used during the test; 2) inadequate data collection or test methods were used during the test; 3) the hydraulic condition of the well was unstable, as is the case during well development; or 4) the contribution of water from the aquifer was not uniform along the entire length of well screen over the range of pumping rates, as might occur due to the pump setting in relation to the screen or to vertical heterogeneity of the aquifer materials.

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

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

Taking logs of both sides of the equation,

$$\log [(s/Q) - B] = \log C + (n - 1) \log Q \qquad (6)$$

A plot of $(s_o/Q) - B$ versus Q can be made on logarithmic graph paper from step-test data by replacing s with s_o. Values of B are determined by trial and error until the data form a straight line (Figure 7). 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, plotting the data is facilitated if Q is plotted as ft^3/sec, and $(s_o/Q) - B$ is plotted as seconds per foot squared (sec/ft^2). It also is convenient to use these same units in the Jacob method.

Step-Test Procedure

The primary objective of a step drawdown test (or step test) is to determine the well-loss coefficient (and exponent, if Rorabaugh's method is used). With this information, the turbulent well-loss portion of drawdown for any pumping rate of interest can be estimated. During the test, the discharge rate is successively increased or decreased from the previous rate, in approximately equal increments, in order to facilitate the data analysis. Each pumping 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. If data are collected manually, water-level measurements are made every minute for the first six minutes, every two minutes for the next ten minutes, then every four to five minutes thereafter until the end of the step. For the step tests in this study, an Omnidata datalogger, an In-Situ Hermit datalogger, or an electric dropline was used to collect the data. Generally, the dataloggers were programmed to collect water-level data at least once each minute during the step test. Water levels were measured for 30 minutes per step for this investigation. At the end of each 30-minute interval, the pumping rate was immediately changed, and water levels were monitored for another 30-minute interval until a wide range of pumping rates within the capacity of the pump was tested.

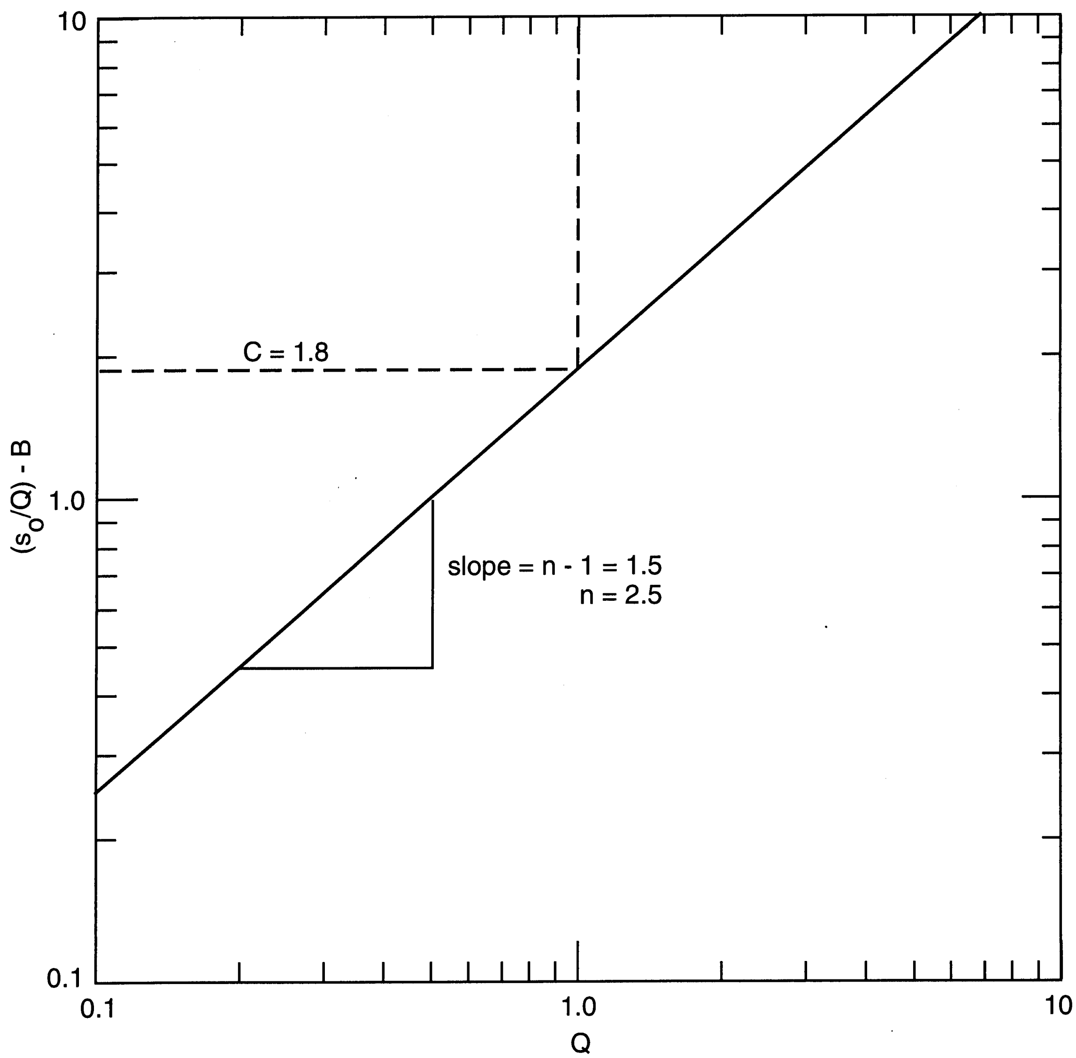

Figure 7. Graphical solution of Rorabaugh's equation for well loss coefficient (C) and exponent(n)

Schematically, the relationship between time and water level resembles that shown for a five-step test in Figure 8. Incremental 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 are small-diameter wells with a short length of screen; they are used to measure water levels (head) at a point in space within an aquifer. They often are used in clustered sets to measure variations in water levels with depth. For well-loss studies, piezometers can be used to measure head losses across a well screen, gravel pack, or well bore. As previously described, 53 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. Historical monitoring of the difference in head (Δh) between water levels in the well and in the adjacent piezometer has been used to help detect and track well deterioration problems.

Measuring piezometer water levels continuously during each step test also allows an indication of turbulent well losses in the pumped well to be found by plotting the Δh data over a large range of pumping rates. If turbulent losses exist within that range, the head differences should be nonlinear with increasing pumping rate. In addition, it sometimes can 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, this relationship will be nonlinear.

Field Results

Well Selection for Step Tests

Eighteen wells were step tested in FY 00 (Phase 17). Of these 18 step tests, 11 were post-chemical-treatment step tests, 5 were routine condition assessment step tests on existing wells, and 2 were condition assessments on newly constructed wells.

The five wells selected for routine condition assessment step tests were:

1-70	Wells 4, 5, 6, 14, and 15

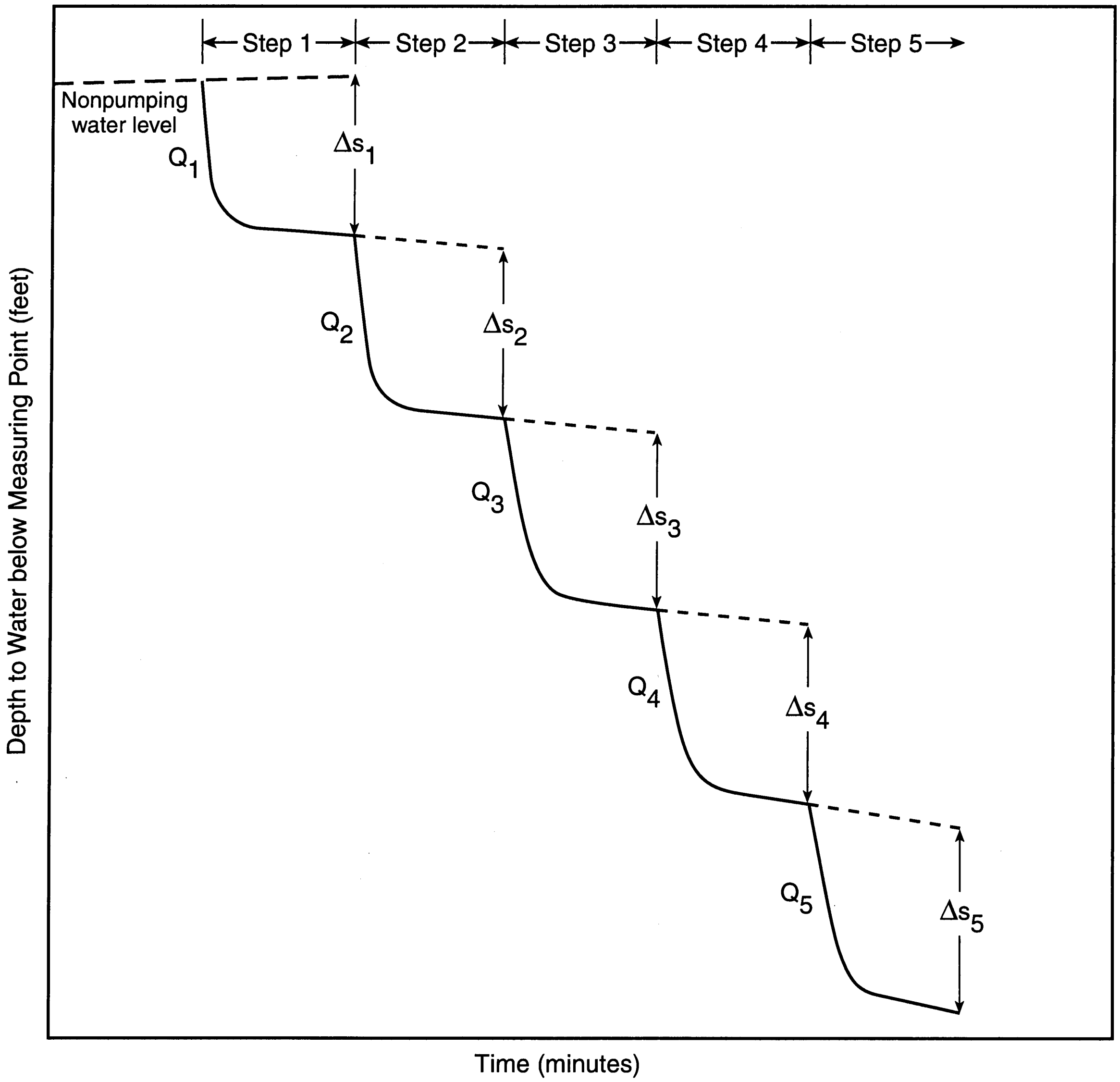

Figure 8. Relationship between time and water level during a five-step drawdown test

The 11 wells tested in posttreatment step tests were:

I-70	Wells 2A and 8A
25th Street	2, 3, 4, 5, 7, 8, and 9
Missouri Avenue	2 and 3

The two newly constructed wells which were step tested were:

Missouri Avenue	Well 4
25th Street	Well 6A

Step Tests

Field Testing Procedure

The ISWS staff conducted field work with the assistance of the IDOT Bureau of Maintenance pump crew. The IDOT crew made all necessary wellhead pipe modifications and provided special piping adapters that allowed connection of the ISWS flexible hose and orifice tube to measure the flow rate. Discharge from the orifice tube was directed to nearby stormwater drains.

Orifice tubes are standard equipment for accurately measuring flow rates. The orifice tube and orifice plate used to measure the range of flow rates were previously calibrated at the University of Illinois Hydrosystems Laboratory under discharge conditions similar to those expected in the field.

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 30-minute steps as possible at 300 gpm or greater for each well. Early experience with the step tests showed that, at rates of less than about 300 gpm, well-loss coefficients rarely could be determined from the collected data. Also, such a low pumping rate often results from a very low specific capacity, indicating a well already in poor condition. When there is a maximum pumping rate less than about 300 gpm during a step test for a dewatering well, the drawdown in water levels is observed for a period of 30 to 60 minutes to obtain an approximate specific capacity for later comparison; this, then, is called a drawdown test instead of a step test.

Prior to the start of each test, the water levels in the well and piezometer were measured with a steel tape or electric dropline. Pressure transmitters coupled to one of the previously mentioned dataloggers were placed in the pumped well and the adjacent piezometer (if available) to measure water levels during the step tests.

During the step tests, the discharge from each well also was checked for the presence of sand (unless the site accessibility or site condition precluded set-up of the testing equipment) by directing the open flow from the orifice tube into a 1,000-gallon portable tank. The tank acts as a sedimentation basin, allowing sand grains to be caught and collected at the end of the step test as the tank is drained. Water samples were collected at the time of each test and analyzed for chemical/mineral content and nuisance bacteria. The results from the water sample analyses are described in the following sections and are presented in Appendix B.

Results of Step Tests

The step-test data were analyzed by using the Jacob method, as described earlier in this report. Table 1 summarizes results of the analyses of data from the 18 step tests conducted for the FY 00 investigation. The Δh values reported in Table 1 have been observed or estimated for the standardized rate of 600 gpm. However, comparisons of Δh values are valid only among step tests on the same well because of the varying distances of the piezometers from individual dewatering wells.

As mentioned above, five wells were selected for routine condition assessment step tests. These wells are located at the I-70 site and are Wells 4, 5, 6, 14, and 15. The observed specific capacities for these five wells ranged from 25.1 to 65.2 gpm/ft, which generally corresponds to very poor to fair conditions, respectively. Subsequently, it was recommended that these five wells be chemically treated (rehabilitated) in FY 01. (For results of the posttreatment step tests conducted on I-70 Wells 2A and 8A, as well as those for 25th Street Wells 2, 3, 4, 5, 7, 8, and 9, and Missouri Avenue Wells 2 and 3, see the section, Chemical Treatment Results.)

Since FY 84 (Phases 1-17), a total of 212 step tests (including six drawdown tests) have been completed at the five dewatering sites in the Metro East area. The observed specific capacity data are summarized in Table 2. The average observed specific capacity for all 212 step tests is 78 gpm/ft. By excluding the results from 91 pretreatment step tests and other step tests that show wells in poor condition, the average observed specific capacity of 121 step tests is 100 gpm/ft. The highest observed specific capacities for all step tests conducted are generally found at the I-64 site, at which 24 step tests have been completed. Observed specific capacities for all step tests at the I-64 site averaged 92 gpm/ft, or 105 gpm/ft if the seven pretreatment step tests are excluded. Without the pretreatment step tests and other step tests on wells in poor condition, the 25th Street wells would have produced the highest specific capacities on average. The average observed specific capacity for wells in good condition or posttreatment is 111 gpm/ft at the 25th Street site.

Well Rehabilitation

Chemical Treatment Procedure

The specifications for the well rehabilitation work initially were developed in FY 86 by IDOT and the ISWS based on chemical treatment practices in common use. Revisions to the specifications have been made periodically, based on results and experience from chemical treatment of the dewatering wells since 1986. Similar treatment procedures were used for all wells treated in FY 00, although adjustments occurred as specific conditions were encountered

Table 1. Results of State Water Survey Step Tests on IDOT Wells, FY 00 (Phase 17)

Well	*Date of step test*	*Well loss at 600 gpm (ft)*	*Drawdown at 600 gpm (ft)*	*Well loss portion (%)*	*Observed specific capacity (gpm/ft)*	*Δh* at 600 gpm (ft)*	*Observed Q_{max} (gpm)*	*Remarks*
I-70								
No. 2A	10/13/99	0.44 e	7.27	6.0	75.1	2.08 e	510	T
No. 4	11/04/99	2.87 e	2.87 e	14.7	28.2	P	590	CA
No. 5	11/04/99	**	10.88	**	49.5	P	595	CA
No. 6	11/10/99	0.02	10.79	0.2	50.9	8.23	640	CA
No. 8A	10/14/99	0.12	6.96	1.7	79.3	1.75 e	730	T
No. 14	11/03/99	0.10	8.37	1.2	65.2	4.78 e	580	CA
No. 15	11/05/99	**	21.93	**	25.1	15.52	545	CA
25th St.								
No. 2	04/04/00	**	6.25	**	96.5	2.01	820	T
No. 3	05/11/00	**	7.45	**	82.1	1.41	820	T
No. 4	05/11/00	**	7.86	**	77.2	3.33	780	T
No. 5	05/10/00	**	5.07	**	114.5	1.74	820	T
No. 6A	05/02/00	0.27	7.83	3.5	70.9	3.49	750	PC
No. 7	05/03/00	**	5.73	**	98.6	1.61	810	T
No. 8	05/03/00	0.03	6.03	0.6	92.6	1.01	800	T
No. 9	04/06/00	**	5.20	**	108.5	1.80	760	T
MO Ave.								
No. 2	06/08/00	0.18	4.84 e	3.7	121.1	0.44 e	1,475	T
No. 3	06/09/00	1.19 e	9.29 e	12.7	60.4	2.22 e	1,275	T
No. 4	06/07/00	0.36 e	3.68 e	9.9	155.3	0.32 e	1,550	PC

Notes:

* Head difference between pumped well and adjacent piezometer.
** Coefficient immeasurable. Turbulent well loss negligible over the pumping rates tested.
e = Estimate based on interpolated values adjusted to 600 gpm.
P = Piezometer plugged or partially plugged.

CA = Condition assessment.
T = Posttreatment step test.
PC = Postconstruction.

Table 2. Average Observed Specific Capacity of Dewatering Wells Based on Step-Test Data from 212 Tests since FY 84

	Dewatering well site locations					
Well category	*I-70*	*I-64*	*25th St.*	*Venice*	*MO Ave.*	*All sites*
All wells:						
Number of step tests	94	24	40	37	17	212
Average observed specific capacity, gpm/ft	72	92	85	76	80	78
Wells in good condition or posttreatment:						
Number of step tests	48	17	24	22	10	121
Average observed specific capacity, gpm/ft	95	105	111	96	93	100
Wells in poor condition or pretreatment:						
Number of step tests	46	7	16	15	7	91
Average observed specific capacity, gpm/ft	49	61	46	47	62	50

from day to day and from well to well. Table 3 summarizes the treatment procedure as required by IDOT specifications.

Figure 9 shows schematically the typical injection assembly/discharge apparatus used by the contractor for injecting solutions and acid into the wells, to pump spent solutions to waste, and to conduct drawdown pumping tests during the treatment. The well rehabilitation work was observed and documented by ISWS staff.

Chemical Treatment Results

The wells were selected for chemical treatment on the basis of data from the most recent ISWS step tests and available Δh information (see section, Piezometers). Under an FY 00 IDOT contract, Layne-Western Company, Inc., chemically treated five dewatering wells, and Brotcke Engineering treated seven wells between September 1, 1999, and June 23, 2000.

As indicated in Table 3, the chemical treatment procedure required that the contractor conduct 60-minute drawdown tests to measure the specific capacity after each successive treatment step. Table 4 summarizes drawdown pumping test data collected as part of the field documentation during the chemical treatment of each dewatering well. Table 4 shows the measured specific capacity before treatment and after each step in the treatment process (polyphosphate or acid injection episode). The average specific capacity for all wells prior to treatment and at each of the first three steps in the treatment process is given at the end of Table 4 with an analysis of the improvement between steps. In general, the percentage of improvement in specific capacity diminishes with each successive step of the treatment. This trend also has been noted in the results of the chemical treatment in prior years. In FY 00 about 55 percent of the total improvement occurred during the first polyphosphate treatment, and about 14 percent occurred during the second polyphosphate treatment (following acidization). This trend of reduced

Table 3. Outline of Typical Well Rehabilitation

<u>Day 1</u>

1. Pretreatment drawdown test (contractor orifice tube, open to free discharge, used for flow measurements).

   a. Measurement of SWL (static water level) following 30 or more minutes of well inactivity.
   b. Measurement of PWL (pumping water level) and orifice piezometer tube following 60 or more minutes of pumping.

2. Polyphosphate application, 400 pounds, and displacement with 16,000 gallons of water containing at least 500 ppm (mg/L) chlorine.

   a. Initial chlorination of well with 2,500 gallons of water containing 500 ppm or more of chlorine injected at a minimum rate of 750 gpm (actual rate: 1,300-2,100 gpm).
   b. Injection of polyphosphate solution at a minimum rate of 2,000 gpm (actual rate: 1,500-2,100 gpm) in two 1,800-gallon batches, each batch containing 200 pounds of polyphosphate.
   c. Displacement injection of 16,000 gallons of water chlorinated to at least 500 mg/L in 2,000-gallon batches at a minimum rate of 1,500 gpm (actual rate: 800-2,900 gpm).
   d. Time allowance for chemicals to react, 1-2 hours.
   e. Repeatedly surge and backflush well to loosen encrustants with multiple cycles (actual rate: 9-19) of pumping well at high rates (actual: 700-2,300 gpm) to fill 2,000 gallon holding tank and pumping the contents of the tank back into the well at high rates (actual rate: 960-3,600 gpm).

3. Pump to waste and check specific capacity.

   a. Pump continuously for 6 or more hours to clear well of chemicals (actual time, when known: 15.5-19.75 hours).
   b. Same procedure for specific capacity check as Day 1, step 1.

<u>Day 2</u>

1. Acidization with 1,000 gallons 20° Baume-inhibited muriatic (hydrochloric) acid and displacement with 4,000-5,000 gallons of water (not chlorinated).

   a. Pump 1,000 gallons of bulk-inhibited acid into well within 1 hour, 17 gpm minimum (actual rate: 23-130 gpm).
   b. Allowance time for acid to react, 1 hour.
   c. Injection of 4,000-5,000 gallons of water at 1,000-2,000 gpm (actual rate: 1,500-3,000 gpm).
   d. Allowance for reaction, 2-3 hours.
   e. Repeatedly surge and backflush well to loosen encrustants with multiple cycles (actual rate: 9-14) of pumping well at high rates (actual rates: 222-1,100 gpm) to fill a 2,000-gallon holding tank, then pumping the contents of the tank back into the well at high rates (actual rate: 1,000-2,700 gpm).

Table 3. Continued

2. Pump to waste and check specific capacity.

    a. Pump continuously for 3 or more hours (actual time: 17 hours) to clear well of acid.
    b. Same procedure for specific capacity check as Day 1, step 1.

Day 3

1. Polyphosphate application, 600 pounds, and displacement with 30,000 gallons of water containing at least 500 ppm chlorine.

    Same procedure as Day 1, step 2, except three batch injections of 1,800 gallons (5,400 gallons total) with 200 pounds of phosphate each in part b, and injection of 30,000 gallons in part c.

    Noted actual pumping rates and surging cycles for indicated steps of procedure:

    a. Initial chlorination: 1,800-2,500 gpm.
    b. Polyphosphate solution injections: 1,300-3,000 gpm.
    c. Displacements: 1,500-3,000 gpm.
    d. No change.
    e. Surging/backflushing actual cycles: 18-25; well to tank pumping rate: 800-1,400 gpm; tank to well pumping rate: 1,800-2,900 gpm).

2. Pump to waste and check specific capacity.

    a. Pump continuously for 6 or more hours to clear well of chemicals (actual time: 17.5-65.5 hours).
    b. Same procedure for specific capacity check as Day 1, step 1.

Day 4 (Optional)

1. Polyphosphate application, 600 pounds, and displacement with 54,000 gallons of water containing at least 500 ppm chlorine.

    Same procedure as Day 1, step 2, except three batch injections of 1,800 gallons (5,400 gallons total) with 200 pounds phosphate each in part b, and injection of 54,000 gallons in part c.

    Noted actual pumping rates and surging cycles for indicated steps of procedure:

    a. Initial chlorination: 1,412 gpm.
    b. Polyphosphate solution injections: 2,300-2,700 gpm.
    c. Displacements: 1,100-2,600 gpm.
    d. No change.
    e. Surging/backflushing actual cycles: 25; well to tank pumping rate: 1,300-1,500 gpm; tank to well pumping rate: 2,400-3,000 gpm.

Table 3. Concluded

2. Pump to waste and check specific capacity.

    a. Pump continuously for 6 or more hours to clear well of chemicals (actual time: 14 hours).
    b. Same procedure for specific capacity check as Day 1, step 1.

<u>Day 5</u> (Optional)

1. Polyphosphate application, 400 pounds, and displacement with 16,000 gallons of water containing at least 500 ppm chlorine.

    Same procedure as Day 1, step 2.

2. Pump to waste and final drawdown test.

    a. Pump continuously for 6 or more hours to clear well of chemicals.
    b. Same procedure for specific capacity check as Day 1, step 1.

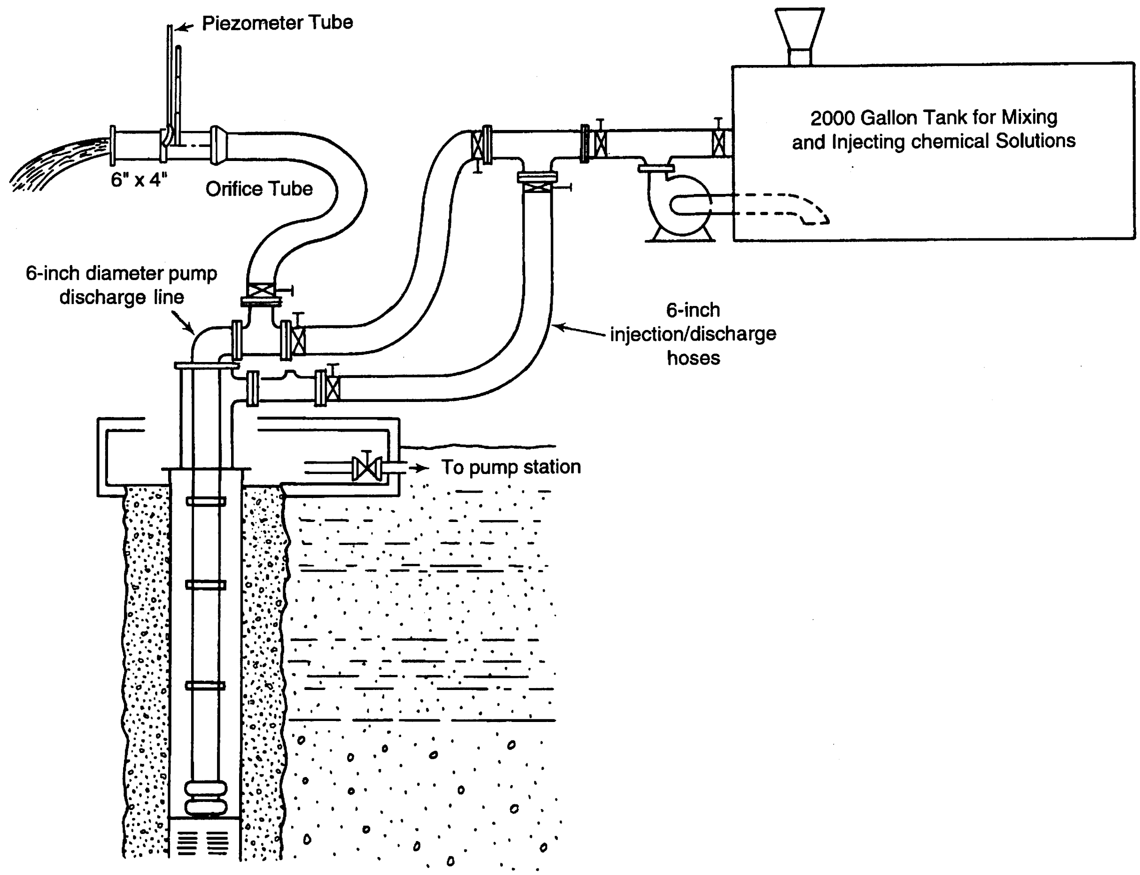

Figure 9. Schematic diagram of equipment used in well rehabilitation

Table 4. Drawdown Test Data Collected by Contractor during Well Rehabilitation

	Pretreatment	*1st PPP treatment*	*Acid treatment*	*2nd PPP treatment*	*3rd PPP treatment*	*4th PPP treatment*
I-70 Well 2A						
Date (1999)	9/14	9/15	9/16	9/17	9/20	9/21
SWL	33.98	35.45	35.52	35.72	36.36	37.37
PWL	45.75	47.05	47.50	47.74	48.00	47.45
s	11.77	11.60	11.98	12.02	11.64	10.08
Q	853	968	944	988	980	984
Q/s	72.5	83.4	78.8	82.2	84.2	97.6
I-70 Well 8A						
Date (1999)	9/22	9/24	9/27	9/28	9/29	not done
SWL	9.28	10.60	13.20	11.60	11.47	
PWL	34.95	23.95	23.03	22.38	22.37	
s	25.67	13.35	9.83	10.78	10.90	
Q	936	964	802	936	968	
Q/s	36.5	72.2	81.6	86.8	88.8	
25th St. Well 2						
Date (1999)	10/5	10/7	10/8	10/11	10/12	10/13
SWL	14.77	14.75	14.40	14.55	14.40	14.38
PWL	32.30	23.4	19.63	20.08	19.53	19.25
s	17.53	8.6	5.23	5.53	5.13	4.87
Q	597	641	431	513	498	509
Q/s	34.1	74	82.4	92.8	97.1	104.5
25th St. Well 3						
Date (1999)	9/27	9/28	9/29	9/30	10/1	10/1
SWL	12.50	13.26	13.87	13.96	13.96	13.68
PWL	32.67	24.31	23.10	22.32	21.16	20.74
s	20.17	11.05	9.23	8.36	7.20	7.06
Q	685	687	699	693	662	656
Q/s	34.0	62.2	75.7	82.9	91.9	92.9
25th St. Well 4						
Date (1999)	9/13	9/15	9/17	9/22	9/23	9/24
SWL	12.10	13.83	14.10	14.82	14.92	14.97
PWL	47.83	23.83	22.95	23.11	22.96	22.50
s	35.73	10.00	8.85	8.29	8.04	7.53
Q	679	600	647	641	665	647
Q/s	19.0	60.0	73.1	77.3	82.7	85.9

Table 4. Continued

	Pretreatment	*1st PPP treatment*	*Acid treatment*	*2nd PPP treatment*	*3rd PPP treatment*	*4th PPP treatment*
25th St. Well 5						
Date (1999)	9/2	9/3	9/8	9/9	9/10	not done
SWL	13.61	14.00	12.98	13.65	13.69	
PWL	26.78	20.06	19.14	19.17	18.96	
s	13.17	6.06	6.16	5.52	5.27	
Q	647	610	607	613	629	
Q/s	49.1	100.7	98.5	111.0	119.3	
25th St. Well 7						
Date (1999)	11/4	11/5	11/8	11/9	11/10	11/11
SWL	14.50	14.97	14.85	14.85	14.85	measurement
PWL	55.35	25.08	23.90	22.85	22.05	not
s	40.85	10.11	9.05	8.00	7.20	possible
Q	702	767	777	772	787	
Q/s	17.2	75.9	85.8	96.5	109.3	
25th St. Well 8						
Date (1999)	10/27	10/28	10/29	11/1	11/2	11/3
SWL	14.95	15.15	15.27	15.59	15.40	15.00
PWL	42.20	25.50	24.56	23.76	23.07	22.30
s	27.25	10.35	9.29	8.17	7.67	7.30
Q	777	767	785	777	762	780
Q/s	28.5	74.1	84.5	95.1	99.3	106.8
25th St. Well 9						
Date (1999)	10/19	10/20	10/21	10/22	10/22	not done
SWL	26.15	27.03	27.66	27.69	27.26	
PWL	61.17	37.46	36.7	35.93	34.96	
s	35.02	10.43	9.08	8.24	7.70	
Q	958	910	910	906	906	
Q/s	27.4	87.2	100.2	110.0	117.6	
Missouri Ave. Well 1						
Date (2000)	6/21	6/22	6/23	6/23	not done	not done
SWL	30.6	32.3	32.42	measure-		
PWL	42.8	44.5	44.47	ment		
s	12.2	12.2	12.05	not		
Q	449	449	498	possible		
Q/s	36.8	36.8	41.3			

Table 4. Concluded

	Pretreatment	*1st PPP treatment*	*Acid treatment*	*2nd PPP treatment*	*3rd PPP treatment*	*4th PPP treatment*
Missouri Ave.						
Well 2						
Date (2000)	1/20	1/21	1/25	1/26	1/27	1/27
SWL	37.47	37.50	37.9	43.3	42.6	43.73
PWL	46.85	44.76	46.3	37.3	37.6	37.62
s	9.38	7.26	8.4	5.6	5	6.11
Q	772	802	1004	752	693	844
Q/s	82.3	110.5	119	134	139	138.1
Missouri Ave.						
Well 3						
Date (2000)	1/12	1/13	1/14	1/17	1/18	not done
SWL	33.84	34.47	34.65	34.67	34.61	
PWL	55	45.55	43.40	42.57	43.80	
s	21	11.08	8.75	7.9	9.19	
Q	521	564	550	528	570	
Q/s	25	50.9	62.8	66.8	62.0	
Averages						
Q/s:	38.5	74.0	82.0	94.1	99.2	104.3
ΔQ/s:		35.5	8.0	8.5	5.1	5.3
% increase over original Q/s:		124.3	30.0	26.1	17.9	14.2
% of total improvement:		55.0	19.7	13.5	7.0	13.1

Notes:

SWL = Static (nonpumping) water level, feet
PWL = Pumping water level, feet
s = Drawdown (PWL-SWL), feet
Q = Pumping rate, gpm
Q/s = Specific capacity, gpm/ft
PPP = Polyphosphate

improvement for successive treatment steps agrees well with the results of the treatment for the preceding years when this general well treatment procedure has been followed: one polyphosphate treatment, followed by a muriatic acid treatment, followed by up to three polyphosphate treatments (Sanderson and Olson, 1999).

Table 5 summarizes the results of the posttreatment step tests conducted during FY 00 and summarizes results for comparison with the contractor's drawdown tests conducted during the well treatment. In most cases, the contractor reports a much higher improvement in specific capacity following well treatment. This can be accounted for by the further deterioration in the condition of the well between the time the ISWS conducts a condition assessment step test and the time when the contractor begins chemical treatment of the well. A similar delay (and further deterioration in a well's condition) exists between completion of well treatment (and contractor's drawdown test) and the posttreatment step test by the ISWS.

Sand Pumpage Investigation

Field Procedure

Prior occurrences of sand pumpage from the dewatering wells resulted in the standard practice of checking for the presence of sand in the discharge during each step test, unless precluded by site conditions and available equipment. To continue to address these concerns, the possibility of sand pumpage was investigated during 15 of the 18 step tests conducted in FY 00 (Phase 17). The other three wells, Missouri Avenue Wells 2, 3, and 4, are located where the site conditions preclude use of the settling tank.

During each step test when site conditions allowed, water was discharged from the orifice tube into a portable 1,000-gallon tank (Figure 10). Siphon tubes were used, as necessary, to help control the discharge from the tank. The tank acts as a sedimentation basin that, under ideal conditions, should allow sand with grain diameters of about 0.1 millimeter (mm) and larger to settle out at the design pumping rates of the wells (600-800 gpm). Usually 80 to 90 percent or more of the aquifer material in the screened interval of the wells exceeds the 0.1-mm grain size (Suiden, 1989).

Sand Sample Collection

Samples were collected following the step tests whenever a significant quantity (approximately a tablespoon or more) of sediment remained in the tank. In all, three of the 15 step tests in which the portable tank was used generated a sample large enough for collection. The samples collected and a brief description of each follows.

25th St. Well 2:

Approximately one teaspoon of gravel pack was collected from the portable tank following the FY 00 posttreatment step test on April 4, 2000.

Table 5. Results of Chemical Treatment,

FY 00 (Phase 17)

Site	Well	Test	Pretreatment Date	Pretreatment Q/s (gpm/ft)	Posttreatment Date	Posttreatment Q/s (gpm/ft)	% Change
I-70	2A	ISWS	12/10/97	74.8	10/13/99	82.6	+10
		LWC	09/14/99	72.5	09/21/99	97.6	+35
I-70	8A	ISWS	06/26/96	78.5	10/14/99	85.4	+9
		LWC	09/22/99	36.5	09/29/99	88.8	+143
25th St.	2	ISWS	06/19/97	70.8	04/04/00	96.5	+36
		BEC	10/05/99	34.1	10/13/99	104.5	+206
25th St.	3	ISWS	04/15/96	57.9	05/11/00	82.1	+42
		BEC	09/27/99	34.0	10/01/99	92.9	+173
25th St.	4	ISWS	11/26/96	26.6	05/11/00	77.2	+190
		BEC	09/13/99	19.0	09/24/99	85.6	+350
25th St.	5	ISWS	02/25/97	66.3	05/10/00	122.1	+84
		BEC	09/02/99	49.1	09/10/99	119.3	+143
25th St.	7	ISWS	11/19/96	24.4	05/03/00	105.1	+331
		BEC	11/04/99	17.2	11/10/99	109.3	+536
25th St.	8	ISWS	11/14/96	42.4	05/03/00	99.2	+134
		BEC	10/27/99	28.5	11/03/99	106.8	+275
25th St.	9	ISWS	02/11/97	19.3	04/06/00	116.3	+503
		BEC	10/19/99	27.4	10/22/99	117.6	+329
Missouri Ave.	2	ISWS	12/02/98	95.0	06/08/00	118.0	+24
		LWC	01/20/00	82.3	01/27/00	138.1	+68
Missouri Ave.	3	ISWS	12/01/98	55.8	06/09/00	57.1	+2
		LWC	01/12/00	25.0	01/18/00	62.0	+148
Average		ISWS		55.6		94.7	+124
		LWC/BEC		38.7		102.0	+219

Notes:
Q/s = Specific capacity, gpm/ft
ISWS = Illinois State Water Survey
LWC = Layne-Western Company, Inc.
BEC = Brotcke Engineering Company, Inc.

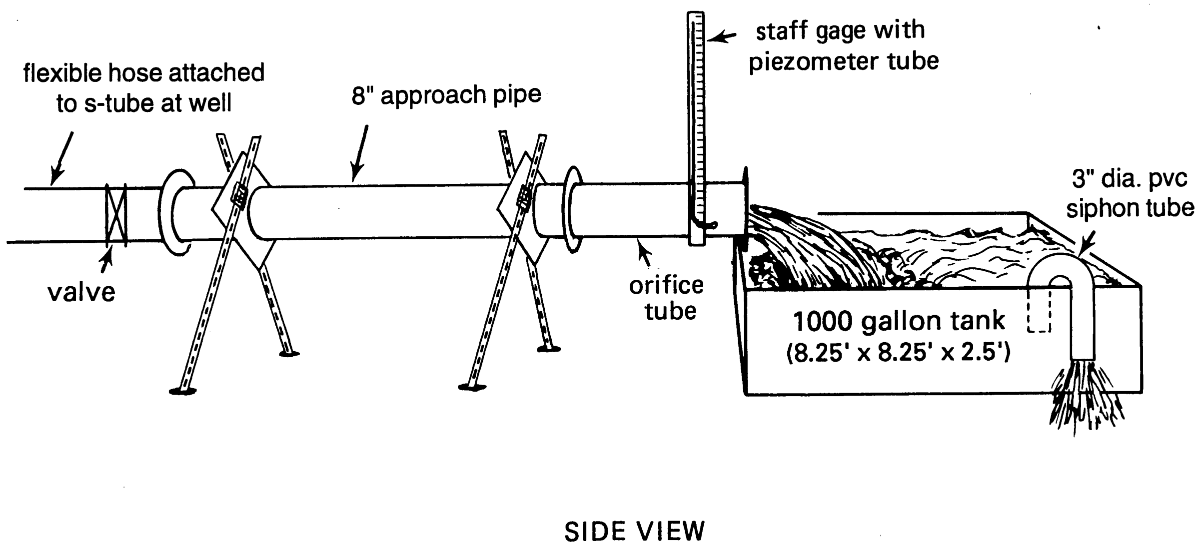

Figure 10. Sand pumpage test setup

25th St. Well 3:

Approximately one tablespoon of fine sand and iron residue was collected from the portable tank following the FY 00 posttreatment step test on May 11, 2000.

25th St. Well 4:

Approximately one cup of fine sand was collected from the portable tank following the FY 00 posttreatment step test on May 11, 2000.

Evaluation of Groundwater Quality

Internal Analytical Services staff at the ISWS analyzed water samples collected during all 18 step tests. Appendix B reports the results. Analytical methods used conform to the latest procedures certified by the U.S. Environmental Protection Agency (1979). The sample temperature was determined in the field at each well site, and the pH of samples was determined in the laboratory. Table 6 presents the range of concentrations and potential influence of the major water-quality parameters analyzed.

Although the water chemistry of the groundwater samples varies, generally the groundwater can be described as highly mineralized, very hard, and alkaline, with unusually high concentrations of soluble iron. The water quality is consistent with that of previously analyzed samples from the dewatering wells.

Table 6. Range of Concentrations and Potential Influence of Common Dissolved Constituents, FY 00 (Phase 17)

	Concentration, mg/L		
Parameter	*Minimum*	*Maximum*	*Potential influence*
Iron (Fe)	9.42	20.88	Major - incrustative
Manganese (Mn)	0.37	1.33	Major - incrustative
Calcium (Ca)	143	234	Major - incrustative
Magnesium (Mg)	36.8	59.3	Minor - incrustative
Sodium (Na)	16.4	331	Neutral
Silica (SiO_2)	29.2	38.4	Minor - incrustative
Nitrate (NO_3)	<0.06	<0.13	Neutral
Chloride (Cl)	28	194	Moderate - corrosive
Sulfate (SO_4)	138	952	Major - corrosive
Alkalinity (as $CaCO_3$)	364	628	Major - incrustative
Hardness (as $CaCO_3$)	639	795	Major - incrustative
Total dissolved solids	684	1877	Major - corrosive
pH	6.9	7.2	Neutral

Nuisance Bacteria Sampling

Nuisance bacteria (e.g., iron bacteria, sulfate-reducing bacteria) that inhabit wells, gravel packs, and the aquifer matrix often produce well-plugging biofilms, as well as a favorable environment for chemical deposition and corrosion processes. To explore the possibility that such nuisance bacteria might be present in the dewatering wells, the Biological Activity Reaction Test (BART), developed by Droycon Bioconcepts, Inc., Regina, Saskatchewan, Canada, was conducted on water samples collected from the well discharge at the time of the step tests. The BART tests are customized to detect three general classes of nuisance bacteria commonly associated with problems in wells: iron-related bacteria (IRB), slime-forming bacteria (SLYM), and sulfate-reducing bacteria (SRB).

The testing protocol requires placing a water sample in a vial for examination over a period of days, and documenting any reactions that may occur. The bacterial population or activity in the water sample is inversely related to the length of time before reactions occur. Reaction types and patterns of occurrence depend on the dominant bacterial groups present in the water sample (Cullimore, 1990). Thus, the type and size of the bacterial community can be inferred from this reaction signature. Multiple sets of samples collected at time intervals of pumping are recommended for detailed analysis of the bacterial activity (Mansuy et al., 1990).

The BART samples were collected during the 18 step tests conducted during FY 00, all using the same procedure. Because the purpose was simply to determine whether nuisance bacteria are present in the wells, only one sample set, consisting of IRB, SLYM, and SRB samples was collected for each step-tested well. Samples were collected from the orifice tube discharge, usually in sequence with the other water samples being collected for analysis of the dissolved constituents.

The results for most of the BART samples indicated high to moderate amounts of nuisance bacteria activity in the discharge water from all the wells. Generally, the IRB tests appeared to show moderate microbial activity. The SLYM tests indicated slightly more aggressive microbial activity than the IRB tests, and the SRB tests showed predominantly very aggressive microbial activity (Table 7).

The BART samples were collected near the end of the step tests, after many well casing and screen volumes of water were pumped, so it is assumed that the water sampled is being derived totally from the aquifer. Therefore, the rapid bacterial activity usually observed suggests that there is substantial biomass development within the well casing and screen that is slowly sloughing off during the step-test pumping on most of the wells, or a significant population of the bacteria is present in the aquifer, or both.

When taking into consideration that the tops of the dewatering wells, except those at the Missouri Avenue site, are located in pits that can be readily subjected to contamination from pit seepage or spill water, the high degree of nuisance bacteria activity is not surprising. Although nuisance bacteria can be present in groundwater, most of these types of bacteria are ubiquitous

Table 7. Biological Aggressivity, FY 00 (Phase 17)

			Aggressiveness		
Site	*Well no.*	*Type of step test*	*Iron-related bacteria (IRB)*	*Slime-forming bacteria (SLYM)*	*Sulfate-reducing bacteria (SRB)*
I-70	2A	Posttreatment	4	3	2
	4	Condition assessment	3	3	2
	5	Condition assessment	3	3	2
	6	Condition assessment	3	3	2
	8A	Posttreatment	4	3	2
	14	Condition assessment	4	3	2
	15	Condition assessment	4	3	2
Site average			3.6	3.0	2.0
25th Street	2	Posttreatment	4	2	2
	3	Posttreatment	3	3	2
	4	Posttreatment	3	3	2
	5	Posttreatment	3	2	2
	6A	Postconstruction	3	2	2
	7	Posttreatment	3	2	2
	8	Posttreatment	2	3	2
	9	Posttreatment	3	2	2
Site average			3.0	2.4	2.0
Missouri Ave.	2	Posttreatment	2	3	2
	3	Posttreatment	2	3	2
	4	Postconstruction	2	2	2
Site average			2.0	2.7	2.0
Overall average			3.1	2.7	2.0

Notes:
1 = extremely aggressive
2 = very aggressive
3 = moderately aggressive
4 = background flora
5 = negative

in the surface environment. The use of sanitary wellheads and using precautions such as disinfection after performing maintenance activities on the wells are good preventative measures for keeping the wells free of bacterially induced problems.

Conclusions and Recommendations

Condition Assessments of Wells

Results of the step tests conducted to assess the condition of I-70 Wells 4, 5, 6, 14, and 15 show that Wells 4 and 15 are in poor condition, with observed specific capacities of 28.2 gpm/ft and 25.1 gpm/ft, respectively. These observed specific capacities are well below the average of wells in good condition at both the I-70 site and at all the Metro East dewatering sites. Average specific capacities for wells in good condition at the I-70 site and all of the five dewatering sites are 95 gpm/ft and 100 gpm/ft, respectively.

The condition of the three remaining I-70 wells (Wells 5, 6, and 14) at which condition assessment step tests were conducted were only a little better. These wells had specific capacities of 49.5 gpm/ft, 50.9 gpm/ft, and 65.2 gpm/ft, respectively. These wells are in generally poor to fair condition. Chemical treatment during FY 2001 was recommended for all five of the I-70 wells discussed in this section.

Well Rehabilitations

Results of the evaluation of well rehabilitation activities range from fair to good. Evaluation of posttreatment step-test data show specific capacities ranging from 61 to 127 percent of the respective site averages for wells in good condition at each site. Based on data collected by the contractor during well treatment, percent increases in specific capacity for individual wells range from 35 to 536 percent and averaged 219 percent. Based on pre- and posttreatment step tests conducted by the ISWS, increases in specific capacity for individual wells ranged from 2 to 503 percent and averaged 121 percent.

The change in chemical treatment specifications made in FY 90 to provide for optional polyphosphate treatment steps after the second application reduced the total number of polyphosphate treatments applied to the 11 wells chemically treated during FY 00. On the basis of the field observations made at the time of the treatment, the optional third polyphosphate treatment step was not omitted for any of the 11 wells treated, but the optional fourth polyphosphate treatment step was dropped at I-70 Well 8A and 25th Street Wells 5, 7, 9, and Missouri Avenue Well 3.

Sand Pumpage Investigations

Discharge from 15 dewatering wells was examined for sand pumpage during 15 of the 18 step tests conducted for FY 00. For the three step tests on Missouri Avenue Wells 2, 3, and 4, the discharge could not be checked because of site conditions. The three wells that yielded sand-and/or-gravel pack material were 25th Street Wells 2, 3, and 4.

Results of the tests for sand pumpage from the dewatering wells for this and prior years have yielded interesting information. Chemical treatment of some wells to restore production capacity may influence the tendency for a dewatering well to pump sand. In some instances, it appears that the treatment may cause sufficient disturbance of the gravel pack and native aquifer material to allow the well to either pump sand for some period of time after treatment or pump sand of a somewhat coarser grain size than is pumped in routine operation.

Based on the FY00 step tests, the results indicate that the most significant sand pumpage appears to be occurring at 25th Street Well 4, and it may be occurring on a continuing basis in routine operation. It is recommended that testing for the presence of sand in the discharge be continued during future step tests. This will continue to allow a qualitative assessment of the sand pumpage problem. Some wells may produce sand occasionally because of well development, as might occur immediately after an idle well is restarted. This can be verified as more wells are checked repeatedly during the step tests.

Nuisance Bacteria Sampling

The BART samples were collected by using the same procedure during step tests on 18 dewatering wells in FY 00. Although relatively high levels of nuisance bacteria were identified in the dewatering wells, the data clearly show that even wells in good condition contain the bacteria. Chemical treatments used to rehabilitate the wells apparently do not eliminate the nuisance bacteria from the wells. The prevalence of bacteria in the wells sampled might mean that they are indigenous to the groundwater, or that they are being regularly introduced into the wells from some other source. In either case, the problems associated with their presence will need to be managed on a continual basis. It is recommended that more background data be collected using the BART sets as additional dewatering wells are step tested. Although the use of BART sets for more detailed analysis of some wells probably is not warranted now, it may be considered in the future.

Future Investigations

A program of continued investigation of the condition of the dewatering wells is recommended. Measuring the difference between water levels in a well and the adjacent piezometer will continue to be an important first step in determining whether or not a well is a candidate for future step tests or treatment. In addition, a well pumping sand may indicate a potentially major problem with the well. A sand pumpage investigation is recommended as a standard part of each step test.

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Appendix A

Dewatering Well Groundwater Levels and Operation
FY 00 (Phase 17)

Appendix A. Dewatering Well Groundwater Levels and Operation, FY 00 (Phase 17)

I-70 Site

Well/ Piez.		*MP elev.*	*Temp MP*	*October 5, 1999*		*December 21, 1999*		*April 5, 2000*		*June 28, 2000*	
				GW elev.	*Pump* Δh	*GW elev.*	*Pump* Δh	*GW elev.*	*Pump* Δh	*GW elev.*	*Pump* Δh
W	1A	407.7	414.8	381.3	Off	376.3	Off	375.08	Off	372.73	Off
P	1A	*									
W	2A	408.2	413.9	379.6	Off	368.9	On	367.45	On	365.6	On
P	2A	*				370.9				45.93	
W	3A	402.6	407.5	377.1	Off	366.6	On	362.86	On	359.6	On
P	3A	*				368.9				42.47	
W	4	389.1	396.6	352.9	On	375.9	Off	374.79	Off	372.22	On
P	4			cascading water?							
W	5	385.9	391.1	375.0	Off	377.6	Off	376.47	Off	374.19	Off
P	5	391.1									
W	6	386.6	391.7	377.5	Off	379.4	Off	378.11	Off	376.21	Off
P	6	391.9									
W	7A	*		11.5	Off	22.06	On	25.18	On	27.15	On
P	7A	*				20.42		22.80		24.37	
W	8A	*		16.01	On	13.10	Off	14.40	Off	16.56	Off
P	8A	*		14.21							
W	9A		407.8	367.9	On	375.3	Off	374.05	Off	370.62	Off
P	9A	407.5		372.8		Was "on" at panel					
W	10	401.5	410.2	374.3	Off	372.6	Off	371.47	Off	360.26	On
P	10	409.8								piez. plugged	
W	11A	*		45.34	On	24.93	Off	26.10	Off	28.92	Off
P	11A	*		29.17							

Appendix A. (Continued)

I-70 Site (Concluded)

Well/ Piez.		*MP elev.*	*Temp MP*	*October 5, 1999*		*December 21, 1999*		*April 5, 2000*		*June 28, 2000*	
				GW elev.	*Pump Δh*	*GW elev.*	*Pump Δh*	*GW elev.*	*Pump Δh*	*GW elev.*	*Pump Δh*
W	12A		395.8	375.2	On	375.2	On	372.00	On	369.94	On
P	12A	395.8		375.3	pump rev.?	Small delta h again		374.44		372.42	
W	13	397.0	407.0	368.6	On	368.6	On	363.46	On	360.40	On
P	13	407.2		371.1		371.1		369.65			
W	14	382.5	391.0	376.8	Off	376.8	Off	375.74	Off	373.36	Off
P	14	390.8									
W	15	*		35.04	On	12.93	Off	14.19	Off	16.16	Off
P	15	*		20.36							
RW		390.6		376.9		371.1		373.75		370.0	

Appendix A. (Continued)

I-64 Site (Westbound)

Well/ Piez.		MP elev.	Temp MP	October 5, 1999 GW elev.	October 5, 1999 Pump Δh	December 21, 1999 GW elev.	December 21, 1999 Pump Δh	April 5, 2000 GW elev.	April 5, 2000 Pump Δh	June 28, 2000 GW elev.	June 28, 2000 Pump Δh
W	1	399.7	407.6	380.5	Off	379.0	Off	377.7	Off	374.8	Off
P	1	406.6									
W	2	397.1	402.1	383.7	Off	382.1	Off	380.8	Off	378.62	Off
P	2	401.5									
W	3	394.6	402.1	385.2	Off	383.6	Off	382.2	Off	380.2	Off
P	3	400.0									
W	4	394.0	400.2	386.1	Off	384.4	Off	383.0	Off	381.0	Off
P	4	399.4									
W	5	396.5	401.1	387.0	Off	385.3	Off	383.9	Off	381.7	Off
P	5	400.2									
W	6	394.3	400.2	387.5	Off	385.8	Off	384.5	Off	381.9	Off
P	6	399.9									
W	7	392.2	398.0	387.4	Off	385.8	Off	384.4	Off	381.2	Off
P	7	397.6									
W	8	396.7	405.5	386.6	Off	385.1	Off	383.8	Off	376.7	On
P	8	404.9								piez. plugged	
W	9	391.4	397.4	371.5	On	367.1	On	361.7	On	382.4	Off
P	9	397.0		380.8		378.4		375.7			
W	10	395.4	404.7	387.6	Off	386.1	Off	384.8	Off	382.7	Off
P	10	404.6									
RW	1	403.0		385.2		383.7		382.5		380.5	

Appendix A. (Continued)

I-64 Site (Eastbound)

Well/ Piez.		*MP elev.*	*Temp MP*	*October 5, 1999* *GW elev.*	*Pump Δh*	*December 21, 1999* *GW elev.*	*Pump Δh*	*April 5, 2000* *GW elev.*	*Pump Δh*	*June 28, 2000* *GW elev.*	*Pump Δh*
W	11	397.0	402.8	386.6	Off	381.8	Off	380.4	Off	378.4	Off
P	11	402.5									
W	12	395.2	401.6	384.8	Off	383.1	Off	381.6	Off	379.5	Off
P	12	401.5									
W	13	394.3	399.1	386.0	Off	384.3	Off	382.8	Off	380.7	Off
P	13	399.1									
W	14	396.0	400.5	386.8	Off	385.1	Off	383.6	Off	381.5	Off
P	14	399.7									
W	15	395.1	400.5	387.5	Off	385.8	Off	384.3	Off	381.9	Off
P	15	399.7									
W	16	393.7	399.8	387.7	Off	386.0	Off	384.6	Off	381.7	Off
P	16	398.8									
W	17	392.1	398.0	387.3	Off	385.8	Off	384.4	Off	375.7	On
P	17	397.8								piez. plugged	
W	18	391.3	396.6	386.4	Off	384.8	Off	383.6	Off	381.3	Off
P	18	396.4									
W	19	391.8	397.0	367.1	On	362.8	On	358.1	On	381.9	Off
P	19	397.0		381.4		379.8		378.8			
W	20	395.4	405.3	388.8	Off	387.3	Off	385.9	Off	377.5	On
P	20	404.7								piez. not found	
RW	2	398.2		385.6		383.58		382.6		381.8	

Appendix A. (Continued)

25th Street Site

Well/ Piez.		MP elev.	Temp MP	*October 5, 1999* GW elev.	*October 5, 1999* Pump Δh	*December 21, 1999* GW elev.	*December 21, 1999* Pump Δh	*April 5, 2000* GW elev.	*April 5, 2000* Pump Δh	*June 28, 2000* GW elev.	*June 28, 2000* Pump Δh
W	1	399.7	407.4	391.8	Off	392.1	Off	abandoned		abandoned	
P	1	407.3									
W	2	394.6	402.8	No access		no access	Off	388.1	Off	378.2	On
P	2	401.9		Well treatment						383.5	
W	3	390.4	400.3	384.0	On	no access	Off	379.4	On	383.8	Off
P	3	400.2		384.6							
W	4	392.4	401.6	380.3	On	no access	Off	386.6	Off	383.7	Off
P	4	401.5		piez. plugged							
W	5	396.2	404.2	382.2	On	no access	Off	387.6	Off	385.2	Off
P	5	403.8		piez. plugged							
W	6	396.5	405.4	388.7	Off	no access	Off	386.04	Off	384.1	Off
P	6	404.5									
W	7	392.6	402.9	369.5	On	386.3	On	380.72	On	378.7	On
P	7	402.0		piez. plugged						381.7	
W	8	390.8	401.0	374.8	On	390.6	Off	380.22	On	377.5	On
P	8	400.5		385.0						380.0	
W	9	409.4	414.5	383.3	On	386.5	On	388.47	Off	386.8	Off
P	9	414.7		390.4							
W	10	398.6	407.5	392.5	Off	392.1	Off	abandoned		abandoned	
P	10	406.1									
RW		401.4		390.6		389.4		388.1		387.5	

Appendix A. (Continued)

Venice Site

Well/ Piez.		MP elev.	Temp MP	*October 5, 1999* GW elev.	Pump Δh	*December 21, 1999* GW elev.	Pump Δh	*April 5, 2000* GW elev.	Pump Δh	*June 28, 2000* GW elev.	Pump Δh
W	1	405.6	411.6	382.4	On	381.9	On	378.9	On	379.4	On
P	1	411.2		piez. plugged		piez. plugged		piez. plugged		piez. plugged	
W	2	405.6	411.0	383.6	On	389.1	Off	388.9	Off	391.9	Off
P	2	410.3		385.7							
W	3	402.6	408.6	386.5	On	384.0	On	388.5	Off	387.0	On
P	3	408.4		388.5		386.4				389.4	
W	4	403.1	408.1	390.1	Off	388.7	Off	384.3	On	391.2	Off
P	4	407.2									
W	5	401.1	407.4	375.4	On	377.4	On	388.9	Off	391.9	Off
P	5	407.2		piez. plugged		391.9					
W	6A	400.8	408.4	389.8	Off	388.8	Off	389.2	Off	392.1	Off
P	6A	408.6									
W	7	399.3	407.5	373.6	On	382.6	Off	382.6	Off	386.5	Off
P	7	409.1		381.2							
RW		407.3		389.5		387.8		388.6		381.5	

Appendix A. (Concluded)

Missouri Avenue Site

Well/ Piez.		MP elev.	Temp MP	October 5, 1999		December 21, 1999		April 5, 2000		June 28, 2000	
				GW elev.	*Pump Δh*	*GW elev.*	*Pump Δh*	*GW elev.*	*Pump Δh*	*GW elev.*	*Pump Δh*
W	1	408.7		357.8	On	368.4	On	369.2	On	well trtment	On
W	2	417.6	Off	381.1	Off	378.7	On	378.9	On	367.5	On
W	3	415.4		363.2	On	365.0	On	372.2	On	377.8	Off
P	2-93	415.5		381.8		380.4		376.4		379.3	
OW	3(br.)	402.5		386.7		384.4		383.2		<377.5	

Notes:
* Measuring point elevations not available; depths to water recorded
** Pump removed from well
GW elev. = ground-water elevation
MP elev. = measuring point elevation
OW = observation well
P or piez. = piezometer
Pump = pump operation status
RW = recorder well
Temp MP = elevation of temporary measuring point
W = well
? Status uncertain/not verified
Δh = difference in ground-water elevation between well and piezometer

Appendix B

Chemical Quality of Groundwater from Dewatering Wells
FY 00 (Phase 17)

Appendix B. Chemical Quality Data, FY 00 (Phase 17)

Well	*Date*	*Lab No.*	*Iron*	*Manganese*	*Calcium*	*Magnesium*	*Sodium*	*Silica*	*Nitrate*	*Chloride*	*Sulfate*	*Alkalinity*	*Hardness*	*TDS*
I-70 Site														
2A	13-Oct-99	231537	13.43	1.33	234	50.5	193	32.4	<0.13	194.0	409	512	792	1465
4	4-Nov-99	231539	12.92	0.99	199	47.5	61.4	29.2	<0.13	96.7	337	414	692	1076
5	4-Nov-99	231540	9.65	0.55	143	36.8	50.9	30.9	<0.13	95.5	138	384	508	766
6	10-Nov-99	231560	15.95	0.65	199	59.3	98.9	33.0	<0.13	105	197	628	741	1064
8A	14-Oct-99	231538	9.58	0.89	188	41.3	89.0	31.6	<0.13	100	286	448	639	1047
14	3-Nov-99	231541	9.42	0.79	155	39.0	58.3	31.2	<0.13	85.4	171	376	547	777
15	5-Nov-99	231542	15.50	0.65	191	54.5	99.6	32.5	<0.13	152	182	541	701	1069
25th Steet Site														
2	4-Apr-00	231689	20.88	0.77	215	55.7	331.0	33.8	<0.06	45.3	952	438	766	1877
3	11-May-00	231758	14.61	0.61	200	48.2	208	32.7	<0.06	54.2	613	451	697	1452
4	11-May-00	231759	10.98	0.55	166	43.0	18.6	36.2	<0.06	37.1	161	398	591	711
5	10-May-00	231757	9.65	0.52	162	41.1	16.9	35.2	<0.06	28.0	159	399	573	690
6A	2-May-00	231754	11.54	0.37	149	40.9	16.4	35.7	<0.06	32.2	160	380	540	686
7	3-May-00	231755	11.76	0.46	149	41.6	20.4	35.0	<0.06	37.8	164	364	543	684
8	3-May-00	231756	11.59	0.52	145	41.6	28.9	38.4	<0.06	39.8	166	365	533	689
9	6-Apr-00	231690	12.89	0.55	170	48.7	67.8	34.3	<0.06	38.3	298	395	625	894
Missouri Avenue Site														
2	8-Jun-00	231829	10.02	0.89	201	42.2	77.9	31.0	<0.06	74.9	296	438	675	1041
3	9-Jun-00	231828	11.50	0.83	181	39.0	78.5	33.2	<0.06	64.2	258	427	612	959
4	7-Jun-00	231827	13.23	1.14	226	56.0	73.8	31.4	<0.06	88.8	370	533	795	1262

Notes:

TDS - Total dissolved solids

All chemical concentration data units are in mg/L

* - Reported as calcium carbonate ($CaCO_3$)

Appendix B. Chemical Quality Data (Concluded)

Fluoride	*Aluminum*	*Arsenic*	*Barium*	*Beryllium*	*Boron*	*Cadmium*	*Chromium*	*Copper*	*Lead*	*Mercury*	*Nickel*	*Potassium*	*Selenium*	*Silver*	*Zinc*
0.3	<0.02	<0.11	0.08		0.89	<0.017	<0.007	<0.01	<0.066		<0.031	15.0	<0.18		<0.02
0.3	0.02	<0.11	0.09		0.39	<0.017	<0.007	<0.01	<0.066		<0.031	14.6	<0.18		<0.02
0.3	0.02	<0.11	0.08		0.23	<0.017	<0.007	<0.01	<0.066		<0.031	11.4	<0.18		<0.02
0.3	<0.02	<0.11	0.13		0.85	<0.017	<0.007	<0.01	<0.066		<0.031	5.9	<0.18		<0.02
0.2	<0.02	<0.11	0.08		0.85	<0.017	<0.007	<0.01	<0.066		<0.031	15.7	<0.18		<0.02
0.3	0.03	<0.11	0.08		0.34	<0.017	<0.007	<0.01	<0.066		<0.031	11.3	<0.18		<0.02
0.3	0.03	<0.11	0.13		0.66	<0.017	<0.007	<0.01	<0.066		<0.031	13.8	<0.18		<0.02
0.7	0.04	<0.089	0.07		0.45	<0.013	<0.007	<0.01	<0.041		<0.015	10.0	<0.27		<0.01
0.5	<0.03	<0.089	0.07		0.38	<0.013	<0.007	<0.01	<0.041		0.015	16.7	<0.27		<0.01
0.2	0.08	<0.089	0.23		0.15	<0.013	<0.007	<0.01	<0.041		<0.015	8.7	<0.27		<0.01
0.3	<0.03	<0.089	0.29		0.10	<0.013	<0.007	<0.01	<0.041		<0.015	10.9	<0.27		<0.01
0.3	<0.03	<0.089	0.27		0.08	<0.013	<0.007	<0.01	<0.041		<0.015	10.1	<0.27		<0.01
0.3	<0.03	<0.089	0.19		0.15	<0.013	<0.007	<0.01	<0.041		<0.015	8.3	<0.27		<0.01
0.3	<0.03	<0.089	0.10		0.22	<0.013	<0.007	<0.01	<0.041		<0.015	9.8	<0.27		<0.01
0.2	0.03	<0.089	0.16		0.20	<0.013	<0.007	<0.01	<0.041		<0.015	6.5	<0.27		<0.01
0.3	<0.03	<0.089	0.09		0.95	<0.013	<0.007	<0.01	<0.041		<0.015	13.0	<0.27		<0.01
0.3	<0.03	<0.089	0.09		1.06	<0.013	<0.007	<0.01	<0.041		<0.015	8.5	<0.27		<0.01
0.2	<0.03	<0.089	0.12		1.19	<0.013	0.007	<0.01	<0.041		<0.015	20.0	<0.27		<0.01

Illinois State WATER Survey (1895)

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