ONONDAGA LAKE CAPPING, DREDGING, HABITAT AND PROFUNDAL ZONE (SMU 8) FINAL DESIGN

MODIFIED PROTECTIVE CAP RA-C-1 DESIGN REVISION

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SUMMARY OF DESIGN REVISION

This cap design revision pertains to a small portion of Remediation Area (RA) C where movement of the cap and underlying sediment occurred during construction due to the presence of soft (low strength) sediment on relatively steep slopes that was not identified during the pre-design phase despite extensive investigations. This design revision also addresses small areas immediately adjacent to the cap movement area with similar soft sediment conditions as well as the small adjacent area in Sediment Management Unit 8 (SMU 8) where sediment movement was also identified. For a capping project of the scale of Onondaga Lake Remediation, it is not unusual to expect to incur field conditions in minor areas throughout the implementation that may require adjustments to the cap system to achieve the remedial goals for the project. As discussed below, the modified protective cap (MPC) in the area of cap movement and the thin layer cap (TLC) in the adjacent area in SMU 8 will be protective for more than 1,000 years, consistent with the evaluation timeframe used in the Final Design (Parsons and Anchor QEA 2012a).

Capping operations have been underway in Onondaga Lake since August 21, 2012. During capping in RA-C, movement of a small area of the cap and underlying sediment as well as adjacent SMU 8 sediment was observed east of the Department of Transportation (DOT) turnaround area on September 5, 2012 (Figure 1). Capping operations were subsequently revised to significantly reduce the likelihood of cap movement. Despite those efforts, in early November of 2014, movement of the sediment cap and underlying sediments within a small portion of RA-D was observed shortly following completion of cap placement within that area. Movement of the sediments in a small adjacent area within SMU-8 was also observed. The combined total area of cap movement in RA-C and RA-D is approximately 7 acres, which represents approximately 1.6% of the total capping area under the lake remediation program. The combined area of sediment movement in SMU 8 adjacent to RA-C and RA-D cap movement areas is approximately 39 acres, which represents approximately 2% of SMU 8. A portion of the movement area in SMU 8 adjacent to RA-D was determined not to require remediation as documented in the final Design Revision for RA-D. The area of sediment movement in RA-C extended to a maximum depth of approximately four feet.

In addition to the areas of cap movement discussed above, a small area (approximately 0.14 acres) of subsidence of sediments underlying cap materials occurred to the east of the RA-C cap movement area on October 4, 2012. At the time of the subsidence, the cap had been fully placed in the area of the subsidence. The thickness and composition of cap material placed in the area of the cap movement and subsidence areas as well as in the immediately surrounding areas is shown in Figure 2. The total average cap material thickness placed in the subsidence area was approximately 31 inches. Based on subsequent bathymetry measurements, the area subsided by approximately 1 to 2 feet. Diver visual inspections performed in October of 2012 and December of 2014 after the subsidence indicate a continuous layer of cap materials remained in the area of subsidence. The post subsidence bathymetry in this area indicates the cap surface is approximately

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9 inches above the original sediment surface, also indicating significant cap material remains in this area. No additional cap material will be placed in this area. As shown in Figure 2, there is a small area immediately east of the subsidence area where the complete cap has been placed except for the final 6 inches of habitat layer. Given the significant amount of cap material placed in this area and its direct proximity to the subsidence area, no additional cap material will be placed in this area.

Subsequently collected in situ data and geotechnical analyses indicated that the localized areas of movement resulted from underlying sediments that were softer than previously identified during the pre-design investigation. The design of the MPC for the area of cap movement in RA-C and adjacent areas, referred to as MPC RA-C-1, and the thin layer cap in the adjacent SMU 8 area is presented in this design revision. The design of the MPC for the area of movement in RA-D and the thin layer cap in the adjacent SMU 8 area is presented in a separate design revision (Parsons and Anchor QEA 2015).

Following the occurrence of the cap disturbance in 2012, extensive field investigations were performed with equipment that is both more accurate than that used during the 2005 to 2008 predesign investigation (PDI) and capable of assessing conditions in the deeper water portions of the lake where softer sediments have been identified. This has included cone penetrometer testing (CPT), full flow penetrometer (FFP), and additional vane sheer testing (VST). In addition to the improved accuracy of these measurements, the use of these methods in areas of the site with previously placed cap materials has allowed an assessment of cap placement induced strength gain (from consolidation) in the sediment, which has been a key consideration in the slope stability assessments in some cap areas.

The evaluation of strength data collected between 2012 and 2015 indicate that the sediments in portions of the remediation areas are significantly softer than anticipated based on the PDI conducted prior to 2012. Comparison between the estimated strength parameters from the field VST data (from the PDI) and the post-PDI VST data conducted after 2012 indicates that, in general, the PDI data showed higher shear strengths for the shallow sediments than the recent (post-2012) data. The technical report titled "Development of Geotechnical Design Parameters for Lakebed Sediments in Onondaga Lake Capping Areas" (Geosyntec, October 2015) presents a comparison of the PDI and post-PDI sediment strength data.

Subsequent to the movement of the cap and sediments in RA-C, surface sediment samples were collected in 2014 from throughout the movement area in SMU 8 and analyzed for the constituents used to quantify the Mean Probable Effects Concentration Quotient (Mean PECQ): total mercury, ethylbenzene, xylenes, certain chlorinated benzenes, polynuclear aromatic hydrocarbons (PAHs), and total polychlorinated biphenyls (PCBs) based on Aroclors (Parsons 2015). As detailed in the Final Design, the sediment compliance depth for the Mean PECQ used for determining the extent of remedial action in SMU 8 is 4 cm, consistent with the SMU 8 mercury PEC compliance depth. Sample locations where the Mean PECQ of 1 was exceeded in the 0 to 4 cm sampling interval were used in conjunction with post-movement bathymetry survey results to delineate the remedial boundaries in the SMU 8 movement area shown on Figure 1. The Mean PECQ exceeded 1 in three of the five sample locations in the 0 to 4 cm interval; therefore, the

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extent of remedial action in SMU 8 conservatively includes the entire area of movement based on bathymetry measurements indicating the extent of disturbance. Samples were also collected from 4 to 15 cm at all 2014 sampling locations. Results from both intervals were used in development of the design revision, as detailed in Attachment 2.

The MPC and TLC designs shown in Figure 3 were determined to be stable based on substantial geotechnical data collected in this area subsequent to the Final Design and detailed geotechnical analysis, as presented in Attachment 1. The MPC designs were optimized to maximize the total thickness of the cap while still meeting the required factor of safety based on geotechnical considerations. The thickness and composition of the various layers comprising the MPCs are summarized below and shown in Figure 3. Chemical isolation modeling was completed to determine the granular activated carbon (GAC) application rates that result in a cap that is protective for isolation of organic contaminants for at least 1000 years, consistent with the evaluation timeframe used in the Final Design, as documented in Attachment 2. Modeling also verified that the MPCs will be protective for isolation of mercury for at least 1000 years, although it may take longer for mercury to achieve the cap performance criteria in a small portion of this MPC than originally anticipated, as further discussed below.

The thickness and composition of the various layers comprising the MPCs, including the updated GAC application rates based on the modeling, are summarized below.

RA-C-1A (Multi-Layer Cap) - GAC application rate of 0.39 lbs/sf

- 9-inch minimum sand habitat/erosion protection layer
- 4.5-inch minimum sand/GAC chemical isolation layer
- 1.5-inch minimum of sand/siderite mixing layer

RA-C-1B (GAC Direct Application) - GAC application rate of 0.73 lbs/sf

• Will include a volume of sand during placement of GAC approximately equal to 0.5 inches to facilitate placement

RA-C-1C (GAC Direct Application over Existing Sand/Siderite Layers) - GAC application rate of 0.73 lbs/sf

- GAC direct application. Will include a volume of sand during placement of GAC approximately equal to 0.5 inches to facilitate placement
- 3-inch minimum sand/siderite layer (existing)
- 3-inch minimum of sand/siderite mixing layer (existing)

RA-C-1D (Multi-Layer Cap, Conservatively Modeled as a Mono-layer Cap) - GAC application rate of 0.73 lbs/sf

• 4.5-inch average sand layer

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- 4.5-inch average sand//GAC/siderite layer
- Existing cap material (various thicknesses and compositions, see Figure 2)

SMU 8 Thin Layer Cap

• 4.5-inch average sand

SMU 8 GAC Direct Application - GAC application rate of 0.73 lbs/sf

• Will include a volume of sand during placement of GAC approximately equal to 0.5 inches to facilitate placement

SMU 8/RA-C1 Transition Area – GAC application rate of 0.73 lb/sf

• Various thicknesses as cap thickness transitions step-wise from SMU 8 direct application area to RA-C-1 (see Figure 10 in Attachment 1). The GAC will be placed in the lower lifts in this area.

The area where GAC will be directly applied to the surface of the sediments in MPC C1 and the adjacent SMU 8 area is very small (1.5 acres), which represents only about 0.3% of the total capped area. As documented in Attachment 1, the recommended approach in these areas is direct application of GAC to the sediment surface because geotechnical stability considerations limit placement of a sand cap in these small areas. The GAC will mix with the surface sediments through bioturbation, as discussed in Attachment 2. Mechanical mixing of GAC with the surface sediments is not considered practical because it could disturb the sediments sufficiently to result in potential slope instability. Bioturbation has proven to be effective at other sediment remediation sites in mixing amendments such as GAC throughout the biologically active upper layer of sediment. The GAC will adsorb the organic contaminants of concern within the sediment porewater and prevent them from being available to small organisms within the surface sediments or migrating into the water column. As detailed in Attachment 2, sufficient GAC will be applied to achieve protection for at least 1000 years.

In the small GAC direct application area in SMU 8 (1.1 acres), post movement mercury concentrations in surface sediment samples did not exceed the mercury criteria of 2.2 mg/kg, therefore there are no significant risks due to exposure to mercury in this area. There are portions of the small area (0.4 acres) of direct GAC application (RA-C-1B) within the originally capped area that may currently exceed the mercury criteria based on pre-movement sediment samples throughout the area. The vast majority of this area is in water depths greater than 20 feet and thus may be considered net depositional. Mercury concentrations will decrease over time and are projected to meet the mercury criteria within 15 to 30 years in this area as cleaner sediments are naturally deposited, as discussed in Attachment 2. Mercury concentrations in RA-C-1B, which represents less than 0.1% of the total area capped within the littoral zone, will be higher than anticipated in the Final Design for the lake. However, the bioaccumulation-based sediment quality value (BSQV) of 0.8 mg/kg will continue to be met in this portion of the lake. Also, it is not

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anticipated that this will effect achievement of remedial goals relating to mercury levels in fish in the lake due to the small areal extent of RA-C-1B compared to overall capped areas within the lake littoral zone.

A very small portion of RA-C-1B (approximately 0.03 acres) is in water depths less than 20 feet and therefore would not be considered net depositional; however, surface concentrations are expected to be reduced over time in this small area as new cleaner sediments deposit and mix with the existing surface sediments.

The cap design in this area originally included siderite in order to neutralize pH and promote biological decay within the cap. Based on consideration of near-neutral pH in this area and the cap modeling specific to this area, pH amendment is not required, as discussed in Attachment 2. However, for consistency with the design, it will be included in MPC areas RA-C-1A and RA-C-1D, and the sand siderite layer has already been placed in RA-C-1C. It will not be included in the SMU 8 transition area or direct amendment application areas. Cap modeling of the multilayer cap in this area incorporated biodegradation. Biodegradation of organic contaminants is also expected to occur in the mono-layer caps, including the area of direct amendment application. However, the GAC application rates in these areas were conservatively developed through modeling assuming there was no biological decay. The siderite ore application rate based on lbs/sf will be consistent with the Final Design in all of the RA-C-1 MPCs where siderite will be incorporated. The siderite percent by weight within the sand/siderite mixture will be increased to account for the thinner sand/siderite layers (when less than 6 inches) as compared to the Final Design. The revised design as it pertains to the pH neutralization provides a level of protection that is equivalent to that of the original design even though the cap thickness over which the siderite is distributed will be decreased in some areas, as detailed in the Modified Protective Cap RA-D-1 Design Revision (Parsons and Anchor QEA 2015). Siderite is not required in the SMU-8 areas.

To provide consistency with the application methods used in other areas, a low volume of sand (equivalent to approximately 0.5 inches of sand placement on average) will be mixed with GAC during the direct application process to promote GAC distribution and settlement, as well as provide increased stability of the GAC following placement prior to its expected mixing with the sediment via bioturbation. It is anticipated that the GAC/sand mixture will be placed in the direct application area using the same equipment and methods (hydraulic spreader barge) that have been successfully used throughout the program to place finer-grained cap material, including sand/GAC mixtures. A comprehensive Construction Quality Assurance Plan (CQAP) (Parsons and Anchor QEA, 2012) was developed and is being implemented to verify that the cap is constructed consistent with the Final Design, including thickness and amendment application rate requirements. The construction verification methods will be revisited as necessary to verify the MPCs, including the GAC direct amendment areas, are constructed consistent with this design modification.

Post-construction monitoring and maintenance of the capped areas throughout the lake, inclusive of the MPC areas addressed in this design revision, will be performed to verify that the overall integrity of the cap remains physically stable (i.e., does not erode) and chemically protective over time. Long-term monitoring of the caps will include physical monitoring to verify

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stability and sampling of the caps to verify their chemical integrity, as summarized below. Longterm monitoring will also include macrobenthic community sampling and documentation of vegetation recovery, as appropriate. Details of the monitoring methods, frequencies, and procedures and response actions (including possible cap maintenance) will be developed based on joint discussions with NYSDEC and will be presented in the Onondaga Lake Monitoring and Maintenance Scoping document (OLMMS).

Physical monitoring of the capped areas, including the MPC areas included in this design revision, will involve verifying that the various layers of cap material placed are stable and intact using a combination of methods including bathymetric surveys, sediment probing and coring, and/or other geophysical methods. The cap integrity will be monitored routinely and following wind/wave, tributary inflow, ice scour or seismic events that exceed a threshold design magnitude that may impact a specific cap area, consistent with USEPA (2005) recommendations. The frequency of routine monitoring will be greater initially after construction (e.g., multiple monitoring events within the first 5 to 10 years), and reduced over time once the monitoring is able to establish a consistent pattern of cap performance.

Chemical monitoring will involve measuring chemical concentrations within the caps to verify that contaminants are not moving through or accumulating within the cap at rates and concentrations that exceed specified remedy success metrics. Samples will also be collected within MPC areas as the different cap configurations in these areas will likely result in different monitoring approaches, depths, and compliance points. The frequency of routine monitoring may be reduced over time once the monitoring is able to establish a consistent pattern of cap performance.

Monitoring of the RA-C-1 and SMU 8 direct GAC application areas will also be completed as part of the long-term cap monitoring program described above. Long-term monitoring will be implemented to verify that the GAC/sand remains in place and is protective. Compliance with criteria in the GAC direct application areas will be verified by sampling of the porewater within the biologically active portion of the surface sediments. Specific monitoring methods applicable to this area will be developed.

In the event that the monitoring plan discussed above identifies areas where the cap may not be performing consistent with expectations, follow-up assessments and/or response actions will be implemented. Follow-up assessments/actions may include additional investigation to further evaluate potential deficiencies, continued monitoring and assessment of overall remedy effectiveness over time, and/or placement of additional cap materials. Cap maintenance and response actions will be detailed in the OLMMS.

REFERENCES

Parsons, (2015), "Onondaga Lake Modified Protective Cap Areas RA-C-1 and RA-D-1 Mean PECQ Investigation Results"

Parsons and Anchor QEA (Anchor QEA, LLC), 2012a. "Onondaga Lake Capping, Dredging, Habitat and Profundal Zone (SMU 8) Final Design." Prepared for Honeywell. March 2012.

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- Parsons and Anchor QEA. 2012b. "Construction Quality Assurance Plan Onondaga Lake Capping, Dredging and Habitat."
- Parsons and Anchor QEA. 2015. "Onondaga Lake Capping, Dredging, Habitat and Profundal Zone (SMU 8) Final Design Modified Protective Cap RA-D-1 Design Revision"
- United States Environmental Protection Agency. 2005. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites. EPA-540-R-05-012. OSWER 9355.0-85. Office of Solid Waste and Emergency Response. December 2005.











	2012 Cap Movement
	2012 Cap Subsidance
	Cap Status
	Full Siderite Layer Placed (6" min) (Avg 7.3" Measured)
	Full Siderite & GAC Layers Placed (15" min combined) (Avg 20.4" Measured)
	2012 Cap Startup Area (Avg 13" Sand Measured)
	Full Cap Placed Not Approved (Avg 31" Measured)
	Full Siderite & GAC Layers & First Lift of Habitat Placed (~21'') (Avg 26.7'' Measured)
	Full Cap Placed (27" min combined) & Approved (Avg 38.8" Measured)
	FIGURE 2
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MODIFIED PROTECTIVE CAP RA-C1 PLACED CAP MATERIALS

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Figure 3 Modified Protective Caps in RA-C-1 Onondaga Lake

ATTACHMENT 1

MODIFIED PROTECTIVE CAP RA-C-1 GEOTECHNICAL ANALYSIS

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Client:	Honeywell Pr	oject: Cap l	Placement in ctive Cap Ar	n Modified rea RA-C-1	Project No.: D5837	Ta	isk No.:	03

SLOPE STABILITY ANALYSIS FOR CAP PLACEMENT IN MODIFIED PROTECTIVE CAP AREA RA-C-1

INTRODUCTION

This report evaluates the geotechnical aspects of a modified protective cap in a small area (approximately 1.1 acres) of Remediation Area C (RA-C) as well as approximately 7.4 acres in the adjacent area in Sediment Management Unit 8 (SMU-8). The analysis recommends various modified protective cap designs in the multiple subareas of RA-C-1 evaluated.

In the areas where multi-lift caps are recommended, the strength of the shallow sediments under the cap will increase with time, therefore a minimum one-week waiting period between placements of lifts is required. The effectiveness of the modified protective cap designs will be documented in a separate submittal to the New York State Department of Environmental Conservation (NYSDEC).

Sediment capping operations have been underway in Onondaga Lake since August 21, 2012. During capping in RA-C, movement of a small area of the cap and underlying sediment was observed on September 5, 2012 east of the Department of Transportation (DOT) turnaround area (Figure 1). Movement of the sediments in a small adjacent area in SMU-8 was also observed. At the time of cap movement, the thickness of the RA-C cap in this area was between approximately 25 and 40 inches within the area of movement, including approximately 7 to 10 inches of sand and siderite placed in August 2012, 9 to 15 inches of sand and granular activated carbon (GAC) placed in August and September 2012, and 9 to 15 inches of sand habitat layer placed in September 2012.

Capping operations were subsequently revised to significantly reduce the likelihood of cap movement. In early November of 2014, movement of the sediment cap and underlying sediments within and adjacent to a small portion of RA-D was observed shortly following completion of cap placement within RA-D. At the time of cap movement, a full cap thickness was completed in this area of RA-D and the area upslope of the cap movement area. The areas where modified protective caps are being developed to address this movement are referred to as modified cap areas RA-C-1 and RA-D-1. The combined total area of cap movement in RA-C and RA-D is approximately 7 acres, which represents approximately 1.6% of the total capping area under the lake remediation program. Subsequent analysis indicates that these localized areas of movement resulted from underlying sediments that were softer than previously identified during the predesign investigation. This comparison has been discussed in a separate report titled

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"Development of Geotechnical Design Parameters for Lakebed Sediments in Onondaga Lake Capping Areas" (Geosyntec, 2015a). Geotechnical analysis associated with capping in modified protective cap area RA-D-1 has been provided in a separate submittal [Geosyntec, 2015b].

In addition to the areas of cap movement discussed above, a small area (approximately 0.1 acres) of subsidence of sediments underlying cap materials occurred to the east of the RA-C cap movement area on October 4, 2012. At the time of the subsidence, the sand/siderite and sand/GAC layers had been placed (combined minimum thickness of 15 inches) and the habitat layer (sand) was in the process of being placed (minimum thickness of 12 inches) over the area of subsidence. The thickness and composition of cap material placed in the area of the cap movement and subsidence areas as well as in the immediately surrounding areas is shown in Figure 2. The total average cap material thickness placed in the subsidence area was approximately 31 inches. Based on subsequent bathymetry measurements, the area subsided by approximately 1 to 2 feet. Based on subsequent diver visual inspections, a continuous layer of cap materials remained in the area of subsidence. The post subsidence bathymetry in this area indicates the cap surface is approximately 9 in. above the original sediment surface, also indicating significant cap material remains in this area. Also, the results of the CPT (OL-CPT-03) performed within the area of subsidence indicated a very large tip resistance ((q_t) of approximately 30,000 psf) which indicates the presence of more than 3 ft of granular cap materials in this area. Below the cap layer, the CPT data (OL-CPT-03) indicate the presence of lake bottom sediments. For a portion of RA-C-1C which is between the cap movement area and the cap subsidence area, at least six inches of cap material has been placed throughout most of this area, and in some portions significantly more cap material has been placed.

For purposes of stability evaluation, the RA-C cap movelement area was divided into the following sub-areas (Figure 1):

- RA-C-1A is the area of cap movement that originally included a full-thickness cap that has a relatively shallow slope (0.7 acres);
- RA-C-1B is the area of cap movement that originally included a full-thickness cap that has a relatively steep slope (0.4 acres);
- RA-C-1C is the adjacent capping area to the west that has already received some capping material (1 acre). This area also includes a small buffer area to the east of the cap movement area that was developed to avoid potential stability concerns associated with capping immediately adjacent to the movement area; and
- RA-C-1D is the adjacent capping area to the east that has already received some capping material (0.5 acres).
- Adjacent SMU 8 area (7.4 acres) where there was sediment movement.

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Additional details pertaining to development of the cap modeling areas and chemical isolation modeling results are provided in a separate submittal.

SLOPE STABILITY ANALYSES

The slope stability analyses were performed using Janbu's simplified method [Janbu, 1973] for block failure slip surfaces and Spencer's method [Spencer, 1973] for the circular slip surfaces, as implemented in the computer program SLIDE, version 6.026 [Rocscience, 2013]. Spencer's method, which satisfies vertical and horizontal force equilibrium and moment equilibrium, is considered to be more rigorous than other methods, such as the Janbu's simplified method [Janbu, 1973] and the simplified Bishop's method [Bishop, 1955]. However, Spencer's method often encounters numerical convergence difficulties when considering block slip surfaces. Therefore, Spencer's method was used for the circular slip surfaces, while Janbu's method was used for block slip surfaces.

The rotational and block mode (i.e., the circular slip surface and optimized block slip surface) were considered in the analyses. In general, the block mode generated slip surfaces with a lower calculated factor of safety (FS) than the rotational mode. The optimized block slip surface was used as it allows the computer program to search for slip surfaces with lower FS by optimizing the locations of an initial slip surface. Information required for the stability analyses include the slope geometry, subsurface soil stratigraphy, lake water level elevation, external loading condition, cap lift thickness and properties, waiting period between each lift (resulting in strength gain of underlying sediments), and properties of subsurface materials.

Target Factor of Safety

The critical condition for the geotechnical stability of a cap is when it is being placed and the underlying sediments are in the undrained condition. In this interim condition, excess pore water pressure due to cap loading is generated in the soft sediments and shear strength gain in the sediments has not yet occurred. The technical approach presented in this report considers the undrained condition for the first lift of cap. For subsequent lifts, it takes into account the partial strength gain of sediments during the waiting period after previous lifts. Typically, the recommended target slope stability FS is 1.3 for the interim undrained condition and 1.5 for the drained condition. However, selection of the target FS also depends on the costs and consequences of a slope failure as well as uncertainty of strength measurements, as indicated by

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Duncan and Buchignani (1975). Considering these factors and since the process of capping involves both the interim undrained condition and the partially drained condition, a target FS of 1.5 was targeted in the analyses presented herein. This is consistent with the target FS selected for previous slope stability analyses, including the FS used for stability analysis of the In-lake Waste Deposit (ILWD) area included as Appendix H to the Final Design. The FS of 1.5 for the ILWD stability analysis was specified in the Statement of Work included as part of the Remedial Design/Action Consent Decree for the lake. Given the potential implications of additional cap movement, as demonstrated by the prior areas of cap movement, a FS of 1.5 is appropriate for this analysis consistent with prior stability analysis associated with the remediation design.

Subsurface Stratigraphy

Because the sediments are soft, no undisturbed samples could be collected in the field and tested in the laboratory for shear strength and consolidation properties. Therefore, the information regarding the subsurface stratigraphy was obtained from in situ field testing techniques, including the Cone Penetrometer Test (CPT), Full-Flow Penetrometer test (FFP), and Vane Shear Test (VST). The locations of in situ tests are presented in Figure 1. The location of the CPT tests and the FFP tests are the same. The in situ tests were performed both in the shallow slope areas (slope < 10%) and steep slope areas (slope > 10%) to obtain representative undrained shear strength estimates in different regions of RA-C. These tests provided information to characterize the in situ shear strength and consolidation properties of soft sediments; however, the FFP is generally more accurate for assessing the low shear strength of soft sediments than the CPT. Two FFP tests (OL-FFP-01 and OL-FFP-11) were performed in the RA-C steep slope area following the movement. OL-FFP-01 and OL-FFP-11 were collected in areas where cap movement was not observed. The undrained shear strengths from these tests were limited to the sediments in the upslope area of the cap movement area where the sediment is considered undisturbed. Also, for developing the subsurface stratigraphy and strength of the lakebottom sediments adjacent to the RA-C movement area, the nearby FFP and CPT data (OL-FFP/CPT-04 to FFP/CPT-06 in Figure 1) have been used.

Figure 5 shows the results of the FFP tests in RA-C steep slope areas following the movement. The assumed shear strength profile for stability analyses is also shown on this figure. In addition to testing in the steep slope area, two additional FFP tests (OL-FFP-02 and OL-FFP-10) were performed in the shallow slope area. The results from these two tests along with the assumed shear strength profile are also shown in Figure 5 for Cross Section A.

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For Cross Sections B and C, the stability of the cap is mainly controlled by presence of soft sediments in relatively shallow slopes as reflected in collected OL-FFP-04, OL-FFP-05, and OL-FFP-06 which are projected along these cross sections and soft sediments in steeper portion of slopes as reflected in OL-FFP-01, OL-CPTu-01 and OL-FFP-11.

The development of geotechnical parameters used for the lakebed sediments is described in a separate Geosyntec report submitted to NYSDEC [Geosyntec 2015a].

GEOTECHNICAL STABILITY EVALUATION

Pore Water Pressure Dissipation

Figure 3 shows the plot of calculated pore water pressure dissipation with time for the soft sediments. The sediments were assumed to have a one-way drainage path toward the top, which is covered by a cap, with fine-grained materials below inhibiting downward drainage. Figure 3 shows that the degree of consolidation, U_c (i.e., equal to $100\% - \Delta U$, where ΔU is the percentage of the developed excess pore water pressure), is greater in the upper portions of the sediments and decreases significantly with increased drainage distance for deeper sediments.

Shear Strength Gain

The shear strength gain caused by the increase in vertical effective stress (in this case, as a result of cap placement) is proportional to the degree of consolidation. The shear strength gain considered in the analyses for RA-C-1 was consistent with the method described in Geosyntec [2015a] and summarized below.

The shear strength gain, ΔS_u , can be calculated using Eq. 1, where the undrained shear strength ratio, R_{Su} , and increase in vertical effective stress, $\Delta \sigma'_v$, are known:

$$\Delta S_u = \Delta \sigma'_v \times R_{Su}$$
 Eq. 1

The increase in vertical effective stress is calculated by:

$$\Delta \sigma'_{v} = (\gamma_{sc} - \gamma_{w}) \times t_{c} \times U_{c}$$
 Eq. 2

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where γ_{sc} is the saturated unit weight of cap (assumed to be 120 pounds per cubic foot), γ_w is the unit weight of water, t_c is the cap lift thickness, and U_c is the degree of consolidation for that cap lift.

The shear strength ratio R_{Su} was selected to be 0.3 from the results of in situ FFP tests as discussed in Geosyntec [2015a]. It is noted that the increase in undrained shear strength due to each lift of cap material should be calculated independently. For example, if the first cap lift is placed at time 0 and the second cap lift is placed at time 7 days, the strength gain of sediments at time 14 days is the sum of strength gain from the first lift during the 14 days and that from the second lift during the 7 days. Figure 4 illustrates the concept of strength gain from different cap lifts with time.

The shear strength gain due to the sediment consolidation described above is for normally consolidated sediments as identified by FFPs in this area. Approximately the top 2 ft of material within the modified protective cap areas RA-C-1A, RA-C-1B, and the adjacent SMU-8 area is considered to be disturbed and normally consolidated; thus, strength gain in the top 2 ft of sediments was considered in the slope stability analyses after the placement of any cap lifts. No strength gain was considered within sediments deeper than 2 ft in RA-C-1A, RA-C-1B, and adjacent SMU-8, as these sediments are overconsolidated after the removal of overlying sediments caused by the movement.

Geotechnical Parameters

The material properties used for the geotechnical slope stability analysis herein are presented in Table 1. In summary, the subsurface materials in the modified protective cap area RA-C-1 consist of three strata: Soft Sediments, Marl, and Silt and Clay. Soft sediments extend to about 30-ft depth. Marl lies between 30-ft and 60-ft. Beyond 60-ft is Silt and Clay.

ANALYZED CROSS SECTIONS

Three cross sections (Cross Sections A, B, and C) were selected for slope stability analysis as representative cross section in the RA-C disturbed area and adjacent area for slope stability analysis. The cross sections analyzed in this calculation package are shown on Figure 1. These cross sections are based on a multi-beam bathymetry survey conducted in 2015. Single-beam and multi-beam bathymetry survey were also completed in 2012 following the cap movement. Based on a comparison of the 2015 survey to the 2012 surveys, there were no significant changes in the bathymetry since 2012 and no evidence of additional cap or sediment movement. The 2015 survey indicated there was some apparent self-leveling of minor small surface irregularities

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within portions of the movement area. The remaining small surface irregularities based on the 2015 multi-beam bathymetry dictate the small area (between Stations 350 ft and 480 ft on Figures 9 and 10) where no cap placement is recommended, as discussed in the results section below.

Cross Sections A to C are shown in Figure 5 to Figure 7 with the pre and post-movement (or capping) bathymetry of the lake bottom. Cross Section C is in an area where no cap movement was observed. Figure 5 shows the movement of about 4 ft of the lake bottom sediments. It should be noted that the collected FFP data at the location of FFP-10 and FFP-02 show a 2-ft thick disturbed zone under the post-movement mulline with s_u of about 10 pounds per square foot (psf) which appears to be reasonable due to the movement along the failure surface. A majority of the movement was observed in the shallow slope (slope < 10%) areas (Station 125 to 500 ft in Figure 5). Figure 5 shows Cross Section A with the locations of RA-C cap-only area (station 100 to 250 ft) and SMU-8 (after station 250 ft) along the cross section. Sediments have moved between stations 100 and 750 ft and accumulated between stations 750 and 1200 ft.

ANALYSES RESULTS

Figure 8 shows the calculated FS for Cross Section A under current conditions. The minimum calculated FSs in the current condition (i.e., subsequent to the sediment movement and prior to additional cap placement) are:

- 1.15 to 1.33 in SMU-8 (between Stations 350 ft and 480 ft); and
- greater than 1.5 in other areas of RA-C-1.

Figure 9 shows the calculated FS after placement of the first 2 in. lift of cap material for Cross Section A. The minimum calculated FSs after placement of the first lift are:

- 1.08 in RA-C-1B (steep slope area of movement between Stations 100 ft and 125 ft)
- 1.03 to 1.17 in SMU-8 (between Stations 350 ft and 480 ft); and
- greater than 1.5 in other areas of RA-C-1 and SMU 8.

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The calculated FS in RA-C-1B and portions of SMU-8 (between Stations 350 ft and 480 ft) is below the target FS of 1.5 and close to a FS of 1 and in a marginally stable condition. In order to avoid the areas where the FS is lower than 1.5 and prevent localized failures that could cause larger progressive failure, it is recommended no additional cap material be placed in these small areas, as shown in Figures 10 and 13.

Figure 10 shows the calculated FS for Cross Section A after placement of seven cap lifts with the total average cap thickness of 25.5 inches with a 1-week waiting period between lifts. The thickness of each lift was maximized and the setbacks at the edge of each lift were minimized, while still maintaining a minimum FS of 1.5 for each lift. The minimum calculated FS after placement of the seventh lift is 1.54. Additional lifts would require similar setbacks. Given the narrow width of this area, additional lifts would cover ever decreasing area and provide minimal incremental value and therefore were not evaluated.

In general, the calculated failure surfaces in Cross Section A are within the upper zone of the disturbed sediments (i.e., depth of 2 to 6 feet).

Figure 11 shows the calculated FS for Cross Section B under the current conditions. The minimum calculated FS in the current condition (i.e., subsequent to the sediment movement and prior to additional cap placement) is 1.24 which is bellow the target FS of 1.5, due to relatively steep slopes in the upslope side of the cap movement area and presence of a weak sediment layer with undrained shear strength of 55 psf. Additional cap placement in this area is predicted to result in a FS below the target FS of 1.5; For example, placing 4.5 in. of cap material in addition to the existing Siderite layers in this area would result in FS of 1.21. Therefore, no additional cap placement is recommended in this area. Capping in the disturbed area of this cross section follows the recommendation presented for the steep portion of Cross Section A - i.e., no additional cap placement is recommended.

Figure 12 shows the calculated FS for Cross Section C under the current conditions. The minimum calculated FS in the current condition (i.e., existing cap on slopes and prior to additional cap placement) is 1.59. The calculated FS for Cross Section C after placement of a cap lift with a 4.5-in. thicknesss over the entire cross section, which has already been partially capped as shown in Figure 2. The minimum calculated FS is 1.45 which is below the target FS of 1.5. The calculated FS of 1.45 is due to relatively steep slopes (20% slope) in the area upslope of this cross section and the presence of shallow sediment with undrained shear strength of 40

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psf. Therefore, no additional cap material placement is recommended in the steep area, as presented in Figure 13. For the flatter portion of the slope, the FS after placement of two 4.5-in thick lifts exceeds 1.5. Given the small size of this area, the presence of previously placed cap material, and the proximity to the prior cap movement and subsidence areas, only two lifts of cap material in addition to what has already been placed is recommended. The capping operations in this area prior to the cap movement included capping lanes that ran perpendicular to the slope and extended into SMU 8. As the hydraulic capping barge moved from one lane to the next, cap material continued to be placed, resulting in additional capping material at the lane ends in SMU 8. Therefore, to avoid potential stability concerns associated with this extra capping material, no feathering into SMU 8 is included in this area.

The cap placement procedures in RA-C-1 and adjacent SMU-8 includes a verification of successful placement through methods such as coring and bathymetric surveying. However, the monitoring and verification of successful lift placement will not provide information regarding whether additional lift placements would be stable, it only verifies that it was stable for what was already placed. Therefore, real time monitoring would not allow additional cap material to be placed.

Other engineering methods to improve stability and allow additional cap material placement in RA-C-1, such as toe berms and keyways, were considered. However, the critical slip surfaces are related to multiple localized surface irregularities and localized steep areas rather than a single large slip surface that could potentially be mitigated using methods such as toe berms and keyways. Therefore, implementation of these methods would not be effective for this area.

It should be noted that the potential for creep behavior (as stated in Geosyntec 2015b) would be offset by the strength gain due to consolidation with time, resulting in an increase in the calculated FS over time. Additional long-term analysis of slope stability for a representative cross section (Cross Section A) was conducted. The calculated FS for the long-term condition (after consolidation of sediments under the cap loading is completed) in Cross Section A is 2.6 (compared to the calculated FS of 1.5, immediately after the cap placement). Also, the longterm presence and performance of the cap throughout the lake, including the MPC areas, will be verified as part of the long-term cap monitoring program.

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CONCLUSIONS

Figure 13 shows the recommendation for cap placement in the modified protective cap area RA-C-1. The results of the slope stability analyses show that in general the modified protective cap design consists of

- Seven lifts of cap with an average total thickness of 25.5 inches in RA-C-1A;
- A thin cap layer with an average thickness of 4.5 inches in portion of SMU-8 (downslope of station 480 ft in Figure 10);
- At least one lift with an average thickness of 4.5 inches per lift in RA-C-1A transition area;
- Two cap lifts with an average thickness of 4.5 inches per lift in RA-C-1D;
- No additional sand cap material beyond what has already been placed in RA-C-1C and RA-C-1B, due to the presence of steep slopes. For direct application of GAC in this area, mixing of approximately 0.5 inch of sand with GAC is recommended; and
- No sand cap placement in a small portion of SMU 8 (Station 350 to 480 ft in Figure 10) due to the presence of numerous surface irregularities. For direct application of GAC in this area, mixing of approximately 0.5 inch of sand with GAC is recommended.

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Table 1. Summary of Material Properties for the Slope Stability Analysis in modified protective cap area RA-C-1

Material	Total Unit Weight (pcf)	Undrained Shear Strength, s _u (psf)
Soft Sediments	85	Figure 5, Figure 6, and Figure 7
Marl	100	440, for depth > 30 ft
Silt and Clay	110	$\frac{s_u}{\sigma_v} = 0.3$

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Figure 1. Modified protective cap area RA-C-1 in Remediation Area C (RA-C) and locations of in situ tests and analyzed cross sections (the FFP locations are the same as the CPT locations).







Figure 2. The thickness and composition of cap material placed in the area of the cap movement, subsidence, and the surrounding areas in RA-C-1.

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Figure 3. Pore water pressure dissipation vs. time for soft sediments in RA-C.

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Figure 4. Concept of shear strength gain for soft sediments under different lifts of cap.

Time: t₁ (placement of second lift)



Figure 5. Pre and post-movement mudline of Cross Section A showing projected FFP data.







Figure 6. Pre and post-movement mudline of Cross Section B showing projected FFP data.





Figure 7. Pre and post-movement mulline of Cross Section C showing projected FFP data.







Figure 8. Calculated factors of safety and critical slip surfaces of Cross Section A (post-movement mudline prior to capping). The modified protective cap (MPC) area RA-C-1 is separated into RA-C cap-only area and SMU-8



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Figure 9 Calculated factors of safety and critical slip surfaces for first 2-in. cap material placed over post-movement mudline of Cross Section A.





Figure 10 Calculated factors of safety and critical slip surfaces after seven cap lifts placed over post- movement mudline of Cross Section A.





Figure 11. Calculated factors of safety and critical slip surfaces for Cross Section B.







Figure 12. Calculated factors of safety and critical slip surfaces for Cross Section C.



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Figure 13. Cap placement recommendation in modified protective cap area RA-C-1.



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ATTACHMENT 2

MODIFIED PROTECTIVE CAP RA-C-1 CHEMICAL ISOLATION MODELING



FINAL MEMORANDUM

То:	Ed Glaza, Parsons	Date:	April 21, 2016					
From:	Deirdre Reidy and Kevin Russell, Anchor QEA, LLC	Project:	E50139-09.02					
Cc:	Paul LaRosa and Ram Mohan, Anchor QEA, LLC							
Re:	Cap Modeling in Modified Protective Cap Area RA-C-1 and Adjacent SMU 8							

1 INTRODUCTION

This memorandum documents the numerical modeling conducted for the Modified Protective Cap (MPC) in area RA-C-1, as well as for the direct application of granular activated carbon (GAC) and the thin-layer cap (TLC) in portions of the adjacent area of Sediment Management Unit 8 (SMU 8; Figure 1). The numerical modeling was conducted to develop GAC application rates that would be required for these caps to be protective for more than 1,000 years, consistent with the evaluation timeframe used in the final design. The modeling also verified that the TLC in SMU 8 would achieve long-term protectiveness goals consistent with the final design.

For a capping project of the scale of Onondaga Lake Remediation, it is not unusual to expect previously unforeseen field conditions in small areas that may warrant adjustments to the cap system to achieve the remedial goals for the project. During capping in Remediation Area (RA)-C, movement of a small area of the cap and underlying sediment was observed in a portion of this area in September 2012. Capping operations were subsequently revised to significantly reduce the likelihood of cap movement. Subsequent to the cap movement, additional in situ data collection and geotechnical analyses were conducted. These recent geotechnical stability evaluations have indicated that the cap thicknesses developed as part of the final design (Parsons and Anchor QEA 2012a) need to be reduced in the small areas of cap movement, as well as in other small portions of Onondaga Lake RAs where the sediments are much softer than previously identified.





Figure 1 Modified Protective Caps in RA-C-1 Onondaga Lake This memorandum consists of the following sections:

- Section 2 describes the general modeling approach used to evaluate the various modified cap configurations, as well as the modeling details specific to RA-C-1 and the adjacent area of SMU 8.
- Section 3 presents the GAC application rate required in each area to meet the target criteria for more than 1,000 years.
- Section 4 presents model sensitivity analyses.
- Section 5 presents a list of references.
- Attachment 1 includes the model files associated with the direct amendment application in RA-C-1 and portions of the adjacent SMU 8, as well as the SMU 8 TLC modeling.

2 MODELING APPROACH

2.1 General Approach

The modeling approaches employed for the proposed modified protective cap configurations identified from the geotechnical analyses can be simplified into three basic categories:

- 1. Multi-layer caps (simulated with the transient numerical model)
- 2. Mono-layer caps, including direct GAC amendment application (simulated with the transient numerical model)
- Modeling deposition effects for mercury and TLCs (simulated with the SMU 8 monitored natural recovery [MNR] model)

Detailed descriptions of the modeling approach for each of these categories were provided in the first memorandum in this series (Anchor QEA 2015) and are not repeated here. Considerations specific to area RA-C-1 and the adjacent direct amendment and TLC areas in SMU 8 are described in the following two subsections. These considerations include the sitespecific cap configuration, chemical source term (i.e., initial sediment porewater concentrations), groundwater upwelling velocity, bioturbation depth, and biological decay rate.

2.2 Modeling Approach for RA-C-1 Modified Protective Caps

The area of RA-C-1 was determined based on a bathymetric survey completed subsequent to the cap movement that occurred in this area, as documented in a separate submittal to the New York State Department of Environmental Conservation (NYSDEC). The modeling conducted for RA-C-1 was performed for four separate subareas (designated as RA-C-1A, RA-C-1B, RA-C-1C, and RA-C-1D; Figure 1). Results of slope stability analyses showed these areas can accommodate a range of MPC configurations, which can be categorized into two general MPC types—multi-layer MPCs and mono-layer MPCs (including direct application of GAC).

Subareas defined as multi-layer MPCs will have sufficient thicknesses based on geotechnical analysis such that there will be separate habitat and chemical isolation layers. These multi-layer MPCs were simulated in the model consistent with the final design cap configuration (except using the reduced thicknesses, as discussed in Section 2.1 of Anchor QEA [2015]). Multi-layer MPCs having a sand/siderite layer placed separately from the GAC-amended chemical isolation layer were evaluated incorporating biological degradation (which is expected to occur over the long term following porewater pH neutralization by siderite), consistent with the final design, as discussed in Section 2.1 of Anchor QEA (2015).

Consistent with the approach described in Anchor QEA (2015), subareas identified as mono-layer caps or direct application of GAC areas were evaluated in the model as mono-layer caps and were simulated in a manner consistent with the Modified Erosion Resistant Cap (MERC) that was designed and constructed in the area of the Metro deepwater outfall (Parsons and Anchor QEA 2014). All mono-layer caps in the littoral zone, including those used for evaluating direct amendment application, were represented in the model using a total 6-inch thickness for the purposes of defining a GAC application rate.¹ This is appropriate because the GAC will be distributed over time by bioturbation (the littoral zone

¹ Studies have shown that toxicity and bioaccumulation in benthic organisms decrease with the addition of GAC to sediments due to reductions in contaminant concentrations in porewater (Janssen and Beckingham 2013). If GAC with adsorbed contaminants is ingested by benthic organisms, it would likely pass through their digestive system with minimal, if any, impact. Organic chemicals strongly bind to GAC and, therefore, would not be assimilated into the organism.

bioturbation depth used in the final design was 6 inches) as detailed in Section 2.2 of Anchor QEA (2015).

The cap configurations and modeling conducted to define the GAC application rate required in the RA-C-1 MPCs are described in the subsections that follow.

2.2.1 Transient Numerical Modeling to Develop GAC Application Rate

Chemical isolation cap modeling using the numerical transient model was conducted to develop the MPC GAC application rate in the following four subareas of RA-C-1:

- **RA-C-1A:** This subarea will include a multi-layer cap consisting of the following:
 - 9 inches minimum of sand (habitat restoration layer)
 - 4.5 inches minimum of sand/GAC (chemical isolation layer)
 - 1.5 inches minimum of sand/siderite (which were excluded from modeling due to assumed mixing with underlying sediments; mixing layer)
- **RA-C-1B:** This subarea will include direct application of GAC to sediments.²
- **RA-C-1C:** This subarea will include direct application of GAC on top of the existing 6 inches of sand/siderite that was previously placed.²
- RA-C-1D: This subarea will include a 4.5-inch average layer of sand placed over a 4.5-inch average layer of sand/GAC/siderite and was simulated as a mono-layer cap.² Previously placed cap material in portions of this area is conservatively ignored for cap modeling purposes.

All 25 of the organic chemicals evaluated during final design (i.e., VOCs, PAHs, and PCBs), were evaluated with the transient numerical model to identify the GAC application rate that would be needed to maintain concentrations below the applicable probable effects concentrations (PECs; or porewater-equivalent PECs in the case of the mono-layer caps) and sediment screening concentrations (SSCs) for more than 1,000 years. All mono-layer caps, including areas of direct GAC application, were represented in the model using a total 6-inch thickness for the purposes of defining a GAC application rate based on the thickness over which the GAC will be distributed over time by bioturbation (the littoral zone bioturbation

² Simulated as a 6-inch mono-layer cap.

depth used in the final design was 6 inches), with the exception of mercury in areas where the bioturbation depth exceeds the cap thickness (RA-C-1B). In RA-C-1B, mercury was simulated using the MNR model, as discussed in Section 2.2.2, because the MNR model more accurately accounts for deposition. In areas where the placed cap material meets or exceeds the bioturbation zone thickness of 6 inches, mercury was simulated with the cap model. Although RA-C-1C is an area of direct application of GAC, mercury was simulated with the cap model because 6 inches of sand had previously been placed and verified to still be present during the 2015 multi-beam bathymetry survey of this area.

These simulations were conducted using the 95th percentile porewater concentrations used during the final design for Model Area C3. The cap design in this area originally included siderite based on consideration of pH levels throughout Model Area C3. Siderite was included in model areas where the pH exceeded 8 in order to promote biological decay of contaminants within the cap. However, based on consideration of pH and the cap modeling specific to MPC RA-C-1, siderite is not required.³ For consistency with the original design, it will be included in MPC areas RA-C-1A and RA-C-1D, and the sand/siderite layer has already been placed in RA-C-1C. However, based on the near-neutral pH in this area, it will be excluded from the direct application area RA-C-1B. Based on this, biological decay would be expected to occur throughout this area. However, biodegradation was conservatively excluded from the modeling of the direct GAC-amended and mono-layer cap areas. Although portions of the 6- to 9-meter zone may be considered net depositional, that process was conservatively not incorporated into the modeling for chemicals other than mercury in subarea RA-C-1B (see below).

Within most of RA-C-1, the deeper sediments (below approximately 2 feet) are considered to be over-consolidated as a result of the cap and sediment movement (i.e., the current overburden load is less than it has been historically), which reduces the amount of settlement that will result from cap placement. In addition, the direct application of GAC results in significantly less loading to the underlying sediment than the full-thickness cap that was used as the basis for the final design porewater flux estimates. Therefore,

³ Values for pH were collected from 51 samples collected from 10 sediment cores in this area. Of these, only 8 samples had a pH greater than 8, with a maximum of 8.4.

consolidation settlement and porewater flux estimates from the final design are considered conservative for this MPC evaluation.

Probabilistic modeling was not conducted for these MPCs. During the final design, although probabilistic modeling was performed for 13 separate modeling areas, the GAC dose was increased in one model area only—WBB1-8, which is not an area of concern for these evaluations. In this area, the GAC application rate increased by less than 10%. These results indicate that the deterministic modeling drives the GAC application rate in nearly all cases, and probabilistic modeling is not needed for these evaluations.

2.2.2 MNR Modeling to Evaluate Mercury in RA-C-1B

For mercury, the protectiveness evaluations conservatively assumed adsorption is not enhanced by the presence of GAC, consistent with the final design. Thus, in this modeling approach, the deposition of new sediments over time provides protectiveness for mercury by providing a layer over which adsorption to new sediments and dispersion attenuate porewater concentrations. Consideration of deposition is appropriate in model area RA-C-1B because a majority of the area is located in water depths greater than 6 meters, which may be considered net depositional as documented in Section 10 of Appendix D of the final design. A very small portion of RA-C-1B (approximately 0.03 acre) is located in water depths less than 20 feet and, therefore, would not be considered net depositional; however, surface concentrations are expected to be reduced over time in this small area as new, cleaner sediments (i.e., from gross deposition/resuspension) mix with the existing surface sediments. Because deposition rates have not been measured within the 6- to 9-meter zone, the modeling with the MNR model for areas within the 6- to 9-meter zone was conducted for a range of deposition rates observed in SMU 8. Mercury, therefore, was evaluated with the MNR model to evaluate concentration reductions over time for the RA-C-1B subarea as described in Section 2.3 of Anchor QEA (2015). In RA-C-1B, concentrations within the mixed layer were compared to the mercury PEC of 2.2 mg/kg. The specific inputs for RA-C-1B are as follows:

- The model mixed layer thickness was set to 6 inches.
- Because the sediments in this area have been disturbed and no recent measurements have been collected within the area, the initial mixed layer and buried layer

concentrations were set to the average concentration measured in sediment samples collected within RA-C-1B (all depths). These locations include OL-VC-20196, OL-VC-20173, and S38. Because of the wide range of concentrations observed, sensitivity to this parameter was assessed by simulating the maximum mercury concentration observed in this area (all depths; see Section 4.3).

- Sediment deposition rates in the 6- to 9-meter zone have not been measured. Deposition rates reported in Appendix M of the final design indicate the lower end of the range observed in SMU 8 is 0.08 g/cm²/year, and the midpoint of the range observed in SMU 8 is 0.25 g/cm²/year. Sediment traps deployed at South Deep station in 2012 resulted in deposition rates ranging from 0.1 g/cm²/year to 0.62 g/cm²/year (average of 0.26 g/cm²/year, which is similar to the deposition rate of 0.25 g/cm²/year used in the MNR modeling for SMU 8 during the final design). Consistent with the approach used for the SMU 8 MNR modeling presented in Appendix M of the final design, it is appropriate to use average deposition rates for long-term simulations. Because the 6- to 9-meter zone may be considered net depositional, it is expected that deposition rates in this area are greater than zero and may be similar to or less than deposition rates measured in SMU 8. Therefore, to capture the range of deposition rates that could be observed, caps within the 6- to 9-meter zone were simulated using an average deposition rate equal to the midpoint of the range observed in SMU 8 $(0.25 \text{ g/cm}^2/\text{year})$, as well as an average deposition rate of 0.08 g/cm²/year, which is equal to the low end of the range observed in SMU 8 based on the lowest mid-range rate from post-1986 sediment trap and core data, as presented in Appendix M of the final design.
- The model simulation period for mercury was 500 years (long enough to reach steady-state concentrations).

2.3 Adjacent SMU 8

The area of sediment movement in SMU 8 adjacent to Model Area C3 was delineated based on post-movement bathymetry and surface sediment sample results collected in 2014, which were provided in a separate submittal to NYSDEC. Based on the results of slope stability analyses, the portion of the cap movement area in SMU 8 is defined by three subareas (Figure 1). The subarea immediately adjacent to RA-C-1A is the SMU 8 RA-C-1A Transition Area, where the lifts from the multi-layer cap in RA-C-1A will transition into SMU 8 in a step-wise fashion from its full thickness at the RA-C-1A border to direct application only at the border out farther in SMU 8. GAC will be placed in the lower lift(s) of cap material extending into this Transition Area at the GAC application rate defined for the mono-layer cap in RA-C-1D. Based on the results of slope stability analyses, it is recommended that no cap material be placed within the portion of the cap movement area in SMU 8 adjacent to the Transition Area (shown on Figure 1 as Direct Application of GAC in portion of SMU 8). Instead, GAC will be applied directly to the sediment in this area. Farther out into SMU 8, slope stability analyses indicated that a thin layer of cap material could be placed (identified as Thin Layer Cap in Portions of SMU 8 on Figure 1). The following subsections describe the details of the modeling conducted for these two areas of sediment movement in SMU 8.

2.3.1 Direct Application of Amendments Subarea of SMU 8

Direct GAC amendment in one subarea of SMU 8 (see Figure 1) was represented in the model as a mono-layer cap as described in Section 2.2 of Anchor QEA (2015), consistent with the MERC that was designed and constructed in the area of the Metro deepwater outfall (Parsons and Anchor QEA 2014). However, the depth of bioturbation in the profundal zone differs from that in the littoral zone (6 inches): in SMU 8, the bioturbation depth was identified as 4 cm in the final design (Parsons and Anchor QEA 2012b); therefore, the model was configured to simulate the single GAC-amended chemical isolation layer having a thickness of 4 cm (it is expected that GAC will be mixed to a depth of 4 cm due to bioturbation). A nominally small thickness (1 cm) was specified for each of the other layers represented in the model, including the habitat restoration layer (0.5 cm of which was defined in the model as the bioturbation zone over which the model simulates mixing) and foundation layer. Mixing due to bioturbation was essentially ignored in this application. Consistent with modeling of mono-layer caps in the littoral zone, where the modeled thickness is equal to the bioturbation zone depth, the point of compliance for this 4-cm mono-layer cap (representing the bioturbation depth in the profundal zone) was in the middle of the bioturbation zone (i.e., middle of the 4-cm-thick active layer, which is 3 cm from the top of the 6-cm model domain).

Model input parameters for the direct application of GAC subarea of SMU 8 were consistent with those used in the final design for Model Area C3, with the following exceptions:

- In 2014, sediment cores were collected from the cap movement area and analyzed for VOCs, PAHs, PCBs, and mercury. The initial porewater concentrations in the model were set to the sediment concentrations measured within the SMU 8 direct application of GAC portion of SMU 8 converted to porewater using equilibrium partitioning. Of the four samples measured in this area, the highest concentration, OC-VC-80225 (0.13- to 0.49-foot interval), is much higher than any of the other samples, including the sediment samples from Model Area C3 used in the final design. For example, the naphthalene concentration of 2,300 mg/kg from OC-VC-80225 (0.13- to 0.49-foot interval) in the SMU 8 portion of the cap movement area compares with concentrations less than 100 mg/kg in all other samples in the SMU 8 cap movement area and a maximum of 770 mg/kg in Model Area C3 (Figure 2). It is possible that these high concentrations could indicate that this sample was affected by the presence of GAC placed prior to the cap movement (which would have absorbed high concentrations of contaminants), which would explain the unusually high concentrations; however, no core logs from this sampling event were available to corroborate this hypothesis. Because this sample does not appear to represent this cap area (even the sample collected from the depth interval above it is much lower), the organic chemical concentrations from the sample having the second-highest mean probable effects concentration quotient (PECQ), collected from location OL-VC-80224 (0.13- to 0.49-foot interval), were used in the analysis and considered representative of maximum contaminant concentrations in the area. These sediment concentrations were converted to porewater concentrations using the partition coefficients for sediment from Model Area C3 in the final design and the sample-specific total organic carbon results. Use of sediment data and partitioning theory to develop porewater concentrations for use in modeling in these areas was appropriate given that there are no new or historical porewater data from this area.
- Because this model subarea is located within SMU 8, the groundwater upwelling velocity was set to 1 cm/year, which is consistent with the value used in the final design SMU 8 MNR modeling (Parsons and Anchor QEA 2012b).



Figure 2

Probability Distribution of Naphthalene Concentrations in Sediment from Model Area C3 and Adjacent SMU 8 Cap Movement Area

Modified Protective Caps in Remediation Area C Onondaga Lake



MK - \\helios\D_Drive\Projects\Honeywell\Onondaga_Lake_Remediation(090139-01)\Cap_Modeling\Construction\RA-C_Disturbance\Data\prob_plot_analysis\OLP_prob_plot_RAC.pro Wed Mar 02 10:18:15 2016

For mercury, the protectiveness evaluations conservatively assumed sorption is not enhanced by presence of GAC, consistent with the final design. During final design, the thickness of the cap was relied on to provide the protectiveness required. In the case of direct GAC amendment, where no appreciable thickness of cap material is being placed, natural recovery of mercury was assessed with the MNR model. Mercury concentrations in the mixed and buried layer were set to 1.9 mg/kg, which is the maximum concentration measured in the direct application of GAC subarea of SMU 8.

The model-predicted porewater concentrations at the midpoint of the mixed layer from the transient numerical model, along with the MNR model-predicted mercury concentrations within the mixed layer, were used to calculate a time-variable mean PECQ using PEC-equivalent porewater values (Anchor QEA 2015 [Table 1]), which, along with the mercury PEC of 2.2, is the TLC protectiveness goal in SMU 8. Results from the transient numerical modeling and the mercury concentrations predicted from the MNR model were combined to calculate a mean PECQ. The method for calculating the mean PECQ involves removing non-detect concentrations. Therefore, model-predicted concentrations less than an assumed detection limit of 0.001 μ g/L were removed from the calculation. The transient numerical modeling was conducted starting with the minimal practical GAC application rate of 0.1 lb/sf, and the application rate was increased as necessary to meet a mean PECQ of 1 for more than 1,000 years. In addition, MNR model results were evaluated to verify that mercury concentrations within the mixed layer remain less than a mercury concentration of 2.2 mg/kg for more than 1,000 years.

2.3.2 Thin-layer Cap

Consistent with the Record of Decision and final design, a TLC is appropriate in SMU 8. Because the chemical concentrations are relatively low in this TLC area of SMU 8, a non-amended TLC is proposed. The TLC in SMU 8 was simulated with the MNR model developed for SMU 8 and modified to include organic chemicals, as described in Anchor QEA (2015). The TLC in this area will consist of an average thickness of 4.5 inches of sand. However, the depth of mixing in the profundal zone differs from that in the littoral zone (6 inches): in SMU 8, the mixing depth was identified as 4 cm in the final design (Parsons and Anchor QEA 2012b). Although the mixing depth in the profundal zone is 4 cm as shown on Figure 3 (schematic on the left), limits of the MNR model require that the mixed layer be set to the TLC thickness of 4.5 inches (as shown on Figure 3, schematic on the right). Compliance in this model is assessed within the mixed layer thickness, which is conservative because the depth of mixing (and exposure) is limited to the upper 4 cm.



Figure 3

TLC Area Cap Configuration

Notes: The schematic on the left illustrates the caps as proposed. The schematic on the right illustrates the caps as represented in the model.

Model input parameters for the TLC area were consistent with those used in the final design for Model Area C3, with the following exceptions:

- Biodegradation was conservatively excluded from the modeling.
- In 2014, sediment cores were collected from the TLC area and analyzed for VOCs, PAHs, PCBs, and mercury. The initial buried layer sediment concentration in the model was set to the concentrations from the TLC area surface sample from this sampling event having the highest mean PECQ collected from location OL-VC-80226 (0.13- to 0.49-foot interval).
- Because this model subarea is located within SMU 8, the groundwater upwelling velocity was set to 1 cm/year, which is consistent with the value used in the final design SMU 8 MNR modeling (Parsons and Anchor QEA 2012b).
- Organic compound concentrations on depositing particles were set to the average concentrations in surface sediments (0 to 4 cm) in the SMU 8 North Basin. These samples were chosen as they are likely representative of concentrations on settling particles that are not proximate to in-lake sources being remediated and, therefore, serve as a representative upper bound for future concentrations on settling particles.

The model-predicted sorbed-phase concentrations within the mixed layer were used to calculate a time-variable mean PECQ, which, along with the mercury PEC of 2.2, are the TLC protectiveness goals in SMU 8. Simulations were conducted to verify that the concentrations within the mixed layer remain below the mean PECQ of 1, as well as below a mercury concentration of 2.2 mg/kg for more than 1,000 years. The method for calculating the mean PECQ involves removing non-detect concentrations. Therefore, model-predicted sorbed-phase concentrations less than an assumed detection limit of 1 μ g/kg were removed from the calculation.

3 RESULTS

3.1 RA-C-1 MPCs

The GAC application rates for the four RA-C-1 subareas were developed based on the numerical modeling described in the preceding sections. For the multi-layer cap in RA-C-1A, where the design includes a designated habitat layer (sand or fine gravel), compliance with the PECs and SSCs was assessed against the maximum concentration within the habitat layer, consistent with the final design. For the mono-layer caps, where compliance is assessed within the sand/GAC layer, compliance was assessed against the PEC-equivalent porewater concentrations and SSCs for each of the chemicals evaluated at the midpoint of the 6-inch layer. For RA-C-1B, where less than 6 inches of cap material is placed, mercury was evaluated with the MNR model and compliance with the PEC of 2.2 mg/kg was assessed over the average concentration within the 6-inch bioturbation zone.

Transient numerical model results for the multi-layer cap in RA-C-1A indicates that 0.39 lb/sf GAC is sufficient to meet the PECs and SSCs for all 26 chemicals. The subareas RA-C-1B, RA-C-1C, and RA-C-1D were each modeled as a 6-inch mono-layer cap and the results indicate that a GAC application rate of 0.73 lb/sf is sufficient for all 25 organic chemicals to meet the target criteria for more than 1,000 years in these areas. For RA-C-1C and RA-C-1D, where cap material thickness (including already placed material) is equivalent to (or greater than) the modeled thickness, the transient numerical model results indicate that mercury will meet the PEC of 2.2 mg/kg for more than 1,000 years. In subarea RA-C-1B where GAC is placed directly onto sediments and the modeled cap thickness is greater than the placed cap thickness, the MNR model was used to evaluate mercury. Results of the MNR

modeling conducted for mercury in RA-C-1B indicate that at the mid-range value deposition rate of 0.25 g/cm²/year, mercury concentrations fall below the mercury PEC of 2.2 mg/kg within 15 years, reaching a steady-state concentration of 1.27 mg/kg. At the minimum deposition rate of 0.08 g/cm²/year, mixed layer concentrations fall below the PEC of 2.2 mg/kg within 30 years, reaching a steady-state concentration of 1.63 mg/kg.

3.2 SMU 8 RA-C-1A Transition Area

The RA-C-1A cap design transitions into SMU 8 in a step-wise fashion from its full thickness at the RA-C-1A border to direct application only at the border out farther in SMU 8. The lower lift(s) of cap material placed in this Transition Area will contain 0.73 lb/sf GAC, based on the transient numerical modeling conducted for the mono-layer cap in RA-C-1D.

3.3 SMU 8 Direct Amendment Area

Compliance for the direct GAC application portion of SMU 8 was assessed against a mean PECQ of 1 and a mercury PEC of 2.2 mg/kg within the model's mixed layer. The model results indicated that a GAC application rate of 0.1 lb/sf would be required to meet the mean PECQ of 1 in this area. However, given the uncertainty in concentrations within this area (see Section 2.3.1), the required GAC application rate of 0.73 lb/sf based on modeling conducted in the direct application of GAC areas RA-C-1B and RA-C-1C adjacent to SMU 8 will conservatively be applied to this direct amendment area as well. This GAC application rate of 0.73 lb/sf results in a GAC concentration of 12.5% by weight within the surface sediments assuming it is mixed throughout the 4-cm bioturbation zone assumed for SMU 8. This concentration of GAC within sediment is at the upper end of the literature-based range within which potential impacts to benthic growth and survival would not be expected (Janssen and Beckingham 2013). Therefore, higher GAC direct application rates are not recommended for this area. The maximum mercury concentration measured in this area was 1.9 mg/kg. The MNR modeling confirms that concentration of 0.68 mg/kg within 20 years.

3.4 SMU 8 Thin-layer Cap

Compliance for the TLC located in SMU 8 was assessed against a mean PECQ of 1 and a mercury PEC of 2.2 mg/kg within the model's mixed layer. The MNR model results

indicated that the predicted steady-state concentrations within the 4.5-inch TLC in SMU 8 result in a mean PECQ of 0.76 and a mercury concentration of 1.07 mg/kg and, therefore, the target criteria are met for the SMU 8 TLC.

4 SENSITIVITY ANALYSIS

This section describes sensitivity analyses that were conducted to evaluate select model input parameters.

4.1 Depth of Mixing

The model approach for subareas RA-C-1B, RA-C-1C, and RA-C-1D assumes the GAC placed directly on top of sediments will be mixed to a depth of 6 inches, which is the depth of mixing due to bioturbation in the littoral zone. Although bioturbation occurs to a depth of 6 inches, a sensitivity analysis was conducted to evaluate the impacts on model results if the GAC mixed to a depth that is 25% less than the bioturbation depth. To evaluate this scenario, the modeling for the direct application of GAC in these RA-C-1 subareas was repeated at a GAC application rate of 0.73 lb/sf and a thickness of 4.5 inches (with all other model settings unchanged, including assessing compliance at the midpoint of the bioturbation depth, or 3 inches). Results indicated that all chemicals meet the SSCs and porewater equivalent PECs for more than 1,000 years, except xylene, which was predicted to exceed the porewater-equivalent PEC after 569 years, and naphthalene, which was predicted to exceed the porewater-equivalent PEC after 920 years. However, compliance is expected for longer than this prediction because both biological decay of contaminants and natural deposition of clean sediments over time were conservatively excluded from the modeling simulation (using the low end of the deposition rate discussed in Section 2.2 results in a predicted deposition of 3.5 feet of new sediment during the 1,000-year modeling period).

4.2 Mercury Diffusion Coefficient in MNR Model for RA-C-1B

The molecular diffusion coefficient for mercury in the MNR model used to evaluate natural recovery in SMU 8 sediments during the final design was set to 202 cm²/year based on literature. The molecular diffusion coefficient for mercury in the cap modeling conducted during final design was 61.8 cm²/year, which was also based on literature (but a different source). The mercury molecular diffusion coefficient of 61.8 cm²/year was used to maintain

consistency with the final design cap modeling. Therefore, to evaluate its impact on results, a sensitivity analysis was conducted on the molecular diffusion coefficient of 202 cm²/year in the MNR model used to simulate mercury in RA-C-1. Simulations using this value were conducted for the low-end deposition rate of 0.08 g/cm²/year and the midpoint of the range observed in SMU 8 (0.25 g/cm²/year). The use of the higher diffusion coefficient of 202 cm²/year in the MNR model indicates that mercury concentrations are predicted to be less than the PEC of 2.2 mg/kg within 12 years, reaching a steady-state concentration of 1.70 mg/kg, when simulating the average deposition rate of 0.25 g/cm²/year with the higher molecular diffusion coefficient. Mercury concentrations are predicted to be less than the PEC of 2.2 mg/kg within 20 years, reaching a steady-state concentration of 1.97 mg/kg when simulating the low-end deposition rate of 0.08 g/cm²/year in conjunction with the higher molecular diffusion coefficient.

4.3 RA-C-1B MNR Model Initial Mercury Concentrations

Mercury concentrations in sediment (all depths) within the cap movement area of RA-C-1B range from non-detect to 15.9 mg/kg, with an average of 3.88 mg/kg. Because the sediments in this area have been disturbed and no recent measurements have been collected within the area, the average concentration from samples at all depths was deemed appropriate. However, given the large range of concentrations, a sensitivity analysis was conducted to evaluate the impact on results of using the maximum mercury concentration in RA-C-1B. Simulations using the maximum concentration of 15.9 mg/kg were conducted for the midpoint deposition rate observed in SMU 8 (0.25 g/cm²/year). MNR model results indicate that mercury concentrations are predicted to remain greater than the PEC of 2.2 mg/kg, reaching a steady-state concentration of 4.84 mg/kg.

5 REFERENCES

- Anchor QEA (Anchor QEA, LLC), 2015. Cap Modeling in Modified Protective Cap Area RA-D-1 and Adjacent Amended Thin-layer Cap in SMU 8. Prepared for Parsons. October 2015.
- Janssen, E.M.L. and B.A. Beckingham, 2013. Biological Responses to Activated Carbon Amendments in Sediment Remediation. *Environ. Sci. Technol.* 470:7595-7607.

- Parsons and Anchor QEA, 2012a. Onondaga Lake Capping, Dredging, Habitat and Profundal Zone (SMU 8) Final Design. Appendix B – Cap Modeling. Prepared for Honeywell. March 2012.
- Parsons and Anchor QEA, 2012b. Onondaga Lake Capping, Dredging, Habitat and Profundal Zone (SMU 8) Final Design. Appendix M MNR Modeling. Prepared for Honeywell. March 2012.
- Parsons and Anchor QEA, 2014. Onondaga Lake Capping, Dredging, Habitat and Profundal Zone (SMU 8) Final Design Metro Outfall Vicinity Design Addendum. Attachment 2
 Modified Erosion Resistant Cap Chemical Isolation Layer Modeling. Prepared for Honeywell. October 2014.

ATTACHMENT 1 ONONDAGA LAKE CAP MODELING FILES FOR MPC AREA RA-C-1 AND ADJACENT SMU 8



ATTACHMENT 1: MODEL FILES

This attachment details the files and directory structure associated with the numerical modeling conducted for the Modified Protective Cap (MPC) and the direct Application of GAC in RA-C-1 as well as for the thin-layer cap (TLC) and direct GAC amendment area in the adjacent area of Sediment Management Unit 8 (SMU 8). The cap modeling files are organized into two main folders:

- 1. Numerical Model
- 2. MNR Model

The following sections describe the files and subfolders contained in each folder.

Numerical Model

The numerical cap modeling files are contained in two subfolders:

- 1. Inputs
- 2. Outputs

The contents of each of these subfolders are described in this section. Please reference Attachment 4 to Appendix B of the final design (Parsons and Anchor QEA 2012¹) for the numerical model code files and their descriptions. In addition, the structure and formatting of the input and output files for this numerical cap modeling is identical to that from the final design; differences in input values from the final design associated with using the model to represent MPCs and the direct application of GAC are mainly what is described in the subsections that follow.

Numerical Model Inputs

The input files used for simulations with the numerical model are located in the *Numerical_Model**Inputs*| folder. Separate input files are used for each of the unique model areas evaluated as part of the RA-C-1 MPC and the direct amendment area in the adjacent portion of SMU 8 modeling efforts:

¹ Parsons and Anchor QEA (Anchor QEA, LLC), 2012. *Onondaga Lake Capping, Dredging, Habitat and Profundal Zone (SMU 8) Final Design.* Prepared for Honeywell. March 2012.

- 1. RA-C-1A-7lay.xls (RA-C-1A multi-layer MPC)
- 2. RA-C-1B.xls (RA-C-1B direct application of GAC onto sediments)
- 3. RA-C-1B-45in.xls (RA-C-1B.xls mono-layer MPC modeled as 4.5-inch cap for sensitivity analysis)
- 4. RA-C-1C.xls (RA-C-1C direct application of GAC onto layer of sand/siderite previously placed, and RA-C-1D mono-layer MPC²)
- 5. Direct application of GAC in SMU 8

The input files are identical in format and layout to those described and included in Attachment 4 to Appendix B of the final design. Each input file contains one tab per chemical modeled, as well as an *Input_Matrix* tab, which specifies the inputs for the various model parameters. Changes made to input values used in the final design for this modeling effort (e.g., initial porewater concentrations, cap configuration, decay parameters) are described in detail below.

RA-C-1A-7lay.xls

The input file titled *RA-C-1A-7lay.xls* was set up for modeling the RA-C-1A multi-layer MPC. Changes to this file, as compared to the Model Area C3 final design modeling, are highlighted in orange on the *Input_Matrix* tab, as well as the chemical-specific tabs, where applicable. The following changes were made:

- 1. The following inputs for cap configuration were specified for the purposes of developing GAC amendment application rates for all chemicals:
 - a. The habitat restoration layer thickness was set to a thickness of 22.86 cm.
 - b. The chemical isolation layer thickness was set to a thickness of 11.43 cm.
 - c. The foundation/siderite layer thickness was set to a nominal thickness of 1 cm.
- 2. The minimum number of grid points, in the "simulation parameters" section on each chemical-specific tab, was increased to 1,100 for numerical stability purposes.

² The modeling performed for RA-C-1C is also applicable to RA-C-1D because the same model input parameters, model construct, and chemicals evaluated are appropriate for both areas, as discussed in the main memorandum.

RA-C-1B.xls

The input file titled *RA-C-1B.xls* was set up for modeling the RA-C-1B direct application of GAC. Changes to this file, as compared to the Model Area C3 final design modeling, are highlighted in orange on the *Input_Matrix* tab, as well as the chemical-specific tabs, where applicable. The following changes were made:

- 1. Decay rates for volatile organic compounds (VOCs) were set to 1E-12 to effectively eliminate the effects of degradation kinetics in the model simulations (1E-12 is used because a non-zero number is necessary for model function).
- Organic carbon fraction (FOC) in the bioturbation zone was set to a nominally low value of 0.022% (the value used in the final design for cap sand) so that sorption would be negligible.
- 3. The following inputs for cap configuration were specified to represent the total simulated thickness of 6 inches for the purposes of developing GAC amendment application rates for all chemicals except mercury (which was simulated with the MNR model as described in the last section of this attachment):
 - a. The habitat restoration layer thickness was set to a nominal thickness of 1 cm.
 - b. The bioturbation zone thickness was set to a nominal thickness of 0.5 cm.
 - c. The chemical isolation layer thickness was set to a thickness of 15.24 cm.
 - d. The foundation/siderite layer thickness was set to a nominal thickness of 1 cm.
- 4. The minimum number of grid points, in the "simulation parameters" section on each chemical-specific tab, was increased to 1,100 for numerical stability purposes.

RA-C-1B-45in.xls

The input file titled *RA-C-1B-45in.xls* was set up for modeling the RA-C-1B, RA-C-1C, and RA-C-1C subareas as a 4.5-inch cap. Changes to this file, as compared to the Model Area C3 final design modeling, are highlighted in orange on the *Input_Matrix* tab, as well as the chemical-specific tabs, where applicable. Changes to this file compared to the Model Area C3 final design modeling are the same as those described above for *RA-C-1B.xls* modeling, except the cap thickness. The following inputs for cap configuration were specified to

represent the total simulated thickness of 4.5 inches for the purpose of evaluating sensitivity of GAC mixing to a depth that is 25% less than the depth of mixing due to bioturbation:

- 1. The habitat restoration layer thickness was set to a nominal thickness of 1 cm.
- 2. The bioturbation zone thickness was set to a nominal thickness of 0.5 cm.
- 3. The chemical isolation layer thickness was set to a thickness of 11.43 cm.
- 4. The foundation/siderite layer thickness was set to a nominal thickness of 1 cm.

RA-C-1C.xls

The input file titled *RA-C-1C.xls* was set up for modeling the RA-C-1C direct application of GAC onto sand/siderite layer that was previously placed and the RA-C-1D mono-layer MPC. Changes to this file, as compared to the Model Area C3 final design modeling, are the same as those described for RA-C-1B above, with the exception that mercury is included in the RA-C-1C.xls model file.

RA-C-1 SMU 8 Direct Application of GAC

The input file for modeling the direct application of GAC in adjacent SMU 8 is titled *RA-C-1-SMU8-DA.xls*. Changes to this file, as compared to the Model Area C3 final design modeling, are highlighted in orange on the *Input_Matrix* tab, as well as the chemical-specific tabs, where applicable. The following changes were made:

- 1. Decay rates for VOCs were set to 1E-12 to effectively eliminate the effects of degradation kinetics in the model simulations (1E-12 is used because a non-zero number is necessary for model function).
- 2. FOC in the bioturbation zone was set to a nominally low value of 0.022% (the value used in the final design for cap sand) so that sorption would be negligible.
- 3. The following inputs for cap configuration were specified to represent the direct application of GAC in model simulations to develop amendment application rates for this evaluation:
 - a. The habitat restoration layer thickness was set to a nominal thickness of 1 cm.
 - b. The bioturbation zone thickness was set to a nominal thickness of 0.5 cm.
 - c. The chemical isolation layer thickness was set to a thickness of 4 cm.
 - d. The foundation/siderite layer thickness was set to a nominal thickness of 1 cm.

- 4. The Darcy velocity was set to 1 cm/yr to represent groundwater upwelling velocities observed in SMU 8.
- 5. Initial buried layer porewater concentrations for each chemical were set to those found in the second-highest mean probable effects concentration quotient (PECQ) sample (OL-VC-80224 [0.13- to 0.49-foot interval]), with exception of mercury, which was modeled with the MNR model.

Numerical Model Outputs

The numerical model output files are located in the *Numerical_Model*|*Outputs*|*Det_Output*| folder. Within this folder, outputs for the model area evaluated are contained in a folder with the model area name. The outputs are saved in comma-delimited format (*.csv). Output file names used the same naming convention from the final design, which helps to understand the model scenario:

"Output_"<Model Area>"_"<Chemical Name Abbreviation>"_"<GAC application rate>"-"<Initial Concentration Type>

For file-naming purposes, the GAC application rate component of the file name does not include a decimal point. It should be understood that the decimal place is located between the first and second digits. For example, *Output_RA-C-1B_EB_073-C95_UT2.csv* is the file containing outputs from the model simulation of ethylbenzene using the 95th percentile porewater concentrations in Model Area RA-C-1B with a 0.73 lb/sf GAC application rate.

MNR Model

The MNR model was used to simulate mercury for the direct application of GAC in subarea RA-C-1B and to evaluate concentration reductions over time in the direct application area in the adjacent SMU 8; it was also used to simulate the TLC for all chemicals in SMU 8 (*MNR_TLC_revised_20160211.xlsm*). The model is based on the SMU 8 MNR model used in the final design, with slight modifications to allow for the simulation of organic chemicals.

These changes are described in Attachment 1 to Anchor QEA (2015)³. Model input settings specific to RA-C-1 and the adjacent TLC are as follows:

- For the case of the direct application of GAC in RA-C-1B (*MNR_Modeling_Mercury_RA-C-1 B_revised_20160201.xlsm*), the following specifications were made:
 - a. The model mixed layer thickness was set to a thickness of 6 inches.
 - b. The mixed layer and buried layer initial concentration was set to 3.88 mg/kg.
 - c. The sediment deposition rate was set to 0.25 g/cm²/yr to represent the midpoint of the range of deposition rates observed in SMU 8. Model simulations were also conducted using the lower end rate of 0.08 g/cm²/yr.
- For the case of the direct application of GAC in SMU 8 (MNR_Modeling_Mercury_RA-C_SMU_8_DA.xlsm), the following specifications were made:
 - a. The model mixed layer thickness was set to a thickness of 4 cm.
 - b. The initial mixed layer and buried layer concentration was set to 1.9 mg/kg, which is the mercury concentration from the sample with the highest mean PECQ as well as the maximum mercury concentration from this subarea.
 - c. The sediment deposition rate was set to 0.25 g/cm²/yr, which is the midpoint deposition rate measured in SMU 8.
- For TLC in SMU 8 (*MNR_TLC_Revised_20160211.xlsm*), the following specifications were made:
 - a. The mixed layer thickness was set to 4.5 inches.
 - b. The mixed layer was configured to initially represent the placed cap material (i.e., sand) by setting the initial concentration to zero.
 - c. The buried layer in the MNR model was set to the sediment concentrations that will be present beneath the placed cap material, based on concentrations from the 2014 surface sediment sample having the maximum mean PECQ (as described in the main memorandum).
 - d. The organic chemical concentrations on depositing particles was set to the average concentration measured in surface sediments in the North Basin.

³ Anchor QEA, 2015. *Cap Modeling in Modified Protective Cap Area RA-D-1 and Adjacent Amended Thinlayer Cap in SMU 8.* Prepared for Parsons. October 2015.

Everything else associated with this model file works similar to the SMU 8 MNR model from the final design (e.g., the "Run Model" button executes the code to run the model and outputs are generated for each simulated chemical; see "Instructions" worksheet for more detail).