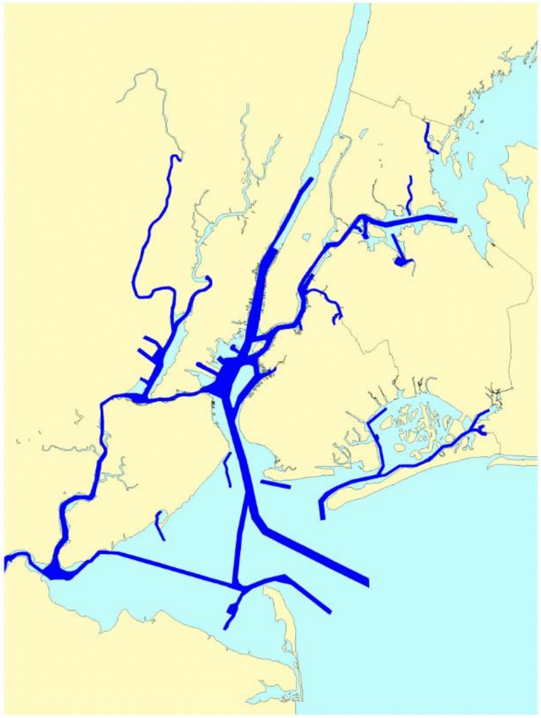
2024

Contamination Assessment and Reduction Project – Phase 2 (CARP II)

Appendix A-5. CARP II Model Future Projections Report



CARP MODELS FUTURE PROJECTION SCENARIOS

NY/NJ Harbor Contamination Assessment and Reduction Project, CARP II

New Jersey Department of Transportation,

Under Agreement with Monmouth University and the Hudson River Foundation

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PREFACE

The modeling work reported here is one of several efforts undertaken in connection with the Contamination Assessment and Reduction Project (CARP). The overall purpose of CARP and the context for the CARP modeling work are outlined below.

What is CARP?

CARP is a landmark project bringing together federal, state, and non-government partners in a determined effort to better understand and reduce contamination within the New York/New Jersey Harbor Estuary. This contamination has led to environmental harm and economic hardships. Notably, dredging and disposal activities connected to port activities were severely curtailed in the early 1990's as dredging managers and regulators struggled with finding management options for handling contaminated dredged material. While dredging has since proceeded, the costs have escalated to 10 to 30 times previous levels, largely because of sediment contamination. Other negative impacts continue to plague the system, including fish advisories and substandard water quality, which are impeding the recovery and utilization of many of the estuary's natural resources.

Through workgroup deliberations in connection with the Dredged Material Forum and the NY/NJ Harbor Estuary Program (HEP), a general plan was developed to address the problem of continued contamination of sediments requiring dredging. The operative management questions included: Which sources of contaminants need to be reduced or eliminated to render future dredged material clean? Which actions can yield the greatest benefits? and, which actions are necessary to achieve the 2040 targets recommended in the Dredged Material Management Plan for the Harbor? CARP was initiated to address these questions.

CARP has been implemented in two phases having shared goals and objectives. The second phase of CARP served as a supplement and complement to the first phase. The two phases of CARP are referred to as CARP 1 and CARP 2. The primary funding mechanism for CARP 1 was the 1996 Joint Dredging Plan for the Port of New York and New Jersey, an agreement between the States of New York and New Jersey that was funded by the Port Authority of New York and New Jersey (Port Authority). Additional funds were obtained from the New Jersey Department of Transportation (NJDOT), the Empire State Development Corporation, The U.S. Army Corps of Engineers, the Hudson River Estuary Management Program, the Harbor and Estuary Program (HEP), and the Hudson River Foundation. CARP 2 was made possible by research funding from NJDOT awarded to Monmouth University.

The specific objectives of the CARP are to: 1. Identify and quantify sources of contaminants of concern to the NY/NJ Harbor Estuary from a dredged material standpoint; 2. Establish baseline levels of contaminants of concern in water, sediments, and biota; 3. Determine the relative significance of contaminant inputs in controlling the concentrations of those contaminants in water, sediment and biota: 4. Forecast future conditions in light of various contaminant reduction scenarios; 5. Take action to reduce levels of contaminants of concern in water, sediments, and fish tissue.

CARP is a unique partnership of governmental and non-governmental entities whose activities have been guided by a management committee composed of representatives from the U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, New Jersey Department of Environmental Protection (NJDEP), New York State Department of Environmental Conservation (NYSDEC), New Jersey Department of Transportation (NJDOT), Empire State Development Corporation, Port Authority, Environmental Defense Fund, and the Hudson River Foundation. During CARP 1, NYSDEC and NJDEP completed objectives 1 and 2 above through a comprehensive data collection (sampling and testing) program, which represents about 90% of the $32 million total funding for CARP 1.

It was the consensus of the CARP Management Committee that mathematical modeling tools were needed to help understand the results of the data collection program and the fate and transport of contaminants through the Harbor. These models provide a means for integrating data in a mass balance framework such that relationships between loadings and contaminant concentrations in water, sediment and biota can be evaluated and quantified. Moreover, these models can provide the predictive capacity that managers and scientists need to assess the consequences of existing contaminant loads and potential remedial actions. The CARP 1 modeling work performed by HydroQual, Inc., therefore addressed Objectives 3 and 4 above, and represents about 10% of the total funding for CARP 1.

Utility of CARP to Regional Stakeholders

The major focus of CARP has been on an objective evaluation of the fate and transport of contaminants throughout the entire NY/NJ Harbor Estuary system. The CARP Management Committee guiding CARP 1 and CARP 2 efforts intended for CARP work products to lead to sustained action to reduce both ongoing and historic contamination. The CARP Management Committee includes representatives of federal and state government agencies and is therefore mindful of the various regulatory programs that are in place to address contaminant issues. Consequently, since the inception of CARP, agencies on the Committee have made comments and recommendations to make CARP as relevant as possible to these programs. However, the CARP data collection and modeling efforts were not designed specifically to comply with the requirements of a particular regulatory program. CARP products, especially the modeling results, provide important information for these programs to consider, but further data collection and model refinement may be necessary to suit the scale and requirements of a particular program. And it is only those charged with regulatory responsibilities that can judge whether CARP products comply with their requirements.

CARP Modeling

Given the vast complexities of the entire estuary and the processes that affect contaminant fate and transport, modeling of this system has been a great technical challenge. From the initiation of CARP, it was understood that some aspects of the modeling would be limited because of scientific uncertainties in fully understanding all relevant processes. To ensure that the model components would be state-of-the-science, a Model Evaluation Group (MEG) was established at the outset of the project. Experts in organic and inorganic geochemistry, hydrodynamics, sediment transport and contaminant modeling were solicited to be members of the MEG. The MEG's first responsibility was to be part of the team to select a modeling contractor. It then met repeatedly over five years, to review and comment on the acceptability of modeling concepts and formulations to reproduce estuarine processes, including the review of CARP 1 model validation and hindcast results. The comments and suggestions of the MEG have been addressed by HydroQual, Inc., and a summary of the responses are included in CARP 1 model reports. In addition, the MEG provided comments and guidance on the use and application of the CARP 1 modeling products.

While some CARP model components were verified, refined, and successfully used in other venues prior to CARP, other components were newly designed for CARP 1 or CARP 2. The CARP modeling has elements that could be considered applied science and engineering, while others would be better characterized as research and development. The CARP MEG generally found that the CARP 1 modeling effort has advanced the understanding of contaminant behavior in the estuary and does a very credible job of characterizing the relationships between contaminant loadings and concentrations in the environment.

One of the more challenging issues that the CARP Management Committee addressed was the development of realistic contaminant reduction scenarios to use as an illustration of the CARP modeling framework capability. As the CARP modeling activities progressed, it became increasingly clear that legacy contamination of sediments was a dominant feature in controlling levels of contaminants in the system.

Since two large-scale sediment remediation projects (namely the Hudson River Superfund and Lower Passaic River Superfund projects) were being developed during CARP 1, it made sense to include these projects in the CARP 1 scenario analyses. While neither project was fully defined during CARP 1, the CARP 1 model scenario analyses gave a first glimpse of the potential for these sites (remediated or not) to influence sediment and water quality in the Harbor over the long term. The CARP 1 scenario analyses were refreshed and greatly expanded during CARP 2 with further CARP Management Committee guidance and two Records of Decision for the Lower Passaic River and the completion of remedial dredging on the Upper Hudson River. The CARP 2 scenarios analyses also consider the specific long-term future influences of the sites associated with the in-progress Newark Bay and Lower Hackensack River Superfund projects.

CARPs First Phase, CARP 1

More information on CARP 1 is readily available in a CARP 1 project summary report which references numerous CARP 1 reports:

> Lodge, J., Landeck Miller, R.E., Suszkowski, D., Litten, S., Douglas, S. 2015. Contaminant Assessment and Reduction Project Summary Report. Hudson River Foundation, New York, NY. [CARP-summary-report-online.pdf (hudsonriver.org)].

CARPs Second Phase, CARP 2

The NJDOT commissioned CARP 2 as a research project in response to needs identified by the Harbor's Dredged Material Strategic Planning Group (DMSPG), a task force convened by the U.S. Army Corps of Engineers (USACE). The DMSPG acknowledged that while CARP 1 modeling and the Region's bioaccumulation testing provided evidence that dredged material quality was improving, more information was needed to accurately forecast future HARS suitability for specific channels and berthing areas. Such information is critical for estimating the financial resources needed to maintain the Harbor and/or to determine the impact of planned remediation. The question that CARP 2 answers is the current and future levels (i.e., to 2040, inclusive of the DMSPG's 15-year and 25-year planning horizons) of contaminants within navigation channels of NY/NJ Harbor. The focus of CARP 2 is to demonstrate if the Region is getting closer to HARS suitability. CARP 2 estimation of progress toward HARS suitability in specific reaches of the Harbor at a higher spatial resolution than CARP 1 can guide dredged material managers in selectively pursuing HARS disposal options and spending on dredged material testing.

Other needs and information gaps addressed by CARP 2 include (1) the compilation and assimilation of relevant data collected in the years between CARP 1 and CARP 2; (2) the collection of new field measurements of loading contaminant concentrations and ambient conditions in the Estuary; (3) the evaluation, update, and refinement of models developed and applied during CARP 1; (4) the characterization of sediments in navigation channels and in adjacent off-channel areas; (5) the development of a method for predicting bioaccumulation of sedimentary contaminants in dredged material test organisms; and (6) the evaluation of a passive sampler method for potential prediction of HARS suitability more quickly and at a cost lower than the Region's current laboratory testing.

CARP 2 was initiated in March 2017 and leveraged CARP 1 financial investments by building upon the foundation of CARP 1 measurements and modeling. The CARP 2 principal investigators include Monmouth University, the Hudson River Foundation, HDR, Inc., Manhattan College, NYSDEC (retired personnel), Rutgers University, and the University of Rhode Island. The CARP 2 measurement and modeling work products include a CARP 2 project summary report which references several individual modeling and sampling/measurement-based CARP 2 report deliverables.

The CARP 2 individual report deliverables referenced in the CARP 2 project summary report include:

A. CARP 2 Modeling Report Deliverables:
   1. Evaluation of CARP 1 Models
      a. Task 3.1 Post-Audit Evaluation of the Original CARP Model Projections
   2. Update of the CARP Models
      a. Task 3.2 Update External Forcing Functions for Water Years 2002-2016
      b. Task 3.3 Refine the CARP Models
   3. CARP 2 Future Projections Scenarios
      a. Task 3.4 Projections of Current and Future Levels of Contamination in the Sediments within Navigation Channels of NJ/NY Harbor
B. Other deliverables:
   4. Measurement Summary Reports
      a. Historic Measurement Review
      b. CARP 2 Measurement Collection and Analysis
         i. Loadings Measurements and Ambient Conditions
         ii. Comparison of sediments in navigation channels and off-channel areas
         iii. Data Dictionary
   5. Prediction of Bioaccumulation of Sedimentary Contaminants in Dredged Material Test Organisms

The report included herein is the CARP2 modeling deliverable for Task 3.4, pertaining to CARP 2 future projection scenarios, identified as A3a above.

Future Intention

The CARP models should not only be viewed as management tools, but as research tools from which fuller understandings of the fate and transport of contaminants can be gleaned today. In addition, it is the hope of the CARP Management Committee that the CARP modeling work and underlying measurements serve as a foundation for the future from which even more advanced models could be developed and applied, as/if needed, for new management issues as they emerge.

CARP MODELS FUTURE PROJECTION SCENARIOS

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ABSTRACT

A final CARP 2 modeling task, applying the updated CARP models for future projection scenarios, has been completed. The future projection scenarios estimate levels of contaminants throughout the NY/NJ Harbor between now and the water year 2038-39 for 2040 planning. With the use of Biota-Sediment Accumulation Factors (BSAFs), CARP model estimates of future contaminant concentrations in the Harbor also provide estimates of future contaminant body burdens in dredged material test organisms. Contaminant body burdens in dredged material test organisms are necessary for evaluating the suitability of dredged material for disposal at the Historic Area Remediation Site (HARS). The full suite of updated CARP models was applied for two future projection scenarios. Both future projection scenarios assume full implementation of the two approved Lower Passaic River Records of Decision (RODs) starting in October 2030. One of the future projection scenarios also assumes full remediation of the Newark Bay Study Area and the Lower Hackensack River starting in October 2030. Methods were developed for estimating future years bathymetry and future years hydrodynamic and sediment transport and organic carbon production, necessary for the future projection scenarios using the CARP contaminant fate and transport model. Starting in October 2030 when the Lower Passaic River remediation is simulated, the CARP sediment transport and organic carbon production model used for the future projection scenarios includes increased sediment bed particle mixing rates in the Lower Passaic River, equivalent to those modeled throughout the less contaminated Harbor. The methods developed for the contaminant fate and transport model application for future projections include estimation of post-dredging PCBs loadings from the Upper Hudson River. BSAFs applied to the Harbor contaminant concentrations calculated for the future projection scenarios include those from the dredged material testing program, from in-situ field organisms and Harbor sediments collected during CARP 1, and from CARP 2 laboratory exposures using Harbor sediments from up to sixty-eight locations. The BSAFs from these programs vary considerably. The variation within CARP 2 laboratory measurements of bioaccumulation is represented by fiftieth and ninetieth percentile BSAFs. The CARP 2 ninetieth percentile BSAFs are comparable to BSAFs from the dredged material testing program used for CARP 1 projections of HARS suitability. The results of the CARP future projection scenarios when combined with 90th percentile BSAFs from CARP 2 specifically indicate that Newark Bay sediments in the future will meet the Historic Area Remediation Site (HARS) disposal criteria for bioaccumulation for both 2,3,7,8-TCDD and total PCB with the completion of the simulated remediation efforts in the Lower Passaic and Hackensack Rivers and in the Newark Bay Study Area.

KEY WORDS: CARP, model, HARS suitable, navigation channel, PCB, dioxin, NY/NJ Harbor and Estuary, dredged material testing, contaminant sources, bioaccumulation

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1.0 INTRODUCTION

The Contamination Assessment and Reduction Project (CARP) 1 model was developed as a series of sub-models to provide a detailed representation of the hydrodynamics, sediment transport, organic carbon cycling, and fate and transport of contaminants in the NY/NJ Harbor and Estuary (HydroQual 2007a, 2007b, 2008). The CARP 1 sub-models were calibrated using field measurements that were primarily collected during the 1999-2002 CARP 1 sampling program. The calibrated sub-models were applied in 2002 to project concentrations of PCBs and PCDD/Fs for a 37-year period commencing in October 2002 and ending in September 2039. The projections made in 2002 were necessarily based on information available at that time. Model-projected concentrations were assessed relative to dredged material testing endpoints to estimate the time when Harbor sediments would meet Historic Area Remediation Site (HARS) disposal criteria.

Since the 2002 CARP 1 model projections of time to HARS suitable Harbor sediments were made, the bathymetry of the Harbor has changed significantly. Deepening of navigation channels was accomplished by several projects. In addition, the Harbor has experienced extreme flow events (including Tropical Storms Irene, Lee, and Sandy) that were not simulated in the CARP 1 model projections. Further, measurement collection related to several Superfund projects in the Harbor has been ongoing since 2002. Therefore, to provide NJDOT with a tool for determining the current and future levels of contamination in the sediments within navigation channels of NJ/NY Harbor, refinement of the CARP sub-models was undertaken to account for the deepening of navigation channels, to assess the impacts of extreme flow events on contaminant responses in Harbor sediments, and to consider additional measurements of Harbor contaminant concentrations. The effort to ultimately provide NJDOT with a tool for determining the current and future levels of contamination in the sediments within navigation channels was performed in a series of subtasks which started with a post-audit evaluation of the CARP 1 model (Landeck Miller et al., 2019). The second subtask in the series is the update of model external loading forcing functions (Landeck Miller et al., 2022). The third subtask in the series is the update of the CARP models (Landeck Miller et al., 2023). The series of subtasks ends with revised projections of PCB and PCDD/Fs contamination in Harbor sediments and dredged-material-test organisms as described herein based on new measurements and model refinements.

In consultation with the CARP Management Committee, two future projection scenarios were defined and implemented. The methods for conducting the two future projection scenarios along with a consideration of the results follows. The consideration of results includes calculations using several different Biota-Sediment Accumulation Factors (BSAFs).

2.0 METHODS

The methods developed and applied for the two CARP future projection scenarios are discussed separately in Sections 2.1 to 2.3 for each of the CARP models involved: hydrodynamic, sediment transport/organic carbon production, and contaminant fate and transport and in Section 2.4 for the use of various BSAFs.

2.1 Methods for CARP Future Projection Scenarios, Hydrodynamic Model

The future projection scenarios required forty-one water years of hydrodynamic model simulations on the CARP 127 x 205 model computational grid. Hydrodynamic model simulations for the eighteen water years spanning October 1998 through September 2016 were available for use “as is” directly from the model calibration effort (Landeck Miller et al., 2023). The remaining twenty-three water years spanning October 2016 through September 2039 first required assignment of a surrogate year from the calibration years along with the selection of appropriate bathymetry conditions. The surrogate years were established by assigning October 1998 through September 2016 to October 2016 through September 2034 and assigning October 1998 through September 2003 to October 2034 through September 2039. In discussion with the CARP Management Committee, it was decided that the bathymetry conditions established during model calibration representative of the 52' Harbor deepening projects starting in water year 2010-11 (Landeck Miller et al., 2023) would be carried forward for all subsequent water years.

To achieve both the assignment of waters years and the desired bathymetry conditions for the future projection simulations, it was necessary to conduct twelve new hydrodynamic model simulations due to pairings of water years and bathymetry differing from the calibration conditions. For example, in the calibration the 1998-99 water year was simulated with pre-deepening projects (i.e., < 40') bathymetry. For purposes of the future projection scenarios, it was necessary to simulate the 1998-99 water year with bathymetry reflecting completion of 52' deepening projects to represent the 2016-17 and 2034-35 future water years. The twelve new hydrodynamic model simulations conducted were for applying bathymetry conditions including 52' deepening projects to the water years October 1998 to September 2010 to represent the future water years October 2016 to September 2028 and October 2034 to September 2039.

The tracking of the assignment of water years and bathymetry conditions and the new hydrodynamic simulations needed for the future projection scenarios are summarized in Table 2-1. The twelve water years of new hydrodynamic model simulations on the 127 x 205 CARP model computational grid apply to both future projection scenarios evaluated.

2.2 Methods for CARP Future Projection Scenarios, Sediment Transport and Organic Carbon Production Model

The future projection scenarios required forty-one water years of sediment transport and organic carbon production model simulations on the CARP 127 x 205 model computational grid. Sediment transport and organic carbon production model simulations for the eighteen water years spanning October 1998 through September 2016 were available for use "as is" directly from the model calibration effort (Landeck Miller et al., 2023). It was necessary to conduct new sediment transport and organic carbon production model simulations for the remaining twenty-three water years spanning October 2016 through September 2039 for several reasons. These reasons include both using hydrodynamic transport for all future years with bathymetry reflecting 52' deepening projects and having each year of sediment transport and organic carbon production model simulation run consecutively, including a "hot start" off the previous year. The "hot start" allows for the passing of sediment bed accumulation from one year to the next as stored in the modeled sediment bed archive layer. In addition, specific to the nine water years spanning October 2030 to September 2039, the sediment transport and organic carbon model future projection scenarios on the CARP 127 x 205 model computational grid include particle mixing rates for the Lower Passaic River restored to levels used everywhere on the 49 x 84 model computational grid and everywhere else for model calibration on the 127 x 205 model computational grid (Landeck Miller et al. 2023).

The removal of altered sediment bed particle mixing rates for the Lower Passaic River starting in the 2030-31 water year (i.e., increasing the rates to levels used elsewhere in the model domain) is in anticipation of simulating the remediation of the Lower Passaic River with the contaminant fate and transport model future projection scenarios which should also reflect post-remediation bioturbation by organisms in the Lower Passaic River. Successful calibration of the CARP model on the 127 x 205 model computational grid for the eighteen water years spanning October 1998 to September 2016 for the temporal trend in dioxin concentrations in the sediment bed of the Newark Bay complex required a reduction to particle mixing rates in the Lower Passaic River. Presumably, the real-world explanation for the model calibration reduction in particle mixing rates is that the organisms carrying out bioturbation were either present only in reduced numbers and/or were metabolically impaired because of dioxin present in the Lower Passaic River (Landeck Miller et al., 2023). A reduction to particle mixing rates in the Lower Passaic River was also applied during Superfund modeling efforts to achieve model calibration. If the presumed real-world explanation for the required reductions to modeled particle mixing rates to achieve model calibration is valid, it follows that a future projection scenario including remediation should also remove the calibration reduction to particle mixing rates.

The tracking of the assignments of hydrodynamic transport and bathymetry, "hot starting", sediment bed particle mixing rates, and the new sediment transport and organic carbon production model simulations needed for the future projection scenarios are summarized in Table 2-2. The forty-one water years of new sediment transport and organic carbon production model simulations on the 127 x 205 CARP model computational grid apply to both future projection scenarios evaluated.

2.3 Methods for CARP Future Projection Scenarios, the Contaminant Fate and Transport Model

The first of two future projection scenarios required forty-one water years of contaminant fate and transport model simulations on the CARP 127 x 205 model computational grid. Contaminant fate and transport model simulations for the eighteen water years spanning October 1998 through September 2016 were available for use "as is" directly from the model calibration effort (Landeck Miller et al., 2023). It was necessary to conduct new contaminant fate and transport model simulations for the remaining twenty-three water years spanning October 2016 through September 2039 for several reasons. These reasons include having each year of contaminant fate and transport model simulation run consecutively, including a "hot start" off the previous year, and using results from the sediment transport model also run consecutively with "hot start". The "hot start" allows for the development and progression of sediment bed conditions to be tracked over time. Specific to the contaminant fate and transport model, utilization of regression equations to calculate Upper Hudson PCB loadings reflective of post-dredging conditions (Landeck Miller et al., 2023) also necessitated new contaminant fate and transport model simulations for the twenty-three water years spanning October 2016 through September 2039. Further, new contaminant fate and transport model simulations were needed to include remediation of portions of the sediment bed starting in the 2030-31 water year.

As part of the future projection scenarios, the post-dredging regression equations for estimation of the Upper Hudson River PCB loadings were applied for the twenty-three water years October 2016 through September 2039 using surrogate hydrographs from October 1998 through September 2016. As part of model calibration, the post-dredging regression equations for estimation of the Upper Hudson River PCB loadings were applied only for the nine-month period January to September 2016 (Landeck Miller et al., 2023). The future projection scenarios include post-dredging PCB loadings from the Upper Hudson River for a much longer additional twenty-three-year period and wider hydrograph range as compared to the calibration.

In addition, specific to the nine water years spanning October 2030 to September 2039, the contaminant fate and transport model future projection scenarios on the CARP 127 x 205 model computational grid include adjustments to sediment bed contaminant concentrations in the Lower Passaic River reflective of the completion of two USEPA Superfund Records of Decision (RODs) (USEPA, 2016a, 2016b, and 2021), simulated for CARP purposes as starting October 1, 2030. The remediated Lower Passaic River sediment bed concentrations used in the future projection scenarios on the CARP 127 x 205 model computational grid were extracted from the USEPA RODs. A variation for the nine water years spanning October 2030 to September 2039 is unique to a second future projection scenario on the CARP 127 x 205 model computational grid. The second scenario additionally simulates full remediation adjustments (i.e., applying zero concentration) to sediment bed contaminant concentrations in Newark Bay and the Lower Hackensack River starting October 1, 2030. It is noted that the full bank-to-bank remediation adjustments to zero concentrations simulated for Newark Bay and the Lower Hackensack River in the second future projection scenario are not regulatory requirements and are a first-time projection consideration for CARP.

Completion of the second future projection scenario on the CARP 127 x 205 model computational grid required running the contaminant fate and transport model only for the final nine water years. Consistent with the Superfund Study Area (Figure 1-2 in GSH, 2019), the simulated full remediation for Newark Bay for the second future projection scenario includes Newark Bay, the Arthur Kill and Kill van Kull between the Goethals and Bayonne Bridges, and the Lower Hackensack River to the Conrail Bridge. The simulated full remediation of the Lower Hackensack River for the second projection scenario includes the Lower Hackensack River between the Oradell Dam and the Conrail Bridge and the contiguous tributaries and marsh areas within the CARP 127 x 205 model computational grid.

The tracking of the assignments of hydrodynamic transport and bathymetry, "hot starting", sediment transport and organic carbon production, Upper Hudson River PCB loading regressions, bed contaminant concentration adjustments, and the new contaminant fate and transport model simulations needed for the future projection scenarios are summarized in Table 2-3. Related Tables 2-4 and 2-5 summarize the adjusted sediment bed contaminant concentrations used for the simulation of the completion of the Lower Passaic River RODs with the CARP contaminant fate and transport model on the 127 x 205 model computational grid.

2.4 Methods for CARP Future Projection Scenarios, BSAFs and HARS Disposal Criteria

Four sets of Biota-Sediment Accumulation Factors (BSAFs) were utilized to transform model calculations of future contaminant concentrations in Harbor sediments to likely contaminant body burdens in worms for comparisons to HARS disposal criteria. The four sets of BSAFs, dredged material testing, CARP 1, CARP 2 fiftieth percentile, and CARP 2 ninetieth percentile, are presented in Table 2-6. Table 2-6 provides descriptions, references, and units for the BSAFs. The underlying probability distributions for the CARP 2 fiftieth and ninetieth percentile BSAFs are shown on Figure 2-1. Model calculations of contaminant concentrations in Harbor sediments were multiplied by BSAFs to obtain contaminant body burdens in worms. The calculated contaminant body burdens were compared to HARS disposal criteria. The HARS disposal criteria considered include 1 ppt 2,3,7,8-TCDD and 113 ppb total PCB worm body burdens.

Per the instructions of USEPA Region 2 during CARP 1 (HydroQual, 2007) and recent confirmation from the CARP Management Committee, for consistency with the protocols of the Region's dredged material testing program, the use of BSAFs derived from 28-day laboratory exposures (i.e., from the dredged material testing program and from CARP 2) with the total PCB HARS criterion (113 ppb) requires a doubling of the total PCB worm concentrations. The use of the doubling of total PCB worm concentrations offsets a perceived mismatch between 28-day testing and a longer-term exposure underlying the 113-ppb PCB criterion. While results are presented and discussed for the application of dredged material testing program, CARP 1, fiftieth percentile CARP 2, and ninetieth percentile CARP 2 BSAFs to CARP contaminant fate and transport model outputs, emphasis is placed on results using the ninetieth percentile BSAFs from CARP 2. This emphasis is consistent with direction from the CARP Management Committee.

3.0 RESULTS

Culminative results for the future projection scenarios applying the full suite of CARP models on the 127 x 205 model computational grid include time series displays of contaminant concentrations in the sediment bed and the water column and spatial maps of HARS suitability. The contaminant concentration results are presented for the six contaminants 2,3,7,8-TCDD, 2,3,4,7,8-PCDF, di-CB, tetra-CB, hexa-CB, and octa-CB. The HARS suitability results are presented for 2,3,7,8-TCDD and total PCB. As identified during model calibration, total PCB is represented by twice the summation of the di-CB, tetra-CB, hexa-CB, and octa-CB homologs (Landeck Miller et al., 2023).

3.1 Results for CARP Future Projection Scenarios, Sediment Bed Contaminant Concentrations

Sediment bed contaminant concentration results for the future projection scenarios are presented in Appendix 1 with an x-axis (i.e., time) extension of the calibration model and measurement comparison diagrams for the 127 x 205 model computational grid (Landeck Miller at al., 2023). Like the calibration, the results of the future projection scenarios for sediment bed contaminant concentrations are presented on two hundred twenty-four pages in Appendix 1 for six contaminants and a PCB summation, ninety-five locations, and solids and organic carbon normalizations. In addition, for future projection scenarios, an additional reach with six locations was added to monitor model results at the top of the Lower Hackensack River bringing the Appendix 1 page count to two hundred thirty-eight pages and the locations count to one-hundred-one. The future projection results in Appendix 1 for sediment bed contaminant concentrations include seventeen pages for each of seven contaminants/summations and for each of two normalizations with each page representing results for a reach containing five or six discrete locations.

Each reach page, in Appendix 1 and on Figures 3-1 to 3-5, includes a location map with the 127 x 205 model computational grid shown. On the map, the model computational grid cells for the five or six discrete locations for which the time series of model results are presented are colored in bright green. Pastel colors are used on the map to indicate the surrounding model computational grid cells from which measurements have been aggregated for comparisons and from which ranges of model results are derived. The pastel colors on the map correspond to the original 49 x 84 model computational grid considered during the post-audit (Landeck Miller et al., 2019) and used previously for CARP (HydroQual, 2007a, 2007b, 2007c).

At each location shown in Appendix 1 and on Figures 3-1 to 3-5, measurements representing up to the top 15 cm of the sediment bed are presented. Measurements from various sources as compiled and described for the CARP post-audit (Landeck Miller et al., 2019) are shown with blue and red circles for in-channel and off-channel samples, respectively, in Appendix 13 and on Figures 3-1 to 3-5. Additional measurements have been added since the completion of the post-audit (Landeck Miller, et al., 2019) and are shown with various symbols and colors as identified in the legend on the diagrams in Appendix 1 and on Figures 3-1 to 3-5. The additional measurements are derived from sampling conducted in support of contemporary navigational maintenance dredging projects (shown with brown triangles, labelled “Dredge data”) and from the work of other CARP investigators (shown with pink and green squares, labelled “CARP2”). A listing of the contemporary navigational maintenance dredging projects from which measurements were obtained is provided in Appendix 15 of Landeck Miller et al., 2023. Reporting for CARP 2 data collection is in preparation.

Various model timeseries results for sediment bed contaminant concentrations are displayed in Appendix 1 and on Figures 3-1 to 3-5 with several different lines and shading. A lime green line is used to show the timeseries of thirty-day-average contaminant concentrations calculated by the model for the top 10 cm of the bed in a single model grid cell (identified in bright green on the maps). A lime green shade is used to show the range in the top 10 cm calculated by the model for each thirty-day interval for the single model grid cell. A grey shade is used to show the range of contaminant concentrations for the top 10 cm of the bed calculated by the model for the several surrounding model grid cells from which measurements were aggregated (identified with pastel colors on the maps). A pale blue line is used for reference to show the contaminant concentrations calculated by the model for the sediment bed archive layer for the same single model grid cell as was shown in lime for the model calculated concentrations in the top 10 cm. The sediment bed archive layer of variable depth is used by the model to store and track mass specified through initial bed thickness or whenever appreciable deposition exceeding resuspension is calculated and to provide the inventory of mass available for subsequent resuspension.

The lime green lines, lime green shades, grey shades, and pale blue lines shown in Appendix 1 and on example Figures 3-1 to 3-5 and used to display model results for sediment bed contaminant concentrations include results for model calibration (October 1998 to September 2016) and the first and second future projection scenarios (October 2016 to September 2039). The interval October 2016 to September 2030, common to both future projection scenarios, provides an opportunity to assess CARP model predictions in the future without further management action and to assess the long-term influence of reduced loadings from the Upper Hudson River after completion of dredging in 2015. For the interval October 2030 to September 2039, two sets of future projection scenarios model results are shown on the same axes. The two sets of future projection scenarios model results reflect full implementation of the two approved Lower Passaic River Records of Decision (RODs) both without and in combination with full remediation of the Newark Bay and the Lower Hackensack River Superfund Study Areas described in Section 2.3.

Although not specifically discussed, solids and organic carbon normalized bed contaminant concentrations results presented in Appendix 1 are similar. There are only a few instances, such as several locations in Upper and Lower New York Bays shown in Appendix 1, with discernible differences in solids and organic carbon normalized bed concentrations of 2,3,7,8-TCDD and total PCB.

Figures 3-1 and 3-5 are examples of the future projection scenarios bed contaminant concentrations results, from the CARP contaminant fate and transport model using the 127 x 205 model computational grid, included in Appendix 1. On Figure 3-1 and 3-2, results are shown for the sediment bed at six locations in Lower Newark Bay. On Figure 3-3 and 3-4, results are shown for the sediment bed at six locations in the Hudson and East Rivers. Figures 3-1 and 3-3 show results for 2,3,7,8-TCDD solids-normalized concentrations in the bed. Figures 3-2 and 3-4 show results for total PCB solids-normalized concentrations in the bed. On Figures 3-2 and 3-4, the measurements represent ten PCB homologs, and the model results are based on twice the summation of the four PCB homologs modeled for calibration and future projection purposes. The application of the factor of two to the summation of four PCB homologs (i.e., di-CB, tetra-CB, hexa-CB, and octa-CB) to approximate total PCB was established during CARP 1 (HydroQual, 2007c) and was further verified during CARP 2 method validation efforts (Landeck Miller et al., 2023).

Figure 3-5 displays the future projection scenarios bed contaminant concentrations results at six locations in the northern Arthur Kill for 2,3,7,8-TCDD (top) and total PCB (bottom). Figure 3-5 highlights differences in the spatial expanse of responses in the future projection scenarios bed contaminant concentrations results for the two contaminants in the northern Arthur Kill.

3.2 Results for CARP Future Projection Scenarios, Water Column Contaminant Concentrations

Water column contaminant concentration results for the future projection scenarios are presented in Appendix 2 as an extension of the calibration model and measurement comparison diagrams for the 127 x 205 model computational grid (Landeck Miller at al., 2023). Like the calibration, the results of the future projection scenarios for water column contaminant concentrations are presented on eighty-four pages in Appendix 2 for six contaminants and a PCB summation at sixty-one locations. The model and measurement comparison results in Appendix 2 for water column contaminant concentrations include twelve pages for each contaminant/summation with each page representing results for a reach containing three to six discrete locations.

Each reach page, in Appendix 2 and on Figures 3-6 to 3-9, includes a location map with the 127 x 205 model computational grid shown. On the map, the model computational grid cells for three to six discrete locations for which the time series of model results are presented are shown. At each location shown in Appendix 2 and on Figures 3-6 to 3-9, measurements representing the water column are presented. Measurements from various sources as compiled and described for the CARP post-audit (Landeck Miller et al., 2019) are shown with red squares in Appendix 2 and on Figures 3-6 to 3-9. Many of the compiled measurements are reported and displayed at detection limits as shown with pale pink squares in Appendix 2 and on Figures 3-6 to 3-9, especially for concentrations of 2,3,4,7,8-PCDF in Appendix 2. Measurements shown at detection limit are an important consideration for the evaluation of model and measurement comparisons. Additional measurements have been added since the completion of the post-audit (Landeck Miller, et al., 2019) and are shown with bright pink circles as identified in the legend on the diagrams in Appendix 2 and on Figures 3-6 to 3-9. The additional measurements are derived from the recent work of other CARP investigators. Reporting for CARP 2 data collection is in preparation.

Various model timeseries results for water column contaminant concentrations are displayed in Appendix 2 and on Figures 3-6 to 3-9 with several different lines and shading. A blue line is used to show the timeseries of thirty-day average contaminant concentrations calculated by the model over depth. A blue shade is used to show the contaminant concentration range over depth in the water column calculated by the model for each thirty-day interval. For reference, a gray line is used to show the timeseries of thirty-day average contaminant concentrations in the particulate phase calculated by the model over depth in the water column. For reference, a gray shade is used to show the timeseries of the thirty-day range of contaminant concentrations in the particulate phase calculated by the model over depth in the water column.

The blue lines, blue shades, grey lines, and grey shades shown in Appendix 2 and on example Figures 3-6 to 3-9 and used to display model results for water column contaminant concentrations include results for model calibration (October 1998 to September 2016) and the first and second future projection scenarios (October 2016 to September 2039). The interval October 2016 to September 2030, common to both future projection scenarios, provides an opportunity to assess CARP model predictions in the future without further management action and to assess the long-term influence of reduced loadings from the Upper Hudson River after completion of dredging in 2015. For the interval October 2030 to September 2039, two sets of future projection scenarios model results are shown on the same axes. The two sets of future projection scenarios model results reflect full implementation of the two approved Lower Passaic River Records of

Decision (RODs) both without and in combination with full remediation of Newark Bay and the Lower Hackensack River.

Figures 3-6 and 3-7 are examples of the future projection scenarios water column contaminant concentrations results, from the CARP contaminant fate and transport model using the 127 x 205 model computational grid, included in Appendix 2. On Figure 3-6 and 3-7, results are shown for the water column at six locations in Upper Newark Bay. On Figure 3-8 and 3-9, results are shown for the water column at five locations in the Hudson River. Figures 3-6 and 3-8 show results for 2,3,7,8-TCDD concentrations in the water column. Figures 3-7 and 3-9 show results for total PCB concentrations in the water column. On Figures 3-7 and 3-9, the measurements and the model results are based on twice the summation of the four PCB homologs modeled for calibration and future projection purposes. The application of the factor of two to the summation of four PCB homologs (i.e., di-CB, tetra-CB, hexa-CB, and octa-CB) to approximate total PCB was established during CARP 1 (HydroQual, 2007c) and was verified during CARP 2 method validation efforts (Landeck Miller et al., 2023).

3.3 Results for CARP Future Projection Scenarios, HARS Suitability

The independent applications of various sets of BSAFs (see Table 2-6) to future projection scenarios sediment bed contaminant concentrations results, from the CARP contaminant fate and transport model using the 127 x 205 model computational grid and provided in Appendix 1, produced estimates of contaminant body burdens in worms. The estimates for contaminant body burdens in worms were divided by contaminant specific HARS disposal criteria, 1 ppt for 2,3,7,8-TCDD and 113 ppb for total PCB, to produce ratio results for HARS disposal suitability. The HARS disposal suitability results are presented as ratios by location at various points in time. Sediments from locations with ratios significantly below 1 are strongly HARS suitability and sediments from locations with ratios significantly larger than 1 are strongly not HARS suitability. Figures in Appendices 3, 4, 5, and 6 display the HARS suitability ratio results as color maps with shades of green (HARS suitable) and red (non HARS suitable) increasing in intensity as the magnitude of the ratio results deviate from 1. Appendix 3 includes results when BSAFs from the Region's dredged material testing program are used. Appendix 4 includes results when CARP 1 field derived BSAFs are used. Appendix 5 includes results when fiftieth percentile CARP 2 laboratory derived BSAFs are used. Appendix 6 includes results when ninetieth percentile CARP 2 laboratory derived BSAFs are used.

In each of Appendices 3 through 6, six color ratio maps on six pages displaying HARS suitability ratio results are presented for different time horizons. The six horizons include 1998-99 annual average, 1998-2002 four-year average, 2022-23 current year annual average, 2029-2030 future without further action annual average, 2038-39 future nine years after simulated completion of Lower Passaic River Superfund RODS (USEPA, 2016a, 2016b, and 2021), and 2038-39 future nine years after simulated completion of Lower Passaic River Superfund RODS plus complete remediation of the Lower Hackensack River and Newark Bay. Appendix 3 includes twelve pages and provides HARS suitability results for 2,3,7,8-TCDD and for total PCB estimated from doubling a summation of four homolog. Appendices 4, 5, and 6 each include eighteen pages since results for 2,3,4,7,8-PCDF using the disposal criterion for 2,3,7,8-TCDD are included in addition to results for 2,3,7,8-TCDD and for total PCB estimated from doubling a summation of four homologs.

Example HARS suitability ratio maps from Appendix 6 are shown on Figures 3-10 and 3-11 for 2,3,7,8-TCDD and total-PCB, respectively. The examples on Figures 3-10 and 3-11 show the projected HARS suitability assuming ninetieth percentile CARP 2 BSAFs for both the current 2022-23 water year and the 2038-39 year assuming the October 2030 completion of the Lower Passaic River Superfund RODs plus complete remediation of the Lower Hackensack River and Newark Bay Study Area. Additional example HARS suitability ratio maps from Appendices 4 and 5 are shown on Figure 3-12 for total-PCB. The examples on Figure 3-12 show the projected HARS suitability for the current year (i.e., water year 2022-

23) assuming PCB homolog BSAFs from CARP 1 field observations (highest BSAFs) and from fiftieth percentile CARP 2 laboratory results (lowest BSAFs).

Lastly, for context, results of contaminant measurements in worms collected during CARP 2 at various locations are displayed with comparisons to HARS criteria on Figure 3-13. The CARP 2 Management Committee suggested that it might be appropriate to double the measured contaminant tissue concentrations for PCBs from 28-day exposures when making comparisons to HARS disposal criteria. The doubling was not implemented for Figure 3-13 which is based strictly on observations.

4.0 DISCUSSION

The discussion of the results for the future projection scenarios applying the full suite of CARP models on the 127 x 205 model computational grid is framed around the time series displays of contaminant concentrations in the sediment bed and the water column and spatial maps of HARS suitability based on worm bioaccumulation estimated with BSAFs.

4.1 Discussion of CARP Future Projection Scenarios, Sediment Bed Contaminant Concentrations

Separate discussion is provided for the sediment bed 2,3,7,8-TCDD and total PCB concentration results for the future projection scenarios.

4.1.1 Discussion of CARP Future Projection Scenarios, Sediment Bed Contaminant Concentrations, 2,3,7,8-TCDD

The sediment bed 2,3,7,8-TCDD concentration time series diagrams in Appendix 1 and on Figures 3-1 and 3-3 provide an opportunity to assess model and measurement comparison results for 2019 after the 2016 end of the model calibration period. The model results are generally within the middle to high end of the range of 2019 measurements and are also generally mutually consistent with the 2011 and 2015 measurements for the locations within the lower Newark Bay (Figure 3-1) and Hudson/East River (Figure 3-3) reaches. Similar model performance is also observed for 2,3,7,8-TCDD at other locations and reaches as displayed in Appendix 1 although there are often fewer measurements in other reaches as compared to Newark Bay. As shown in Appendix 1, at some locations within western Raritan Bay, 2,3,7,8-TCDD concentrations after the 2016 end of the model calibration period are gradually increasing, likely due to continued transport of 2,3,7,8-TCDD from the Lower Passaic and Newark Bay through the Arthur Kill prior to simulated future projection scenarios remediation starting in 2030.

The sediment bed 2,3,7,8-TCDD concentration time series diagrams in Appendix 1 and on Figures 3-1 and 3-3 provide an opportunity to assess CARP future projection scenario results. Based on the sediment bed 2,3,7,8-TCDD concentration time series for the top 10 cm (green lines and green and gray shades), the Lower Passaic River would not become re-contaminated for 2,3,7,8-TCDD after remediation (Appendix 1). Based on the sediment bed 2,3,7,8-TCDD concentration time series for the top 10 cm (green lines and green and gray shades), Newark Bay (Figure 3-1 and Appendix 1) and the Lower Hackensack River (Appendix 1) would become rapidly re-contaminated from zero 2,3,7,8-TCDD concentrations (Projection Run 2, lower green lines and green and gray shades) to 2,3,7,8-TCDD concentrations lower than those with only Lower Passaic River remediation (Projection Run 1, upper green lines and green and gray shades). The 2,3,7,8-TCDD re-contamination source is likely ongoing external loadings and transport from other parts of the Harbor. The 2,3,7,8-TCDD re-contamination in Projection Run 2 in Newark Bay and the Lower Hackensack River from the assigned zero concentration remains lower than the 8.3 ppt Superfund Record of Decision residual assigned for the Lower Passaic River lower 8.3 miles remediation. 2,3,7,8-TCDD re-contamination of the archive storage layer (pale blue line) in the Lower Hackensack River and Newark Bay Study Area occurs more slowly than the top 10 cm, evidencing that deeper bed inventory of 2,3,7,8-TCDD has effectively been removed from the model per the assumptions of the future projection scenarios.

The future projection scenarios sediment bed 2,3,7,8-TCDD concentration time series results indicate that the spatial influence of the Lower Passaic and Hackensack Rivers and Newark Bay Study Area remediations have impacts outside the remediation footprints. The extended spatial impact is most readily apparent in Appendix 1 for six Kill van Kull, twelve Arthur Kill, six Raritan Bay, and some Upper and Lower New York Bay locations where differences between sediment bed 2,3,7,8-TCDD concentration results for the projection scenarios are apparent (i.e., two separate sets of plotted model results starting October 1, 2030, appear differently in the time series diagrams). The top of Figure 3-5 displays examples from Appendix 1 of the 2,3,7,8-TCDD remediation responses for three Arthur Kill locations within the remediation footprints and three Arthur Kill locations outside the remediation footprints.

4.1.2 Discussion of CARP Future Projection Scenarios, Sediment Bed Contaminant Concentrations, Total PCB

The sediment bed total PCB concentration time series diagrams in Appendix 1 and on Figures 3-2 and 3-4 provide an opportunity to assess model and measurement comparison results for 2019 after the 2016 end of the model calibration period. The model results are generally within the low end of the range of 2019 measurements and are also generally mutually consistent with the 2011 and 2015 measurements for the locations within the lower Newark Bay (Figure 3-2) and Hudson/East River (Figure 3-4) reaches. The 2011 and 2015 measurements (shown with brown triangles, from dredging projects) are often slightly lower than the 2019 measurements (shown with pink and green squares, from CARP 2). The measurement discrepancy does not have a known mechanistic causation and is likely related to analytical methods differences. The CARP model results from the 127 x 205 model computational grid future projection scenarios simulations typically fall between the two sets of measurements. Similar model performance is also observed for total PCB at other locations and reaches as displayed in Appendix 1.

The sediment bed total PCB concentration time series diagrams in Appendix 1 and on Figures 3-2 and 3-4 provide an opportunity to assess CARP future projection scenario results. Based on the sediment bed total PCB concentration time series for the top 10 cm (green lines and green and gray shades), the Lower Passaic River would not become re-contaminated for total PCB after remediation (Appendix 1). Based on the sediment bed total PCB concentration time series for the top 10 cm (green lines and green and gray shades), Newark Bay (Figure 3-2 and Appendix 1) and the Lower Hackensack River (Appendix 1) would become rapidly re-contaminated from zero total PCB concentrations (Projection Run 2, lower green lines and green and gray shades) to total PCB concentrations approaching those with only Lower Passaic River remediation (Projection Run 1, upper green lines and green and gray shades). The total-PCB re-contamination source is likely ongoing external loadings and transport from other parts of the Harbor. The total PCB re-contamination in Projection Run 2 in Newark Bay and the Lower Hackensack River from the assigned zero concentration approaches several hundred ppb, as expected for the Lower Hudson River opposite Manhattan. Total-PCB re-contamination of the archive storage layer (pale blue line) in the Lower Hackensack River and Newark Bay Study Area occurs more slowly than the top 10 cm, evidencing that deeper bed inventory of total PCB has effectively been removed from the model per the assumptions of the future projection scenarios.

Unlike 2,3,7,8-TCDD results, the future projection scenarios sediment bed total PCB concentration time series results indicate that the spatial influence of the Lower Passaic and Hackensack Rivers and Newark Bay Study Area remediations have modest, if any, impacts outside the remediation footprints. This is most readily apparent in Appendix 1 for numerous Kill van Kull and Arthur Kill locations just beyond the Newark Bay Study Area, as well as in other Harbor locations, where differences between sediment bed total PCB concentration results for the two projection scenarios are barely noticeable or are even non-discernible (i.e., two separate sets of plotted model results starting October 1, 2030, appear as only one set of model results in the time series diagrams). The bottom of Figure 3-5 displays examples from Appendix 1 of the total PCB remediation responses for three Arthur Kill locations within the remediation footprints and three Arthur Kill locations outside the remediation footprints. Further, the total PCB results shown on the bottom of Figure 3-5 as compared to the 2,3,7,8-TCDD results shown on the top of Figure 3-5 illustrate the contaminant-specific modeled spatial impacts of the remediations considered in the two future projection scenarios.

4.2 Discussion of CARP Future Projection Scenarios, Water Column Contaminant Concentrations

Separate discussion is provided for the water column 2,3,7,8-TCDD and total PCB concentration results for the future projection scenarios.

4.2.1 Discussion of CARP Future Projection Scenarios, Water Column Contaminant Concentrations, 2,3,7,8-TCDD

The water column 2,3,7,8-TCDD concentration time series diagrams in Appendix 2 and on Figures 3-6 and 3-8 provide a limited opportunity to assess model and measurement comparison results for 2019 after the 2016 end of the model calibration period. The model results are on the high end of the range of 2019 measurements for a single location within the Hudson River reach (Figure 3-8). Similar model performance is observed for 2,3,7,8-TCDD at other locations and reaches as displayed on pages 2 to 13 of Appendix 2. For the Upper Newark Bay reach (Figure 3-6) water column 2,3,7,8-TCDD measurements after the 2016 end of the model calibration were not available and measurements available for 2010-2014 include non-detected samples at detection limits (pale pink squares).

The water column 2,3,7,8-TCDD concentration time series diagrams in Appendix 2 and on Figures 3-6 and 3-8 provide an opportunity to assess CARP future projection scenario results. Simulated sediment bed cleanups of the Lower Passaic River alone and in combination with the Hackensack River and Newark Bay Study Area starting in October 2030 for both scenarios modeled show a decline in Upper Newark Bay water column 2,3,7,8-TCDD concentrations (Figure 3-6). Somewhat different 2,3,7,8-TCDD concentration results at the Upper Newark Bay water column locations (Figure 3-6) occur for the two scenarios modeled. Through 2039, the 2,3,7,8-TCDD water column results in Upper Newark Bay (Figure 3-6) for the first future projection scenario (i.e., Lower Passaic River remediation only) decline toward the residual achieved by the second future projection scenario (i.e., combined Lower Passaic and Hackensack Rivers and Newark Bay Study Area remediation). The combined scenario achieves smaller water column concentrations of 2,3,7,8-TCDD somewhat more rapidly and flatly maintains those concentrations. In other reaches such as the Arthur Kill (page 9 of Appendix 2), 2,3,7,8-TCDD water column concentration results from both future projection scenarios decline continuously through 2039 with a noticeable difference in concentrations between the two simulations. Within Raritan Bay, Upper NY Bay, the East River, and Jamaica Bay (pages 10, 12, and 13 of Appendix 2), it is difficult to distinguish the declining 2,3,7,8-TCDD water column concentration projection results for the two scenarios. Water column 2,3,7,8-TCDD concentration responses to simulated remediation of the Lower Passaic and Hackensack Rivers and Newark Bay Study Area sediment beds starting in October 2030 are not apparent at locations in the Lower Hudson River above Manhattan (locations 1 to 4 on Figure 3-8).

4.2.2 Discussion of CARP Future Projection Scenarios, Water Column Contaminant Concentrations, Total PCB

The water column total PCB concentration time series diagrams in Appendix 2 and on Figures 3-7 and 3-9 provide a limited opportunity to assess model and measurement comparison results for 2019 after the 2016 end of the model calibration period. The model results are within the center of the range of 2019 measurements for a single measurement location within the Hudson River reach (Figure 3-9). Similar model performance is observed for total PCB at other locations and reaches as displayed in Appendix 2. For the Upper Newark Bay reach (Figure 3-7) water column total PCB measurements after the 2016 end of the model calibration were not available. There is generally a declining trend for the total PCB concentrations in the water column of the Upper Newark Bay and Hudson River reaches through 2029.

The water column total PCB concentration time series diagrams in Appendix 2 and on Figures 3-7 and 3-9 provide an opportunity to assess CARP future projection scenario results. The occurrence of reduced Upper Hudson River total PCB loading after the completion of remedial dredging in 2016 is apparent in total PCB water column concentration results (blue lines and shades) in the Hudson River near Poughkeepsie (locations 1 and 2 on Figure 3-9). Simulated sediment bed cleanups of the Lower Passaic and Hackensack Rivers and Newark Bay Study Area starting in October 2030 for both scenarios modeled show a decline in water column total PCB concentrations within those remediation areas (Figure 3-7). There are very similar overlapping and reduced PCB concentration results at the Upper Newark Bay water column locations (Figure 3-7) for the two scenarios modeled. Water column total PCB concentration responses to simulated remediation of the Lower Passaic and Hackensack Rivers and Newark Bay Study Area sediment beds starting in October 2030 are not apparent at locations in the Hudson River (Figure 3-9).

4.3 Discussion of CARP Future Projection Scenarios, HARS Suitability

Before considering the map displays of CARP HARS suitability results, an element of the methods used to conduct the future projection scenarios warrants discussion specific to HARS suitability projections. Newark Bay and the portions of the Kill van Kull and Arthur Kill between the Goethals and Bayonne Bridges, considered as the Newark Bay Study Area, are areas of overlap between in-progress Superfund efforts and dredged material management interests. The Superfund effort has not yet established eventual remediation goals for these areas. For CARP 2 future projection scenario simulations, a cleanup to zero concentration was assumed and the model results show rapid re-contamination due to ongoing sources of 2,3,7,8-TCDD and total PCB. This temporal behavior is evident on Figures 3-1 and 3-2 and other timeseries diagrams in Appendix 1. It is expected that even with a remediation goal set greater than zero at a small residual concentration for Newark Bay and portions of the Kills, the calculated concentrations after recontamination would still be similar and should not appreciably alter the projected HARS suitability results. The projected HARS suitability results are for the first time inclusive of cleanups of the Newark Bay Study Area and the Lower Hackensack River.

Further consideration and context for the map displays of CARP HARS suitability is the varying magnitudes of the BSAFs presented in Table 2-6. In the case of PCB homologs (and therefore total PCB), the greater magnitudes of the CARP 1 BSAFs, and to a lesser extent the Dredged Material Testing BSAFs and CARP 2 ninetieth percentile BSAFs, as compared to the CARP 2 fiftieth percentile BSAFs, are enough to yield different conclusions for current and future HARS suitability. The CARP 2 fiftieth percentile BSAFs for PCB homologs (results in Appendix 5 and on Figure 3-12 bottom panel) indicate that the modeled concentrations for total PCB in sediments for the current year and future years are HARS suitable. The CARP 1 BSAFs for PCB homologs indicate that the modeled concentrations for total PCB in sediments for the current year and future years are not HARS suitable (results in Appendix 4 and on Figure 3-12 top panel). Similar dependence of HARS suitability conclusions on the BSAF applied is also apparent for 2,3,7,8-TCDD and 2,3,4,78-PCDF on the map diagrams provided in Appendices 3 through 6. For 2,3,7,8-TCDD specifically, after the simulated cleanups for the Lower Passaic River, Lower Hackensack River, and the Newark Bay Study Area (i.e., projection simulation 2), use of the dredged material testing and CARP 2 BSAFs (both fiftieth and ninetieth percentiles) indicate the Harbor would be largely HARS suitable. The use of the field-derived CARP 1 BSAF indicates that portions of the Arthur Kill and Raritan Bay would not be HARS suitable. Accordingly, the selection of the 2,3,7,8-TCDD and PCB homolog BSAFs to be used for interpreting model outputs for dredged material management planning purposes is critical.

In consultation with the CARP Management Committee and CARP 2 principal investigators for bioaccumulation, ninetieth percentile CARP 2 BSAFs have been recommended as appropriate for purposes of future projections of HARS suitability and are more robust and modern than the Dredged Material Testing BSAFs. The less conservative CARP 2 fiftieth percentile BSAFs might be useful for other purposes such as for making economic decisions about conducting HARS suitability testing or pursuing other dredged material disposal options without HARS testing. The field-derived CARP 1 BSAFs are likely to be most useful for Harbor sediment quality issues beyond evaluating dredged material disposal options.

The specific example HARS suitability maps shown in the bottom panels on Figures 3-10 and 3-11 indicate that HARS suitability would be attained for 2,3,7,8-TCDD and total PCBs in Newark Bay and the majority of the Harbor assuming ninetieth percentile CARP 2 BSAFs with a factor of two multiplier for total PCB worm concentrations and the October 2030 completion of the Lower Passaic River Superfund RODS plus complete remediation of the Lower Hackensack River and Newark Bay Study Area. The specific example HARS suitability maps shown on Figure 3-12 illustrate the calculated range in HARS suitability for total PCB for the current 2022-23 water year based on the range of homolog BSAFs evaluated.

5.0 CONCLUSION

The CARP 1 management conclusion for attaining a HARS Suitable Newark Bay (HydroQual, 2007c) by 2040 after remediation efforts continues to hold true based on CARP 2 measurement and modeling efforts.

Specifically, for 2,3,7,8-TCDD, based on ninetieth percentile CARP 2 BSAFs and CARP 2 future projection modeling results, a HARS suitable Newark Bay (and practically entire Harbor) for 2,3,7,8-TCDD is expected in the future after the implementation of two Superfund Records of Decision (RODs) for the Lower Passaic River and full remediation of the Lower Hackensack River and Newark Bay. Further, the application of dredged material testing program BSAFs, used for CARP 1 projections, to the CARP 2 future projection modeling results does not alter this HARS suitability conclusion.

Specifically, for total PCB based on ninetieth percentile CARP 2 BSAFs and CARP 2 future projection modeling results, a HARS suitable Newark Bay for total PCB is expected in the future after the implementation of two Superfund Records of Decision (RODs) for the Lower Passaic River and full remediation of the Lower Hackensack River and Newark Bay. Further, the application of BSAFs from the dredged material testing program, as were applied for CARP 1 projections, to the CARP 2 future projection modeling results, does not alter this HARS suitability conclusion for Newark Bay total PCB. In other areas of the Harbor, the CARP 2 future projection modeling results for total PCB HARS suitability are more favorable when the ninetieth percentile CARP 2 BSAFs are applied as compared to applying BSAFs from the dredged material testing program.

6.0 ACKNOWLEDGMENTS AND DISCLAIMERS

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8.0 SECTION 2 TABLES AND FIGURES

Table 2- 1. Future projection scenarios tracking of water years, bathymetry conditions, and new hydrodynamic model simulations.

Assumptions for Hydrodynamic Conditions (i.e., hydrographs and bathymetry) for the Single Hydrodynamic/Sediment Transport Future Projection Condition Supporting Two Contaminant Future Projections, 127 x 205 Model Grid

ACTUAL	ASSIGNED		SOURCE
Water Years (WYs) Oct. 1 to Sept. 30	**Hydrodynamic Model WYs Flow Conditions**	**Hydrodynamic Model Bathymetry**	**Hydrodynamic Modeling Effort**
1998-99	1998-99	< 40', pre-deepening	from calibration (Landeck Miller at al., 2023)
1999-2003	1999-2003	interim KVK, NB, PJC	
2003-07	2003-07	45' – 47' NB, KVK	
2007-10	2007-10	interim NB, Kills	
2010-16	2010-16	52' NB, Kills, PJC, Anchorage, Ambrose	
2016-2028	1998-2010	52' NB, Kills, PJC, Anchorage, Ambrose	simulated for future projection
2028-2034	2010-16	52' NB, Kills, PJC, Anchorage, Ambrose	from calibration
2034-2039	1998-2003	52' NB, Kills, PJC, Anchorage, Ambrose	uses 2016 to 2021 simulations

Notes

Abbreviations: WYs = water years, KVK = Kill van Kull, NB = Newark Bay, PJC = Port Jersey Channel, Kills = Arthur Kill and Kill van Kull, Anchorage and Ambrose refer to the Anchorage and Ambrose Channels

Contemplated 55' Deepening and Widening, Not Included: Given the numerous contingencies and uncertainties, associated with the contemplated National Economic Development Plan for deepening and widening in NY/NJ Harbor channels, at the time the CARP future projection scenarios were developed, the contemplated National Economic Development Plan has not been reflected in the CARP models future projection scenarios. The CARP future projection scenarios do not include deepening beyond the 52' deepening projects. The contemplated National Economic Development Plan would involve deepening the pathways to the Elizabeth – Port Authority Marine Terminal and the Port Jersey – Port Authority Marine Terminal by 5 feet to a maintained depth of -55 feet MLLW (i.e., initial deepening to 57'). The contemplated plan would involve deepening Ambrose Channel, Anchorage Channel, the Kill van Kull, Newark Bay Channel, South Elizabeth Channel, Elizabeth Channel, and Port Jersey Channel. This would include the additional width required for structural stability and for the navigation of the design vessel to transit from the sea to the Elizabeth – Port Authority Marine Terminal and the Port Jersey – Port Authority Marine Terminal. Channel configurations would avoid and minimize environmental and cultural resource impacts while still meeting navigation safety requirements. The plan would allow for calling vessels to increase their loads. The increase in cargo per vessel call would yield economic benefits by allowing for more efficient use of containerships. If successfully incorporated in the FY24 Water Resources Development Act (WRDA), construction would start FY 25/26 and go for 15 years, completing June 30, 2040.

Table 2- 2. Future projection scenarios tracking of water years, hydrodynamic conditions, sediment bed particle mixing rates, and new sediment transport and organic carbon production model simulations.

Assumptions for Sediment Transport (i.e., hydrodynamic transport and particle mixing rates) for the Single Sediment Transport and Organic Carbon Production Future Projection Condition Supporting Two Contaminant Fate and Transport Future Projections, 127 x 205 Model Grid			
ACTUAL	ASSIGNED		SOURCE
Water Years (WYs) Oct. 1 to Sept. 30	**Hydrodynamic Model WYs Flow Conditions**	**Decreased Bed Mixing in Lower Passaic River (yes/no)**	**Sediment Transport Modeling Effort**
1998-99 to 2015-16	1998-99 to 2015-16 from calibration	yes	from calibration, Landeck Miller et al., 2023
2016-17 to 2027-28	1998-99 to 2009-10 projection version[1]	yes	simulated for future projection[2]
2028-29 to 2029-30	2010-11 to 2011-12 from calibration	yes	simulated for future projection[2]
2030-31 to 2033-34	2012-13 to 2015-16 from calibration	no, restored to Harbor-wide levels	simulated for future projection[2]
2034-35 to 2038-39	1998-99 to 2002-03 projection version[1]	no, restored to Harbor-wide levels	simulated for future projection[2]

Notes:
[1]Projection hydrodynamics incorporate the bathymetry of 2010-11 to 2015-16 for all future years.
[2]For each water year starting October 1, there is a "hot start" from September 30 of the previous water year such that the simulation is continuous. For example, 2016-17 has a "hot start" where 2015-16 ended, 2017-18 has a "hot start" where 2016-17 ended, etc.

Table 2- 3. Future projection scenarios tracking of water years, hydrodynamic conditions, sediment transport conditions, contaminant loadings, contaminant bed concentrations, and new contaminant fate and transport model simulations.

Assumptions for Contaminant Conditions (i.e., hydrodynamic transport, sediment transport, loadings, and bed concentrations) for Two Contaminant Future Projections, 127 x 205 Model Grid					
ACTUAL	ASSIGNED				SOURCE
Water Years (WYs) October 1 to September 30	**Hydrodynamic Model WYs Flow Conditions**	**Sediment Transport Model Conditions**	**Upper Hudson PCB Loading**	**Remediated bed chemical concentrations (yes/no)**	**Contaminant Transport Modeling Effort**
1998-99 to 2015-16	1998-99 to 2015-16 from calibration	1998-99 to 2015-16 from calibration	measurements plus pre-, during, and post-dredging regressions	no	from calibration, Landeck Miller et al., 2023
2016-17 to 2027-28	1998-99 to 2009-10 projection version[1]	2016-17 to 2038-39 from sediment transport projection simulation	post-dredging regressions only	no	simulated for future projection[2]
2028-29 to 2029-30	2010-11 to 2011-12 from calibration			no	simulated for future projection[2]
2030-31 to 2033-34	2012-13 to 2015-16 from calibration			yes, for October 1, 2030[3,4,5]	simulated for future projection[2]
2034-35 to 2038-39	1998-99 to 2002-03 projection version[1]			no	simulated for future projection[2]

Notes:

[1]Projection hydrodynamics incorporate the bathymetry of 2010-11 to 2015-16 for all future years.

[2]For each water year starting October 1, there is a "hot start" from September 30 of the previous water year such that the simulation is continuous. For example, 2016-17 is to "hot start" where 2015-16 ended, 2017-18 is to "hot start" where 2016-17 ended, etc.

[3]On October 1, 2030, for the entire lower 8.3 miles of the Lower Passaic River, model archive and active layer bed contaminant concentrations are set to a small residual per 2016 ROD. Applied to both future projections. See Table 2-4.

[4]On October 1, 2030, for approximately 33% of miles 15 to 8.3 of the Lower Passaic River that will be dredged, per 2021 ROD, archive layer and active layer bed concentrations (based on reach wide SWACs) are set to a small residual. Applied to both future projections. See Table 2-5.

[5]On October 1, 2030, for Newark Bay and Lower Hackensack River, model archive and active layer bed contaminant concentrations are set to zero. Applied to second future projection only.

Table 2- 4. Future projection scenarios contaminant bed concentrations assigned to Lower Passaic River lower 8.3 miles for October 1, 2030, assumed completion of 2016 ROD.

CONTAMINANT	CONCENTRATION	RATIONALE
2,3,7,8-TCDD	8.3 ppt	"Alternative 3 Cap/Dredge Flood/Navigation with DMM Scenario B" in USEPA, 2016a on page 94 third bullet, on Figure 19, top panel, and on Table 25, USEPA remediation goal.
2,3,4,7,8-PCDF	2 ng/kg	"Full Capping PP RTC" in USEPA, 2016b, page 62, Figure 15.9-61, Superfund model projection after ROD implementation.
di-CB	5 ug/kg	"Full Capping PP RTC" in USEPA, 2016b, pages 87, 97, 107, and 122, Figures 15.9-86, 15.9-96, 15.9-106, and 15.9-121, Superfund model projection after ROD implementation. It is noted that the sum of the 4 homologs is 51 ug/kg, about ½ of the assumed attainable remediation goal of 100 ug/kg for total PCBs based on Figure 20 in USEPA, 2016a.
tetra-CB	25 ug/kg	
hexa-CB	18 ug/kg	
octa-CB	2.9 ug/kg	

Table 2- 5. Future projection scenarios contaminant bed concentrations assigned to Lower Passaic River miles 15 to 8.3 for October 1, 2030, assumed completion of 2021 ROD.

CONTAMINANT	CONCENTRATION	RATIONALE
2,3,7,8-TCDD	≤ 75 ppt	"Alternative 3" in USEPA, 2021, Attachment A, Proposed Plan and ~93% reduction from the current Surface Area Weighted Average Concentration (SWAC) from USEPA, 2021, page 78.
2,3,4,7,8-PCDF	0.07 multiplier in specific model grid cells	Same ~93% reduction as 2,3,7,8-TCDD applied to 2,3,4,7,8-PCDF concentrations from CARP 127 x 205 model grid projections for September 30, 2030, only for those model grid cells where it was necessary to reduce the CARP model calculated 2,3,7,8-TCDD concentrations to achieve 75 ppt.
di-CB	0.0135 ppm	USEPA, 2021, page 78, Total PCB = 0.27 ppm, and represents an 83% reduction from the current SWAC based on currently available data and is below the PCB background level. 0.27 ppm for total PCB implies 0.135 ppm for four homologs. Assume fractions for the four PCB homologs based on USEPA, 2016a, Figure 20 of 10%, 50%, 35%, 5%.
tetra-CB	0.0675 ppm	
hexa-CB	0.04725 ppm	
octa-CB	0.00675 ppm	

Table 2- 6. Worm Biota-Sediment Accumulation Factors (BSAFs) used to transition future sediment bed contaminant concentration estimates to body burdens in worms for dredged material HARS suitability determinations.

BSAF SOURCE	2,3,7,8-TCDD	2,3,4,7,8-PCDF	Di-CB	Tetra-CB	Hexa-CB	Octa-CB
	WORM BSAFs (gm-DW/gm-WW) [A,G,H]					
NY/NJ Dredged Material Testing [B,C]	0.052[B]	NA	0.243[C]	0.300 [C]	0.496 [C]	0.216 [C]
CARP 1 Field-Derived [D]	0.170	0.198	0.200	0.972	1.808	1.407
CARP 2 Laboratory, 50%[E]	0.035	0.039	0.009	0.063	0.189	0.144
CARP 2 Laboratory, 90%[F]	0.067	0.079	0.018	0.126	0.397	0.332

Notes:

[A] DW = dry weight, WW = wet weight

[B] Schrock et al., 1997 samples re-worked for units. BSAF = 0.363 gm-sed-DW/gm-worm-DW divided by approximately 7 gm-worm-WW/gm-worm-DW[D]

[C] Dredged material testing BSAFs provided by USEPA Region 2

[D] HydroQual, 2007c

[E] Developed by other CARP 2 investigators based on the geometric means (i.e., fiftieth percentiles) from up to sixty-eight tissue and sediment samples with 28-day exposures. Report in preparation.

[F] Developed by other CARP 2 investigators based on the ninetieth percentiles from up to sixty-eight tissue and sediment samples with 28-day exposures. Report in preparation.

[G] Reporting units driven by dredged material testing BSAFs provided by USEPA Region 2 during CARP 1

[H] The BSAFs in this table are reported as measured. Multipliers used for the application of the PCB BSAFs are not included in the tabulated BSAFs.

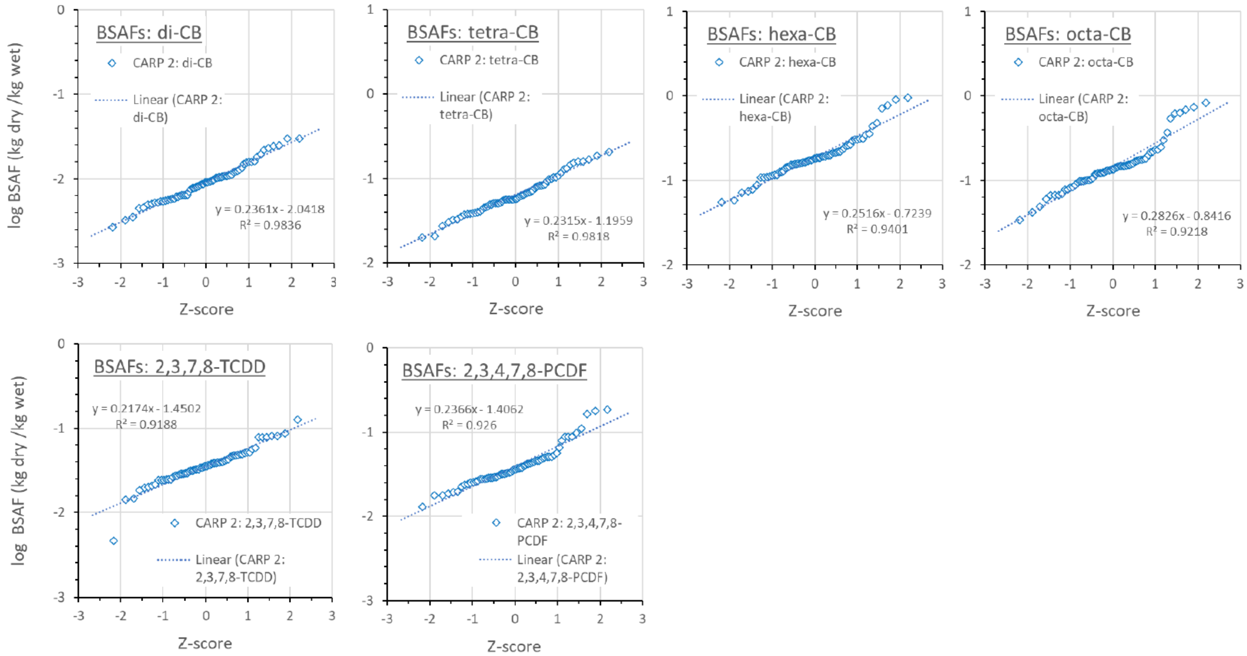


Figure 2- 1. Log normal probability distributions of CARP 2 Biota-Sediment Accumulation Factors (BSAFs) developed from up to sixty-eight twenty-eight-day laboratory exposures of worms to Harbor sediments. The individual calculated CARP 2 BSAFs are shown with diamonds. The fitted log normal probability distributions are shown with lines. The equations of the fitted log normal probability distribution lines are provided in slope-intercept form along with the coefficients of determination (R^2). The fiftieth and ninetieth percentiles from the fitted log normal probability distributions are included in Table 2-6.

9.0 SECTION 3 FIGURES

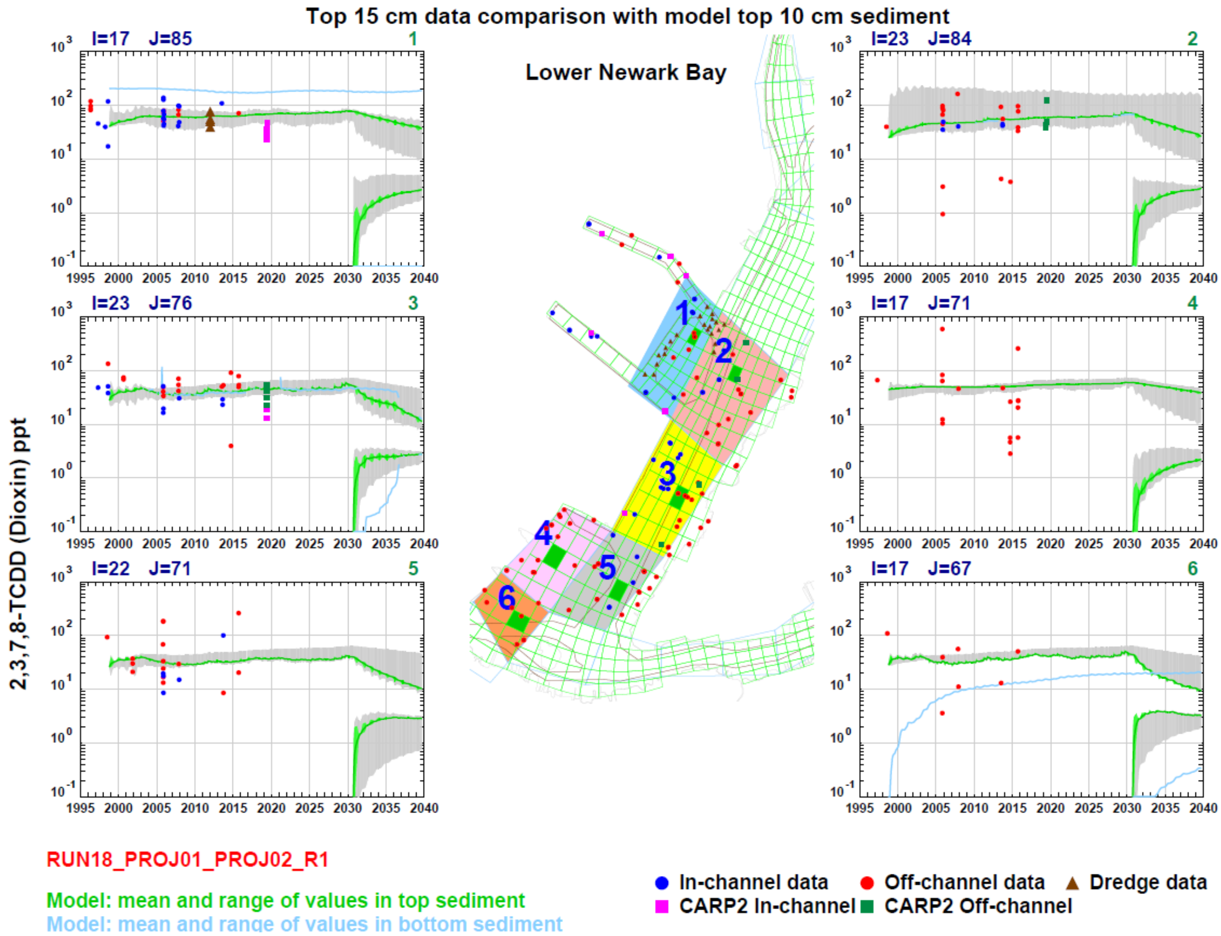


Figure 3- 1. 2,3,7,8-TCDD solids-normalized sediment bed concentrations model results for the calibration period and for two future projection scenarios for six locations in Lower Newark Bay. The model results (green lines and green and gray shades) compare well to measurements collected for multiple programs. Model and measurement results suggest relatively flat temporal gradients through September 2030. The simulation of the Lower Passaic River Superfund RODs starting October 1, 2030, decreases modeled 2,3,7,8-TCDD sediment bed concentrations in lower Newark Bay (upper set of green lines and green and gray shades). The simulation of Lower Hackensack River and Newark Bay Study Area remediations simultaneously with the Lower Passaic River Superfund RODS rapidly further decreases modeled 2,3,7,8-TCDD sediment bed concentrations in lower Newark Bay (lower set of green lines and green and gray shades).

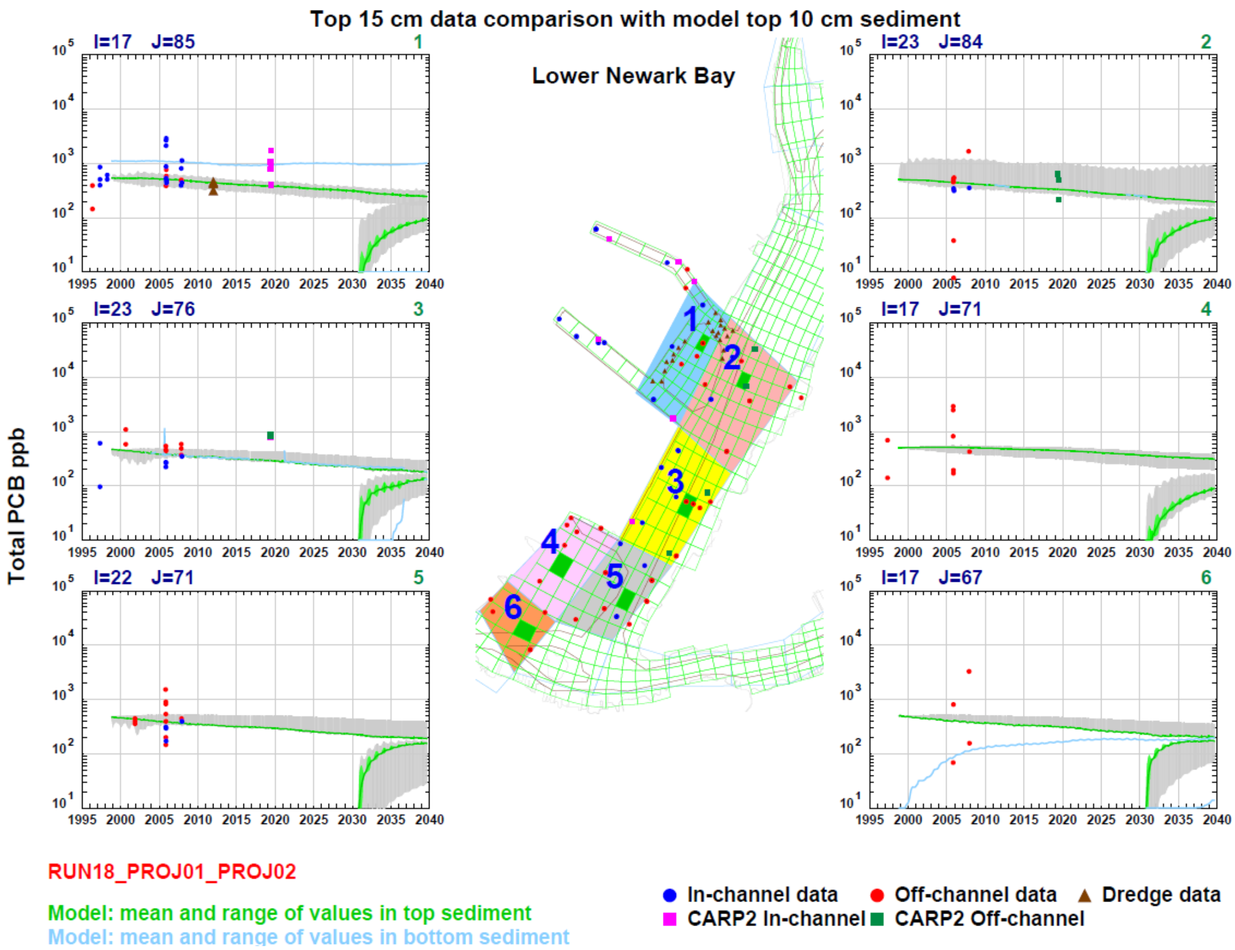


Figure 3- 2. Total PCB solids-normalized sediment bed concentrations model results for the calibration period and two future projection scenarios for six locations in Lower Newark Bay. The model results (green lines and green and gray shades, twice the sum of four homologs) compare well to measurements collected for multiple programs. Model and measurement results suggest relatively flat/slightly declining temporal gradients through September 2030. The simulation of the Lower Passaic River Superfund RODs starting October 1, 2030, does not appreciably change the time behavior of PCB sediment bed concentrations in lower Newark Bay (upper set of green lines and green and gray shades). The simulation of Lower Hackensack River and Newark Bay Study Area remediations simultaneously with the Lower Passaic River Superfund RODs, changes the time behavior of PCB sediment bed concentrations only temporarily with recontamination by 2040 in lower Newark Bay (lower set of green lines and green and gray shades) approaching total PCB solids-normalized sediment bed concentrations without the additional remediations.

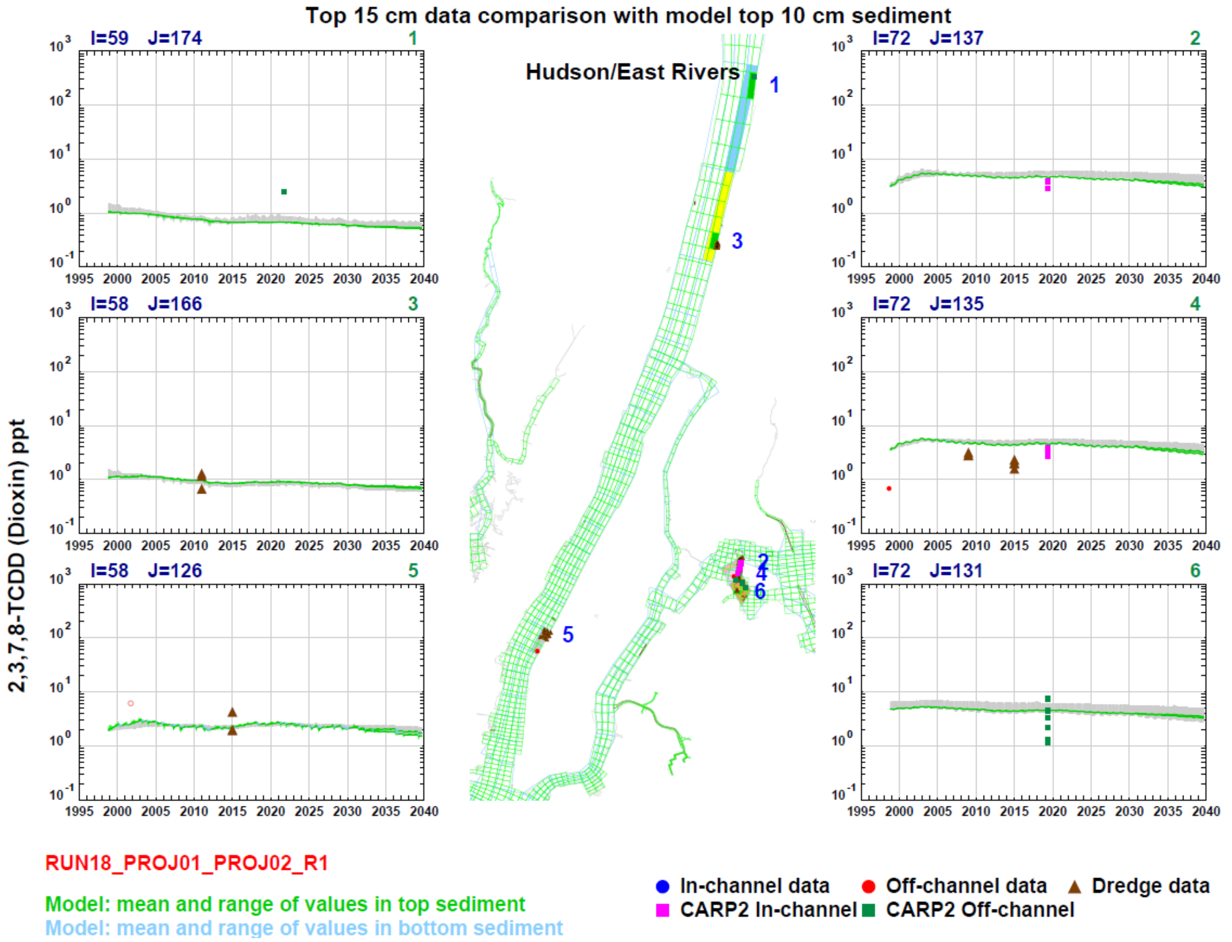


Figure 3- 3. 2,3,7,8-TCDD solids-normalized sediment bed concentrations model results for the calibration period and two future projection scenarios for six locations in the Hudson and East Rivers. The model results (green lines and green and gray shades, twice the sum of four homologs) compare well to limited measurements collected for multiple programs. Stronger model and measurement comparisons at locations 3 and 5 may offset the importance of the potential underprediction further upstream at location 1. Model and measurement results suggest relatively flat/slightly declining temporal gradients through September 2030. The simulation of the Lower Passaic River Superfund RODs and the Lower Hackensack River and Newark Bay Study Area remediations starting October 1, 2030, do not appreciably change the time behavior of 2,3,7,8-TCDD sediment bed concentrations in the Hudson and East Rivers.

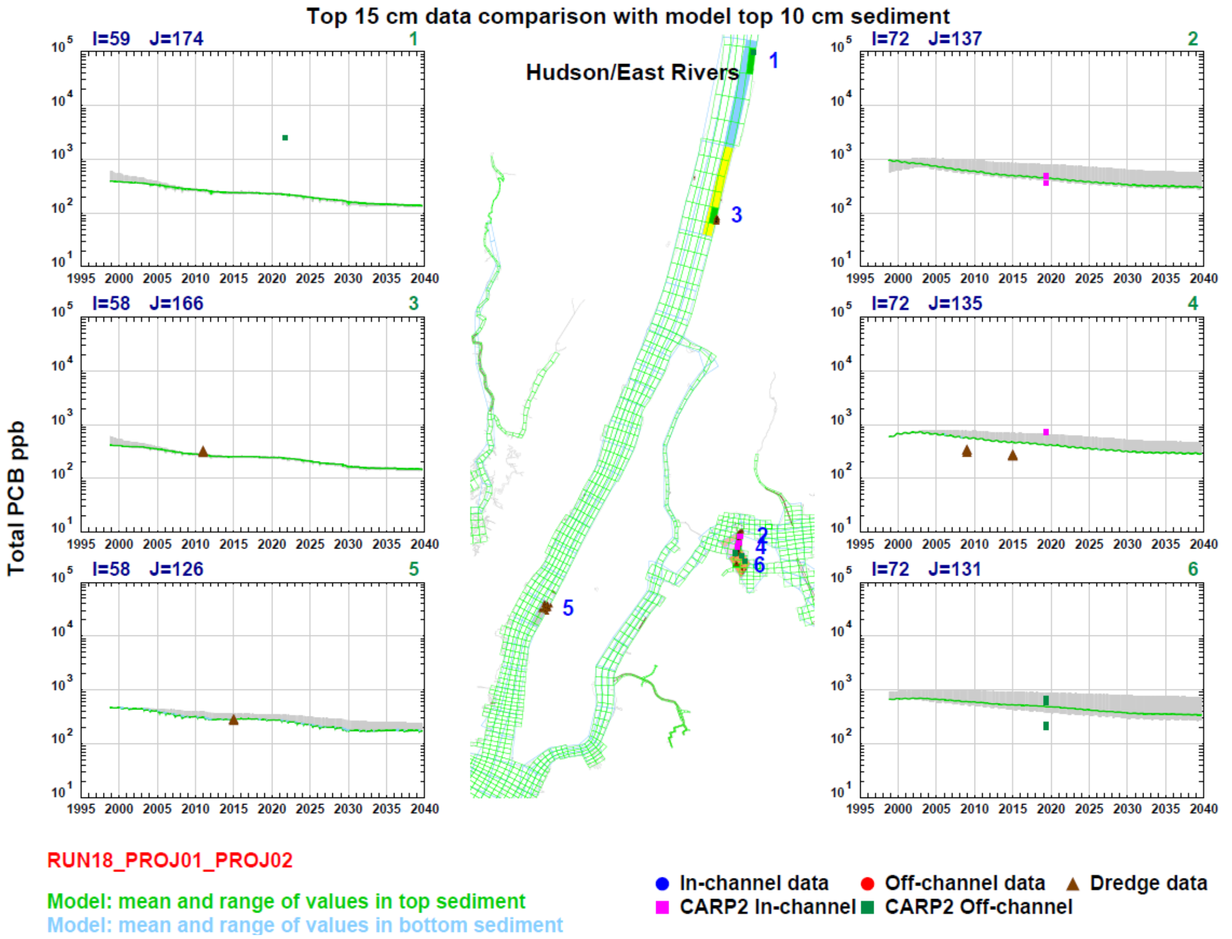


Figure 3- 4. Total PCB solids-normalized sediment bed concentrations results for the calibration period and two future projection scenarios for six locations in the Hudson and East Rivers. The model results (green lines and green and gray shades, twice the sum of four homologs) compare well to limited measurements collected for multiple programs. Stronger model and measurement comparisons at locations 3 and 5 may offset the importance of the potential underprediction further upstream at location 1. Model and measurement results suggests slightly declining temporal gradients through September 2030. The simulation of the Lower Passaic River Superfund RODs and the Lower Hackensack River and Newark Bay Study Area remediations starting October 1, 2030, do not appreciably change the time behavior of PCB sediment bed concentrations in the Hudson and East Rivers.

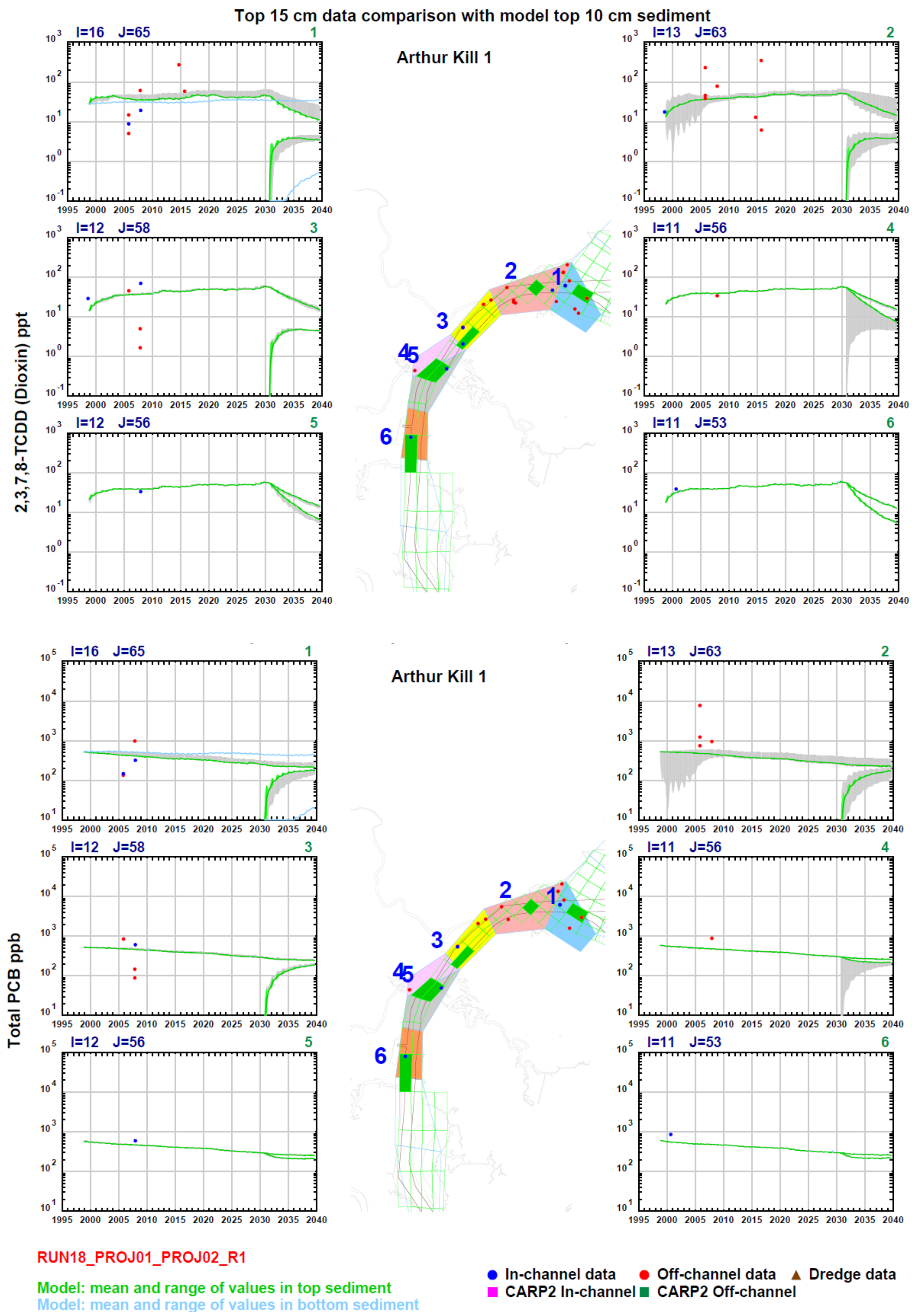


Figure 3- 5. 2,3,7,8-TCDD (top) and total PCB (bottom) solids-normalized sediment bed concentrations results for the calibration period and two future projection scenarios for six locations in the northern Arthur Kill. For locations 1 to 3 within the remediation footprint of the Newark Bay Study area, the model results (lower sets of green lines and green and gray shades) for 2,3,7,8-TCDD (top) and total PCB (bottom) show a benefit for Lower Hackensack River and Newark Bay Study Area remediations starting October 1, 2030, as compared to implementation of the Lower Passaic RODs alone (upper sets of green lines and green and gray shades). The modeled total PCB (bottom) benefits are temporary. For locations 4 to 6 outside of the remediation footprint of the Newark Bay Study area, the model results (lower sets of green lines and green and gray shades) for 2,3,7,8-TCDD show a benefit for Lower Hackensack River and Newark Bay Study Area remediations starting October 1, 2030, as compared to implementation of the Lower Passaic RODs alone (upper sets of green lines and green and gray shades). For locations 4 to 6, the model results for total PCB show little added benefit (i.e., almost coincident green lines) for Hackensack River and Newark Bay Study Area remediations.

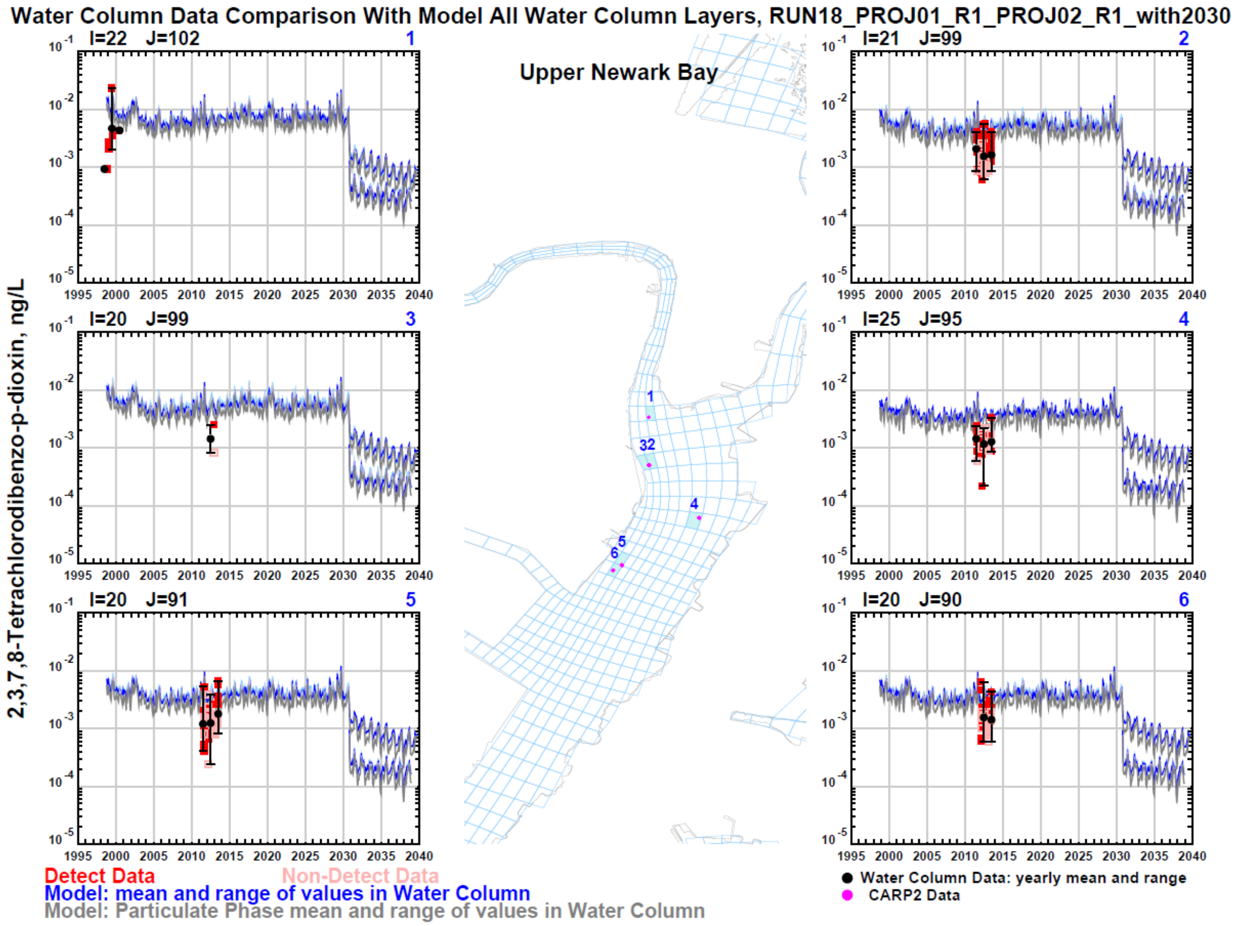


Figure 3- 6. 2,3,7,8-TCDD model results for the calibration period and for two future projection scenarios for six locations in upper Newark Bay. The model results (blue lines and shades) for simulated cleanups of the Lower Passaic River alone (scenario 1, upper profile) and in combination with the Hackensack River and Newark Bay Study Area (scenario 2, lower profile) starting in October 2030 show declines in 2,3,7,8-TCDD concentration results for both future projection scenarios at these water column locations. The model results suggest that 2,3,7,8-TCDD concentrations at these locations in Upper Newark Bay achieved from Lower Passaic River cleanup alone (upper profile) might eventually decline to approach the levels attained by including cleanups of the Hackensack River and Newark Bay Study Area (lower profile). For reference, model results for particulate phase concentrations of 2,3,7,8-TCDD are shown in gray.

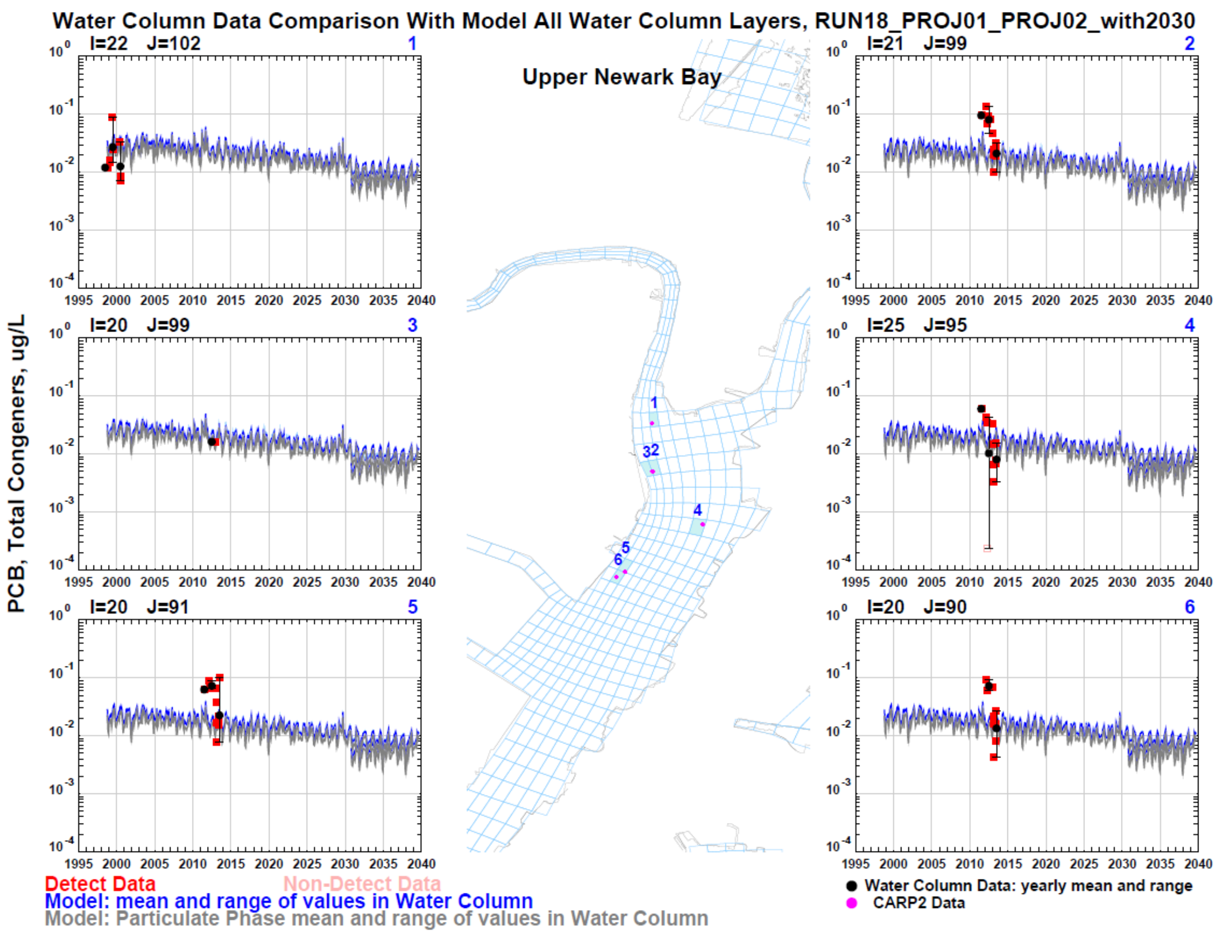


Figure 3- 7. Total PCB water column concentrations (estimated as twice the summation of four homologs) model results for the calibration period and for two future projection scenarios for six locations in upper Newark Bay. The model results (blue lines and shades) decline somewhat. For reference, model results for particulate phase concentrations of total PCB are shown in gray. Simulated cleanups of the Lower Passaic and Hackensack Rivers and Newark Bay Study Area starting in October 2030 show a further decline with very similar overlapping PCB concentration results for both future projection scenarios at these water column locations.

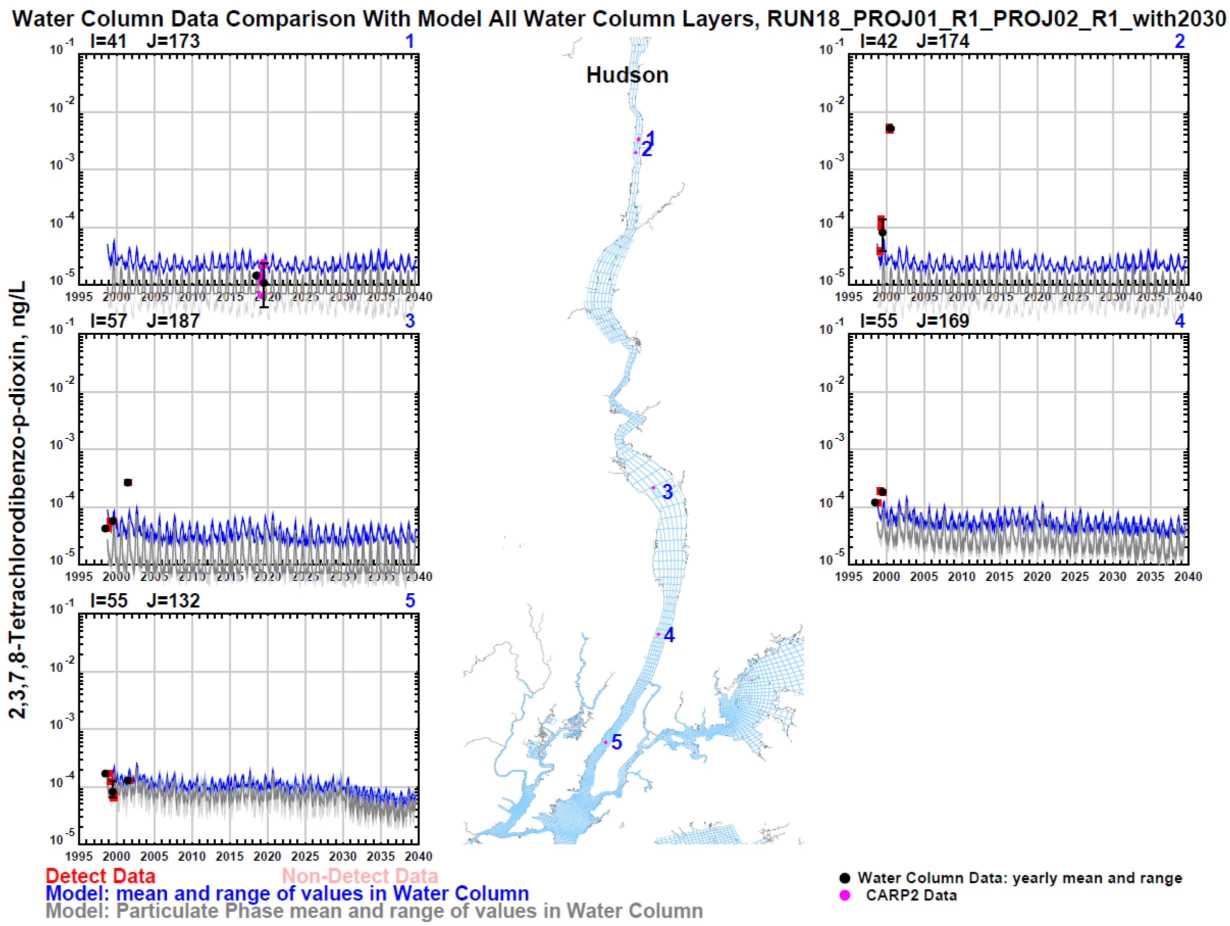


Figure 3- 8. 2,3,7,8-TCDD water column concentrations model results for the calibration period and for two future projection scenarios for five locations in the Hudson River. The model results (blue lines and shades) for simulated cleanups of the Lower Passaic River alone (scenario 1) and in combination with the Hackensack Rivers and Newark Bay Study Area (scenario 2) starting in October 2030 overplot and are not discernible at these locations. Results for both scenarios suggest some decline starting in October 2030 at the most downstream location shown. For reference, model results for particulate phase concentrations of total PCB are shown in gray.

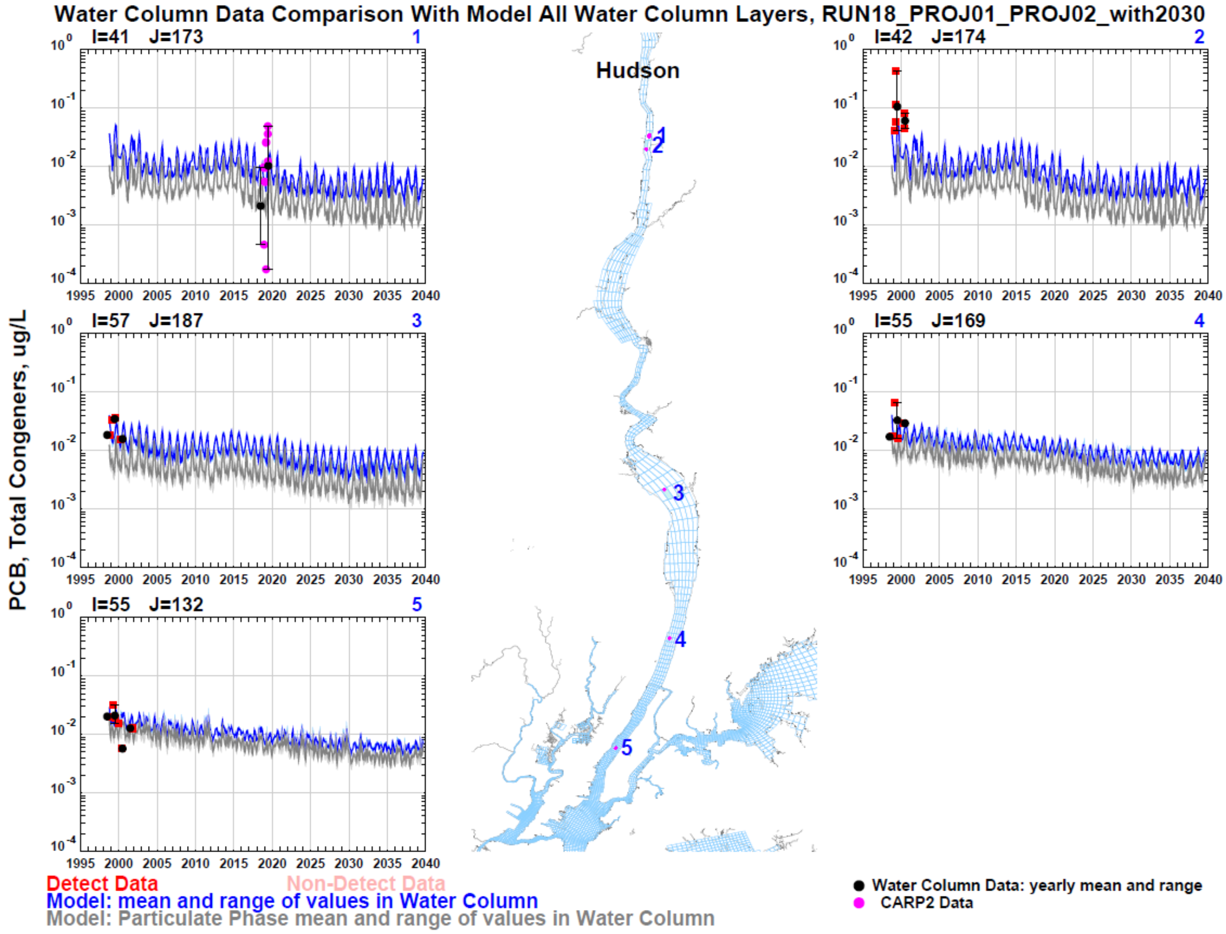


Figure 3- 9. Total PCB water column concentrations (estimated as twice the summation of four homologs) model results for the calibration period and for two future projection scenarios for five locations in the Hudson River. The model results (blue lines and shades) decline, with a response to post-dredging loadings from the Upper Hudson River starting in January 2016, apparent near Poughkeepsie (locations 1 and 2). For reference, model results for particulate phase concentrations of total PCB are shown in gray. Simulated cleanups of the Lower Passaic and Hackensack Rivers and Newark Bay Study Area starting in October 2030 are not discernible at these locations.

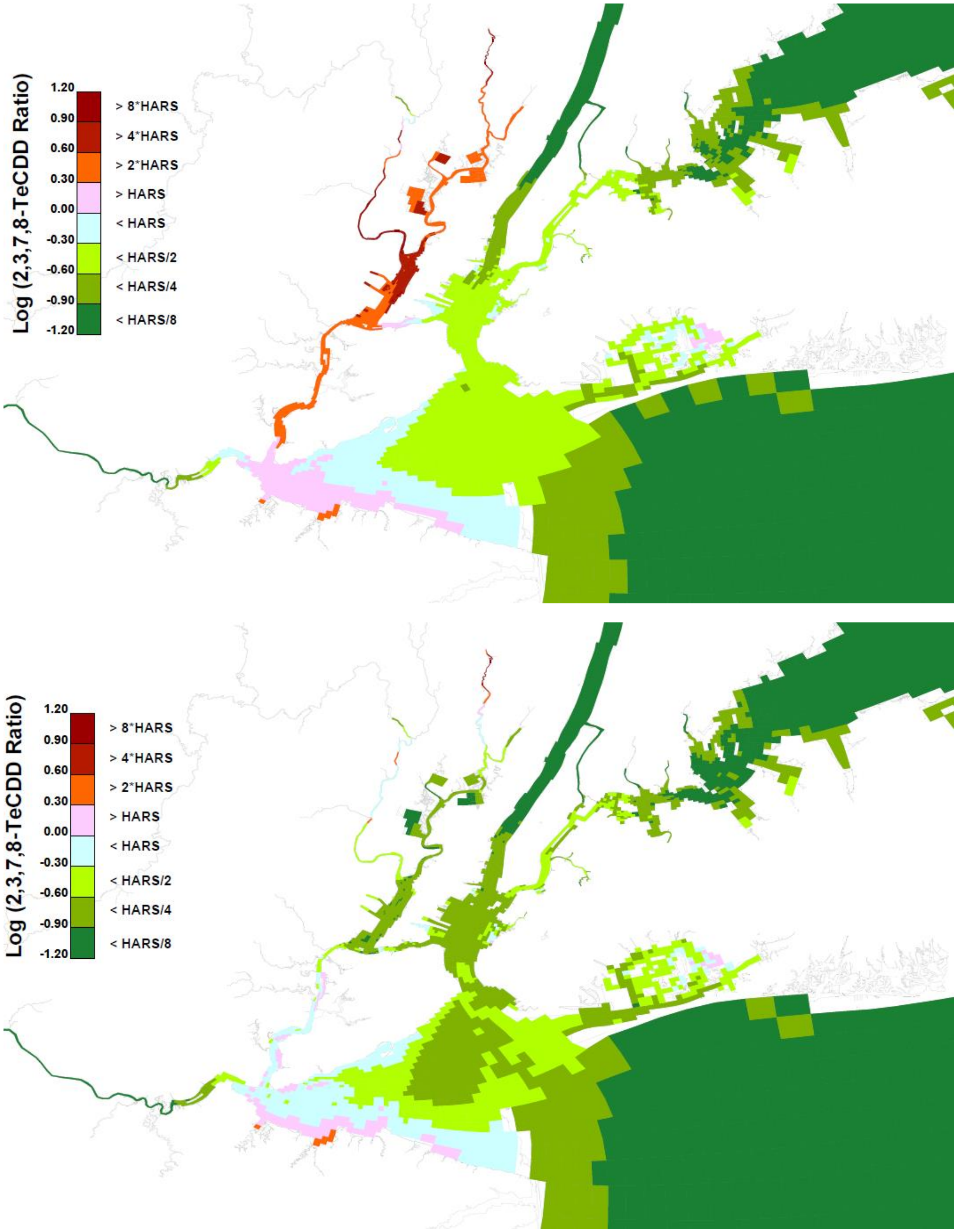
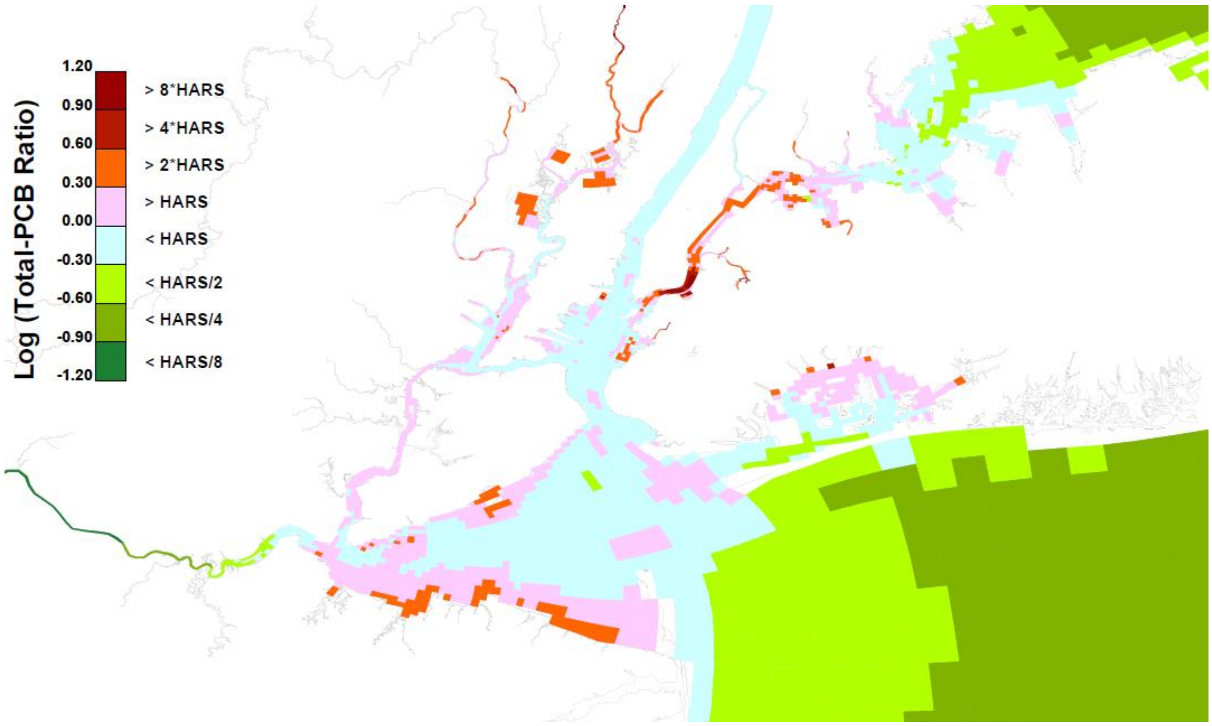


Figure 3- 10. CARP future projection scenarios HARS suitability ratio results for 2,3,7,8-TCDD using the CARP 2 ninetieth percentile BSAFs for 2,3,7,8-TCDD and a HARS criterion of 1 ppt in a worm. The top panel shows 2022-23 results. The bottom panel shows 2038-39 results after the October 2030 simulated remediation of the Lower Passaic and Hackensack Rivers and the Newark Bay Study Area. With very few exceptions (pink/red) the simulated remediation efforts attain HARS suitability (blue/green).



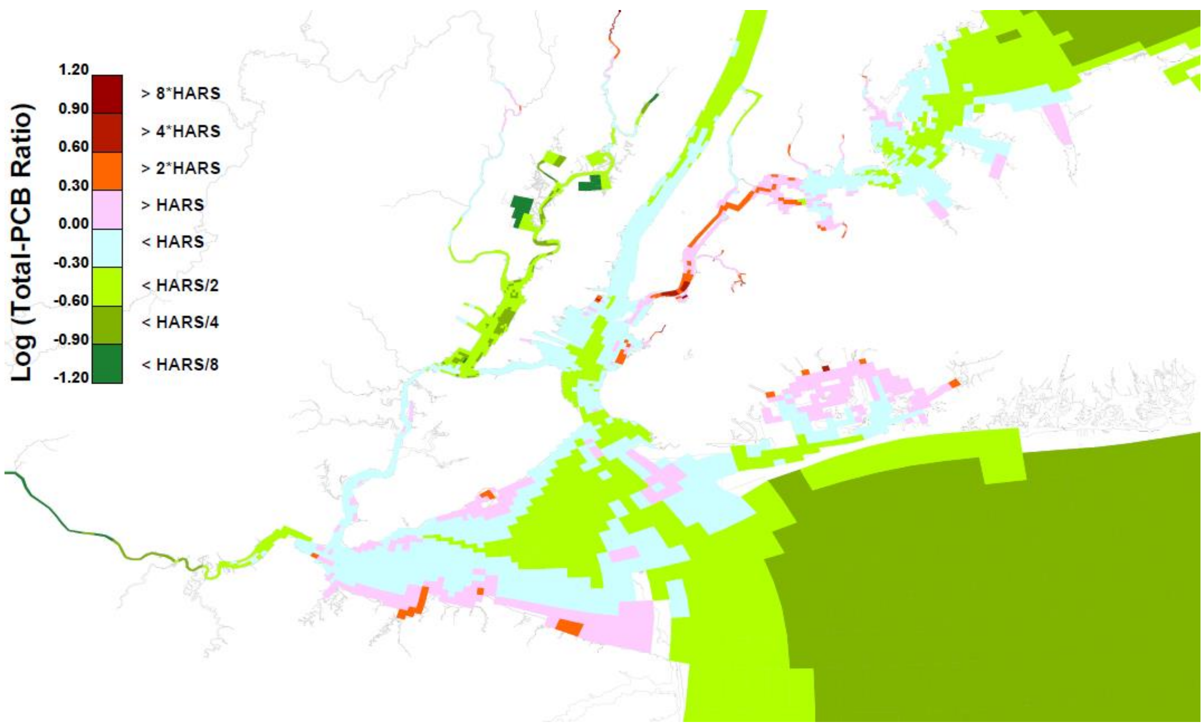
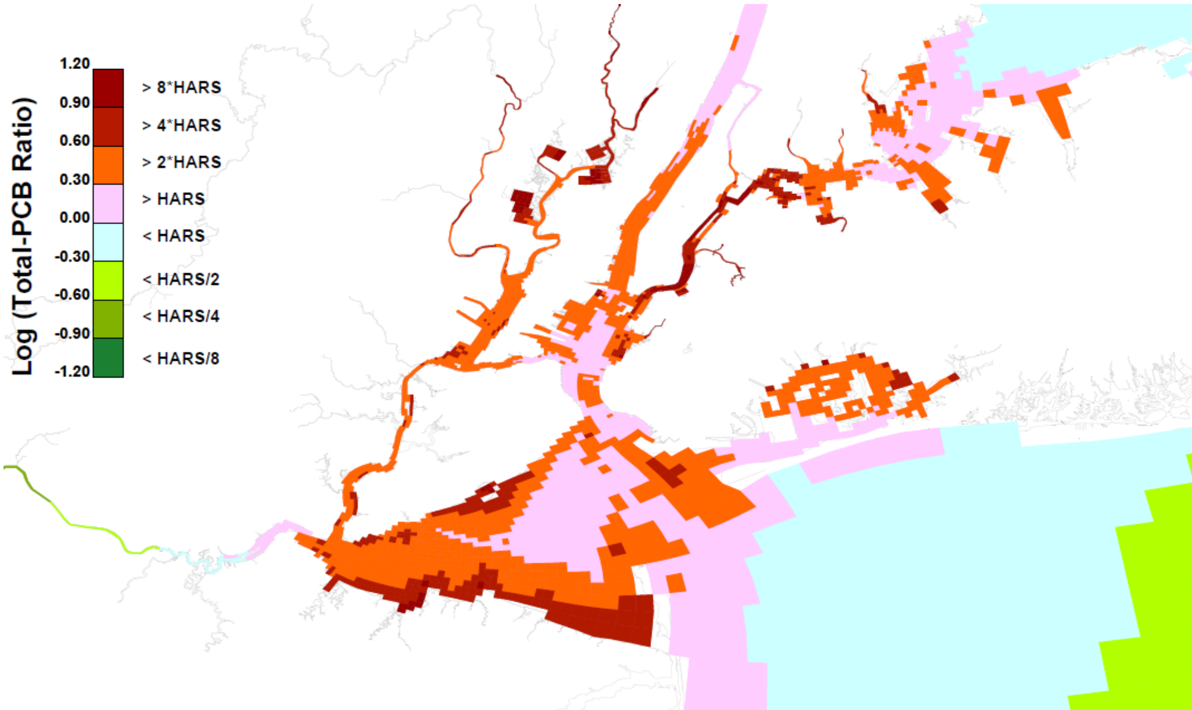


Figure 3- 11. CARP future projection scenarios HARS suitability ratio results for total PCB as twice the sum of four homologs using CARP 2 ninetieth percentile BSAFs for PCB homologs with a factor of two multiplier and a HARS criterion of 113 ppb in a worm. The top map shows 2022-23 results. The bottom map shows 2038-39 results after the October 2030 simulated remediation of the Lower Passaic and Hackensack Rivers and the Newark Bay Study Area. Simulated remediation efforts attain HARS suitability in much of the Harbor (blue/green) with some portions of the Harbor remaining in non-attainment (pink/red).



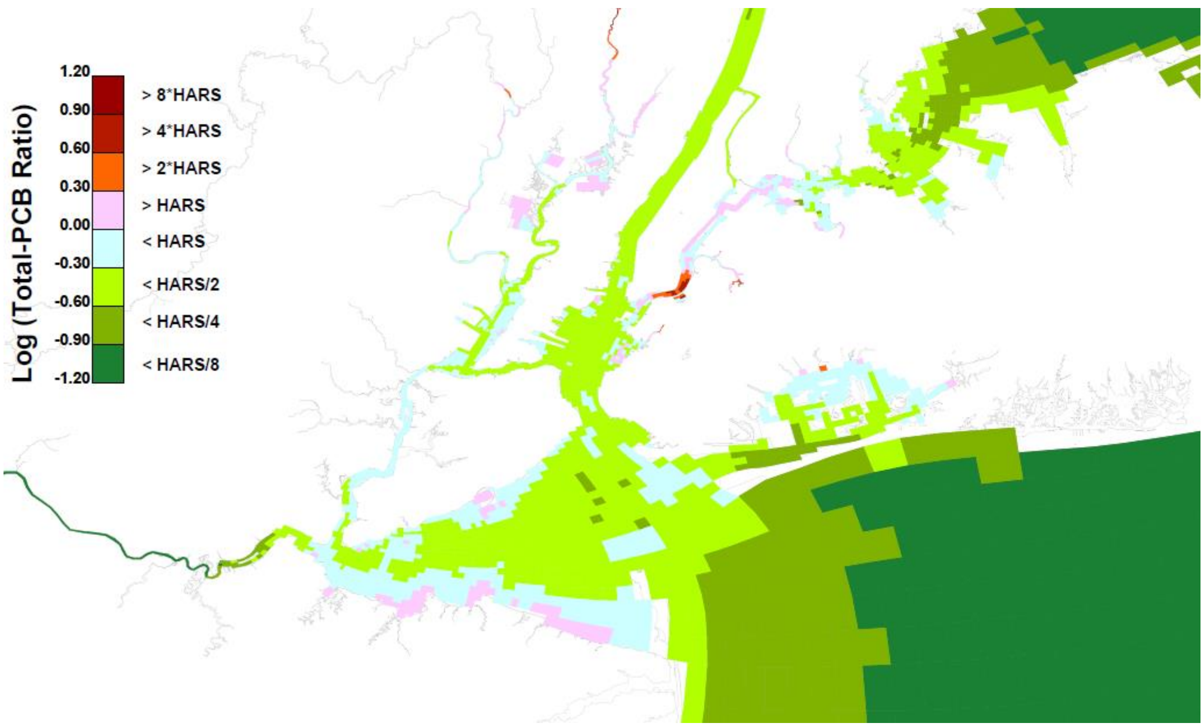


Figure 3- 12. CARP future projection scenarios HARS suitability ratio results for 2022-23 for total PCB as twice the sum of four homologs using CARP 1 and CARP 2 homolog BSAFs and a HARS criterion of 113 ppb in a worm. The top map shows results largely in non-attainment (pink/red) using the CARP 1 field-derived homolog BSAFs. The bottom map shows results largely in attainment (blue/green) using the CARP 2 fiftieth percentile laboratory homolog BSAFs with a factor of two multiplier. The selection of PCB homolog BSAFs is of critical importance for determining HARS suitability.

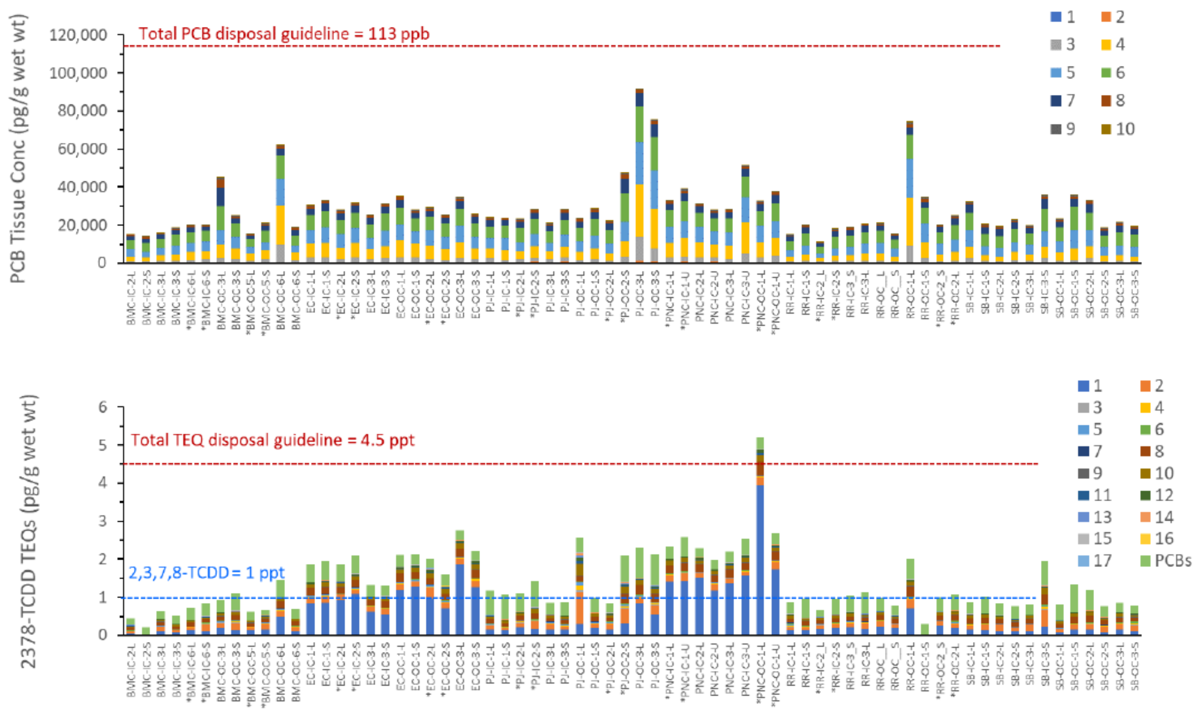
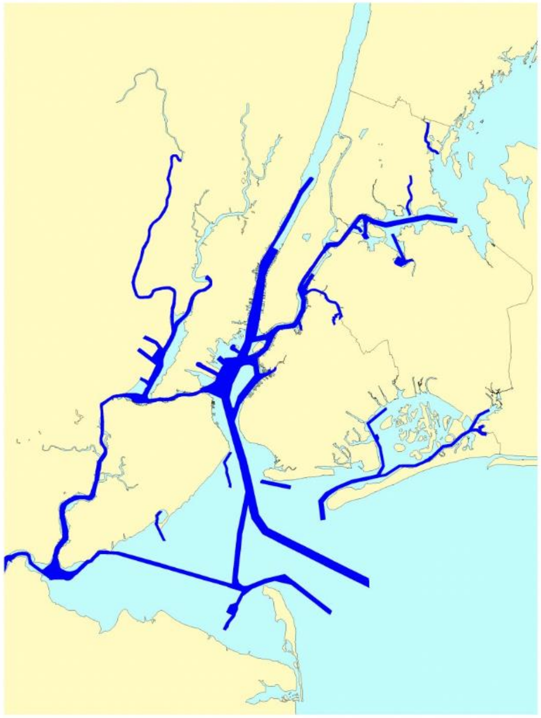


Figure 3- 13. CARP 2 measured PCB homologs and dioxin congers concentrations in worm tissue after 28-day exposures to Harbor sediments. PCB results are shown as measured and have not yet been doubled as established within the region for comparisons to HARS disposal guidelines. The measured tissue concentrations for PCBs well below 113 ppb are consistent with the 2022-23 HARS suitability model results using multiplied fiftieth percentile CARP 2 BSAFs shown in the bottom panel of Figure 3-12. The measured tissue concentrations for 2,3,7,8-TCDD above 1 ppt (bottom-most blue portion of plotted bars) are consistent with 2022-2023 HARS suitability model results regardless of BSAF applied (2022-23 diagrams in Appendices 3 through 6). In addition to 2,3,7,8-TCDD, measured TEQ values for other dioxin and furan congeners and PCB congeners exhibiting dioxin-like toxicity are shown as compared to the 4.5 ppt TEQ HARS guideline and show non-attainment only at a single location in Port Newark Channel. At that location, the measured non-attainment is driven by 2,3,7,8-TCDD (bottom-most blue portion of plotted bar). 2,3,7,8-TCDD TEQ values are measured tissue contaminant concentrations for seventeen dioxin/furan congeners and selected PCB congeners scaled by equivalency fractions of the toxicity of 2,3,7,8-TCDD. The canonical 2,3,7,8-TCDD toxicity equivalency fractions or factors for the congeners as developed by the World Health Organization in 2005 can be obtained from sources such as Van den Berg et al., 2006.

APPENDICES

HDR



CARP MODELS FUTURE PROJECTION SCENARIOS

NY/NJ Harbor Contamination Assessment and Reduction Project, CARP II

New Jersey Department of Transportation,

Under Agreement with Monmouth University and the Hudson River Foundation

June 30, 2023

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PREFACE

The modeling work reported here is one of several efforts undertaken in connection with the Contamination Assessment and Reduction Project (CARP). The overall purpose of CARP and the context for the CARP modeling work are outlined below.

What is CARP?

CARP is a landmark project bringing together federal, state, and non-government partners in a determined effort to better understand and reduce contamination within the New York/New Jersey Harbor Estuary. This contamination has led to environmental harm and economic hardships. Notably, dredging and disposal activities connected to port activities were severely curtailed in the early 1990's as dredging managers and regulators struggled with finding management options for handling contaminated dredged material. While dredging has since proceeded, the costs have escalated to 10 to 30 times previous levels, largely because of sediment contamination. Other negative impacts continue to plague the system, including fish advisories and substandard water quality, which are impeding the recovery and utilization of many of the estuary's natural resources.

Through workgroup deliberations in connection with the Dredged Material Forum and the NY/NJ Harbor Estuary Program (HEP), a general plan was developed to address the problem of continued contamination of sediments requiring dredging. The operative management questions included: Which sources of contaminants need to be reduced or eliminated to render future dredged material clean? Which actions can yield the greatest benefits? and, which actions are necessary to achieve the 2040 targets recommended in the Dredged Material Management Plan for the Harbor? CARP was initiated to address these questions.

CARP has been implemented in two phases having shared goals and objectives. The second phase of CARP served as a supplement and complement to the first phase. The two phases of CARP are referred to as CARP 1 and CARP 2. The primary funding mechanism for CARP 1 was the 1996 Joint Dredging Plan for the Port of New York and New Jersey, an agreement between the States of New York and New Jersey that was funded by the Port Authority of New York and New Jersey (Port Authority). Additional funds were obtained from the New Jersey Department of Transportation (NJDOT), the Empire State Development Corporation, The U.S. Army Corps of Engineers, the Hudson River Estuary Management Program, the Harbor and Estuary Program (HEP), and the Hudson River Foundation. CARP 2 was made possible by research funding from NJDOT awarded to Monmouth University.

The specific objectives of the CARP are to: 1. Identify and quantify sources of contaminants of concern to the NY/NJ Harbor Estuary from a dredged material standpoint; 2. Establish baseline levels of contaminants of concern in water, sediments, and biota; 3. Determine the relative significance of contaminant inputs in controlling the concentrations of those contaminants in water, sediment and biota: 4. Forecast future conditions in light of various contaminant reduction scenarios; 5. Take action to reduce levels of contaminants of concern in water, sediments, and fish tissue.

CARP is a unique partnership of governmental and non-governmental entities whose activities have been guided by a management committee composed of representatives from the U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, New Jersey Department of Environmental Protection (NJDEP), New York State Department of Environmental Conservation (NYSDEC), New Jersey Department of Transportation (NJDOT), Empire State Development Corporation, Port Authority, Environmental Defense Fund, and the Hudson River Foundation. During CARP 1, NYSDEC and NJDEP completed objectives 1 and 2 above through a comprehensive data collection (sampling and testing) program, which represents about 90% of the $32 million total funding for CARP 1.

It was the consensus of the CARP Management Committee that mathematical modeling tools were needed to help understand the results of the data collection program and the fate and transport of contaminants through the Harbor. These models provide a means for integrating data in a mass balance framework such that relationships between loadings and contaminant concentrations in water, sediment and biota can be evaluated and quantified. Moreover, these models can provide the predictive capacity that managers and scientists need to assess the consequences of existing contaminant loads and potential remedial actions. The CARP 1 modeling work performed by HydroQual, Inc., therefore addressed Objectives 3 and 4 above, and represents about 10% of the total funding for CARP 1.

Utility of CARP to Regional Stakeholders

The major focus of CARP has been on an objective evaluation of the fate and transport of contaminants throughout the entire NY/NJ Harbor Estuary system. The CARP Management Committee guiding CARP 1 and CARP 2 efforts intended for CARP work products to lead to sustained action to reduce both ongoing and historic contamination. The CARP Management Committee includes representatives of federal and state government agencies and is therefore mindful of the various regulatory programs that are in place to address contaminant issues. Consequently, since the inception of CARP, agencies on the Committee have made comments and recommendations to make CARP as relevant as possible to these programs. However, the CARP data collection and modeling efforts were not designed specifically to comply with the requirements of a particular regulatory program. CARP products, especially the modeling results, provide important information for these programs to consider, but further data collection and model refinement may be necessary to suit the scale and requirements of a particular program. And it is only those charged with regulatory responsibilities that can judge whether CARP products comply with their requirements.

CARP Modeling

Given the vast complexities of the entire estuary and the processes that affect contaminant fate and transport, modeling of this system has been a great technical challenge. From the initiation of CARP, it was understood that some aspects of the modeling would be limited because of scientific uncertainties in fully understanding all relevant processes. To ensure that the model components would be state-of-the-science, a Model Evaluation Group (MEG) was established at the outset of the project. Experts in organic and inorganic geochemistry, hydrodynamics, sediment transport and contaminant modeling were solicited to be members of the MEG. The MEG's first responsibility was to be part of the team to select a modeling contractor. It then met repeatedly over five years, to review and comment on the acceptability of modeling concepts and formulations to reproduce estuarine processes, including the review of CARP 1 model validation and hindcast results. The comments and suggestions of the MEG have been addressed by HydroQual, Inc., and a summary of the responses are included in CARP 1 model reports. In addition, the MEG provided comments and guidance on the use and application of the CARP 1 modeling products.

While some CARP model components were verified, refined, and successfully used in other venues prior to CARP, other components were newly designed for CARP 1 or CARP 2. The CARP modeling has elements that could be considered applied science and engineering, while others would be better characterized as research and development. The CARP MEG generally found that the CARP 1 modeling effort has advanced the understanding of contaminant behavior in the estuary and does a very credible job of characterizing the relationships between contaminant loadings and concentrations in the environment.

One of the more challenging issues that the CARP Management Committee addressed was the development of realistic contaminant reduction scenarios to use as an illustration of the CARP modeling framework capability. As the CARP modeling activities progressed, it became increasingly clear that legacy contamination of sediments was a dominant feature in controlling levels of contaminants in the system.

Since two large-scale sediment remediation projects (namely the Hudson River Superfund and Lower Passaic River Superfund projects) were being developed during CARP 1, it made sense to include these projects in the CARP 1 scenario analyses. While neither project was fully defined during CARP 1, the CARP 1 model scenario analyses gave a first glimpse of the potential for these sites (remediated or not) to influence sediment and water quality in the Harbor over the long term. The CARP 1 scenario analyses were refreshed and greatly expanded during CARP 2 with further CARP Management Committee guidance and two Records of Decision for the Lower Passaic River and the completion of remedial dredging on the Upper Hudson River. The CARP 2 scenarios analyses also consider the specific long-term future influences of the sites associated with the in-progress Newark Bay and Lower Hackensack River Superfund projects.

CARPs First Phase, CARP 1

More information on CARP 1 is readily available in a CARP 1 project summary report which references numerous CARP 1 reports:

> Lodge, J., Landeck Miller, R.E., Suszkowski, D., Litten, S., Douglas, S. 2015. Contaminant Assessment and Reduction Project Summary Report. Hudson River Foundation, New York, NY. CARP-summary-report-online.pdf (hudsonriver.org).

CARPs Second Phase, CARP 2

The NJDOT commissioned CARP 2 as a research project in response to needs identified by the Harbor's Dredged Material Strategic Planning Group (DMSPG), a task force convened by the U.S. Army Corps of Engineers (USACE). The DMSPG acknowledged that while CARP 1 modeling and the Region's bioaccumulation testing provided evidence that dredged material quality was improving, more information was needed to accurately forecast future HARS suitability for specific channels and berthing areas. Such information is critical for estimating the financial resources needed to maintain the Harbor and/or to determine the impact of planned remediation. The question that CARP 2 answers is the current and future levels (i.e., to 2040, inclusive of the DMSPG's 15-year and 25-year planning horizons) of contaminants within navigation channels of NY/NJ Harbor. The focus of CARP 2 is to demonstrate if the Region is getting closer to HARS suitability. CARP 2 estimation of progress toward HARS suitability in specific reaches of the Harbor at a higher spatial resolution than CARP 1 can guide dredged material managers in selectively pursuing HARS disposal options and spending on dredged material testing.

Other needs and information gaps addressed by CARP 2 include (1) the compilation and assimilation of relevant data collected in the years between CARP 1 and CARP 2; (2) the collection of new field measurements of loading contaminant concentrations and ambient conditions in the Estuary; (3) the evaluation, update, and refinement of models developed and applied during CARP 1; (4) the characterization of sediments in navigation channels and in adjacent off-channel areas; (5) the development of a method for predicting bioaccumulation of sedimentary contaminants in dredged material test organisms; and (6) the evaluation of a passive sampler method for potential prediction of HARS suitability more quickly and at a cost lower than the Region's current laboratory testing.

CARP 2 was initiated in March 2017 and leveraged CARP 1 financial investments by building upon the foundation of CARP 1 measurements and modeling. The CARP 2 principal investigators include Monmouth University, the Hudson River Foundation, HDR, Inc., Manhattan College, NYSDEC (retired personnel), Rutgers University, and the University of Rhode Island. The CARP 2 measurement and modeling work products include a CARP 2 project summary report which references several individual modeling and sampling/measurement-based CARP 2 report deliverables.

The CARP 2 individual report deliverables referenced in the CARP 2 project summary report include:

A. CARP 2 Modeling Report Deliverables:
   1. Evaluation of CARP 1 Models
      a. Task 3.1 Post-Audit Evaluation of the Original CARP Model Projections
   2. Update of the CARP Models
      a. Task 3.2 Update External Forcing Functions for Water Years 2002-2016
      b. Task 3.3 Refine the CARP Models
   3. CARP 2 Future Projections Scenarios
      a. Task 3.4 Projections of Current and Future Levels of Contamination in the Sediments within Navigation Channels of NJ/NY Harbor
B. Other deliverables:
   4. Measurement Summary Reports
      a. Historic Measurement Review
      b. CARP 2 Measurement Collection and Analysis
         i. Loadings Measurements and Ambient Conditions
         ii. Comparison of sediments in navigation channels and off-channel areas
         iii. Data Dictionary
   5. Prediction of Bioaccumulation of Sedimentary Contaminants in Dredged Material Test Organisms

The report included herein is the CARP2 modeling deliverable for Task 3.4, pertaining to CARP 2 future projection scenarios, identified as A3a above.

Future Intention

The CARP models should not only be viewed as management tools, but as research tools from which fuller understandings of the fate and transport of contaminants can be gleaned today. In addition, it is the hope of the CARP Management Committee that the CARP modeling work and underlying measurements serve as a foundation for the future from which even more advanced models could be developed and applied, as/if needed, for new management issues as they emerge.

CARP MODELS FUTURE PROJECTION SCENARIOS

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ABSTRACT

A final CARP 2 modeling task, applying the updated CARP models for future projection scenarios, has been completed. The future projection scenarios estimate levels of contaminants throughout the NY/NJ Harbor between now and the water year 2038-39 for 2040 planning. With the use of Biota-Sediment Accumulation Factors (BSAFs), CARP model estimates of future contaminant concentrations in the Harbor also provide estimates of future contaminant body burdens in dredged material test organisms. Contaminant body burdens in dredged material test organisms are necessary for evaluating the suitability of dredged material for disposal at the Historic Area Remediation Site (HARS). The full suite of updated CARP models was applied for two future projection scenarios. Both future projection scenarios assume full implementation of the two approved Lower Passaic River Records of Decision (RODs) starting in October 2030. One of the future projection scenarios also assumes full remediation of the Newark Bay Study Area and the Lower Hackensack River starting in October 2030. Methods were developed for estimating future years bathymetry and future years hydrodynamic and sediment transport and organic carbon production, necessary for the future projection scenarios using the CARP contaminant fate and transport model. Starting in October 2030 when the Lower Passaic River remediation is simulated, the CARP sediment transport and organic carbon production model used for the future projection scenarios includes increased sediment bed particle mixing rates in the Lower Passaic River, equivalent to those modeled throughout the less contaminated Harbor. The methods developed for the contaminant fate and transport model application for future projections include estimation of post-dredging PCBs loadings from the Upper Hudson River. BSAFs applied to the Harbor contaminant concentrations calculated for the future projection scenarios include those from the dredged material testing program, from in-situ field organisms and Harbor sediments collected during CARP 1, and from CARP 2 laboratory exposures using Harbor sediments from up to sixty-eight locations. The BSAFs from these programs vary considerably. The variation within CARP 2 laboratory measurements of bioaccumulation is represented by fiftieth and ninetieth percentile BSAFs. The CARP 2 ninetieth percentile BSAFs are comparable to BSAFs from the dredged material testing program used for CARP 1 projections of HARS suitability. The results of the CARP future projection scenarios when combined with 90th percentile BSAFs from CARP 2 specifically indicate that Newark Bay sediments in the future will meet the Historic Area Remediation Site (HARS) disposal criteria for bioaccumulation for both 2,3,7,8-TCDD and total PCB with the completion of the simulated remediation efforts in the Lower Passaic and Hackensack Rivers and in the Newark Bay Study Area.

KEY WORDS: CARP, model, HARS suitable, navigation channel, PCB, dioxin, NY/NJ Harbor and Estuary, dredged material testing, contaminant sources, bioaccumulation

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1.0 INTRODUCTION

The Contamination Assessment and Reduction Project (CARP) 1 model was developed as a series of sub-models to provide a detailed representation of the hydrodynamics, sediment transport, organic carbon cycling, and fate and transport of contaminants in the NY/NJ Harbor and Estuary (HydroQual 2007a, 2007b, 2008). The CARP 1 sub-models were calibrated using field measurements that were primarily collected during the 1999-2002 CARP 1 sampling program. The calibrated sub-models were applied in 2002 to project concentrations of PCBs and PCDD/Fs for a 37-year period commencing in October 2002 and ending in September 2039. The projections made in 2002 were necessarily based on information available at that time. Model-projected concentrations were assessed relative to dredged material testing endpoints to estimate the time when Harbor sediments would meet Historic Area Remediation Site (HARS) disposal criteria.

Since the 2002 CARP 1 model projections of time to HARS suitable Harbor sediments were made, the bathymetry of the Harbor has changed significantly. Deepening of navigation channels was accomplished by several projects. In addition, the Harbor has experienced extreme flow events (including Tropical Storms Irene, Lee, and Sandy) that were not simulated in the CARP 1 model projections. Further, measurement collection related to several Superfund projects in the Harbor has been ongoing since 2002. Therefore, to provide NJDOT with a tool for determining the current and future levels of contamination in the sediments within navigation channels of NJ/NY Harbor, refinement of the CARP sub-models was undertaken to account for the deepening of navigation channels, to assess the impacts of extreme flow events on contaminant responses in Harbor sediments, and to consider additional measurements of Harbor contaminant concentrations. The effort to ultimately provide NJDOT with a tool for determining the current and future levels of contamination in the sediments within navigation channels was performed in a series of subtasks which started with a post-audit evaluation of the CARP 1 model (Landeck Miller et al., 2019). The second subtask in the series is the update of model external loading forcing functions (Landeck Miller et al., 2022). The third subtask in the series is the update of the CARP models (Landeck Miller et al., 2023). The series of subtasks ends with revised projections of PCB and PCDD/Fs contamination in Harbor sediments and dredged-material-test organisms as described herein based on new measurements and model refinements.

In consultation with the CARP Management Committee, two future projection scenarios were defined and implemented. The methods for conducting the two future projection scenarios along with a consideration of the results follows. The consideration of results includes calculations using several different Biota-Sediment Accumulation Factors (BSAFs).

2.0 METHODS

The methods developed and applied for the two CARP future projection scenarios are discussed separately in Sections 2.1 to 2.3 for each of the CARP models involved: hydrodynamic, sediment transport/organic carbon production, and contaminant fate and transport and in Section 2.4 for the use of various BSAFs.

2.1 Methods for CARP Future Projection Scenarios, Hydrodynamic Model

The future projection scenarios required forty-one water years of hydrodynamic model simulations on the CARP 127 x 205 model computational grid. Hydrodynamic model simulations for the eighteen water years spanning October 1998 through September 2016 were available for use “as is” directly from the model calibration effort (Landeck Miller et al., 2023). The remaining twenty-three water years spanning October 2016 through September 2039 first required assignment of a surrogate year from the calibration years along with the selection of appropriate bathymetry conditions. The surrogate years were established by assigning October 1998 through September 2016 to October 2016 through September 2034 and assigning October 1998 through September 2003 to October 2034 through September 2039. In discussion with the CARP Management Committee, it was decided that the bathymetry conditions established during model calibration representative of the 52' Harbor deepening projects starting in water year 2010-11 (Landeck Miller et al., 2023) would be carried forward for all subsequent water years.

To achieve both the assignment of waters years and the desired bathymetry conditions for the future projection simulations, it was necessary to conduct twelve new hydrodynamic model simulations due to pairings of water years and bathymetry differing from the calibration conditions. For example, in the calibration the 1998-99 water year was simulated with pre-deepening projects (i.e., < 40') bathymetry. For purposes of the future projection scenarios, it was necessary to simulate the 1998-99 water year with bathymetry reflecting completion of 52' deepening projects to represent the 2016-17 and 2034-35 future water years. The twelve new hydrodynamic model simulations conducted were for applying bathymetry conditions including 52' deepening projects to the water years October 1998 to September 2010 to represent the future water years October 2016 to September 2028 and October 2034 to September 2039.

The tracking of the assignment of water years and bathymetry conditions and the new hydrodynamic simulations needed for the future projection scenarios are summarized in Table 2-1. The twelve water years of new hydrodynamic model simulations on the 127 x 205 CARP model computational grid apply to both future projection scenarios evaluated.

2.2 Methods for CARP Future Projection Scenarios, Sediment Transport and Organic Carbon Production Model

The future projection scenarios required forty-one water years of sediment transport and organic carbon production model simulations on the CARP 127 x 205 model computational grid. Sediment transport and organic carbon production model simulations for the eighteen water years spanning October 1998 through September 2016 were available for use "as is" directly from the model calibration effort (Landeck Miller et al., 2023). It was necessary to conduct new sediment transport and organic carbon production model simulations for the remaining twenty-three water years spanning October 2016 through September 2039 for several reasons. These reasons include both using hydrodynamic transport for all future years with bathymetry reflecting 52' deepening projects and having each year of sediment transport and organic carbon production model simulation run consecutively, including a "hot start" off the previous year. The "hot start" allows for the passing of sediment bed accumulation from one year to the next as stored in the modeled sediment bed archive layer. In addition, specific to the nine water years spanning October 2030 to September 2039, the sediment transport and organic carbon model future projection scenarios on the CARP 127 x 205 model computational grid include particle mixing rates for the Lower Passaic River restored to levels used everywhere on the 49 x 84 model computational grid and everywhere else for model calibration on the 127 x 205 model computational grid (Landeck Miller et al. 2023).

The removal of altered sediment bed particle mixing rates for the Lower Passaic River starting in the 2030-31 water year (i.e., increasing the rates to levels used elsewhere in the model domain) is in anticipation of simulating the remediation of the Lower Passaic River with the contaminant fate and transport model future projection scenarios which should also reflect post-remediation bioturbation by organisms in the Lower Passaic River. Successful calibration of the CARP model on the 127 x 205 model computational grid for the eighteen water years spanning October 1998 to September 2016 for the temporal trend in dioxin concentrations in the sediment bed of the Newark Bay complex required a reduction to particle mixing rates in the Lower Passaic River. Presumably, the real-world explanation for the model calibration reduction in particle mixing rates is that the organisms carrying out bioturbation were either present only in reduced numbers and/or were metabolically impaired because of dioxin present in the Lower Passaic River (Landeck Miller et al., 2023). A reduction to particle mixing rates in the Lower Passaic River was also applied during Superfund modeling efforts to achieve model calibration. If the presumed real-world explanation for the required reductions to modeled particle mixing rates to achieve model calibration is valid, it follows that a future projection scenario including remediation should also remove the calibration reduction to particle mixing rates.

The tracking of the assignments of hydrodynamic transport and bathymetry, “hot starting”, sediment bed particle mixing rates, and the new sediment transport and organic carbon production model simulations needed for the future projection scenarios are summarized in Table 2-2. The forty-one water years of new sediment transport and organic carbon production model simulations on the 127 x 205 CARP model computational grid apply to both future projection scenarios evaluated.

2.3 Methods for CARP Future Projection Scenarios, the Contaminant Fate and Transport Model

The first of two future projection scenarios required forty-one water years of contaminant fate and transport model simulations on the CARP 127 x 205 model computational grid. Contaminant fate and transport model simulations for the eighteen water years spanning October 1998 through September 2016 were available for use “as is” directly from the model calibration effort (Landeck Miller et al., 2023). It was necessary to conduct new contaminant fate and transport model simulations for the remaining twenty-three water years spanning October 2016 through September 2039 for several reasons. These reasons include having each year of contaminant fate and transport model simulation run consecutively, including a “hot start” off the previous year, and using results from the sediment transport model also run consecutively with “hot start”. The “hot start” allows for the development and progression of sediment bed conditions to be tracked over time. Specific to the contaminant fate and transport model, utilization of regression equations to calculate Upper Hudson PCB loadings reflective of post-dredging conditions (Landeck Miller et al., 2023) also necessitated new contaminant fate and transport model simulations for the twenty-three water years spanning October 2016 through September 2039. Further, new contaminant fate and transport model simulations were needed to include remediation of portions of the sediment bed starting in the 2030-31 water year.

As part of the future projection scenarios, the post-dredging regression equations for estimation of the Upper Hudson River PCB loadings were applied for the twenty-three water years October 2016 through September 2039 using surrogate hydrographs from October 1998 through September 2016. As part of model calibration, the post-dredging regression equations for estimation of the Upper Hudson River PCB loadings were applied only for the nine-month period January to September 2016 (Landeck Miller et al., 2023). The future projection scenarios include post-dredging PCB loadings from the Upper Hudson River for a much longer additional twenty-three-year period and wider hydrograph range as compared to the calibration.

In addition, specific to the nine water years spanning October 2030 to September 2039, the contaminant fate and transport model future projection scenarios on the CARP 127 x 205 model computational grid include adjustments to sediment bed contaminant concentrations in the Lower Passaic River reflective of the completion of two USEPA Superfund Records of Decision (RODs) (USEPA, 2016a, 2016b, and 2021), simulated for CARP purposes as starting October 1, 2030. The remediated Lower Passaic River sediment bed concentrations used in the future projection scenarios on the CARP 127 x 205 model computational grid were extracted from the USEPA RODs. A variation for the nine water years spanning October 2030 to September 2039 is unique to a second future projection scenario on the CARP 127 x 205 model computational grid. The second scenario additionally simulates full remediation adjustments (i.e., applying zero concentration) to sediment bed contaminant concentrations in Newark Bay and the Lower Hackensack River starting October 1, 2030. It is noted that the full bank-to-bank remediation adjustments to zero concentrations simulated for Newark Bay and the Lower Hackensack River in the second future projection scenario are not regulatory requirements and are a first-time projection consideration for CARP.

Completion of the second future projection scenario on the CARP 127 x 205 model computational grid required running the contaminant fate and transport model only for the final nine water years. Consistent with the Superfund Study Area (Figure 1-2 in GSH, 2019), the simulated full remediation for Newark Bay for the second future projection scenario includes Newark Bay, the Arthur Kill and Kill van Kull between the Goethals and Bayonne Bridges, and the Lower Hackensack River to the Conrail Bridge. The simulated full remediation of the Lower Hackensack River for the second projection scenario includes the Lower Hackensack River between the Oradell Dam and the Conrail Bridge and the contiguous tributaries and marsh areas within the CARP 127 x 205 model computational grid.

The tracking of the assignments of hydrodynamic transport and bathymetry, "hot starting", sediment transport and organic carbon production, Upper Hudson River PCB loading regressions, bed contaminant concentration adjustments, and the new contaminant fate and transport model simulations needed for the future projection scenarios are summarized in Table 2-3. Related Tables 2-4 and 2-5 summarize the adjusted sediment bed contaminant concentrations used for the simulation of the completion of the Lower Passaic River RODs with the CARP contaminant fate and transport model on the 127 x 205 model computational grid.

2.4 Methods for CARP Future Projection Scenarios, BSAFs and HARS Disposal Criteria

Four sets of Biota-Sediment Accumulation Factors (BSAFs) were utilized to transform model calculations of future contaminant concentrations in Harbor sediments to likely contaminant body burdens in worms for comparisons to HARS disposal criteria. The four sets of BSAFs, dredged material testing, CARP 1, CARP 2 fiftieth percentile, and CARP 2 ninetieth percentile, are presented in Table 2-6. Table 2-6 provides descriptions, references, and units for the BSAFs. The underlying probability distributions for the CARP 2 fiftieth and ninetieth percentile BSAFs are shown on Figure 2-1. Model calculations of contaminant concentrations in Harbor sediments were multiplied by BSAFs to obtain contaminant body burdens in worms. The calculated contaminant body burdens were compared to HARS disposal criteria. The HARS disposal criteria considered include 1 ppt 2,3,7,8-TCDD and 113 ppb total PCB worm body burdens.

Per the instructions of USEPA Region 2 during CARP 1 (HydroQual, 2007) and recent confirmation from the CARP Management Committee, for consistency with the protocols of the Region's dredged material testing program, the use of BSAFs derived from 28-day laboratory exposures (i.e., from the dredged material testing program and from CARP 2) with the total PCB HARS criterion (113 ppb) requires a doubling of the total PCB worm concentrations. The use of the doubling of total PCB worm concentrations offsets a perceived mismatch between 28-day testing and a longer-term exposure underlying the 113-ppb PCB criterion. While results are presented and discussed for the application of dredged material testing program, CARP 1, fiftieth percentile CARP 2, and ninetieth percentile CARP 2 BSAFs to CARP contaminant fate and transport model outputs, emphasis is placed on results using the ninetieth percentile BSAFs from CARP 2. This emphasis is consistent with direction from the CARP Management Committee.

3.0 RESULTS

Culminative results for the future projection scenarios applying the full suite of CARP models on the 127 x 205 model computational grid include time series displays of contaminant concentrations in the sediment bed and the water column and spatial maps of HARS suitability. The contaminant concentration results are presented for the six contaminants 2,3,7,8-TCDD, 2,3,4,7,8-PCDF, di-CB, tetra-CB, hexa-CB, and octa-CB. The HARS suitability results are presented for 2,3,7,8-TCDD and total PCB. As identified during model calibration, total PCB is represented by twice the summation of the di-CB, tetra-CB, hexa-CB, and octa-CB homologs (Landeck Miller et al., 2023).

3.1 Results for CARP Future Projection Scenarios, Sediment Bed Contaminant Concentrations

Sediment bed contaminant concentration results for the future projection scenarios are presented in Appendix 1 with an x-axis (i.e., time) extension of the calibration model and measurement comparison diagrams for the 127 x 205 model computational grid (Landeck Miller at al., 2023). Like the calibration, the results of the future projection scenarios for sediment bed contaminant concentrations are presented on two hundred twenty-four pages in Appendix 1 for six contaminants and a PCB summation, ninety-five locations, and solids and organic carbon normalizations. In addition, for future projection scenarios, an additional reach with six locations was added to monitor model results at the top of the Lower Hackensack River bringing the Appendix 1 page count to two hundred thirty-eight pages and the locations count to one-hundred-one. The future projection results in Appendix 1 for sediment bed contaminant concentrations include seventeen pages for each of seven contaminants/summations and for each of two normalizations with each page representing results for a reach containing five or six discrete locations.

Each reach page, in Appendix 1 and on Figures 3-1 to 3-5, includes a location map with the 127 x 205 model computational grid shown. On the map, the model computational grid cells for the five or six discrete locations for which the time series of model results are presented are colored in bright green. Pastel colors are used on the map to indicate the surrounding model computational grid cells from which measurements have been aggregated for comparisons and from which ranges of model results are derived. The pastel colors on the map correspond to the original 49 x 84 model computational grid considered during the post-audit (Landeck Miller et al., 2019) and used previously for CARP (HydroQual, 2007a, 2007b, 2007c).

At each location shown in Appendix 1 and on Figures 3-1 to 3-5, measurements representing up to the top 15 cm of the sediment bed are presented. Measurements from various sources as compiled and described for the CARP post-audit (Landeck Miller et al., 2019) are shown with blue and red circles for in-channel and off-channel samples, respectively, in Appendix 13 and on Figures 3-1 to 3-5. Additional measurements have been added since the completion of the post-audit (Landeck Miller, et al., 2019) and are shown with various symbols and colors as identified in the legend on the diagrams in Appendix 1 and on Figures 3-1 to 3-5. The additional measurements are derived from sampling conducted in support of contemporary navigational maintenance dredging projects (shown with brown triangles, labelled “Dredge data”) and from the work of other CARP investigators (shown with pink and green squares, labelled “CARP2”). A listing of the contemporary navigational maintenance dredging projects from which measurements were obtained is provided in Appendix 15 of Landeck Miller et al., 2023. Reporting for CARP 2 data collection is in preparation.

Various model timeseries results for sediment bed contaminant concentrations are displayed in Appendix 1 and on Figures 3-1 to 3-5 with several different lines and shading. A lime green line is used to show the timeseries of thirty-day-average contaminant concentrations calculated by the model for the top 10 cm of the bed in a single model grid cell (identified in bright green on the maps). A lime green shade is used to show the range in the top 10 cm calculated by the model for each thirty-day interval for the single model grid cell. A grey shade is used to show the range of contaminant concentrations for the top 10 cm of the bed calculated by the model for the several surrounding model grid cells from which measurements were aggregated (identified with pastel colors on the maps). A pale blue line is used for reference to show the contaminant concentrations calculated by the model for the sediment bed archive layer for the same single model grid cell as was shown in lime for the model calculated concentrations in the top 10 cm. The sediment bed archive layer of variable depth is used by the model to store and track mass specified through initial bed thickness or whenever appreciable deposition exceeding resuspension is calculated and to provide the inventory of mass available for subsequent resuspension.

The lime green lines, lime green shades, grey shades, and pale blue lines shown in Appendix 1 and on example Figures 3-1 to 3-5 and used to display model results for sediment bed contaminant concentrations include results for model calibration (October 1998 to September 2016) and the first and second future projection scenarios (October 2016 to September 2039). The interval October 2016 to September 2030, common to both future projection scenarios, provides an opportunity to assess CARP model predictions in the future without further management action and to assess the long-term influence of reduced loadings from the Upper Hudson River after completion of dredging in 2015. For the interval October 2030 to September 2039, two sets of future projection scenarios model results are shown on the same axes. The two sets of future projection scenarios model results reflect full implementation of the two approved Lower Passaic River Records of Decision (RODs) both without and in combination with full remediation of the Newark Bay and the Lower Hackensack River Superfund Study Areas described in Section 2.3.

Although not specifically discussed, solids and organic carbon normalized bed contaminant concentrations results presented in Appendix 1 are similar. There are only a few instances, such as several locations in Upper and Lower New York Bays shown in Appendix 1, with discernible differences in solids and organic carbon normalized bed concentrations of 2,3,7,8-TCDD and total PCB.

Figures 3-1 and 3-5 are examples of the future projection scenarios bed contaminant concentrations results, from the CARP contaminant fate and transport model using the 127 x 205 model computational grid, included in Appendix 1. On Figure 3-1 and 3-2, results are shown for the sediment bed at six locations in Lower Newark Bay. On Figure 3-3 and 3-4, results are shown for the sediment bed at six locations in the Hudson and East Rivers. Figures 3-1 and 3-3 show results for 2,3,7,8-TCDD solids-normalized concentrations in the bed. Figures 3-2 and 3-4 show results for total PCB solids-normalized concentrations in the bed. On Figures 3-2 and 3-4, the measurements represent ten PCB homologs, and the model results are based on twice the summation of the four PCB homologs modeled for calibration and future projection purposes. The application of the factor of two to the summation of four PCB homologs (i.e., di-CB, tetra-CB, hexa-CB, and octa-CB) to approximate total PCB was established during CARP 1 (HydroQual, 2007c) and was further verified during CARP 2 method validation efforts (Landeck Miller et al., 2023).

Figure 3-5 displays the future projection scenarios bed contaminant concentrations results at six locations in the northern Arthur Kill for 2,3,7,8-TCDD (top) and total PCB (bottom). Figure 3-5 highlights differences in the spatial expanse of responses in the future projection scenarios bed contaminant concentrations results for the two contaminants in the northern Arthur Kill.

3.2 Results for CARP Future Projection Scenarios, Water Column Contaminant Concentrations

Water column contaminant concentration results for the future projection scenarios are presented in Appendix 2 as an extension of the calibration model and measurement comparison diagrams for the 127 x 205 model computational grid (Landeck Miller at al., 2023). Like the calibration, the results of the future projection scenarios for water column contaminant concentrations are presented on eighty-four pages in Appendix 2 for six contaminants and a PCB summation at sixty-one locations. The model and measurement comparison results in Appendix 2 for water column contaminant concentrations include twelve pages for each contaminant/summation with each page representing results for a reach containing three to six discrete locations.

Each reach page, in Appendix 2 and on Figures 3-6 to 3-9, includes a location map with the 127 x 205 model computational grid shown. On the map, the model computational grid cells for three to six discrete locations for which the time series of model results are presented are shown. At each location shown in Appendix 2 and on Figures 3-6 to 3-9, measurements representing the water column are presented. Measurements from various sources as compiled and described for the CARP post-audit (Landeck Miller et al., 2019) are shown with red squares in Appendix 2 and on Figures 3-6 to 3-9. Many of the compiled measurements are reported and displayed at detection limits as shown with pale pink squares in Appendix 2 and on Figures 3-6 to 3-9, especially for concentrations of 2,3,4,7,8-PCDF in Appendix 2. Measurements shown at detection limit are an important consideration for the evaluation of model and measurement comparisons. Additional measurements have been added since the completion of the post-audit (Landeck Miller, et al., 2019) and are shown with bright pink circles as identified in the legend on the diagrams in Appendix 2 and on Figures 3-6 to 3-9. The additional measurements are derived from the recent work of other CARP investigators. Reporting for CARP 2 data collection is in preparation.

Various model timeseries results for water column contaminant concentrations are displayed in Appendix 2 and on Figures 3-6 to 3-9 with several different lines and shading. A blue line is used to show the timeseries of thirty-day average contaminant concentrations calculated by the model over depth. A blue shade is used to show the contaminant concentration range over depth in the water column calculated by the model for each thirty-day interval. For reference, a gray line is used to show the timeseries of thirty-day average contaminant concentrations in the particulate phase calculated by the model over depth in the water column. For reference, a gray shade is used to show the timeseries of the thirty-day range of contaminant concentrations in the particulate phase calculated by the model over depth in the water column.

The blue lines, blue shades, grey lines, and grey shades shown in Appendix 2 and on example Figures 3-6 to 3-9 and used to display model results for water column contaminant concentrations include results for model calibration (October 1998 to September 2016) and the first and second future projection scenarios (October 2016 to September 2039). The interval October 2016 to September 2030, common to both future projection scenarios, provides an opportunity to assess CARP model predictions in the future without further management action and to assess the long-term influence of reduced loadings from the Upper Hudson River after completion of dredging in 2015. For the interval October 2030 to September 2039, two sets of future projection scenarios model results are shown on the same axes. The two sets of future projection scenarios model results reflect full implementation of the two approved Lower Passaic River Records of

Decision (RODs) both without and in combination with full remediation of Newark Bay and the Lower Hackensack River.

Figures 3-6 and 3-7 are examples of the future projection scenarios water column contaminant concentrations results, from the CARP contaminant fate and transport model using the 127 x 205 model computational grid, included in Appendix 2. On Figure 3-6 and 3-7, results are shown for the water column at six locations in Upper Newark Bay. On Figure 3-8 and 3-9, results are shown for the water column at five locations in the Hudson River. Figures 3-6 and 3-8 show results for 2,3,7,8-TCDD concentrations in the water column. Figures 3-7 and 3-9 show results for total PCB concentrations in the water column. On Figures 3-7 and 3-9, the measurements and the model results are based on twice the summation of the four PCB homologs modeled for calibration and future projection purposes. The application of the factor of two to the summation of four PCB homologs (i.e., di-CB, tetra-CB, hexa-CB, and octa-CB) to approximate total PCB was established during CARP 1 (HydroQual, 2007c) and was verified during CARP 2 method validation efforts (Landeck Miller et al., 2023).

3.3 Results for CARP Future Projection Scenarios, HARS Suitability

The independent applications of various sets of BSAFs (see Table 2-6) to future projection scenarios sediment bed contaminant concentrations results, from the CARP contaminant fate and transport model using the 127 x 205 model computational grid and provided in Appendix 1, produced estimates of contaminant body burdens in worms. The estimates for contaminant body burdens in worms were divided by contaminant specific HARS disposal criteria, 1 ppt for 2,3,7,8-TCDD and 113 ppb for total PCB, to produce ratio results for HARS disposal suitability. The HARS disposal suitability results are presented as ratios by location at various points in time. Sediments from locations with ratios significantly below 1 are strongly HARS suitability and sediments from locations with ratios significantly larger than 1 are strongly not HARS suitability. Figures in Appendices 3, 4, 5, and 6 display the HARS suitability ratio results as color maps with shades of green (HARS suitable) and red (non HARS suitable) increasing in intensity as the magnitude of the ratio results deviate from 1. Appendix 3 includes results when BSAFs from the Region's dredged material testing program are used. Appendix 4 includes results when CARP 1 field derived BSAFs are used. Appendix 5 includes results when fiftieth percentile CARP 2 laboratory derived BSAFs are used. Appendix 6 includes results when ninetieth percentile CARP 2 laboratory derived BSAFs are used.

In each of Appendices 3 through 6, six color ratio maps on six pages displaying HARS suitability ratio results are presented for different time horizons. The six horizons include 1998-99 annual average, 1998-2002 four-year average, 2022-23 current year annual average, 2029-2030 future without further action annual average, 2038-39 future nine years after simulated completion of Lower Passaic River Superfund RODS (USEPA, 2016a, 2016b, and 2021), and 2038-39 future nine years after simulated completion of Lower Passaic River Superfund RODS plus complete remediation of the Lower Hackensack River and Newark Bay. Appendix 3 includes twelve pages and provides HARS suitability results for 2,3,7,8-TCDD and for total PCB estimated from doubling a summation of four homolog. Appendices 4, 5, and 6 each include eighteen pages since results for 2,3,4,7,8-PCDF using the disposal criterion for 2,3,7,8-TCDD are included in addition to results for 2,3,7,8-TCDD and for total PCB estimated from doubling a summation of four homologs.

Example HARS suitability ratio maps from Appendix 6 are shown on Figures 3-10 and 3-11 for 2,3,7,8-TCDD and total-PCB, respectively. The examples on Figures 3-10 and 3-11 show the projected HARS suitability assuming ninetieth percentile CARP 2 BSAFs for both the current 2022-23 water year and the 2038-39 year assuming the October 2030 completion of the Lower Passaic River Superfund RODs plus complete remediation of the Lower Hackensack River and Newark Bay Study Area. Additional example HARS suitability ratio maps from Appendices 4 and 5 are shown on Figure 3-12 for total-PCB. The examples on Figure 3-12 show the projected HARS suitability for the current year (i.e., water year 2022-

23) assuming PCB homolog BSAFs from CARP 1 field observations (highest BSAFs) and from fiftieth percentile CARP 2 laboratory results (lowest BSAFs).

Lastly, for context, results of contaminant measurements in worms collected during CARP 2 at various locations are displayed with comparisons to HARS criteria on Figure 3-13. The CARP 2 Management Committee suggested that it might be appropriate to double the measured contaminant tissue concentrations for PCBs from 28-day exposures when making comparisons to HARS disposal criteria. The doubling was not implemented for Figure 3-13 which is based strictly on observations.

4.0 DISCUSSION

The discussion of the results for the future projection scenarios applying the full suite of CARP models on the 127 x 205 model computational grid is framed around the time series displays of contaminant concentrations in the sediment bed and the water column and spatial maps of HARS suitability based on worm bioaccumulation estimated with BSAFs.

4.1 Discussion of CARP Future Projection Scenarios, Sediment Bed Contaminant Concentrations

Separate discussion is provided for the sediment bed 2,3,7,8-TCDD and total PCB concentration results for the future projection scenarios.

4.1.1 Discussion of CARP Future Projection Scenarios, Sediment Bed Contaminant Concentrations, 2,3,7,8-TCDD

The sediment bed 2,3,7,8-TCDD concentration time series diagrams in Appendix 1 and on Figures 3-1 and 3-3 provide an opportunity to assess model and measurement comparison results for 2019 after the 2016 end of the model calibration period. The model results are generally within the middle to high end of the range of 2019 measurements and are also generally mutually consistent with the 2011 and 2015 measurements for the locations within the lower Newark Bay (Figure 3-1) and Hudson/East River (Figure 3-3) reaches. Similar model performance is also observed for 2,3,7,8-TCDD at other locations and reaches as displayed in Appendix 1 although there are often fewer measurements in other reaches as compared to Newark Bay. As shown in Appendix 1, at some locations within western Raritan Bay, 2,3,7,8-TCDD concentrations after the 2016 end of the model calibration period are gradually increasing, likely due to continued transport of 2,3,7,8-TCDD from the Lower Passaic and Newark Bay through the Arthur Kill prior to simulated future projection scenarios remediation starting in 2030.

The sediment bed 2,3,7,8-TCDD concentration time series diagrams in Appendix 1 and on Figures 3-1 and 3-3 provide an opportunity to assess CARP future projection scenario results. Based on the sediment bed 2,3,7,8-TCDD concentration time series for the top 10 cm (green lines and green and gray shades), the Lower Passaic River would not become re-contaminated for 2,3,7,8-TCDD after remediation (Appendix 1). Based on the sediment bed 2,3,7,8-TCDD concentration time series for the top 10 cm (green lines and green and gray shades), Newark Bay (Figure 3-1 and Appendix 1) and the Lower Hackensack River (Appendix 1) would become rapidly re-contaminated from zero 2,3,7,8-TCDD concentrations (Projection Run 2, lower green lines and green and gray shades) to 2,3,7,8-TCDD concentrations lower than those with only Lower Passaic River remediation (Projection Run 1, upper green lines and green and gray shades). The 2,3,7,8-TCDD re-contamination source is likely ongoing external loadings and transport from other parts of the Harbor. The 2,3,7,8-TCDD re-contamination in Projection Run 2 in Newark Bay and the Lower Hackensack River from the assigned zero concentration remains lower than the 8.3 ppt Superfund Record of Decision residual assigned for the Lower Passaic River lower 8.3 miles remediation. 2,3,7,8-TCDD re-contamination of the archive storage layer (pale blue line) in the Lower Hackensack River and Newark Bay Study Area occurs more slowly than the top 10 cm, evidencing that deeper bed inventory of 2,3,7,8-TCDD has effectively been removed from the model per the assumptions of the future projection scenarios.

The future projection scenarios sediment bed 2,3,7,8-TCDD concentration time series results indicate that the spatial influence of the Lower Passaic and Hackensack Rivers and Newark Bay Study Area remediations have impacts outside the remediation footprints. The extended spatial impact is most readily apparent in Appendix 1 for six Kill van Kull, twelve Arthur Kill, six Raritan Bay, and some Upper and Lower New York Bay locations where differences between sediment bed 2,3,7,8-TCDD concentration results for the projection scenarios are apparent (i.e., two separate sets of plotted model results starting October 1, 2030, appear differently in the time series diagrams). The top of Figure 3-5 displays examples from Appendix 1 of the 2,3,7,8-TCDD remediation responses for three Arthur Kill locations within the remediation footprints and three Arthur Kill locations outside the remediation footprints.

4.1.2 Discussion of CARP Future Projection Scenarios, Sediment Bed Contaminant Concentrations, Total PCB

The sediment bed total PCB concentration time series diagrams in Appendix 1 and on Figures 3-2 and 3-4 provide an opportunity to assess model and measurement comparison results for 2019 after the 2016 end of the model calibration period. The model results are generally within the low end of the range of 2019 measurements and are also generally mutually consistent with the 2011 and 2015 measurements for the locations within the lower Newark Bay (Figure 3-2) and Hudson/East River (Figure 3-4) reaches. The 2011 and 2015 measurements (shown with brown triangles, from dredging projects) are often slightly lower than the 2019 measurements (shown with pink and green squares, from CARP 2). The measurement discrepancy does not have a known mechanistic causation and is likely related to analytical methods differences. The CARP model results from the 127 x 205 model computational grid future projection scenarios simulations typically fall between the two sets of measurements. Similar model performance is also observed for total PCB at other locations and reaches as displayed in Appendix 1.

The sediment bed total PCB concentration time series diagrams in Appendix 1 and on Figures 3-2 and 3-4 provide an opportunity to assess CARP future projection scenario results. Based on the sediment bed total PCB concentration time series for the top 10 cm (green lines and green and gray shades), the Lower Passaic River would not become re-contaminated for total PCB after remediation (Appendix 1). Based on the sediment bed total PCB concentration time series for the top 10 cm (green lines and green and gray shades), Newark Bay (Figure 3-2 and Appendix 1) and the Lower Hackensack River (Appendix 1) would become rapidly re-contaminated from zero total PCB concentrations (Projection Run 2, lower green lines and green and gray shades) to total PCB concentrations approaching those with only Lower Passaic River remediation (Projection Run 1, upper green lines and green and gray shades). The total-PCB re-contamination source is likely ongoing external loadings and transport from other parts of the Harbor. The total PCB re-contamination in Projection Run 2 in Newark Bay and the Lower Hackensack River from the assigned zero concentration approaches several hundred ppb, as expected for the Lower Hudson River opposite Manhattan. Total-PCB re-contamination of the archive storage layer (pale blue line) in the Lower Hackensack River and Newark Bay Study Area occurs more slowly than the top 10 cm, evidencing that deeper bed inventory of total PCB has effectively been removed from the model per the assumptions of the future projection scenarios.

Unlike 2,3,7,8-TCDD results, the future projection scenarios sediment bed total PCB concentration time series results indicate that the spatial influence of the Lower Passaic and Hackensack Rivers and Newark Bay Study Area remediations have modest, if any, impacts outside the remediation footprints. This is most readily apparent in Appendix 1 for numerous Kill van Kull and Arthur Kill locations just beyond the Newark Bay Study Area, as well as in other Harbor locations, where differences between sediment bed total PCB concentration results for the two projection scenarios are barely noticeable or are even non-discernible (i.e., two separate sets of plotted model results starting October 1, 2030, appear as only one set of model results in the time series diagrams). The bottom of Figure 3-5 displays examples from Appendix 1 of the total PCB remediation responses for three Arthur Kill locations within the remediation footprints and three Arthur Kill locations outside the remediation footprints. Further, the total PCB results shown on the bottom of Figure 3-5 as compared to the 2,3,7,8-TCDD results shown on the top of Figure 3-5 illustrate the contaminant-specific modeled spatial impacts of the remediations considered in the two future projection scenarios.

4.2 Discussion of CARP Future Projection Scenarios, Water Column Contaminant Concentrations

Separate discussion is provided for the water column 2,3,7,8-TCDD and total PCB concentration results for the future projection scenarios.

4.2.1 Discussion of CARP Future Projection Scenarios, Water Column Contaminant Concentrations, 2,3,7,8-TCDD

The water column 2,3,7,8-TCDD concentration time series diagrams in Appendix 2 and on Figures 3-6 and 3-8 provide a limited opportunity to assess model and measurement comparison results for 2019 after the 2016 end of the model calibration period. The model results are on the high end of the range of 2019 measurements for a single location within the Hudson River reach (Figure 3-8). Similar model performance is observed for 2,3,7,8-TCDD at other locations and reaches as displayed on pages 2 to 13 of Appendix 2. For the Upper Newark Bay reach (Figure 3-6) water column 2,3,7,8-TCDD measurements after the 2016 end of the model calibration were not available and measurements available for 2010-2014 include non-detected samples at detection limits (pale pink squares).

The water column 2,3,7,8-TCDD concentration time series diagrams in Appendix 2 and on Figures 3-6 and 3-8 provide an opportunity to assess CARP future projection scenario results. Simulated sediment bed cleanups of the Lower Passaic River alone and in combination with the Hackensack River and Newark Bay Study Area starting in October 2030 for both scenarios modeled show a decline in Upper Newark Bay water column 2,3,7,8-TCDD concentrations (Figure 3-6). Somewhat different 2,3,7,8-TCDD concentration results at the Upper Newark Bay water column locations (Figure 3-6) occur for the two scenarios modeled. Through 2039, the 2,3,7,8-TCDD water column results in Upper Newark Bay (Figure 3-6) for the first future projection scenario (i.e., Lower Passaic River remediation only) decline toward the residual achieved by the second future projection scenario (i.e., combined Lower Passaic and Hackensack Rivers and Newark Bay Study Area remediation). The combined scenario achieves smaller water column concentrations of 2,3,7,8-TCDD somewhat more rapidly and flatly maintains those concentrations. In other reaches such as the Arthur Kill (page 9 of Appendix 2), 2,3,7,8-TCDD water column concentration results from both future projection scenarios decline continuously through 2039 with a noticeable difference in concentrations between the two simulations. Within Raritan Bay, Upper NY Bay, the East River, and Jamaica Bay (pages 10, 12, and 13 of Appendix 2), it is difficult to distinguish the declining 2,3,7,8-TCDD water column concentration projection results for the two scenarios. Water column 2,3,7,8-TCDD concentration responses to simulated remediation of the Lower Passaic and Hackensack Rivers and Newark Bay Study Area sediment beds starting in October 2030 are not apparent at locations in the Lower Hudson River above Manhattan (locations 1 to 4 on Figure 3-8).

4.2.2 Discussion of CARP Future Projection Scenarios, Water Column Contaminant Concentrations, Total PCB

The water column total PCB concentration time series diagrams in Appendix 2 and on Figures 3-7 and 3-9 provide a limited opportunity to assess model and measurement comparison results for 2019 after the 2016 end of the model calibration period. The model results are within the center of the range of 2019 measurements for a single measurement location within the Hudson River reach (Figure 3-9). Similar model performance is observed for total PCB at other locations and reaches as displayed in Appendix 2. For the Upper Newark Bay reach (Figure 3-7) water column total PCB measurements after the 2016 end of the model calibration were not available. There is generally a declining trend for the total PCB concentrations in the water column of the Upper Newark Bay and Hudson River reaches through 2029.

The water column total PCB concentration time series diagrams in Appendix 2 and on Figures 3-7 and 3-9 provide an opportunity to assess CARP future projection scenario results. The occurrence of reduced Upper Hudson River total PCB loading after the completion of remedial dredging in 2016 is apparent in total PCB water column concentration results (blue lines and shades) in the Hudson River near Poughkeepsie (locations 1 and 2 on Figure 3-9). Simulated sediment bed cleanups of the Lower Passaic and Hackensack Rivers and Newark Bay Study Area starting in October 2030 for both scenarios modeled show a decline in water column total PCB concentrations within those remediation areas (Figure 3-7). There are very similar overlapping and reduced PCB concentration results at the Upper Newark Bay water column locations (Figure 3-7) for the two scenarios modeled. Water column total PCB concentration responses to simulated remediation of the Lower Passaic and Hackensack Rivers and Newark Bay Study Area sediment beds starting in October 2030 are not apparent at locations in the Hudson River (Figure 3-9).

4.3 Discussion of CARP Future Projection Scenarios, HARS Suitability

Before considering the map displays of CARP HARS suitability results, an element of the methods used to conduct the future projection scenarios warrants discussion specific to HARS suitability projections. Newark Bay and the portions of the Kill van Kull and Arthur Kill between the Goethals and Bayonne Bridges, considered as the Newark Bay Study Area, are areas of overlap between in-progress Superfund efforts and dredged material management interests. The Superfund effort has not yet established eventual remediation goals for these areas. For CARP 2 future projection scenario simulations, a cleanup to zero concentration was assumed and the model results show rapid re-contamination due to ongoing sources of 2,3,7,8-TCDD and total PCB. This temporal behavior is evident on Figures 3-1 and 3-2 and other timeseries diagrams in Appendix 1. It is expected that even with a remediation goal set greater than zero at a small residual concentration for Newark Bay and portions of the Kills, the calculated concentrations after recontamination would still be similar and should not appreciably alter the projected HARS suitability results. The projected HARS suitability results are for the first time inclusive of cleanups of the Newark Bay Study Area and the Lower Hackensack River.

Further consideration and context for the map displays of CARP HARS suitability is the varying magnitudes of the BSAFs presented in Table 2-6. In the case of PCB homologs (and therefore total PCB), the greater magnitudes of the CARP 1 BSAFs, and to a lesser extent the Dredged Material Testing BSAFs and CARP 2 ninetieth percentile BSAFs, as compared to the CARP 2 fiftieth percentile BSAFs, are enough to yield different conclusions for current and future HARS suitability. The CARP 2 fiftieth percentile BSAFs for PCB homologs (results in Appendix 5 and on Figure 3-12 bottom panel) indicate that the modeled concentrations for total PCB in sediments for the current year and future years are HARS suitable. The CARP 1 BSAFs for PCB homologs indicate that the modeled concentrations for total PCB in sediments for the current year and future years are not HARS suitable (results in Appendix 4 and on Figure 3-12 top panel). Similar dependence of HARS suitability conclusions on the BSAF applied is also apparent for 2,3,7,8-TCDD and 2,3,4,78-PCDF on the map diagrams provided in Appendices 3 through 6. For 2,3,7,8-TCDD specifically, after the simulated cleanups for the Lower Passaic River, Lower Hackensack River, and the Newark Bay Study Area (i.e., projection simulation 2), use of the dredged material testing and CARP 2 BSAFs (both fiftieth and ninetieth percentiles) indicate the Harbor would be largely HARS suitable. The use of the field-derived CARP 1 BSAF indicates that portions of the Arthur Kill and Raritan Bay would not be HARS suitable. Accordingly, the selection of the 2,3,7,8-TCDD and PCB homolog BSAFs to be used for interpreting model outputs for dredged material management planning purposes is critical.

In consultation with the CARP Management Committee and CARP 2 principal investigators for bioaccumulation, ninetieth percentile CARP 2 BSAFs have been recommended as appropriate for purposes of future projections of HARS suitability and are more robust and modern than the Dredged Material Testing BSAFs. The less conservative CARP 2 fiftieth percentile BSAFs might be useful for other purposes such as for making economic decisions about conducting HARS suitability testing or pursuing other dredged material disposal options without HARS testing. The field-derived CARP 1 BSAFs are likely to be most useful for Harbor sediment quality issues beyond evaluating dredged material disposal options.

The specific example HARS suitability maps shown in the bottom panels on Figures 3-10 and 3-11 indicate that HARS suitability would be attained for 2,3,7,8-TCDD and total PCBs in Newark Bay and the majority of the Harbor assuming ninetieth percentile CARP 2 BSAFs with a factor of two multiplier for total PCB worm concentrations and the October 2030 completion of the Lower Passaic River Superfund RODS plus complete remediation of the Lower Hackensack River and Newark Bay Study Area. The specific example HARS suitability maps shown on Figure 3-12 illustrate the calculated range in HARS suitability for total PCB for the current 2022-23 water year based on the range of homolog BSAFs evaluated.

5.0 CONCLUSION

The CARP 1 management conclusion for attaining a HARS Suitable Newark Bay (HydroQual, 2007c) by 2040 after remediation efforts continues to hold true based on CARP 2 measurement and modeling efforts.

Specifically, for 2,3,7,8-TCDD, based on ninetieth percentile CARP 2 BSAFs and CARP 2 future projection modeling results, a HARS suitable Newark Bay (and practically entire Harbor) for 2,3,7,8-TCDD is expected in the future after the implementation of two Superfund Records of Decision (RODs) for the Lower Passaic River and full remediation of the Lower Hackensack River and Newark Bay. Further, the application of dredged material testing program BSAFs, used for CARP 1 projections, to the CARP 2 future projection modeling results does not alter this HARS suitability conclusion.

Specifically, for total PCB based on ninetieth percentile CARP 2 BSAFs and CARP 2 future projection modeling results, a HARS suitable Newark Bay for total PCB is expected in the future after the implementation of two Superfund Records of Decision (RODs) for the Lower Passaic River and full remediation of the Lower Hackensack River and Newark Bay. Further, the application of BSAFs from the dredged material testing program, as were applied for CARP 1 projections, to the CARP 2 future projection modeling results, does not alter this HARS suitability conclusion for Newark Bay total PCB. In other areas of the Harbor, the CARP 2 future projection modeling results for total PCB HARS suitability are more favorable when the ninetieth percentile CARP 2 BSAFs are applied as compared to applying BSAFs from the dredged material testing program.

6.0 ACKNOWLEDGMENTS AND DISCLAIMERS

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8.0 SECTION 2 TABLES AND FIGURES

Table 2- 1. Future projection scenarios tracking of water years, bathymetry conditions, and new hydrodynamic model simulations.

Assumptions for Hydrodynamic Conditions (i.e., hydrographs and bathymetry) for the Single Hydrodynamic/Sediment Transport Future Projection Condition Supporting Two Contaminant Future Projections, 127 x 205 Model Grid			
ACTUAL	ASSIGNED		SOURCE
Water Years (WYs) Oct. 1 to Sept. 30	**Hydrodynamic Model WYs Flow Conditions**	**Hydrodynamic Model Bathymetry**	**Hydrodynamic Modeling Effort**
1998-99	1998-99	< 40‘, pre-deepening	from calibration (Landeck Miller at al., 2023)
1999-2003	1999-2003	interim KVK, NB, PJC	
2003-07	2003-07	45’ – 47’ NB, KVK	
2007-10	2007-10	interim NB, Kills	
2010-16	2010-16	52’ NB, Kills, PJC, Anchorage, Ambrose	
2016-2028	1998-2010	52’ NB, Kills, PJC, Anchorage, Ambrose	simulated for future projection
2028-2034	2010-16	52’ NB, Kills, PJC, Anchorage, Ambrose	from calibration
2034-2039	1998-2003	52’ NB, Kills, PJC, Anchorage, Ambrose	uses 2016 to 2021 simulations

Notes

Abbreviations: WYs = water years, KVK = Kill van Kull, NB = Newark Bay, PJC = Port Jersey Channel, Kills = Arthur Kill and Kill van Kull, Anchorage and Ambrose refer to the Anchorage and Ambrose Channels

Contemplated 55’ Deepening and Widening, Not Included: Given the numerous contingencies and uncertainties, associated with the contemplated National Economic Development Plan for deepening and widening in NY/NJ Harbor channels, at the time the CARP future projection scenarios were developed, the contemplated National Economic Development Plan has not been reflected in the CARP models future projection scenarios. The CARP future projection scenarios do not include deepening beyond the 52’ deepening projects. The contemplated National Economic Development Plan would involve deepening the pathways to the Elizabeth – Port Authority Marine Terminal and the Port Jersey – Port Authority Marine Terminal by 5 feet to a maintained depth of -55 feet MLLW (i.e., initial deepening to 57’). The contemplated plan would involve deepening Ambrose Channel, Anchorage Channel, the Kill van Kull, Newark Bay Channel, South Elizabeth Channel, Elizabeth Channel, and Port Jersey Channel. This would include the additional width required for structural stability and for the navigation of the design vessel to transit from the sea to the Elizabeth – Port Authority Marine Terminal and the Port Jersey – Port Authority Marine Terminal. Channel configurations would avoid and minimize environmental and cultural resource impacts while still meeting navigation safety requirements. The plan would allow for calling vessels to increase their loads. The increase in cargo per vessel call would yield economic benefits by allowing for more efficient use of containerships. If successfully incorporated in the FY24 Water Resources Development Act (WRDA), construction would start FY 25/26 and go for 15 years, completing June 30, 2040.

Table 2- 2. Future projection scenarios tracking of water years, hydrodynamic conditions, sediment bed particle mixing rates, and new sediment transport and organic carbon production model simulations.

Assumptions for Sediment Transport (i.e., hydrodynamic transport and particle mixing rates) for the Single Sediment Transport and Organic Carbon Production Future Projection Condition Supporting Two Contaminant Fate and Transport Future Projections, 127 x 205 Model Grid			
ACTUAL	ASSIGNED		SOURCE
Water Years (WYs) Oct. 1 to Sept. 30	**Hydrodynamic Model WYs Flow Conditions**	**Decreased Bed Mixing in Lower Passaic River (yes/no)**	**Sediment Transport Modeling Effort**
1998-99 to 2015-16	1998-99 to 2015-16 from calibration	yes	from calibration, Landeck Miller et al., 2023
2016-17 to 2027-28	1998-99 to 2009-10 projection version[1]	yes	simulated for future projection[2]
2028-29 to 2029-30	2010-11 to 2011-12 from calibration	yes	simulated for future projection[2]
2030-31 to 2033-34	2012-13 to 2015-16 from calibration	no, restored to Harbor-wide levels	simulated for future projection[2]
2034-35 to 2038-39	1998-99 to 2002-03 projection version[1]	no, restored to Harbor-wide levels	simulated for future projection[2]

Notes:
[1]Projection hydrodynamics incorporate the bathymetry of 2010-11 to 2015-16 for all future years.
[2]For each water year starting October 1, there is a “hot start” from September 30 of the previous water year such that the simulation is continuous. For example, 2016-17 has a “hot start” where 2015-16 ended, 2017-18 has a “hot start” where 2016-17 ended, etc.

Table 2- 3. Future projection scenarios tracking of water years, hydrodynamic conditions, sediment transport conditions, contaminant loadings, contaminant bed concentrations, and new contaminant fate and transport model simulations.

<table>
<tr><th colspan="6">Assumptions for Contaminant Conditions (i.e., hydrodynamic transport, sediment transport, loadings, and bed concentrations) for Two Contaminant Future Projections, 127 x 205 Model Grid</th></tr>
<tr><td>ACTUAL</td><td colspan="4">ASSIGNED</td><td>SOURCE</td></tr>
<tr><th>Water Years (WYs) October 1 to September 30</th><th>Hydrodynamic Model WYs Flow Conditions</th><th>Sediment Transport Model Conditions</th><th>Upper Hudson PCB Loading</th><th>Remediated bed chemical concentrations (yes/no)</th><th>Contaminant Transport Modeling Effort</th></tr>
<tr><td>1998-99 to 2015-16</td><td>1998-99 to 2015-16 from calibration</td><td>1998-99 to 2015-16 from calibration</td><td>measurements plus pre-, during, and post-dredging regressions</td><td>no</td><td>from calibration, Landeck Miller et al., 2023</td></tr>
<tr><td>2016-17 to 2027-28</td><td>1998-99 to 2009-10 projection version[1]</td><td rowspan="4">2016-17 to 2038-39 from sediment transport projection simulation</td><td rowspan="4">post-dredging regressions only</td><td>no</td><td>simulated for future projection[2]</td></tr>
<tr><td>2028-29 to 2029-30</td><td>2010-11 to 2011-12 from calibration</td><td>no</td><td>simulated for future projection[2]</td></tr>
<tr><td>2030-31 to 2033-34</td><td>2012-13 to 2015-16 from calibration</td><td>yes, for October 1, 2030[3,4,5]</td><td>simulated for future projection[2]</td></tr>
<tr><td>2034-35 to 2038-39</td><td>1998-99 to 2002-03 projection version[1]</td><td>no</td><td>simulated for future projection[2]</td></tr>
<tr><td colspan="6"><u>Notes:</u>
[1]Projection hydrodynamics incorporate the bathymetry of 2010-11 to 2015-16 for all future years.
[2]For each water year starting October 1, there is a “hot start” from September 30 of the previous water year such that the simulation is continuous. For example, 2016-17 is to “hot start” where 2015-16 ended, 2017-18 is to “hot start” where 2016-17 ended, etc.
[3]On October 1, 2030, for the entire lower 8.3 miles of the Lower Passaic River, model archive and active layer bed contaminant concentrations are set to a small residual per 2016 ROD. Applied to both future projections. See Table 2-4.
[4]On October 1, 2030, for approximately 33% of miles 15 to 8.3 of the Lower Passaic River that will be dredged, per 2021 ROD, archive layer and active layer bed concentrations (based on reach wide SWACs) are set to a small residual. Applied to both future projections. See Table 2-5.
[5]On October 1, 2030, for Newark Bay and Lower Hackensack River, model archive and active layer bed contaminant concentrations are set to zero. Applied to second future projection only.</td></tr>
</table>

Table 2- 4. Future projection scenarios contaminant bed concentrations assigned to Lower Passaic River lower 8.3 miles for October 1, 2030, assumed completion of 2016 ROD.

CONTAMINANT	CONCENTRATION	RATIONALE
2,3,7,8-TCDD	8.3 ppt	"Alternative 3 Cap/Dredge Flood/Navigation with DMM Scenario B" in USEPA, 2016a on page 94 third bullet, on Figure 19, top panel, and on Table 25, USEPA remediation goal.
2,3,4,7,8-PCDF	2 ng/kg	"Full Capping PP RTC" in USEPA, 2016b, page 62, Figure 15.9-61, Superfund model projection after ROD implementation.
di-CB	5 ug/kg	"Full Capping PP RTC" in USEPA, 2016b, pages 87, 97, 107, and 122, Figures 15.9-86, 15.9-96, 15.9-106, and 15.9-121, Superfund model projection after ROD implementation. It is noted that the sum of the 4 homologs is 51 ug/kg, about ½ of the assumed attainable remediation goal of 100 ug/kg for total PCBs based on Figure 20 in USEPA, 2016a.
tetra-CB	25 ug/kg	
hexa-CB	18 ug/kg	
octa-CB	2.9 ug/kg	

Table 2- 5. Future projection scenarios contaminant bed concentrations assigned to Lower Passaic River miles 15 to 8.3 for October 1, 2030, assumed completion of 2021 ROD.

CONTAMINANT	CONCENTRATION	RATIONALE
2,3,7,8-TCDD	≤ 75 ppt	"Alternative 3" in USEPA, 2021, Attachment A, Proposed Plan and ~93% reduction from the current Surface Area Weighted Average Concentration (SWAC) from USEPA, 2021, page 78.
2,3,4,7,8-PCDF	0.07 multiplier in specific model grid cells	Same ~93% reduction as 2,3,7,8-TCDD applied to 2,3,4,7,8-PCDF concentrations from CARP 127 x 205 model grid projections for September 30, 2030, only for those model grid cells where it was necessary to reduce the CARP model calculated 2,3,7,8-TCDD concentrations to achieve 75 ppt.
di-CB	0.0135 ppm	USEPA, 2021, page 78, Total PCB = 0.27 ppm, and represents an 83% reduction from the current SWAC based on currently available data and is below the PCB background level. 0.27 ppm for total PCB implies 0.135 ppm for four homologs. Assume fractions for the four PCB homologs based on USEPA, 2016a, Figure 20 of 10%, 50%, 35%, 5%.
tetra-CB	0.0675 ppm	
hexa-CB	0.04725 ppm	
octa-CB	0.00675 ppm	

Table 2- 6. Worm Biota-Sediment Accumulation Factors (BSAFs) used to transition future sediment bed contaminant concentration estimates to body burdens in worms for dredged material HARS suitability determinations.

BSAF SOURCE	2,3,7,8-TCDD	2,3,4,7,8-PCDF	Di-CB	Tetra-CB	Hexa-CB	Octa-CB
	WORM BSAFs (gm-DW/gm-WW) [A,G,H]					
NY/NJ Dredged Material Testing [B,C]	0.052[B]	NA	0.243[C]	0.300 [C]	0.496 [C]	0.216 [C]
CARP 1 Field-Derived [D]	0.170	0.198	0.200	0.972	1.808	1.407
CARP 2 Laboratory, 50%[E]	0.035	0.039	0.009	0.063	0.189	0.144
CARP 2 Laboratory, 90%[F]	0.067	0.079	0.018	0.126	0.397	0.332

Notes:

[A] DW = dry weight, WW = wet weight

[B] Schrock et al., 1997 samples re-worked for units. BSAF = 0.363 gm-sed-DW/gm-worm-DW divided by approximately 7 gm-worm-WW/gm-worm-DW[D]

[C] Dredged material testing BSAFs provided by USEPA Region 2

[D] HydroQual, 2007c

[E] Developed by other CARP 2 investigators based on the geometric means (i.e., fiftieth percentiles) from up to sixty-eight tissue and sediment samples with 28-day exposures. Report in preparation.

[F] Developed by other CARP 2 investigators based on the ninetieth percentiles from up to sixty-eight tissue and sediment samples with 28-day exposures. Report in preparation.

[G] Reporting units driven by dredged material testing BSAFs provided by USEPA Region 2 during CARP 1

[H] The BSAFs in this table are reported as measured. Multipliers used for the application of the PCB BSAFs are not included in the tabulated BSAFs.

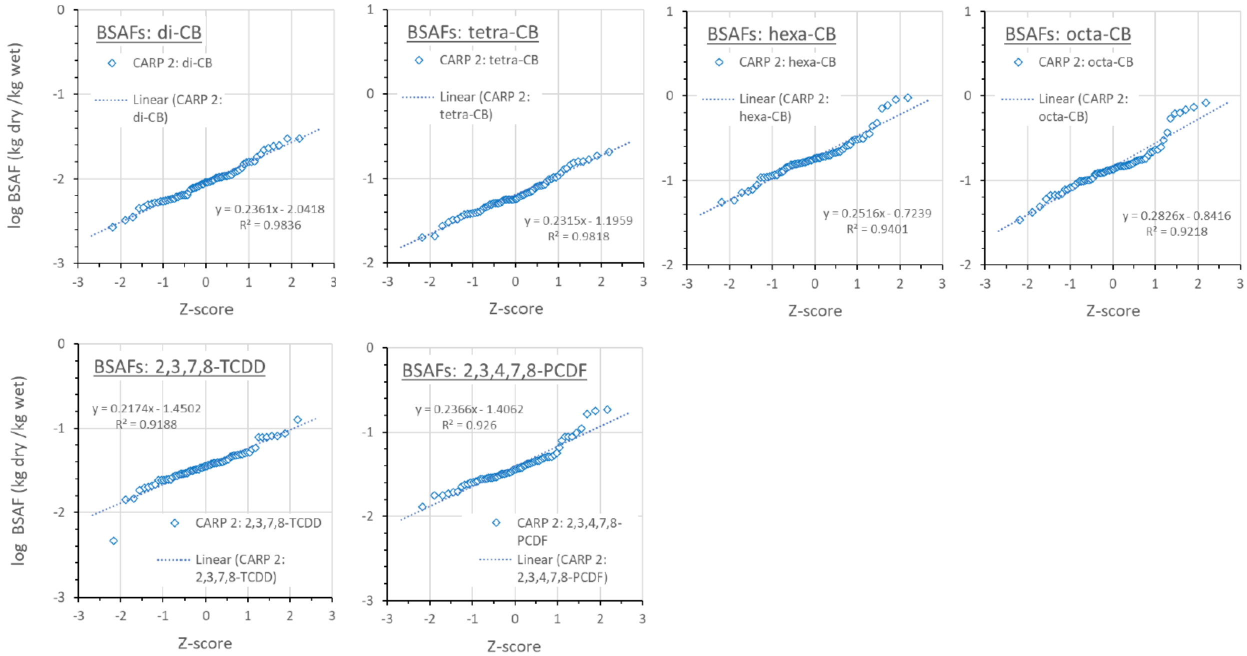


Figure 2- 1. Log normal probability distributions of CARP 2 Biota-Sediment Accumulation Factors (BSAFs) developed from up to sixty-eight twenty-eight-day laboratory exposures of worms to Harbor sediments. The individual calculated CARP 2 BSAFs are shown with diamonds. The fitted log normal probability distributions are shown with lines. The equations of the fitted log normal probability distribution lines are provided in slope-intercept form along with the coefficients of determination (R^2). The fiftieth and ninetieth percentiles from the fitted log normal probability distributions are included in Table 2-6.

9.0 SECTION 3 FIGURES

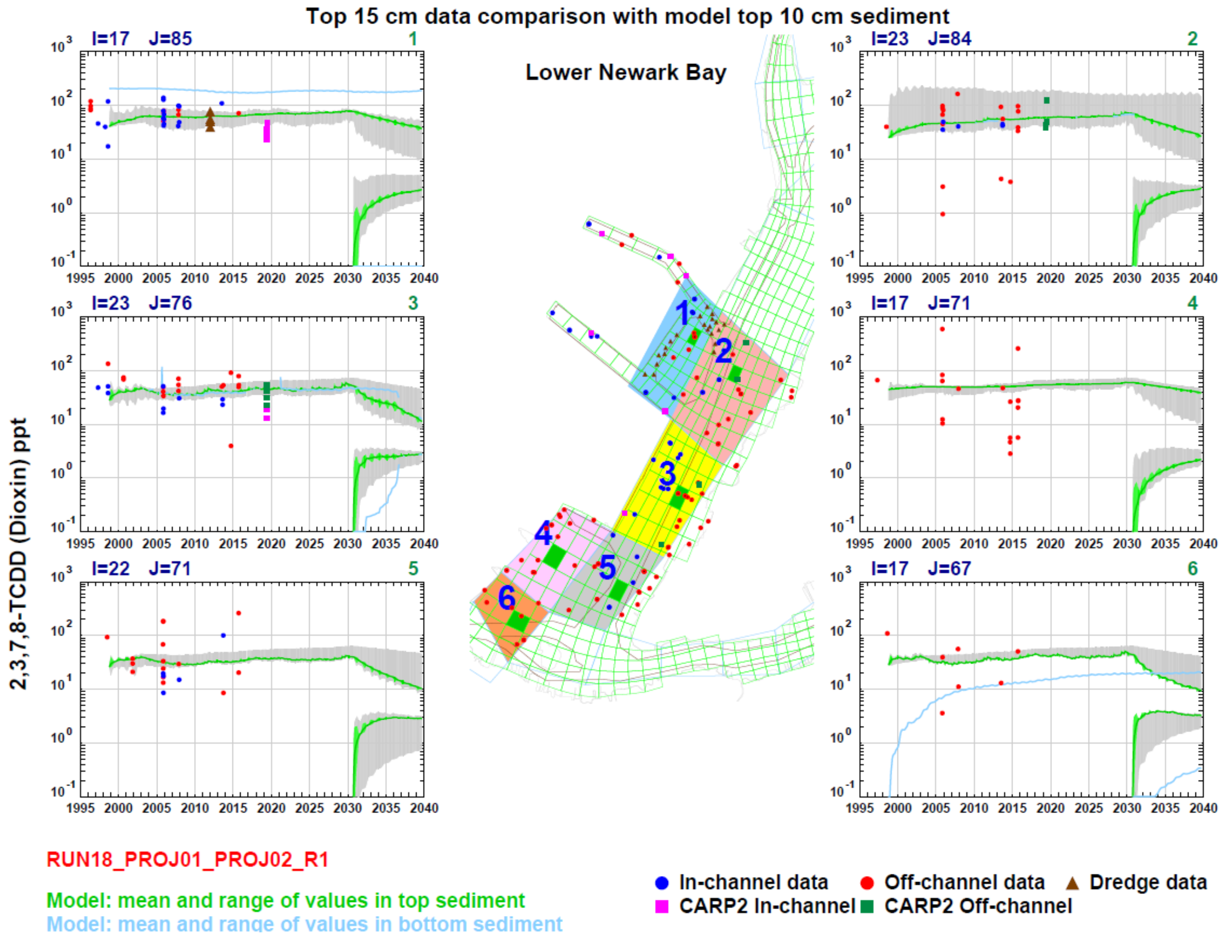


Figure 3- 1. 2,3,7,8-TCDD solids-normalized sediment bed concentrations model results for the calibration period and for two future projection scenarios for six locations in Lower Newark Bay. The model results (green lines and green and gray shades) compare well to measurements collected for multiple programs. Model and measurement results suggest relatively flat temporal gradients through September 2030. The simulation of the Lower Passaic River Superfund RODs starting October 1, 2030, decreases modeled 2,3,7,8-TCDD sediment bed concentrations in lower Newark Bay (upper set of green lines and green and gray shades). The simulation of Lower Hackensack River and Newark Bay Study Area remediations simultaneously with the Lower Passaic River Superfund RODS rapidly further decreases modeled 2,3,7,8-TCDD sediment bed concentrations in lower Newark Bay (lower set of green lines and green and gray shades).

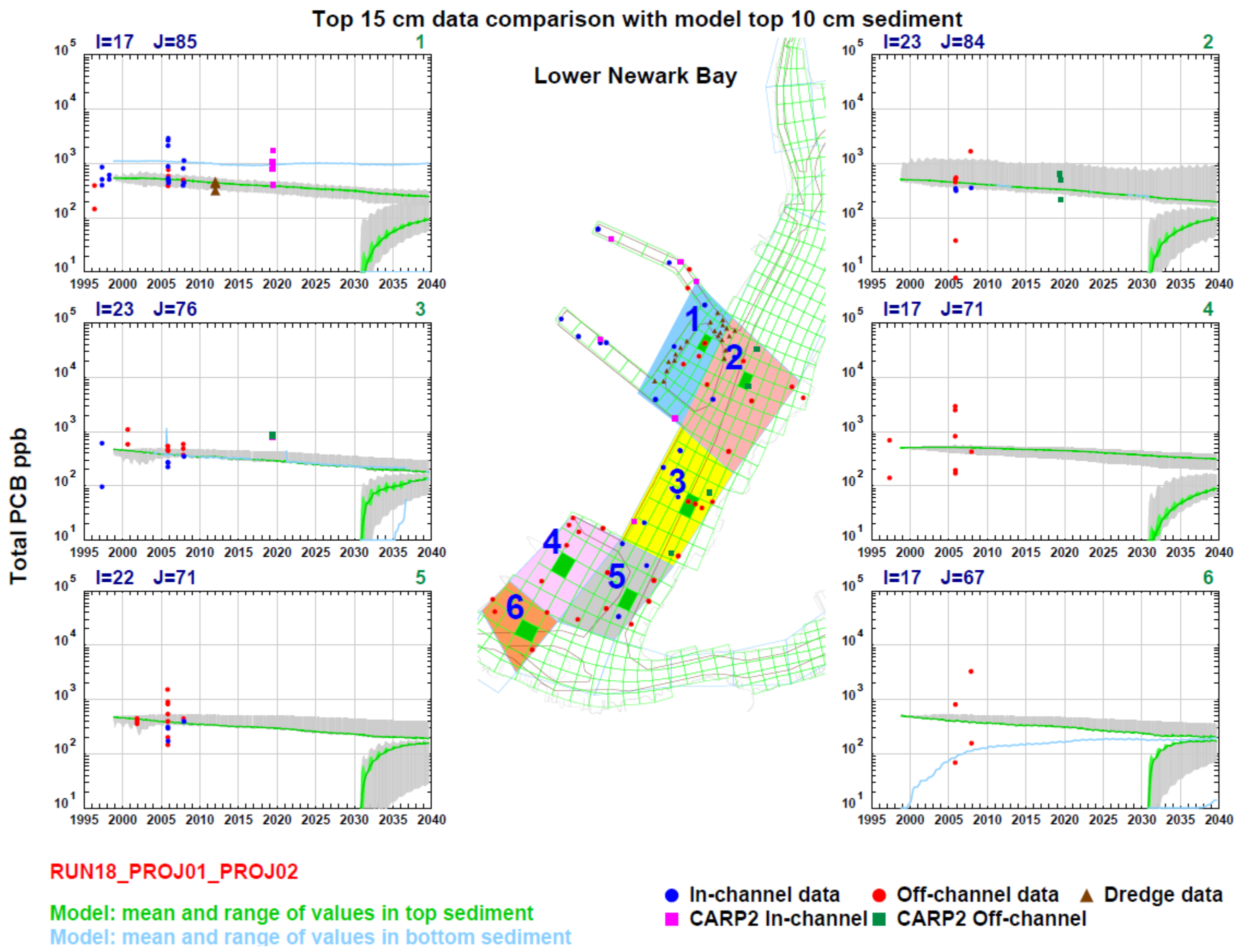


Figure 3- 2. Total PCB solids-normalized sediment bed concentrations model results for the calibration period and two future projection scenarios for six locations in Lower Newark Bay. The model results (green lines and green and gray shades, twice the sum of four homologs) compare well to measurements collected for multiple programs. Model and measurement results suggest relatively flat/slightly declining temporal gradients through September 2030. The simulation of the Lower Passaic River Superfund RODs starting October 1, 2030, does not appreciably change the time behavior of PCB sediment bed concentrations in lower Newark Bay (upper set of green lines and green and gray shades). The simulation of Lower Hackensack River and Newark Bay Study Area remediations simultaneously with the Lower Passaic River Superfund RODs, changes the time behavior of PCB sediment bed concentrations only temporarily with recontamination by 2040 in lower Newark Bay (lower set of green lines and green and gray shades) approaching total PCB solids-normalized sediment bed concentrations without the additional remediations.

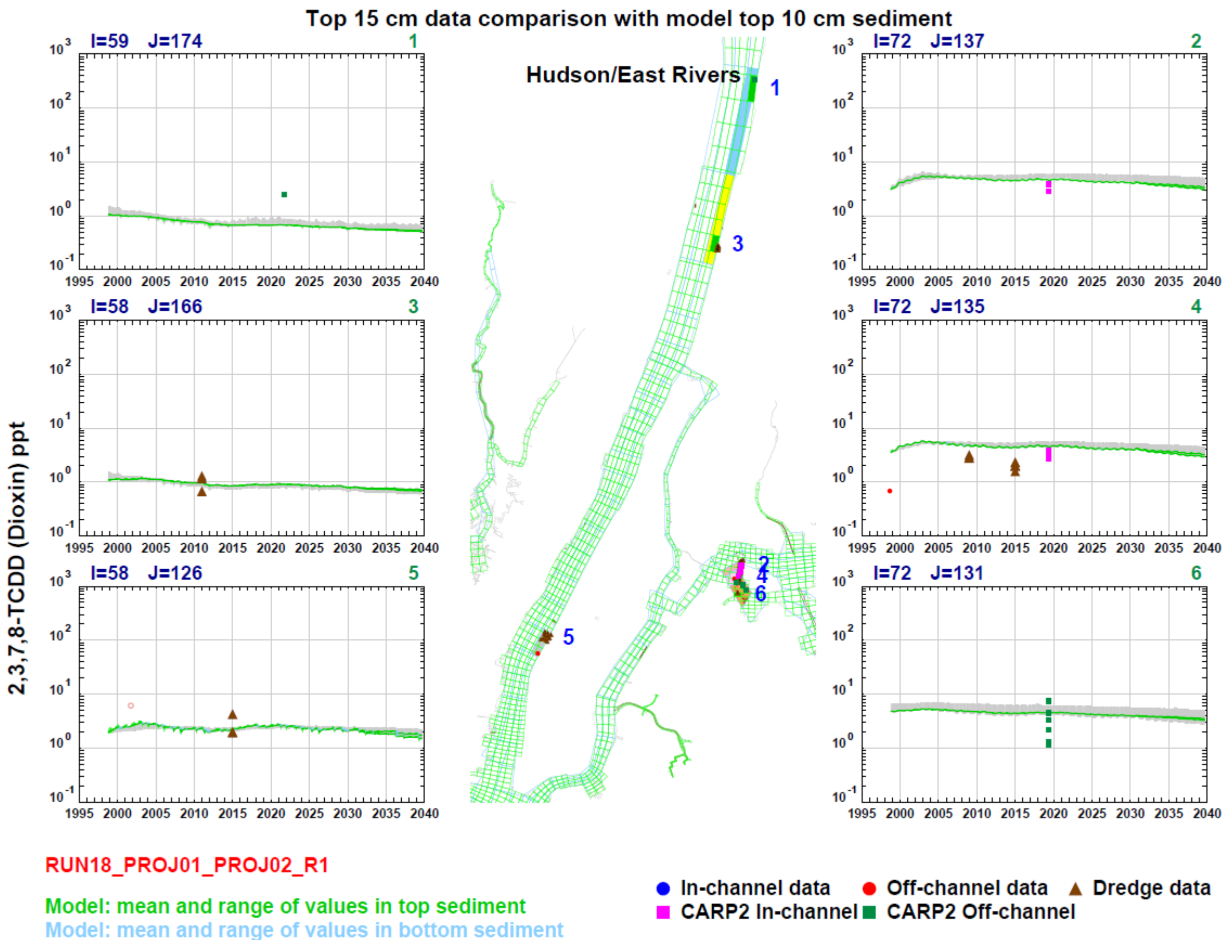


Figure 3- 3. 2,3,7,8-TCDD solids-normalized sediment bed concentrations model results for the calibration period and two future projection scenarios for six locations in the Hudson and East Rivers. The model results (green lines and green and gray shades, twice the sum of four homologs) compare well to limited measurements collected for multiple programs. Stronger model and measurement comparisons at locations 3 and 5 may offset the importance of the potential underprediction further upstream at location 1. Model and measurement results suggest relatively flat/slightly declining temporal gradients through September 2030. The simulation of the Lower Passaic River Superfund RODs and the Lower Hackensack River and Newark Bay Study Area remediations starting October 1, 2030, do not appreciably change the time behavior of 2,3,7,8-TCDD sediment bed concentrations in the Hudson and East Rivers.

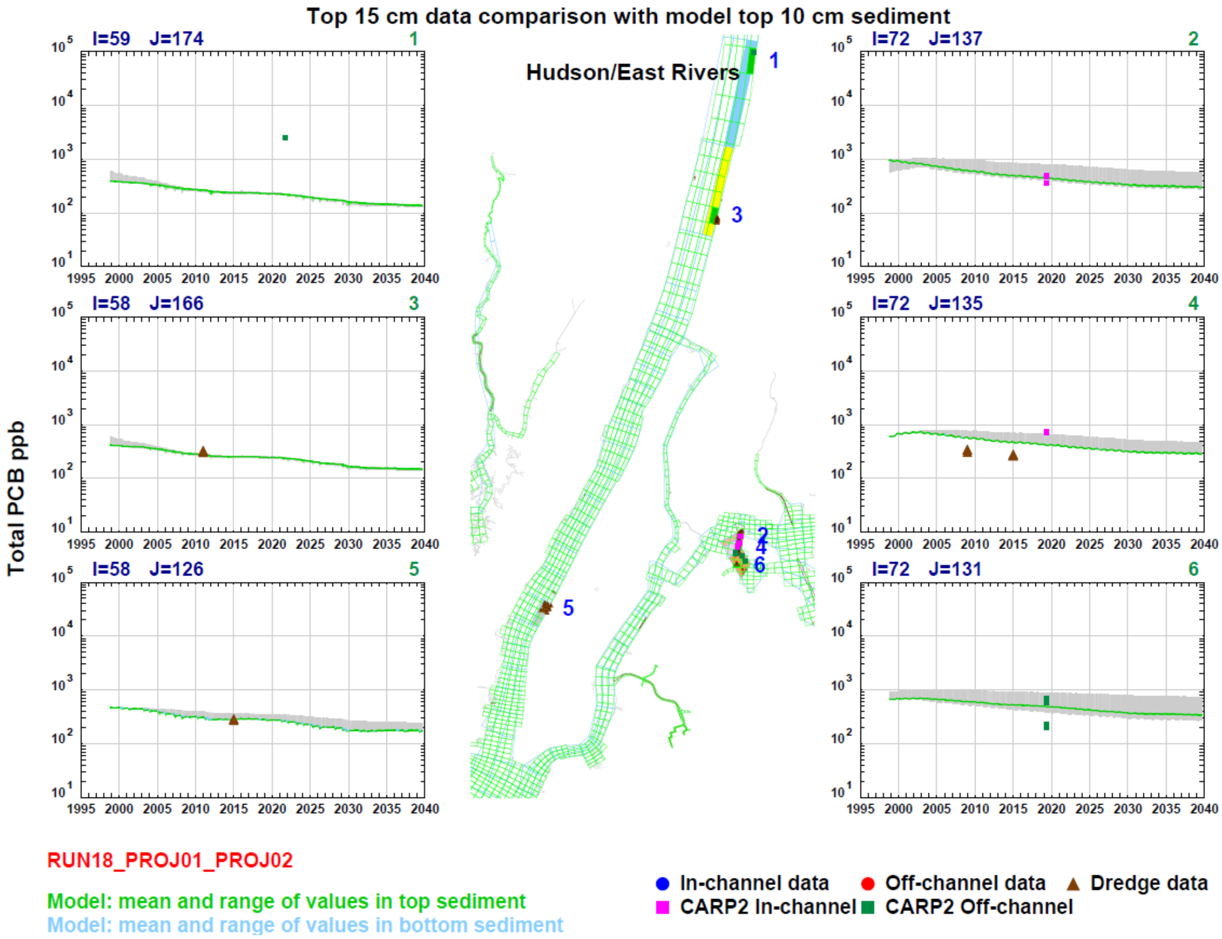


Figure 3- 4. Total PCB solids-normalized sediment bed concentrations results for the calibration period and two future projection scenarios for six locations in the Hudson and East Rivers. The model results (green lines and green and gray shades, twice the sum of four homologs) compare well to limited measurements collected for multiple programs. Stronger model and measurement comparisons at locations 3 and 5 may offset the importance of the potential underprediction further upstream at location 1. Model and measurement results suggests slightly declining temporal gradients through September 2030. The simulation of the Lower Passaic River Superfund RODs and the Lower Hackensack River and Newark Bay Study Area remediations starting October 1, 2030, do not appreciably change the time behavior of PCB sediment bed concentrations in the Hudson and East Rivers.

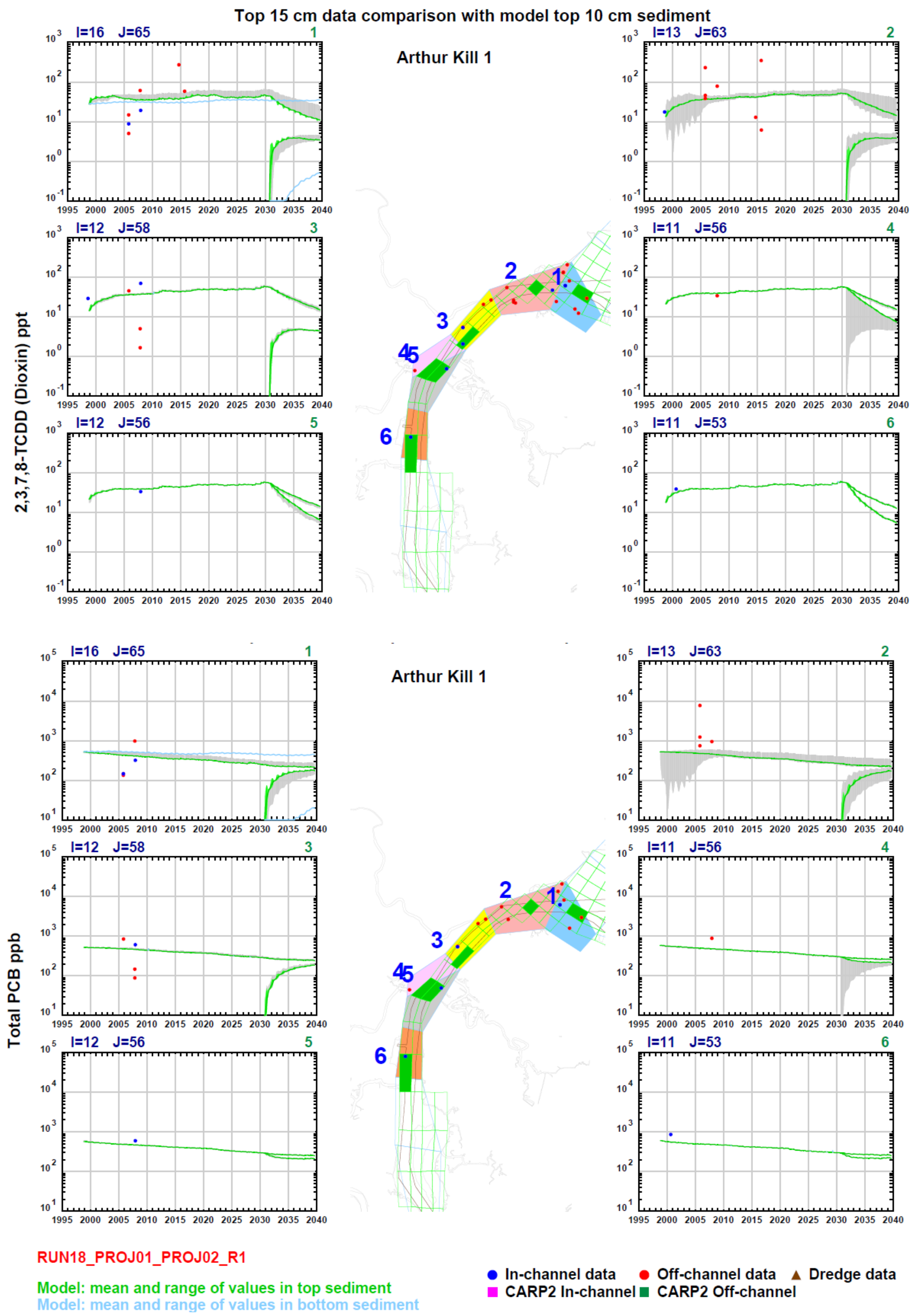


Figure 3- 5. 2,3,7,8-TCDD (top) and total PCB (bottom) solids-normalized sediment bed concentrations results for the calibration period and two future projection scenarios for six locations in the northern Arthur Kill. For locations 1 to 3 within the remediation footprint of the Newark Bay Study area, the model results (lower sets of green lines and green and gray shades) for 2,3,7,8-TCDD (top) and total PCB (bottom) show a benefit for Lower Hackensack River and Newark Bay Study Area remediations starting October 1, 2030, as compared to implementation of the Lower Passaic RODs alone (upper sets of green lines and green and gray shades). The modeled total PCB (bottom) benefits are temporary. For locations 4 to 6 outside of the remediation footprint of the Newark Bay Study area, the model results (lower sets of green lines and green and gray shades) for 2,3,7,8-TCDD show a benefit for Lower Hackensack River and Newark Bay Study Area remediations starting October 1, 2030, as compared to implementation of the Lower Passaic RODs alone (upper sets of green lines and green and gray shades). For locations 4 to 6, the model results for total PCB show little added benefit (i.e., almost coincident green lines) for Hackensack River and Newark Bay Study Area remediations.

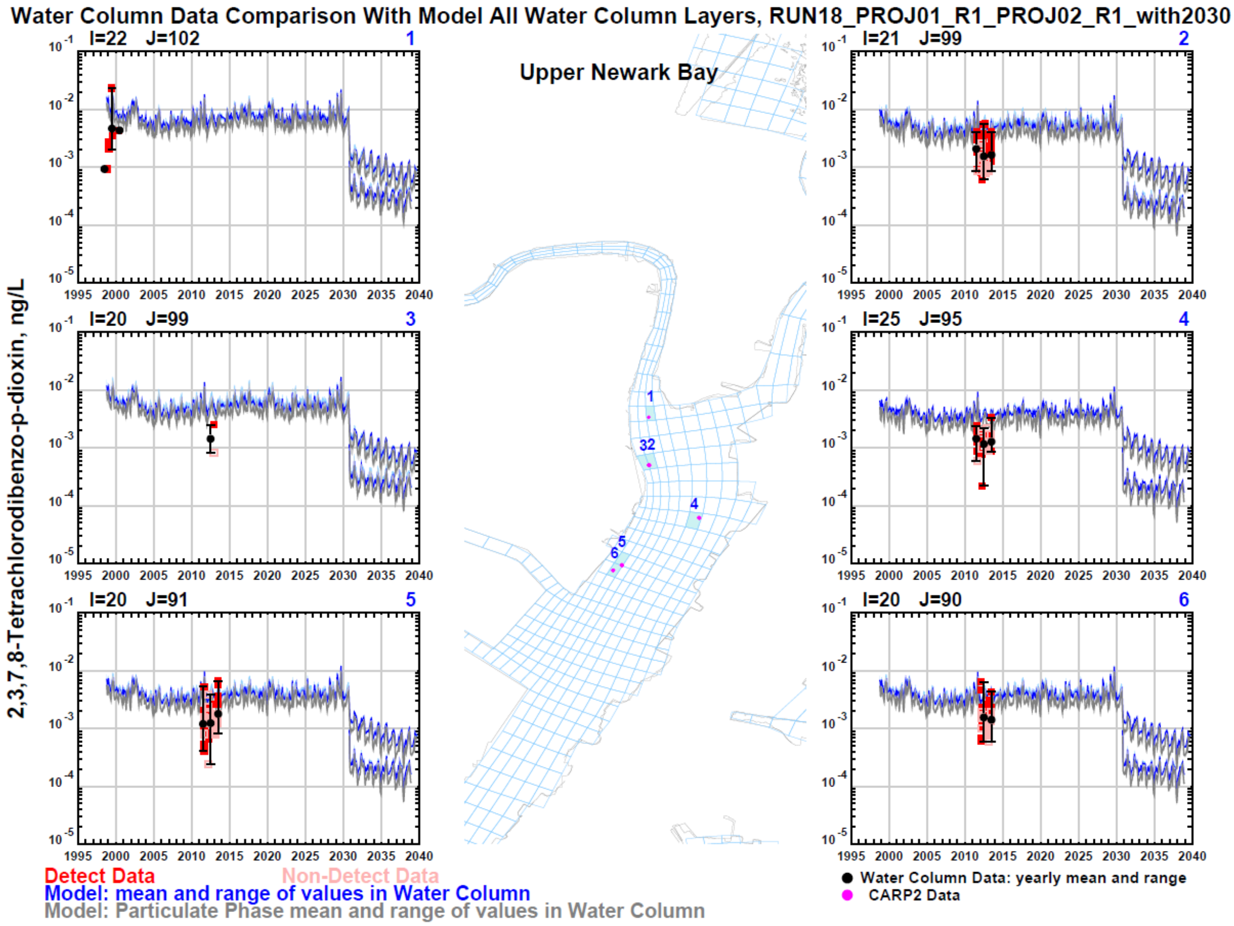


Figure 3- 6. 2,3,7,8-TCDD model results for the calibration period and for two future projection scenarios for six locations in upper Newark Bay. The model results (blue lines and shades) for simulated cleanups of the Lower Passaic River alone (scenario 1, upper profile) and in combination with the Hackensack River and Newark Bay Study Area (scenario 2, lower profile) starting in October 2030 show declines in 2,3,7,8-TCDD concentration results for both future projection scenarios at these water column locations. The model results suggest that 2,3,7,8-TCDD concentrations at these locations in Upper Newark Bay achieved from Lower Passaic River cleanup alone (upper profile) might eventually decline to approach the levels attained by including cleanups of the Hackensack River and Newark Bay Study Area (lower profile). For reference, model results for particulate phase concentrations of 2,3,7,8-TCDD are shown in gray.

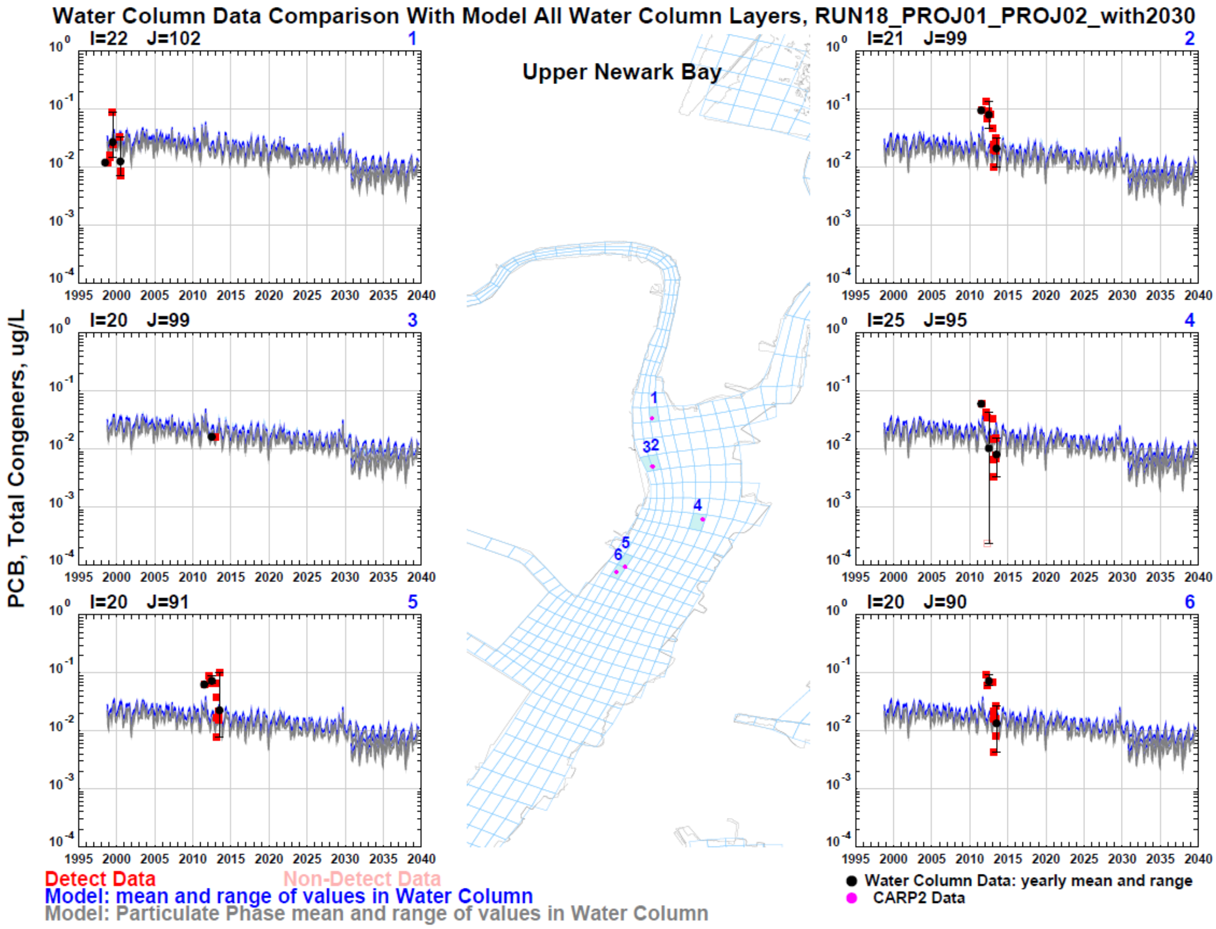


Figure 3- 7. Total PCB water column concentrations (estimated as twice the summation of four homologs) model results for the calibration period and for two future projection scenarios for six locations in upper Newark Bay. The model results (blue lines and shades) decline somewhat. For reference, model results for particulate phase concentrations of total PCB are shown in gray. Simulated cleanups of the Lower Passaic and Hackensack Rivers and Newark Bay Study Area starting in October 2030 show a further decline with very similar overlapping PCB concentration results for both future projection scenarios at these water column locations.

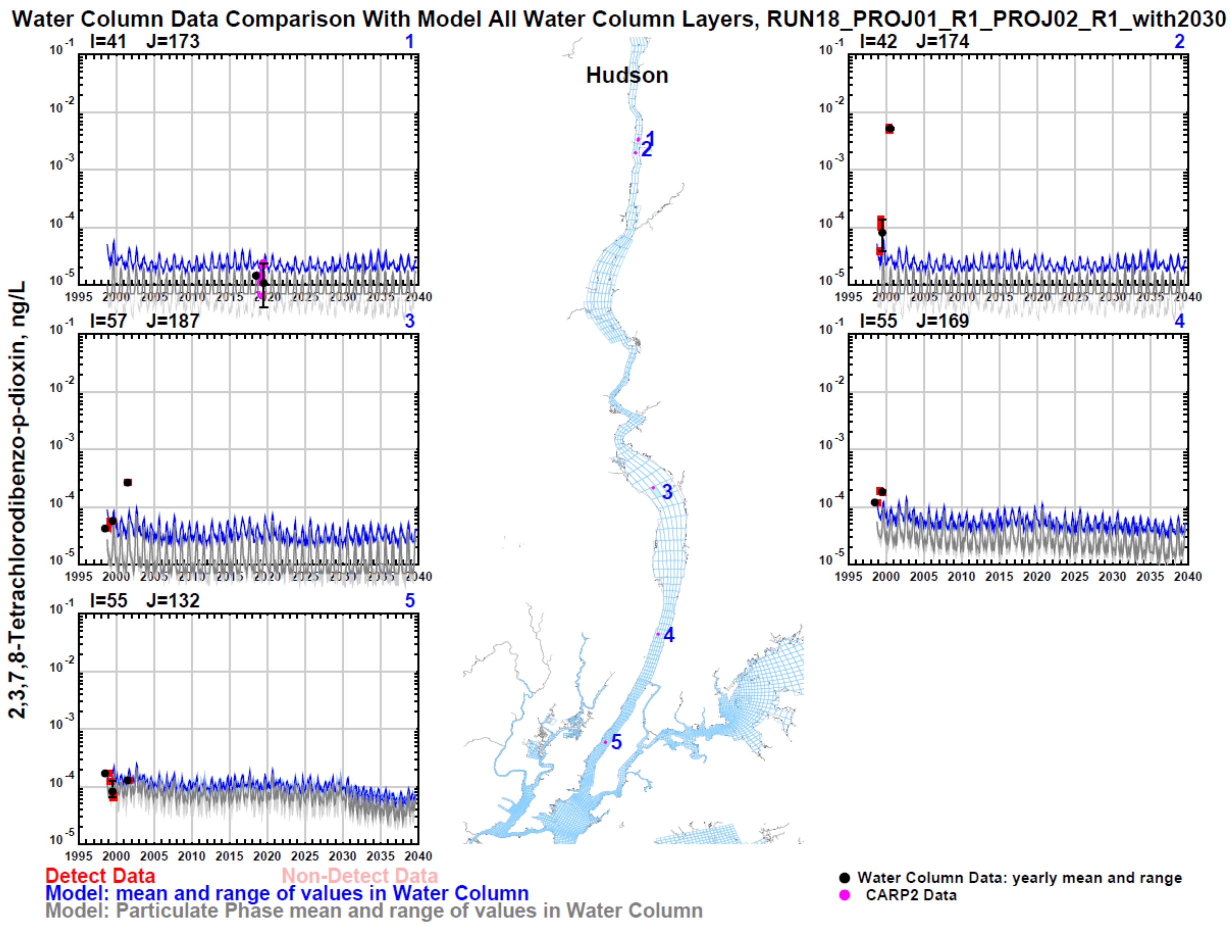


Figure 3- 8. 2,3,7,8-TCDD water column concentrations model results for the calibration period and for two future projection scenarios for five locations in the Hudson River. The model results (blue lines and shades) for simulated cleanups of the Lower Passaic River alone (scenario 1) and in combination with the Hackensack Rivers and Newark Bay Study Area (scenario 2) starting in October 2030 overplot and are not discernible at these locations. Results for both scenarios suggest some decline starting in October 2030 at the most downstream location shown. For reference, model results for particulate phase concentrations of total PCB are shown in gray.

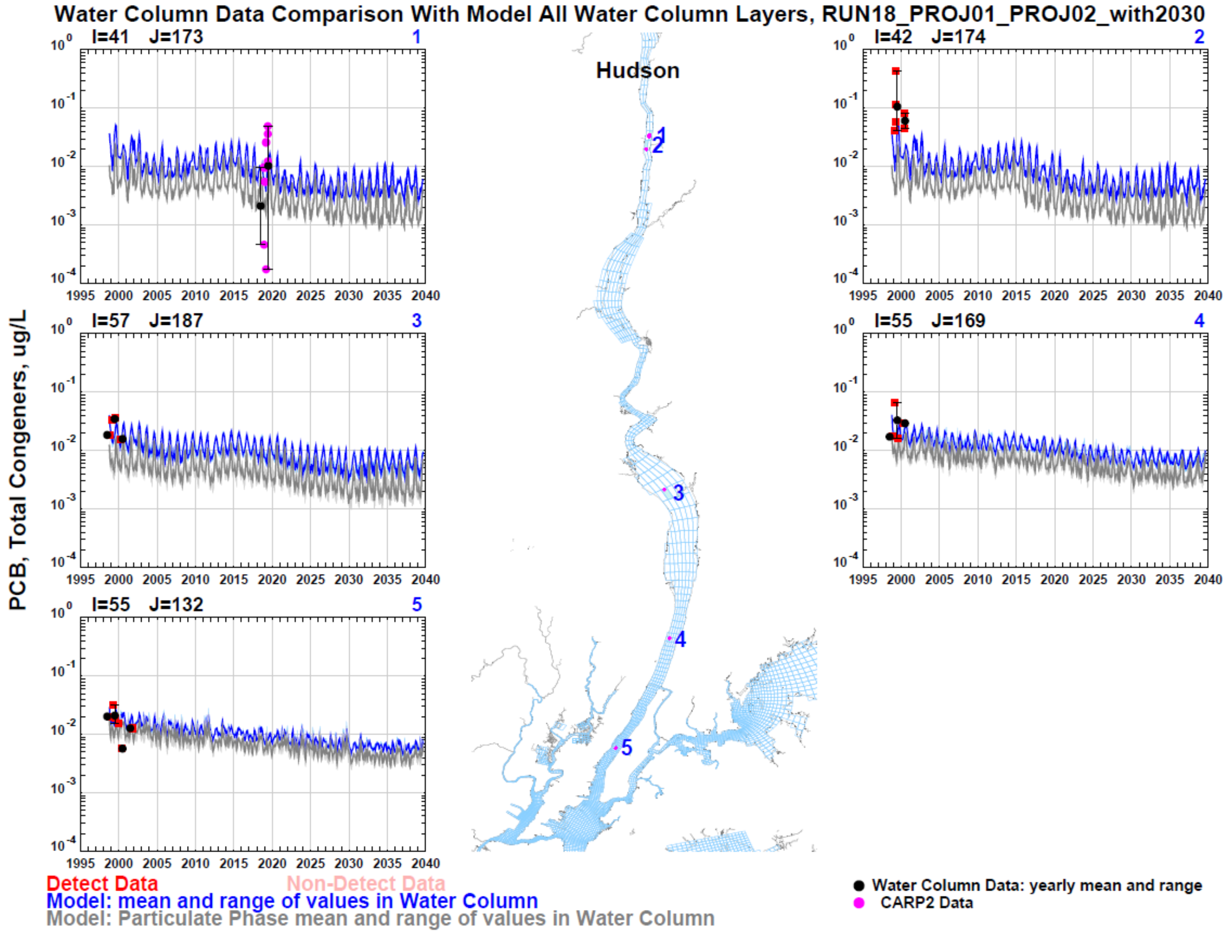


Figure 3- 9. Total PCB water column concentrations (estimated as twice the summation of four homologs) model results for the calibration period and for two future projection scenarios for five locations in the Hudson River. The model results (blue lines and shades) decline, with a response to post-dredging loadings from the Upper Hudson River starting in January 2016, apparent near Poughkeepsie (locations 1 and 2). For reference, model results for particulate phase concentrations of total PCB are shown in gray. Simulated cleanups of the Lower Passaic and Hackensack Rivers and Newark Bay Study Area starting in October 2030 are not discernible at these locations.

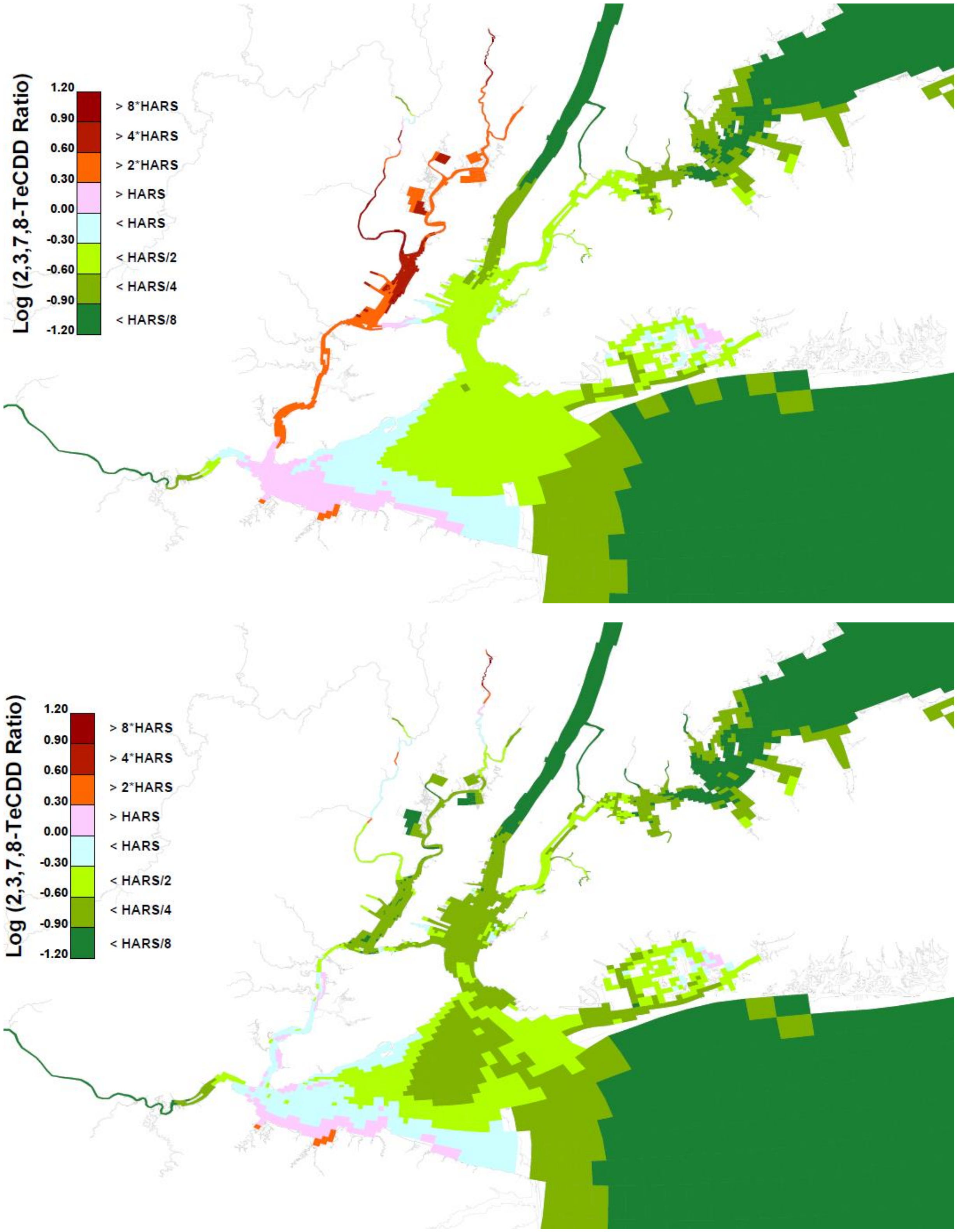


Figure 3- 10. CARP future projection scenarios HARS suitability ratio results for 2,3,7,8-TCDD using the CARP 2 ninetieth percentile BSAFs for 2,3,7,8-TCDD and a HARS criterion of 1 ppt in a worm. The top panel shows 2022-23 results. The bottom panel shows 2038-39 results after the October 2030 simulated remediation of the Lower Passaic and Hackensack Rivers and the Newark Bay Study Area. With very few exceptions (pink/red) the simulated remediation efforts attain HARS suitability (blue/green).

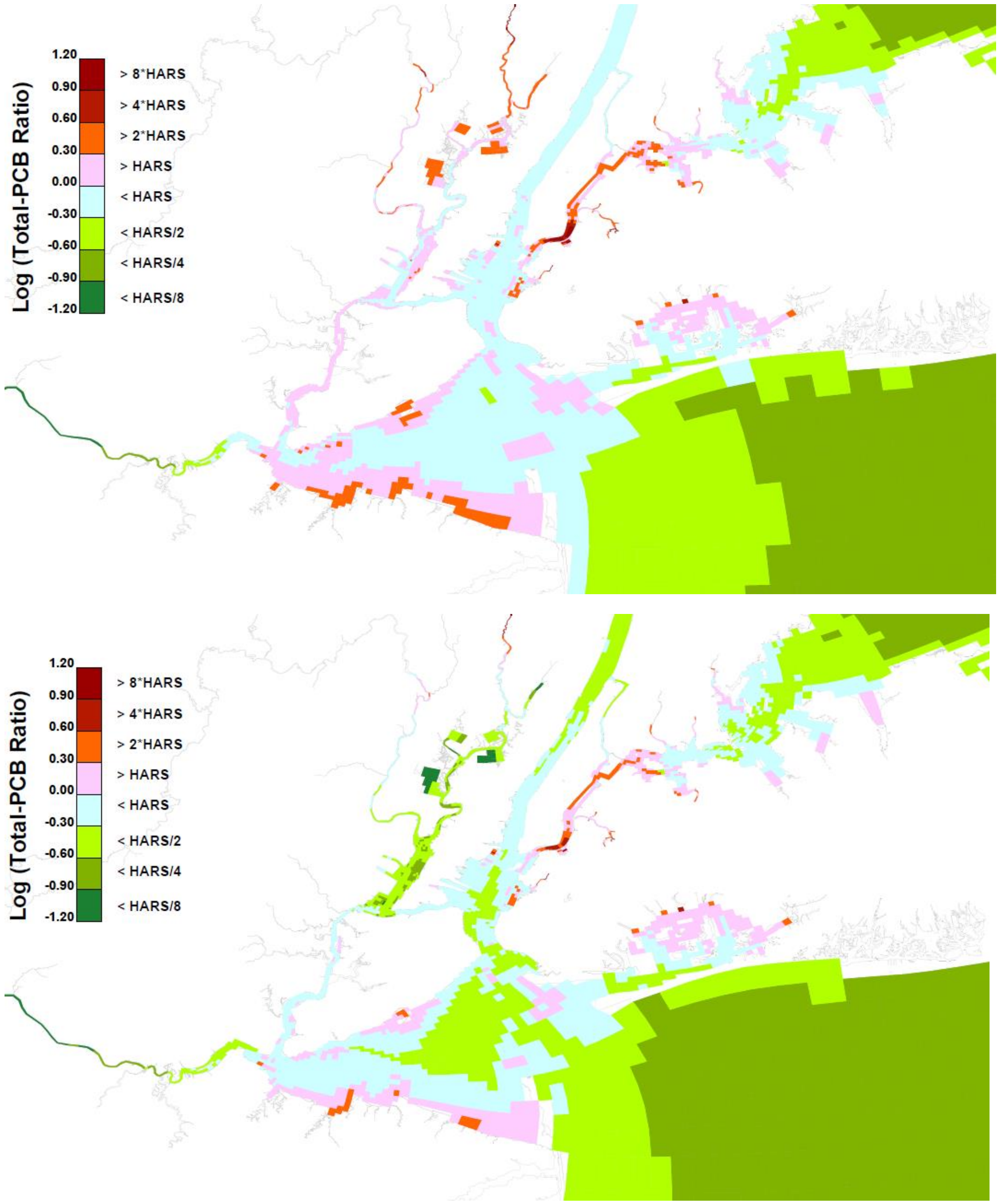
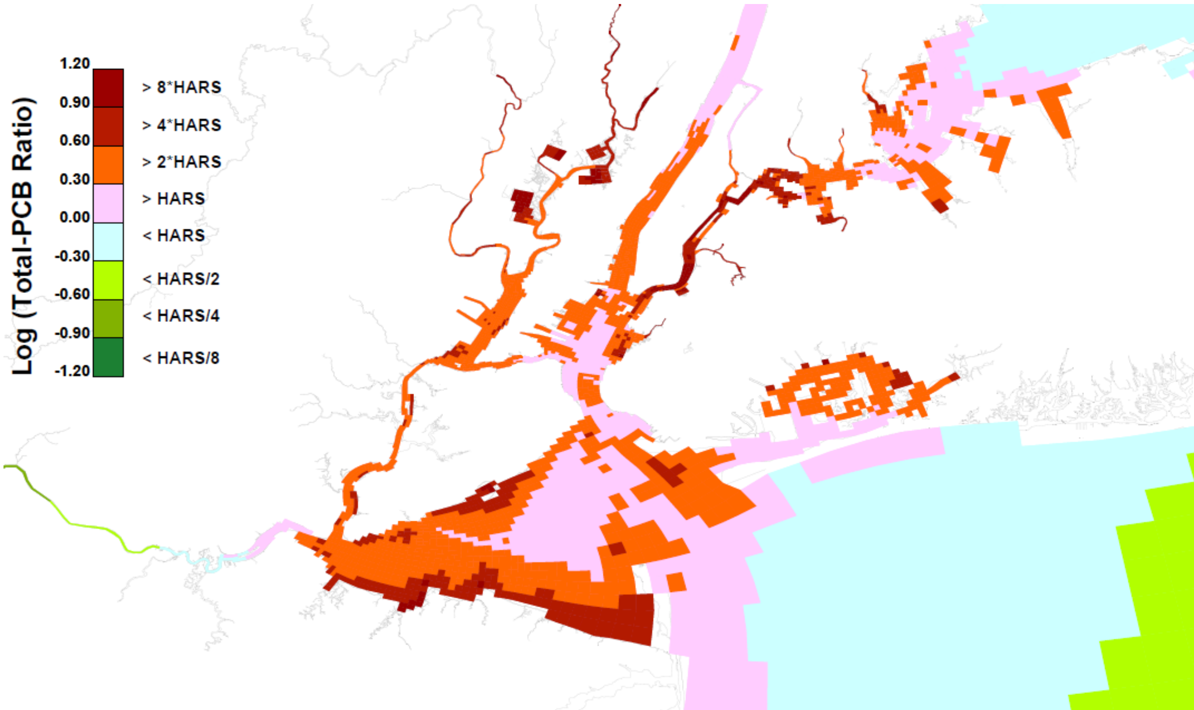


Figure 3- 11. CARP future projection scenarios HARS suitability ratio results for total PCB as twice the sum of four homologs using CARP 2 ninetieth percentile BSAFs for PCB homologs with a factor of two multiplier and a HARS criterion of 113 ppb in a worm. The top map shows 2022-23 results. The bottom map shows 2038-39 results after the October 2030 simulated remediation of the Lower Passaic and Hackensack Rivers and the Newark Bay Study Area. Simulated remediation efforts attain HARS suitability in much of the Harbor (blue/green) with some portions of the Harbor remaining in non-attainment (pink/red).



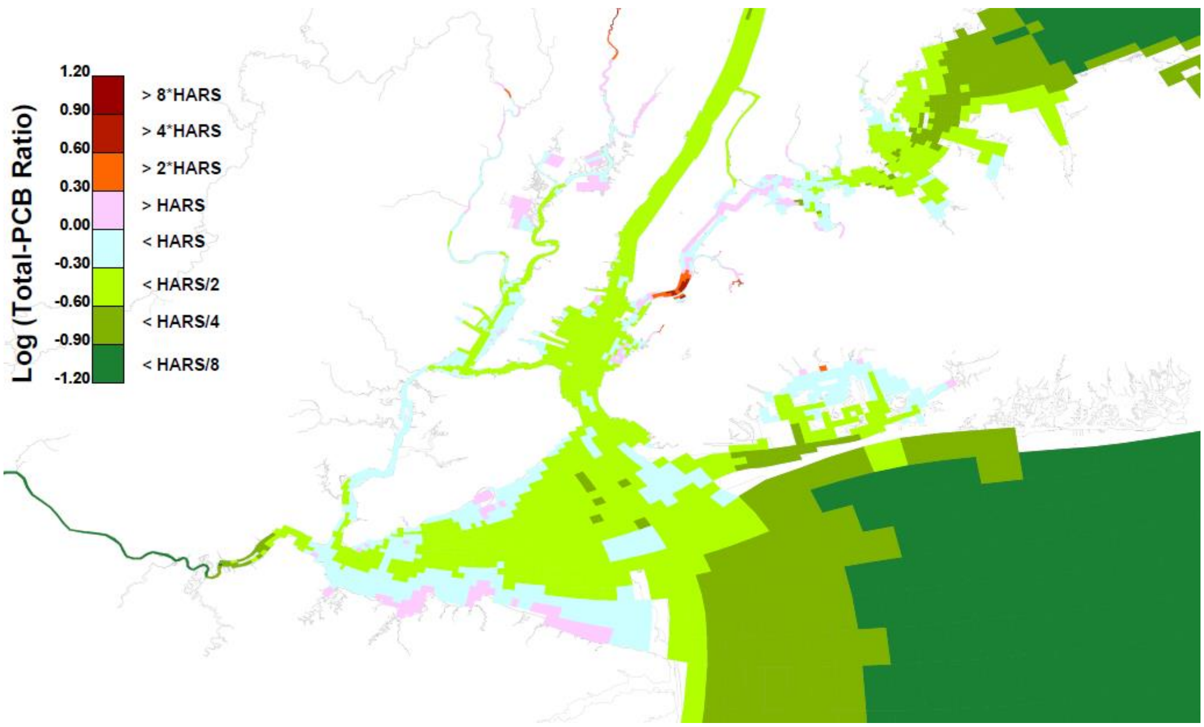


Figure 3- 12. CARP future projection scenarios HARS suitability ratio results for 2022-23 for total PCB as twice the sum of four homologs using CARP 1 and CARP 2 homolog BSAFs and a HARS criterion of 113 ppb in a worm. The top map shows results largely in non-attainment (pink/red) using the CARP 1 field-derived homolog BSAFs. The bottom map shows results largely in attainment (blue/green) using the CARP 2 fiftieth percentile laboratory homolog BSAFs with a factor of two multiplier. The selection of PCB homolog BSAFs is of critical importance for determining HARS suitability.

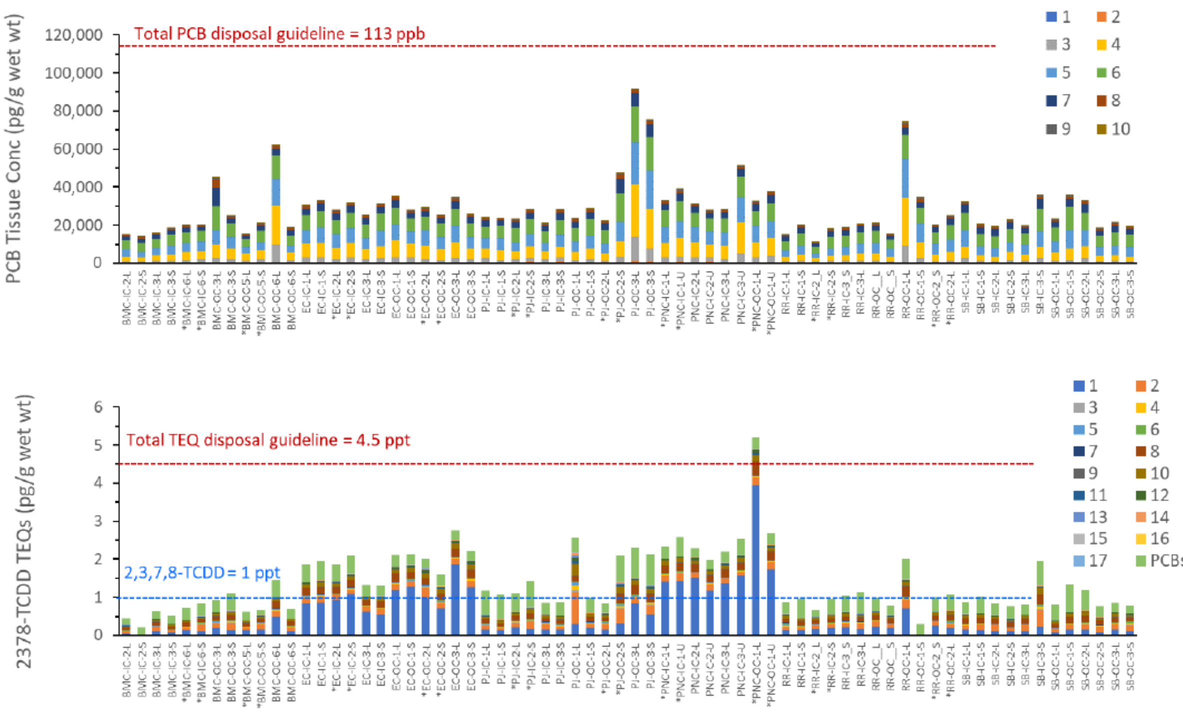


Figure 3- 13. CARP 2 measured PCB homologs and dioxin congers concentrations in worm tissue after 28-day exposures to Harbor sediments. PCB results are shown as measured and have not yet been doubled as established within the region for comparisons to HARS disposal guidelines. The measured tissue concentrations for PCBs well below 113 ppb are consistent with the 2022-23 HARS suitability model results using multiplied fiftieth percentile CARP 2 BSAFs shown in the bottom panel of Figure 3-12. The measured tissue concentrations for 2,3,7,8-TCDD above 1 ppt (bottom-most blue portion of plotted bars) are consistent with 2022-2023 HARS suitability model results regardless of BSAF applied (2022-23 diagrams in Appendices 3 through 6). In addition to 2,3,7,8-TCDD, measured TEQ values for other dioxin and furan congeners and PCB congeners exhibiting dioxin-like toxicity are shown as compared to the 4.5 ppt TEQ HARS guideline and show non-attainment only at a single location in Port Newark Channel. At that location, the measured non-attainment is driven by 2,3,7,8-TCDD (bottom-most blue portion of plotted bar). 2,3,7,8-TCDD TEQ values are measured tissue contaminant concentrations for seventeen dioxin/furan congeners and selected PCB congeners scaled by equivalency fractions of the toxicity of 2,3,7,8-TCDD. The canonical 2,3,7,8-TCDD toxicity equivalency fractions or factors for the congeners as developed by the World Health Organization in 2005 can be obtained from sources such as Van den Berg et al., 2006.

APPENDICES

LIST OF APPENDICES (Appendices are provided separately.)

APPENDIX 1 – Future Projection Scenarios Contaminant Concentrations Time Series, Sediment Bed

APPENDIX 2 – Future Projection Scenarios Contaminant Concentrations Time Series, Water Column

APPENDIX 3 – Future Projection Scenarios HARS Suitability Ratio Maps, Dredged Material Testing Program BSAFs

APPENDIX 4 – Future Projection Scenarios HARS Suitability Ratio Maps, CARP 1 BSAFs

APPENDIX 5 – Future Projection Scenarios HARS Suitability Ratio Maps, 50^{th} % CARP 2 BSAFs

APPENDIX 6 – Future Projection Scenarios HARS Suitability Ratio Maps, 90^{th} % CARP 2 BSAFs