SITE CHARACTERIZATION REPORT – GROUNDWATER FLOW MODEL

HYDE PARK LANDFILL SITE
TOWN OF NIAGARA, NEW YORK

Prepared For:

Miller Springs Remediation Management, Inc.

Prepared by:

S. S. Papadopulos & Associates, Inc.
Services Environmental, Inc.
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<u>TABLE OF CONTENTS</u>

<u>LIST OF FIGURES</u>
(Following Text)

LIST OF FIGURES
(Following Text)

LIST OF FIGURES

(Following Text)

LIST OF FIGURES

(Following Text)

LIST OF TABLES
(Following Text)

LIST OF APPENDICES
(Following Text)

1.0 INTRODUCTION

1.1 OVERVIEW

This report has been prepared for Miller Springs Remediation Management, Inc. (MSRM) to support a hydrogeologic re-characterization of the Hyde Park Landfill Site (the Site). The Site is located in the Town of Niagara, New York.

In February 2002, MSRM submitted a report to the U.S. EPA and the New York State Department of Environmental Conservation (NYSDEC), *Site Characterization Report: Revised Geologic and Hydrogeologic Characterization* (SCR-G). The report described an extensive field and office investigation of the Site completed in 2001. The SCR-G presented a new hydrogeologic framework for the Site. The new framework has eleven discrete, bedding-parallel flow zones separated by aquitards. This framework is consistent with published regional studies by Johnston (1964), Kappel and Tepper (1992), and Yager (1996). At the time the SCR-G was completed, there were neither flow zone-specific water levels nor detailed transmissivity data to support the interpretation of groundwater flow within the new framework. The SCR-G included recommendations for additional investigations to complete the Site characterization.

The additional investigations proposed in the SCR-G were initiated in 2002 and completed in early February 2003. The results of the investigations are summarized in the report *Site Characterization Report: Hydrologic Characterization* (SCR-H). The data collected during the SCR-H have resulted in a refined understanding of groundwater flow at the Site. The results of the SCR-H hydraulic testing and monitoring support the framework defined in the SCR-G. The SCR-G idealized the flow zones and aquitards as areally extensive layers with uniform hydraulic properties. The results of the SCR-H investigations identified significant spatial variations in transmissivity within key flow zones. Complex groundwater flow patterns arise within the flow zones due to the heterogeneity. Extensive dewatered areas were identified under pumping conditions. These dewatered areas could not be observed with the existing long-interval wells at the Site, as these wells provided only a composite of the levels in the individual flow zones. Data collected during the SCR-H also demonstrated the significant influence on groundwater flow patterns arising from the vertical connection between flow zones along the wellbores of the purge wells.

This report, *Site Characterization Report – Groundwater Flow Model*, presents the third component of the re-characterization of the Site, the development of a new numerical flow model. The modeling study will be referred to as the SCR-M in the remainder of this report. The model provides a quantitative representation of the hydrogeologic framework presented in the SCR-G, and hydraulic data from the SCR-H. The model includes eleven discrete, bedding-parallel flow zones and intervening aquitards in the bedrock, and provides a quantitative assessment of conditions within the discrete flow zones, under the influence of precipitation recharge, the gorge of the Lower Niagara River, and the hydraulic structures of the NYPA Niagara Power Project.

The model is a work in progress. The Draft version of the SCR-M was submitted on April 30, 2003, only two months after the completion of SCR-H, the source of the hydrologic data used for model setup and calibration. The model developed for the SCR-M has been improved significantly since the Draft was submitted. The model has been improved in two major areas. First, a new approach has been developed to represent the purge wells. This approach achieves more realistic water levels and discharge distributions in the flow zones intersected by the open intervals of the wells. Second, the water level data have been evaluated critically, and the calibration has been improved by weighting the data according to their reliability. Data collection is continuing on the Site, and the model developed for the SCR-M will evolve as these data and revised interpretations become available. There is less than six months of hydraulic monitoring data for the conceptual model with eleven flow zones. A proposal is in preparation for closing a number of long open interval monitoring wells that, as described in the SCR-H, can have a significant influence on groundwater level. Groundwater quality monitoring is currently ongoing. All of these new data will influence the model design and calibration.

The model is an essential tool for testing our quantitative understanding of the Site. A model is the only means available for integrating the hydrogeologic data that have been collected within the detailed framework developed in the SCR-G and the SCR-H, and with a consideration of the effects of natural and man-made boundary conditions.

This report is the product of MSRM and the following consultants:

- S.S. Papadopulos & Associates, Inc. (SSPA);
- Services Environmental, Inc. (SEI) and
- Conestoga-Rovers & Associates, Inc. (CRA).

MSRM, Glenn Springs Holdings, Inc. (GSHI) and these consultants represent the "technical team". This report is the work product of the technical team. The lead modeler for the project is Mark A. Kuhl, S.S. Papadopulos & Associates, Inc.

1.2 MODELING OBJECTIVES

The groundwater flow model has been developed to synthesize the Site characterization framework and data developed in the SCR-G and the SCR-H in a coherent, quantitative representation of the groundwater flow system. The specific objectives of the modeling study are:

1. To synthesize the characterization of the Site developed in the SCR-G and the SCR-H reports into a conceptual model that places the Site within a regional hydrogeologic setting;
2. To develop and calibrate a groundwater flow model to represent pumping and non-pumping conditions in the 11 discrete flow zones, under the influence of precipitation recharge, the gorge of the Lower Niagara River, and the hydraulic structures of the NYPA Niagara Power Project; and

The final objective of the Site characterization activities (the SCR-G, SCR-H, and SCR-M studies) is to develop a practical monitoring program that can support the evaluation of the hydraulic performance of the Bedrock APL and Bedrock NAPL Plume Containment Systems. The model will not be the basis for demonstration of containment. Recommendations for containment monitoring will be developed based on the available data and our understanding of that data. The groundwater model is a critical tool for understanding these data and for assessing alternative monitoring networks.

2.0 CONCEPTUAL MODEL

The conceptual model provides the basis for the numerical simulation of the hydrogeologic system. The conceptual model of the Hyde Park Site has been revised significantly since the development of the original numerical model of the Site (SSP&A, 2001). The new numerical model described here synthesizes the results of the hydrogeologic and hydrologic re-characterization described in *Site Characterization Report–Revised Geologic and Hydrogeologic Characterization* (Conestoga-Rovers & Associates and others, 2002) and *Site Characterization Report-Hydrologic Characterization* (Services Environmental, Inc. and others, 2003).

2.1 GENERAL SETTING

The location of the Hyde Park Landfill Site is shown on Figure 2-1. A detailed map of the Site showing the locations of the wells at the Site is shown on Plate 1 of the SCR-H report. The deep gorge of the Lower Niagara River is located less than one mile west of the Site. The New York Power Authority (NYPA) operates major power installations north and east of the Site. Power from the Lewiston Plant is generated from a large pumped-storage reservoir northeast of the Site. The discharge from the Lewiston Plant empties into the Forebay north of the Site, which in turn supplies the Robert Moses Niagara Power Plant. The Lewiston reservoir and Forebay are supplied by diversions from the Upper Niagara River; the diversions are conducted through twin buried conduits located less than a mile from the eastern boundary of the Site.

2.2 GEOLOGIC CHARACTERIZATION

The Geologic Characterization is presented in the SCR-G. A brief overview is presented here.

The region surrounding the Site is underlain by Pleistocene unconsolidated deposits. The deposits consist of glacial till, lake deposits, and a few small sand and gravel deposits. These deposits are referred to collectively here as the "Overburden".

The bedrock in the Niagara region consists of nearly flat-lying sedimentary rocks of Paleozoic age. South of the Niagara Escarpment, the uppermost bedrock unit is the Lockport Dolomite, of Silurian age. The Lockport Dolomite is absent over limited areas along the Niagara River gorge and the Escarpment where the upper bedrock units consist of a sequence of relatively thin limestones, shales, and sandstones. North of the Niagara Escarpment, the overburden is underlain directly by the Queenston Shale formation, of Ordovician age.

A generalized stratigraphic section for the bedrock beneath the Site is presented on Table 3-1 of the SCR-G report. Prior to the development of the revised geologic and hydrogeologic characterization of the SCR-G, the stratigraphic designations of Zenger (1965) were used at the Site. The stratigraphic divisions and nomenclature adopted for the SCR-G follow recent work of the United States Geological Survey (USGS) (Brett et al., 1995). The USGS made two major changes to the previous stratigraphic model of Zenger (1965): first, the status of the Lockport was changed from a formation to a group; second, the Oak Orchard Dolomite was divided into an upper portion, the Guelph Dolomite, and a lower portion, the Eramosa Dolomite. The Guelph Formation is not present at the Site.

The most recent names of the stratigraphic units of the Lockport Group are listed below in order of increasing depth:

- Eramosa Formation;
- Vinemount Member of the Goat Island Formation;
- Ancaster Member of the Goat Island Formation;
- Niagara Falls Member of the Goat Island Formation;
- Pekin Member of the Gasport Formation; and
- Gothic Hill Member of the Gasport Formation.

The zone of active groundwater flow in the bedrock also includes the unit immediately underlying the Lockport Group, the DeCew Formation, a member of the Clinton Group.

The Burleigh Hill Member of the Rochester Shale underlies the zone of active groundwater flow. Beneath the Rochester lie the following units of the Clinton Group, in order of increasing depth:

- Irondequoit Limestone;
- Reynales Limestone; and
- Neahga Shale.

Key findings of the revised geologic characterization developed in the SCR-G are listed below:

1. The Site stratigraphy is generally consistent in lithology, thickness, and orientation with published regional geologic information from the USGS, the New York State Geological Survey, and others. The geologic logs of wells at the Site were re-interpreted in the SCR-G to be consistent with the revised USGS nomenclature.
2. In the vicinity of the Site, the strike of the bedding is approximately N.70°E. The bedding dips to the southeast at approximately 40 feet per mile.
3. Petrophysical testing confirms that the Site-specific bedrock properties are consistent with published values for dolostone. The hydraulic conductivity of the intact dolostone is very low. These low hydraulic conductivities suggest that groundwater flow occurs only through the connected fractures in the rock.
4. Approximately 90 percent of the fractures identified are near-horizontal, bedding plane features. Bedding-plane fractures are distributed evenly within the Eramosa, Vinemount, Ancaster/Niagara Falls, and Pekin units. Approximately 10 percent of the fractures identified are near-vertical. Near-vertical fractures were not observed in the Rochester Shale, consistent with regional observations. Relatively few fractures are dipping (4 percent of the fractures dip between 6 and 31 degrees).
5. In general, the average number of fractures per vertical foot of bedrock appears to decrease gradually with depth below the top of bedrock.

2.3 HYDROGEOLOGIC CHARACTERIZATION

2.3.1 REGIONAL OVERVIEW

Johnston (1964) of the USGS evaluated the groundwater resources of the Niagara Falls, New York area. His seminal fieldwork conducted between 1960 and 1962 constitutes the foundation for all subsequent work in the area. Johnston tabulated records of 298 wells and 18 springs in the Niagara Falls area.

Johnston (1964) proposed that groundwater flow in the Niagara Falls area occurs primarily within discrete horizontal flow zones in the rocks of the Lockport Group. These flow zones corresponded to major horizontal bedding planes. Johnston mapped the flow zones along excavations made for the NYPA Niagara Power Project, at the Forebay and along the length of the power conduits from the Upper Niagara River. Johnston identified seven flow zones. At the location nearest the Site, the outlet of the conduits to the Forebay, Johnston observed six of the seven flow zones. The uppermost flow zone was not identified at this location; the flow zone is likely within about 5 feet of the top of bedrock, and it may not be impossible to distinguish the fracture zone because of weathering.

The USGS conducted detailed geological and hydrogeological studies in the Niagara region in the 1980s and 1990s. Kappel and Tepper (1992) confirmed the basic conceptualization of discrete flow zones in the Lockport Dolomite. The USGS expanded on Johnston's work to include a thicker vertical section of the Lockport Group, and mapped the flow zones laterally across the region. The work of the USGS demonstrated that the elevations of the flow zones within the stratigraphic sequence could be correlated regionally. The "final" USGS conceptualization of the Lockport Dolomite is described in the report documenting the development of the regional groundwater model (Yager, 1996). The essential elements of the USGS regional conceptualization include:

- The hydraulic properties of the Lockport Group are the result of secondary permeability caused by bedding-plane fractures and vugs;
- The principal water-bearing zones are the weathered bedrock surface and horizontal-fracture zones occurring at or near stratigraphic contacts; and
- Vertical leakage occurs through high-angle fractures.

The USGS identified nine regionally extensive flow zones in the Lockport Group. The flow zone mapping of Johnston (1964) and the current USGS interpretation are compared in Figure 4.2 of the SCR-G report. Johnston (1964) identified two lower flow zones that are below the bottom of the USGS regional flow model. The USGS flow model identified four flow zones not included in Johnston's mapping. A synthesis of the flow zone mapping therefore comprises a total of 11 flow zones.

Figures 4-2 and 4-3 of the SCR-G report show the USGS log of well LW-1, located along the south berm of the Lewiston Reservoir. The log presents the core breaks that potentially indicate the locations of fractures or planes of weakness in the rock. It can be seen that the core breaks do not always correlate with the flow zones, and that some flow zones do not coincide with core breaks. This suggests that the USGS recognized implicitly that significant groundwater flow occurs in only a subset of the bedrock fractures. The lack of core breaks at flow zones II, VI, and VIII also suggests that the USGS conceived of the flow zones as regional features that are continuous but not transmissive everywhere in the Niagara Region.

2.3.2 SITE HYDROSTRATIGRAPHY

The revised hydrogeologic and hydrologic characterization presented in the SCR-G and the SCR-H divided the subsurface beneath the Site into four intervals:

- Overburden;
- Flow zones in the Lockport Dolomite;
- Aquitards between the flow zones in the Lockport Dolomite; and
- The Rochester Shale and underlying units.

The characteristics of these intervals are described below.

<u>Overburden</u>

The Overburden deposits in contact with the bedrock are generally described as lacustrine silts and clays, and glacial till. As discussed in the SCR-H, previous testing has shown that the lacustrine silts and clays have relatively low hydraulic conductivity. Slug tests in Overburden wells at the Site have consistently indicated relatively low hydraulic conductivity, on the order of 10^{-6} to 10^{-5} cm/sec.

Descriptions of the till in well logs suggested that the material was sand and gravel, with potentially high hydraulic conductivity. To further characterize the hydraulic properties of the till, samples were collected during the SCR-H for grain-size analyses and permeameter testing. The grain-size distributions of the till samples collected for the SCR-H showed consistently high contents of fine-grained materials (silts and clays). The grain size distributions show fines content ranging from 43 percent to 98 percent. These fine sediments fill the pore space between the sand and gravel, and reduce the permeability by several orders of magnitude compared to clean sand and gravel. To illustrate the effect of the fine-grained materials, data compiled by Cedergren (1977) are plotted in Figure 2-2. As shown on the figure, the hydraulic conductivity of clean sand declines by orders-of-magnitude for even relatively small amounts of fine-grained material.

Fill materials, including reworked native sediments, construction debris, and non-native fill are encountered across much of the Town of Niagara. These widespread areas of surficial fill are related to community and industrial development. Regrading for home and street construction, installation of sewers, and locally, the abandonment of an old railroad cut, have resulted in widespread distribution of fill. In most cases, the fill appears to be a veneer of redistributed native materials and most likely has low hydraulic conductivity. Where cuts have been made to install sewers and railroads, gravel bedding is typically placed in the bottom of the cuts. This bedding can create a network of high permeability conduits. These drains may have an impact on bedrock groundwater flow where the sewers and railroad cut to and into the bedrock. The locations of the sewers and tunnels are presented on Plate 1 of the SCR-H report.

Flow zones in the Lockport Dolomite

Based on extensive geophysical and borehole flowmeter investigations conducted for the SCR-G in 2001, the Technical Team concluded that a combined total of 11 flow zones identified in Johnston (1964) and Yager (1996) are present at the Site. The eight deepest flow zones have been identified positively at the Site. The three shallowest flow zones appear to be present; however, they are difficult to identify with certainty. The three uppermost flow zones occur in the Eramosa; the Eramosa is eroded such that these flow zones subcrop beneath the Landfill.

In the SCR-G, the 11 flow zones were characterized as being regionally extensive, discrete zones of active groundwater flow, separated by intervals of intact rock having low transmissivity. The flow zones were identified on the basis of geophysical logs developed for all wells at the Site (in particular the caliper, temperature, and conductivity logs).

The interpretations of the geophysical logs were confirmed by examining all available cores of the wells, and with high-resolution borehole flowmeter profiling conducted on selected wells. The positions of the flow zones in the wells were closely correlated to the peaks in the gamma log signatures that indicated zones with higher contents of clay minerals. Based on this correlation, the gamma logs were used to define a vertical reference system for correlating the results from the individual wells. The results of the interpretation of the gamma logs showed that the flow zones were near-horizontal, and bedding-parallel.

The flow zones have been idealized in the SCR-G and the SCR-H as 4-feet thick intervals. It is important to bear in mind that this idealization is not an indication of their true thickness. Rather, it reflects the accuracy with which the elevation of a flow can be known at any location. On the basis of our inspection of cores and outcrops, and our interpretation of the gamma signatures, we believe that that the flow zones comprise regions of thin, coalescing, horizontal fractures that are planes of weakness associated with beds of higher shale content. The individual fractures likely have apertures ranging from a few microns (10^{-6} m) to several hundreds of microns. According to the cubic flow law (Snow, 1968), the equivalent parallel-plate aperture of a fracture zone with a transmissivity of 0.1 ft^2/day is about 50 microns, and for 1,000 ft^2/day is about 1000 microns (1 mm).

As part of the SCR-H, extensive packer testing was conducted with a 5-foot open interval between the packers. The test results are presented in the SCR-H as transmissivity profiles at each testing location. In general, the results of the packer testing demonstrated that there were discrete horizontal zones with relatively high transmissivity, surrounded by intervals with very low transmissivity (the detection limit of the testing equipment and procedures was about 0.001 ft^2/day). The locations of high transmissivity matched the elevations of the flow zones predicted with the correlation equations presented in the SCR-G. In addition to confirming the presence of the discrete flow zones identified in the SCR-G, the results of the packer testing provided preliminary estimates of the transmissivities of the flow zones and the intervening aquitards.

The SCR-H report uses the term "dry areas" to describe areas in flow zones where water levels in piezometers are close to the elevation of the flow zones (at or below the top of the piezometer sand pack). We believe that this designation is appropriate, as it is most realistic to conceive of the fractures that comprise the flow zones as being either water-filled or essentially completely drained. The pressure-saturation relation for the flow zones is essentially a step function, and it is unlikely that unsaturated flow occurs within a flow zone. The water observed in piezometers in flow zones that we have identified as dry is likely stagnant water that has remained in the sandpack. Although it is possible that water can creep along dip, the mean flow is driven by the bulk hydraulic gradients.

<u>Aquitards between the flow zones in the Lockport Dolomite</u>

The results of petrophysical testing of drill core samples conducted as part of the SCR-G indicated that the intact bedrock at the Site has very limited ability to conduct water. The permeabilities of the core samples reported in Appendix F of the SCR-G report varied from 5.8×10^{-4} to 5.3×10^{-1} millidarcies. These permeabilities correspond to a range of hydraulic conductivities from 4×10^{-10} to 4×10^{-7} cm/sec, a range that is consistent with literature values reported for intact dolostone (Table 2.2, Freeze and Cherry, 1979). The hydraulic conductivity of the intact rock is so low that we expect that groundwater flow between the flow zones occurs through vertical and dipping fractures and not through the rock matrix.

Packer testing conducted for the SCR-H confirms that the rock between the flow zones has relatively low transmissivity. Although the transmissivities from tests between flow zones vary over a large range, the majority of values are well below 1 ft^2/day. The median transmissivity of tests between flow zones was 0.03 ft^2/day. It is important to bear in mind that packer tests provide estimates of the horizontal properties of an interval. Groundwater flow in the aquitards between the flow zones will be primarily vertical. Therefore, the mean transmissivity of the aquitards presented here must be regarded as only an approximate starting point for further analysis. The bulk vertical conductivity between the flow zones can be determined only through calibration of a numerical model.

Rochester Shale and Underlying Units

The Rochester Shale has been characterized as a regionally extensive aquiclude, across which there is negligible groundwater flow (Kappel and Tepper, 1992; Yager, 1996). The results of the Intermediate Formations Study (CRA, 1990) confirmed that the hydraulic conductivities of the Rochester Shale, and Irondequoit Limestone and Reynales Limestone are very low in the vicinity of the Site. Typical results from sampling wells open across these formations show very long recovery times, consistent with the initial hydraulic testing. Ongoing monitoring of wells penetrating these units confirms that there is no apparent connection between the units of the Lockport Dolomite and these deeper units; water levels are erratic and are not correlated with conditions in the upper bedrock (SEDA, 2001).

2.4 HYDROLOGIC CHARACTERIZATION

The results of the regional and Site-specific groundwater investigations demonstrate that there are zones of enhanced hydraulic conductivity aligned parallel to the bedding in the rocks of the Lockport Group. Groundwater flow occurs primarily within the planes of these flow zones. The refined hydrogeologic characterization developed in the SCR-G estimated the elevations of the flow zones. Equations defining the planes-of-best-fit for the flow zones were presented in Section 4.3.4 of the SCR-G report. A crucial element of the synthesis of the results of the geophysical and borehole flowmeter investigations at the Site was the definition of a frame of reference defined by the peaks of the response in the gamma logs. Results shown in the SCR-G demonstrate the consistency of the equations across the Site. The results of high-resolution packer testing presented in the SCR-H also confirm the presence of the flow zones.

The flow zones identified in the SCR-G were numbered following the convention set by the USGS (Yager, 1996). The nine flow zones identified in Yager (1996) were numbered in the SCR-G as flow zones FZ-01 through FZ-09. The two additional flow zones identified in Johnston (1964) were designated as FZ-10 and FZ-11. This numbering convention has carried over to the hydrologic characterization described in the SCR-H, and is also used for the numerical model described in the present report.

2.4.1 SUMMARY OF FLOW ZONE TRANSMISSIVITIES

A summary of the results of hydraulic tests conducted at the Site in the 1980s and 1990s was presented in Appendix H of the SCR-G report. Although the scale of the testing was not consistent with the current conceptualization of discrete flow zones, the results do serve to indicate that the hydraulic properties of the flow zones vary in space.

The results of an extensive program of hydraulic testing of the discrete flow zones were reported in the SCR-H. The program included:

- Complete slug testing of the existing Lower wells at the Site;
- Packer testing at selected wells; and
- Slug testing of the flow-zone piezometers after they were developed.

The existing Lower wells at the Site are generally open across only FZ-10 and FZ-11. The geophysical data collected during the SCR-G and the packer testing conducted during the SCR-H both indicated that FZ-11 is generally much more transmissive than FZ-10. In light of the consistent construction of the Lower wells, and the insignificance of FZ-10, the results of the Lower well slug testing provide a reliable impression of local variations of transmissivity in FZ-11. The results of the slug testing indicated that there are large areas in the vicinity of the Site where FZ-11 has very low transmissivity.

Packer testing for the SCR-H was conducted over 5.2-5.4 foot intervals, using a combination of slug tests and constant-rate pumping tests. The results from 259 tests were presented in the SCR-H, with accompanying plots of spatial distributions and statistical analyses. The transmissivity estimates exhibited a large range, from less than 0.001 ft^2/day to almost 10,000 ft^2/day. In general, the lower values of the range are the results of tests conducted in the aquitards between the flow zones. However, low transmissivities were also estimated at some locations in flow zones; the testing indicated that the transmissivity within the individual flow zones was highly heterogeneous.

The packer testing conducted for the SCR-H also confirmed the decision to not place piezometers in FZ-03 and FZ-10. The median transmissivities in these flow zones were 0.3 ft^2/day and 0.03 ft^2/day, respectively. The low transmissivities in these flow zones suggests that there is no significant groundwater flow within them at the Site. Piezometers were not installed in FZ-08. FZ-07, FZ-08, and FZ-09 are too close together in the vertical to construct a reliable seal between them. The packer testing results for FZ-08 suggest that the flow zone has negligible transmissivity west of the Landfill.

All 113 flow-zone piezometers installed during the SCR-H were slug tested after they were developed. The transmissivity estimates obtained from the slug tests were presented in the SCR-H, with accompanying plots of spatial distributions and statistical analyses. The results of the slug testing were generally consistent with the packer testing, and confirmed that transmissivity was heterogeneous within each flow zone.

A total of 168 transmissivity values for the 11 flow zones were assembled in the SCR-H. The median transmissivities for each flow zone are listed below.

Flow zone	*Number of transmissivity values*	*Range of transmissivities (ft^2/day)*	*Median transmissivity (ft^2/day)*
FZ-01	6	0.5 to 410	70
FZ-02	11	0.5 to 90	9
FZ-03	6	0.05 to 40	0.3
FZ-04	15	<0.001 to 422	0.6
FZ-05	16	<0.001 to 360	1.1
FZ-06	22	<0.001 to 218	0.9
FZ-07	24	<0.001 to 2,600	0.3
FZ-08	12	<0.001 to 240	1.0
FZ-09	26	<0.001 to 2,300	90
FZ-10	10	<0.001 to 50	0.03
FZ-11	20	<0.001 to 520	1.8

The average values tabulated above provide a consistent indication that the dominant flow zones at the Site are FZ-01, FZ-02, FZ-09, and FZ-11. The following overall findings regarding the transmissivity were presented in the SCR-H:

- The dominant flow zone is FZ-09;
- The transmissivities of flow zones 03 through 08 are low; and
- The transmissivity of flow zone 10 is very low.

2.4.2 FLOW ZONE TRANSMISSIVITY DISTRIBUTIONS

Maps of the transmissivity distribution for each flow zone are presented on Figures 2-3 through 2-13. As indicated in the SCR-H, the zonations should be considered approximate; they provide a starting approximation for the numerical model. The transmissivity zones presented on the figures have been developed based on the results of the hydraulic testing (including the Lower well slug tests), the piezometer water level records, and the long-term responses of the Lower wells.

Water levels collected in the SCR-H are an invaluable source of additional qualitative information on the distributions of transmissivity in some of the flow zones. To emphasize the significance of the water levels with respect to the structure of transmissivity, Figures 2-3 through 2-13 show the interpreted water level contours developed for the SCR-H superimposed on the tentative zonations of transmissivity. It is important to note that with the exception of FZ-11, the transmissivity zones presented in the SCR-H were developed independently of the water level contours. Therefore, there may be some inconsistencies between the transmissivity zones and water levels. This is to be expected, as both the development of the transmissivity distributions and water level patterns should be interpreted as works-in-progress. A numerical model is an effective tool for developing an internally consistent synthesis of both datasets.

The water level contours developed for the SCR-H also provide important indirect indications of larger scale variations of the transmissivities of the individual flow zones. For example, in the case of FZ-11, historical water-level data from the existing Lower wells plotted on Figure 3-21 of the SCR-H indicate that there are three subzones in FZ-11 that appear to respond independently. The hydrographs suggest that there must be area of low transmissivity separating these subzones.

The water levels also provide an indication of the relative transmissivity at the scale of the individual piezometers. In particular, the lack of response to fluctuations in barometric pressure indicates that the piezometer is located in a zone where the transmissivity is locally very low. Indirect evidence of low transmissivity can be inferred from the hydrograph for ABP-1-07, for example. A comparison of the hydrographs for ABP-1-07 and ABP-1-09 presented in Appendix B3 of the SCR-H report reveals that the water level in ABP-1-09 fluctuates in response to changes in barometric pressure, while the water level in ABP-1-09 does not. This is consistent with the transmissivities estimated from the piezometer slug tests: the transmissivity estimated for ABP-1-09 was 2.6 ft^2/day, and the transmissivity estimated for ABP-1-07 was <0.001 ft^2/day.

Slow and constant recovery during the water level monitoring period also indicates areas of local low transmissivity. This response is indicated in several wells, including D2M-07, F4L-11, H5-06, I1-09, and I1-11. For all of these piezometers, negligible recovery was observed during slug testing and the transmissivities were too low to quantify.

The following sections describe the most important features of the transmissivity distributions inferred from the hydraulic testing of each flow zone. It is important to bear in mind that transmissivity zones developed during the SCR-H are approximate and may not be representative. Some adjustment of the zonation may be required in order for the numerical model to match observed water level patterns. The transmissivity distributions developed during calibration of the numerical model are presented in Section 5.4.1.

The transmissivity estimates for each flow zone must also be regarded as first-order estimates. The transmissivity values were developed using classic porous media analyses, for which the conceptual models differ greatly from conditions at the Site. These methods conceive of the flow zones as laterally extensive, homogeneous porous media; they cannot account for subcropping of flow zones and large-scale changes in transmissivity. The issue of the scale in transmissivity estimation is discussed in Section 2.4.3.

In some cases, the heterogeneities inferred in the transmissivity testing are below the scale of resolution of the model. For example, the transmissivities in FZ-09 at PW-1L and PMW-1L-09 are 2,300 ft^2/day and 60 ft^2/day, respectively, over a distance of only 350 feet. The local heterogeneity at these two locations may be associated with small-scale, natural depositional features, or may reflect the presence of NAPL. In the model, the overall effects of heterogeneities are accounted for by using formal parameter estimation techniques to assist in identifying large-scale, "effective" transmissivities.

FZ-01

The transmissivity values estimated for FZ-01 are shown in Figure 2-3. The transmissivity values for the 6 locations in FZ-01 range from 0.5 to 410 ft^2/day, with a median value of about 70 ft^2/day. A uniform transmissivity of 70 ft^2/day is assumed as a starting approximation for FZ-01 in the numerical model, because the available data are not sufficient to support identification of distinct zones.

FZ-02

The transmissivity values estimated for FZ-02 are shown in Figure 2-4. The transmissivity values for the 11 locations in FZ-02 range from 0.5 to 90 ft^2/day, with a median value of about 9 ft^2/day. As a first approximation, the transmissivity values were divided into three zones for the SCR-H. The approximate bulk transmissivities inferred for each zone are:

- High T zone: 80 ft^2/day (range: 70 to 90 ft^2/day);
- Intermediate T zone: 20 ft^2/day (range: 9 to 30 ft^2/day); and
- Low T zone: 1 ft^2/day (range: 0.5 to 2 ft^2/day)

FZ-03

The transmissivity values estimated for FZ-03 are shown in Figure 2-5. Although no piezometers were completed in FZ-03, transmissivity estimates for the flow zone are available from the packer testing. The transmissivity values for the 6 locations in FZ-03 range from 0.05 to 40 ft^2/day, with a median value of about 0.3 ft^2/day. The transmissivities are low (<1 ft^2/day) in the vicinity of the Site. A uniform transmissivity is assumed for FZ-03 in the model, because the available data are not sufficient to support identification of distinct zones.

FZ-04

The transmissivity values estimated for FZ-04 are shown in Figure 2-6. The transmissivity values for 15 locations in FZ-04 range from essentially zero (<0.001 ft^2/day) to 422 ft^2/day, with a median value of about 0.6 ft^2/day. The transmissivities are generally low (<1 ft^2/day) in the vicinity of the Site. As a first approximation, the transmissivity values were divided into two zones for the SCR-H. The approximate bulk transmissivities inferred for each zone are:

- High T zone: 100 ft^2/day (range: 1.4 to 422 ft^2/day); and
- Low T zone: 0.1 ft^2/day (range: <0.001 to 4.2 ft^2/day).

FZ-05

The transmissivity values estimated for FZ-05 are shown in Figure 2-7. The transmissivity values for 16 locations in FZ-05 range from <0.001 ft^2/day to 360 ft^2/day, with a median value of about 1.1 ft^2/day. The transmissivity distribution was divided into two zones for the SCR-H, reflecting the observation that the transmissivities are generally low (<1 ft^2/day) south of the Landfill. The approximate bulk transmissivities inferred for each zone are:

- High T zone: 100 ft^2/day (range: 2.1 to 360 ft^2/day); and
- Low T zone: 0.1 ft^2/day (range: <0.001 to 0.7 ft^2/day).

FZ-06

The transmissivity values estimated for FZ-06 are shown in Figure 2-8. The transmissivity values for 23 locations in FZ-06 range from <0.001 ft^2/day to 218 ft^2/day, with a median value of about 0.9 ft^2/day. Three transmissivity zones were identified for the SCR-H. The transmissivities are generally low (<1 ft^2/day) west of the middle of the Landfill. Transmissivities appear to be higher east of the middle of the Landfill, and south of the Site. The approximate bulk transmissivities inferred for each zone are:

- High T zone: 100 ft^2/day (range: 58 to 218 ft^2/day);
- Intermediate T zone: 10 ft^2/day (range: <0.001 to 20 ft^2/day); and
- Low T zone: 0.1 ft^2/day (range: <0.001 to 11 ft^2/day).

FZ-07

The transmissivity values estimated for FZ-07 are shown in Figure 2-9. The transmissivity values for the 24 locations in FZ-07 range from <0.001 ft^2/day to 2,600 ft^2/day, with a median value of about 0.3 ft^2/day. The zonation of transmissivity in FZ-07 is relatively complex. Three zones were identified tentatively for the SCR-H. The narrow band running across the middle of the Landfill represents a transition zone between an area of low transmissivity east and south of the Site, and a zone of very high transmissivity north of the Site. The water level monitoring has demonstrated that the piezometers in the high transmissivity zone are connected to the NYPA Forebay and closely follow its water level fluctuations. The hydraulic connection between the Forebay and flow zones at the Site is discussed in Section 2.5.2.

The approximate bulk transmissivities inferred for each transmissivity zone in FZ-07 are:

- High T zone: 1,000 ft^2/day (range: 65 to 2,600 ft^2/day);
- Intermediate T zone: 100 ft^2/day (range: 40 to 219 ft^2/day); and
- Low T zone: 0.1 ft^2/day (range: <0.001 to 13 ft^2/day).

FZ-08

The transmissivity values estimated for FZ-08 are shown in Figure 2-10. Although no piezometers were completed in FZ-08, transmissivity estimates are available from the packer testing. The 12 transmissivity values for FZ-08 range from <0.001 ft^2/day to 240 ft^2/day, with a median value of about 1 ft^2/day. As a first approximation, the transmissivity values have been divided into two zones with the following bulk transmissivities:

- Intermediate T zone: 50 ft^2/day (range: 0.2 to 240 ft^2/day); and
- Low T zone: 0.001 ft^2/day (range: <0.001 to 0.04 ft^2/day).

FZ-09

The transmissivity values estimated for FZ-09 are shown in Figure 2-11. The transmissivity values for 25 locations in FZ-09 range from <0.001 ft^2/day to 2,300 ft^2/day, with a median value of about 90 ft^2/day. A zonation similar to FZ-07 was developed for the SCR-H. West of the Landfill, the piezometers exhibited strong responses to bedrock pumping. North of the Landfill, the water levels in the piezometers followed closely the fluctuations in the level in the NYPA Forebay. The approximate bulk transmissivities inferred for each zone are:

- High T zone: 1,000 ft^2/day (range: 0.002 to 2,300 ft^2/day);
- Intermediate T zone: 100 ft^2/day (range: 2.6 to 1,000 ft^2/day); and
- Low T zone: 0.01 ft^2/day (range: <0.001 to 4.9 ft^2/day).

FZ-10

The transmissivity values estimated for FZ-10 are shown in Figure 2-12. Although no piezometers were completed in FZ-10, transmissivity estimates are available from the packer testing. The 10 transmissivity values for FZ-10 range from <0.001 ft^2/day to 50 ft^2/day, with a median value of about 0.03 ft^2/day. A uniform transmissivity of 0.03 ft^2/day is assumed as a starting approximation in the numerical model, because the available data are not sufficient to support identification of distinct zones.

FZ-11

The transmissivity values estimated for FZ-11 are shown in Figure 2-13. The transmissivity values for 19 locations in FZ-11 range from <0.001 ft^2/day to 520 ft^2/day, with a median value of about 1.8 ft^2/day. Five transmissivity zones were identified in the SCR-H. The zones were delineated based on the results of the hydraulic testing (including the Lower zone slug testing), the long-term water level data from Lower zone wells, and the responses observed in the FZ-11 piezometers.

The most significant feature in FZ-11 is a zone of relatively high transmissivity immediately west of the Landfill. The three piezometers located in this zone, B2L-11, D1L-11, and PMW-1L-11, were the only piezometers that exhibited recoveries following the shutdown of the bedrock purge wells.

As indicated in the SCR-H, the existing Lower wells at the Site are generally open across only FZ-10 and FZ-11. Therefore, the historical water level data from the Lower Bedrock wells can be used to supplement the evaluation of conditions in FZ-11. We have used the long-term water level responses and the hydraulic testing results from G2L, G3L, and G5L to support the definition of a zone of high transmissivity around these wells.

The approximate bulk transmissivities inferred for each zone are:

- High T zones:

  Near G1L: 200 ft^2/day (range: 12 to 430 ft^2/day);

  Near PW-1L: 300 ft^2/day (range: <0.001 to 540 ft^2/day);
- Intermediate T zones:

  Near AGW-2L: 10 ft^2/day (range: <0.001 to 470 ft^2/day);

  Near D1L: 20 ft^2/day (range: 4 to 68 ft^2/day); and
- Low T zone: 0.01 ft^2/day (range: <0.001 to 100 ft^2/day).

2.4.3 SCALE ISSUES IN TRANSMISSIVITY ESTIMATION

The transmissivity estimates presented here are derived from single-well slug tests, and the bulk properties of the flow zones may be significantly different. We believe that the most appropriate quantitative approach for evaluating scale effects is the development of a numerical model that integrates local-scale observations within the regional context beyond the limits of the Site.

The single-well tests conducted during the SCR-H provide estimates that are representative of conditions close to the individual piezometers. Although the pressure pulse arising from the initial disturbance may propagate significant distances into a fractured medium, research in settings similar to the Hyde Park Landfill has shown that slug tests have a small radius of influence (Novakowski and others, 1999). With packer tests, the focus is even narrower; these tests provide semi-quantitative characterizations of the zones immediately adjacent to the packed-off interval.

In contrast to the single-well tests, the pumping tests conducted at the Site after the installation of the bedrock purge wells provide transmissivity estimates that are representative of a relatively large volume of rock.

The results from the purge well testing at PW-2M provide important insights into the representativeness of the transmissivity estimates derived from the single-well tests. This well is particularly significant because it has historically provided about half of the total discharge from the bedrock purge well system. PW-2M is open across FZ-06, FZ-07, FZ-08 and FZ-09. The cumulative transmissivity for these flow zones in the vicinity of PW-2M estimated from Figures 2-8 through 2-11 is about 200 ft^2/day.

We have re-analyzed the results of the prototype purge well testing conducted in 1993 and obtained a somewhat higher transmissivity estimate of about 500 ft^2/day, based an analysis of the drawdown data from only the pumping well. The influence of the three-day pumping test is much larger than the slug and packer tests, and the difference in transmissivity estimates derived from the slug and pumping tests is consistent with observations compiled for other fractured-rock sites (Clauser, 1992; Sanchez-Vila and others, 1996; Shulze-Makuch and Cherkauer, 1998). It is important to note, however, that although the transmissivity estimated from the purge well testing may be more representative, it is still an estimate. The purge well tests provide only a composite impression of the bulk properties of the flow zones; furthermore, the analyses of the drawdown data assume that flow in the fractured bedrock satisfies the highly idealized assumptions of the pump test analysis methods.

2.5 HYDROLOGIC BOUNDARIES

Groundwater flow patterns at the Site are controlled by the following boundary conditions:

- The gorge of the Niagara River,
- The NYPA Niagara Project Forebay;
- The NYPA buried conduits; and
- Infiltration of precipitation.

The boundary conditions that control groundwater flow in the region surrounding the Site are discussed in more detail in the following sections.

2.5.1 GORGE OF THE LOWER NIAGARA RIVER

The deep gorge of the Lower Niagara River is located less than one mile west of the Site. Along the gorge, the ground surface drops 325 feet over a distance of about 800 ft, to a river level of about 250 ft MSL. The bedrock units of interest with respect to groundwater flow at the Site all terminate at the gorge. Figure 4.17 of the SCR-G shows schematically how the gorge intercepts the flow zones.

Previous modeling of the Hyde Park Landfill area conducted by Maslia and Johnston (1982) and Maslia and Johnston (1984/1985) suggested an extensive seepage face at the gorge. Maslia and Johnston's analyses with a variably saturated finite-element model predicted the elevation of the seepage face at about 552 ft MSL. It is important to note that Maslia and Johnston represented the Lockport Group as a single unit in their analysis. While their general inference of a seepage face is reasonable, their predicted elevation of the seepage face is not applicable for a detailed analysis that considers the discrete flow zones.

Observations of the gorge face reported in the SCR-G confirm seepage from the flow zones at the gorge. The water levels in the piezometers installed in the wells closest to the gorge, ABP-1, AFW-1, and AFW-2, provide an indication of conditions in FZ-06 and FZ-07 at their intersection with the gorge. A simplified cross-section along these wells is shown in Figure 2-14. The dashed lines in the figure indicate the predicted elevations of FZ-06 and FZ-07. As shown in the figure, the average water levels observed in the piezometers in January 2003 are very close to the predicted elevations of the flow zones.

2.5.2 NYPA NIAGARA PROJECT FOREBAY

The New York Power Authority (NYPA) operates major power installations north of the Site, shown in Figure 2-1. A large pumped-storage reservoir, the Lewiston Reservoir, supplies water for the Lewiston Power Plant. The discharge from the Lewiston Plant empties into the Forebay that in turn discharges to the Robert Moses Power Plant. The Forebay is pumped to fill the Lewiston Reservoir, it is supplied by diversions from the Upper Niagara River that are transported through twin buried conduits.

The NYPA Forebay is located about one mile north of the Site. The Forebay is an unlined trench excavated through the entire thickness of the Lockport Group and into the Rochester Shale. A cross-section along the Forebay is shown in Figure 2-15; the location of the cross-section is indicated as A-A′ in Figure 2-1. The bottom of the Forebay at the Lewiston pump/generating plant end is 510 ft MSL. The bottom of the Forebay at the Robert Moses power plant end is 488 ft MSL. The Rochester Shale lies at 516 ft MSL at the west end of the Forebay, and at 506 ft MSL near the conduit entrance. By projecting the flow zone planes defined at the Site to the Forebay, we estimate that the Forebay intercepts FZ-07 through FZ-11.

Water levels in the Forebay fluctuate in a complex manner dictated by NYPA power requirements, and restrictions based on the time of day, the day of the week, and the season. These fluctuations have daily, weekly, and seasonal periodicities. Continuous records of Forebay levels are available for October-November 1994 (Figure 7, Miller and Kappel, 1987), February, May, and September 1992 (during the prototype purge well tests), April-June 2001 (2001 Purge well shutdown), and December 2002-January 2003 (SCR-H). These records indicate the levels in the Forebay range from about 536 ft MSL to 563 ft MSL, with a typical daily range of between 15 and 26 feet.

Forebay levels on January 6, 2003, when the bedrock wells at the Site were pumping, are plotted on Figure 2-16. The level in the Forebay on January 6 fluctuated between an elevation of about 542 ft MSL and 557 ft MSL, with a time-averaged level of 550.4 ft MSL. The Forebay levels between January 23 and 24, 2003, when the bedrock wells at the Site were not pumping, are plotted on Figure 2-17. The Forebay level on January 23-24 fluctuated between an elevation of about 550 ft MSL and 558 ft MSL, with a time-averaged level of 554.2 ft MSL.

As indicated in the Figure 2-15, FZ-06, FZ-07, and FZ-08 are not always submerged along the full length of their intersection with the Forebay. This has important implications with respect to the interaction between the Forebay and the Site. In order for FZ-06 to be recharged by the Forebay, the water level in the Forebay must be above an elevation of about 558 ft MSL. The significance of the elevation of the flow zone can be seen in the water levels observed in AGW-1U-06, for example. The hydrograph for this piezometer is shown in Figure 2-18. As shown in the figure, the water level in the Forebay is generally below the threshold elevation for flow into FZ-06. Under these conditions, there is a free surface in FZ-06 and the water levels in the piezometer follow fluctuations in barometric pressure. The transient response in the piezometer changes abruptly when the Forebay level exceeds the threshold; under these conditions the piezometer water level changes to a confined response and the piezometer levels track closely the fluctuations in the Forebay levels.

The piezometer water levels collected during the SCR-H indicate that there is a direct connection between the Forebay and portions of FZ-06, FZ-07, and FZ-09 at the Site. For example, the Forebay and piezometer water levels at J5M-09 are plotted on Figure 2-19. In general, the piezometers in which the water levels tracked the Forebay fluctuations are located in the high-T zones indicated on the transmissivity maps for FZ-07 and FZ-09. The piezometers that showed the strongest connection to the Forebay were at AGW-1 (AGW-1U-06; AGW-1M-07; AGW-1M-09), H2M-09, I1-07, J5M (J5M-07; J5M-09), and J6 (J6-07; J6-09).

As part of this study, we analyzed the water level fluctuations at the piezometers to demonstrate that the connection to the Forebay could be evaluated quantitatively, and to obtain an estimate of the bulk flow zone transmissivities between the Forebay and the Site. The analysis was developed from a generalized version of the Ferris (1951) solution. The results of one of the analyses are shown on Figure 2-20. The circles on the figure designate the observed water levels in J5M-09, and the solid line designates the water levels calculated with an analytical solution. A uniform transmissivity of 1,000 ft^2/day and a storage coefficient of 10^{-6} were assumed in this simplified analysis. The results of additional analytical calculations indicate that similar water levels are calculated for higher transmissivities, so the value of 1,000 ft^2/day represents a likely lower bound estimate.

Average Forebay levels change over an annual cycle of operation. The changes in average Forebay levels may have an important effect on the total flow from the Forebay to the Site. Additional data will be acquired from NYPA to assess seasonal fluctuations and their influence on the Site groundwater levels.

2.5.3 NYPA NIAGARA PROJECT BURIED CONDUITS

The buried conduits of the NYPA Niagara Power Project are located about one mile east of the Site. The buried conduits are concrete-lined tunnels. A north-south cross-section along the conduits is shown in Figure 2-21. The location of the section is indicated as B-B′ in Figure 2-1. The southern end of the section is at the end of the model area, about halfway between the Forebay and the Upper Niagara River.

The elevation of the base of the conduits ranges from about 490 ft MSL at the inlet at the Upper Niagara River, to 475 ft MSL at the intersection with the Forebay. The transition between the bottoms of the conduits at 475 ft MSL and the bottom of the Forebay at 510 ft MSL occurs over a distance of about 1,000 feet.

Construction details of the buried conduits are presented in Miller and Kappel (1987); drawings of these details are reproduced in Figures 2-22A and 2-22B. The conduits are concrete structures and are not in direct communication with the bedrock. There are drains along the sides and bottom of the conduits. These drains lie directly against the bedrock. Two sumps maintain water levels in the drains. One sump is located near the Falls Street Tunnel, the other is located near the Forebay. The water collected in the sumps is discharged to the conduits. The outlet levels of the sumps are fixed; the sumps discharge to the conduits at fixed elevations of 560 ft MSL near the Falls Street Tunnel and 550 ft MSL near the Forebay.

As shown in Figure 2-21, at the outlet to the Forebay, the conduits intercept FZ-06 through FZ-11. However, more flow zones are intercepted further south along the conduits. Johnston (1964) concluded that the NYPA Project has had an important effect on groundwater levels and flow patterns in the bedrock. He suggested that prior to construction of the conduits, groundwater flow in the Lockport Group was directed predominantly towards the Niagara River gorge. In 1987, Miller and Kappel of the USGS conducted an extensive study of the effects of the NYPA Project. The water level data collected throughout 1985 by Miller and Kappel suggest that the conduit drain system maintains groundwater levels in the Lockport between 550 ft and 555 ft MSL in the vicinity of the conduits. Their data showed that the construction of the buried conduits has created a groundwater divide almost immediately east of the Landfill.

2.5.4 INFILTRATION OF PRECIPITATION

The bedrock groundwater flow system is recharged by the vertical infiltration of precipitation through the Overburden. In the following sections we review the precipitation data and summarize the results of analyses of infiltration through the Overburden and final Landfill cap. We conclude the discussion with an overview of the conceptual model for recharge.

Precipitation data

Precipitation data from three stations of the U.S. Weather Bureau were reviewed during the development of the first numerical model for the Site (SSP&A, 2001). Johnston (1964) compiled monthly and annual average precipitation data for the weather stations at Lewiston and Lockport, for the period 1936-1960. The average annual precipitation over this period was 29.6 and 32.4 inches per year for the Lewiston and Lockport stations, respectively. The difference between the two averages is about 10 percent of the total. As shown on Johnston (1964) Table 4, the seasonal variations in precipitation are similar for the two stations. The average monthly precipitation of about 2.5 inches per month fluctuates in a relatively narrow band between 2 and 3.25 inches.

A continuous record of precipitation data for Buffalo is available starting in 1922. The average annual precipitation between 1922 and 1999 is 36.1 inches per year. For the period of 1936-1960, the average annual precipitation was 35.6 inches. For this period, the magnitudes and seasonal trends in precipitation observed at Buffalo were similar to those reported by Johnston (1964).

Precipitation data have also been compiled for the Niagara Falls Airport. To determine whether there are significant variations in precipitation patterns between the Site and the Niagara Falls Airport, a rain gauge was installed at the Site to measure daily precipitation during 2001. The cumulative precipitation recorded during each month is plotted along with the data from the Buffalo and Niagara Falls airports on Figure 2-23. The total annual precipitation at the Site, and at the Niagara Falls and Buffalo airports was 25.6, 29.6, and 35.2 inches, respectively. It should be noted that the Site rain gauge data have not been subject to the same level of QA/QC as the Buffalo and Niagara Falls Airport data. Nevertheless, the monthly trends in the precipitation records were very similar, suggesting that the data from either airport can serve as a long-term precipitation record for the Site.

Analysis of infiltration through the overburden

The Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder and others, 1994a and 1994b) has been applied during this study to obtain an independent estimate of the infiltration rate through the Overburden. The analysis provides estimates of the recharge to the bedrock beyond the capped area of the Site. The following average annual rates have been calculated for a 25-year simulation:

Component	Calculated average rate (inches/year)
Precipitation	32.90
Runoff	9.34
Evapotranspiration	20.68
Infiltration to bedrock	2.75

For steady-state conditions, the average infiltration rate (*I*) must be equal to the difference between the precipitation (*P*) and the sum of the runoff (*R*) and evapotranspiration (*E*):

$$I = P - (R + E)$$

For the base case HELP analysis, the right-hand side of this equation yields 2.88 inches/year, which is about 5 percent larger than the calculated average infiltration rate of 2.75 inches/year. The slight discrepancy is due to a small increase in the volume of water stored in the soil column over the duration of the simulation. The results from additional analyses indicate that the average infiltration rate does not vary significantly when the duration of the simulation is extended, confirming that conditions are nearly stable after 25 years.

An overburden thickness of 336 inches (28 feet) has been assumed in the base case HELP analysis. Contour maps of the available data show that the thickness of the overburden ranges from about 4 feet to 38 feet in the vicinity of the Site. The overburden thickness affects only the length of time required to attain quasi-steady conditions. The base case analysis was repeated with an overburden thickness of 4 feet. The resulting average infiltration rate of 2.93 inches/year after 25 years is only about 6 percent higher than the base case result.

An Overburden hydraulic conductivity of 1.20×10^{-5} cm/sec has been assumed for the base case HELP analysis; this value represents the geometric mean of the values obtained from slug tests at the Site (Section 3.2.1 of the SCR-H report). It is expected that the slug tests (especially any single average value derived from them) provide only an approximate measure of the Overburden hydraulic conductivity. A sensitivity analysis was conducted to assess the significance of hydraulic conductivity on infiltration rate. The HELP analyses were repeated considering soils that encompasses the range of hydraulic conductivities obtained from the slug tests ($K=2\times10^{-7}$ cm/sec to 2×10^{-4} cm/sec). The results of the sensitivity analysis are plotted on Figure 2-24. The results of the sensitivity analysis with respect to the hydraulic conductivity suggest that the likely range in the infiltration rate through the Overburden is between 2 inches/year and 6 inches/year, beyond the capped area of the Site.

Analysis of infiltration through the Landfill cap

As part of the final Landfill cap design, CRA carried out infiltration analyses using the HELP model to estimate the leakage through the proposed cap (CRA, 1994). The analyses assumed a landfill top having a 300 ft drainage length at 7.5 percent slope, and side slopes having a 100 ft drainage length at 33 percent slope. The cap design specified a grass cover with 6 inches of topsoil, 18 inches of loam fill, a geocomposite drainage layer and a 24-inch composite liner with a geomembrane. The predicted infiltration rate through the cap were very small:

- Top: 550,000 ft^2 area, average infiltration rate of 0.0006 inches/year; and
- Sides: 440,000 ft^2 area, average infiltration rate of ~ 0 inches/year.

The total area of the landfill cap assumed in the HELP analysis was 990,000 ft^2. The total infiltration flow through the cap was predicted to be about 220 gallons per year, compared with a total precipitation over the cap of approximately 23 million gallons per year.

Observations of flows made during 2001 are consistent with the prediction of low infiltration rates through the cap. Figure 2-25 shows the flows of the Overburden Collection System (OBCS) and the bedrock purge well system (PW) superimposed on the 2001 precipitation record from the Site weather station. The data plotted on the figure demonstrate that the precipitation at the Site results in immediate increases in the OBCS flows, except for some portions of the winter months when the precipitation is in the form of snow.

During relatively dry months (in particular July and September 2001) there is negligible flow in the OBCS. This suggests that the infiltration through the cap, which would provide baseflow for the OBCS, is very low. The total flow rate from the bedrock purge well system does not exhibit short-term responses to precipitation events.

Conceptual model for recharge by the infiltration of precipitation

Away from the landfill cap, water that reaches the bedrock as infiltration through the overburden flows downwards and laterally away from the Site. Both the historical water levels observed in the existing Upper, Middle and Lower Bedrock wells, and the recent water levels observed in the flow zone piezometers, indicate very large downward vertical hydraulic gradients at the Site. For example, the vertical hydraulic gradients between piezometers in FZ-01 and FZ-02 are tabulated below.

Wells	**Vertical gradient Jan. 06/07, 2003 (ft/ft)**	**Vertical gradient Jan. 23/24, 2003 (ft/ft)**
G1U-01/G1-02	0.47	0.42
H2U-01/H2U-02	0.89	0.79
H5-01/H5-02	0.76	0.73
I1-01/I1-02	0.97	0.94

The vertical gradients are calculated by dividing the water level differences by the distance between the mid-point of the piezometer screens:

$$Vertical\ gradient = \frac{h_{FZ-01} - h_{FZ-02}}{z_{FZ-01} - z_{FZ-02}}$$

where *h* designates the average water level in a flow zone piezometer, and *z* designates the elevation of the midpoint of a piezometer screen.

The calculated vertical gradients demonstrate that the vertical gradient between the uppermost flow zones at the Site is close to one. A vertical hydraulic gradient of one represents a physical upper limit for groundwater flow under saturated conditions. The significant vertical hydraulic gradients suggest that the principal source of water to the uppermost bedrock flow zones is infiltrating precipitation. The recharge to the top-of-bedrock flows vertically downwards towards successively deeper flow zones, to be captured by the bedrock purge wells or to discharge eventually by horizontal flow to the regional hydrologic boundaries.

2.6 OTHER SOURCES AND SINKS OF WATER

The sources and sinks of water for the bedrock groundwater flow system at the Site are:

- The gorge of the Lower Niagara River;
- The NYPA Niagara Project Forebay;
- The NYPA Niagara Project buried conduits;
- Infiltration of precipitation;
- Groundwater pumping; and
- Sewers and tunnels.

The first three components of the water balance are represented as boundary conditions in the model and are discussed in Sections 2.5.1, 2.5.2, and 2.5.3. Infiltration of precipitation is represented as a hydraulic source and is discussed in Section 2.5.4. Groundwater pumping and the sewers and tunnels are discussed in the following sections.

2.6.1 BEDROCK PUMPING AT THE SITE

There are currently 19 wells pumping from the bedrock at the Site. The locations of the wells and the flow zones intersected by the open intervals of the wells are listed on the following table. The average pumping rates are also indicated. These rates were estimated from a visual examination of the moving averages plotted in Appendix B4 of the SCR-H report, for the week preceding the January 2003 shutdown (December 30, 2002 to January 6, 2003).

Bedrock pumping at the Hyde Park Site, Dec. 2002-Jan. 2003

Well	Easting	Northing	Flow zones intersected	Average pumping rate (gpm)
APW-1	1025714.5	1142554.7	07-11	1.0
APW-2	1025451.3	1142307.4	08-11	0.4
PW-1U	1026449.0	1141559.7	05-06	0.4
PW-1L	1026418.7	1141560.4	08-11	10.3
PW-2UR	1026836.6	1141260.5	03-05	0.4
PW-2M	1026610.1	1140948.1	06-09	28.0
PW-2L	1026891.5	1141161.0	10-11	0.0
PW-3M	1027458.2	1140825.9	05-09	0.0
PW-3L	1027538.5	1140772.5	10-11	5.0
PW-4U	1027842.7	1140674.4	02-05	0.4
PW-4M	1027916.8	1140663.3	06-09	0.0
PW-5UR	1027462.8	1140459.0	02-05	4.3
PW-6UR	1027621.8	1140154.4	01-05	1.8
PW-6MR	1027790.1	1140164.4	06-09	2.4
PW-7U	1026231.3	1141540.9	06	0.5
PW-8U	1026608.0	1141707.9	06	0.8
PW-8M	1026686.4	1141591.2	06-09	0.5
PW-9U	1026846.8	1141794.2	06	0.8
PW-10U	1027367.3	1141725.1	03-06	5.3

The average total rate for the week preceding the January 2003 shutdown was 62.3 gpm. Two wells, PW-2M and PW-1L, accounted for over 60 percent of the total pumping.

No other groundwater pumping is known in the modeled area.

2.6.2 SEWERS AND TUNNELS

Tunnels and sewers are cut into the bedrock near the Site for storm and wastewater control. As part of the SCR-H, historical maps were reviewed to confirm the locations and elevation of these features. During this review, an abandoned railroad cut into the bedrock was also identified. The locations and elevations of the sewers and tunnels are presented on Plate 1 of the SCR-H. As indicated in the SCR-H, these features may affect groundwater flow at the Site. A numerical model is an effective tool for evaluating the significance of these features.

3.0 SIMULATION APPROACH AND CODE SELECTION

3.1 SIMULATION APPROACH

We have adopted a "Hybrid Equivalent Porous Medium" (H-EPM) approach to simulate groundwater flow at the Hyde Park Site. The 11 primary flow zones identified in the SCR-G are represented explicitly, with each of these flow zones conceived as a porous medium. The aquitards separating the flow zones are also represented as equivalent porous media. Models based on the EPM approach have been adopted at other sites in the Niagara frontier (see for example, Yager, 1996). These models adopt a relatively coarse representation of flow in the bedrock. In contrast, the simulation approach adopted in this study incorporates a level of detail in representing discrete flow zones that has not to our knowledge been attempted in any other modeling in the Niagara Falls region.

3.2 SIMULATION CODE

The numerical simulation code adopted for the SCR-M is the USGS three-dimensional, finite-difference groundwater flow simulator, MODFLOW96 (Harbaugh and McDonald, 1996a,b). The MODFLOW code has been selected for this study because it offers flexibility and generality in representing three-dimensional complex bedrock structures, boundary conditions, and sources and sinks. The MODFLOW family of simulation tools comprise the most widely used set of hydrogeologic modeling codes in the world. The MODFLOW code has been tested and applied extensively, and it enjoys widespread acceptance in the North American and international groundwater research and consulting communities. MODFLOW is supported by the USGS, and is being extended continuously by the USGS and third-party users. The code is in the public domain.

MODFLOW can simulate steady and transient flow in complex flow systems. Aquifer layers may be confined or unconfined. Flow from sources or sinks, such as wells, recharge from infiltration of precipitation, evapotranspiration, drains and rivers can be simulated. Hydraulic conductivities or transmissivities may vary spatially and be anisotropic. Storage coefficients may be assigned to represent confined or unconfined processes, and may be heterogeneous. MODFLOW can incorporate specified-head, specified-flux, and head-dependent flux boundary conditions.

MODFLOW solves the groundwater flow equation using the block-centered finite-difference method. The flow system is subdivided into blocks in which the medium properties are assumed to be uniform. The horizontal discretization is rectangular and may be variably spaced, forming a grid of perpendicular lines. In the vertical direction, zones of varying thickness are transformed into a set of layers. Mass balances are computed for each time step and as a cumulative volume from each source and type of discharge.

MODFLOW employs an iterative method to obtain the solution to the governing equation of groundwater flow. This method involves assigning initial estimates of groundwater levels for each grid block. The calculation procedure then adjusts these estimated values, producing a new set of estimates that are closer to the correct solution of the system of equations. This procedure is repeated until the maximum difference between successive estimates of water levels fall below a user-specified closure criterion.

Four matrix inversion techniques are available for use with MODFLOW:

- Strongly Implicit Procedure (SIP), (McDonald and Harbaugh, 1988);
- Slice-successive Over-Relaxation Procedure (SSOR), (McDonald and Harbaugh, 1988);
- Pre-conditioned Conjugate Gradient Procedure (PCG), (Hill, 1990); and
- Direct Solution Procedure (DE4), (Harbaugh, 1995).

The PCG solver has been used for the modeling, as it incorporates increased control on the rate of convergence, and a closure criterion on the flow balance discrepancy. The additional closure criterion on the flow balance is used to ensure reliable converged solutions. The simulations for the SCR-M have been executed with a water level closure criterion of 0.05 ft, and a flow balance closure criterion of 5.0 ft^3/day.

The Hyde Park Landfill model has been developed within the graphical user interface, Groundwater Vistas (Environmental Simulations, Inc., 1998). Groundwater Vistas provides a user-friendly, graphically-based framework for visualizing the model parameterization and the results of the model calculations.

3.3 ASSUMPTIONS IN THE APPLICATION OF MODFLOW

MODFLOW is designed to simulate aquifer systems under the following general conditions:

- Darcy's Law applies;
- The porous medium is saturated;
- The density of ground water is constant; and
- The principal directions of horizontal hydraulic conductivity or transmissivity are parallel to the axes of the model grid.

The implications of these assumptions with respect to modeling of the Hyde Park Site are discussed briefly below.

Darcy's law is generally assumed to be valid under typical groundwater velocities in porous media. In fractured rocks, groundwater velocities may be sufficiently high in some areas that Darcy's law is violated locally. In particular, this may arise the immediate proximity to extraction wells, but the area affected is likely to be only a small portion of the subsurface.

The water table in the region surrounding the Site is located close to the overburden/bedrock contact. Away from the pumping centers of the Site and the gorge of the Niagara River, the discrete flow zones are fully saturated. As indicated in the SCR-H, under pumping conditions some of the areas influenced by pumping are dewatered. These areas were identified in the SCR-H where the observed water levels were within the sand pack of the piezometers. Although some water was observed in all piezometers, at these locations the water is likely trapped in the pores of the sand pack and is effectively immobile. Although MODFLOW is capable of simulating complete dewatering, this capability is not utilized in the SCR-M modeling, as it renders simulations numerically unstable and would preclude the use of MODFLOW within the context of computer-assisted parameter estimation. Rather, groundwater flow is allowed to occur in dewatered areas. This is the only feasible approach for proceeding with a large-scale analysis. We believe that the errors introduced by this approach are relatively small, and are localized to the immediate vicinity of purge wells.

The density of the groundwater is uniform within the flow zones of interest. Kappel and Tepper (1992) have shown that the pore waters in the deeper bedrock formations underlying the Site are saline. These waters may have a higher density. However, the Rochester Shale and deeper formations underlying the Site have relatively little permeability and little circulation, consistent with the observation that very high salt concentrations persist over large areas of western New York (Waller and others, 1978). The Rochester Formation represents a lower limit to active groundwater flow at the Site, and our model is restricted to the relatively shallow bedrock in which groundwater is predominantly fresh.

Fractured rocks are typically anisotropic in both the horizontal and vertical directions. The USGS conducted an extensive sensitivity analysis during their regional modeling and determined that the effects of horizontal anisotropy are likely to be relatively insignificant at the Site. Our review of data collected for the SCR-H confirms this finding. The water level and transmissivity data from the SCR-H suggests that groundwater flow patterns are controlled by large-scale heterogeneities in transmissivity and not by anisotropy in the planes of the flow zones. As a result, the finite-difference grid may be oriented in any direction. The vertical anisotropy is incorporated explicitly in the analysis.

4.0 MODEL CONSTRUCTION

4.1 MODEL DOMAIN

The limits of the model area are shown in Figure 4-1. The model is intended to support a detailed analysis in the vicinity of the Site, but is extended to natural or man-made boundaries where possible. The model grid is oriented north-south and the horizontal extents of the model are 2 miles (north-south) and about 3 miles (east-west).

The northern boundary of the model is the NYPA Forebay. The Forebay is cut into the Rochester Shale and intercepts all flow zones that are not subcropped. The eastern boundary of the model runs along the buried conduits of the NYPA project. The buried conduits intercept all of the flow zones at the Site. The gorge of the Lower Niagara River forms the western boundary of the model.

The model is truncated in the south along a presumed groundwater divide that is assumed to extend across the full thickness of the Lockport Dolomite. This divide is evident in shallow bedrock groundwater levels south of the Site and reflects the presence of a buried valley and a high in the top of bedrock mapped by the USGS (Miller and Kappel, 1987).

4.2 MODEL DISCRETIZATION

4.2.1 HORIZONTAL DISCRETIZATION

The MODFLOW finite-difference grid is shown in Figure 4-2. As no horizontal anisotropy has been identified in regional modeling studies, or in any of the Site investigations, the model grid could be oriented in any direction. The grid was oriented east-west and north-south for convenience. The model has been designed so that in the detail model area there is adequate resolution of horizontal hydraulic gradients; and the grid is sufficiently fine to allow incorporation of details in the distributions of the hydraulic properties and locations of wells, sewers, and shafts. The grid has 225 columns (east-west) and 171 rows (north-south). In the vicinity of the Landfill, the grid blocks are 50 feet by 50 feet. The spacing between cells expands from 100 feet to 250 feet towards the edges of the model.

The variable grid spacing provides a high level of detail in areas critical to analysis of the Site remediation program, but less detail in areas of low interest. This design reduces the total number of model cells and allows the model to obtain a solution more rapidly.

4.2.2 VERTICAL DISCRETIZATION

Top of the model

The top of the model is defined by ground surface elevations from the USGS regional Digital Elevation Model (DEM). The horizontal resolution of the DEM is 10 m (32.8 feet). In the vicinity of the Site, the ground surface elevations have been adjusted locally to incorporate the detailed mapping of the top-of-bedrock elevations developed in the SCR-G and the SCR-H (SCR-H Figures 3-2 and 3-3). The base of the model is set at the top of the Rochester Shale. As presented in the SCR-G, a plane developed from a synthesis of Site data and regional interpretations defines the top of the Rochester Shale.

Model layers

The layers of the MODFLOW model are shown in a cross-section through the model grid in Figure 4-3. The model is divided into 22 layers.

The uppermost model layer represents the Overburden. All cells in the layer are presently inactive; the layer has been incorporated for possible future extensions. The water table is located close to the bottom of the overburden, and the hydraulic conductivity of the overburden is relatively low. Therefore, we do not consider the Overburden to be a zone of active groundwater flow with respect to the bedrock. The uppermost layer is treated in a similar manner in the USGS regional model (Yager, 1996).

The remaining 21 layers of the model represent the discrete bedrock flow zones and the intervening aquitards. This fine level of vertical discretization has been adopted to support representation of the discrete flow zones. A single model layer is specified to represent each of the eleven flow zones. This is consistent with the conceptualization of the flow zones as thin intervals in which groundwater flow is predominantly in the plane of the flow zone. With the exception of flow zones FZ-07, FZ-08, and FZ-09, which are all within a 10-foot vertical interval, each of the intervening aquitards is also represented with a model layer.

The vertical discretization that has been adopted represents a compromise between the requirements for resolution of groundwater flow patterns and the requirement that the model size be manageable. Specifying a larger number of layers would have rendered the model unwieldy; for example, execution times and computer memory must be modest to support computer-assisted calibration and sensitivity analysis. The model design is sufficient to resolve vertical hydraulic gradients and to locate the open intervals of the bedrock purge wells.

The total number of grid blocks in the model is 846,450. Our experience suggests that by contemporary standards this is a very large model. In comparison, the regional model of Yager (1986) contains 49,990 grid blocks.

Interpretation of thicknesses of the flow zone layers

The elevations of the middle of the flow zone model layers are specified using the equations that define the planes-of-best-fit presented in the SCR-G. The flow zone model layers are assigned uniform thicknesses of 4 feet. The flow zones are actually intervals of coalescing, bedding-parallel fractures. The analysis of data in the SCR-G concluded that the vertical location of a flow zone could generally be predicted within about +/- 2 feet. Thus, a 4-foot flow zone thickness represents the uncertainty in the flow zone elevation and not an actual transmissive thickness identified by any study. The assumed thickness of the flow zones has no impact on the groundwater flow analyses, because the hydraulic properties of the flow zones are cast in terms of transmissivity, which represents the product of the actual thickness and the effective horizontal hydraulic conductivity.

The top-of-bedrock elevations presented in the SCR-H have been used to identify the areas where the flow zones subcrop. Flow zones that are subcropped in the model are assigned a nominal thickness of 0.2 feet, and are assigned transmissivities and vertical conductances values of 0.0. In effect, the cells representing the subcropped flow zones are inactive with respect to flow. The recharge that is applied is passed vertically through these cells with no resistance.

Specification of vertical hydraulic properties

The vertical hydraulic properties of each cell are represented within MODFLOW in terms of the lumped parameter, *VCONT*. *VCONT* is calculated from the vertical hydraulic conductivities and layer thicknesses according to:

$$VCONT_{k/k+1} = \left[\frac{\Delta z_k / 2}{K_{V\,k}} + \frac{\Delta z_{k+1} / 2}{K_{V\,k+1}} \right]^{-1}$$

where *k* and *k+1* designated successive model layers, and Δz and K_V denote the cell thickness and vertical hydraulic conductivity, respectively. The cell thicknesses and vertical hydraulic conductivities are specified external to MODFLOW, and values of *VCONT* are calculated as a preprocessing step.

4.3 MODEL BOUNDARY CONDITIONS

The boundary conditions for each flow zone are shown in Figures 4-4 through 4-14.

4.3.1 GORGE OF THE LOWER NIAGARA RIVER

The gorge of the Lower Niagara River is simulated using the MODFLOW Drain package. A drain cell can receive water discharging from a flow zone. However, it cannot contribute water to the flow zone. Discharge to the gorge occurs at drain cells in which the calculated water level exceeds the control level. The operation of a drain cell can be summarized as follows:

$$\begin{aligned} Q_D &= -C_D \left(h - h_D \right) \quad ; h > h_D \\ &= 0 \quad ; h \le h_D \end{aligned}$$

where Q_D is the flow from the drain cell, h is the water level in the drain cell, and h_D and C_D are the drain control level and conductance, respectively.

The control level for each drain cell representing the gorge is set 0.1 feet above the base of the 4-foot thick model layer representing the flow zone.

The conductance of each drain cell is set proportional to the length of the cell, and the transmissivity and thickness of the cell, according to:

$$C(j,i,k) = delc(i) * \frac{T(j,i,k)}{dz(j,i,k)} * gorge\_mult$$

where:

j = column number of the cell within the finite-difference model grid;
i = row number of the cell within the finite-difference model grid;
k = layer number of the cell within the finite-difference model grid;
C(j,i,k) = the conductance of the drain cell (ft^2/day);
delc(i) = row spacing of row *i* within the finite-difference model grid (ft);
T(j,i,k) = the transmissivity of the cell containing the drain (ft^2/day);
dz(j,i,k) = cell thickness (ft); and
gorge_mult = a multiplier (constant) that may be adjusted during calibration.

The basic formula for the drain conductances along the gorge is developed from a simple model of linear flow to the drain. The gorge multiplier term, *gorge_mult*, is included in the conductance calculation to accommodate complexities in the actual flow conditions at the gorge. The gorge multiplier term is included as a calibration parameter in the model.

No drains are specified along the gorge for flow zones that are subcropped. For example, no drains are specified for FZ-01, as the flow zone subcrops beneath the Landfill about 3,000 feet east of the gorge.

4.3.2 NYPA NIAGARA PROJECT FOREBAY

The NYPA Niagara Project Forebay and the open portion of the NYPA buried conduits are simulated using the MODFLOW General-Head Boundary (GHB) package. GHBs are head-dependent boundary conditions that conceive of a specified-head condition separated from the flow system by a resistance to flow. GHB cells may act as a source or sink for groundwater.

The operation of a GHB cell can be summarized as follows:

$$Q_G = -C_G \left(h - h_G \right)$$

where Q_G is the flow from the GHB cell, h is the water level in the GHB cell, and h_G and C_G are the GHB control level and conductance, respectively. The GHB Package allows discharge to or recharge from the Forebay, depending on the relative water levels in the Forebay and the flow zones. If the water level in a flow zone exceeds the control level of the Forebay, then there is discharge from the flow zone to the Forebay. If the water level in a flow zone is below the control level of the Forebay, then there is recharge from the Forebay to the flow zone.

Model cells that have a bottom elevation above the average level in the Forebay are assigned a GHB control level of 0.1 foot above the bottom of the cell. In this case the GHBs act as drains, similar to the representation of the gorge. However, the use of GHBs allows for flexibility in considering Forebay levels higher than those specified in the model calibration scenarios.

Flow zones with bottom elevations below the average level in the Forebay are assigned a GHB control level equal to the level in the Forebay. Pumping conditions correspond to the period between midnight on January 6 and midnight on January 7, 2003. The average level recorded by NYPA in the Forebay during this period was 550.4 ft MSL. Non-pumping conditions correspond to the period between 8:20 AM on January 23 and 8:20 AM on January 24, 2003. The average level in the Forebay recorded by NYPA during this period was 554.2 ft MSL.

The Forebay elevations recorded by NYPA were adjusted by adding 3.0 ft in order to match water levels collected at the Site. This adjustment is supported by continuous water level data collected for the SCR-H. Under pumping conditions, water levels in FZ-09 piezometers that respond to the Forebay (J6-09, AGW-1M-09, J5M-09, H2M-09, and H5-09) averaged about 553.3 ft MSL (refer to Figure 3-32 of the SCR-H report). The time-averaged Forebay level during the corresponding time period was 550.4 ft MSL.

Under non-pumping conditions, the average water level of the same set of FZ-09 piezometers was 556.7 ft MSL. The time-averaged Forebay level during the corresponding time period was 554.2 ft MSL.

The conductance of each of the GHBs is set proportional to the cell dimension and the transmissivity of the cell, as follows:

$$C(j,i,k) = delr(j) * \frac{T(j,i,k)}{dz(j,i,k)} * ghb\_mult$$

where *delr(j)* is the size of column *j* within the finite-difference model grid (ft), and *ghb_mult* is a multiplier (constant) that may be adjusted during calibration.

Similar to the approach adopted for the gorge drains, the basic formula for the GHB conductances along the Forebay is developed from a simple model of linear flow to the drain. The GHB multiplier term, *ghb_mult*, is included in the conductance calculation to accommodate complexities in the actual flow conditions at the Forebay. The GHB multiplier term is included as a calibration parameter in the model.

No GHBs are specified along the Forebay or conduits for flow zones that are subcropped south of the Forebay. For example, no GHBs are specified for FZ-01.

4.3.3 NYPA NIAGARA PROJECT BURIED CONDUITS

The buried portion of the NYPA Niagara Project conduits is simulated using the MODFLOW Drain package. The implementation of the drains along the conduits is similar to that adopted to represent the NYPA Forebay. The buried conduits intercept all of the flow zones, and drains are specified in all of the model layers representing the flow zones. The control level is set at 550 ft MSL, which corresponds to the control elevation of the conduit drain system pumping station near the Forebay. Model cells with bottom elevations above 550 ft MSL are assigned control levels set at 0.1 feet above the base of the cell; a control elevation of 550 ft MSL is specified for model cells with a bottom elevation less than 550 ft MSL.

The approach adopted to represent the conduits differs from that adopted the USGS regional model (Yager, 1996) and in the previous model of the Site developed by SSP&A. In the two earlier models, very large transmissivities were assigned to the cells representing the conduits. The approach adopted in the previous models is not consistent with the observations made by Miller and Kappel (1987) that the fluctuations in Forebay levels are damped along the length of the conduits.

The conductance of each of the drains cells representing the buried conduits is set proportional to the cell dimension and the transmissivity of the cell, as follows:

$$C(j,i,k) = delc(i) * \frac{T(j,i,k)}{dz(j,i,k)} * conduit\_mult$$

where *conduit_mult* is a multiplier (constant) that may be adjusted during calibration. In the model, the ratio of the transmissivity and cell thickness is interpreted as an effective horizontal hydraulic conductivity within the conduits, and is treated as a calibration parameter K_H. No physical significance is attached to K_H. Instead, the product of K_H and the conduit multiplier, *conduit_mult*, should be interpreted as a lumped parameter that accounts for the complexities of flow patterns in the immediate vicinity of the conduits.

4.4 OTHER HYDRAULIC SOURCES AND SINKS IN THE MODEL

The components of the water balance for the bedrock are listed below:

- Recharge from Forebay;
- Discharge to gorge;
- Discharge to the buried conduits;
- Infiltration of precipitation;
- Pumping from bedrock extraction wells;
- Sewers and tunnels; and
- Shafts.

The first three components of the water balance have been treated as boundary conditions in the model, and the modeling approaches adopted to represent them are described in the previous section. The remaining components of the water balance are simulated as hydraulic sources or sinks, using appropriate MODFLOW stress packages. The approaches adopted to model these features are described in the following sections.

4.4.1 INFILTRATION OF PRECIPITATION

Although the top of the model is set at ground surface, groundwater flow is not simulated in the Overburden. Instead, infiltration of precipitation through the Overburden is applied as a source directly to the uppermost active bedrock model layer, using the MODFLOW Recharge package. This approach follows the methodology adopted by the USGS in their regional simulation (Yager, 1996) and carried over to the original Site model (SSPA, 2001). The zonation of recharge is shown in Figure 4-15. As shown in the figure, a simple zonation for recharge has been adopted. A uniform rate is applied over the entire model, except beneath the final Landfill cap. No recharge is applied to the bedrock underlying the cap.

4.4.2 PURGE WELLS

The purge wells are shown in Figure 4-16. Two key factors in the construction and operation of the purge wells complicate the analysis of groundwater flow at the Site. First, the purge wells are open across multiple flow zones. Second, the pumping levels in the purge wells are in many cases below the flow zones intersected by the wells. These factors preclude the use of a conventional modeling approach to represent the purge wells.

We have developed an innovative, physically-based approach to address the complications inherent in the modeling of purge wells at the Site. The approach for modeling the extraction wells is shown schematically in Figure 4-17. The bedrock purge wells and APW wells are represented using the MODFLOW GHB package. The discharge rate from each flow zone intersected by the open interval of a purge well is calculated from:

$$Q_W(n) = -C_W(n)\left[h(n) - h_W(n)\right]$$

where $Q_W(n)$ designates the discharge rate from an individual flow zone n, $C_W(n)$ is the conductance for flow zone n, and $h(n)$ and $h_W(n)$ are the water level and control level in flow zone n. The GHB Package allows discharge to or recharge from a flow intersected by a purge well. If the water level in a flow zone exceeds the specified control level, there is discharge from the flow zone to the purge well. If the water level in a flow zone is below the specified control level, a portion of the flow along the wellbore recharges the flow zone.

If the water level in a purge well is below the elevation of an intersected flow zone, the control level is specified as 0.1 feet above the bottom of the flow zone layer. If the water level in a purge well is above the elevation of an intersected flow zone, the control level is set equal to the water level in the well.

The conductance of the GHB cells that represent the purge wells are set proportional to the purge well diameter and the transmissivity of the intersected flow zone according to:

$$C_W(n) = \frac{2\pi T(n)}{\ln \frac{r_{eff}}{r_w}}$$

where r_w is the radius of the wellbore, and r_{eff} is the effective radius of the GHB cell. The effective radius of the GHB cell is calculated according to the Peaceman (1983) formula:

$$r_{eff} = 0.208\Delta X$$

where ΔX represents the grid block spacing (50 feet in the area of the purge wells). The approach adopted here for representing the purge wells automatically corrects for converging flow within a model cell that is larger than the actual wellbore. The approach also accommodates the fact that purge wells are open across flow zones that may have very different transmissivities.

The net discharge rates from the purge wells are not prescribed in the analysis. In the simulation approach adopted for this study, the observed net discharge rates are instead treated as targets to be matched during the computer-assisted calibration. That is, the calibration attempts to match the following additional condition:

$$\sum_{n=1}^{NF} Q_W(n) = Q_{W\,OBS}$$

where *NF* designates the total number of flow zones intersected by the well, and $Q_{W\,OBS}$ is the observed discharge rate from the well.

The present approach also allows MODFLOW to allocate internally the discharge from the individual flow zones intersected by the well, based on the relative transmissivities and water levels of the individual flow zones. This approach also allows the simulation of flow along the wellbore between flow zones under non-pumping conditions, although no constraint is applied to ensure that the flows along a wellbore are internally consistent.

4.4.3 SEWERS AND TUNNELS

The potentially important effects of sewers and tunnels in the vicinity of the Site were discussed in the SCR-H. The major sewers and shafts near the Site are represented in the model using the MODFLOW Drain package. During the initial model development, it was not clear whether these features would need to be represented in the numerical model. However, during model calibration it became evident that these features need to be represented in order to achieve an acceptable match between calculated and observed water levels and flow patterns.

The locations of the sewers and tunnels with respect to the flow zones are shown in Figures 4-4 through 4-14. Following the convention adopted for the SCR-H, sewers in the Overburden are indicated by a solid blue line; sewers in the bedrock by a dashed blue line; and tunnels by a red line.

The control elevations of the drains cells representing sewers and tunnels are based on the invert elevations. Linear interpolation is applied to calculate the drain elevation for each model cell lying between each set of invert elevations. The conductance of the drain cells representing sewers is set proportional to the sewer diameter and the estimated effective hydraulic conductivity of the sewer pipe and bedding material according to:

$$C(j,i,k) = \frac{2\pi}{\ln \frac{r_o}{r_i}} K_p L$$

where:

K_p = effective hydraulic conductivity of the sewer pipe and bedding material (ft/day), (adjusted during model calibration);
L = the length of the sewer traversing the finite-difference cell (ft);
r_o = the outside diameter of the sewer pipe (ft), assumed to be ri+0.25 ft in all cases; and
r_i = the inside diameter of the sewer pipe (ft).

The approach adopted to represent the sewers is similar to that adopted for the gorge and conduit drains, and the Forebay GHBs. The conductance formula presented above is developed from a simple model of radial flow to a drain. As with the conduit hydraulic conductivity, the effective conductivity in the vicinity of the sewer pipe, K_p, should be interpreted as a lumped parameter that accounts for the complexities of flow patterns in the immediate vicinity of the sewers.

Several tunnels connect the bottoms of the vertical shafts. In the model area, the tunnels are typically completed at or just below the top of the Rochester Shale. All of the tunnels connect to a tunnel that flows south along the gorge, and is collected and treated by the Niagara Falls POTW (Publicly Owned Treatment Works).

The tunnels are represented as drain cells. The elevation of each drain is set to the invert elevations of the tunnel. The conductance of each of the drain cells representing tunnels is set proportional to the tunnel width and the transmissivity of the model cell according to:

$$C(j,i,k) = 2DL * \frac{T(j,i,k)}{dz(j,i,k)} * tunnel\_mult$$

where:

D = height of the tunnel (ft);
L = the length of the sewer traversing the finite-difference cell (ft); and
tunnel_mult = a multiplier (constant) (ft^{-1}) that may be adjusted during calibration.

4.4.4 SHAFTS

Vertical shafts that extend to the Rochester Shale supply several of the tunnels in the vicinity of the Site. The locations of the shafts with respect to the flow zones are shown in Figures 4-4 through 4-14.

The approach adopted to represent the shafts is similar to that adopted for the simulation of purge wells that are open across multiple flow zones. There is an important difference, however. Water entering a vertical shaft will fall to the bottom of the shaft and flow away in the tunnel. Thus, water never builds up in the vertical shafts as it can in a well that intercepts multiple flow zones. The control level for each flow zone intersected by a shaft is set at 0.1 feet above the bottom of the model cell

4.5 REPRESENTATION OF DEWATERED AREAS

Data collected during the SCR-H revealed that there are extensive dewatered areas in some of the flow zones. Dewatered areas (indicated as "dry" in the SCR-H) were identified from piezometers where the observed water levels were within the sand pack. In the SCR-M analyses, cells remain active regardless of the calculated water levels. That is, groundwater flow is allowed to occur in dewatered areas even if calculated water levels are below the bottom of the cell. In general, the error associated with this approximation is small. In dewatered areas near purge wells, this approach has the advantage of allowing a flow zone to contribute water although the pumping level may be below its base. For the SCR-M analyses, all areas where the calculated water levels are less than 0.1 feet above the base of the model cells are designated as dewatered, and are indicated explicitly on all water level maps.

5.0 MODEL CALIBRATION

Model calibration is the process of adjusting selected model parameters systematically to match observed data. The description of the model calibration is divided into six parts:

- Calibration strategy;
- Calibration methodology;
- Calibration scenarios and targets;
- Calibrated model parameters; and
- Calibration results.

5.1 CALIBRATION STRATEGY

Calibration must be founded on these two principles: first, as much of the available data as possible must be considered; second, the most defensible model is obtained when as few parameters as possible are adjusted. The confidence with which we can use a numerical groundwater model for predictive purposes is strengthened if it can be shown that the model can match observed water levels for different conditions, and the model parameters are constrained by the available data.

Two calibration scenarios have been considered based on the data collected during the SCR-H study:

- Pumping conditions immediately prior to shutdown of the bedrock purge wells; and
- Non-pumping conditions immediately prior to the resumption of the bedrock purge well pumping.

The calibration datasets assembled for each of these two scenarios are presented in Section 5.2.

The model calibration has been evaluated using both quantitative and qualitative measures. Quantitative evaluation consists of statistical comparison between observed and calculated water levels. Statistics are calculated for the calibration target residuals, where a residual is defined as the difference between calculated and observed water levels at a particular observation point. The definition of a residual is expressed as:

Residual = Calculated water level – Observed water level

Typical statistics include the mean of the residuals, the mean of the absolute values of the residuals, the sum of squared residuals, and the residual standard deviation divided by the range in observed water levels (American Society for Testing and Materials, 1993).

Qualitative evaluation consists of the visual comparison of groundwater flow directions and key hydrologic features, such as groundwater flow divides. Qualitative evaluation also includes checking the calculated flow balance to ensure that is components fall within physically realistic bounds that are consistent with the Site conceptual model. Qualitative evaluation includes the preparation of scatter plots of computed versus observed water levels. Scatter plots are a standard method of providing a visual impression of the quality of fit for a steady-state model (American Society for Testing and Materials, 1993).

5.2 CALIBRATION METHODOLOGY

The process of model calibration has been approached with a deliberate reluctance to add complexity to the model unless clearly warranted. For example, the representation of sewers and tunnels was only added to the model because an acceptably calibrated model could not be obtained without representing these features. The refined model is complex; there are many model parameters that can be adjusted. A key guideline has been to make as many simplifications as possible. We believe that this is the single most important element in developing a model that is useful for predictive purposes, but yet remains defensible.

The model calibration approach consists of a combination of manual parameter adjustments, and the application of a model-independent, non-linear parameter estimation code, PEST (Doherty, 2002). The formal calibration objective is the minimization of the sum-of-squared errors (*SSE*), defined as follows:

$$SSE = \sum_{i=1}^{NOBS} \left(h_{obs} - h_{calc} \right)^2$$

where:

$NOBS$ = number of water level observations;
h_{obs} = observed water level (ft); and
h_{calc} = calculated water level (ft).

As discussed in Section 4.4.2, the cumulative discharges from the flow zones intersected by each purge well are introduced as an additional calibration target.

The adjustable model parameters include:

- Transmissivity values assigned to the zones representing the distribution within each flow zone;
- Vertical hydraulic conductivity for each flow zone;
- Hydraulic properties of the aquitard layers (horizontal and vertical hydraulic conductivities);
- Rate of recharge from precipitation infiltration; and
- Conductance of drains and GHBs.

The starting points for the adjustable model parameters are described below.

Estimates of the transmissivity distributions within each flow zone were presented in the SCR-H and are discussed in Sections 2.4.1 and 2.4.2 of this report. The transmissivity distributions for each of the flow zones in the calibrated model are very similar to those presented in the SCR-H. The final calibrated model flow zone transmissivity distributions are presented in detail in Section 5.4.

In keeping with the calibration philosophy of parsimony with respect to the number of adjustable parameters, all aquitard layers were assumed to have uniform properties. It is further assumed that all aquitard layers have the same hydraulic properties. Similarly, a simple recharge distribution is employed: zero under the landfill perimeter cap, and a uniform value elsewhere.

A single conductance multiplier is applied for each of the following boundary conditions:

- Drain cells representing the Niagara River Gorge;
- Drain cells representing the buried conduits;
- GHB cells representing the NYPA Forebay;
- Drains cells representing sewers; and
- Drains cells representing tunnels.

5.3 CALIBRATION SCENARIOS AND TARGETS

The calibration scenarios are derived from the data collected during the SCR-H study. During the SCR-H study, water levels were collected from all 113 flow zone piezometers under both pumping and non-pumping conditions. These two conditions comprise the two calibration scenarios considered during model calibration.

5.3.1 PUMPING CONDITIONS

The calibration dataset for pumping conditions is the average water level in each flow zone piezometer over the period January 6, 2003 00:00 to January 7, 2003 00:00 [SCR-H Table 3-2]. The purge well flow rates and pumping levels are listed on Table 5-1.

The calibration dataset consists of 110 of the 113 piezometers monitored. The three piezometers that have been excluded entirely from the dataset are:

- ABP-7-06 ;
- I1-09; and
- I1-11.

FZ-06 is not present in the model at the location of ABP-7. Stabilized water levels at I1-09 and I1-09 were not attained during the monitoring period, likely due to very low transmissivities at these locations.

5.3.2 NON-PUMPING CONDITIONS

The calibration dataset for non-pumping conditions is the average water level in each flow zone piezometer over the period January 23, 2003 08:20 to January 24, 2003 08:20 [SCR-H Table 3-2]. The purge well levels under non-pumping levels are listed on Table 5-1.

The calibration dataset consists of 110 of the 113 piezometers monitored. The same three wells excluded from the pumping conditions calibration dataset are excluded from this scenario for the same reasons.

5.4 CALIBRATED MODEL PARAMETERS

The final calibrated model is discussed in terms of the adjustable parameters identified in Section 5.2. To achieve a satisfactory match to observed water levels, it was necessary to introduce the following additional factors:

- The bedrock above FZ-01 was assigned unique hydraulic properties independent of the remaining aquitard layers;
- Cells representing the buried conduits were assigned unique hydraulic properties; and
- Additional transmissivity zones were introduced into the FZ-09 transmissivity zonation presented in Section 2.4.2.

These features are discussed in more detail in the following sections.

5.4.1 CALIBRATED FLOW ZONE TRANSMISSIVITY DISTRIBUTIONS

The calibrated model consists of transmissivity distributions for each flow zone that are very similar to those presented in the SCR-H and revisited in Section 2.4.2 of this report. The calibrated transmissivity distributions for each flow zone layer determined with computer-assisted parameter estimation are presented and discussed in turn. In general, the calibrated transmissivities are very similar to those presented in the Draft SCR-M report submitted April 30, 2003.

FZ-01

The calibrated transmissivity distribution for the model layer representing FZ-01 (model layer 3) is presented in Figure 5-1. Following the conceptual model, a single value of transmissivity has been specified for FZ-01. The calibrated transmissivity of 26 ft^2/day is within the range of the slug and packer test transmissivities presented in Section 2.4.2, and similar to the median of the test values, 70 ft^2/day.

FZ-02

The transmissivity distribution for the model layer representing FZ-02 (model layer 5) is presented in Figure 5-2. No attempt was made to incorporate the transmissivity zonation suggested on Figure 2-4. Preliminary modeling indicated that it was not necessary to introduce multiple zones to achieve a reasonable match to water levels in FZ-02. A single value of transmissivity has been specified for FZ-02. The calibrated transmissivity of 27.9 ft^2/day agrees closely with the arithmetic mean value of the transmissivities estimated from hydraulic tests of 23 ft^2/day, and is relatively close to the median transmissivity of 9 ft^2/day presented in Section 2.4.2.

FZ-03

The transmissivity distribution for the model layer representing FZ-03 (model layer 7) is presented in Figure 5-3. A uniform value of transmissivity is assigned for the flow zone layer. The calibrated transmissivity of 0.387 ft^2/day agrees closely with the median transmissivity of 0.3 ft^2/day presented in Section 2.4.2.

FZ-04

The transmissivity distribution for the model layer representing FZ-04 (model layer 9) is presented in Figure 5-4. The model zonation consists of two zones of transmissivity and is similar to the zonation presented in Figure 2-6. The calibrated transmissivity of 72.1 ft^2/day for the high T zone agrees closely with the value of 100 ft^2/day suggested in Section 2.4.2. The calibrated transmissivity of 1.66 ft^2/day for the low T zone is higher than the value of 0.1 ft^2/day suggested in Section 2.4.2, but is within the range of the transmissivities estimated by hydraulic tests.

FZ-05

The transmissivity distribution for the model layer representing FZ-05 (model layer 11) is presented in Figure 5-5. The model zonation consists of two zones of transmissivity, similar to the zonation presented in Figure 2-7. The calibrated transmissivities of 27.7 ft^2/day for the high T zone is similar to the value of 100 ft^2/day suggested in Section 2.4.2. The calibrated transmissivity value of 12.4 ft^2/day for the low T zone is higher than the range of estimates from hydraulic tests presented in Section 2.4.2 (<0.001 to 0.7 ft^2/day).

FZ-06

The transmissivity distribution for the model layer representing FZ-06 (model layer 13) is presented in Figure 5-6. The model zonation consists of three zones of transmissivity, similar to the zonation presented in Figure 2-8. The calibrated transmissivity of 77.8 ft^2/day for the high T zone agrees closely with the T of 100 ft^2/day presented in Section 2.4.2. Similarly, the calibrated transmissivity of 8.8 ft^2/day for the intermediate T zone agrees closely with the T of 10 ft^2/day presented in Section 2.4.2. The calibrated value of 5.24 ft^2/day for the low T zone is higher than value of 0.1 ft^2/day suggested in Section 2.4.2. However, the calibrated value is within the range of transmissivities estimated for this zone (<0.001 ft^2/day to 11 ft^2/day). The calibrated value appears to be more representative than the rough estimate of transmissivity suggested in Section 2.4.2.

FZ-07

The transmissivity distribution for the model layer representing FZ-07 (model layer 15) is presented in Figure 5-7. The model zonation consists of three zones of transmissivity, similar to the zonation presented in Figure 2-9. The model transmissivity of 1,511 ft^2/day for the high T zone agrees closely with the value of 1,000 ft^2/day suggested in Section 2.4.2. Similarly, the model transmissivity of 113 ft^2/day for the intermediate T zone agrees closely with the T of 100 ft^2/day suggested in Section 2.4.2. The model value of 100 ft^2/day for the low T zone is higher than the estimated value of 0.1 ft^2/day suggested in Section 2.4.2. The transmissivity estimates for this zone range from <0.001 ft^2/day to 13 ft^2/day. As with FZ-06, this may indicate that the suggested value is not representative of conditions beyond the Site.

FZ-08

The transmissivity distribution for the model layer representing FZ-08 (model layer 16) is presented in Figure 5-8. The model zonation consists of two zones of transmissivity, similar to the zonation presented in Figure 2-10. The calibrated transmissivity of 5.76 ft^2/day for the intermediate T zone is lower than the value of 50 ft^2/day suggested in Section 2.4.2. The model transmissivity of 0.018 ft^2/day for the low T zone is higher than the value of 0.001 ft^2/day suggested in Section 2.4.2, but is within the range of transmissivity estimates presented in Section 2.4.2 (<0.001 to 0.04 ft^2/day). The transmissivity of this portion of FZ-08 is relatively low.

FZ-09

The transmissivity distribution for the model layer representing FZ-09 (model layer 17) is presented in Figure 5-9. The model zonation consists of five zones of transmissivity. The zonation presented in Figure 2-11 consists of only three zones, and formed the starting point for the model FZ-09 zonation. During calibration, it became evident that there must be a low-transmissivity feature separating the high T and intermediate T zones. Without this low-transmissivity feature, the sharp drop in FZ-09 water levels that is observed under pumping conditions cannot occur. In particular, the water levels at piezometers within the intermediate T zone in Figure 2-11 (B2M-09, D1M-09, D2M-09, F2M-09, F4M-09, and PMW-1M-09) are all approximately identical under pumping conditions. The one-order-of-magnitude change in transmissivity suggested in Figure 2-11 is not sufficient to provide the hydraulic separation required to achieve the "zero-gradient" condition observed.

The calibrated transmissivity of 1,404 ft^2/day for the high T zone agrees closely with the T of 1,000 ft^2/day suggested in Section 2.4.2. Similarly, the calibrated transmissivity of 124 ft^2/day for the intermediate T zone agrees closely with value of 100 ft^2/day suggested in Section 2.4.2. The calibrated transmissivity of 0.00493 ft^2/day for the low T zone is consistent with the estimated value of 0.01 ft^2/day suggested in Section 2.4.2. The zone with a calibrated transmissivity of T=57.9 ft^2/day was introduced in attempt to obtain a better match at ABP-7-09 and C3-09; however, this additional zone did not yield a significantly better match to observed water levels. Additional discussion of conditions around these wells is provided in Section 5.5.

FZ-10

The transmissivity distribution for the model layer representing FZ-10 (model layer 19) is presented in Figure 5-10. Following the conceptual model, a single value of transmissivity has been specified for FZ-10. The model transmissivity of 0.0778 ft^2/day agrees closely with the median value of about 0.03 ft^2/day presented in Section 2.4.2.

FZ-11

The transmissivity distribution for the model layer representing FZ-11 (model layer 21) is presented in Figure 5-11. The model zonation consists of five zones of transmissivity and is similar to the zonation presented in Figure 2-13. The magnitudes of the transmissivities of these five zones agree fairly closely with those presented in Section 2.4.2:

- High T zones:

  Near G1L: model value of 231 ft^2/day versus suggested value of 200 ft^2/day

  Near PW-1L: model value of 218 ft^2/day versus suggested value of 300 ft^2/day.
- Intermediate T zones:

  Near AGW-2L: model value of 54.3 ft^2/day versus suggested value of 10 ft^2/day.

  Near D1L: model value of 80.2 ft^2/day versus suggested value of 20 ft^2/day.
- Low T Zone: model value of 0.186 ft^2/day versus suggested value of 0.01 ft^2/day.

In summary, the calibrated transmissivity distributions for each flow zone are in close agreement with the conceptual model presented in Section 2. The only significant exception is in FZ-09, where an additional zone was identified during model calibration. This zone was required to match the observed area of flat water levels west of the Landfill. The flat zone was observed in the SCR-H and during the 2001 system shutdown.

5.4.2 FLOW ZONE VERTICAL HYDRAULIC CONDUCTIVITY

A vertical hydraulic conductivity has been assigned to each transmissivity zone in the individual flow zone model layers. The vertical hydraulic conductivity values are estimated for each flow zone, using computer-assisted calibration techniques. The calibrated values for each layer are listed below.

Flow zone	Number of transmissivity zones	Calibrated Vertical Hydraulic Conductivities (ft/day)
1	1	0.22
2	1	0.53
3	1	0.0066
4	2	0.0071; 0.63
5	2	0.0035; 0.66
6	3	0.025; 0.10; 3.14
7	3	0.33; 1.17; 16.1
8	2	3.88×10^{-5}; 0.01
9	5	0.00015; 1.51; 17.85; 0.00011; 0.66
10	1	0.00036
11	5	0.013; 1.22; 0.52; 4.33; 1.86

5.4.3 AQUITARD HYDRAULIC PROPERTIES

Each model layer representing an aquitard is assigned uniform hydraulic properties. To limit the number of fitted parameters, it has been assumed that the aquitard layers have identical hydraulic properties. The calibrated horizontal hydraulic conductivity of the aquitard layers is 0.0075 ft/day. This is very similar to the value of 0.0125 ft/day presented in the Draft SCR-M report. If the calibrated hydraulic conductivity of the aquitards is multiplied by the length of the packer testing interval (5.2 feet), the resulting transmissivity is 0.039 ft^2/day. This is very close to the median aquitard transmissivity value of 0.03 ft^2/day presented in Section 3.2.6.3 of the SCR-H report.

The calibrated vertical hydraulic conductivity for the aquitard layers is small, 0.00040 ft/day. The vertical hydraulic conductivity of the aquitards exerts a primary control on vertical flow in the bedrock system. The calibrated values of the vertical properties of the flow zones and the aquitards incorporate the effects of the artificial vertical connections introduced by the long open-intervals of the purge wells and the existing monitoring wells at the Site. If the existing monitoring wells at the Site are abandoned, then water levels in the flow zones may change significantly at some locations and the model calibration may have to be revisited.

5.4.4 BEDROCK ABOVE FZ-01

As presented in the SCR-H, there is evidence that some areas in the rock above FZ-01 are very transmissive, and on average that the rock may not behave as an aquitard. In the SCR-M analysis, the bedrock above FZ-01 (model layer 2) has been allowed to take on a different transmissivity than specified in the other aquitard layers. The calibrated hydraulic conductivity for this layer is 0.81 ft/d; over two orders of magnitude higher than for the aquitard layers. The thickness of this model layer is variable, so the transmissivity may range from very small values where it is essentially absent, to significant values comparable to the transmissivities of the flow zones.

The vertical hydraulic conductivity of the rock above FZ-01 determined from the parameter estimation is 0.0053 ft/day. This value is relatively low, but over one order of magnitude higher than for the aquitard layers.

5.4.5 HYDRAULIC PROPERTIES OF THE BURIED NYPA CONDUITS

During model calibration, model cells containing the buried conduits were permitted to take on unique properties. The calibrated hydraulic conductivity of the conduits cells is 0.51 ft/day, and the vertical hydraulic conductivity is 0.10 ft/day. These values should be considered in the context of the approach adopted to assign the conductances along the conduits. As discussed in Section 4.3.3, the conductance of each of the drains cells representing the buried conduits is set proportional to the length of the cell and the properties of the model layer adjacent to the drain cell. The conductance formula can be written in simplified form as:

$$C(j,i,k) = delc(i) * K_H * conduit\_mult$$

where K_H designates the flow zone horizontal hydraulic conductivity at the conduits. No physical significance should be attached to K_H. Instead, the product of K_H and the conduit multiplier, *conduit_mult*, should be interpreted as a lumped parameter that accounts for the complexities of flow patterns in the immediate vicinity of the conduits.

The calibrated conductances of the NYPA conduits appear to be consistent with an enhanced permeability in both the horizontal and vertical directions. This enhanced permeability is likely associated with the extensive drain network that underlies the conduits.

5.4.6 RECHARGE FROM PRECIPITATION INFILTRATION

The calibrated uniform recharge rate is 3.5 inches/year. This value is consistent with the estimated range of the recharge rate of between 2 and 6 in/yr suggested from the HELP analyses discussed in Section 2.5.4.

5.4.7 DRAIN AND GHB CONDUCTANCE MULTIPLIERS

The conductance multipliers for drains representing the Niagara River Gorge, the NYPA buried conduits, and the sewers and tunnels were allowed to vary in the model calibration. The conductance multiplier for the GHBs representing the NYPA Forebay was also treated as a fitting parameter. The magnitudes of the calibrated conductances multipliers are listed on the following table.

Boundary Conditions	*Magnitude of Conductance Multiplier*
Drains representing Niagara River Gorge	94
Drains representing Buried Conduits	0.12
Drains representing Sewers	13.2
Drains representing Tunnels	18,786
GHBs representing NYPA Forebay	0.018

5.4.8 SUMMARY OF CALIBRATION PARAMETERS

The final values of the model calibration parameters are listed on Table 5-2. The parameter value are listed with a precision that is consistent with the reported output from PEST; the number of significant figures should not be interpreted as an indication of the precision with which these values can be estimated. The calibrated parameters are all slightly different from those presented in the Draft SCR-M report, reflecting improvements made to the design of the model, and additional calibration.

5.5 CALIBRATION RESULTS

In an ideal world, a groundwater simulation would replicate exactly the groundwater system and we would not require a discussion of the match between observations and model calculations. In reality, the natural groundwater system is dynamic and can never be characterized completely. Water levels in wells may change rapidly, and errors may arise in their measurement. Furthermore, a well is an imperfect instrument for determining water levels in the subsurface. Therefore, a groundwater model can provide only an approximate representation of a complex physical system, and an evaluation of the match between the observations and the model calculations is required. There is no standard methodology for making such an evaluation. The American Society for Testing and Materials (ASTM) has published guidelines for comparing model results against observations (ASTM Standard Guide D5490-93). The ASTM guidelines are incorporated as appropriate in the following discussion.

The goodness-of-fit is evaluated by comparing the water levels simulated by the model and the water levels measured in wells. Qualitative assessment is made with visual comparisons. In assessing the goodness-of-fit, we examine:

- The shape of the contours, evaluating whether flow patterns are similar;
- The hydraulic gradients; and
- The absolute groundwater levels.

The model results are also evaluated by plotting the calculated and observed water levels at the individual wells on a scatter plot. For example, Figure 5-12 presents the scatter plot for the pumping conditions calibration scenario. The abscissa (x-axis) represents the observed water level, and the ordinate (y-axis) represents the calculated water level at the location of the well. For a perfect match between the model calculations and the observation, the points fall on a straight line shown by the solid line on Figure 5-12. The scatter plot is inspected for deviations of the data from the solid line. The data points on the scatter plot are also inspected for patterns. For example, if the slope of a line through the data points is steeper or shallower than the solid line, this suggests an error in the overall hydraulic gradient. As with the visual comparison of water level contours, examination of the scatter plot is a qualitative assessment.

The goodness-of-fit of the model is assessed quantitatively by calculating residuals, defined as the difference between the calculated and observed water levels. Statistical measures calculated with the residuals provide the modeler with a means of determining whether revisions to the model have yielded a demonstrably better match to the observations. Four statistical measures are calculated:

1. Mean residual error, MRE (arithmetic average of the residuals)

$$MRE = \frac{1}{N}\sum_{i=1}^{N}\left(cal_i - obs_i\right)$$

where N is the number of observations; cal_i is the calculated water level at piezometer i; and obs_i is the observed water level at piezometer i.

2. Mean absolute error, MAE (arithmetic average of the absolute value of the residuals)

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|cal_i - obs_i\right|$$

3. Standard deviation of residuals, SDEV

$$SDEV = \left[\frac{1}{N-1}\sum_{i=1}^{N}\left(cal_i - obs_i\right)^2 - \frac{N}{N-1}MRE^2\right]^{1/2}$$

4. Sum of squared residuals, SSE

$$SSE = \sum_{i=1}^{N}\left(cal_i - obs_i\right)^2$$

A mean residual of zero indicates that the calculated water levels are at the right average level, but is not a reliable indicator of a good match, because large negative and positive residuals may cancel out. The mean of the absolute residuals and the sum of the squared residuals do support a quantitative assessment of the goodness-of-fit. One of our goals during calibration is to minimize both values. The sum of squared residuals provides an overall quantitative measure of the match between the model and the observations, and is the formal objective function for the automatic parameter estimation.

The model results are discussed for both calibration scenarios for each flow zone in turn.

5.5.1 CALIBRATION RESULTS - PUMPING CONDITIONS

Overview of calibration results

The overall match between the observed water levels and water levels calculated with the model for pumping conditions is presented in Figure 5-12. The calibration residuals are presented on Table 5-3. Table 5-3 also includes detailed summary statistics for the calibration.

As shown in Figure 5-12, the calibration points fall relatively close to the line of perfect match. The model provides a good match between calculated and observed water levels, based on the following criteria:

- Most of the calibration residuals fall within 10 feet of the line of equality;
- The residuals are scattered randomly about the line of equality; and
- The mean of the absolute values of the residuals divided by the range in the observed head is relatively small (Anderson and Woessner, 1992).

The calibration summary statistics are improved slightly compared to those obtained for the Draft SCR-M. The mean of the absolute values of the residuals is 7.40 feet, which is 6.3 percent of the range in the observed head (117.76 ft). The standard deviation of the residuals is 9.17 feet; the standard deviation of the residuals divided by the range in the observed heads is 7.79 percent. This value is less than the target of 10 percent for a reliable model suggested by Spitz and Moreno (1996).

Calculated water levels

The calculated water level distributions under pumping conditions are discussed in the following section. In the following discussion we use the term “dewatered" to refer to calculated water levels that are effectively below the bottom of a flow zone.

FZ-01

The calculated water levels for FZ-01 are shown in Figures 5-13 and 5-14. The model predicts that the flow zone is dewatered towards its northern subcrop. This reflects the fact that the conduit levels are below the bottom of the flow zone layer. The model predicts that groundwater flow converges towards the sewer south of Maple Ave. The local calculated contours are generally consistent with the contours developed in the SCR-H.

The model residuals are shown in Figure 5-15. The residuals at H2U-01 and H5-01 are relatively small; they are within one contour interval of 10 feet adopted for the interpretation of the observed average water levels in the SCR-H study. The water levels at I1-01 and G1U-01 are under and overpredicted by similar amounts, about 7 feet.

FZ-02

The calculated water levels for FZ-02 are shown in Figures 5-16 and 5-17. The model predicts that the flow zone is dewatered towards its northern subcrop; the conduit levels are below the bottom of the flow zone layer. The model predicts that the flow zone is also dewatered at the Niagara River gorge. The model predicts a localized dewatered area in the vicinity of PW-4U and PW-5UR. This is consistent with the data presented on the contour map in SCR-H.

The model residuals are shown in Figure 5-18. In general the residuals are within one contour interval of the observed average water levels. The model residual is high at F2U-02, +13.4 feet. The hydrograph for F2U-02 suggests that the flow zone is dry at this location, under both pumping and non-pumping conditions. This may be related to unidentified sewers located nearby.

FZ-03

The calculated water levels for FZ-03 are shown in Figures 5-19 and 5-20. The model predicts that the flow zone is dewatered at the gorge. The model also predicts that the flow zone is dewatered towards its northern subcrop, and along its subcrop beneath the Landfill. No observations are available to evaluate residuals in FZ-03.

FZ-04

The calculated water levels for FZ-04 are shown in Figures 5-21 and 5-22. The model predicts that the flow zone is dewatered at the Forebay and further south along the conduits. The model also predicts that the flow zone is dewatered at its western limits and southwards along the Niagara River gorge. The model predicts that the flow zone is drained over some portions of its subcrop along the filled railroad trench. The model predicts a small influence of PW-4U, and a small cone of depression around PW-6UR. The model also predicts a localized area near the subcrop of FZ-04 beneath the Landfill that is dewatered; the dewatered area is centered on PW-2UR. This is consistent with the data presented on the contour map in the SCR-H report.

The model residuals are shown in Figure 5-23. In general the residuals are relatively large, exceeding one contour interval (5 feet). The model predicts dewatered conditions in the vicinity of D1U-04 and D2U-04. This suggests that the impact of the sewer along Lafayette Ave. may be exaggerated in this flow zone. The model also predicts lower than observed water levels along the gorge. The hydrograph of AFW-2-04 suggests that the flow zone is likely dewatered at this location; the "true" water level at the gorge may in fact be below FZ-04.

FZ-05

The calculated water levels for FZ-05 are shown in Figures 5-24 and 5-25. The groundwater flow directions are consistent from those inferred from the contours presented in the SCR-H report. The model predicts that the flow zone is dewatered at the Forebay and further south along the conduits. The model also predicts that the flow zone is dewatered along the gorge. The flow zone is also drained along the southern extent of its subcrop close to the filled railroad trench.

The model residuals are shown in Figure 5-26. High residuals are calculated at D1U-05 and D2U-05. The model predicts dewatered conditions in the vicinity of these piezometers. This suggests that the impact of the sewer along Lafayette Ave. may be exaggerated in this flow zone. The model also predicts low water levels along the gorge. The hydrograph of AFW-2-05 suggests that the flow zone is likely dry at this location; the "true" water level at the gorge may be below FZ-05.

FZ-06

The calculated water levels for FZ-06 are shown in Figures 5-27 and 5-28. The model predicts that the flow zone is dewatered at the intersection of the Forebay and the buried conduits. This is consistent with the relative elevation of the flow zone and the average level in the Forebay, as shown in Figure 2-17. The model also predicts that under pumping conditions the flow zone is dewatered along the Niagara River gorge. The model predicts that water levels are depressed over the area immediately west of the Landfill under pumping conditions. This is caused by the purge wells PW-1U, PW-7U, PW-8U, PW-9U and PW-2M. The calculated water levels are close to the bottoms of the model cells; this is consistent with the contours presented in the SCR-H report.

The model residuals are shown in Figure 5-29. In general the residuals are within 5 to 10 feet in FZ-06, that is, within one contour interval. The residuals at AGW-1U-06 and J5M-06 are high at +15.6 and +20.2 feet, respectively. The hydrographs for these piezometers suggest that the FZ-06 is dry at these locations. Although a residual is shown for H2M-06, its water level was excluded from the SCR-H contouring. The model confirms that the observed water level at this H2M-06 is well above the expected water level in FZ-06 at this location. The model matches conditions observed along the gorge. This suggests that the discharge to the gorge is simulated appropriately in FZ-06.

FZ-07

The calculated water levels for FZ-07 are shown in Figures 5-30 and 5-31. The model predicts that under pumping conditions, the flow zone is dewatered along the Niagara River gorge. The model predicts a small cone of depression around PW-2M. The model predicts that the cone of depression around the other purge wells open across FZ-07 is more significant. The simulated allocation of purge well flows in FZ-07 will be a subject of ongoing examination.

The model residuals are shown in Figure 5-32. In general the residuals are relatively small in FZ-07.

FZ-08

The calculated water levels for FZ-08 are shown in Figures 5-33 and 5-34. The model predicts that the flow zone is dewatered along the Niagara River gorge. No observations are available to evaluate residuals in FZ-08.

FZ-09

The calculated water levels for FZ-09 are shown in Figures 5-35 and 5-36. The model predicts that under pumping conditions, the flow zone is dewatered along the Niagara River gorge. The model predicts that groundwater flow converges towards PW-2M and PW-8M. The extent of dewatered conditions northwest of the Landfill matches the interpretation developed for the SCR-H. The remaining purge wells open across FZ-09 have little effect on water levels.

The model residuals are shown in Figure 5-37. The residuals closest to the Site are relatively small in FZ-09. A high residual is calculated at I1-09. A very low transmissivity was estimated from the slug test at this piezometer (<0.001 ft^2/day) and the hydrograph for I1-09 suggests that the water level had not stabilized during the SCR-H monitoring period. The results of the model may provide insight into the eventual stabilized level at this location.

FZ-10

The calculated water levels for FZ-10 are shown in Figures 5-38 and 5-39. The model predicts that groundwater converges towards PW-1L. The remaining purge wells that are open across FZ-10 have little effect on water levels. No observations are available to evaluate residuals in FZ-10.

FZ-11

The calculated water levels for FZ-11 are shown in Figures 5-40 and 5-41. The model predicts that under pumping conditions, the flow zone is dewatered along the Niagara River gorge. The calculated water level patterns closely match those developed for the SCR-H. The model predicts that groundwater converges towards PW-1L. The remaining purge wells open across FZ-11 have little effect on water levels.

The model residuals are shown in Figure 5-42. The residual for piezometer I1-11 is high at +40.8 feet. The hydrograph for I1-11 suggests that the water level had not stabilized during the SCR-H monitoring period; the results of the model may provide insight into the eventual stabilized level at this location.

5.5.2 WATER BALANCE FOR PUMPING CONDITIONS

The model water balance for the simulation of pumping conditions is presented on Table 5-4. The water balance is presented in terms of inflows and outflow to/from each individual model layer. This breakdown provides a general impression of the system and allows for a qualitative assessment of the conceptual model.

Infiltration of precipitation

The total recharge from the infiltration of precipitation over the top of bedrock is 80,400 ft^3/day (418 gpm). The model predicts that infiltration of precipitation represents 72 percent of the total inflow to the model of 111,400 ft^3/day (579 gpm). About half of the recharge is applied to model layer 2, the bedrock above FZ-01. The remainder of the recharge is applied to lower layers in the model. This reflects the fact that first the bedrock above FZ-01, and then successively lower flow zones and intervening aquitards, subcrop across the model domain.

NYPA Forebay and buried conduits

The predicted inflow from the NYPA Forebay to the bedrock groundwater system is 31,000 ft^3/day (161 gpm). This represents 27.8 percent of the total inflow to the model domain. The majority of the flow from the NYPA Forebay is provided through FZ-07 and FZ-09.

The model also predicts that there are small flows from FZ-02, FZ-05, and FZ-06 into the Forebay, 2,160 ft^3/day (11.2 gpm). These flows occur where the water levels in FZ-02, FZ-05, and FZ-06 adjacent to the Forebay exceed the specified control levels, set at the bottom of the flow zones. The flows from the bedrock into the Forebay represent about 7 percent of the Forebay inflows to the bedrock groundwater system.

The predicted discharge from the bedrock to the buried NYPA conduits under pumping conditions is 23,175 ft^3/day (120 gpm). This represents about 20 percent of the total outflow from the model, and corresponds to 75 percent of the Forebay inflow.

Niagara River gorge

The calculated discharge to the gorge of the Niagara River is 57,700 ft^3/day (299.5 gpm); this represents 52 percent of the total outflow from the model. Discharges to the gorge occur primarily through FZ-07 and FZ-09.

Bedrock purge wells

The model results indicate that the purge wells act both as sources and withdrawals. The simulated withdrawal of water from the purge wells is 17,565 ft^3/day (91 gpm). The model predicts that FZ-07 and FZ-09 account for 78 percent of the total purge well withdrawals. The total purge well flow of 91 gpm predicted by the model is somewhat higher than the total withdrawal rate observed on January 6, 2003, 66 gpm. There are two reasons the predicted purge well rates do not match the observed pumping rates presented on Table 5-1:

- Outflows from the pumping wells into the flow zones occur even when a well is pumping. This phenomenon was discussed in the SCR-H for well PW-10U; and
- As described in Section 4.4.2, the pumping rates are not prescribed in the model. Instead, the flow rates are calculated based on the differences between the calculated water levels and the control levels that are specified for each flow zone intersected by a purge well.

The calculated flow rates for the purge wells and shafts are listed on Table 5-5. The calculated allocation of flow from the individual flow zones intersected by each purge well and shaft is presented in Appendix B, Figures B-1 through B-25.

Sewers, shafts, and tunnels

As indicated previously, the sewers, tunnels, and shafts appear to have important local effects on groundwater levels. The model predicts that the sewers and tunnels remove 9,070 ft^3/day from the model, or about 47 gpm. The shafts remove a net rate of 1,660 ft^3/day from the model, or about 9 gpm. The total withdrawal from the sewers, tunnels, and shafts represents 10 percent of the total inflow to the model outflow from the model, or about 61 percent of the total purge well withdrawals.

Although the predicted flow rates are relatively small for the sewers, shafts, and tunnels, the influence of these features on water levels may be very large in areas of low transmissivity. A flow of 0.1 gpm is insignificant in an area with a transmissivity of 500 ft^2/day. However, 0.1 gpm has a huge influence on water levels in an area with a transmissivity of 0.005 ft^2/day.

Overall water balance

The total inflows and outflows reported in Table 5-4 indicate that the model is internally consistent with respect to calculated water balances within each flow zone, and within the model as a whole. This is a necessary requirement for a converged numerical solution. The overall water balance is summarized below. The overall volumetric balance discrepancy is very low.

Component of overall water balance	**Value (ft^3/day)**	**Value (gpm)**
Inflows from precipitation recharge	80,399.5	417.7
Inflows from Forebay	31,002.0	161.0
Total inflows	**111,401.5**	**578.7**
Outflows to gorge	57,661.9	299.5
Outflows to Forebay	2,156.3	11.2
Outflows to NYPA conduits	23,175.2	120.4
Outflows from purge wells (net)	17,565.5	91.2
Outflows from sewers and tunnels	9,069.7	47.1
Outflows from shafts (net)	1,659.3	8.6
Total outflows	**111,287.9**	**578.0**
Overall volumetric discrepancy	**0.1%**	

5.5.3 CALIBRATION RESULTS – NON-PUMPING CONDITIONS

Overview of calibration results

The overall match between the observed and 0calculated water levels under non-pumping conditions is presented in Figure 5-43. The calibration residuals are presented on Table 5-6. Table 5-6 also includes detailed summary statistics for the calibration.

The calibration summary statistics are improved slightly compared to those obtained for the Draft SCR-M. The model for non-pumping conditions also provides a good match between calculated and observed water levels. The mean of the absolute values of the residuals is 7.23 feet; the mean of the absolute residuals corresponds to 6.3 percent of the range in the observed head (115.52 feet). The standard deviation of the residuals divided by the range in the observed heads is 7.93 percent. This value is again less than the target of 10 percent for a reliable model suggested by Spitz and Moreno (1996).

Calculated water levels

The calculated water level distributions under non-pumping conditions are discussed below. The SCR-H water level monitoring period was too brief to observe fully recovered conditions in all flow zones. In contrast, the model simulates average water levels under fully recovered conditions. Therefore, it is not entirely appropriate to compare the model results with the SCR-H interpretations.

FZ-01

The calculated water levels for FZ-01 under non-pumping conditions are shown in Figures 5-44 and 5-45. The model residuals are shown in Figure 5-46. In general, the calculated water levels are very similar to those calculated for pumping conditions; these results are consistent with the interpretations of the SCR-H.

FZ-02

The calculated water levels for FZ-02 are shown in Figures 5-47 and 5-48. The model residuals are shown in Figure 5-49. As expected, water levels under non-pumping conditions are higher.

FZ-03

The calculated water levels for FZ-03 are shown in Figures 5-50 and 5-51. The model predicts that water levels at the center of the Landfill are about 10 feet higher under non-pumping conditions.

FZ-04

The calculated water levels for FZ-04 under non-pumping conditions are shown in Figures 5-52 and 5-53. The model residuals are shown in Figure 5-54. Predicted water levels are about 10 feet higher at the center of the Landfill, but the model still predicts a dewatered area around D1U-04 and D2U-04. Under both pumping and non-pumping conditions, the sewer along Lafayette Ave. acts to dewater FZ-04 in this area.

FZ-05

The calculated water levels for FZ-05 under non-pumping conditions are shown in Figures 5-55 and 5-56. The model residuals are shown in Figure 5-57. Predicted water levels are about 10 feet higher at the center of the Landfill, and no dewatering is predicted along the Lafayette Ave. sewer. The model predicts a localized cone of depression around PW-3M under non-pumping conditions, indicating that there is some drawdown in FZ-05 when the well is not pumping. The drawdown at PW-3M is much larger under pumping conditions, but is more widespread and therefore not as clearly evident.

FZ-06

The calculated water levels for FZ-06 under non-pumping conditions are shown in Figures 5-58 and 5-59. The model residuals are shown in Figure 5-60. The model residuals in FZ-06 are relatively high, indicating that the model overpredicts water levels under non-pumping conditions.

FZ-07

The calculated water levels for FZ-07 under non-pumping conditions are shown in Figures 5-61 and 5-62. The model residuals are shown in Figure 5-63. A very small horizontal hydraulic gradient is calculated in the vicinity of the Landfill. The model predicts that FZ-07 is dry at the gorge under both pumping and non-pumping conditions. At the gorge, the calculated residuals are within one contour level of the observations, suggesting that conditions along the gorge are simulated appropriately.

FZ-08

The calculated water levels for FZ-08 are shown in Figures 5-64 and 5-65. The model predicts that FZ-08 is dry at the gorge under non-pumping conditions. The model predicts that the shaft at Lewiston Road, and the tunnel connecting the shafts at Lewiston Road and Lafayette Avenue, drain a significant portion of FZ-08 east from gorge.

FZ-09

The calculated water levels for FZ-09 under non-pumping conditions are shown in Figures 5-66 and 5-67. The model residuals are shown in Figure 5-68. The model predicts that the gorge is dry under both pumping and non-pumping conditions. The model predicts that the shaft at Lewiston Road, and the tunnel connecting the shafts at Lewiston Road and Lafayette Avenue, also have an important effect in draining FZ-09 east from gorge. A comparison of the predicted pumping and non-pumping water levels (Figures 5-35 and 5-67) reveals the extensive dewatering in FZ-09 caused by the bedrock purge wells at the Site.

FZ-10

The calculated water levels for FZ-10 under non-pumping conditions are shown in Figures 5-69 and 5-70.

FZ-11

The calculated water levels for FZ-11 under non-pumping conditions are shown in Figures 5-71 and 5-72. The model residuals are shown in Figure 5-73. The flow patterns inferred from the calculated water levels are similar to those for pumping conditions, and are consistent with the interpretations developed for the SCR-H. The model results suggest that groundwater flow in FZ-11 is controlled by the transmissivity distribution. A comparison of water levels calculated under non-pumping and pumping conditions (Figures 5-72 and 5-41, respectively) indicates that the drawdowns in FZ-11 are due primarily to PW-1L and PW-2L. The effect of pumping at PW-3L is limited to the immediate vicinity of the well.

5.5.4 WATER BALANCE FOR NON-PUMPING CONDITIONS

The model water balance for the simulation of pumping conditions is presented on Table 5-7. The water balance is presented in terms of inflows and outflow to/from each individual model layer, as well as totals for the model.

Infiltration of precipitation

The total recharge from precipitation infiltration over the top of bedrock is 80,399.5 ft^3/day. This is the same as under pumping conditions. The analysis for non-pumping conditions predicts that recharge represents 72 percent of the total inflow to the model.

NYPA Forebay and buried conduits

The predicted inflow from the NYPA Forebay to the bedrock groundwater system under non-pumping conditions is 31,812 ft^3/day (165 gpm), an increase of about 3 percent over pumping conditions. The inflow represents 28.4 percent of the total inflow to the model domain, a small increase compared with 27.8 percent for pumping conditions.

The total discharge from higher flow zones into the Forebay under non-pumping conditions is 2,560 ft^3/day (12.3 gpm). The flows from the bedrock into the Forebay represent about 8 percent of the Forebay inflows to the bedrock groundwater system.

The predicted discharge from the bedrock to the buried NYPA conduits under non-pumping conditions is 27,530 ft^3/day (143 gpm). This represents a 19 percent increase with respect to pumping conditions. The discharge to the conduits corresponds to 86 percent of the Forebay inflow, increased from 75 percent under pumping conditions.

Niagara River gorge

The calculated discharge to the gorge of the Niagara River under non-pumping conditions is 77,673 ft^3/day (403 gpm); an increase of about 35 percent over pumping conditions. The discharge to the gorge represents 51 percent of the total outflow from the model. Discharges to the gorge occur primarily through FZ-07 and FZ-09.

Bedrock purge wells

The model results indicate that the purge wells act as more significant conduits for flow under non-pumping conditions. The total addition of water from the purge wells is 9,065 ft^3/day (47.1 gpm).

The calculated flow rates for the purge wells and shafts are listed on Table 5-8. The calculated allocation of flow from the individual flow zones intersected by each purge well and shaft is presented in Appendix B, Figures B-26 through B-50.

Overall water balance

The total inflows and outflows reported in Table 5-7 indicate that the model is internally consistent with respect to calculated water balances within each flow zone, and within the model as a whole. This is a necessary requirement for a converged numerical solution. The overall water balance is summarized below. The overall volumetric balance discrepancy is very low.

Component of overall water balance	**Value (ft^3/day)**	**Value (gpm)**
Inflows from precipitation recharge	80,399.5	417.7
Inflows from Forebay	31,812.1	165.3
Total inflows	**112,211.6**	**583.0**
Outflows to gorge	77,673.5	403.5
Outflows to Forebay	2,563.9	13.3
Outflows to NYPA conduits	27,531.3	143.0
Outflows from purge wells (net)	-9,065.0	-47.1
Outflows from sewers and tunnels	11,074.0	57.5
Outflows from shafts (net)	2,382.5	12.4
Total outflows	**112,160.2**	**582.6**
Overall volumetric discrepancy	**0.04%**	

6.0 SUMMARY

A numerical groundwater flow model of the Hyde Park Landfill Site has been developed that synthesizes the new characterization of the Site developed in the SCR-G and the SCR-H. The model captures the essential elements of the groundwater flow system at the Site, and does so at a relatively high resolution. The model includes eleven discrete, bedding-parallel flow zones that are separated by layers of intact, low permeability rock. The model provides a quantitative assessment of conditions within the discrete flow zones in the bedrock, under the influence of precipitation recharge, the gorge of the Lower Niagara River, and the hydraulic structures of the NYPA Niagara Power Project.

A model of the Site was developed in 2001 (SSP&A, 2001). That original model was divided into three bedrock flow intervals. The findings of this early model, and extensive field investigations completed in 2001 and 2002 (described in the SCR-G and SCR-H) resulted in a completely revised characterization of the Site bedrock hydrogeology. It was recognized that the original model was insufficient for simulation of the hydrogeologic regime. In particular, the model could not support a detailed demonstration of containment at the Site. The new model presented here builds on the framework established in the SCR-G and SCR-H, a framework that is developed from an extensive accumulation of data and careful interpretations.

Two water level data sets were determined in the SCR-H, pumping conditions and non-pumping conditions. The numerical model was calibrated to water levels under both conditions. The SCR-H identified several limitations associated with the water level data presented in that report:

- The water levels were influenced by monitoring and production wells that intercepted multiple flow zones, and
- The non-pumping water levels may not have represented fully recovered conditions.

The model described in the Draft SCR-M submitted on April 30, 2003 has been improved significantly in the last month. The model has been improved in two major areas. First, a new approach has been developed to represent the purge wells. This approach achieves more realistic water levels and discharge distributions in the flow zones intersected by the open intervals of the wells. Second, the water level data have been evaluated critically, and the calibration has been improved by weighting the data according to their reliability.

Ongoing evaluation of the model may suggest improvements in its design and/or parameterization. Prior to improving the model further, it is important that two issues with monitoring groundwater levels be addressed as soon as possible:

- The interconnection of flow zones by long open interval wells should be eliminated. These wells confound the detailed interpretation of Site conditions. Furthermore, they represent significant vertical pathways for groundwater flow and chemical transport.
- Collection of continuous water levels in selected discrete flow zone piezometers should continue. Although the water level data collected during the SCR-H represent an enormous accomplishment, the data collection period was in fact relatively brief, about two months. Water levels continue to be collected at the Site and the model will be refined as the data become available. The long-term continuous records will also provide important insights into the effects of seasonal changes in operation of the NYPA facilities.

The ultimate application of the numerical model will be to analyze the hydraulic performance of the Bedrock NAPL Plume Containment System. The model will support the development of an effective monitoring program and be crucial in optimizing the hydraulic performance of the containment.

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SITE CHARACTERIZATION REPORT – GROUNDWATER FLOW MODEL

FIGURES

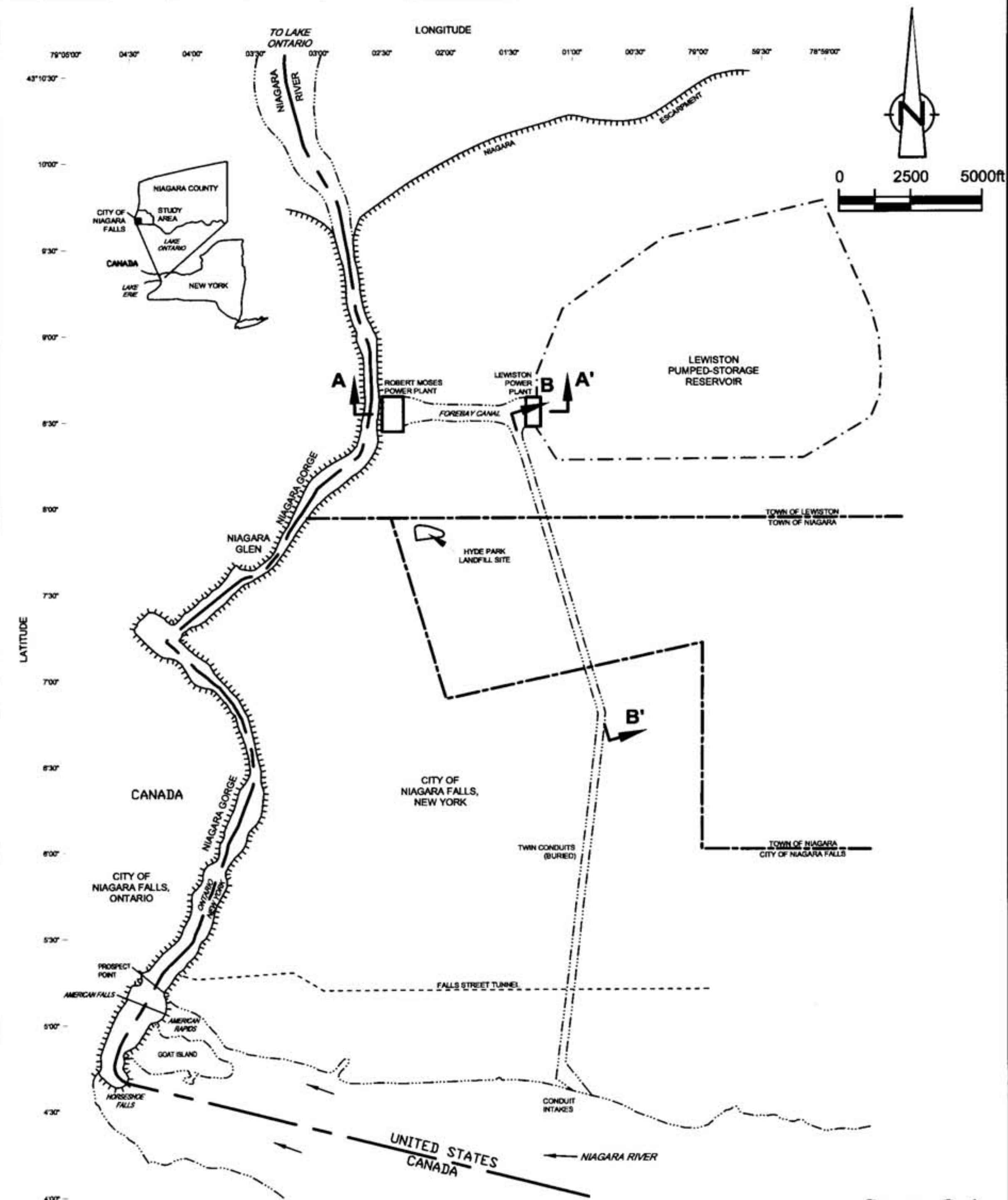

figure 2-1

SOURCE: MILLER AND KAPPEL, 1987

SITE LOCATION
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

01069-30(333)GN-WA001 MAY 29/2003

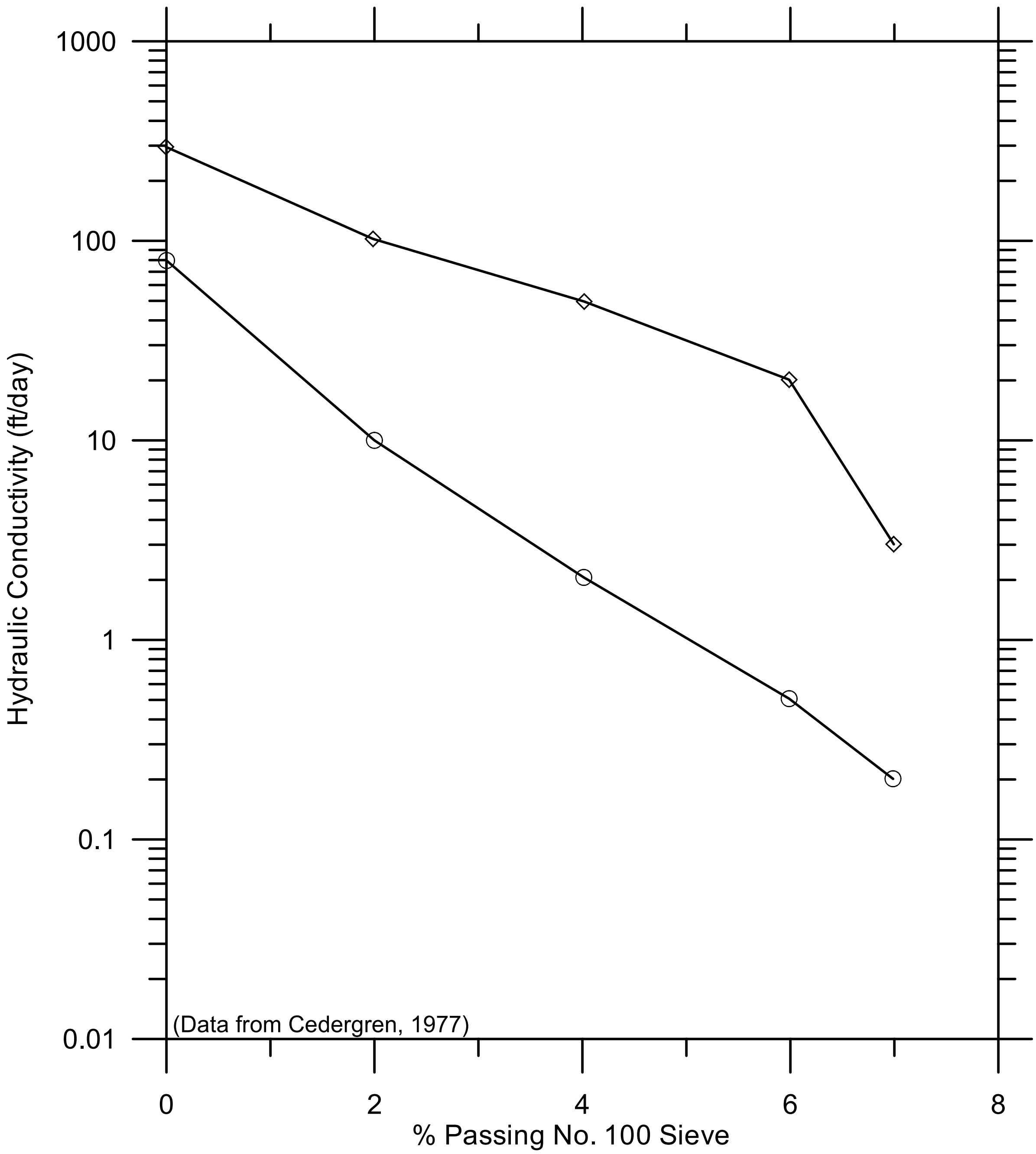

figure 2-2

REDUCTION OF HYDRAULIC CONDUCTIVITY CAUSED BY FINE-GRAINED MATERIALS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management

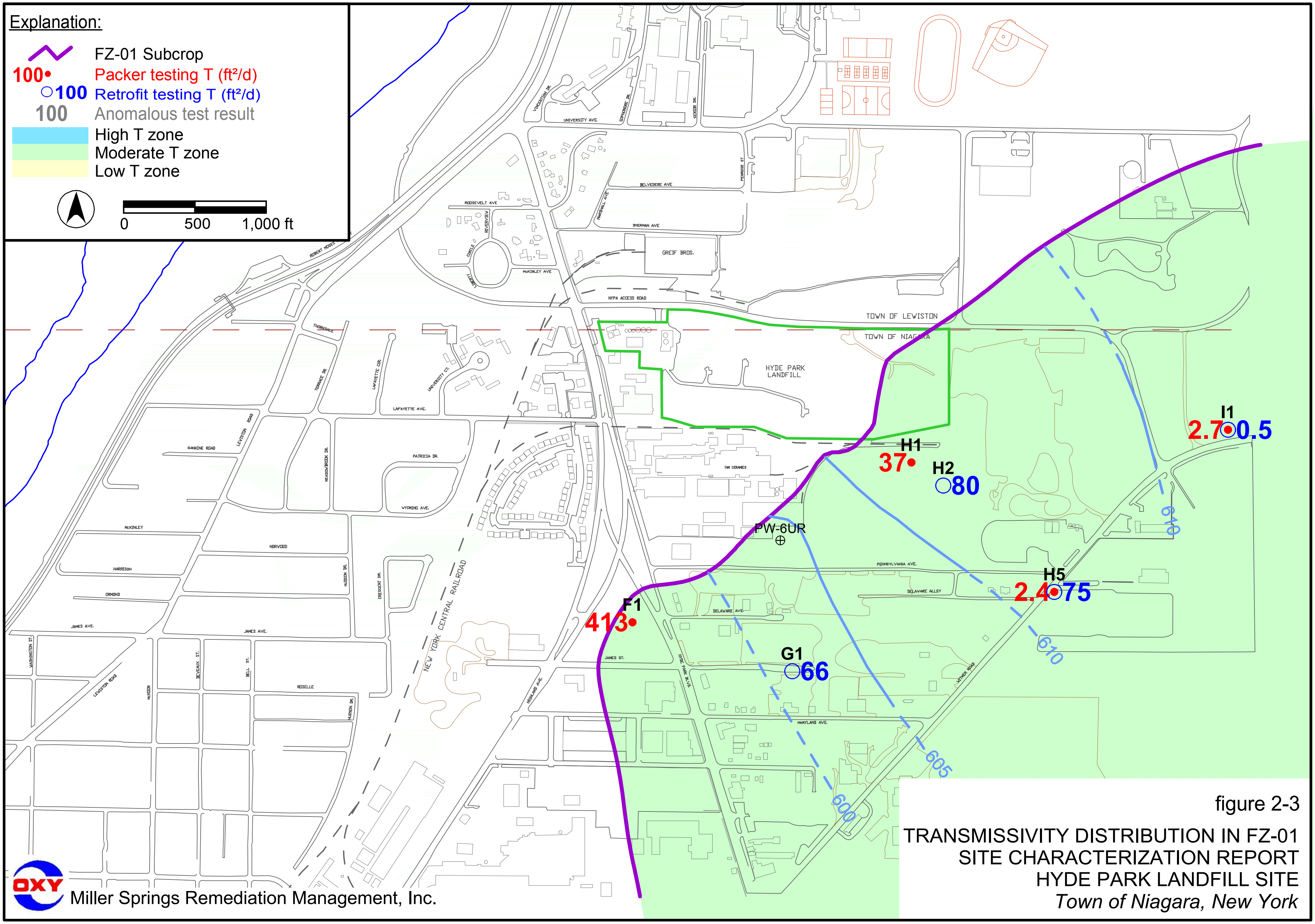

figure 2-3

TRANSMISSIVITY DISTRIBUTION IN FZ-01
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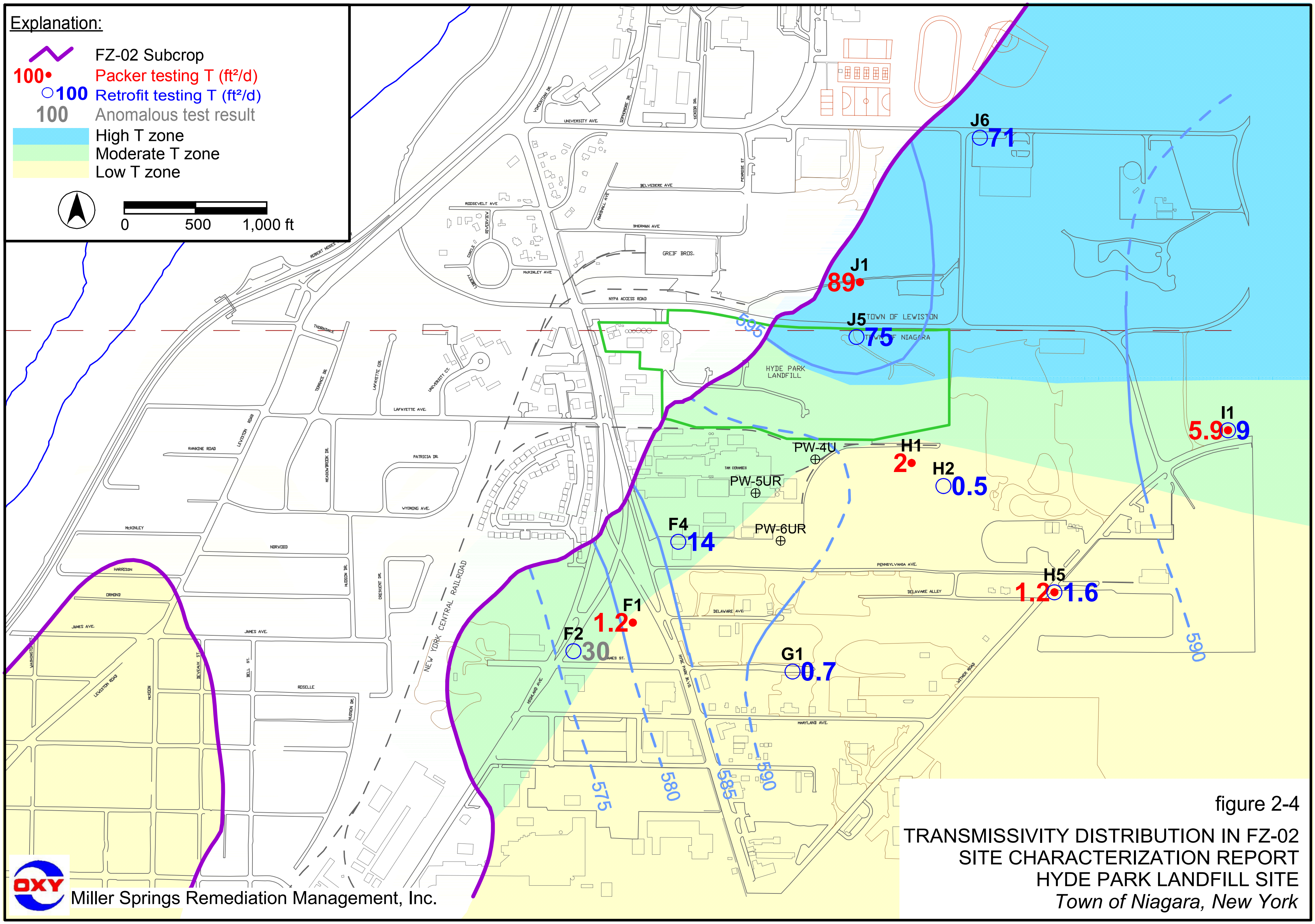

figure 2-4

TRANSMISSIVITY DISTRIBUTION IN FZ-02
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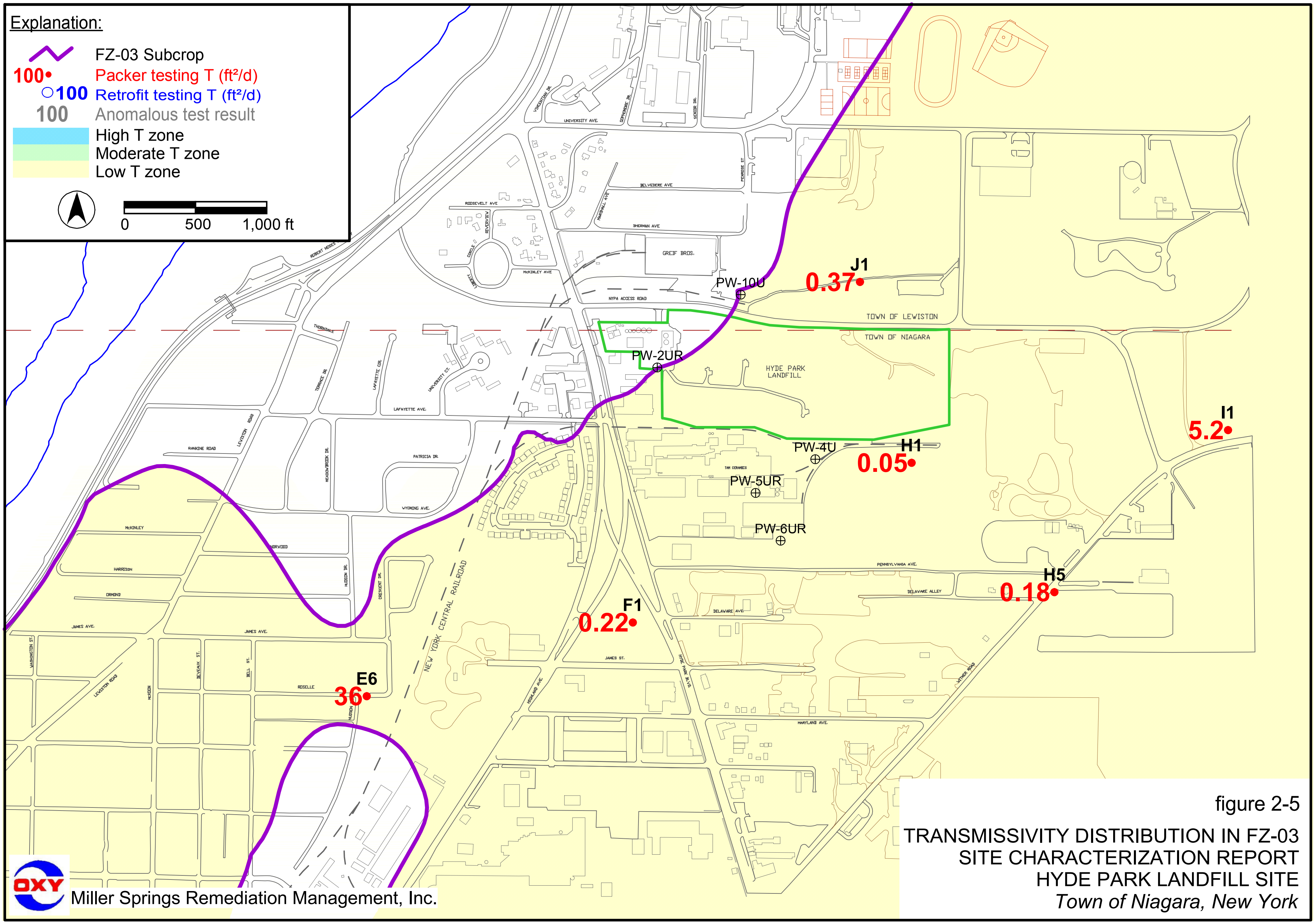

figure 2-5

TRANSMISSIVITY DISTRIBUTION IN FZ-03
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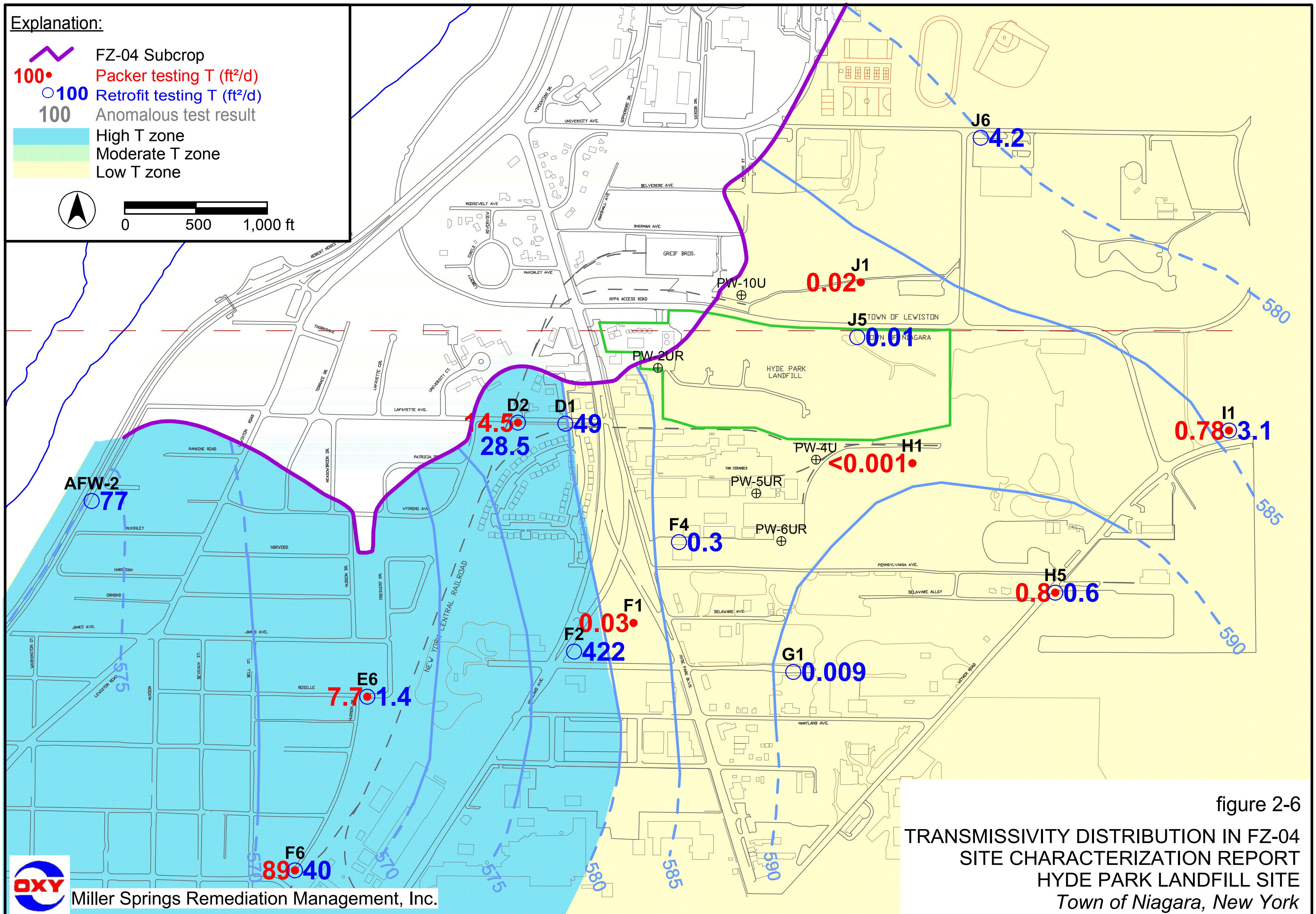
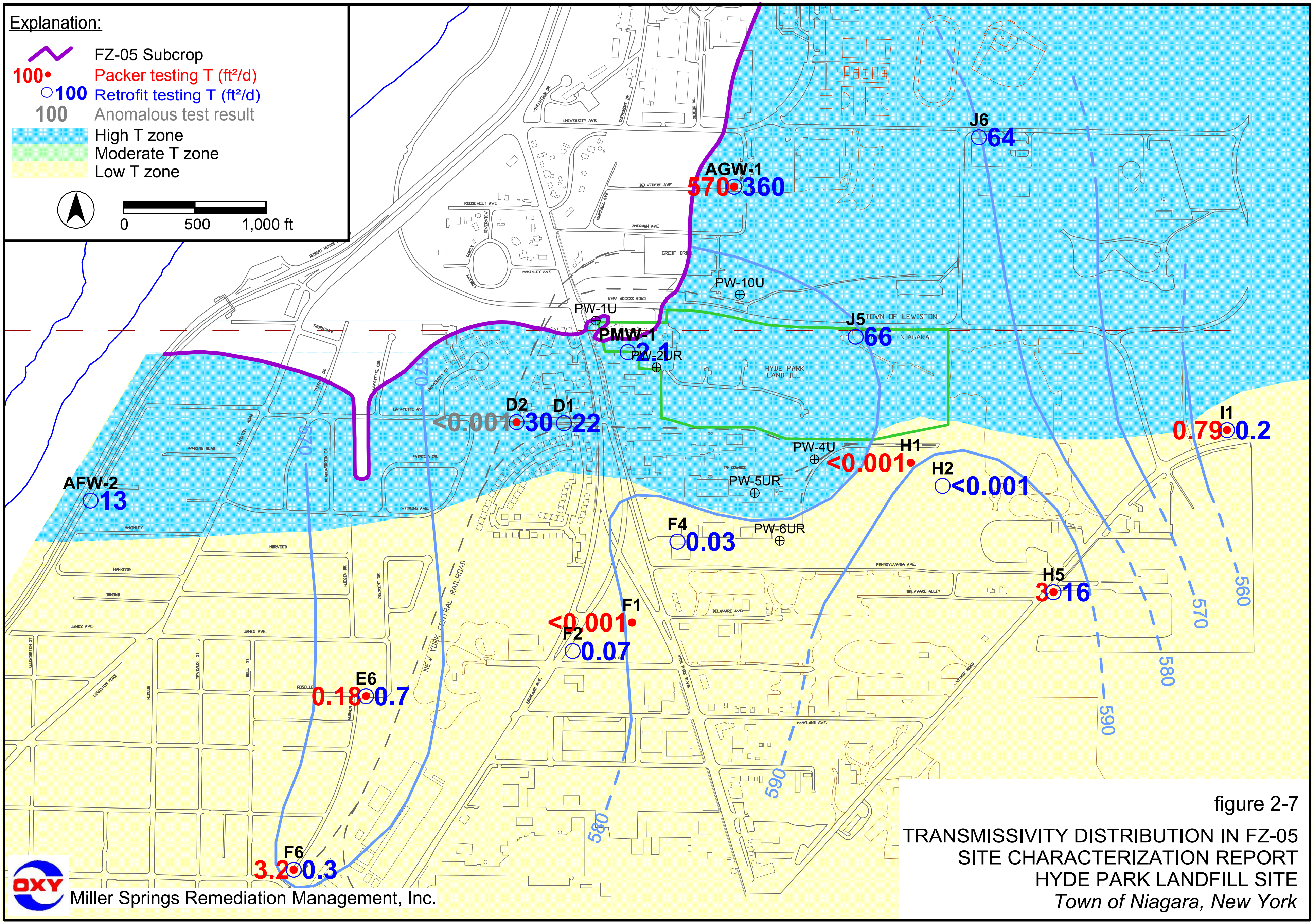


figure 2-6

TRANSMISSIVITY DISTRIBUTION IN FZ-04
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

26-May-2003 R:\ssp610\SCR_Model\Conceptual model\Flow zone transmissivities\Tests in FZ-04.srf



Miller Springs Remediation Management, Inc.

figure 2-7

TRANSMISSIVITY DISTRIBUTION IN FZ-05
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

26-May-2003 R:\ssp610\SCR_Model\Conceptual model\Flow zone transmissivities\Tests in FZ-05.srf

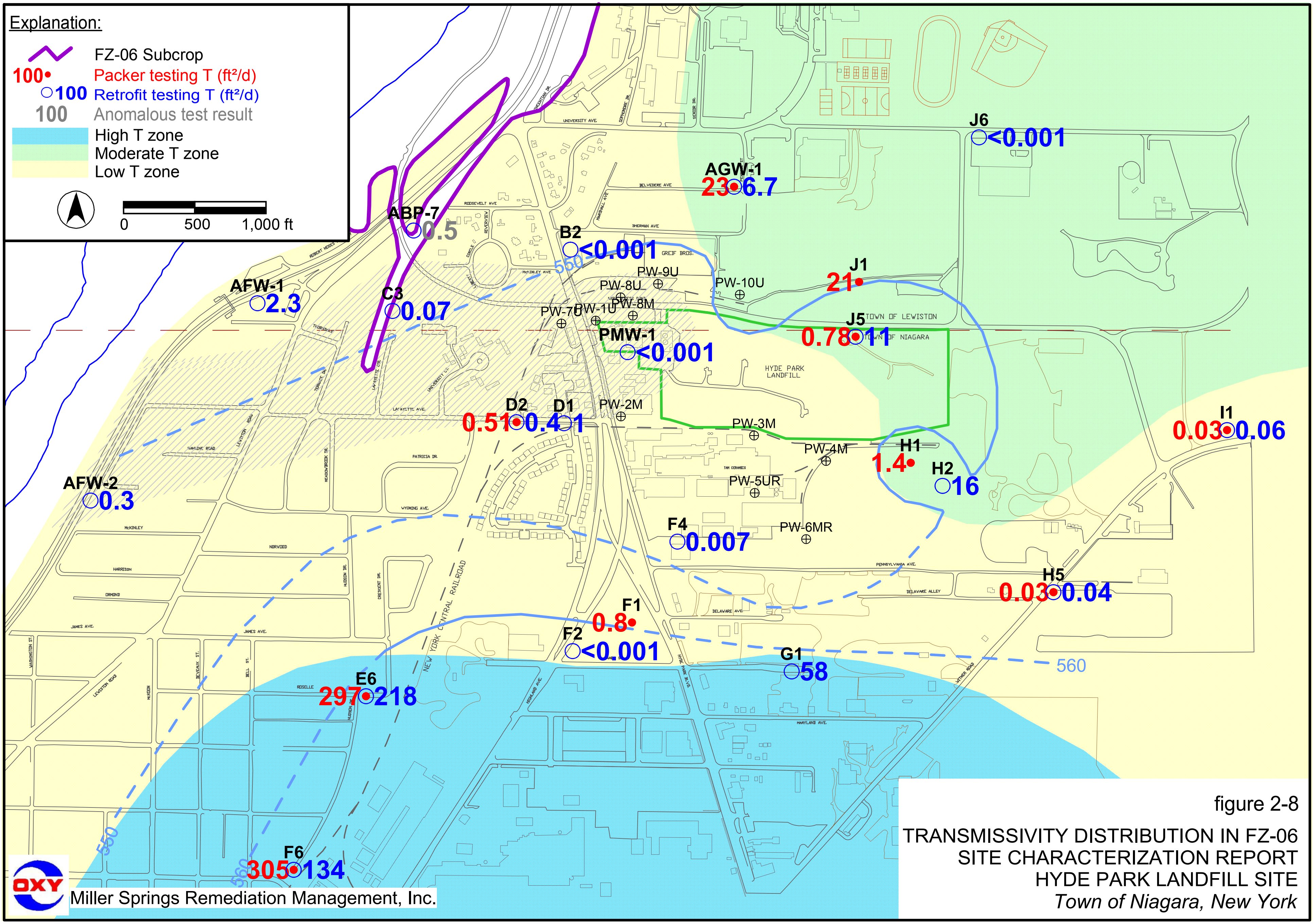


figure 2-8

TRANSMISSIVITY DISTRIBUTION IN FZ-06
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

26-May-2003 R:\ssp610\SCR_Model\Conceptual model\Flow zone transmissivities\Tests in FZ-06.srf

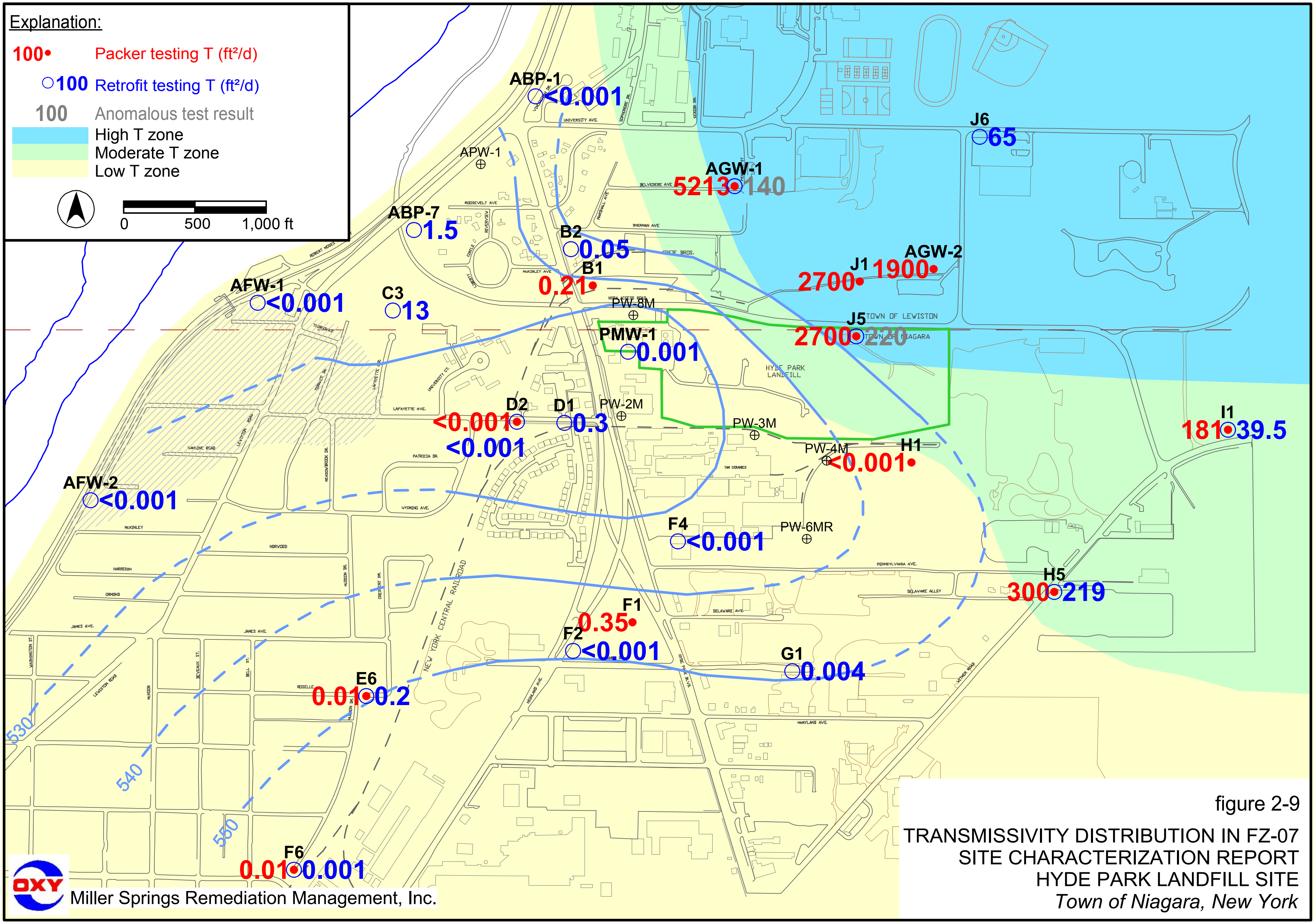
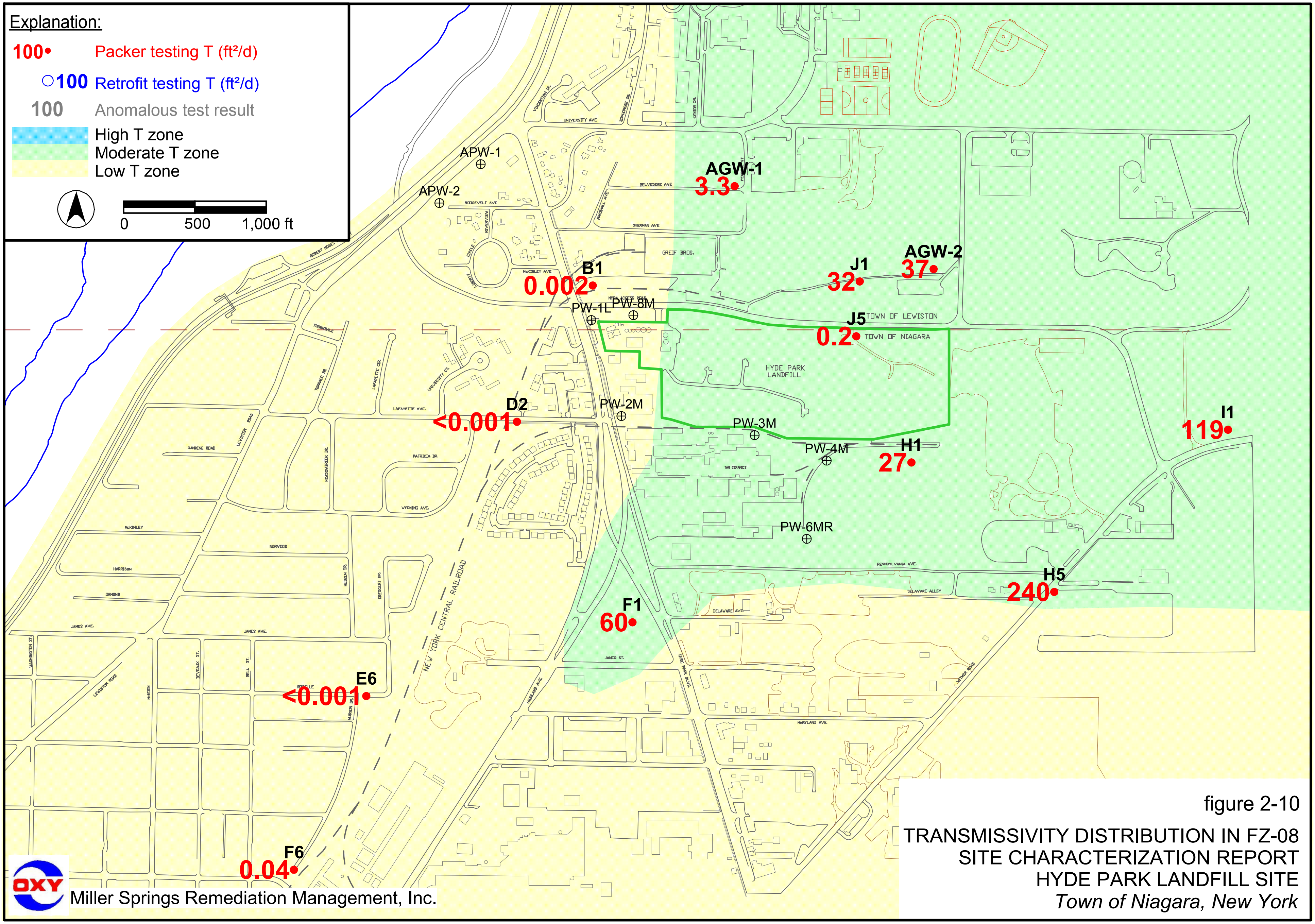


figure 2-9

TRANSMISSIVITY DISTRIBUTION IN FZ-07
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

26-May-2003 R:\ssp610\SCR_Model\Conceptual model\Flow zone transmissivities\Tests in FZ-07.srf


Explanation:
100• Packer testing T (ft²/d)
○100 Retrofit testing T (ft²/d)
100 Anomalous test result
High T zone
Moderate T zone
Low T zone
0
500
1,000 ft
APW-1
APW-2
AGW-1
3.3
AGW-2
37
J1
32
B1
0.002
PW-1L
PW-8M
J5
0.2
TOWN OF LEWISTON
TOWN OF NIAGARA
HYDE PARK LANDFILL
D2
<0.001
PW-2M
PW-3M
PW-4M
H1
27
I1
119
PW-6MR
H5
240
F1
60
E6
<0.001
F6
0.04
NEW YORK CENTRAL RAILROAD
GREIF BROS.
Miller Springs Remediation Management, Inc.
figure 2-10
TRANSMISSIVITY DISTRIBUTION IN FZ-08
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

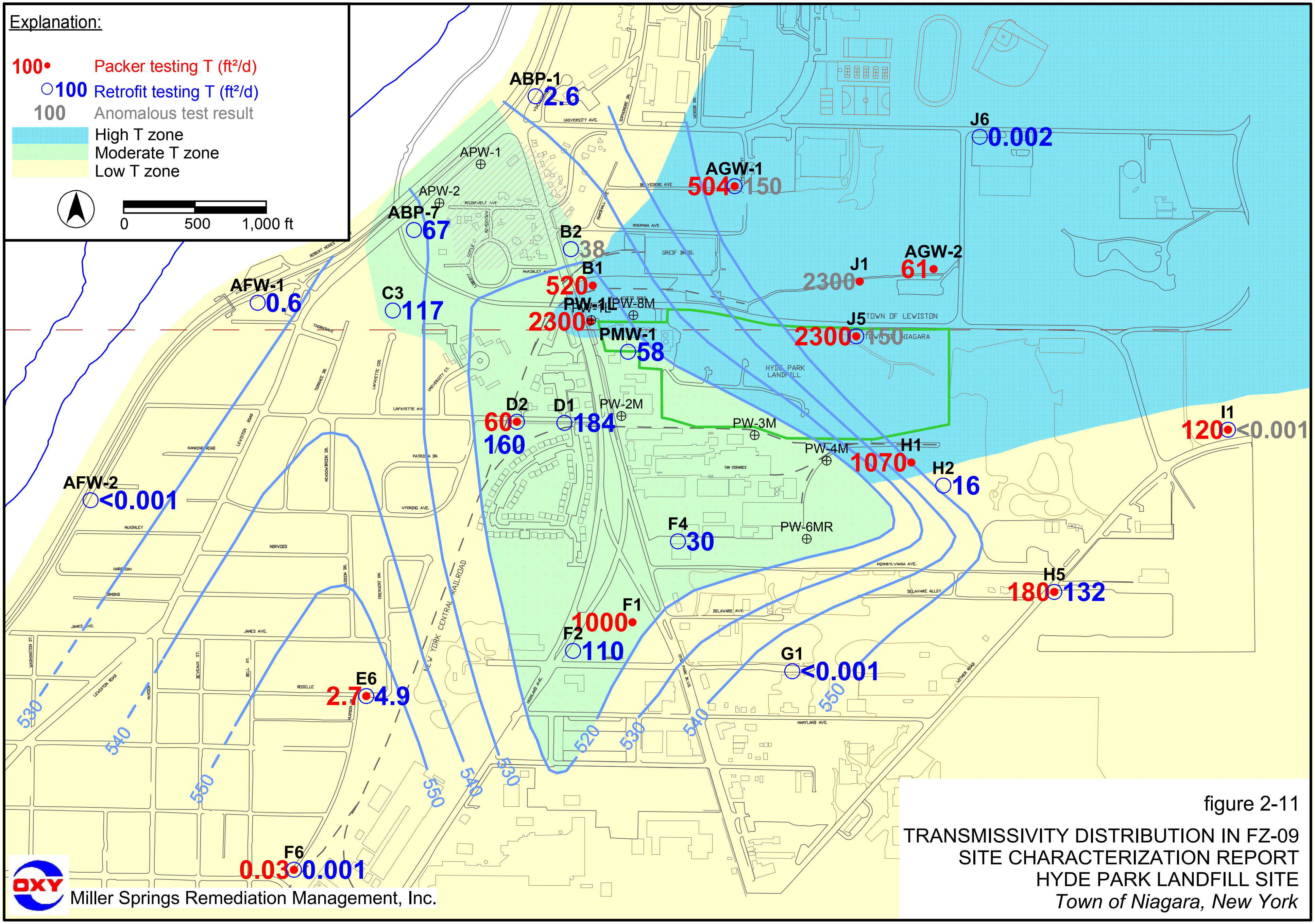


figure 2-11

TRANSMISSIVITY DISTRIBUTION IN FZ-09
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

26-May-2003 R:\ssp610\SCR_Model\Conceptual model\Flow zone transmissivities\Tests in FZ-09.srf

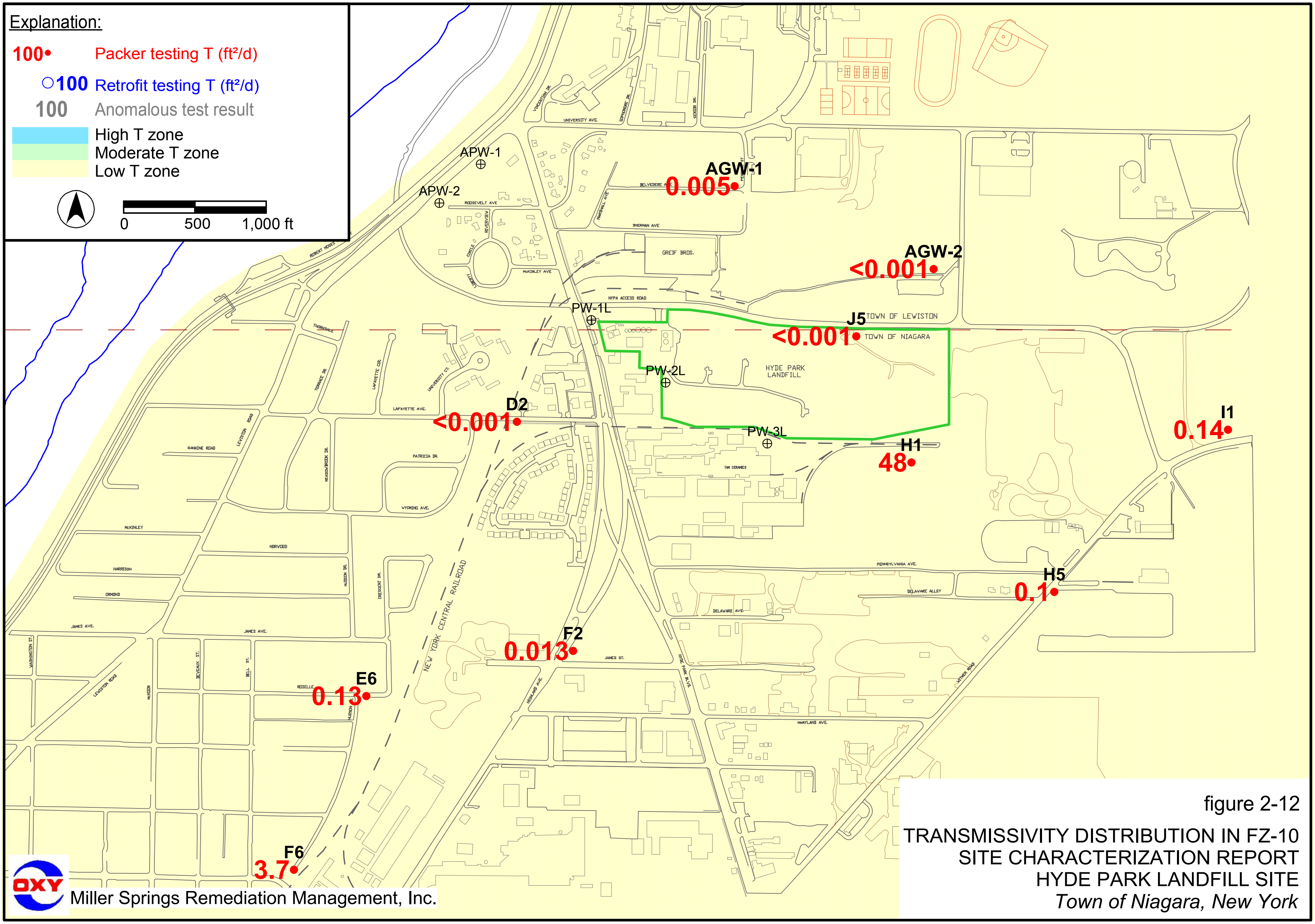


figure 2-12

TRANSMISSIVITY DISTRIBUTION IN FZ-10
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

27-May-2003 R:\ssp610\SCR_Model\Conceptual model\Flow zone transmissivities\Tests in FZ-10.srf

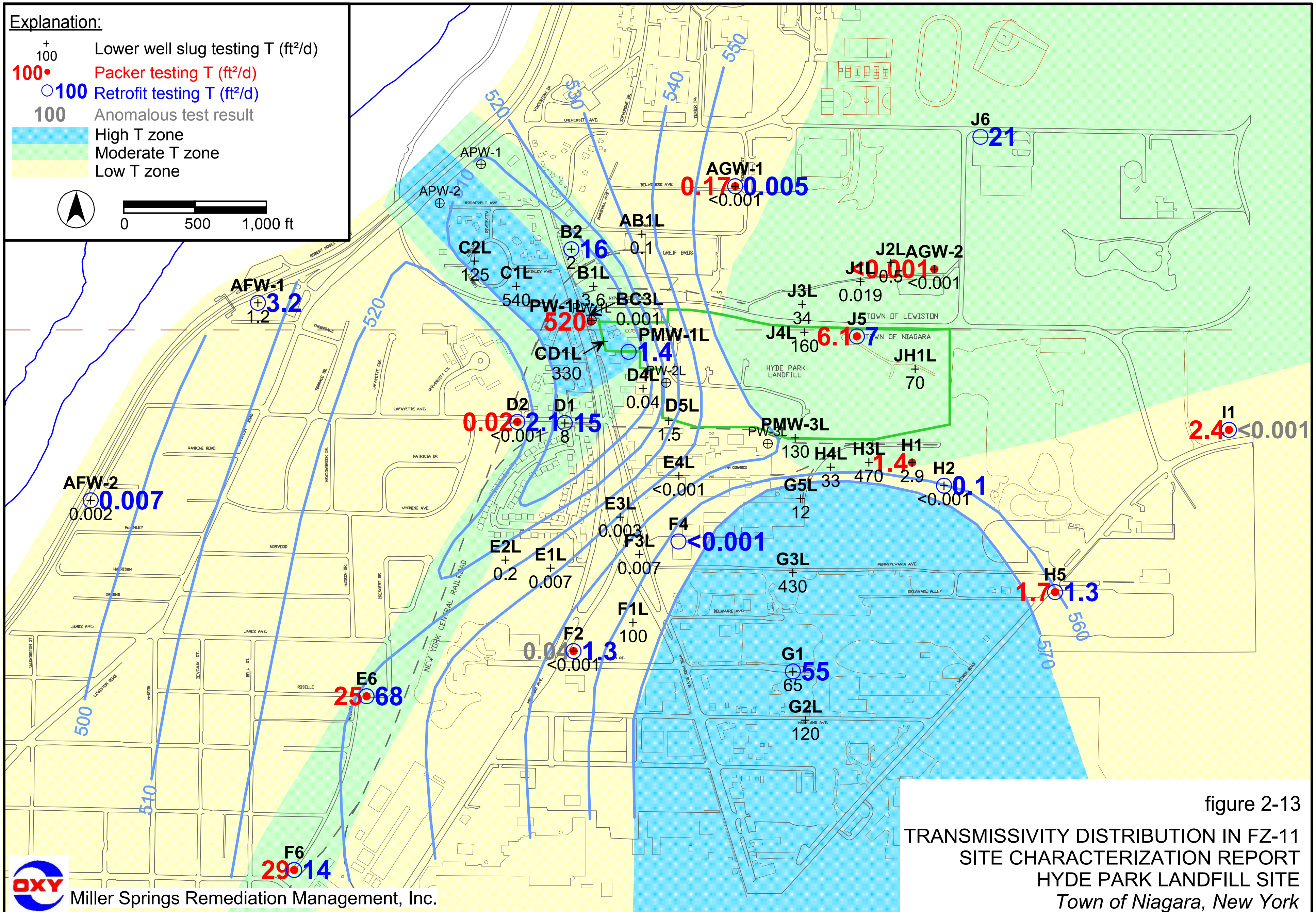


figure 2-13

TRANSMISSIVITY DISTRIBUTION IN FZ-11
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

26-May-2003 R:\ssp610\SCR_Model\Conceptual model\Flow zone transmissivities\Tests in FZ-11.srf

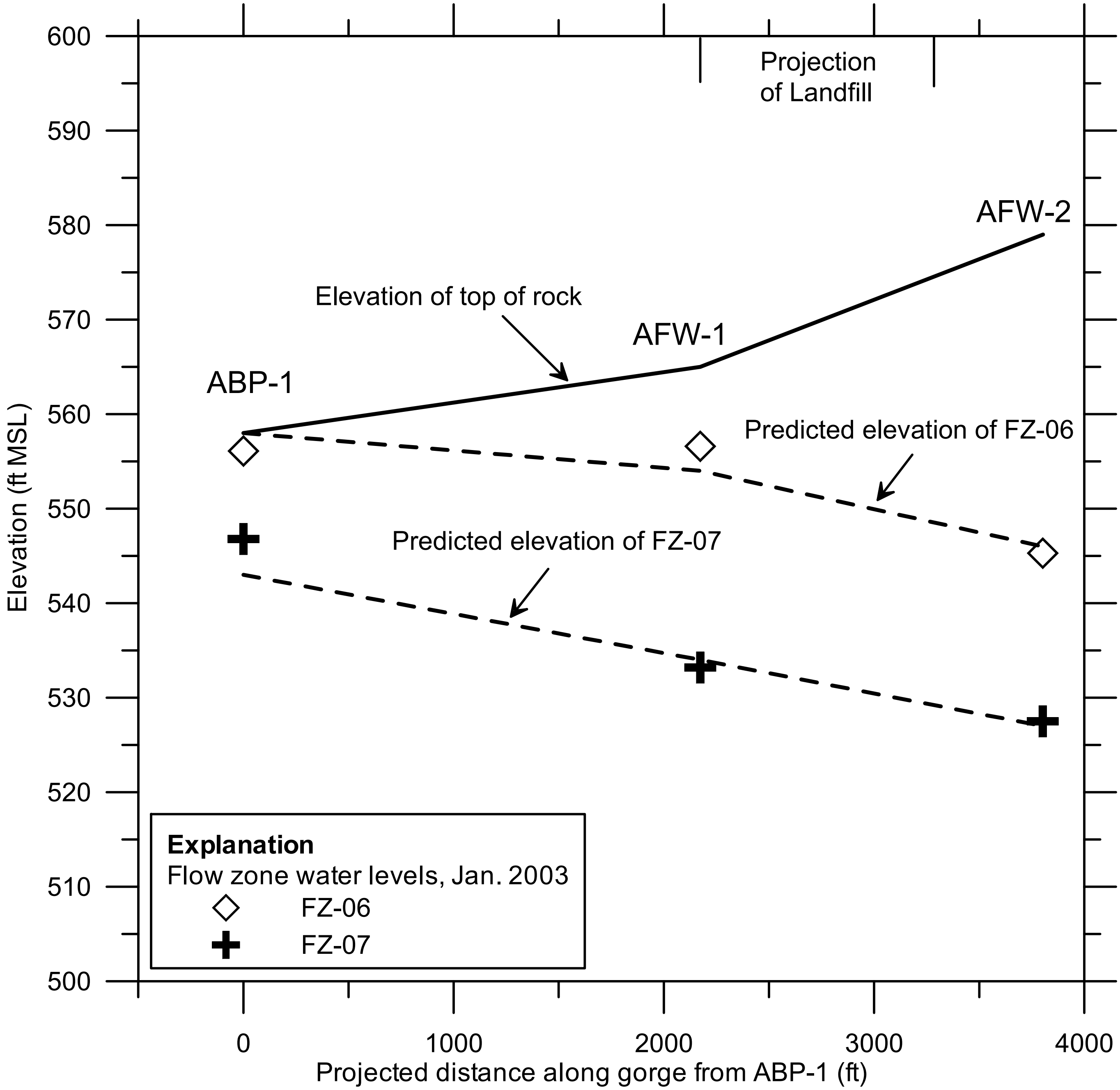


figure 2-14

WATER LEVELS IN FZ-06 AND FZ-07 ALONG THE NIAGARA RIVER GORGE
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management

22-Apr-2003 R:\SSP610\SCR_Model\Conceptual Model\Gorge\FZ water levels.grf

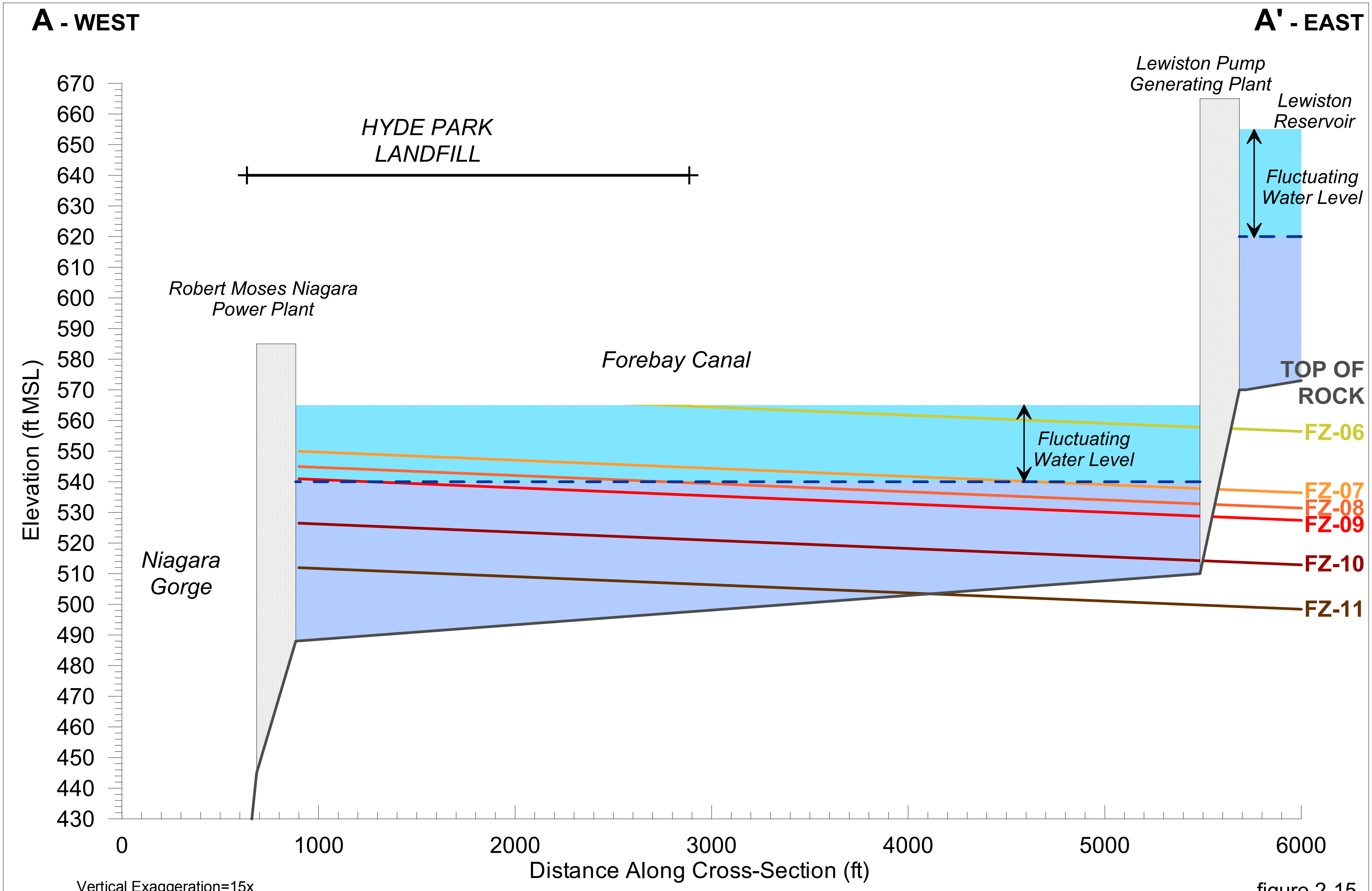


figure 2-15

CROSS-SECTION ALONG NYPA FOREBAY CANAL SHOWING RELATIONSHIP TO ESTIMATED FLOW ZONE LOCATIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 R:\SSP610\SCR_Model\Conceptual Model\FZ Intersecting Boundaries\forebay.grf

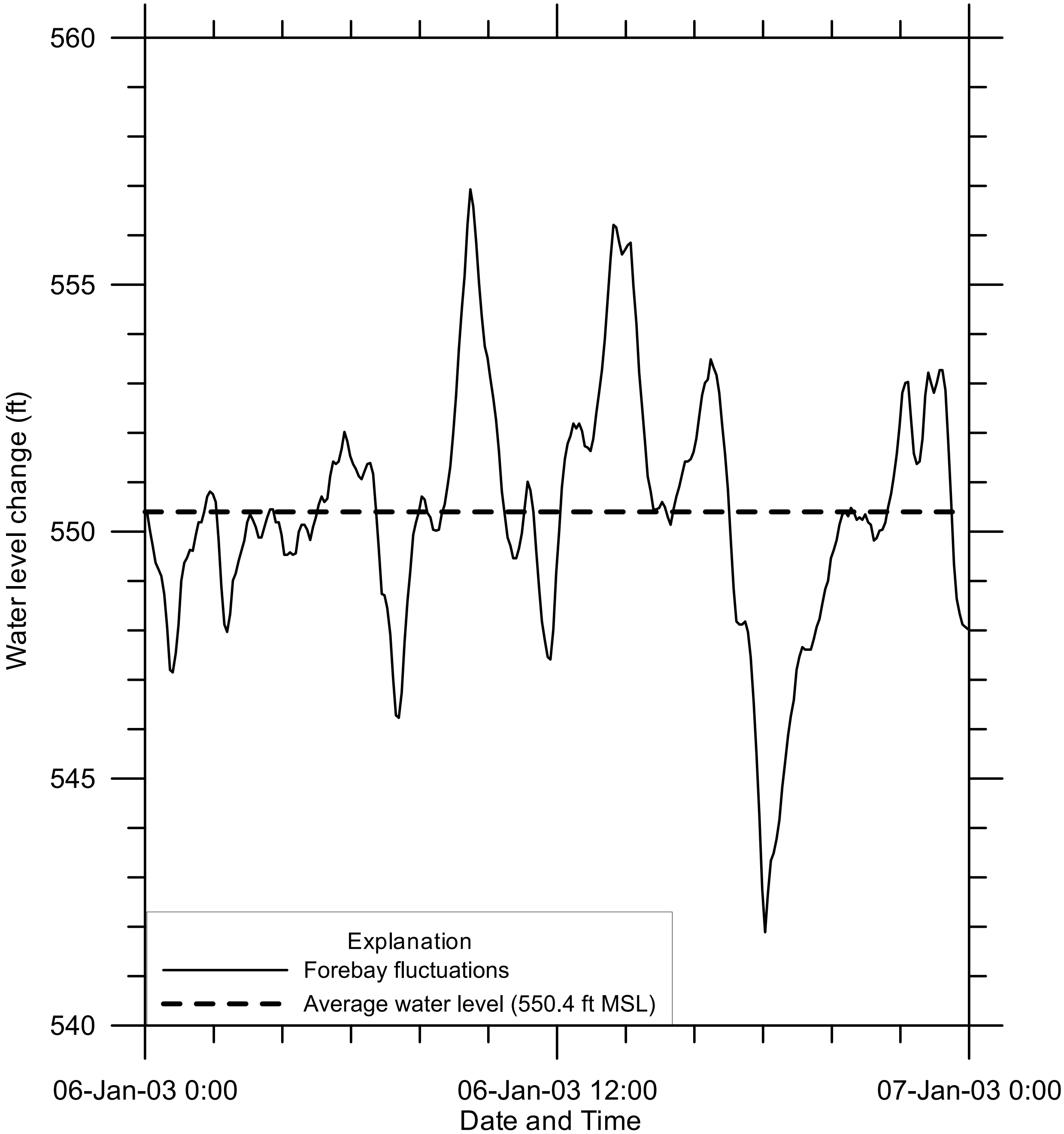


figure 2-16

FOREBAY WATER LEVELS: PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management

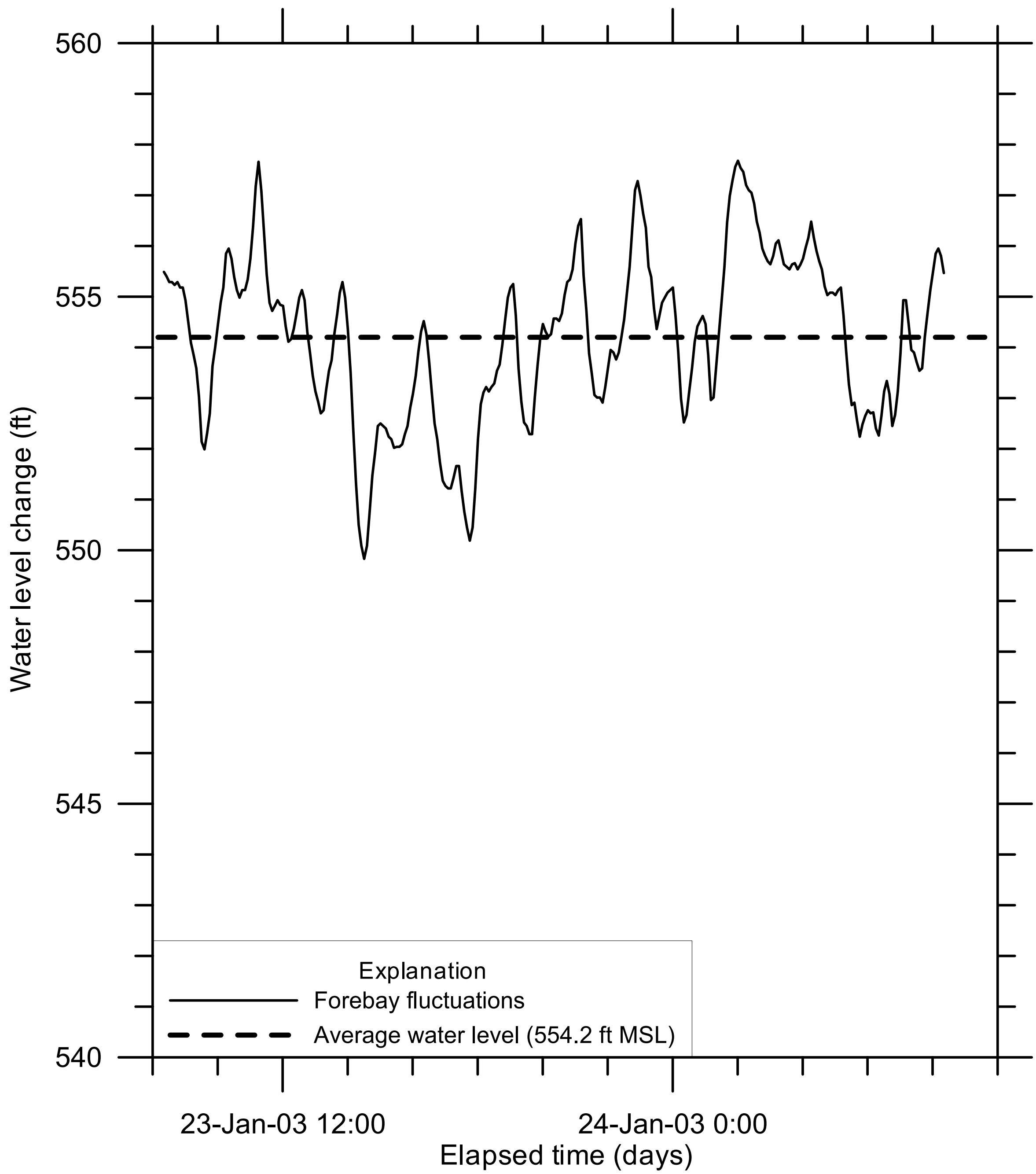


figure 2-17

FOREBAY WATER LEVELS: NON-PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

27-May-2003 R:\SSP-610\SCR_Model\Conceptual Model\Forebay\Water levels\Forebay_non-pumping.grf

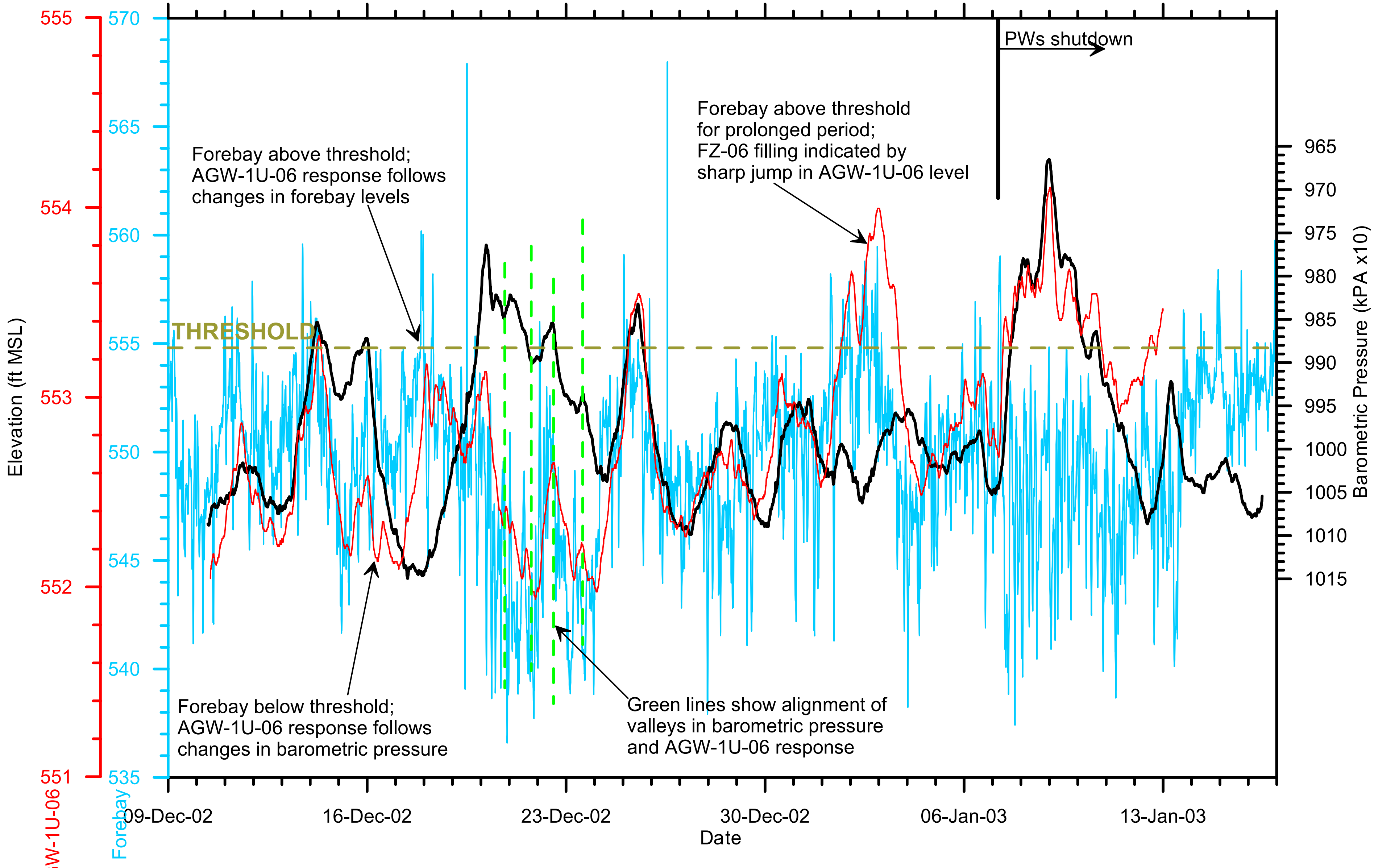


figure 2-18

RESPONSE AT AGW-1U-06 VERSUS NYPA FOREBAY LEVELS AND FLUCTUATIONS IN BAROMETRIC PRESSURE
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

22-Apr-2003 R:\SSP610\SCR_Model\Conceptual Model\Forebay\Water levels\AGW-1U-06_response.grf

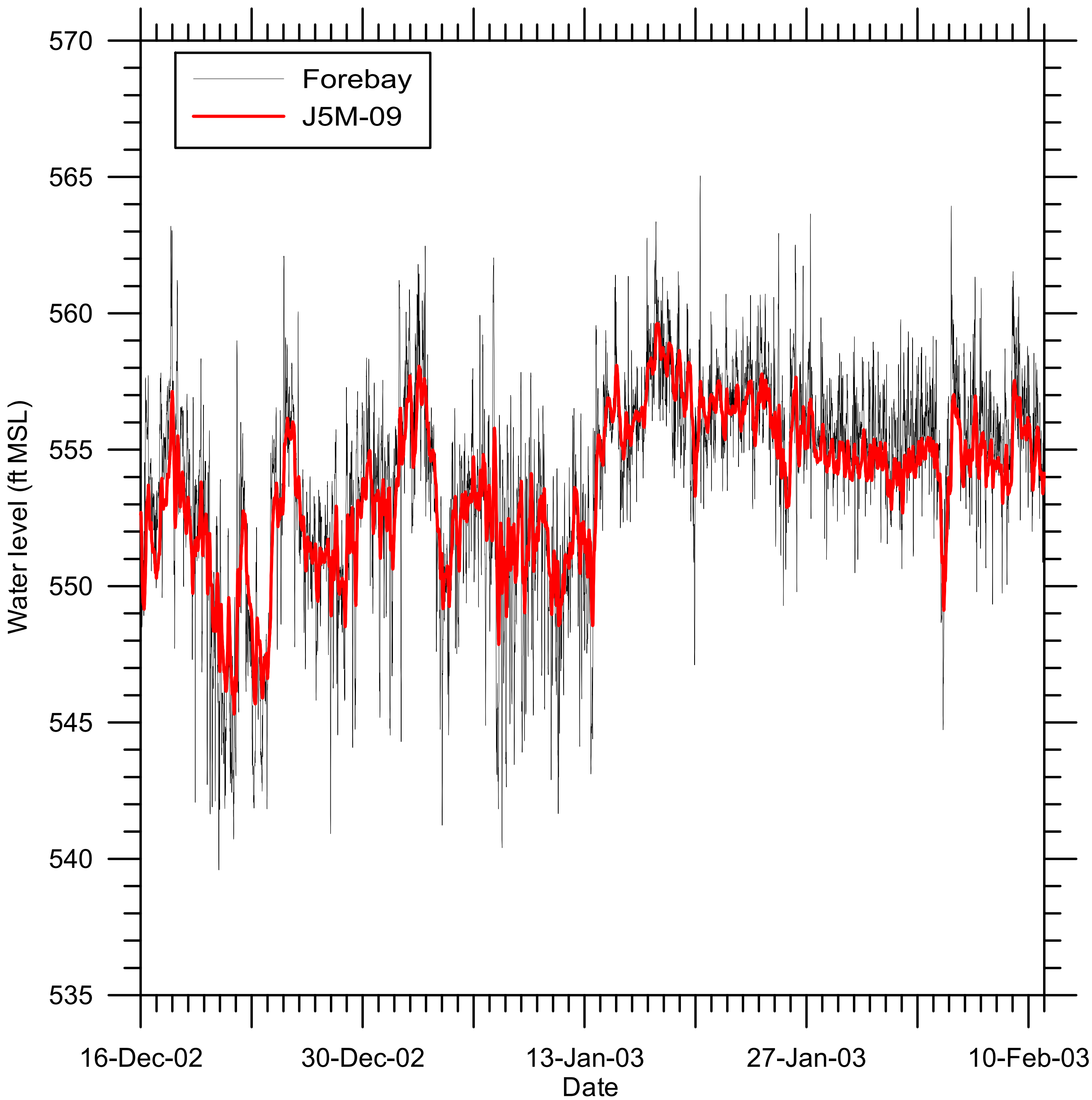


figure 2-19

J5M-09 WATER LEVEL RESPONSE AND NYPA FOREBAY LEVELS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

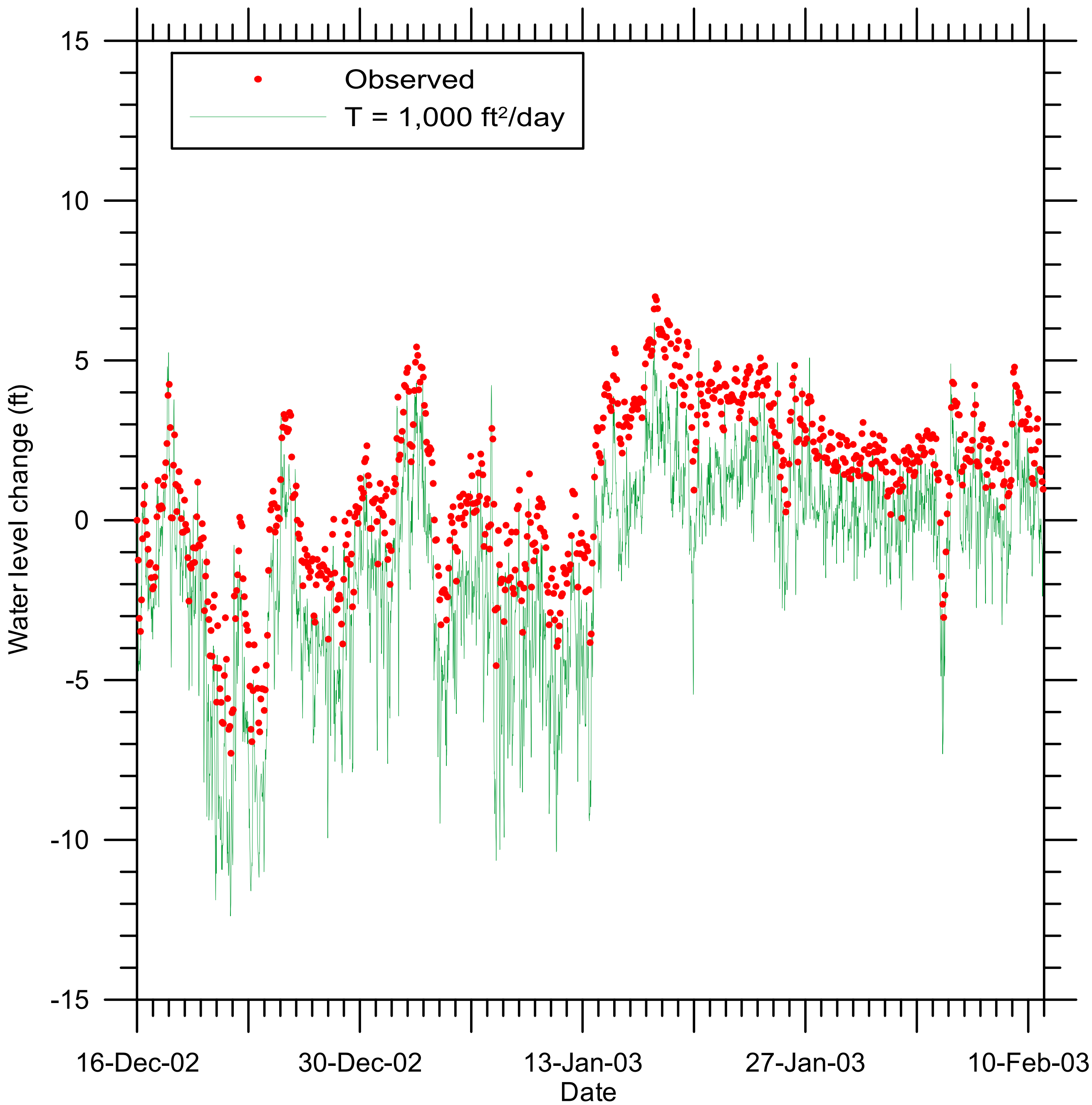


figure 2-20
ANALYSIS OF WATER LEVEL CHANGES AT J5M-09
IN RESPONSE TO NYPA FOREBAY FLUCTUATIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

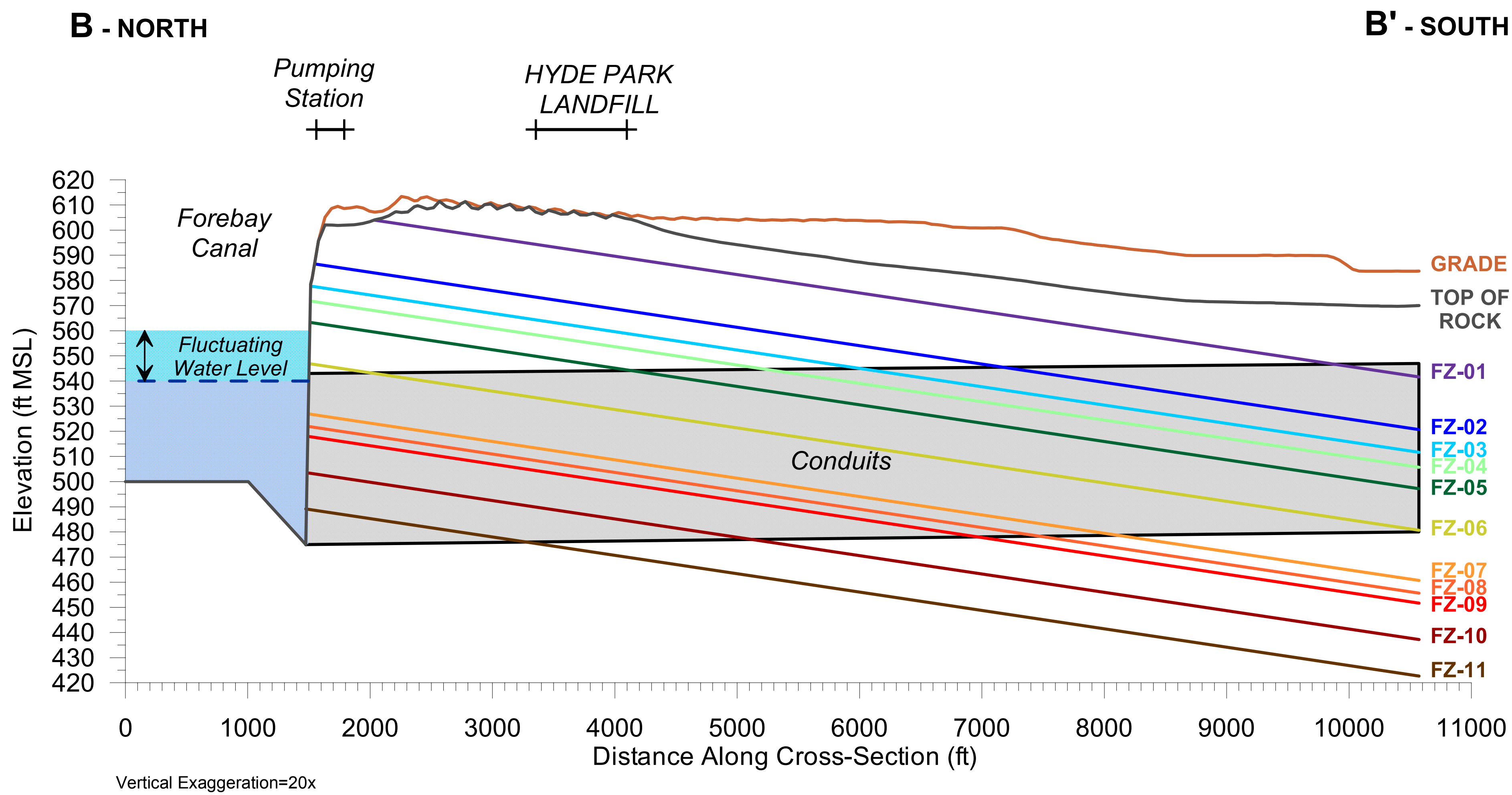
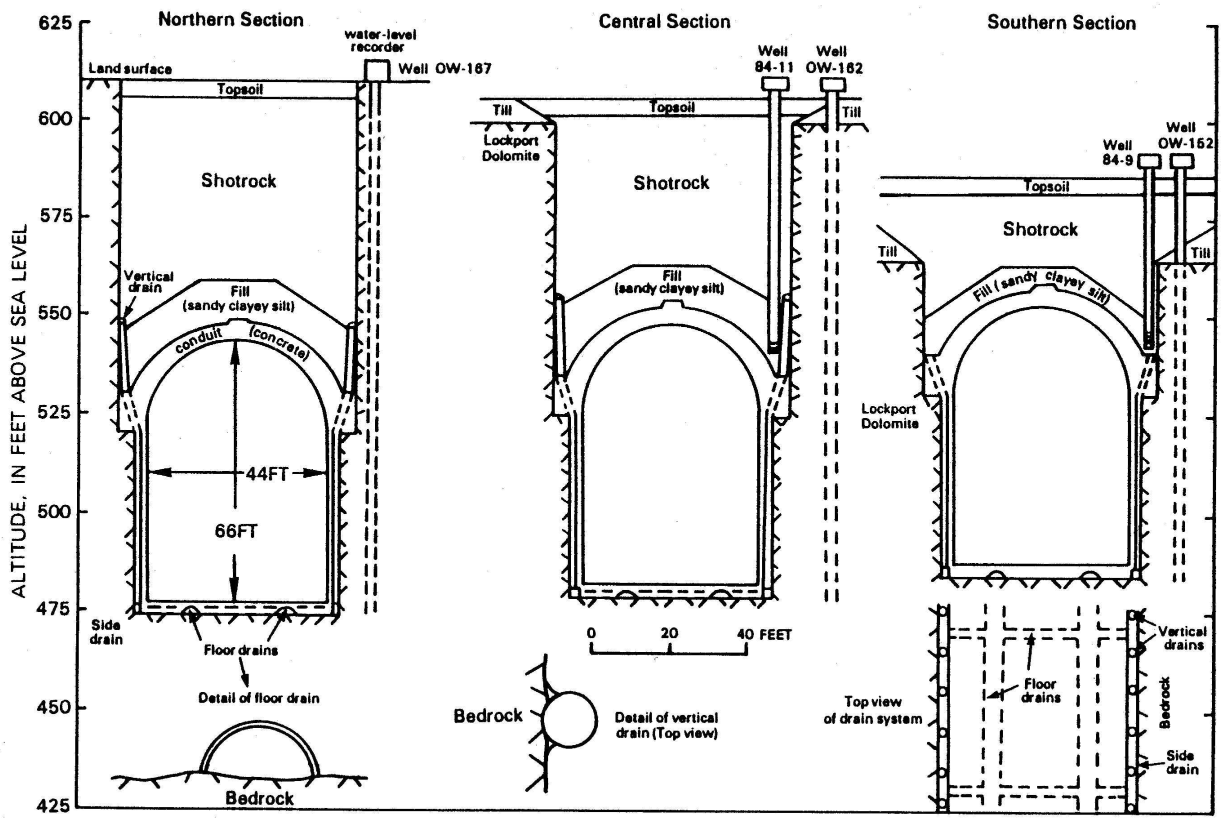


figure 2-21

CROSS-SECTION ALONG NYPA CONDUIT SHOWING PROJECTED ELEVATIONS OF FLOW ZONES
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management

30-Apr-2003 R:\SSP610\SCR_Model\Conceptual Model\FZ Intersecting Boundaries\conduits.grf



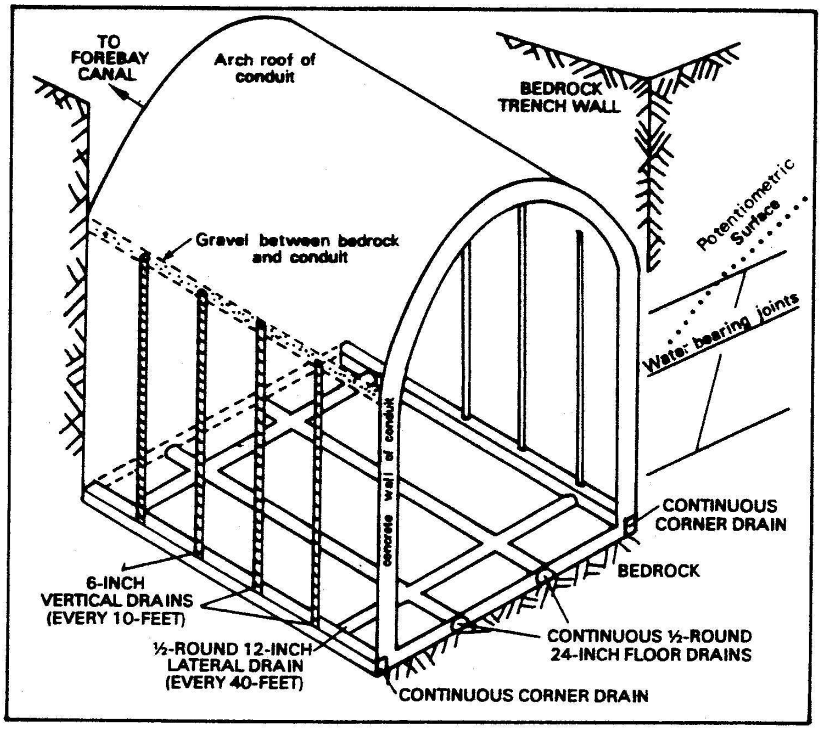
SOURCE: MILLER AND KAPPEL, 1987

figure 2-22A

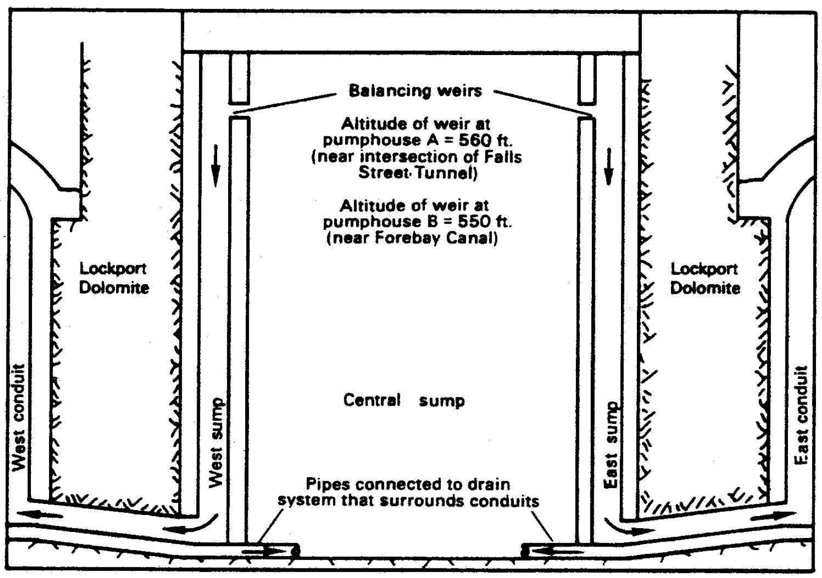
CROSS-SECTIONS OF NYPA CONDUITS WITH GENERALIZED CONSTRUCTION DETAILS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

EXTERIOR DRAIN SYSTEM



PUMPHOUSE



SOURCE: MILLER AND KAPPEL, 1987

figure 2-22B

NYPA CONDUITS - ADDITIONAL CONSTRUCTION DETAILS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

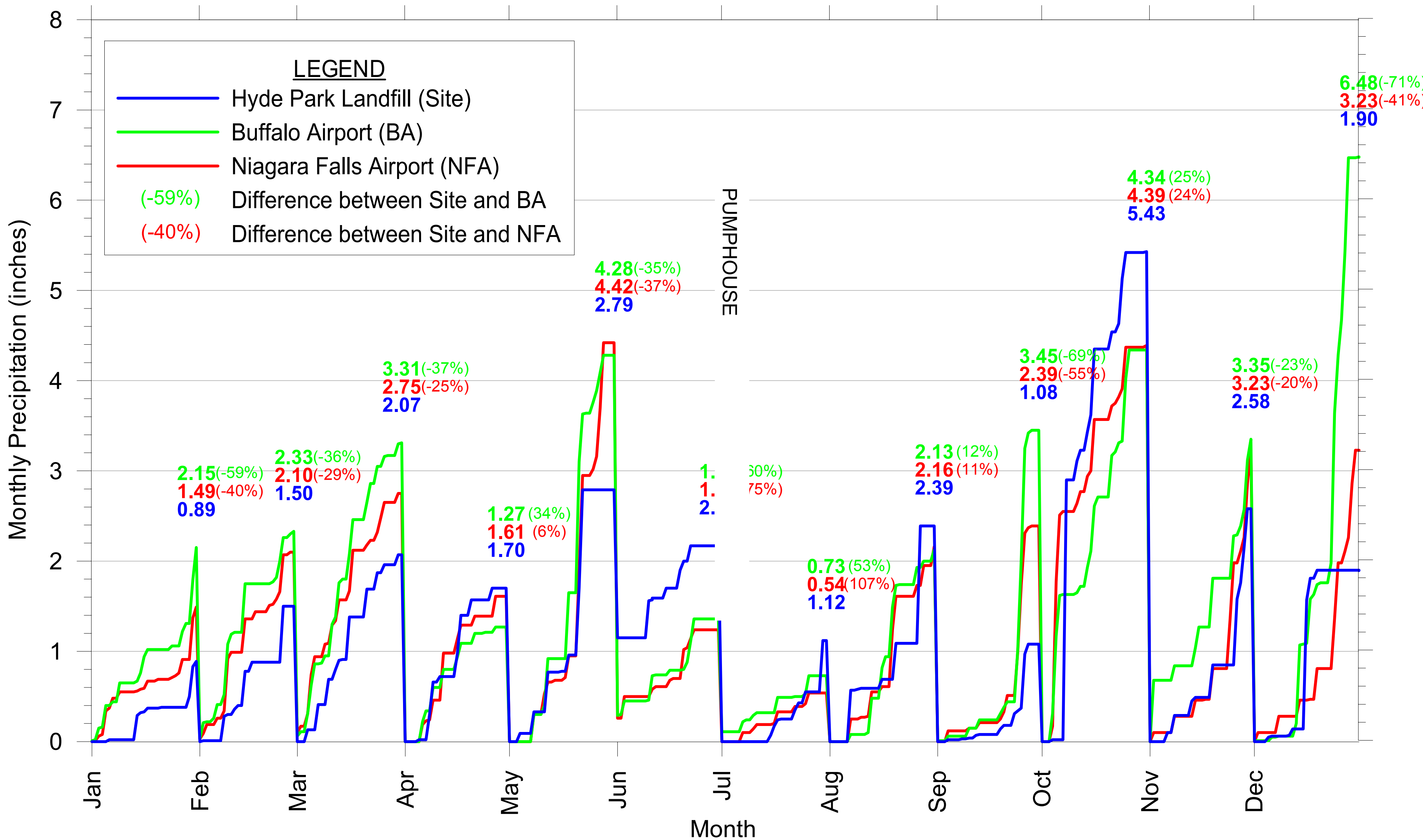


figure 2-23

2001 PRECIPITATION RECORDS FOR HYDE PARK LANDFILL, BUFFALO AIRPORT AND NIAGARA FALLS AIRPORT
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 R:\SSP610\SCR_Model\Conceptual Model\Recharge\site_vs_nfia_and_buff.grf

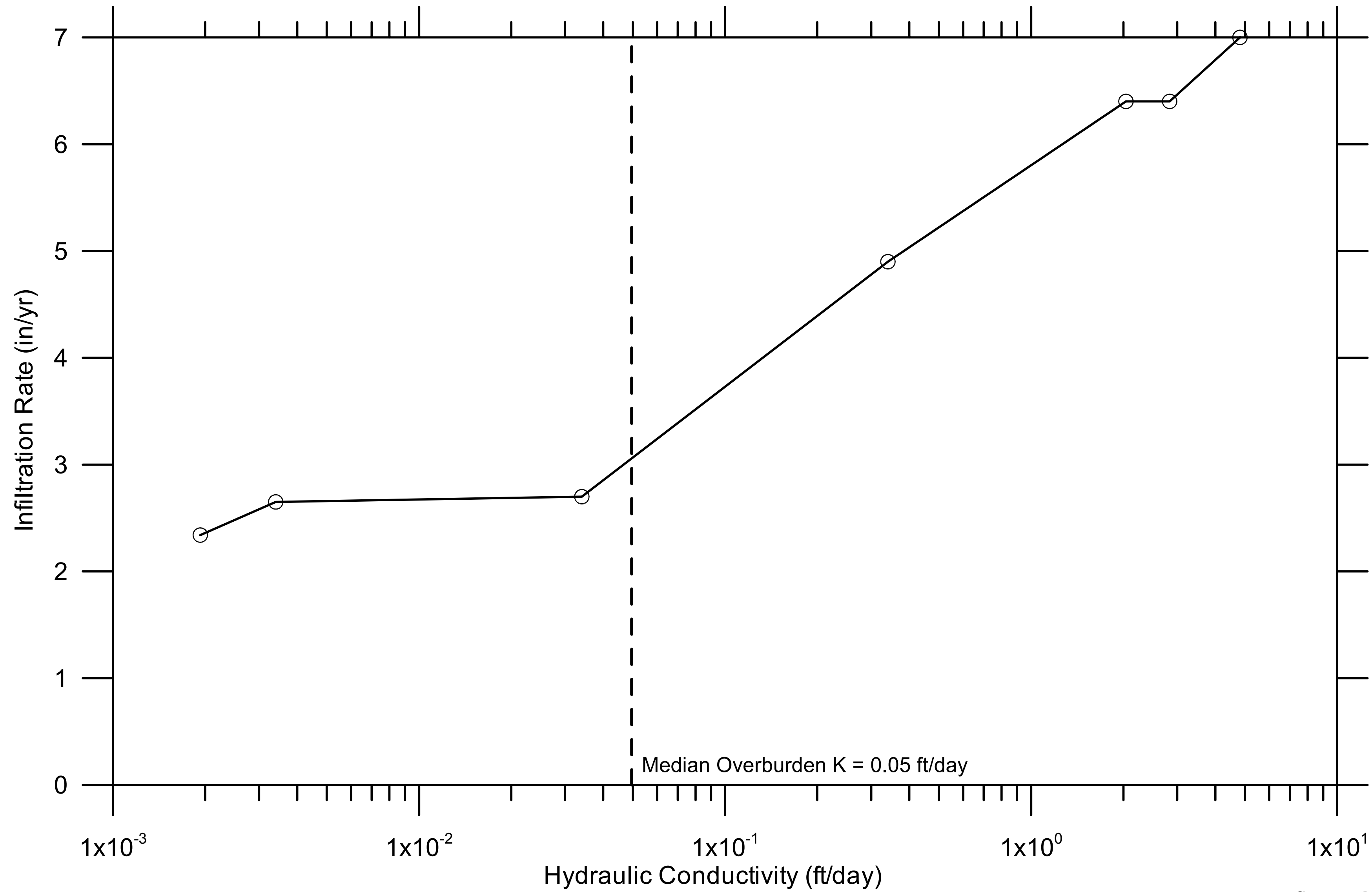


figure 2-24

RESULTS OF HELP SENSITIVITY ANALYSIS FOR INFILTRATION RATE TO BEDROCK
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 R:\ssp610\SCR_Model\Conceptual Model\HELP Analysis\HELP Analysis.grf

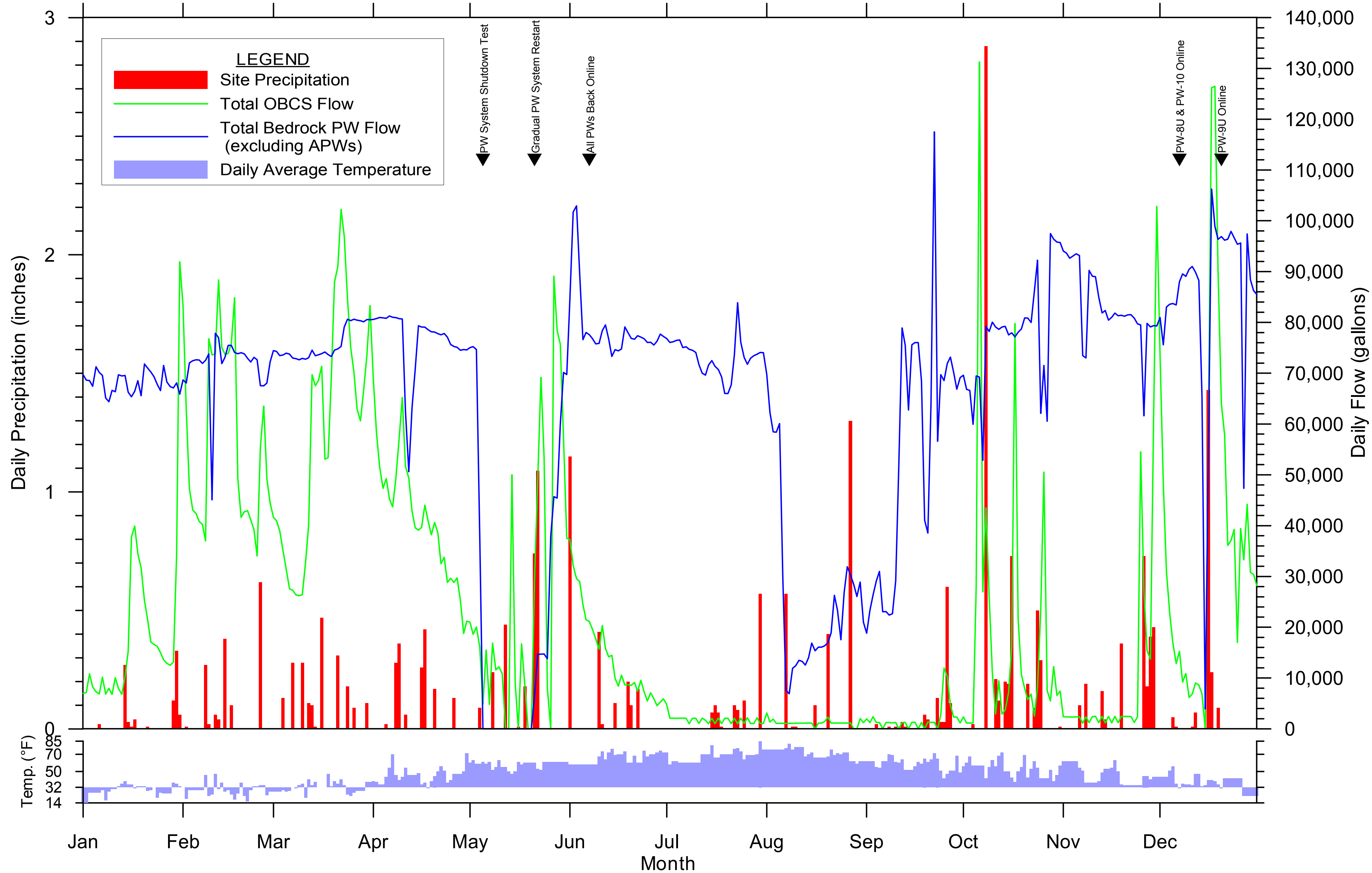


figure 2-25

COMPARISON OF 2001 DAILY PRECIPITATION, OVERBURDEN COLLECTION SYSTEM (OBCS) AND BEDROCK PURGE WELL (PW) FLOWS

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 R:\ssp610\SCR_Model\Conceptual Model\Recharge\precip_vs_site_flows.grf

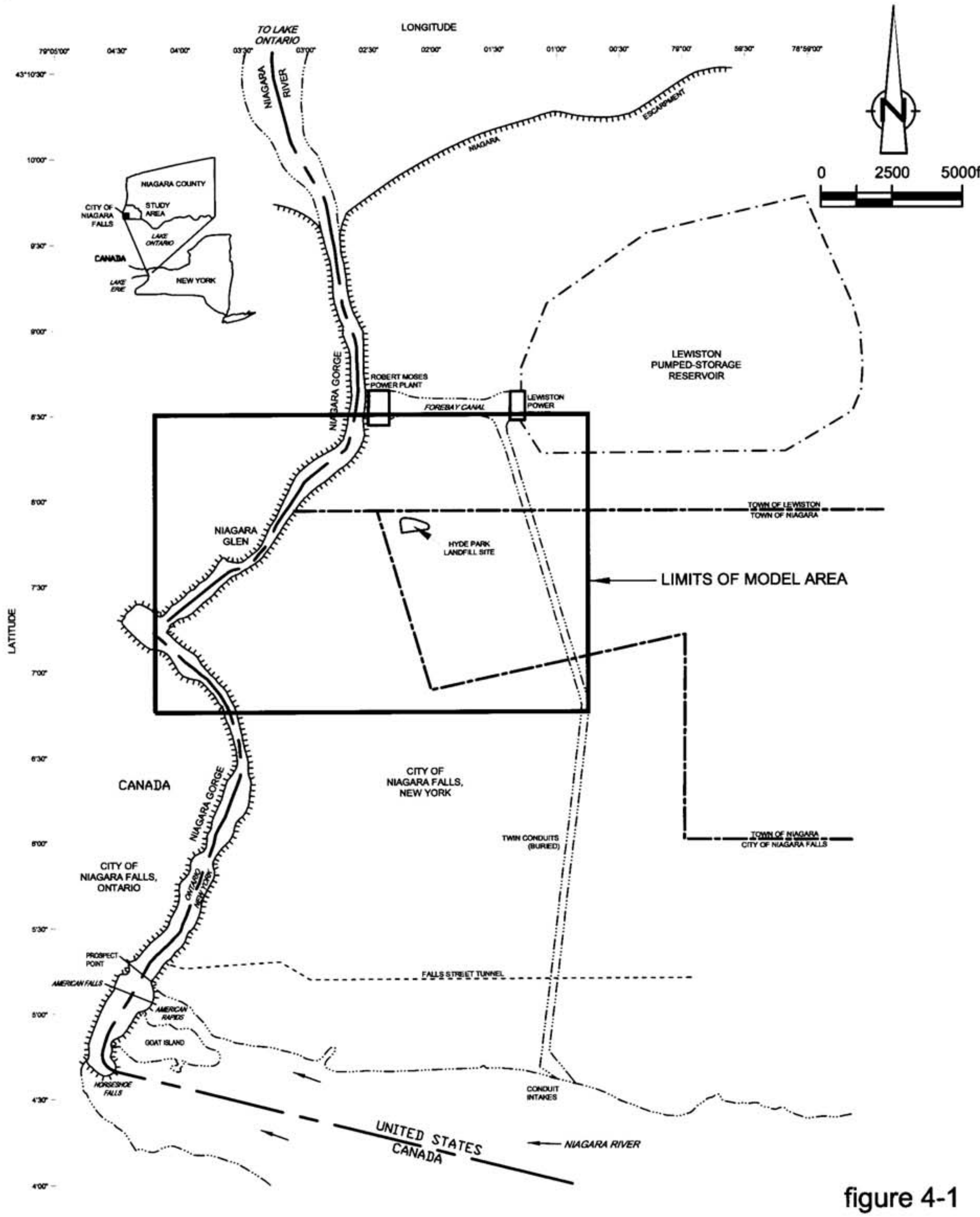


figure 4-1

SOURCE: MILLER AND KAPPEL, 1987

LIMITS OF MODEL AREA
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

01069-30(333)GN-WA002 MAY 30/2003

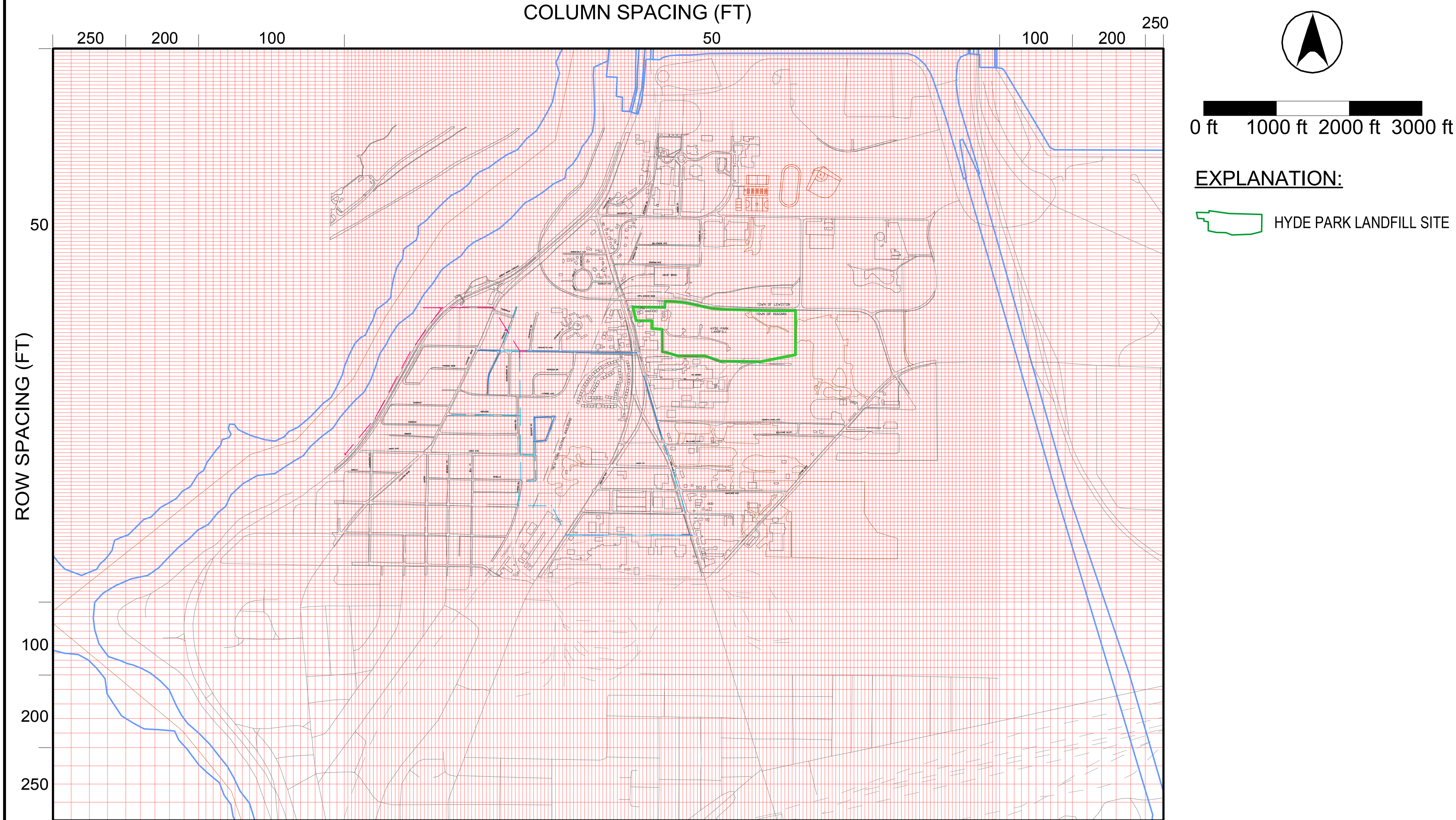


figure 4-2
FINITE-DIFFERENCE GRID
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f04_02_fd_grid.srf

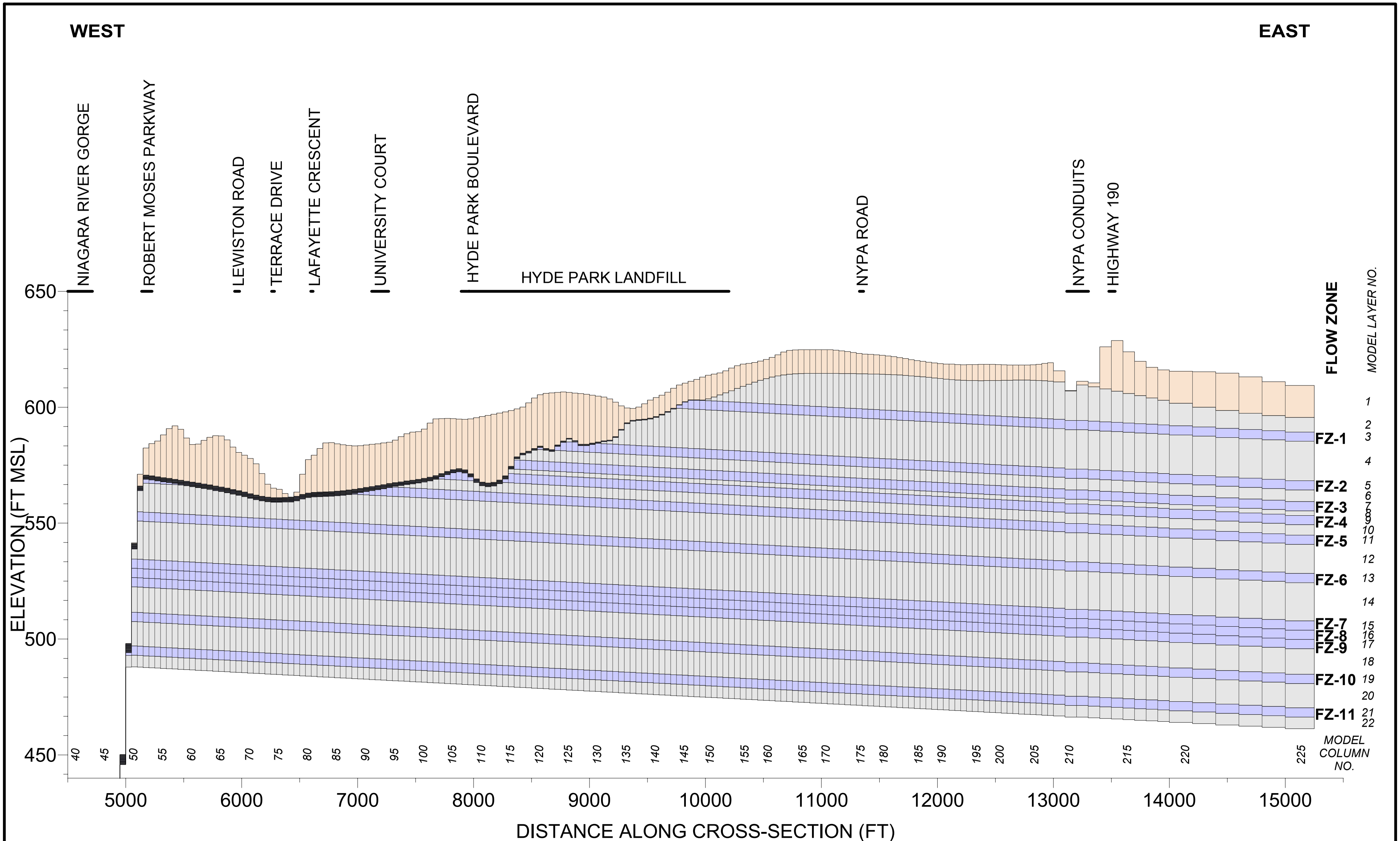


figure 4-3

SCHEMATIC VERTICAL DISCRETIZATION

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f04_03_grid_xsect.srf

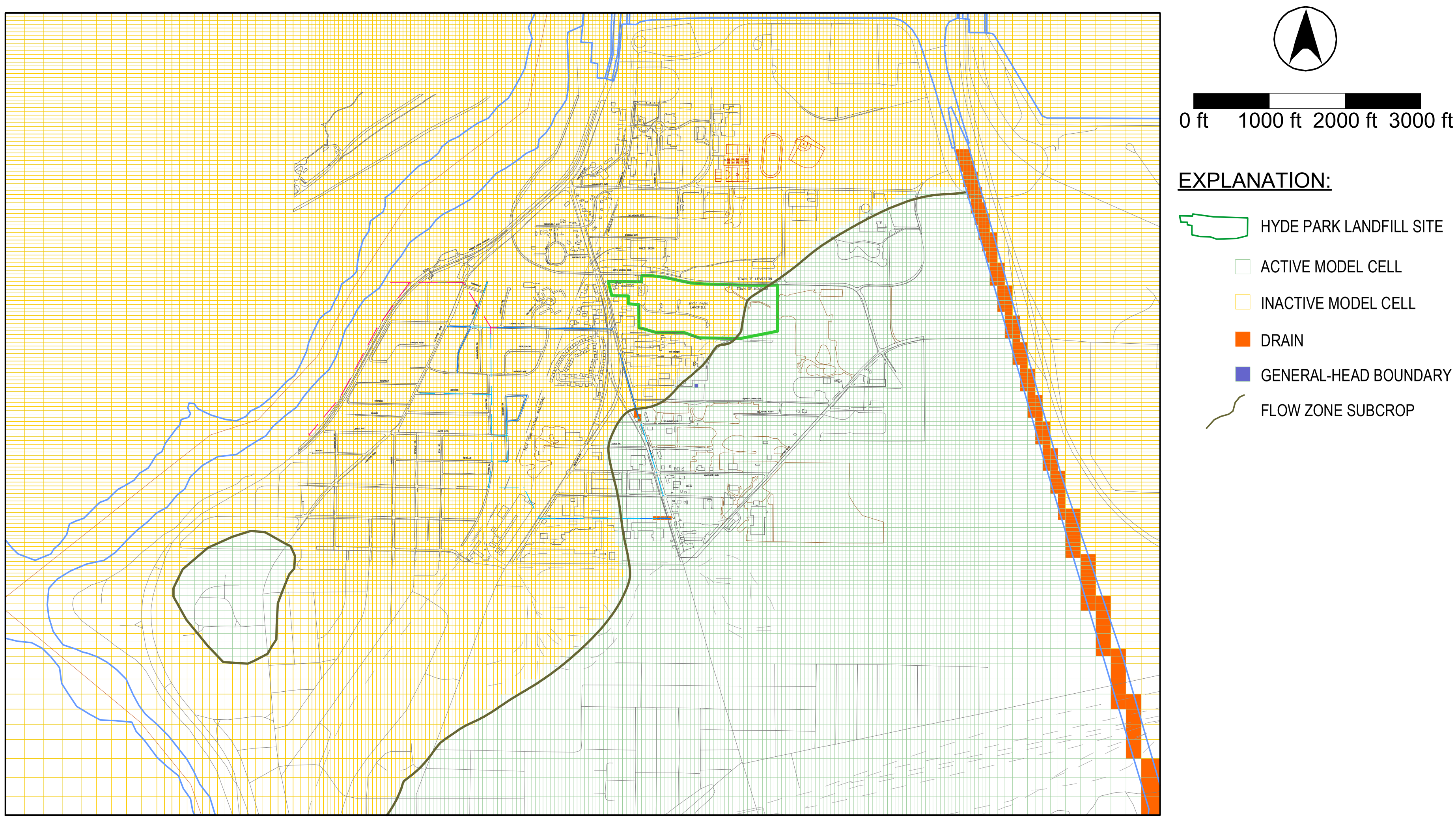


figure 4-4
FLOW ZONE 01 BOUNDARY CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f04_04_fz01_bcs.srf

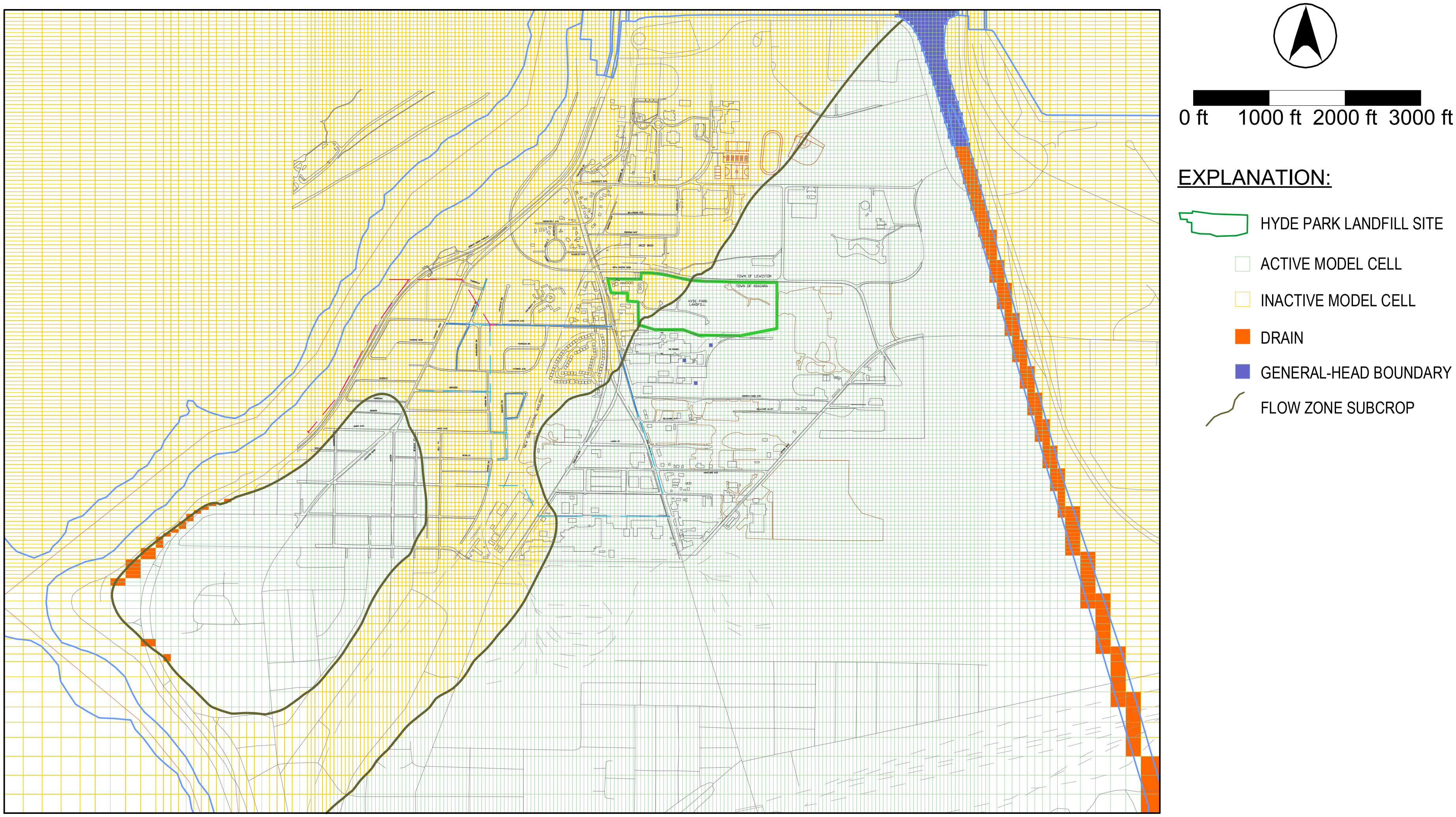


figure 4-5
FLOW ZONE 02 BOUNDARY CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f04_05_fz02_bcs.srf

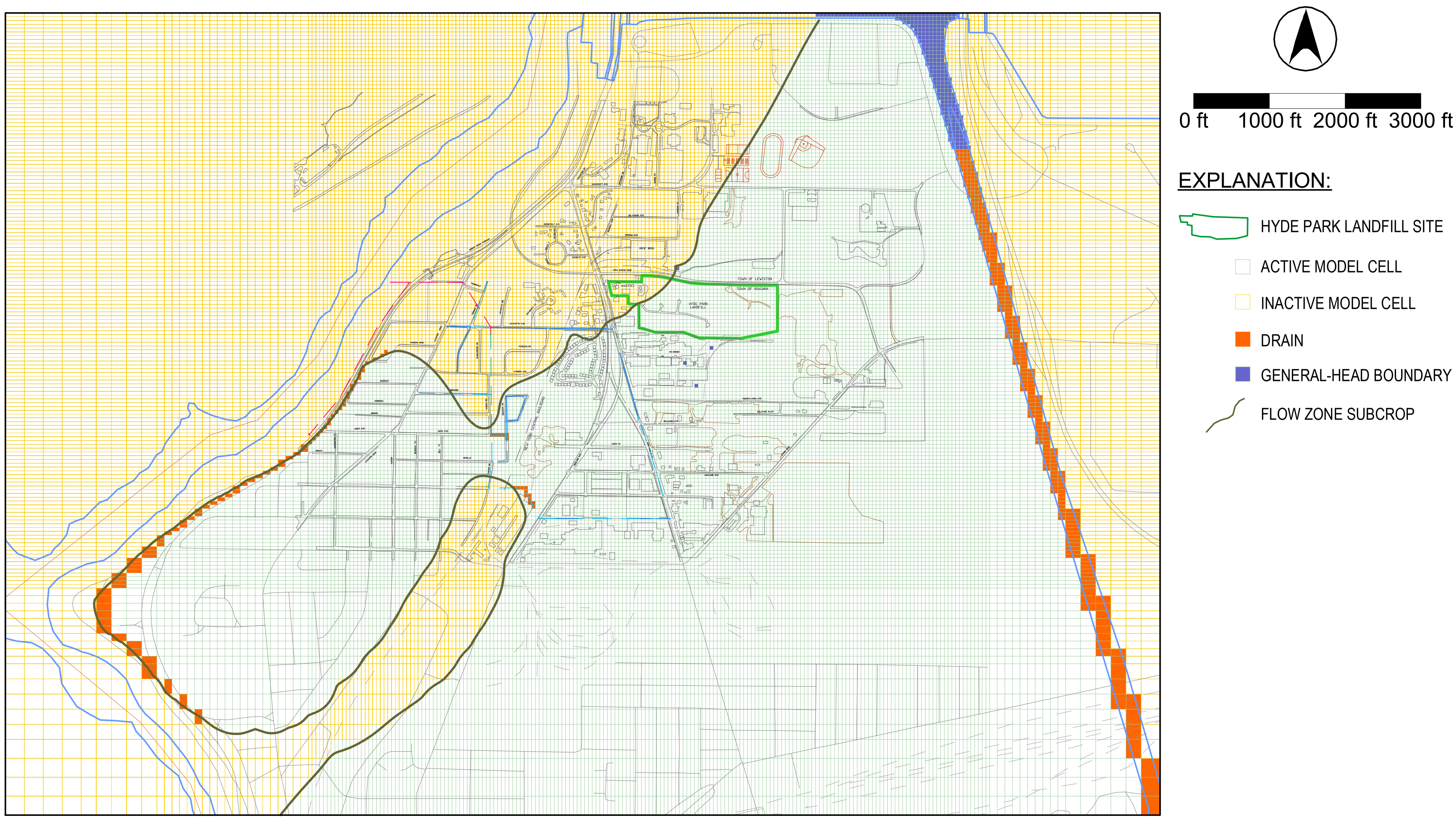


figure 4-6
FLOW ZONE 03 BOUNDARY CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f04_06_fz03_bcs.srf

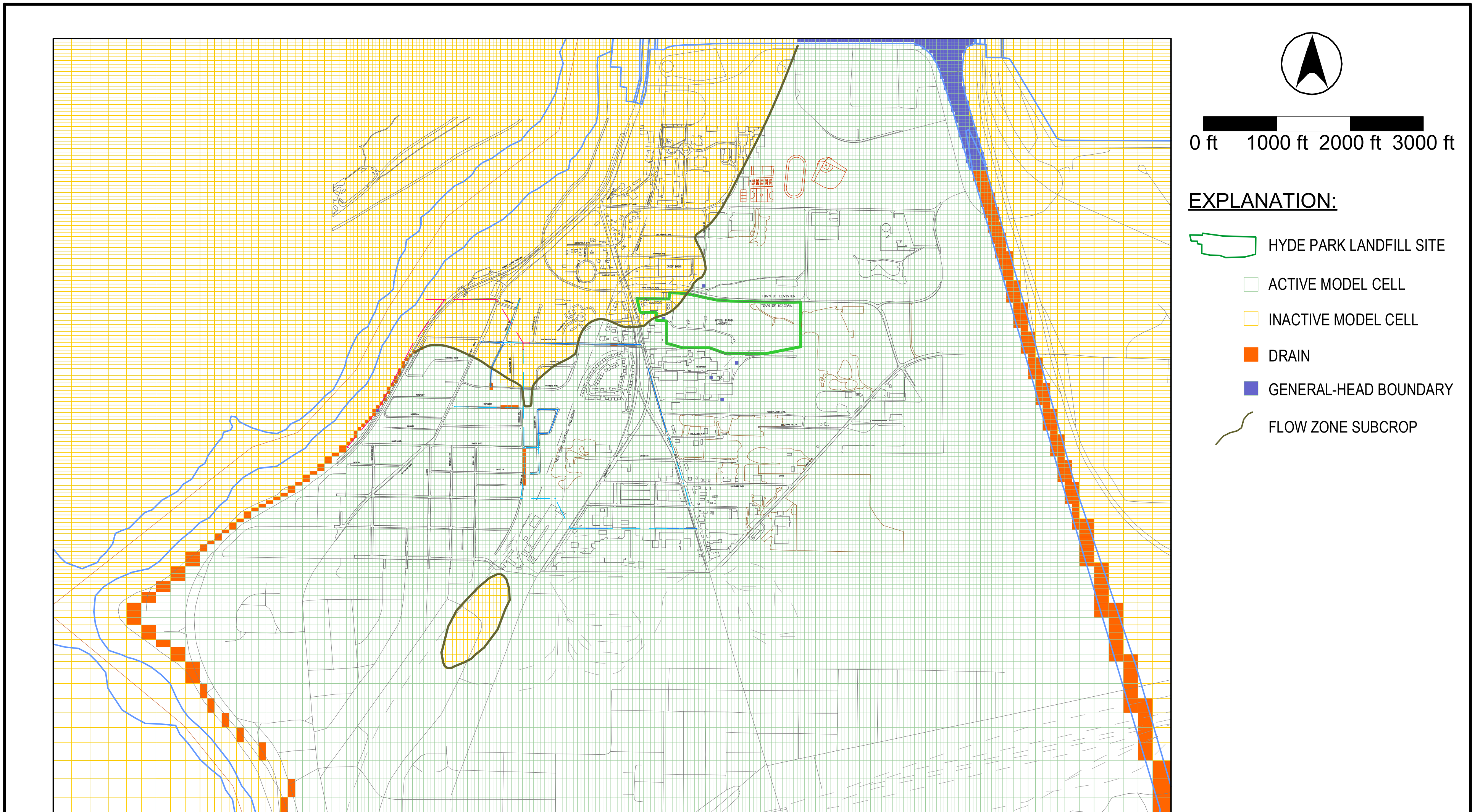


figure 4-7
FLOW ZONE 04 BOUNDARY CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f04_07_fz04_bcs.srf

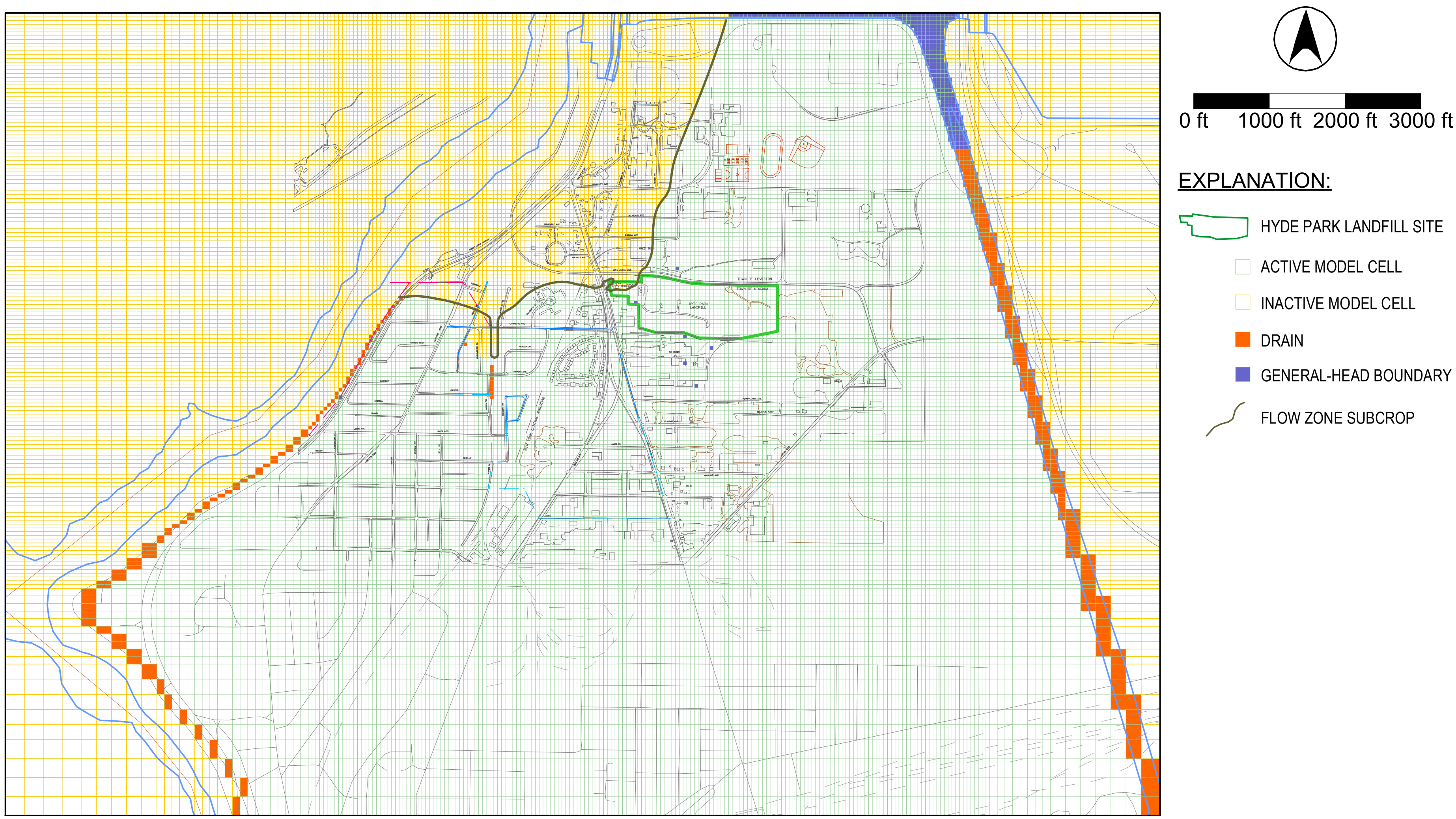


figure 4-8
FLOW ZONE 05 BOUNDARY CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f04_08_fz05_bcs.srf

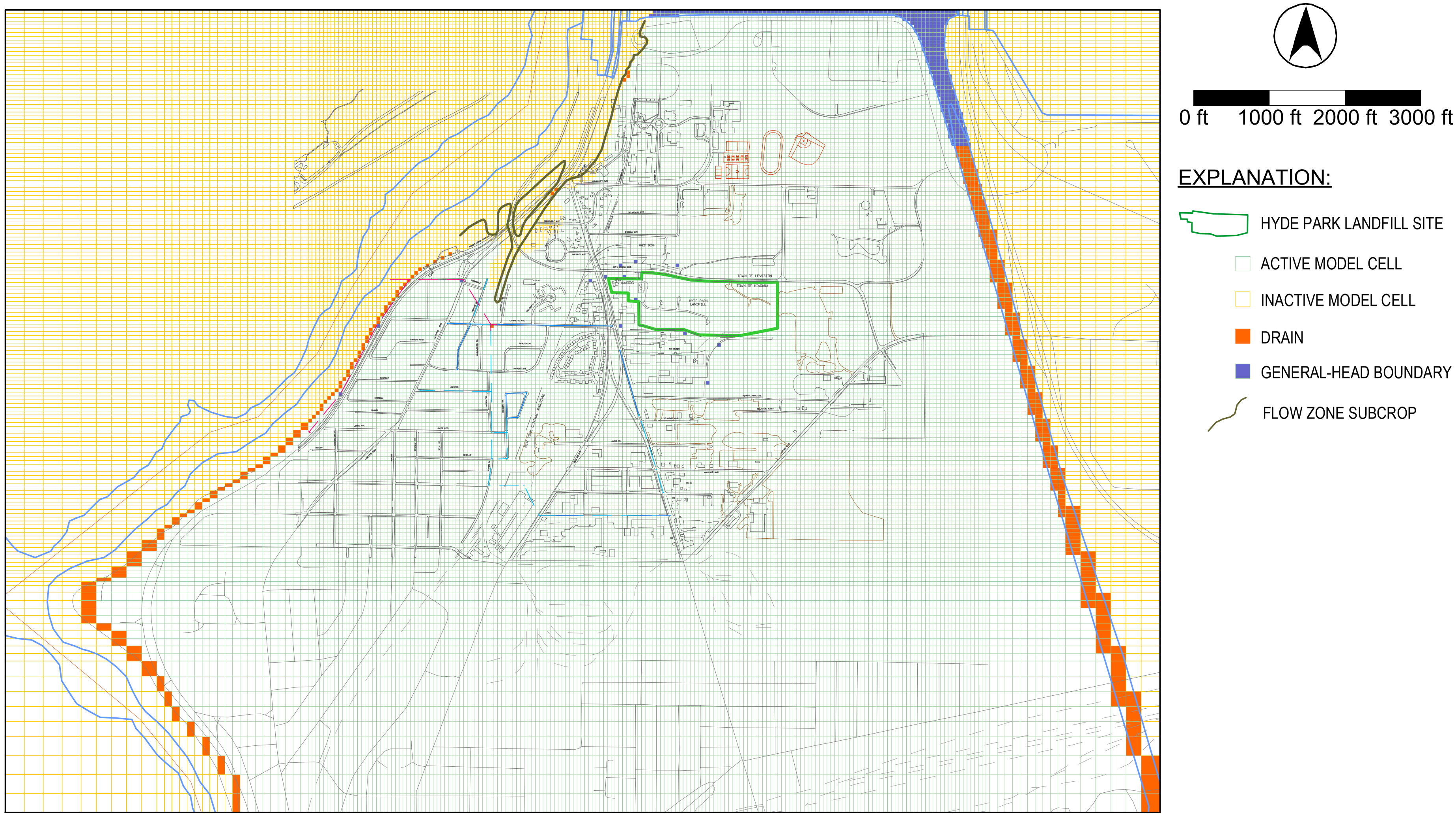


figure 4-9
FLOW ZONE 06 BOUNDARY CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f04_09_fz06_bcs.srf

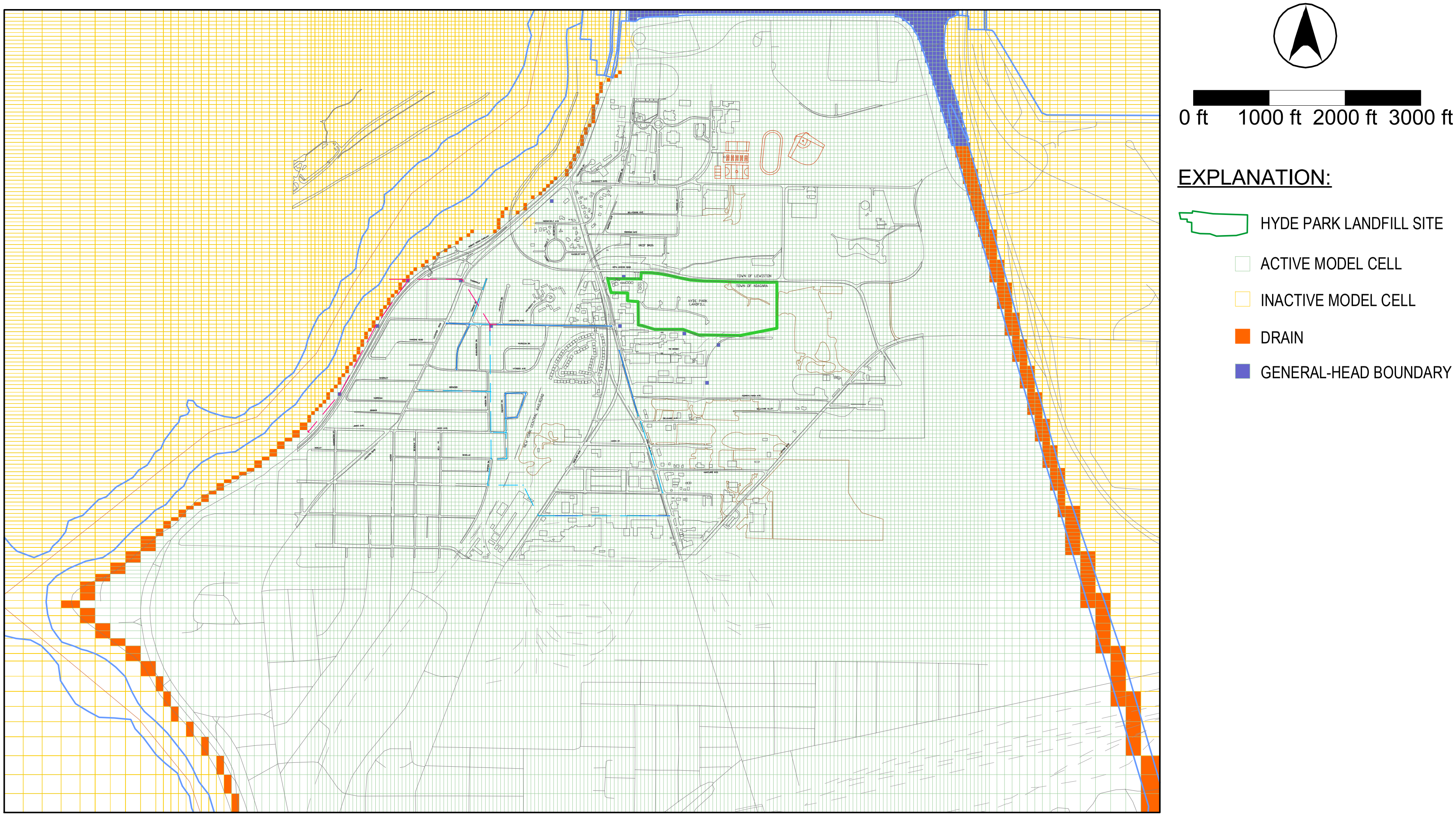


figure 4-10
FLOW ZONE 07 BOUNDARY CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f04_10_fz07_bcs.srf

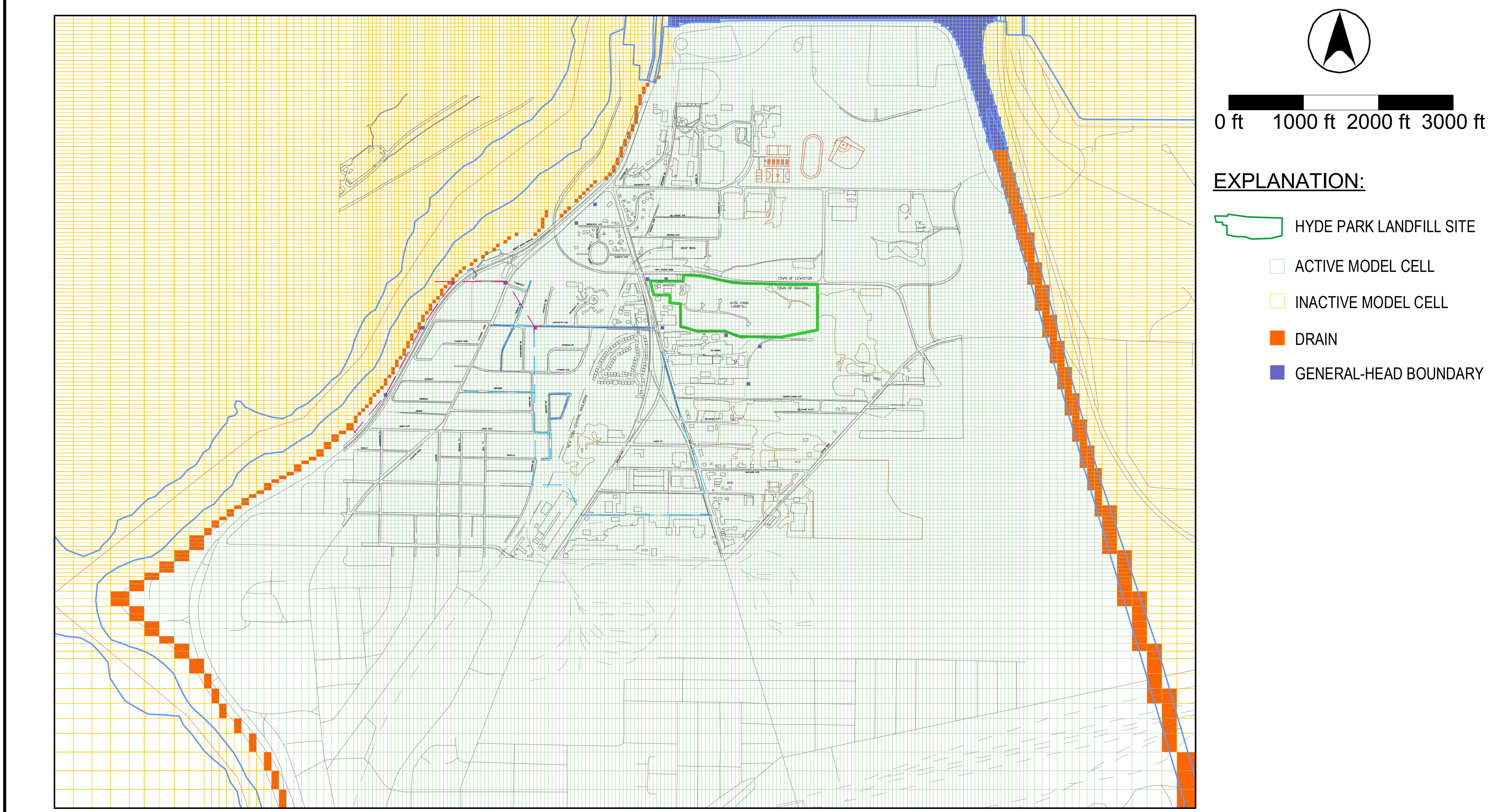


figure 4-11
FLOW ZONE 08 BOUNDARY CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f04_11_fz08_bcs.srf

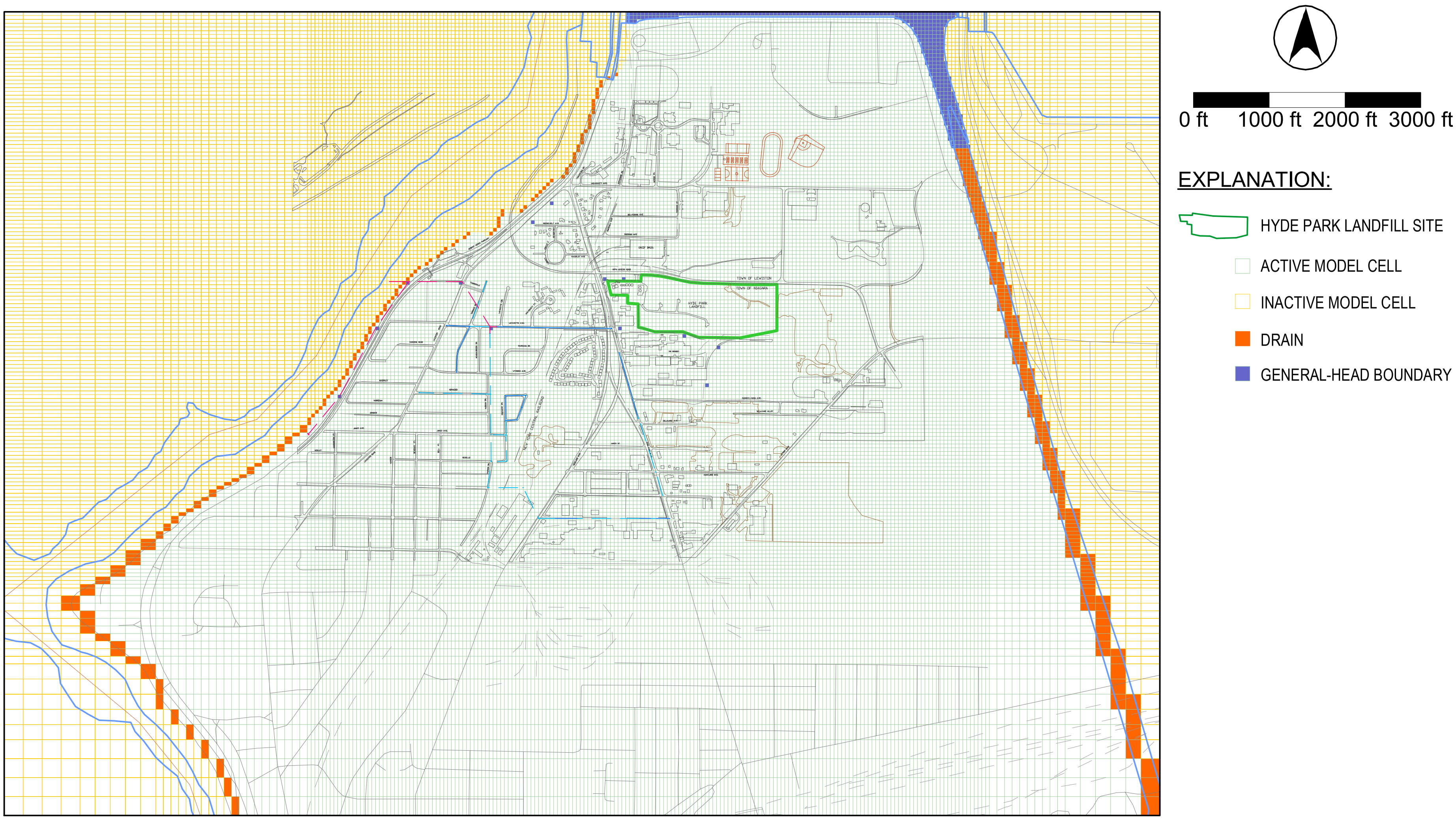


figure 4-12
FLOW ZONE 09 BOUNDARY CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f04_12_fz09_bcs.srf

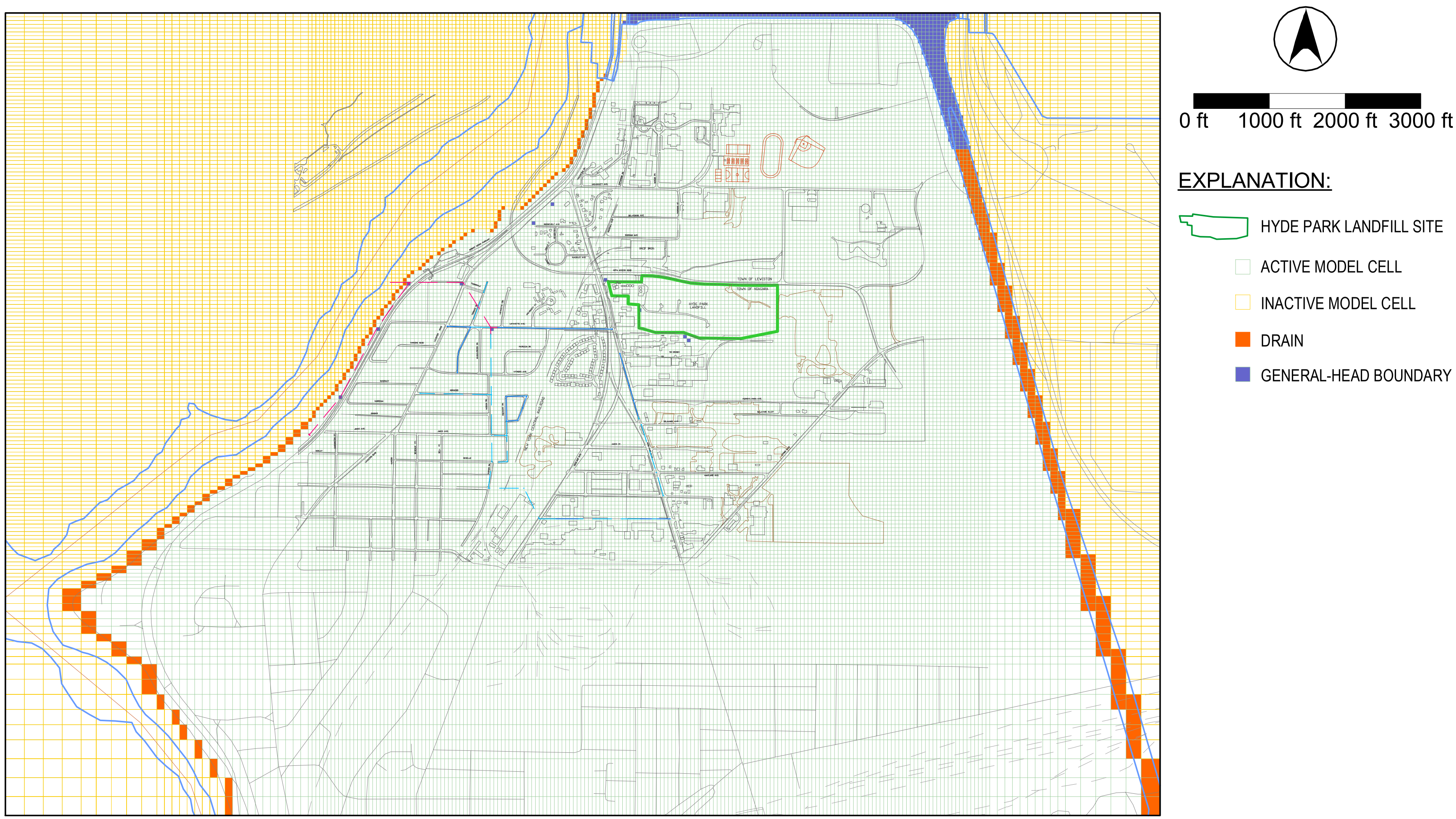


figure 4-13
FLOW ZONE 10 BOUNDARY CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f04_13_fz10_bcs.srf

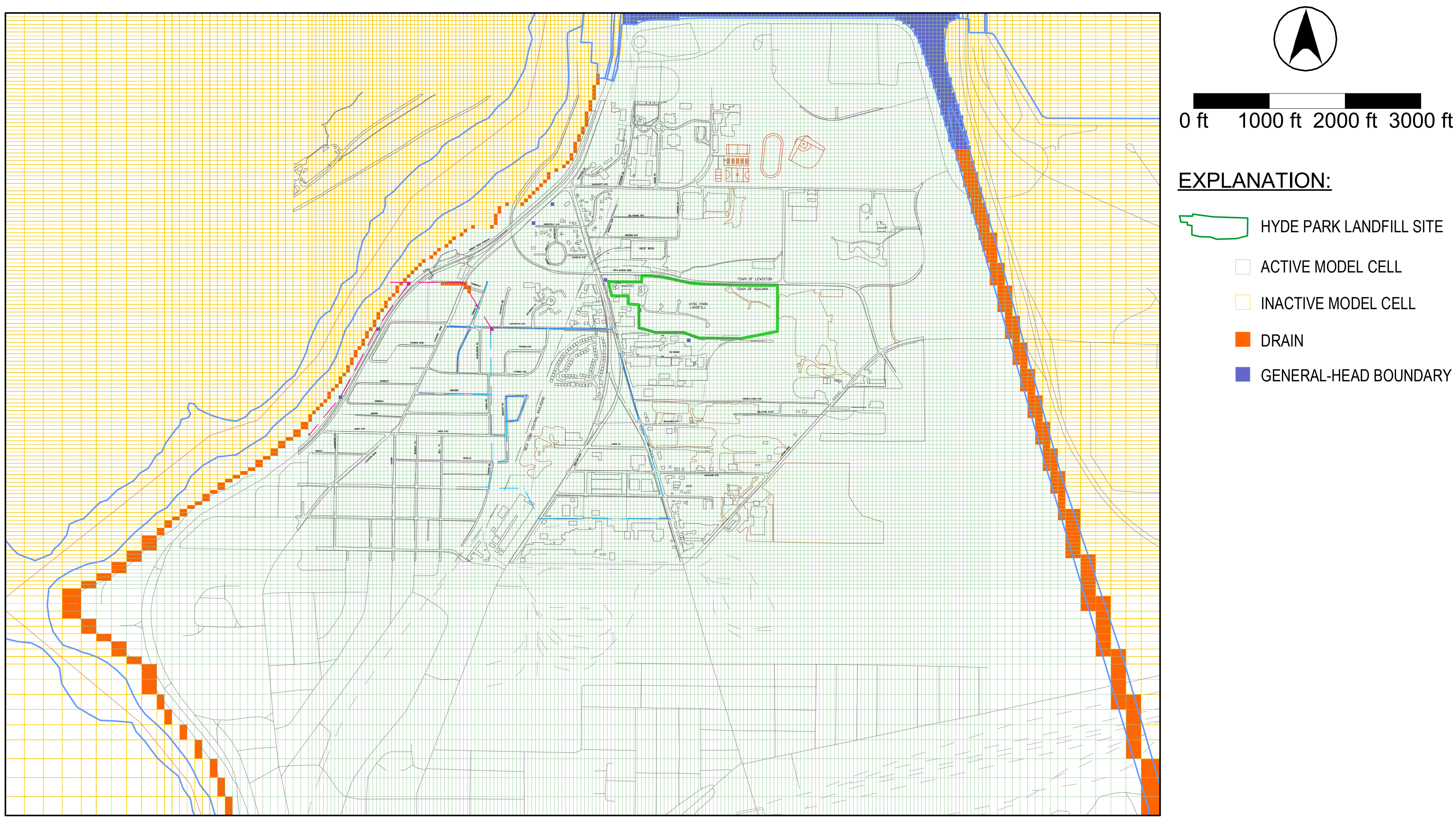


figure 4-14
FLOW ZONE 11 BOUNDARY CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-Apr-2003 d:\sspa\projects\ssp610\model3\Report Figures\f04_14_fz11_bcs.srf

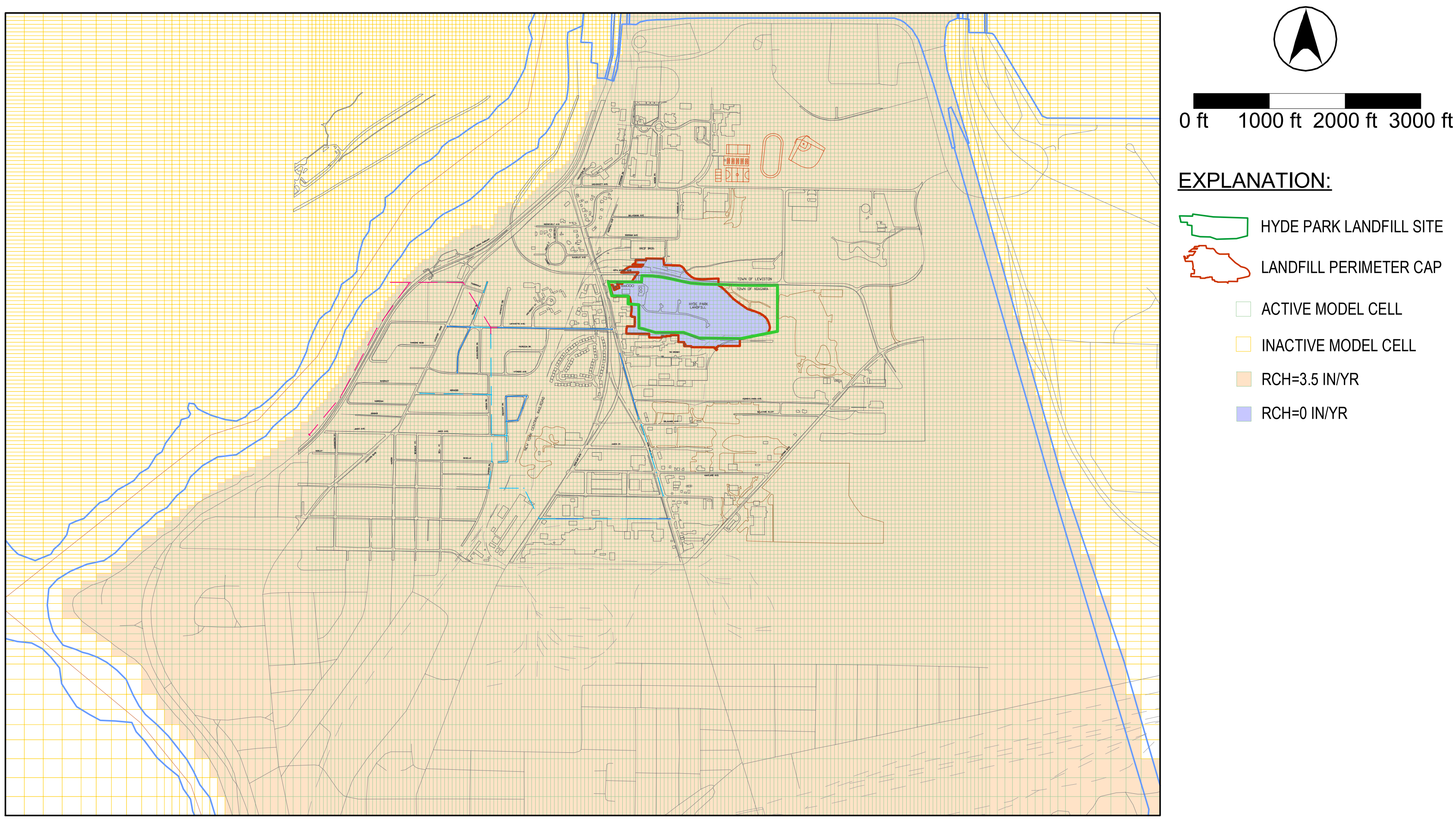


figure 4-15
RECHARGE ZONATION
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f04_15_rch_zon.srf

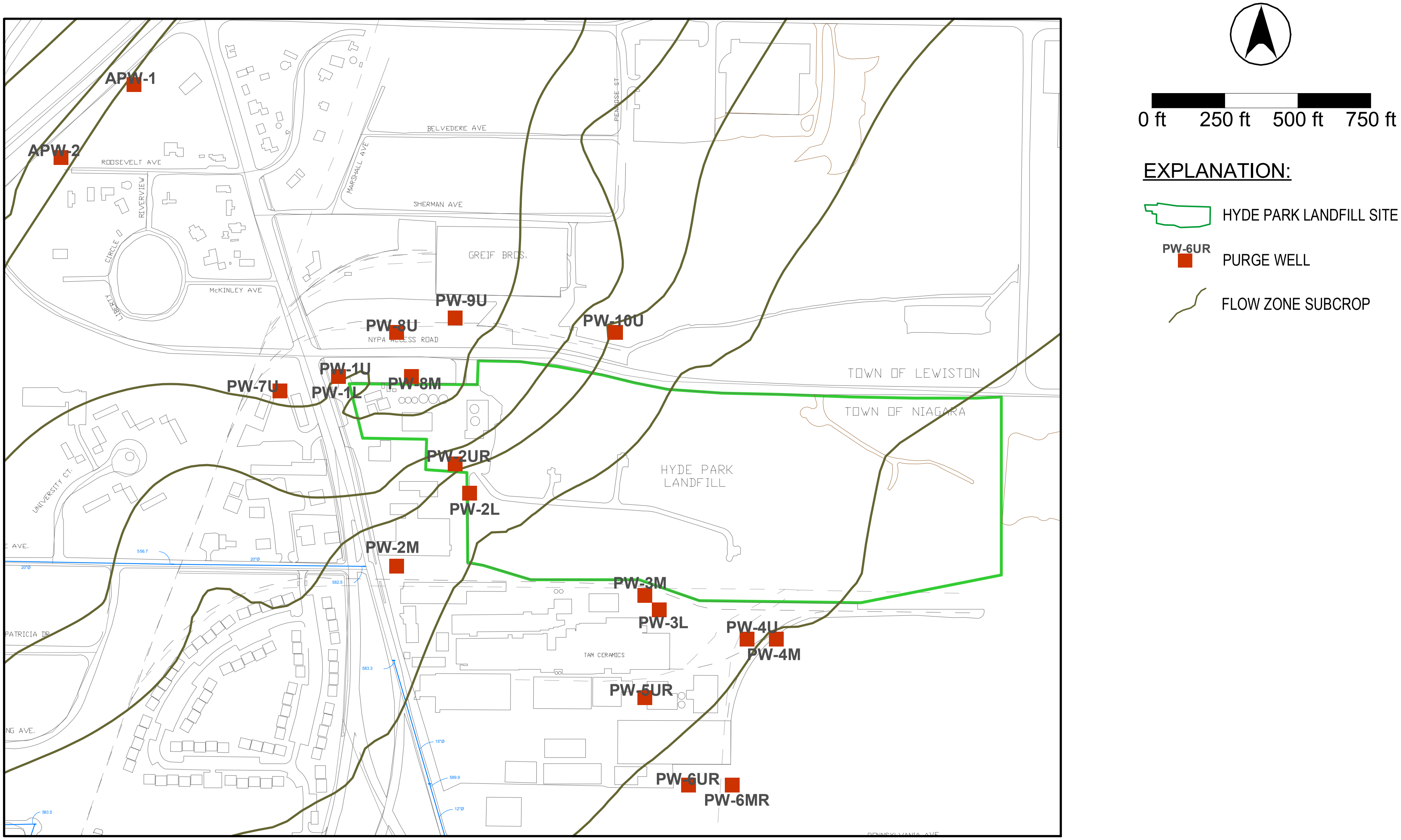
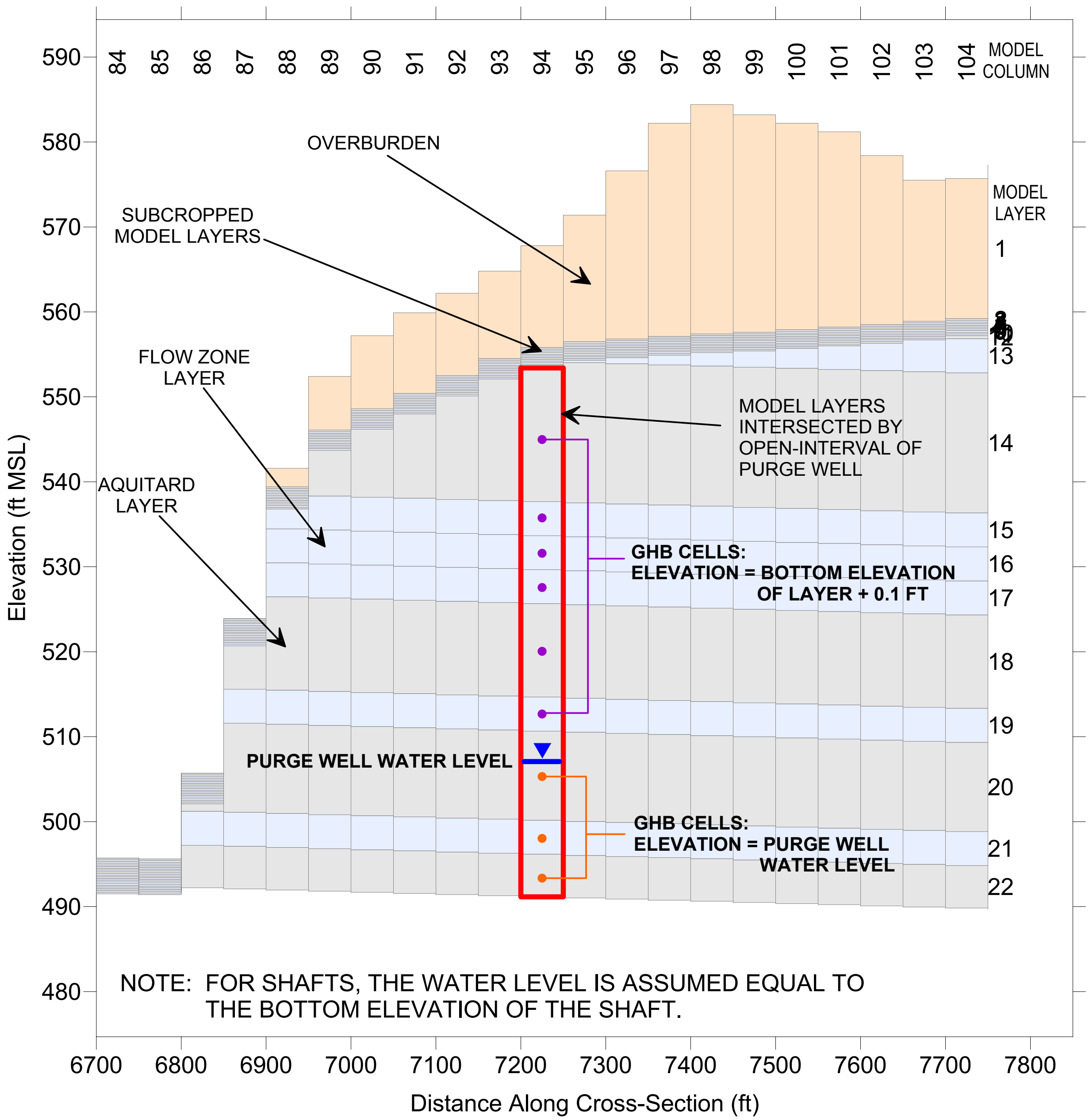


figure 4-16
BEDROCK PURGE WELLS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f04_16_br_pws.srf



VERTICAL EXAGGERATION=10x

figure 4-17
SIMULATION APPROACH FOR PURGE WELLS & SHAFTS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f04_17_pw_approach.srf

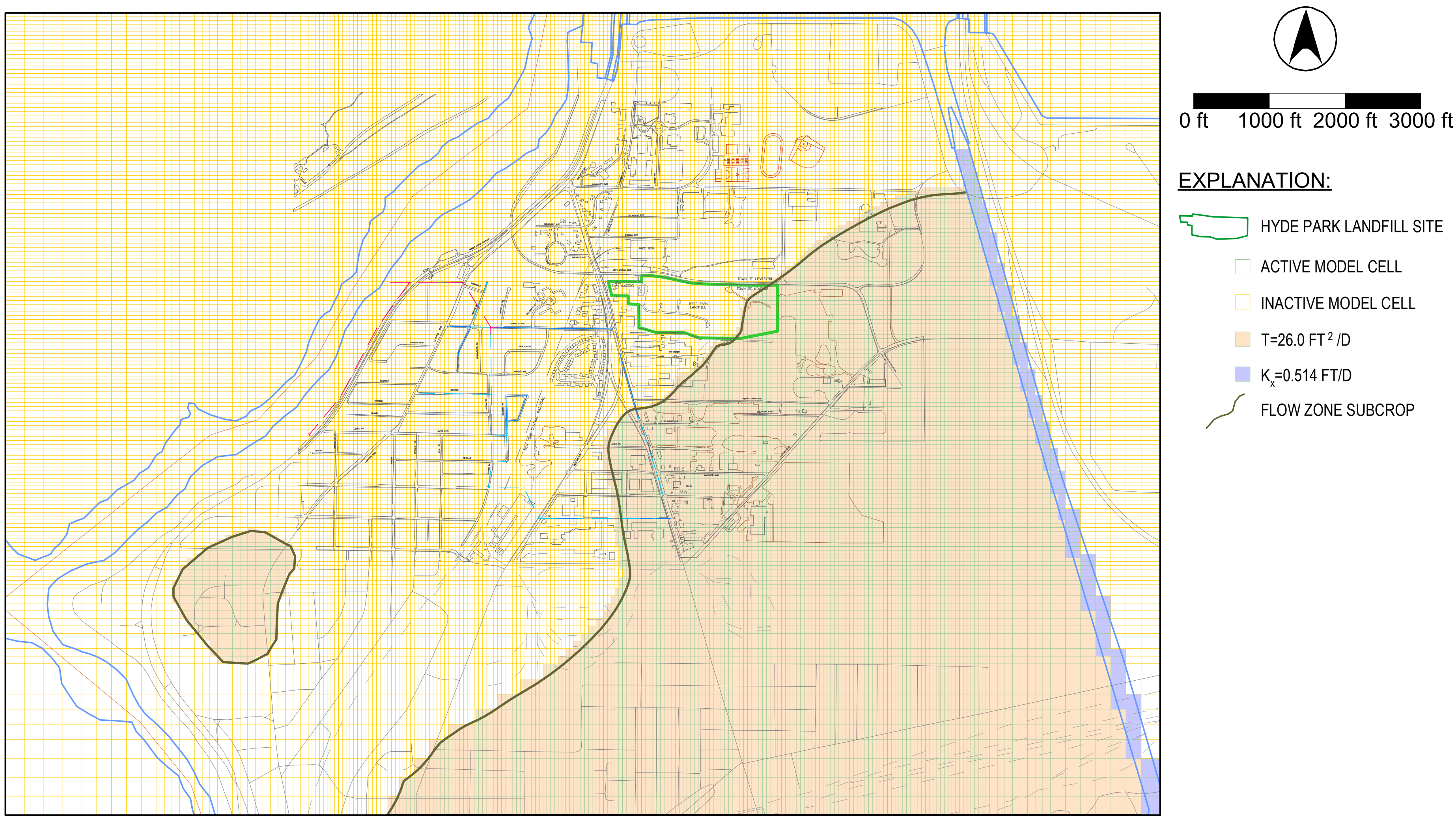


figure 5-1
FLOW ZONE 01 TRANSMISSIVITY ZONATION
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f05_01_fz01_zon.srf

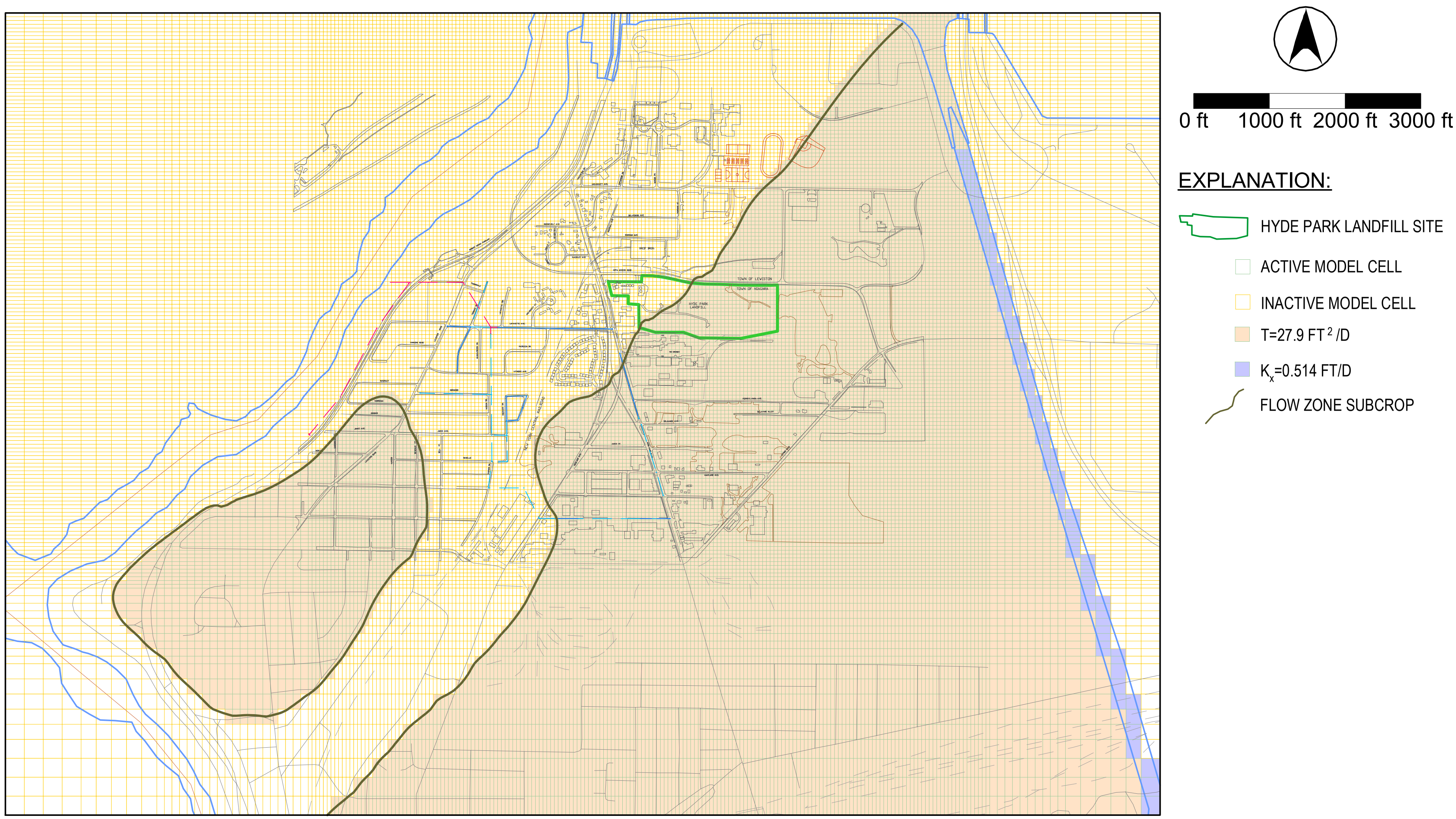


figure 5-2
FLOW ZONE 02 TRANSMISSIVITY ZONATION
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f05_02_fz02_zon.srf

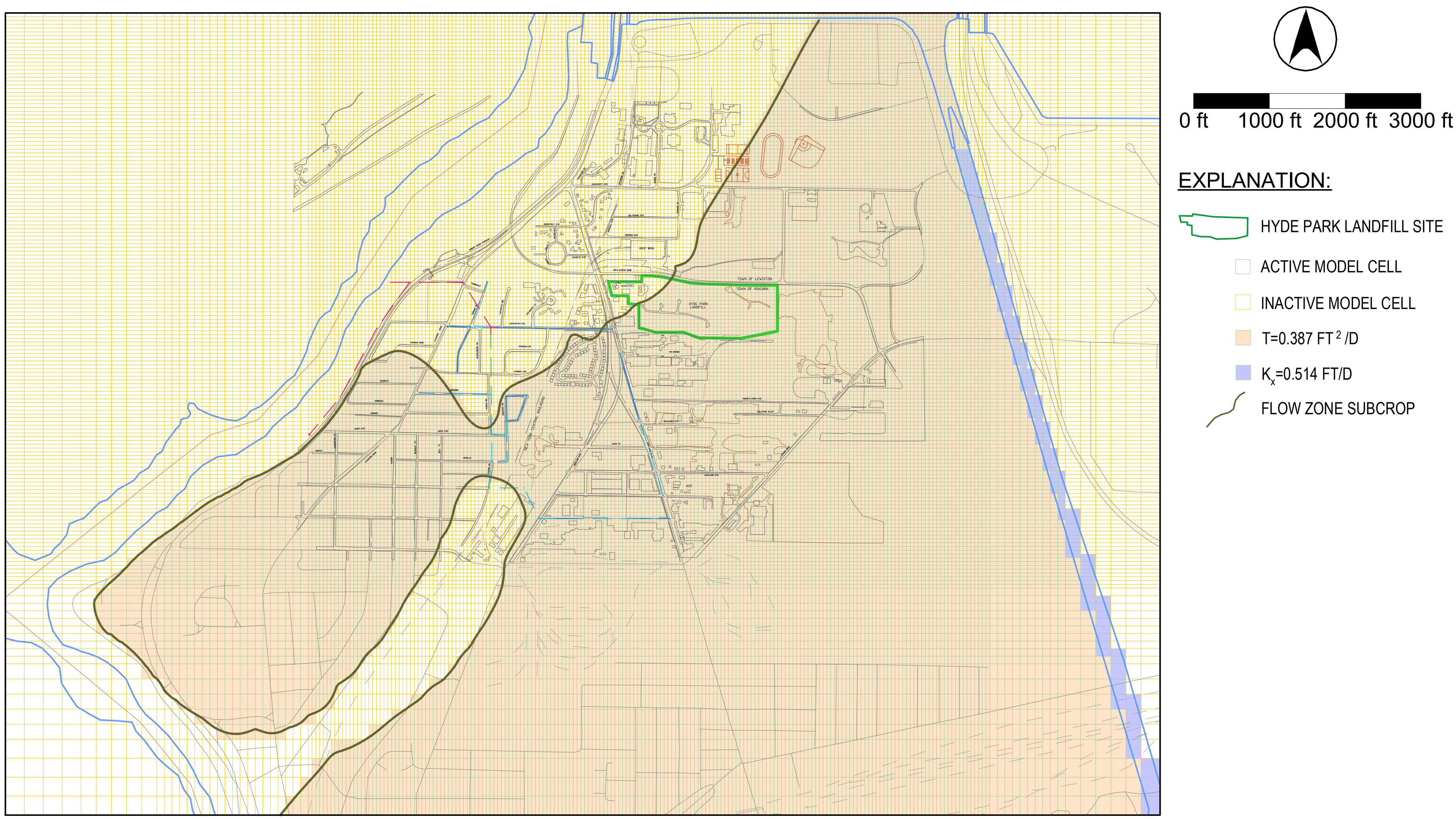
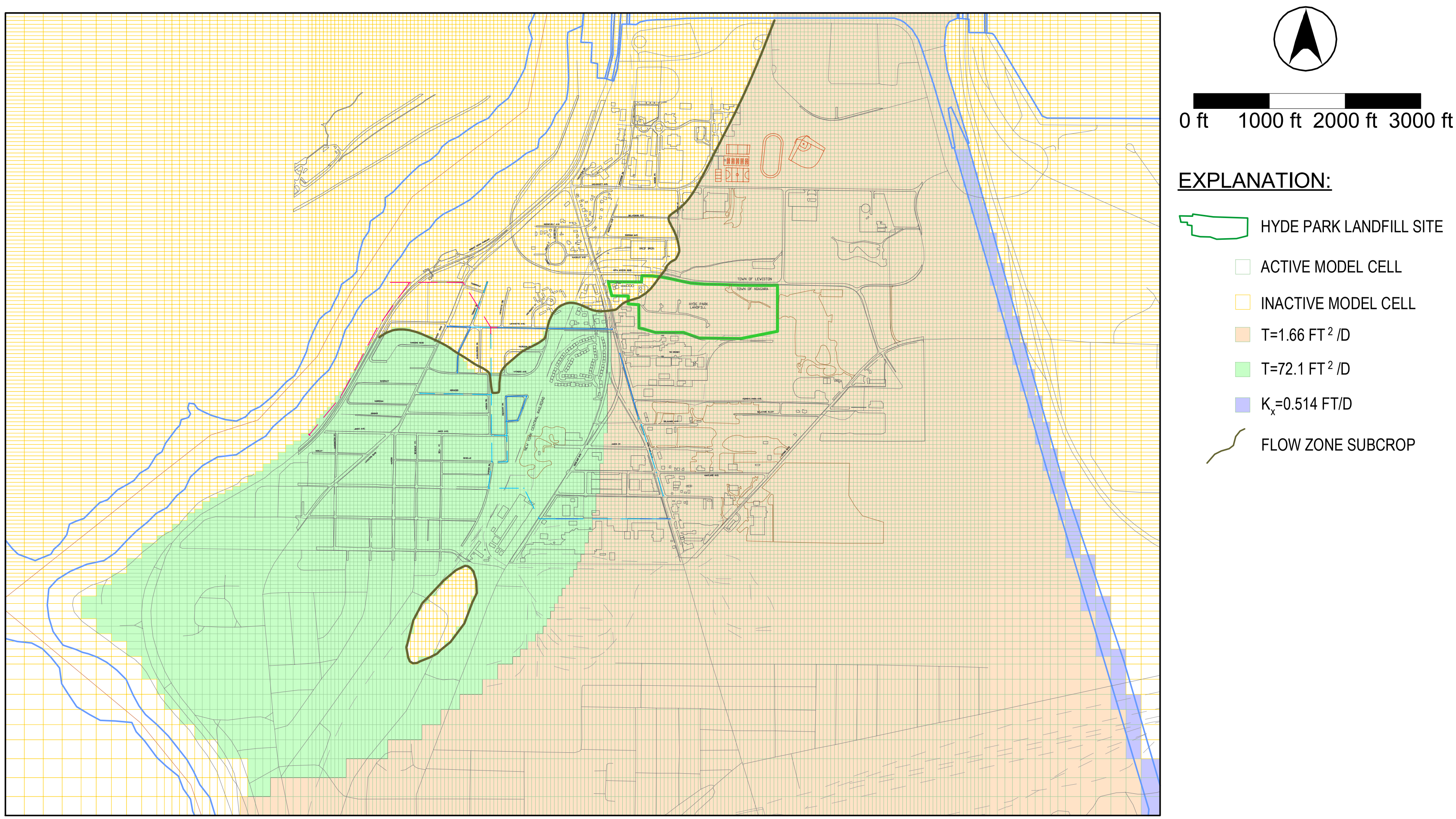


figure 5-3
FLOW ZONE 03 TRANSMISSIVITY ZONATION
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f05_03_fz03_zon.srf



Miller Springs Remediation Management, Inc.

figure 5-4
FLOW ZONE 04 TRANSMISSIVITY ZONATION
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f05_04_fz04_zon.srf

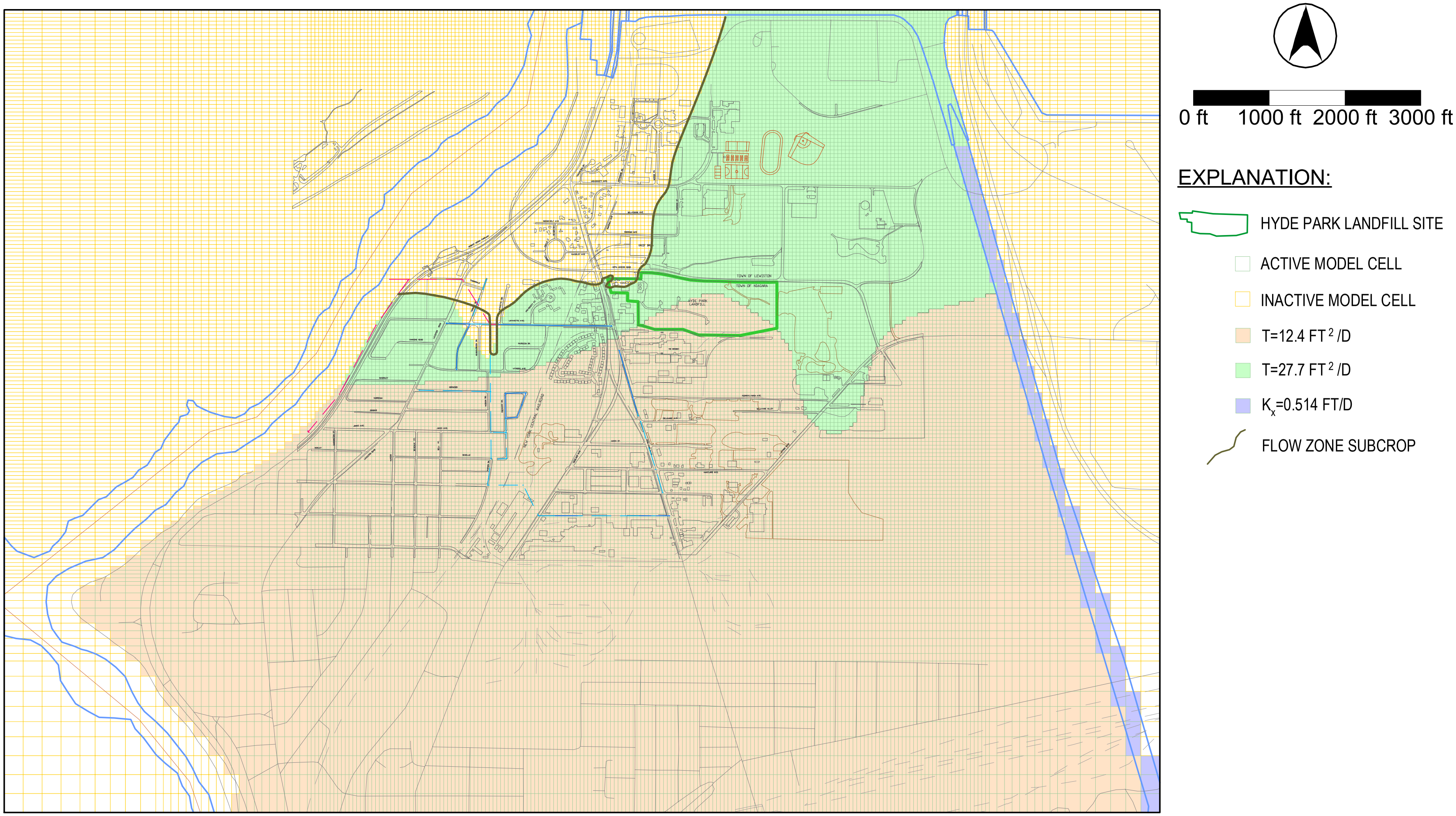


figure 5-5
FLOW ZONE 05 TRANSMISSIVITY ZONATION
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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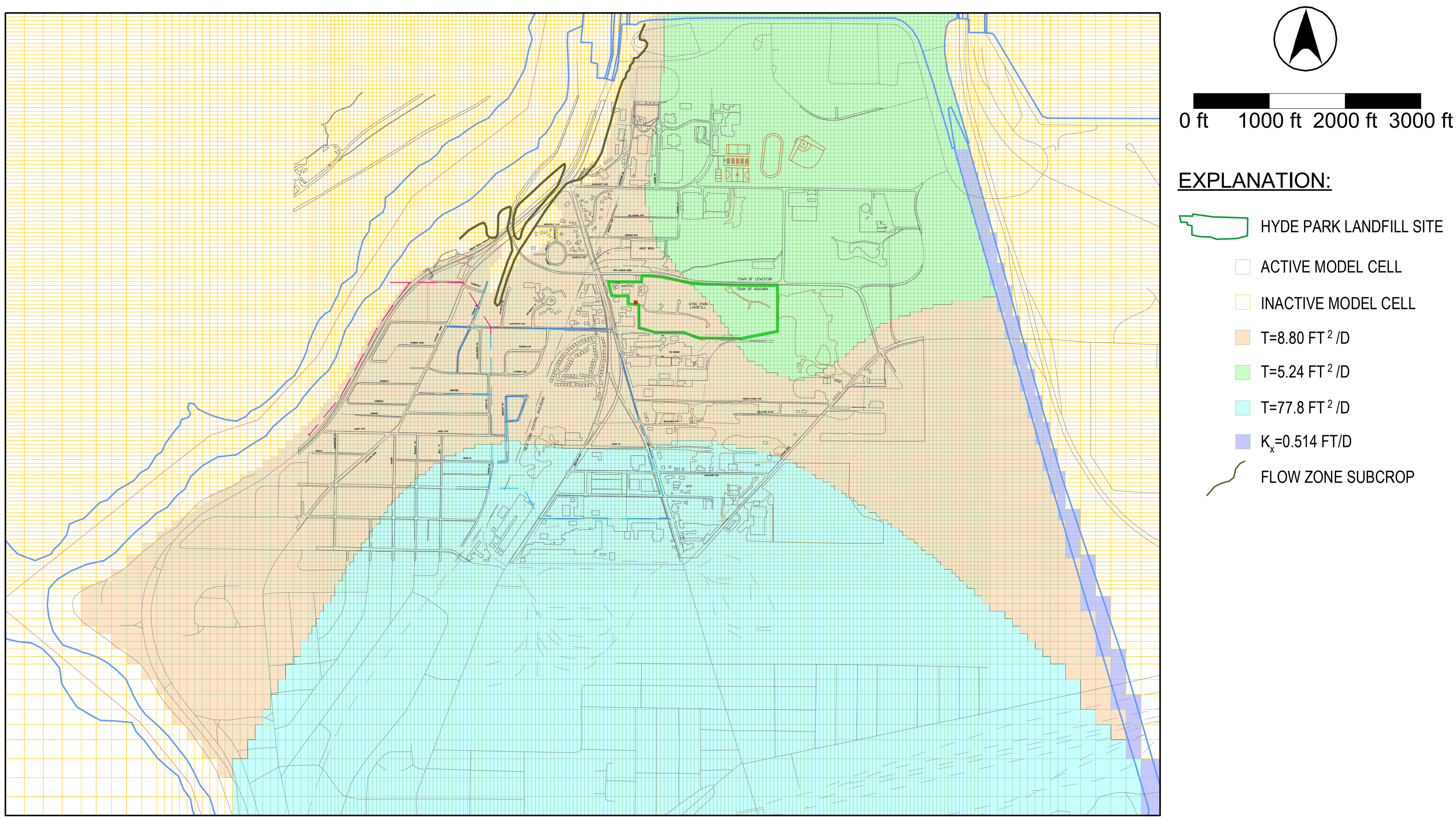

figure 5-6
FLOW ZONE 06 TRANSMISSIVITY ZONATION
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f05_06_fz06_zon.srf

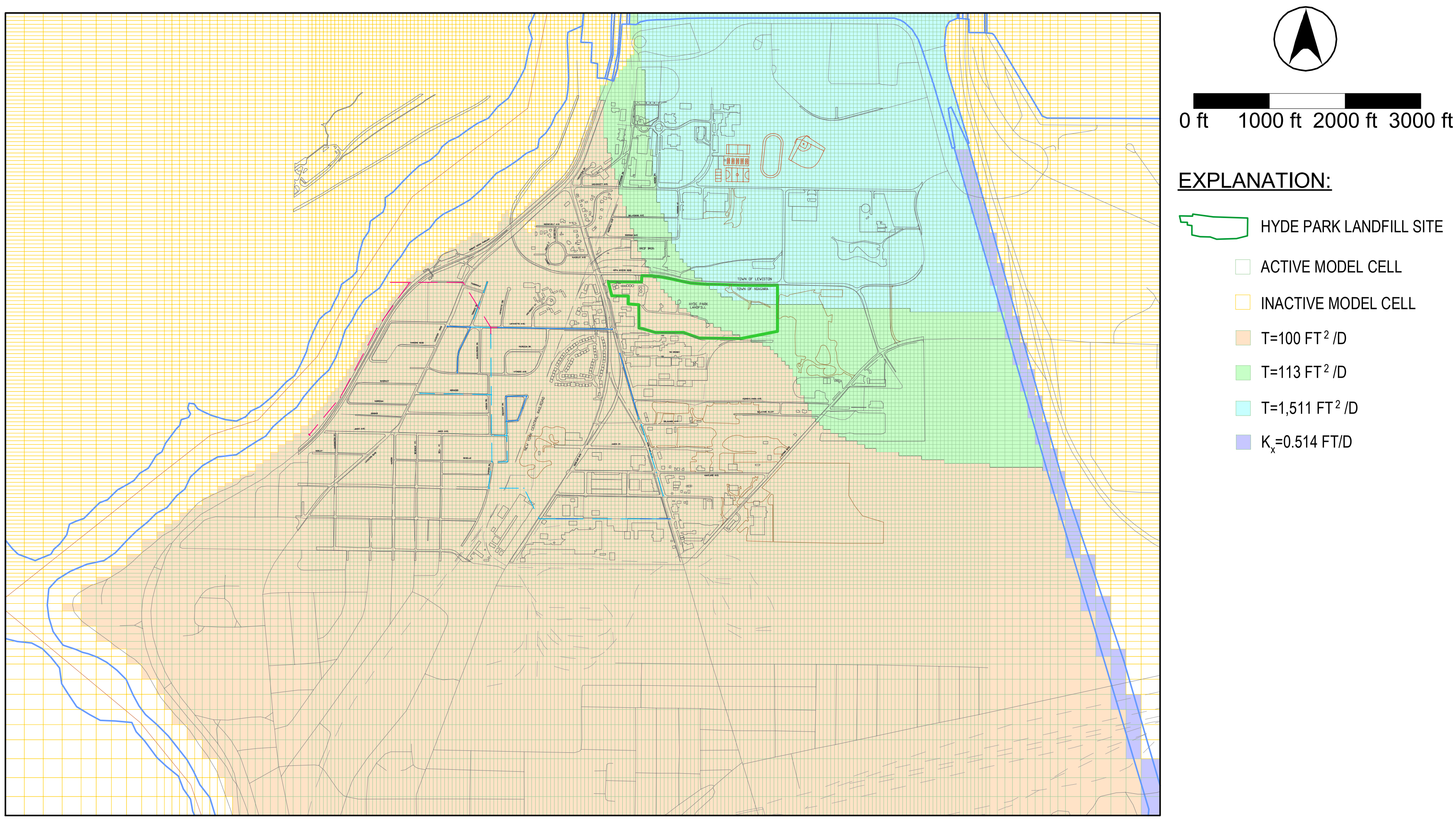

figure 5-7
FLOW ZONE 07 TRANSMISSIVITY ZONATION
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f05_07_fz07_zon.srf

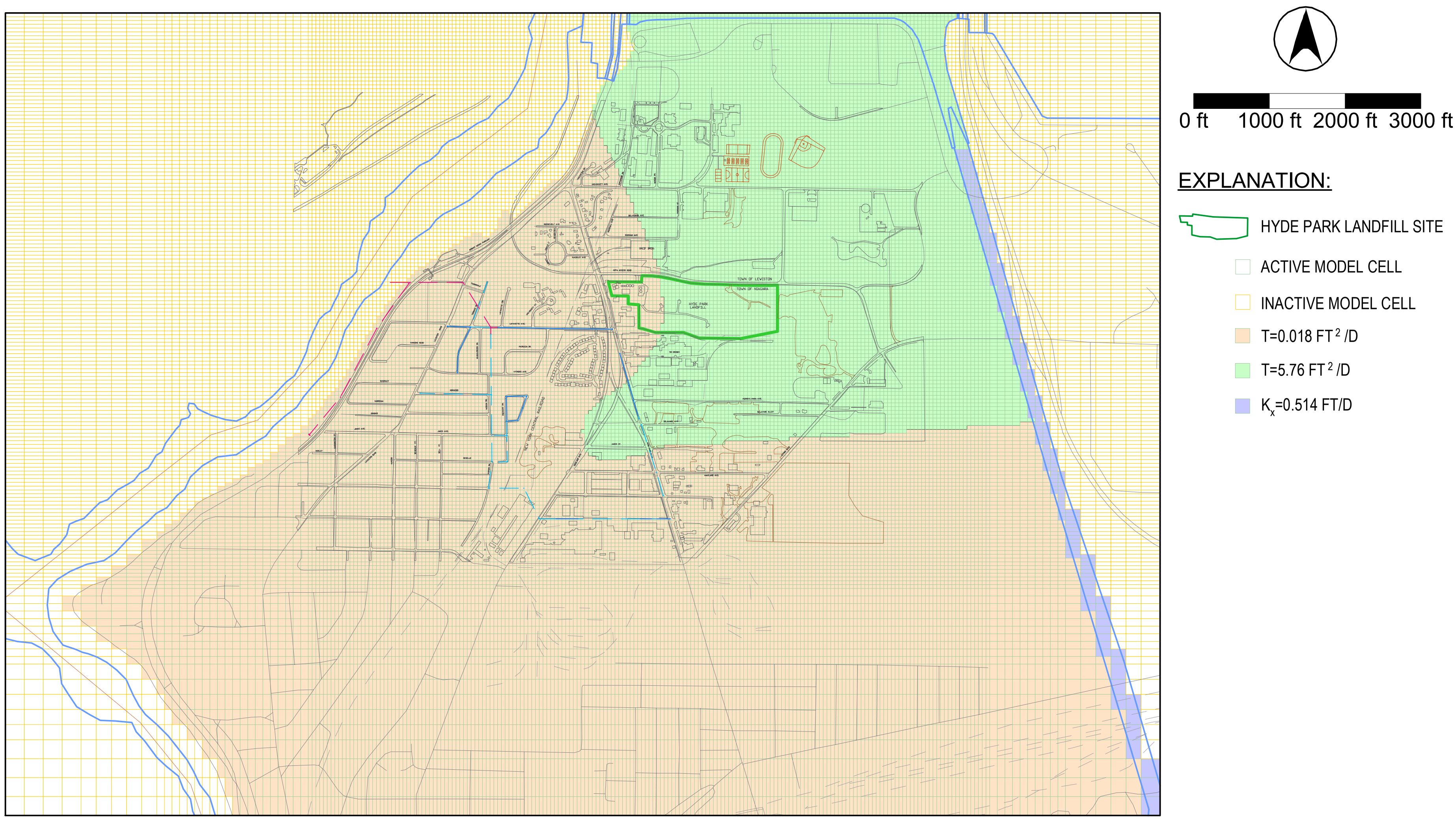

figure 5-8

FLOW ZONE 08 TRANSMISSIVITY ZONATION

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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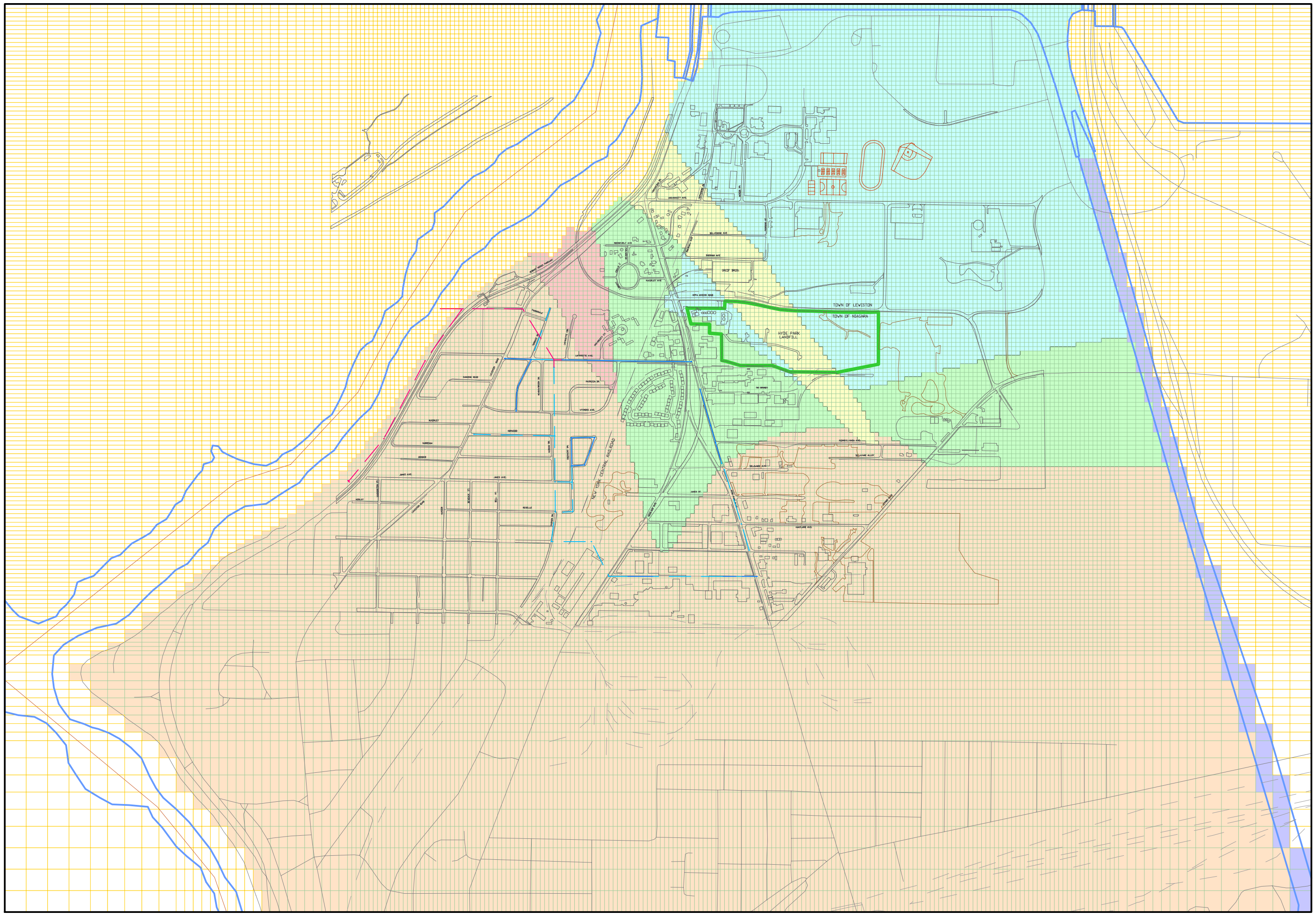

figure 5-9
FLOW ZONE 09 TRANSMISSIVITY ZONATION
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\Report Figures\f05_09_fz09_zon.srf

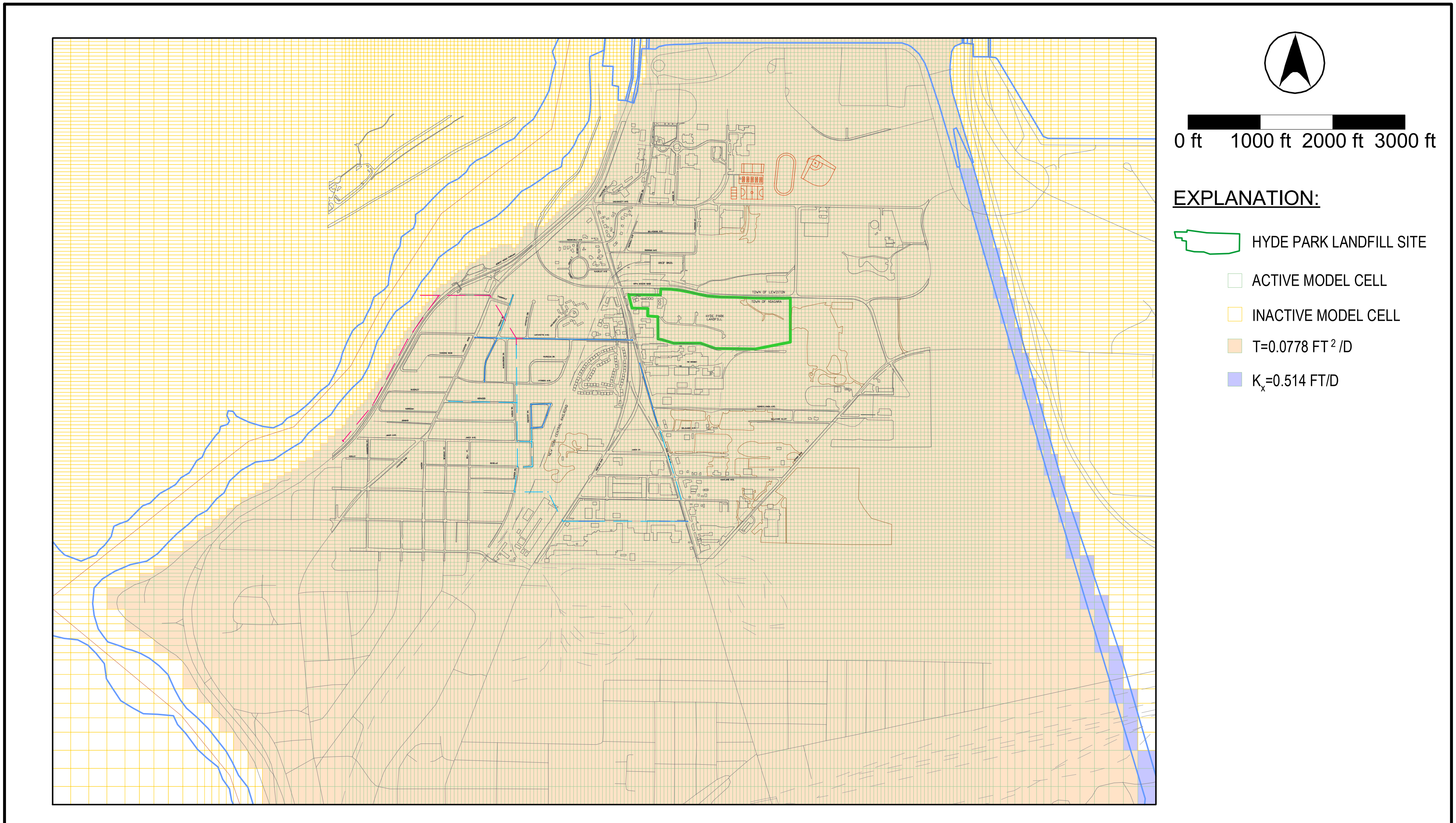

figure 5-10
FLOW ZONE 10 TRANSMISSIVITY ZONATION
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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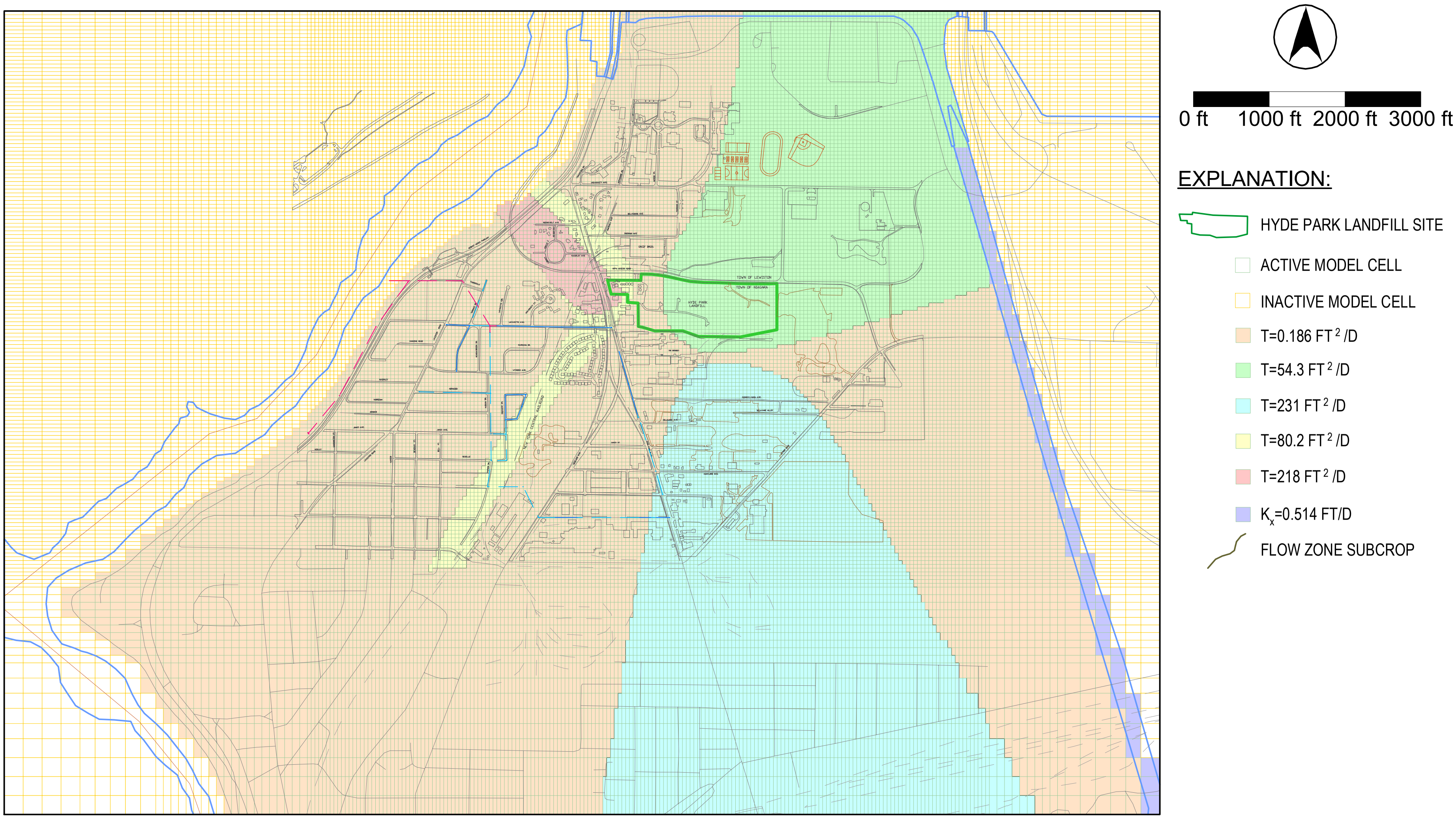

figure 5-11
FLOW ZONE 11 TRANSMISSIVITY ZONATION
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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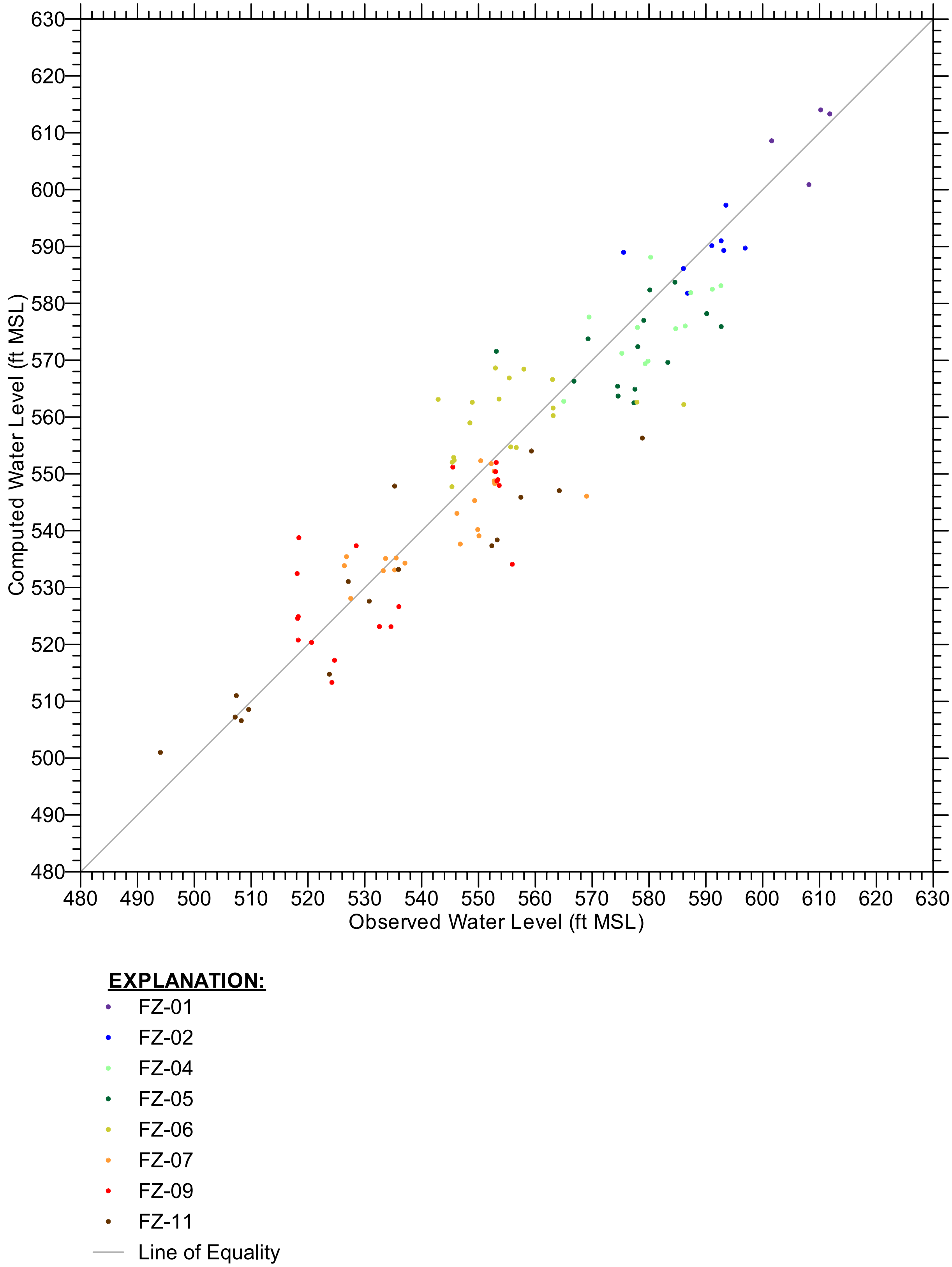

figure 5-12
CALCULATED VERSUS OBSERVED WATER LEVELS; PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

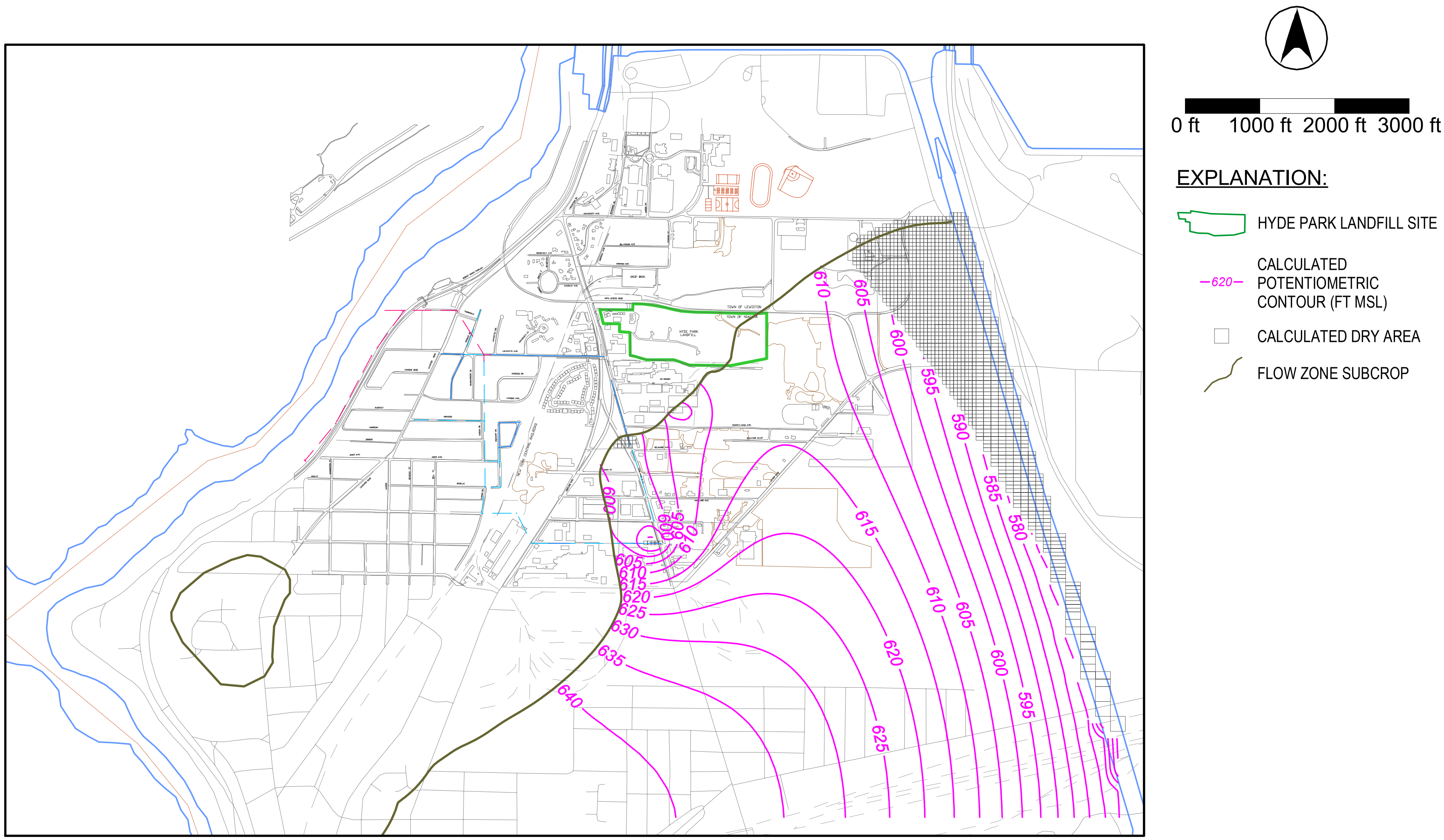

figure 5-13
CALCULATED POTENTIOMETRIC CONTOURS IN FZ-01, PUMPING CONDITIONS - REGIONAL
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\f05_13_hp011p_fz01_wls_r.srf

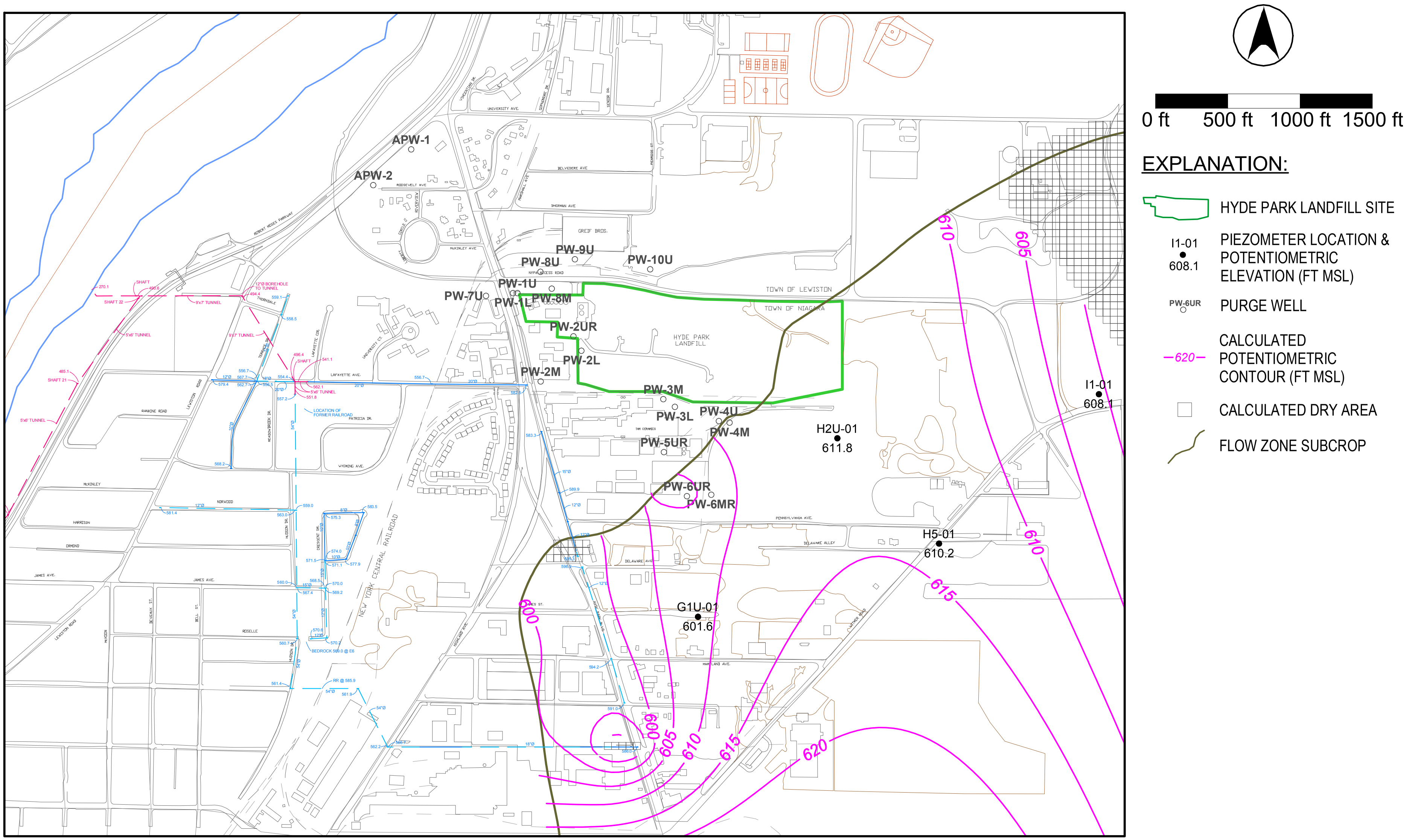

figure 5-14

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-01, PUMPING CONDITIONS - LOCAL SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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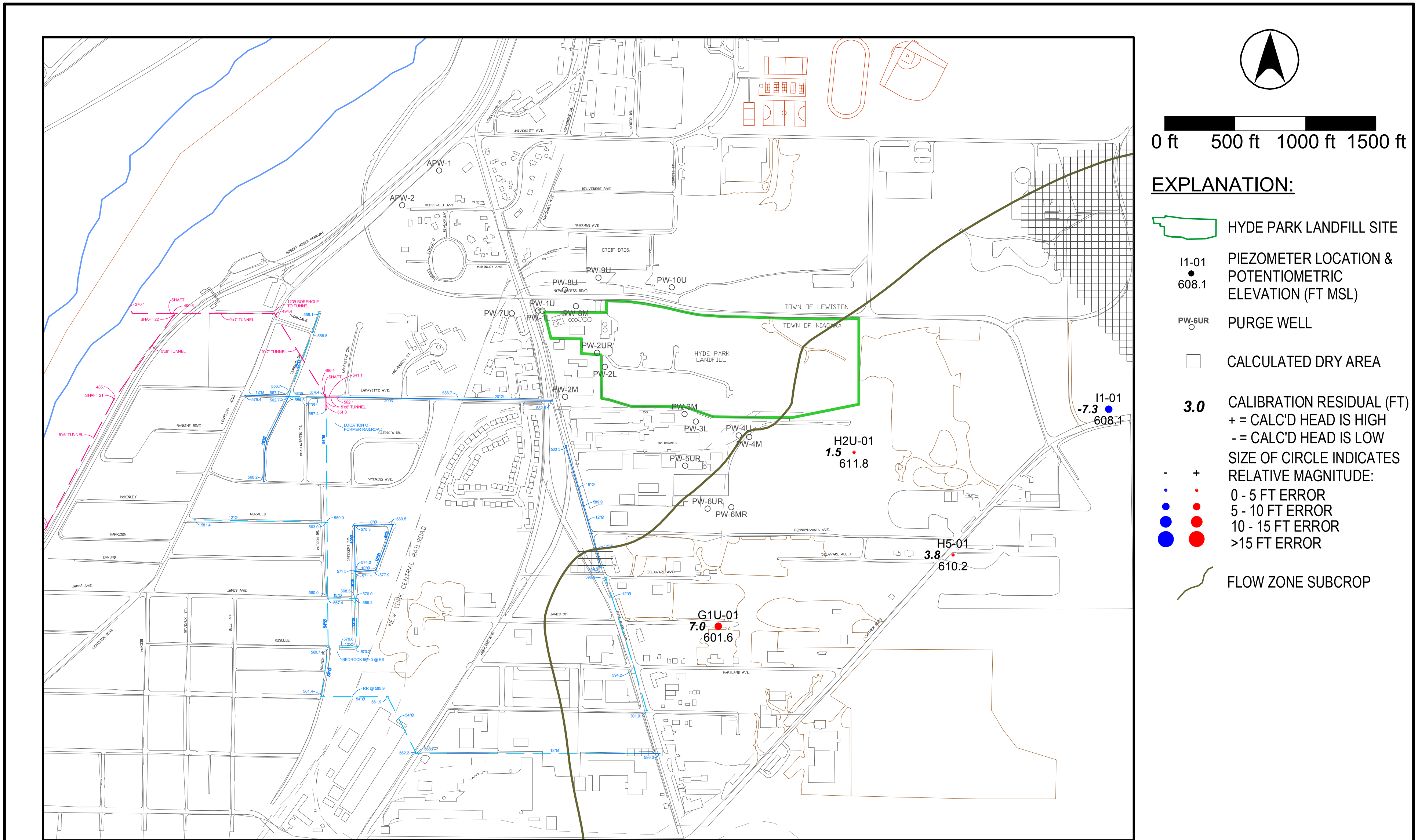

figure 5-15

CALIBRATION RESIDUALS IN FZ-01, PUMPING CONDITIONS

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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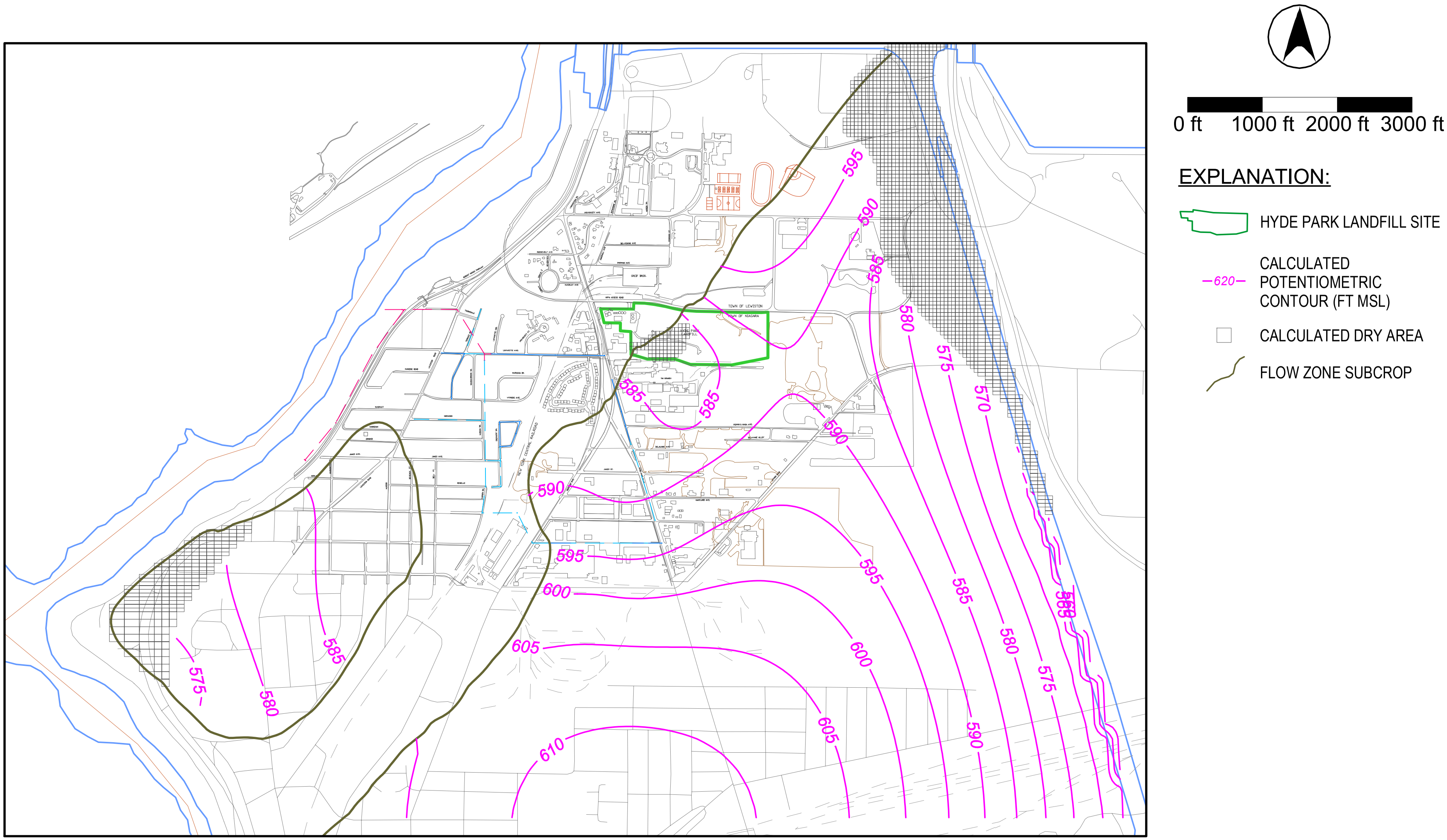

figure 5-16
CALCULATED POTENTIOMETRIC CONTOURS IN FZ-02, PUMPING CONDITIONS - REGIONAL
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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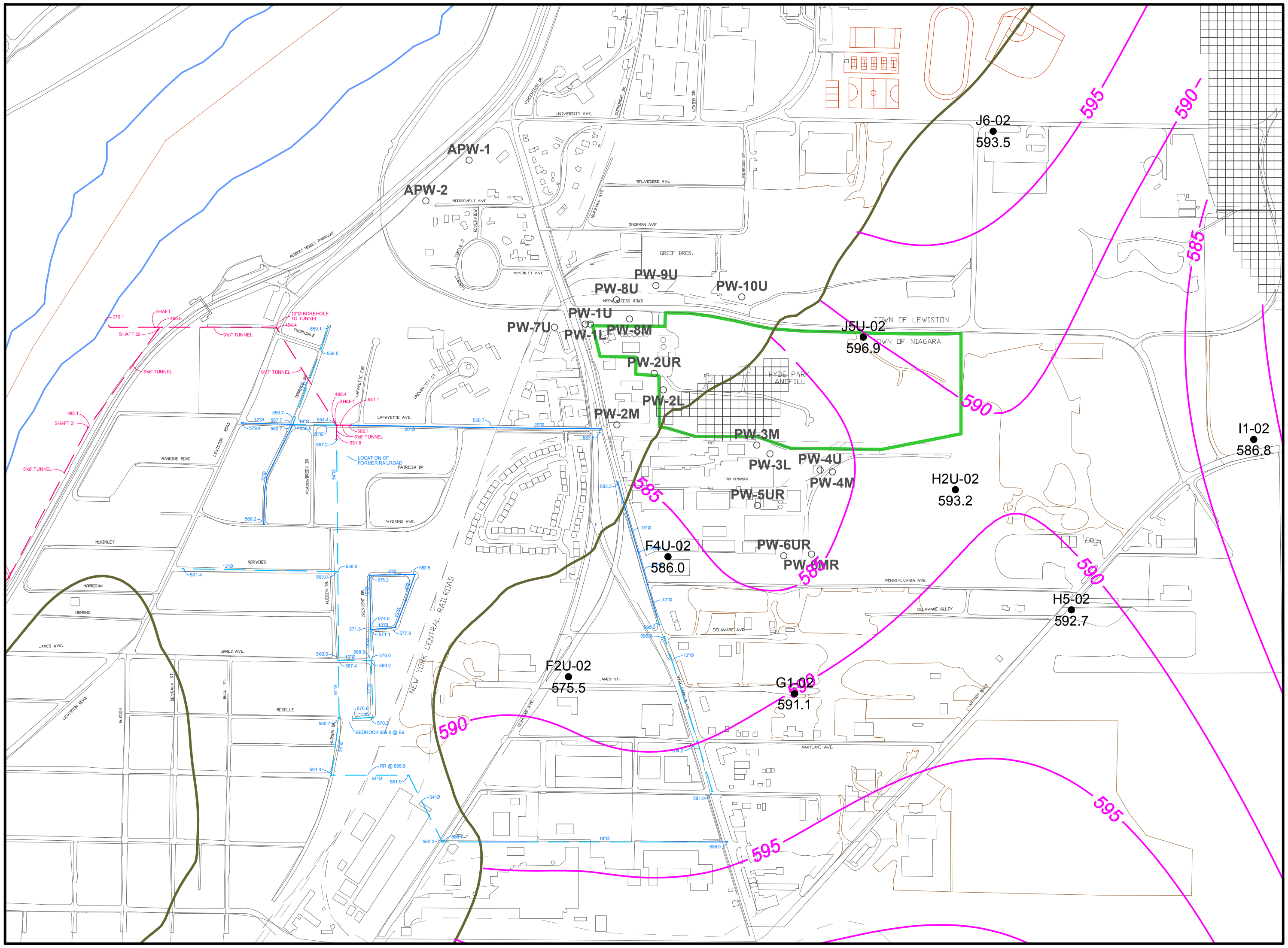

EXPLANATION:

- HYDE PARK LANDFILL SITE
- I1-01 608.1 — PIEZOMETER LOCATION & POTENTIOMETRIC ELEVATION (FT MSL)
- PW-6UR — PURGE WELL
- 620 — CALCULATED POTENTIOMETRIC CONTOUR (FT MSL)
- CALCULATED DRY AREA
- FLOW ZONE SUBCROP

figure 5-17

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-02, PUMPING CONDITIONS - LOCAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\f05_17_hp011p_fz02_wls.srf

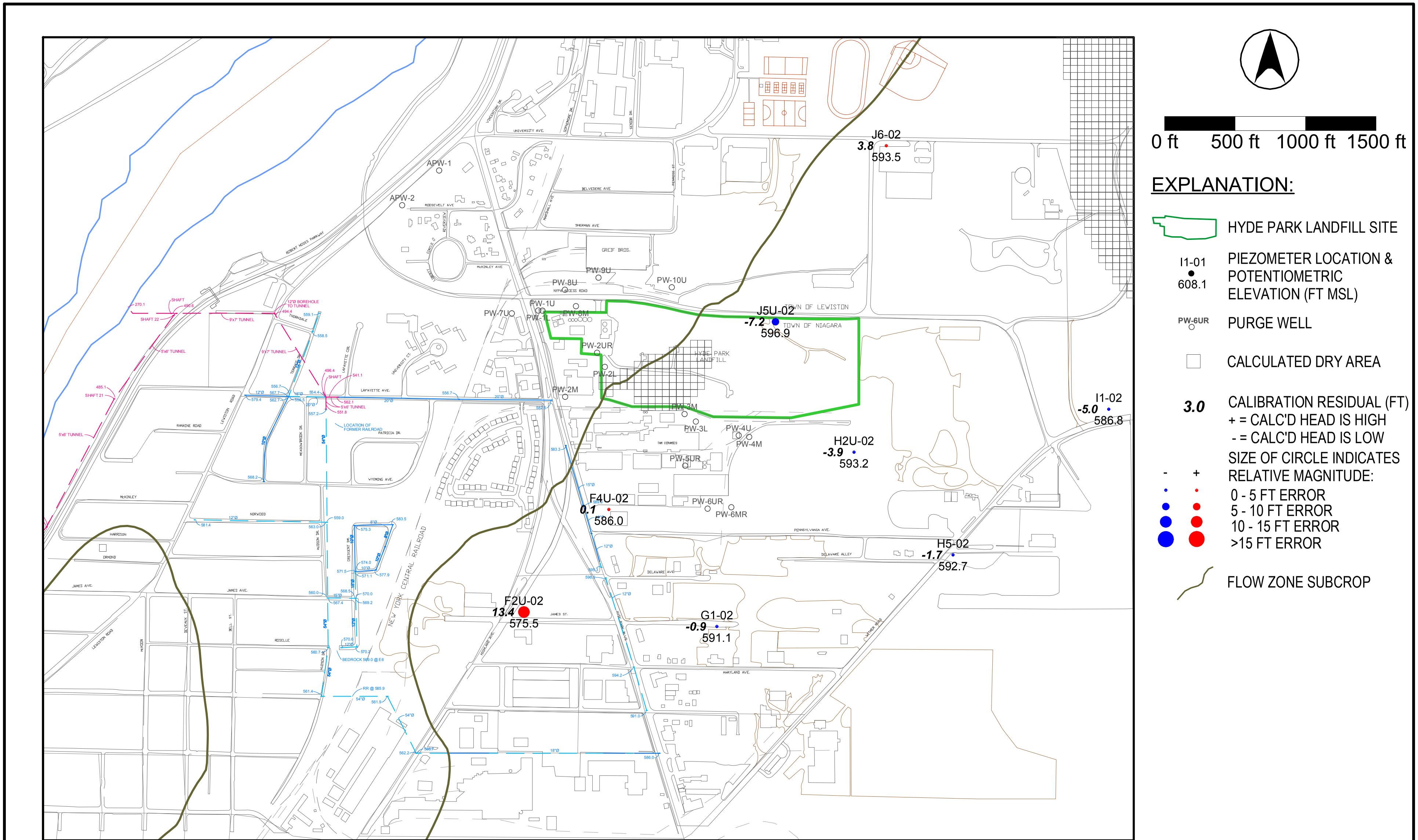

figure 5-18

CALIBRATION RESIDUALS IN FZ-02, PUMPING CONDITIONS

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\f05_18_hp011p_fz02_wls.srf

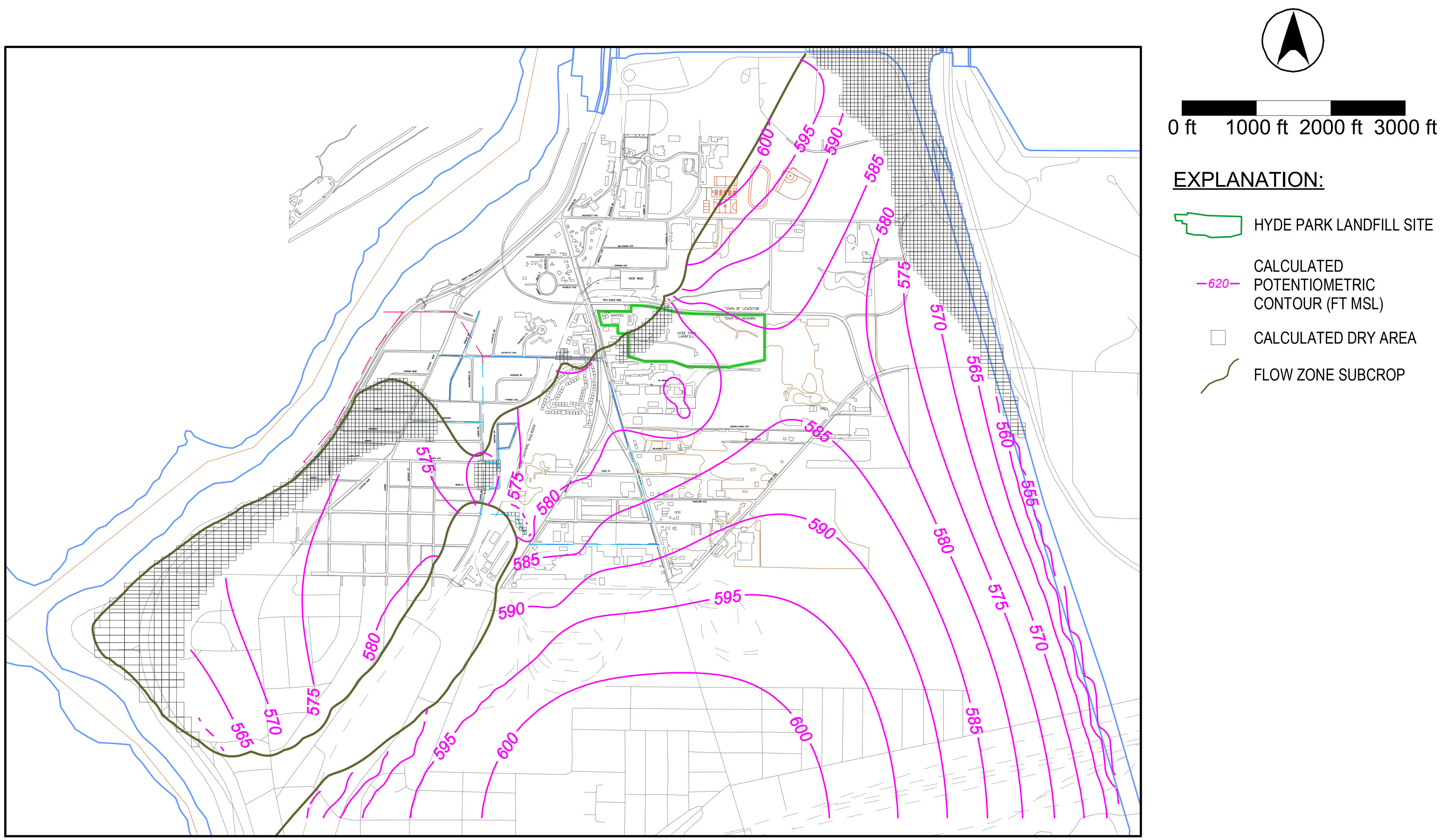

figure 5-19
CALCULATED POTENTIOMETRIC CONTOURS IN FZ-03, PUMPING CONDITIONS - REGIONAL
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\f05_19_hp011p_fz03_wls_r.srf

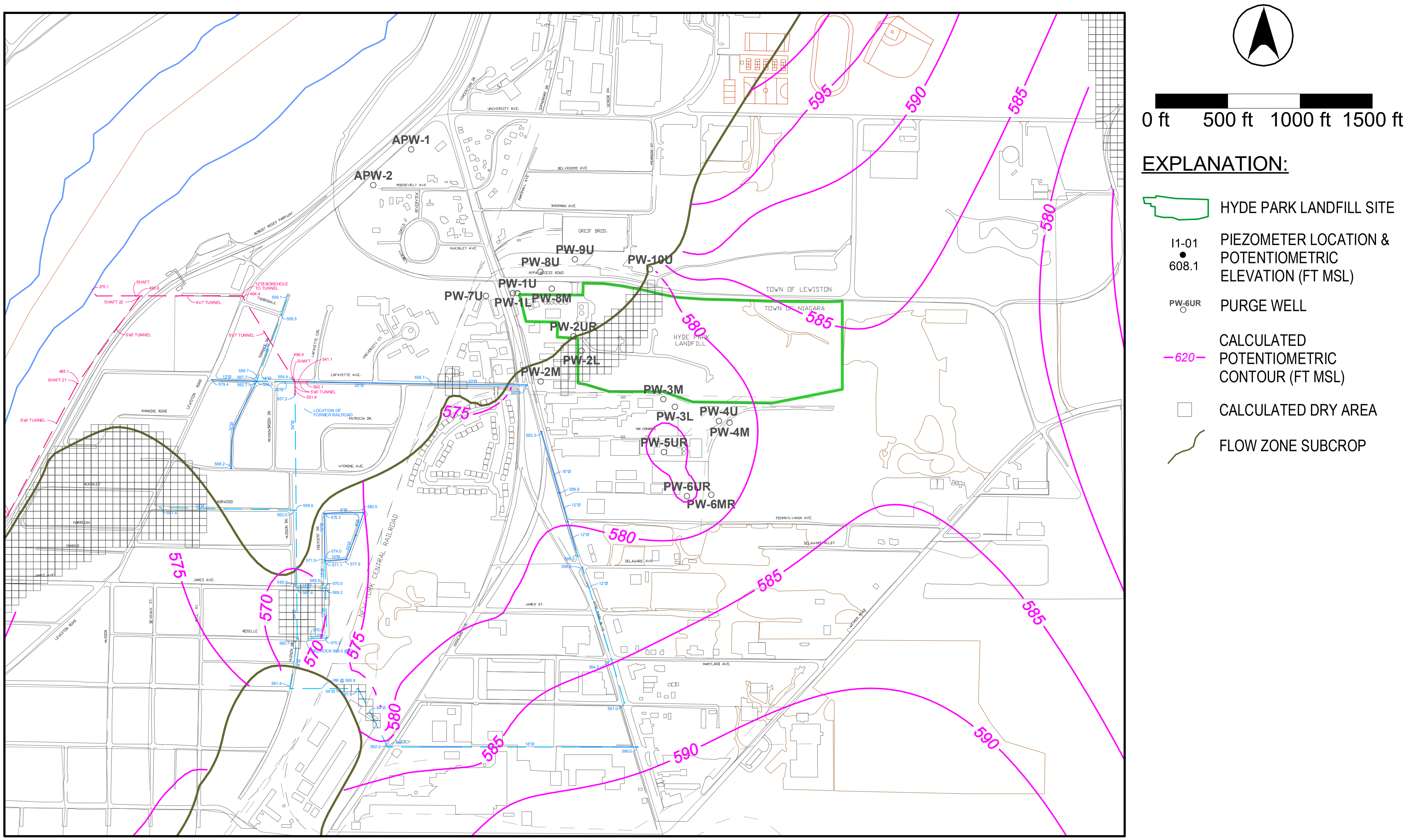

figure 5-20

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-03, PUMPING CONDITIONS - LOCAL
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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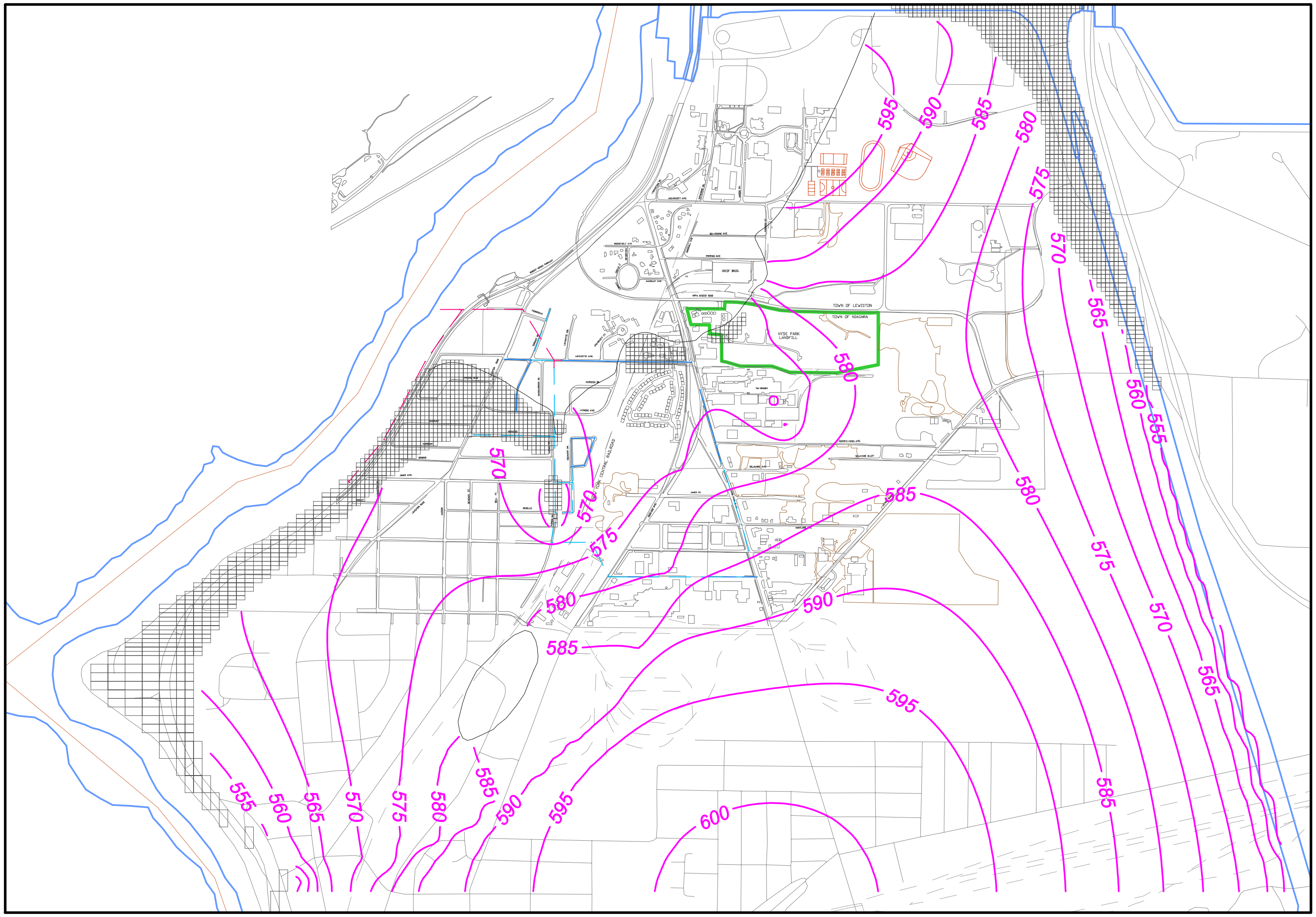

0 ft 1000 ft 2000 ft 3000 ft

EXPLANATION:

HYDE PARK LANDFILL SITE

620 CALCULATED POTENTIOMETRIC CONTOUR (FT MSL)

CALCULATED DRY AREA

FLOW ZONE SUBCROP

figure 5-21

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-04, PUMPING CONDITIONS - REGIONAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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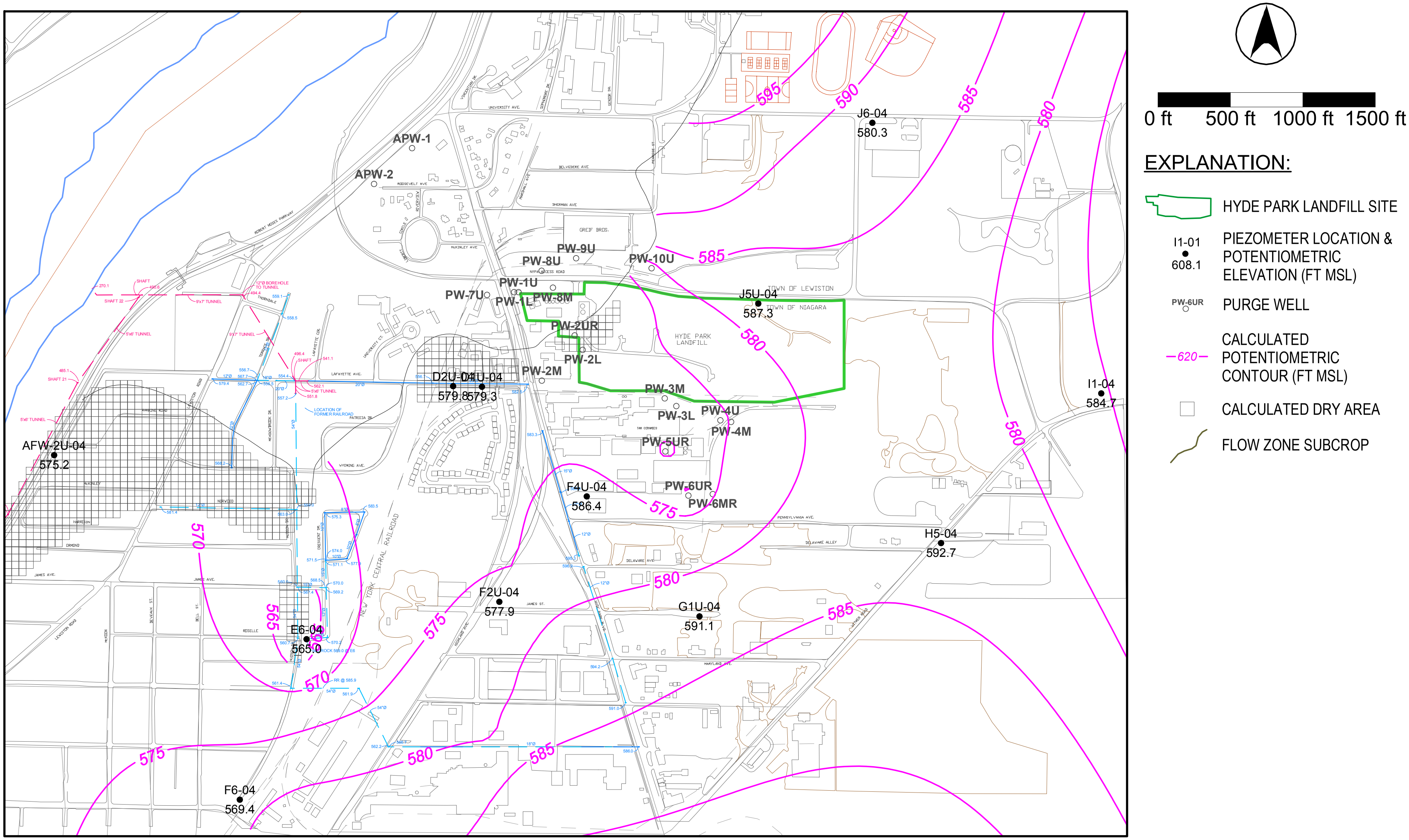

figure 5-22

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-04, PUMPING CONDITIONS - LOCAL SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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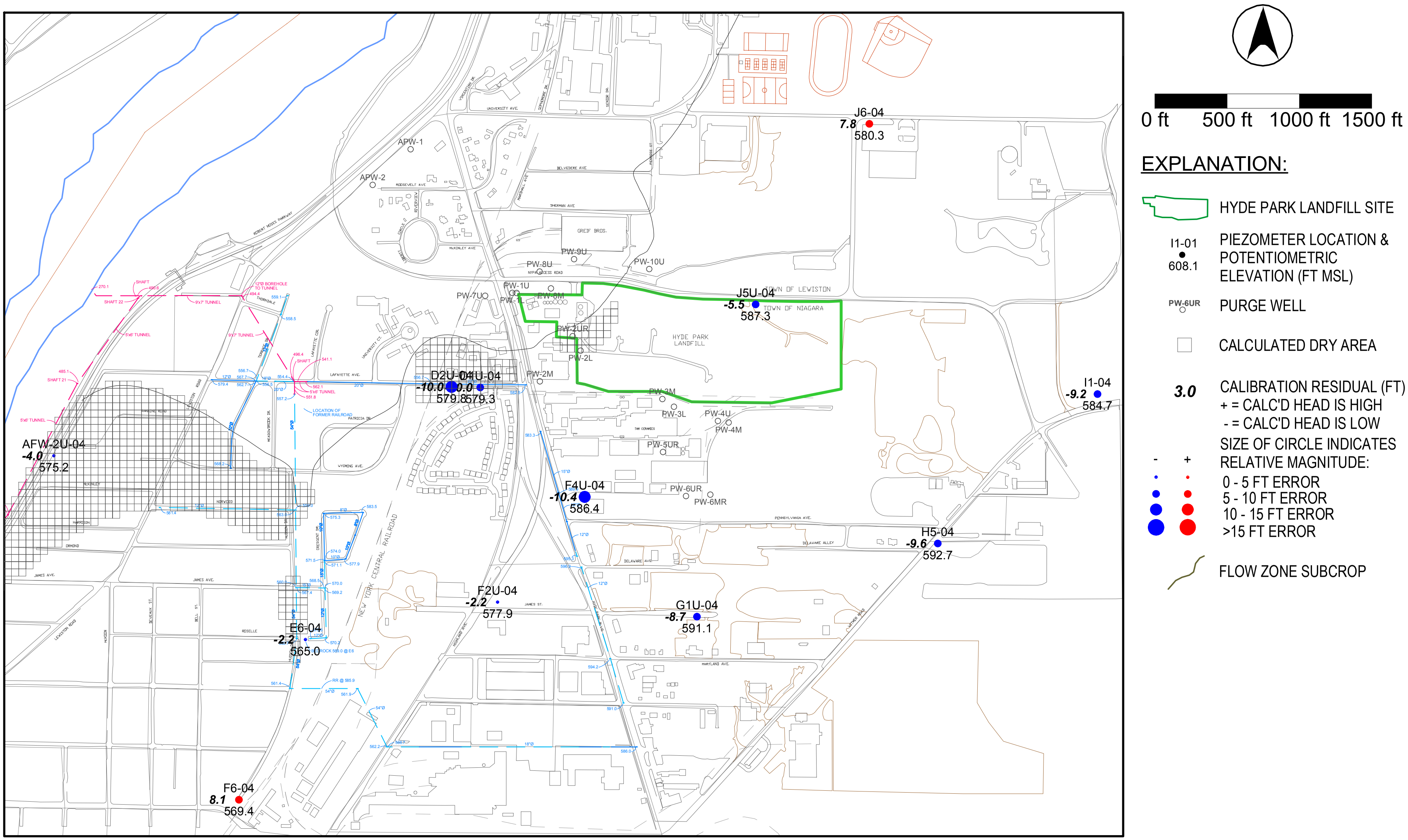

figure 5-23

CALIBRATION RESIDUALS IN FZ-04, PUMPING CONDITIONS

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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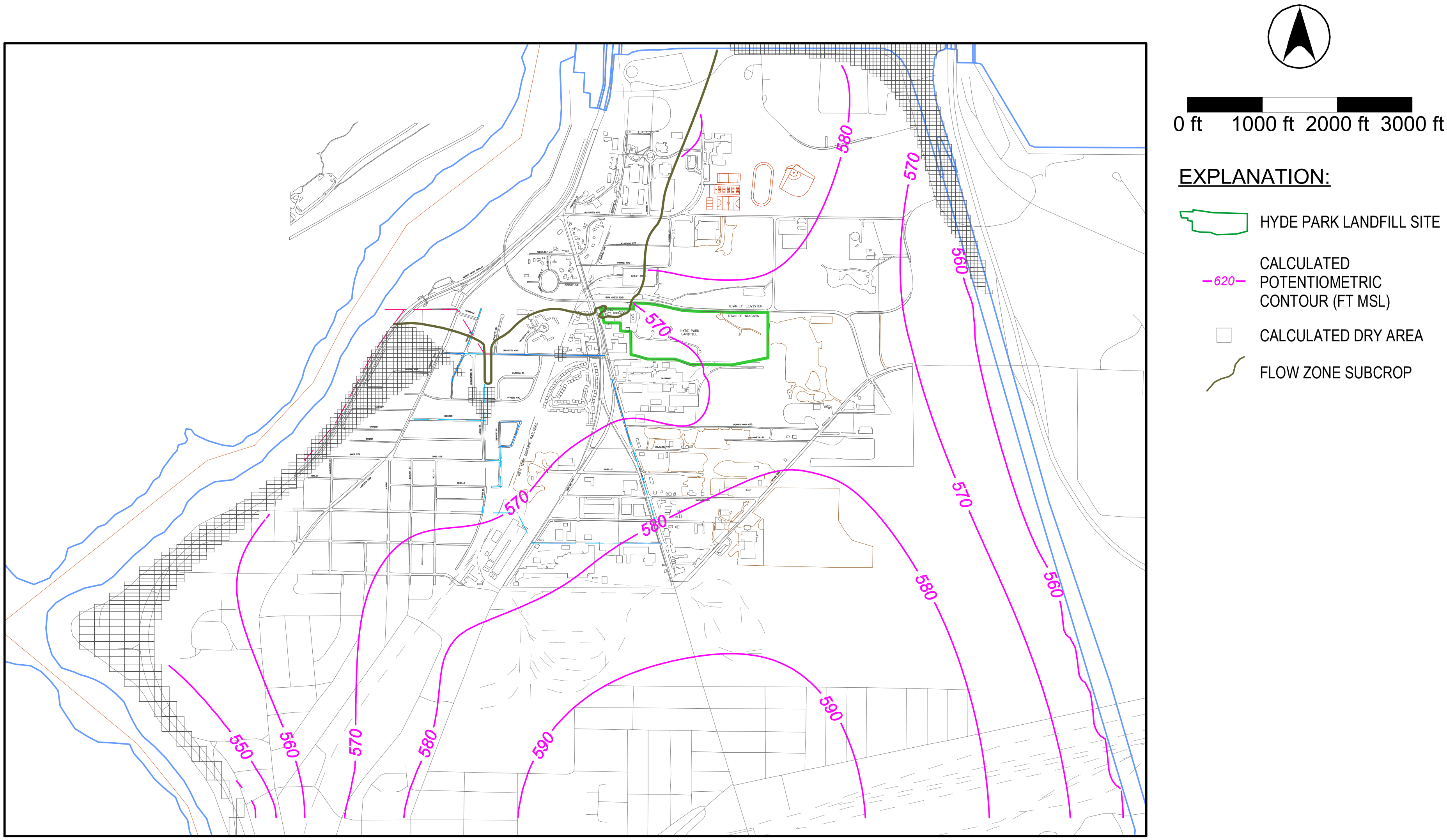

figure 5-24
CALCULATED POTENTIOMETRIC CONTOURS IN FZ-05, PUMPING CONDITIONS - REGIONAL
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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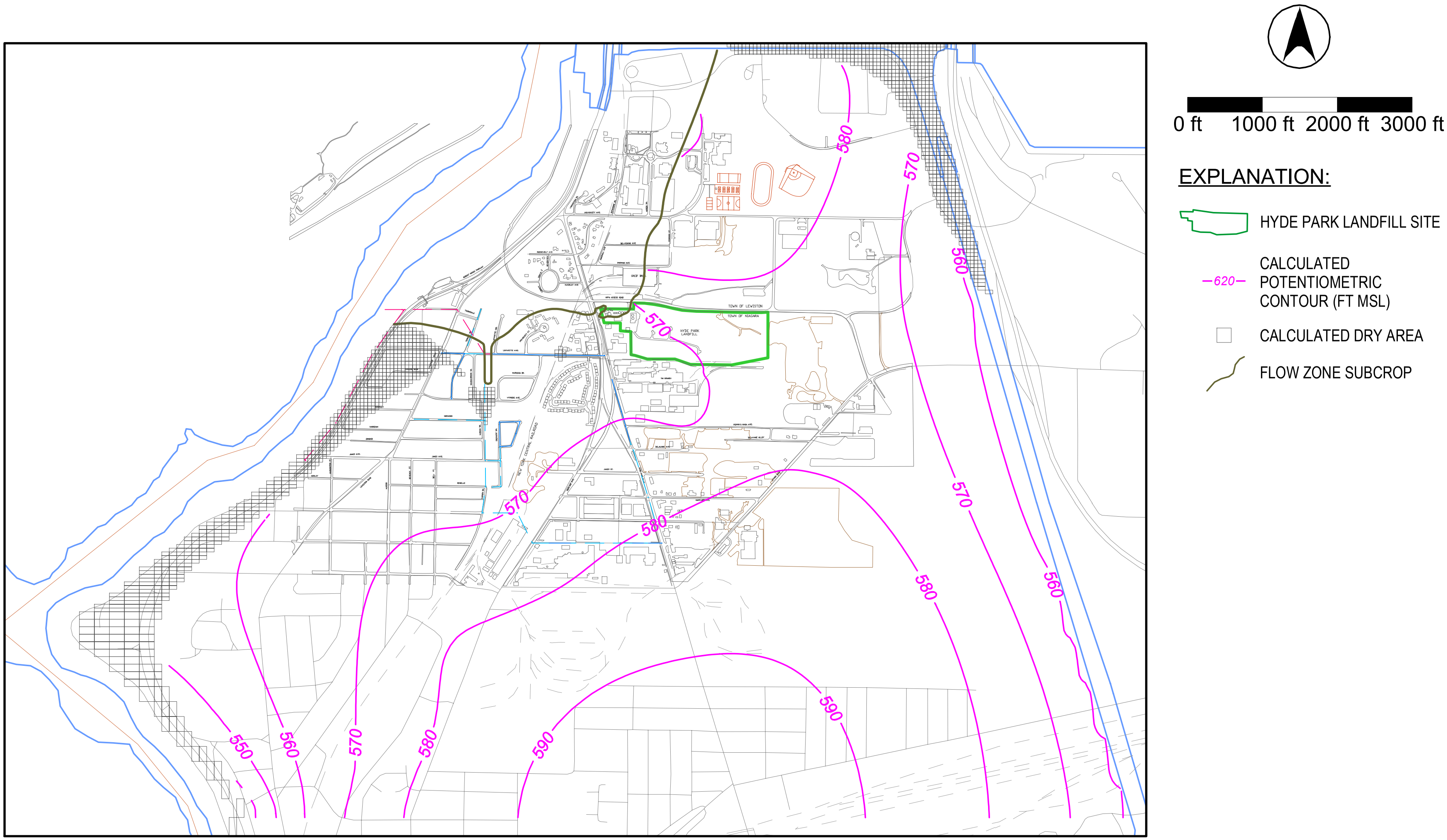

figure 5-24
CALCULATED POTENTIOMETRIC CONTOURS IN FZ-05, PUMPING CONDITIONS - REGIONAL
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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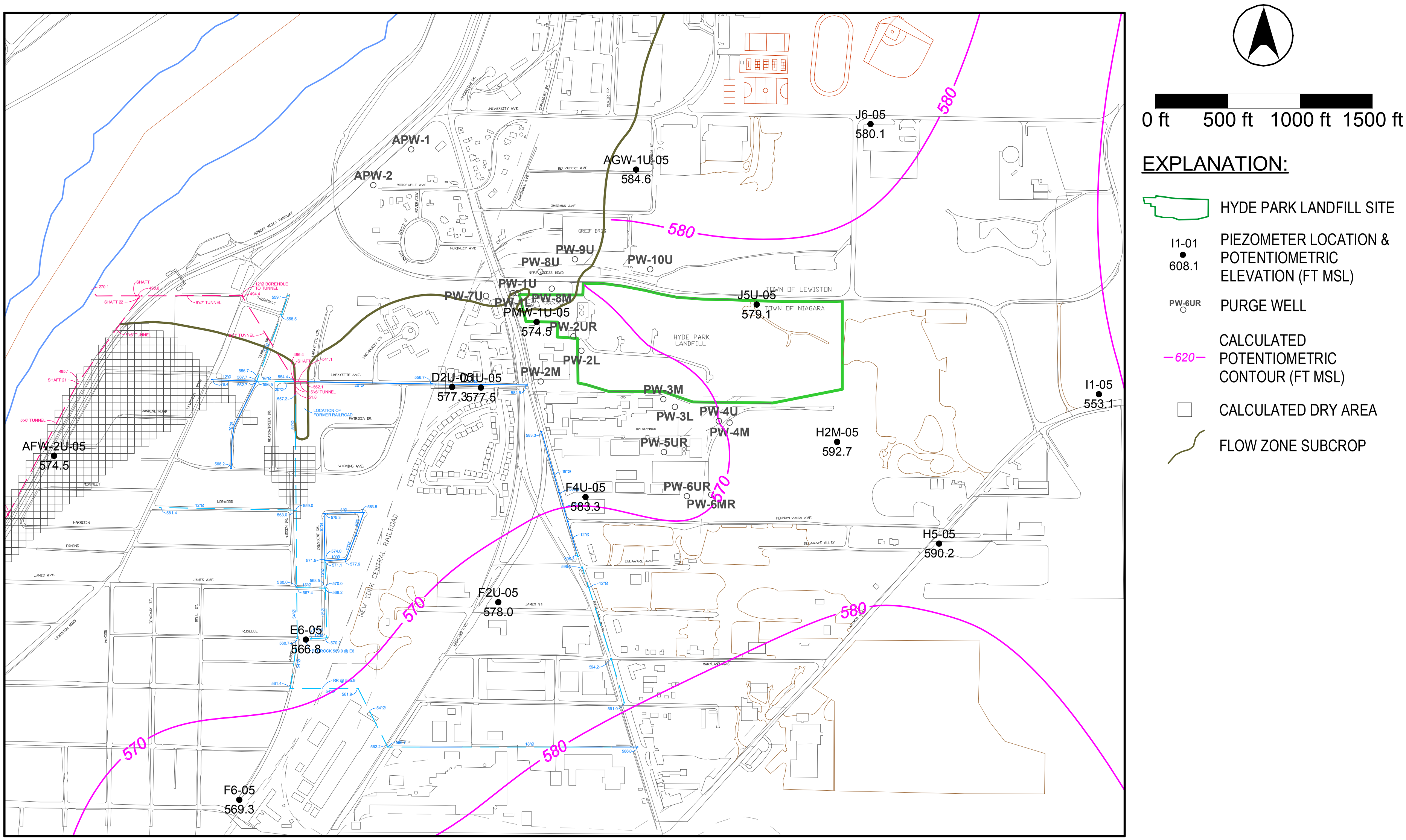

figure 5-25

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-05, PUMPING CONDITIONS - LOCAL SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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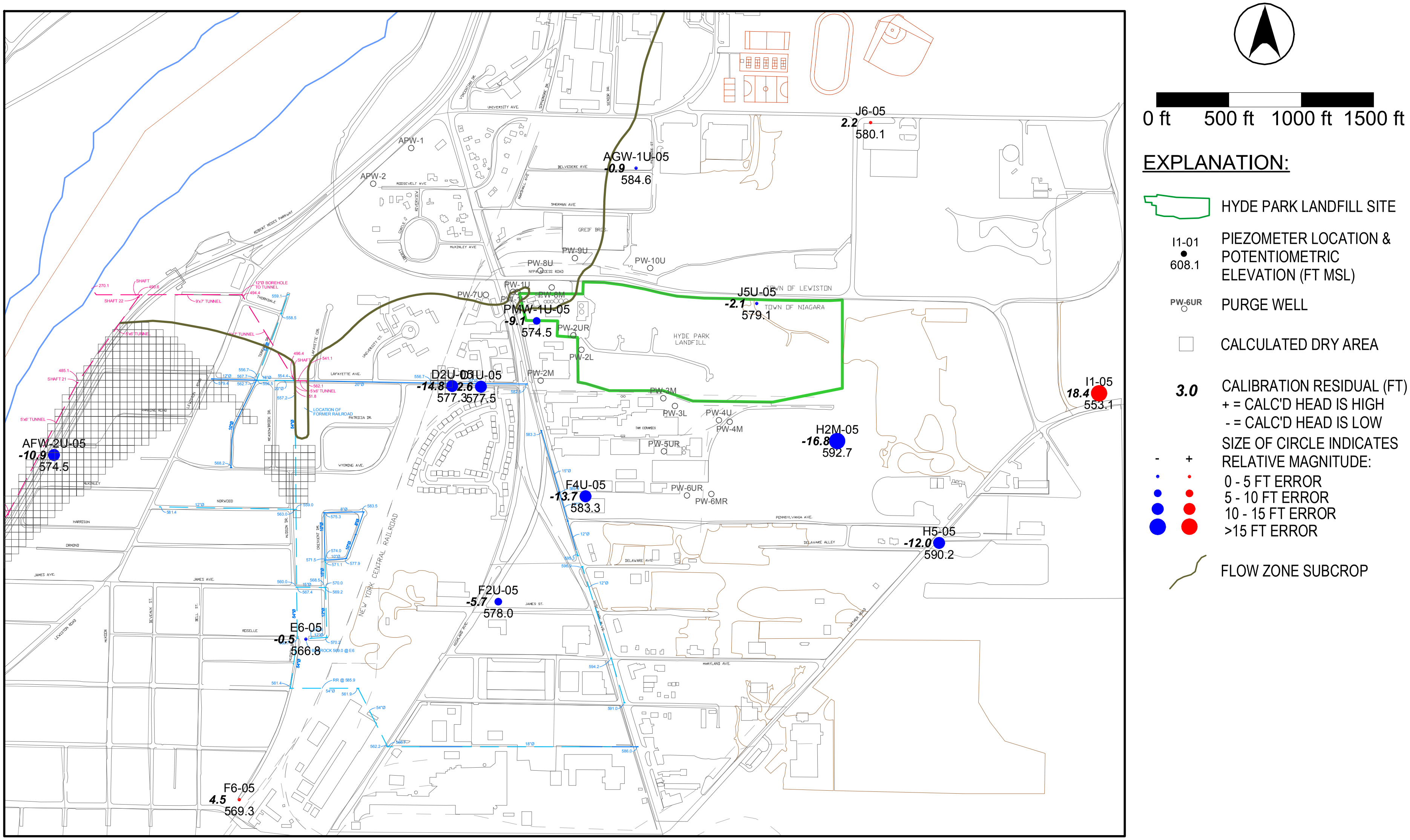

figure 5-26

CALCULATION RESIDUALS IN FZ-05, PUMPING CONDITIONS

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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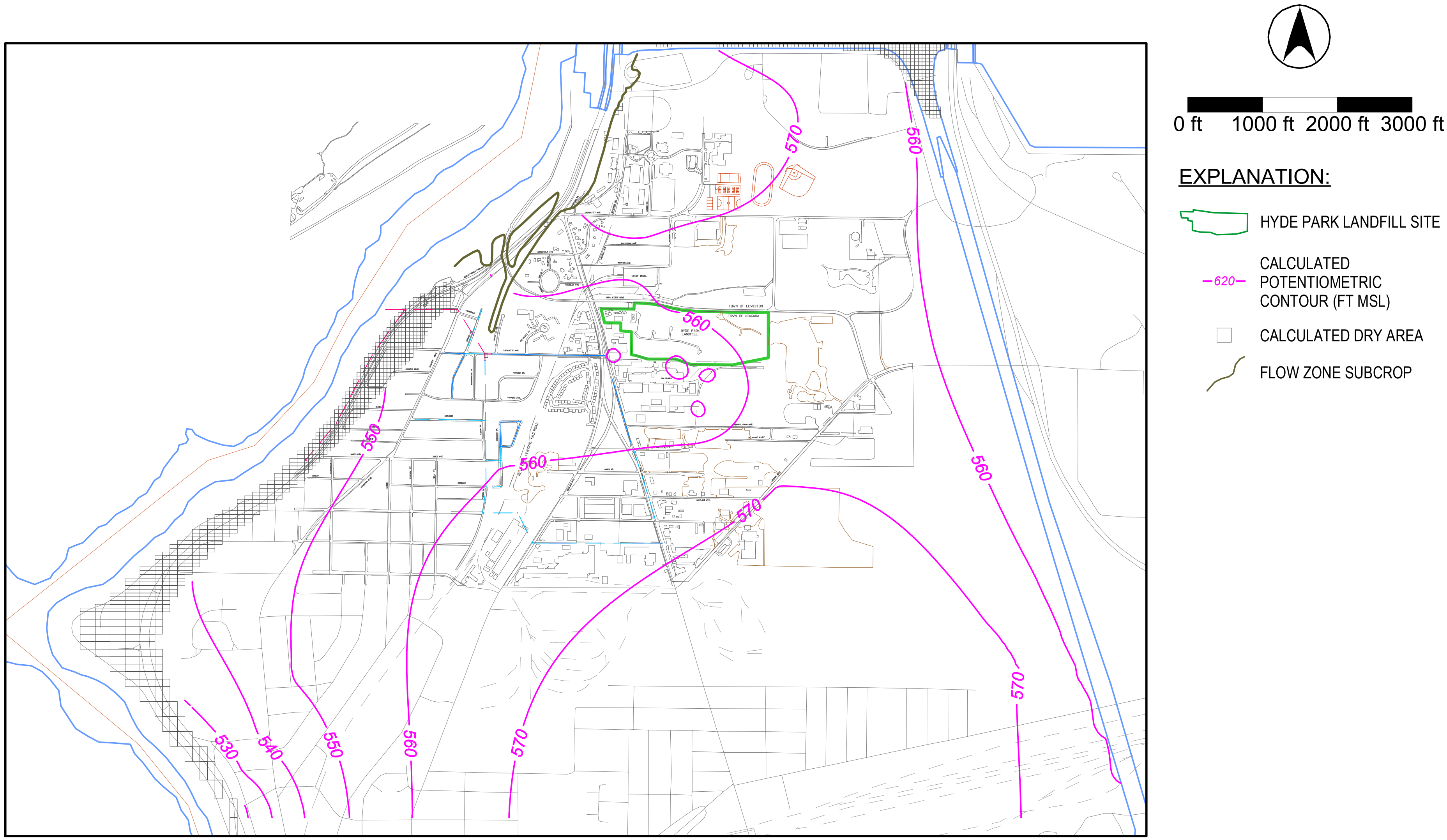

figure 5-27
CALCULATED POTENTIOMETRIC CONTOURS IN FZ-06, PUMPING CONDITIONS - REGIONAL
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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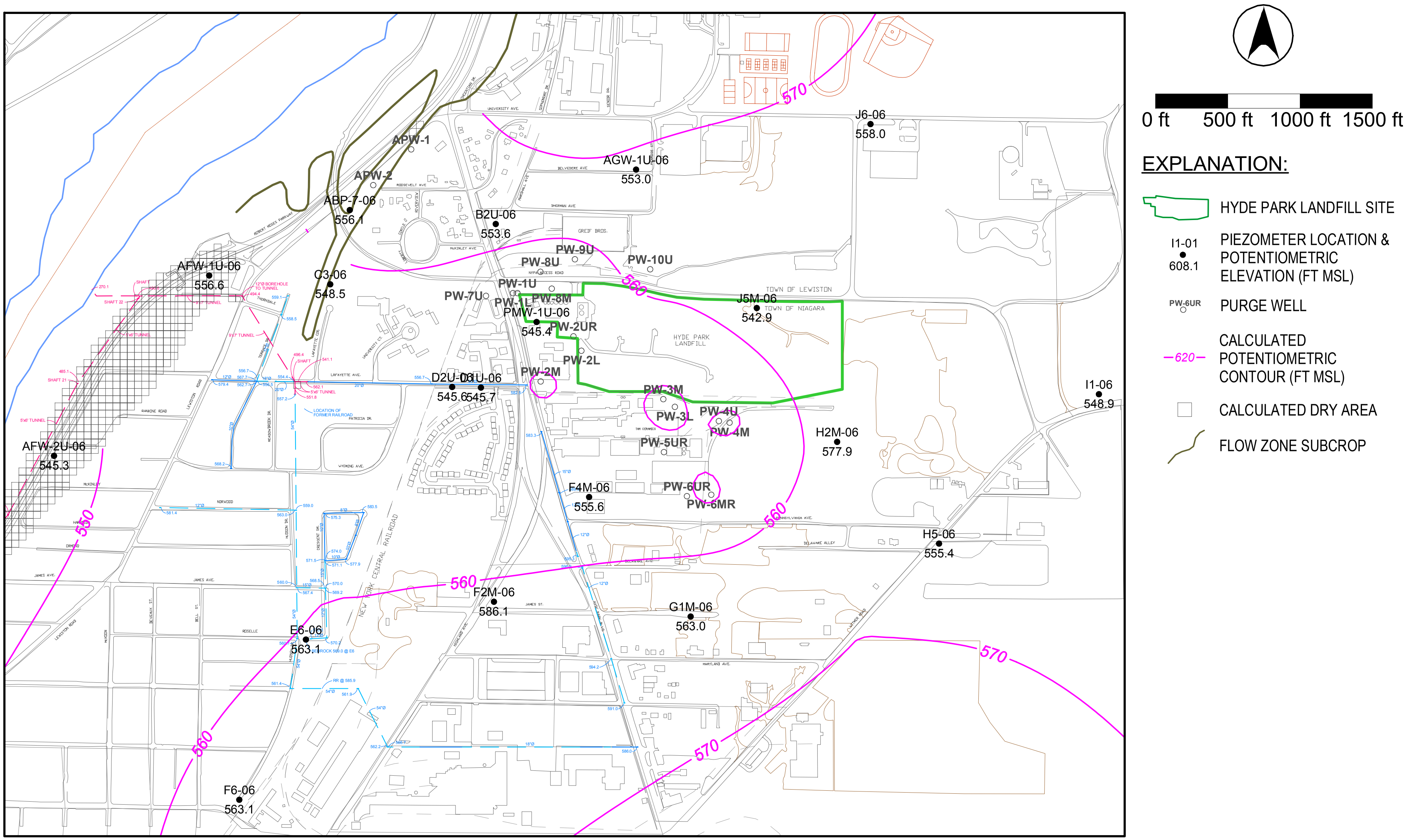

figure 5-28

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-06, PUMPING CONDITIONS - LOCAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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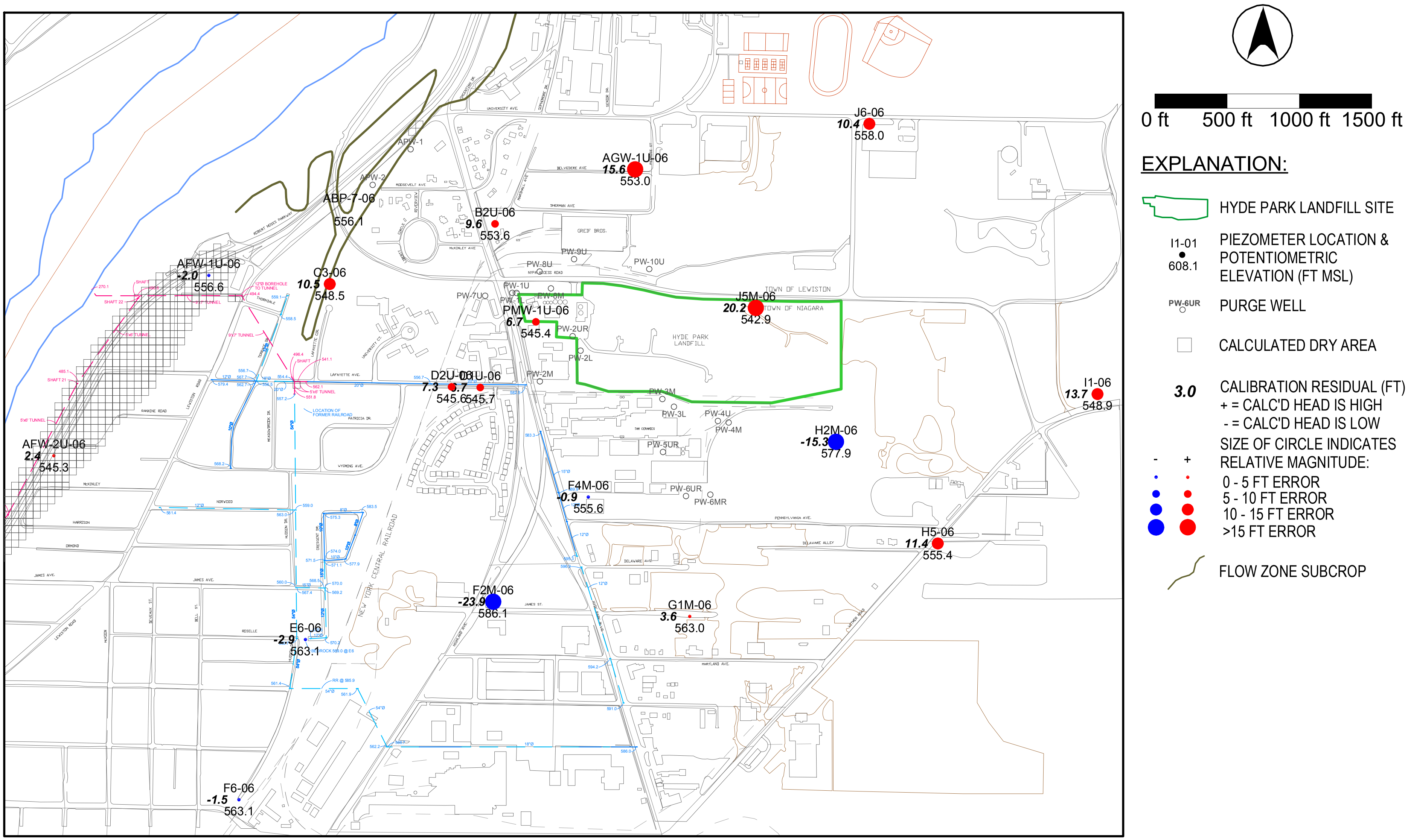

figure 5-29
CALIBRATION RESIDUALS IN FZ-06, PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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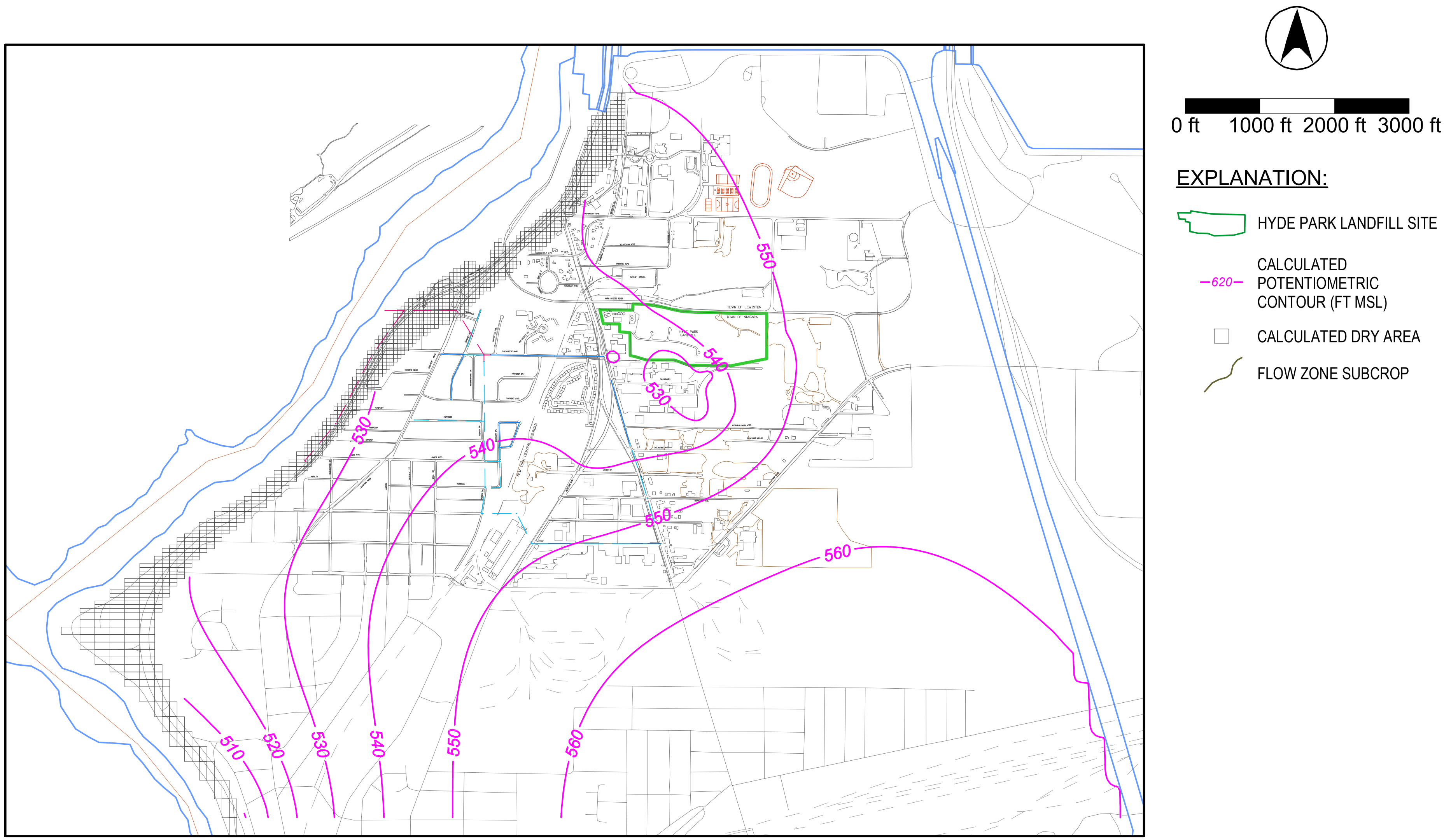

figure 5-30
CALCULATED POTENTIOMETRIC CONTOURS IN FZ-07, PUMPING CONDITIONS - REGIONAL
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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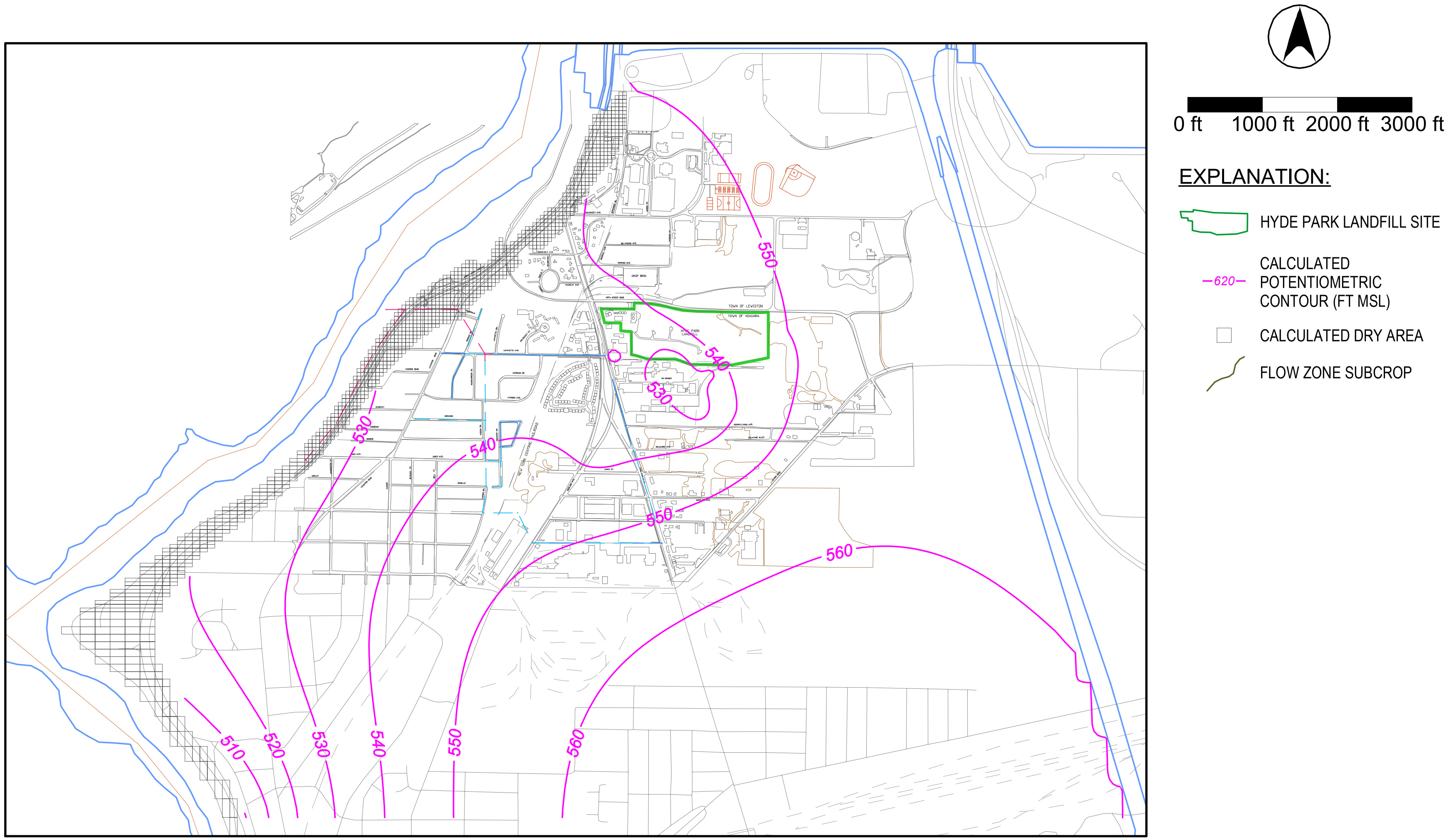

figure 5-30
CALCULATED POTENTIOMETRIC CONTOURS IN FZ-07, PUMPING CONDITIONS - REGIONAL
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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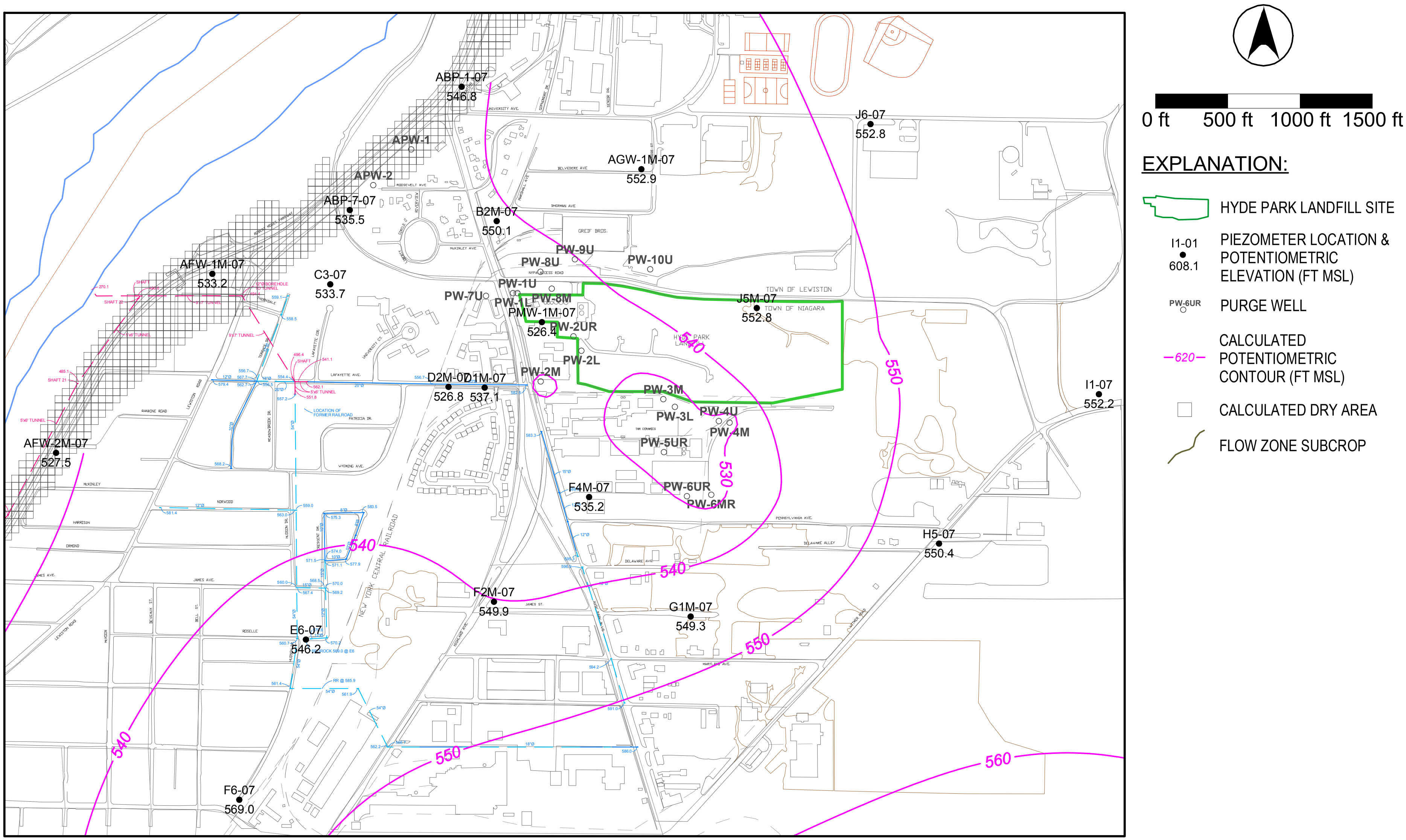

figure 5-31

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-07, PUMPING CONDITIONS - LOCAL
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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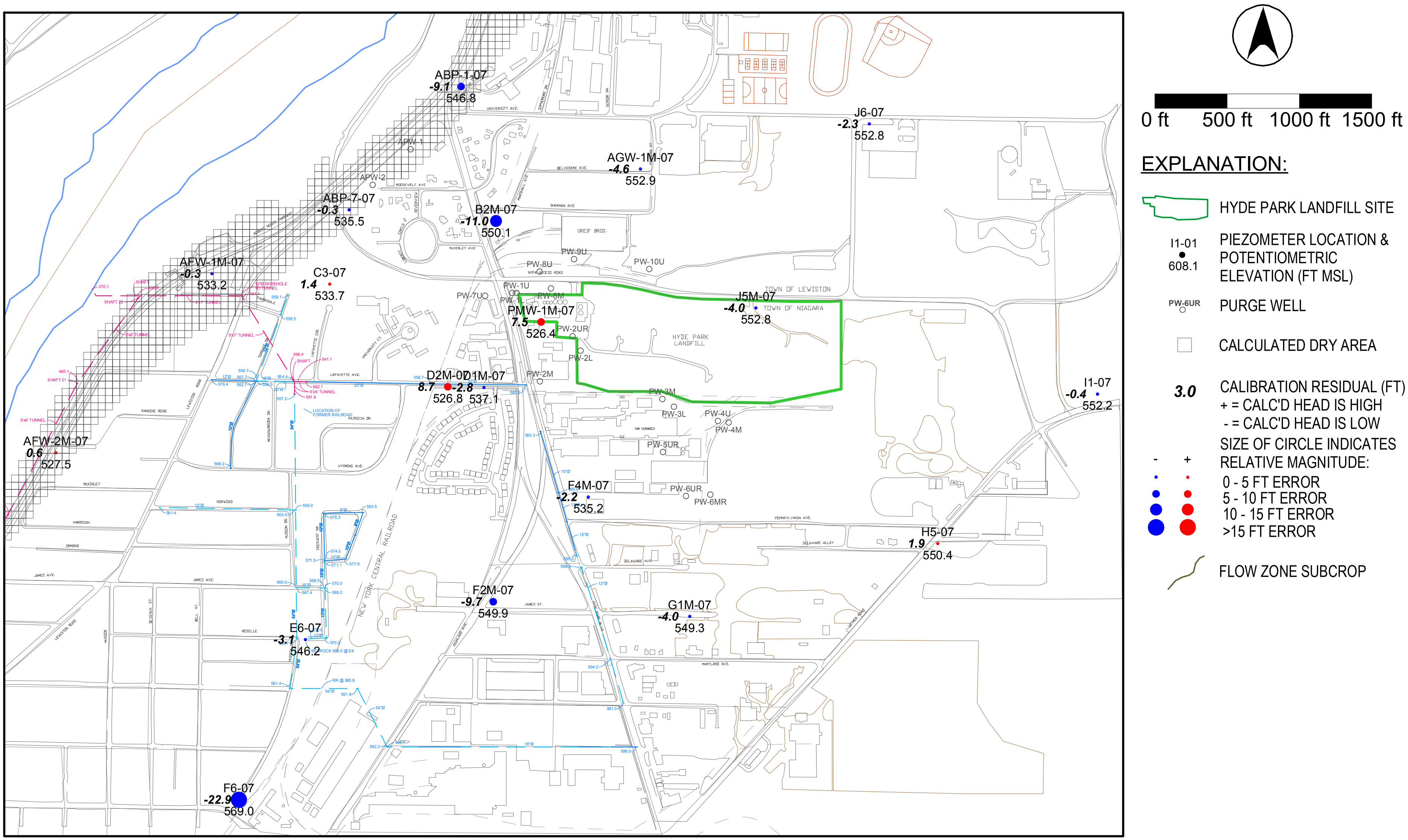

figure 5-32

CALIBRATION RESIDUALS IN FZ-07, PUMPING CONDITIONS

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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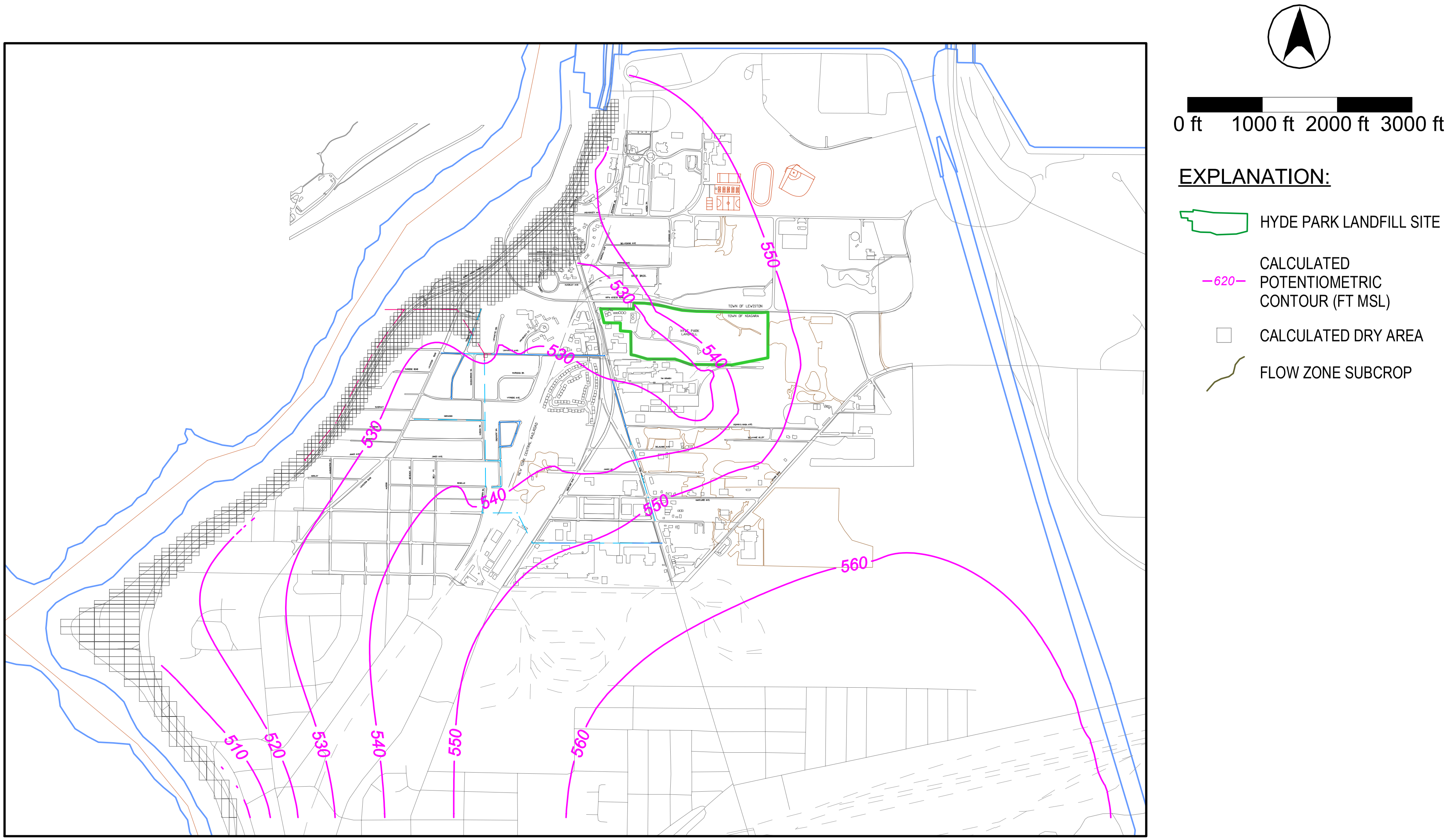

figure 5-33
CALCULATED POTENTIOMETRIC CONTOURS IN FZ-08, PUMPING CONDITIONS - REGIONAL
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\f05_33_hp011p_fz08_wls_r.srf

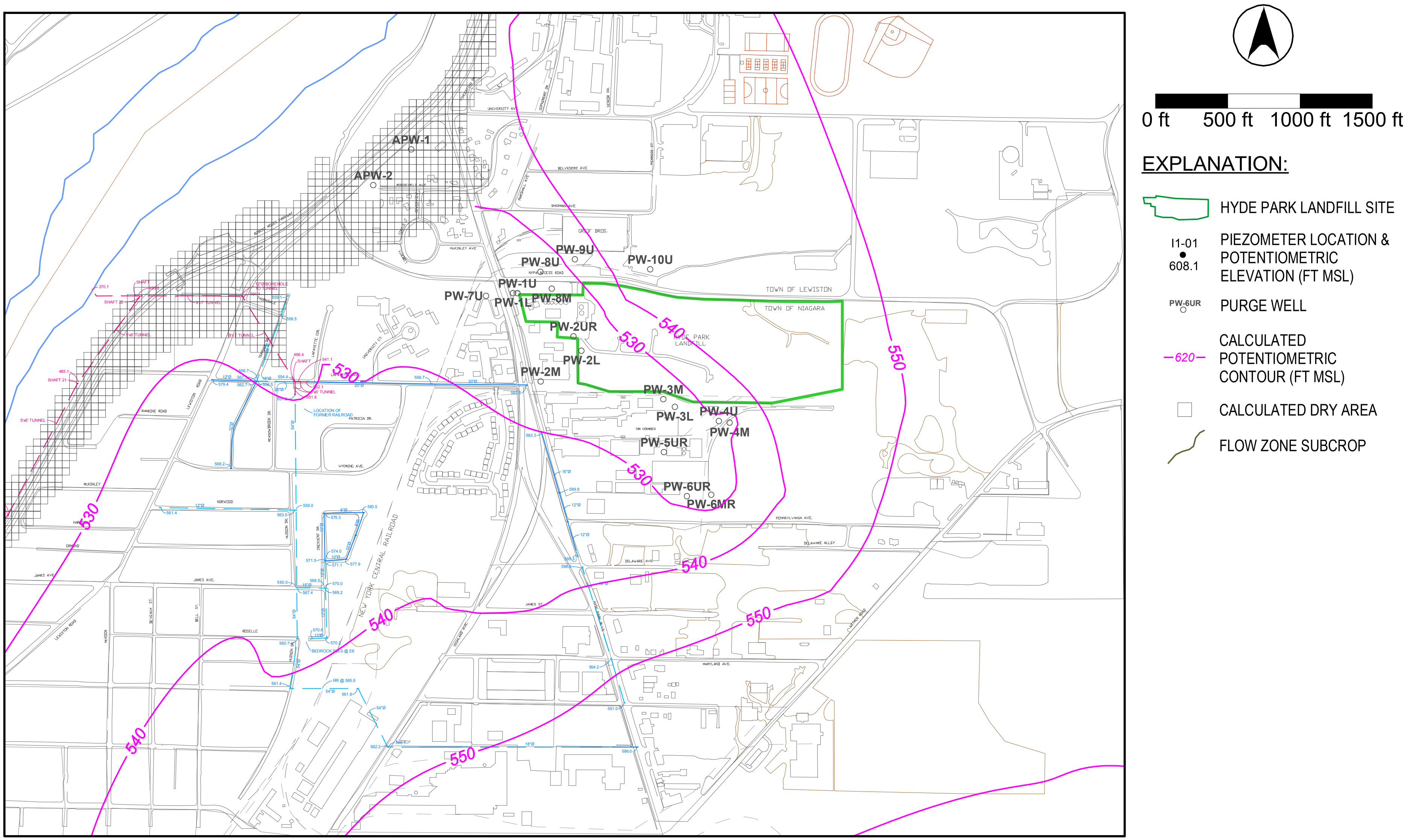

figure 5-34

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-08, PUMPING CONDITIONS - LOCAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\f05_34_hp011p_fz08_wls.srf

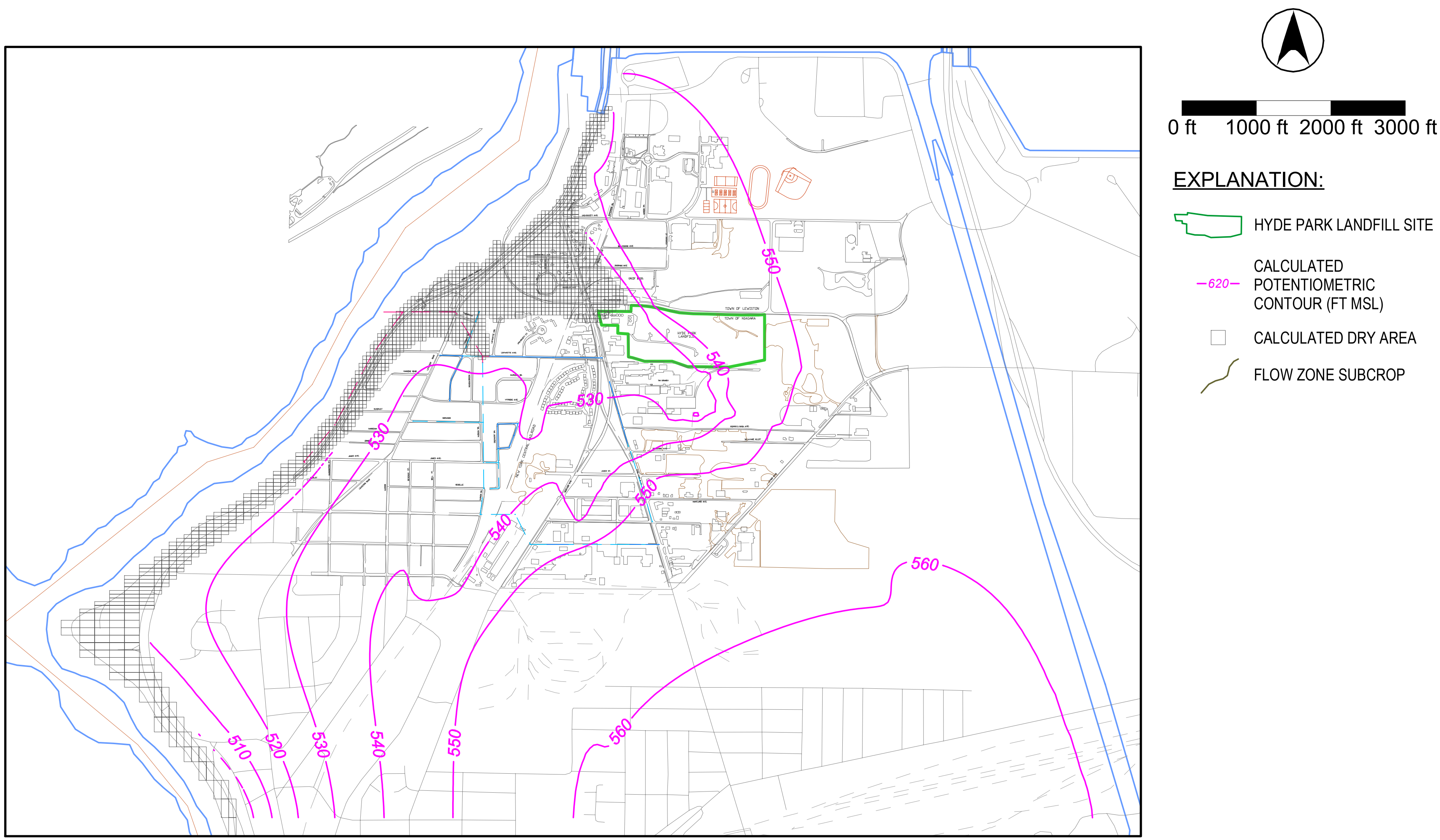

figure 5-35
CALCULATED POTENTIOMETRIC CONTOURS IN FZ-09, PUMPING CONDITIONS - REGIONAL
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

27-May-2003 d:\sspa\projects\ssp610\model3\f05_35_hp011p_fz09_wls_r.srf

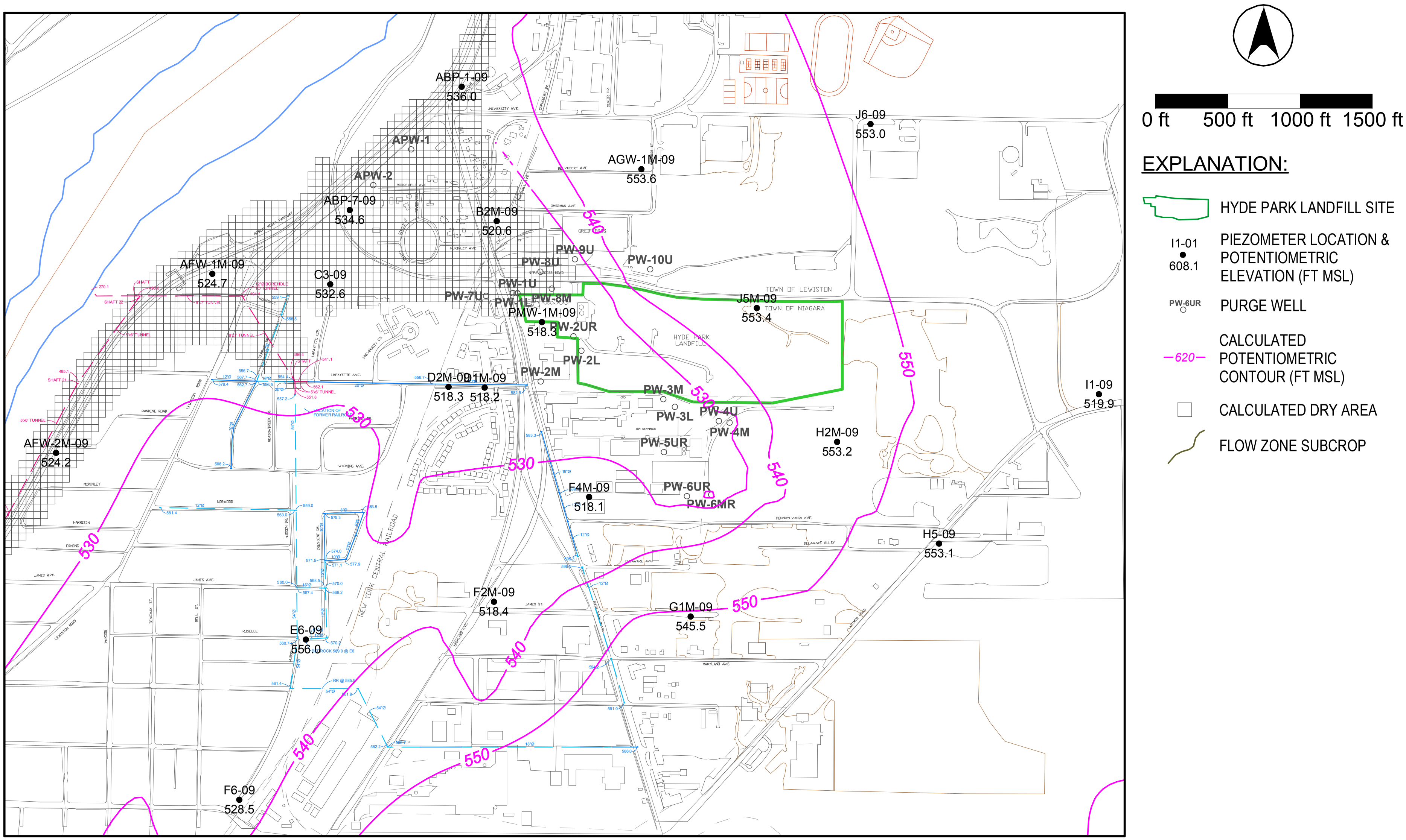

figure 5-36

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-09, PUMPING CONDITIONS - LOCAL SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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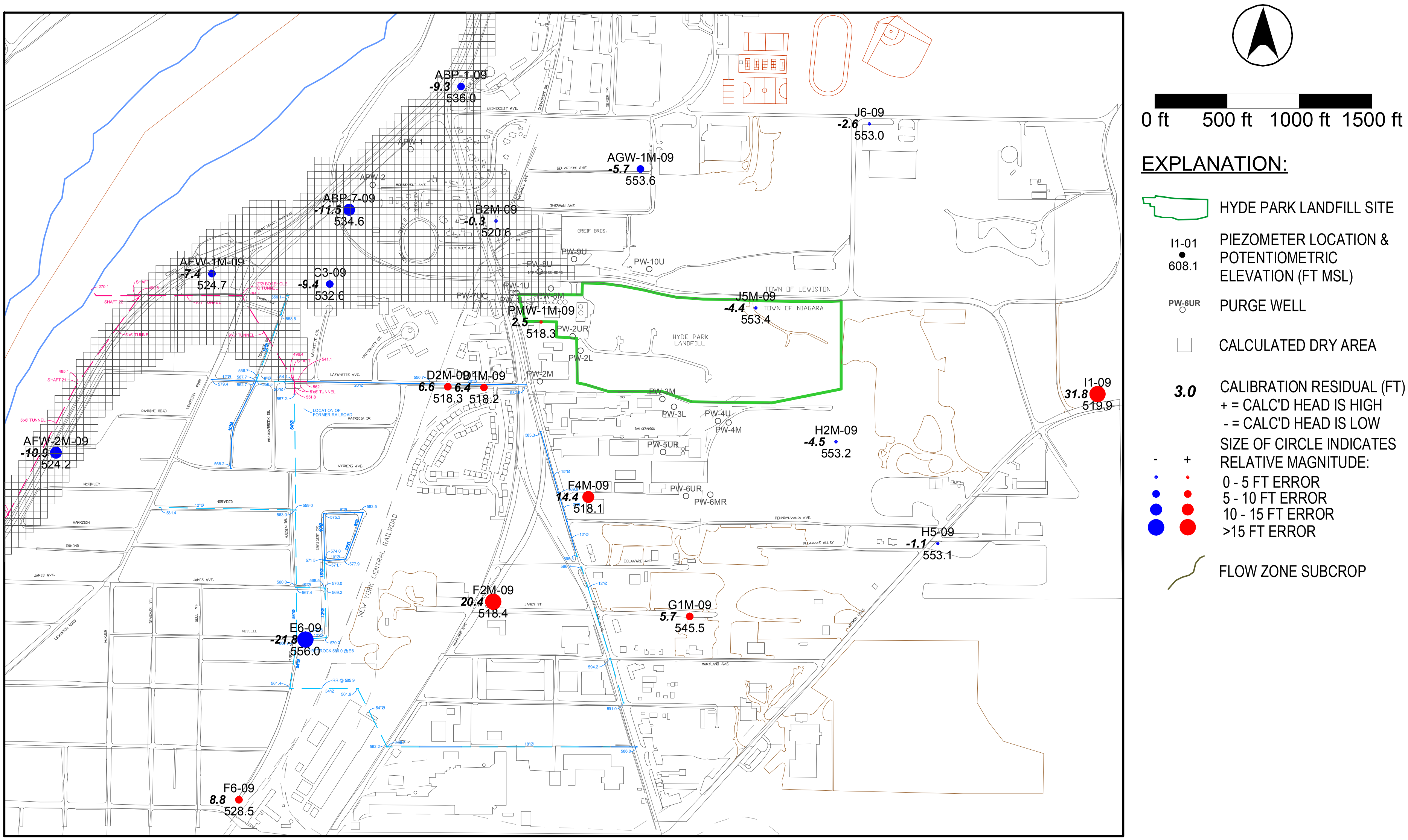

figure 5-37

CALIBRATION RESIDUALS IN FZ-09, PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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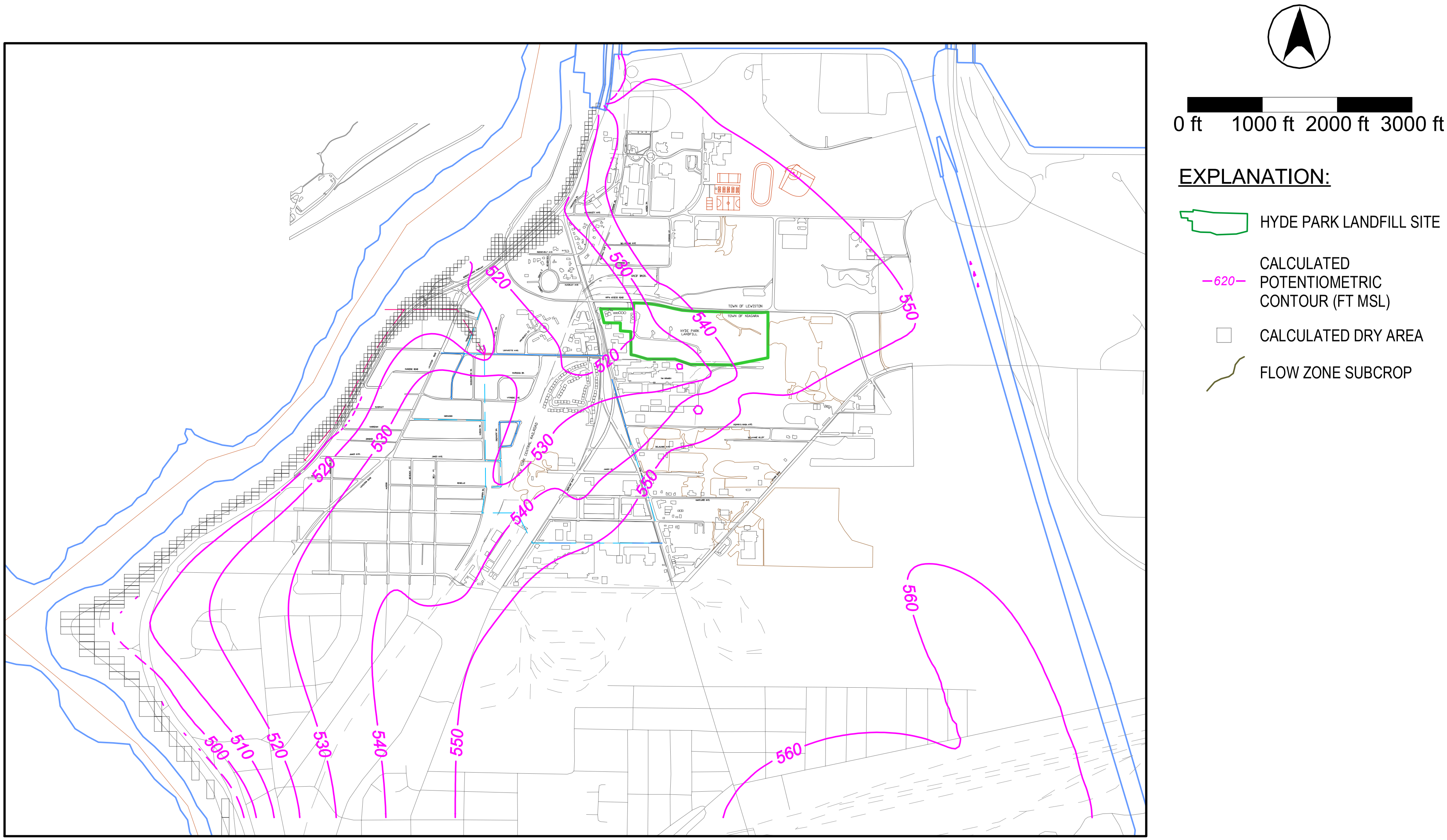

figure 5-38

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-10, PUMPING CONDITIONS - REGIONAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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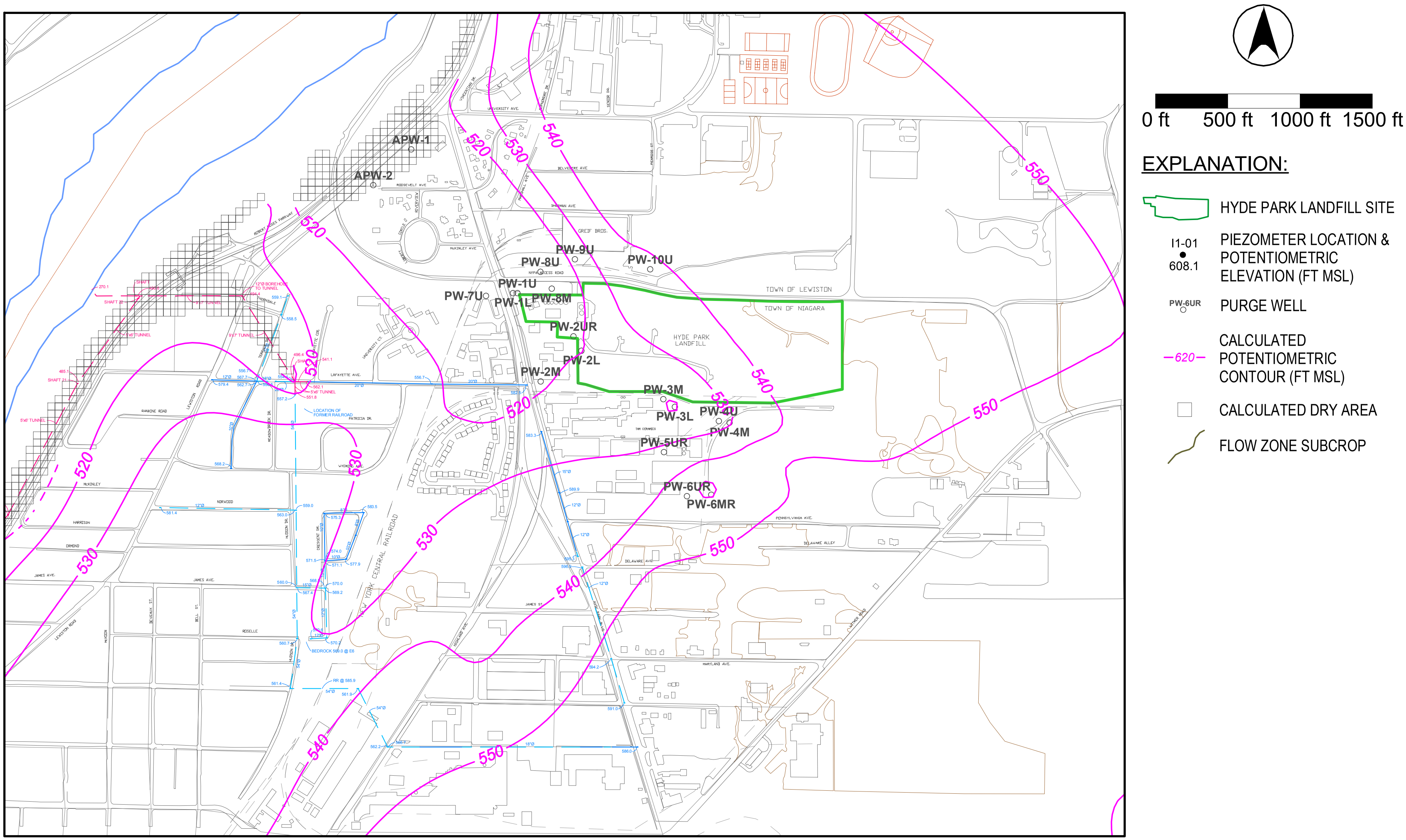

figure 5-39

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-10, PUMPING CONDITIONS - LOCAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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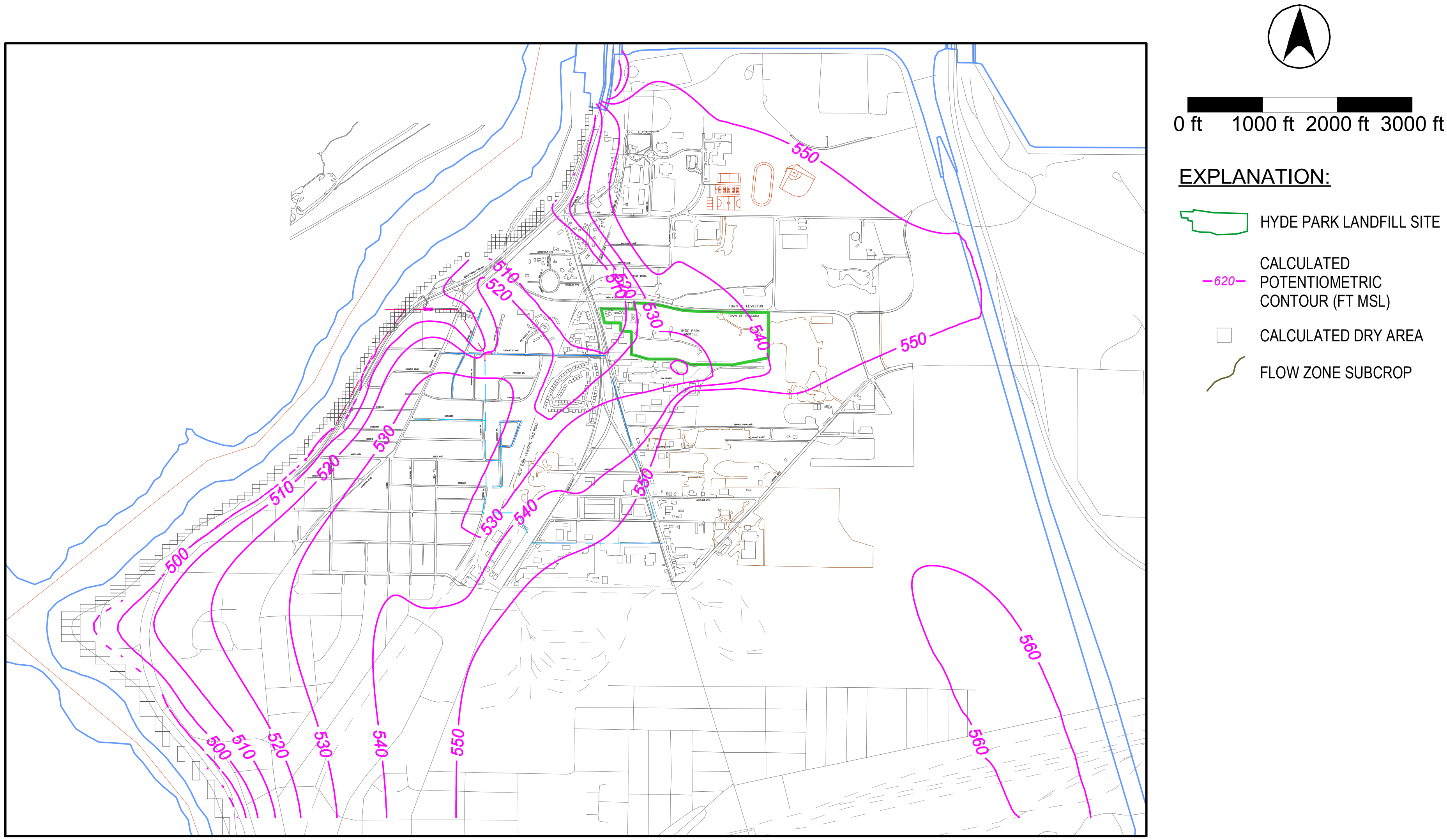

figure 5-40

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-11, PUMPING CONDITIONS - REGIONAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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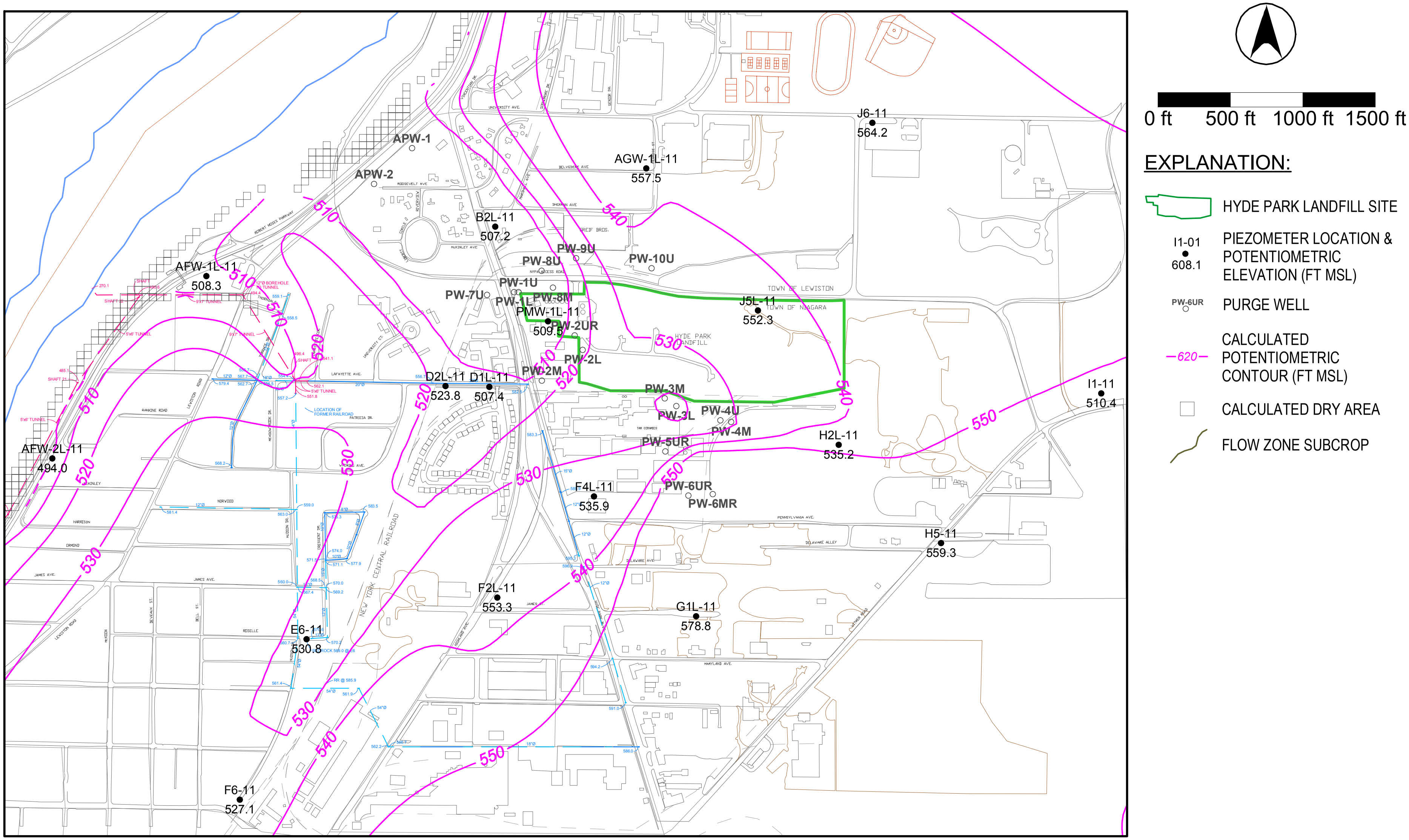

figure 5-41

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-11, PUMPING CONDITIONS - LOCAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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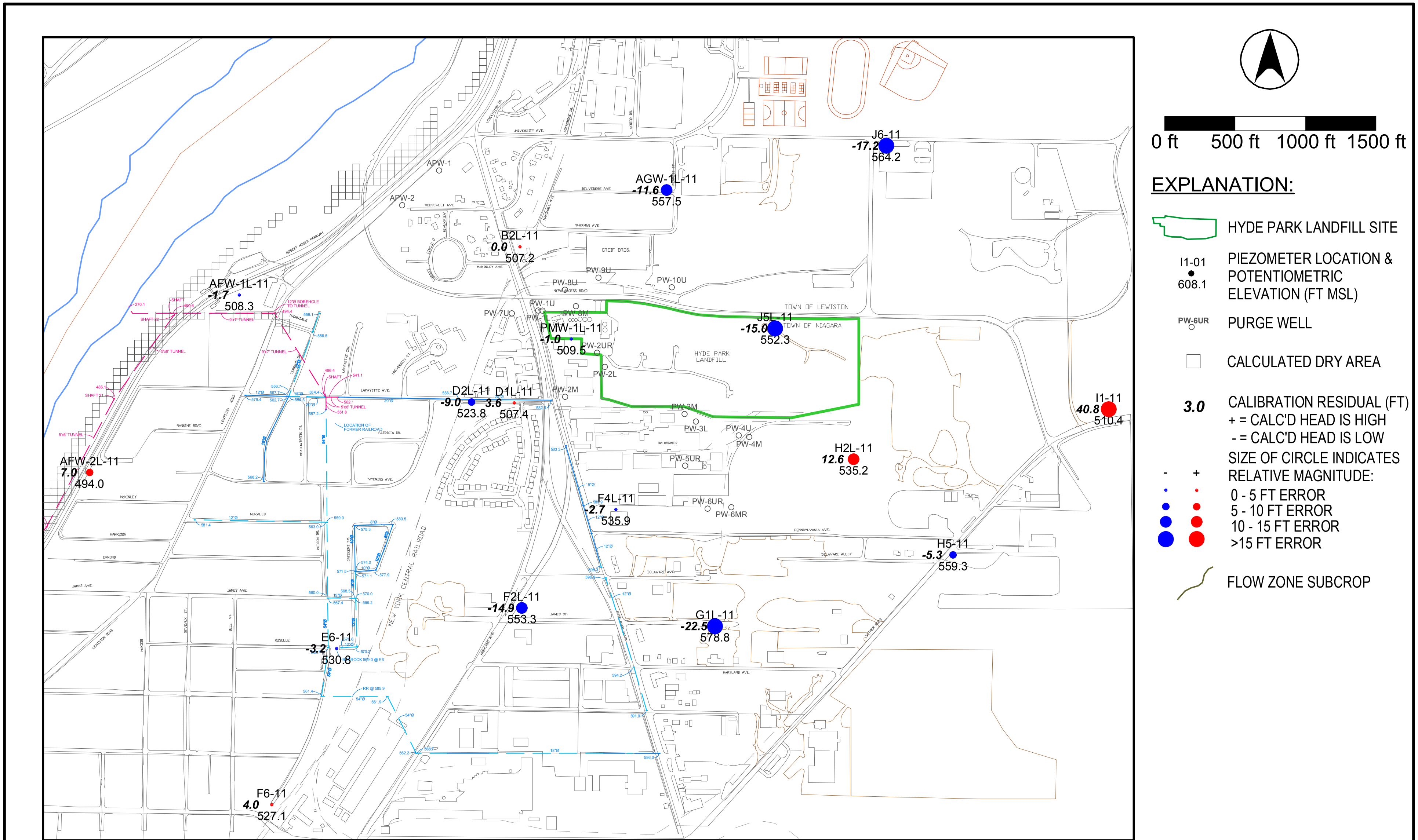

figure 5-42
CALIBRATION RESIDUALS IN FZ-11, PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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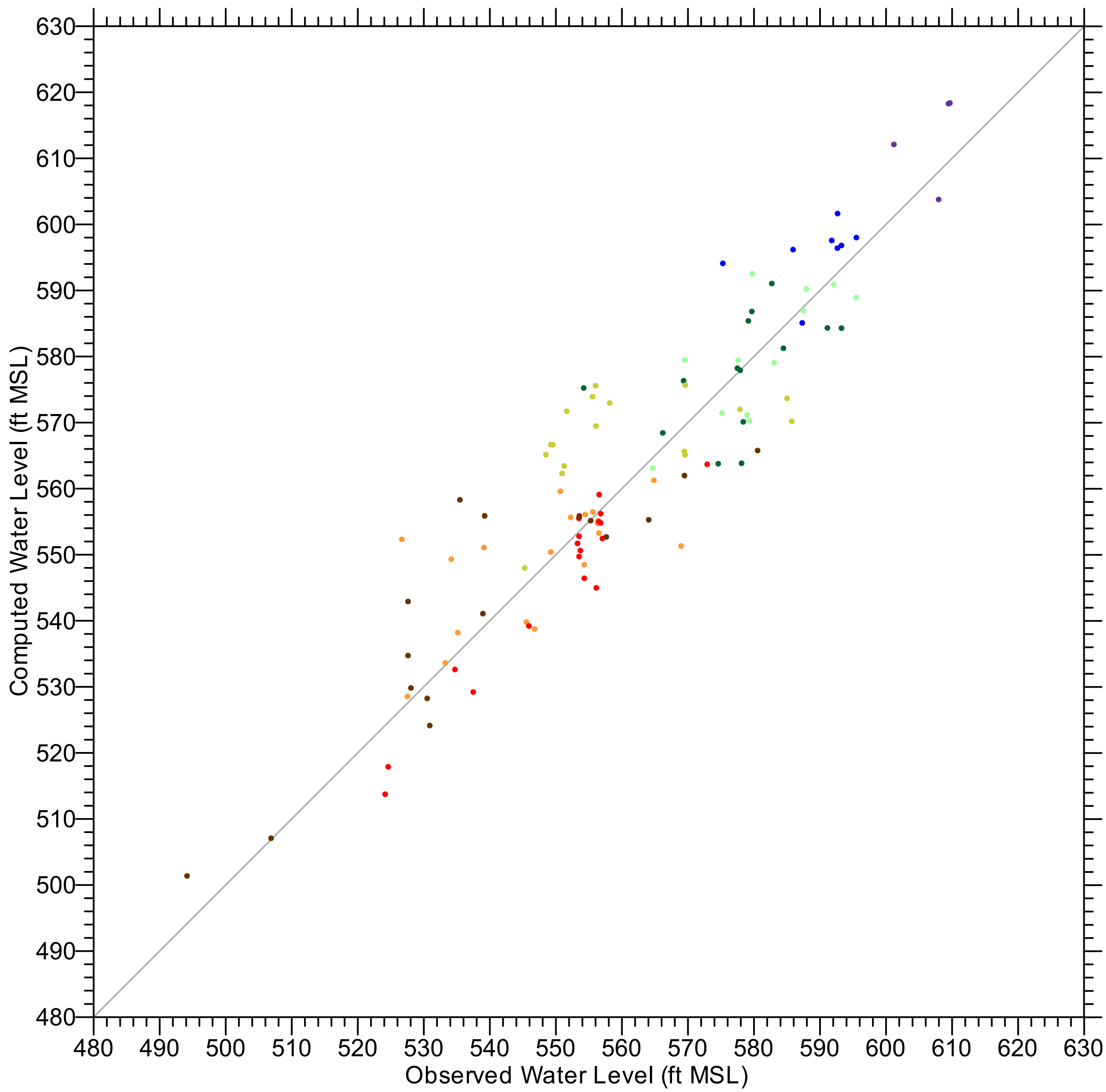

EXPLANATION:

- FZ-01
- FZ-02
- FZ-04
- FZ-05
- FZ-06
- FZ-07
- FZ-09
- FZ-11
- Line of Equality

figure 5-43
CALCULATED VERSUS OBSERVED WATER LEVELS; NON-PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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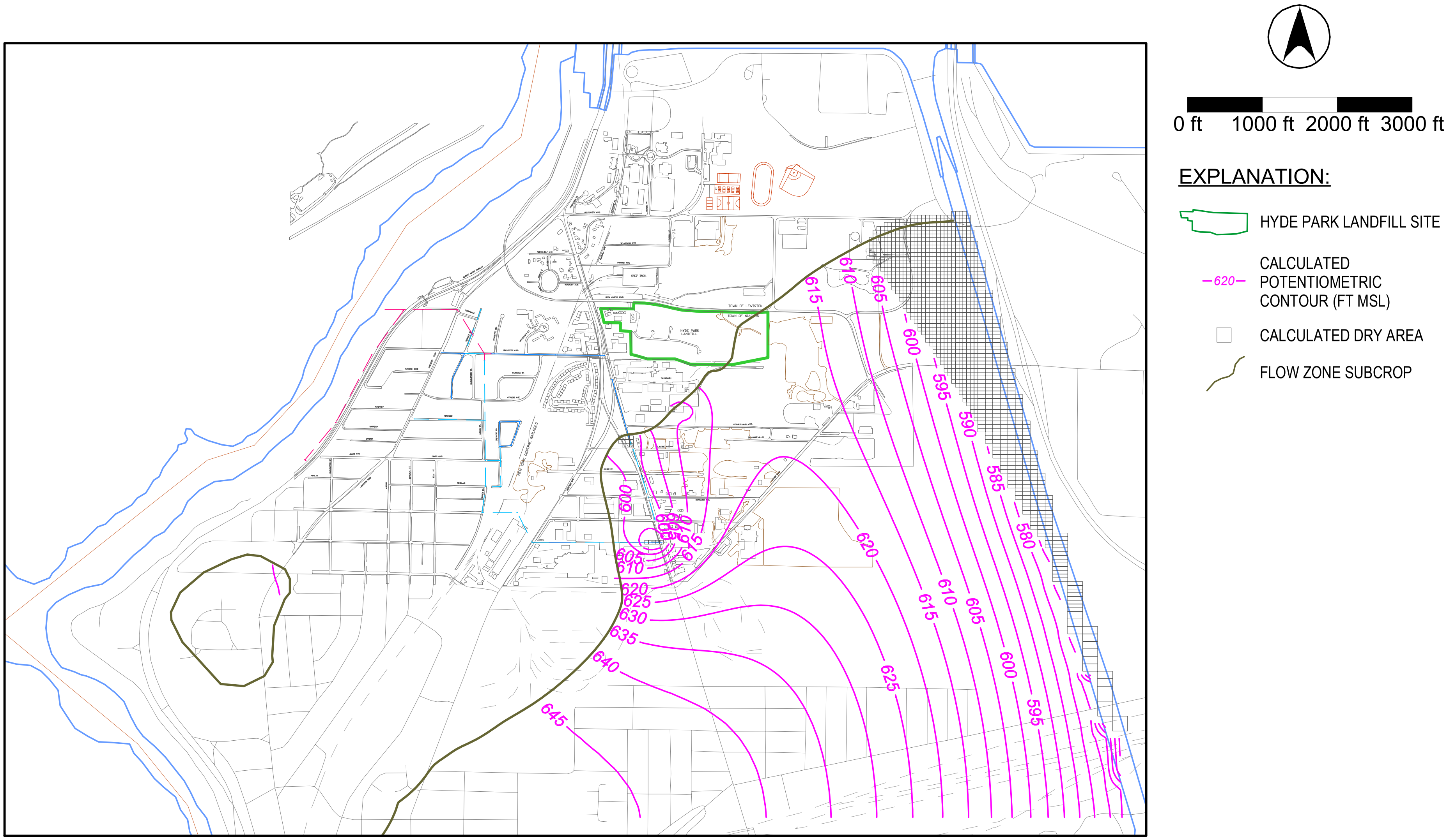

figure 5-44

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-01, NON-PUMPING CONDITIONS - REGIONAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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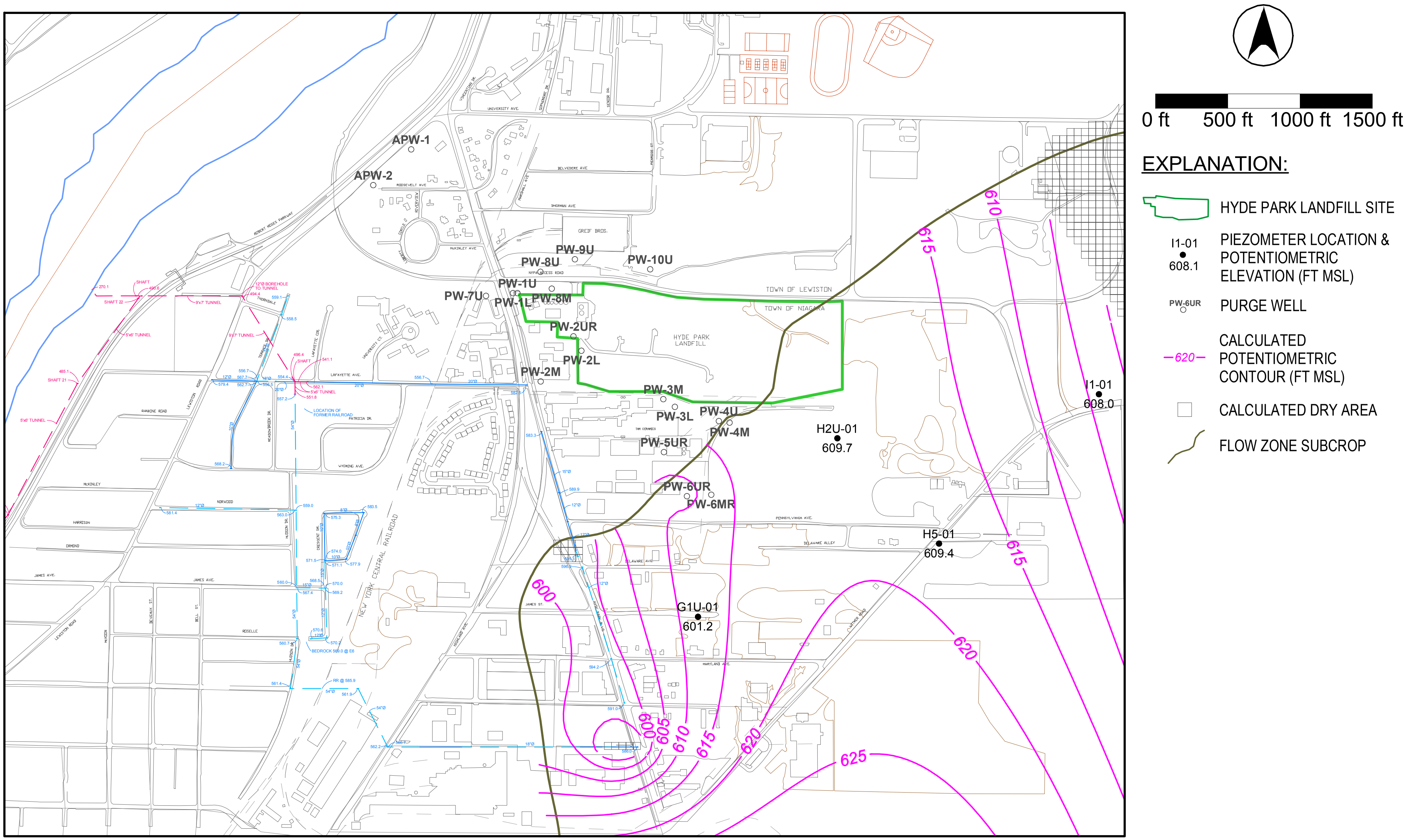

figure 5-45

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-01, NON-PUMPING CONDITIONS - LOCAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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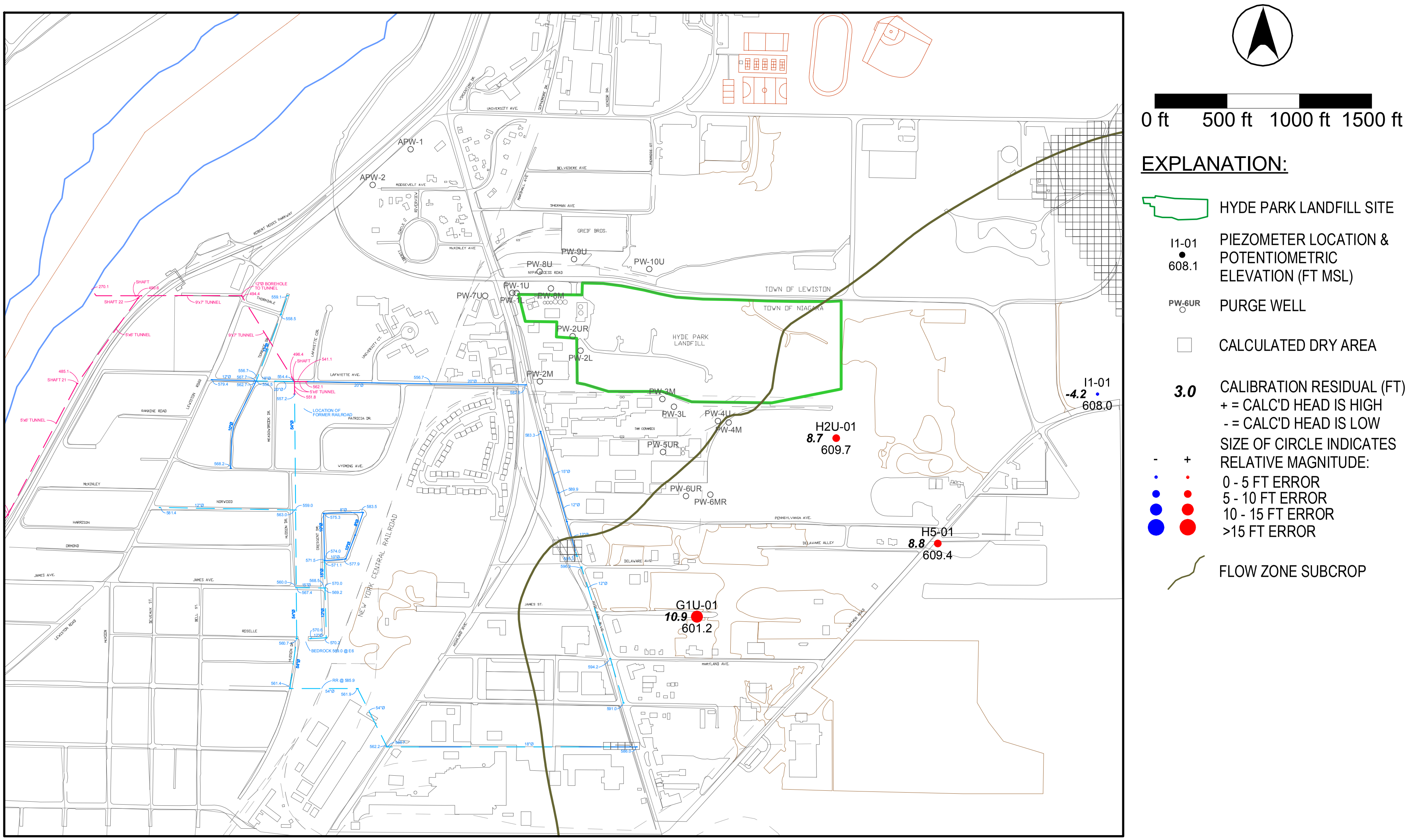

figure 5-46

CALIBRATION RESIDUALS IN FZ-01, NON-PUMPING CONDITIONS

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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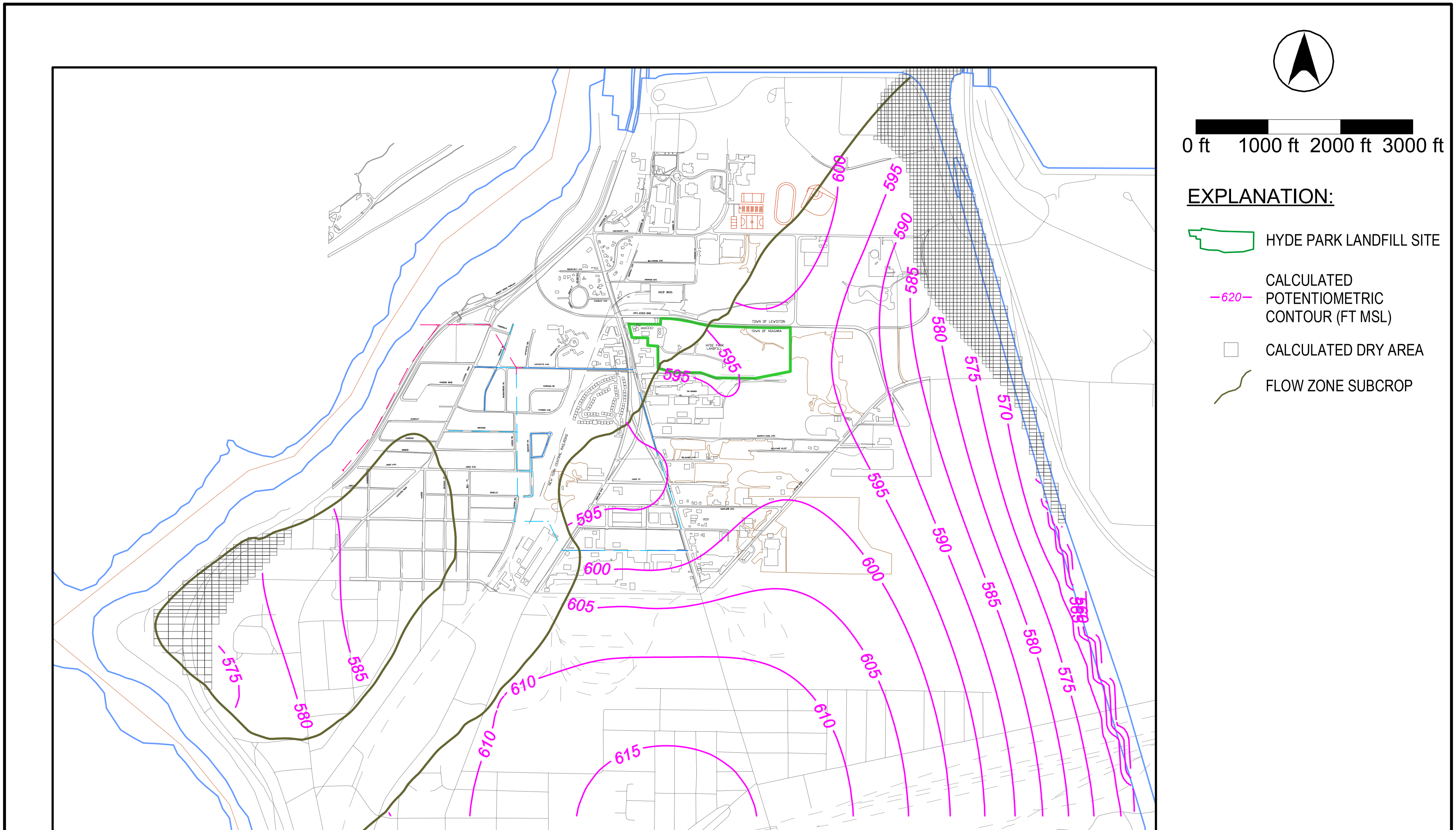

figure 5-47
CALCULATED POTENTIOMETRIC CONTOURS IN FZ-02, NON-PUMPING CONDITIONS - REGIONAL
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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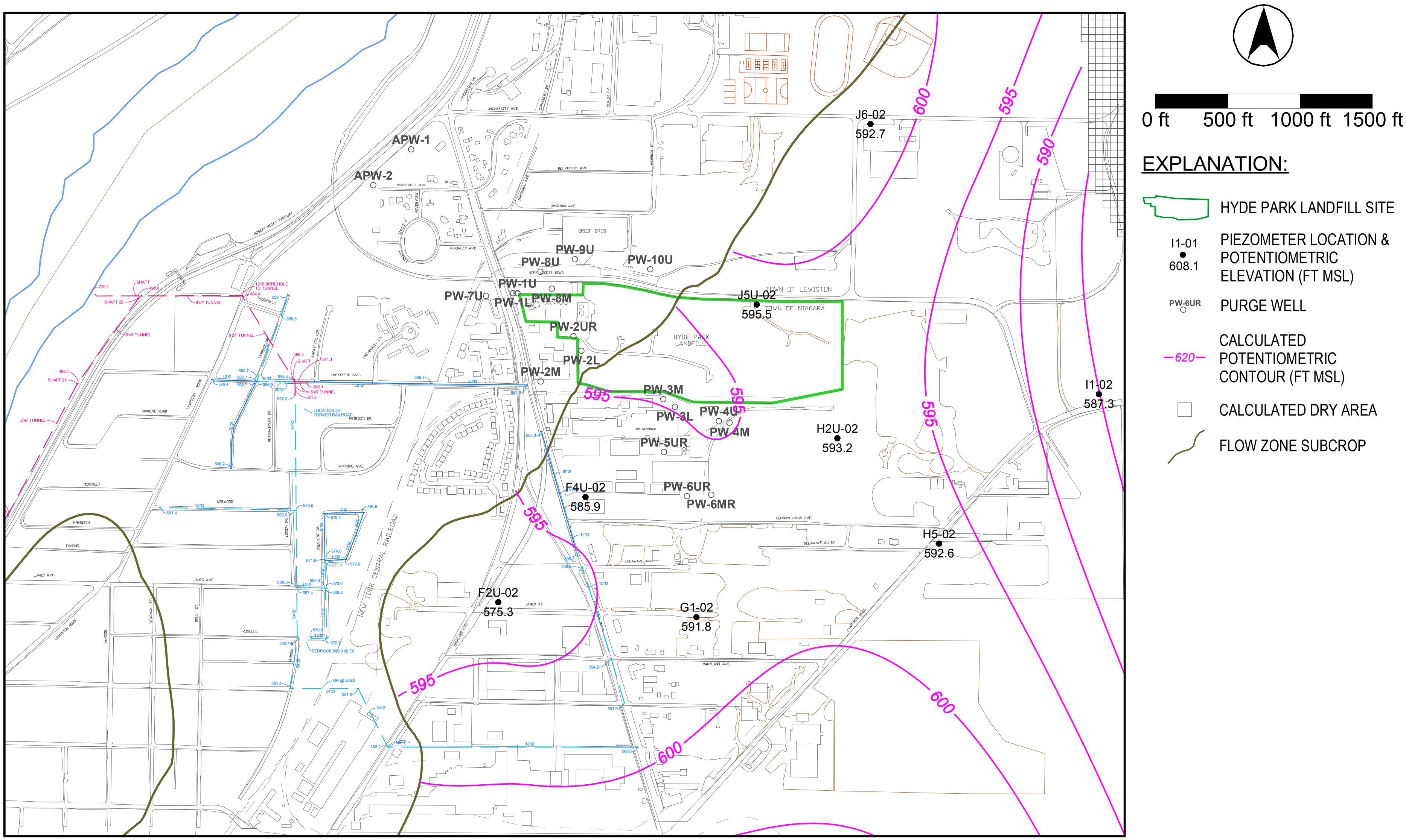

figure 5-48

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-02, NON-PUMPING CONDITIONS - LOCAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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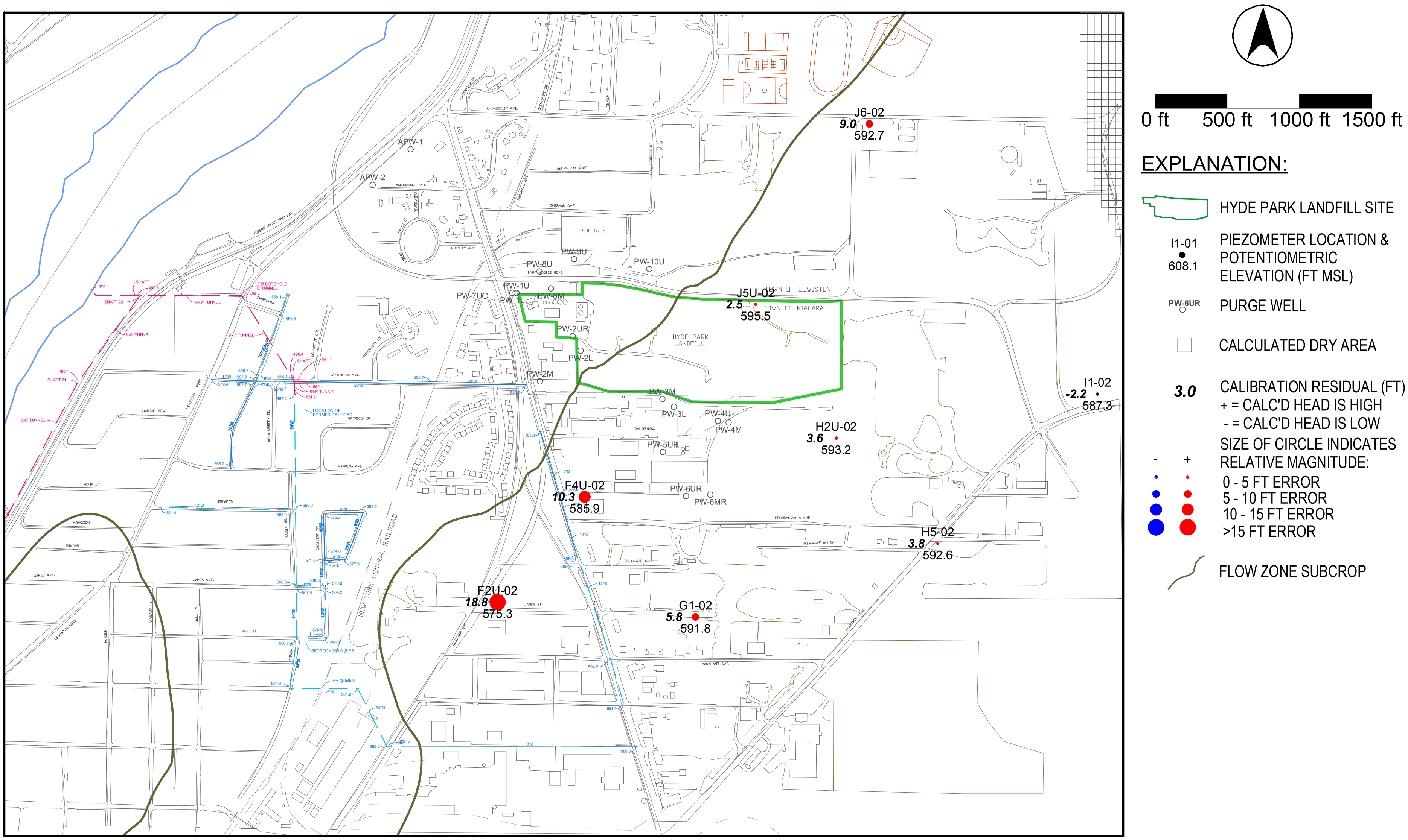

figure 5-49

CALIBRATION RESIDUALS IN FZ-02, NON-PUMPING CONDITIONS

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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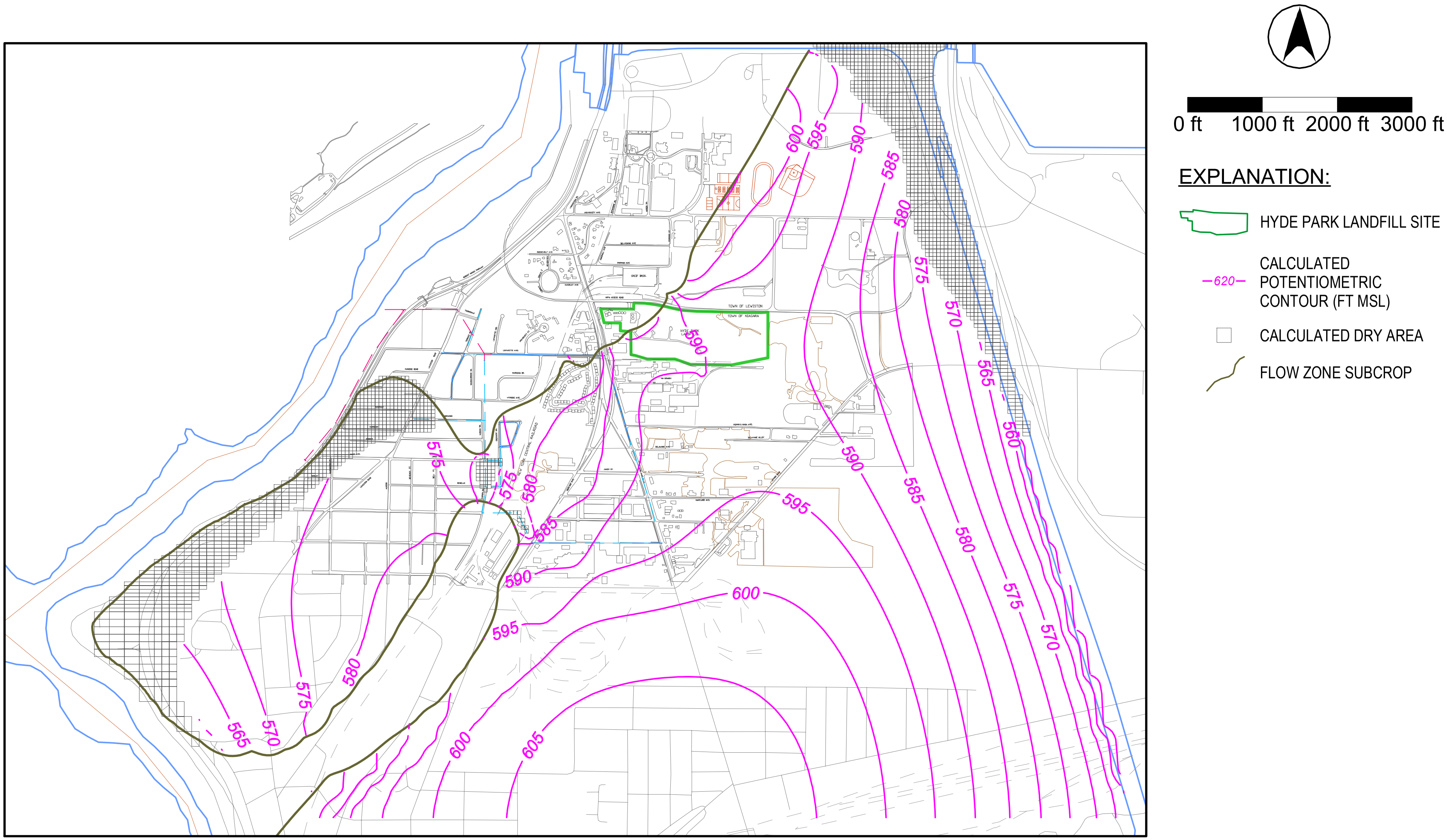

figure 5-50
CALCULATED POTENTIOMETRIC CONTOURS IN FZ-03, NON-PUMPING CONDITIONS - REGIONAL
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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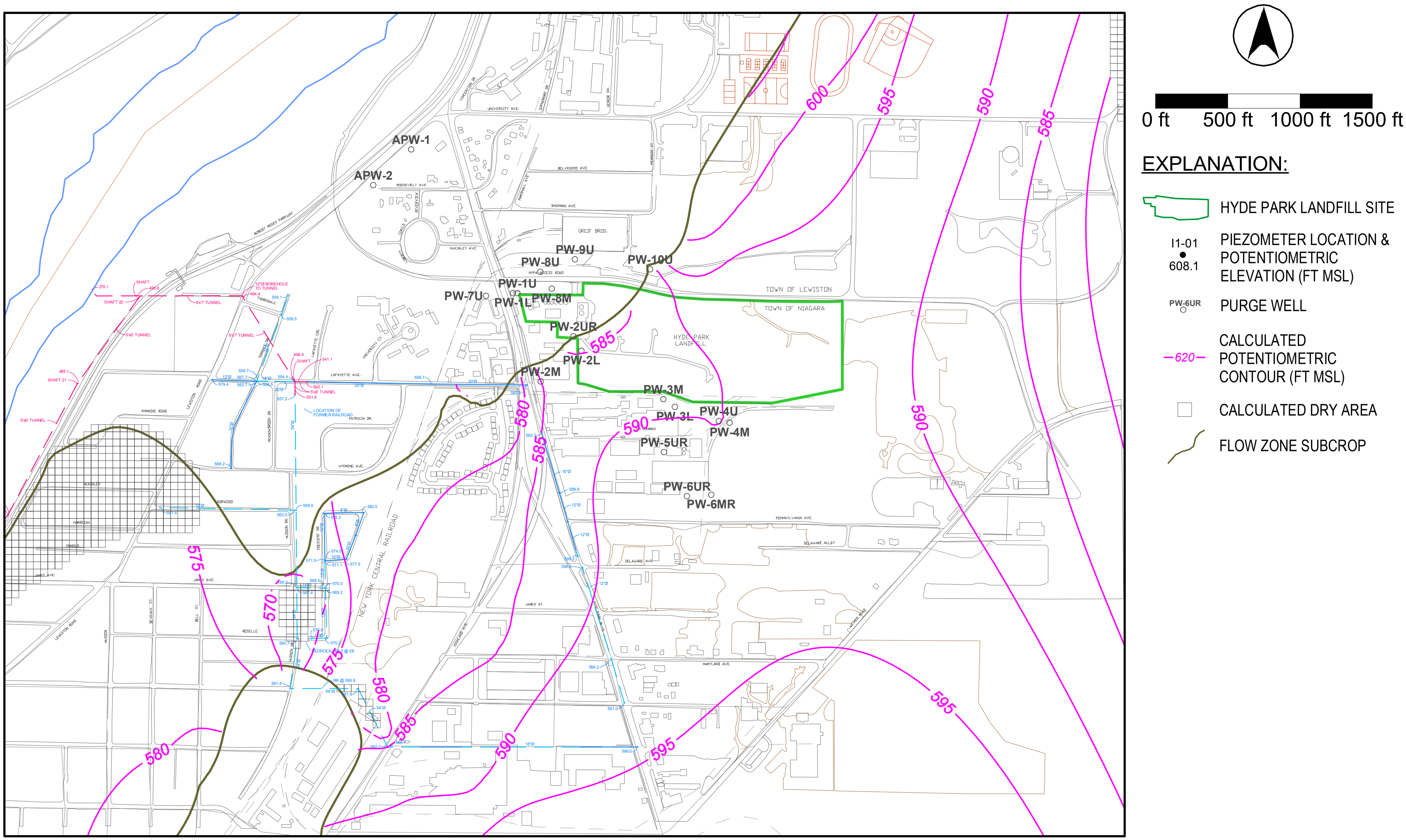

figure 5-51

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-03, NON-PUMPING CONDITIONS - LOCAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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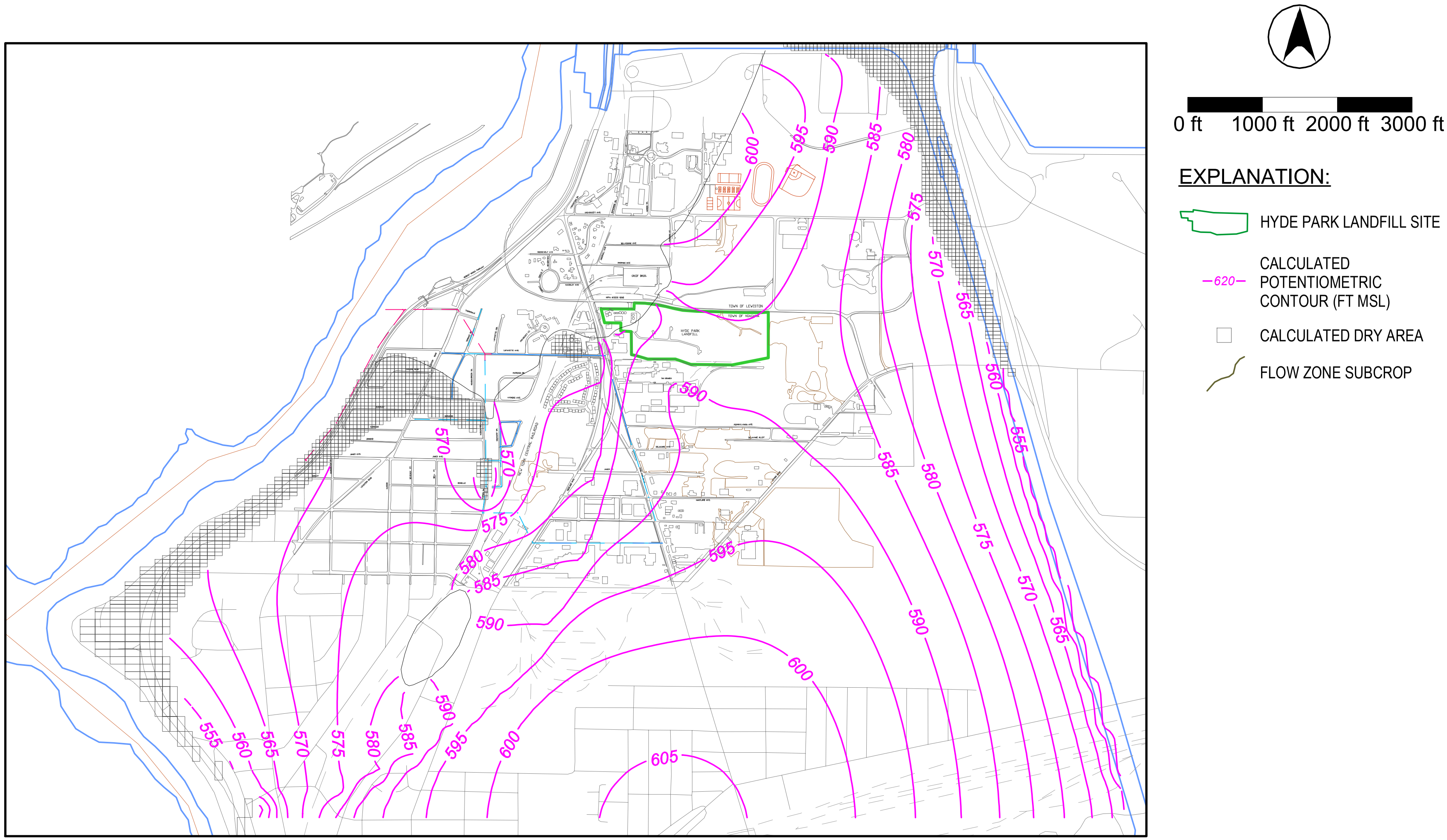

figure 5-52

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-04, NON-PUMPING CONDITIONS - REGIONAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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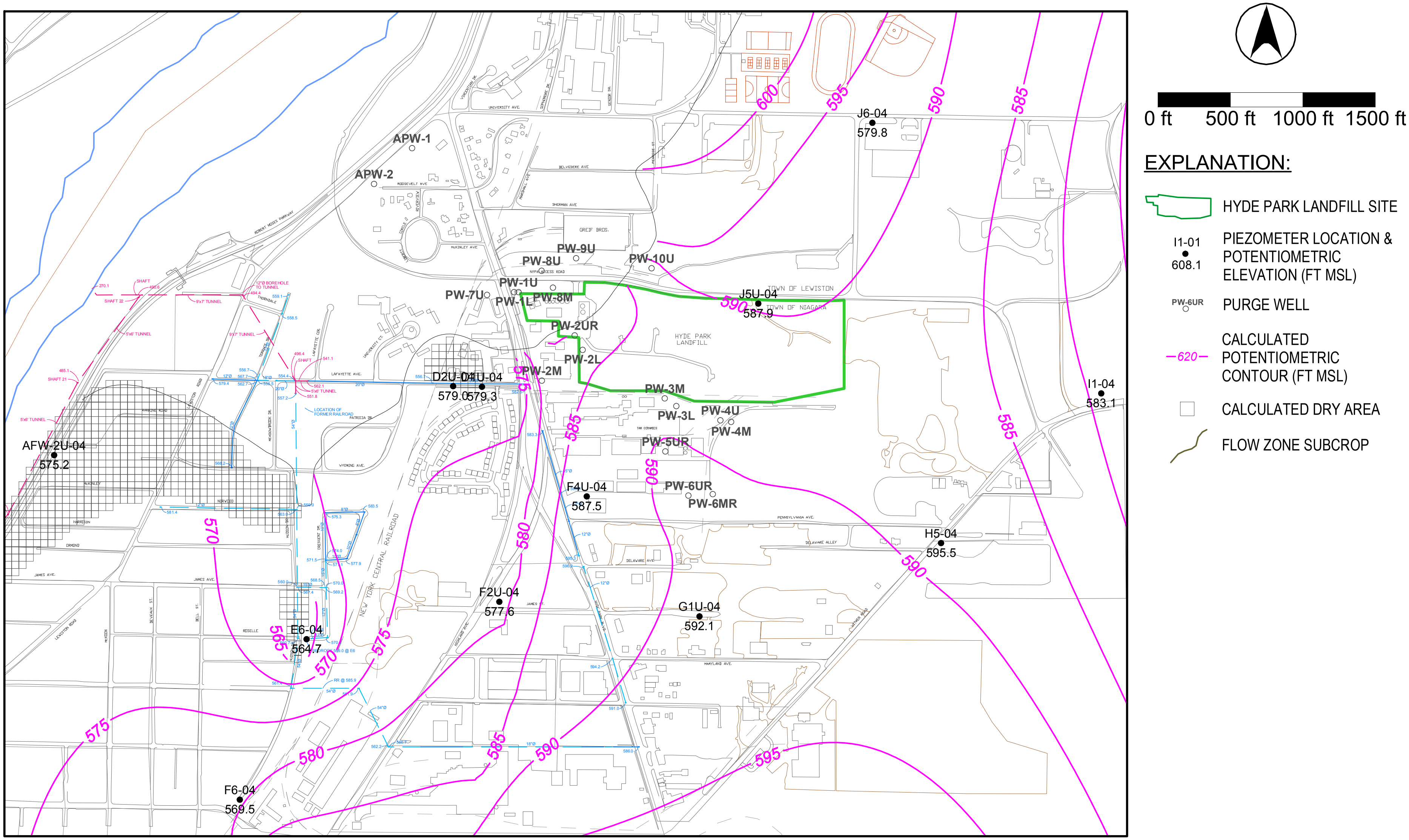

figure 5-53

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-04, NON-PUMPING CONDITIONS - LOCAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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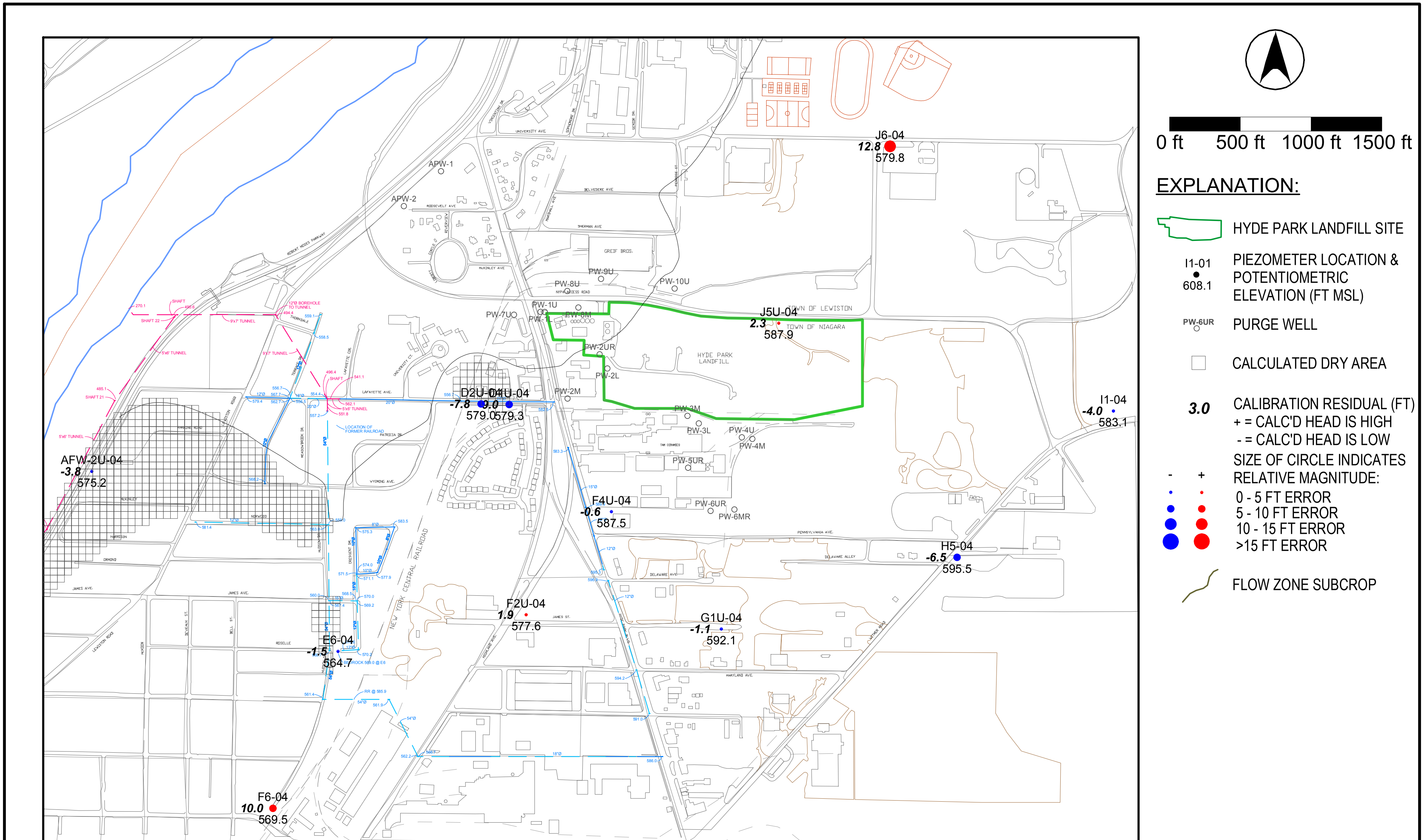

figure 5-54

CALIBRATION RESIDUALS IN FZ-04, NON-PUMPING CONDITIONS

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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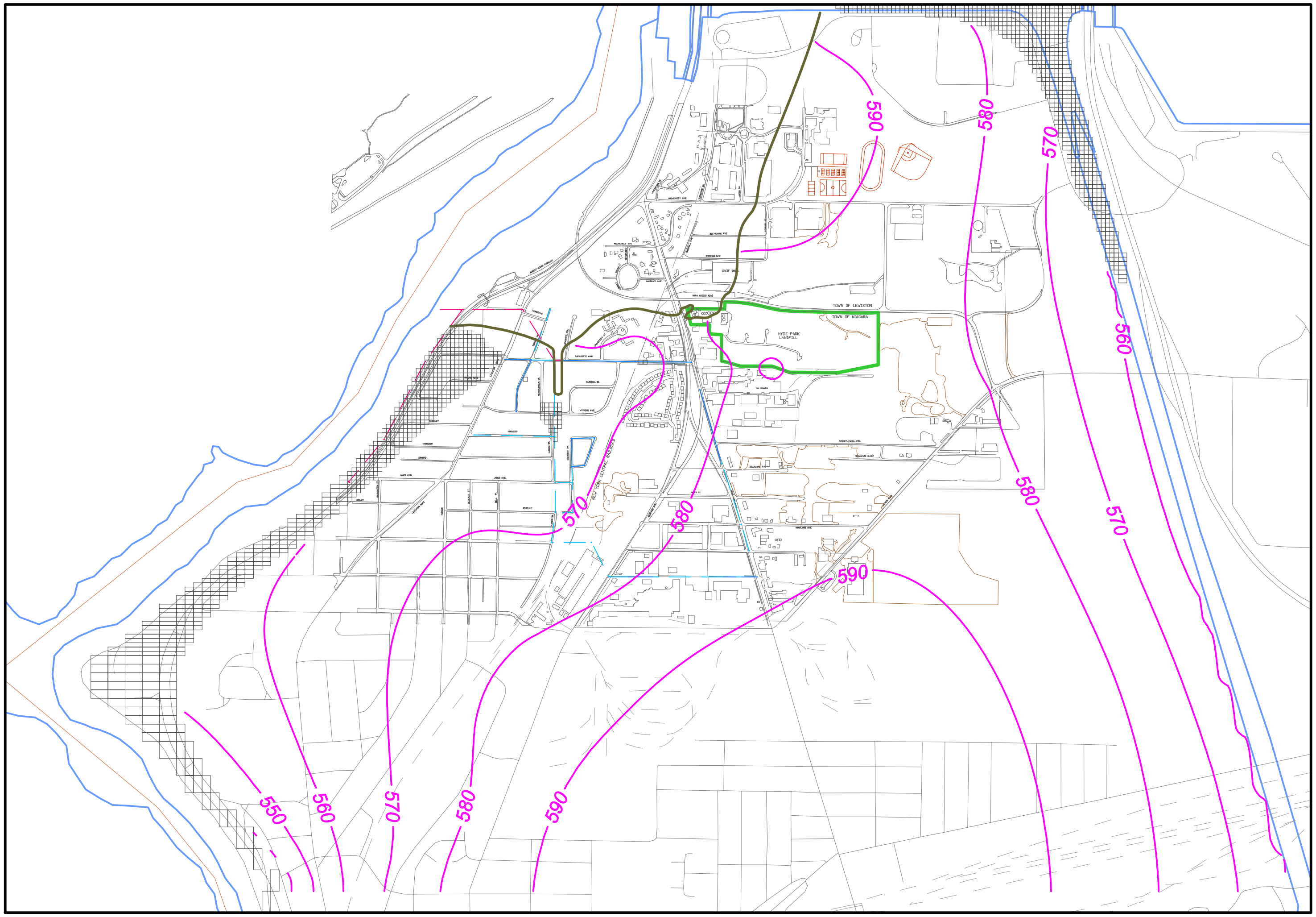

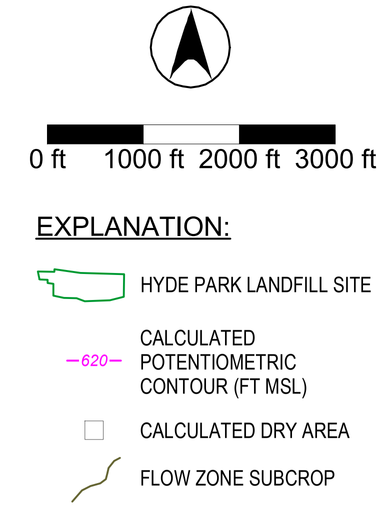

figure 5-55

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-05, NON-PUMPING CONDITIONS - REGIONAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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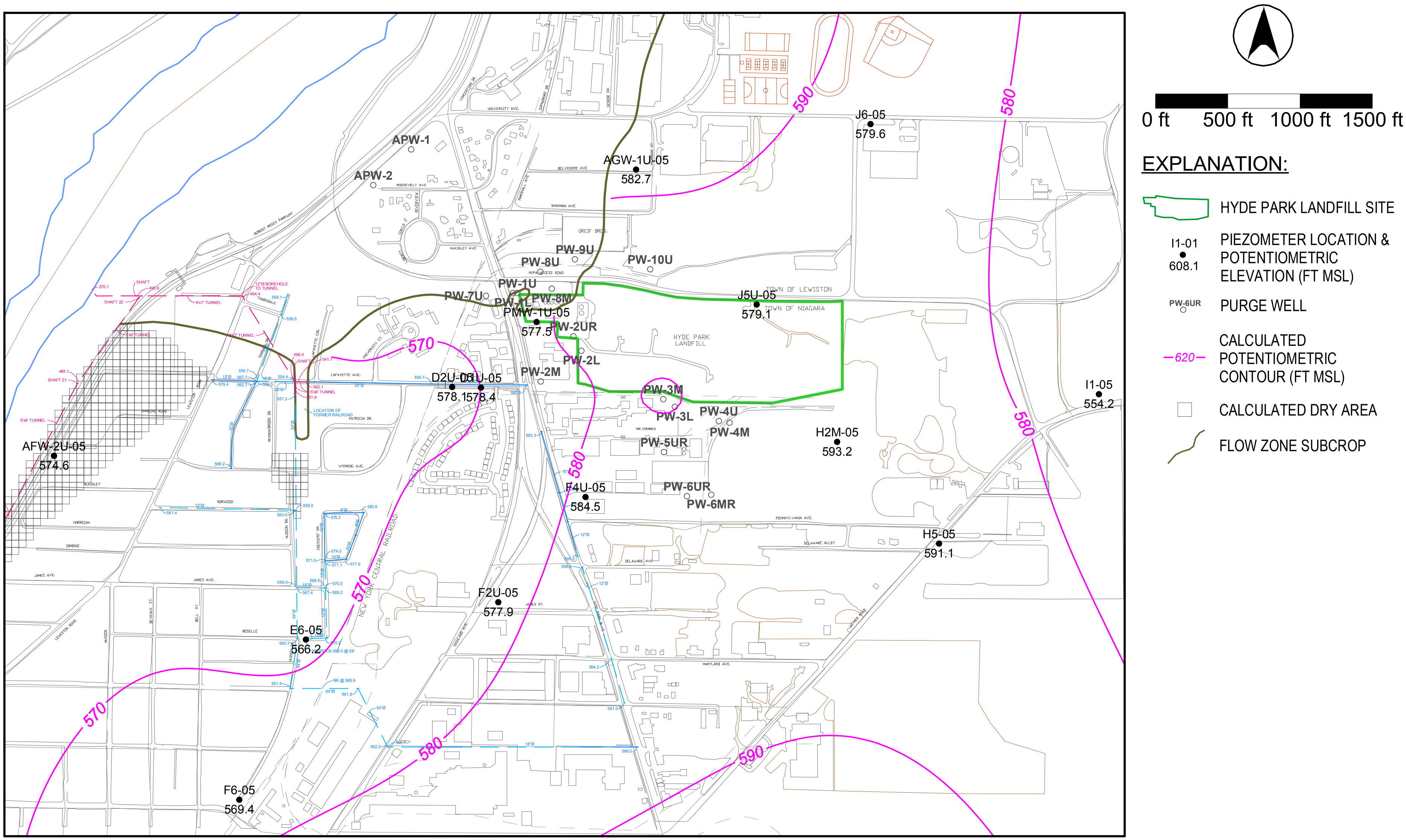

figure 5-56

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-05, NON-PUMPING CONDITIONS - LOCAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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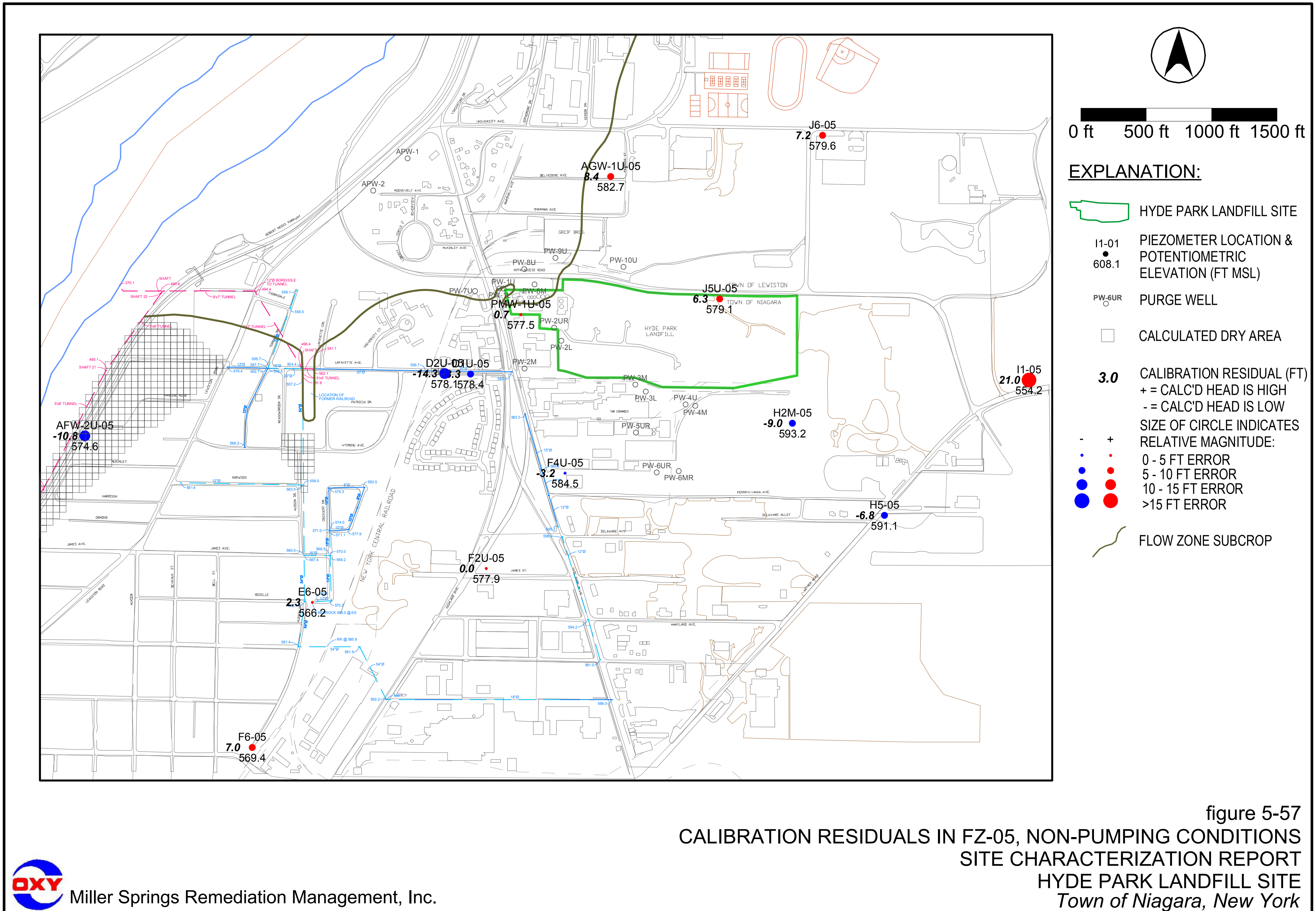

figure 5-57

CALCULATION RESIDUALS IN FZ-05, NON-PUMPING CONDITIONS

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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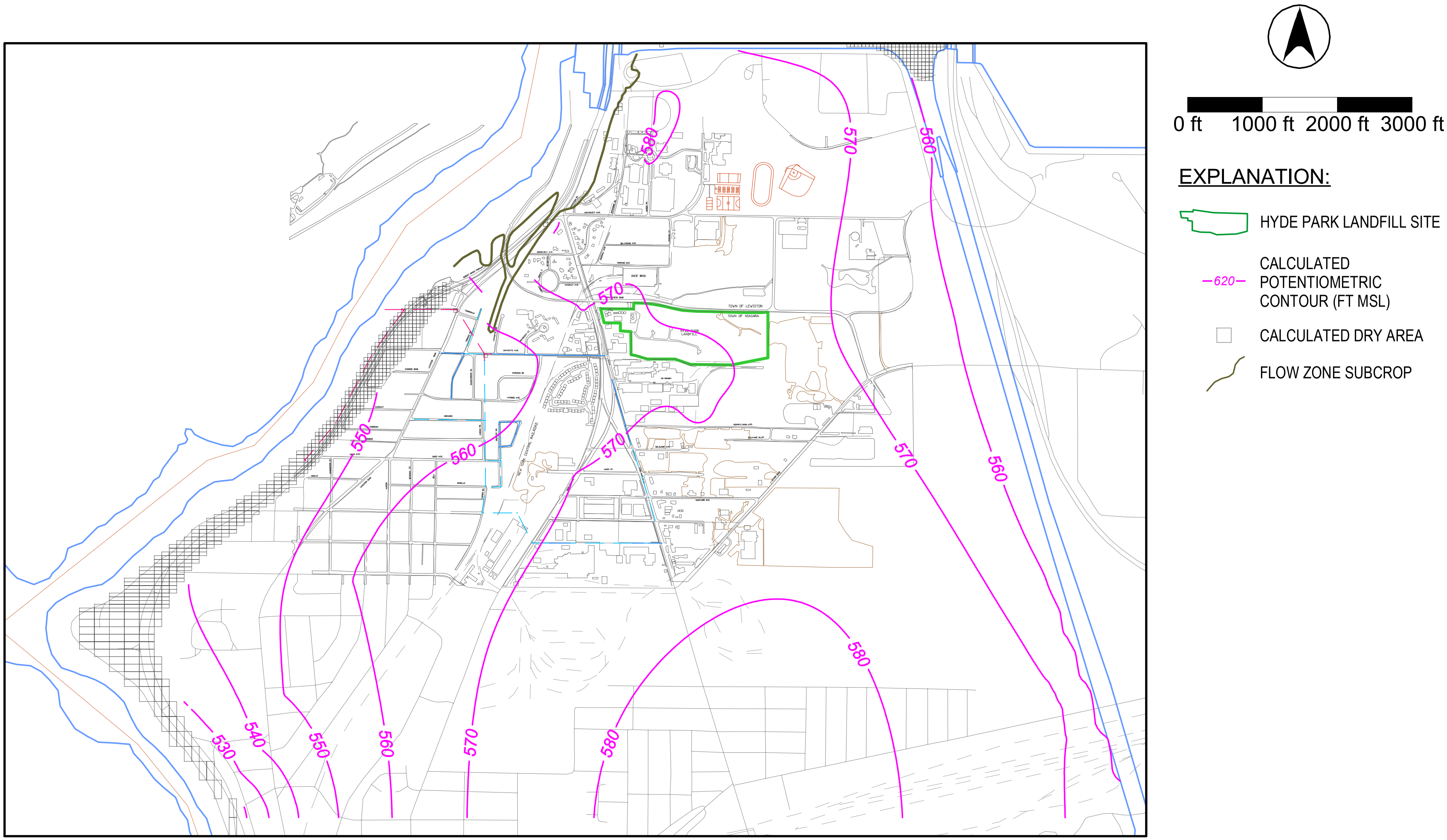

figure 5-58
CALCULATED POTENTIOMETRIC CONTOURS IN FZ-06, NON-PUMPING CONDITIONS - REGIONAL
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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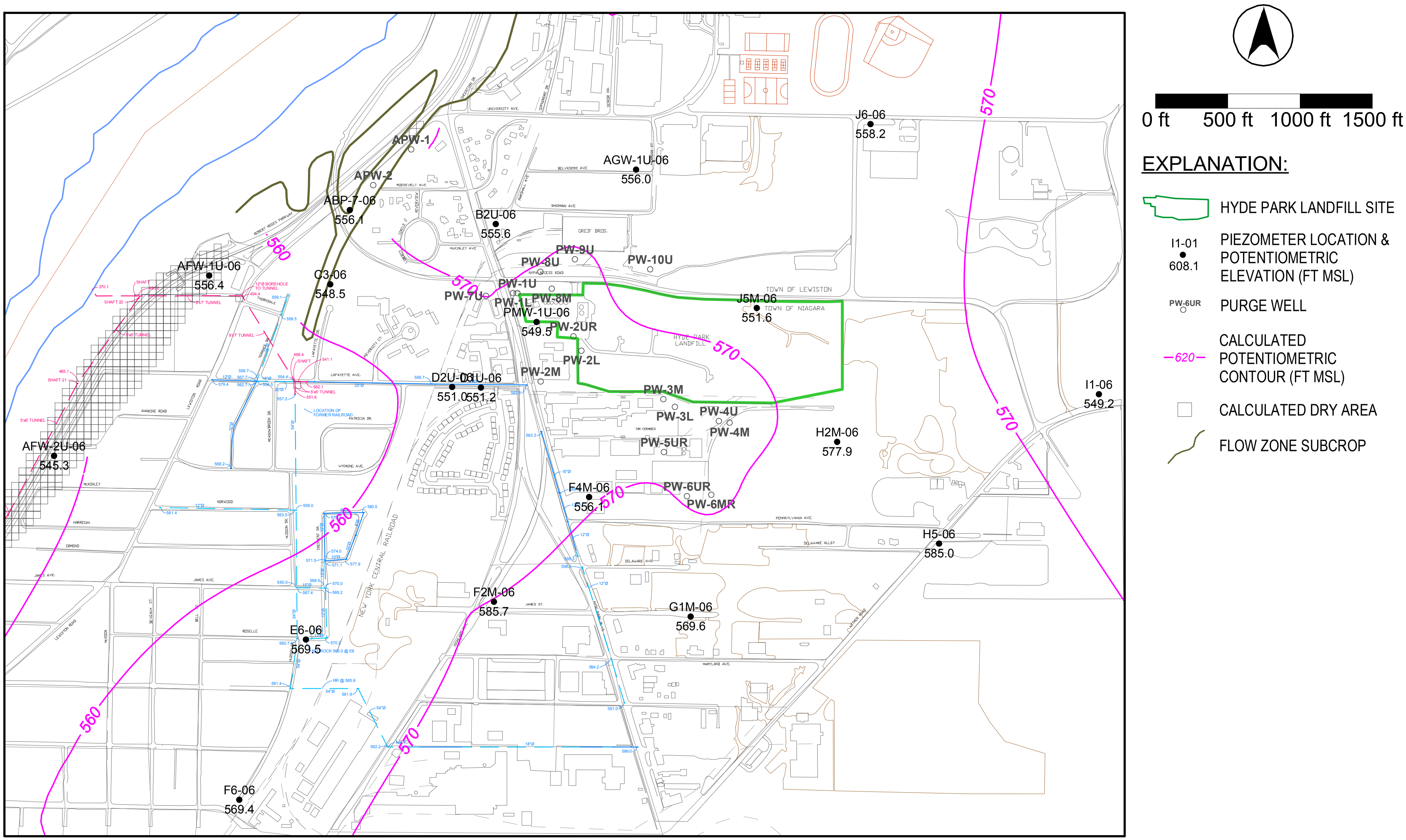

figure 5-59

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-06, NON-PUMPING CONDITIONS - LOCAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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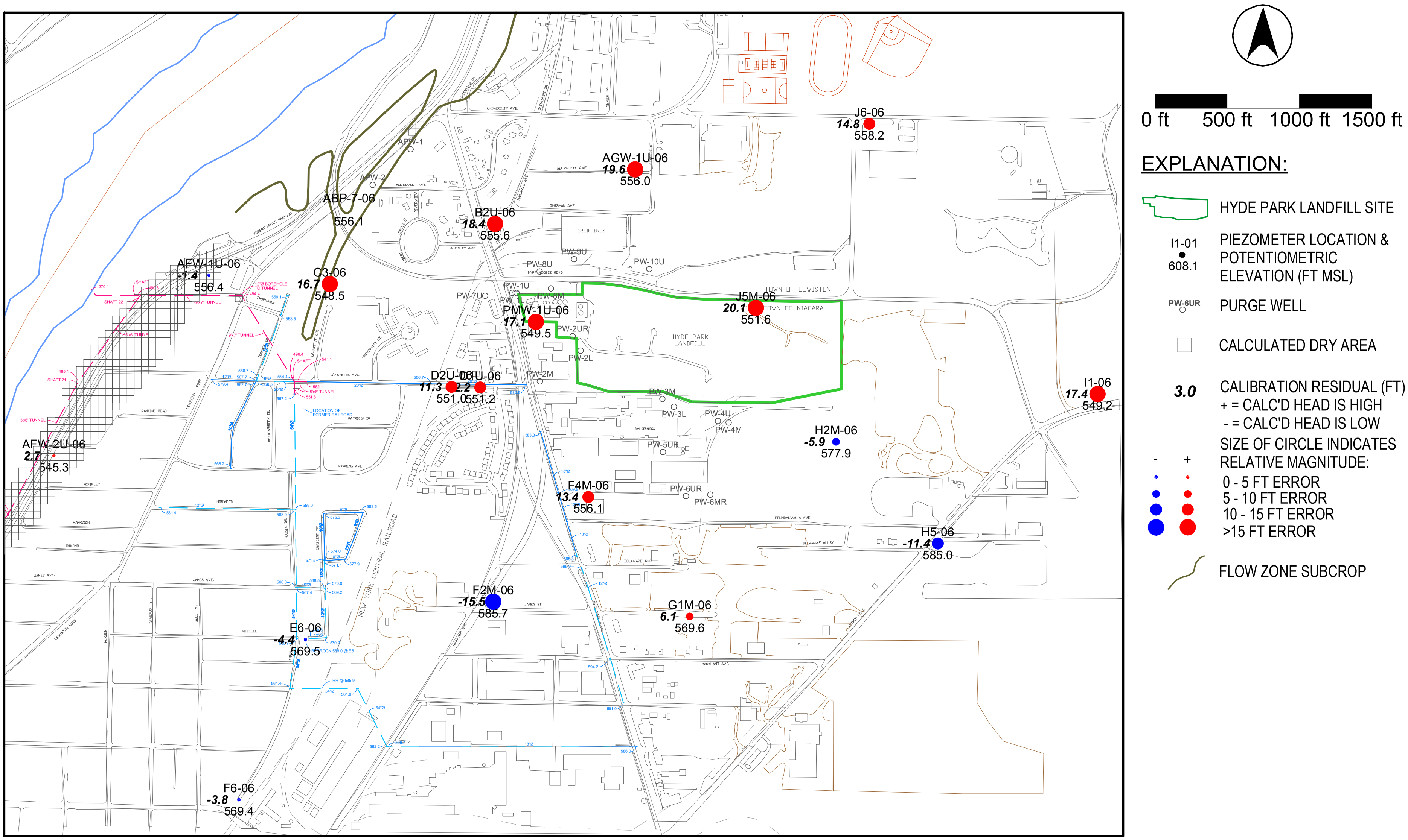

figure 5-60
CALIBRATION RESIDUALS IN FZ-06, NON-PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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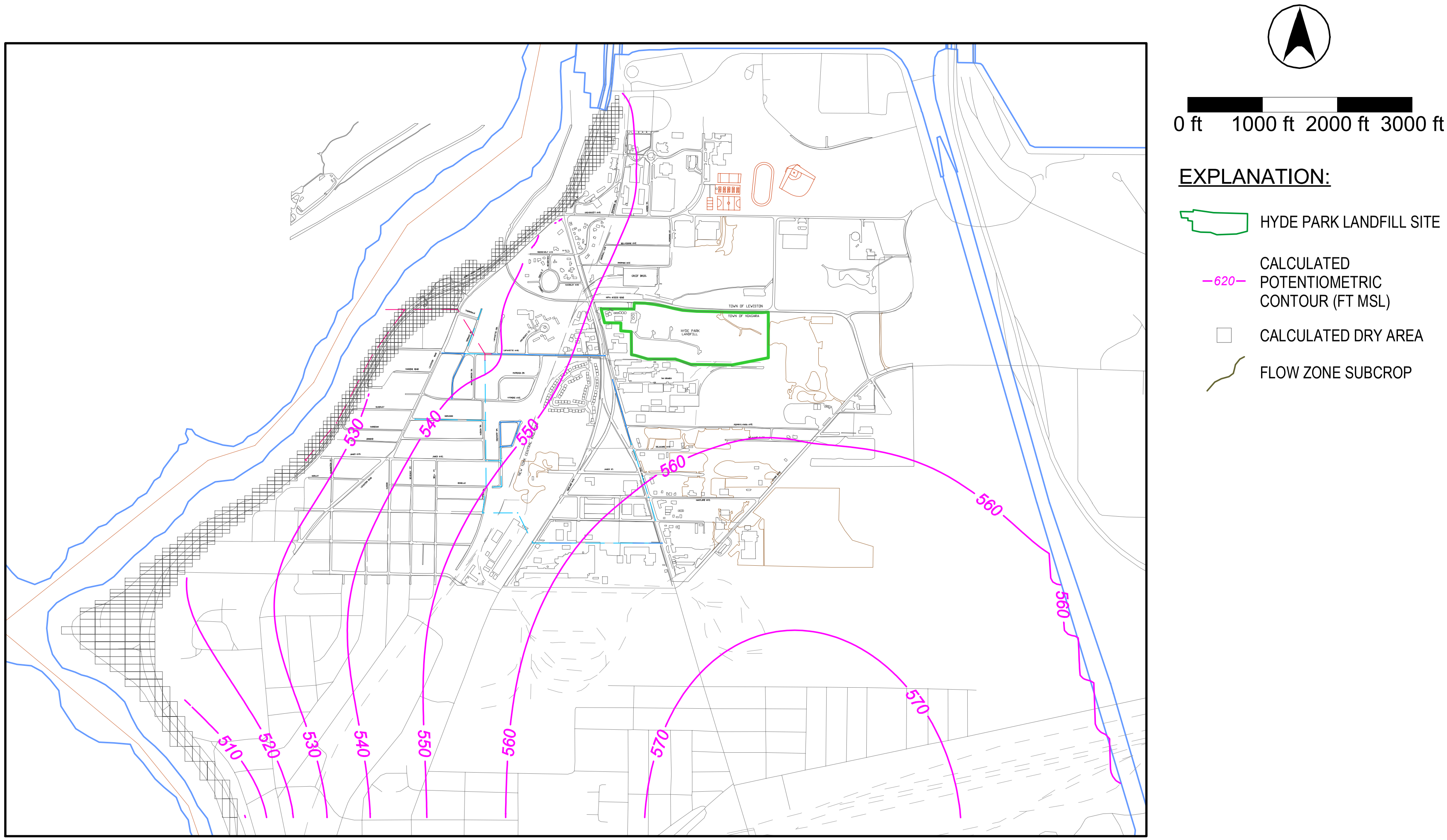

figure 5-61
CALCULATED POTENTIOMETRIC CONTOURS IN FZ-07, NON-PUMPING CONDITIONS - REGIONAL
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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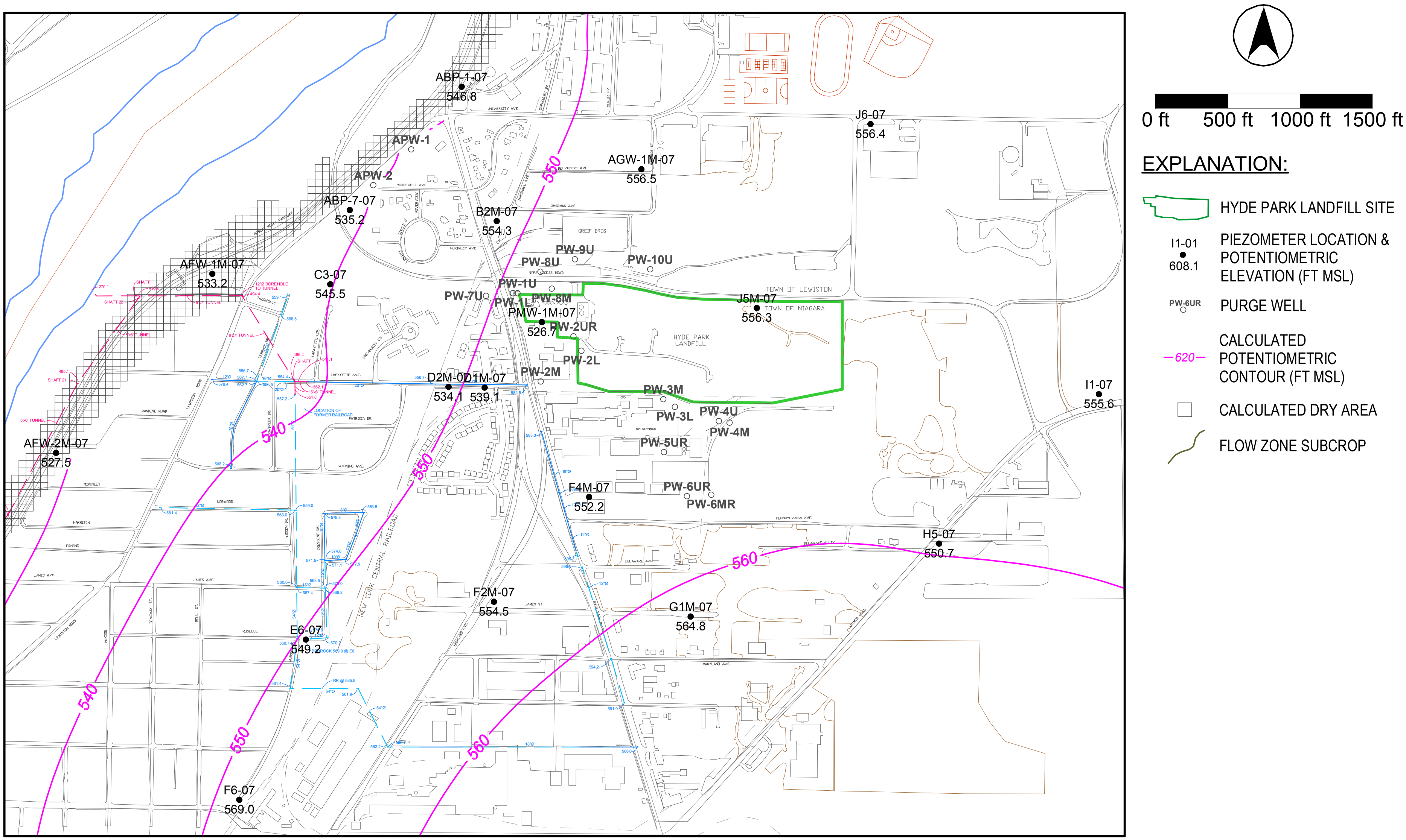

figure 5-62

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-07, NON-PUMPING CONDITIONS - LOCAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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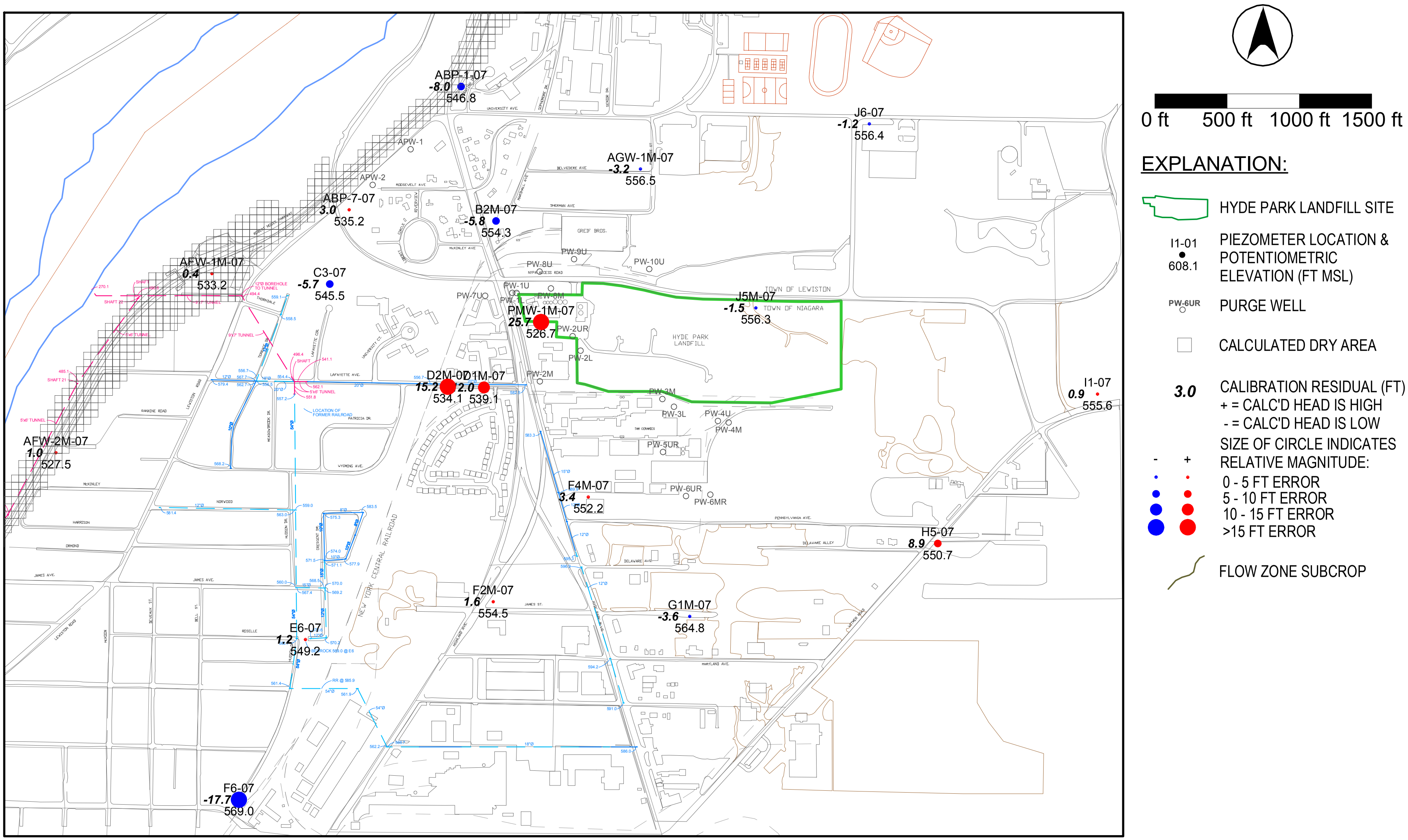

figure 5-63

CALCULATION RESIDUALS IN FZ-07, NON-PUMPING CONDITIONS

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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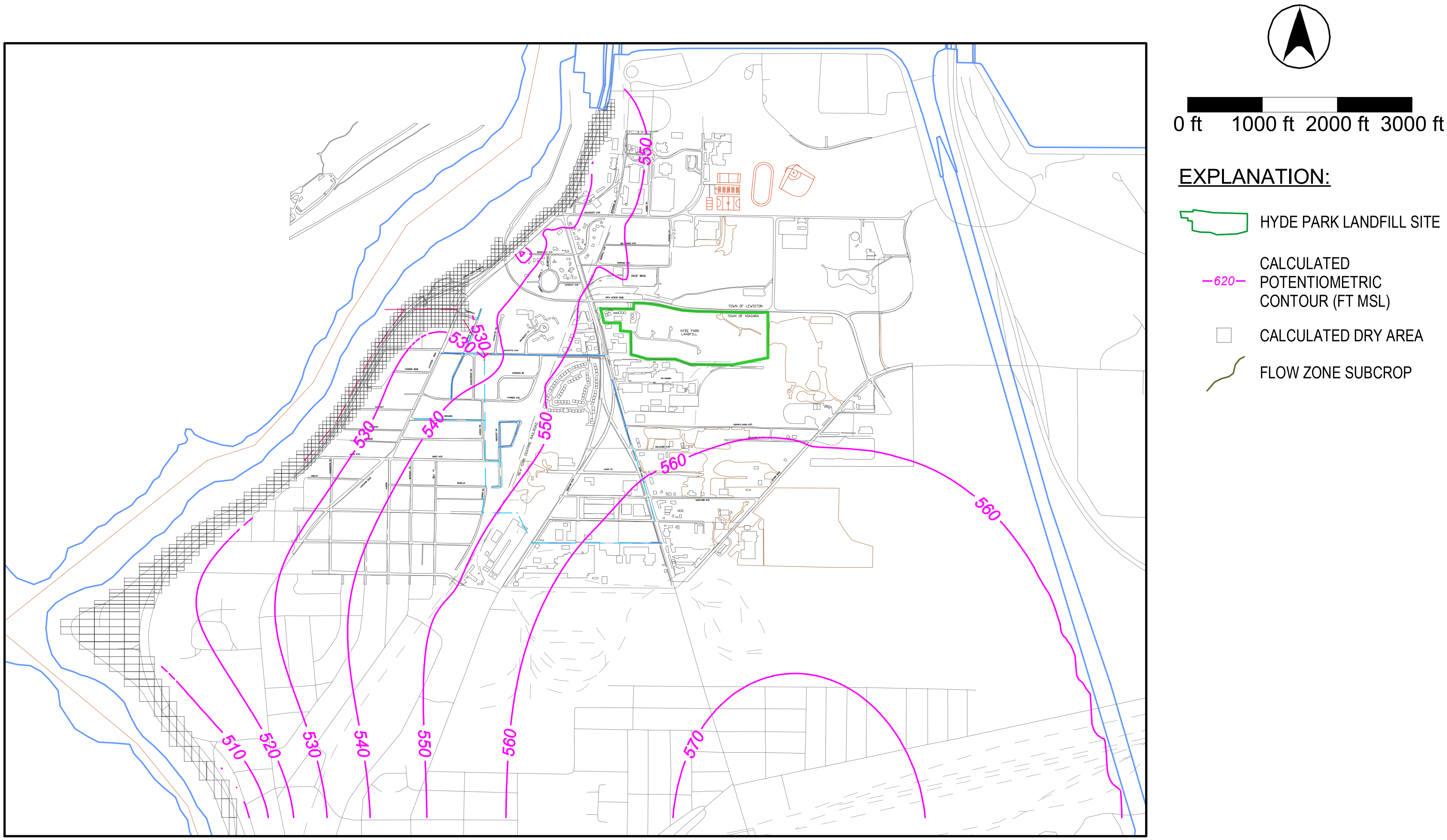

figure 5-64

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-08, NON-PUMPING CONDITIONS - REGIONAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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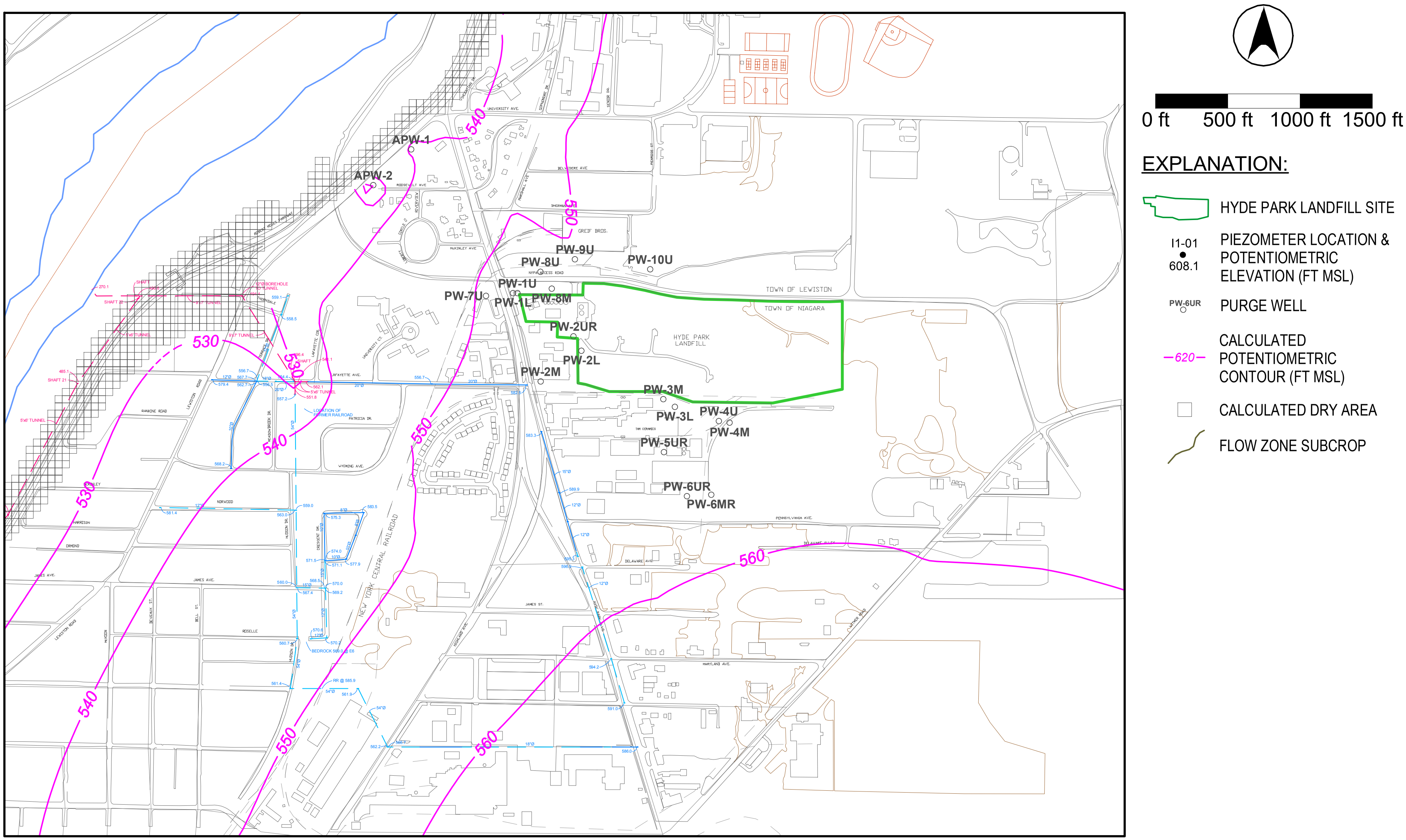

figure 5-65

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-08, NON-PUMPING CONDITIONS - LOCAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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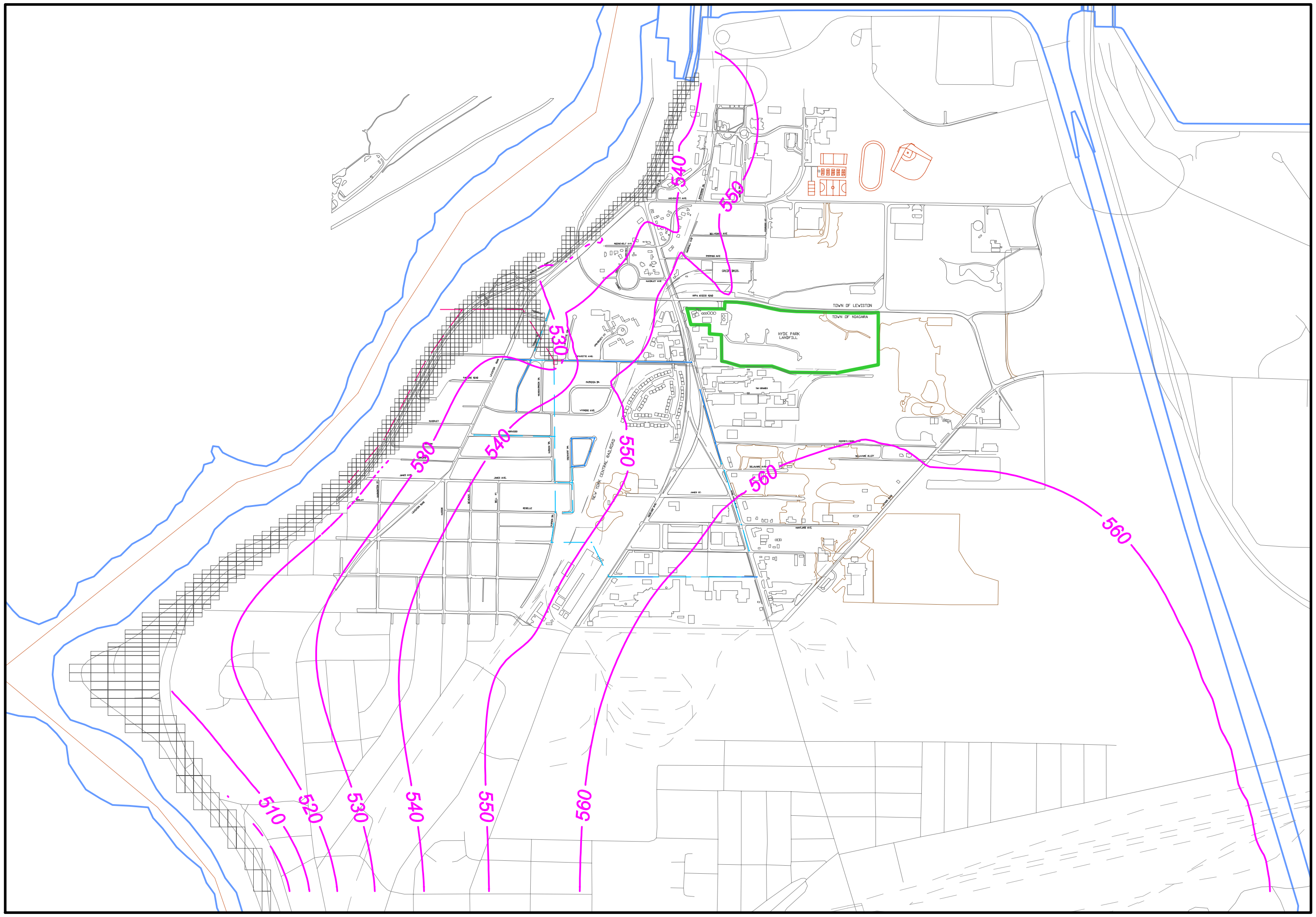

0 ft 1000 ft 2000 ft 3000 ft

EXPLANATION:

- HYDE PARK LANDFILL SITE
- 620 — CALCULATED POTENTIOMETRIC CONTOUR (FT MSL)
- CALCULATED DRY AREA
- FLOW ZONE SUBCROP

figure 5-66
CALCULATED POTENTIOMETRIC CONTOURS IN FZ-09, NON-PUMPING CONDITIONS - REGIONAL
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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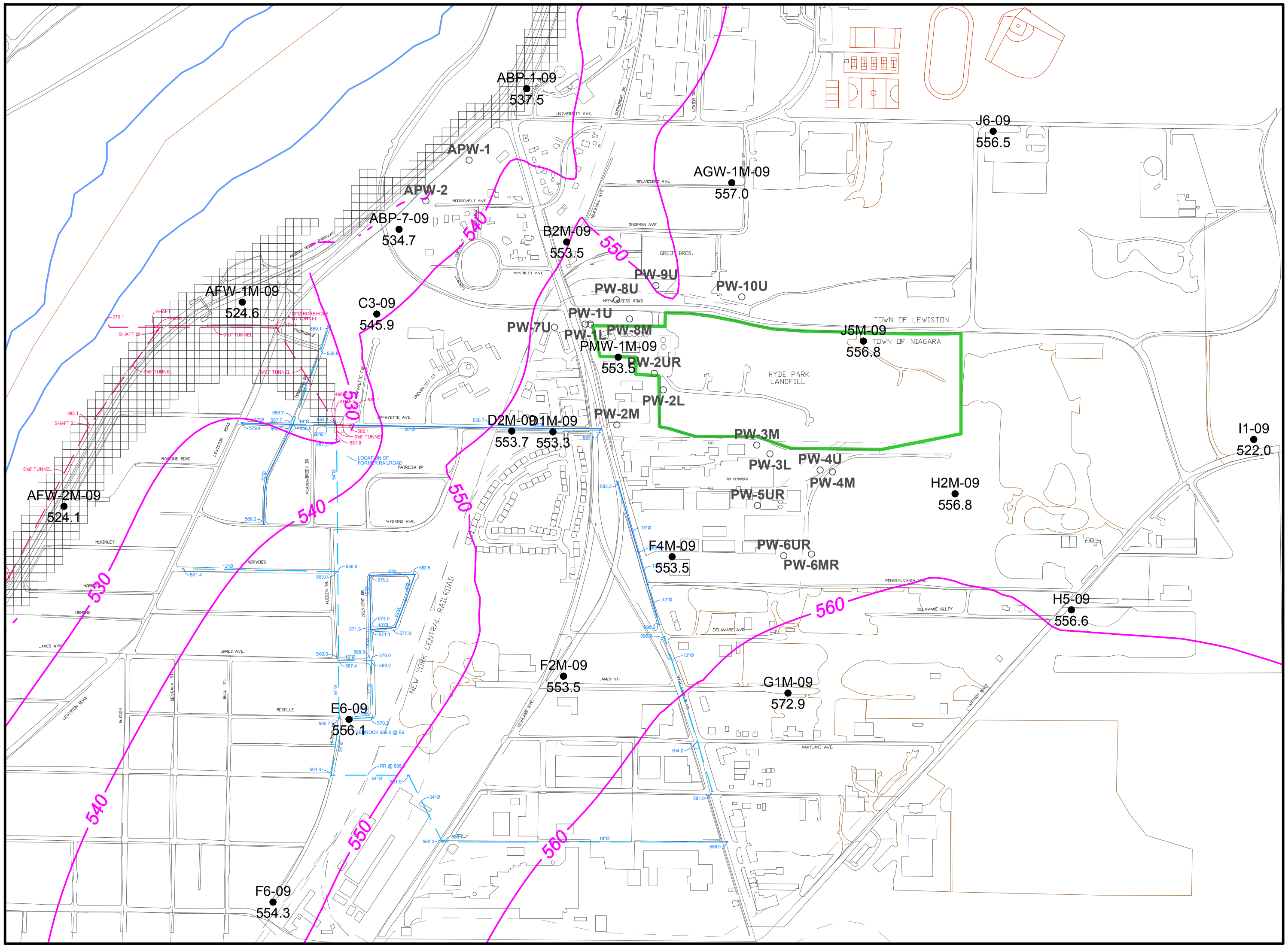

0 ft 500 ft 1000 ft 1500 ft

EXPLANATION:

- HYDE PARK LANDFILL SITE
- I1-01 608.1 — PIEZOMETER LOCATION & POTENTIOMETRIC ELEVATION (FT MSL)
- PW-6UR — PURGE WELL
- 620 — CALCULATED POTENTIOMETRIC CONTOUR (FT MSL)
- CALCULATED DRY AREA
- FLOW ZONE SUBCROP

figure 5-67

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-09, NON-PUMPING CONDITIONS - LOCAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\f05_67_hp011np_fz09_wls.srf

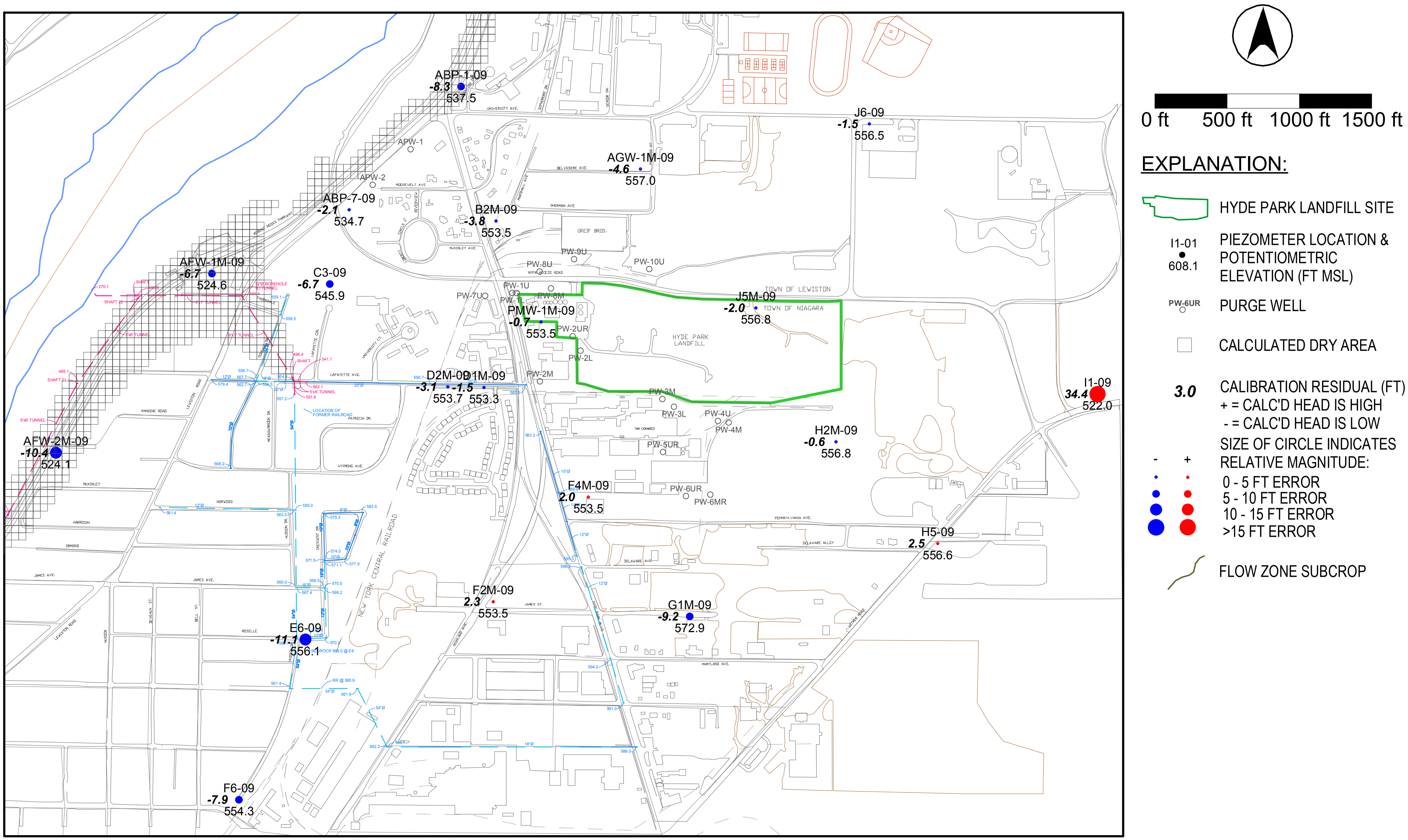

figure 5-68

CALIBRATION RESIDUALS IN FZ-09, NON-PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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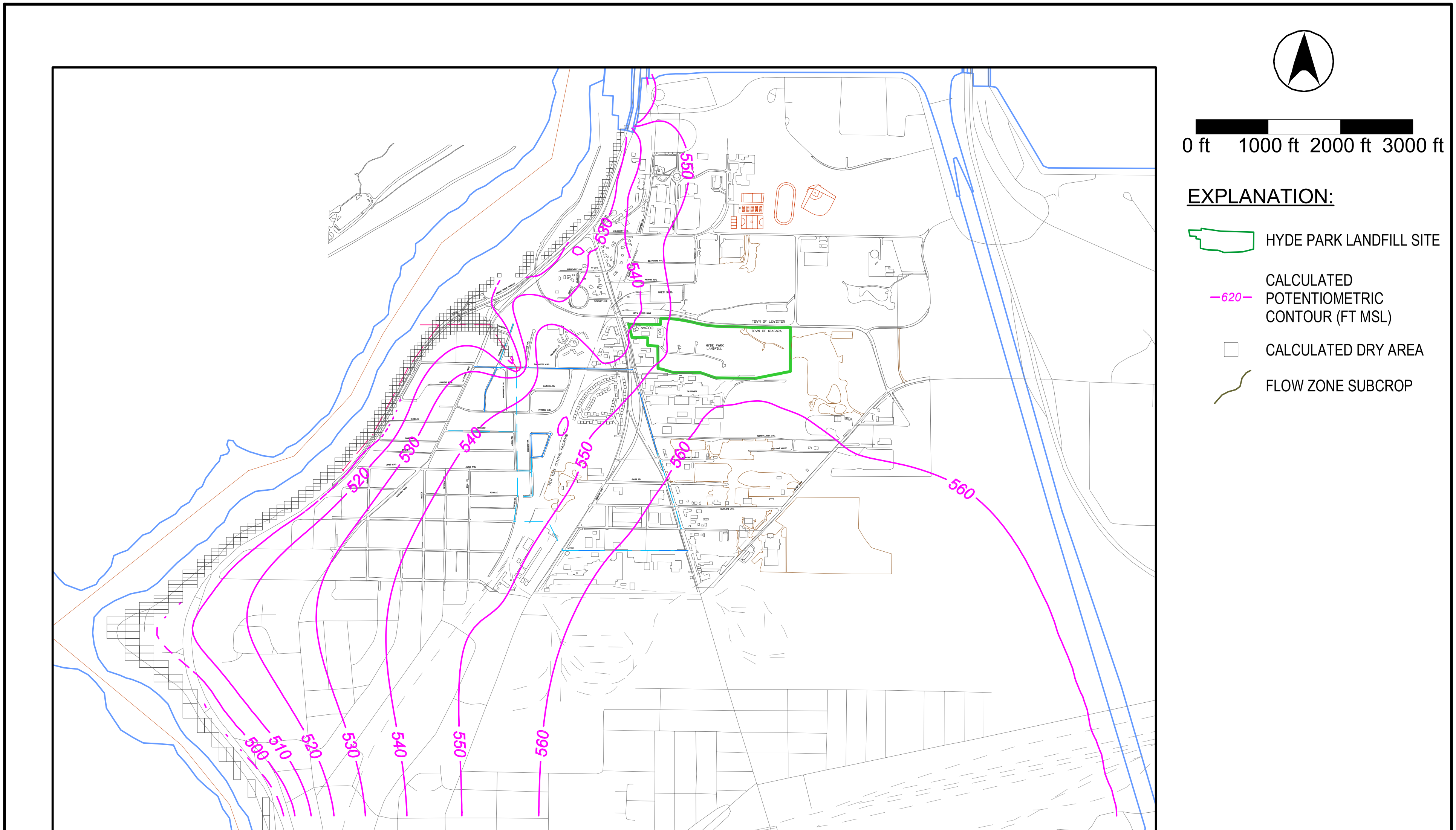

figure 5-69
CALCULATED POTENTIOMETRIC CONTOURS IN FZ-10, NON-PUMPING CONDITIONS - REGIONAL
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\f05_69_hp011np_fz10_wls_r.srf

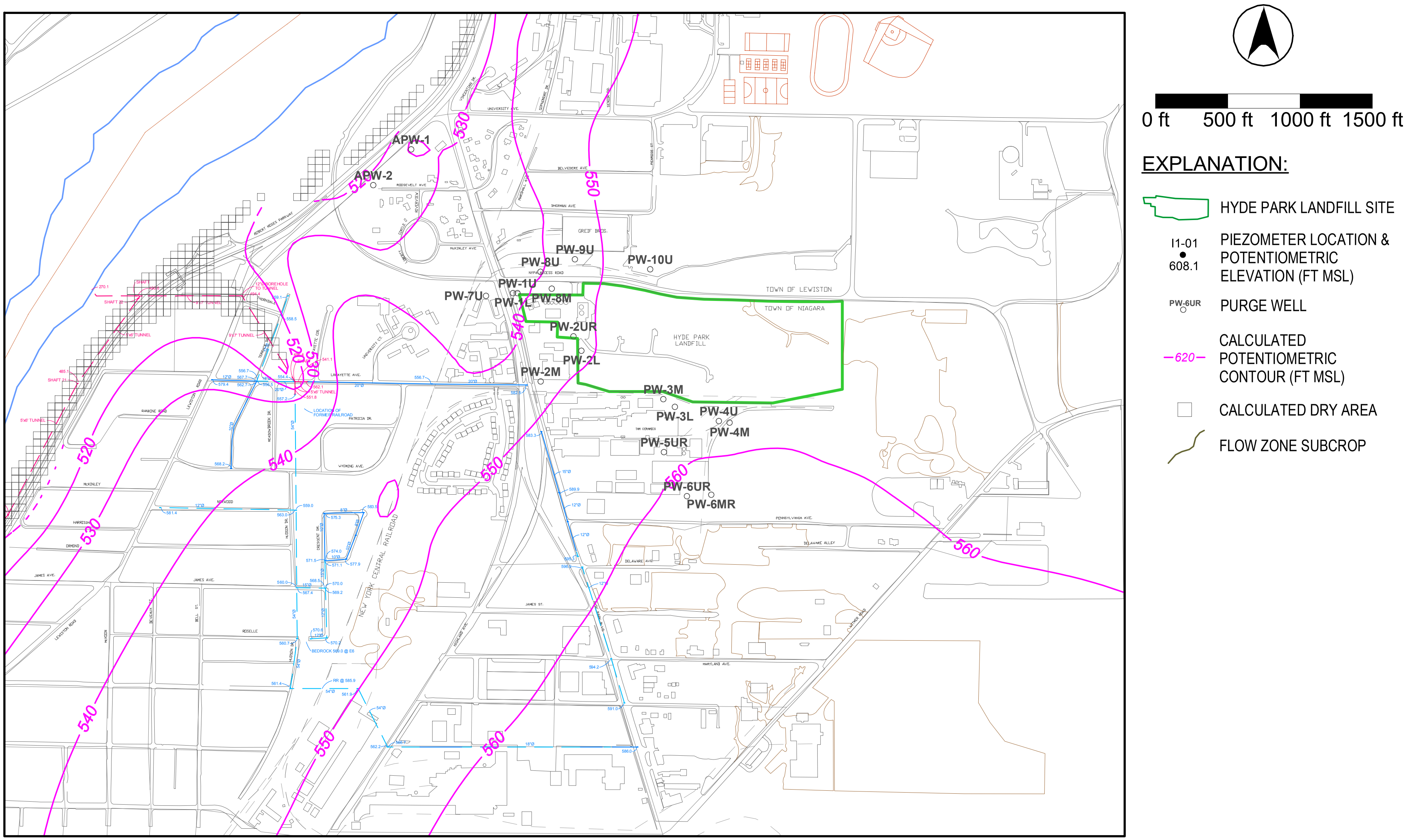

figure 5-70

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-10, NON-PUMPING CONDITIONS - LOCAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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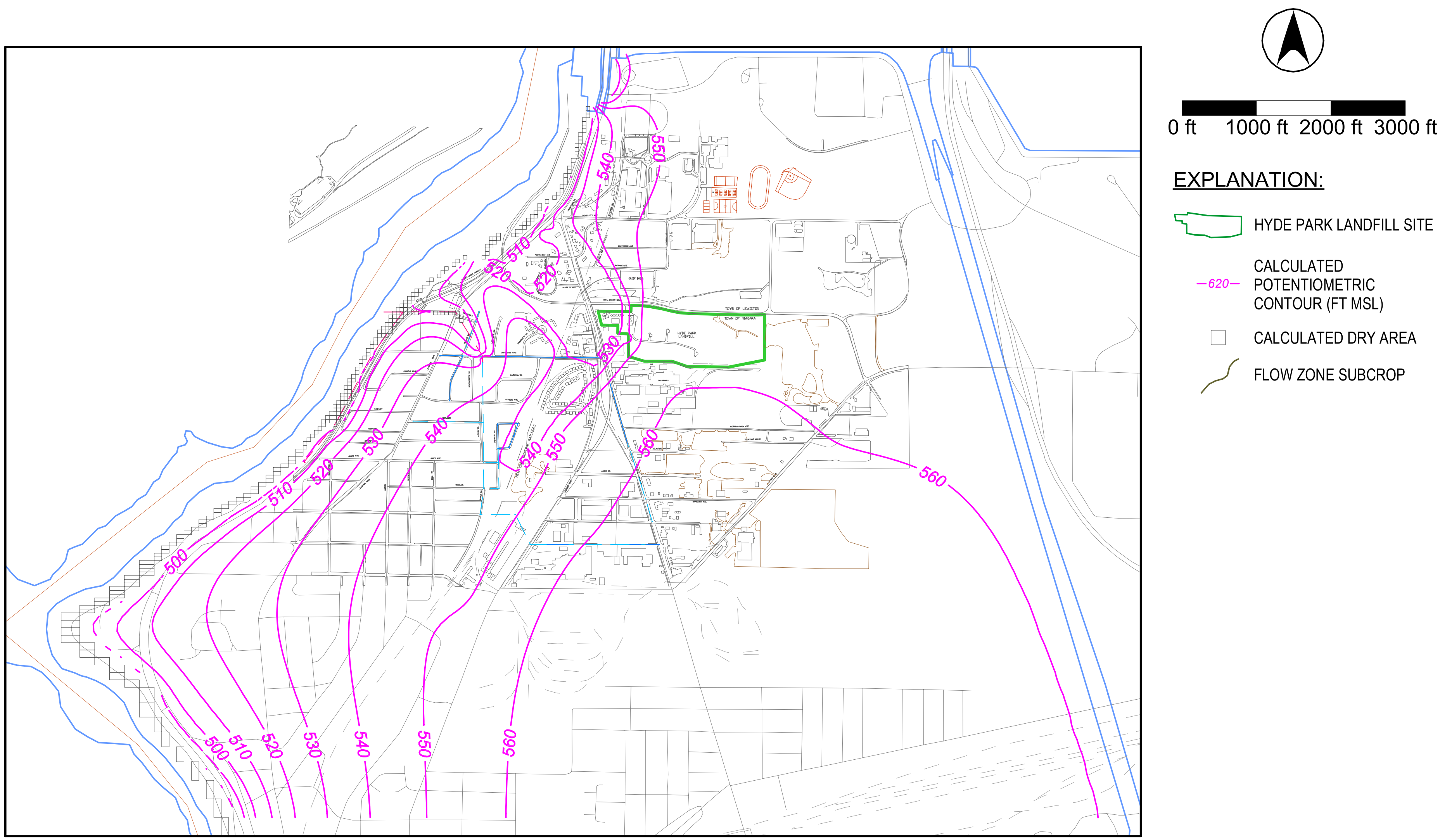

figure 5-71

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-11, NON-PUMPING CONDITIONS - REGIONAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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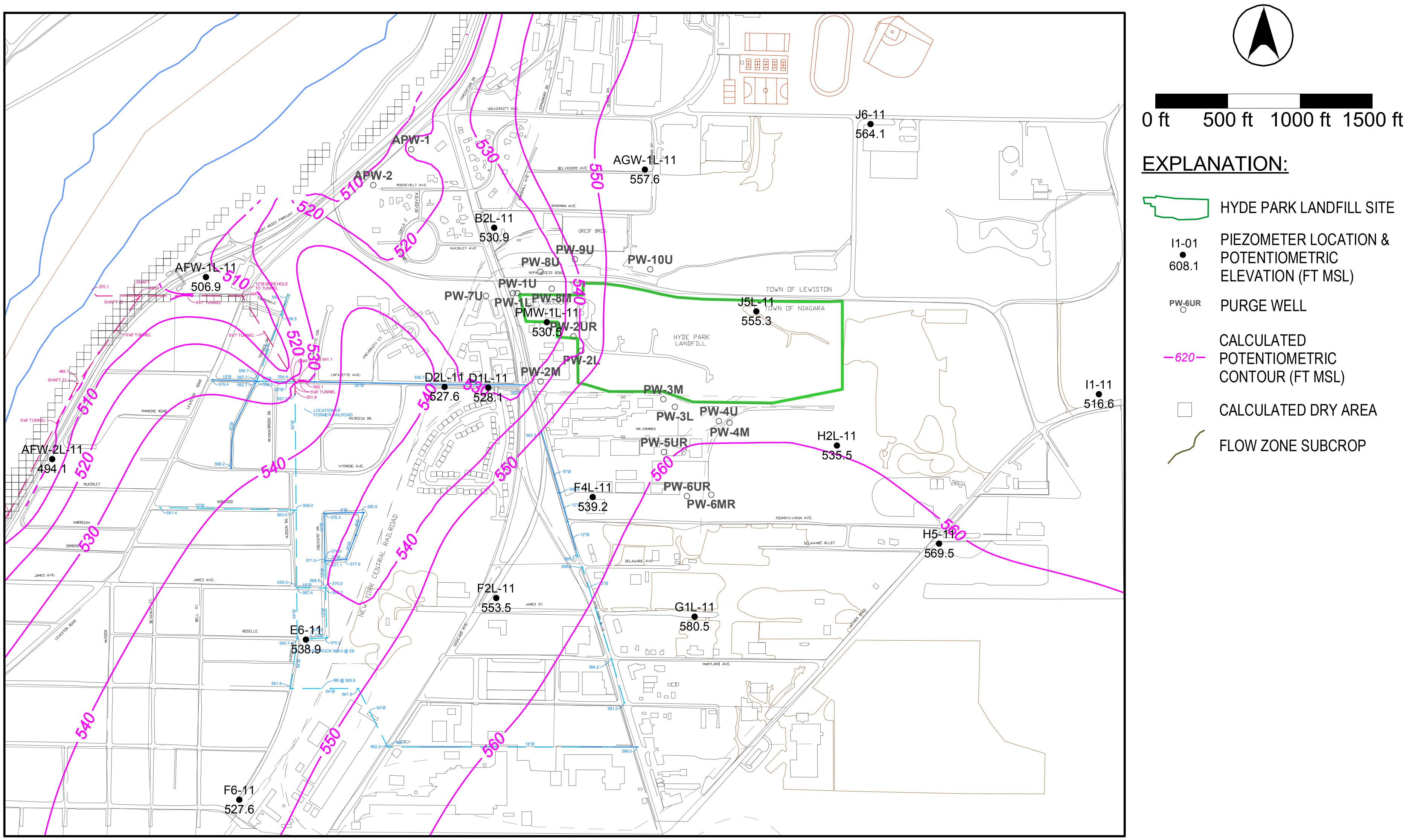

figure 5-72

CALCULATED POTENTIOMETRIC CONTOURS IN FZ-11, NON-PUMPING CONDITIONS - LOCAL

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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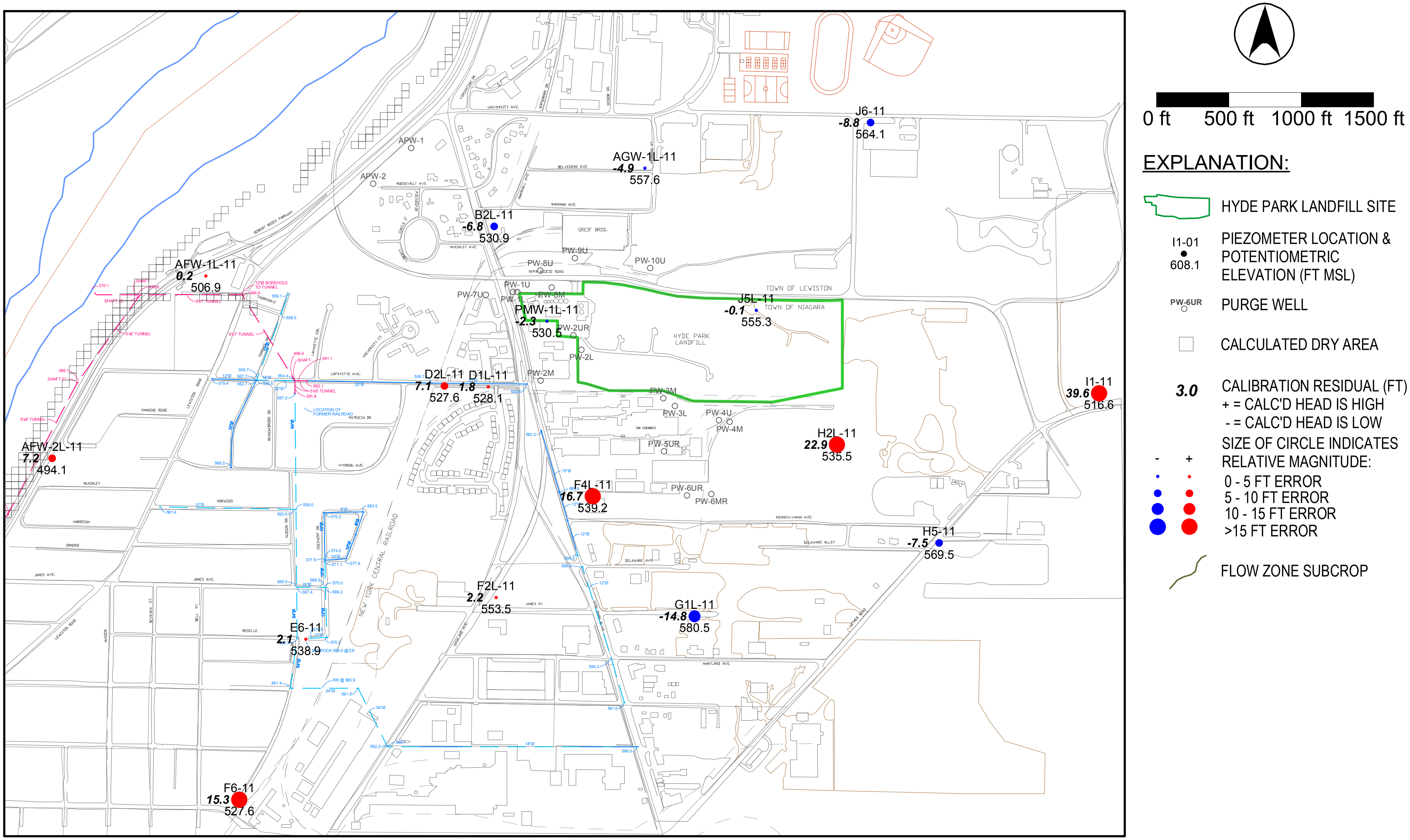

figure 5-73

CALIBRATION RESIDUALS IN FZ-11, NON-PUMPING CONDITIONS

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

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SITE CHARACTERIZATION REPORT – GROUNDWATER FLOW MODEL

TABLES

Table 5-1
Purge Well Pumping Rates and Control Levels

Purge Well Location	Easting	Northing	Average Pumping Rate [1] (gpm)	Average Pumping Rate [1] (ft^3/d)	Control Level (ft MSL) [2] Pumping	Control Level (ft MSL) [2] Non-Pumping
APW-1	1025714.45	1142554.70	0.79	152.8	508.66	549.51
APW-2	1025451.31	1142307.42	0.24	47.0	512.00	523.60
PW-1U	1026448.98	1141559.71	0.44	84.5	548.93	569.60
PW-1L	1026418.66	1141560.35	10.35	1,992.1	507.42	553.5 / 531.0 [3]
PW-2UR	1026836.57	1141260.47	0.18	34.4	558.88	587.17
PW-2M	1026610.06	1140948.14	31.64	6,090.1	517.82	554.81
PW-2L	1026891.48	1141160.99	0.00	0.0	512.92	517.80
PW-3M	1027458.20	1140825.87	0.00	0.0	516.93	555.20
PW-3L	1027538.50	1140772.54	4.00	769.1	499.93	555.65
PW-4U	1027842.69	1140674.42	0.44	85.6	571.16	588.35
PW-4M	1027916.83	1140663.29	0.00	0.0	511.86	553.87
PW-5UR	1027462.81	1140459.02	4.92	946.5	555.00	597.65
PW-6UR	1027621.77	1140154.40	1.80	345.5	558.90	598.65
PW-6MR	1027790.05	1140164.42	3.35	644.2	505.16	555.20
PW-7U	1026231.25	1141540.90	0.56	107.1	540.07	572.67
PW-8U	1026608.01	1141707.91	0.86	164.9	547.59	570.50
PW-8M	1026686.35	1141591.19	0.48	91.4	520.45	553.14
PW-9U	1026846.83	1141794.20	0.91	175.1	541.26	558.32
PW-10U	1027367.33	1141725.10	5.39	1,038.2	576.59	585.18

Notes: (1) The pumping rates are based on the average pumping rates over the period 6-Jan-2003 00:00 to 7-Jan-2003 00:00.
(2) The control levels are based on the average water levels over the period 6-Jan-2003 00:00 to 7-Jan-2003 00:00 for pumping conditions; and the average water levels over the period 23-Jan-2003 08:20 to 24-Jan-2003 08:20 for non-pumping conditions.
(3) Two control levels are specified for PW-1L in the simulation of non-pumping conditions to account for the presence of the packer installed between FZ-09 and FZ-10.

Table 5-2
Calibrated Values of Model Parameters

Parameter	Value
Aquitard Layers Horizontal Hydraulic Conductivity	0.00752 ft/day
Aquitard Layers Vertical Hydraulic Conductivity	0.000398 ft/day
Conduits Horizontal Hydraulic Conductivity	0.514 ft/day
Conduits Vertical Hydraulic Conductivity	0.102 ft/day
Rock Above FZ-01 Horizontal Hydraulic Conductivity	0.814 ft/day
Rock Above FZ-01 Vertical Hydraulic Conductivity	0.00526 ft/day
FZ-01 Transmissivity	26.0 ft^2/day
FZ-01 Vertical Hydraulic Conductivity	0.220 ft/day
FZ-02 Transmissivity	27.9 ft^2/day
FZ-02 Vertical Hydraulic Conductivity	0.526 ft/day
FZ-03 Transmissivity	0.387 ft^2/day
FZ-03 Vertical Hydraulic Conductivity	0.00657 ft/day
FZ-04 Transmissivity (Low) - 90	1.66 ft^2/day
FZ-04 Vertical Hydraulic Conductivity (Low) - 90	0.00710 ft/day
FZ-04 Transmissivity (High) - 91	72.1 ft^2/day
FZ-04 Vertical Hydraulic Conductivity (High) - 91	0.630 ft/day
FZ-05 Transmissivity (Low) - 110	12.4 ft^2/day
FZ-05 Vertical Hydraulic Conductivity (Low) - 110	0.00348 ft/day
FZ-05 Transmissivity (High) - 111	27.7 ft^2/day
FZ-05 Vertical Hydraulic Conductivity (High) - 111	0.656 ft/day
FZ-06 Transmissivity (Low) - 130	8.80 ft^2/day
FZ-06 Vertical Hydraulic Conductivity (Low) - 130	0.0248 ft/day
FZ-06 Transmissivity (Moderate) - 131	5.24 ft^2/day
FZ-06 Vertical Hydraulic Conductivity (Moderate) - 131	0.102 ft/day
FZ-06 Transmissivity (High) - 132	77.8 ft^2/day
FZ-06 Vertical Hydraulic Conductivity (High) - 132	3.14 ft/day
FZ-07 Transmissivity (Low) - 150	100 ft^2/day
FZ-07 Vertical Hydraulic Conductivity (Low) - 150	0.335 ft/day
FZ-07 Transmissivity (Moderate) - 151	113 ft^2/day
FZ-07 Vertical Hydraulic Conductivity (Moderate) - 151	1.17 ft/day
FZ-07 Transmissivity (High) - 152	1511 ft^2/day
FZ-07 Vertical Hydraulic Conductivity (High) - 152	16.1 ft/day
FZ-08 Transmissivity (Low) - 160	0.0185 ft^2/day
FZ-08 Vertical Hydraulic Conductivity (Low) - 160	0.0000388 ft/day
FZ-08 Transmissivity (Moderate) - 161	5.76 ft^2/day
FZ-08 Vertical Hydraulic Conductivity (Moderate) - 161	0.0104 ft/day
FZ-09 Transmissivity (Low) - 170	0.00493 ft^2/day
FZ-09 Vertical Hydraulic Conductivity (Low) - 170	0.000153 ft/day
FZ-09 Transmissivity (Moderate) - 171	124 ft^2/day
FZ-09 Vertical Hydraulic Conductivity (Moderate) - 171	1.51 ft/day
FZ-09 Transmissivity (High) - 172	1404 ft^2/day
FZ-09 Vertical Hydraulic Conductivity (High) - 172	17.8 ft/day
FZ-09 Transmissivity (North Sub-Zone) - 173	0.0123 ft^2/day
FZ-09 Vertical Hydraulic Conductivity (North Sub-Zone) - 173	0.000114 ft/day
FZ-09 Transmissivity (South Sub-Zone) - 174	57.9 ft^2/day
FZ-09 Vertical Hydraulic Conductivity (South Sub-Zone) - 174	0.658 ft/day
FZ-10 Transmissivity	0.0778 ft^2/day
FZ-10 Vertical Hydraulic Conductivity	0.000361 ft/day
FZ-11 Transmissivity (Low) - 210	0.186 ft^2/day
FZ-11 Vertical Hydraulic Conductivity (Low) - 210	0.0128 ft/day
FZ-11 Transmissivity (Moderate) - 211	80.2 ft^2/day
FZ-11 Vertical Hydraulic Conductivity (Moderate) - 211	1.22 ft/day
FZ-11 Transmissivity (Moderate) - 212	54.3 ft^2/day
FZ-11 Vertical Hydraulic Conductivity (Moderate) - 212	0.523 ft/day
FZ-11 Transmissivity (High) - 213	218 ft^2/day
FZ-11 Vertical Hydraulic Conductivity (High) - 213	4.34 ft/day
FZ-11 Transmissivity (High) - 214	231 ft^2/day
FZ-11 Vertical Hydraulic Conductivity (High) - 214	1.86 ft/day
Recharge Rate	0.000809 ft/day (3.54 in/yr)
Forebay GHB Conductance Multiplier	0.0179
Gorge Drain Conductance Multiplier	94.0
Conduit Drain Conductance Multiplier	0.118
Sewer Drain Conductance Multiplier	13.2
Tunnels Drain Conductance Multiplier	18786

Table 5-3
Calibration Residuals - Pumping Conditions

Well	Weight [1]	Observed Head (ft MSL)	Computed Head (ft MSL)	Residual (ft)
ABP-1-07	1.0	546.79	537.65	9.14
ABP-1-09	1.0	535.97	526.64	9.34
ABP-7-07	1.0	535.51	535.19	0.33
ABP-7-09	1.0	534.61	523.12	11.49
AFW-1U-06	0.0	556.63	554.64	1.99
AFW-1M-07	0.0	533.25	532.94	0.31
AFW-1M-09	0.0	524.65	517.21	7.44
AFW-1L-11	1.0	508.26	506.58	1.68
AFW-2U-04	1.0	575.21	571.20	4.01
AFW-2U-05	1.0	574.54	563.69	10.86
AFW-2U-06	0.0	545.32	547.74	-2.42
AFW-2M-07	0.0	527.52	528.09	-0.57
AFW-2M-09	0.0	524.22	513.31	10.91
AFW-2L-11	1.0	494.02	501.00	-6.98
AGW-1U-05	1.0	584.55	583.70	0.85
AGW-1U-06	1.0	552.98	568.62	-15.63
AGW-1M-07	1.0	552.86	548.28	4.58
AGW-1M-09	1.0	553.62	547.96	5.67
AGW-1L-11	0.1	557.45	545.86	11.59
B2U-06	1.0	553.60	563.16	-9.56
B2M-07	1.0	550.09	539.09	11.00
B2M-09	1.0	520.64	520.34	0.30
B2L-11	1.0	507.20	507.21	-0.02
C3-06	0.0	548.47	558.98	-10.51
C3-07	1.0	533.67	535.11	-1.44
C3-09	1.0	532.55	523.12	9.43
D1U-04	1.0	579.32	569.37	9.95
D1U-05	1.0	577.53	564.90	12.63
D1U-06	0.0	545.71	552.40	-6.69
D1M-07	0.1	537.06	534.28	2.78
D1M-09	1.0	518.18	524.58	-6.41
D1L-11	1.0	507.40	510.97	-3.57
D2U-04	1.0	579.83	569.82	10.00
D2U-05	1.0	577.34	562.51	14.82
D2U-06	0.0	545.63	552.90	-7.27
D2M-07	0.0	526.75	535.42	-8.67
D2M-09	1.0	518.28	524.89	-6.60
D2L-11	0.1	523.76	514.77	8.99
E6-04	1.0	565.00	562.76	2.24
E6-05	1.0	566.79	566.29	0.50
E6-06	1.0	563.14	560.24	2.90
E6-07	0.1	546.20	543.05	3.15
E6-09	1.0	555.95	534.11	21.84
E6-11	1.0	530.78	527.61	3.17

Table 5-3
Calibration Residuals - Pumping Conditions

Well	Weight [1]	Observed Head (ft MSL)	Computed Head (ft MSL)	Residual (ft)
F2U-02	1.0	575.52	588.97	-13.44
F2U-04	1.0	577.95	575.74	2.20
F2U-05	1.0	578.01	572.36	5.65
F2M-06	0.0	586.09	562.17	23.92
F2M-07	1.0	549.88	540.18	9.70
F2M-09	1.0	518.40	538.77	-20.37
F2L-11	0.1	553.28	538.37	14.91
F4U-02	1.0	586.04	586.10	-0.06
F4U-04	1.0	586.37	576.00	10.37
F4U-05	1.0	583.32	569.60	13.72
F4M-06	0.1	555.65	554.74	0.91
F4M-07	1.0	535.23	533.07	2.16
F4M-09	1.0	518.08	532.45	-14.37
F4L-11	0.1	535.92	533.19	2.72
F6-04	1.0	569.44	577.57	-8.13
F6-05	1.0	569.28	573.75	-4.47
F6-06	1.0	563.13	561.59	1.54
F6-07	0.1	569.00	546.08	22.92
F6-09	0.0	528.48	537.33	-8.85
F6-11	1.0	527.09	531.04	-3.95
G1U-01	1.0	601.58	608.59	-7.01
G1-02	1.0	591.06	590.12	0.94
G1U-04	1.0	591.13	582.47	8.66
G1M-06	1.0	563.02	566.61	-3.58
G1M-07	1.0	549.31	545.29	4.01
G1M-09	0.0	545.49	551.19	-5.71
G1L-11	1.0	578.84	556.30	22.54
H2U-01	1.0	611.79	613.31	-1.53
H2U-02	1.0	593.16	589.30	3.86
H2M-05	0.1	592.69	575.90	16.79
H2M-06	1.0	577.88	562.61	15.27
H2M-09	1.0	553.25	548.74	4.50
H2L-11	0.0	535.24	547.83	-12.59
H5-01	1.0	610.20	614.00	-3.80
H5-02	1.0	592.67	590.97	1.70
H5-04	1.0	592.67	583.09	9.57
H5-05	1.0	590.15	578.19	11.97
H5-06	0.0	555.42	566.86	-11.44
H5-07	1.0	550.39	552.28	-1.89
H5-09	1.0	553.11	551.99	1.12
H5-11	1.0	559.32	554.01	5.31
I1-01	1.0	608.13	600.86	7.26
I1-02	1.0	586.77	581.77	4.99
I1-04	1.0	584.68	575.53	9.15

Table 5-3
Calibration Residuals - Pumping Conditions

Well	Weight (1)	Observed Head (ft MSL)	Computed Head (ft MSL)	Residual (ft)
I1-05	1.0	553.13	571.56	-18.43
I1-06	1.0	548.90	562.59	-13.70
I1-07	1.0	552.23	551.79	0.43
J5U-02	1.0	596.91	589.72	7.19
J5U-04	1.0	587.33	581.87	5.46
J5U-05	1.0	579.08	576.99	2.09
J5M-06	0.1	542.90	563.08	-20.18
J5M-07	1.0	552.77	548.74	4.03
J5M-09	1.0	553.40	548.97	4.43
J5L-11	1.0	552.33	537.33	15.00
J6-02	1.0	593.52	597.27	-3.75
J6-04	1.0	580.30	588.10	-7.80
J6-05	1.0	580.14	582.34	-2.21
J6-06	0.1	557.99	568.43	-10.44
J6-07	1.0	552.75	550.48	2.27
J6-09	1.0	553.00	550.37	2.63
J6-11	1.0	564.20	547.03	17.17
PMW-1U-05	1.0	574.48	565.42	9.06
PMW-1U-06	0.1	545.38	552.03	-6.66
PMW-1M-07	0.0	526.40	533.85	-7.45
PMW-1M-09	1.0	518.28	520.77	-2.49
PMW-1L-11	1.0	509.55	508.55	1.00

Number of active observation points=	110	
Number of inactive observation points=	0	
Mean of Residuals=	1.93	ft
Mean of Absolute Residuals=	7.40	ft
Standard Deviation of Residuals=	9.17	ft
Sum of Squared Resdiuals=	9,660.78	ft^2
Minimum Residual=	-20.37	ft
Maximum Residual=	23.92	ft
Range in Observed Heads=	117.76	ft
Standard Deviation of Residuals / Range in Observed Heads=	7.79	%

Notes: (1) The observation weight is applied only during the parameter estimation process.
The weight is not applied during the calculation of residuals, or residual statistics.

Table 5-4
Model Water Balance by Model Layer - Pumping Conditions

Model	Flow Zone/	Inflows (ft^3/d)						Outflows (ft^3/d)							
Layer	Aquitard	Recharge	Forebay	Purge Wells	Shafts	Above	Below	Forebay	Conduits	Gorge	Sewers/Tunnels	Purge Wells	Shafts	Above	Below
1	Overburden(1)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	Rock Above FZ-01(2)	38,832.8	0.0	0.0	0.0	0.0	2,307.4	0.0	401.0	0.0	945.9	6.6	0.0	0.0	39,785.4
3	FZ-01	2,386.6	0.0	0.0	0.0	39,785.4	5.8	0.0	562.3	0.0	2,181.9	347.6	0.0	2,307.4	36,777.8
4	Aquitard	12,950.0	1.1	0.0	0.0	36,777.8	239.2	3.8	1,347.2	10.9	211.4	7.1	0.0	5.8	48,381.2
5	FZ-02	3,025.7	336.8	0.0	0.0	48,381.2	0.0	123.4	1,503.7	344.2	0.0	717.3	0.0	239.2	48,813.6
6	Aquitard	4,182.6	0.5	0.0	0.0	48,813.6	15.9	0.3	1,929.0	2.8	20.9	1.3	0.0	0.0	51,058.2
7	FZ-03	3,834.7	22.5	0.0	0.0	51,058.2	85.7	0.6	1,485.0	24.5	167.3	12.1	0.0	15.9	53,293.3
8	Aquitard	1,911.3	2.1	0.0	0.0	53,293.3	214.3	0.0	1,637.4	122.0	35.6	0.5	0.0	85.7	53,539.9
9	FZ-04	3,584.0	17.5	0.0	0.0	53,539.9	59.2	70.9	1,438.8	4,014.4	4,195.3	63.0	17.0	214.3	47,200.0
10	Aquitard	1,939.6	0.1	0.0	0.1	47,200.0	90.4	1.5	1,657.2	67.4	56.2	1.2	0.1	59.2	47,386.0
11	FZ-05	1,100.3	29.1	48.8	5.7	47,386.0	18.3	1,224.6	1,363.2	1,750.5	835.9	601.8	9.9	90.4	42,710.8
12	Aquitard	3,610.2	0.0	1.1	0.0	42,710.8	35.4	11.3	2,042.5	391.8	70.9	13.3	2.4	18.3	43,829.2
13	FZ-06	863.6	0.0	100.2	1.8	43,829.2	2.3	706.9	1,683.7	2,630.1	131.7	926.2	69.7	35.4	38,614.5
14	Aquitard	1,106.3	0.0	3.4	0.0	38,614.5	56.7	6.8	1,363.7	562.5	0.0	18.1	6.7	2.3	37,820.6
15	FZ-07	123.4	13,006.0	0.0	0.0	37,820.6	2,809.6	0.4	1,183.1	14,119.1	0.0	7,709.6	1,575.6	56.7	29,088.0
16	FZ-08	119.3	62.9	0.0	0.3	29,088.0	3,160.9	0.0	1,104.9	53.3	0.0	328.8	0.1	2,809.6	28,134.0
17	FZ-09	109.2	17,055.6	858.9	0.3	28,134.0	508.6	0.0	1,052.0	29,644.4	0.0	8,283.3	0.0	3,160.9	4,454.2
18	Aquitard	271.0	0.4	0.2	0.6	4,454.2	493.2	0.1	991.5	157.6	0.0	8.6	1.2	508.6	3,552.1
19	FZ-10	89.0	1.0	0.0	0.7	3,552.1	491.0	0.9	117.0	44.5	0.0	4.2	1.0	493.2	3,472.9
20	Aquitard	204.3	0.4	0.4	0.0	3,472.9	554.8	0.7	110.4	230.9	79.7	2.9	2.1	491.0	3,315.0
21	FZ-11	58.7	465.7	1,802.1	21.1	3,315.0	78.0	3.6	102.0	2,753.1	43.0	1,326.4	3.5	554.8	913.8
22	Aquitard	97.1	0.4	0.2	0.0	913.8	0.0	0.6	99.6	738.1	94.0	0.7	0.8	78.0	0.0
	TOTALS	80,399.5	31,002.0	2,815.2	30.7	662,140.3	11,226.6	2,156.3	23,175.2	57,661.9	9,069.7	20,380.7	1,690.0	11,226.6	662,140.3

Notes: (1) Layer 1 (overburden) is entirely inactive.
(2) Layer 2 represents the rock overlying FZ-01. This rock appears to be highly fractured and does not appear to act as an aquitard.

Table 5-5
Calculated Purge Well Flows - Pumping Conditions

Purge Well Location	Simulation of Pumping Conditions (gpm)			
	Inflow (1)	Outflow (2)	Net (3)	Pumpage (4)
APW-1	1.31	3.87	-2.56	0.79
APW-2	0.01	7.98	-7.97	0.24
PW-1U	0.25	0.00	0.25	0.44
PW-1L	18.98	0.00	18.98	10.35
PW-2UR	1.11	0.06	1.05	0.18
PW-2M	10.96	0.00	10.96	31.64
PW-2L	0.02	0.00	0.02	0.00
PW-3M	14.93	0.00	14.93	0.00
PW-3L	6.19	0.00	6.19	4.00
PW-4U	1.17	0.13	1.04	0.44
PW-4M	11.59	0.00	11.59	0.00
PW-5UR	1.95	0.00	1.95	4.92
PW-6UR	4.25	0.00	4.25	1.80
PW-6MR	25.17	0.00	25.17	3.35
PW-7U	0.45	0.00	0.45	0.56
PW-8U	0.37	0.00	0.37	0.86
PW-8M	6.62	1.97	4.65	0.48
PW-9U	0.53	0.00	0.53	0.91
PW-10U	0.03	0.60	-0.57	5.39

Notes: (1) Inflow is the flow into GHB cells acting as a sinks.
(2) Outflow is the flow out of GHB cells acting as sources.
(3) Net = Inflow - Outflow. A positive net flow represents a surplus available for extraction; a negative net flow indicates a water deficit.
(4) Pumpage is the average extraction rate of the purge well over the period 6-Jan-2003 00:00 to 7-Jan-2003 00:00.

Table 5-6
Calibration Residuals - Non-Pumping Conditions

Well	Observed Head (ft MSL)	Computed Head (ft MSL)	Residual (ft)
ABP-1-07	546.76	538.75	8.01
ABP-1-09	537.47	529.20	8.26
ABP-7-07	535.17	538.21	-3.05
ABP-7-09	534.70	532.63	2.07
AFW-1U-06	556.42	555.07	1.35
AFW-1M-07	533.25	533.60	-0.35
AFW-1M-09	524.60	517.89	6.70
AFW-1L-11	506.88	507.08	-0.20
AFW-2U-04	575.17	571.41	3.76
AFW-2U-05	574.59	563.77	10.82
AFW-2U-06	545.30	547.97	-2.67
AFW-2M-07	527.52	528.52	-0.99
AFW-2M-09	524.12	513.75	10.37
AFW-2L-11	494.14	501.38	-7.24
AGW-1U-05	582.68	591.06	-8.38
AGW-1U-06	556.01	575.57	-19.55
AGW-1M-07	556.50	553.26	3.24
AGW-1M-09	557.03	552.45	4.58
AGW-1L-11	557.64	552.69	4.95
B2U-06	555.56	573.91	-18.35
B2M-07	554.29	548.47	5.83
B2M-09	553.50	549.70	3.80
B2L-11	530.89	524.13	6.77
C3-06	548.47	565.15	-16.68
C3-07	545.52	539.79	5.73
C3-09	545.92	539.22	6.70
D1U-04	579.29	570.25	9.03
D1U-05	578.36	570.11	8.26
D1U-06	551.22	563.43	-12.21
D1M-07	539.11	551.09	-11.98
D1M-09	553.26	551.72	1.54
D1L-11	528.05	529.82	-1.77
D2U-04	578.95	571.16	7.79
D2U-05	578.10	563.85	14.25
D2U-06	550.96	562.28	-11.32
D2M-07	534.14	549.32	-15.17
D2M-09	553.72	550.62	3.10
D2L-11	527.60	534.73	-7.13
E6-04	564.65	563.11	1.54
E6-05	566.18	568.44	-2.26
E6-06	569.55	565.10	4.44
E6-07	549.22	550.40	-1.19
E6-09	556.10	544.97	11.13
E6-11	538.95	541.09	-2.14

Table 5-6
Calibration Residuals - Non-Pumping Conditions

Well	Observed Head (ft MSL)	Computed Head (ft MSL)	Residual (ft)
F2U-02	575.28	594.11	-18.83
F2U-04	577.57	579.43	-1.86
F2U-05	577.91	577.93	-0.02
F2M-06	585.71	570.19	15.52
F2M-07	554.45	556.07	-1.62
F2M-09	553.55	555.86	-2.31
F2L-11	553.53	555.70	-2.17
F4U-02	585.91	596.20	-10.29
F4U-04	587.49	586.91	0.58
F4U-05	584.45	581.23	3.22
F4M-06	556.09	569.46	-13.37
F4M-07	552.24	555.66	-3.42
F4M-09	553.46	555.51	-2.05
F4L-11	539.21	555.87	-16.66
F6-04	569.52	579.48	-9.96
F6-05	569.35	576.34	-6.99
F6-06	569.44	565.64	3.79
F6-07	568.97	551.30	17.67
F6-09	554.29	546.43	7.85
F6-11	527.61	542.91	-15.30
G1U-01	601.18	612.11	-10.93
G1-02	591.77	597.56	-5.79
G1U-04	592.08	590.93	1.14
G1M-06	569.60	575.65	-6.06
G1M-07	564.84	561.26	3.58
G1M-09	572.91	563.68	9.24
G1L-11	580.54	565.76	14.78
H2U-01	609.66	618.36	-8.70
H2U-02	593.23	596.82	-3.58
H2M-05	593.24	584.28	8.95
H2M-06	577.86	572.00	5.86
H2M-09	556.78	556.22	0.56
H2L-11	535.45	558.32	-22.87
H5-01	609.44	618.25	-8.82
H5-02	592.62	596.40	-3.78
H5-04	595.48	588.95	6.53
H5-05	591.10	584.30	6.80
H5-06	585.00	573.65	11.35
H5-07	550.68	559.60	-8.92
H5-09	556.55	559.10	-2.54
H5-11	569.47	561.97	7.50
I1-01	607.95	603.77	4.18
I1-02	587.29	585.07	2.22
I1-04	583.06	579.05	4.00

Table 5-6
Calibration Residuals - Non-Pumping Conditions

Well	Observed Head (ft MSL)	Computed Head (ft MSL)	Residual (ft)
I1-05	554.22	575.23	-21.01
I1-06	549.24	566.65	-17.41
I1-07	555.59	556.48	-0.89
J5U-02	595.49	598.00	-2.52
J5U-04	587.91	590.25	-2.34
J5U-05	579.13	585.39	-6.26
J5M-06	551.62	571.72	-20.10
J5M-07	556.31	554.76	1.55
J5M-09	556.75	554.80	1.95
J5L-11	555.26	555.15	0.11
J6-02	592.65	601.64	-8.99
J6-04	579.77	592.53	-12.76
J6-05	579.65	586.82	-7.17
J6-06	558.15	572.98	-14.83
J6-07	556.36	555.11	1.24
J6-09	556.51	555.00	1.51
J6-11	564.06	555.29	8.77
PMW-1U-05	577.48	578.21	-0.73
PMW-1U-06	549.53	566.63	-17.11
PMW-1M-07	526.66	552.33	-25.67
PMW-1M-09	553.50	552.79	0.71
PMW-1L-11	530.51	528.24	2.27

Number of active observation points=	110	
Number of inactive observation points=	0	
Mean of Residuals=	-1.63	ft
Mean of Absolute Residuals=	7.23	ft
Standard Deviation of Residuals=	9.16	ft
Sum of Squared Resdiuals=	9,530.54	ft^2
Minimum Residual=	-25.67	ft
Maximum Residual=	17.67	ft
Range in Observed Heads=	115.52	ft
Standard Deviation of Residuals / Range in Observed Heads=	7.93	%

Table 5-7
Model Water Balance by Model Layer - Non-Pumping Conditions

Model	Flow Zone/	Inflows (ft^3/d)						Outflows (ft^3/d)							
Layer	**Aquitard**	**Recharge**	**Forebay**	**Purge Wells**	**Shafts**	**Above**	**Below**	**Forebay**	**Conduits**	**Gorge**	**Sewers/Tunnels**	**Purge Wells**	**Shafts**	**Above**	**Below**
1	Overburden[1]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	Rock Above FZ-01[2]	38,832.8	0.0	0.0	0.0	0.0	2,586.5	0.0	422.6	0.0	1,186.2	13.5	0.0	0.0	39,796.2
3	FZ-01	2,386.6	0.0	0.0	0.0	39,796.2	15.7	0.0	589.0	0.0	2,440.8	354.2	0.0	2,586.5	36,228.3
4	Aquitard	12,950.0	1.0	0.0	0.0	36,228.3	280.9	3.9	1,415.4	12.0	247.9	5.0	0.0	15.7	47,759.7
5	FZ-02	3,025.7	293.9	89.3	0.0	47,759.7	0.0	179.4	1,587.2	372.0	0.0	196.4	0.0	280.9	48,552.7
6	Aquitard	4,182.6	0.4	0.3	0.0	48,552.7	18.3	0.4	2,048.6	3.3	24.7	0.2	0.0	0.0	50,677.5
7	FZ-03	3,834.7	20.5	5.0	0.0	50,677.5	105.0	1.1	1,584.5	26.4	193.8	1.7	0.0	18.3	52,814.1
8	Aquitard	1,911.3	2.0	0.2	0.0	52,814.1	243.0	0.1	1,751.4	128.1	39.4	0.1	0.0	105.0	52,946.7
9	FZ-04	3,584.0	15.5	33.8	0.0	52,946.7	117.2	82.2	1,551.8	4,297.5	5,090.1	7.6	19.9	243.0	45,419.3
10	Aquitard	1,939.6	0.1	1.0	0.1	45,419.3	159.5	1.7	1,804.4	68.3	70.4	0.1	0.1	117.2	45,455.9
11	FZ-05	1,100.3	23.5	585.2	5.7	45,455.9	37.1	1,522.1	1,587.6	1,856.6	1,265.9	260.0	10.6	159.5	40,545.9
12	Aquitard	3,610.2	0.0	4.6	0.0	40,545.9	68.1	11.3	2,374.6	394.6	95.0	12.8	2.5	37.1	41,302.8
13	FZ-06	863.6	4.7	174.7	1.8	41,302.8	15.6	751.3	2,039.6	2,841.9	181.2	713.2	81.5	68.1	35,691.4
14	Aquitard	1,106.3	0.1	6.7	0.0	35,691.4	229.7	4.8	1,753.2	570.7	0.0	5.5	7.4	15.6	34,676.7
15	FZ-07	123.4	13,097.1	1,338.5	0.0	34,676.7	260.0	0.0	1,625.6	18,883.9	0.0	363.7	2,286.6	229.7	26,121.7
16	FZ-08	119.3	66.6	2.6	0.3	26,121.7	542.3	0.0	1,550.3	68.0	0.0	19.4	0.2	260.0	24,954.8
17	FZ-09	109.2	17,912.2	4,280.7	0.3	24,954.8	343.9	0.0	1,495.9	40,028.4	0.0	1,136.5	0.0	542.3	4,353.6
18	Aquitard	271.0	0.4	2.5	0.5	4,353.6	335.5	0.1	1,405.9	169.5	0.0	4.5	1.7	343.9	3,037.9
19	FZ-10	89.0	1.2	2.3	0.6	3,037.9	381.6	0.9	240.9	52.6	0.0	4.0	1.4	335.5	2,877.2
20	Aquitard	204.3	0.4	3.3	0.0	2,877.2	572.5	0.6	237.7	244.6	96.5	2.8	2.2	381.6	2,691.5
21	FZ-11	58.7	372.1	5,640.2	26.7	2,691.5	65.4	3.5	236.4	6,914.1	46.7	5.7	3.5	572.5	1,033.3
22	Aquitard	97.1	0.4	1.3	0.1	1,033.3	0.0	0.6	228.5	740.9	95.6	0.4	0.8	65.4	0.0
	TOTALS	80,399.5	31,812.1	12,172.3	36.0	636,937.1	6,377.5	2,563.9	27,531.3	77,673.5	11,074.0	3,107.3	2,418.5	6,377.5	636,937.1

Notes: (1) Layer 1 (overburden) is entirely inactive.
(2) Layer 2 represents the rock overlying FZ-01. This rock appears to be highly fractured and does not appear to act as an aquitard.

Table 5-8
Calculated Purge Well Flows - Non-Pumping Conditions

Purge Well	Simulation of Non-Pumping Conditions (gpm)		
Location	Inflow (1)	Outflow (2)	Net (3)
APW-1	0.01	31.10	-31.09
APW-2	5.25	9.42	-4.17
PW-1U	0.01	0.04	-0.03
PW-1L	0.02	12.10	-12.08
PW-2UR	0.00	1.25	-1.25
PW-2M	0.46	1.93	-1.47
PW-2L	0.07	0.00	0.07
PW-3M	1.88	0.50	1.38
PW-3L	0.00	0.08	-0.08
PW-4U	1.04	0.31	0.73
PW-4M	1.74	0.00	1.74
PW-5UR	0.01	1.18	-1.17
PW-6UR	1.91	1.19	0.72
PW-6MR	2.35	0.00	2.35
PW-7U	0.00	0.20	-0.20
PW-8U	0.00	0.10	-0.10
PW-8M	0.72	3.42	-2.70
PW-9U	0.55	0.00	0.55
PW-10U	0.12	0.42	-0.30

Notes: (1) Inflow is the flow into GHB cells acting as a sinks.
(2) Outflow is the flow out of GHB cells acting as sources.
(3) Net = Inflow - Outflow. A positive net flow represents a surplus available for extraction; a negative net flow indicates a water deficit.
(4) Pumpage is the average extraction rate of the purge well over the period 6-Jan-2003 00:00 to 7-Jan-2003 00:00.

SITE CHARACTERIZATION REPORT – GROUNDWATER FLOW MODEL

APPENDIX A

SITE CHARACTERIZATION REPORT – GROUNDWATER FLOW MODEL

HYDE PARK LANDFILL SITE
TOWN OF NIAGARA, NEW YORK

APPENDIX A – HELP ANALYSIS

Prepared For:
Miller Springs Remediation Management, Inc.

Prepared By:
Conestoga-Rovers & Associates

CONESTOGA-ROVERS & ASSOCIATES

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MEMORANDUM

TO:	Chris Neville	REF. NO.:	1069-70
FROM:	Amy Domaratzki	DATE:	July 27, 2001
C.C.:	Nicholas Fitzpatrick, Mike Mateyk		
RE:	**Hyde Park Landfill HELP Model**		

The Hydrologic Evaluation of Landfill Performance (HELP) model version 3.07 (Schroeder, 1994a and 1994b) was used to provide an independent estimate of the infiltration rate through the overburden in the vicinity of the Hyde Park Landfill in Niagara Falls, New York.

1. Climatic Data

The climatic data were synthetically generated using the coefficients for Buffalo, New York provided in the HELP database, with a specified latitude of 43.13° N.

The precipitation data were modified using data from the Niagara Falls Airport. The Niagara Falls Airport data are available from the World WeatherDisc (WeatherDisc Associates, Inc., 1994). The average monthly precipitation rates for the 14-year record available are:

Month	*Average Precipitation (in)*	*Month*	*Average Precipitation (in)*
January	2.97	July	2.32
February	2.81	August	4.47
March	2.91	September	2.74
April	2.96	October	2.57
May	3.07	November	2.64
June	1.71	December	2.89

There are two options for weather data in HELP. Actual measured values can be used for the length of the simulation, or average monthly values can be used to generate synthetic daily data for the duration of the simulation. The synthetic generation option was used for this analysis. The synthetic data preserve the dependence in time, the correlation between variables and the seasonal characteristics in the actual weather data (Schroeder et al., 1994a, pg. 9).

2. Surface cover parameters

The following additional parameters were used in the analysis:

Ground Cover	Fair Stand of Grass
Maximum Leaf Area Index	4.0
Evaporative Zone Depth	20 inches

An SCS curve number of 85.3 was computed from a default soil data base using soil texture number 12 with a fair stand of grass, a surface slope of 0.5 percent and a slope length of 5200 feet.

Soil texture 12 is described as SiCl (USDA) or CL (USCS). The default hydraulic conductivity for soil texture 12 is 4.2×10^{-5} cm/sec. For the purposes of SCS curve number calculation, this default K cannot be changed. However, site-specific values for hydraulic conductivity are used in the subsequent infiltration analysis.

3. Soil and Design Data

The following profile was specified in the HELP model:

Type	vertical percolation
HELP Soil No.	12 (with K modified as indicated below)
Thickness	336 inches
Porosity	0.471
Field Capacity	0.342
Wilting Point	0.210
Effective Sat. Hyd Cond.	1.20×10^{-5} cm/s

The value of the effective saturated hydraulic conductivity was chosen as the geometric mean of the values obtained from slug test results listed in CRA's e:DAT database. The value is relatively close to the default value assigned for HELP soil number 12, suggesting that soil number 12 is an appropriate selection for the calculation of the SCS soil curve number.

4. Duration of the analysis

The simulation was run for 25 years.

5. Base case results

The following average annual rates were computed over the 25-year simulation:

Component	*(in/yr)*
Precipitation	32.90
Runoff	9.34
Evapotranspiration	20.68
Infiltration to Bedrock	2.75

6. Sensitivity analyses

6.1 Duration of the simulation

The base case analysis was executed for a 25-year period. This presumes that 25 years is sufficiently long for flow through the overburden to become steady, that is, no more major changes in storage occur through time. Steady flow requires that the average infiltration rate (I) be equal to the difference between the precipitation (P) and the sum of the runoff (R) and evapotranspiration (E):

$$I = P - (R + E).$$

For the base case analysis, the right-hand side of this equation yields 2.88 in/yr, which is slightly different from the reported average infiltration rate of 2.75 in/yr. The discrepancy is due to a small increase in the volume of water stored in the soil column over the duration of the simulation.

In order to investigate the influence of the duration of the simulation, the analysis was repeated for three longer periods with the following results:

Duration of simulation, yrs	**Average Infiltration Rate in/yr**
25	2.75
50	3.02
75	3.04
100	3.00

The results from the additional analyses indicate that the average infiltration rate does not vary significantly when the duration of the simulation is extended, confirming that conditions are nearly stable after 25 years.

6.2 SCS curve number

The base case analysis assumes that the soil is covered by a "fair stand of grass". This is an appropriate assumption for some of the area surrounding the Site, but there are a variety of land uses and ground cover over the model area. The HELP analysis was repeated for different SCS soil curve numbers:

Ground Cover	Curve Number	Recharge (in/yr)
Bare Ground	94.2	1.72
Fair Stand of Grass	85.3	2.75
Excellent Stand of Grass	76.9	3.35

The results of the sensitivity analysis suggest that the results of the analysis are very sensitive to the assumed soil cover since evapotranspiration represents the dominant fraction of the precipitation (63% in the base case).

6.3 Wilting point

No independent estimates are available for the wilting point at the Site. Therefore, a sensitivity analysis was conducted to assess the significance of wilting point on infiltration rate.

Wilting Point	Recharge rate (in/yr)
0.018	2.78
0.210	2.75

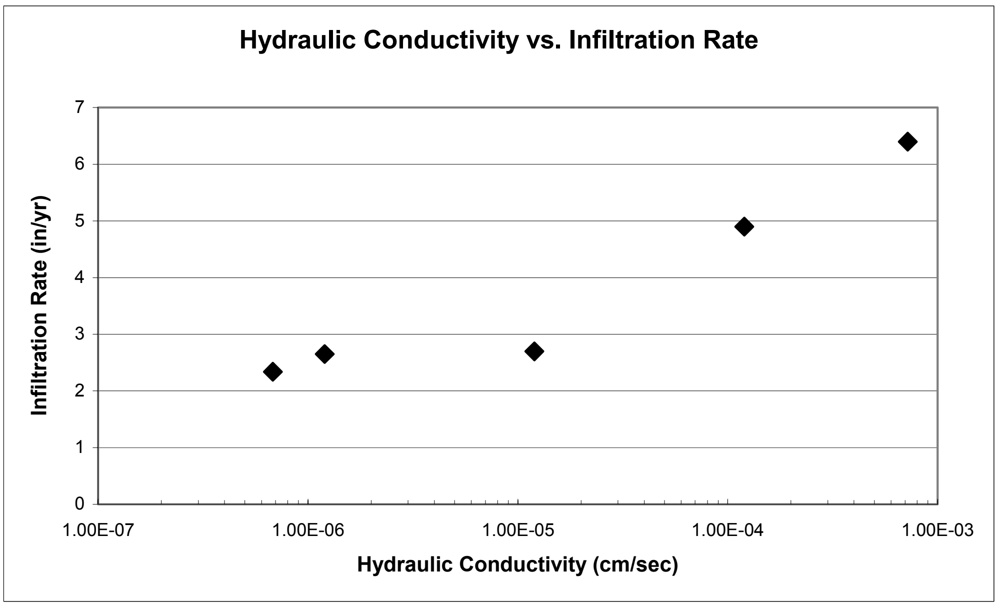
The wilting point value of 0.018 is the lowest value listed in the HELP documentation for any soil type. The value of 0.210 is the value selected by HELP for the base case soil type. According to the HELP documentation, wilting point should be equal to approximately ½ or less of the field capacity. Thus, the default value of 0.210 is a maximum value. The results of the additional analysis demonstrate that the calculated infiltration rate is insensitive to the assumed value of the wilting point.

6.4 Thickness of the overburden

An overburden thickness of 336 inches (28 ft) is assumed in the base case analysis. Contour maps of the available data show that the thickness of the overburden ranges from about 4 ft to 38 ft in the vicinity of the Site. The overburden thickness affects only the length of time required to attain pseudo-steady conditions. The base case analysis was repeated with an overburden thickness of 4 ft. The resulting average infiltration rate is 2.93 in/yr after 25 years, which is close to the value obtained from running the 28 ft simulation for 50 years (3.02 in/yr).

6.5 Hydraulic conductivity

The effective hydraulic conductivity of 1.20 x 10^{-5} cm/s is the geometric mean of the values obtained from slug test results listed in CRA's e:DAT database. It is expected that the slug tests (especially any single average value derived from them) provide a very rough measure of the overburden hydraulic conductivity (K). A sensitivity analysis was conducted to assess the significance of hydraulic conductivity on infiltration rate. The HELP analyses were repeated considering soils that encompasses the range of hydraulic conductivities obtained from the slug tests (K = $2x10^{-7}$ cm/sec to $2x10^{-4}$ cm/sec). The results of the sensitivity analysis are plotted below.



The sensitivity analysis for hydraulic conductivity was conducted using different soil types for each run. It is possible to adjust only the value of the K between simulations, but that could result in the specification of incompatible soil parameters. For example, this approach could lead to specifying a soil that is described as clay (and has the porosity, field capacity and wilting point of a clay) but has a hydraulic conductivity that is more appropriate for a silty loam.

The results of the sensitivity analysis with respect to the hydraulic conductivity suggest that the hydraulic conductivity may vary from about 2 in/yr to over 6 in/yr over the range of slug test values obtained at the Site.

7. References

Schroeder, P. R., T. S. Dozier, P. A. Zappi, B. M. McEnroe, J. W. Sjostrom, and R. L. Peyton, *The Hydrologic Evaluation of Landfill Performance (HELP) Model - Engineering Documentation for Version 3*, Risk Reduction Engineering Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, EPA/600/R-94/168b, Cincinnati, Ohio, September 1994a.

Schroeder, P. R., C. M. Lloyd, P. A. Zappi, and N. .M. Aziz, *The Hydrologic Evaluation of Landfill Performance (HELP) Model - User's Guide for Version 3*, Risk Reduction Engineering Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, EPA/600/R-94/168a, Cincinnati, Ohio, September 1994b.

HELP output for the base case analysis

```
 ******************************************************************************
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 **                                                                          **
 **                                                                          **
 **              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
 **                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
 **                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
 **                    USAE WATERWAYS EXPERIMENT STATION                     **
 **             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
 **                                                                          **
 **                                                                          **
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 ******************************************************************************


 PRECIPITATION DATA FILE:    h:\software\help3\1069PREC.D4
 TEMPERATURE DATA FILE:      h:\software\help3\1069TEMP.D7
 SOLAR RADIATION DATA FILE:  h:\software\help3\1069SOL.D13
 EVAPOTRANSPIRATION DATA:    h:\software\help3\1069EVAP.D11
 SOIL AND DESIGN DATA FILE:  h:\software\help3\1069_2.D10
 OUTPUT DATA FILE:           h:\software\help3\1069_2.OUT


 TIME:  13:53     DATE:   7/ 6/2001


******************************************************************************

      TITLE:  1069 Hyde Park Landfill Recharge Estimate

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      NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
               COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                  LAYER  1
                                  --------

                    TYPE 1 - VERTICAL PERCOLATION LAYER
                        MATERIAL TEXTURE NUMBER   0
           THICKNESS                 =    336.00   INCHES
           POROSITY                  =      0.4710 VOL/VOL
           FIELD CAPACITY            =      0.3420 VOL/VOL
           WILTING POINT             =      0.2100 VOL/VOL
           INITIAL SOIL WATER CONTENT  =      0.3612 VOL/VOL
           EFFECTIVE SAT. HYD. COND.   =  0.120000004000E-04 CM/SEC




                  GENERAL DESIGN AND EVAPORATIVE ZONE DATA
                  ----------------------------------------

         NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
                  SOIL DATA BASE USING SOIL TEXTURE #12 WITH A
                  FAIR STAND OF GRASS, A SURFACE SLOPE OF  1.%
                  AND A SLOPE LENGTH OF 5200. FEET.
```

```
SCS RUNOFF CURVE NUMBER               =     85.30
FRACTION OF AREA ALLOWING RUNOFF      =    100.0    PERCENT
AREA PROJECTED ON HORIZONTAL PLANE    =      1.000  ACRES
EVAPORATIVE ZONE DEPTH                =     20.0    INCHES
INITIAL WATER IN EVAPORATIVE ZONE     =      8.882  INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE    =      9.420  INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE    =      4.200  INCHES
INITIAL SNOW WATER                    =      0.000  INCHES
INITIAL WATER IN LAYER MATERIALS      =    121.363  INCHES
TOTAL INITIAL WATER                   =    121.363  INCHES
TOTAL SUBSURFACE INFLOW               =      0.00   INCHES/YEAR
```

EVAPOTRANSPIRATION AND WEATHER DATA

```
NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
         BUFFALO               NEW YORK

    STATION LATITUDE                        =  43.13 DEGREES
    MAXIMUM LEAF AREA INDEX                 =   4.00
    START OF GROWING SEASON (JULIAN DATE)   =    126
    END OF GROWING SEASON (JULIAN DATE)     =    285
    EVAPORATIVE ZONE DEPTH                  =  20.0  INCHES
    AVERAGE ANNUAL WIND SPEED               =  12.10 MPH
    AVERAGE 1ST QUARTER RELATIVE HUMIDITY   =  76.00 %
    AVERAGE 2ND QUARTER RELATIVE HUMIDITY   =  68.00 %
    AVERAGE 3RD QUARTER RELATIVE HUMIDITY   =  72.00 %
    AVERAGE 4TH QUARTER RELATIVE HUMIDITY   =  76.00 %
```

```
NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
         COEFFICIENTS FOR    BUFFALO             NEW YORK
```

NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
2.97	2.81	2.91	2.96	3.07	1.71
2.32	4.47	2.74	2.57	2.64	2.89

```
NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
         COEFFICIENTS FOR    BUFFALO             NEW YORK
```

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
23.50	24.50	33.00	45.40	56.10	66.00
70.70	68.90	62.10	51.50	40.30	28.80

```
NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
         COEFFICIENTS FOR    BUFFALO             NEW YORK
           AND STATION LATITUDE  =  43.13 DEGREES
```

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1 THROUGH 25

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	2.93	2.80	2.94	2.81	2.81	1.67
	2.20	4.17	2.64	2.61	2.74	2.60
STD. DEVIATIONS	0.88	1.10	0.93	1.24	1.19	0.67
	1.18	2.14	1.17	1.21	1.17	0.59
RUNOFF						
TOTALS	0.957	1.213	4.664	1.654	0.081	0.003
	0.018	0.197	0.055	0.091	0.110	0.299
STD. DEVIATIONS	1.043	0.970	2.479	1.666	0.173	0.011
	0.038	0.400	0.149	0.191	0.219	0.398
EVAPOTRANSPIRATION						
TOTALS	0.465	0.419	0.464	1.862	3.044	3.961
	2.072	3.462	2.216	1.230	0.903	0.581
STD. DEVIATIONS	0.078	0.093	0.136	0.740	0.860	0.773
	1.060	1.365	0.910	0.255	0.169	0.105
PERCOLATION/LEAKAGE THROUGH LAYER 1						
TOTALS	0.1552	0.1395	0.2374	0.3247	0.2154	0.0750
	0.1151	0.2351	0.3190	0.3358	0.3139	0.2812
STD. DEVIATIONS	0.1187	0.1110	0.1154	0.0877	0.0683	0.0660
	0.0990	0.1323	0.0967	0.0683	0.0533	0.0824

AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 25

	INCHES		CU. FEET	PERCENT
PRECIPITATION	32.90	(3.576)	119440.1	100.00
RUNOFF	9.340	(2.2690)	33905.62	28.387
EVAPOTRANSPIRATION	20.679	(2.3914)	75063.84	62.846
PERCOLATION/LEAKAGE THROUGH LAYER 1	2.74732	(0.59718)	9972.778	8.34961
CHANGE IN WATER STORAGE	0.137	(2.0990)	497.84	0.417

```
******************************************************************************

            PEAK DAILY VALUES FOR YEARS    1 THROUGH   25
   ------------------------------------------------------------------------
                                              (INCHES)      (CU. FT.)
                                             ----------   -------------
      PRECIPITATION                            2.74          9946.200

      RUNOFF                                   4.169        15132.7266

      PERCOLATION/LEAKAGE THROUGH LAYER  1     0.029591       107.41471

      SNOW WATER                               7.69         27930.7187

      MAXIMUM VEG. SOIL WATER (VOL/VOL)                0.4600

      MINIMUM VEG. SOIL WATER (VOL/VOL)                0.2100

******************************************************************************


******************************************************************************

               FINAL WATER STORAGE AT END OF YEAR   25
    ----------------------------------------------------------------------
                LAYER        (INCHES)       (VOL/VOL)
                -----        --------       ---------
                  1          123.0132         0.3661

               SNOW WATER       1.779

******************************************************************************
******************************************************************************
```

SITE CHARACTERIZATION REPORT – GROUNDWATER FLOW MODEL

APPENDIX B – MODEL FLOWS ALONG PURGE WELLS & SHAFTS

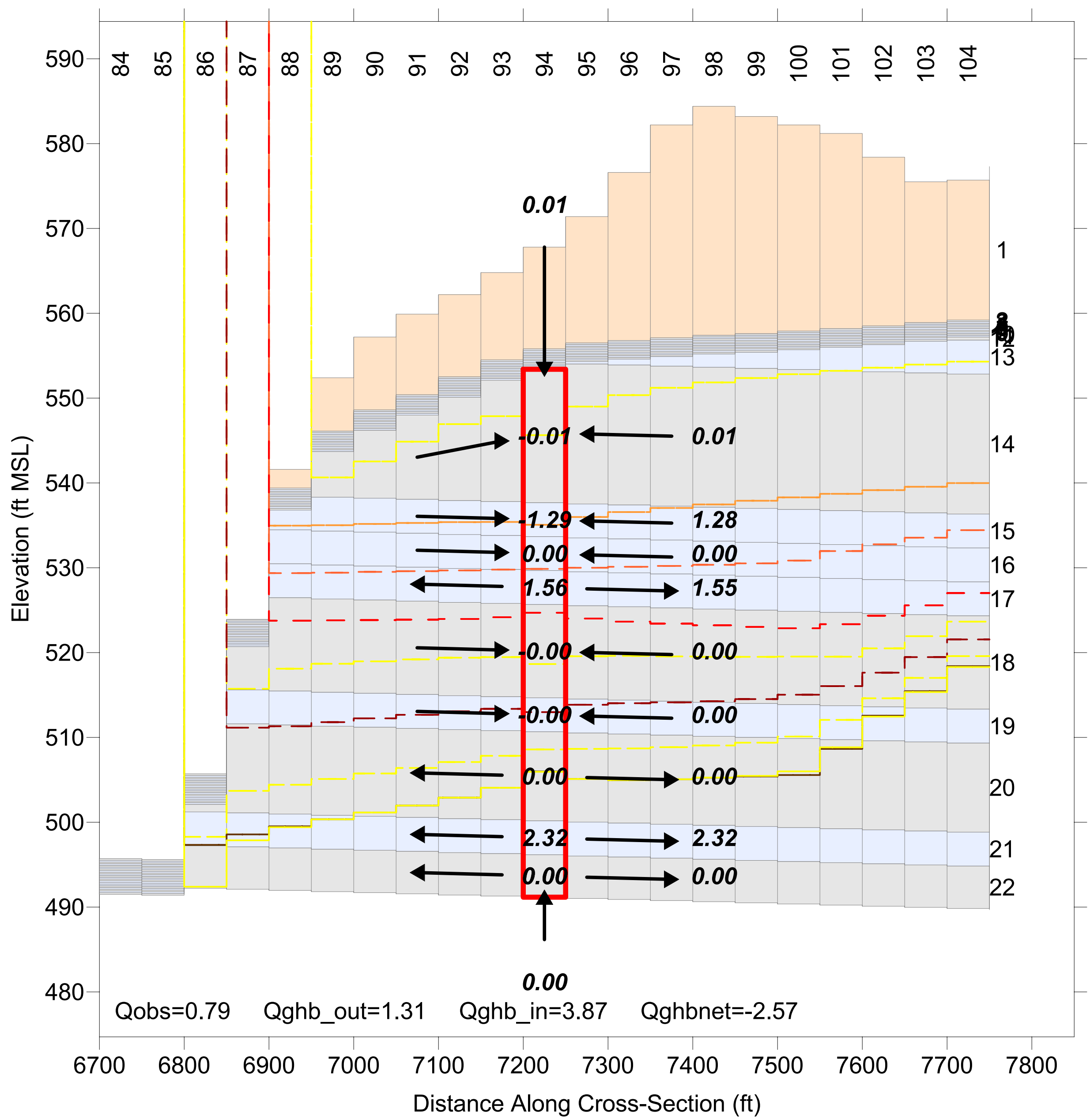
SITE CHARACTERIZATION REPORT – GROUNDWATER FLOW MODEL

HYDE PARK LANDFILL SITE
TOWN OF NIAGARA, NEW YORK

APPENDIX B – MODEL FLOWS ALONG PURGE WELLS & SHAFTS

Prepared For:
Miller Springs Remediation Management, Inc.

Prepared By:
S.S. Papadopulos & Associates, Inc.

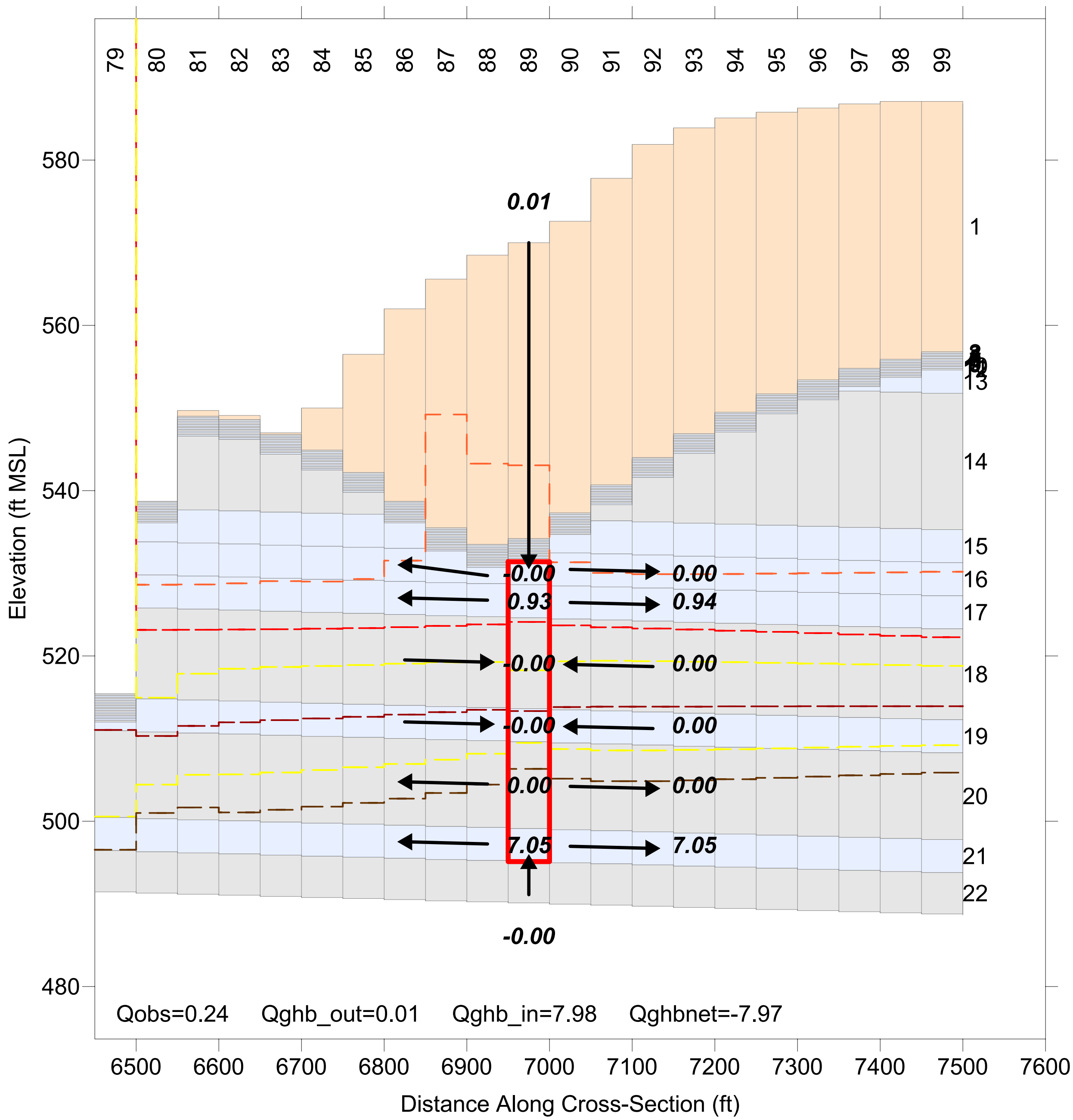


VERTICAL EXAGGERATION=10x

figure B-1
MODEL FLOWS ALONG APW-1; PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\APW-1_flows.srf



VERTICAL EXAGGERATION=10x

figure B-2

MODEL FLOWS ALONG APW-2; PUMPING CONDITIONS

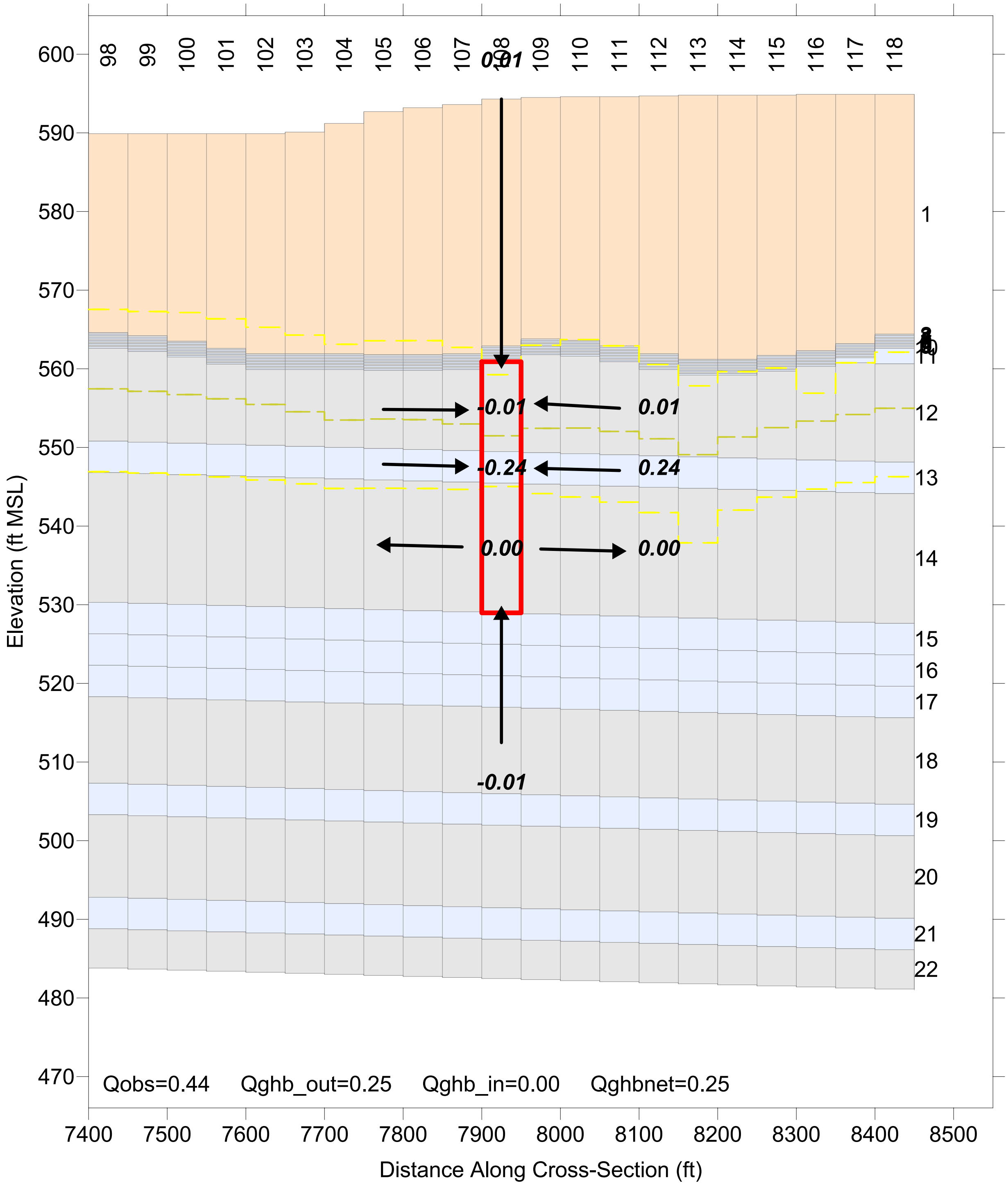
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\APW-2_flows.srf

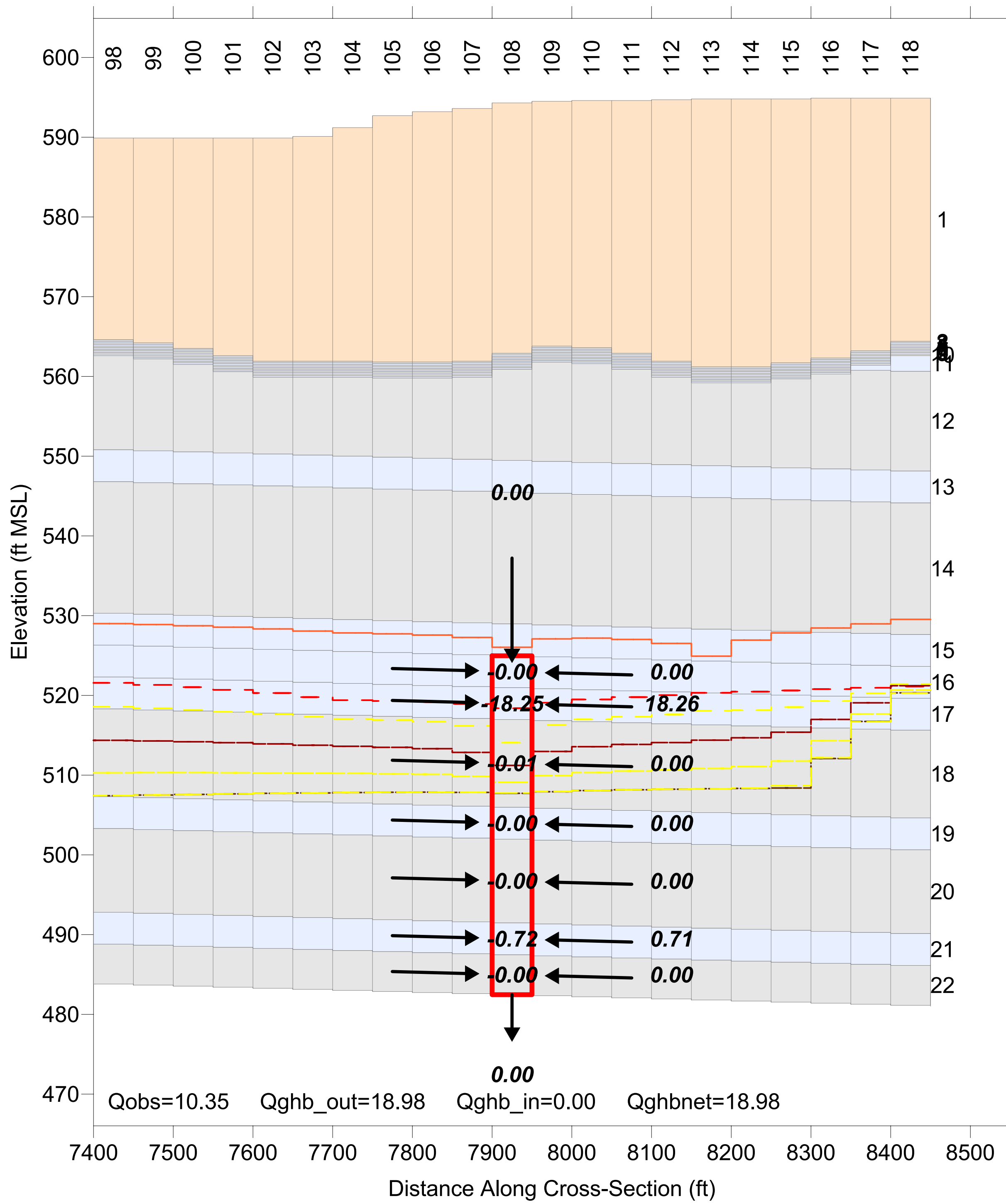


VERTICAL EXAGGERATION=10x

figure B-3
MODEL FLOWS ALONG PW-1U; PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-1U_flows.srf



VERTICAL EXAGGERATION=10x

figure B-4

MODEL FLOWS ALONG PW-1L; PUMPING CONDITIONS

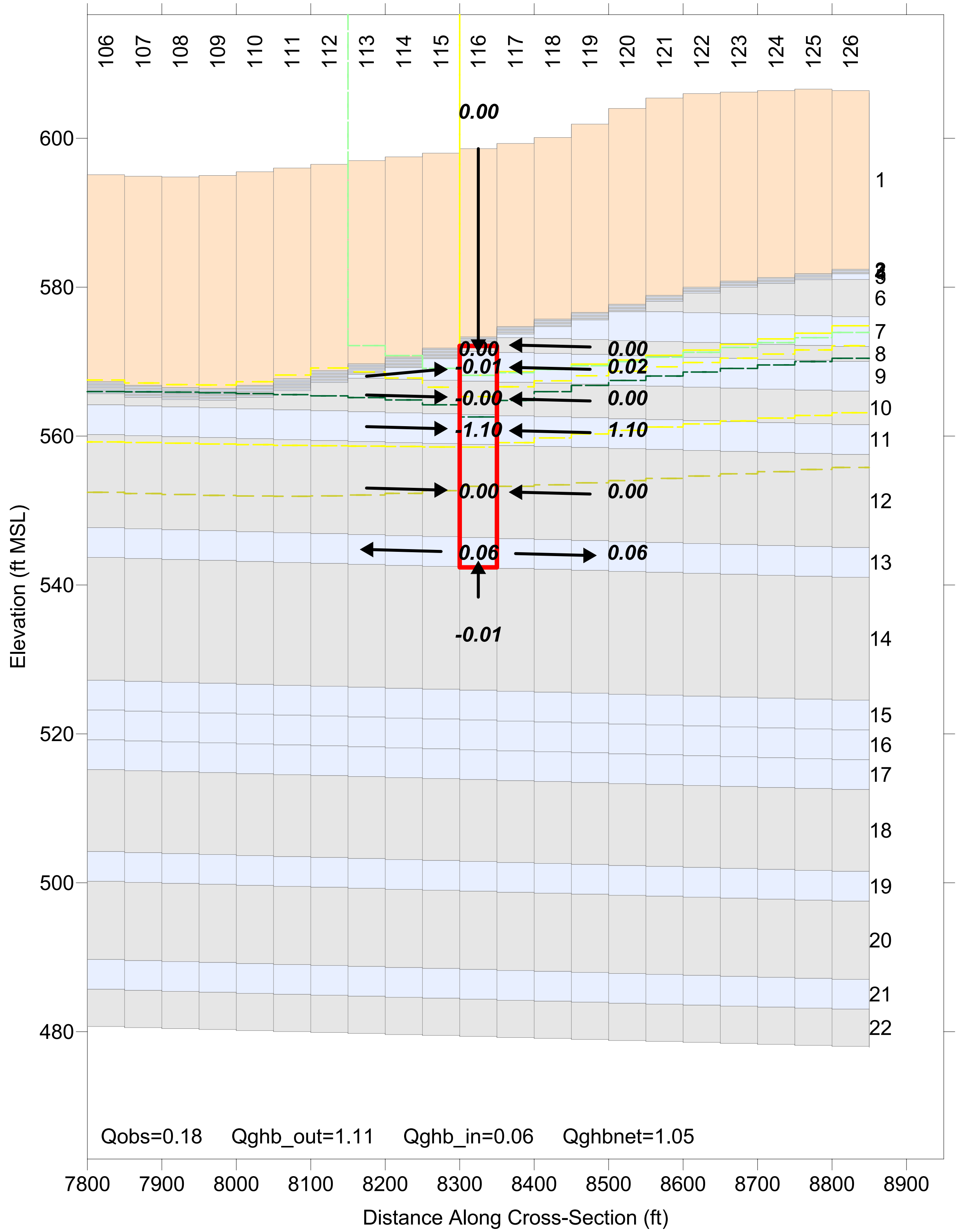
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-1L_flows.srf



VERTICAL EXAGGERATION=10x

figure B-5

MODEL FLOWS ALONG PW-2UR; PUMPING CONDITIONS

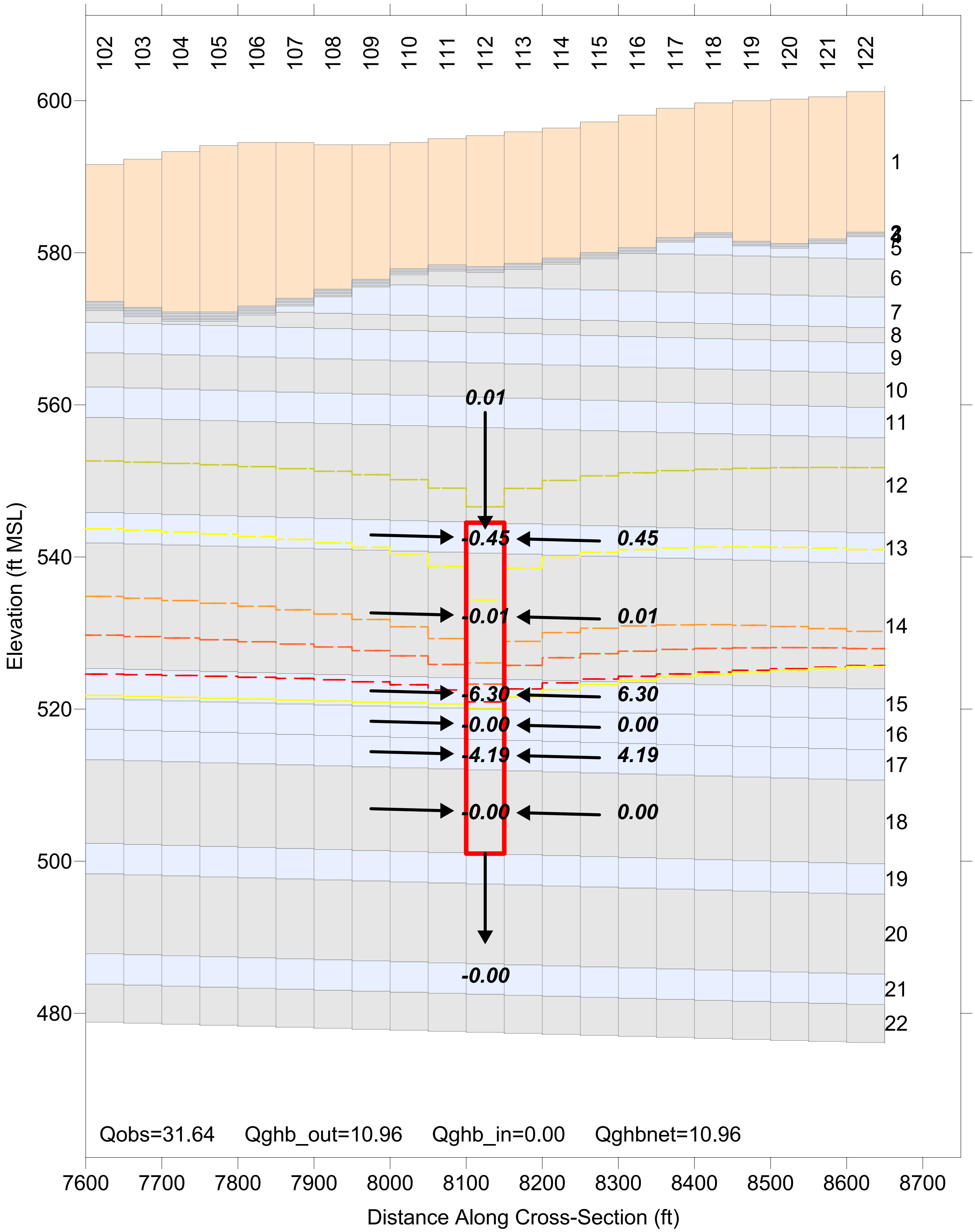
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-2UR_flows.srf

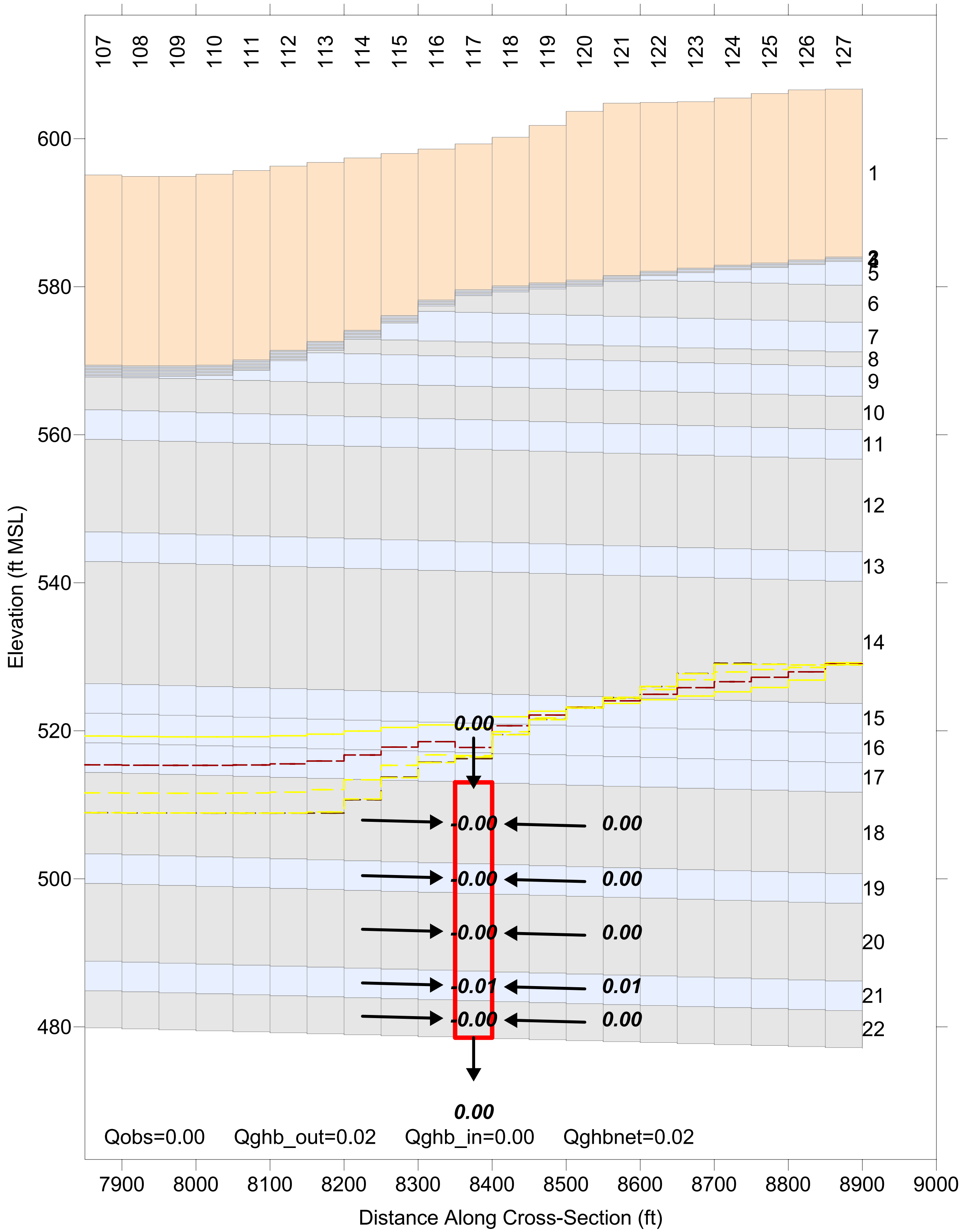


VERTICAL EXAGGERATION=10x

figure B-6
MODEL FLOWS ALONG PW-2M; PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-2M_flows.srf



VERTICAL EXAGGERATION=10x

figure B-7

MODEL FLOWS ALONG PW-2L; PUMPING CONDITIONS

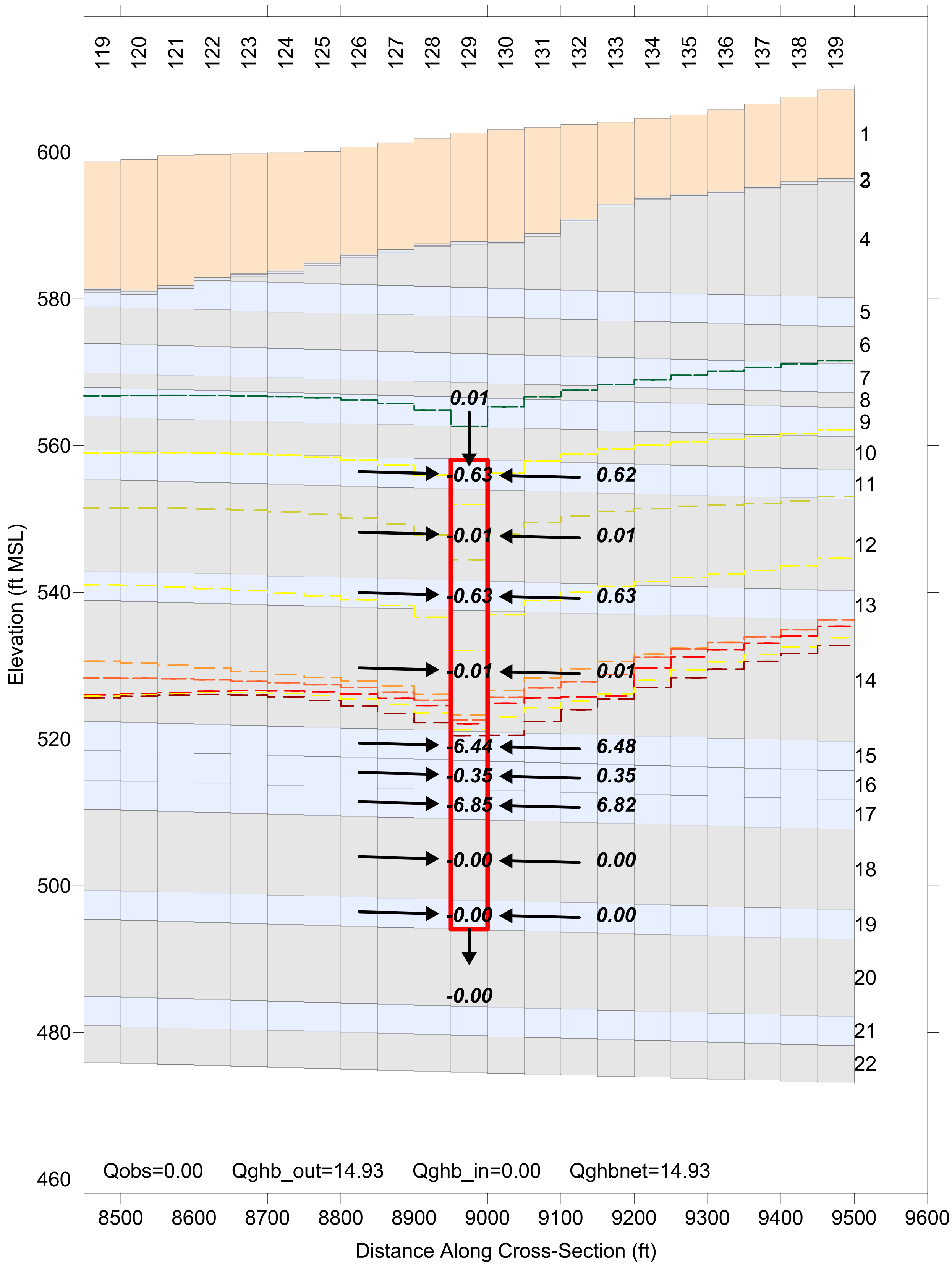
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-2L_flows.srf

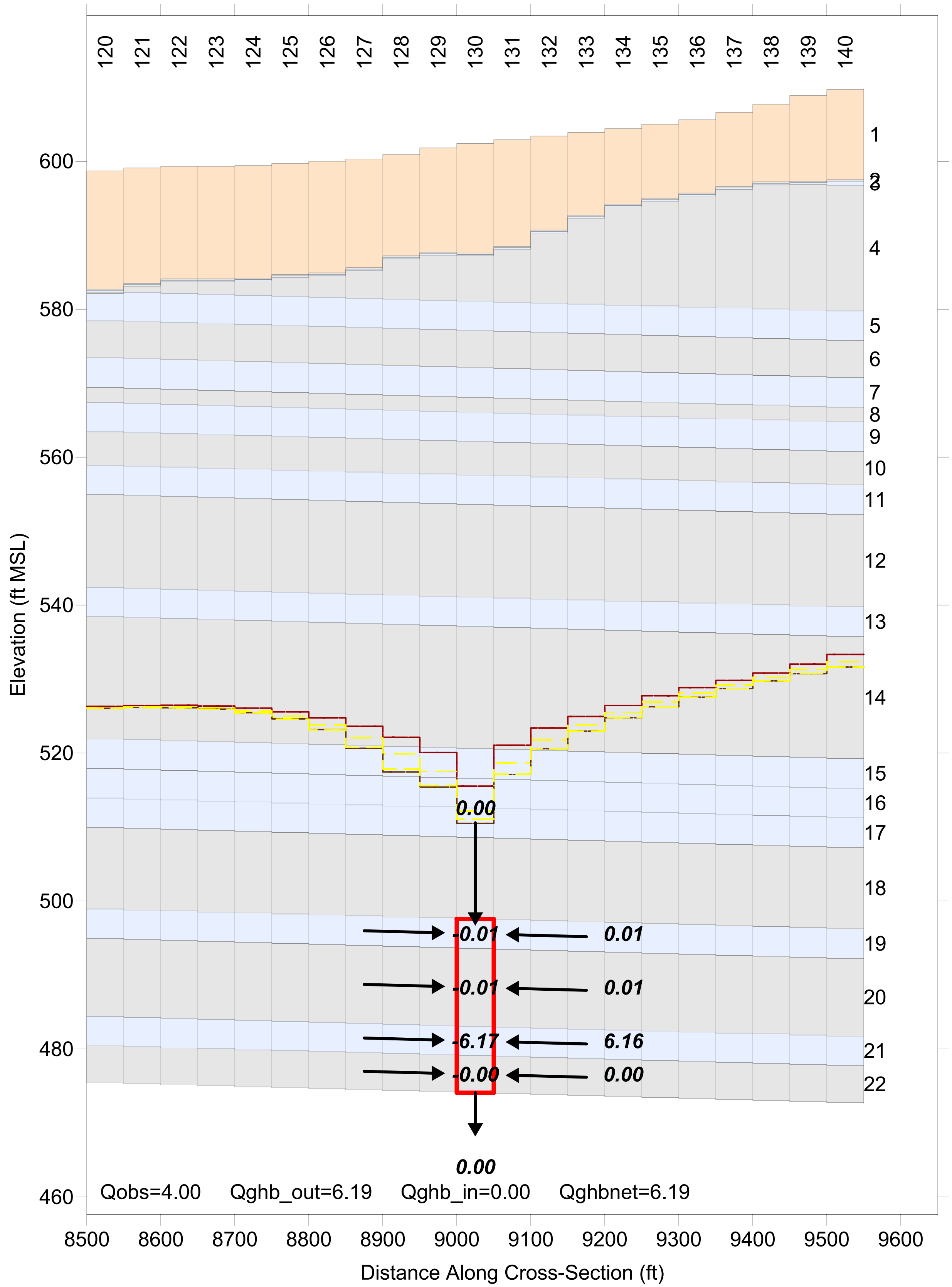


VERTICAL EXAGGERATION=10x

figure B-8
MODEL FLOWS ALONG PW-3M; PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-3M_flows.srf



VERTICAL EXAGGERATION=10x

figure B-9
MODEL FLOWS ALONG PW-3L; PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-3L_flows.srf

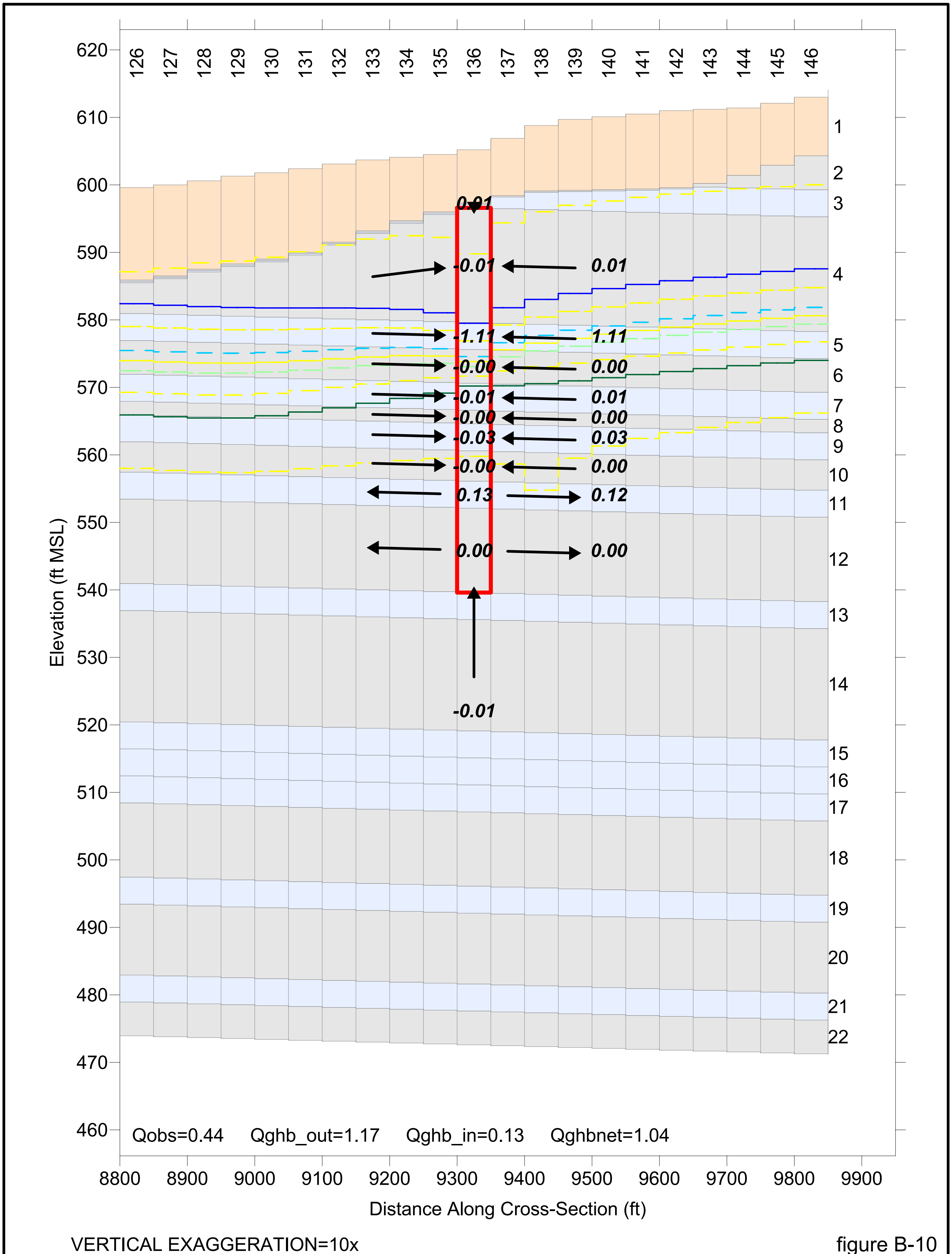
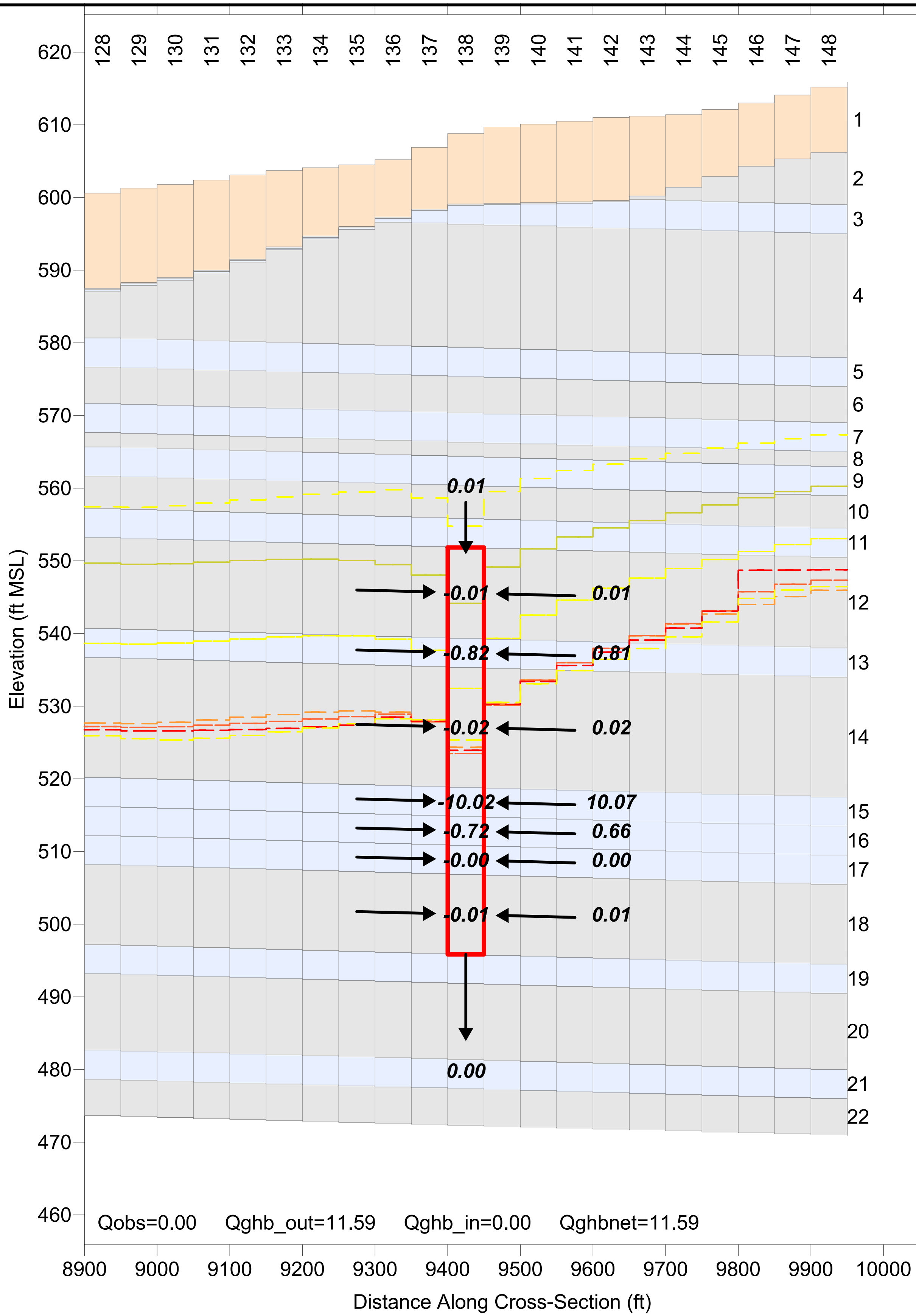


figure B-10
MODEL FLOWS ALONG PW-4U; PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-4U_flows.srf

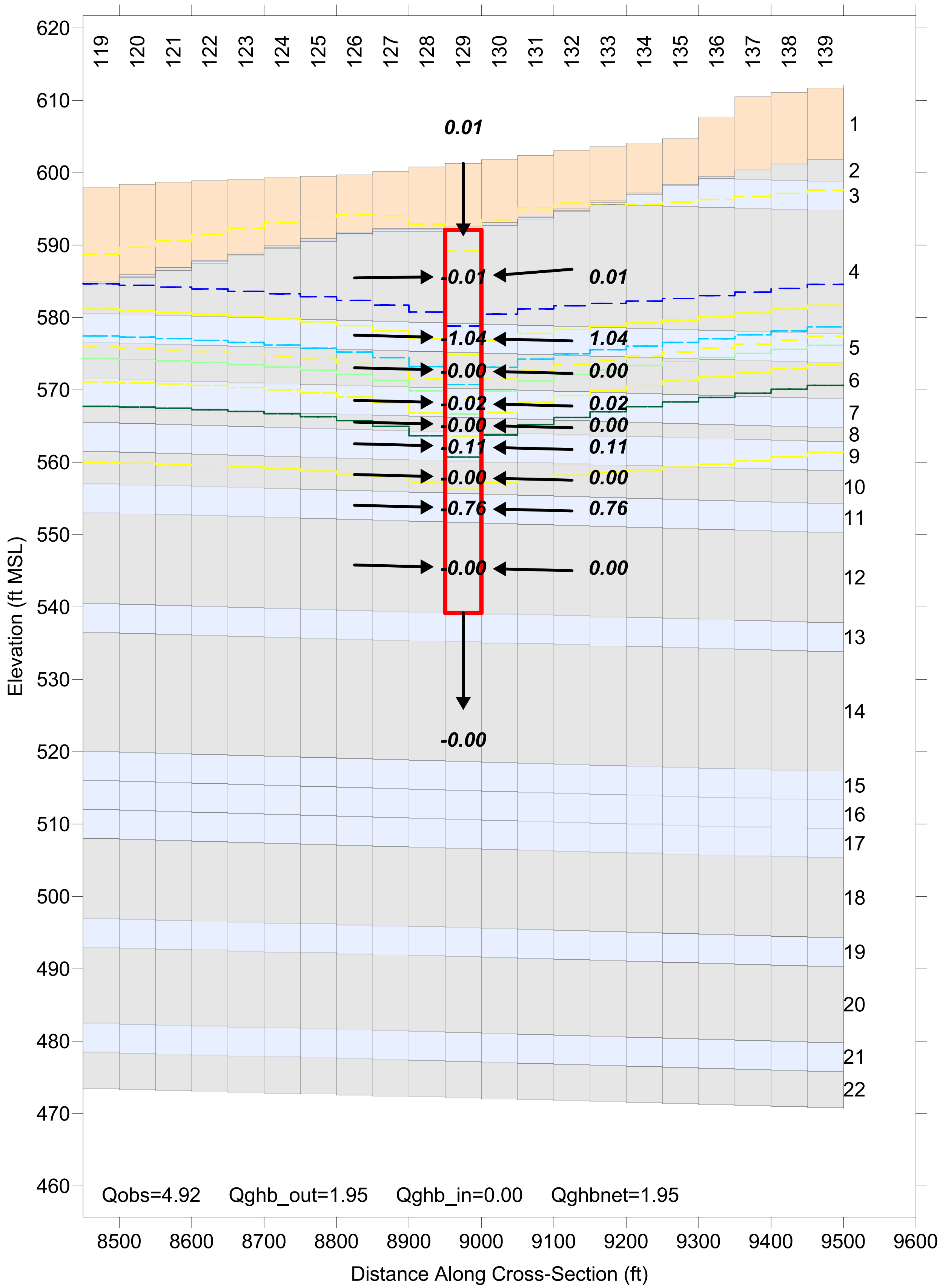


VERTICAL EXAGGERATION=10x

figure B-11
MODEL FLOWS ALONG PW-4M; PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-4M_flows.srf

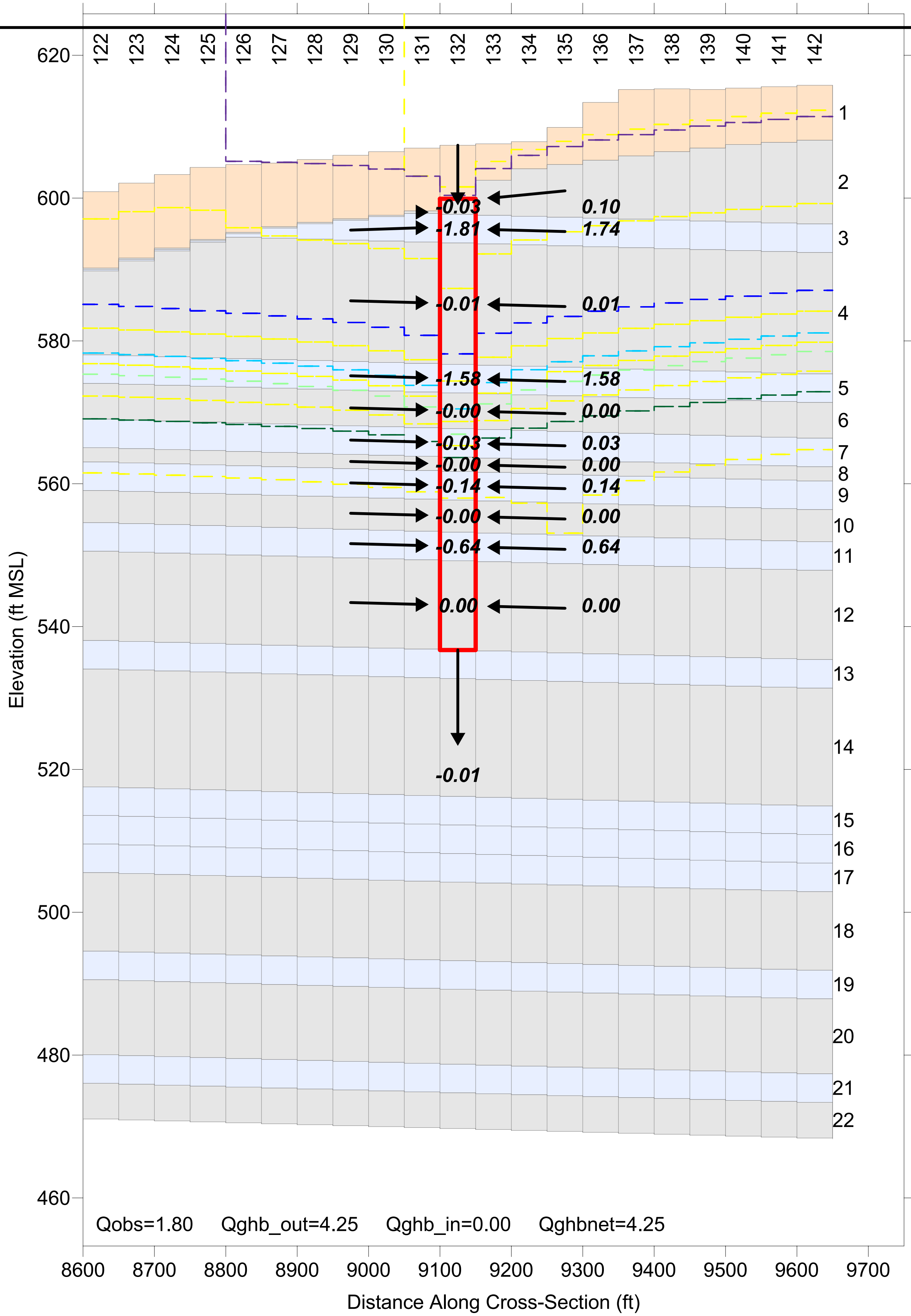


VERTICAL EXAGGERATION=10x

figure B-12
MODEL FLOWS ALONG PW-5UR; PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-5UR_flows.srf



VERTICAL EXAGGERATION=10x

figure B-13

MODEL FLOWS ALONG PW-6UR; PUMPING CONDITIONS

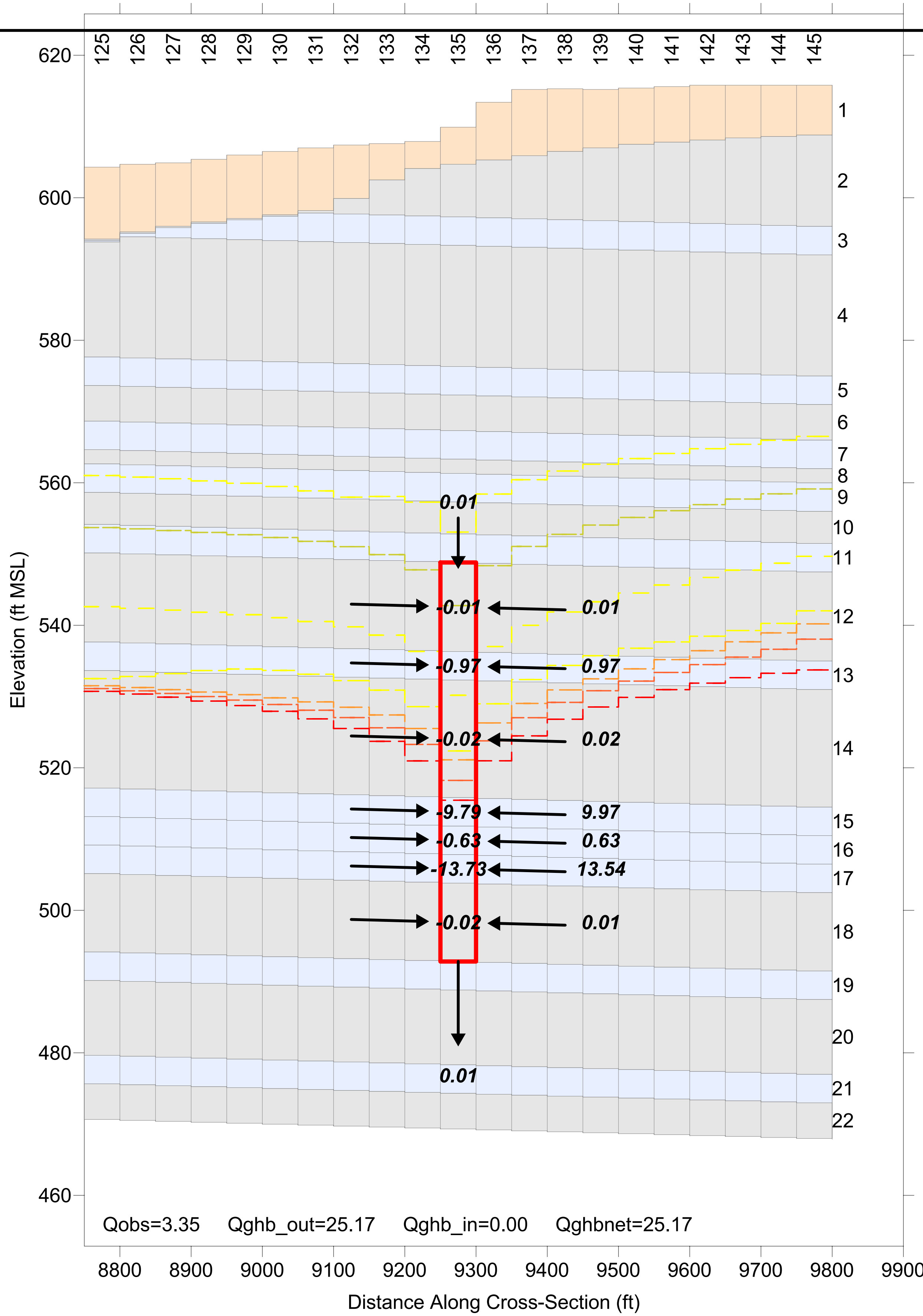
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-6UR_flows.srf



VERTICAL EXAGGERATION=10x

figure B-14

MODEL FLOWS ALONG PW-6MR; PUMPING CONDITIONS

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

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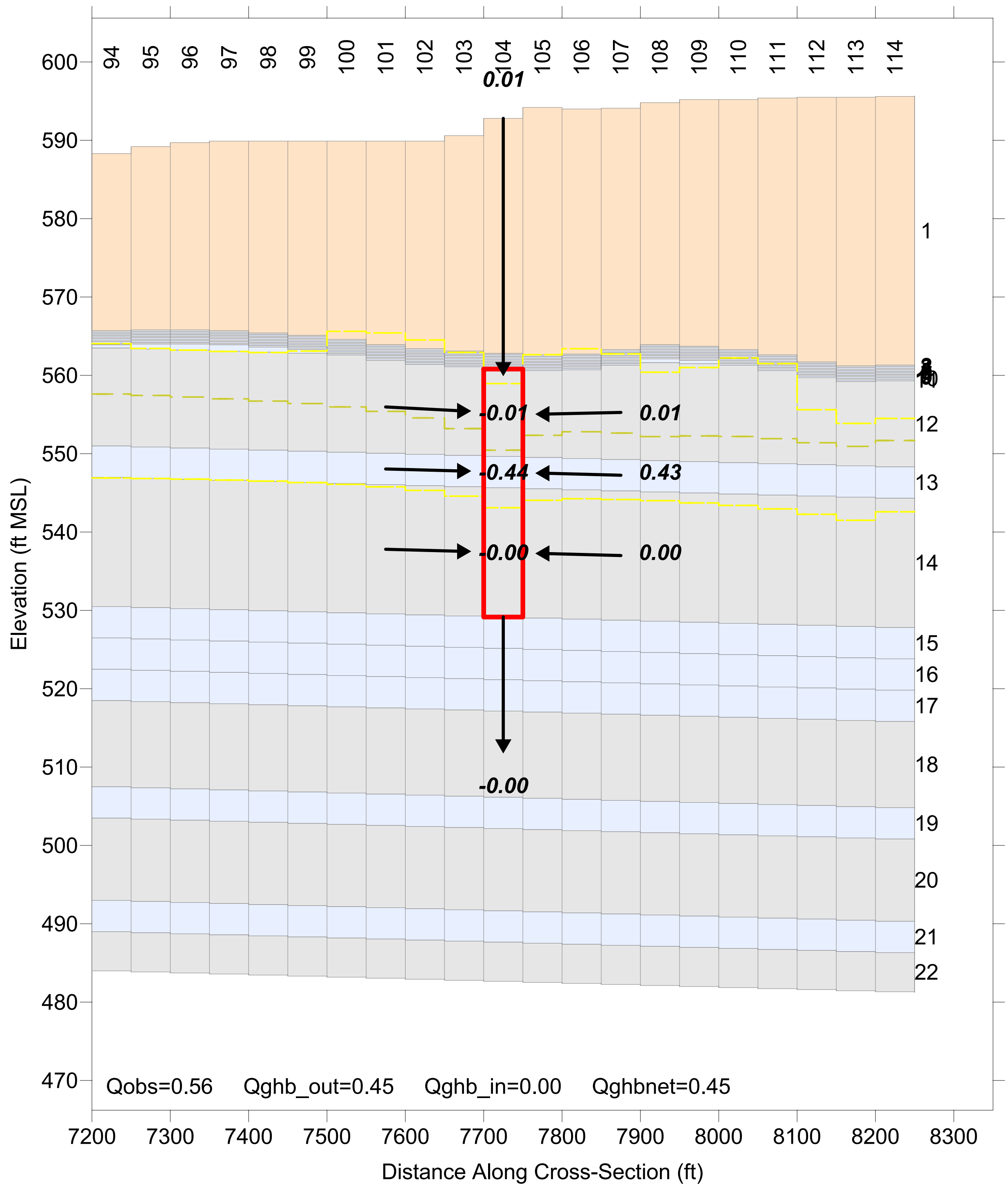


VERTICAL EXAGGERATION=10x

figure B-15

MODEL FLOWS ALONG PW-7U; PUMPING CONDITIONS

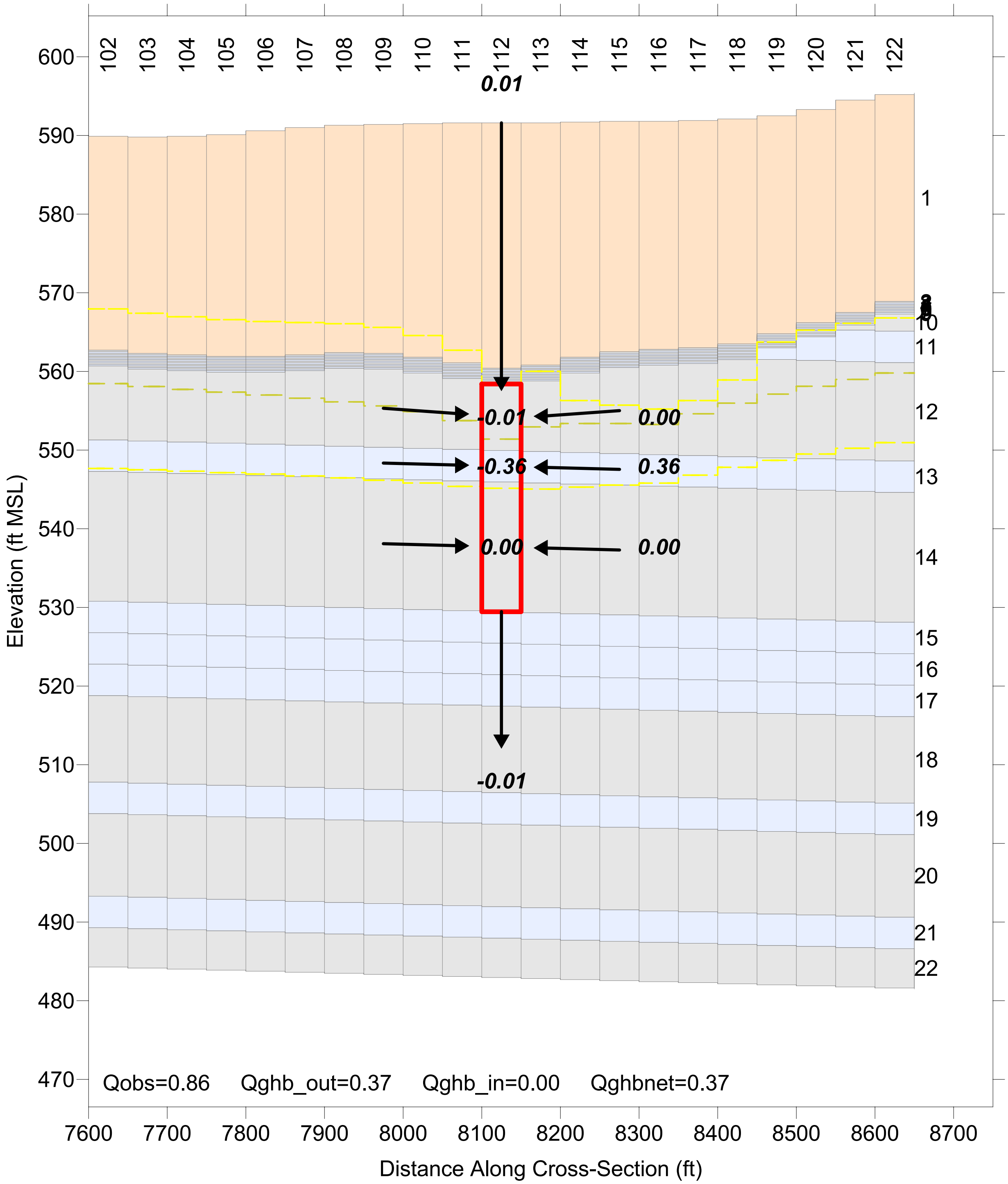
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-7U_flows.srf

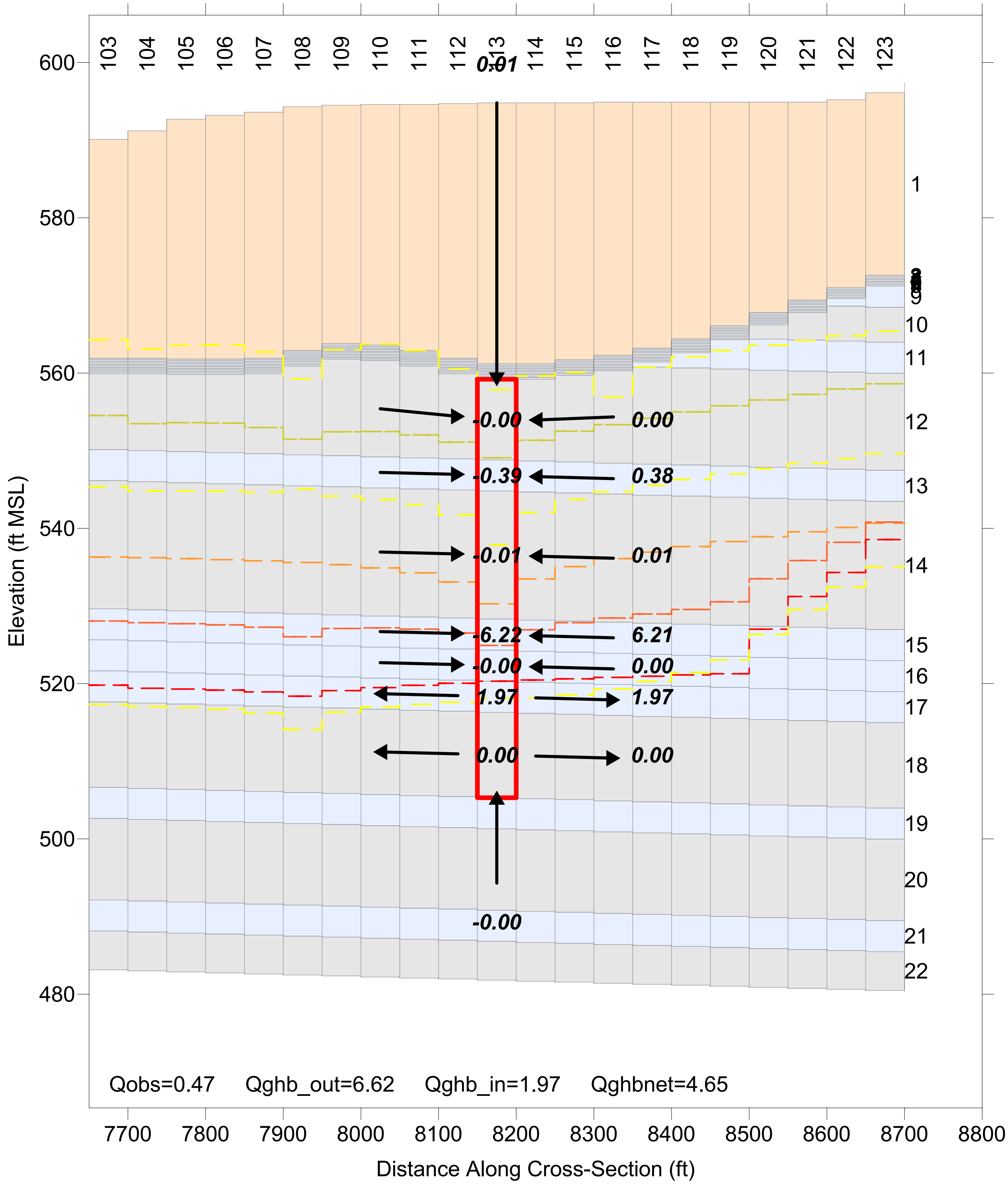


VERTICAL EXAGGERATION=10x

figure B-16
MODEL FLOWS ALONG PW-8U; PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

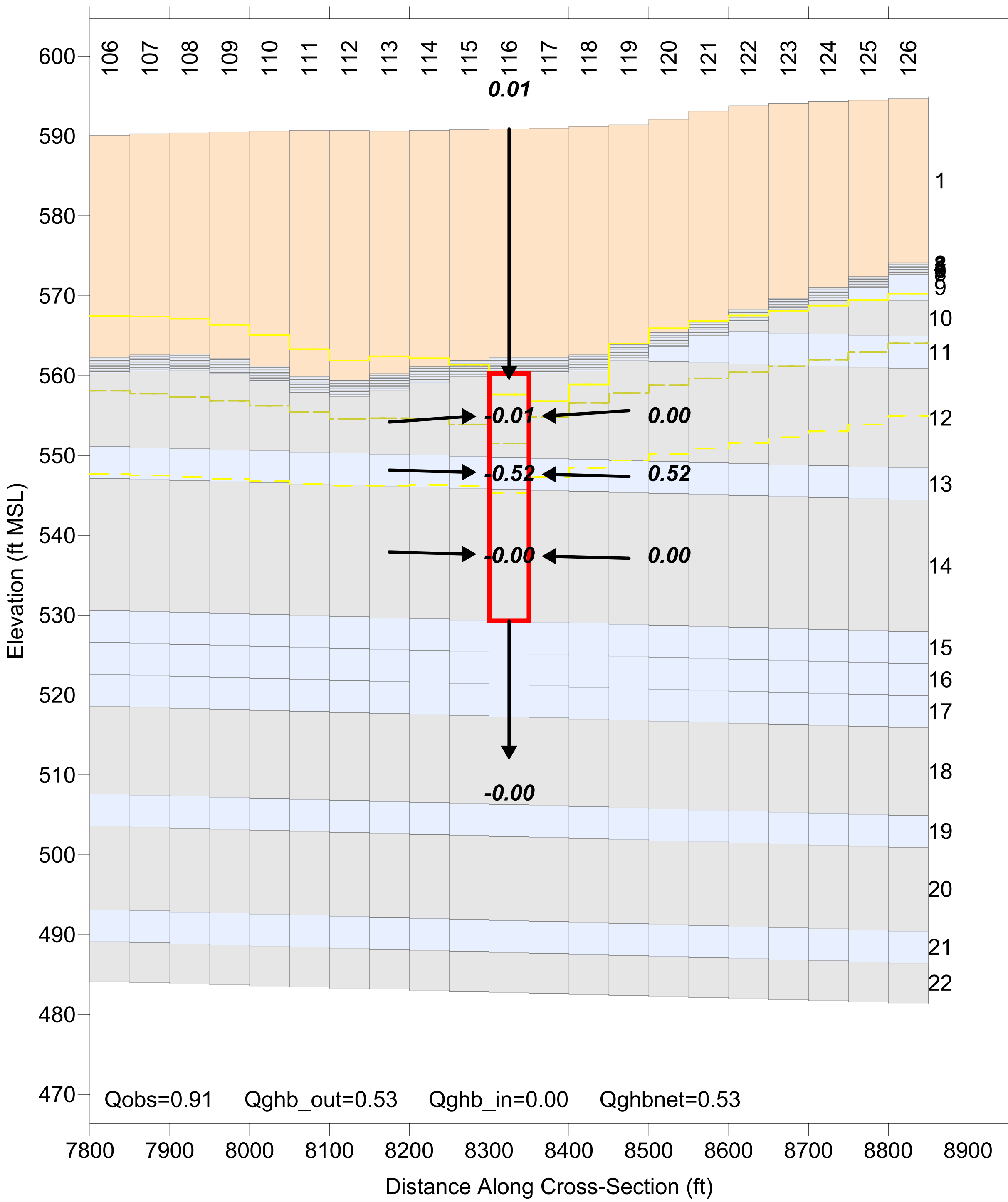
28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-8U_flows.srf



VERTICAL EXAGGERATION=10x

figure B-17
MODEL FLOWS ALONG PW-8M; PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

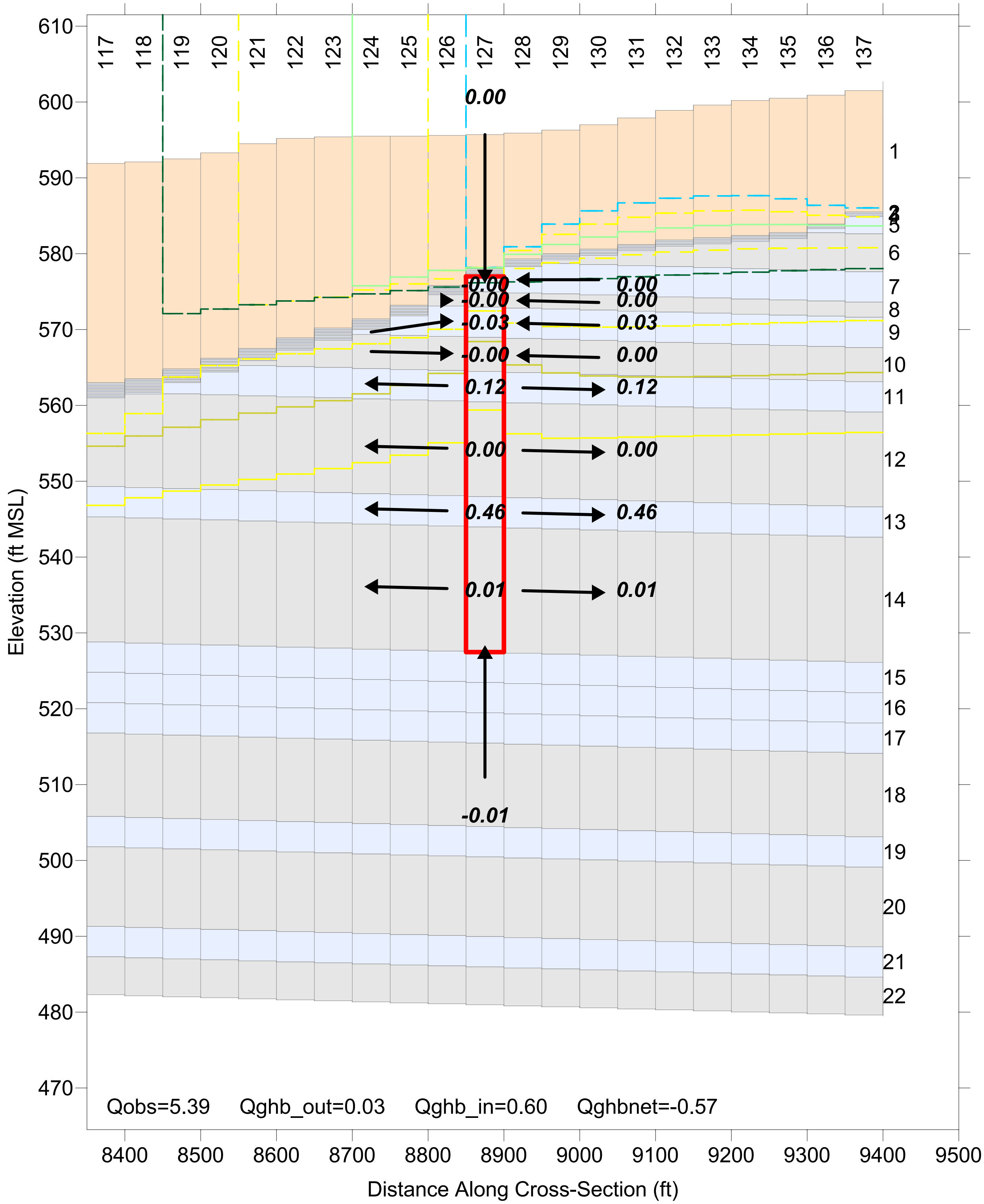


VERTICAL EXAGGERATION=10x

figure B-18
MODEL FLOWS ALONG PW-9U; PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-9U_flows.srf



VERTICAL EXAGGERATION=10x

figure B-19

MODEL FLOWS ALONG PW-10U; PUMPING CONDITIONS

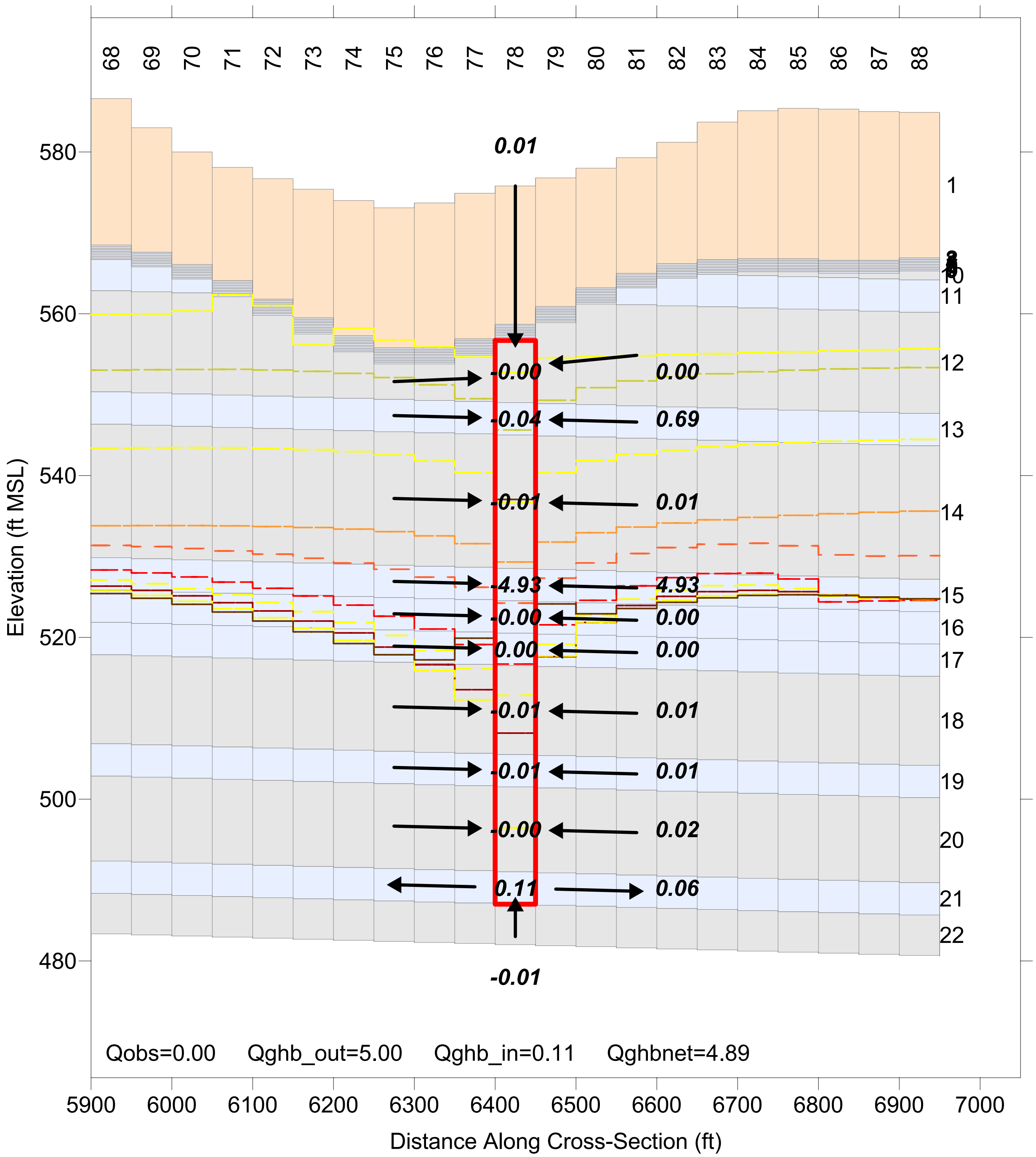
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-10U_flows.srf

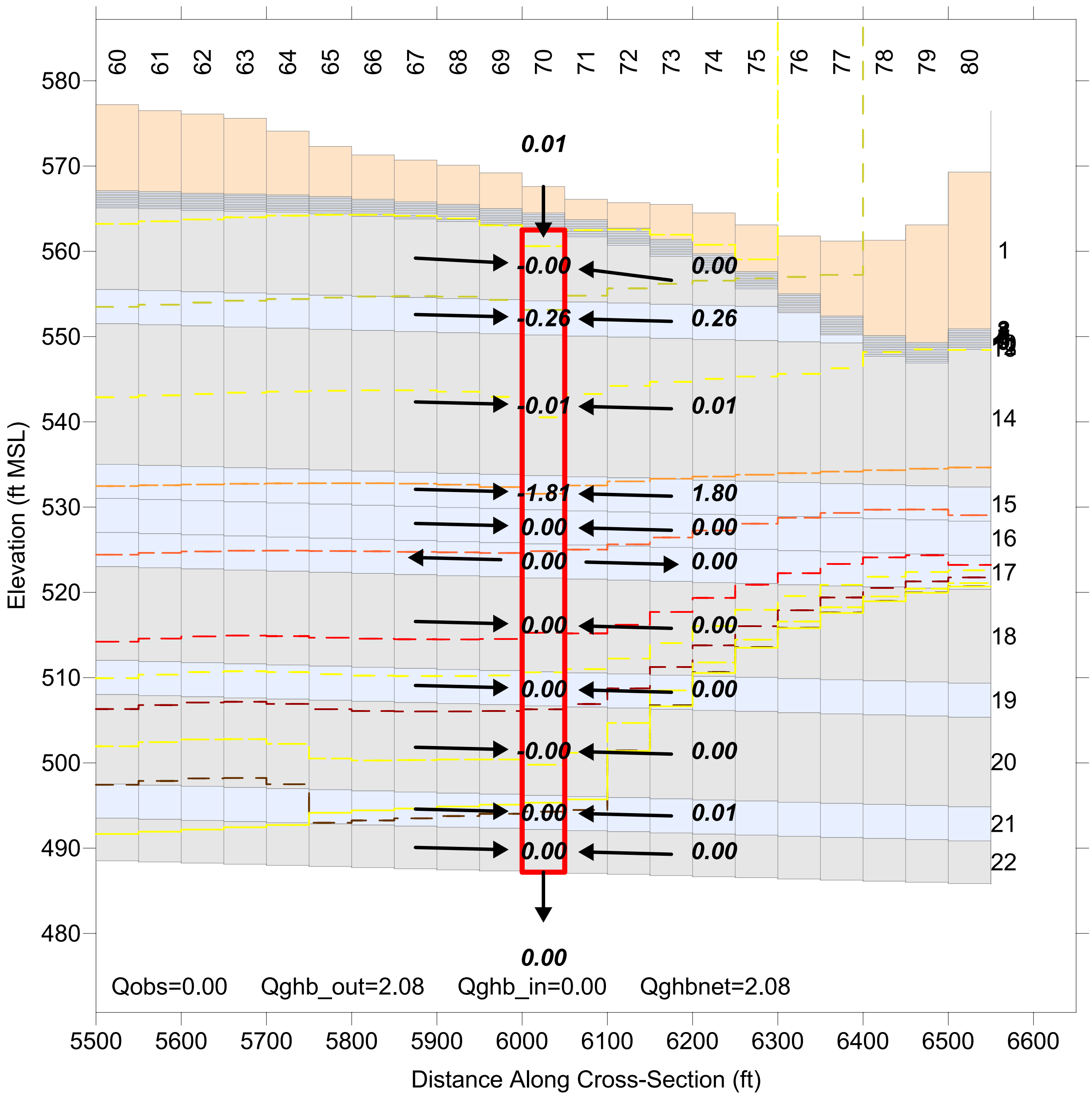


VERTICAL EXAGGERATION=10x

figure B-20
MODEL FLOWS ALONG SH_1; PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\SH_1_flows.srf

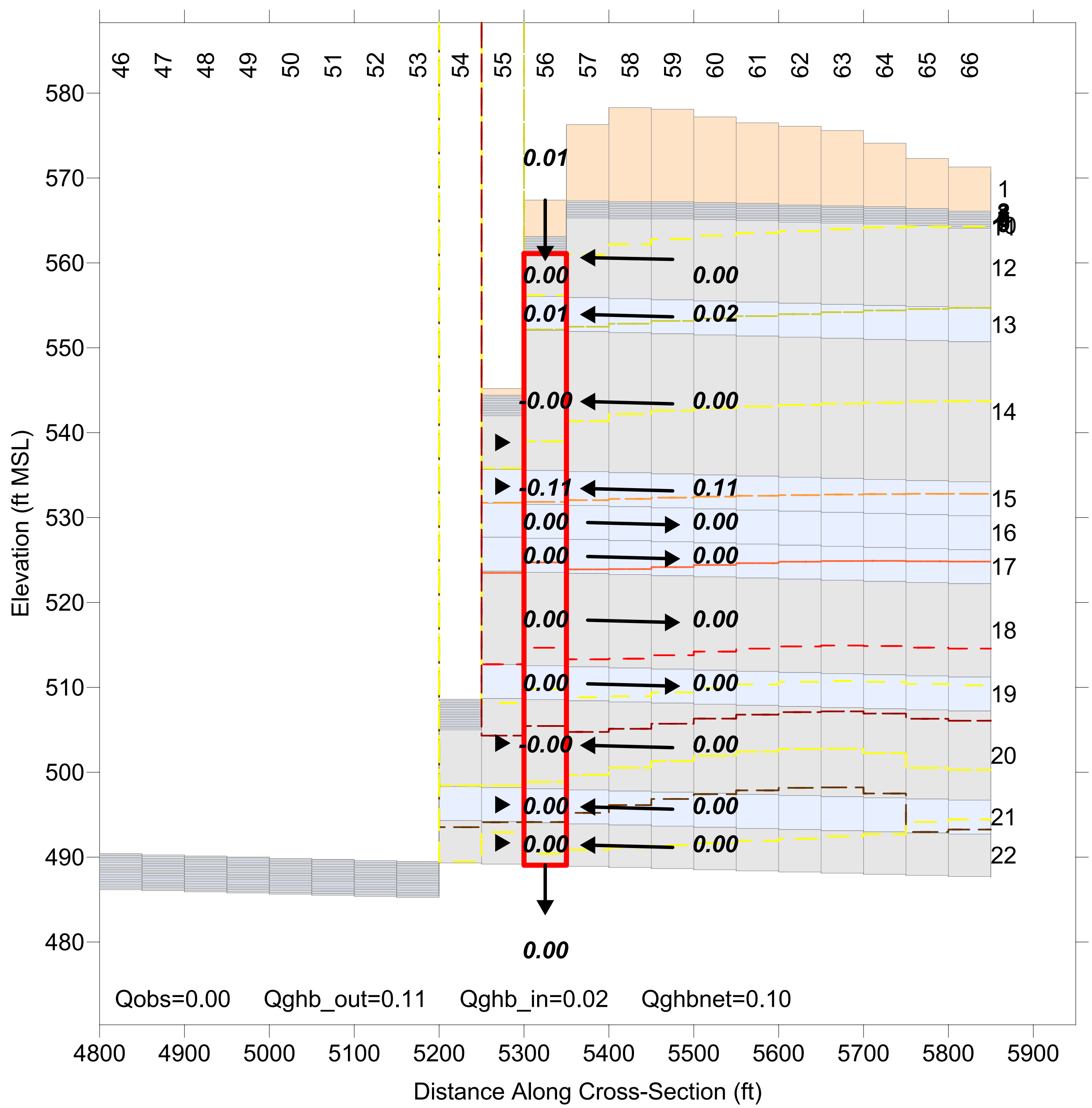


VERTICAL EXAGGERATION=10x

figure B-21
MODEL FLOWS ALONG SH_2; PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\SH_2_flows.srf

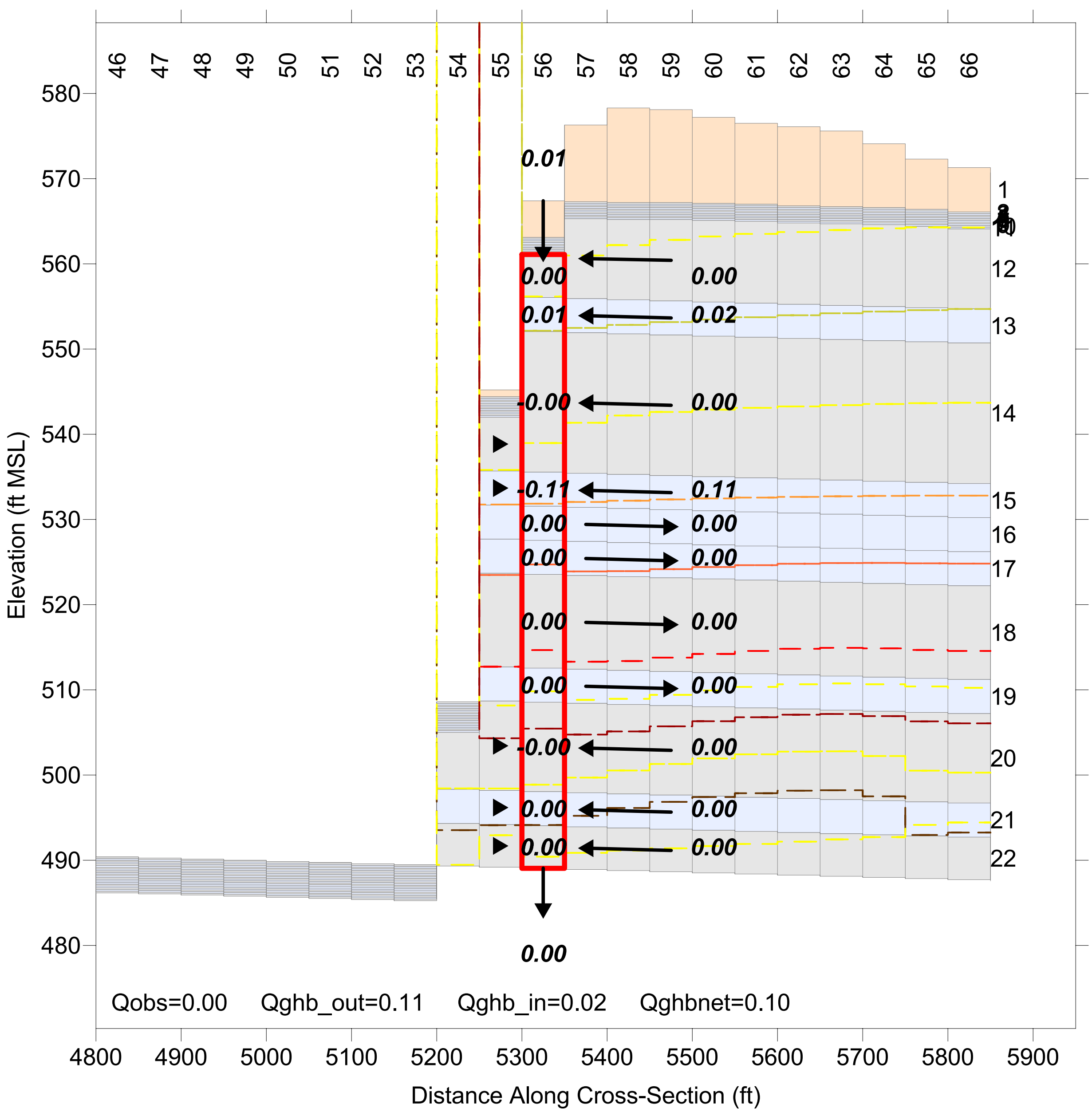


VERTICAL EXAGGERATION=10x

figure B-22
MODEL FLOWS ALONG SH_3; PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\SH_3_flows.srf

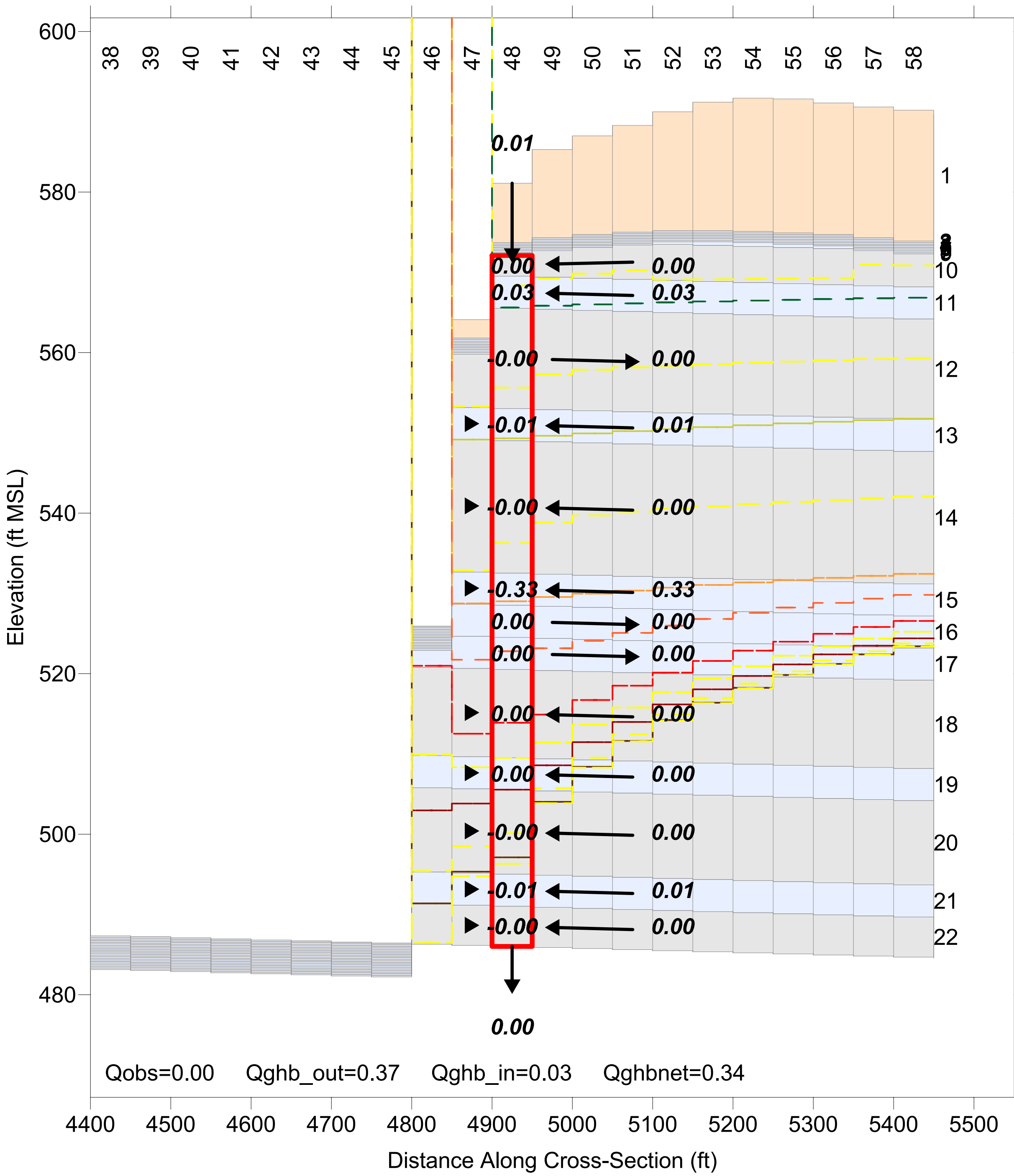


VERTICAL EXAGGERATION=10x

figure B-23
MODEL FLOWS ALONG SH_4; PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\SH_4_flows.srf

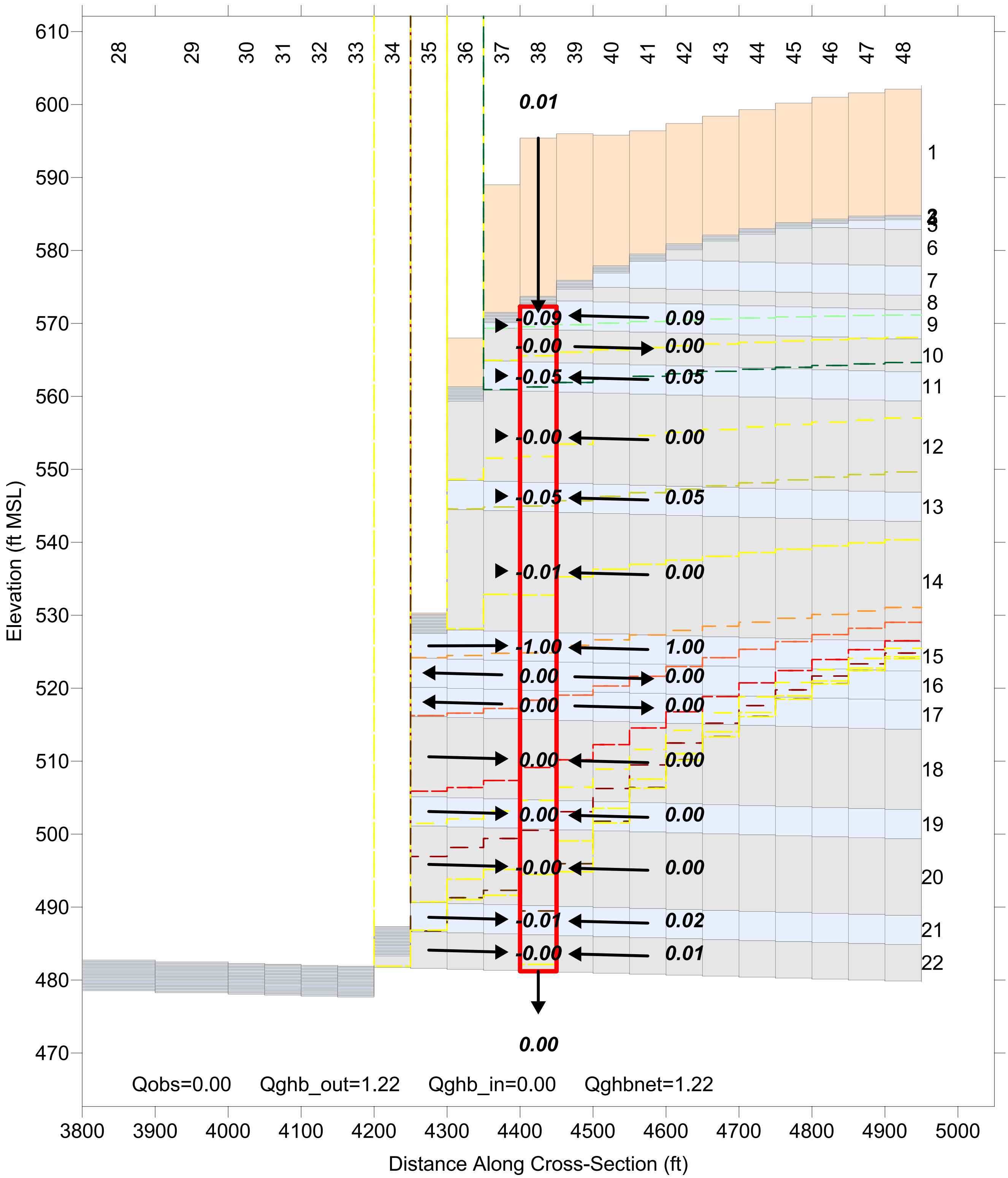


VERTICAL EXAGGERATION=10x

figure B-24
MODEL FLOWS ALONG SH_5; PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\SH_5_flows.srf



VERTICAL EXAGGERATION=10x

figure B-25

MODEL FLOWS ALONG SH_6; PUMPING CONDITIONS

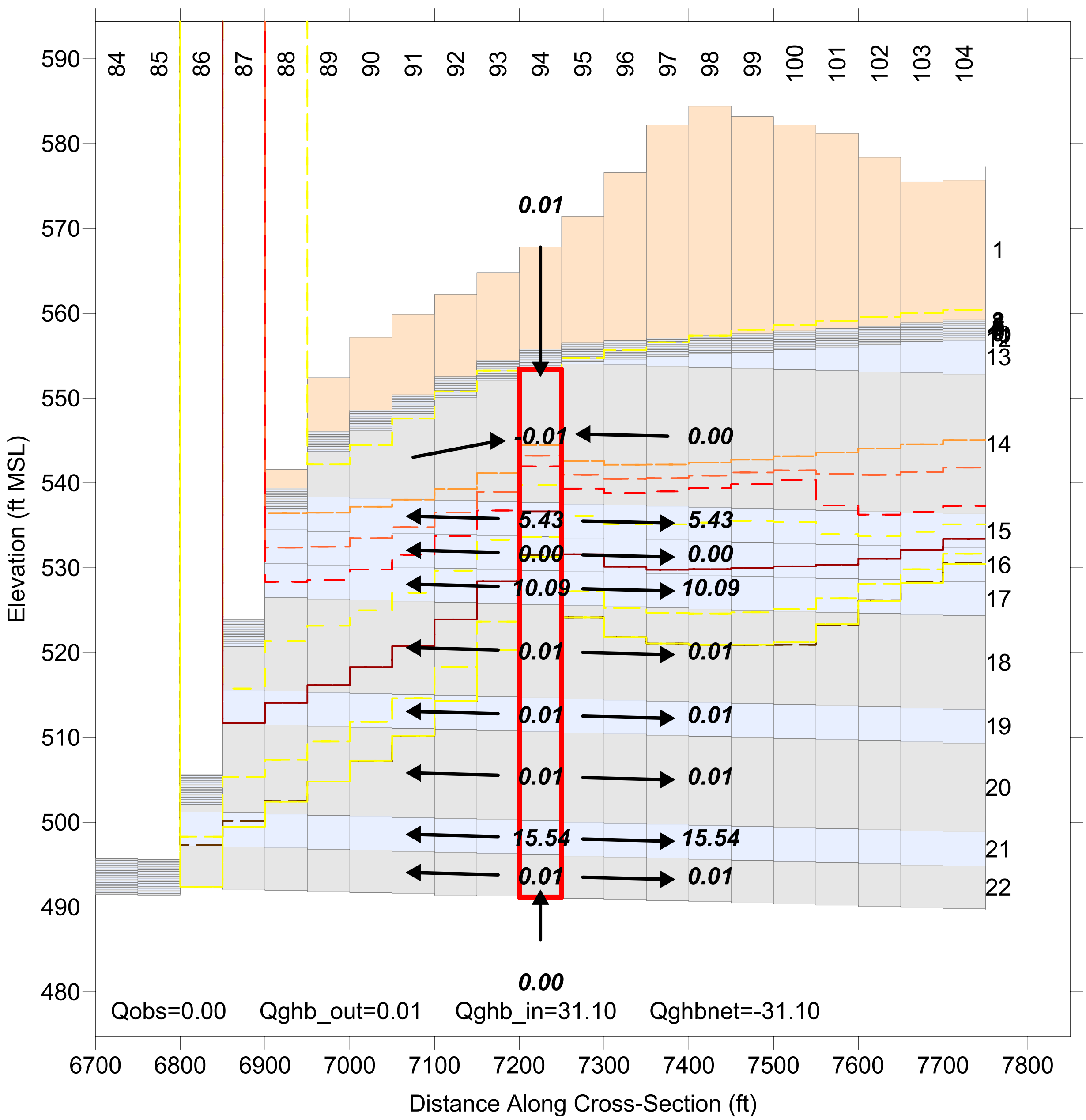
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\SH_6_flows.srf



VERTICAL EXAGGERATION=10x

figure B-26

MODEL FLOWS ALONG APW-1; NON-PUMPING CONDITIONS

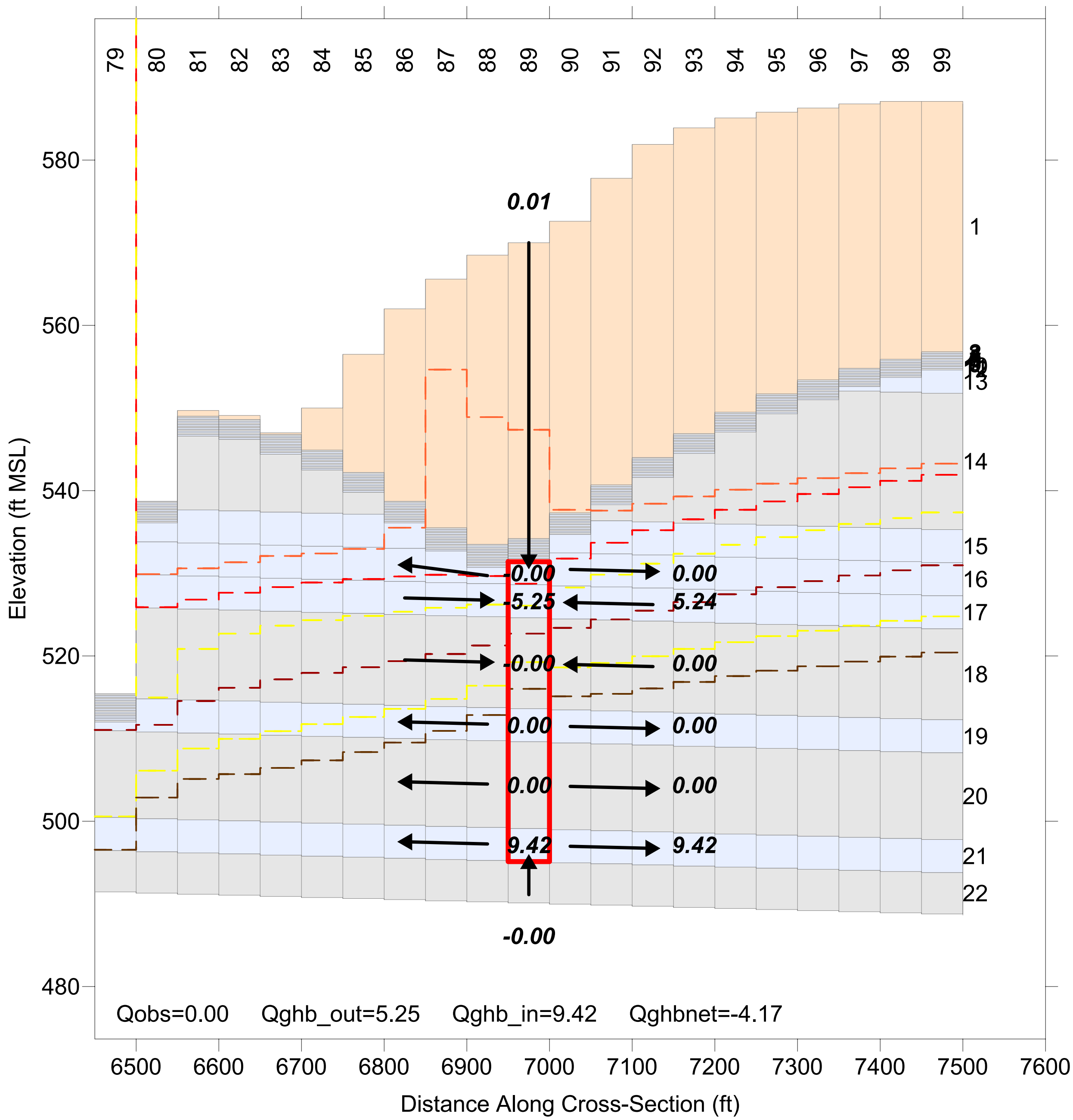
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\APW-1_flows.srf



VERTICAL EXAGGERATION=10x

figure B-27

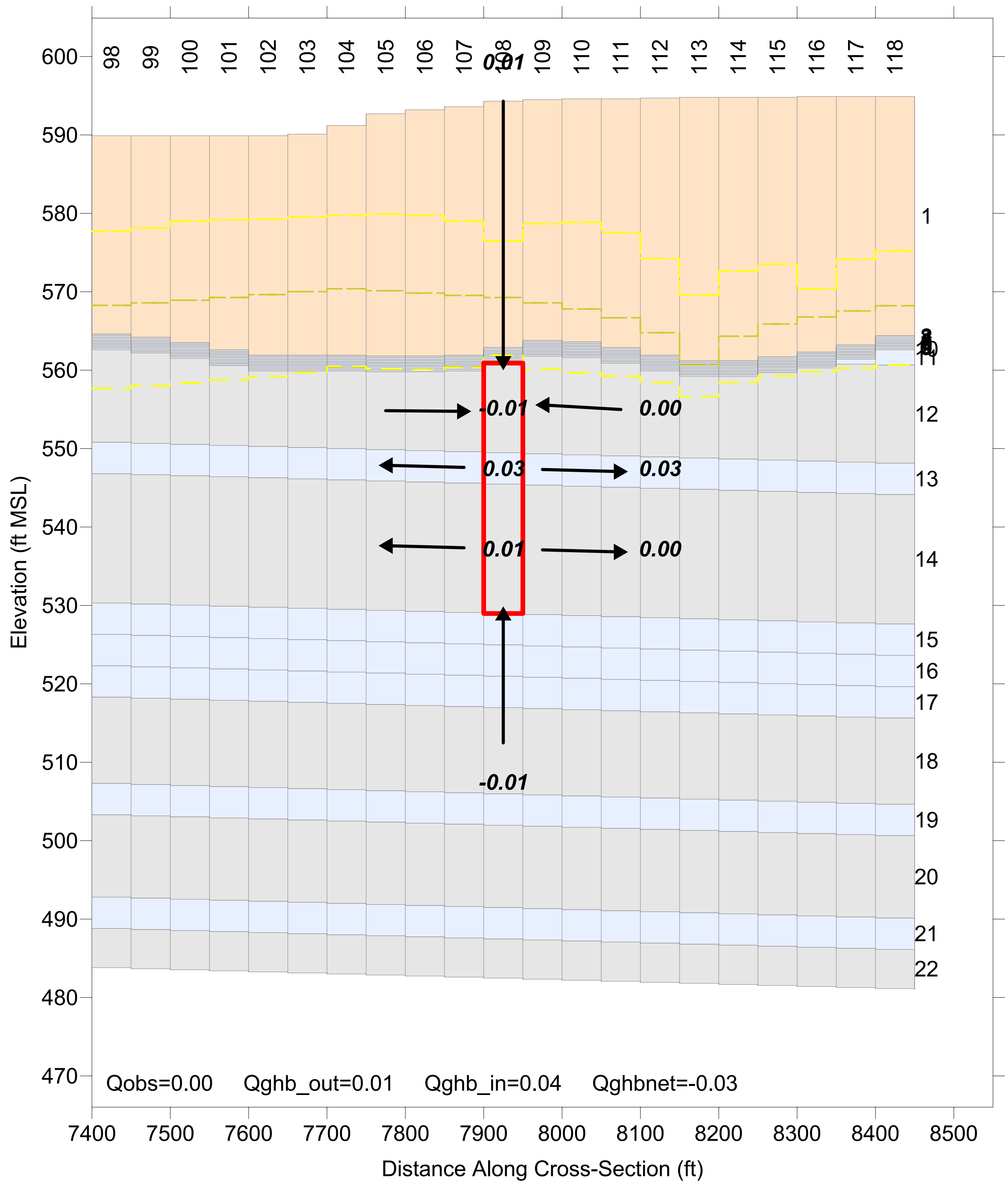
MODEL FLOWS ALONG APW-2; NON-PUMPING CONDITIONS

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.



VERTICAL EXAGGERATION=10x

figure B-28

MODEL FLOWS ALONG PW-1U; NON-PUMPING CONDITIONS

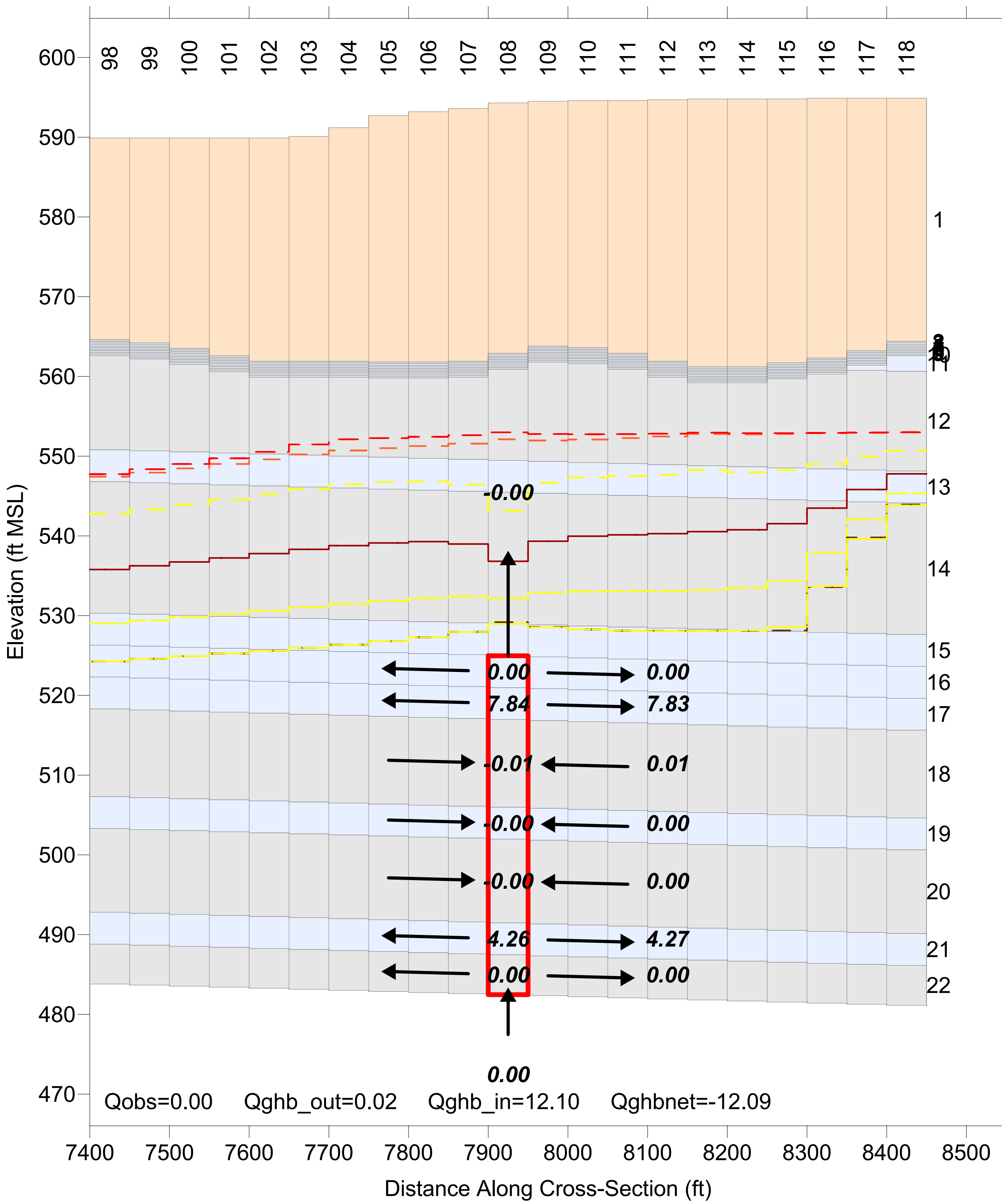
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-1U_flows.srf



VERTICAL EXAGGERATION=10x

figure B-29

MODEL FLOWS ALONG PW-1L; NON-PUMPING CONDITIONS

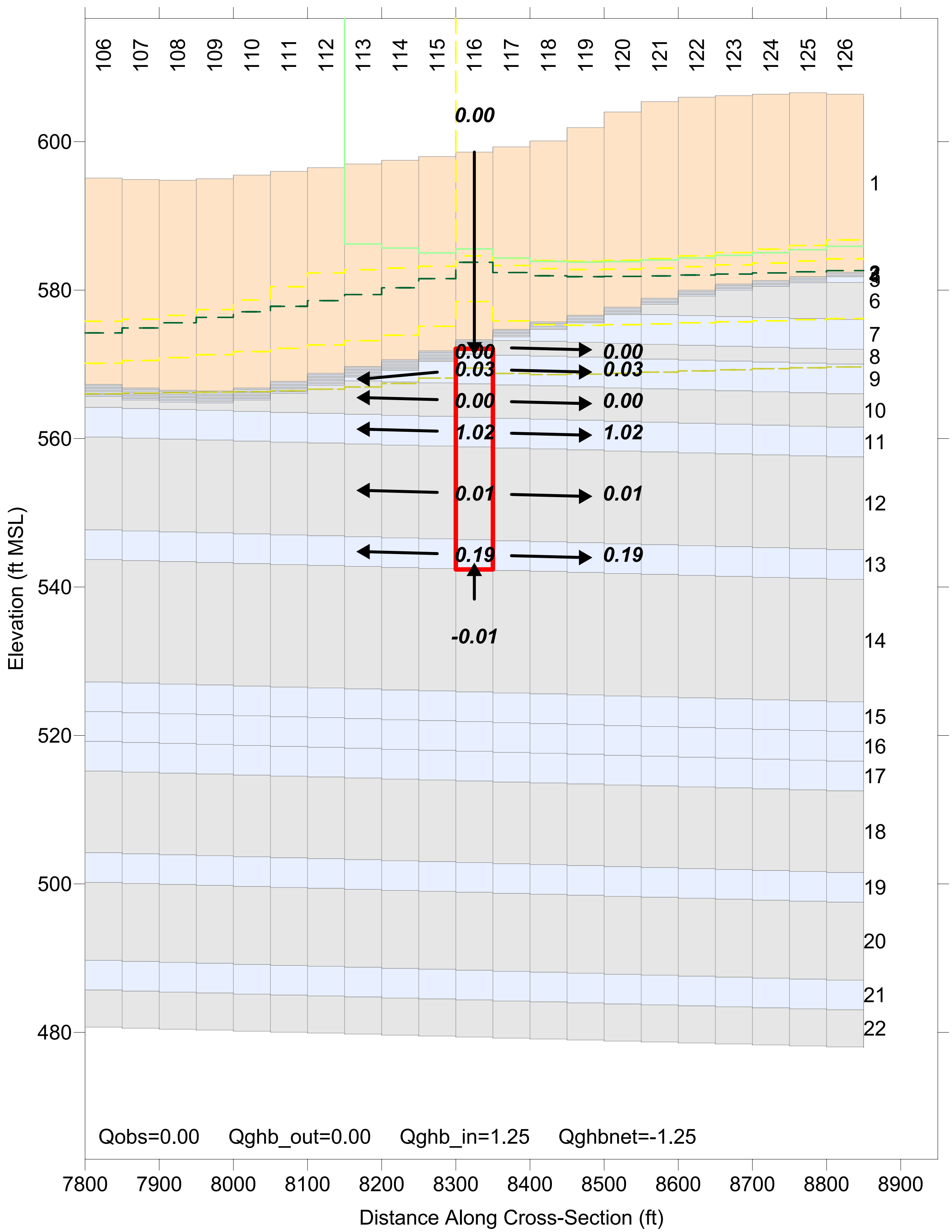
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-1L_flows.srf



VERTICAL EXAGGERATION=10x

figure B-30

MODEL FLOWS ALONG PW-2UR; NON-PUMPING CONDITIONS

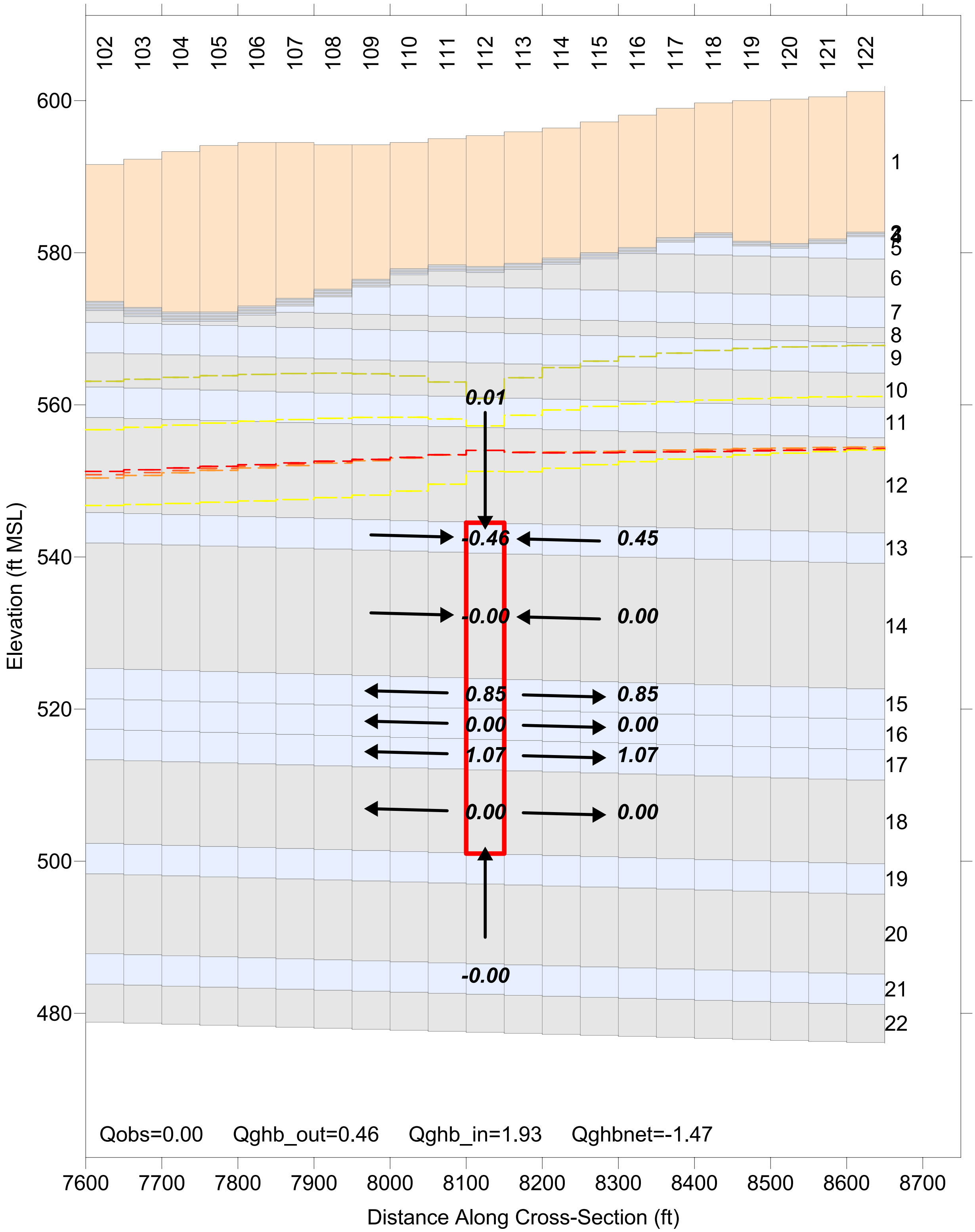
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-2UR_flows.srf



VERTICAL EXAGGERATION=10x

figure B-31

MODEL FLOWS ALONG PW-2M; NON-PUMPING CONDITIONS

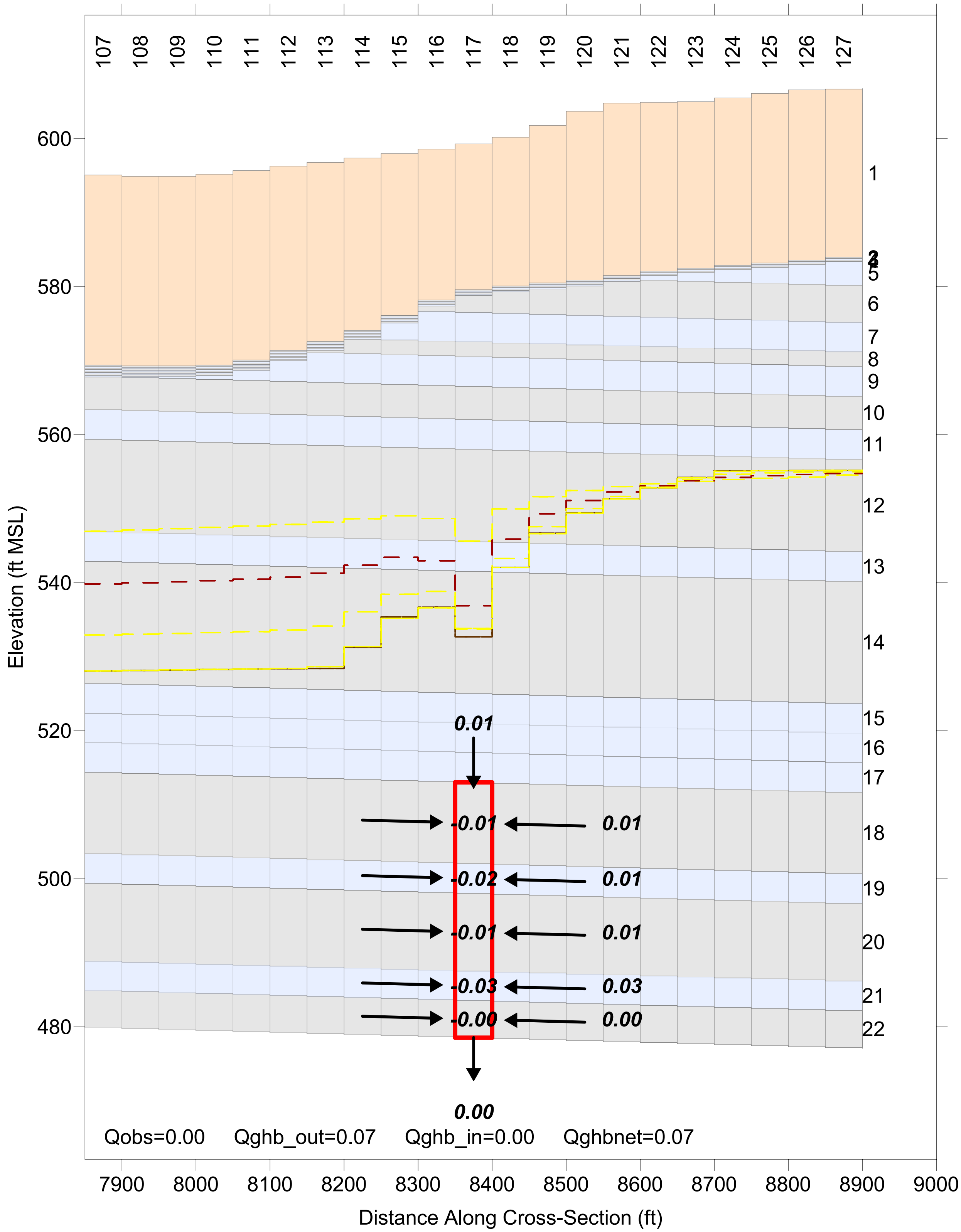
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-2M_flows.srf



VERTICAL EXAGGERATION=10x

figure B-32

MODEL FLOWS ALONG PW-2L; NON-PUMPING CONDITIONS

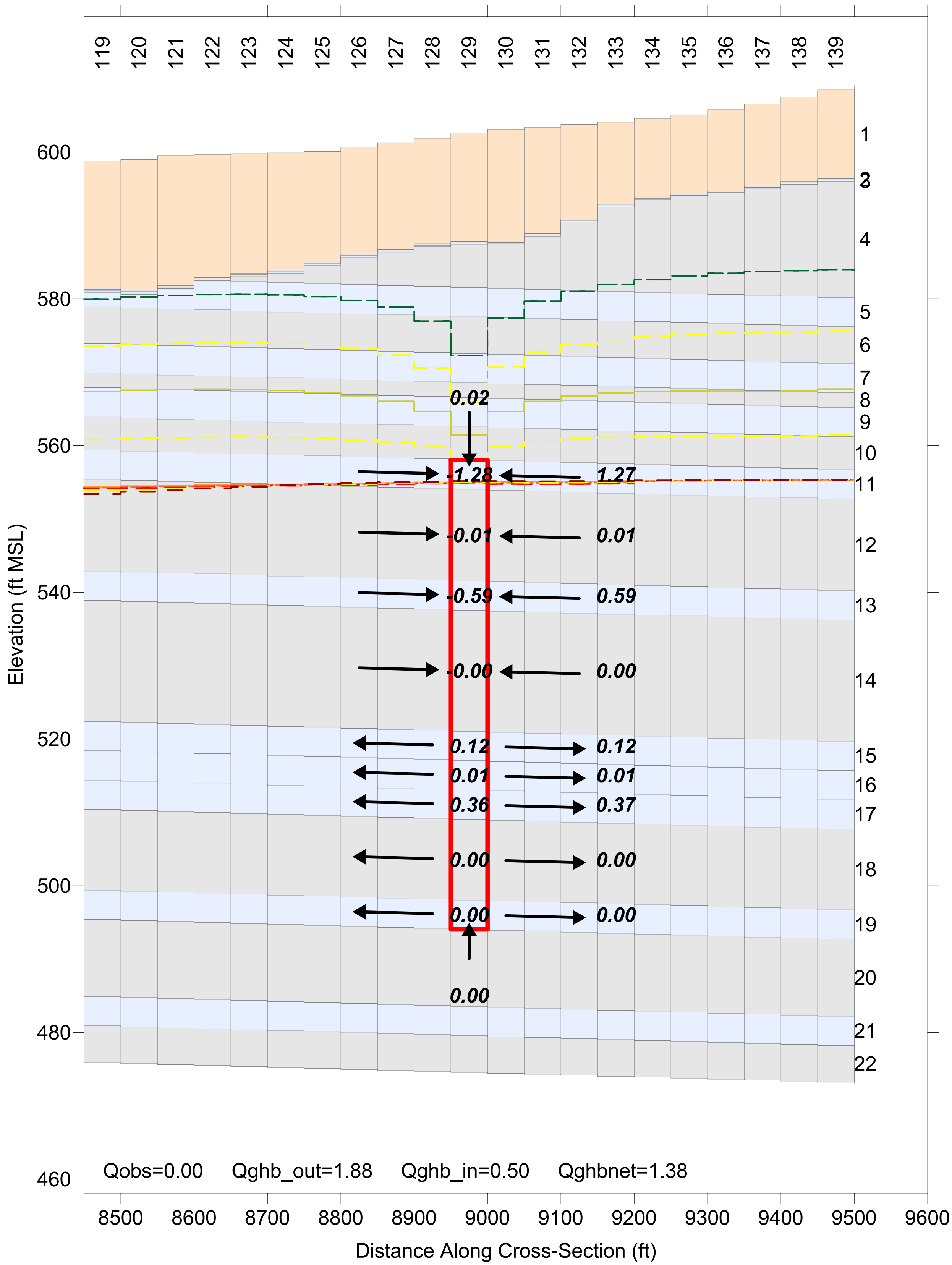
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-2L_flows.srf



VERTICAL EXAGGERATION=10x

figure B-33

MODEL FLOWS ALONG PW-3M; NON-PUMPING CONDITIONS

SITE CHARACTERIZATION REPORT

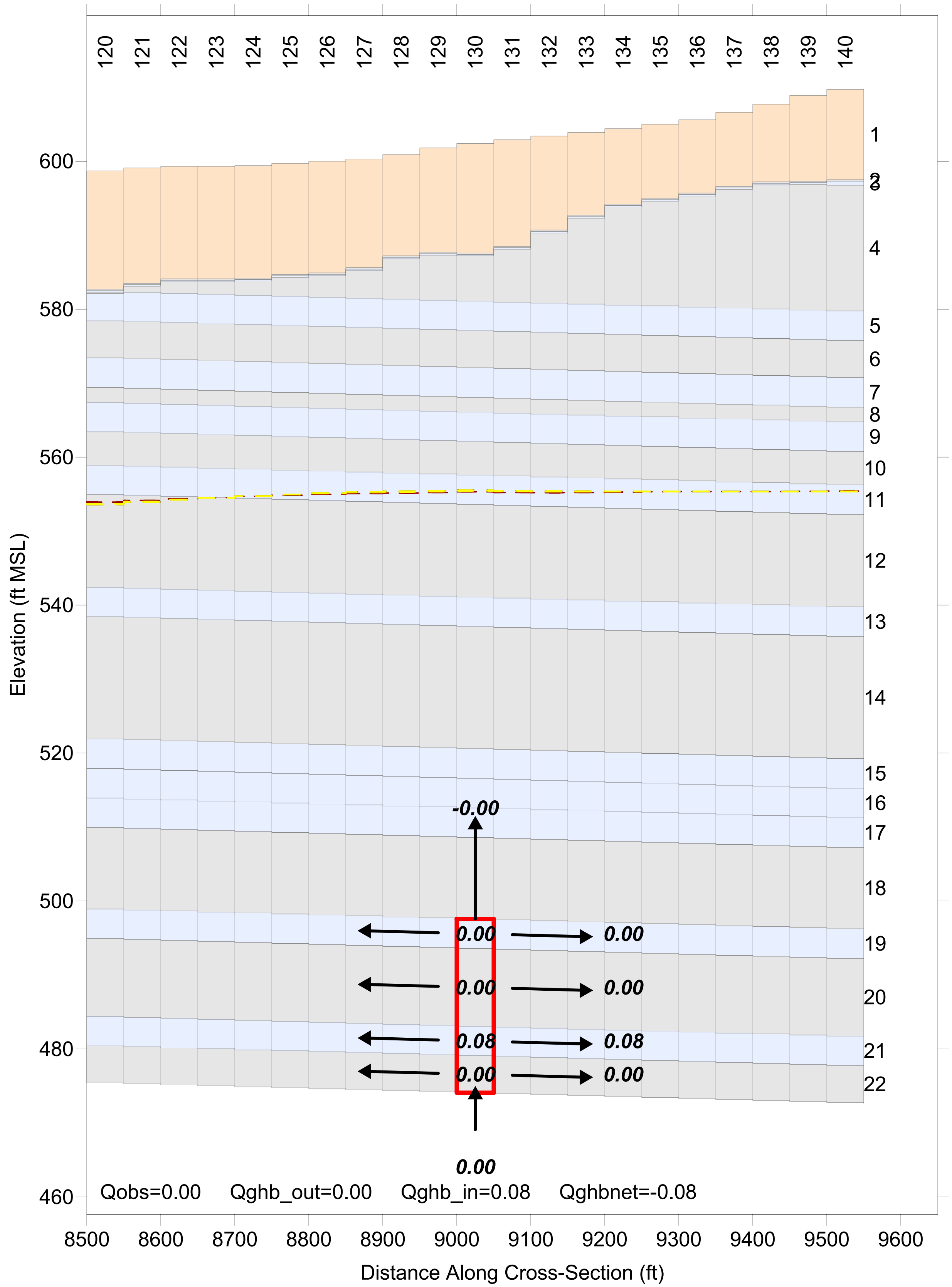
HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-3M_flows.srf



VERTICAL EXAGGERATION=10x

figure B-34

MODEL FLOWS ALONG PW-3L; NON-PUMPING CONDITIONS

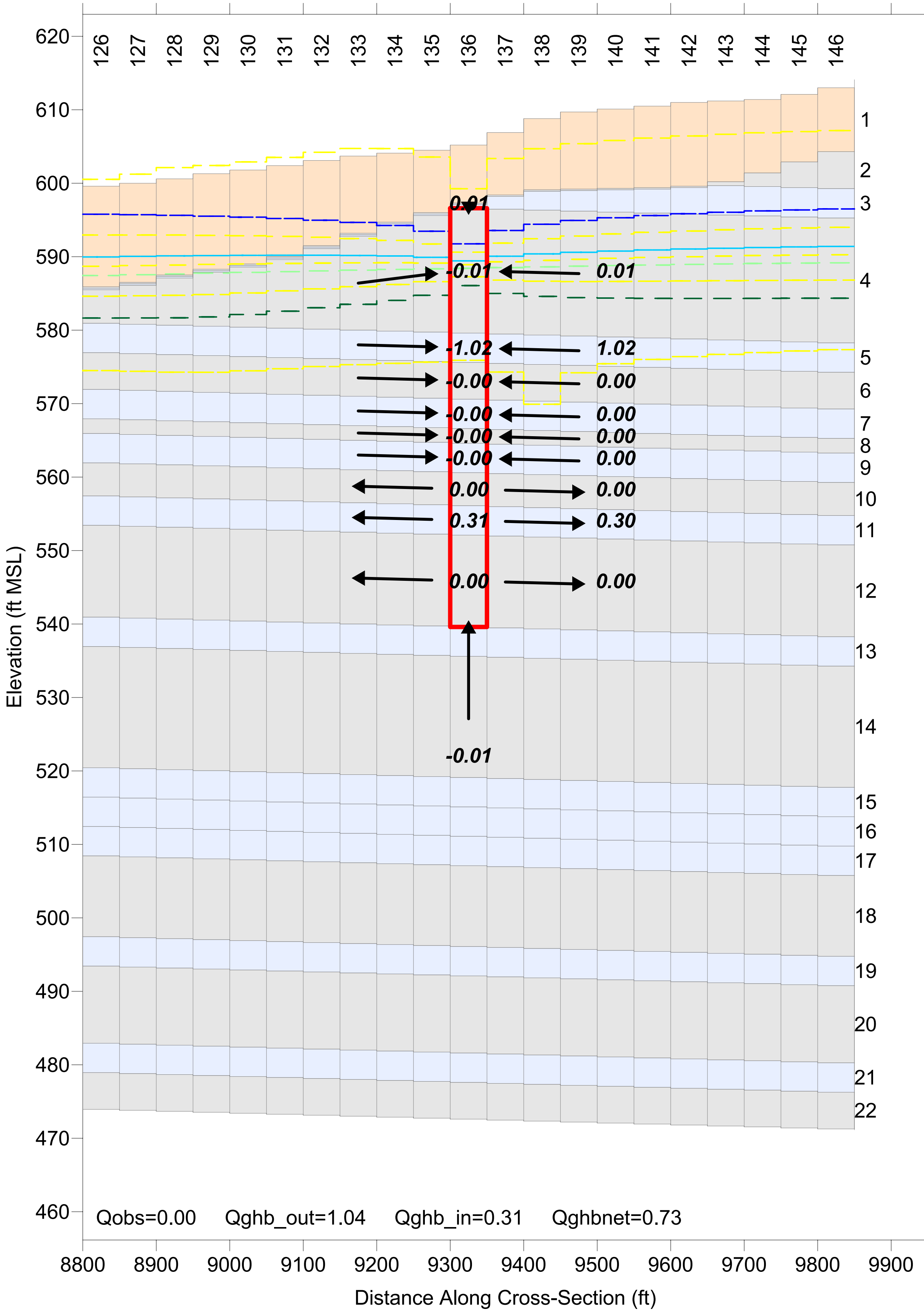
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-3L_flows.srf



VERTICAL EXAGGERATION=10x

figure B-35

MODEL FLOWS ALONG PW-4U; NON-PUMPING CONDITIONS

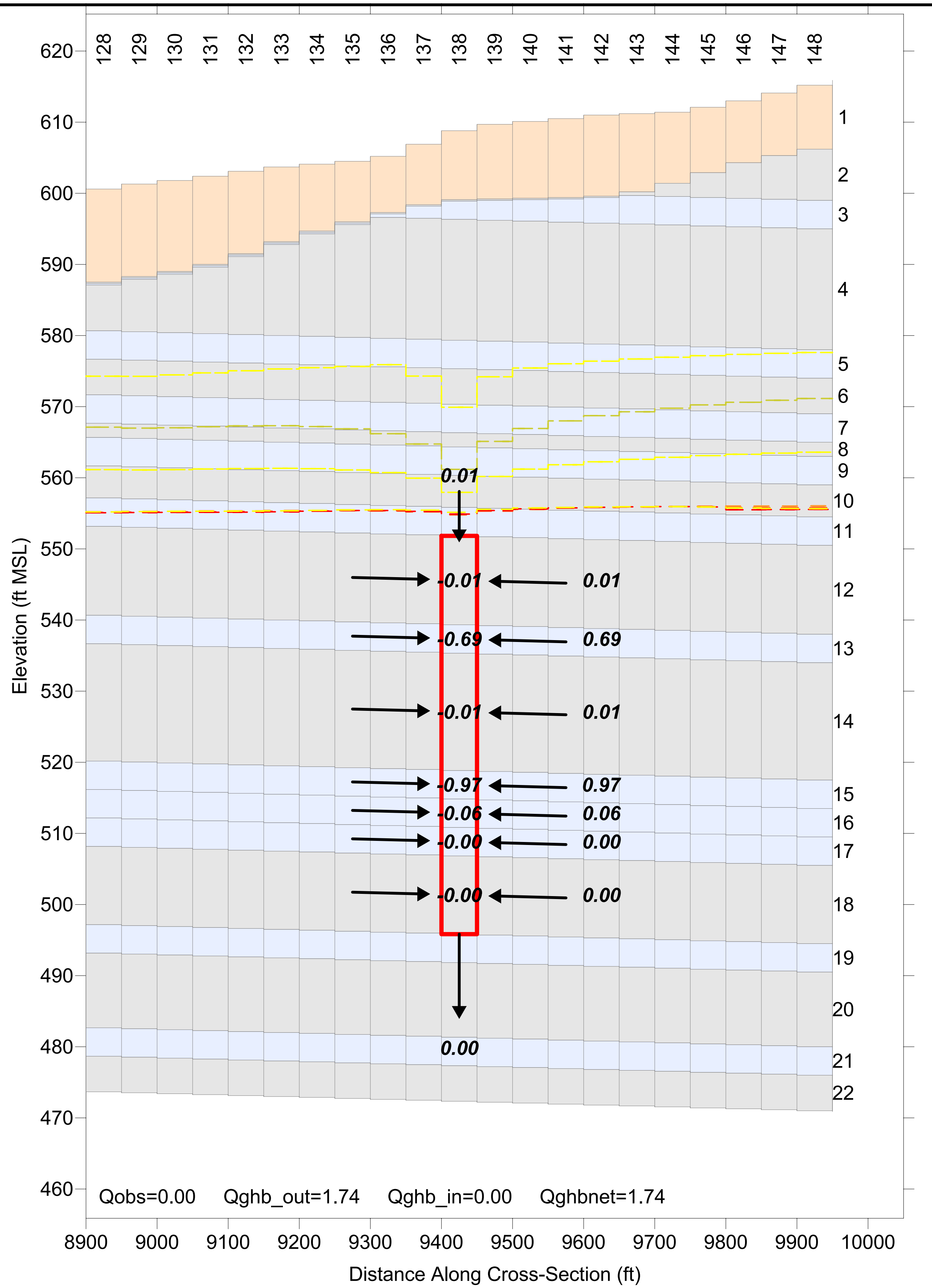
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-4U_flows.srf



VERTICAL EXAGGERATION=10x

figure B-36

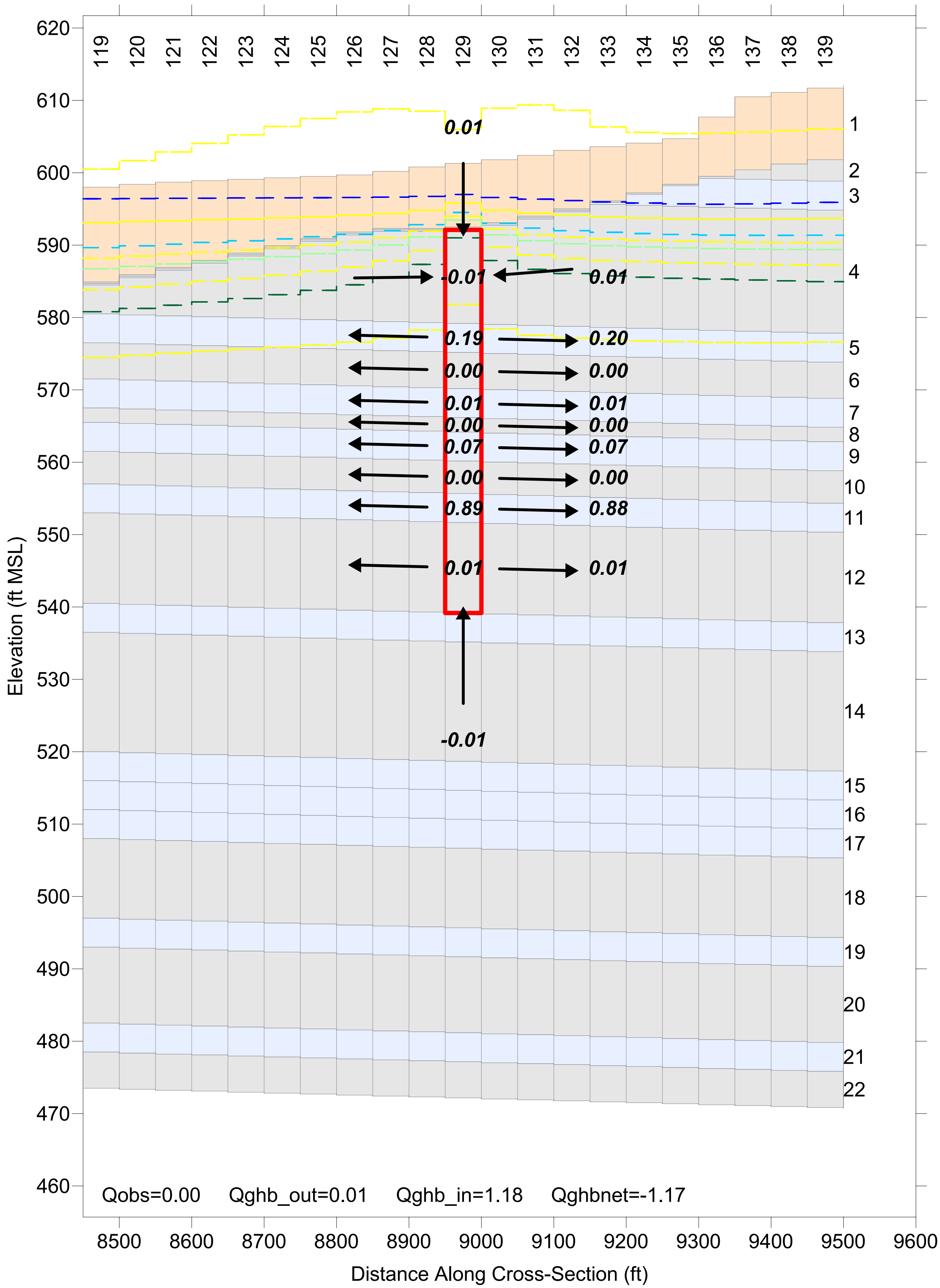
MODEL FLOWS ALONG PW-4M; NON-PUMPING CONDITIONS

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.



VERTICAL EXAGGERATION=10x

figure B-37

MODEL FLOWS ALONG PW-5UR; NON-PUMPING CONDITIONS

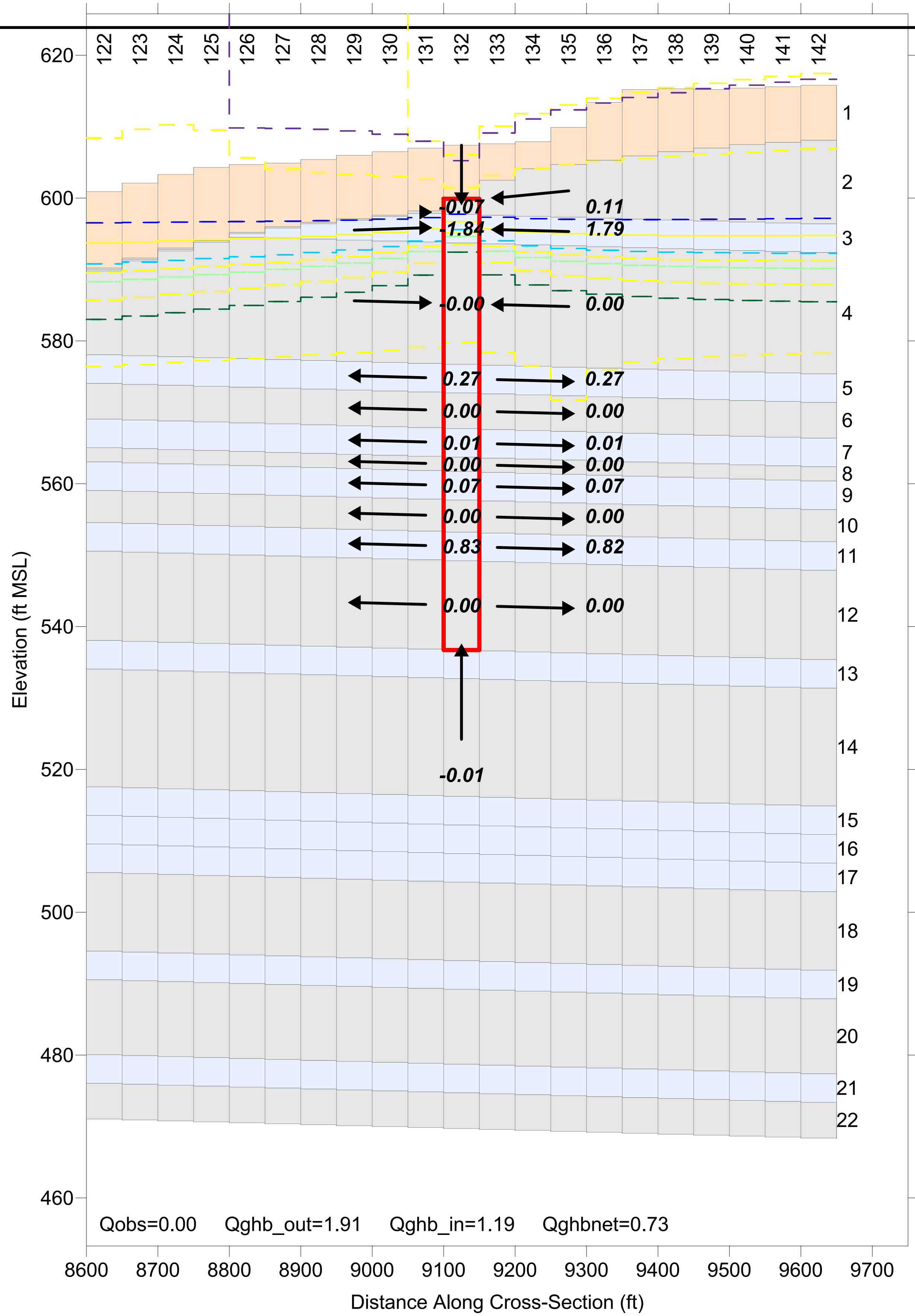
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-5UR_flows.srf



VERTICAL EXAGGERATION=10x

figure B-38

MODEL FLOWS ALONG PW-6UR; NON-PUMPING CONDITIONS

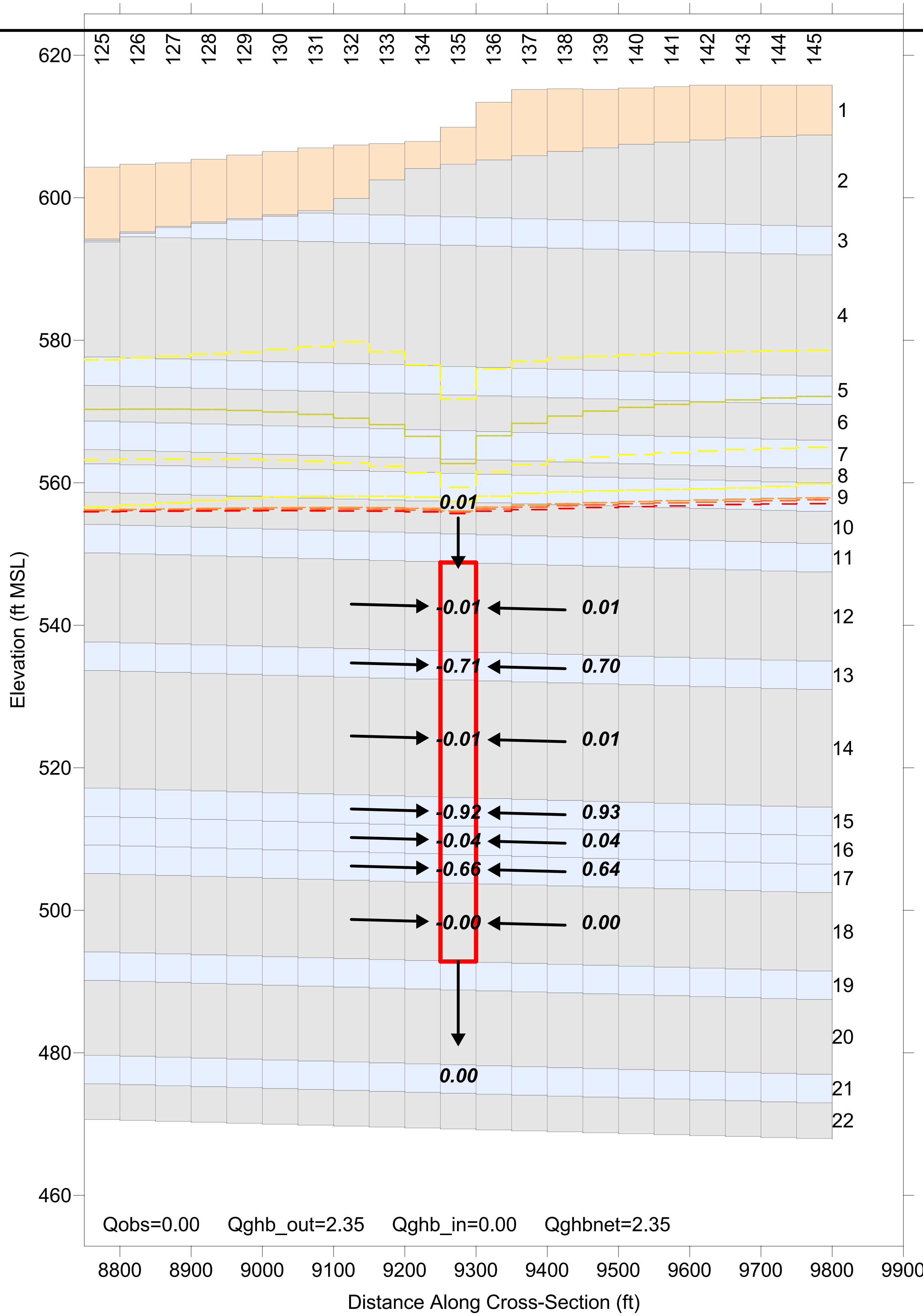
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-6UR_flows.srf



VERTICAL EXAGGERATION=10x

figure B-39

MODEL FLOWS ALONG PW-6MR; NON-PUMPING CONDITIONS

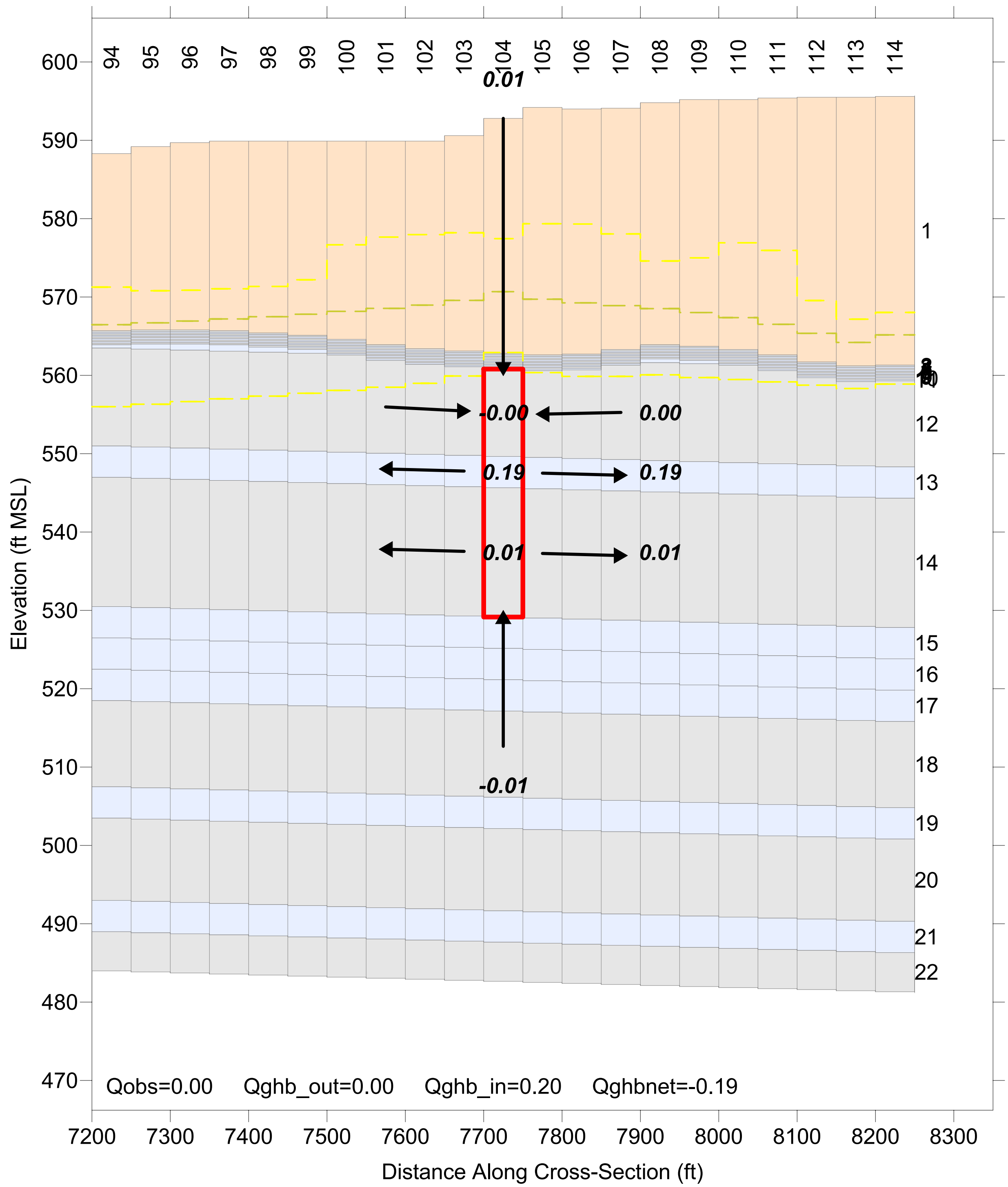
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-6MR_flows.srf



VERTICAL EXAGGERATION=10x

figure B-40

MODEL FLOWS ALONG PW-7U; NON-PUMPING CONDITIONS

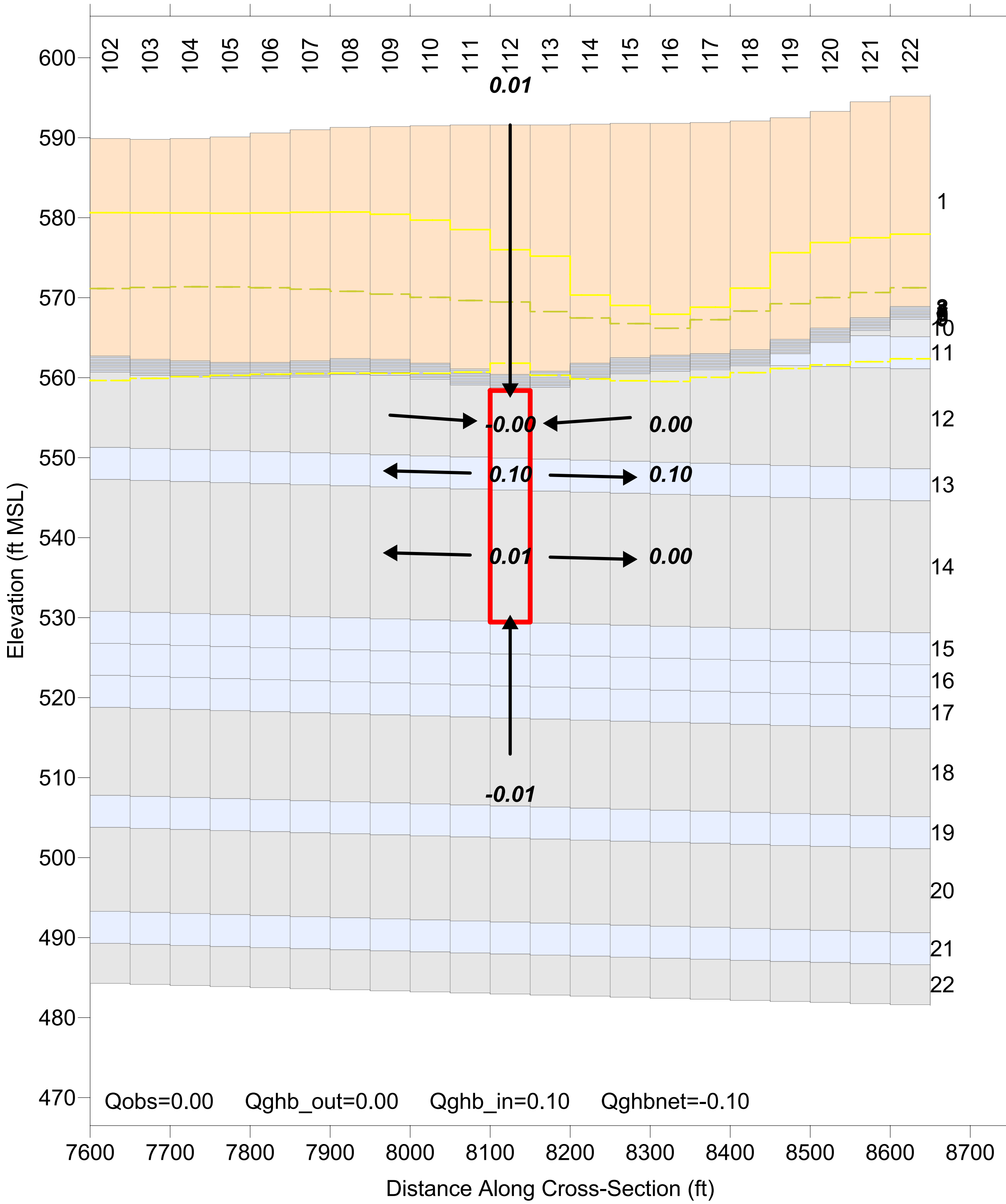
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-7U_flows.srf



VERTICAL EXAGGERATION=10x

figure B-41

MODEL FLOWS ALONG PW-8U; NON-PUMPING CONDITIONS

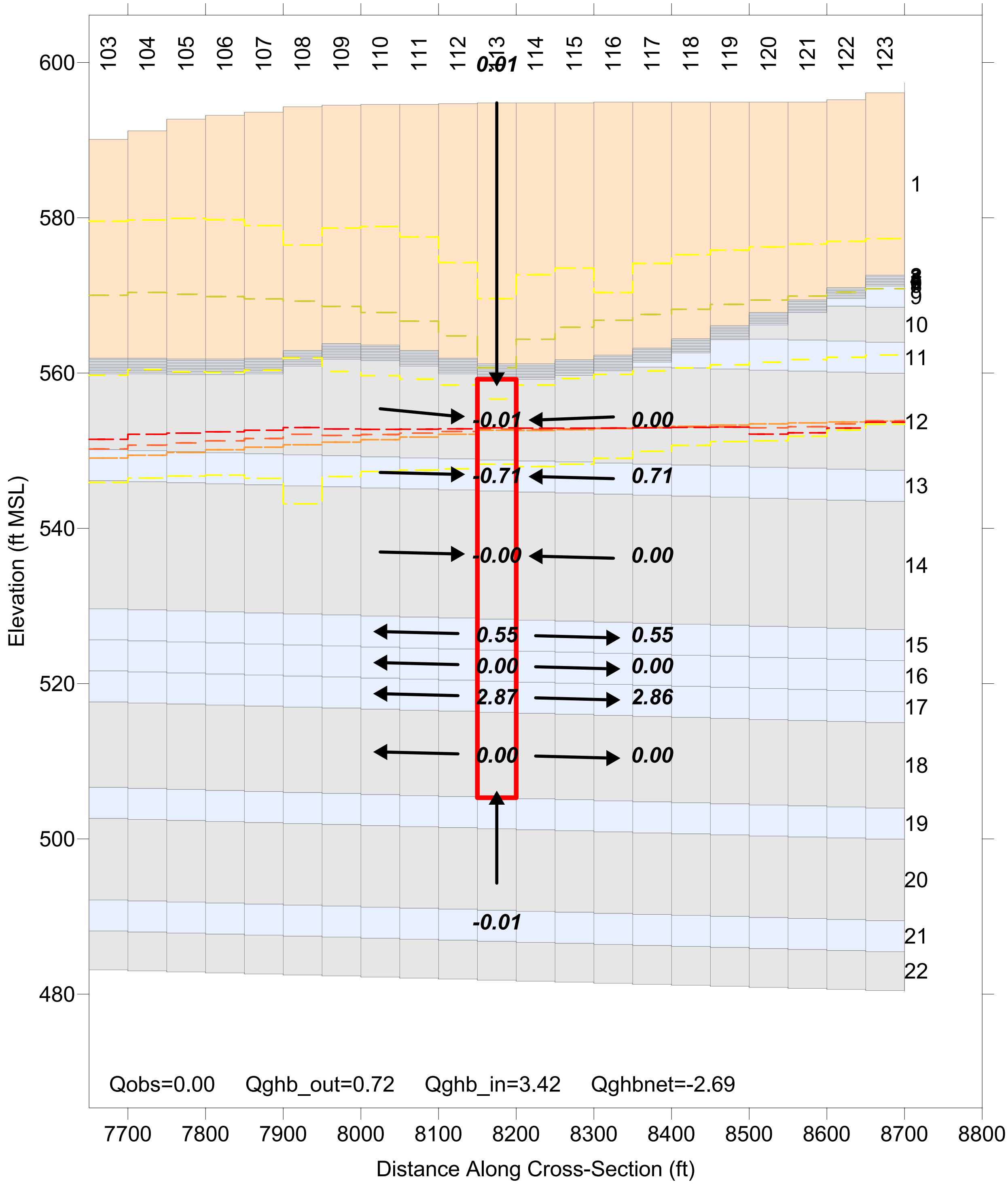
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-8U_flows.srf



VERTICAL EXAGGERATION=10x

figure B-42

MODEL FLOWS ALONG PW-8M; NON-PUMPING CONDITIONS

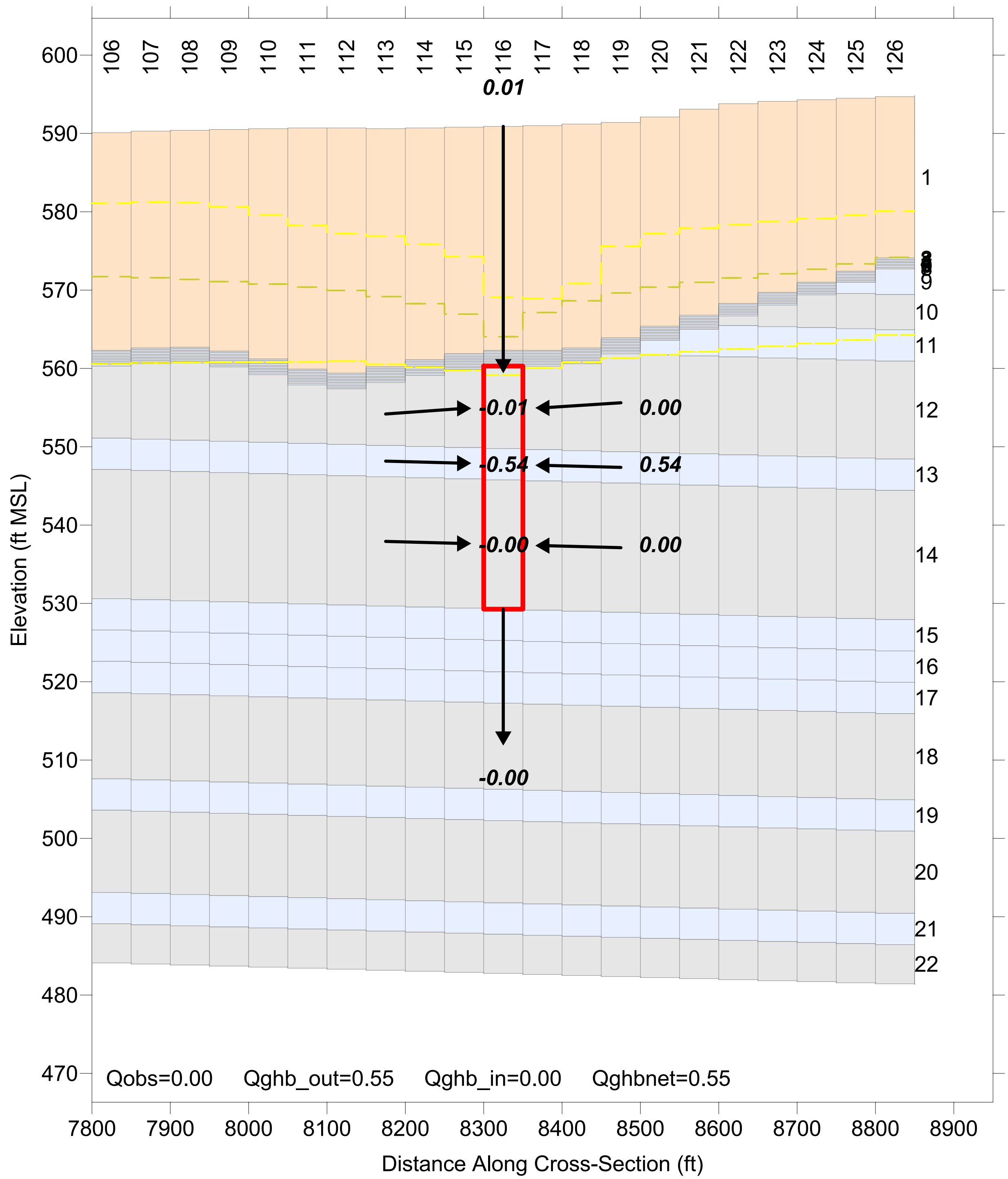
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-8M_flows.srf

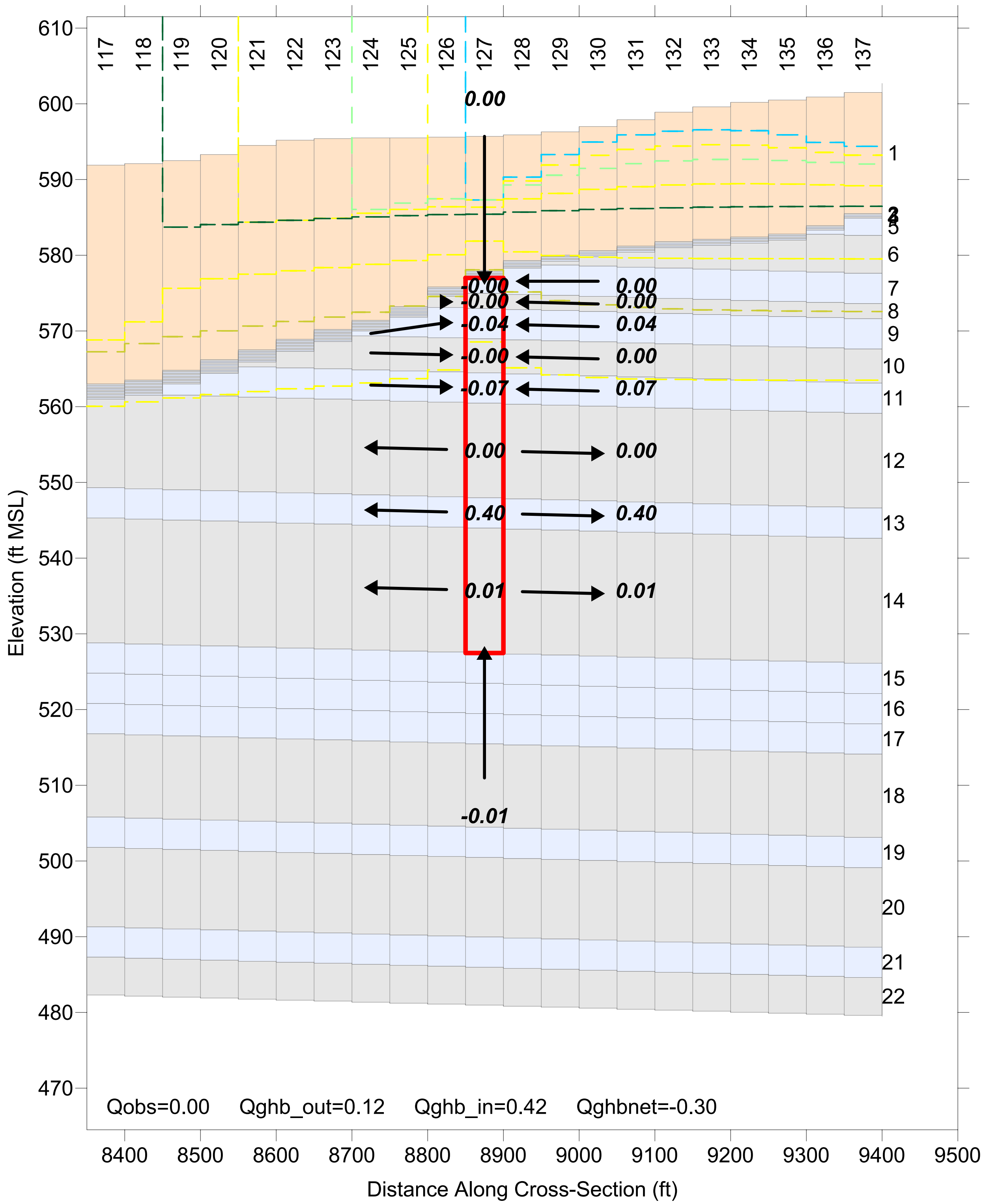


VERTICAL EXAGGERATION=10x

figure B-43
MODEL FLOWS ALONG PW-9U; NON-PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-9U_flows.srf



VERTICAL EXAGGERATION=10x

figure B-44

MODEL FLOWS ALONG PW-10U; NON-PUMPING CONDITIONS

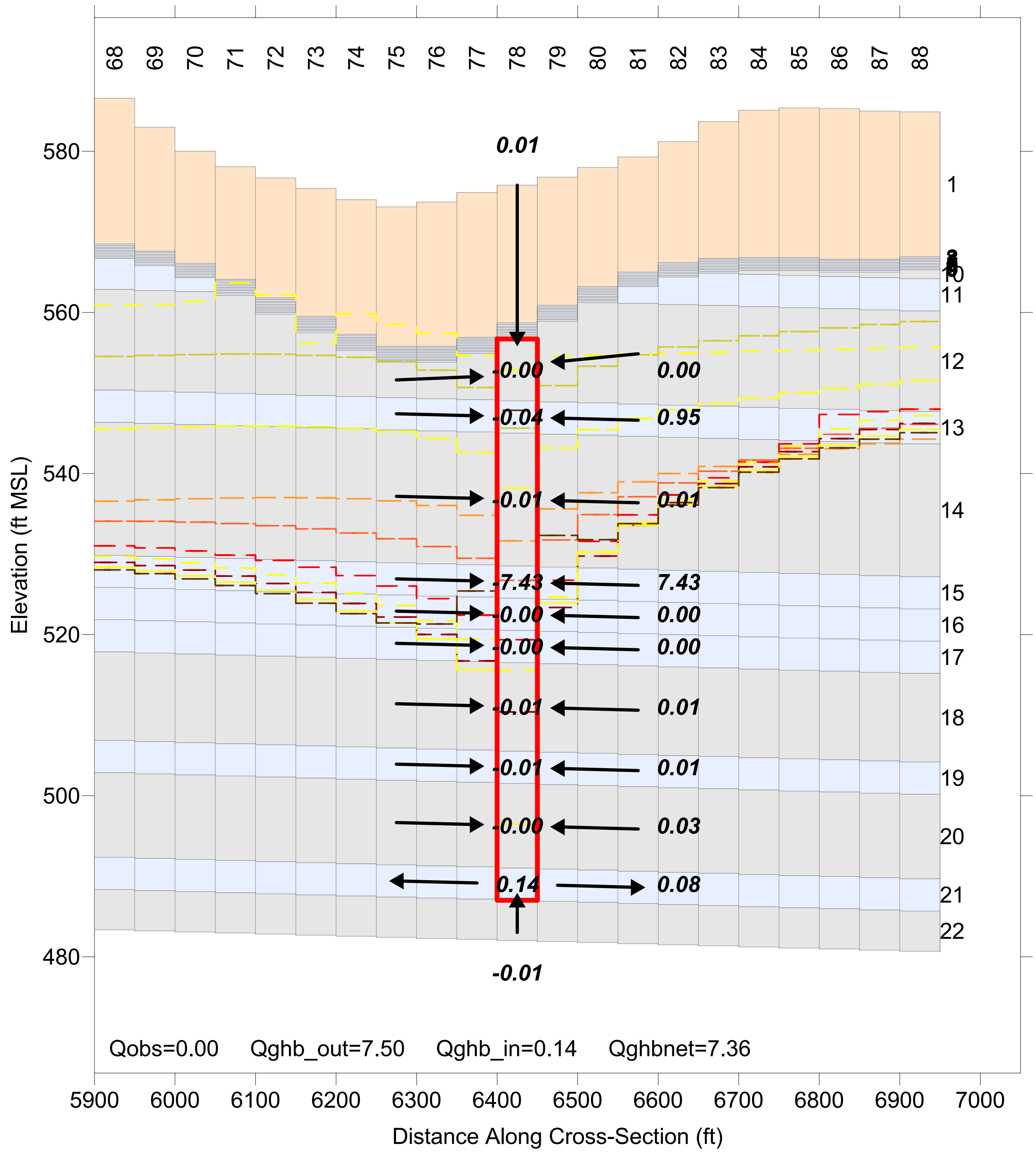
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\PW-10U_flows.srf



VERTICAL EXAGGERATION=10x

figure B-45

MODEL FLOWS ALONG SH_1; NON-PUMPING CONDITIONS

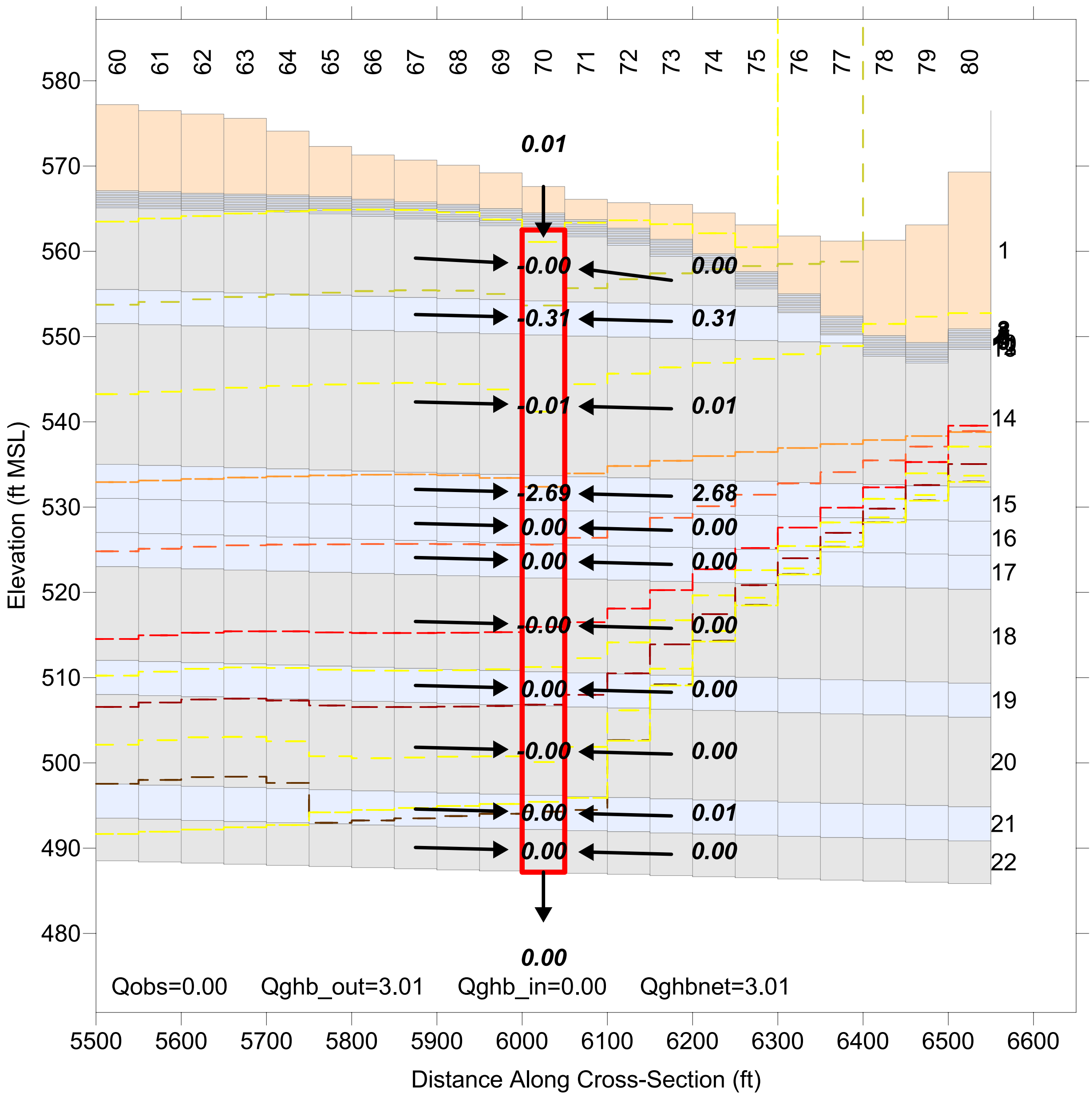
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\SH_1_flows.srf

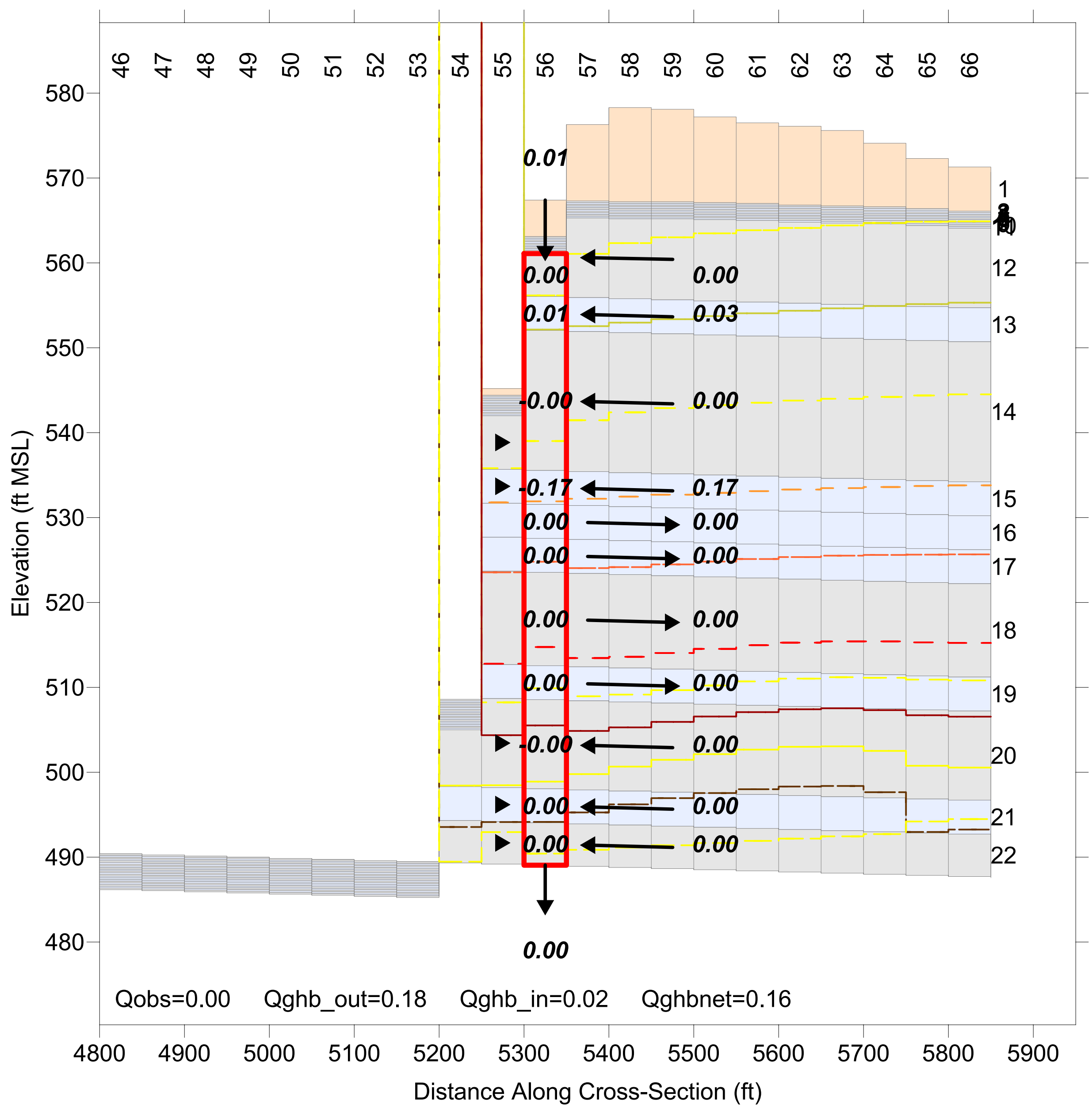


VERTICAL EXAGGERATION=10x

figure B-46
MODEL FLOWS ALONG SH_2; NON-PUMPING CONDITIONS
SITE CHARACTERIZATION REPORT
HYDE PARK LANDFILL SITE
Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\SH_2_flows.srf



VERTICAL EXAGGERATION=10x

figure B-47

MODEL FLOWS ALONG SH_3; NON-PUMPING CONDITIONS

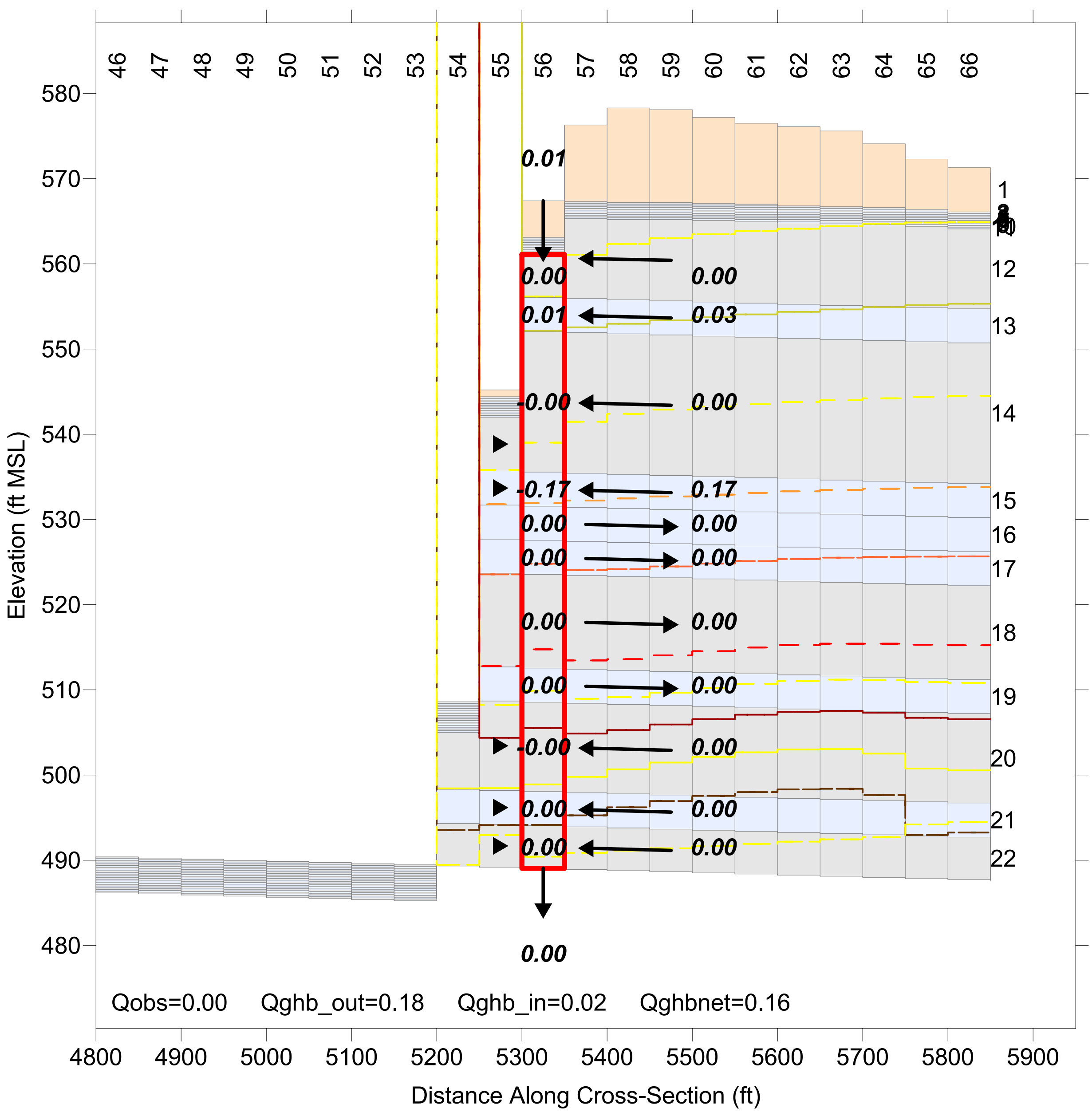
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\SH_3_flows.srf



VERTICAL EXAGGERATION=10x

figure B-48

MODEL FLOWS ALONG SH_4; NON-PUMPING CONDITIONS

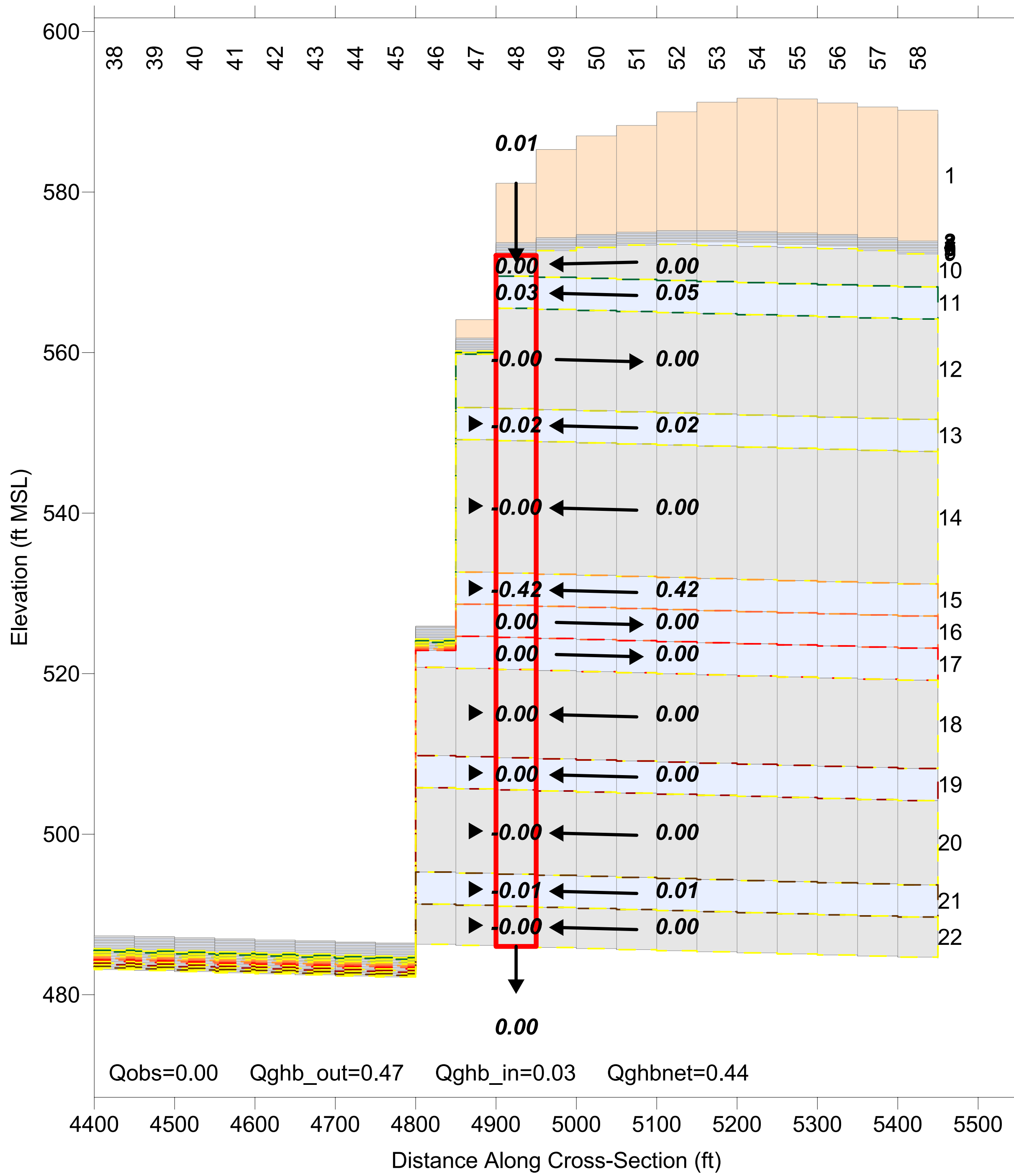
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

OXY Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\SH_4_flows.srf



VERTICAL EXAGGERATION=10x

figure B-49

MODEL FLOWS ALONG SH_5; NON-PUMPING CONDITIONS

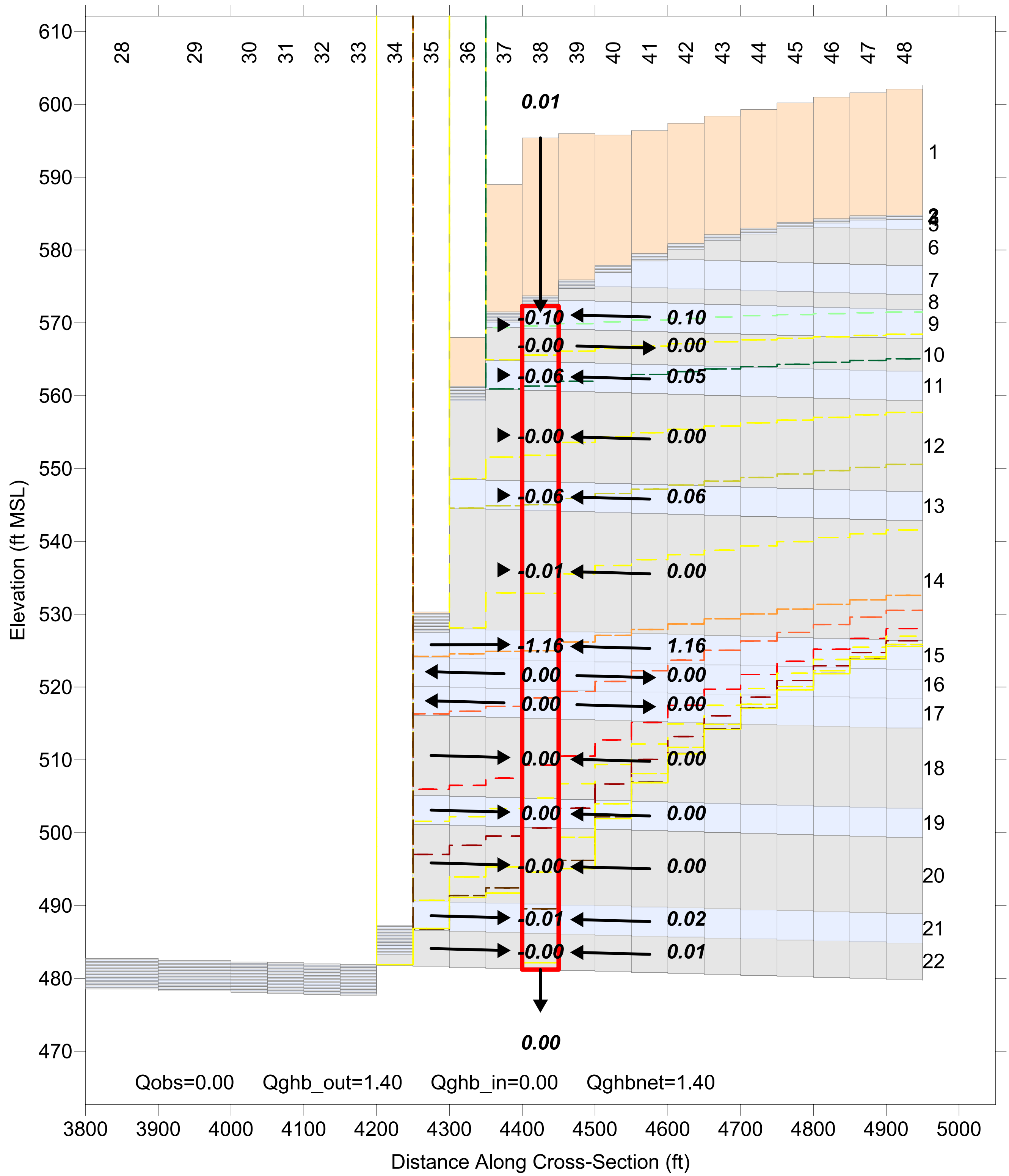
SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\SH_5_flows.srf



VERTICAL EXAGGERATION=10x

figure B-50

MODEL FLOWS ALONG SH_6; NON-PUMPING CONDITIONS

SITE CHARACTERIZATION REPORT

HYDE PARK LANDFILL SITE

Town of Niagara, New York

Miller Springs Remediation Management, Inc.

28-May-2003 d:\sspa\projects\ssp610\model3\pwf\SH_6_flows.srf