Roosevelt Drive Horizontal Drain Requirements—Derby, Connecticut

Prepared by Losonsky & Associates Inc. for Tennessee Valley Authority and U.S. Environmental Protection Agency, Boston, Massachusetts.

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1.0 Introduction

Losonsky & Associates, Inc. has completed a series of tasks aimed at determining the feasibility of using a horizontal drain to prevent oil migration into a tailrace structure at a hydroelectric power facility on Roosevelt Drive in Derby, Connecticut. The work was conducted under contract with the Tennessee Valley Authority, and under the direction of the U.S. Environmental Protection Agency in Boston, Massachusetts. This report presents the results of the final work effort, intended to provide design specifications needed to solicit Requests for Proposals for the installation of the horizontal drain.

2.0 Background

The design work presented in this report was preceded by several tasks completed by Losonsky & Associates, partly in collaboration with Shaw Environmental & Infrastructure:

- Slug tests and pumping tests at selected wells in and around the hydroelectric plant building
- Groundwater flow modeling to determine the general feasibility of several configurations of horizontal drains and trenches under the hydroelectric plant building and its immediate vicinity in order to control flow of non-aqueous phase liquid (NAPL)—primarily petroleum hydrocarbons in the form of #6 oil—into the tail race beneath the building
- Groundwater flow modeling to determine the effectiveness of modifying the wall structure of the tail race by installing an additional wall, or “false wall”

The previous work effort led to two key conclusions:

- Horizontal drains are an effective means of controlling the migration of NAPL at the site
- A “false wall” modification of the tail race structure would divert NAPL onto flow paths that would exacerbate the NAPL problems and increase the risk of NAPL entering the Housatonic River

Based on these findings, Losonsky & Associates used groundwater flow modeling to determine the optimal location and depth of a horizontal drain beneath the hydroelectric plant building that can reverse the hydraulic gradient behind the wall of the tailrace sufficiently to prevent NAPL migration into the tailrace. The modeling effort indicated the expected range of flow rate that the drain is expected to produce under normal tidal fluctuation conditions. Losonsky & Associates used the information to propose a pre-treatment tank and oil-water separator system and that can process the water collected by the horizontal drain so that it can be redirected into the tailrace. The system will be installed in two stages:

1. Stage 1: Initial Installation and Production Testing of Horizontal Drain. The first 3 to 6 months of operation of the horizontal drain will comprise Stage 1, during which the long-term total fluids recovery rate and the oil-to-water ratio (water cut) will be estimated
2. Stage 2: Final Fluids Treatment System Installation. Analysis of the transient water and oil flow data during Stage 1 will yield the specifications of the oil-water separator system and the final configuration and operation and maintenance plan of the horizontal drain system.

This report presents the results of the horizontal drain design considerations and the components of Stages 1 and 2 of its implementation.

3.0 Stage 1: Installation and Production Testing of Horizontal Drain

The layout of the horizontal drain and pre-treatment tank is shown in **Figure 1**:

1. Entry point vault
2. Proximal (northern, entry-end), 6-inch stainless steel riser pipe
3. 6-inch stainless steel screen section
4. Distal (southern, exit-end), 6-inch high-density polyethylene (HDPE) riser pipe
5. Exit-end, above-ground wellhead
6. Pre-treatment tank

Details of the pre-treatment tank and associated conveyance and lift system are shown in **Figure 2**:

1. Inclined, above-ground stick-up of 6-inch HDPE riser pipe
2. 1-inch polyvinyl chloride (PVC) conveyance line
3. Diaphragm lift pump powered by air compressor
4. Shutoff valve
5. 4-foot tall, 500-gallon cylindrical pre-treatment tank
6. 2-inch PVC discharge line to tail race

Stage 1 components will be constructed in two phases by two contractors. A directional drilling contractor, to be selected by competitive bidding based on the specifications and conditions detailed in Sections 3.1 through 3.5 of this document, will install the horizontal drain. The site environmental contractor will install, or employ remediation system contractors to install, the treatment system described in Section 3.6.

3.1 Entry Point Vault

The drilling contractor will excavate an approximately 5-by-5-foot, 2-foot deep entry pit for collecting drilling fluid returns (**Figure 1**). Upon completion of the horizontal drain, the wellhead will be installed in a 6-by-4-by-4-foot, H-20 rated underground vault, flush with the ground surface. The vault must provide direct access into the riser pipe using drill rods for future re-development or additional outfitting. The vault cover will support normal vehicle traffic.

The entry point and vault will be located in the walled-in yard area (courtyard) north of the hydroelectric plant building (plant building) (**Figure 1**). (The courtyard is to the right of the plant building when approached from Roosevelt Drive.) A brick building is located within the courtyard; the entry point vault will be installed in the courtyard area along a line coincidental with the brick building's western wall, approximately 20 feet north of the northwest corner of the brick building. The distance between the northwest corner of the brick building and the courtyard wall to the north is 70 feet, leaving ample room for the drill rig to be positioned behind the entry pit. The location of the entry point of the horizontal drain will be identified during a site walk for prospective bidders.

The top of the concrete pad of recovery well RW-3, located about 25 feet west of the entry point location, has an elevation of 21.03 mean seal level (MSL).

3.1.1 Mobilization

The drilling contractor will provide a list of all equipment that will be brought to the site, and propose equipment layout for the drilling, installation, grouting and development phases of the drain construction process. Prior to mobilization, the drilling contractor will describe how the drilling operation will be executed within the logistical limitations of the site. The site environmental contractor will provide maps of known utilities, building foundations, wells, and any other potential subsurface obstructions.

3.1.2 Drilling Plan

Once the equipment and drilling crew have been mobilized to the site, the drilling contractor will finalize a previously outlined drilling plan that specifies every step of the well installation process, including pilot wellbore drilling, reaming operations, well completion, development and grouting. The plan will account for all logistical impediments and limitations encountered at the site. The drilling contractor will confirm the well path in collaboration with the site environmental contractor or their representative.

3.2 Northern Riser Section

The first section to be drilled will be the northern, proximal riser section, extending from the entry point to the northern wall of the plant building (**Figure 1**). The northern riser section will be completed with 6-inch, schedule 5 or 10 stainless steel pipe. The end of the riser inside the vault will be outfitted with a removable cap. The drilling contractor will determine the pipe schedule required to ensure successful installation of the well. The riser pipe will intersect the ground surface at an angle between 10 and 20 degrees (18 to 38 percent), based on drilling requirements to be determined by the drilling contractor. The riser pipe will run along the 30-foot long western wall of the brick building, parallel to Roosevelt Drive. The distance between the brick building and the plant building is 48 feet. The starting point of the screen section of the horizontal drain will coincide with the northern wall of the plant building, and its location will be identified during a site walk for prospective bidders. The total horizontal displacement between the entry point and the screen section will be approximately 100 feet. The angle of inclination of the riser path will gradually decrease away from the entry point and attain horizontal orientation at the northern plant building wall. The riser section will be drilled with no more than 6 percent pitch change per drill rod in order to avoid restricting entry of rehabilitation tools or remediation-related accessories through the riser section in the future.

The depth of the wellbore can be surveyed against several benchmarks along its path. The top of the concrete pad of a remediation well located about 20 feet west of the entry point is at an elevation of 21.03 feet MSL, and the cover of well HD-1, located in the sidewalk parallel to the northern riser and near the northern wall of the plant building, has an elevation of 25.69 feet MSL. The riser pipe will intersect the plant building at an elevation of +0.5 feet MSL, corresponding to a depth of 13.8 feet below ground surface (bgs) in the basement of the plant building. The basement is at an elevation of 14.3 feet MSL. The point of intersection with the plant building is 25.8 feet below the elevation of the main floor, which is at an elevation of 26.3 feet MSL. Relative to the concrete well pad near the entry point and the drill rig, the depth of the well path at the point of intersection with the northern plant building wall will be 20.5 feet bgs.

3.2.1 Power and Water Supply

Three-phase power is available at a corner of the northern promontory of the plant building, approximately 100 feet west of the entry pit (**Figure 1**). A water spigot is available along the western wall of the brick building in the courtyard, along the northern riser path of the horizontal drain. Power is also available within the plant building. The closest fire hydrant is approximately 200 feet north of the site, in front of a neighboring former manufacturing building.

3.2.2 Drilling Fluids Management

The drilling contractor will select appropriate drilling fluid additives to ensure wellbore stability, filtration control, and cuttings removal. Both biodegradable polymers and bentonite-based drilling fluids are acceptable, if the drilling contractor implements an effective well development program. The drilling contractor will provide a material safety data sheet (MSDS) for each additive used to drill and install the horizontal drain.

A drilling fluids recycling system will be used in order to control the volume of waste generated by the drilling operation. The drilling contractor will describe the mechanical means of separating cuttings from drilling returns in the recycling system, such as shaker screens and de-silter cones. The drilling contractor will estimate the volume of drilling-derived waste generated by the drilling and installation process, and coordinate with site management to ensure that adequate storage volume is supplied in lined roll-off boxes or tanker trucks to accommodate all drilling returns generated by the drilling operation.

3.3 Screen Section

The horizontal drain will be installed beneath the plant building, parallel to the eastern wall of the plant building that runs along Roosevelt Drive (**Figure 1**). The screen section will be completed with custom slotted, 6-inch, schedule 10 stainless steel pipe. The screen section will be 150 feet long, extending between the northern and southern walls of the plant building, at a constant distance of 19 feet from the eastern wall of the plant building. The screen section will grade 1.3 percent toward the southern end. At its northern endpoint, the screen will be at an elevation of +0.5 feet MSL (13.8 feet below the basement floor of the plant building). The midpoint of the screen will occur at a building foundation that intersects the well path. The screen depth at the midpoint will be at an elevation of -0.5 feet MSL, corresponding to 14.8 feet below the basement floor. At its southern endpoint, the screen will be at an elevation of -1.5 feet MSL, or 15.8 feet below the basement floor, and 22.5 feet below the top of casing (TOC) of well SMW-3 (20.96 feet MSL). Well SMW-3 is located along the southern wall of the plant building, near its point of intersection with the horizontal drain. Relative to the entry point and rig location, the northern and southern endpoints of the screen section will be 20.53 and 22.53 feet deep, respectively, and midpoint of the screen section will be 21.5 feet deep.

The drill path is expected to encounter obstacles, including known building foundations and possible large fill debris fragments. Building foundations are expected at both building walls. A foundation structure intersects the drill path about halfway across the building (**Figure 1**). The drilling contractor may choose to attempt drilling through the foundation, or the drill path may be adjusted to avoid the foundation by following a curved path around the eastern edge of the foundation structure. Displacing the entire drill path southward to avoid the foundation is not acceptable, as the drain must fit within a narrow strip constrained by north-south oriented structures within the southern portion of the plant building. The constraints of the drill path, and the required points of intersection with the plant building walls, will be identified during the site walk for prospective bidders.

3.3.1 Screen Slotting

The screen section will be custom slotted to specifications to be provided during the site walk for prospective bidders. Slots will be cut in the transverse direction, normal to the axis of the screen pipe. Slot aperture will be 0.015 inch, and slot length will be between 1.0 and 1.5 inches on the inside diameter of the pipe. Slots will be arranged in three or four rows arranged evenly around the circumference of the pipe. Slots will be regularly spaced along the axis of the pipe. Slot spacing will be determined by the open area requirements of the screen section.

3.3.2 Placement Accuracy

A well tracking system will be employed during drilling of the pilot wellbore. The tracking system will be used to ensure accurate placement of the screen section of the horizontal drain. The drilling contractor will describe the tracking method, and demonstrate how it will ensure that the screen section will meet the accuracy requirements. Accuracy requirements include entering and exiting the plant building at the prescribed locations and depths; placing the screen section within one foot horizontally of the prescribed location, and within 4 inches vertically of the prescribed depth at each location. The drilling contractor will explain the methods of tracking and control of the well path within the building that will ensure a steady grade as specified for the screen section.

While drilling the pilot wellbore, the drilling contractor will clearly mark, on the ground, the location and depth of the wellbore at the drill bit after advancing each drilling rod. If the wellbore is reamed more than once, the location and depth of the wellbore will be measured again by recording depth and rod pitch measured at the drill bit after advancing or retreating each drill rod.

3.4 Southern Riser Pipe

The last section to be drilled will be the southern, distal riser section, extending from the southern wall of the plant building to the exit point (**Figure 1**). The southern riser section will be completed with 6-inch, SDR-11 high-density polyethylene (HDPE) pipe. The riser pipe will intersect the southern wall of the plant building at an elevation of -1.0 feet MSL, corresponding to a depth of 22 feet below the TOC of well SMW-3. The riser pipe will intersect the ground surface at a point approximately 40 feet south of the plant building, at an angle to be determined by the drilling contractor. The drilling contractor will specify an appropriate transition coupling between the stainless steel screen and the HDPE riser. The location of the exit point is constrained by concrete block structures outside of the plant building, and it will not be aligned with the screen section of the well. The HDPE riser section will follow a curved path connecting the prescribed southern endpoint of the screen section and the area where the wellhead must be located.

3.4.1 Sanitary Seals

The drilling contractor will describe the method for emplacing an adequate cement-bentonite grout seal within the annular space of both the northern and southern riser sections of the horizontal drain. The description will include volume calculations and the proportions and means of mixing and emplacing the cement-bentonite grout.

3.4.2 Well Development

The drilling contractor will describe the well development program, which will aim to remove break down and remove residual biopolymer drilling fluid additives, or deflocculate, disperse and remove bentonite-based additives. The drilling contractor will provide MSDS sheets for any acids, dispersants or other well development additives applied to the horizontal drain. The drain will be considered developed when returns are free of residual drilling fluid. The drain will be developed prior to grout seal emplacement. A sufficiently large roll-off box or tanker will remove fluid returns generated by the well development operation. The drilling contractor will determine the size of the roll-off box, depending on the anticipated volume of returns.

3.5 Southern Wellhead

The southern wellhead will be completed above-ground within a grassy area located approximately 40 feet south of the plant building, bounded to the north by a concrete block structure supporting a trailer, to the east by a retaining wall, and to the west by a concrete structure housing a vertical recovery well (**Figure 1**). The vertical recovery well is not operating, and will not operate during installation or operation of the horizontal drain. The area within which the southern wellhead must be constructed will be identified during a site walk for the prospective bidders. Concrete structures, fences, and other obstacles to the installation of the horizontal drain that may be removed by others, prior to drilling in order to facilitate drilling and installation, will be identified during a site walk for prospective bidders.

The southern wellhead will consist of a three-foot stick-up section of the 6-inch HDPE riser pipe, exiting the ground at the riser exit angle determined by the drilling contractor, anticipated to be approximately 20 degrees (35 to 40 percent grade) (**Figure 2**). The drilling contractor will outfit the end of the HDPE pipe with a removable cap that provides an entry hole for insertion, by others, of a 1-inch polyvinyl chloride (PVC) or HDPE drop tube. The drop tube will terminate at the southern starting point of the screen section of the horizontal drain, and it will connect to a diaphragm pump.

3.5.1 Demobilization

The site will be restored to its original condition in the courtyard area where the northern, vaulted wellhead will be constructed. The site environmental contractor and the drilling contractor will agree on any site restoration activities to be completed by the drilling contractor near the southern, stick-up wellhead prior to leaving the site. The site environmental contractor will be responsible for disposing of drilling- and development-derived waste.

3.5.2 As-Built Diagram

The drilling contractor will provide an as-built diagram of the completed horizontal drain. The diagram will include both a map and profile of the drain. The map will show locations of the well at each drilling rod endpoint. The drain profile will show the entire drill path of the wellbore, from entry point to exit point, and it will indicate the depth and rod pitch measured at the drill bit after advancing each drill rod, throughout the wellbore drilling and reaming process. Re-surveying of the wellbore following multiple reaming runs (Section 3.3.2), if executed, will be documented in a separate wellbore profile.

3.6 Pre-Treatment System

The site environmental contractor will arrange for the construction of the pre-treatment system following the completion of the horizontal drain. The system will lift total fluids from the horizontal drain into a 500-gallon tank for holding, oil-phase separation, and skimming (**Figure 2**). Separated water will discharge by gravity into the tail race under the plant building.

3.6.1 Drop Tube

A 1-inch PVC or HDPE drop tube will be attached to a diaphragm pump and placed inside the horizontal drain riser (**Figure 2**). The drop tube will be approximately 40 feet long, reaching to the southern end of the screen section of the horizontal drain. A PVC drop tube is preferable as the exact location of its endpoint within the well can be controlled, and it can be advanced further into the screen section if needed, based on the flow rate and oil-to-water production ratio of the well. Typically, the performance of non-aqueous phase production wells improves if the point of extraction is moved to different locations along the screen over time. The ability to control the advancement of an HDPE drop tube will be limited, but this feature is not critical during Stage 1 of the operation of the horizontal drain.

3.6.2 Diaphragm Pump

A double diaphragm pump, such as an Ingersoll-Rand ARO or equivalent pump rated for at least 14 gpm, will lift total fluids from inside the horizontal drain into a 500-gallon pre-treatment tank (**Figure 2**). **Appendix A** contains the pump specifications. The pump will be powered by a continuous duty air compressor, sized to correspond with the diaphragm pump capacity and expected maximum flow rate of 20 gallons per minute (gpm). The flow rate will be regulated to provide adequate residence time in the pre-treatment tank to allow separation of aqueous and non-aqueous phase liquids. The residence time required will be determined during the first month of operation. Flow through the diaphragm pump will be throttled back using one of two mechanisms: compressor output and intake size. If lowering compressor output does not sufficiently throttle pump production, a bushing will be placed to reduce the PVC intake line to ½-inch diameter. This will further reduce the flow rate, if necessary, to maintain adequate residence time in the pre-treatment tank. A flow totalizer will be placed in the 1-inch PVC line between the pump and the pre-treatment tank. Heat tracing of all piping and major components will prevent freezing.

3.6.3 Pre-Treatment Tank

A 4-foot tall, 500-gallon capacity total fluids pre-treatment reservoir tank will be placed within 20 feet of the southern wellhead of the horizontal drain (**Figures 1 and 2**). The purpose of the pre-treatment tank is to separate and remove the bulk non-aqueous liquid fraction of the total fluids extracted from the horizontal drain, while allowing groundwater to flow from the horizontal drain, through the tank and into the tail race.

The tank will have variable storage capacity, and its inflow will be controlled by the diaphragm pump, described in Section 3.6.2 (**Figure 2**). A deflector at the termination of the inflow line inside the tank will prevent turbulence at the liquid surface, thereby avoiding interference with the oil-water separation process. Outflow will be driven by gravity drainage through a 2-inch PVC or flexible hose discharge hose, connected to the tank by punch-lok hose fittings. The discharge hose material will be determined by the site environmental consultant based on logistical requirements. Water discharge will commence when the liquid level in the tank reaches above the 2-inch ball valve mounted in the 2-inch discharge line just outside of the pre-treatment tank. The outflow line will continue to convey water from the tank to the tail race while the liquid level in the tank gradually decreases, until it reaches the bottom of the outflow line, which will be placed within a few inches of the bottom of the tank. When the liquid surface reaches this level, a vacuum-break device within the 2-inch discharge line, just past the ball valve outside of the tank, will be activated. The vent on the vacuum breaker will terminate the siphon action driving the water discharge.

The flow rate through the pre-treatment tank will be controlled so that water will be discharged only after it has had sufficient residence time in the pre-treatment tank to separate and remove the bulk of non-aqueous phase in the tank. Monitoring during the first month of Stage 1 operation will determine the residence time needed to adequately separate oil from groundwater in the tank. Oil may be removed during operation of the horizontal drain using hydrophobic skimmers or by directly skimming or siphoning the oil. Oil may also be removed when the drain is shut off, allowing the tank to be drained, first of water and then of the remaining oil.

4.0 Final Fluids Treatment System Installation

Flow rate and oil-water ratio data collected during Stage 1 production testing of the horizontal drain will be used to develop the specifications of an oil-water separator (OWS), which will be placed in the vicinity of the pre-treatment tank at a topographically lower location selected by the site environmental consultant based on site logistical considerations (**Figure 3**). The OWS will be placed in a manner that allows for a gradient of at least 3 inches of vertical drop from the outlet point of the pre-treatment tank to the OWS inlet point. Local topography may allow a gradient of approximately one foot.

4.1 Oil-Water Separator

The OWS will be equal or larger in capacity to a *Carbonair COWS15F* unit (**Figure 3**). The throughput of the OWS is not expected to exceed 20 gpm, but the OWS will have a maximum hydraulic capacity of 75 gpm. The OWS will have a clean water reservoir with 65 gallon capacity. The OWS will be protected against freezing. It will be constructed primarily from fiberglass material. A sight glass assembly will house the float stem control for the pump. The sight glass will be connected to the OWS with unions to facilitate maintenance. The float stem will be designed with three floats. Two floats will control the pump and one float will act as a pump failure alarm. Effluent from the OWS will discharge through a 2-inch flexible hose to the tail race or to the Housatonic River. The discharge line will incorporate a ball valve, allowing manual flow control and a backflow prevention device. A flow totalizing device calibrated for water may also be inserted in order to compare water discharge with total fluid extraction from the horizontal drain. The discharge point and analytical testing requirements of the effluent will be determined by the site environmental contractor. The OWS will have a 2-inch ball valve (equal in size to the sediment drain) placed in a straight connection, to facilitate cleanout of accumulated sediment. The product skimming effluent will consist of a ball valve to shut off the skimmer and a cam fitting to connect a chemically resistant hose to the 100-gallon free product storage tank.

4.2 Free Product Storage

The free product storage tank should be designed to minimized maintenance needs. A 100-gallon poly tank is proposed to provide large storage capacity and minimize system shutdowns. A 55-gallon drum or other container could be used instead, depending on the amount of free product produced per year and the method of disposal. Regardless of the tank size, the system will have a float switch mounted at the top of the tank to prevent over-filling the tank.

4.3 Control Panel

The control panel for the system will contain the relays necessary to operate the OWS pump and the actuated ball valve that shuts off the horizontal drain in the event of an alarm. All alarms will shut off the horizontal drain. An optional control panel would inform the system operator of the alarm condition via telemetry. Two float stem alarms—one to detect OWS pump failure and one to detect a full free product storage tank—would be used to shut off the horizontal drain automatically with the actuated ball valve. The control panel would have an easy user interface to monitor alarms and reset the alarms after maintenance events.

5.0 Groundwater Hydraulics of Drain

Three-dimensional groundwater flow simulation using the finite-difference groundwater flow modeling code MODFLOW provided the basis for the horizontal drain design. **Appendix B** includes a map and cross sections showing the model construction. The model was calibrated using slug test and pumping test data collected during a series of field tests in April 2008.

Figure 4 shows drain discharge rates simulated by the groundwater flow model based on field data. The flow rate (shown in red) fluctuates in response to semi-diurnal tidal fluctuations (shown in blue). The flow rate of the horizontal drain oscillates between 4 and 6 gallons per minute (gpm) twice a day at lower river stages, and between 8 and 10 gpm at higher river stages. Low river stages are typical in late summer months, exemplified by site water level data collected in August 2007. High river stages are typical in the spring. Water level data collected during the aquifer response testing conducted in April 2008 represents a moderately high river stage. The model simulation began at low river stage and transitioned into high river stage. The moving average of the drain flow rate (shown in black) over the course of the model simulation ranges from 5 to 9 gpm, reflecting the change in river stage.

Figure 5 shows water level fluctuations simulated by the groundwater flow model based on field data. The water level at the inflow end of the horizontal drain (shown in green) is fairly level, whereas the water level at the outflow end of the horizontal drain (shown in red) fluctuates in response to the tidal fluctuation of the river stage (shown in blue). Water levels in other wells near the horizontal drain (MW-4, MW-5, HD-6R, INT-1 and SMW-3) are also shown, and show varying degrees of tidal fluctuation, depending on their distance from the riverbank. The water level near the outlet end of the horizontal drain fluctuates by approximately 1 foot, which equals about half of the tidal fluctuation.

The groundwater flow model was used to simulate the impact of the operating horizontal drain on water table elevations under both low and high river stage conditions. **Figure 6** shows the groundwater head simulation when the river stage is low, close to mean sea level (MSL). The figure shows groundwater head contours (blue lines) with a contour interval of 0.1 foot, the Housatonic River (red field), structural foundations associated with the hydroelectric plant building (brown lines), other structures (purple lines), and the horizontal drain (staggered gray line segments). Steep head gradients develop along some building foundations and other structural features. The horizontal drain creates an elliptical trough of depression, with a hydraulic gradient of 0.02 foot per foot (ft/ft) toward the drain within approximately 30 feet of the drain, increasing to 0.01 ft/ft within 100 feet of the drain. The hydraulic gradient outside of the zone of influence of the horizontal drain is approximately 0.001 ft/ft.

Figure 7 shows the groundwater head simulation when the river stage is moderately high, as during the April 2008 aquifer field test. The contour interval is 0.1 foot. The head gradients across structural foundations are steeper than at low river stage. Water levels at the north end of the hydroelectric plant building are only 1 foot above the river level, compared to 4 feet at low river stage. The elliptical trough of depression is essentially the same as during high river stage, with similar hydraulic gradients toward the horizontal drain. A critical aspect of the water table response to the operation of the horizontal drain is the reversal of the hydraulic gradient between the eastern tailrace wall and the horizontal drain. This reversal is maintained throughout the model simulation, at both low and high river stages.

Appendix C shows color versions of **Figures 6** and **7** (green represents higher water table elevations, and blue represents lower water table elevations). At low river stage, the horizontal well outlet point is slightly above the river stage. At high river stage, the entire screen of the horizontal drain is below the river stage.

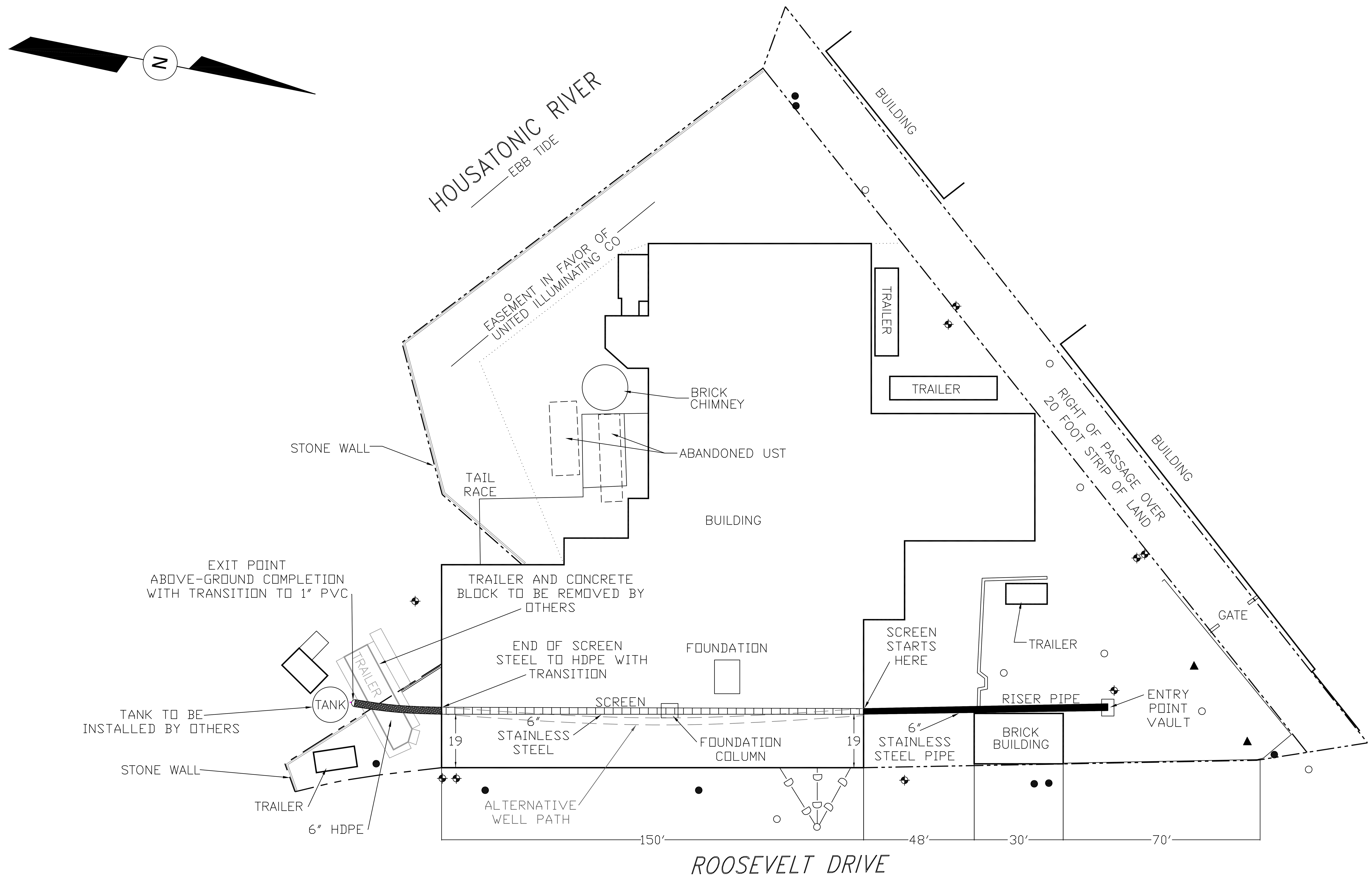
Appendix D includes a map with ground surface elevation contours (topographic map), and a top of bedrock elevation map (structure contour map of bedrock).

6.0 Conclusions

A 150-foot long horizontal drain, completed with 6-inch diameter, Schedule 10 stainless steel pipe, will be placed under the hydroelectric plant building to stop the leakage of NAPL into the tailrace of the building. The drain will develop an elliptical trough of depression that will reverse the hydraulic gradient between the eastern tailrace wall and the horizontal drain, causing groundwater and NAPL to flow away from the wall and into the drain, instead of flowing toward the wall. The screen section of the drain will be placed at an elevation of +0.5 to -1.5 feet MSL. The screen section will have a gentle grade of about 1.33 percent, dropping southward. The depth of the screen will be between 20.5 and 22.5 feet relative to the rig location, corresponding to 13.8 to 15.8 feet below the basement floor in the plant building.

Groundwater and oil from the well will be collected in a 500-gallong pre-treatment tank, where the non-aqueous phase will be allowed to separate. In the first 3 to 6 months of operation, water from this tank will discharge directly into the tailrace under the plant building. This first stage of operation (Stage 1) will confirm the long-term flow rate, oil-water ratio, and fluctuations in both flow rate and oil-water ratio. Based on this information, the final system will be specified (Stage 2). In Stage 2, the pre-treatment tank is anticipated to discharge into a 20 gpm, baffle-type oil-water separator, which will gravity-discharge treated water into the tailrace or into the Housatonic River.

FIGURES



HORIZONTAL DRAIN LAYOUT MAP

Losonsky & Associates, Inc.

Baton Rouge, Louisiana

LEGEND

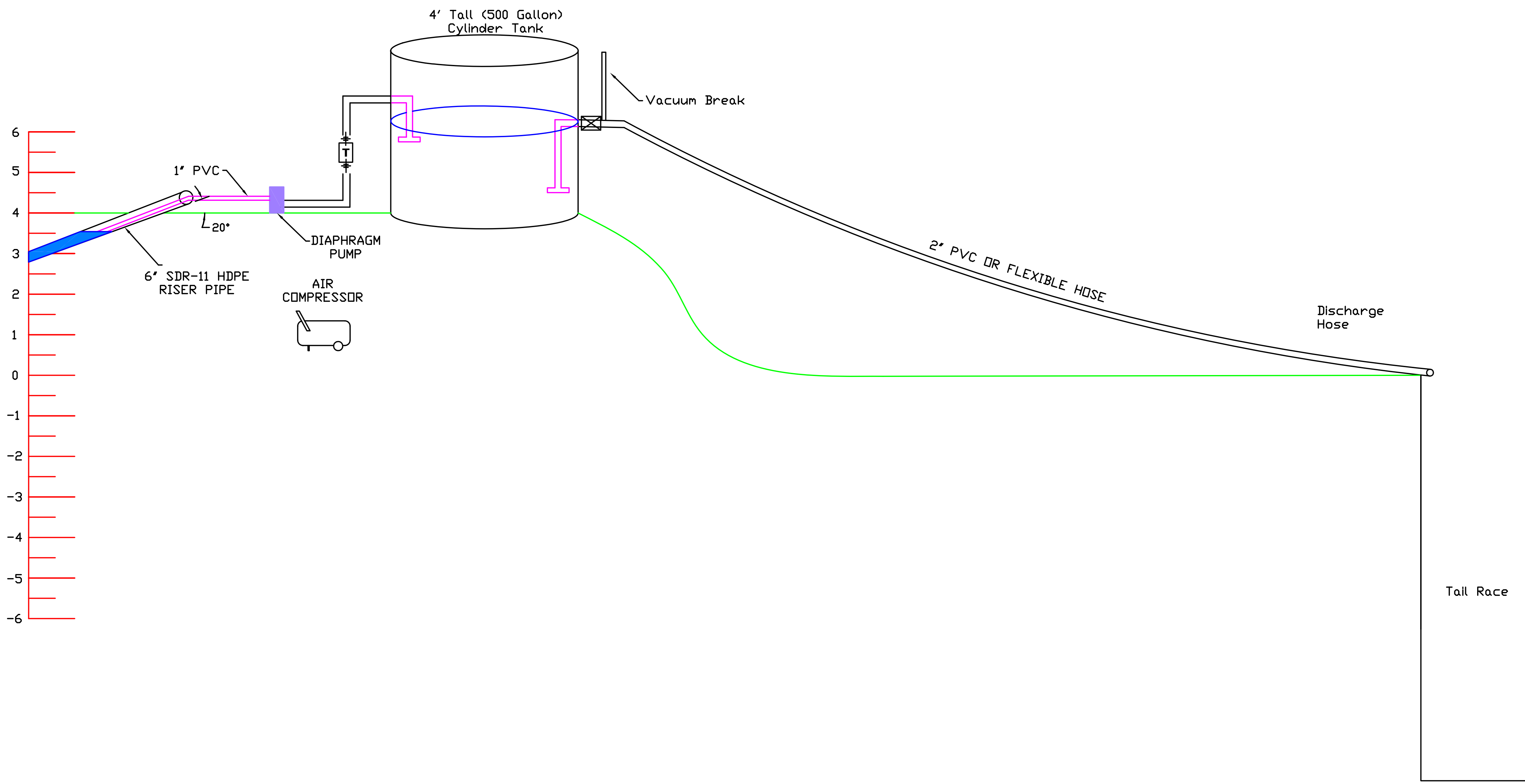
- HORIZONTAL WELL RISER PIPE
- HORIZONTAL WELL SCREEN SECTION
- HORIZONTAL WELL HDPE PIPE

Scale in Feet (Approximate)

0 10 20

1" = 20'- 0"

FIGURE # 1



NOTE: ALL PIPING IS NOT TO SCALE

STAGE 1 SYSTEM DIAGRAM

LOSONSKY & ASSOCIATES, INC.

BATON ROUGE, LOUISIANA

LEGEND

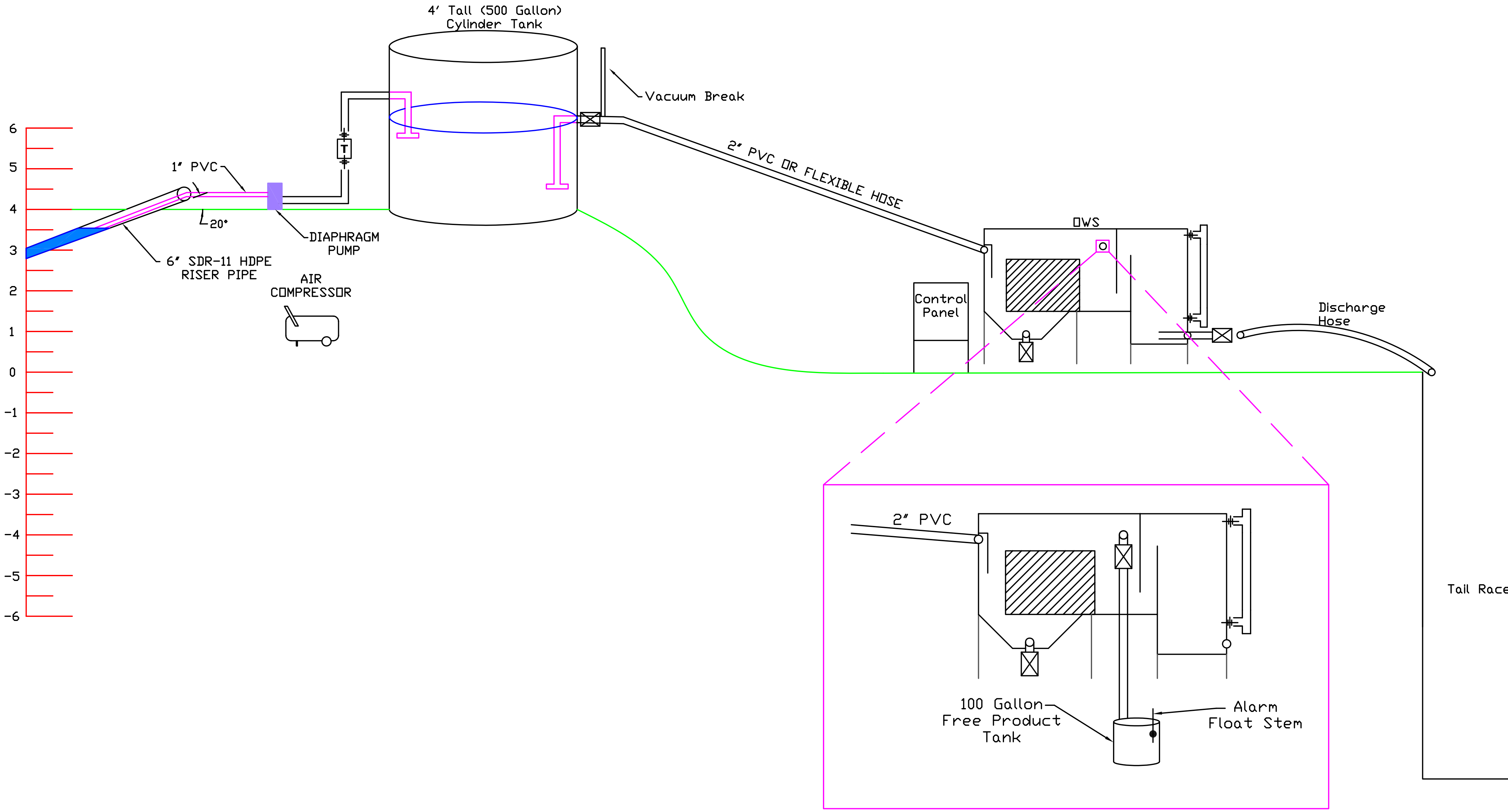
- Union
- Flow Totalizer
- 2" Ball Valve
- Diaphragm Pump

Scale in Feet (Approximate)

0 1.5 3

1" = 3'- 0"

FIGURE # 2



NOTE: ALL PIPING IS NOT TO SCALE

STAGE 2 FINAL SYSTEM DIAGRAM

LOSONSKY & ASSOCIATES, INC.

BATON ROUGE, LOUISIANA

LEGEND

- Union
- Flow Totalizer
- 2" Ball Valve
- Diaphragm Pump

Scale in Feet (Approximate)
0 1.5 3
1" = 3'- 0"

FIGURE # 3

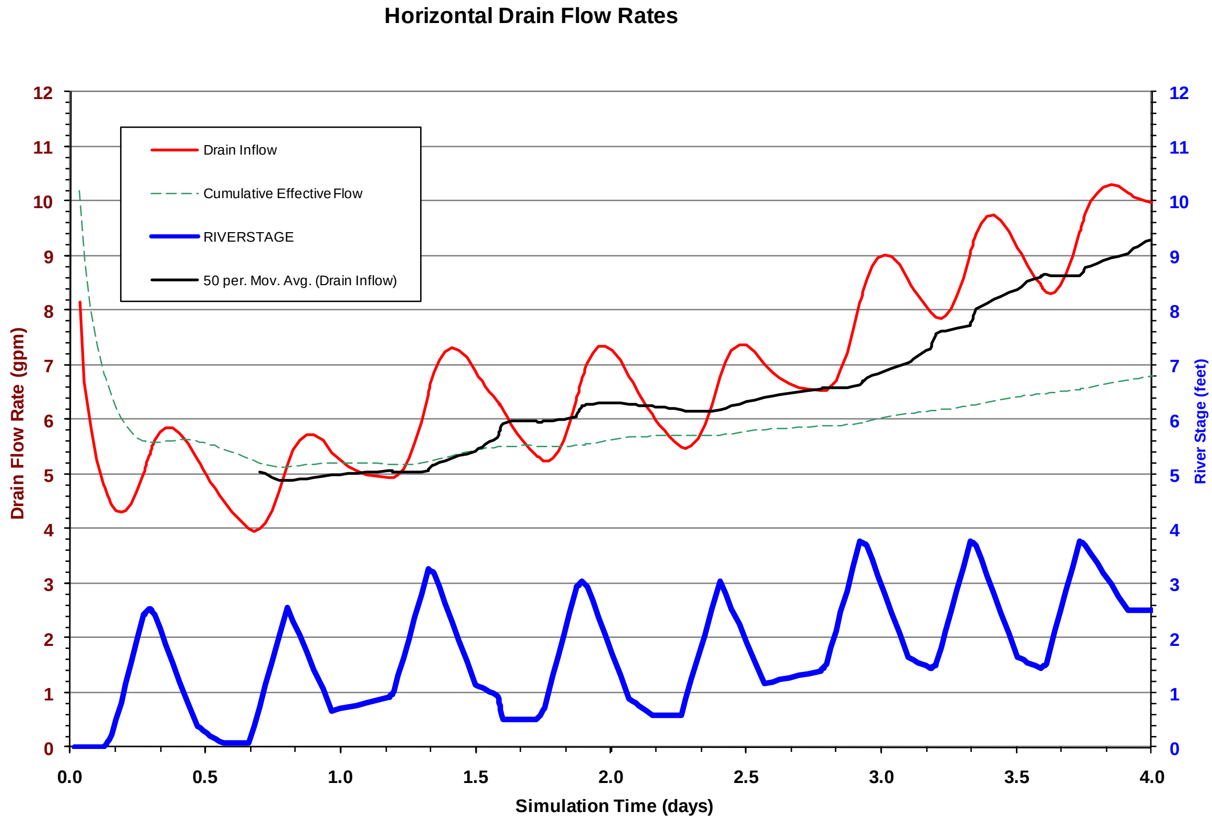


Figure 4. Drain discharge rates.

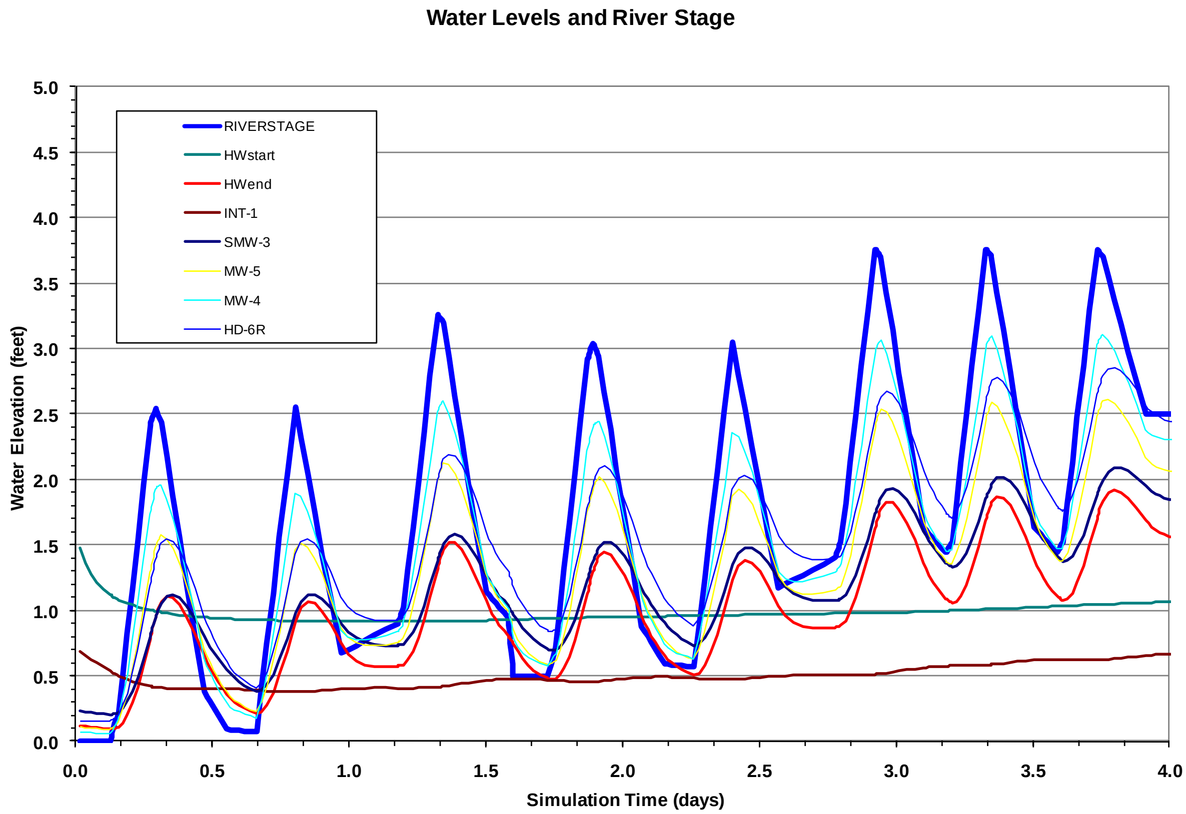


Figure 5. Water level fluctuations.

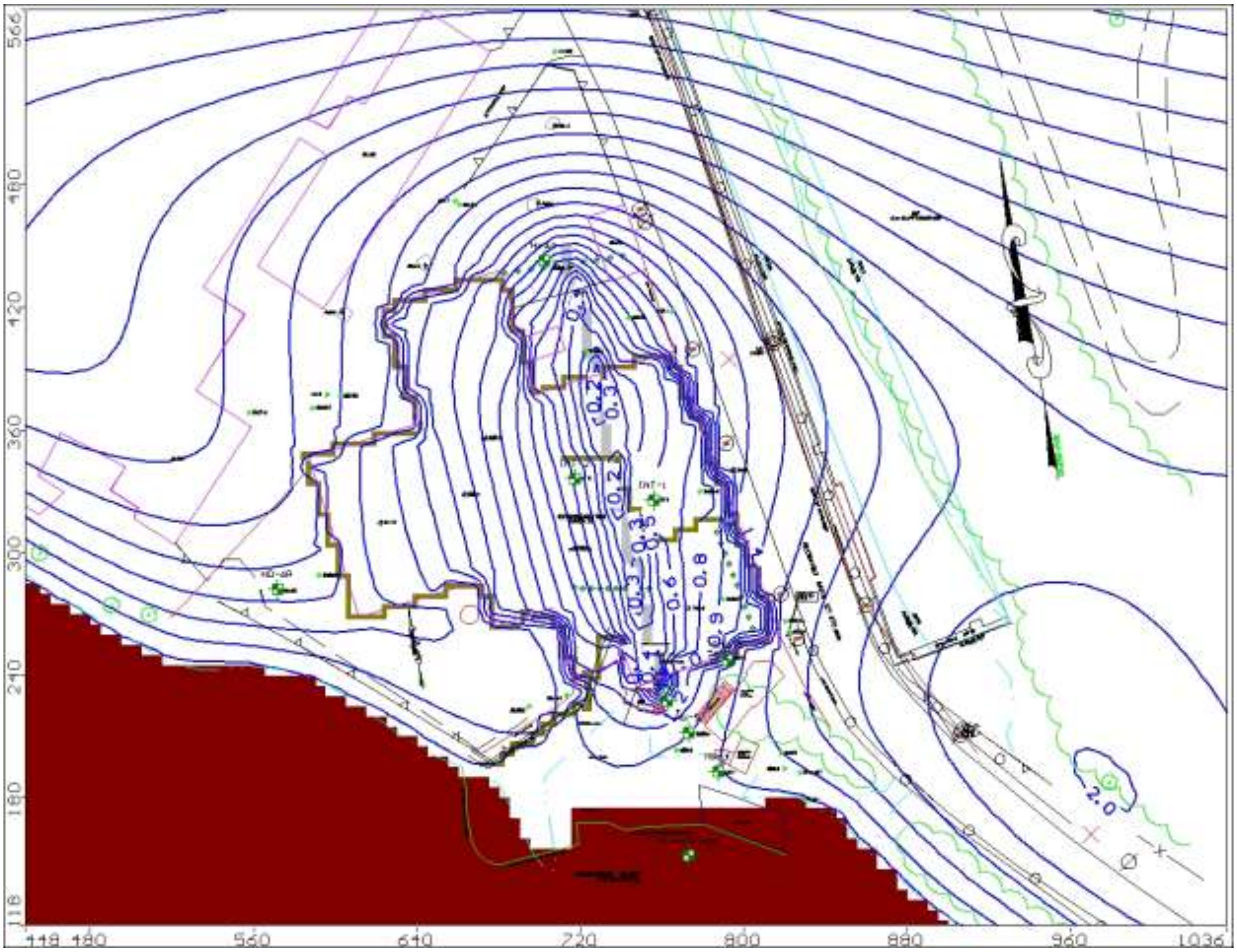


Figure 6. Groundwater head elevations at low river stage.

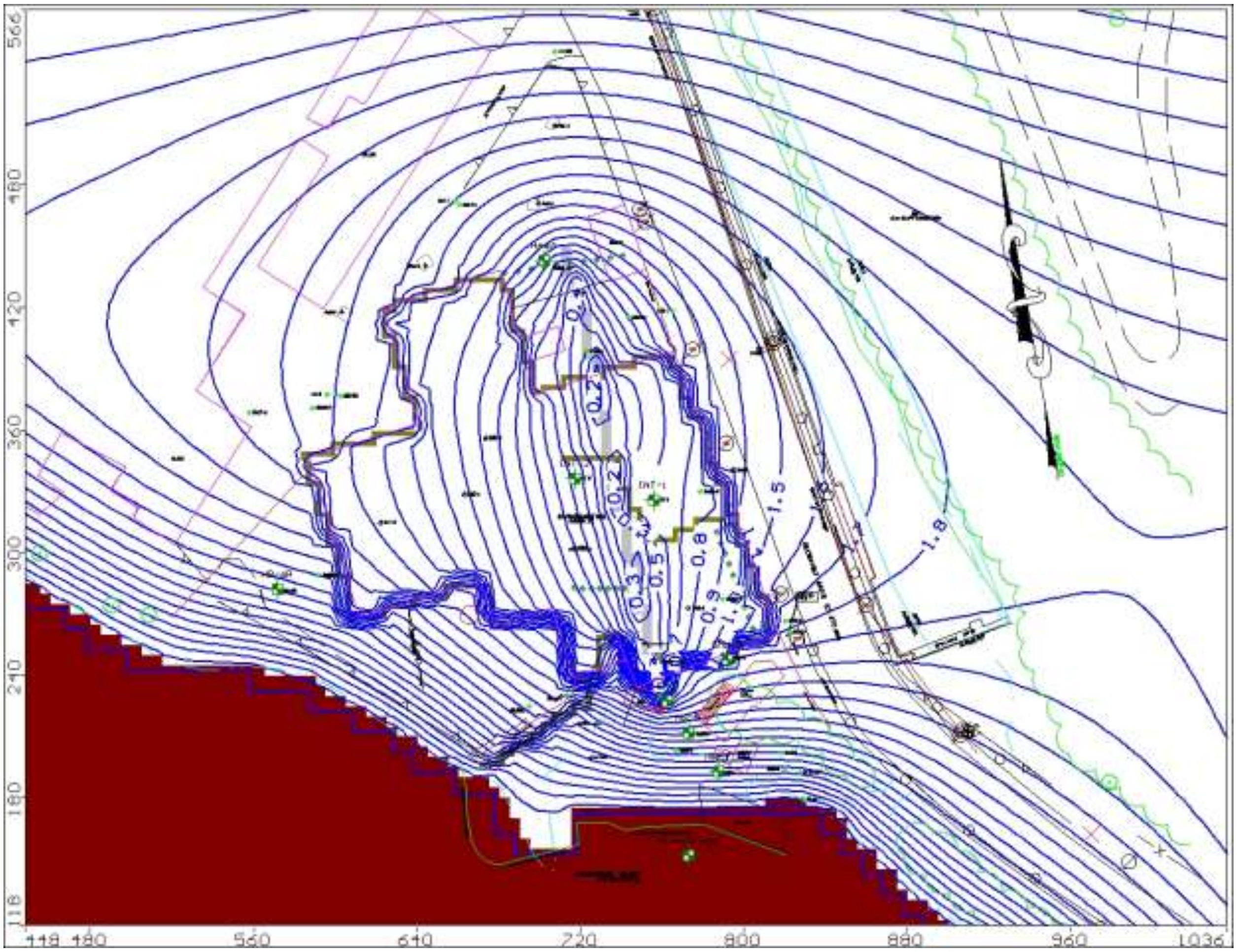


Figure 7. Groundwater head elevations at high river stage.

APPENDIX A

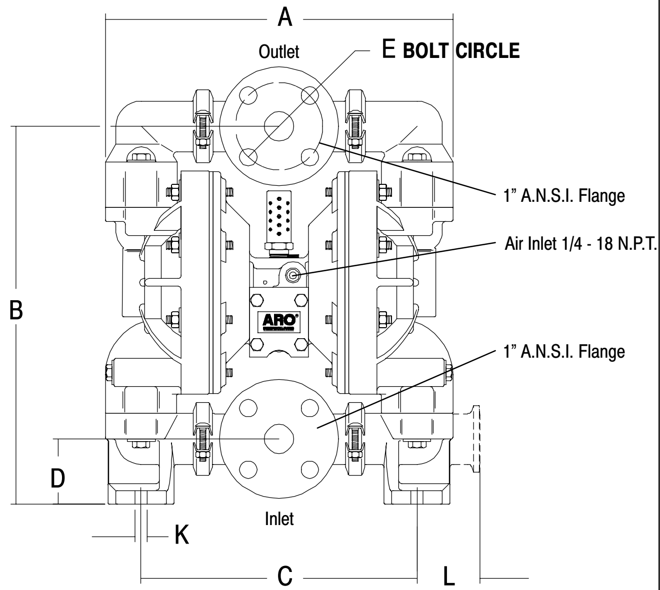
SALES & ENGINEERING DATA

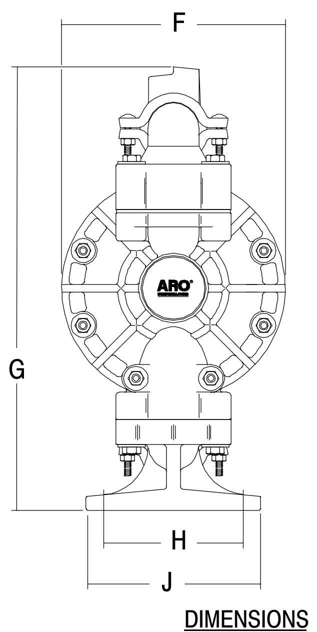
RATIO SERIES:	1:1
FLUID P.S.I. RANGE:	20 - 120

6661AX-XXX-C THRU 6661BX-XXX-C
1" NON-METALLIC DIAPHRAGM PUMP

RELEASED: 1-31-97
REVISED: 6-15-01
S-873

DIMENSIONAL DATA





DIMENSIONS

A	12-11/16" (322 mm)	E	3-3/16" (81 mm)	J	6-5/16" (160 mm)
B	13-13/16" (351 mm)	F	8-1/16" (204 mm)	K	7/16" (11 mm)
C	10-1/16 (255 mm)	G	16" (406 mm)	L	2-1/4" (57 mm)
D	2-3/8" (60 mm)	H	5-1/16" (129 mm)		

NOTE: Dimensions are shown in inches and (mm), supplied for reference only and are typically rounded up to the nearest 1/16 inch.

SPECIFICATIONS

CONSTRUCTION

Model Series		6661AX-XXX-C thru 6661BX-XXX-C
Pump Type		Non-Metallic, Air Operated, Double Diaphragm
Ratio		1:1
Material Inlet / Outlet		1" Flange, ANSI Class 150
Air Inlet (female)		1/4 - 18 N.P.T.
Air Exhaust (female)		3/8 - 18 N.P.T.F. - 1
Weight	6661A3-3XX-C	20.25 lbs (9.2 kgs)
	6661A4-4XX-C	28.5 lbs (12.9 kgs)
	6661B3-3XX-C	28.8 lbs (13.06 kgs)
	6661B4-4XX-C	37 lbs (16.78 kgs)
Air Section Service Kit		637118-C
Fluid Section Service Kit		637161-XX-C

6661AX - X X X - C
637161 - X X - C
- first X — Ball Material
- second X — Diaphragm Material

EXAMPLE: Model 6661A3-311-C
Fluid Section Service Kit is 637161-11-C

PERFORMANCE

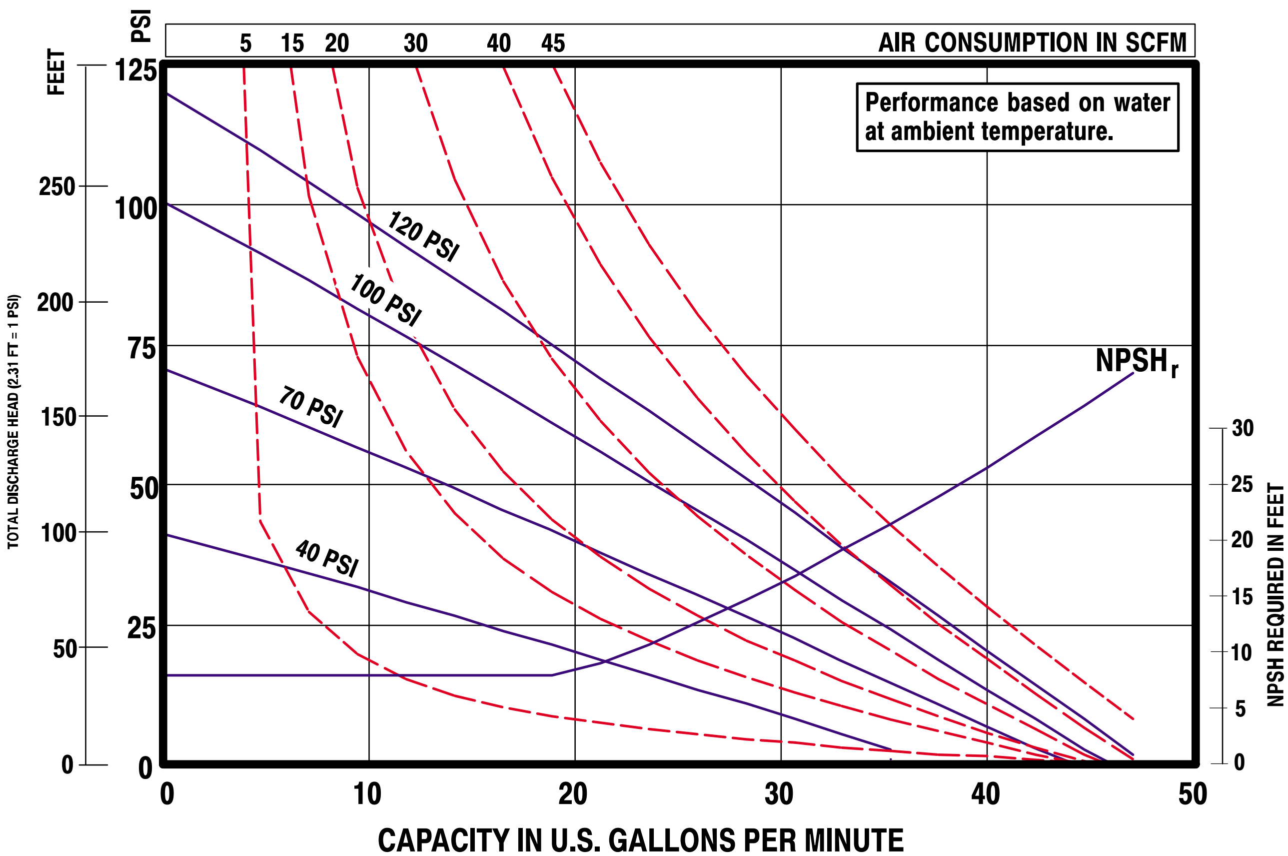
Air Inlet Pressure Range	20 - 120 p.s.i. (1 - 8.3 bar)
Maximum Material Inlet Pressure	10 p.s.i. (0.69 bar)
Fluid Pressure Range	20 - 120 p.s.i. (1 - 8.3 bar)
Maximum Flow Rate (flooded inlet)	47 g.p.m. (178 l.p.m.)
Maximum Particle Size	1/8" dia. (3.2 mm)
Maximum Temperature Limits	
Polypropylene	35° to 150°F (2° to 66°C)
Kynar (PVDF)	10° to 200°F (-12° to 93°C)
Displacement / Cycle @ 100 p.s.i.	0.17 gal. (.64 lit.)
Noise Level @ 70 p.s.i. - 60 c.p.m.①	64.5 db(A)②

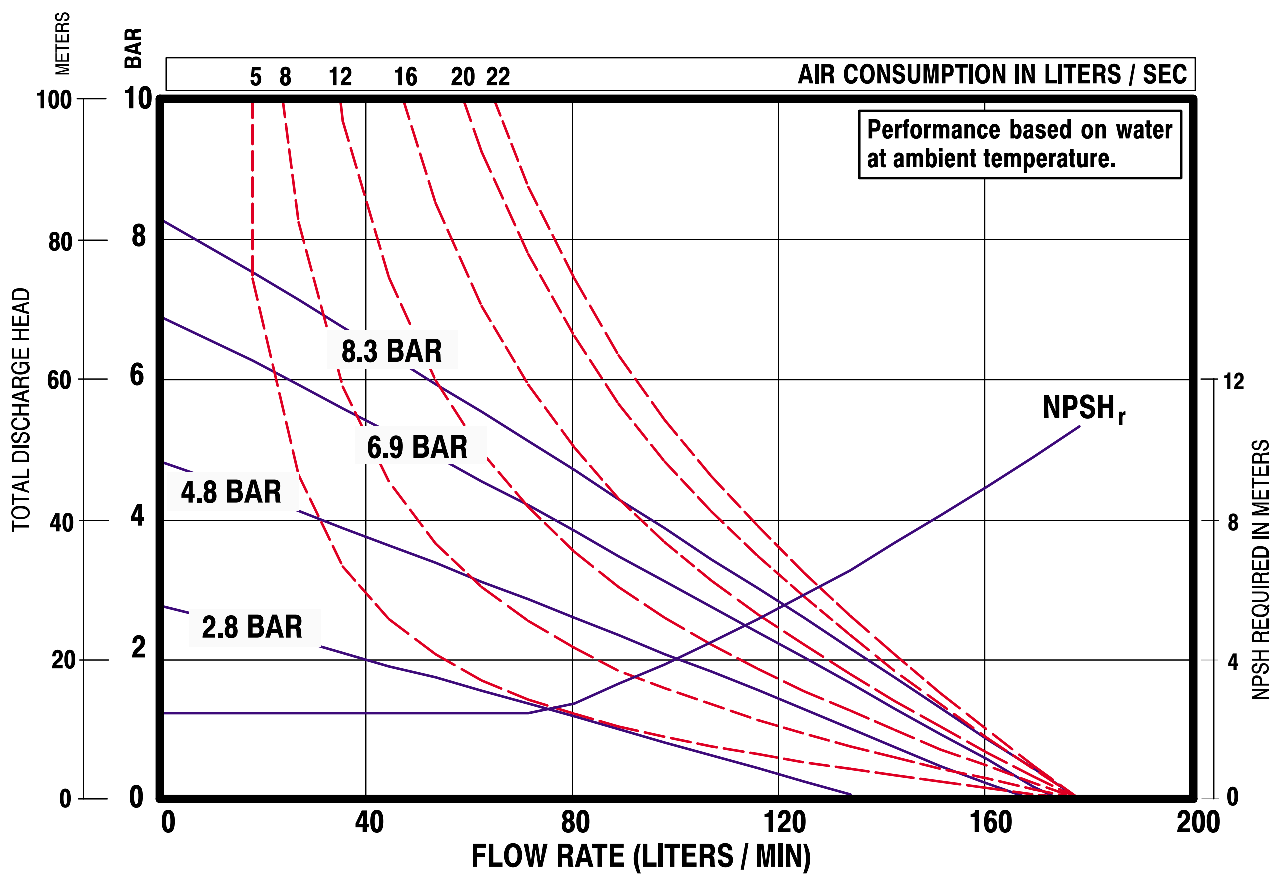
① Tested with 93110 muffler installed.
② The pump sound pressure level has been updated to an Equivalent Continuous Sound Level (L_{Aeq}) to meet the intent of ANSI S1. 13-1971, CAGI-PNEUROP S5.1 using four microphone locations.

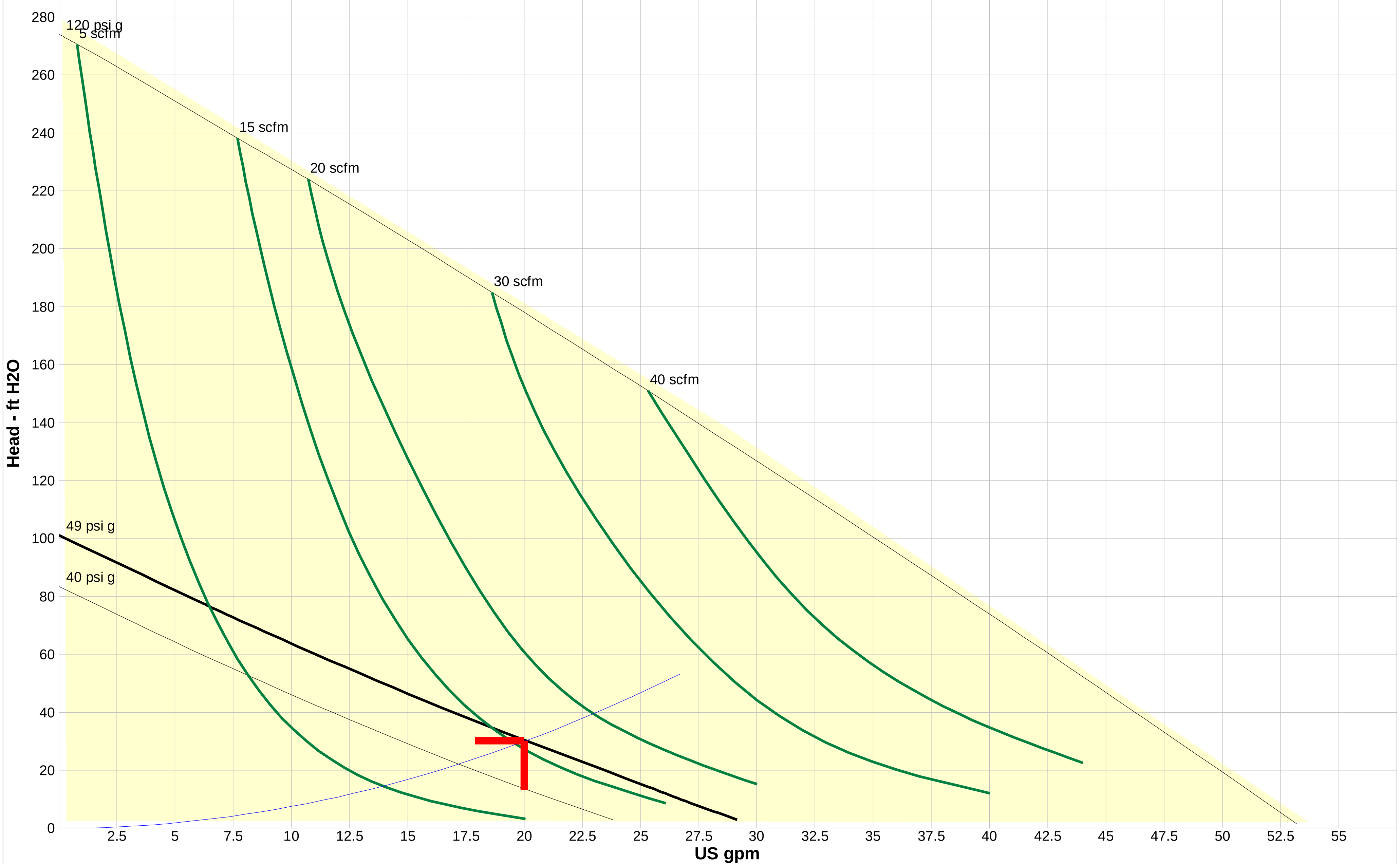
ACCESSORIES:
65010 Neoprene "O" Ring Air Motor Kit
65764 Viton "O" Ring Air Motor Kit
66073-1 Air Line Kit
67078 Flange Kit

INGERSOLL-RAND COMPANY
ONE ARO CENTER • BRYAN, OHIO 43506-1100
✆ (419) 636-4242 • FAX (419) 633-1674

6661XX-XXX-C 1" NON-METALLIC DIAPHRAGM PUMP







Company: NA
Name: NA
10/25/2011

IR ARO
Catalog: IR ARO, Vers 1.2
Pro-Series
Design Point: 20 US gpm, 30 ft H2O

Model: 1" Plastic PD10E-FES-PXX
Air consumption: 12.9 scfm
Air pressure: 49 psi g

Pump Data Sheet - IR ARO

Company: NA
Name: NA
Date: 10/25/2011

Pump:

Model: 1" Plastic PD10E-FES-PXX
Type: Pro-Series
Curve:
Dimensions: Suction: 1 in
Discharge: 1 in

Search Criteria:

Flow: 20 US gpm Head: 30 ft H2O

Fluid:

Water, Fresh
Viscosity: 1 cP

Pump Limits:

Sphere size: 0.125 in

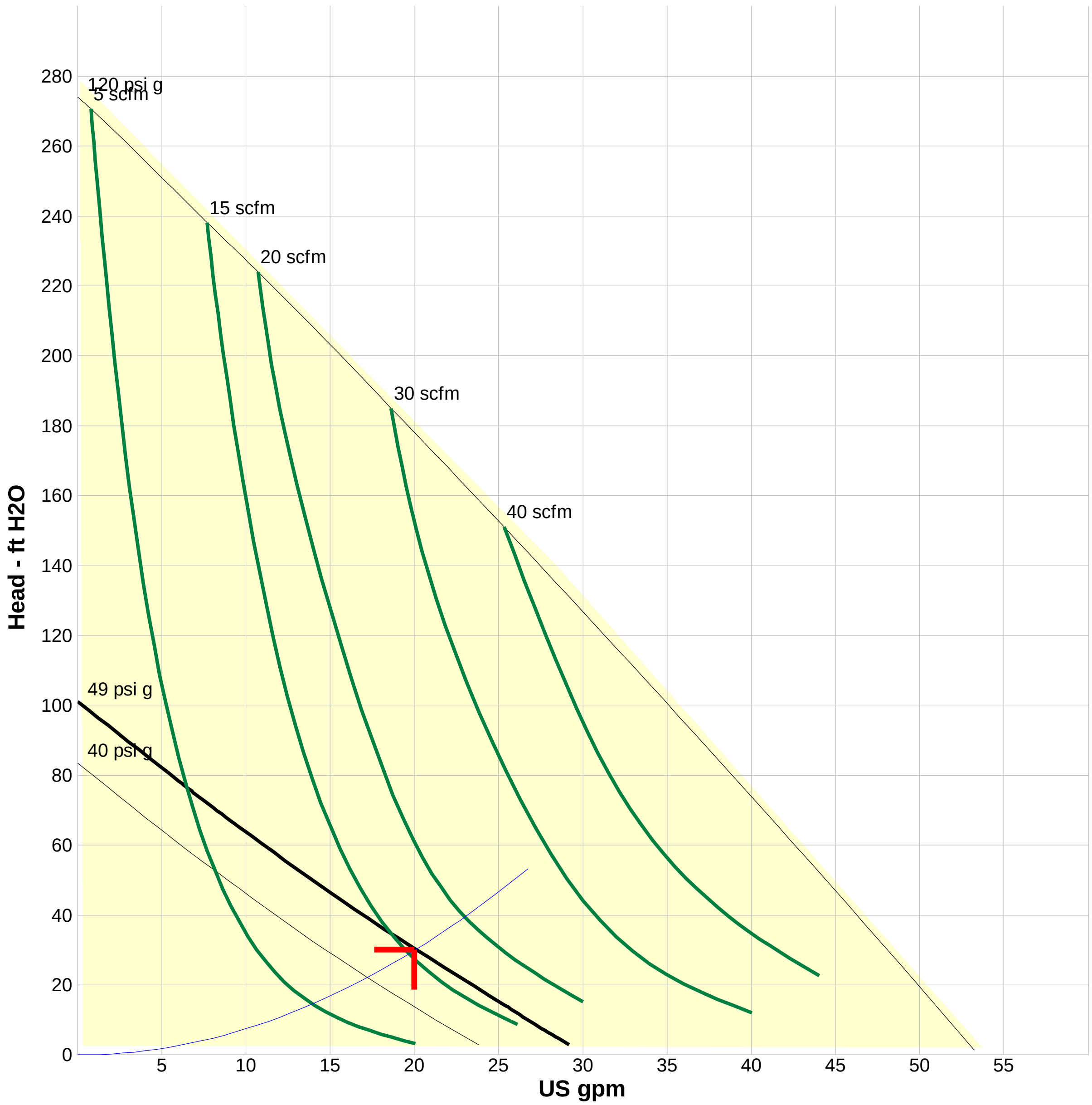
---- Data Point ----	
Flow:	20 US gpm
Head:	30.7 ft H2O
Air consumption:	12.9 scfm
Air pressure:	49 psi g
---- Design Curve ----	
Shutoff head:	101 ft H2O

Material Compatibility

Wetted parts
- A - Conductive Polypropylene

Elastomers
- A - Hytrel
- A - Nitrile (TPE)
- A - PTFE
- A - Santoprene
- B - Viton

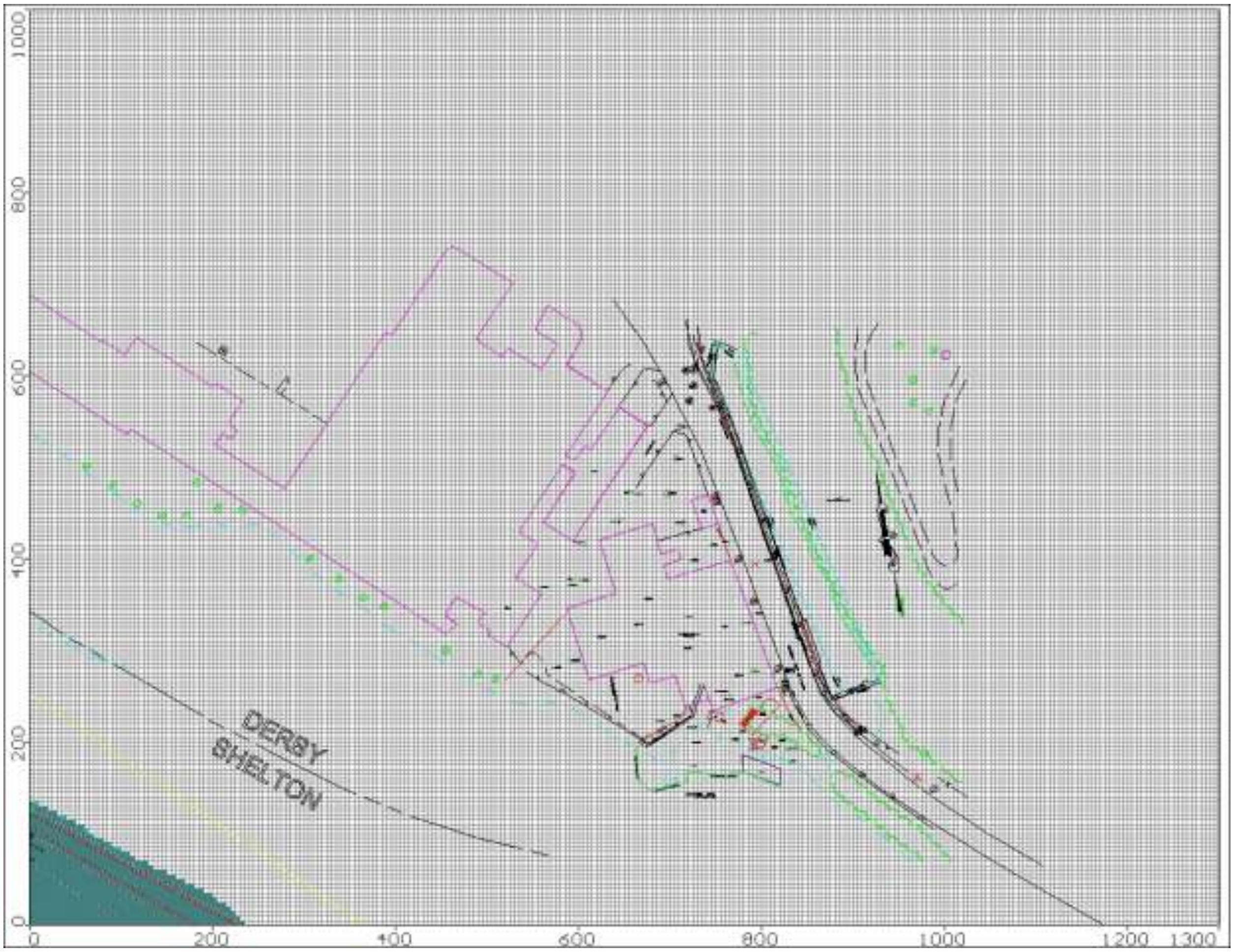
Key: A - Excellent, B - Good, C - Fair to Poor, D - Not Recommended, X - No Data Available, () No Data Available, Rating Based on Experience



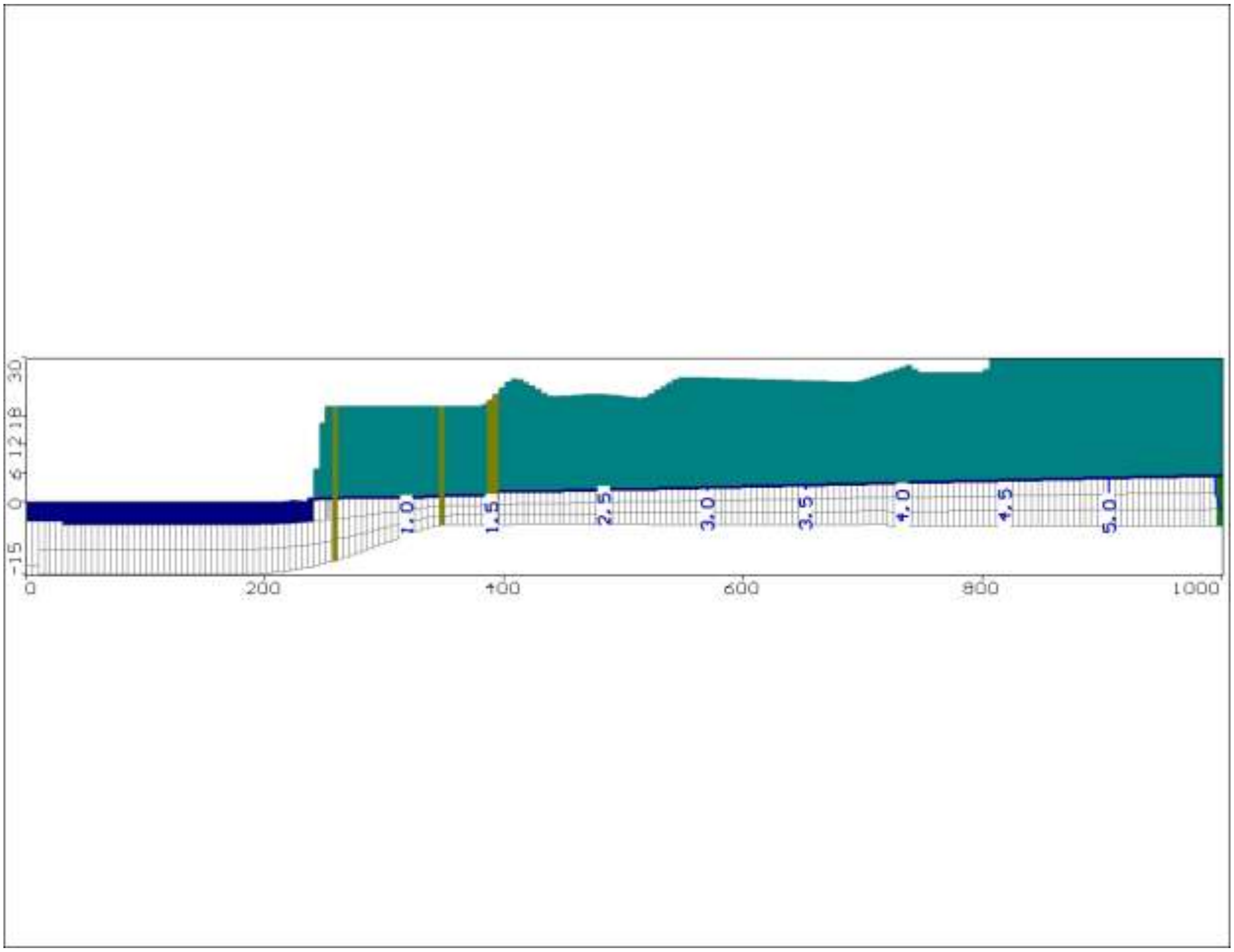
Performance Evaluation:

Flow US gpm	Head ft H2O	Air Consumption scfm
24	18.3	12.8
20	30.7	12.9
16	43.1	12.7
12	56.9	9.8
8	70.9	6.2

APPENDIX B

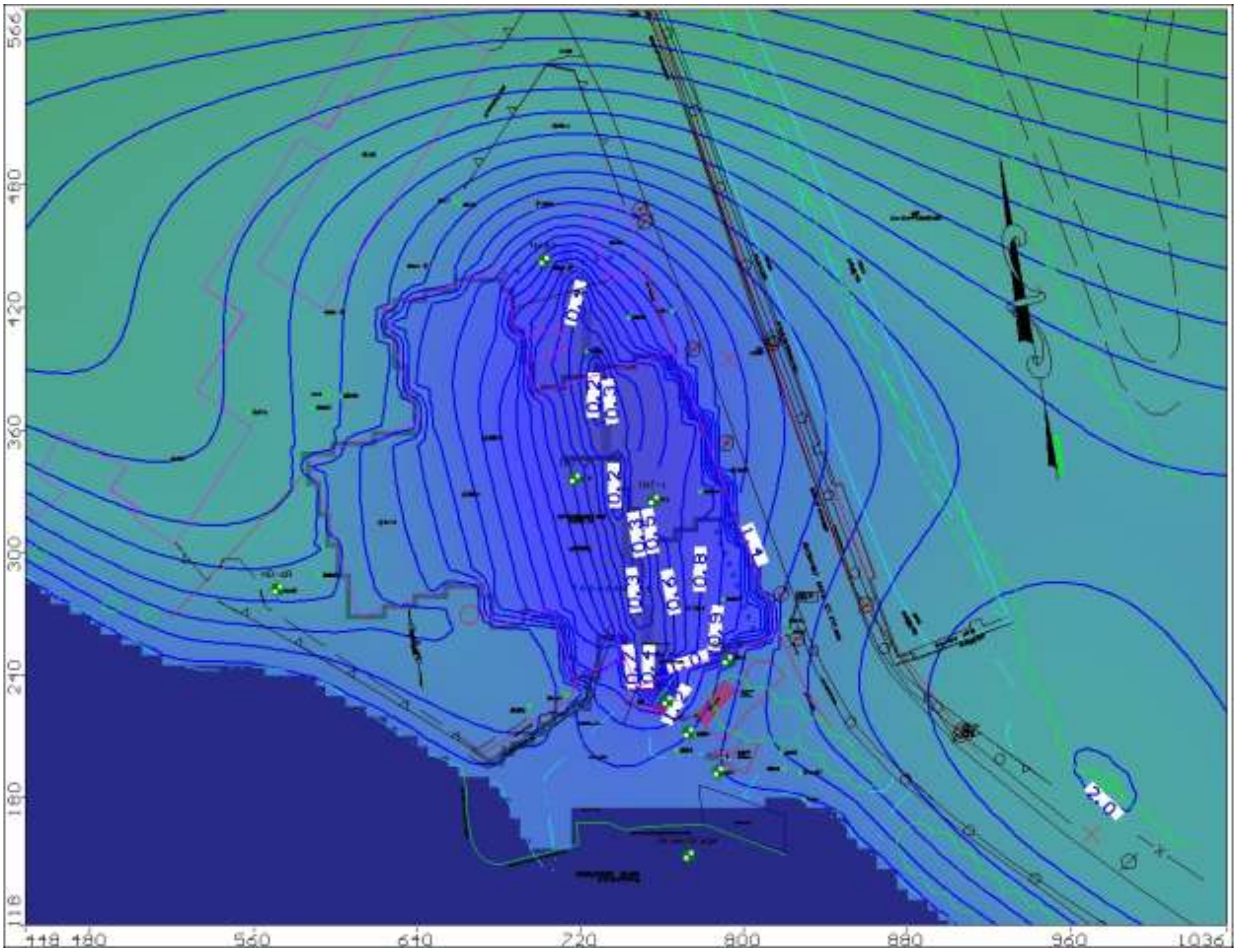


Appendix B, Figure B1. Groundwater flow model cell construction map.

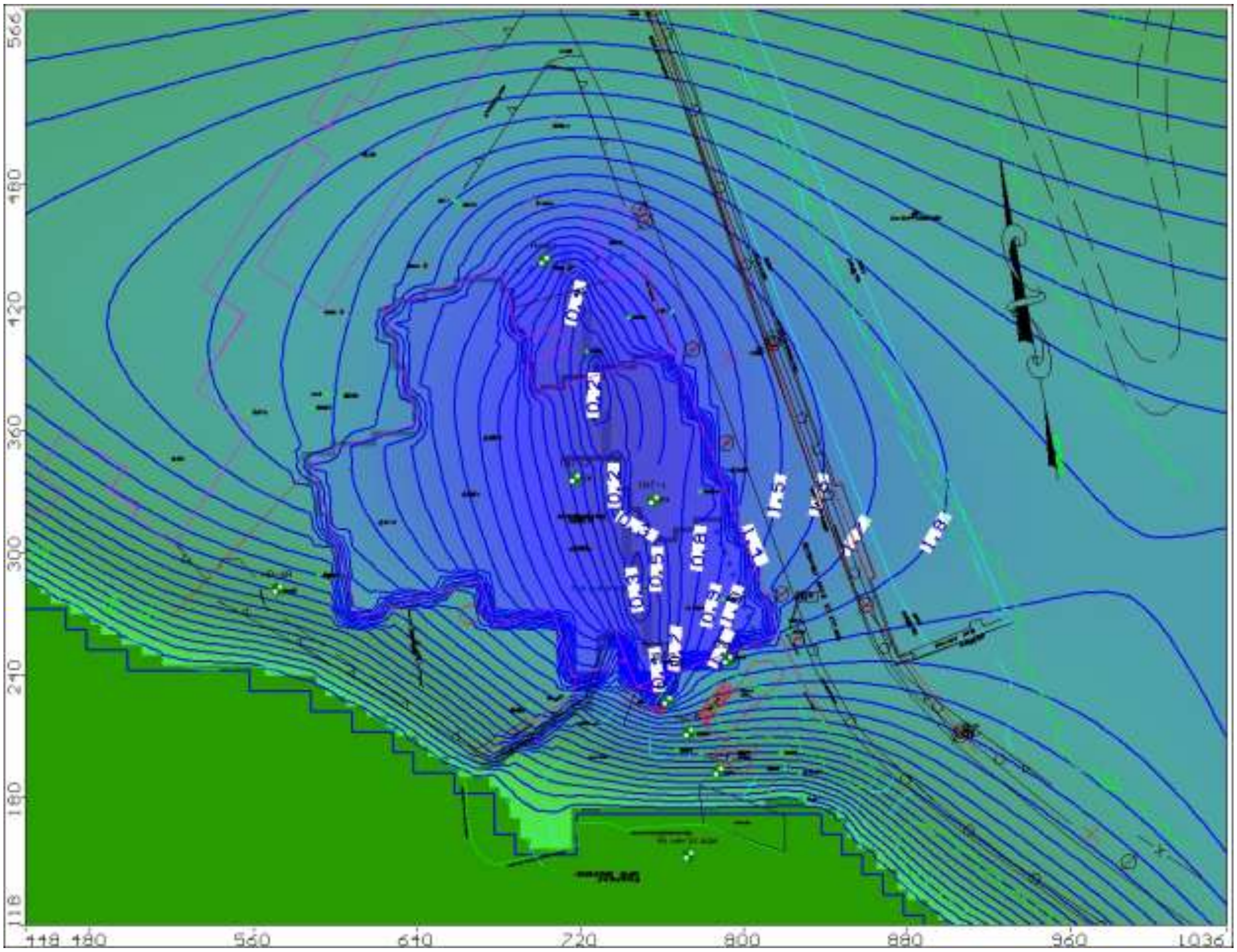


Appendix B, Figure B2. Groundwater flow model layer construction profile.

APPENDIX C

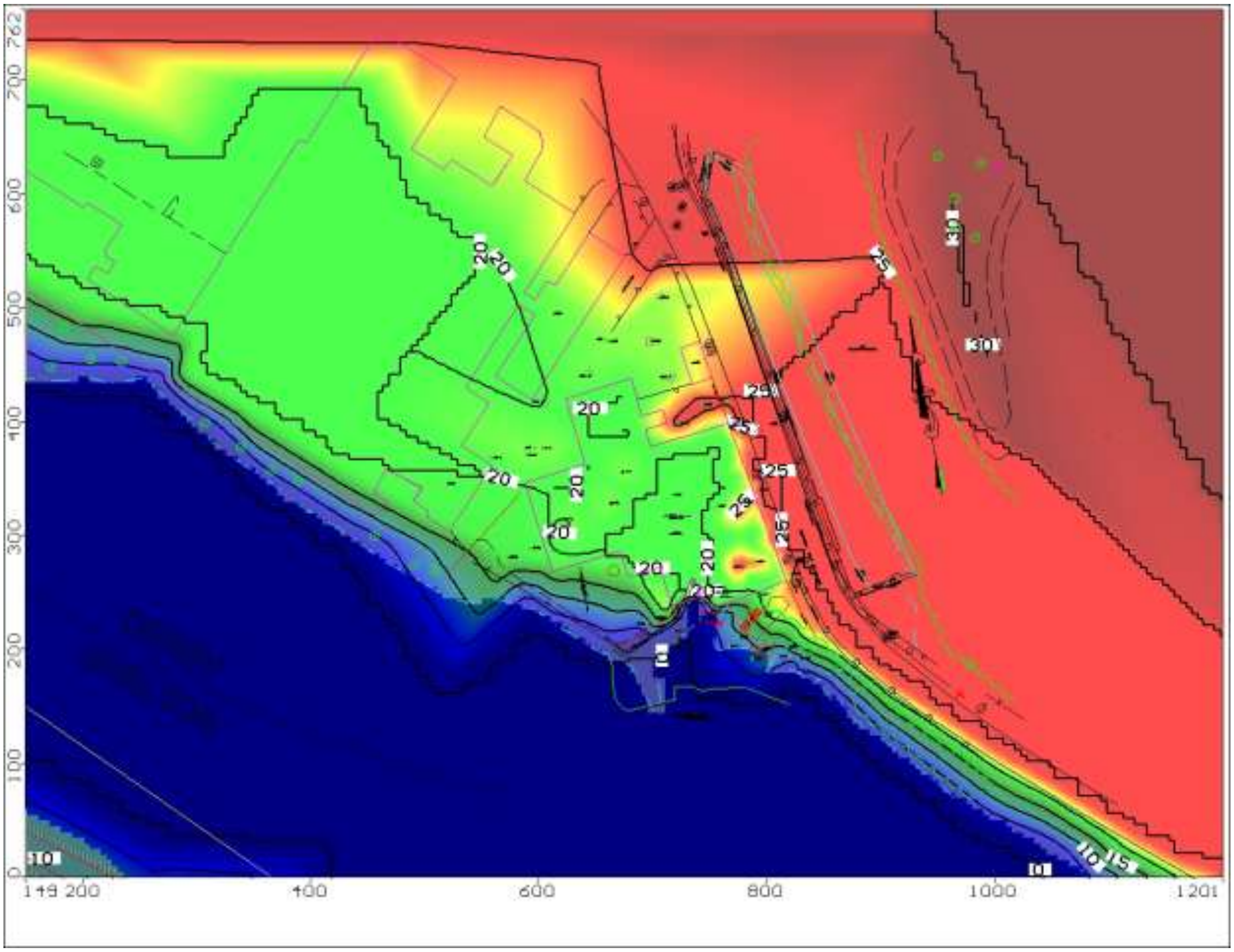


Appendix C, Figure C1. Water table elevation map at low river stage

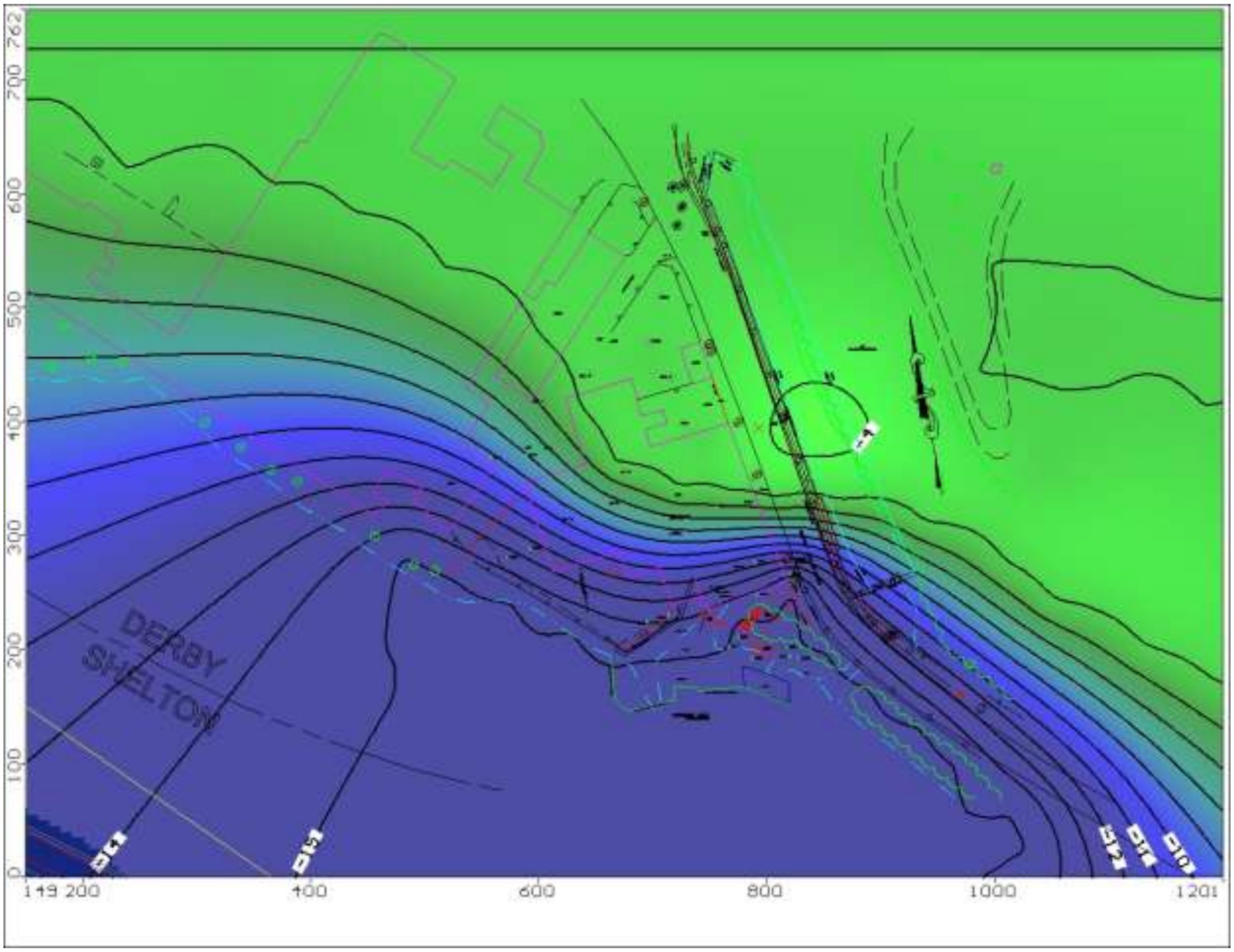


Appendix C, Figure C2. Water table elevation map at high river stage

APPENDIX D



Appendix D, Figure D1. Topographic contour map.



Appendix D, Figure D2. Bedrock structure contour map.