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PRECISION DUAL-AQUIFER DEWATERING AT A LOW LEVEL RADIOLOGICAL CLEANUP IN NEW JERSEY

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ABSTRACT

Cleanup of low-level radioactive wastes at the Wayne Interim Storage Site (WISS), Wayne, New Jersey during the period October, 2000 through November, 2001 required the design, installation and operation of a dual-aquifer dewatering system to support excavation of contaminated soils. Waste disposal pits from a former rare-earth processing facility at the WISS had been in contact with the water table aquifer, resulting in moderate levels of radionuclides being present in the upper aquifer groundwater. An uncontaminated artesian aquifer underlies the water table aquifer, and is a localized drinking water supply source. The lower aquifer, confined by a silty clay unit, is flowing artesian and exhibits potentiometric heads of up to 4.5 meters above grade. This high potentiometric head presented a strong possibility that unloading due to excavation would result in a “blowout”, particularly in areas where the confining unit was < 1 meter thick. Excavation of contaminated materials was required down to the surface of the confining unit, potentially resulting in an artesian aquifer head of greater than 8 meters above the excavation surface. Consequently, it was determined that a dual-aquifer dewatering system would be required to permit excavation of contaminated material, with the water table aquifer dewatered to facilitate excavation, and the deep aquifer depressurized to prevent a “blowout”. An additional concern was the potential for vertical migration of contamination present in the water table aquifer that could result from a vertical gradient reversal caused by excessive pumping in the confined system. With these considerations in mind, a conceptual dewatering plan was developed with three major goals: 1) dewater the water table aquifer to control radionuclide migration and allow excavation to proceed; 2) depressurize the lower, artesian aquifer to reduce the potential for a “blowout”; and 3) develop a precise dewatering level control mechanism to insure a vertical gradient reversal did not result in cross-contamination. The plan was executed through a hydrogeologic investigation culminating with the design and implementation of a complex, multi-phased dual-aquifer dewatering system equipped with a state of the art monitoring network.

INTRODUCTION

Site Background

The Wayne Interim Storage Site (WISS) is located at 868 Black Oak Ridge Road, at the intersection with Pompton Plains Cross Road in Passaic County, New Jersey. The WISS is located in a highly developed area of New Jersey, approximately 32 kilometers north-northwest of Newark, New Jersey. The area of the site is approximately 2.6 hectares.

From 1948 through 1971, Rare Earths/W.R. Grace Company processed monazite sand at the property to extract thorium and rare earths. After processing ceased in 1971, the facility was licensed for storage only. In 1974, W.R. Grace partially decontaminated the site and the Nuclear Regulatory Commission (NRC) assumed licensing responsibilities formerly held by the U.S. Atomic Energy Commission. The storage license for radioactive materials was terminated by the NRC following site decommissioning, and the site was released without further restriction, stipulating that the property deed state that radioactive materials were buried on the property.

In 1981, the NRC measured direct radiation levels and radionuclide concentrations in soil on the property. Elevated survey measurements were noted, indicating that the site was contaminated with Radium (Ra)-226, Thorium (Th)-232, and Uranium (U)-238. The site was placed on the National Priorities List (NPL) on September 21, 1984. The Department of Energy (DOE) was authorized by the Energy and Water Appropriations Act of 1984 to conduct decontamination research and development at the site. From 1984 to October 1997, the DOE managed the WISS under the Formerly Used Sites Remedial Action Program (FUSRAP). In October 1997, FUSRAP was transferred from DOE to the U.S. Army Corps of Engineers through an act of Congress.

Between 1985 and 1987, removal actions were conducted to remove contaminated material from off-site locations in the vicinity of the site. Excavated waste materials, containing radioactively contaminated soil and building rubble from the remediated off-site properties, was placed in an interim storage pile at the WISS. The interim disposal pile was removed in 1997 and the material was shipped off-site for disposal. The underlying waste process soil remained in place at this time.

The WISS is presently in the final phases of a removal action conducted in accordance with a Record of Decision (ROD) dated April 27, 2000 (1). The major components of the selected remedy under the ROD included:

- Excavation and disposal of the remaining contaminated subsurface materials to an average concentration of 5 picoCuries/gram (pCi/g) of Ra-226 and Th-232 combined, and an average of 100 pCi/g of total U above naturally occurring background as determined by surveys consistent with the Multi-agency Survey and Site Investigation Manual, eliminating risks above the Comprehensive Environmental Response, Compensation, and Liability Act risk threshold for unrestricted use scenarios.
- Excavation and disposal of chemically contaminated soils above levels calculated to be protective of groundwater or above levels protective for unrestrictive uses of the property.
- Removal and treatment of groundwater encountered during excavation.
- Decontamination, demolition and offsite disposal of the remaining building at the WISS, and removal and offsite disposal of contamination of material underneath it.

- Implementation of a five-year groundwater monitoring program to establish groundwater quality after contaminated soil has been removed.
- Ensured protection of a clay confining layer separating two distinct aquifers identified on the site, and disposal of contaminated waste at an appropriate commercial facility.

Based upon a review of earlier investigative reports (3,6), it was recognized that excavation and removal of the deeper contaminated soils at the WISS site would require some level of dewatering to address groundwater inflow to the open excavation pit.

SITE DESCRIPTION

Physiography

The WISS site is located in the Piedmont physiographic province of Northern New Jersey. This area was subject to glacial action that eroded ridges and deposited a variety of unconsolidated materials throughout the general area. The WISS is situated in the drainage basin of the Pompton River, which is a tributary of the Passaic River. Site elevation ranges from 60 to 65.5 meters above mean sea level, and the topography is gently westward sloping

Geology

Bedrock underlying the WISS is comprised of igneous and sedimentary rock of the Lower Jurassic System. The bedrock in the area consists of the Brunswick Group, which includes the Boontoon Formation and the Hook Mountain Basalt (2). The Boontoon Formation, previously the Brunswick Formation, is composed of alternating beds of sandstone, mudstone, shale, and conglomerate. The thickness of the Boontoon Formation is approximately 500 meters. The strike of the Brunswick Group is estimated to be 15 to 20 degrees northwest, based on the orientation of the crest of an adjacent ridge. Structural dip, based upon description of cores retrieved at the WISS, is estimated to be 13 to 17 degrees southwest. The Hook Mountain Basalt is one of three sheets of basalt formed during a series of lava flows that occurred during the deposition of the Brunswick Group. The basalt forms resistant ridges in the area, including a ridge just east of the WISS and underlies the Boontoon Formation at depth. No borings drilled at the WISS have encountered basalt, which is estimated to lie at a depth of 107 meters on the basis of strike and dip of the rock units in the immediate area (3).

Unconsolidated Pleistocene glaciofluvial deposits and a thin veneer of Holocene sediments overlie the bedrock at the WISS. Based upon test borings taken at the site, the lowermost sediments deposited on bedrock are poorly sorted, sand-rich, well compacted glacial till. The lower portions of the unconsolidated sediments are composed of poorly sorted clay, sand and gravel. The sediments display a fining upward sequence, and are likely attributed to the formation of ancient Lake Passaic in the region. This unit is generally referred to as the “sand and gravel unit” throughout the text. Overlying these unconsolidated sediments is a clay layer, likely deposited during a period in time in which the WISS area was completely inundated by Lake Passaic. This clay probably covered the entire site at one time, but the total thickness has been reduced due to subsequent erosion and, in the northern portion of the site, completely removed as the result of post-glacial fluvial channels (3). Present thickness of this clay ranges from 0 to 6 meters. This clay unit represents an important confining layer, discussed further in subsequent sections. The post-glacial fluvial channel filling material that overlies the confining clay represents the uppermost surficial unit. It is composed of material similar to those deposited in the lower part of the section: poorly sorted clays, sands and gravel overlain by several feet of soil, and is referred to as the “upper unconsolidated material” throughout the text. Geologic cross sections of the WISS are illustrated in Figure 1.

Hydrogeology

The WISS is located within the northern-most extension of the EPA-designated Buried Valley sole source aquifer (4). Groundwater in the Buried Valley sole source aquifer is classified as IIa, with a designated use of potable groundwater with conventional water supply treatment. Although partially within the Buried Valley Aquifer Boundaries, the drinking water supply in Passaic County, where the WISS is located, is obtained primarily from surface sources (5).

There are two primary aquifers present at the WISS. The shallow groundwater system is composed of the waters within the unconsolidated sediments above the aforementioned confining layer. The upper system is referenced in this text as the “water table aquifer.” The lower groundwater system is within the lower unconsolidated sediments and underlying bedrock below the confining clay. The lower system is referred to as the “confined aquifer” in this text. Static water table conditions exist in the upper groundwater system, while the lower system exhibits artesian conditions, with the potentiometric surface measured up to 4.5 meters above grade. Groundwater levels from all wells completed in bedrock were above ground level, except in the extreme southeastern portion of the site. The highest potentiometric surface measurements and the shallowest depths to groundwater at the site occur north of the 5100 coordination line. The is primarily a function of topography. The site slopes gently northwestward, with the lowest elevations exhibited in the northwest corner.

The shallow groundwater flow direction is from the east to the west with an approximate horizontal gradient of 0.055. The westerly gradient resembles the surface topography at WISS. The average horizontal groundwater velocity in shallow aquifer is estimated at 21 meters per year (m/y), and likely discharges to Scheffield Brook, a small stream located approximately 76 meters west of the site (3).

Mapping of the potentiometric surface of the confined groundwater system is problematic because of the flowing nature of most wells, which required measurement using elevated sections of clear tubing. The gradient is inferred to resemble that of the upper system, with the potentiometric surface above ground level. The average horizontal velocity of the confined groundwater system is estimate to be 24 to 126 m/y.

Low-level radionuclide contamination was evident in the water table aquifer due to residual contamination within the interim storage pile and associated waste pits. The confined system was historically clean, and is utilized within the township as a potable water source, so the prevention of aquifer cross contamination during dewatering and excavation activities was a necessity.

HYDROGEOLOGIC INVESTIGATION

Existing Data Review and Dewatering Design Investigation

The site excavation plan required overburden removal to the upper surface of the confining layer in most areas of the site. In addition this would leave only a relatively thin confining layer thickness (in some areas less than 1 meter) during excavation, it was recognized that high

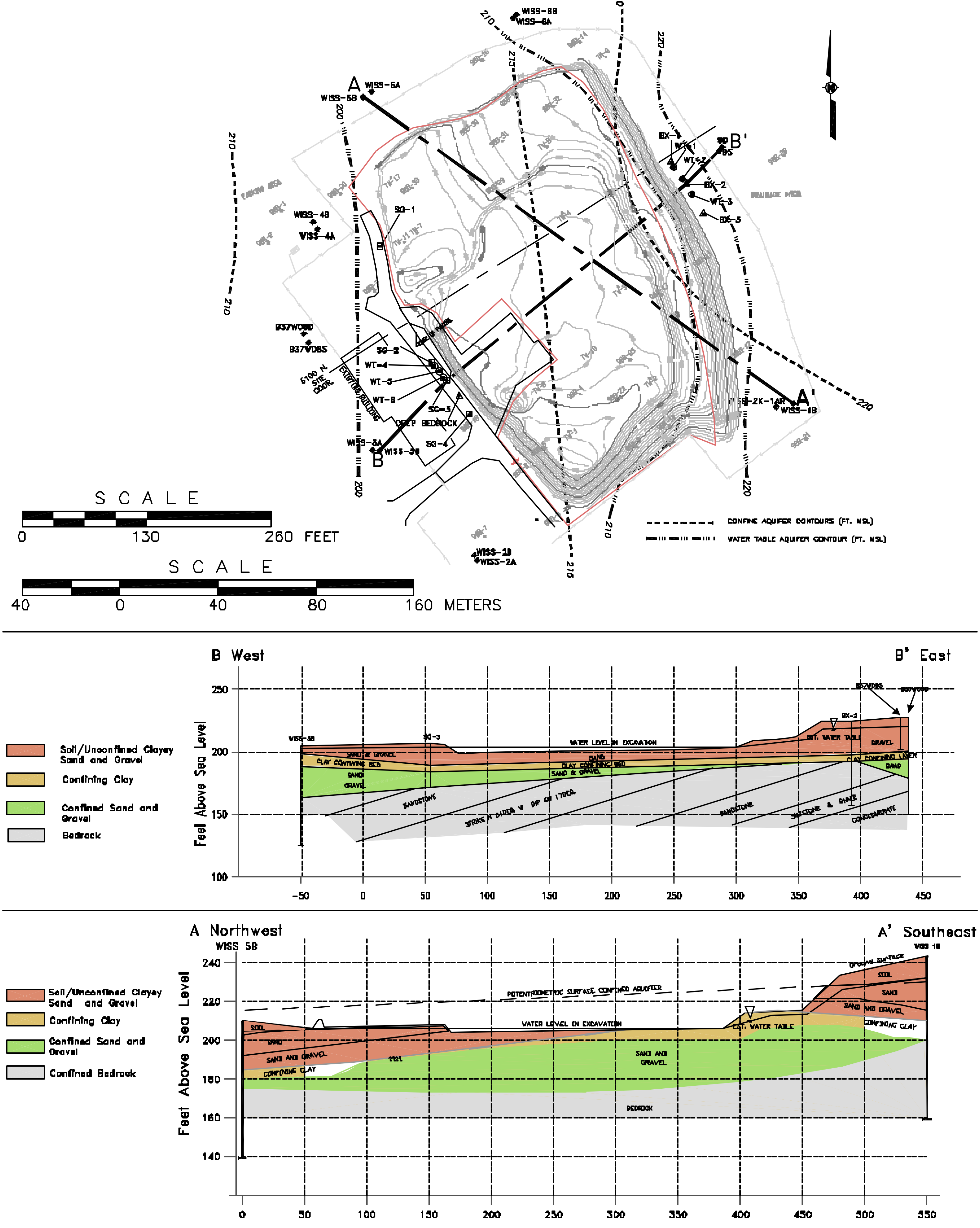


Figure 1 - Geologic Cross Sections And Static Water Levels

pressures in the confined aquifer could potentially cause a failure resulting in uncontrolled discharge of confined aquifer groundwater into the excavation. Dewatering of the water table aquifer was required to allow excavation to proceed under non-saturated conditions, to prevent excavation flooding, and to control any potential lateral migration of residual radionuclide contaminants. Due to hydrogeologic complexities, dewatering design efforts needed to consider both the water table aquifer and confined aquifer. The confined aquifer exhibited high potentiometric heads (up to 4.5 meters above grade) in the northern end of the site, An evaluation of confined aquifer pressure heads verses the thickness and density of the confining layer indicated a high probability that a “blowout” would occur during excavation north of the North 5100-foot Site Coordinate Line (Figure 1). Therefore, the dewatering plan would need to incorporate depressurization of the confined aquifer north of that line, in concert with water table dewatering.

An additional dewatering system design consideration was the prevention of potential migration of residual contamination from the water table aquifer, downward into the confined aquifer. The confined aquifer is a localized water supply source, with numerous private and public wells within a 1-mile radius. Since the dewatering system design would necessitate pumping from both the water table and confined aquifers, it was recognized that a reversal of vertical gradients could result in contaminants being drawn into the confined aquifer, potentially impacting local water supply wells. Consequently, the dewatering design needed to include precise drawdown regulation of the confined aquifer, to insure confined aquifer levels were not drawn below adjacent water table levels.

Although a review of previous investigations performed at the WISS site revealed the need for these dewatering objectives, there was some question as to the technical practicability of these goals. To establish if the conceptual dewatering approach was viable, and to determine site-specific design details, additional investigation activities were necessary. The dewatering system was designed using a groundwater flow model to evaluate various dewatering system scenarios. To ensure the groundwater flow model had accurate, site specific input data, additional wells installed and a series of pumping tests were conducted with to provide representative data from both the water table and confined aquifers.

Well logs from earlier investigations were reviewed, to determine the most beneficial locations to perform pumping tests and to identify lithologic data gaps. Measured well yields and related data from earlier reports were used to estimate optimum well spacing for pumping tests in the water table aquifer, the sand and gravel unit and in bedrock. The expected radius of influence for pumping tests in each of these formations was calculated using the Modified Theis Non-Equilibrium Equation (7), with estimated values for hydraulic conductivity, storage, and flow rate taken from earlier reports. Variable observation well distances were substituted in the equation, with the equation solved for drawdown. This evaluation indicated that the radius of influence in the water table aquifer would be approximately 12 meters, while the sand and gravel/bedrock radius of influence would be approximately 76 meters. Based on these results, well spacing for each pumping test was planned accordingly, using existing monitoring wells wherever practical. A total of 14 monitoring and pumping wells were utilized for the dewatering system design pumping tests.

Monitoring Well Installation

Test wells were completed in three distinct stratigraphic units: the unconsolidated material overlying the confining layer, the sand and gravel unit underlying the confining unit and bedrock. Monitoring well installation and completion procedures were designed to prevent any possible hydraulic connection between each of these units, both to prevent cross-contamination and to ensure representative water levels. Down-hole geophysical logs were run at all existing and newly installed wells to evaluate variations in lithology. Water table wells were installed by hollow-stem auger drilling method, while sand and gravel unit wells and bedrock wells were completed using mud-rotary drilling. Water table wells were constructed of single PVC casings and screens. Sand and gravel unit wells were installed with steel outer casings notched and grouted into the confining layer, followed by installation of a PVC inner well screened in the sand and gravel unit.

Bedrock wells that penetrated the sand and gravel unit incorporated double outer casings, sealed in the confining unit and upper bedrock, respectively, and completed as open-hole wells. Bedrock wells that did not encounter the sand and gravel unit were completed with single outer steel casings grouted into the upper bedrock surface, completed as open-hole wells.

Aquifer Pumping Tests

Two pumping test areas were selected, located on the northeastern and northwestern perimeters of the excavation. Each pumping test location included water table and confined aquifer test pumping wells in close proximity. This allowed simultaneous controlled pumping from both aquifers, so gradient reversals could be prevented. Monitoring wells in both aquifers were spaced according to the anticipated radius of influence for each aquifer, and situated along north-south and east-west orientations from the pumping well where possible. Following completion and development of the new test wells, synoptic water level rounds were obtained, with these data used for steady-state calibration of the groundwater flow model. Static (non-pumping) groundwater elevations in the water table and confined aquifers from synoptic water level measurements are illustrated on Figure 1.

Pumping tests were conducted for each of the two test areas. Each test consisted of background monitoring, an 8-hour step-pumping test, followed by a 12 or 48 hour constant rate test, depending on yield. Recovery periods after the step-pumping and constant rate tests were included, resulting in a one-week testing period for each test area. Each pumping test addressed both the water table and confined aquifer simultaneously; to ensure that vertical gradient reversals did not occur. Test pumping always started with the water table aquifer, subsequently followed by pumping in the confined aquifer to prevent a reversal in vertical gradient. Shutdown procedures were reversed, with the confined aquifer test turned off prior to the water table pump, again to insure water levels in the confined aquifer always remained higher than those in the water table aquifer. Target drawdowns for each pumping test equaled two-thirds of available drawdown in the water table test pumping well, with confined well drawdown maintained at a minimum of 0.3 meters above the measured water table pumping level.

The setup at each pumping test location utilized generator powered submersible pumps, with flow control valves, flow meters and sampling ports. A total of 33 *In-Situ Mini-Troll*™ water level recorders were situated on site wells, and connected to a dedicated personal computer (PC) to facilitate monitoring water level changes. An ambient pressure *Mini-Troll*™ was used for barometric readings, allowing subsequent atmospheric pressure data corrections. All water level recordings were confirmed with hand measurements, and distant wells not equipped with water level recorders were hand measured at 3-hour intervals.

Pumping test results were analyzed using time/drawdown and distance/drawdown solutions by Cooper-Jacob, Theis, Moench, and Hantush. Time/drawdown methods were segregated into early–time and late-time data sets, for additional comparison. After selecting the most representative solutions, and averaging the results, the following hydraulic conductivity values were derived:

- 212 to 319 liter/day/square meter(lpd/m^2) in the water table aquifer
- 177 to 530 lpd/m^2 in the sand and gravel unit
- 177 to 266 lpd/m^2 in the bedrock.

Aquifer storage values were as follows:

- $4.4x10^{-3}$ in the water table aquifer
- $9.3\ x10^{-4}$ in the sand and gravel unit
- $8.6\ x10^{-5}$ in the bedrock unit.

Major conclusions from the pumping test results were:

- The water table aquifer is hydraulically separated from the confined aquifer in most areas of the site
- The sand and gravel aquifer is hydraulically connected with the bedrock aquifer (forming the confined aquifer)
- There is a distinctive preferential north-south transmissivity along the western edge of the excavation area.

The preferential transmissivity was observed to a lesser degree at other areas of the site and, as it parallels strike, it is suspected to be due to secondary porosity (fractures) in bedrock.

Groundwater Flow Modeling

The results of pumping tests, along with synoptic water level data, well logs, and published regional geologic data, were used to develop the site-specific groundwater flow model. The selected modeling software was MODFLOW (8), which is three-dimensional flow code, using block centered finite-difference approach to approximate partial differential groundwater flow equations. The model was constructed with 5 layers, representing the water table, the confining unit, the sand and gravel unit (where present), and upper and lower bedrock. The model covered an area approximately 0.8 km by 0.8 km, spatially discretized into 110 rows and 113 columns. The model was calibrated to steady-state conditions using synoptic water level data, and to transient conditions based on observed pumping test water levels from the conclusion of the constant rate testing.

Following model calibration, predictive dewatering simulations under transient conditions were performed to establish if the dewatering goals could be met, and to determine the most appropriate and efficient dewatering system design. Existing wells were utilized in the model development where possible, to reduce the actual number wells to be installed. Correcting for vertical gradient reversal effects from various dewatering scenarios proved difficult in early model runs. This was resolved in latter model runs by including water table dewatering wells in southern areas of the excavation, in order to lower water table levels to below depressurized confined aquifer levels. Initially 13 individual predictive model runs were performed in order to develop a scenario that met WISS dewatering performance goals. Three additional model runs were subsequently performed that addressed a two-phase approach to startup and operation. These runs also addressed requirements for dewatering in the northwestern portion of the site, where the vertical extent of contamination was poorly understood.

The selected model scenario included phased installation and startup of the dewatering system, with up-gradient dewatering wells (Phase I) started several weeks prior to the whole system (Phase II). Phased approach model runs were used to refine excavation plans, provide indications of where and to what depth excavation could safely proceed, and confirm that partial operation of the dewatering system would not cause any adverse effects. The phased dewatering approach allowed installation of the dewatering system to proceed in stages, which assisted in coordination of drilling activities along the perimeter of the excavation. The greatest benefit of the phased approach was in scheduling, as it permitted dewatering operations to proceed ahead of schedule, thereby allowing an accelerated soil excavation schedule. Output figures from the final model scenario that was selected (Model Run P) are illustrated on Figure 2. These figures emphasize model results for Layer 4 (bedrock), as this was a model target layer for dewatering design decisions.

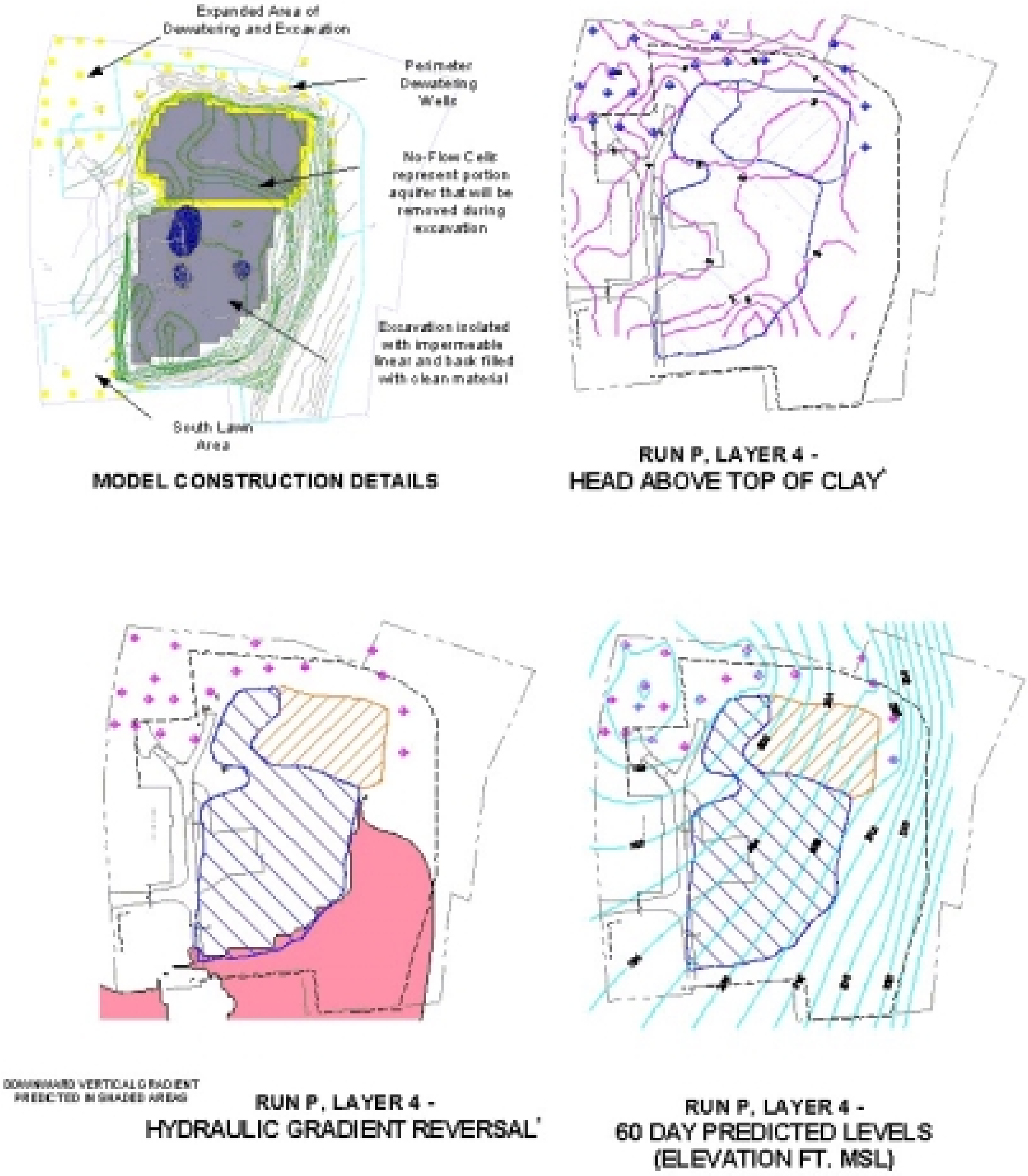
Final model results indicated that dewatering goals could best be achieved using 45 water table wells, 3 sand and gravel wells, and 19 bedrock wells, situated around the northern and western perimeter of the excavation. Model outputs included well locations and model construction detail figures, head above clay / gradient reversal maps, and 3-day, 30-day and 60-day transient runs depicting predicted water level contours. The well location and model construction details showed the position of proposed dewatering wells and site conditions the model was based on (e.g. no flow cells in areas already excavated, backfill and liner details, etc.). The 3-day and 30-day runs allowed flow estimations for determining maximum water treatment capacity, and for developing staged excavation plans. Sixty-day model runs were used to evaluate long-term drawdown effects and yields. The final 60-day model run predicted drawdowns of greater than 10-feet near the center of the excavation pit, and flow rates of approximately 17-gpm for the water table aquifer and 14-gpm for the confined aquifer.

The model indicated that there would be the need for numerous additional wells to adequately dewater the extreme northwestern portion of the site, but this area was not addressed initially, rather a decision was made to characterize the vertical extent of contamination and review dewatering effects prior to installing wells.

DEWATERING SYSTEM DESIGN

Design Considerations

Following completion of the MODFLOW modeling efforts, detailed design of the WISS dewatering system was initiated. Design parameters for the WISS dewatering system were as follows:



MODEL CONSTRUCTION DETAILS

RUN P, LAYER 4 -
HEAD ABOVE TOP OF CLAY'

RUN P, LAYER 4 -
HYDRAULIC GRADIENT REVERSAL'

RUN P, LAYER 4 -
60 DAY PREDICTED LEVELS
(ELEVATION FT. MSL)

Fig. 2 – Groundwater Flow Model Outputs

- Design a dual aquifer dewatering system based on the final MODFLOW model results, which will effectively dewater the water table aquifer to facilitate excavation work, and depressurize the confined aquifer sufficiently to prevent an uncontrolled release of groundwater (“blowout”).
- Design the dewatering system to allow precise control of dewatering levels in both aquifers, to prevent any possibility of a vertical gradient reversal.
- Design the dewatering system for implementation in two phases.
- Design a groundwater level monitoring system capable of continuously recording dewatering levels achieved in both aquifers, to confirm vertical gradient.
- Provide sufficient flexibility in the design to accommodate excavation of soils around the dewatering system, as required.
- Incorporate separate discharge streams for water table and confined aquifer flow, in order to simplify water treatment.

Dewatering System Mechanical Design

While the MODFLOW model provided solid design information regarding dewatering well placement, anticipated yields, and phased approach methodology, determining the most effective pumping system required considerable engineering evaluation. Pumping test results indicated low hydraulic conductivity in the water table aquifer, causing difficulty in dewatering using conventional wells or well points. After considering a variety of pumping methodologies, it was decided that water table dewatering would utilize vacuum-enhanced pumping. Vacuum-enhanced pumps operate using applied suction to both extract fluids and apply a vacuum in the vadose zone to increase effective well efficiency. This application typically results in the largest effective pumping influence, and it has the added benefit of allowing surface suction pumps to be used (lift requirements were typically less than 6 meters). The use of fewer pumps provided greater flexibility to accommodate soil excavation work around dewatering wells. The selected design incorporated a series of suction header pipes, with flexible suction hoses routed to each dewatering well. Suction headers utilized were 15 cm diameter, light gauge steel pipes (Bauer Pipe™). These header pipes featured quick-connect fittings that allowed pipes to be joined at angles up to 30˚, allowing considerable flexibility in pipe routing. Regulation of applied suction to individual dewatering wells would be accomplished using valves attached to the suction header, allowing the draw from each well to be balanced.

Although adjustable based on actual field conditions, water table dewatering wells were designed with suction pipe intakes positioned approximately 15 cm off each well bottom, and sealed wellhead fittings to allow vacuum enhanced pumping conditions to be established. This allowed water table dewatering wells to be almost completely dewatered, with lateral pumping influences enhanced due to the vacuum effects in the vadose zone. The confined aquifer dewatering wells did not require vacuum enhanced pumping, so they would be operated under atmospheric conditions. Intakes on each confined aquifer dewatering well would be placed at, or above the design dewatering level, providing a positive control measure to prevent the possibility of a vertical gradient reversal. Intake levels in all dewatering wells were adjustable, to allow fine-tuning as necessary.

Water produced by the water table aquifer was known to have residual radionuclide contamination, whereas the confined aquifer was historically uncontaminated. Therefore, it was decided that discharge streams from each aquifer would be kept separate, to facilitate water treatment measures. Separate headers, pumps and discharge piping were used for water table dewatering wells and confined aquifer dewatering wells. The resultant design incorporated a total of three pumps, with two pumps drawing from suction headers connected to water table and confined aquifer dewatering wells in the northern end of the site, and the third pump addressing southern area water table wells. The diesel powered suction pumps utilized were capable of producing vacuum levels of up to 710 millimeters of mercury, and flow rates of well over 450 liters per minute each. As noise restrictions at the site were a major consideration, these pumps were jacketed in noise reduction containers (quiet- packs), and placed in noise suppression enclosures. Discharge from the water table aquifer system and the confined aquifer system were routed around the site perimeter to separate 20,000-gallon holding tanks for subsequent treatment.

Monitoring System Design

Due to the possibility of a vertical gradient reversal, resulting in aquifer cross-contamination, the dewatering system design incorporated a state of the art water level monitoring system, similar to that used during the hydrogeologic investigation. The monitoring system utilized eight existing perimeter monitoring wells, along with twelve additional monitoring wells installed at select locations. These twenty wells were situated in ten well pairs, with each pair having a water table aquifer well and an adjacent confined aquifer well. The well pairs were strategically located to allow water elevations in both aquifers to be closely monitored in areas of critical importance to the dewatering effort, as illustrated on Figure 3.

Continuous water level recorders (*In-Situ Mini-Trolls*™) were placed in each well, and connected via cable network to a computer located in a site trailer. The networked water level monitoring system displayed real-time water levels in all connected wells, and recorded water level trends in arithmetic or logarithmic scales. Downloads from each *Mini-Troll*™ were stored in the monitoring computer as Microsoft Excel files, and were used for developing trends graphs, as warranted.

DISCUSSION AND RESULTS

A total of 67 wells were initially utilized for groundwater extraction and water level monitoring: 22 in the confined aquifer, and 45 in the unconfined aquifer. Existing monitoring wells were used whenever possible, including eight monitoring wells for water level monitoring, and six existing wells for dewatering. Installation techniques for new wells were similar to those described for pumping tests, however three confined wells were installed as screened wells in an effort to exploit the water-bearing sand and gravel layer lying on top of bedrock.

Shallow extraction wells were sealed so that vacuum applied to the well would propagate into the formation for improved yield. A header isolation valve controlled vacuum at each well, while a wellhead sample port was used for vacuum monitoring and as an air-bleed to improve flow. Due to flowing artesian conditions, confined aquifer wellheads included a sealed lid with fittings for the vacuum extraction drawpipe, and an air inlet bleed valve. Wellheads for the confined aquifer monitoring wells also included a fitting for the water level data logger cable, and additional fittings to enable water level measurements both below and above the wellhead. Inductor pipes, constructed of 1inch diameter PVC, were installed in each confined well, with intakes positioned at the design drawdown elevation (0.6 m higher than intakes in adjacent water table wells to reduce the likelihood of a vertical gradient reversal). Flow rates in the confined aquifer

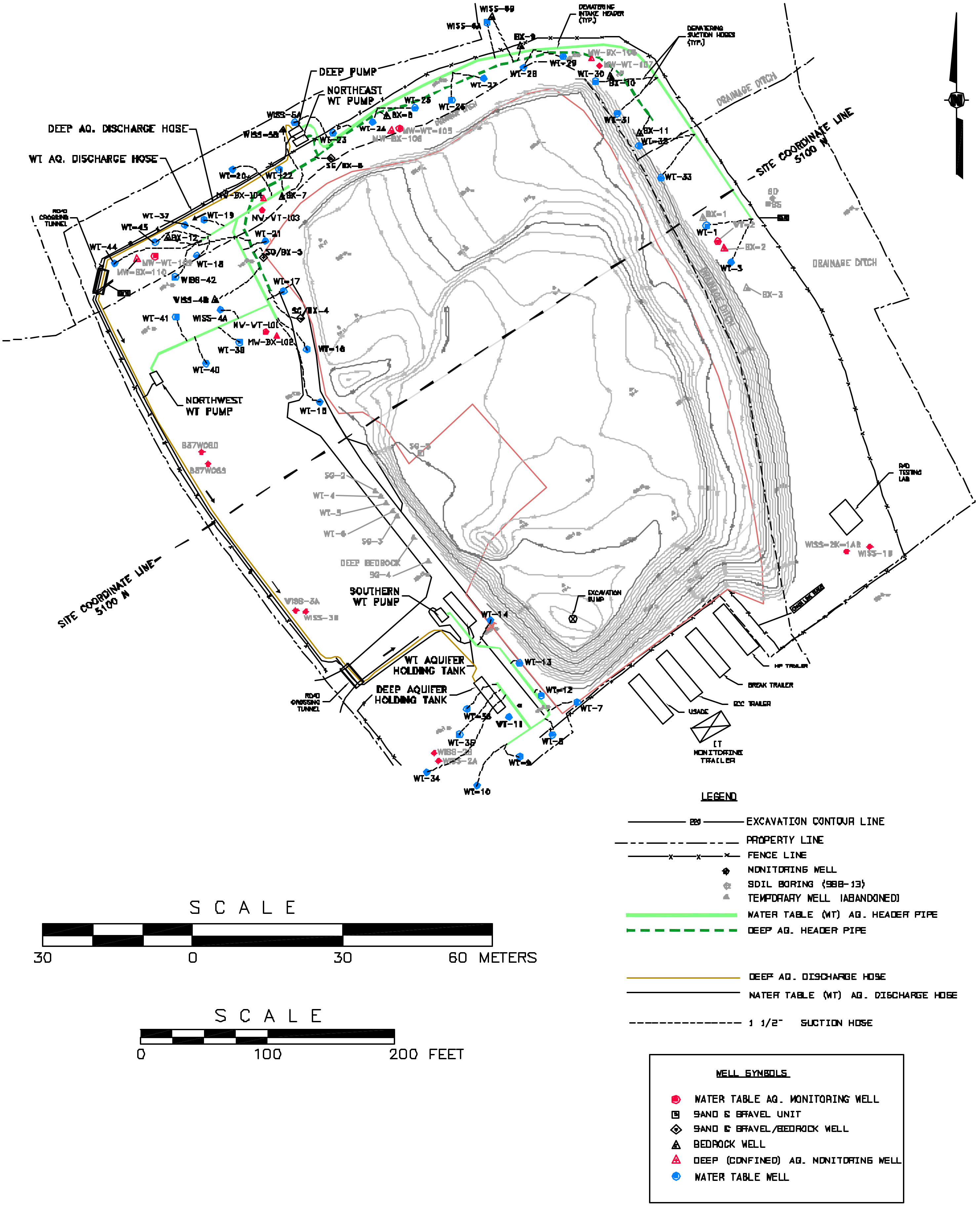


Figure 3 - Dewatering System Layout

dewatering wells were adjusted to slightly exceed well recharge at the dewatering design elevation, to maintain proper drawdown.

The dewatering system was brought on line using the phased approach previously described. This permitted dewatering operations to proceed ahead of schedule, as only part of the system had to be fully operational for excavation to commence, allowing an accelerated schedule.

Water level monitoring was conducted throughout dewatering to ensure that system criteria were met, and that the upward gradient between the deep and shallow wells was maintained. Water levels were recorded automatically at 15-minute intervals with electronic in-well data loggers, verified daily by hand. Each of the 20 monitoring wells was equipped with a data logger connected by a serial cable to a computer in the monitoring trailer. As a matter of procedure, computer water level data was reviewed every 2 to 3 hours throughout the project duration, 24 hours a day, 7 days a week. During each inspection, the data was evaluated for the gradient relationship between the shallow and deep aquifer. If the gradient in any well pair came close to inverting, flow rates would be adjusted to maintain the upward gradient. Individual well flow rates were adjusted at each well by controlling the amount of vacuum through the header intake valve to maintain the design water levels, thus balancing the system. The flow rate of the shallow and deep systems was measured at least once a day to evaluate pump operation. Changing flow rates often indicated the need to balance the wells, or inspect the pumps. A contingency plan detailed the actions required if one of the operating criteria was not met. This plan consisted of a designed sequence of events for balancing or shutting down the system in a manner that would retain the natural upward groundwater gradient between the two aquifers. An example of monitoring well cluster hydrographs is included on Figure 4.

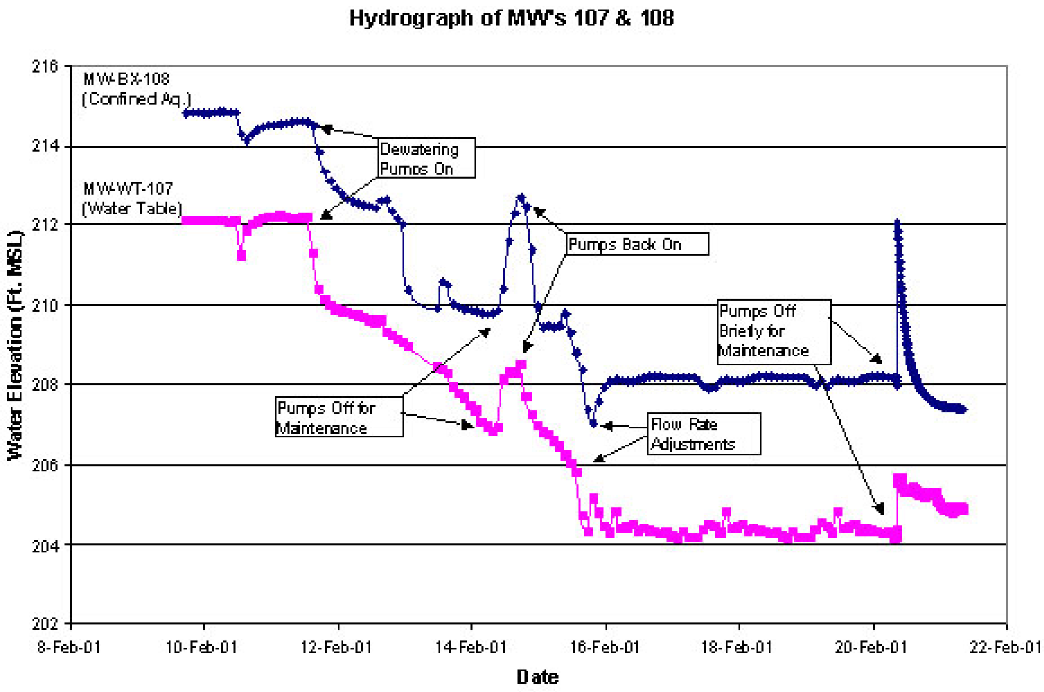


Fig. 4- Typical Monitoring Well Cluster Hydrograph

Operational procedures for the dewatering system included many factors to effectively control the water levels in the upper and lower aquifers, without reversing the natural upward gradient. The operational theory in removing water from as much as 8 meters below grade was to induce a high vacuum within the suction header system, while balancing all the flow control valves at each wellhead. Clear suction hoses enabled the operator to set the valves such that water was moving slowly into the header, rather than at high velocities, which was less efficient for the vacuum pumps. Balancing the system involved frequently inspecting all the valves to ensure they were open enough to withdraw water, but not excessively open, causing the header to lose vacuum.

Although the system was constructed to model specifications, several noteworthy problems were encountered during operation which required system modification to remedy:

- During the startup period, pronounced aquifer communication between confined system wells was observed along a north-south orientation. Significant drawdown was measured in the confined aquifer monitoring wells on the far south side of the site, approximately 150 meters away from the pumping wells on the north side of the site. Although the groundwater computer model predicted this area would be problematic, the array of water table wells installed near the south side of the site were not effectively lowering the water table in the area surrounding monitoring wells WISS-2A and 2B (Figure 3). To remedy this situation, and prevent a gradient reversal in the vicinity of this well pair, three additional shallow wells were installed in the southern portion of the site to effectively lower the water table before the system was operated at full capacity.

- It was recognized in the design phase of the dewatering system that additional wells were needed in the northwest corner of the site (an area previously used as a parking lot). After dewatering operations commenced, a subsurface soil survey was conducted to delineate the extent of contamination in this area. The survey revealed contamination down to depth of 8 feet below grade. Although the final predictive model run recommended the usage of up two 14 additional dewatering wells to adequately depressurize and dewater this area for excavation, a determination was made, based upon actual dewatering water level data, to install eight additional unconfined dewatering wells in this area. Adjacent confined aquifer wells had already adequately depressurized the lower system sufficiently for excavation. These eight additional wells were installed and plumbed into the initial Phase II shallow system. A fourth vacuum pump was brought on site to handle the additional wells, which in turn supplemented the Phase II system as a whole by increasing capacity in the tight overburden.

- Notable problems with the monitoring system occurred during the spring of 2001 when frequent electrical storms caused multiple failures. The computer was protected with an uninterruptible power system (UPS) but the network cable itself, although grounded, was not exempt from electrical damage. A single specialty cable adapter routed to the computer failed several times, requiring all monitoring well water levels to be obtained by hand. Replacing the adapters remedied the problem initially, but the were several recurrences. Communications with the vendor ultimately resulted in the acquisition of a new optical isolation adapter that permanently resolved the problem. Although these failures complicated work, they caused no down-time for excavation activities.

The WISS Dewatering system operated continuously for approximately 8 1/2 months. During that time, over 11 million liters of groundwater was extracted from the confined aquifer, and approximately 3 million liters was removed from the shallow aquifer.

Drawdown levels achieved on site met or exceeded the levels predicted by the groundwater model after approximately 30 days of dewatering. The potentiometric surface of the lower aquifer was lowered an average of 3.6 meters in the northwest corner of the site, where potentiometric heads were highest under static conditions. Although small seeps were observed in this area of the site at the lowest elevations during the final excavation, no significant influx of artesian water entered the open excavation. Throughout the project, the potentiometric surface of the confined aquifer was not allowed to drop below the water table, except for very brief periods during the startup phase or while servicing the pumps or sampling wells. When the gradient reversal did occur, it was noticed immediately from the data logger system, and corrective measures were implemented. These corrective measures consisted of rebalancing the system, as described previously in the text, by reducing the discharge in the confined system, and/or increasing the discharge of the shallow system. Corrective measures were implemented whenever the difference in elevations between the two aquifer systems fell to less than one foot, although this rarely occurred.

The successful implementation of the dewatering system allowed the excavation and backfilling operations to proceed unimpeded. When these operations came close to the dewatering suction header or discharge hose, the system was re-located easily, due to the flexibility of the design.

CONCLUSION

Stratigraphic heterogeneities, combined with remediation requirements, posed significant challenges to the design and execution of the dewatering at the WISS site. The potential for aquifer cross contamination necessitated the use of an innovative system design, beyond the typical scope for construction dewatering. Through careful evaluation of site geologic and hydrologic conditions, a multi-phased dual-aquifer dewatering system was designed, utilized and decommissioned with a high degree of success. The system facilitated the removal of over 47,000 m^2 of soil for subsequent off site disposal while maintaining the integrity of the confining layer, and the water quality of the confined system.

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