

Appendix H
Water Quality Modeling Report

Report

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**Milwaukee Estuary AOC Dredged Material
Management Facility**

Project I.D.: 19W012

**WEC Energy Group – Business Services
Milwaukee, Wisconsin**

November 2020



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Project ID: 19W012

Prepared for
WEC Energy Group – Business Services
Milwaukee, Wisconsin

Prepared by
Foth Infrastructure & Environment, LLC

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List of Abbreviations, Acronyms, and Symbols

AOC	Area of Concern
cm/sec	centimeters per second
COC	contaminant of concern
CSO	Combined Sewer Outfall
DMDF	Milwaukee Jones Island Dredged Material Disposal Facility
DMMF	Dredged Material Management Facility
Foth	Foth Infrastructure & Environment, LLC
GLLA	Great Lakes Legacy Act
GLNPO	Great Lakes Program Office
IARC	International Agency for Research on Cancer
ITRC	Interstate Technology Regulatory Council
LWD	Low Water Datum
mg/kg	milligrams per kilogram
MMSD	Milwaukee Metropolitan Sewerage District
OU	Operable Unit
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PDI	Pre-Design Investigation
PFAS	per- and polyfluoroalkylated substances
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonate
TOC	total organic carbon
TSCA	Toxic Substances Control Act
USACE	U.S. Army Corps of Engineers
USEPA	United States Environmental Protection Agency
WDNR	Wisconsin Department of Natural Resources
WPDES	Wisconsin Pollutant Discharge Elimination System

1 Project Objectives and Approach

1.1 Objective

Foth Infrastructure & Environment, LLC (Foth) is developing a design for a potential Dredged Material Management Facility (DMMF) to contain dredged material from within the Milwaukee Estuary Area of Concern (AOC), on the behalf of WEC Energy Group-Business Services and Port Milwaukee. The DMMF will be located to the north of and adjacent to the existing Milwaukee Jones Island Dredged Material Disposal Facility (DMDF), with approximate location shown on Figure 1. The proposed DMMF described in the *DMMF Final Design Report* (Foth, 2020a), is to facilitate disposal of up to approximately 1.9 million cubic yards of impacted sediment from the downstream areas of the Milwaukee, Menomonee, and Kinnickinnic Rivers. The potential contaminants of concern (COCs) in these contaminated sediments are polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and metals.

The purpose of this *Water Quality Modeling Report*, which is Appendix H of the *DMMF Final Design Report*, is to describe how pore water quality within the DMMF is estimated, and evaluate the potential for contaminant transport across the proposed cellular cofferdam structure that will separate the DMMF from the waters of Lake Michigan. The contaminant transport evaluation also incorporates the portion of the DMMF southeastern perimeter where a connector platform and concrete grout-filled mattress-lined rubble mound dike (DMMF-DMDF Connector) will tie-in the cofferdam structure to the northeast corner of the existing DMDF rubble mound dike.

Pore water is defined as the water that occurs in the spaces between sediment particles within the DMMF. This *Water Quality Modeling Report* focuses on the prediction of water quality with respect to metals, PAHs, and PCBs during two phases: (1) initial pore water chemistry within the DMMF due to desorption of contaminants from dredged material; and (2) potential transport out of the DMMF into the waters of Lake Michigan. Predicted contaminant values are compared relative to current understanding of potentially applicable water quality standards. Assumptions upon which the models are based are described in detail in this report and include existing AOC sediment chemistry concentrations, equilibrium partitioning coefficients, desorption behavior, and contaminant transport mechanisms including resistance to pore water flux and seepage offered by the cofferdam structure, the grouted rubble mound connector, and lakebed sediment and clay.

1.2 Background and Design Considerations

The DMMF-DMDF Connector is necessary due to the presence of a rubble debris field adjacent to the existing DMDF, which prevents the placement of an additional cofferdam cell in that area. Foth considered several alternatives for connecting the cofferdam wall with the DMDF rubble mound dike:

1. Direct connection of a cofferdam cell with the DMDF rubble mound dike.

2. Cement-bentonite grouted rubble mound connector dike of similar design to the DMDF dike, between the DMMF and DMDF, utilizing a cement-bentonite slurry trench.
3. Connector platform based on steel sheet pile construction similar to the cofferdam cells and a rubble mound connector lined with concrete grout-filled mattresses.

The consideration of the alternatives identified significant implementability obstacles associated with the first two alternatives:

1. Cofferdams must be comprised of a series of complete cells to ensure full structural integrity. Installation of a full cell at the intersection of the DMMF wall and the existing DMDF rubble mound dike would require extensive removal of a portion of the DMDF dike in addition to clearing the armor stone along the slopes and toe of the structure. These materials would need to be removed to ensure that all of the sheet piles that comprise the cell can be driven to the proper embedment depth. The DMDF dike has been in place for nearly 50 years and disturbing it could compromise its structural integrity.
2. Installation of a cement-bentonite slurry trench through a rubble mound connector dike, while feasible, would be difficult to construct in a timely fashion and present significant field quality control testing obstacles over the full length necessary to span the gap between the last cofferdam cell and the DMDF dike.

The DMDF dike has functioned well as a containment and confinement structure for dredged material from the Milwaukee Estuary AOC for over 40 years, indicating that a connector dike designed to the same general specifications could be expected to perform equally as well. To minimize the length of the connector dike, a sheet pile-based connector platform can be constructed across the portion of the gap between the last cofferdam cell and the DMDF dike, covering the area of existing lakebed outside the toe of the DMDF dike. The connector platform will have the same sealed interlocks between the sheet piles on the interior face as designed for the cofferdam cells. The DMMF-DMDF Connector can be considered a “hybrid” of the cofferdam and rubble mound approaches.

For the reasons described above, the DMMF-DMDF Connector was selected as the best alternative for connecting the final cofferdam cell to the DMDF dike. To further improve the performance of the DMMF-DMDF Connector dike design, a concrete grout-filled mattress will be incorporated into the structure that will extend from the top of the dike to -5 Low Water Datum (LWD). The existing DMDF dike has provided adequate containment with a grout mattress that is placed from +10 LWD to -5 LWD and is not keyed into the lakebed sediments. Further, the concrete grout-filled mattress will be extended a distance of 50 feet along the surface of the existing outer face of the north dike of the DMDF from the same +10 LWD to -5 LWD elevation, to improve the containment properties of this portion of the dike.

Prior to construction of the DMMF, the Combined Sewer Outfall (CSO) 195, which is located within the footprint of the proposed location of the DMMF, along with the other related outfalls that discharge into the DMMF footprint, will be plugged and relocated. The Milwaukee

Metropolitan Sewerage District (MMSD) has proposed to relocate CSO 195 and these other outfalls, and the United States Environmental Protection Agency (USEPA) Great Lakes Program Office (GLNPO) has determined that the design of the CSO 195 relocation is a part of the January 6, 2020 Great Lakes Legacy Act (GLLA) Project Agreement among the Non-Federal Sponsors. The Project Agreement will be the ultimate vehicle for funding the implementation of dredging projects in the AOC, and represents a firm commitment to complete the relocation. Design of CSO 195 is included in MMSD's 2021 budget; design and construction of the sewer relocation is expected to seal the hole left by what would be the former CSO 195 discharge location.

1.3 Site Conceptual Model

The DMMF is envisioned to have two project phases from a water quality modeling perspective.

1.3.1 Operations Phase

The first phase, during operations, will occur after construction of the cofferdam and during filling of the dredged material into the DMMF, as described in more detail in the *Final Design Report*. During this phase of dredged material placement into the DMMF, an inward hydraulic gradient will be maintained and, as water is pumped out, it will be treated at an on-site water treatment plant to meet water quality limits under a Wisconsin Pollutant Discharge Elimination System (WPDES) permit. Design of the water treatment facility, with specifications to meet the associated permit, will be determined by others as the details of the individual projects intending to dispose of dredged material within the DMMF are developed. The evaluation of anticipated concentrations of COCs in the sediments to be dredged and disposed of in the DMMF, as described in Appendix E of this *Final Design Report*, present no particular treatment design difficulties for the associated carriage water. Discussion of the carriage water handling systems for the DMMF are included in Appendix M of this *Final Design Report*.

It is not necessary to always maintain an inward gradient in order to prevent the release of contaminants from the DMMF but, as proposed, the inward gradient provides an added level of protection. At times, it may not be feasible to maintain an inward gradient over the short term (i.e., hours) should Lake Michigan water levels fluctuate significantly due to seiche or storm surges, surpassing reasonable pumping capacity to draw down water levels within the facility. In addition, it may not be cost effective to operate a water treatment system over the winter with no dredging operations. The water travel time through the sealed sheet piles within the cofferdam structure is estimated to be thousands of years and offers adequate control by itself, as described in Section 4 of this appendix.

1.3.2 Closure Phase

The second phase of the project, from the water quality modeling perspective, concerns the long-term behavior of the DMMF in closure, as described in more detail in the *Final Design Report*. During this phase, the sediment will be contained within the cofferdam structure under saturated conditions. The objective of the water quality modeling report is to predict water quality within the DMMF during the closure phase and to understand the potential for contaminant transport through pathways, as presented on Figures 2 through 5.

2 Initial Pore Water Calculations

Initial pore water concentrations within the DMMF due to desorption of contaminants from dredged material can be estimated using an input of predicted sediment concentrations from the AOC and assumed chemical-specific, sediment-water partitioning coefficients, also known as distribution coefficients. The geochemical mechanism accounted for in this calculation is desorption, whereby contaminants sorbed to sediment become soluble and mobile in the aqueous pore water phase. The concentrations of contaminants in the pore water are dictated by the associated contaminant-specific equilibrium partitioning coefficient. The calculations used to derive pore water concentrations from sediment and the selection of appropriate and representative partitioning coefficients are described herein.

2.1 Partitioning Coefficient Values

The partitioning coefficient describes the equilibrium relationship between contaminant concentrations in the sorbed-to-sediment phase and the aqueous dissolved phase within the saturated dredged material of the DMMF. In general, the partitioning coefficient for a chemical, K_d , can be described using the following equation:

$$K_d = C_{\text{sediment}}/C_{\text{pore water}}$$

where:

C_{sediment} is the concentration of contaminant in the sediment or dredged material, and
 $C_{\text{pore water}}$ is the concentration of contaminant in the dissolved aqueous phase.

Beyond this general equation, the specific application of partitioning coefficients differs for each of the COCs. The degree of sorption/desorption depends on the nature and the mass of the contaminant in solution or bound to sediments; for organic contaminants such as PAHs and PCBs, concentrations in pore water are also a function of the amount of organic material present in the sediment.

The K_d values are important to estimate the retardation behavior of a particular contaminant or chemical in sediment or other porous media. Chemical retardation occurs when a contaminant reacts with the sediment/porous media and its rate of movement is retarded relative the advective groundwater velocity because in addition to movement as dissolved phase in water, there is transfer of contaminant mass between water and the solids in the porous media. Retardation rates of contaminants are highly variable and depend upon the chemical specific parameter K_d and media specific parameters such as bulk density and porosity as follows:

$$R_f = 1 + (\rho_b \cdot K_d)/n$$

where:

ρ_b is bulk density of sediment /porous media

n is the effective porosity of the sediment / porous media

The greatest limitation of using a published K_d value to calculate a retardation term is that it is only applicable to a single set of environmental conditions. Geochemical factors such as pH, redox state, sediment characteristics, and the nature and concentration of sorbents in the system

can exert strong influence on the magnitude of K_d (USEPA, 2005; PNNL, 1989; USEPA, 1996). Coefficient values reported in the literature for contaminants may vary several orders of magnitude, and thus predicted pore water concentrations can differ based on the value chosen partitioning coefficient.

A literature survey was conducted to identify appropriate, representative, and generally conservative partitioning coefficients for each contaminant. Previous studies reporting results of more exhaustive literature surveys have documented the large variation and range in K_d values for metals (USEPA, 2005), PAHs (Arp, 2009), PCBs (International Agency for Research on Cancer [IARC], 2018), and per- and polyfluoroalkylated substances (PFAS) (Interstate Technology Regulatory Council [ITRC], 2020).

The K_d values used by the U.S. Army Corps of Engineers (USACE) Tier II Screening Evaluations for Confined Disposal Facility Contaminant Pathway Migration are provided in the Chemical Data Base associated with this tool (USACE, 2003). The K_d values for metals, PAHs, and PCBs were chosen for use at this DMMF because they are within the middle range of published K_d values and lean towards conservative assessments of contaminant transport. These values have been used successfully at other comparable waste disposal sites that have similar geochemical context, and they represent accepted values from a risk evaluation perspective.

2.1.1 Metals

The sediment-water partitioning coefficient for metals is affected by many geochemical processes and parameters, including pH, sorption to clays, organic matter, iron oxides, and other sediment sorbing sites, background pore water chemistry, and speciation of metal. Metals behavior is also strongly dependent upon the redox conditions in the environment. Because of the complexity of environmental factors that influence metal sorption, the reported measured values for metal K_d values can range up to seven orders of magnitude (USEPA, 1996). Partitioning coefficients for each metal are taken from the USACE Tier II spreadsheet tool and are listed in Table 1.

2.1.2 PAHs

Hydrophobic contaminants in sediment, such as PAHs, partition between the organic carbon fraction in sediment and sediment pore water in a constant ratio, and that ratio can be used to predict the fraction of a contaminant that is freely dissolved in pore water from the concentration in the sediment. The ratio is called the organic carbon partitioning coefficient, K_{oc} . The n-octanol-water partition coefficient K_{ow} is a ratio describing the partitioning of a nonpolar organic compound between water and octanol. Published values are typically either for K_{oc} or for K_{ow} , which are similar and can be related to one another through the following equation (Karickhoff et al., 1979):

$$\text{Log } K_{oc} = -0.21 + \text{log } K_{ow}$$

Similarly to K_d values for metals, the K_{oc} values in literature can have significant variability, with reported measured values for a given compound varying several orders of magnitude (USEPA, 1996). The solubility of individual PAHs varies based on the molecular weight of the compounds, with low molecular weight compounds being more soluble and having less affinity

for surfaces than do high molecular weight compounds. The K_{oc} values used here and presented in Table 1 are taken from the USACE Tier II spreadsheet tool. The K_{oc} is related to K_d by the fraction of organic (f_{oc}) matter present in the sediment or porous media as follows:

$$K_d = K_{oc} * f_{oc}$$

The calculated K_d values for PAHs were used with site-specific AOC bulk input sediment concentration to calculate initial pore water concentrations.

2.1.3 PCBs

Hydrophobic contaminants such as PCBs have a low solubility in water and sorb strongly to organic material in sediment and suspended solids. The solubility of individual PCBs varies based on the molecular weight, with low molecular weight compounds being more soluble and having less affinity for surfaces than do high molecular weight compounds. PCBs sorption behavior can be modeled in a manner comparable to PAHs, using published K_{oc} or K_{ow} values, and assuming a fraction of organic matter. We chose to model the sorption of PCB Aroclors rather than specific congeners because of the availability of K_d values and to facilitate comparison to the potentially applicable water quality criteria. The K_{oc} values used are taken from the USACE Tier II spreadsheet tool and presented in Table 1.

2.1.4 PFAS

PFAS typically consist of a carbon-fluorine “tail” that is hydrophobic and lipophobic and a nonfluorinated, polar functional “head” group that is hydrophilic. These competing tendencies mean multiple partitioning mechanisms can influence their mobility and add complexity in modeling their transport. Regarding sorption, PFAS tend to associate with the organic carbon fraction present in sediment. Sorption and retardation generally increase with increasing tail length, suggesting that the short-chain PFAS are retarded less than long-chain counterparts. In addition, sulfonates sorb more strongly than do carboxylates, and branched isomers sorb less than linear forms. Decreasing pH and increasing concentration of polyvalent cations can cause increased sorption. The K_{oc} values presented in Table 1 are the midpoint of the range of values presented in Table 4 of the *Environmental Fate and Transport for Per- and Polyfluoroalkyl Substances*, (Interstate Technology Regulatory Council, 2020).

2.2 Organic Carbon Percent

Measured values for the fraction of organic carbon, f_{oc} , are available for sediments planned for containment within the DMMF, as some previous investigations have included Total Organic Carbon (TOC) in their assays. The *Focused Feasibility Study Report* (CH2M, 2019) reported TOC concentrations, in surface (0 to 0.5 foot) and subsurface sediment in the Milwaukee River Operable Unit (OU) 2, were relatively similar and that average TOC concentrations ranged from 36,862 milligrams per kilogram (mg/kg) to 45,920 mg/kg in the subsurface sediment. Conservatively using the lowest reported value, the assumed value for fraction of organic carbon is 3.6% (f_{oc} is the TOC content expressed as percentage).

2.3 Sediment Chemistry

In addition to selection of the partitioning coefficient, use of site AOC data and data use assumptions on initial sediment concentrations is an important factor in estimating pore water concentrations.

To conservatively estimate concentrations of each COC in dredged material contained within the DMMF, the median concentration of the COC was calculated from dredged material sourced from the AOC river segment reach that contains the most elevated concentrations of the given COC. The median concentration of the COC was used instead of the 95% upper confidence limit because the dataset was already censored to be conservatively biased to the worst-case reaches of the AOC. Filling of the DMMF will occur from all river segments of the AOC, thus relying upon input sediment concentrations from the most elevated river segment is a conservative approach. A more detailed description of the input sediment chemistry, including statistical summaries of available data, is provided in *the Milwaukee Estuary Area of Concern Sediment Report* (Foth, 2020b), which is Appendix E of the *Final Design Report*.

2.3.1 Metals

To estimate concentrations of metals in sediment to be contained within the DMMF, the median concentrations of metals were calculated from sediment collected from Reach 4 of the Milwaukee River, the area of the Milwaukee Estuary AOC that contains the highest sediment metal concentrations of those areas previously investigated. The metals concentrations from previous investigations are described in detail in the *Milwaukee Estuary AOC Sediment Report* (Appendix E of the *Final Design Report*). Metals concentrations in Reach 4 vary over a range that is up to 4 orders of magnitude; median concentrations are presented in Table 7 of the *Milwaukee Estuary AOC Sediment Report*.

2.3.2 PAHs

To estimate concentrations of PAHs in sediment to be contained within the DMMF, the median concentrations of PAHs were calculated from Milwaukee River OU2 sediment – the area of the Milwaukee Estuary AOC that contains the highest sediment PAHs concentrations of those areas previously investigated. The PAHs concentrations from previous investigations, including OU2, are described in detail in the *Milwaukee Estuary AOC Sediment Report*. PAHs concentrations in OU2 vary over a range that is up to 6 orders of magnitude; median concentrations are presented in Table 7 of the *Milwaukee Estuary AOC Sediment Report*.

2.3.3 PCBs

Concentrations of PCB in sediment to be contained within the DMMF were estimated by two approaches. The first and more conservative assumption was that PCB sediment concentration may fall just below the Toxic Substances Control Act (TSCA) limit of 50 mg/kg. The second assumed input was based on the median concentrations of PCBs calculated from measured values from Milwaukee River Reach 4 sediment, the area of the Milwaukee Estuary AOC that contains the highest sediment PCB concentrations of those areas previously investigated. The PCB concentrations from previous investigations, including Reach 4, are described in detail in the *Milwaukee Estuary AOC Sediment Report*. PCB concentrations in Reach 4 vary over a range

that is up to 4 orders of magnitude; median concentrations are presented in Table 7 of the *Milwaukee Estuary AOC Sediment Report*.

2.3.4 PFAS

Site-specific data regarding PFAS concentrations within the immediate vicinity of the Milwaukee Estuary AOC were sampled by Wisconsin Department of Natural Resources (WDNR) in November 2019. The PFAS concentrations for 35 different PFAS compounds are presented in Table 6 of the *Milwaukee Estuary AOC Sediment Report*, Appendix E of the *Final Design Report*. Summary statistics for the two PFAS compounds for which water quality criteria have been proposed in Wisconsin (perfluorooctanoic acid [PFOA] and perfluorooctane sulfonate [PFOS]) are presented in Table 8 of Appendix E of the *Final Design Report*. To estimate concentrations of PFOA and PFOS in sediment to be contained within the DMMF, the median concentrations of PFAS were calculated from the Kinnickinnic River sediment – the area of the Milwaukee Estuary AOC that contains the highest sediment PFAS concentrations of those areas sampled. The PFAS concentrations from WDNR sediment sampling in the Milwaukee River Estuary are discussed in more detail in *PFAS Sampling Results in the Milwaukee Estuary AOC* (WDNR, 2020). PFAS concentrations for PFOS and PFOA vary over a range that is one order of magnitude; median concentrations are presented in Table 8 of the *Milwaukee Estuary AOC Sediment Report*.

3 Initial Pore Water Estimate

Initial pore water concentrations were calculated for each parameter by dividing the input representative AOC bulk sediment concentrations by the respective partitioning coefficients. This can be expressed mathematically as:

$$C_{\text{porewater}} = C_{\text{sediment}} / (K_{\text{oc}} * f_{\text{oc}})$$

As described in Section 2, the C_{sediment} and f_{oc} values are representative of measured concentrations within the Milwaukee Harbor AOC sediment whereas the OC partitioning coefficients (K_{oc}) are literature-derived values. The predicted equilibrium pore water concentrations are presented in Table 1.

3.1 Applicable Water Quality Criteria

Concentrations of contaminants in the modeled initial pore water were compared to applicable water quality criteria. The COCs that are predicted to be highest concentration relative to potentially applicable water quality criteria are mercury and PCBs, and are considered the “drivers” of the transport model, and used to inform design of the DMMF wall material and structure. The contaminant transport model, which accounts for migration of COCs from within the DMMF to the waters of Lake Michigan, is discussed in more detail in Section 4.

The applicable water quality criteria are presented in Table 2, and help to evaluate the significance of the initial predicted equilibrium pore water concentrations and to identify the specific contaminants that can be the focus of the contaminant transport model. As mentioned, two COCs, mercury and PCBs, identified as bioaccumulating chemicals of concern, have low applicable water quality criteria and predicted pore water concentrations significantly higher than the water quality criteria. Thus, these two COCs have the largest factor of difference, several orders of magnitude, between the predicted pore water concentrations in Table 1 and the applicable water quality criteria in Table 2.

Using this approach, the focus of the contaminant transport modeling centers on mercury and PCBs, as the projected pore water concentrations within the DMMF for these two contaminants are significantly above the water quality criteria when the prediction is based on the K_d value from USACE.

It is noteworthy that based on the range of K_d values available in published literature, the calculated pore water value for mercury and for PCBs could be much less than presented here.

4 Contaminant Transport

The potential for transport of contaminants, from the pore water in the DMMF to the waters of Lake Michigan, is evaluated in this section of the report. The hydraulic characteristics of the interface between the DMMF and the waters of Lake Michigan are critical to the evaluation as the primary pathway for this pore water and associated contaminants to reach Lake Michigan is by passing through the multiple components of the DMMF outer wall (cellular cofferdam). The cellular cofferdam is the primary structure separating the dredged sediments within the DMMF from the waters of Lake Michigan, while a limited portion of the DMMF perimeter consists of a steel sheet pile connector platform and a concrete grout-filled mattress-lined rubble mound connector. The DMMF-DMD Connector, shown in Appendix J - Sheets S01, S06, and S24-26, serves to tie-in the last cell of the cellular cofferdam structure to the northeast corner of the rubble mound dike of the existing DMDF. The required tie-in distance between the toe of the DMDF berm and the last cofferdam cell is approximately 27 feet.

The cross section of the connector berm portion of the DMMF-DMDF Connector is a trapezoidal shape with the crest of the berm having a width of 50 feet, and the base of the berm being approximately 110 feet in width. Per the design, the cellular cofferdam walls and the DMMF-DMDF Connector will provide an essentially non-transmissive barrier to the flow of water, thereby effectively preventing the migration of suspended solids and dissolved contaminants from within the DMMF's contaminated dredged material into the waters of Lake Michigan. Further details regarding the design and effectiveness of the cofferdam are provided below and in the design sections of this *Final Design Report*.

4.1.1 Contaminant Migration Pathway Conceptual Models

Conceptual models illustrating important contaminant transport pathways are presented on Figures 1 through 5; details are discussed further in Sections 4.2, 4.3, and 4.4. Figure 1 shows an aerial view of the DMMF location, with the location of representative cross sections. Contaminant transport pathways that are important considerations during operations phase are conceptualized in the not-to-scale illustrations on Figure 2, showing the cofferdam, and on Figure 3, showing the rubble mound connector. Contaminant transport pathways that are important considerations during the closure phase are conceptualized in the not-to-scale illustrations on Figure 4, showing the cofferdam, and on Figure 5, showing the rubble mound connector.

Figures 2 and 3 present the DMMF during operations. The dredged material is underlain by sandy silty sediments, which in turn are underlain by lakebed sediments. An existing sheet pile wall forms the western boundary of the proposed DMMF location. The lakeside is shown to the right (east) side of the figures, and accounts for potential water level fluctuation. The water layer that overlies the dredged material within the DMMF will be pumped to maintain an inward gradient during dredging and filling operations. The blue arrows highlight potential contaminant transport processes incorporated in this evaluation, and include precipitation of rain and snow, infiltration, volatilization, leaching and seepage. On Figure 2, pore water flux out of the DMMF is restricted or cut off at the sheet pile on the DMMF side, which will be built to meet performance specifications for sealant installation or welding and keyed into the native sediments to essentially prevent contaminant transport. Similarly, seepage and transport of pore

water out of the DMMF into the lakebed sediments and clay will be restricted due to the low hydraulic conductivity of those native materials.

The DMMF-DMDF Connector will act in a similar manner as the cofferdam to restrict contaminant transport. On Figure 3, pore water flux out of the DMMF will be restricted or cut off, modeled as a grout/cement wall within the rubble mound connector, which will be built to meet performance specifications for thickness and material properties and keyed into the existing DMDF to effectively prevent contaminant transport. As on Figure 2, seepage of pore water from within the DMMF is envisioned to be essentially prevented at the lakebed sediment/clay horizon, which has very low hydraulic conductivity discussed further in Section 4.2.

Figures 4 and 5 present the DMMF in closure, after filling with dredged material is complete. In these figures, the dredged material is no longer covered by water, as a final soil cover is present, but may be saturated at depth, partially saturated in some zones, and unsaturated towards the surface. The cofferdam wall shown on Figure 4 will continue to restrict transport of contaminants out of the DMMF, as will the rubble mound portion of the DMMF-DMDF Connector shown on Figure 5. Seepage of pore water from within the DMMF will be restricted at the lakebed sediment due to its low hydraulic conductivity. As the site is developed by Port Milwaukee, the surface may be paved or otherwise covered with additional materials that will further limit infiltration.

4.2 Relevant Design Features of Cofferdam

A steel cellular cofferdam design is planned for the DMMF. The structure is planned to be tied into the existing sheet pile bulk head at its western end, while the eastern end of the structure will terminate into a breakwater that ties into the existing breakwater of the existing DMDF. As a result, the contaminated sediments will effectively be enclosed inside a virtually impermeable structure. Potential movement of water, such as the DMMF pore water, and consequent migration of contaminants dissolved in the pore water, could only occur through isolated spots in the structure such as the joints between individual sheet piles constituting the cofferdam. As described below, the cofferdam is comprised of steel sheet piles on the interior and exterior face, separated by 42 feet of engineered fill. Any water originating from the interior of the DMMF must follow a tortuous pathway through these multiple layers before reaching the external wall and the waters of Lake Michigan.

The plan view of the cellular cofferdam structure is provided in Appendix J of the *Final Design Report*. Sheet S01 shows that the structure will act as a barrier between the contaminated sediments in the DMMF and the waters of Lake Michigan. Detailed layouts of various sections of the cofferdam structure are shown on Sheets S02 through S08.

Planned elements of the structure that are relevant to the flow of water include the following:

- ◆ Each individual cell is 46 feet in diameter.
- ◆ The cell wall will be built using AS500 sheet pile type or equivalent.
- ◆ Each sheet will be 1.64 feet (0.5 meters) wide.

The seams of the sheets facing the DMMF side, i.e., exposed to pore water within the contaminated sediments, will be sealed or welded, thereby essentially eliminating significant flow of water through the structure. Approximately 83,000 linear feet of cumulative seams between the dredged materials and the cells will be sealed or welded. The decision to seal or to weld will be made by the selected contractor prior to installation and will be based in part on meeting performance specifications, which will effectively create an impermeable barrier. This impermeable barrier to flow will result in compliance with NR 299.04 (1) (b) water quality standards by practically eliminating transport through the barrier such that the pathway for the contaminants is eliminated and no longer needs to be evaluated further nor monitored for compliance.

- ◆ The sheets facing Lake Michigan will be connected using interlocks, which significantly restrict, but do not completely eliminate seepage. This serves as a second line of defense, preceded by the sheets facing the DMMF described previously. Since the travel time between the two sets of sheets is thousands of years, approaching 9,000 to 15,000 years based on the selection of sealants or welding, the compliance with NR 299.04 (1) (b) water quality standards will already be demonstrated upgradient of the sheets facing Lake Michigan. Therefore, sealing of interlocks for the sheets facing Lake Michigan is not necessary.
- ◆ The interior of each cell will be filled with compacted engineered fill with a bulk density of 125 pounds per cubic foot.

Sheets S07 and S08, which are provided in Appendix J of the *Final Design Report*, depict detailed cross sections of the cofferdam structure. The sheet piles constituting the inner and outer walls of the cofferdam structure will be embedded to -52 feet LWD to ensure their stability as a freestanding, gravity-supported structure. This embedment depth is well below the mudline, thus effectively eliminating the under toe seepage pathway for contaminant migration for the cofferdam portion of the DMMF.

4.3 Relevant Design Features of DMMF-DMDF Connector

The relevant sections of the DMMF-DMDF Connector will be built to the same general specifications as the cellular cofferdam and the existing DMDF with a grout mattress incorporated into the interior face of the dike. In addition, concrete grout-filled mattresses will be placed between the rubble mound connector's edge and the connector platform and at the slope between the rubble mound connector and the existing DMDF. The grout-filled mattresses will extend a distance of 50 feet along the surface of the existing outer face of the north dike of the DMDF from +10 LWD to -5 LWD elevation, to improve the containment properties of this portion of the dike. Sheet S26 in Appendix J of the *Final Design Report* depicts detailed cross sections of the rubble mound connector structure.

The grout mattresses will be built to performance specifications that will include:

- ◆ A design hydraulic conductivity of 1×10^{-8} centimeter per second (cm/sec) or lower. Field testing will validate the in place grout-filled mattresses, to the extent possible.

The flow underneath the connector will be controlled by the hydraulic conductivity of the underlying lakebed sediments. A review of the literature suggests that the lakebed sediments in Lake Michigan have low hydraulic conductivities. For the purpose of migration of contaminants from the DMMF into Lake Michigan waters via seepage through the bottom, the model calibrated vertical hydraulic conductivity values of lakebed sediments range from 3.5×10^{-7} cm/sec to 3.5×10^{-5} cm/sec (USGS, 2010), while a regional study by Bradbury and Taylor (1984) indicates that the clayey material at the Lake bottom has hydraulic conductivity in the range of 5×10^{-8} to 2×10^{-5} cm/sec. These materials will restrict flow through the bottom of the DMMF. Boring logs from the existing DMDF as well as the borings from the Pre-Design Investigation (PDI) confirm the presence of clay underneath the DMMF area. Hydraulic conductivities of lakebed sediments in the DMMF area were estimated in the lab from five samples collected during the PDI investigation, with values that range from 1×10^{-8} to 5×10^{-8} cm/sec, indicating strong resistance to contaminant migration. The boring logs and the hydraulic conductivity report from the PDI are provided in Appendix L of the *Final Design Report*.

4.4 Implications on Contaminant Transport

4.4.1.1 Cofferdam

A cofferdam design using sheet piles provides an impervious structure and therefore greatly minimizes water flow, with the possible exception of interlocks that connect the individual sheets. The interlocks offer resistance to flow which minimizes the conductance of water and therefore seepage across the sheet piles. However, the sheet piles with interlocks will not completely eliminate flow unless additional design components are integrated into the cofferdam structure. These additional components are discussed below as they will be incorporated into the DMMF design.

A 2017 research study on impervious sheet pile interlocks was performed by ArcelorMittal, the largest world-wide producer of sheet pile, in collaboration with Deltares Netherlands Centre for Coastal Research (Delft Geotechnics). The resulting in-situ measurements of resistance to flow offered by sheet pile interlocks under various configurations are available at:

http://www.arcelorprojects.com/projects/europe/foundationsolutions/ADNL/PDF/impervious_EN.pdf.

The goal of the referenced study was to quantify seepage or flow through sheet piles that were connected with empty interlocks, interlocks filled with various sealants, or welded interlocks. The seepage (discharge) through the interlock is proportional to two primary factors:

- ◆ The pressure drop across the sheet due to the difference in water levels on either side of the sheet.
- ◆ The conductance of water through the interlock.

The study compared the rate of seepage through sheet pile with interlocks to an equivalent slurry wall that is approximately 2 feet thick. Findings concluded that the use of sealants can reduce the seepage through the interlocks by several orders of magnitude, depending upon the type of sealant used, is shown as follows:

Sealant Type	Normalized Seepage (Empty Interlock used as Base Case)	Equivalent Hydraulic Conductivity (cm/sec)
Empty Interlock	1	2.4E-05
Beltan Plus	1.E-01	5.1E-06
Arcoseal	1.E-01	5.1E-06
Roxan Plus	1.E-04	2.6E-09
AKILA	7.E-05	1.6E-09

Notes: For comparison, unconsolidated sediment hydraulic conductivities are provided below:

- ♦ Clay- 1E-09 to 1E-06 cm/sec.
- ♦ Silt, sandy silts, clayey sands – 1E-06 to 1E-04 cm/sec.

Expected travel times for contaminants through the sheet piles with various interlock sealants, assuming no adsorption (i.e., the contaminants are not retarded and travel at the same velocity as water), are shown in Table 3. An empty interlock with no sealant will transmit water at a slow rate, such that it may take approximately one year for the water and any dissolved contaminants to seep through. However, sealants offer varying degrees of resistance to flow, with the strongest sealant slowing down the seepage to a miniscule rate such that it can take thousands of years for the water to seep through the sealed interlock. A sealant that offers a hydraulic conductivity near 1×10^{-9} cm/sec, either Roxan Plus, AKILA, or an equivalent, will be required in the final specifications for use in the DMMF construction. Welded sheets can offer even higher flow resistance. Therefore, water flow or seepage and contaminant migration is expected to be insignificant through the sealed or welded sheets over the life of the DMMF structure.

4.4.2 Rubble Mound Connector Portion of the DMMF-DMDF Connector

The rubble mound portion of the DMMF-DMDF Connector with concrete-grout filled mattresses on the interior face and at the connections at the edges is expected to perform to specifications that will offer resistance to water flow on the basis of the specified low hydraulic conductivity of 1×10^{-8} cm/sec and therefore minimize the conductance of water and seepage across the connector into Lake Michigan. Expected travel times for contaminants through the connector, assuming no adsorption (i.e., the contaminants are not retarded and travel at the same velocity as water), are shown in Table 4. The evaluation conservatively assumes that head inside the DMMF is about 1 foot higher than outside the DMMF in Lake Michigan, creating an outward hydraulic gradient that remains consistent over time. In reality, the head differential varies over time, and the DMMF will be operated through pumping during dredging and filling to maintain a water surface elevation below lake level, resulting in lack of potential flow from the DMMF to Lake Michigan. The connector will transmit water at a slow rate ranging from 0.014 to 0.005 feet per year based on the effective porosity of the grout. As a result, it may take approximately 290 to 870 years for the water and any dissolved contaminants to seep through the modeled equivalent 4-foot grout layer in the unlikely instance of a 1-foot head inside the DMMF. Therefore, water flow or seepage and contaminant migration is not expected to be significant through the connector over the life of the DMMF structure.

5 Conclusions

Initial pore water concentrations within the DMMF due to desorption of contaminants from dredged sediments were estimated using 1) a literature based chemical-specific, sediment-water partitioning coefficient taken from the USACE (2003); 2) input dredged sediment concentrations, estimated at the average median concentration of each contaminant from representative reaches of the Milwaukee Estuary AOC that contain the highest concentrations of respective COCs; and 3) recent data collected by WDNR on sediment concentrations of PFAS in the Milwaukee Estuary AOC.

Comparing concentrations of contaminants in the modeled initial pore water to applicable water quality criteria showed that mercury and PCBs have the largest factor of difference, several orders of magnitude, between the predicted pore water concentrations in and the applicable water quality criteria. Potential contaminant transport mechanisms focused on these two parameters. The contaminant transport modeling has demonstrated that flow or seepage will be adequately restricted with the proposed cofferdam design, such that conservative water quality criteria certification can be granted for placement of dredged material within the DMMF. Final water quality limits will be determined at a later date by the WDNR, in the individual permit for the point source discharge from the future water treatment plant.

The proposed design of the cellular cofferdam structure, including the DMMF-DMDF Connector between the last cell of the cofferdam structure and the existing DMMF, will keep the contaminated dredged material within the DMMF isolated from the waters of Lake Michigan adjacent to the DMMF. The underlying clay sediments, into which these structures will be keyed, will prevent seepage from the bottom of the DMMF into Lake Michigan. These design features will significantly minimize or eliminate seepage of contaminated pore water out of the DMMF.

6 References

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Tables

Table 1
Estimated Pore Water Chemistry

Analyte	TEF	Sample Count (n)	Min	Max	Median	Average	95-UCL	Input Bulk Sediment Concentration (mg/Kg)	K _{ow} (from USACE) (L/kg)	log K _{oc} (L/kg)	f _{oc} (fraction organic material, assumed 3.6% from MKE river OU2)	K _d (L/kg)	Predicted Equilibrium Pore Water Concentration (µg/L)
Acenaphthene		-	0.0008	539	0.1	12	18.8	0.114	8.3E+03	3.7	0.036	1.8E+02	0.61
Acenaphthylene		-	0.0006	93	0.1	2	3.3	0.065	1.0E+04	3.8	0.036	2.2E+02	0.29
<i>Anthracene</i>		-	0.0008	408	0.2	9	13.4	0.217	3.2E+04	4.3	0.036	7.0E+02	0.31
Benzo(a)anthracene	0.1	-	0.0012	244	0.7	6	9.1	0.668	5.0E+05	5.5	0.036	1.1E+04	0.06
Benzo(a)pyrene	1	-	0.0006	144	0.7	5	6.7	0.740	1.1E+06	5.8	0.036	2.4E+04	0.03
Benzo(b)fluoranthene	0.1	-	0.0008	133	0.7	5	7.3	0.739	2.8E+06	6.2	0.036	6.1E+04	0.01
Benzo(e)pyrene		-	0.0007	101	0.6	3	4.7	0.596	1.6E+06	6.0	0.036	3.5E+04	0.02
Benzo(g,h,i)perylene	0.01	-	0.0006	70	0.5	3	3.5	0.475	5.0E+06	6.5	0.036	1.1E+05	0.00
Benzo(k)fluoranthene	0.01	-	0.0009	28	0.5	2	2.1	0.507	1.6E+06	6.0	0.036	3.5E+04	0.01
Chrysene	0.001	-	0.0007	195	0.9	6	9.1	0.877	5.0E+05	5.5	0.036	1.1E+04	0.08
Dibenz(a,h)anthracene	1	-	0.0006	22	0.2	1	1.1	0.175	5.0E+06	6.5	0.036	1.1E+05	0.00
Fluoranthene	0.001	-	0.0021	362	1.7	11	15.8	1.650	1.7E+05	5.0	0.036	3.7E+03	0.45
<i>Fluorene</i>		-	0.0017	317	0.1	6	10.3	0.131	1.6E+04	4.0	0.036	3.5E+02	0.37
Indeno(1,2,3-cd)pyrene	0.1	-	0.0005	48	0.4	2	2.7	0.447	4.5E+06	6.4	0.036	9.9E+04	0.00
Naphthalene	--	-	0.0051	897	0.1	26	38.3	0.093	2.2E+03	3.1	0.036	4.9E+01	1.90
Phenanthrene	0.001	-	0.0040	1,320	1.0	29	46.2	0.953	2.9E+04	4.3	0.036	6.4E+02	1.49
Pyrene	0.001	-	0.0017	509	1.3	14	20.4	1.340	1.3E+05	4.9	0.036	2.8E+03	0.48
PAH-17	--	-	0.0232	5,428.9	9.8	142.9	70	9.782	2.3E+07	7.1	0.036	5.0E+05	0.02
cPAH (group of 10)^{1,2}	--	-	0.0015	211.62	1.11	7.06	10.7	1.114					0.04
PCBs													
<i>Total PCBs³</i>								49	6.5	6.29	0.036	7.0E+04	7.0E-01
<i>Total PCBs⁴</i>	--							0.547	6.5	6.29	0.036	7.0E+04	7.8E-03
Aroclor 1221									4.08	3.87	0.036	2.7E+02	
Aroclor 1232									3.2	2.99	0.036	3.5E+01	
Aroclor 1016									5.58	5.37	0.036	8.4E+03	
Aroclor 1242									4.11	3.9	0.036	2.9E+02	
Aroclor 1248									5.76	5.55	0.036	1.3E+04	
Aroclor 1254									6.04	5.83	0.036	2.4E+04	
Aroclor 1260									7.1	6.89	0.036	2.8E+05	
PFAS⁵													
PFOS	--	15	0.0014	0.00907	0.00328	0.004071	0.00231	0.00328		3.1	0.036	4.5E+01	7.24E-02
PFOA	--	15	0.000297	0.000604	0.000375	0.000406	0.0001	0.000375		2.26	0.036	6.6E+00	5.72E-02
Metals^{6,7}													
Arsenic	--	618	0.102	124	5.9	8.49	9.15	5.9				70	84
Cadmium	--	618	0.0462	24.2	1.86	2.92	3.13	1.86				60	31
Chromium	--	618	0.144	6710	121	336	381	121				200	605
Copper	--	618	0.164	470	60.75	75.8	80.3	60.75				120	506
Lead	--	618	0.337	1240	258	267	283	258				300	860
<i>Mercury</i>	--	618	0.0249	31.1	0.5255	1.19	1.33	0.5255				100	5.26
Nickel	--	618	0.106	95.3	13.95	16.7	17.5	13.95				70	199
Zinc	--	618	3.81	1270	266	293	309	266				130	2,046
Selenium	--	33	1.1	3.4	2.1	2.05	2.21	2.1				20	105
Silver	--	33	0.35	7.7	2.3	2.87	3.51	2.3				150	15

Notes:

Bold Analytes have WDNR Proposed Water Quality Criteria.

Red parameters are biological contaminants of concern.

Summary statistics were calculated in Table 6 in Appendix E using detected concentrations and non-detects set at the method detection limit.

¹ PAHs summary stats from Milwaukee River OU2 data (Foth, 2017; CH2M, 2019) (see Table 7, in Appendix E of the 90% Design Report).

² cPAH calculated by multiplying 10 PAHs (at 95-UCL) by corresponding TEFs: Benzo(a)anthracene, Benzo(b)fluoranthene, Benzo(g,h,i)perylene, Benzo(k)fluoranthene, Chrysene, Dibenz(a,h)anthracene, Fluoranthene, Indeno(1,2,3-cd)pyrene, Phenanthrene, Pyrene.

³ For this estimate of porewater concentration, Total PCB concentration is assumed to be 49 mg/kg (most conservative model assumption = just below TSCA limit).

⁴ Median concentrations of PCBs in MKE River Reach 4 are 0.547 mg/kg (see Table 7 in Appendix E of the 90% Design Report).

⁵ PFAS summary statistics from those samples located within the Kinnickinnick River (WDNR, 2020) (see Table 8 in Appendix E of the 90% Design Report). The K_{oc} values from ITRC, 2020.

⁶ Summary statistics for all metals except Selenium and Silver were calculated using the "Reach 4" Milwaukee River Downstream Sediment Site Characterization dataset (CH2M, 2017) (see Table 7 in Appendix E of the 90% Design Report).

⁷ Selenium and Silver summary statistics are estimated from 33 samples collected from 2 locations (i.e. sediment cores) within OU2 (Foth, 2017) (see Table 7 in Appendix E of the 90% Design Report).

Abbreviations and Acronyms:

PAHs = Polycyclic Aromatic Hydrocarbons

PCBs = Polychlorinated Biphenyls

PFAS = Per- and Polyfluoroalkyl Substances

PFOA = Perfluorooctanoic acid

PFOS = Perfluorooctanesulfonic acid

95-UCL = 95% Upper Confidence Limit; Calculated by

TEF = Toxicity Equivalence Factor

UCL = upper confidence limit

µg/L = micrograms per liter

mg/kg = milligrams per kilogram

L/kg = liters per kilogram

K_{oc} = organic carbon partitioning coefficient

K_d = the partitioning coefficient

K_{ow} = n-octanol-water partition coefficient

Prepared by: ASH

Checked by: VXT

Table 2
Applicable Water Quality Criteria Concentrations for COCs

Analyte	Units	Applicable Water Quality Criteria								
		Acute Criteria	Acute Secondary Value	Chronic Criteria	Chronic Secondary Value	Wildlife Criteria	Human Threshold Criteria	Human Threshold Secondary Value	Human Cancer Criteria	BPJ Limit (Monthly Average)
Arsenic	µg/L	340		148		--	--		0.2	--
Cadmium	µg/L	6.2		3.13		--	4.4		--	--
Chromium (+3)	µg/L	2319		111		--	100		--	--
Chromium (+6)	µg/L	16		11		--	83.5		--	--
Copper	µg/L	20.7		13.5		--	--		--	--
Lead	µg/L	144		37.7		--	10		--	--
Mercury ¹	µg/L	0.83		0.44		0.0013	0.0015		--	--
Nickel	µg/L	609		67.7		--	100		--	--
Zinc	µg/L	158		158		--	--		--	--
Selenium	µg/L	--		5		--	50		--	--
Silver	µg/L	--		--		--	140		--	--
Total PCBs ¹	µg/L	--		--		0.12	--		0.000003	--
cPAH (group of 10)	µg/L	--	--	--	--	--	--	--	--	0.1
Benzo(a)pyrene	µg/L	--	--	--	--	--	--	--	--	0.1
Naphthalene	µg/L	--	344.26	--	19.12	--	--	1950	--	70
Fluorene	µg/L	--	58.1	--	3.23	--	--	193.6	--	--
Anthracene	µg/L	--	0.353	--	0.019	--	--	1375.6	--	--

Notes:

1. Mercury and total Polychlorinated Biphenyls (PCBs) are classified as bioaccumulating chemicals of concern (BCCs); no dilution is allowed.

Abbreviations:

COC = contaminant of concern

µg/L = micrograms per liter

PAHs = Polycyclic Aromatic Hydrocarbons

Prepared by: ASH1

Checked by: ECH

Table 3
Travel Time through First Sheet Pile Wall

Parameter	Symbol	Units	Sealant Type ¹				Welded Sheets ⁵
			Empty Interlock	Beltan Plus or Arco Seal	Roxan Plus	AKILA	
Hydraulic Conductivity, equivalent ¹	Ke	cm/sec	2.40E-05	5.10E-06	2.60E-09	1.60E-09	<< 1.0 E-9
Coffer Cell Diameter ²	L	ft	42				
Head Differential Across Cell ³	Δh	ft	1.0				
Hydraulic Gradient	i	ft/ft	0.024				
Porosity of simulated slurry wall ³	n	-	0.3				
Equivalent slurry wall width ⁴		ft	2.0				
Seepage Velocity	Vw	ft/year	2E+00	4E-01	2E-04	1E-04	<<1E-04
Travel Time, water	tw	year	1	5	9,154	14,875	>> 15,000

Prepared by: VXT
Checked by: ASH1

Notes:

1. Hydraulic conductivity values for different sealants taken from ArcelorMittal (2017).
2. From proposed cellular coffer dam design (Appendix J of the *90% Design Report* [Foth, 2020a]).
3. Parameters such as head differential and porosity of the simulated slurry wall are estimates for illustrative purpose of identifying the order of magnitude difference in seepage for interlocks under various setups.
4. The sheet pile wall with interlocks is approximated as an equivalent 2-ft wide slurry wall.
5. Welded sheets are practically impermeable, and provide resistance to flow that is, at a minimum, greater than the interlock with the least permeable sealant.

Abbreviations:

cm/sec = centimeters per second
ft = feet

Table 4
Travel Time through Rubble Mound Connector with Grouted Barrier Wall

Parameter	Symbol	Value		Units
Hydraulic Conductivity	K	1E-07		cm/sec
Grout-Cement Thickness	L	4		ft
Head Differential	Δh	1		ft
Connector width	W	75		ft
Hydraulic Gradient across rubble mound connector	i	0.013		ft/ft
Porosity	n	0.1	0.3	-
Seepage Velocity	Vw	0.014	0.005	ft/year
Travel Time, water	tw	290	870	year

Prepared by: VXT
Checked by: ASH1

Assumptions:

- 1 Transport is primarily through advective flow of groundwater.
- 2 Attenuation/retardation of constituents of interest due to adsorption to porous media is not factored in.
- 3 Secondary transport mechanisms such as dispersion and diffusion are not considered.
- 4 Attenuation due to biodegradation of organic constituents is not considered.
- 5 It is conservatively assumed that head inside the DMMF is about 1-foot higher than outside the DMFF in Lake Michigan, and remains consistent over time. In reality, the head differential varies over time, and at certain times, the head in Lake Michigan is higher resulting in lack of potential flow from the DMMF to Lake Michigan.
- 6 The rubble mound connector between the existing DMDF and the last cell of the proposed DMMF includes a 4-foot wide grouted wall that will be keyed into the underlying clay layer.

Figures

Figure 1: DMMF Aerial View and Location of Cross Sections



Figure 2: Contaminant Transport Conceptual Model for Cofferd Dam Wall during Operations

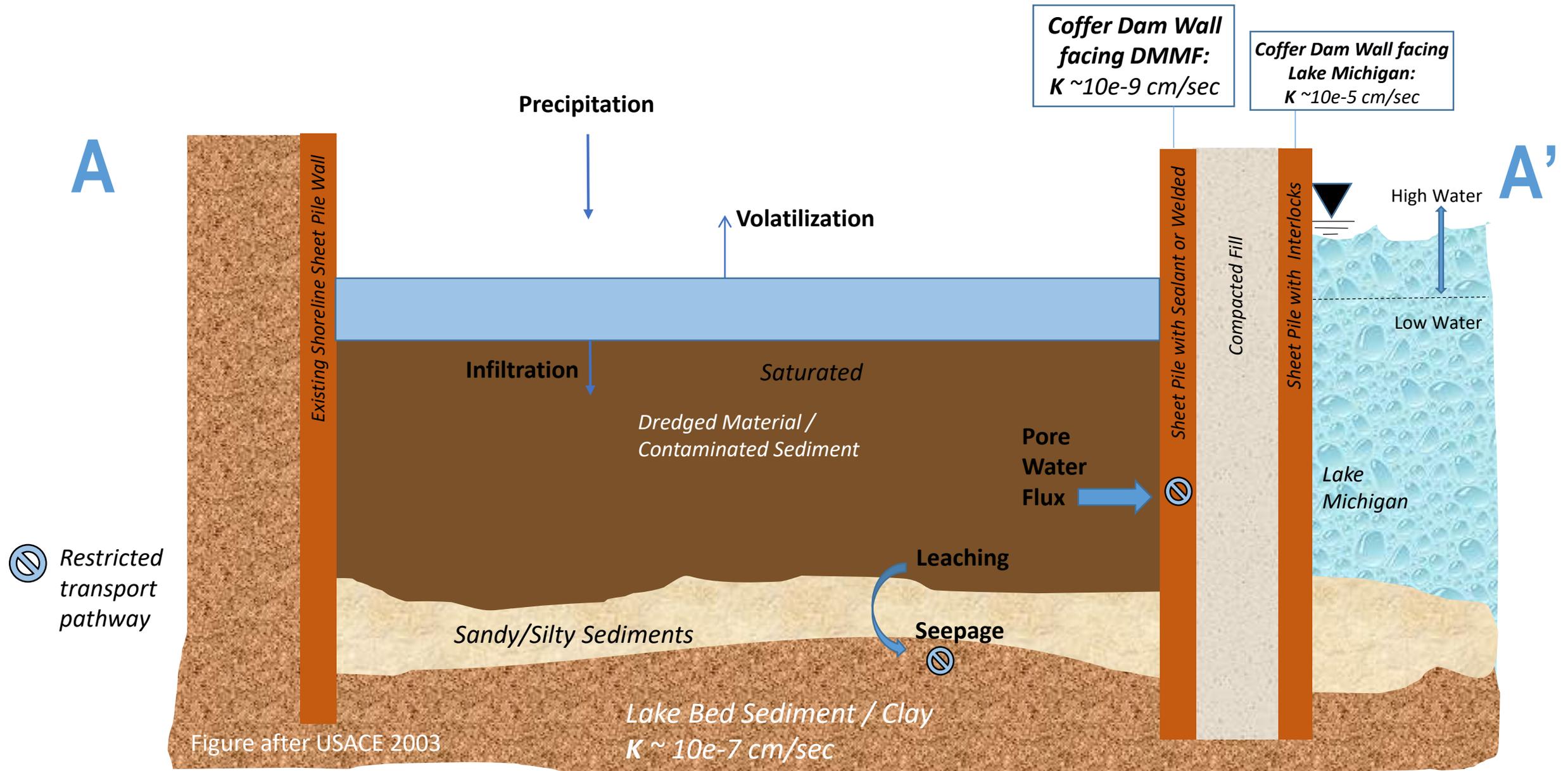


Figure 3 Contaminant Transport Conceptual Model for DMMF-DMDF Connector during Operations

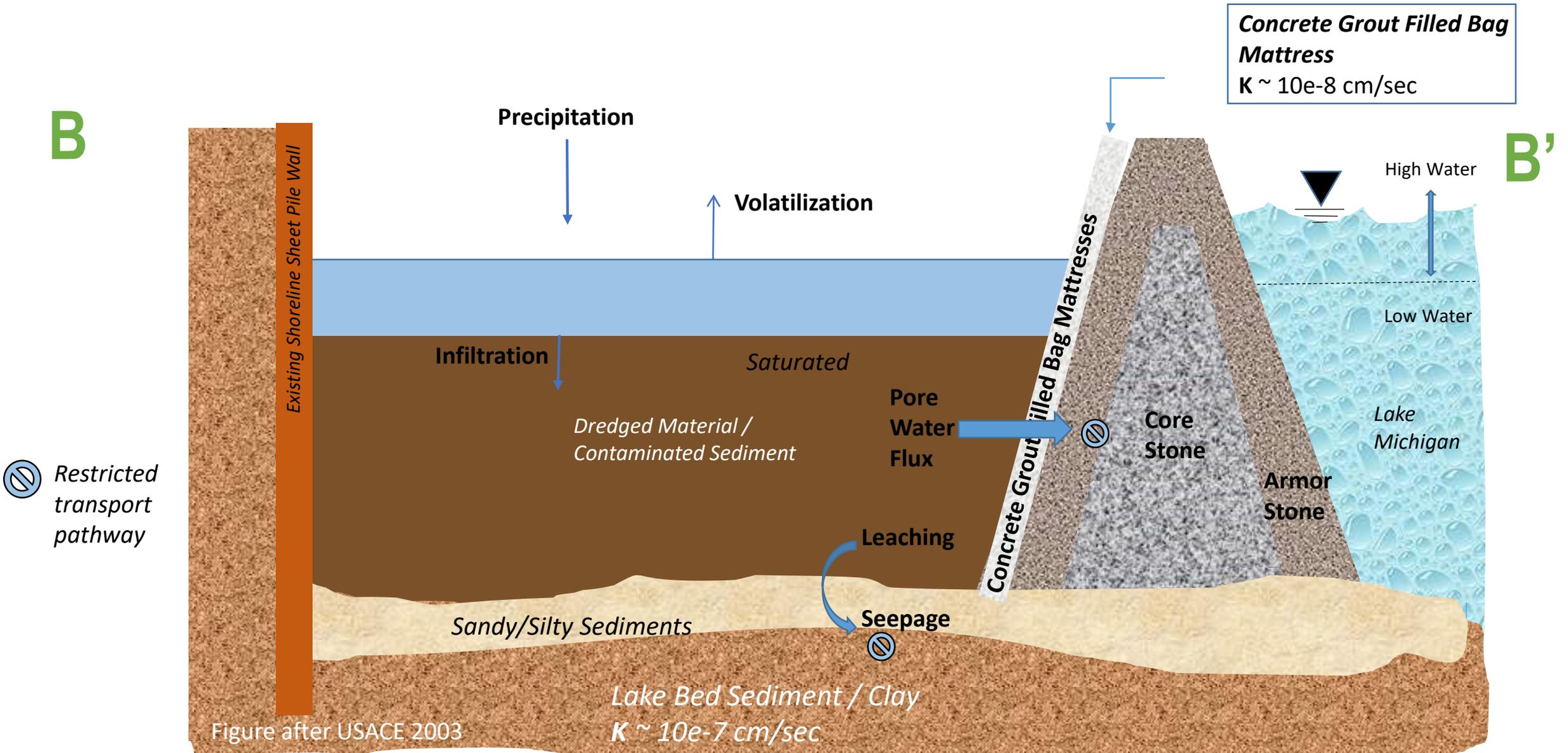


Figure 4: Contaminant Transport Conceptual Model for Cofferdam Wall during Closure

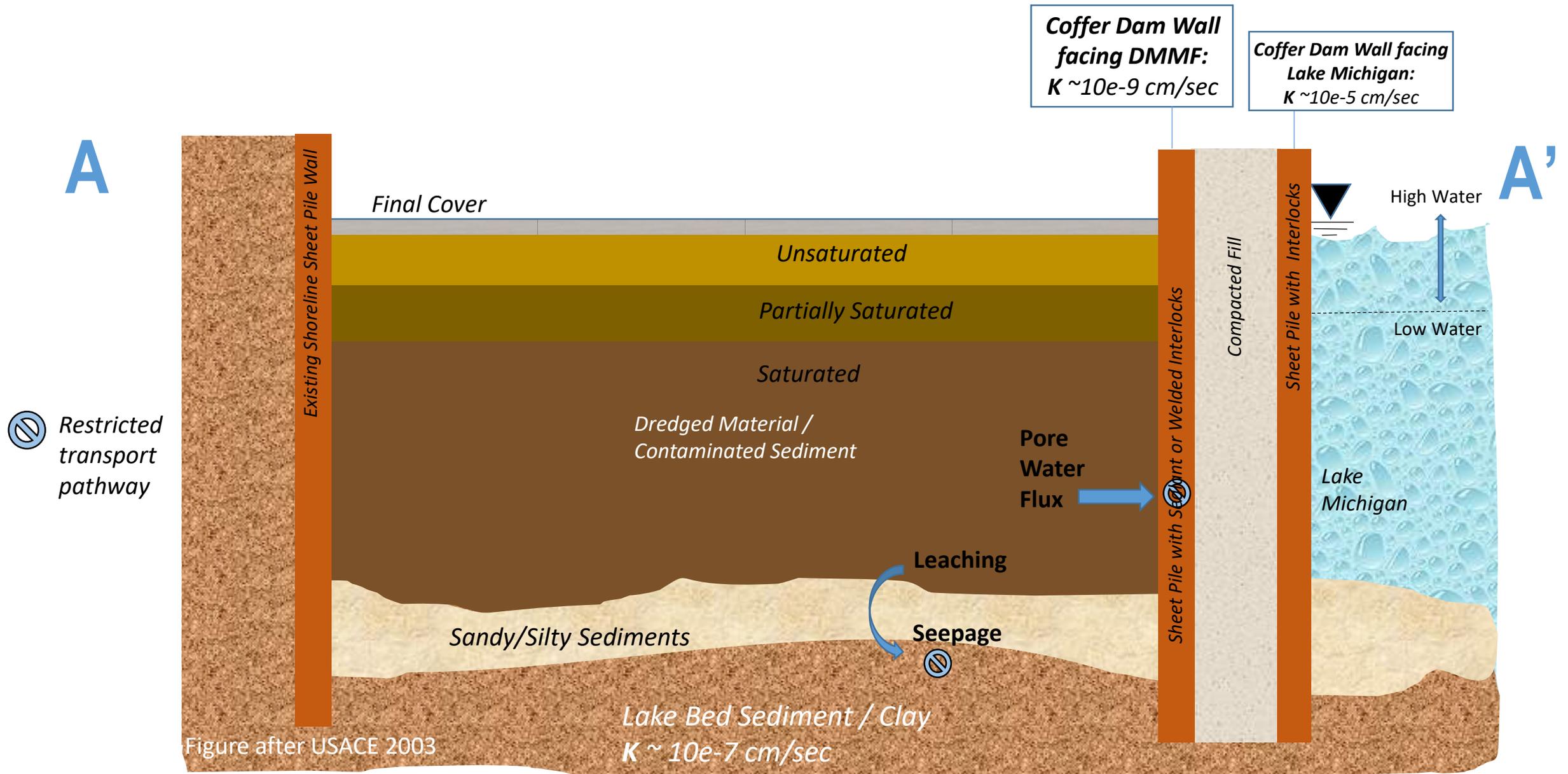


Figure 5 Contaminant Transport Conceptual Model for DMMF-DMDF Connector in Closure

