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## Capstone Projects

### Title

Understanding Mercury Contamination: Management and Testing Recommendations for the Disposal of Dredged Sediments at the LA-3 Ocean Dredged Material Disposal Site

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# Understanding Mercury Contamination: Management and Testing Recommendations for the Disposal of Dredged Sediments at the LA-3 Ocean Dredged Material Disposal Site

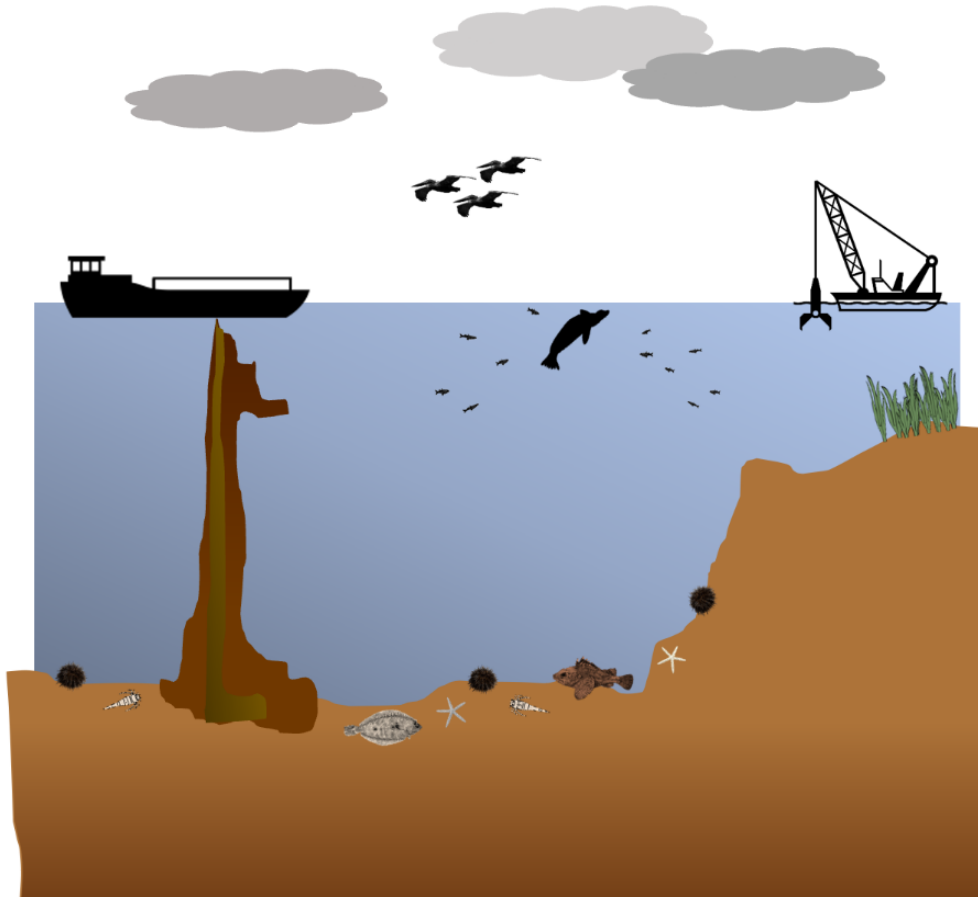


Image adapted from the Inland Testing Manual prepared by the USEPA and USACE, created by the Author

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Capstone Project Report - June, 2022

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## **Abbreviations**

<b>ATLs</b>	Advisory Tissue Levels
<b>CAD</b>	Confined Aquatic Disposal
<b>CCC</b>	California Coastal Commission
<b>CEQA</b>	California Environmental Quality Act
<b>CSTF</b>	Contaminated Sediments Task Force
<b>CWA</b>	Clean Water Act
<b>cy</b>	Cubic yards
<b>CZMA</b>	Coastal Zone Management Act
<b>DMHg</b>	Dimethylmercury
<b>DMMP</b>	Dredge Material Management Plan
<b>DOC</b>	Dissolved organic carbon
<b>DOM</b>	Dissolved organic matter
<b>EIS</b>	Environmental Impact Statement
<b>EPA</b>	U.S. Environmental Protection Agency
<b>ESA</b>	Endangered Species Act
<b>Hg</b>	Mercury
<b>Hg(0)</b>	Elemental mercury
<b>Hg(II)</b>	Divalent mercury
<b>IRB</b>	Iron-reducing bacteria
<b>LC-50</b>	Lethal Concentration 50
<b>London Convention</b>	Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter
<b>LTMS</b>	Long-Term Management Strategy

<b>m</b>	Meters
<b>mg/kg</b>	Milligrams per kilogram
<b>MMHg</b>	Monomethylmercury
<b>MPRSA</b>	Marine Protection, Research and Sanctuaries Act
<b>MSA</b>	Magnuson-Stevens Fisheries Conservation and Management Act
<b>NEPA</b>	National Environmental Policy Act
<b>NMFS</b>	National Marine Fisheries Service
<b>nmi</b>	Nautical mile
<b>NOAA</b>	National Oceanic and Atmospheric Administration
<b>ODMDS</b>	Ocean Dredged Material Disposal Site(s)
<b>OEHHA</b>	California Environmental Protection Agency Office of Environmental Health Hazard Assessment
<b>OTM</b>	Evaluation of Dredged Material Proposed for Ocean Disposal Ocean Testing Manual
<b>PCBs</b>	Polychlorinated Biphenyls
<b>POC</b>	Particulate organic carbon
<b>POM</b>	Particulate organic matter
<b>RGP 54</b>	Regional General Permit 54
<b>RWQCB</b>	Regional Water Quality Control Board
<b>S</b>	Sulfur
<b>SC-DMMT</b>	Southern California Dredged Material Management Team
<b>SCCWRP</b>	Southern California Coastal Water Research Project
<b>SMMP</b>	Site Management and Monitoring Plan
<b>SQG</b>	Sediment Quality Guidelines
<b>SRB</b>	Sulfate-reducing bacteria
<b>TBP</b>	Theoretical Bioaccumulation Potential

<b>TMDL</b>	Total Maximum Daily Load
<b>USACE</b>	U.S. Army Corps of Engineers
<b>WDR</b>	Water discharge requirements



## **Executive Summary**

Mercury (Hg), a neurotoxicant released primarily by anthropogenic activity, is present in all the world's oceans, estuaries, and freshwater bodies.<sup>1</sup> In addition to its toxicity to marine biota, Hg bioaccumulates within fish and other seafoods, presenting a threat to human health since fish remain important sources of protein for people across the world.<sup>1</sup> Despite improvements in Hg pollution control, levels in commonly consumed marine fish such as bluefin tuna often exceed human health guidelines causing recommendations to limit fish consumption.<sup>1</sup> Organic forms of Hg, such as monomethylmercury (MMHg), are more toxic than other forms and are the main causes of concern for human and ecosystem health. Various forms of Hg can transform into MMHg overtime and in certain environments. Elemental mercury (Hg(0)) can transform into different chemical species before becoming MMHg while divalent mercury (Hg(II)) can transform into MMHg through biotic methylation in the water column and sediments under specific chemical and physical conditions.<sup>2</sup>

The U.S. Environmental Protection Agency (EPA) manages approximately 98 ocean dredged material disposal sites (ODMDS) around the country's federal waters. Disposal sites are used for the disposal of nontoxic sediments that are routinely removed to maintain navigational depths in ports, harbors, and marinas, as well as to support national maritime commerce, commercial fisheries, and recreation.<sup>3</sup> The U.S. Army Corps of Engineers (USACE) is planning to dredge federal channel segments in Newport Bay in Newport Beach, California. Based on sediment samples collected and analyzed for ocean disposal testing, the USACE project sediments were found to be high in Hg contamination.<sup>4</sup> However, despite the high Hg levels, toxicity tests indicated suitability for ocean disposal at EPA's LA-3 ODMDS located offshore of Newport Bay.<sup>4</sup> The current Hg levels at the LA-3 disposal site are low to non-detect, and the effects of disposing of sediments loaded with Hg from the Federal channel in Newport Bay are unknown.<sup>5</sup> To address this issue, a literature review of Hg biogeochemical cycling and Hg-methylation was conducted to assist in the understanding of Hg speciation and transport. A policy review was also completed to assess the policies relevant to sediment dredging in California and ocean dumping in federal waters. Related to the policies in place, manuals utilized by USACE and EPA for testing and analysis purposes were reviewed to determine additional sediment and water column tests to minimize the potential risk of Hg contamination in the marine environment. Through the compilation of information, testing and analysis recommendations in addition to current testing were made for the dredge and disposal site locations.

## **Policy and Literature Review**

### ***Part I - EPA Ocean Disposal Sites, Relevant Policies, and Management***

The EPA manages 98 ocean disposal sites in U.S. federal waters as of March 2021.<sup>3</sup> The EPA is currently split into ten regional offices to address health and environmental concerns in specific

areas across the country. Of these ten regions, seven have specific management and monitoring roles and responsibilities for ocean dumping.<sup>6</sup>

The management of disposal sites involves establishing requirements, controls, and conditions for disposal, as well as the regulation of the amount and characteristics of the material being disposed of.<sup>7</sup> Site monitoring is conducted to assess effectiveness of the pre-disposal sediment testing program, compliance with disposal operations, and any potential adverse impacts to human or ecosystem health from disposal operations.<sup>7</sup> ODMDS are designated specifically for the disposal of suitable, uncontaminated sediments from maintenance and new construction dredging projects to maintain navigational depths in ports, harbors, and marinas for the movement of commercial, military, and private vessels. *Figure 1* details the locations of the ODMDS around the country's federal waters. Other materials that are disposed of at separate sites include vessels, marine mammal carcasses, fish wastes, man-made ice piers in Antarctica, and human remains.<sup>8</sup> All of these forms of dumping require a permit under the Marine Protection, Research and Sanctuaries Act (MPRSA; 33 USC 1401 *et seq.*).



*Figure 1:* The red dots signify the ODMDS around the U.S.'s federal waters that are currently in use for the disposal of non-toxic sediments. These dots do not represent the actual surface area of the sites.<sup>9</sup>

### *Relevant International Treaties*

Before laws were enacted to regulate ocean dumping and disposal, various unregulated wastes such as industrial, chemical, radioactive, and sewage wastes were disposed of into the ocean at unknown volumes.<sup>10</sup> As a result of increased concern surrounding the anthropogenic impacts on the marine environment during the 1950s-1970s, the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter of 1972 (London Convention; 26 UST 2403: TIAS 8165) was developed.<sup>11</sup> The London Convention is the principal international agreement governing ocean disposal and was ratified by the United States in 1974.<sup>12</sup> The criteria for ocean disposal that was incorporated into MPRSA was adapted from the information outlined through the London Convention, so material considered acceptable through MPRSA is also acceptable under the London Convention.<sup>12</sup>

The Contracting Parties to the London Convention sought to update and replace the original London Convention agreement to be more protective of the marine environment.<sup>11</sup> As such, the London Protocol was developed in 1996 and entered into force in 2006.<sup>11</sup> All ocean dumping is prohibited through this protocol except for specified items on the “reverse list”, which includes dredged material.<sup>13</sup> The United States signed the London Protocol in 1998, but has not ratified the treaty and is not currently a Contracting Party.<sup>11</sup>

Seven years later, the Minamata Convention on Mercury (TIAS 17-816) was adopted in 2013 and entered into force in 2017.<sup>14</sup> The United States joined the Minamata Convention in 2013.<sup>14</sup> The Convention is named after the city of Minamata in Japan, which experienced a chronic exposure to Hg through industrial wastewater discharged into the Bay.<sup>15</sup> The Convention was developed to protect human health and the environment from the anthropogenic emissions and release of Hg.<sup>14</sup> National governments prepare Minamata Initial Assessments to assist in improvements to national decision-making efforts for implementation of the Parties’ obligations.<sup>14</sup>

### *Relevant Federal Policies*

The MPRSA was enacted in 1972 to regulate the “dumping of all types of materials into ocean waters and to prevent or strictly limit the dumping into ocean waters of any material which would adversely affect human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities.”<sup>16</sup> The MPRSA authorizes the EPA to establish specific criteria for characterizing the material and evaluating the suitability (i.e., non-toxic) of material for ocean disposal. For dredged material, the USACE is responsible for issuing the ocean disposal permits after the EPA has agreed on the suitability of the sediments for ocean disposal and has submitted a written ocean disposal concurrence.<sup>8</sup> The EPA must agree that the sediments meet ocean dumping suitability and that there are no other alternatives available such as beneficial reuse before USACE can issue a permit.<sup>17</sup> Based on the “Water Quality Control Plan for Inland Surface Waters, Enclosed Bays, and Estuaries of California—Tribal and

Subsistence Fishing Beneficial Uses and Mercury Provisions” from the California State Water Resources Control Board referencing federal authorities:

The permitting authority has discretion under existing law to require dischargers to implement total [Hg] monitoring and procedures to control the disturbance and discharge of [Hg]-contaminated material during dredging and disposal of dredged material, and should consider requiring such measures in areas with elevated [Hg] concentrations when adopting, re-issuing, or modifying a water quality certification, [water discharge requirements (WDRs)], or waiver of WDRs.<sup>18</sup>

The EPA and USACE also jointly develop the site management and monitoring plans (SMMP) for each ODMDS.<sup>17</sup> According to MPRSA Section 102(c)(3), the content and development of a SMMP must include:

- (A) a baseline assessment of conditions at the site;
- (B) a program for monitoring the site;
- (C) special management conditions or practices to be implemented at each site that are necessary for protection of the environment;
- (D) consideration of the quantity of the material to be disposed of at the site, and the presence, nature, and bioavailability of the contaminants in the material;
- (E) consideration of the anticipated use of the site over the long term, including the anticipated closure date for the site, if applicable, and any need for management of the site after the closure of the site; and
- (F) a schedule for review and revision of the plan (which shall not be reviewed and revised less frequently than 10 years after adoption of the plan, and every 10 years thereafter).<sup>19</sup>

The Ocean Dumping Management Program through the EPA conducts oceanographic surveys at the disposal sites to:

- (1) evaluate the physical, chemical and biological conditions of the site;
- (2) confirm site conditions are consistent with the pre-disposal testing chemistry of sediments approved for ocean disposal; and
- (3) determine if any management actions may be needed.<sup>20</sup>

The National Environmental Policy Act (NEPA; 42 USC 4321 *et seq.*) was enacted in 1969 to establish a regulatory framework to ensure that environmental consequences of a federal action are incorporated into an agency’s decision-making process.<sup>12</sup> NEPA requires federal agencies to identify and evaluate any and all environmental impacts of their proposed action and consider alternatives to the proposed action through the development of an environmental impact statement (EIS).<sup>21</sup> This evaluation must be made available to the public for comments before any final actions can take place.<sup>21</sup> EPA is the lead action agency for designating new ODMDS and is

responsible for incorporating the NEPA elements into the decision process.<sup>12</sup> Each new designated ODMDS must go through the NEPA process in its entirety.

The Coastal Zone Management Act (CZMA; 16 USC 1456 *et seq.*) was enacted in 1972 and requires any federal agency conducting or in support of activities that directly affect the coast to consider and take into account the state Coastal Zone Management Program requirements.<sup>12</sup> Any federal activity is subject to the CZMA requirement for consistency if it could potentially affect any “natural resources, land uses, or water uses in the coastal zone” according to the Coastal Zone Reauthorization Amendments of 1990.<sup>12</sup> The California Coastal Commission (CCC) reviews permit applications for dredging projects and federal determinations of consistency for federal dredging projects, and checks the projects for consistency with the California Coastal Zone Management Plan.<sup>12</sup> When designating the LA-3 ODMDS, the EPA prepared a coastal consistency determination and CCC concurred on EPA’s determination that the designation and use of the LA-3 site would not result in significant adverse impacts to the marine environment.<sup>12</sup>

The Clean Water Act of 1972 (CWA; 33 USC 1251 *et seq.*) was passed to “restore and maintain the chemical, physical, and biological integrity of the nation’s waters.”<sup>12</sup> The CWA prohibits discharge of any pollutant into navigable waters, unless certain standards are followed. Pollutant is defined very broadly under the CWA, but “dredged spoil” is included in the possible examples.<sup>22</sup> Section 404 of the CWA establishes a program to regulate the discharge of dredge material into navigable waters of the United States.<sup>12</sup> The MPRSA and CWA overlap in authority within the area between the coast, also known as the baseline, and the 3-mile limit, the extent of State waters.<sup>12</sup> Within the 3-mile limit, or state waters, dredged material disposed as waste is subject to the MPRSA, while dredged material discharged as fill is subject to the CWA.<sup>12</sup> If dredged sediments can be used for beneficial reuse purposes, such as beach nourishment, the CWA takes priority over the MPRSA (for example, used as a requirement to consider alternatives to minimize ocean disposal).<sup>12</sup> All disposal of dredged sediments at the LA-3 ODMDS would fall under the MPRSA since the LA-3 site is in federal waters at 5.4 nmi offshore.<sup>12</sup>

Section 303(d) of the CWA outlines the requirements if a waterbody does not, or is not expected to meet, water quality standards.<sup>23</sup> When a water body is listed on the 303(d) list, a Total Maximum Daily Load (TMDL) study must be conducted to assess why the water quality standard is exceeded, and how it can be reduced in the future for specific pollutants.<sup>23</sup> According to a 2002 EPA TMDL report for Newport Bay, the Rhine Channel was listed with Hg as a toxic pollutant of concern along with other metals and organic compounds.<sup>4</sup> San Diego Creek, which feeds into Newport Bay, also exceeds water quality standards for some metals such as cadmium, copper, lead, and organic compounds such as DDTs and PCBs.<sup>4</sup> The Upper and Lower portions of Newport Bay also have a series of metals and organic compound pollutants listed.<sup>4</sup> Under Section 304(a) of the CWA, the EPA must “periodically revise criteria for water quality to

accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects of pollutants on human health.”<sup>24</sup> In 2001, the EPA added water quality criterion thresholds specifically for MMHg levels in fish and shellfish to protect human health and develop standards.<sup>24</sup> EPA has programmatically determined that dredging and disposal at LA-3 can result in a net removal of potential pollutants but also recognizes the need for best management practices (for example, silt curtains) to minimize temporary increases in turbidity during dredging operations.<sup>25</sup>

For the specific protection of wildlife and fisheries resources, the Endangered Species Act of 1973 (ESA; 16 USC 1531 *et seq.*) and the Magnuson-Stevens Fisheries Conservation and Management Act of 1976 (MSA; 16 USC 1801 *et seq.*) are relevant to dredging projects and ocean dumping of dredged material. The ESA “protects threatened and endangered species by prohibiting federal actions that would jeopardize the continued existence of such species or that would result in the destruction or adverse modification of any critical habitat or such species.”<sup>12</sup> Section 7 of the ESA requires formal consultation with the U.S. Fish and Wildlife and the National Marine Fisheries Service (NMFS) before projects can be carried out to confirm that there will be no adverse affect on threatened or endangered species.<sup>12</sup> The MSA was established to authorize NMFS with “identifying, conserving, and enhancing essential fish habitat for those species regulated under a fisheries management plan.”<sup>12</sup> Federal agencies must consult with NMFS to confirm that a proposed agency action will not adversely affect essential fish habitat.<sup>12</sup> NMFS also provides conservation recommendations if adverse impacts are identified, which must be addressed by the agency in writing within 30 days.<sup>12</sup> Consultation with NMFS was required for the designation of the LA-3 ODMDS.<sup>12</sup> Formal consultation was conducted by the EPA as part of the site designation process for the LA-3 ODMDS, including Section 7 of the ESA and essential fish habitat.<sup>12</sup>

Additional federal policies that are relevant to dredging projects and ocean disposal that will not be discussed in detail include, but are not limited to, the Water Resources Development Act of 2020, Clean Air Act of 1970 (42 USC 1451 *et seq.*), Fish and Wildlife Coordination Act of 1958 (16 USC 661 *et seq.*), the Rivers and Harbors Act of 1899 (33 USC 401 *et seq.*), and the National Historic Preservation Act of 1966 (16 USC 470 *et seq.*).

#### *Relevant California State and Local Policies*

The California Environmental Quality Act of 1986 (CEQA; PRC 21000 *et seq.*) establishes similar requirements to those of NEPA except it applies to California state and local government agencies instead of federal agencies.<sup>12</sup> CEQA requires agencies to take into consideration the environmental impacts of a proposed action and provide alternatives, reduce the environmental impacts to the greatest extent possible, and prepare an environmental impact report to inform the government and the public.<sup>28</sup> Projects such as beach nourishment and Confined Aquatic Disposal (CAD) are subject to CEQA guidelines.

The California Coastal Act of 1976 (PRC 30000 *et seq.*) establishes the Coastal Zone Management Plan relevant to the CZMA summary in the federal policies section. All federal agency actions that may impact the coastal zone must follow the Coastal Zone Management Plan to the greatest extent possible and provide a coastal consistency determination with approval from the CCC.<sup>12</sup> Dredging projects are subject to both the CEQA and the California Coastal Act and must comply with the requirements listed.

In California there are regional management teams to assess dredging, disposal, and management of contaminated sediments in the state. The Southern California Dredged Material Management Team (SC-DMMT) covers Orange, Los Angeles, and Ventura Counties and includes members from USACE, EPA, NMFS, CCC, Regional Water Quality Control Board (RWQCB), and California Department of Fish and Wildlife.<sup>4</sup> This group is responsible for reviewing sampling plans, analyzing results, and making suitability determinations for Southern California dredging projects using national and regional sediment testing guidance.<sup>4</sup> This interagency review, testing, and sediment management program was originally developed by the Contaminated Sediments Task Force (CSTF).<sup>4</sup> CSTF was developed in 1998 and includes the same agencies as the currently operating SC-DMMT with additional members from several ports, cities, and organizations.<sup>4</sup> The original goal of the CSTF was to develop a Long-Term Management Strategy (LTMS) that details the “characterization, management, and beneficial reuse of contaminated sediments.”<sup>4</sup> The current SC-DMMT has continued to evaluate dredging projects in a coordinated manner with Federal and State agencies in order to facilitate the permitting process for the more routine projects as well as provide an interagency forum for planning and execution of more complex projects.<sup>29</sup> The USACE developed a similar regional dredge material management plan (DMMP) that focuses on Federal Channels for clean and contaminated sediments and different management options.<sup>4</sup> USACE dredging is not conducted with permits but are subject to and must adhere to the same requirements including sediment testing and alternative analysis as permitted dredged projects.<sup>25</sup>

At a more local level, the City of Newport Beach in California issues the Regional General Permit 54 (RGP 54) for small dredging and dock maintenance projects outside of the federal government’s responsibility.<sup>4</sup> These permits must be approved by the USACE, RWQCB, and CCC.<sup>4</sup> The City of Newport Beach reviews and renews the sediment suitability every 5 years to assess if the bay’s sediments are suitable for beach nourishment or ocean disposal.<sup>4</sup>

Under the existing RGP 54, the City and residential/commercial property owners are authorized to dredge to a maximum depth of -10 feet mean lower low water (MLLW), plus 2 feet of overdredge allowance. Individual projects are limited to no more than 8,000 cy, with a harbor-wide annual maximum volume of 75,000 cy for all projects. There are three disposal options currently approved by all agencies, including open ocean disposal, in-harbor beach nourishment, and upland disposal. The City is proposing two new

alternatives in the latest permit renewal (nearshore ocean placement [of sandy sediments] and disposal [of contaminated sediments] within a CAD site).<sup>4</sup>

### *ODMDS Testing Requirements*

Sediments proposed for ocean disposal must first be characterized through physical and chemical analysis, and undergo a series of acute and chronic toxicity bioassays in accordance with national testing guidance - Evaluation of Dredge Material Proposed for Ocean Disposal – Testing Manual (OTM).<sup>26</sup> The OTM has a four-tiered testing approach where three of the four tiers can be seen in *Figure 2*. The EPA and USACE coordinate on the sediment sampling and analysis plan and jointly review the sediment testing data from the dredge site location.<sup>26</sup>

The tiered testing approach uses effects-based testing to ensure that sediments do not pose an environmental or human health risk.<sup>26</sup> The effects-based testing is intended to assess the effects of multiple contaminants on multiple different indicator organisms exposed to elutriates and bulk sediments, taking into account multiple exposure pathways as well as toxicity and bioavailability.<sup>26</sup> The aquatic exposure pathways include short-term exposure through the water column and long-term exposure in the benthic environment.<sup>26</sup> A reference site is an important aspect of the testing program because suitability of the project sediments proposed to be dredged is determined by comparing its test results to those of the reference site sediments.<sup>26</sup> The reference site sediment should be free from any influence of previous disposal operations, but close enough to the site that it is subject to the same biogeochemical influences from the environment.<sup>26</sup>

### *Tier I and II*

The four tiered testing approach starts at Tier I where existing information from previous testing and studies are compiled to assess known sources of pollution.<sup>26</sup> If the existing information is adequate for the suitability determination, no additional testing is required.<sup>26</sup> If the existing information is inadequate to determine suitability then additional testing is required to provide data for Tier II evaluations, including bulk sediment chemistry and physical parameters.<sup>26</sup> Tier II evaluations include comparisons of sediment chemistry concentrations to values in the National Oceanic and Atmospheric Administration's (NOAA) sediment concentration threshold guidance, which are published bulk chemistry values associated with toxicity effects.<sup>26</sup> Tier II evaluations also include calculation of Theoretical Bioaccumulation Potential (TBP) of certain organic chemicals in the tissues of organisms that could be exposed to the sediment.<sup>26</sup> Suitability for ocean disposal cannot be made in Tier II; however, the information from Tier II is used to determine which contaminants may be influencing the more expensive Tier III bioassay and bioaccumulation testing.<sup>26</sup> If existing information is not adequate to determine suitability for ocean disposal, and if the Tier II sediment chemistry is elevated relative to the SQG or if the TBP calculations predict bioaccumulation above the



reference level, then Tier III level testing is required for determining suitability for ocean disposal.<sup>26</sup>

#### *Tier III and IV*

Tier III level testing consists of seven bioassays, including three suspended particulate phase (elutriate) tests, two bulk sediment acute toxicity tests, and two bulk sediment bioaccumulation tests on samples taken from the dredge site.<sup>26</sup> The suspended particulate tests are water column bioassays conducted with three different species at five different concentrations of elutriate.<sup>26</sup> The different species are exposed for 48-96 hours and the LC-50 is calculated.<sup>26</sup> LC-50 is the “exposure concentration of a toxic substance lethal to half of the test animals.”<sup>27</sup> Benthic toxicity bioassays are also required with at least two different species, of an amphipod and a worm, with 10-day exposures to the bulk, bedded sediments.<sup>26</sup> The survivorship of the test or proposed sediments is compared to that of a reference site sediment.<sup>26</sup> Bioaccumulation testing is also required with at least two different species, a clam and a worm, with 28-day exposures to bulk, bedded sediments.<sup>26</sup> The survivorship of the test or proposed sediments is compared to that of a reference site sediment as well.<sup>26</sup> Analysis of the resulting tissue concentrations can then be performed, including comparison of the tissue concentrations in the test or proposed sediments to that of the reference site sediment as well as reference toxicity values.<sup>26</sup> Sediments are determined to be unsuitable and prohibited for ocean disposal if there are failures in any or all of the following tests, including:

- (1) If water column concentrations exceed 1% of any LC-50 or EC-50 after mixing,
- (2) mean mortality in the solid phase toxicity bioassay exceeds reference mortality by more than 10% (20% for amphipods),
- (3) tissue concentrations exceed reference toxicity values, and/or
- (4) tissue concentrations are modeled to exceed relevant thresholds after transfer up the food webs.<sup>26</sup>

If the information in Tier III is inadequate for making a suitability determination or if the project proponent wants to reduce the volume of unsuitable sediments, Tier IV testing may be an option.<sup>26</sup> Tier IV is very case specific and rarely occurs. It may potentially involve, but is not limited to: higher resolution sampling and testing, site-specific risk assessment, field organism tissue studies, steady-state bioaccumulation exposures, and analysis of confounding factors.<sup>26</sup>

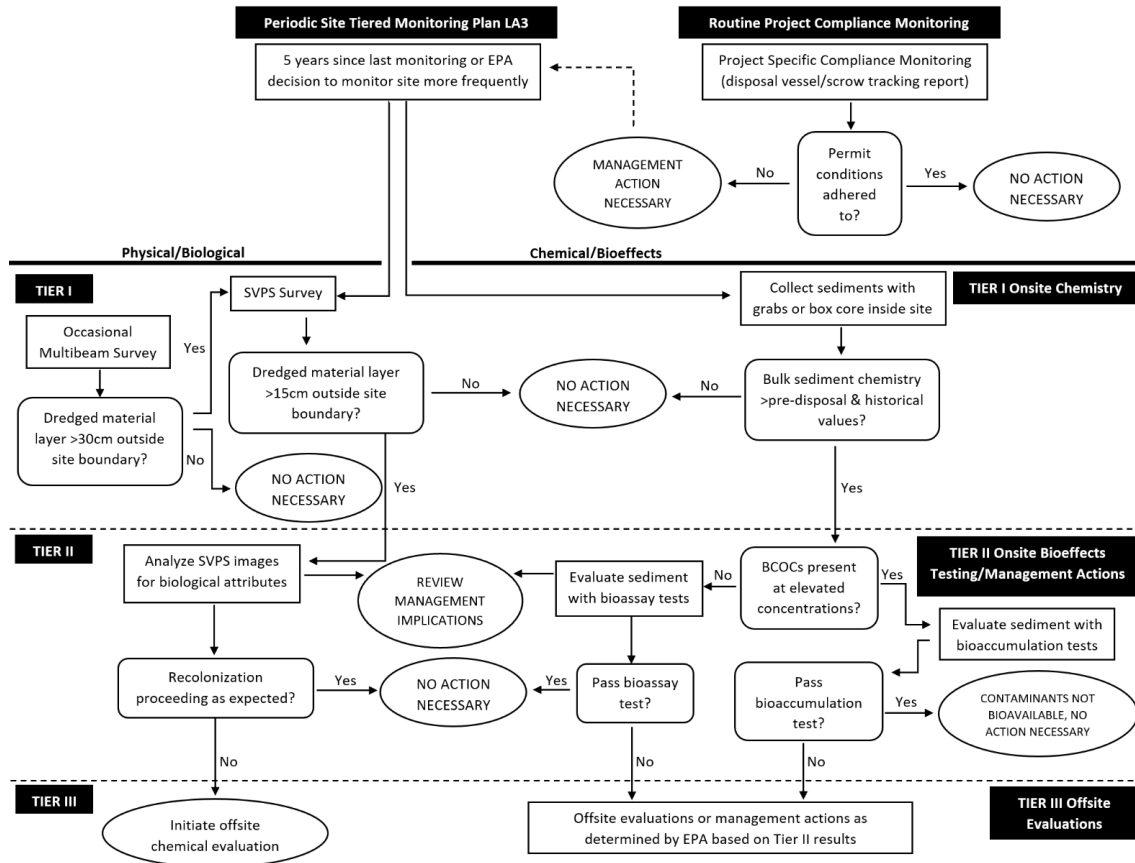


Figure 2: EPA site monitoring scheme to determine necessary steps for ocean sediment disposal for Tier I through III. Abbreviations: SVPS: sediment vertical profiling system, BCOc: bioaccumulative compounds of concern

## Part II - LA-3 Ocean Dredged Material Disposal Site

The LA-3 ODMDS was designated in 2005 as a permanent dump site for uncontaminated dredged sediments, and is monitored and managed by the EPA Region 9 Ocean Dumping Program.<sup>12</sup> It is located approximately 4.5 nautical miles (nmi) off-shore from Newport Bay between Palos Verdes Point and Dana Point.<sup>12</sup> An interim LA-3 site was located around 1.3 nmi northwest from the current LA-3 site and was in use from 1976-2005.<sup>12</sup> It was however not designated as a permanent location and was only temporary.<sup>12</sup> Consistent dredging operations from the greater Los Angeles-Orange County area justified the need for a permanent ODMDS located nearby on a flatter, more even seafloor in order to facilitate site monitoring.<sup>12</sup> The current LA-3 site is in a relatively level, but gently sloping location near the foot of Newport Canyon at around 490 meters in depth.<sup>4</sup> Figure 3 depicts the location of the former and current LA-3 site offshore from Newport Beach, California. Based on results from bathymetric surveys, sediment profile and plan view imaging, and sediment grain size, chemistry, and benthic community sampling of the LA-3 site, all disposed sediments have been properly disposed of within the boundaries.<sup>17</sup> When sediments are initially disposed of, there are minor and localized impacts, but no significant impacts have been observed outside the site boundaries.<sup>17</sup> The previous LA-3

site after decades of dredged sediment disposal is recovering back to the original conditions as well.<sup>17</sup>

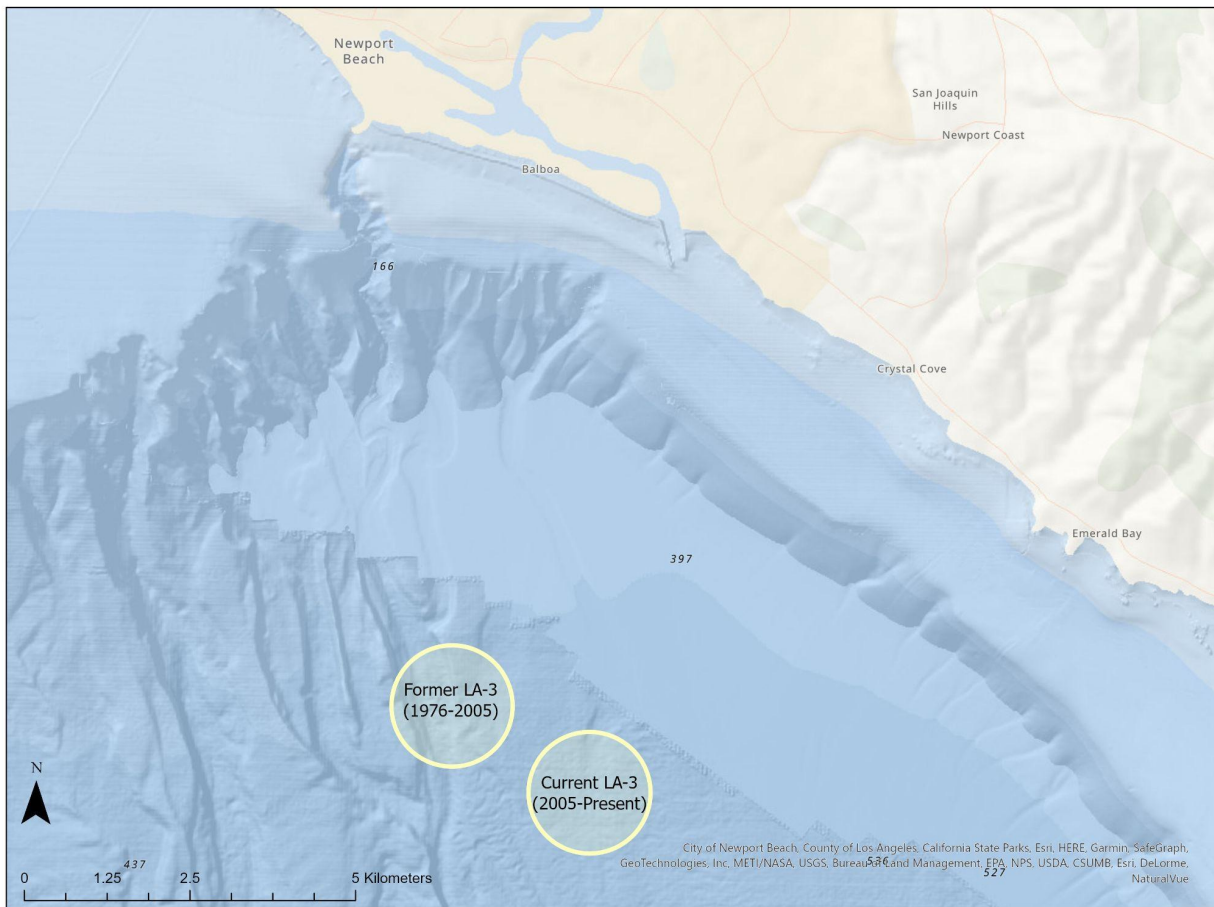


Figure 3: This map shows the former LA-3 site that was in use from 1976-2005, and the current LA-3 site which is currently being used as a permanent ODMDS.

### *The Physical Environment*

The physical environment of the LA-3 site is influenced by the climate, currents, topography, and sediment composition of the area. The climate of southern California is Mediterranean coastal with warm summers and wet, mild winters.<sup>12</sup> Temperatures are relatively stable throughout the year. Predominantly there are westerly winds that carry airborne pollutants inland, but on occasion the easterly Santa Ana winds blow and transport airborne pollutants from inland to offshore which impacts air quality and visibility.<sup>12</sup> The main ocean current that moves through the LA-3 site is the California Current.<sup>12</sup> This is a diffuse and meandering current that flows to the southeast at a speed of 10-15 cm/sec.<sup>12</sup> However, south of Point Conception, the California Current diverges into a gyre known as the Southern California Countercurrent.<sup>12</sup> During spring this countercurrent moves toward the equator instead of toward the North Pole.<sup>12</sup> The speed of the near bottom currents are low and usually less than 6 cm/sec and there is little to no erosion occurring at the LA-3 site.<sup>12</sup> The sediments at the site are mostly sand and gravel with some silt,

which is indicative of dredged material and is different from the surrounding area where silt is predominant.<sup>12</sup>

### *The Biological Environment*

The biological environment of the LA-3 site has been impacted by the disposal of sediments, but the organisms appear to be resilient and recover from increases in sedimentation. Specific benthic invertebrates have increased presence after a major seafloor perturbation, such as sediment disposal, and can be good indicators of resilience and recovery of the ecosystem.<sup>17</sup> The first organisms to appear after perturbation include very small tube-dwelling marine polychaetes.<sup>17</sup> If no other perturbations occur, these polychaetes are followed by “burrowing, head-down deposit feeders”.<sup>17</sup> These stages of benthic invertebrate population presence can be a good indication that there is habitat stability and quality.<sup>17</sup> Plankton populations tend to be patchy usually with increases in population in the early fall and spring.<sup>12</sup> Epibenthic invertebrates are typical for the Southern California Bight and include California heart urchins, fragile sea urchins, and sea stars.<sup>12</sup> Fish species at the depth of the disposal site include longspine thornyhead, dogface witch-eel, Dover sole, and shortspine thornyhead.<sup>12</sup> Seabirds and marine mammals around the disposal site that are typical of the area include Western gulls, sooty shearwater, elegant tern, common dolphin, Pacific white-sided dolphin, bottlenose dolphin, and California sea lion.<sup>12</sup> California brown pelicans and elegant terns have also been observed around the area of the disposal site.<sup>12</sup>

### *Socioeconomic Activity*

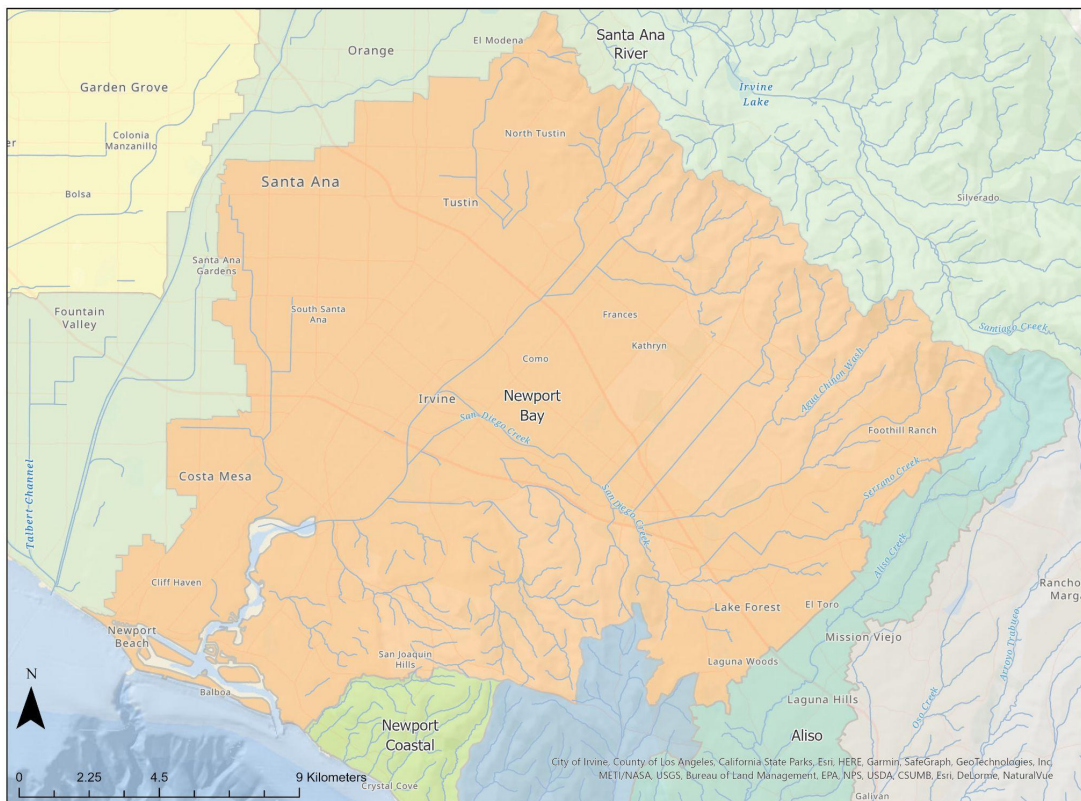
A variety of socioeconomic activities occur in the vicinity of the LA-3 disposal site, including commercial fisheries, a setline dory fishery, container shipping and commercial vessel traffic through multiple ports, military activity, oil and gas lease tracts, as well as recreational activity such as sportfishing, boating, surfing, diving, and swimming.<sup>12</sup> The coast of California and the Channel Islands contain many different types of archaeological, historical, and cultural resources.<sup>12</sup> However, there have been no documented cultural resources within 2.7 nmi of the disposal sites.<sup>12</sup> These aspects of the environment in and around the LA-3 site are important to recognize for a complete understanding of the area and when assessing the possibility of contamination impacts on ecosystem and human health.

## ***Part III - Newport Bay and the Dredging Project***

### *Newport Bay*

Newport Bay is the drainage area to the Pacific Ocean for the Newport Bay/San Diego Creek watershed and is located in Central Orange County, California.<sup>4</sup> The watershed encompasses 154 square miles including portions of major cities such as Santa Ana, Irvine, Costa Mesa, Newport Beach, Tustin, and Laguna Woods.<sup>4</sup> A depiction of the watershed can be seen in *Figure 4*.

Newport Bay has two distinct waterbodies delineated at a narrow channel segment both located with the Coast Highway Bridge. A depiction of Newport Bay can also be seen in *Figure 4*. Most of the maritime commerce, commercial fisheries, and recreational boating occur in Lower Newport Bay, while Upper Newport Bay contains varying levels of development in the southern portion and an ecological reserve, the Upper Newport Bay State Marine Conservation Area, in the northern portion.<sup>4</sup> Due to the agricultural and industrial activity in the watershed, there have been long standing issues of sediment contamination in Newport Bay, including Hg contamination.<sup>4</sup>



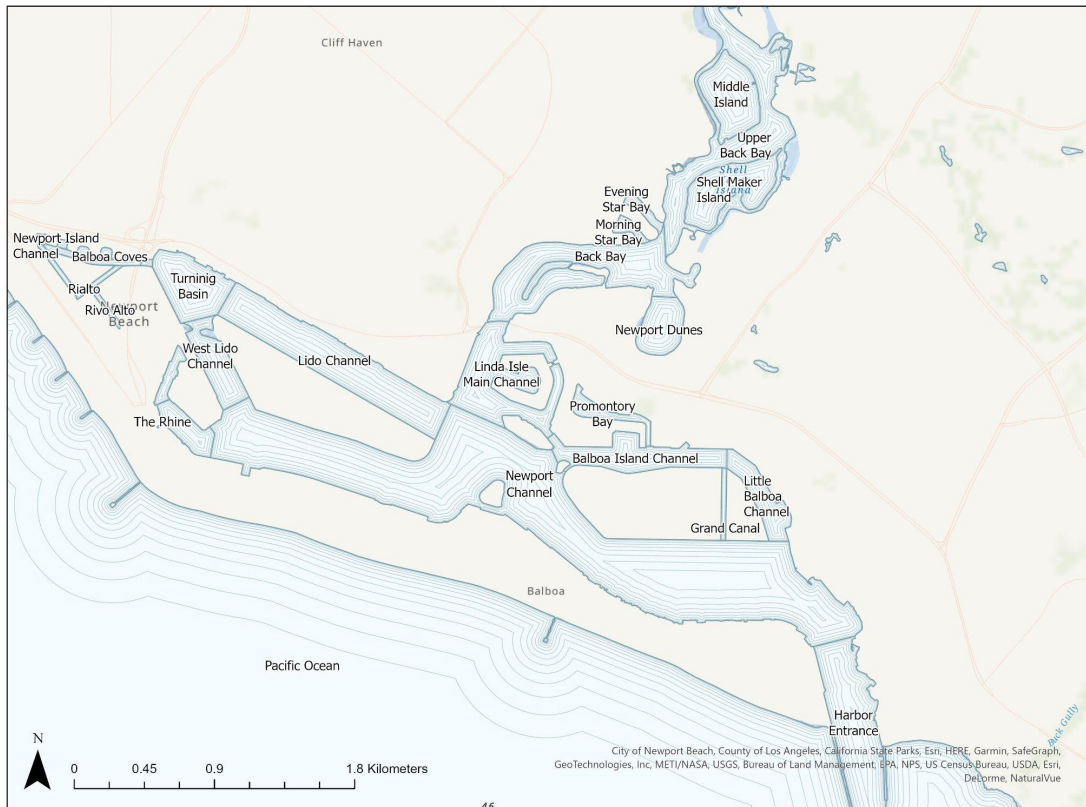


Figure 4: Top image: Newport Bay Watershed, bottom image: Newport Bay with labeled water features.

### *Dredging Project*

The USACE in partnership with the City of Newport Beach is currently planning to dredge eleven Federal channel segments in Newport Bay in the Fall of 2022, where nine of the segments are suitable for open ocean disposal at the EPA’s LA-3 ODMDS.<sup>4</sup> The sites approved for open ocean disposal include the Entrance Channel, Main Channel 1, Main Channel 2, Main Channel 3, Main Channel 4, Main Channel 5, Bay Island Area, Newport Channel 2, and Newport Channel 3.<sup>4</sup> Several sites were deemed unsuitable for ocean disposal based on elevated levels of Hg and/or Polychlorinated Biphenyls (PCBs).<sup>4</sup> The sites that the USACE is planning to dredge are depicted in *Figure 5*.



Figure 5: Federal Channels Maintenance Dredging Sediment Suitability Map, where the blue sections are the nine sites that are suitable for open ocean or nearshore disposal.<sup>4</sup>

Sediments that have been tested and determined to be non-toxic will be dredged and placed into a bottom-dump barge and transported to the LA-3 disposal site.<sup>4</sup> Within the Federal channel segments to be dredged, about 933,700 cubic yards (cy) of sediment was determined to be suitable for ocean disposal by the toxicity bioassays despite the high levels of Hg detected during sediment testing.<sup>4</sup> The current Hg levels at the LA-3 disposal site are low to non-detect, and the effects of disposing of sediments loaded with Hg from the Federal channel in Newport Bay are unknown. Even though all of the samples from the bioassay and bioaccumulation tests passed, the EPA is concerned about the sheer volume of the sediments being disposed of and any adverse impacts caused by the potential loading of MMHg. The EPA concurred with the USACE in 2019, that sediments with Hg up to 1.5 milligrams per kilogram (mg/kg), above the NOAA ER-M screening level, would be suitable for ocean disposal if the City of Newport Beach met the following conditions:

- (1) Develop a long-term Sediment Management Plan (SMP) to address dredged material determined to be unsuitable for open ocean disposal (Hg > 1.5 mg/kg)
- (2) Contribute partial funding towards USEPA monitoring at the LA-3 Ocean Dredged Material Disposal Site (ODMDS) with respect to potential bioaccumulation effects resulting from Hg disposal.<sup>4</sup>

Several disposal projects with varying levels of sediment have occurred each year since the LA-3 ODMDS was designated in 2005. This most recent dredging project could be the largest with contaminant-loading potential that the site has received since designation in 2005.

#### ***Part IV - Mercury Contamination***

##### *The Mercury Cycle*

Hg occurs naturally in the environment, but human-induced pollution through various activities has greatly increased Hg levels cycling in the environment. Hg has many different chemical forms that depend on oxidation-reduction conditions.<sup>30</sup> Each form has a varying impact on the surrounding environment.<sup>30</sup> Hg is typically found in four main species in the marine environment: Hg(0), Hg(II), MMHg and dimethylmercury (DMHg) listed in order from least to most toxic.<sup>31</sup> DMHg is considered the most toxic form of Hg, but levels are very low in the environment due to its volatility and high photosensitivity. MMHg is the most present, toxic form of Hg in the environment.

Hg is released mostly from coal burning, industrial activities and volcanoes as Hg(0) vapor. The operations, industries, and industrial products associated with Hg contamination include antifouling paints, chemical manufacturing, electrical, pigments and inks, pulp and paper mills, utilities, water treatment plants, and boat manufacturing and repair.<sup>32</sup> Once in the air, light or reactions with chemicals in the atmosphere will convert Hg(0) to Hg(II), which sticks to particles where it can be deposited into oceans and freshwater systems. Atmospheric deposition is the primary source of Hg to the oceans.<sup>31, 60</sup> Coastal California receives most of its atmospheric Hg from Asia and minimal amounts Hg from riverine inputs.<sup>33</sup>

Hg(II) is generally introduced into the coastal environment through rivers or atmospheric deposition, where it is either reduced to Hg(0) potentially going back into the atmosphere, or buried in the sediments.<sup>33</sup> A conceptual diagram of this process can be found in *Figure 6*. At the surface of the oceanic water column (>25m) and below the mixed layer, particulate organic matter (POM) is the primary mode of transport for Hg to sink throughout the water column into the pelagic.<sup>34</sup> Dissolved Hg either sorbs to particles or is taken up by phytoplankton. POM with sorbed Hg can be taken up the food web through the consumption by metazoans which disperses through the lower epipelagic and upper mesopelagic from 150-700m.<sup>34</sup> The main source of Hg to the marine food web is particulate Hg.<sup>34</sup>

Hg(II) and Hg(0) can be converted to MMHg abiotically or chemically, and biotically in the environment, with much less being converted to DMHg which mostly goes undetected due to reporting limits.<sup>2</sup> Within the oceanic water column, Hg transformations include not only methylation of Hg(II) by abiotic and biotic processes, but also degradation of MMHg to Hg(II) and Hg(0) by photochemical and dark biotic processes.<sup>34</sup> The rate of abiotic methylation happens



very minimally and can mostly be ignored, except in special environments.<sup>34</sup> Biotic methylation is a cellular reaction where Hg(II) physically enters the microbial cell into the cytoplasm.<sup>34</sup> Many different groups of microorganisms are involved in Hg methylation. A majority of methylation occurs with the presence of sulfate-reducing bacteria (SRB), however other groups also contribute, such as iron-reducing bacteria (IRB), methanogens, and others including fermentative, acetogenic, and cellulolytic microorganisms.<sup>34</sup> However, Hg methylation abilities of SRB, IRB, and methanogens seem to be equally important, and Hg-methylators have been found in all three groups.<sup>2</sup>

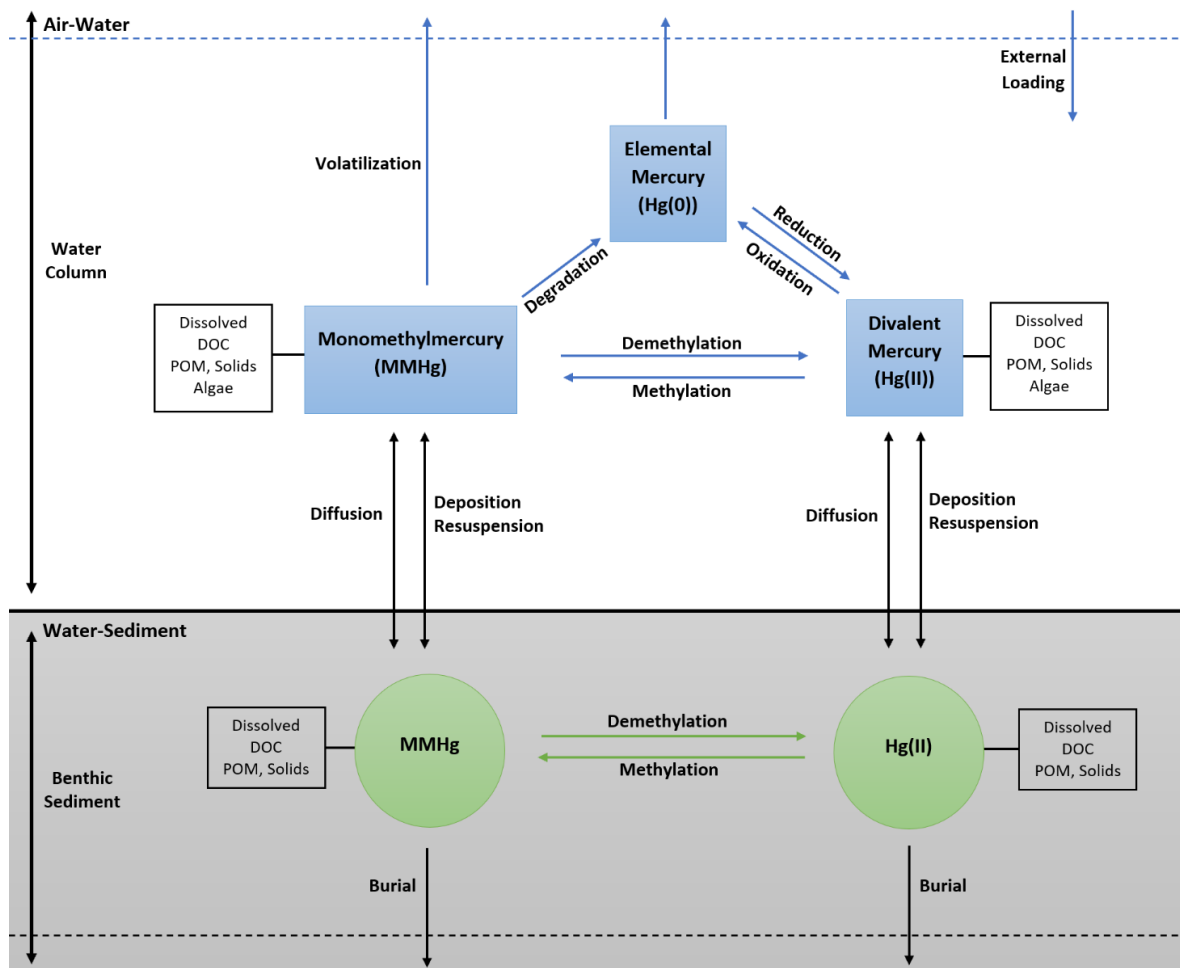


Figure 6: Different species of Hg and their fluxes and transport in an aquatic environment. Image adapted from Lai, Yong et al. 2017.<sup>35</sup> Abbreviations: DOM: dissolved organic carbon, POM: particulate organic matter

MMHg is a small fraction of the total Hg (around 1-10%), but very small increases can impact the environment.<sup>2</sup> MMHg is an organic form of Hg which is toxic and can be absorbed into tissues of animals (bioaccumulation) and accumulate up the food web (biomagnification). Marine biota obtain MMHg from water, sediment, and food and slow rates of elimination relative to the uptake result in bioaccumulation.<sup>31, 61</sup> MMHg typically increases with the age, size, and trophic level of the organism.<sup>31</sup> This can be a cause for concern for animals higher up on the food chain and people who depend on fish as a main protein source. The effects of Hg are highly

dependent on very specific chemical interactions within each organism and in the environment it resides.<sup>36</sup> Toxicity effects are present through many different mechanisms including “DNA damage, redox cycling, metabolic toxicity and enzyme cofactor substitution”, disrupting the essential biological and chemical components to life.<sup>36</sup> This can have adverse impacts on human health such as neurological and cardiovascular issues, decreases in cognitive function, and in very high doses or accumulating over a longer period of time, deformities, and even death in extreme cases.<sup>1</sup>

### *Factors that Influence the Methylation of Mercury*

There are many complex factors that influence the methylation of Hg within the marine environment from physical and oceanographic to chemical factors that influence SRB and other microorganism activity. The concentration and bioavailability of Hg(II) in the water column and sediments control how much MMHg can be produced.<sup>2, 50</sup> Hg(II) must be able to cross the inner and outer membranes of methylating bacteria into the cytoplasm in order to be transformed into MMHg.<sup>2, 50</sup> Passive diffusion is thought to be the main way that Hg(II) is taken up by microorganisms in anaerobic aquatic environments.<sup>2, 51, 52</sup> If Hg(II) is bound to other charged chemicals such as sulfide or dissolved organic matter (DOM), this can inhibit its ability to cross the membranes through passive diffusion.<sup>31, 56, 51, 62</sup> Sulfide is one of the most dominant factors that influence MMHg production, because it can bind to Hg(II) which can influence the bioavailability of Hg(II) to methylating bacteria.<sup>31, 56</sup>

The maximum rates of Hg methylation are often found in accumulated sediments at the oxic-anoxic transition zones, also known as redox transition zones that are close to the sediment water interface in many marine systems, and where SRB activity is high and levels of sulfide are low.<sup>37, 31</sup> Neutral, uncharged, small, and soluble Hg(II) compounds could be taken up through passive diffusion by anaerobic methylating microbes, and due to Hg(II)'s strong affinity to reduced sulfur, complexes such as uncharged Hg(II) sulfide (HgS) could pass through the membranes.<sup>2, 50</sup> HgS dominates at low sulfide and is bioavailable due to its small size and uncharged nature.<sup>38</sup> At high sulfide levels, larger charged species are dominant and less likely to cross the SRB cell membrane by passive diffusion and therefore cannot be methylated.<sup>38</sup> Higher methylation rates are expected when there is sufficient sulfate and when sulfide is low.<sup>38</sup> Lower pH levels increase the methylation rates and lead to higher MMHg concentrations, which may be due to a higher level of uncharged HgS<sub>0</sub>(aq).<sup>38</sup>

Iron-sulfur compounds can also influence the methylation rate of microorganisms. Ferrous ion and sulfur/sulfide can form FeS or FeS<sub>2</sub> in an anaerobic environment.<sup>2</sup> FeS can adsorb Hg(II), which affects the bioavailability of Hg(II), reducing the Hg(II) methylation rate.<sup>2, 53</sup> Further, the formation of FeS reduces pH, a change from neutral to weak acidity, which enhances the solubility of HgS, and reduces the Hg(II) methylation rate.<sup>2</sup>

Hg in the environment exists adsorbed to dissolved organic matter (DOM), and it is predicted that the HgDOM is the dominant speciation for Hg when dissolved sulfide concentrations are less than 0.1mM.<sup>2,50</sup> Areas with less organic matter have more Hg(II) in the dissolved phase, therefore increasing the methylation potential.<sup>2,54</sup> When DOM binds to Hg(II), it could decrease the methylation potential by decreasing the chances that the complex will pass through the membranes of the methylating microorganism. However, MMHg concentrations have been reported by various studies to increase with organic carbon content in sediments and this is most likely due to carbon availability for biological growth and the remaining Hg(II) being taken up by methylating organisms.<sup>2,55</sup> Dissolved organic carbon (DOC) binds to Hg(II) in oxic and low sulfide concentrated waters and is more pronounced at a higher pH.<sup>38</sup> The specific type and components of the DOM available also impacts the methylation rate along with other physical parameters such as the redox potential, pH values, temperatures, humidity, salinity and soil properties.<sup>38</sup>

Specific to the oceanic water column, Hg(0) and ionic Hg enters the surface waters where it is then scavenged by particulate organic carbon (POC) and mineral particles, and enters the biological pump.<sup>33</sup> Once incorporated into marine snow and fecal pellets, the Hg(II) can be methylated as the sorbed particles sink to deeper depths with less oxygen.<sup>33</sup> The area near 300m in depth is characterized by rapid particle disaggregation and POC remineralization.<sup>33</sup> Both MMHg and Hg(II) can be sorbed to particles and incorporated into marine snow and fecal pellets.<sup>33</sup> Hg(II) can be methylated when sorbed to particles during sinking through the water column and can be released into solution when separated from the particles.<sup>33</sup> Maximum levels of methylated Hg species are observed at 300m depth according to the study by K.H. Coale et al. (2018).<sup>33</sup>

Other physical, environmental parameters that can impact methylation are temperature, dissolved oxygen, bioturbation, and seasonal changes. Methylation increases with the increase in temperature up to a certain point, due to the increased catalytic activity from microbes.<sup>30</sup> Bioturbation, or movement of sediment from organisms, can redeposit Hg from the benthic sediments back into the water column.<sup>30</sup> This activity can increase microbial activity and increase the methylation of Hg(II).<sup>30</sup> Seasonal changes can also impact Hg speciation rates. Between May and September, methylation increases at a depth of 400-700m in the Pacific Ocean water column.<sup>34</sup> Seasonal differences in rainfall, such as increased rainfall in winter in Southern California, increases the amount of mercury reaching an estuary.<sup>38</sup> This is the scenario for Newport Bay since it receives the outflow from the Upper Newport Bay State Marine Conservation Area/San Diego creek watershed. Different environments along the coast can cause varied methylation patterns due to tides impacting oxygen levels and other biogeochemical factors. For example, salt marshes are intertidal habitats dominated by plants and SRB is more enhanced in the root zones here, and as a result, the total Hg and MMHg are usually highest here

as compared to upland sites.<sup>38</sup> MMHg levels are higher in marshes as compared to mudflats and tidal creeks due to increased microbial activity from higher organic content from root exudates.<sup>38</sup>

### *Concerns for Marine Life*

MMHg is absorbed into the tissues of individual animals, a process known as bioaccumulation, and MMHg can accumulate over the course of its lifetime. If the organism is consumed by organisms further up on the food web, the MMHg can be transferred to the predator organism, known as biomagnification. The quantity of accumulated Hg in aquatic organisms is affected by its level in the trophic chain (the higher level in the trophic chain, the more Hg is accumulated), the age of the organism (generally, the older the organism, the more Hg is accumulated), the migration pattern of the organism, and all the other factors that influence Hg-methylation previously discussed.<sup>30, 57, 58, 59</sup> The region and depth of where the organism feeds can also influence the exposure to Hg. Coastal fish are more susceptible to anthropogenic Hg contamination due to freshwater inputs, but this doesn't necessarily mean that they will have higher Hg levels in their tissues.<sup>30</sup> Estuaries provide critical habitat for growing fish, but if there are higher Hg levels there, they can be a source of Hg to be bioaccumulated through the food web.<sup>38</sup> If the habitat is also a crucial area for other wildlife such as birds and other mammals, poisoning could occur.<sup>38</sup>

Focusing on the oceanic water column, a study by Szefer in 2002 found that Hg concentrations in mesopelagic species (>300m) were four times higher than those in the epipelagic (<200m).<sup>39, 30</sup> This relates to the factors influencing Hg-methylation described in the previous section where methylating species were maximized at 300m of depth. The main source of Hg to the marine food webs is particulate Hg below the mixed layer from 150-700 m of depth based on a study conducted by Motta, L.C. et al. in 2019 in the North Pacific Ocean.<sup>34</sup> Based on the same study, the smallest size class of zooplankton had the highest Hg concentration in the top 125m of the water column.<sup>34</sup> These small organisms as predators are a source of Hg by generating fecal pellets, contributing to sinking marine snow, and in turn being consumed as prey. Hg increases with depth to 500-700m for all size classes, but below 700m Hg within the smallest size class of zooplankton decreases with depth, while the larger size classes Hg increases with depth.<sup>34</sup> Diurnal variations within the mesopelagic (200-1,500m) showed great variation in Hg, with zooplankton collected at night with higher Hg concentrations compared to samples collected during the day.<sup>34</sup> Hg concentrations in larger, pelagic fish samples were around 10-100 times higher than Hg concentrations in zooplankton from similar depths.<sup>34</sup>

Marine fishes are important environmentally, socially, economically, and culturally to the state of California. However, high concentrations of metals and organic pollutants can cause harm to recreational fishes and in turn can impact human health and wellbeing. The California Environmental Protection Agency Office of Environmental Health Hazard Assessment (OEHHA) developed Advisory Tissue Levels (ATLs) to develop consumption recommendations

to protect the health of fish consumers.<sup>40</sup> “ATLs provide the number of recommended fish servings that correspond to ranges of contaminant concentrations found in edible fish tissues.”<sup>40</sup> When specifically looking at Hg contamination issues in Newport Bay, Hg bioaccumulation has not been a prominent issue in the fishes.<sup>41</sup> None of the fish sampled during a 2004 study done by the Southern California Coastal Water Research Project (SCCWRP) were above the screening value of 0.30mg/kg wet weight for total Hg.<sup>41</sup> The highest values of 0.238, 0.165, and 0.136 were found in yellowfin croaker, spotted sand bass, and jacksmelt respectively.<sup>41</sup>

According to a more recent study by SCCWRP for the Southern California Bight 2018 Regional Monitoring Program, there was detectable Hg in all fish tissues sampled from the 2018 monitoring.<sup>41</sup> While Hg concentrations most frequently exceed ATL thresholds in sport fish in the Southern California Bight and the greatest concern to human health through consumption, the Hg concentrations of fish sampled in Newport Bay were below the “consume not more than 7 servings per week” limit which means that the fish are relatively safe to eat, including Spotted Sand Bass.<sup>40, 41</sup> The relative safety for consumption of fish from Newport Bay may be due to most of the Hg not being bioavailable to methylating microbes as a result of burial and sequestration in the sediments. This can be a cause for concern when dredging occurs and the Hg-loaded sediments could be dispersed locally in the bay within the project area. The dredging could change environmental conditions potentially making the Hg bioavailable to methylating microbes, reverberating up the food web to prey fish or recreational fish in the bay. However, since the large volume of sediments are being removed from the bay and transported to the LA-3 ODMDS, there are greater concerns about the fate of Hg in the offshore ocean environment of the disposal site. More information and analyses are needed to assess the potential impact of Hg contamination through the dredging transport and disposal process.

## **Recommendations**

### ***Introduction***

The goal of this report is to address the Hg sediment contamination concerns and fill in the knowledge gaps for the EPA and local governments regarding the potential Hg-loading at the LA-3 disposal site by a proposed USACE project in Newport Bay, and how an influx of Hg will impact the disposal site and the surrounding marine environment. When taking into account the relevant federal, state and local policies, biogeochemical cycling of Hg, its contamination impacts and methylation factors, and physical attributes of the LA-3 ODMDS and Newport Bay, suggestions for initial sampling and analysis suggestions can be made. In addition to the tiered testing approach, testing for Hg(II) and MMHg buried in the sediments, instead of just total Hg, can assist with the understanding of what is present in the sediments and what may occur when disposed of at an ODMDS. Conducting analyses for Hg(II) and MMHg can assist with modeling efforts of this trace metal cycling as well, allowing for more targeted toxicity testing that accounts for differing conditions at the receiving site, or in this case at LA-3 ODMDS. Testing

for dissolved and sedimentary sulfur levels can help determine if the conditions in the sediment will allow MMHg to be bioavailable and to bioaccumulate. Collection of pore water through passive samplers can provide this additional important information about dissolved metal concentrations that is useful for predicting bioavailability and toxicity at sites with metal contaminated sediments. This report can be used to inform monitoring and management of the LA-3 disposal site and potentially other EPA disposal sites, and the recommendations may apply to other persistent chemicals of concern.

### ***Test for divalent mercury and monomethylmercury***

Based on estimates of Hg concentrations in the Newport Bay sediments and the concentrations of Hg at the LA-3 ODMDS, it was determined that the dredged sediments from Newport Bay suitable for ocean disposal could increase the mercury at the disposal site by as much as 43%. Since MMHg makes up anywhere from 1-10% of total Hg, this can also cause an increase of up to 43% of MMHg at the disposal site, posing a potential risk to organisms in the area of the LA-3 ODMDS if the MMHg at the disposal site and the dredging site have the same proportions. Testing for Hg(II) and MMHg can assist in determining how much MMHg exactly is in the sediments. The data and estimates used for these calculations can be found in Appendix A.

Regulatory criteria is most commonly based on the presence of total Hg. However, testing for Hg(II) and MMHg can provide values for the toxic forms as well as the forms that have the potential to be methylated. DMHg is unstable and rapidly decomposes into MMHg in samples with a degradation rate of around  $0.2 - 2.0 \times 10^{-5} \text{ s}^{-1}$  and measurements for DMHg will likely be combined with MMHg when analyzed and reported as MMHg.<sup>42, 43</sup> Sediment samples for these tests should be taken at the project dredge site location to determine how much MMHg is present. These measurements could be repeated at the disposal site to assess the extent of methylation after transport and disposal in the unconfined ocean setting. Having the values of Hg(II) in the sediments are important for purposes of Hg cycling and determining how much Hg is available to be transformed into MMHg. Through the SMMP, sediment testing for Hg(II) and MMHg when completing routine site monitoring can assist with understanding of Hg cycling within the LA-3 ODMDS. A list of EPA test methods for Hg analyses can be found in Appendix B.

For the analysis of MMHg, distillation is conducted to isolate the MMHg followed by aqueous phase ethylation, and precollection on the Carbotrap, prior to isothermal gas chromatography and cold vapor atomic fluorescence (CV-AFS) detection.<sup>44</sup> Distillation also provides the specific separation of MMHg and DMHg, if there is any DMHg present in the sample at the time of analysis.<sup>44</sup>

Through the CWA, there are specified water quality criteria to protect human and environmental health, but no specified values specifically for MMHg except for in fish tissues. The Tissue

Residue Criterion is 0.3 mg MMHg/kg fish, which is described as “the concentration in fish tissue that should not be exceeded based on a total fish and shellfish consumption-weighted rate of 0.0175 kg fish/day.”<sup>24</sup> While sediment quality criteria do not exist for Hg, sediment screening values developed by Long and Morgan (1991) reported the Effects Range-Low (ERL) for total Hg as 0.15 milligram per kilogram (mg/kg) as dry weight, and the Effects Range-Median (ERM) for total Hg as 0.71 mg/kg based on toxicity effects.<sup>49</sup> The ERL indicates the concentration below which toxic effects are scarcely observed or predicted, and the ERM indicates above which effects are generally or always observed.<sup>49</sup> They are derived from biological toxicity assays and synoptic sampling.<sup>49</sup> MMHg concentrations may be estimated as 1-10% of the total Hg and these estimates may be used for given thresholds of MMHg in the absence of threshold guidance if specified through policy. These suggested analyses would be less for determining specific thresholds and more for understanding the interactions between trace metal cycling in the specific area of concern.

### ***Test for dissolved and sedimentary sulfur***

Along with testing for Hg(II) and MMHg in the sediments, sulfur compounds should also be tested since Hg can bind to charged sulfur compounds, and as a result not be bioavailable to methylating bacteria. Sulfur compounds are not usually analyzed and tested for in the sediments and water column. Passive diffusion deems that the bioavailability of Hg(II) depends mainly on the concentrations of neutrally charged Hg(II) complexes, such as Hg(HS<sub>2</sub>), HgS<sub>0</sub> (aq) and polysulfide HgSn<sub>0</sub> complexes.<sup>2, 50, 56</sup> HgS<sub>0</sub> (aq) is estimated to be the dominant form of dissolved Hg(II) in anaerobic pore water at relatively low sulfide concentrations.<sup>2, 50</sup> Determining the dissolved sulfide and sedimentary sulfur is important for assessing the impacts on bioavailability of MMHg in conjunction with other measured environmental parameters such as dissolved oxygen and temperature. Knowledge of the levels of sulfur compounds locally and at the receiving site, in this case LA-3 ODMDS, can assist with the modeling of trace element cycling as well.

A sampling regime for determining dissolved sulfide and sedimentary sulfur from Gregory Cutter and Thomas Oatts (1987) is described below:

A method employing selective generation of hydrogen sulfide, liquid-nitrogen-cooled trapping, and subsequent gas chromatographic separation/photoionization detection has been developed for such studies. Dissolved sulfide is determined via acidification and gas stripping of a water sample, with a detection limit of 12.7 nM and a precision of 0.5 % (relative standard deviation). With preconcentration steps, the detection limit is 0.13 nM. Hydrogen sulfide is generated from sedimentary acid volatile sulfides (AVS) via acidification, from greigite using sodium borohydride and potassium iodide, and from pyrite using acidic chromium(II). The detection limit for these sulfur species is 6.1 μg of S/g, with the precision not exceeding 7% (relative standard deviation). This method is rapid and free of chemical interference, and field determinations are possible. Numerous

natural water and sediment samples have been analyzed by using the described procedures.<sup>44</sup>

A list of additional EPA test methods for sulfur, sulfate, and sulfide analyses can be found in Appendix C.

### ***Pore water sampling***

Testing the pore water in addition to sediment and water samples for Hg could provide a full picture for contamination in the aquatic ecosystem. Pore water is a key exposure route for benthic organisms, and pore water analyses and tests can provide useful information for contamination, pollution, bioavailability, and toxicity.<sup>45</sup> The sediment-water interface is where most Hg is methylated and sediment-water exchange is an important source of MMHg into the water column through advection, diffusion, sediment resuspension, and bioturbation.<sup>46</sup> Pore water sampling of the sediments can provide the partitioning coefficient ( $K_d$ ) by taking the concentration of Hg in the liquid divided by the concentration of Hg in a bulk. This is useful information to know when assessing movement of contaminants through the environment.

A paper by Marc Greenberg et al. (2014) details the benefits to using passive sampling methods (PSMs) to provide information on bioavailability in the terms of freely dissolved contaminant concentrations ( $C_{free}$ ) to inform management of contaminated sediments.

PSMs can increase certainty in site investigation and management, because  $C_{free}$  is a better predictor of bioavailability than total bulk sediment concentration ( $C_{total}$ ) for 4 key endpoints included in conceptual site models (benthic organism toxicity, bioaccumulation, sediment flux, and water column exposures). The use of passive sampling devices (PSDs) presents challenges with respect to representative sampling for [estimation of] average concentrations and other metrics relevant for exposure and risk assessment. These challenges can be addressed by designing studies that account for sources of variation associated with PSMs and considering appropriate spatial scales to meet study objectives. Possible applications of PSMs include: quantifying spatial and temporal trends in bioavailable contaminants, identifying and evaluating contaminant source contributions, calibrating site-specific models, and, improving weight-of-evidence based decision frameworks. PSM data can be used to assist in delineating sediment management zones based on likelihood of exposure effects, monitor remedy effectiveness, and evaluate risk reduction after sediment treatment, disposal, or beneficial reuse after management actions.<sup>47</sup>



### ***Account for seasonal variations and disposal time frame***

Methylation rates are predicted to be higher than usual from May through September in the North Pacific Ocean.<sup>34</sup> This time frame is when increased productivity occurs where there is an increase in blooms of phytoplankton, bulk nitrogen, DOM, and POM.<sup>34</sup> Due to Hg(II)'s affinity for DOM in the water column and Hg-methylating microbes present, the phytoplankton will take these up making bioaccumulation of MMHg an increased possibility through this time frame. If MMHg levels are known within a specific Newport Bay project, avoiding ocean disposal of sediments from May through September may have an impact on the amount of Hg(II) that may be methylated and the amount of MMHg that can be taken up by organisms during rates of high productivity in the ocean environment. Seasonal variations should also be considered for initial sampling and toxicity testing at source locations, as sampling outside of May through September could imply lower toxicity, due to potentially lower levels of MMHg, compared to high methylation periods.

Taking into consideration movement of migrating animals such as fish, whales, and birds could be another aspect that could impact the time frame for disposal of a large project. Avoiding periods of high migration for sensitive species at the dredging site and the site of disposal could minimize impacts to wildlife from suspended sediments and possible contamination exposure. Imposing a volume cap on the total amount of sediments that can be disposed of with a threshold of specific contaminants would be useful in addition to the standard sediment testing guidelines and alternative analyses.

### ***Additional recommendations from other sources***

A metals sediment study was done post-dredging in Lower Newport Bay by Orange County Coastkeeper and Linda Candelaria, PhD in 2014.<sup>48</sup> The sediment core samples collected before dredging took place found that some areas were contaminated with Hg and other metals.<sup>48</sup> It was noted that when the pre-dredging cores were collected, some sediment cores were homogenized and multiple cores within a site were also combined when analyzed.<sup>48</sup> Compositing of test areas where sediments are expected to be homogenous is the standard approach because dredging operations will tend to homogenize the sediments as they are being excavated and dumped into the transport barge or scow. If composited test results show high concentrations of a chemical contaminant, it makes sense to analyze the individual sediment cores or divide the core at different depths to identify a hotspot in the vertical or horizontal extent.<sup>48</sup> This approach can potentially determine the source of the contamination of Hg and other metals for consideration of future dredging or cleanup projects.

Based on the Sediment-Profile and Plan-View Imaging Survey Report for the LA-3 ODMDS conducted in September 2015 submitted by Battelle and prepared by DAMOSVision provided additional recommendations for statistical analysis. When comparing samples inside the

ODMDS to the reference site outside the ODMDS, statistical analysis can be used if additional studies are needed beyond Tier 1 in the SMMP. There are limitations to any statistical analysis in the standard Tier 1 site monitoring.<sup>5</sup> Specific recommendations and notes from their report include:

- (1) The September 2015 SPI survey at the LA-3 ODMDS showed that recent dredged material was contained within the LA-3 ODMDS, with stations at the northern boundary of the LA-3 ODMDS having no dredged material, and stations at the southern boundary having only trace levels of dredged material present.
- (2) Since dredged material was constrained within the LA-3 ODMDS, the spatial distance between the LA-3 ODMDS and the interim disposal site allowed for positive affirmation of dredged material far outside of the LA-3 ODMDS boundary.
- (3) Given the containment of dredged material within the LA-3 ODMDS (excluding material that exists outside of the LA-3 ODMDS due to the interim disposal site), it is recommended that the disposal approach not be changed. We suggest changing the sampling strategy to either a grid approach or a stratified random sampling design that would better allow for statistical comparison between areas inside and outside of the LA-3 ODMDS.
- (4) The reference area station, though located relatively far from the LA-3 ODMDS, was found to have traces of dredged material. The presence, even in trace amounts, of dredged material at the reference station precluded it from being a suitable representation of undisturbed ambient sediment. It is recommended that in addition to selecting a new reference area, more than one reference station be selected to allow for statistical comparison.
- (5) The main physical change resulting from disposal appeared to be a shift in sediment appearance, with the new layers of dredged material having a grain size major mode that was similar to the ambient sediment with a slightly more mottled appearance and grayish color.
- (6) The ambient surface sediments were fine-grained, uniformly light-colored, and contained relatively low boundary roughness. This suggests the benthic conditions were stable with healthy oxygen conditions and low physical disturbance.
- (7) The aRPD depth at stations within the disposal site and in surrounding areas were equivalent to ambient conditions except at the N and E transect where the aRPD depth increased with distance from the center.
- (8) The benthic habitat at the LA-3 ODMDS stations somewhat contrasted with those of the ambient sediment. The ambient sediment consisted of a uniform layer of light tan colored fine silt-clay with burrows and surface tubes, whereas the disposal site stations were fine mottled silt-clay with worm burrows and fewer tubes. Though there were some differences in benthic habitat type, the benthic communities were mature in both locations indicating recovery had occurred post disposal activity.
- (9) The OSI values presented suggest that the LA-3 ODMDS and surrounding area have not experienced particularly severe benthic habitat disturbance (represented by OSI

values greater than 6). However, use of this index is no longer encouraged (Germano et al. 2011), and these values strongly contradict more accurate assessments of seafloor condition (e.g., aRPD depth, successional stage, benthic habitat type). Going forward we would strongly recommend not incorporating the OSI value into analysis.

- (10) Overall, while the results indicate that the benthic communities at the LA-3 ODMDS and the surrounding area are somewhat different in benthic habitat type and sediment characteristics, disposal operations have not adversely affected the seafloor environment based on the SPI analyses.<sup>5</sup>

### ***Next Steps***

Incorporating a modeling aspect into the environmental parameters and Hg levels from the dredge sediments and the LA-3 ODMDS could assist in greater understanding of Hg cycling at the disposal site. A box model created in MATLAB by Amina Schartup, PhD could be used to supply additional information for levels of Hg in its different forms over time. By inputting physical and chemical parameters of the dredged sediments and the disposal site, estimations of Hg speciation can be made. This could be useful for additional studies looking at Hg cycling at the disposal site.

It would also be useful to share this information with the SC-DMMT and local government agencies so they have a better idea of how much MMHg is present in the sediments before dredging occurs to better protect environmental and human health. Collaboration and coordination should continue between scientists, government, non-governmental organizations, and their communities to ensure that needs are being met. All sectors have their limitations for time and funding, so working together to combat these issues is crucial to make impactful change. These additional tests can assist with modeling and further the understanding of how trace metal cycling happens in the marine environment. This can in turn assist with increased knowledge of what will happen when sediments are disposed of at the LA-3 site, and better prevent unintended contamination and increased toxicity. Hg is also not the only chemical of concern in these sediments. There's PCB, DDT, and other trace metal contaminants present and more information collected can potentially assist with cycling details of other contaminants.

### **Conclusion**

A total of 933,700 cy of sediment from a Newport Bay dredging project is suitable for open ocean disposal at the LA-3 ODMDS, despite concerns about the levels of Hg in the total volume of sediment. Currently, the LA-3 ODMDS has low to non-detect levels of Hg present, and disposing of this amount of sediment with high Hg loads will have unknown impacts to the site and the surrounding environment. Calculations estimate that if all the sediments approved for ocean disposal from Newport Bay were to be disposed of at the LA-3 ODMDS, the Hg levels would increase by up to 43% in the sediments, including levels of toxic MMHg. Through the review of relevant federal, state and local policies, and through increased understanding of the

Hg cycling and factors that influence methylating behavior, additional recommendations for testing can be made to better prevent unintended toxic conditions at receiving dumpsites from contaminated sediments. Increased analysis for several forms of Hg in the sediments and water column can provide values for the toxic forms as well as the forms that are benign in the initial testing phase but have the potential to be methylated into toxic forms once released at the dumpsite. Testing for dissolved and sedimentary sulfur can also provide details into the bioavailability of Hg to methylating bacteria. Pore water sampling can provide important information into the toxicity and bioavailability of inorganic metals, such as Hg. Communicating these recommendations to the local SC-DMMT can influence monitoring and analysis efforts to protect environmental and human health, and increase knowledge surrounding the dredge site and potential trends to understand trace metal cycling in the area.

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# Appendices

## Appendix A

**Table 1**  
Lower Newport Bay Federal Channels 2019 Maintenance Dredging – Summary of Mercury and Total PCB Mass Loadings

Dredge Unit	Dredge Unit Code	Design Depth (feet MLLW)	Estimated Volume to Design Depth (cy)	1-Foot Payable Overdepth Allowance Volume (cy)	1-Foot Non-Pay Overdepth Allowance Volume (cy)	Total Volume (cy)	Total Volume (m <sup>3</sup> ) [1 cy = 0.76455 m <sup>3</sup> ]	Total Solids (%)	Volume of Solids in Dredged Material (m <sup>3</sup> )	Mass of Solids in Dredged Material (kg)	Concentration of Mercury (mg/kg)	Mass of Mercury in Dredged Material (solids portion) (kg)	% of Total Mass of Dredged Material (all areas combined)	Concentration of Total PCBs (µg/kg)	Mass of Total PCBs in Dredged Material (solids portion) (kg)	% of Total Mass of Dredged Material (all areas combined)
Turning Basin	TB	-20	23,066	34,370	34,370	91,806	70,190	45.1	16,756	44,905,657	3.64	163.5	31.7	195.0	8.8	33
Main Channel North 1	MCN1	-20	36,584	13,298	13,298	63,180	48,304	45.5	11,674	31,285,017	1.18	36.9	7.2	41.7	1.3	5
Main Channel North 2	MCN2	-20	37,504	11,587	11,587	60,678	46,391	48.8	12,376	33,166,870	1.04	34.5	6.7	53.4	1.8	7
Main Channel North 3	MCN3	-20	44,505	19,374	19,374	83,252	63,650	52.3	18,780	50,329,395	0.797	40.1	7.8	44.1	2.2	8
Main Channel North 4	MCN4	-20	28,294	13,344	13,344	54,982	42,036	54.8	13,299	35,642,037	0.181	6.5	1.3	29.0	1.0	4
Main Channel North 5	MCN5	-20	50,106	19,798	19,798	89,701	68,581	54.7	21,637	57,988,264	0.205	11.9	2.3	30.6	1.8	7
Bay Island North	BIN	-15	77,358	27,546	27,546	132,450	101,265	51.9	29,541	79,169,872	0.431	34.1	6.6	30.4	2.4	9
Bay Island Middle East	BIME	-15	41,219	12,178	12,178	65,576	50,136	49.2	13,532	36,266,281	0.142	5.1	1.0	23.0	0.8	3
Bay Island Middle West	BIMW	-15	41,121	12,396	12,396	65,912	50,393	48.9	13,483	36,133,629	0.153	5.5	1.1	24.1	0.9	3
Bay Island South	BIS	-15	51,136	15,798	15,798	82,731	63,252	47.5	16,237	43,515,718	0.233	10.1	2.0	22.7	1.0	4
Entrance Channel	EC	-20	51,663	9,595	9,595	70,852	54,170	82.4	34,734	93,087,517	0.0125	1.2	0.2	0.2	0.0	0
Newport Channel 1	NC1	-15	28,216	9,339	9,339	46,894	35,853	<b>55.4</b>	<b>11,532</b>	<b>30,905,234</b>	<b>3.07</b>	<b>94.9</b>	<b>18.4</b>	<b>46.7</b>	<b>1.4</b>	<b>5</b>
Newport Channel 2	NC2	-15	85,798	19,761	19,761	125,319	95,813	65.3	40,054	107,343,402	0.529	56.8	11.0	22.8	2.4	9
Newport Channel 3	NC3	-15	54,155	12,268	12,268	78,690	60,162	73.1	30,632	82,093,806	0.173	14.2	2.8	8.0	0.7	2
<b>Total (All Areas Combined)</b>			650,725	230,649	230,649	1,112,023	850,197				0.84	515		40.83	27	
<b>Total (Excluding Turning Basin and Newport Channel 1)</b>			599,443	186,940	186,940	973,323	744,154		<b>Average Mercury Concentration (mg/kg)</b>		0.42	257		<b>Average Total PCBs Concentration (µg/kg)</b>	27.50	16
<b>Total (Turning Basin and Newport Channel 1 Only)</b>			51,282	43,709	43,709	138,700	106,043				3.36	258		120.85	10	

Notes:  
**Bold Italics** Values are averages calculated from the individual cores that make up the DU. Composite sample was not analyzed based on individual core chemistry.  
*Italics* Values are based on averages taken from individual cores used for total solids, mercury, and total PCB concentrations.  
 µg/kg: microgram per kilogram  
 cy: cubic yard  
 DU: dredge unit  
 kg: kilogram  
 m<sup>3</sup>: cubic meter  
 mg/kg: milligram per kilogram  
 MLLW: mean lower low water  
 PCB: polychlorinated biphenyl

### Disposal site mercury estimations:

$$\begin{aligned}
 & \text{Surface area: } 2,641,026 \text{ m}^2 \\
 & 2,641,026 \text{ m}^2 \times 1 \text{ m of sediment depth} = 2,641,026 \text{ m}^3 \\
 & 2,641,026 \text{ m}^3 \times \frac{1.30795 \text{ cy}}{1 \text{ m}^3} = 3,454,331.592 \text{ cy of sediment} \\
 & \text{weight of sediment: } 3,300 \frac{\text{lbs}}{\text{cy of sand}} \times 3,454,331.592 \text{ cy} \\
 & = 11,399,294,254 \text{ lbs} \times \frac{1 \text{ kg}}{2.205 \text{ lbs}} \\
 & = 5,170,632,897 \text{ kg of sediment at LA - 3 in upper 1 meter} \\
 & 5,170,632,897 \text{ kg} \times 0.13 \frac{\text{mg}}{\text{kg}} \text{ of mercury} = 672,182,277 \text{ mg of Hg at disposal site}
 \end{aligned}$$

### Dredged sediment mercury estimations based on mass loading chart from Anchor QEA, LLC.:

$$\begin{aligned}
 & 686,021,808 \text{ kg of sediment} \times 0.42 \frac{\text{mg}}{\text{kg}} \text{ of mercury} \\
 & = 288,129,159 \text{ mg of Hg in dredged sediments}
 \end{aligned}$$

### Percent increase in total mercury from disposal sediments at the disposal site:

$$\frac{288,129,159 \text{ mg of Hg in dredged sediments}}{672,182,277 \text{ mg of Hg at disposal site}} = 43\% \text{ increase of mercury}$$

**Appendix B**

This table lists the EPA Test Methods relating to mercury as the analyte.

<b>Chemical or Method Description</b>	<b>Method Number</b>	<b>EPA Report #</b>	<b>40 CFR Par</b>	<b>Region 1 #</b>	<b>Electronic Version</b>	<b>Date Issued</b>
Mercury - Cold Vapor, Automated	245.2	600/4-79-020			NEMI	
Mercury - Cold Vapor, Manual	245.1	600/4-79-020			NEMI	3/1/1983
Mercury - Cold Vapor, Sediment Manual	245.5	600/4-79-020			www	
Mercury - CVA Fluorescence spectrometry	245.7	821/R-01-008			CD	2/1/1999
Mercury - Sampling & analysis by CVAFS	IO-5	625/R-96-010 a			ttn/amtic/	7/1/1999
Mercury in Aqueous Samples & Extracts by ASV	7472	SW-84 6 Ch 3.3			www	12/1/1996
Mercury in Fish	PP-006	600/4-81-055				
Mercury in Sediment	PP-007	600/4-81-055				
Mercury in Sediment & Tissue Samples by AFS	7474	SW-84 6 Ch 3.3	Update IVA		www	1/1/1998
Mercury in Sediment by Cold Vapor (CV/AAS)	245.5	600/4-91-010			www	4/1/1991
Mercury in Soil by Immunoassay	4500	SW-84 6 Ch	Update IVA		www	1/1/1998

		3.3				
Mercury in soil/sediment - manual cold vapor	0245.5 CL	ILM04.0		Exhibit D	www clp	
Mercury in Tissues by Cold Vapor (CV/AAS)	245.6	600/4-91-010			www	4/1/1991
Mercury in water - automated cold vapor	0245.2 CL	ILM04.0		Exhibit D	www clp	
Mercury in water - manual cold vapor technique	0245.1 CL	ILM04.0		Exhibit D	www clp	
Mercury in Water by Cold Vapor AAS	245.1	600/R-94-111			www	5/1/1994
Mercury in Water by Oxidation Purge & Trap CVAFS	1631B	821/R-99-005	136 App A		www	6/8/1999
Mercury in Water by Oxidation Purge & Trap CVAFS	1631C	821/R-01-024			NEMI	3/1/2001
Mercury in Water by Oxidation Purge & Trap CVAFS	1631D	821/R-02-019			www	8/1/2002
Mercury in Water/Oxidation, Purge & Trap, CVAFS	1631	821/R-96-012			CD	1/1/1996
Mercury, Inorganic II by HPLC/ECD	245.3	600/4-91-010			www	4/1/1991
Mercury, Total - Sample Preparation	200.2	600/R-94-111			www	5/1/1994
Metals - Atomic Absorption	200	600/4-79-020			www	
Metals and Trace Elements -	200.7	600/R-			www	5/1/1994

ICP/AES		94-111				
Metals by AA (Atomic Absorption Methods)	700A	SW-84 6 Ch 3.3			www	7/1/1992
Metals by ICP, FGAA and CVAA	1620			01A000 6085	CD	9/1/1989
Metals by ICP/MS	6020	SW-84 6 Ch 3.3			www	9/1/1994
Metals in Fish	PP-005	600/4-8 1-055				
Metals in Fish Tissue by ICP/EES	200.11	600/4-9 1-010			www	4/1/1991
Metals in Sediment	PP-005	600/4-8 1-055				
Metals, Total Recoverable Elements - Sample Prep	200.2	600/R- 94-111			www	5/1/1994
Metals, Total Recoverable in Biological Tissues	200.3	600/4-9 1-010			www	5/1/1994
Metals, Trace at Water Quality Criteria Levels	1669	821/R- 96-008			www	1/1/1996
Metals: Arsenic/Cadmium/Chromium/Copper/Lead/Mer	200.1	600/4-9 1-010			www	4/1/1991
Methyl Mercury in Water by Distillation CVAFS	1630			01A000 7846	NEMI	8/1/1998
Organic, inorganic & total mercury in soils	3200	not available	SW-846 dev			
Tissue/Priority Pollutant	ESTUA	430/9-8				3/1/1986

Metals - Bioaccumulat	RI	6-004				
Trace Elements in Ambient Waters by ICP/MS	1638	821/R-96-005			NEMI	1/1/1996
Trace Elements in Marine Water by ICP/MA	200.1	600/4-91-010			NEMI	4/1/1991
Mercury in Solid or Semisolid Waste	7471A	SW-846 Ch 3.3			www	9/1/1994
Mercury in Solid/Semisolid Waste (Manual Cold-Va	7471B	SW-846 Ch 3.3	Update IVA		www	1/1/1998
Mercury in Solids/Solutions - TDA/AAS	7473	SW-846 Ch 3.3	Update IVA		www	1/1/1998

### *Appendix C*

This table lists the EPA Test Methods relating to sulfur as the analyte.

<b>Chemical or Method Description</b>	<b>Method Number</b>	<b>EPA Report #</b>	<b>40 CFR Par</b>	<b>Region 1 #</b>	<b>Electronic Version</b>	<b>Date Issued</b>
Sulfate	300	600/4-79-020			www	
Sulfate - Colorimetric, Automated, Chloranilate	375.1	600/4-79-020			NEMI	
Sulfate - Colorimetric, Automated, Chloranilate	9035	SW-846 Ch 5			www	9/1/1986
Sulfate - Colorimetric, Automated, Methylthymol	375.2	600/4-79-020			NEMI	
Sulfate - Colorimetric, Automated, methylthymol	9036	SW-846 Ch 5			www	9/1/1986

Sulfate - Colorimetry, Automated	375.2	600/R-9 3-100			www	8/1/1993
Sulfate - Gravimetric	375.3	600/4-7 9-020			NEMI	
Sulfate - Turbidimetric	375.4	600/4-7 9-020			NEMI	
Sulfate - Turbidimetric	9038	SW-846 Ch 5			www	9/1/1986
Sulfide - Colorimetric, Methylene Blue	376.2	600/4-7 9-020			NEMI	
Sulfide - Potentiometric in Aqueous/Ion-Sel Ele	9215	SW-846 Ch 5			www	12/1/1996
Sulfide - Titrimetric, Iodine	376.1	600/4-7 9-020			NEMI	
Sulfides, Acid-Soluble & Insoluble - Titrimetric	9034	SW-846 Ch 5			www	12/1/1996
Sulfides, Acid-Soluble & Insoluble - Distillation	9030B	SW-846 Ch 5			www	12/1/1996
Sulfides, Total & Water Soluble	ESTUA RI	430/9-8 6-004				3/1/1986
Sulfite - Titrimetric	377.1	600/4-7 9-020			NEMI	
Sulfur (Semicontinuous Determination)	16			60 App A	/ttn/emc	10/10/1996
Sulfur, Total Reduced - Stationary/Impinger	16			60 App A	/ttn/emc	9/25/1996
Sulfur, Total Reduced (TRS Alt.)	0015A			60 App A	/ttn/emc	4/1/1996

Total Reduced Sulfur - (GC Analysis)	0016B			60 App A	/ttn/emc	4/1/1996
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