APPENDIX B

CAP MODELING

1.0 EXECUTIVE SUMMARY

The Onondaga Lake cap will provide permanent protection of human health and the environment. Design of the chemical isolation layer for the Onondaga Lake sediment cap was accomplished through a rigorous modeling effort. This appendix and its attachments summarize the objectives, application, inputs, results and recommendations from this modeling effort.

The models and modeling framework referenced in this appendix were developed by experts and have been published in peer-reviewed journals and publications such as the *Journal of Soil and Sediment Contamination* (Lampert and Reible, 2009) and “Guidance for *in situ* Subaqueous Capping of Contaminated Sediments” (Palermo et al., 1998).

Design of the chemical isolation layer of the cap, which covers more than 400 acres over five remediation areas of the lake, was accomplished through an extensive series of model simulations. Two models were used for these evaluations; an analytical steady state model and a time-variable numerical model. Both deterministic and probabilistic model evaluations were used in developing the chemical isolation layer design, to ensure that the cap provides long-term protection of human health and the environment. The modeling approach described in this appendix was used to develop the chemical isolation layer design in each of 13 model areas by simulating each of the 26 contaminants for which cap performance criteria have been established.

The chemical isolation layer will consist primarily of sand. Based on treatability testing, amendments will be incorporated into the chemical isolation layer in certain areas to ensure long-term effectiveness of the cap. These amendments will consist of siderite (a naturally occurring mineral) to neutralize elevated pH and maintain conditions conducive to long-term biological decay of key contaminants within the cap, and granular activated carbon (GAC) to improve sorption of contaminants within the cap and provide an added level of protectiveness. Amendments to the cap will be included in Remediation Areas B, C and D and in portions of Remediation Areas A and E. Modeling was conducted for both GAC-amended and non-amended caps.

An initial evaluation of the chemical isolation layer was completed based on the maximum concentrations for contaminant porewater measured (or estimated in cases where measurements were not available) within each respective modeling area and best estimates (mean values) for all other model input parameters (model input parameters are described in Attachment 1 to this Appendix). Polychlorinated Biphenyls (PCBs) and most polycyclic aromatic hydrocarbons (PAHs) are predicted to be below cap performance criteria everywhere for over 1000 years based on the conservative initial model evaluations that were completed. Many VOCs are also predicted to be below their criteria for over 1000 years in several of the model areas based on these conservative simulations. This initial evaluation was based on analytical steady state and transient numerical modeling of a 1-ft. thick chemical isolation layer.

Based on the results from the initial conservative modeling, an evaluation of GAC amendment performance and more rigorous modeling were required for select VOCs and PAHs in some model areas. The recommended design application rate of GAC to isolate these VOCs and PAHs in each model area was determined using best estimates (mean values) for all model input parameters over a long-term (500 years) evaluation period. This GAC modeling is very conservative and as a result underestimates the long-term effectiveness of the cap. There are several natural processes and engineering/constructability considerations that will significantly enhance the long-term performance of the cap, but are difficult to precisely quantify; however, once the cap is constructed in the field, they will contribute to enhanced performance and protectiveness over hundreds to thousands of years, particularly as they pertain to limiting VOC migration within the cap. Specific natural processes and engineering/constructability considerations that were not incorporated into the model, but will result in an even higher level of long-term chemical isolation and protection of human health and the environment than predicted by the model include:

- Long-term anaerobic biodegradation of organic contaminants will occur within the chemical isolation layer and bottom of the habitat layer, lowering long-term contaminant concentrations and transport within the cap.
- Rapid aerobic biodegradation will occur within the upper portion of the habitat layer. This will result in lower contaminant concentrations at the surface of the cap, where essentially all benthic activity occurs.
- Additional cap thickness beyond the design-specified minimum will be placed during construction to ensure that the minimum thickness is achieved everywhere. This material over-placement will result in increased contaminant sorption, biological decay, and amendment application, and will lower concentrations throughout the cap and extend its long-term performance.
- Additional GAC beyond the design-specified minimum will be incorporated into the chemical isolation layer to account for potential unequal mixing of the GAC with the sand.
- Additional material will be placed to account for mixing of the bottom of the cap with the underlying sediment.
- The modeling calculations are based on porewater data from sediments with higher contaminant concentrations that will be removed during dredging, including in-lake waste deposit (ILWD) hot spot areas.

A complete list of model conservatisms is presented in Section 3.3. Taking these factors into consideration qualitatively, it is anticipated based on cap modeling using mean input parameters that the cap will meet long term performance criteria everywhere for 1000 years or more for the vast majority of the twenty six contaminants modeled, and for 500 years or more for a small subset of VOCs in a few areas.

As a final evaluation of the robustness of the cap design, probabilistic model simulations were completed to assess GAC performance against the full range of potential input parameter values. The probabilistic evaluation incorporated the worst-case values for model input parameters as they pertain to predictions of cap performance. GAC application rates from these evaluations based on the 95th percentile of the model outputs were developed. If these GAC application rates exceeded the application rates determined from the prior model runs, the GAC application rate was increased accordingly, providing even greater assurance that the cap would provide complete chemical isolation throughout the model evaluation period and beyond.

Designing the cap to achieve performance criteria for each individual contaminant is conservative based on risk considerations. As documented in the Record of Decision (ROD), the Mean PECQ of 1, which takes into consideration concentrations of multiple contaminants, is an appropriate indicator of benthic toxicity, which is the primary risk consideration for cap effectiveness. The cap will achieve a Mean PECQ of 1 or less everywhere at steady state (i.e., forever), and thus the cap will provide permanent protection of human health and the environment.

2.0 MODELING OBJECTIVES

Contaminant transport modeling was conducted to design a chemical isolation layer for the cap that will meet the ROD requirements and ensure long-term effectiveness. Specifically, the chemical isolation layer performance criterion is to meet the individual probable effects concentrations (PECs) for the 23 contaminants that were linked to toxicity on a lakewide basis and the New York State Department of Environmental Conservation (NYSDEC) sediment screening criteria (SSC) for benzene, toluene, and phenol[1] throughout the habitat layer.

As stated in the ROD, the compliance point for the cap is the bottom of the habitat restoration layer. To ensure protectiveness, the isolation layer has been designed to prevent concentrations of contaminants from exceeding their performance criteria (PEC) throughout the habitat restoration layer.

3.0 DESIGN MODELS

Design evaluations were conducted using two models: an analytical steady state model and a more complex numerical model, which allows for time-varying evaluations and simulation of GAC performance. Both models are described below. The method for applying these two models is provided in Section 7.

3.1 Analytical Steady State Model

The analytical steady state model was developed to simulate cap performance and develop an appropriate chemical isolation layer design for containment of contaminated sediments. Simulated transport processes within the typically homogeneous chemical isolation layer include porewater advection, diffusion and dispersion, reaction (where appropriate), and equilibrium partitioning between the dissolved and sorbed phases of the contaminant. Within the overlying habitat layer, the analytical steady state model includes these same processes, as well as sediment mixing and porewater pumping via bioturbation within the upper zone of that layer. The analytical steady state model thus allows the complexities of the biologically active layer to be considered while maintaining an analytical form for convenient and rapid evaluation. The analytical steady state model evaluates a single material matrix in the chemical isolation layer and is not capable of modeling non-linear sorption processes, which is necessary for evaluating GAC adsorption. The schematic below indicates the general structure and processes included in the analytical steady state cap model.

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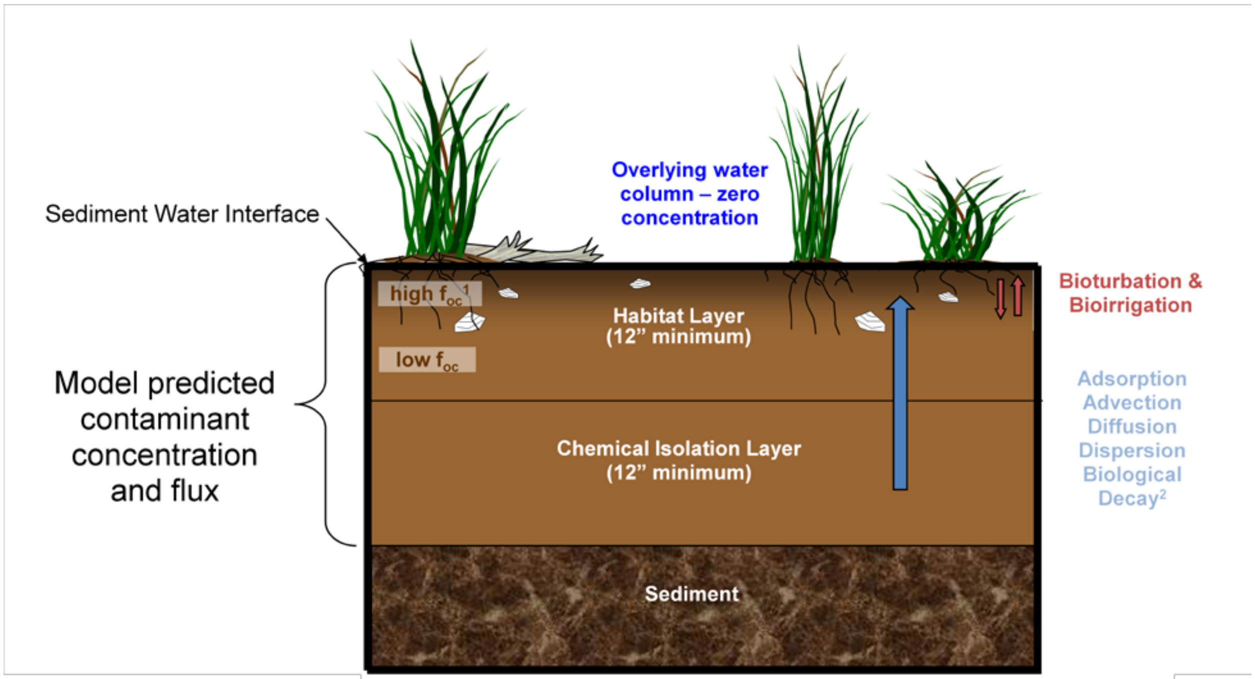
[1] Benzene, toluene and phenol are not associated with lake-wide toxicity. Model results for benzene, toluene and phenol are compared to NYSDEC acute criteria. Comparison to acute criteria is consistent with comparison to PEC values which are based on acute toxicity.

ILLUSTRATION OF CAP PROCESSES MODELED AND STRUCTURE OF ANALYTICAL STEADY STATE MODEL



Note:
1) f_{oc} – fraction organic carbon
2) Biological decay explicitly modeled for phenol , considered qualitatively for other compounds

The analytical steady state model was developed by experts in the field of contaminant transport modeling, and has been published in the peer-reviewed *Journal of Soil and Sediment Contamination* (Lampert and Reible, 2009). Validation of the analytical steady state model code was completed in accordance with Parsons standard procedures for software verification and validation. Model results for various test cases were compared with calculations from well-documented 1-D solute transport equations by an independent reviewer; the model gave similar results using the same parameters and boundary conditions. A complete model validation report is included in Attachment 3.

3.2 Numerical Model

The general structure and processes included in the Onondaga Lake numerical cap model are consistent with those of the analytical steady state model. In addition, the numerical model simulates diffusional gradients in the underlying sediment, non-linear sorption within the isolation layer, and porewater advection due to settlement-inducted consolidation of the underlying sediment. The numerical solution scheme of this model also allows for time-variable simulations of the aforementioned processes. The USEPA guidance document entitled "Guidance for *In Situ* Subaqueous Capping of Contaminated Sediments: Appendix B: Model for Chemical Containment by a Cap" describes the general modeling processes and basis for the numerical model (Palermo et al., 1998). The model code is the result of an extensive development process (fourth generation model) within the research group at the University of Texas (Go, J. et al, 2009 and Lampert, 2010). The University of Texas has developed and implemented the code within the MATLAB platform.

Both the analytical steady state and numerical modeling described herein assume an infinite source of contaminants is present in the underlying sediments. Upwelling velocities in the cap areas are relatively low, so transport from the underlying sediments upwards into the cap will be dominated by diffusion. This causes a concentration gradient to develop at the sediment-cap interface, which results in a decrease in chemical concentration in the sediments just below the sediment-cap interface over time. This, in turn, affects the overall rate of upward transport. In order to represent this process, the sediment underlying the cap is explicitly included as a layer in the numerical model. The sediment layer is modeled as 250 cm thick, with an infinite source boundary condition at the bottom of that layer. The processes modeled in the underlying sediment layer include advective and diffusive transport and partitioning. Biological decay or other source depletion processes in the underlying sediment are conservatively not included in this modeling evaluation. This explicit representation of the underlying sediment is not included in the analytical steady state model, which is an additional conservatism of that model.

Validation of the numerical model was completed in accordance with Parsons standard procedures for software validation and verification. An independent validation of this model was performed by S.S. Papadopoulos and Associates. Multiple test scenarios were simulated with the numerical model and compared to results from MT3D (Zheng and Wang, 1998), a widely used groundwater transport model that has been extensively verified, as well as an analytical solution to the governing equation of the model (Neville, 2005). Additional validation was provided by Parsons and Anchor QEA, who found that the results of long-term simulations of the numerical model were consistent with the results of the analytical steady state model and with other solutions to the one dimensional contaminant transport equation. A complete model validation report is included in Attachment 3.

3.3 Model Conservatism

To ensure that the cap design is conservative and will provide long-term chemical isolation, the modeling used to develop the design of the chemical isolation layer does not incorporate numerous natural processes and engineering/constructability considerations that will significantly contribute to the long-term performance of the cap. Specific concepts and processes that were not incorporated into the model but will result in an even higher level of long-term chemical isolation than predicted by the model are listed below.

- Long-term anaerobic biodegradation of organic contaminants will occur within the chemical isolation layer and bottom of the habitat layer, lowering long-term contaminant concentrations and transport within the cap.
- Rapid aerobic biodegradation will occur within the upper portion of the habitat layer. This will result in lower contaminant concentrations at the surface of the cap, where most benthic activity occurs.

- Additional cap thickness beyond the design-specified minimum will be placed during construction to ensure that the minimum thickness is achieved everywhere. This material over-placement will result in increased contaminant sorption, biological decay, and amendment application, and will lower concentrations throughout the cap and extend its long-term performance. The over-placement thickness is anticipated to average 3 in. or greater for each separate cap layer, which will cause the constructed thickness of the chemical isolation layer to be greater than the design thickness by 25% or more.
- Additional GAC beyond the design-specified minimum will be incorporated into the chemical isolation layer to account for potential unequal mixing of the GAC with the sand.
- Additional material will be placed to account for mixing of the bottom of the cap with the underlying sediment. The bottom 3 in. of cap material placed is assumed to mix with the underlying sediment, and is not considered when meeting the minimum required isolation layer thickness. This material may mix with the underlying sediment and reduce contaminant concentrations in the zone immediately underlying the cap. It is also possible/likely that a portion of the dedicated mixing layer will not mix with the underlying sediment and therefore would provide even more protection as part of the cap.
- The modeling includes porewater data from sediments with higher contaminant concentrations that will be removed during dredging, including in-lake waste deposit (ILWD) hot spot areas.
- The recommended chemical isolation layer design is based on the maximum predicted concentration at any point within the habitat layer. However, benthic organisms move throughout the bioturbation zone, which for cap design purposes has been characterized as the top 6 in. of the habitat layer. As a result, organisms are exposed to concentrations that are better characterized by the average within this zone rather than the maximum. Additionally, literature suggests organisms exposure is more heavily weighted toward the surface of this zone (e.g., Strommer and Smock, 1989). A detailed review of literature supporting that 6 in. is a conservative estimate of the bioturbation zone thickness is provided in Attachment 4.
- Cap modeling is based on a 12 in. thick habitat layer. However, the minimum habitat layer thickness will actually be 24 in. thick in water depths from 0 to 3 ft., and 18 in. thick in water depths from 3 to 7 ft. Overall, the habitat layer will be a minimum of 18 in. thick or greater in over one-third of the capped area. For many contaminants, the critical compliance point is at the bottom of the bioturbation zone rather than at the bottom of the habitat zone due to the higher level of organic carbon anticipated over time in the bioturbation zone. The thicker habitat layer, where present, will result in lower contaminant concentrations in the bioturbation zone than is predicted by the model.
- Clean sediments will be mixed into the habitat layer over time (due to deposition from the overlying water column), a process that will serve to reduce chemical concentrations. The modeling assumes that organic carbon will reach 5% over time at

the bottom of the bioturbation zone as a result of mixing of organic material from the cap surface due to benthic activity. To achieve this level of organic carbon at the bottom of the bioturbation zone, a significant fraction of the material within that zone will have to have originated as new material that deposited from above and mixed in with the cap habitat layer material. Therefore, the model implicitly assumes that deposition and subsequent mixing must occur for the purposes of specifying organic carbon content of the bioturbation zone, but it conservatively does not represent the impact of the deposition process on contaminant levels in the cap.

- The analytical steady state model assumes a constant porewater concentration at the cap/sediment interface. However, as discussed above, mass conservation principles dictate that in order for diffusion to move contaminant mass out of the underlying sediment, a concentration gradient must be established at the sediment-cap interface. Mass transport out of the sediment, as well as any source depletion due to natural decay processes, are not considered in the analytical steady state model. The numerical model likewise assumes an infinite concentration 2.5 meters below the sediment cap interface.
- Due to low groundwater upwelling velocities in areas to be capped, the dominant form of contaminant transport is generally molecular diffusion. In the cap model, only vertical diffusion out of the sediment up into the clean cap material is considered. However, horizontal diffusion will also occur from areas of higher concentration to areas of lower concentration within the underlying sediment and within the cap itself. This process would serve to lower the most-elevated concentrations within the cap, especially over the long timescales considered in this modeling.
- The numerical model considers diffusion/dispersion processes in the underlying sediment, which are in part dependant on sediment porosity. Porosity is set at a fixed value which does not change during the model run (the model input value is based on sediment samples collected in a given Remediation Area, as noted in Table A1.1 of Attachment 1). However, subsequent to cap placement, in those areas where significant dredging has not occurred prior to cap placement, consolidation of underlying sediments will occur as a result of cap placement, which will reduce the porosity of the underlying sediments. The change in porosity will reduce the effective diffusion coefficient in the underlying sediments, which will result in a reduction in contaminant flux.
- In instances where multiple results exist for a given sampling location, maximum sample concentrations were selected from the analytical database. For example, if duplicate samples were collected at a particular location, the maximum value measured was used in the modeled dataset.

In addition to the modeling conservatisms listed above, the cap performance criterion of achieving individual contaminant PECs rather than the mean PECQ of 1, which takes into consideration concentrations of multiple contaminants, is conservative. As specified in the ROD, "PEC values were incorporated into a mean PECQ to select a level of remediation that would address the risk of direct acute toxicity to the benthic invertebrate community from the contamination in lake sediment." The cap will achieve a Mean PECQ of 1 or less, and thus address benthic toxicity, for an even longer period than it will achieve PECs for each individual contaminant. Thus, the cap will provide protection of human health and the environment for significantly longer than the modeling evaluation period used for design of the chemical isolation layer.

4.0 MODELING AREAS

The isolation cap will cover more than 400 acres of the lake bottom in Remediation Areas A, B, C, D, E, and F. For cap design purposes, these remediation areas were subdivided into 13 model areas to account for the spatial variability observed in two of the key model input parameters: groundwater upwelling velocity and porewater contaminant concentrations. Each model area was evaluated independently. Cap design, including recommendations for isolation layer thickness and mass application rate of GAC, was based on the modeling results for each model area and is specific to the conditions present in each area. The 13 model areas are shown on Figure B-1. Supporting information such as figures showing contaminant porewater concentration and pH distributions in each area are provided in Figures B-1 through B-55, and the development of groundwater upwelling distributions for each model area is presented in Appendix C of this design report. The 13 model areas are discussed below.

Remediation Area A was divided into two model areas due to the relatively elevated pH and porewater concentrations of VOCs observed at the mouth of Ninemile Creek and the higher measured groundwater upwelling in this area. The area at the mouth of Ninemile Creek has been designated as Model Area A2, and the remaining portion of the remediation area is designated as A1.

Model area delineation in Remediation Areas B and C was based on consideration of VOC and phenol concentrations and groundwater upwelling conditions (including identifying the portions of these areas that will be influenced by hydraulic barriers that have been or will be constructed and operated along the shoreline, as discussed in Appendix C). Based on this information, Remediation Area B was divided into two model areas (B1 and B2) and Remediation Area C was divided into three model areas (C1, C2, and C3). Model Areas B1 and C1 were then combined into a single model area (referred to hereafter as B1/C1) given the similar levels of concentrations of key compounds such as phenol and benzene and similarities in upwelling velocities.

Remediation Area D was divided into four sub-areas based on chemical concentrations and distributions. Appendix G presents the basis for development of these sub-areas, designated as the SMU 2, West, Center, and East sub-areas of Remediation Area D, as shown on Figure B-1. Due to the measured differences in contaminant concentrations and distributions as well as predicted groundwater upwelling velocities, each of these Remediation Area D sub-areas was modeled independently.

Remediation Area E was divided into three model areas due to the higher porewater concentrations of VOCs observed immediately adjacent to Remediation Area D (Model Area E2) and the elevated concentration of naphthalene offshore and at the mouth of Onondaga Creek

(Model Area E3). Groundwater upwelling estimates are consistent throughout Remediation Area E and did not factor into model area delineation.

Remediation Area F consists of two small areas totaling less than one acre. These areas were delineated based on sediment mercury concentrations that exceed the mercury PEC. Cap modeling was not conducted for these areas. These areas are not close to shore; therefore, groundwater upwelling velocities are expected to be low. Mercury concentrations are much lower in these areas than in other areas where modeling indicates that a 1 ft. chemical isolation layer will be sufficient. Therefore, the chemical isolation layer thickness in this area will be a minimum of 1 ft. consistent with the ROD. The pH in these areas is not elevated, so no amendments are necessary.

5.0 MODEL INPUTS

Accurate characterization of site conditions and cap material performance are critical to developing appropriate model input parameters. Model inputs for the cap were derived from extensive site sampling efforts, bench scale testing, and literature in some cases. Site-specific data have been collected in each model area to accurately characterize the underlying sediment and groundwater flow regime, assess cap material performance under model area specific conditions, and to inform input parameter selection on a model area basis.

Key model input parameters including underlying porewater chemical concentrations and groundwater upwelling velocities, have been evaluated in each individual model area over the course of the six year pre-design investigation (PDI). These data are supplemented by data from the remedial investigation, resulting in an extensive database that forms the basis for specifying the cap model inputs. Sorption parameters (including partitioning to sand cap materials and to GAC amendments) are also a key model input. Site specific data in each model area as well as a multi-phase series of bench-scale evaluations have been ongoing since 2006 to increase understanding and provide site-specific information for these key parameters. Model input parameters for which extensive site-specific field investigation and bench-scale laboratory studies have been performed include:

- Porewater chemical concentration
- Fraction of organic carbon (foc) in the isolation layer and at the cap surface (i.e., the bioturbation zone within the upper portion of the habitat layer)
- Groundwater upwelling velocity
- Organic carbon partitioning coefficient (Koc) for cap materials (as well as the underlying sediments)
- Parameters from the Freundlich isotherm equation to describe the non-linear sorption of VOCs and phenol to GAC
- Biological degradation rate

Attachment 1 contains details on the model input parameters, including the basis for specification of each input (i.e., applicable references and data sources), and a discussion of the statistical distributions used in probabilistic modeling evaluations.

6.0 DESIGN OPTIMIZATION CONSIDERING VARIABILITY IN SITE CONDITIONS

Understanding and accounting for variability in site conditions that constitute the basis for the model input parameters were critical components of completing the modeling to ensure it is truly predictive of future conditions. Variability in the data used to model cap performance originated from two sources: 1) spatial variations due to natural and anthropogenic processes such as contaminant loadings to the lake and heterogeneity in permeability, deposition and erosion; and 2) measurement variability associated with sampling, processing and laboratory analysis, and data interpretation. Characterizing and accounting for these sources of variability to ensure that the cap is protective everywhere was a significant focus of the modeling effort described herein. Details are provided below.

6.1 Extensive Data Collection and Bench Testing

As discussed in Section 4, site-specific data were utilized in the model to maximize the accuracy and reliability of the results. An extensive site-specific database for the most important model input parameters was developed based on the RI and six years of PDI data and laboratory studies. This database includes the analytical results from over 7,000 sediment samples and 5,500 porewater samples. In addition, site-specific measurements of groundwater upwelling velocity were taken at over 350 locations throughout the lake. Finally, extensive bench-scale testing was completed to accurately characterize important processes such as GAC adsorption and biological decay. As a result of this exhaustive data collection effort, uncertainty in input parameters has been minimized and variability can be accurately characterized and taken into consideration during modeling.

6.2 Small Model Areas to Minimize Spatial Variability

Remediation areas were developed to be reflective of localized conditions within the lake, such as contaminant sources and characteristics, water depth, and physical conditions. As discussed in Section 4, the five remediation areas of the lake were further divided into even smaller model areas to ensure that the cap would be designed specific to conditions in an area based on key model input parameters such as groundwater upwelling velocity and contaminant porewater concentrations. By developing these smaller model areas, the spatial variability within each model area is significantly reduced, since zones of high/low concentration and/or upwelling velocity are modeled separately.

6.3 Initial Conservative Modeling Used Maximum Porewater Concentrations

To reduce the number and complexity of subsequent modeling simulations, the first phase of modeling conservatively used maximum porewater contaminant concentrations for analytical steady state simulations and for numerical simulations over a 1000 year evaluation period. Porewater contaminant concentrations are one of the most significant model input parameters. As detailed in Section 7, the results from this initial conservative modeling indicated that cap performance criteria would be met for over 1000 years for a majority of the contaminants in each area.

6.4 Model Conservatisms Offset Potential Impacts of Variability

As discussed in Section 3.3, the model underestimates the effectiveness of the cap because it does not incorporate several natural processes and engineering/constructability considerations that will significantly contribute to the long-term performance of the cap, including biological decay and over-placement of cap materials during construction. For example, in all amended cap areas except Model Areas E2 and E3, the minimum thickness of the GAC-amended isolation layer is 9 in., which is the basis for the modeling and establishment of GAC application rates in these areas. Average over-placement of GAC-amended sand during construction is expected to be approximately 3 in. As a result, the carbon application rate and resulting cap performance will be approximately 33% greater than the design application rate determined from the modeling. Given such model conservatisms, the detailed modeling of VOCs conducted to determine GAC application rates used mean values (rather than the maximum values described above) for model inputs; this approach is appropriate in evaluating whether the cap will be effective everywhere over the minimum evaluation period of 500 years (as presented in Section 7) given the aforementioned conservatisms.

6.5 Mean Values Used as Best Estimate

For modeling that used best estimates of various parameters (Section 7), the mean rather than median values were used as the best estimate of each input parameter in a given model area. The mean values used were always greater than the median, typically by a significant amount for key input parameters. For example, chlorobenzene is a contaminant that dictates the GAC application rate in the ILWD East. The mean value for chlorobenzene porewater concentration in ILWD East used for modeling is 2,360 ug/L, which is higher than 80% of the porewater concentrations measured in that area and more than three times higher than the median value of 730 ug/L.

6.6 Conservative Probabilistic Modeling Used to Evaluate Robustness of Design

Probabilistic evaluations with the numerical model, which explicitly considered site-specific data on the variability of model inputs, were performed as part of the modeling used to determine GAC application rates. Probabilistic analysis is commonly used to account for input variability in models with multiple parameters (e.g., USEPA, 1997). The first step in performing a probabilistic analysis is to estimate a statistical distribution for each key input parameter, based on the data (for example, a normal distribution). Next, a model simulation is performed, selecting randomly from the distribution for each parameter. This represents one “realization,” and produces one possible outcome, in this case, one estimate of sorbed-phase and porewater concentrations within the cap. The model calculation is then repeated many times (5,000 realizations were used in this modeling evaluation), each time selecting a new value for each input parameter from its distribution. This produces a frequency distribution of computed concentrations. Management decisions can then be made using a chosen percentile of this distribution (e.g., 80th, 90th or 95th percentile).

Probabilistic modeling based on the 95th percentile was used as a final conservative evaluation of the carbon application rates that were initially established by deterministic modeling with mean input parameters (see Section 7 for discussion of the modeling approach).

Anaerobic biological decay, which is not included in the chemical isolation modeling, may contribute less to the overall effectiveness of the chemical isolation layer over the short term, until biological communities are fully developed within the chemical isolation layer. Therefore, probabilistic modeling, which is more conservative than the deterministic modeling based on mean values for inputs, was used to evaluate the robustness of the GAC application rates over a shorter term evaluation period of 100 years, a time period after which it is highly likely that anaerobic decay would occur, rather than the 500-year evaluation period used for the deterministic evaluations. The conservatism of this probabilistic modeling provides added assurance that the cap will meet performance criteria everywhere throughout the 500-year modeling evaluation period. Distributions for the probabilistic analysis were developed for each key input parameter based on an analysis of the site data, in light of the underlying physical, chemical, and biological processes, as detailed in Attachment 1.

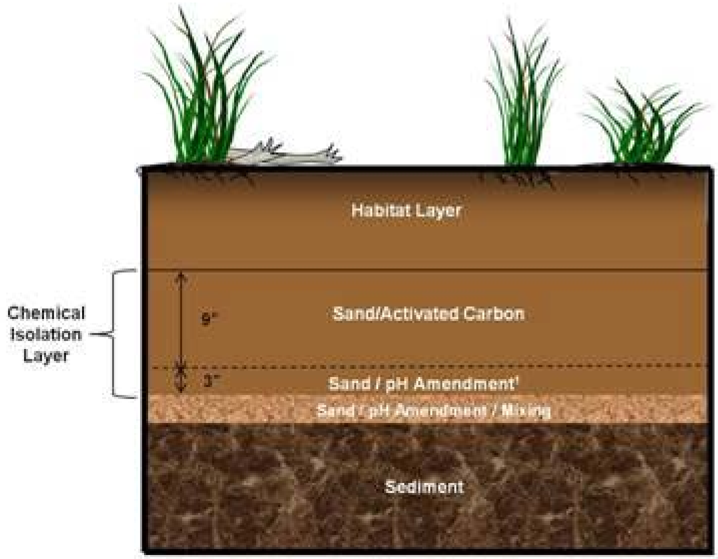
7.0 MODELING APPROACH AND RESULTS

The modeling approach described below was used to develop the chemical isolation layer design in each of the 13 model areas described in Section 4, taking into consideration each of the 26 contaminants for which cap performance criteria were established, as listed below.

SUMMARY OF MODELED COMPOUNDS

Class	Compounds
Mercury	Mercury
VOCs and Phenol (9)	Benzene, Toluene, Ethylbenzene, Xylenes, Chlorobenzene, Dichlorobenzenes, Trichlorobenzenes, Naphthalene, Phenol
PCBs / PAHs (16)	Total PCBs, Fluorene, Phenanthrene, Acenaphthene, Acenaphthylene, Anthracene, Pyrene, Benzo(a)anthracene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Chrysene, Fluoranthene, Benzo(a)pyrene, Dibenz(a,h)anthracene, Indeno(1,2,3-cd)pyrene, Benzo(g,h,i)perylene

The cap modeling was generally based on a 12 in. isolation layer and a 12 in. habitat layer. A general schematic of the amended cap is shown below. In areas where amendments are not required to achieve long-term chemical isolation, the profile will be similar except that the chemical isolation layer will consist of a minimum of 12 in. of sand only.



1. In amended cap areas of Remediation Area E the chemical isolation layer will be 12" sand/carbon mix. Siderite will not be added to the cap as pH levels are at or close to neutral.

Example Schematic of an Amended Cap

For contaminants and/or areas where the attenuation of contaminant flux is provided by the thickness of the sand cap material and not GAC, modeling was based on an 8 in. isolation layer, to allow for inclusion of the ROD-required 50% buffer layer within the required 12 in. of isolation layer material. This model configuration was used for mercury in all areas and for all contaminants in Model Areas A1 and E1 (since initial modeling indicated that no GAC is needed in these two areas). For the remaining contaminants/areas, which include GAC to ensure long term effectiveness across all contaminants (except mercury as noted above), increasing the cap thickness would not have a significant impact on protectiveness (because the GAC application rate is the main determinant of its long-term performance). The modeled thicknesses of each layer are detailed in the table below.

MODELED CAP LAYER THICKNESSES

Cap Model Layers	Sand Cap Areas	Amended Cap Areas	
		GAC and pH Amendment	GAC Only
	A1 and E1	A2, B1/C1, C2, C3, D	E2 and E3
Habitat Layer	12 in. (upper 6 in. represents bioturbation zone)		
Chemical Isolation Layer	Start with 8 in. and increase if needed.	12 in. isolation layer including 9 in. sand/GAC and 3 in. sand/siderite layer. For mercury an 8 in. sand isolation layer was modeled.	12 in. sand/GAC amendment isolation layer. For mercury an 8 in. sand isolation layer was modeled.

The modeling approach consisted of an initial highly-conservative evaluation based on analytical steady state modeling of a sand only chemical isolation layer, followed by more refined evaluations using the transient numerical model (including probabilistic modeling in some cases) for chemicals/areas that did not meet the performance criteria based on the conservative set of input assumptions used during the initial steady state evaluation. The modeling approach differed slightly by chemical class and is described below along with a discussion of the results. Detailed model results are provided in Tables 1 through 3.

7.1 Mercury

Mercury was initially evaluated in each model area using the analytical steady state model. Deterministic simulations were performed using the following inputs:

- Maximum mercury concentration measured in porewater
- Best estimate (mean value) of all other parameters

Based on results from this modeling, if the maximum mercury concentration throughout the habitat layer was less than the PEC, then no further modeling of mercury was required for a given area. As shown on Table 1, mercury concentrations in Model Areas B2 and C3 were predicted to be lower than the PEC throughout the habitat layer based on this analytical steady state modeling evaluation. Therefore, no further modeling was performed for mercury in these two areas.

Given the long time periods required to reach steady state for a more highly sorbing compound such as mercury, a secondary set of conservative model runs using the numerical model was employed. In the model areas remaining following the steady state evaluation described above, mercury was evaluated using the numerical model to evaluate long-term effectiveness under transient conditions using the approach listed below:

- Applying the same parameters used in steady state analysis (maximum values for porewater concentration, best estimate for all others)
- Evaluate mercury concentrations, using a deterministic simulation, throughout the habitat layer over a 1000-year evaluation period
- Reductions in porewater concentrations that will result from siderite and GAC were conservatively were ignored

If the maximum mercury concentration throughout the habitat layer was predicted to be less than the PEC based on this conservative transient modeling, then no further modeling of mercury was required for a given area. This transient modeling evaluation indicated that an 8 in. sand chemical isolation layer would be sufficient to ensure mercury remains below its PEC throughout the habitat layer in all modeling areas, for at least 1000 years (see Table 1).

7.2 VOCs and Phenol

The eight VOCs (see table above) and phenol were initially evaluated within each model area using the analytical steady state model, assuming no GAC was present. Deterministic simulations were performed using the following input configuration:

- Maximum contaminant concentrations measured in porewater (or calculated based on sediment concentrations and partitioning theory for phenol)
- Biological decay was assumed to be zero with the exception of phenol in areas having a native pH of 8 or less (i.e., Areas A1, E1, E2, E3)

- Best estimate (mean value) of all other parameters

Based on the results from these simulations, if the maximum concentration throughout the habitat layer was less than the performance criteria (i.e., PEC or SSC), then no further modeling of that compound was conducted in a given model area.

Results for VOCs and phenol in each model area based on the initial conservative analytical steady state modeling are provided in Table 1. As shown in that table, in Model Areas A1 and E1 all eight VOCs and phenol were predicted to be less than the performance criteria throughout the habitat layer at steady state. This was true in Model Area B2 as well, with the exception of phenol. For the remaining areas, concentrations of two or more of the nine compounds (i.e., eight VOCs plus phenol) were predicted to be higher than the performance criteria under this conservative modeling evaluation. Therefore, the remaining contaminants in each model area were further simulated with the numerical model to evaluate long-term effectiveness of a GAC amended cap under transient conditions, based on the approach described below.

- A series of iterative deterministic simulations was performed using the best estimate (mean value) for all inputs to determine the GAC application rate required to meet the performance criteria (i.e., each remaining compound's PEC/SSC) over a 500-year evaluation period.
- Following these deterministic simulations, a probabilistic evaluation was then performed (see Section 6.6). The probabilistic evaluation was based on the GAC application rate established by the deterministic simulations (described above), and used the full distributions for all key input parameters, as described in Attachment 1. This evaluation resulted in a quantification of the percent of model realizations that met the performance criteria over a 100-year evaluation period.
- If less than 95% of the probabilistic simulations met the performance criteria, the GAC application rate was further increased and probabilistic simulations were repeated until 95% of the realizations were predicted to meet the performance criteria over the 100-year evaluation period. Phenol was excluded from the 100 year probabilistic simulations given the high likelihood that phenol will degrade following pH neutralization in amended cap areas, likely within a timeframe that is short relative to that of the probabilistic evaluation period (100 yrs). This assumption is based on observed degradation in testing for neutral pH sediments to date and the relatively rapid rates of phenol degradation published under methanogenic conditions in literature (Parsons, 2009a and 2009b).

The GAC application rates and the contaminant that dictated the carbon amendment requirement in each area are presented in Table 2. The final GAC application rate in each model area is based on that for which each of the eight VOCs and phenol meet the criteria specified in the steps above (i.e., based on both deterministic and probabilistic modeling). The final recommended GAC application rate is driven by a single compound in each area. The carbon application rate selected for the driving compound in each area is greater than that required for the other compounds. This is demonstrated by Table 3 which shows predicted performance durations for all compounds based on the carbon application rate required for the driving compound.

7.3 PAHs/PCBs

Total PCBs and fifteen PAHs were initially evaluated in each model area using the analytical steady state model assuming no GAC was present. Deterministic simulations were performed using the following inputs:

- Maximum porewater concentration was calculated from sediment data as described in Attachment 2
- Biological decay was assumed to be zero
- Best estimate (mean value) of all other parameters

Based on these results, if the maximum concentration throughout the habitat layer was predicted to be less than the PEC at steady state, then no further modeling of that compound was required in a given area. In Model Areas A1, A2, B1/C1, B2, E1 and E3, all fifteen PAHs were predicted to be less than the performance criteria throughout the habitat layer at steady state. This was true in Model Area E2 as well, with the exception of one PAH (fluorine). Total PCBs were predicted to be less than the performance criteria throughout the habitat layer in all model areas. Table 1 provides the results from this steady state evaluation for PCBS/PAHs.

Given the long time periods required to reach steady state for more sorbing compounds such as PAHs, a secondary set of conservative model runs using the numerical model was conducted. The remaining PAHs in each remaining model area (i.e., C2, C3, the four subareas of ILWD, and E2) were further evaluated using the numerical model to evaluate long-term effectiveness under transient conditions using the approach listed below:

- Apply the same input parameters used in the steady state analysis (i.e., maximum values for porewater concentration, best estimate for all others)
- Use the GAC application rates established from the modeling analysis conducted for VOCs and phenol described above in Section 7.2, conservatively assuming that sorption to GAC for all PAHs is described by the site-specific measurements for naphthalene
- Evaluate concentrations, using a deterministic simulation, throughout the habitat layer over a 1000-year evaluation period

If the maximum concentration throughout the habitat layer was predicted to be less than the PEC for 1000 years, then no further modeling was required for a given PAH/area. The results from these conservative transient simulations for PAHs are provided in Table 1. As Table 1 shows, in Model Areas C3, Remediation Area D East, West, Center and SMU 2, and E2, all PAHs simulated were predicted to remain below the performance criteria throughout the habitat layer for 1000 years.

The remaining PAHs in Model Area C2 were further evaluated using the numerical model to evaluate long-term effectiveness under transient conditions using the approach described below. These runs were conducted to evaluate whether the GAC application rates determined based on the modeling of VOCs and phenol described above needed to be increased further to address any of the individual PAHs.

- Deterministic simulations were performed over the same 500-year evaluation period used for VOCs and phenol based on the best estimate (mean value) for all inputs to evaluate if the PAHs met their performance criteria over this period.
- Probabilistic simulations (based on full distributions for all key inputs, as available) were also used to verify that 95% or more of realizations meet each individual PAH's PEC over a 100-year evaluation period

If the results from the modeling described above indicated that the performance criteria were not met from the deterministic (500-year evaluation period) or probabilistic (100 year evaluation period) model simulations, then the GAC application rate was to be increased to address the PAHs. The results from this additional PAH modeling indicated that the GAC application rates established for VOCs and phenol (i.e., as shown in Table 2) would not need to be increased to address PAHs in Model Area C2. That is, the deterministic simulations based on mean values for inputs resulted in concentrations below PECs for 500 years or more, and the probabilistic modeling results (based on full input distributions) indicated that the PECs were met in 95% or more of the realizations.

7.4 Cap in 6-9 Meter Zone of Remediation Areas A and E

As discussed in Section 4.1.6 of the main report, a modified cap containing a 0.5 ft. chemical isolation layer was considered for the portions of Remediation Areas A and E having water depths from 20 ft. to 30 ft. (6 to 9 meters), since the ROD specified that a thin-layer cap may be appropriate for such areas. To evaluate the effectiveness of the cap in these areas, a series of model simulations with a 4 in. chemical isolation layer (i.e., to account for the 50% safety factor requirement on the target 6 in.) was conducted for the model areas that cover the 6 to 9 m zones of these remediation areas: A1, E1, E2, and E3. The model inputs for these simulations were the same as those described above (except that the isolation layer thickness was set to 4 in.).

Simulations were first performed with the steady state analytical model using the same approach as described in Sections 7.1 through 7.3 (i.e., maximum values for pore water concentration, mean values for all other inputs, no simulation of GAC). The results from these simulations indicated that:

- All chemicals except mercury were predicted to be below performance criteria at steady state in Model Areas A1 and E1, with the thinner isolation layer.
- Mercury, a few VOCs, and one PAH were predicted to be above performance criteria in both Model Areas E2 and E3, which is generally consistent with the results from the initial conservative steady state modeling of these areas summarized in Table 1.

To further assess mercury in these four areas, deterministic simulations with the transient numerical model were conducted using the same approach described in Section 7.1 (i.e., maximum values for pore water concentration, mean values for all other inputs, 1000 year evaluation period), for a 4 in. chemical isolation layer thickness. The results from these simulations indicated that the predicted concentrations at the bottom of the habitat layer were below the mercury PEC for over 1000 years.

Based on the results of the simulations of the 6 to 9 m zones of Remediation Areas A and E, the following can be concluded with respect to the effectiveness of a modified cap:

- A 6 in. chemical isolation layer will meet performance criteria for 1000 years or longer for all chemicals in Model Areas A1 and E1 and for mercury in all of the model areas evaluated (i.e., A1, E1, E2, E3).
- To address certain VOCs and PAHs in the 6 to 9 m zones of Model Areas E2 and E3 with a modified cap, higher GAC application rates (compared to those developed based on a 12 in. chemical isolation layer, as shown in Table 2) may be needed. GAC application rates will be determined as part of the Final Design.

Additional modeling may be conducted as part of final design to further evaluate the use of modified caps in the 6 to 9 m zone of the various capping areas of the lake.

7.5 Mean PECQ Evaluation

To summarize the long-term protectiveness of the cap with respect to reducing benthic toxicity, the model was used to calculate the Mean PECQ that the cap will achieve in each model area. As documented in the ROD, the Mean PECQ, which takes into consideration concentrations of multiple contaminants, is an appropriate indicator of benthic toxicity. To perform this assessment, the analytical steady state model was used with best estimates (i.e., mean values) for all input parameters to calculate the steady state concentration of each contaminant at the bottom of the habitat layer and the bottom of the bioturbation zone (i.e., the two points where peak concentration would occur, depending on the contaminant) within each model area. These concentrations were used along with each contaminant's PEC to calculate the Mean PECQ in each area. The results of these calculations, which are shown in Table 4, indicate that at all points throughout the cap's habitat layer, the Mean PECQ will be less than 1 for every model area at steady state. Because benthic toxicity is the primary risk consideration for evaluating cap effectiveness, these results indicate that the cap will provide protectiveness of human health and the environment on a permanent basis.

7.6 Sources of Uncertainty in Model Results

The input parameters to which the model is most sensitive are porewater concentration, groundwater upwelling velocity and contaminant sorption parameters (including GAC Freundlich coefficients). For each of these parameters, extensive data sets derived from field investigation and bench-scale testing were developed to provide site-specific information. As described in Section 6 specific model areas were developed to address spatial variability and to develop cap designs (i.e., GAC application rates) specific to the conditions in each area. Additional sources of variation and parameter uncertainty were addressed by a combination of conservative initial modeling (e.g., based on maximum measured pore water concentrations) and probabilistic modeling that accounted for the full range of variation in these key input parameters (including worst case conditions).

Sources of uncertainty in the modeling have been addressed through the extensive data gathering effort used to support model input specification, the conservatisms described in Section 3.3 and the design optimization process described in Section 6.0.

8.0 CONCLUSIONS

Design of the Onondaga Lake sediment cap chemical isolation layer considers an extensive collection of site-specific data and evaluation of performance based on the rigorous modeling effort described above. Recommended cap profiles and GAC application rates are presented in the table below. The modeling performed for cap design is conservative and as a result underestimates the long-term effectiveness of the cap. Numerous concepts and processes that will significantly contribute to the long-term performance of the cap but are difficult to quantify over hundreds to thousands of years were conservatively not simulated in the model. Taking these factors into consideration qualitatively, it is anticipated that the cap will meet performance criteria everywhere for 1000 years or more for most contaminants and for at least 500 years for all contaminants.

CHEMICAL ISOLATION LAYER DESIGN SUMMARY

Model Area	Design Thickness and Profile	GAC Application Rate
A1	12-in. (8-in. required) sand cap[1]	None
A2	12-in. amended cap (9-in. GAC, 3-in. sand/siderite)	0.11 lb/sf
B1/C1	12-in. amended cap (9-in. GAC, 3-in. sand/siderite)	0.50 lb/sf
B2	12-in. amended cap (9-in. GAC, 3-in. sand/siderite)	0.33 lb/sf
C2	12-in. amended cap (9-in. GAC, 3-in. sand/siderite)	0.005 lb/sf
C3	12-in. amended cap (9-in. GAC, 3-in. sand/siderite)	0.07 lb/sf
SMU2	12-in. amended cap (9-in. GAC, 3-in. sand/siderite)	0.04 lb/sf
West	12-in. amended cap (9-in. GAC, 3-in. sand/siderite)	0.33 lb/sf
Center	12-in. amended cap (9-in. GAC, 3-in. sand/siderite)	0.78 lb/sf
East	12-in. amended cap (9-in. GAC, 3-in. sand/siderite)	0.22 lb/sf
E1	12-in. (8-in. required) sand cap[1]	None
E2	12-in. GAC amended cap[1]	0.05 lb/sf
E3	12-in. GAC amended cap[1]	0.03 lb/sf

Notes:

1) As discussed in Section 7.5 a 6-in. chemical isolation layer will be placed in the 6-9 meter zone. The GAC application rate in the 6-9 meter zone will be evaluated as part of the Final Design.

Consistent with the ROD documentation, the Mean PECQ of 1, which takes into consideration concentrations of multiple contaminants, is an appropriate indicator of benthic toxicity, which is the primary risk consideration for cap effectiveness. As discussed in Section 7.5, the cap will achieve a Mean PECQ of 1 or less everywhere at steady state (i.e., forever), and thus the cap will provide permanent protection of human health and the environment.

9.0 REFERENCES

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TABLES

TABLE 1

SUMMARY OF COMPOUNDS MEETING PERFORMANCE CRITERIA ASSUMING INITIAL CONSERVATIVE ANALYTICAL STEADY STATE AND TRANSIENT MODEL EVALUATIONS[1]

Group	Chemical	Model Area												
		A1	A2	B1/C1	B2	C2	C3	S[2]	W[2]	C[2]	E[2]	E1	E2	E3
Mercury	**Mercury**	✓✓	✓✓	✓✓	✓	✓✓	✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓
VOCs	**Benzene**	✓	✓		✓	✓	✓					✓	✓	✓
	Toluene	✓	✓		✓	✓	✓	✓				✓	✓	✓
	Ethylbenzene	✓		✓	✓	✓						✓		
	Xylenes	✓			✓	✓						✓		
	Chlorobenzene	✓	✓	✓	✓	✓	✓	✓				✓		✓
	Dichlorobenzenes	✓		✓	✓	✓		✓				✓		✓
	Trichlorobenzenes	✓	✓	✓	✓	✓	✓					✓		✓
	Naphthalene	✓	✓		✓							✓		
	Phenol	✓					✓					✓	✓	✓
PAHs/ PCB	**Total PCBs**	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Fluorene	✓	✓	✓	✓		✓✓	✓✓	✓✓	✓✓	✓✓	✓	✓✓	✓
	Phenanthrene	✓	✓	✓	✓		✓✓	✓✓	✓✓	✓✓	✓	✓	✓	✓
	Acenaphthene	✓	✓	✓	✓	✓✓	✓	✓	✓✓	✓	✓✓	✓	✓	✓
	Acenaphthylene	✓	✓	✓	✓		✓	✓	✓✓	✓	✓✓	✓	✓	✓
	Anthracene	✓	✓	✓	✓		✓✓	✓✓	✓✓	✓✓	✓✓	✓	✓	✓
	Pyrene	✓	✓	✓	✓		✓	✓	✓✓	✓	✓	✓	✓	✓
	Benzo(a)anthracene	✓	✓	✓	✓	✓✓	✓	✓	✓✓	✓	✓	✓	✓	✓
	Benzo(b)fluoranthene	✓	✓	✓	✓	✓✓	✓	✓	✓	✓	✓	✓	✓	✓
	Benzo(k)fluoranthene	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Chrysene	✓	✓	✓	✓	✓✓	✓	✓	✓✓	✓	✓	✓	✓	✓
	Fluoranthene	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
	Benzo(a)pyrene	✓	✓	✓	✓	✓✓	✓	✓	✓	✓	✓✓	✓	✓	✓
	Dibenz(a,h)anthracene	✓	✓	✓	✓	✓✓	✓	✓	✓	✓	✓	✓	✓	✓
	Indeno(1,2,3-cd)pyrene	✓	✓	✓	✓	✓✓	✓	✓	✓	✓	✓	✓	✓	✓
	Benzo(g,h,i)perylene	✓	✓	✓	✓	✓✓	✓	✓	✓	✓	✓	✓	✓	✓

Notes:

2) Table summarizes the results from the conservative analytical steady state (✓) and 1,000 year transient evaluations (✓✓) performed using maximum concentrations discussed in Sections 7.1 through 7.3. These compounds were not subject to additional modeling. Check marks (✓) indicate cases where performance criteria were met.
3) ILWD Subareas: SMU2 (S), West (W), Center (C), East (E)

TABLE 2

CARBON APPLICATION RATE EVALUATION

Model Area	Acres	500-Year Evaluation Period Carbon Application rate[1]		Application rate based on Probabilistic Modeling[2]		Final Carbon Application Rate (lb/sf)
		Controlling Chemical(s)	Carbon Application Rate (lb/sf)	Controlling Chemical(s)	Carbon Application rate (lb/sf)	
A1	69.7	Sand Cap Only				
A2	15.8	Xylenes	0.11	NA	No additional carbon	0.11
B1/C1	12.9	Benzene	0.035	Benzene	0.50	0.50
B2	7.0	Phenol	0.33	NA	No additional carbon	0.33
C2	9.0	--	0	Naphthalene	0.005	0.005
C3	12.4	Xylenes	0.07	NA	No additional carbon	0.07
SMU2	6.8	Naphthalene	0.035	Xylenes	0.04	0.04
West	11.5	Phenol	0.33	NA	No additional carbon	0.33
Center	29.9	Xylenes	0.31	Benzene	0.78	0.78
East	48.7	Chlorobenzene	0.22	NA	No additional carbon	0.22
E1	88.7	Sand Cap Only				
E2	23.7	Dichlorobenzenes	0.03	Chlorobenzene	0.05	0.05
E3	76.3	Naphthalene	0.01	Ethylbenzene	0.03	0.03

Notes:

1) Application rate needed to achieve criteria over 500-year evaluation period in deterministic simulation based on best estimates for model inputs.
2) Application rate needed to achieve criteria over 100-year evaluation period in 95% or more of realizations from probabilistic modeling (Monte Carlo Analysis), excluding phenol.

TABLE 3

EVALUATION OF PERFORMANCE PERIOD[1]

Model Area	Performance Period (years)											
	Mercury	Benzene	Toluene	Ethylbenzene	Xylenes	CB	DCBs	TCBs	Naphthalene	Phenol	PAHs	PCBs
A1	1,000+											
A2	1,000+	1,000+	1,000+	1,000+	523	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+
B1/C1	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+
B2	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+
C2	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+
C3	1,000+	1,000+	1,000+	1,000+	501	1,000+	1,000+	1,000+	942	1,000+	1,000+	1,000+
SMU2	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	594	1,000+	1,000+	1,000+
West	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+
Center	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+
East	1,000+	1,000+	1,000+	1,000+	1,000+	518	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+
E1	1,000+											
E2	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	867	1,000+	1,000+	1,000+	1,000+	1,000+
E3	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+	1,000+

Notes:

1) Table shows performance durations, as predicted by deterministic simulations with mean values for all model inputs, for all compounds based on the carbon application rate required for the driving compound (as established from both deterministic and probabilistic modeling).

Table 4. Calculation of Mean PECQ with Steady State Model

GROUP	**CHEMICAL**	**CAP MODELING AREA**												
		A1	**A2**	**B1/C1**	**B2**	**C2**	**C3**	**SMU2**	**West**	**Center**	**East**	**E1**	**E2**	**E3**
Model-Predicted PECQ Values at the Bottom of the Bioturbation Zone														
VOCs	**Ethylbenzene**	0.0030	0.4421	0.0766	0.0134	0.0171	0.2512	0.2502	0.4761	0.8977	0.6054	0.0045	0.1366	0.1486
	Xylenes	0.0126	1.5556	0.5016	0.0023	0.0663	1.0505	0.6779	2.6651	6.1505	2.5806	0.0051	0.3138	0.0824
	Chlorobenzenes	0.0029	0.0287	0.0005	0.0031	0.0028	0.0809	0.0968	0.9540	0.9568	4.2066	0.0104	0.5471	0.0318
	Dichlorobenzenes	0.0228	0.0815	0.0063	0.0345	0.0297	0.5654	0.1258	1.6897	2.6979	6.7887	0.0297	1.6078	0.0764
	Trichlorobenzenes	0.0067	0.0500	0.0149	0.0584	0.0124	0.1076	0.0565	0.2215	0.2462	0.2266	0.0195	0.1540	0.0456
	Naphthalene	0.0049	0.0044	0.4995	0.0057	0.1762	1.2524	1.4861	3.8761	4.6748	3.8524	0.0263	0.8931	0.5238
Mercury	**Mercury**	0.0011	0.0203	0.0063	0.0003	0.0032	0.0018	0.0157	0.0706	0.0271	0.1381	0.0009	0.0011	0.0023
PCBs / PAH	**Total PCB**	0.0002	0.0012	0.0004	0.0006	0.0059	0.0019	0.0004	0.0002	0.0002	0.0005	0.0005	0.0011	0.0002
	Flourene	0.0004	0.0004	0.0178	0.0061	0.5922	0.3765	0.8008	1.3049	0.0596	0.1668	0.0115	0.0892	0.0164
	Phenanthrene	0.0004	0.0007	0.0175	0.0049	0.2916	0.1782	0.5283	0.8689	0.1119	0.0560	0.0150	0.0260	0.0183
	Acenaphthene	0.0001	0.0000	0.0026	0.0013	0.0363	0.0289	0.1189	0.2493	0.0147	0.0223	0.0047	0.0079	0.0071
	Acenaphthylene	0.0003	0.0002	0.0058	0.0030	0.0413	0.0300	0.0678	0.6663	0.0379	0.0517	0.0040	0.0083	0.0083
	Anthracene	0.0006	0.0005	0.0120	0.0047	0.2415	0.1456	0.4245	0.7433	0.1303	0.1145	0.0175	0.0270	0.0202
	Pyrene	0.0002	0.0004	0.0041	0.0024	0.1156	0.0298	0.0572	0.1221	0.0101	0.0088	0.0040	0.0048	0.0038
	Benzo(a)anthracene	0.0001	0.0002	0.0017	0.0009	0.0797	0.0149	0.0298	0.0771	0.0046	0.0045	0.0021	0.0024	0.0020
	Benzo(b)fluoranthene	0.0000	0.0000	0.0003	0.0003	0.0159	0.0021	0.0040	0.0087	0.0007	0.0010	0.0003	0.0004	0.0003
	Benzo(k)fluoranthene	0.0000	0.0000	0.0006	0.0005	0.0073	0.0035	0.0083	0.0156	0.0017	0.0037	0.0006	0.0007	0.0006
	Chrysene	0.0001	0.0001	0.0011	0.0008	0.0447	0.0100	0.0177	0.0354	0.0042	0.0049	0.0012	0.0016	0.0011
	Flouranthene	0.0001	0.0001	0.0017	0.0008	0.0293	0.0143	0.0287	0.0646	0.0050	0.0055	0.0020	0.0024	0.0021
	Benzo(a)pyrene	0.0001	0.0001	0.0011	0.0008	0.0637	0.0086	0.0161	0.0269	0.0028	0.0042	0.0016	0.0017	0.0015
	Dibenz(a,h)anthracene	0.0000	0.0000	0.0002	0.0002	0.0045	0.0013	0.0022	0.0089	0.0006	0.0026	0.0002	0.0003	0.0002
	Indeno(1,2,3-cd)pyrene	0.0001	0.0001	0.0007	0.0007	0.0274	0.0042	0.0070	0.0152	0.0017	0.0045	0.0007	0.0009	0.0006
	Benzo(g,h,i)perylene	0.0000	0.0000	0.0001	0.0001	0.0049	0.0008	0.0011	0.0054	0.0002	0.0007	0.0002	0.0002	0.0001
All Chemicals	**Mean PECQ**	0.0025	0.0951	0.0510	0.0063	0.0830	0.1809	0.2096	0.6159	0.6973	0.8196	0.0071	0.1665	0.0432
Model-Predicted PECQ Values at the Bottom of the Habitat Layer														
VOCs	**Ethylbenzene**	0.0003	0.0258	0.0069	0.0014	0.0012	0.0207	0.0205	0.0422	0.0869	0.0628	0.0004	0.0113	0.0123
	Xylenes	0.0012	0.0987	0.0492	0.0002	0.0049	0.0942	0.0605	0.2567	0.6474	0.2911	0.0005	0.0282	0.0074
	Chlorobenzenes	0.0004	0.0028	0.0001	0.0005	0.0003	0.0109	0.0130	0.1373	0.1490	0.6966	0.0014	0.0739	0.0043
	Dichlorobenzenes	0.0018	0.0044	0.0005	0.0032	0.0019	0.0433	0.0096	0.1389	0.2423	0.6532	0.0023	0.1233	0.0059
	Trichlorobenzenes	0.0004	0.0018	0.0009	0.0038	0.0005	0.0056	0.0029	0.0125	0.0153	0.0152	0.0010	0.0080	0.0024
	Naphthalene	0.0005	0.0003	0.0551	0.0007	0.0147	0.1262	0.1491	0.4204	0.5552	0.4912	0.0027	0.0902	0.0529
Mercury	**Mercury**	0.1028	0.3135	0.4591	0.0245	0.1317	0.1096	0.9333	4.9296	2.3104	13.8897	0.0776	0.2358	0.1726
PCBs / PAH	**Total PCB**	0.0007	0.0020	0.0015	0.0025	0.0132	0.0056	0.0012	0.0006	0.0009	0.0021	0.0016	0.0032	0.0007
	Flourene	0.0001	0.0000	0.0024	0.0010	0.0548	0.0450	0.0952	0.1722	0.0089	0.0273	0.0014	0.0107	0.0020
	Phenanthrene	0.0001	0.0001	0.0039	0.0013	0.0440	0.0351	0.1034	0.1895	0.0277	0.0153	0.0030	0.0051	0.0036
	Acenaphthene	0.0000	0.0000	0.0003	0.0002	0.0035	0.0034	0.0138	0.0311	0.0020	0.0032	0.0006	0.0009	0.0008
	Acenaphthylene	0.0000	0.0000	0.0004	0.0002	0.0021	0.0019	0.0042	0.0442	0.0027	0.0039	0.0003	0.0005	0.0005
	Anthracene	0.0001	0.0001	0.0024	0.0011	0.0340	0.0261	0.0757	0.1460	0.0286	0.0274	0.0032	0.0049	0.0036
	Pyrene	0.0003	0.0003	0.0051	0.0037	0.0948	0.0328	0.0625	0.1507	0.0144	0.0140	0.0046	0.0053	0.0042
	Benzo(a)anthracene	0.0003	0.0002	0.0048	0.0032	0.1234	0.0338	0.0669	0.2050	0.0151	0.0175	0.0049	0.0055	0.0046
	Benzo(b)fluoranthene	0.0001	0.0000	0.0008	0.0008	0.0278	0.0047	0.0088	0.0211	0.0019	0.0029	0.0007	0.0008	0.0006
	Benzo(k)fluoranthene	0.0001	0.0001	0.0014	0.0012	0.0120	0.0072	0.0169	0.0346	0.0041	0.0098	0.0013	0.0015	0.0013
	Chrysene	0.0002	0.0001	0.0027	0.0023	0.0775	0.0220	0.0386	0.0846	0.0110	0.0140	0.0028	0.0036	0.0025
	Flouranthene	0.0001	0.0001	0.0015	0.0009	0.0178	0.0113	0.0227	0.0568	0.0049	0.0061	0.0017	0.0019	0.0017
	Benzo(a)pyrene	0.0003	0.0002	0.0036	0.0031	0.1338	0.0244	0.0454	0.0857	0.0102	0.0174	0.0045	0.0049	0.0043
	Dibenz(a,h)anthracene	0.0001	0.0000	0.0008	0.0009	0.0114	0.0042	0.0070	0.0315	0.0023	0.0112	0.0008	0.0009	0.0008
	Indeno(1,2,3-cd)pyrene	0.0002	0.0001	0.0015	0.0017	0.0430	0.0080	0.0135	0.0317	0.0038	0.0109	0.0015	0.0018	0.0012
	Benzo(g,h,i)perylene	0.0000	0.0000	0.0004	0.0005	0.0119	0.0024	0.0033	0.0184	0.0009	0.0029	0.0005	0.0006	0.0004
All Chemicals	**Mean PECQ**	0.0048	0.0196	0.0263	0.0026	0.0374	0.0295	0.0769	0.3148	0.1803	0.7081	0.0052	0.0271	0.0126

Note:
Iinitial Porewater concentrations set to the mean value in each area.

FIGURES

(FIGURES B-12 THROUGH B-55
PROVIDED ELECTRONICALLY ON ATTACHED CD)

Path: Q:\GIS\GIS_Lake\CAP\MXD\Intermediate_Design\B-1_Model_Rem_Areas.mxd

Date Revised: 1/3/2011 3:02:30 PM

▭ Remediation Area Boundary

- - Model Area Boundary

■ Sediment Management Unit (SMU) Boundary

- - Extent of ILWD in Littoral Zone

— Willis/Semet IRM Barrier Wall

— West Wall Portion of the WB-B/HB IRM Barrier Wall

- - East Wall Portion of the WB-B/HB IRM Barrier Wall

New York State Digital
Orthoimagery from 2009

1,900 950 0 1,900
Feet

FIGURE B-1

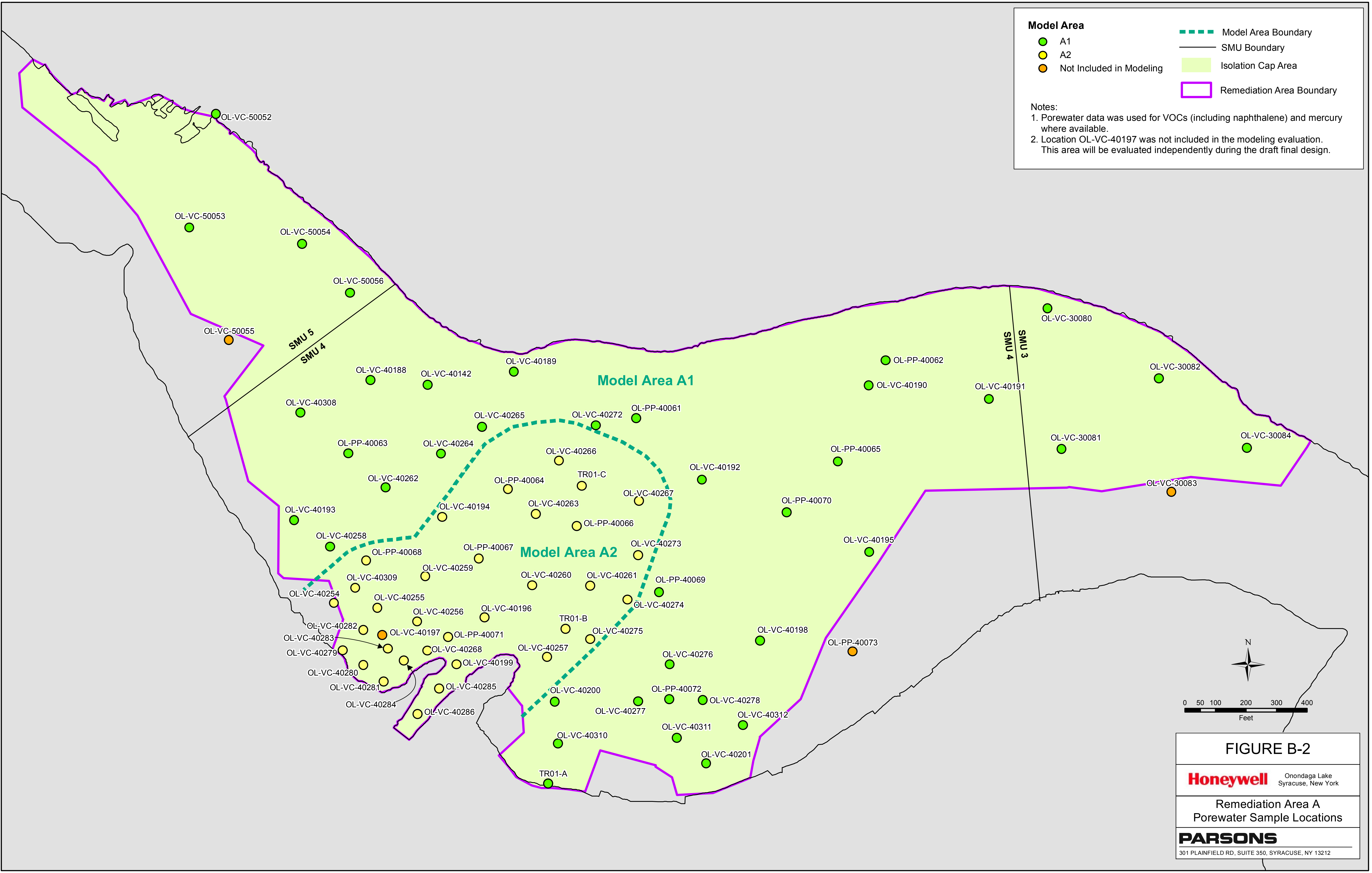
Honeywell

Onondaga Lake
Syracuse, New York

Remediation and Model
Areas Location Map

PARSONS

301 PLAINFIELD RD, SUITE 350, SYRACUSE, NY 13212



Model Area

🟢 A1
🟡 A2
🟠 Not Included in Modeling

▬ ▬ Model Area Boundary
── SMU Boundary
🟩 Isolation Cap Area
▭ Remediation Area Boundary

Notes:
1. Porewater data was used for VOCs (including naphthalene) and mercury where available.
2. Location OL-VC-40197 was not included in the modeling evaluation. This area will be evaluated independently during the draft final design.

FIGURE B-2

Honeywell

Onondaga Lake
Syracuse, New York

Remediation Area A
Porewater Sample Locations

PARSONS

301 PLAINFIELD RD, SUITE 350, SYRACUSE, NY 13212

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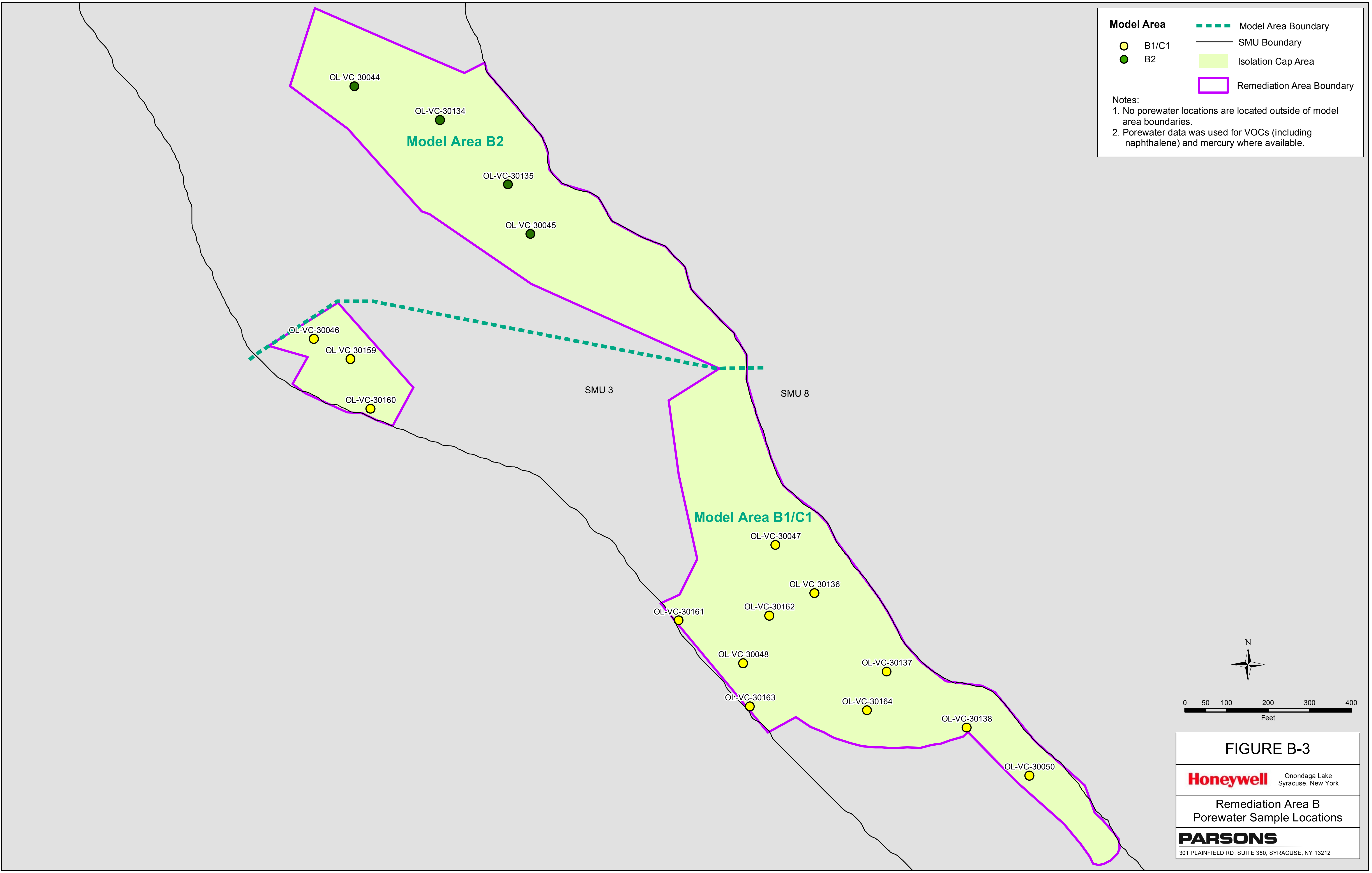

Notes:
1. No porewater locations are located outside of model area boundaries.
2. Porewater data was used for VOCs (including naphthalene) and mercury where available.

FIGURE B-3

Honeywell

Onondaga Lake
Syracuse, New York

Remediation Area B
Porewater Sample Locations

PARSONS

301 PLAINFIELD RD, SUITE 350, SYRACUSE, NY 13212

Date Revised: 12/29/2010 3:23:30 PM

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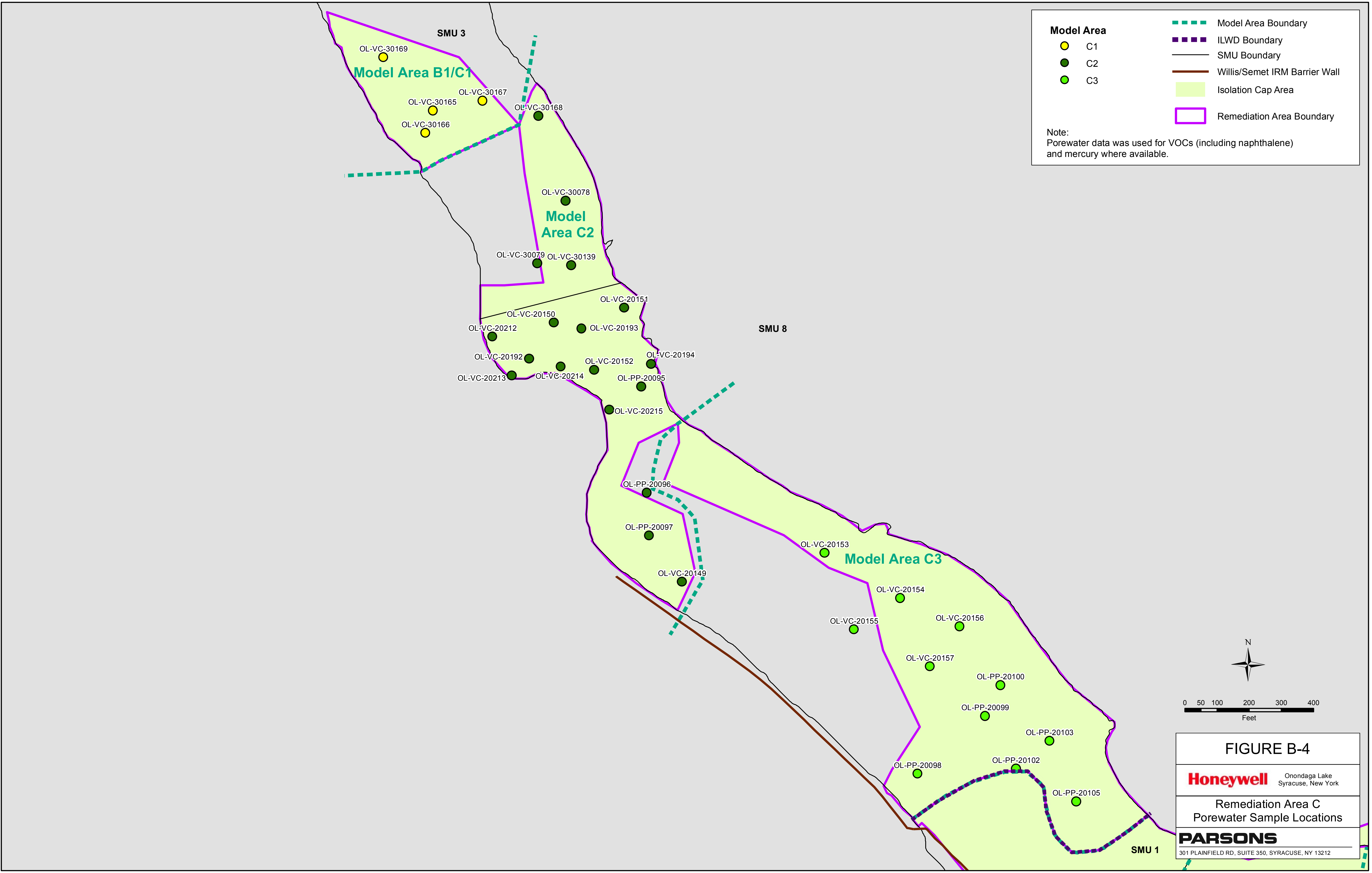

Note:
Porewater data was used for VOCs (including naphthalene) and mercury where available.

FIGURE B-4

Honeywell
Onondaga Lake
Syracuse, New York

Remediation Area C
Porewater Sample Locations

PARSONS
301 PLAINFIELD RD, SUITE 350, SYRACUSE, NY 13212

Path: Q:\GIS\GIS_Lake\CAP\MXD\Intermediate_Design\B-4_RemC_PW_locs.mxd

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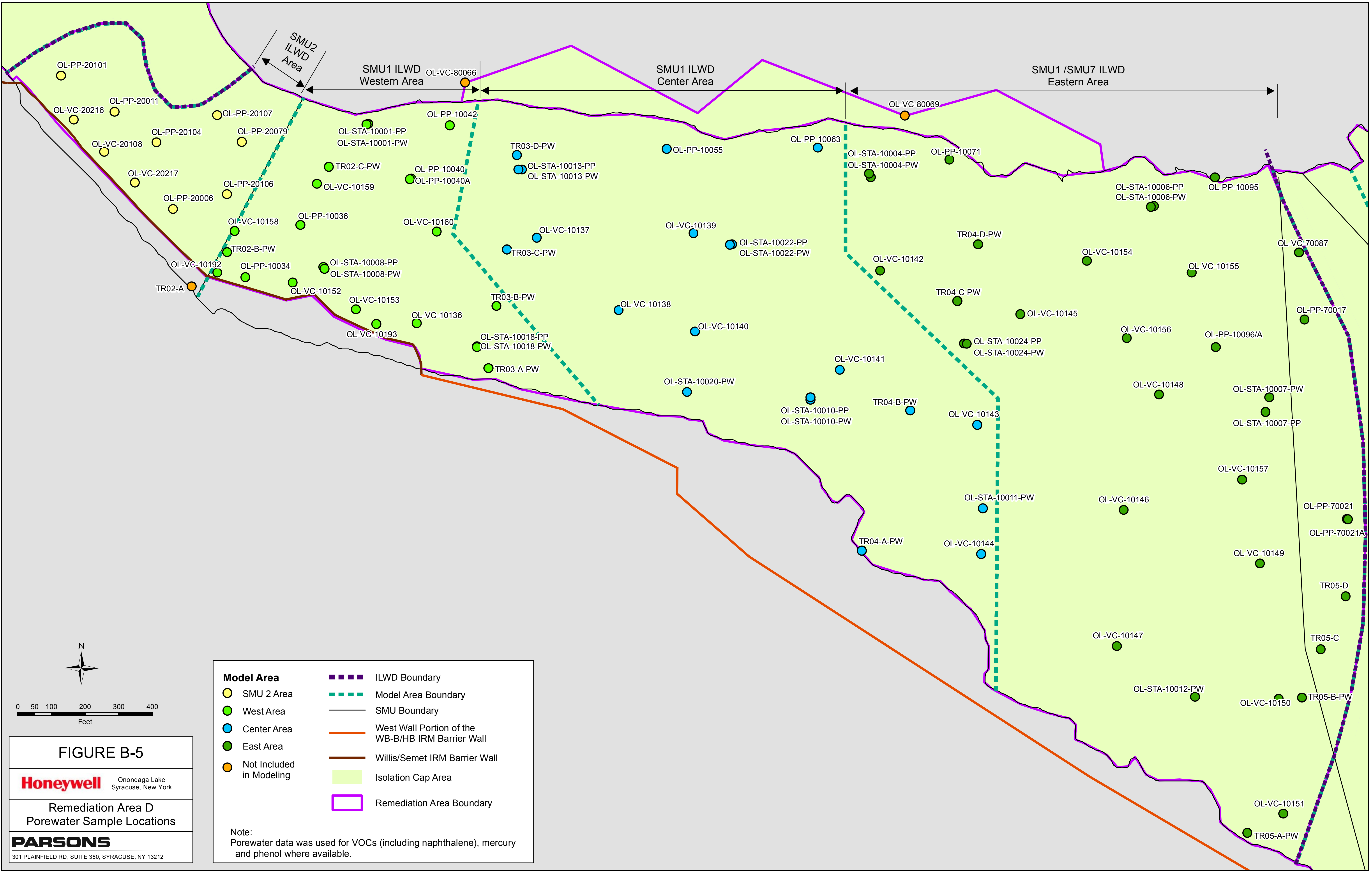

Note:
Porewater data was used for VOCs (including naphthalene), mercury and phenol where available.

FIGURE B-5

Honeywell Onondaga Lake
Syracuse, New York

Remediation Area D Porewater Sample Locations

PARSONS
301 PLAINFIELD RD, SUITE 350, SYRACUSE, NY 13212

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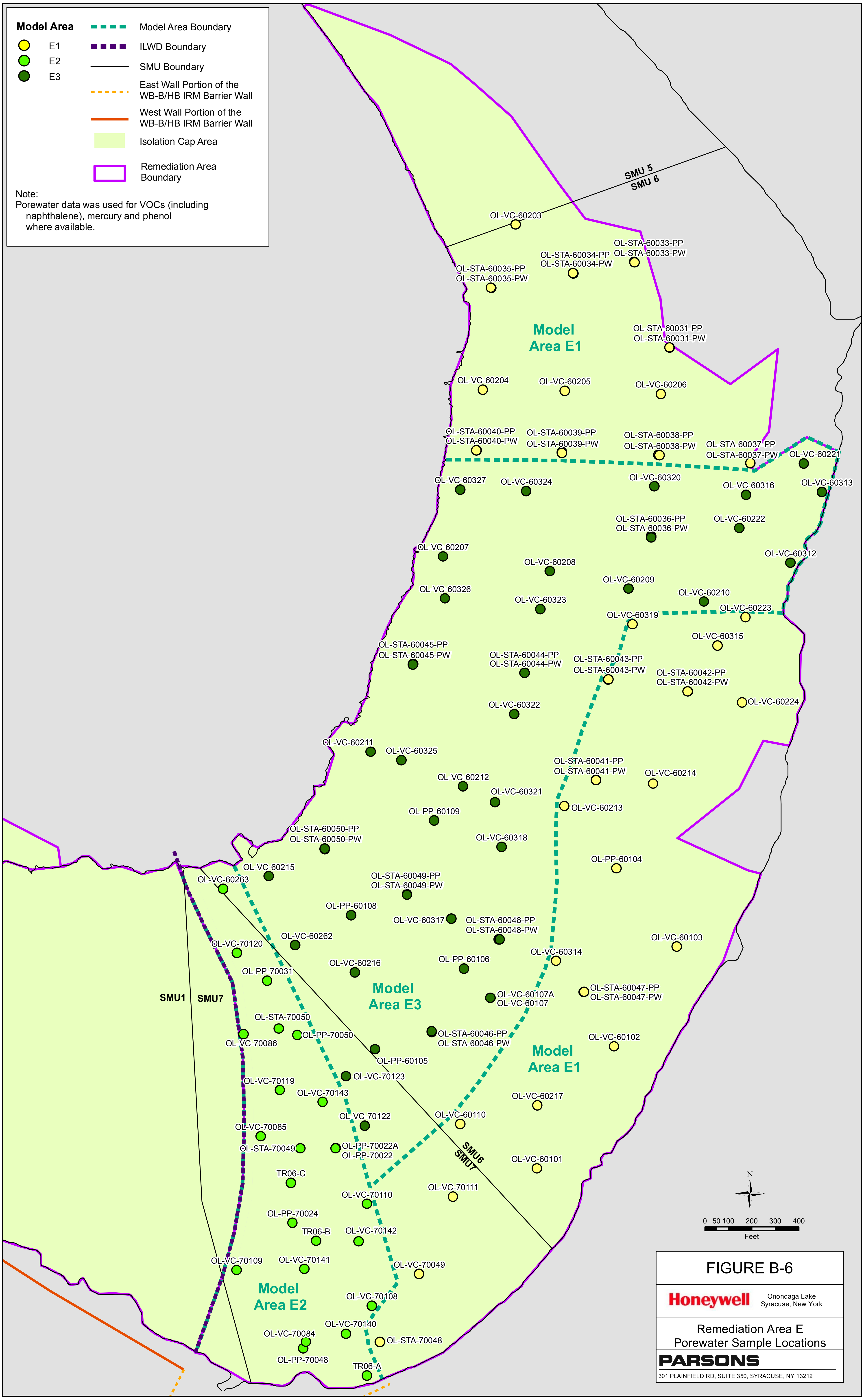

FIGURE B-6

Honeywell
Onondaga Lake
Syracuse, New York

Remediation Area E
Porewater Sample Locations

PARSONS
301 PLAINFIELD RD, SUITE 350, SYRACUSE, NY 13212

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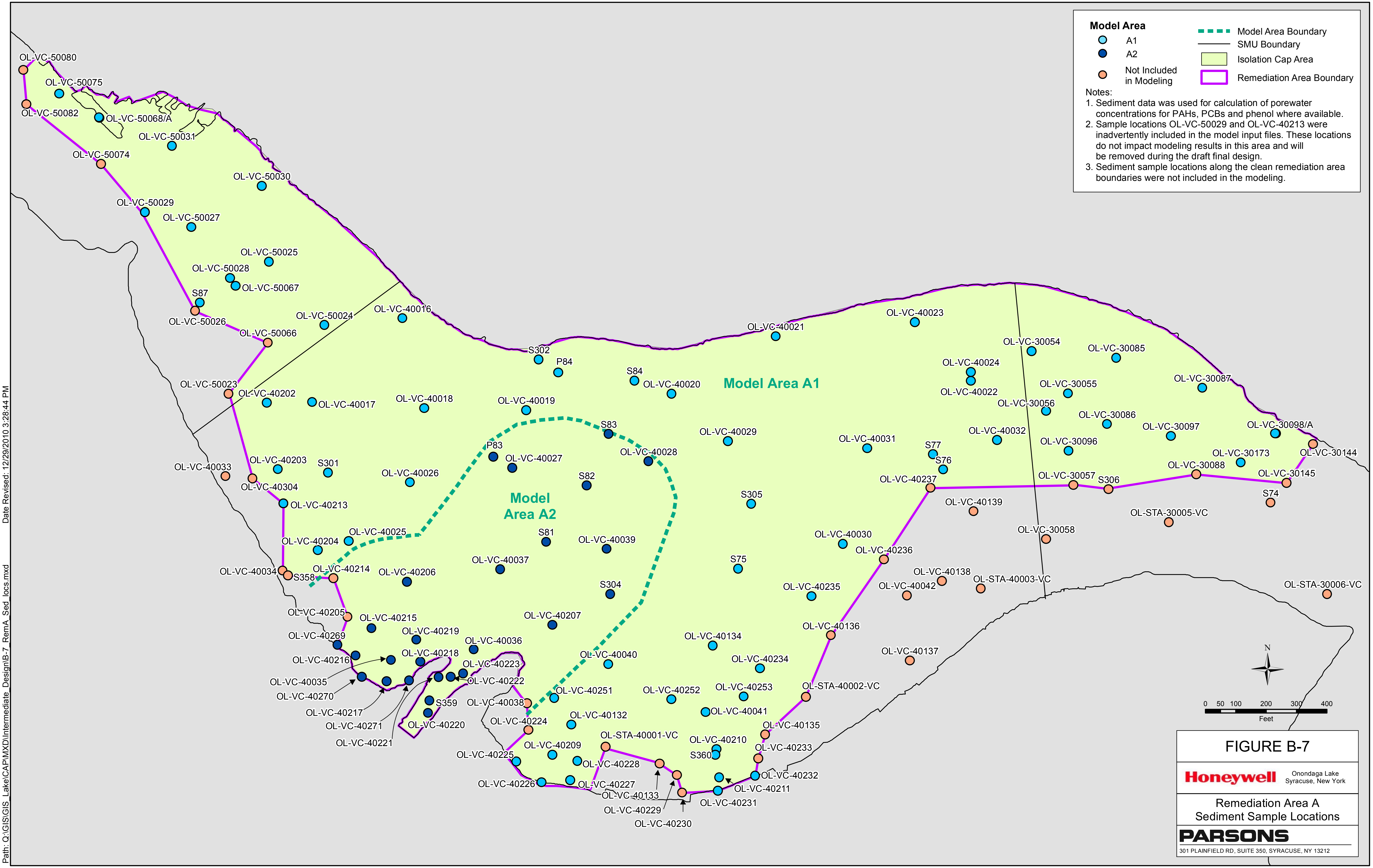
Date Revised: 1/17/2011 9:55:56 AM



Notes:
1. Sediment data was used for calculation of porewater concentrations for PAHs, PCBs and phenol where available.
2. Sample locations OL-VC-50029 and OL-VC-40213 were inadvertently included in the model input files. These locations do not impact modeling results in this area and will be removed during the draft final design.
3. Sediment sample locations along the clean remediation area boundaries were not included in the modeling.

FIGURE B-7

Honeywell

Onondaga Lake
Syracuse, New York

Remediation Area A
Sediment Sample Locations

PARSONS

301 PLAINFIELD RD, SUITE 350, SYRACUSE, NY 13212

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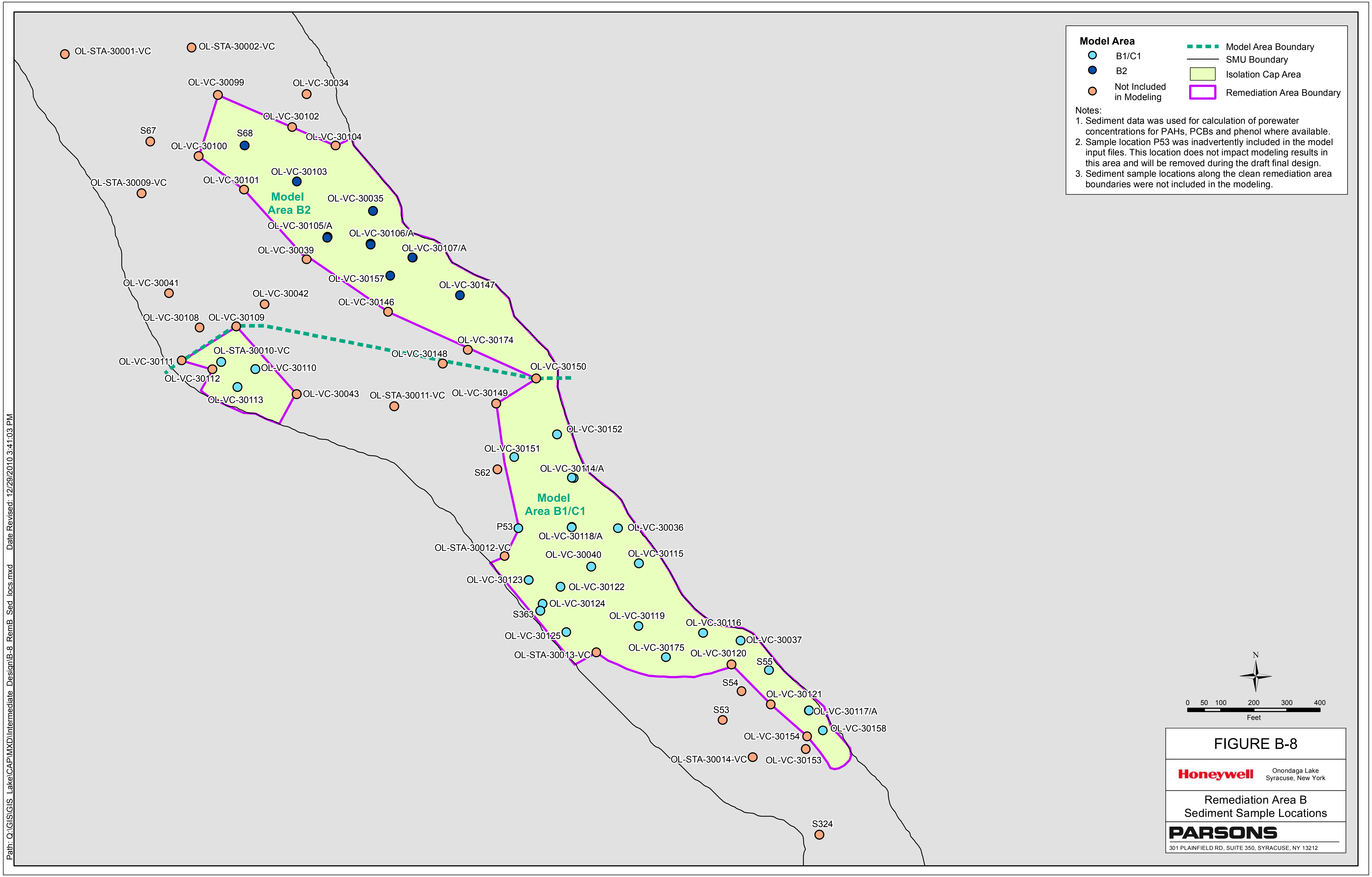

Notes:

1. Sediment data was used for calculation of porewater concentrations for PAHs, PCBs and phenol where available.
2. Sample location P53 was inadvertently included in the model input files. This location does not impact modeling results in this area and will be removed during the draft final design.
3. Sediment sample locations along the clean remediation area boundaries were not included in the modeling.

FIGURE B-8

Honeywell

Onondaga Lake
Syracuse, New York

Remediation Area B
Sediment Sample Locations

PARSONS

301 PLAINFIELD RD, SUITE 350, SYRACUSE, NY 13212

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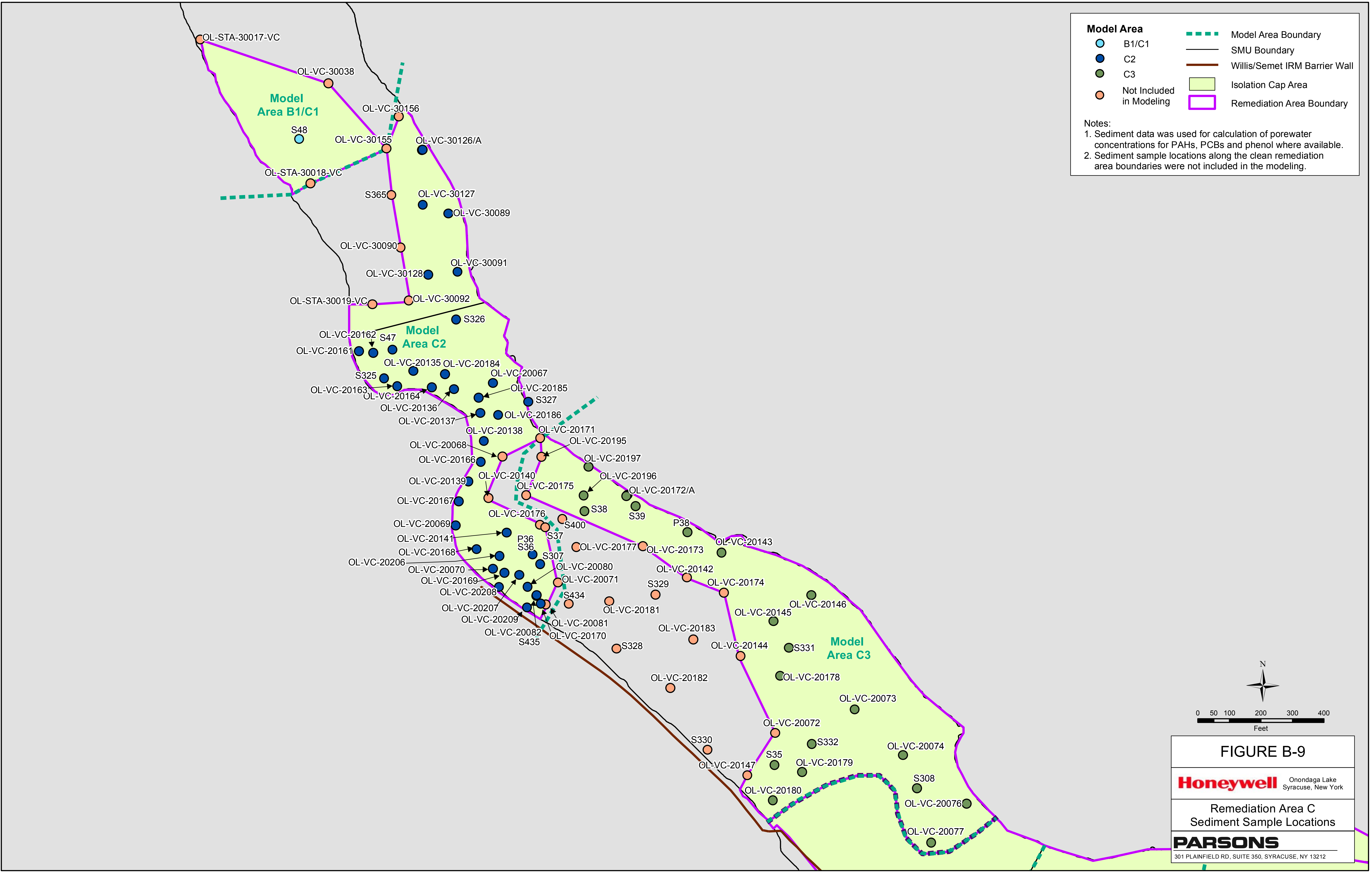

Notes:
1. Sediment data was used for calculation of porewater concentrations for PAHs, PCBs and phenol where available.
2. Sediment sample locations along the clean remediation area boundaries were not included in the modeling.

FIGURE B-9

Honeywell
Onondaga Lake
Syracuse, New York

Remediation Area C
Sediment Sample Locations

PARSONS
301 PLAINFIELD RD, SUITE 350, SYRACUSE, NY 13212

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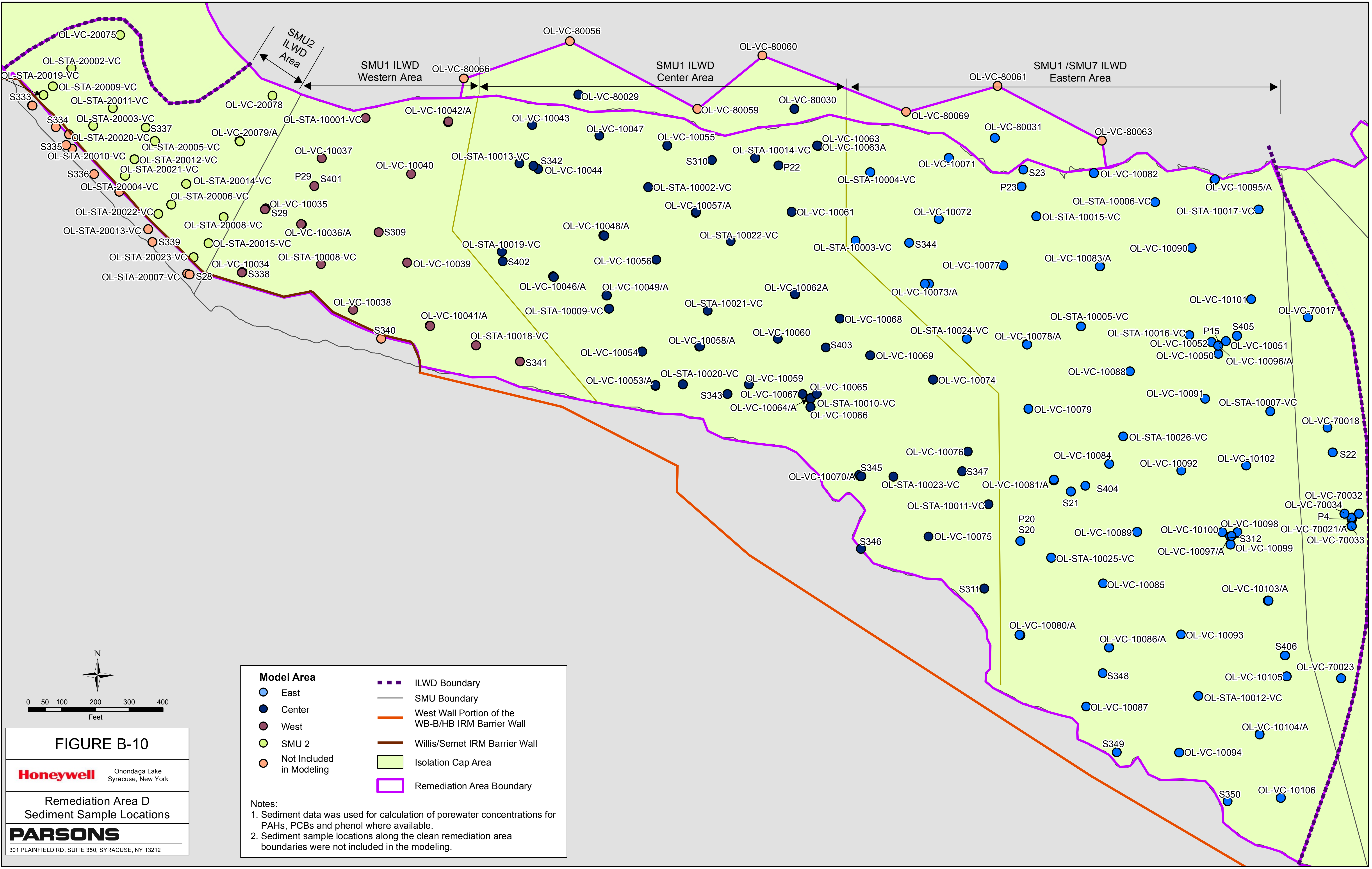

Model Area

- ● East
- ● Center
- ● West
- ● SMU 2
- ● Not Included in Modeling

- ILWD Boundary
- SMU Boundary
- West Wall Portion of the WB-B/HB IRM Barrier Wall
- Willis/Semet IRM Barrier Wall
- 🟩 Isolation Cap Area
- ☐ Remediation Area Boundary

Notes:
1. Sediment data was used for calculation of porewater concentrations for PAHs, PCBs and phenol where available.
2. Sediment sample locations along the clean remediation area boundaries were not included in the modeling.

FIGURE B-10

Honeywell Onondaga Lake
Syracuse, New York

Remediation Area D
Sediment Sample Locations

PARSONS
301 PLAINFIELD RD, SUITE 350, SYRACUSE, NY 13212

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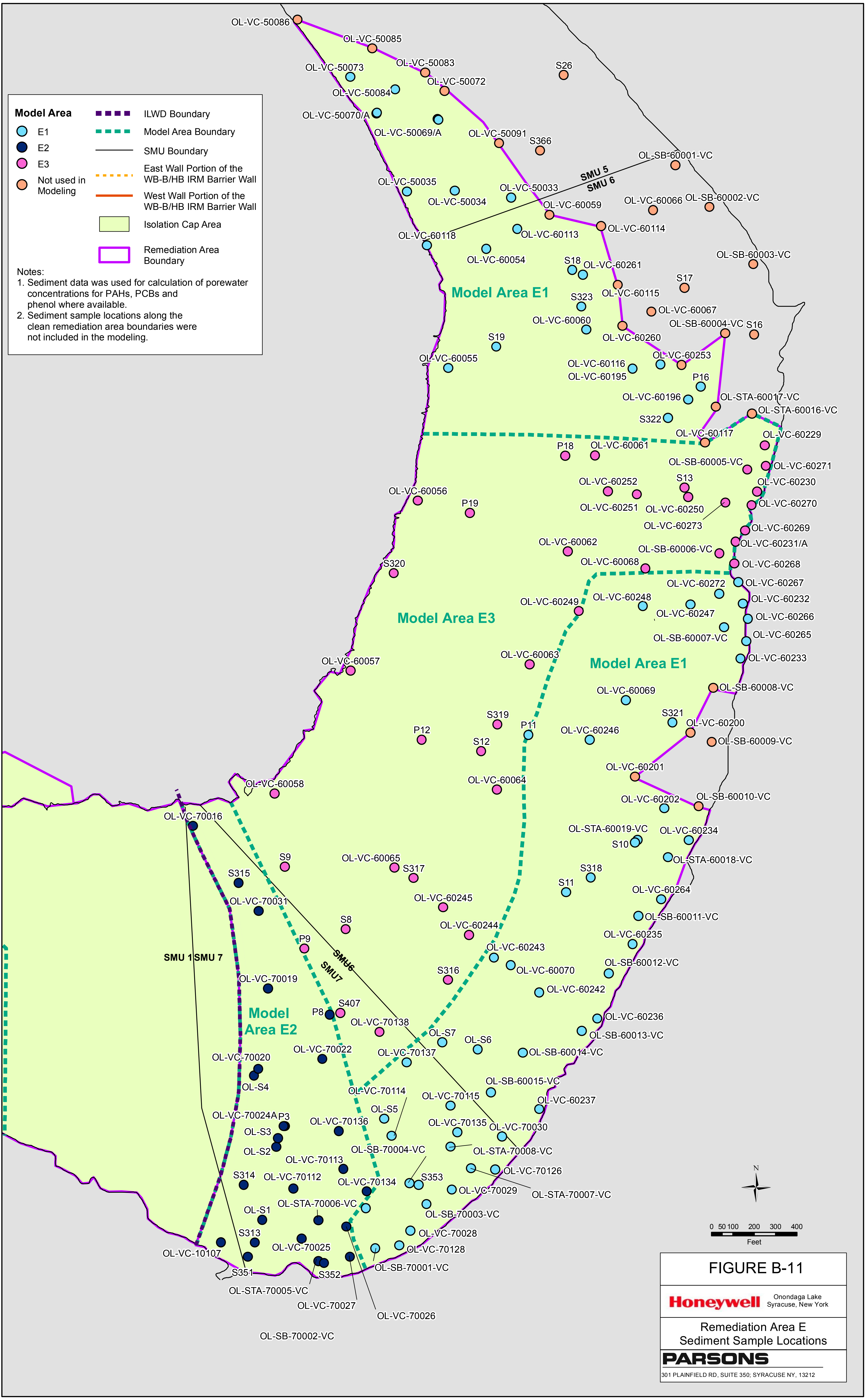

Notes:
1. Sediment data was used for calculation of porewater concentrations for PAHs, PCBs and phenol where available.
2. Sediment sample locations along the clean remediation area boundaries were not included in the modeling.

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Date Revised: 12/29/2010 3:33:14 PM

FIGURE B-11

Honeywell
Onondaga Lake
Syracuse, New York

Remediation Area E
Sediment Sample Locations

PARSONS
301 PLAINFIELD RD, SUITE 350; SYRACUSE NY, 13212