White Paper: Recontamination of Mitigation Sites in the Meadowlands

Prepared by: U.S. Fish and Wildlife Service, New Jersey Field Office
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Introduction

The U.S. Fish and Wildlife Service (Service) has significant concerns about potential recontamination in new mitigation project sites located within the Hackensack Meadowlands, New Jersey (Meadowlands) and its surrounding environs by hazardous substances. The hazardous substances of greatest concern for fish and wildlife resources in the Meadowlands are mercury, polychlorinated dibenzo-*p*-dioxins (dioxins or PCDDs), polychlorinated dibenzofurans (furans or PCDFs), and polychlorinated biphenyls (PCBs). Recontamination of mitigation bank sites may be occurring through a combination of processes including, but not limited, to tidal inundation and biotranslocation. Ultimately, if recontamination levels reach those that are considered to be harmful to fish and wildlife resources, the mitigation bank will not be achieving its intended purposes; would not be ecologically sustainable; and would represent an attractive nuisance to wildlife.

Background

In 2009, the Service elevated a U.S. Army Corps of Engineers (Corps) permit for the proposed Richard P. Kane Mitigation Bank (Kane Bank), pursuant to Section 404 of the Clean Water Act of 1972 (CWA), as amended (86 Stat. 816; 33 U.S.C. Section 1251 *et seq.*). The Service was concerned that construction of the Kane Bank would attract wildlife to the more desirable habitat and thereby increase exposure of Federal trust resources to hazardous substances (*i.e.,* create sink habitat; U.S. Fish and Wildlife Service 2007).

The proposed design of the Kane Bank would have allowed tidal inundation from the Hackensack River to promote the conversion of a mercury-contaminated *Phragmites* wetland into a *Spartina*-dominated marsh community. This design approach has two problematic features. First, the Hackensack River has elevated concentrations of contaminants in its water, sediment, benthic invertebrates, and fish. Levels of mercury, PCDD/Fs, PCBs, and other contaminants in the Hackensack River and its marsh plains frequently exceed levels of regulatory concern and are often at concentrations documented to adversely affect various life stages of many aquatic and water-dependent organisms. Therefore, tidal inundation would likely result in the contamination of clean fill used in the project's construction. Secondly, mercury can bioaccumulate from the environment into plants, especially aquatic species (Zillioux *et al.*, 1993; Heller and Weber, 1998). Mercury concentrations as high as 13 ppm (dry weight) have been found in the wetland vegetation near Berry's Creek (Ludwig, 1988). Several studies conducted in the Meadowlands have evaluated how *Phragmites* and *Spartina alterniflora* bioaccumulate considerable amounts of metals, including mercury, from the sediments into their roots (Burke *et al.*, 2000, Windham *et al.,* 2001a, b,). These studies indicate that in *Spartina* more metals are translocated to aboveground parts of the plant and that *Spartina* leaves release more mercury, copper, chromium, lead, and zinc than *Phragmites*. Therefore, in areas with heavy metal-contaminated sediments, *Phragmites* may better sequester metals whereas *Spartina* may remobilize metals above the soil and redistribute mercury as the *Spartina* leaves decay to detritus, a primary food source for marsh invertebrates and forage fish (Windham *et al.,* 2003; Weis and Weis 2004). Moreover, conversion of mercury-contaminated *Phragmites*-dominated marshes to *Spartina* marshes of lower elevations would likely result in soil geochemical characteristics that promote mercury methylation and mobilization, and/or accelerated mercury translocation and recycling into the detritus. *Phragmites* can, given implementation of appropriate site-specific and local management actions, provide substantial and substantive ecological services (Kiviat, 2010; Kiviat, 2013) until such time when contamination levels in the Meadowland are below those demonstrated to be harmful to fish and wildlife resources.

The Service's elevation case was withdrawn after the Kane Bank sponsor agreed to remove mercury-laden sediments at the site and implement mercury sampling in sediment and fish tissue as a performance standard for a minimum of five years after construction. This monitoring, recommended by the Service as a required condition of the Corps' permit, was intended to evaluate the nature and rate of potential recontamination of the constructed mitigation bank.

Concurrently, two other mitigation projects within the Meadowlands (MRI-3 Mitigation Bank and the Global Terminal mitigation project) were authorized by the Corps, with substantial input from the Service. These projects were required to use the same remediation techniques and performance standards as the Kane Bank. Issuance of the MRI-3 and Global Terminal also required sediments to be tested for the presence of PCDD/Fs as per recommendations of the Service. All three mitigation project sites are hydrologically connected to the Hackensack River.

Contaminants of Concern

As a result of decades of activities associated with local industrialization and urbanization, environmental pollutants are ubiquitously elevated in the water, sediments, soils, and biota of the Meadowlands. At this time mercury, PCDD/Fs, and PCBs are the contaminants of greatest concern to the Service. These substances are persistent in the environment; readily bioaccumulate in living organisms; and are toxic at low concentrations. Their environmental persistence and bioaccumulative nature contributes to chronic exposure in many species. Moreover, their levels in tissues biomagnify as they move up the food chain and therefore can result concentrations in higher trophic organisms that could adversely affect health, reproductive success, and survivability. We present here a brief synopsis of these contaminants and their effects on wildlife.

Mercury

The Meadowlands is heavily contaminated by mercury from the Ventron-Velsicol site (New Jersey Department of Environmental Protection, 2002b; U.S. Environmental Protection Agency, 2004a). The 40-acre Ventron-Velsicol site on Berry's Creek was occupied from 1929 until 1974 by the largest producer of intermediate inorganic mercury compounds and processor of mercury materials in the U.S., and is recognized as among the world's most severely mercury-contaminated aquatic sites (New Jersey Department of Environmental Protection, 2002b; U.S. Environmental Protection Agency, 2004a). Most contamination at the production site (estimates range from 30 to 289 tons) was composed of the liquid, elemental (inorganic) form; nonetheless, as reported in 2002, mercury concentrations in surface (13,800 μg/g) and subsurface (123,000 μg/g) soils were still acutely toxic (New Jersey Department of Environmental Protection, 2002b).

In addition to contaminating the production site, the Ventron-Velsicol plant discharged 0.9 to 1.8 kg of mercury per day into Berry's Creek (Lipsky *et al.*, 1980). Mercury concentrations in surface (0 to 2 cm) sediments have been reported as high as 11,100 μg/g in Berry's Creek (New Jersey Department of Environmental Protection, 2002b); moreover, mercury concentrations in subsurface sediments to at least 6 feet in depth exceed sediment guidelines (U.S. Army Corps of Engineers and U.S. Environmental Protection Agency, 2004). Mercury also dispersed from the Ventron-Velsicol site to nearby waters and wetlands through erosion, ground-water transport, volatilization, and biological transformation and uptake (New Jersey Department of Environmental Protection, 2002b; U.S. Army Corps of Engineers and U.S. Environmental Protection Agency, 2004). Mercury concentrations in ground (8.2 μg/L) and surface (15.6-17.6 μg/L) waters adjacent to the site, including Berry's Creek, exceed the acute and chronic water quality criteria for mercury (Exponent Environmental Group, 1998; New Jersey Department of Environmental Protection, 2002b) and far exceed (more than 30,000 times) the State's draft water quality criterion (530 pg/L) to protect fish and wildlife (Buchanan *et al.*, 2001).

Berry's Creek is a tributary to the Hackensack River. Mercury concentrations in Hackensack River sediments are amongst the highest in the entire Hudson-Raritan Estuary. Pecchioli *et al.* (2003) hypothesized that the mercury concentrations in upper tidal areas of the Hackensack River are higher than areas near the mouth of the river because mercury-contaminated sediments are being resuspended, distributed with flood tidal currents, and deposited in mid-river areas without being flushed from the river.

Mercury is a contaminant that presents many problems for the ecological restoration of the Meadowlands. No known form or compound of mercury has any documented beneficial function in living organisms; thus, any substantial sink of mercury in the environment is potentially a source of contamination to fish and wildlife (Eisler, 1987). Organic mercury, usually in the form of methylmercury, is a potent neurotoxin, can pass through the blood-brain and placental barriers, be transferred to eggs and developing embryos, and cause disruptions at the cellular and nuclear level (Eisler, 1987; Heinz, 1996; Wolfe *et al.*, 1998; Wiener *et al.*, 2003). Organic mercury causes diverse, subtle, sublethal effects (*e.g.*, altered activity patterns and behaviors, poor condition, neural lesions) that broadly impair survival and reproductive success in fishes, birds, and mammals (Eisler, 1987; Heinz, 1996; Wolfe *et al.*, 1998; Wiener *et al.*, 2003). Mercury bioaccumulation has been associated with the decline of federally listed species, including a subspecies of clapper rail, *Rallus longirostris obsoletus*; (Schwarzbach *et al.*, 1996). Eggshells of an eastern U.S. population of clapper rail with high mercury concentrations have exhibited egg-shell thinning and anomalous eggshell microstructure (Rodriguez-Navarro *et al.*, 2002).

Studies establishing definitive causal carcinogenic, mutagenic (causing a mutation, a change in the base sequence of a cell's DNA), and teratogenic (causing a non-heritable mutation or malformation in the developing embryo or fetus when a pregnant female is exposed to that substance) relationships for all forms of mercury have not been conducted (Agency for Toxic Substances and Disease Registry, 2005a). However, mercuric chloride and methylmercury are considered possible carcinogens in humans (U.S. Environmental Protection Agency, 2005b), and methylmercury has been reported to be a mutagen and teratogen in studies of animals (Costa *et al.*, 1991; Agency for Toxic Substances and Disease Registry, 2005a). Though not well studied, mercury's adverse effects may also be synergistic with other contaminants (Beckvar *et al.*, 1996).

While most mercury released at the Ventron-Velsicol site was in elemental or inorganic forms with relatively low toxicity, mercury is readily transformed in aquatic ecosystems into the organic form methylmercury, which is highly toxic to plants, fish, wildlife, and humans (Watras and Huckabee, 1994). The majority of mercury found in living organisms is methylmercury (Wolfe *et al.*, 1998). Methylmercury production is especially high in productive wetland ecosystems, both freshwater (Zillioux *et al.*, 1993) and estuarine (Compeau and Bartha, 1985; Davis *et al.*, 2003); therefore, understanding methylmercury production in the Meadowlands is necessary for evaluating appropriate remediation and restoration activities of mercury-contaminated sites.

Sulfate-reducing bacteria are the most important producers of methylmercury in freshwater and saltwater ecosystems (King *et al.*, 2000). Mercury methylation is highest at the interface of the aerobic and anaerobic layers of sediment, where sulfate-reducing bacteria are most abundant (Bloom and Lasorsa, 1999; Langer *et al.*, 2001). Methylmercury diffuses into the water and is distributed by currents; thus, high methylmercury production in any wetland, such as Berry's Creek, acts as a source for other wetlands (Langer *et al.*, 2001). Methylation of mercury in aquatic systems varies with environmental features (Davis *et al.*, 2003) and also depends on mercury loadings, microbial activity and species, nutrient content, redox condition, suspended sediment load, and sedimentation rates (Compeau and Bartha, 1985; Berman and Bartha, 1986; Jackson, 1986; King *et al.*, 2000). Modifiers of methylation are potentially affected by restoration activities; therefore, restoration of sites with high mercury concentrations has the potential to increase mercury methylation and bioavailability.

Increases in the availability of methylmercury and its subsequent accumulation and biomagnification are problematic to fish and wildlife resources. Methylmercury is moderately lipophilic (soluble in fats) and hydrophilic (soluble in water), properties that facilitate its availability to organisms, especially animals. These properties also ensure the increasing accumulation, or biomagnification, of mercury from one trophic level to the next. Eventually, biomagnification results in higher, more toxic doses of mercury in higher trophic level animals, such as piscivorous wildlife (*e.g.*, herons, bass, mink), insectivorous song birds (*e.g.,* bluebirds, wrens) and humans. For example, total mercury concentrations in water of less than 1 part per trillion may result in mercury concentrations in fish in excess of 1 ppm (Zillioux *et al.*, 1993). Effects of methylmercury exposure on wildlife can include neurological dysfunction, mortality, reduced fertility, slower growth and development and endocrine disruption.

<u>PCDD/Fs</u>

PCDD/Fs are two related classes of aromatic compounds that share certain structural similarities to PCBs and are persistent in the environment. As with PCBs, congeners of PCDDs and PCDFs are hydrophobic and lipophilic, giving them low solubility in water and high affinity for organic particles. In contrast to PCBs, these two classes of compounds have no commercial uses but are formed and are released into the environment as by-products of: (1) chlorine bleaching of pulp and paper, (2) chemical manufacturing of chlorophenols (*e.g.*, pesticides) and other chemicals (*e.g.*, PCBs, polyvinyl chloride [PVC] plastics), and (3) combustion from municipal waste incinerators (Rice *et al.*, 2003).

There are seventeen PCDD/F congeners that are considered highly toxic to vertebrates (Van den Berg *et al.,* 1998; Grassman *et al.*, 1998). There is no clear consensus on the toxicity of other congeners (Rice *et al.*, 2003). Because congeners differ in their toxicity, their potency is expressed in Toxic Equivalents to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD), the most potent, hazardous and well-studied dioxin (Rice *et al.*, 2003). Specific effects of dioxins documented in laboratory mammals and humans include wasting, immunotoxicity, endocrine disruption, reproductive and developmental abnormalities, cancer, and death (*e.g.*, Peterson *et al.*, 1993; Pohjanvirula and Tumost, 1994). Similar adverse effects have been reported for fishes and birds (*e.g.*, Spitsbergen *et al.*, 1991; Walker *et al.*, 1991; Heid *et al.*, 2001). A National Institute of Health study indicates that the dioxin-like congeners are additive in their ability to induce cancerous and precancerous conditions in controlled experiments (Walker *et al.*, 2005).

Dioxins and furans are common throughout the Hudson-Raritan Estuary due to their inadvertent production during industrial processes. In particular, the manufacture of chlorophenols has resulted in considerable contamination of Newark Bay and the Meadowlands with both dioxins and furans. The Kolker Chemical Works' Diamond Alkali plant (ID No. NJD980528996; U.S. Environmental Protection Agency, 2004f) on the Passaic River produced 15 million tons of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T; a chlorophenol herbicide) and 50,000 tons of dichloro-diphenyl-trichloroethane (DDT, a widely used organochlorine pesticide). Some of these products, including impurities in their manufacture (*e.g.*, the most potent and hazardous dioxin congener 2,3,7,8-tetrachloro-dibenzo-*p*-dioxin), were discarded into the lower Passaic River (Wahrman, 2000). The Diamond Alkali plant is recognized as the single largest contributor of 2,3,7,8-tetrachloro-dibenzo-*p*-dioxin to Newark Bay and its tributaries, including the Hackensack River. In addition to the Diamond Alkali site, the Standard Chlorine State Remediation Site (NJDEP Bureau of Case Management No. NJD002175057, proposed EPA Superfund Site ID No. NJD002175057) is a potential source of substantial dioxin and certain other contaminants (*e.g.*, benzene, chlorobenzene, di- and tri-chlorobenzenes, naphthalene, PCBs) to the Hackensack River and nearby wetlands (U.S. Environmental Protection Agency, 2004g). The 2,3,7,8-tetrachloro-dibenzo-*p*-dioxin congener has been found on-site and in nearby river sediments at levels of ecological concern (U.S. Environmental Protection Agency, 2004f).

<u>PCBs</u>

Exposure to PCBs has resulted in acute toxicity and death of fish and wildlife; however, chronic exposures and effects are more commonly reported (Hoffman *et al.*, 1996). Fishes with chronic exposure to PCBs exhibit immune system suppression (Zelikoff, 1994), enzyme modulation (Otto *et al.*, 1997), histopathological lesions (Teh *et al.*, 1997), liver tumors (Barron *et al.*, 1999), and reproductive and developmental impairments (Niimi, 1996). PCBs in Great Lakes fish are believed to adversely affect reproduction of bald eagle, other fish-eating birds, mink (*Mustela vison*), and river otter (*Lutra canadensis*; Wren, 1991; Giesy *et al.*, 1994). Also, reproductive failure, liver damage, immunosuppression, and wasting syndrome in wildlife have been attributed to chronic exposure to PCBs (Hoffman *et al.*, 1996). Improved recognition of the modes of action of specific congeners has resulted in identification of twelve PCBs as dioxin-like (van den Berg *et al.,* 1998). Thus, toxicities of these congeners, such as PCB 77 and PCB126, is expressed in a widely accepted (but not regulatory) protocol as Toxic Equivalency (TEQ), in which the toxicity of these compounds is determined relative to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (Rice *et al.*, 2003).

PCBs are common in the water, sediment, and biota of the NY-NJ Harbor estuary, including Newark Bay and the Hackensack River (Achman *et al*., 1996; Skinner *et al*., 1997; Adams *et al*., 1998; Durell and Lizotte, 1998; Feng *et al*., 1998; Litten, 2003; Monosson *et al*., 2003; Fernandez *et al*., 2004). Nearly 30 years after the ban on their production, PCBs continue to enter the NY-NJ Harbor estuary (including the Hackensack River) through riverine and other inputs (Totten, 2004). For many years, General Electric's Fort Edward and Hudson Falls facilities discharged 500,000 to 1.1 million pounds into the Hudson River (U.S. Environmental Protection Agency, 2004g). These two facilities were considered the primary sources of PCBs to the estuary. Atmospheric input, combined sewer overflows, and stormwater runoff collectively are now thought to contribute nearly as much total PCB-contamination as the Hudson River inputs; landfills may also contribute substantial quantities of PCBs (Totten, 2004). Based on the information currently available, Newark Bay and portions of the Hackensack River (upriver potentially as far as Snake Hill) appear to have among the highest sediment burdens of total PCBs in the entire NY-NJ Harbor estuary. Fish collected in the Hackensack River near Snake Hill had PCB concentrations as high as in the same species collected in the Hudson River (Fernandez *et al*., 2004).

Results of Post-Construction Mitigation Bank Monitoring

As mentioned above, issuance of Corps permits for four mitigation bank construction projects included Service recommended conditions for post-construction monitoring of contaminants in sediments and biota. Preliminary monitoring data has been returned to the Service and presented here.

Sediment mercury concentrations within the Kane Bank, Global Terminal, and MRI-3 mitigation sites have generally increased since construction to the point that most sampling locations now have levels exceeding the Effects Range-Median (ER-M); (Long *et al.* 1995) (see Figures 1 through 4)[1]. The ER-M is a correlative relationship between toxic effects observed in sediment-dwelling organisms to bulk chemical concentrations above which affects frequently occur.

Mercury concentrations at Global Terminal have steadily increased since the completion of construction in 2012, with levels at all sampling locations exceeding the ER-M in 2014 (Figure 1). At Kane Bank, mercury sediment concentrations increased at all sampling locations from 2012 to 2013, with 10 of 12 samples exceeding the ER-M in 2013 (Figure 2). Unfortunately, the

[1] The effects thresholds identified in this review were presented in the site reports and do not necessarily represent those recommended for use by the Service. However, these thresholds are used herein to simplify the discussion regarding the potential for re-contamination and, concomitantly, the viability of mitigation projects in the Meadowlands.

Kane Bank has not been compliant with their Corps permit and contaminant data were not collected after 2013. The most robust dataset exists for MRI-3; at this project site, mercury concentrations at all sampling locations were higher in 2014 than in 2012, with the ER-M being exceeded in nine of ten samples collected in 2014 (Figure 3). Average mercury concentrations at each project site have increased steadily since construction as well (Figure 4). Thus, despite the replacement of two feet of contaminated material with clean fill during construction and the requirement of strict performance standards to maintain high-quality habitats, the post-construction data obtained thus far appear to indicate that these banks are becoming recontaminated with mercury.

Mummichog mercury concentrations have been consistently measured at levels of ecological concern and may be rising. Average values measured in fish for every sampling event at Global, MRI-3, and the Kane Bank exceeded the protective level for wildlife consumers of aquatic biota identified by the Canadian Council of Ministers of the Environment (2001) (Figure 5). Additionally, while fish mercury concentrations at Global and MRI-3 have not increased consistently over time at every sampling location, concentrations at five of the six locations, along with average values for each bank, were higher in 2014 than in 2012 (Figures 5 through 7). Mercury concentrations in fish at the Kane Bank were about the same during the single post-construction monitoring event as they were at construction.

At another Corp-permitted mitigation project in the Meadowlands, Secaucus High School (constructed in 2005), post construction data indicate that mercury concentrations in sediment exceeded the ER-M at two of six sampling locations in 2007 and at all six sampling locations in 2008 (Figure 8).

A re-evaluation of PCDD/F data, incorporating results from 2014 sampling events and excluding those from October 2012 (it was revealed in January 2014 that samples collected in October 2012 were analyzed for PCDD/Fs using a different analytical method, so the results are not comparable) did not indicate a trend of increasing concentrations at Global or MRI-3 (Figures 9 through 14). Given that comparable data are only available for two years, however, it is premature to draw firm conclusions; hopefully continued monitoring will demonstrate that concentrations are, indeed, stable or declining. Notwithstanding, of lingering concern is that sediment concentrations of 2,3,7,8-TCDD and the 2,3,7,8-TCDD Toxic Equivalents (TEQs[2]) at most sampling locations exceeded the Apparent Effects Threshold (AET), the value above which adverse impacts to aquatic biota are predicted (NOAA 2014), with the maximum TEQ approximately 20 times the AET in 2013 and 10 times the AET in 2014. Furthermore, the average TEQ exceeded the AET at both Global and MRI-3 in 2013 and 2014 (Figure 13), while the average 2,3,7,8-TCDD concentration exceeded the AET at MRI-3 in 2014 and at both MRI-3 and Global in 2013 (Figure 14).

The evaluations presented in the annual mitigation bank monitoring reports focus primarily on mercury, and secondarily on PCDD/Fs. However, the effects of these contaminants are not independent and are frequently synergistic or additive. Other compounds, such as PCBs and polycyclic aromatic hydrocarbons, are also prevalent in the Meadowlands. The potential impacts

[2] The Service does not recommend applying TEQs to sediment for the purpose of risk evaluation. However, for the purposes of discussion, TEQs are being used to evaluate re-contamination over time.

from PCDD/Fs, in particular, cannot be fully assessed without considering dioxin-like PCBs, which act through the same receptor-mediated mechanism of action as PCDD/Fs and therefore exert additive toxicity (Van den Berg, *et al.,* 1998; Rice *et al*., 2003).

Other Considerations

Consistency

An objective of the CWA is "… to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." As such, construction of mitigation projects that may increase the likelihood of exposure of aquatic-dependent organisms to unsafe levels of hazardous substances such as mercury, PCDD/Fs, and PCBs is inconsistent with and counter to Congressional intent and mandate of the CWA.

Applicability

During other CWA coordination projects with the New York District Corps (Constable Hook Marine Preservation Mitigation Bank [Upper New York Bay], Tremley Point Mitigation Bank [Rahway River], Evergreen Hackensack Mitigation Bank [Hackensack River], Piles Creek Mitigation Bank [Arthur Kill], Saw Mill Creek [Arthur Kill], and the Port Reading Mitigation Bank [Arthur Kill]), the Service raised similar concerns about increased risks to biota from exposure to contaminants or from potential recontamination from known adjacent sources. Some of these projects were abandoned by their sponsors due to the cost of site remediation and/or the potential for recontamination.

Fish Advisories

The New Jersey Department of Environmental Protection (NJDEP) issued fish consumption advisories, including a "Do Not Eat" advisory for several fish and shellfish species, for the Hackensack River, Passaic River, Newark Bay, Arthur Kill, Kill Van Kull and tidal tributaries, due to mercury, PCBs, and 2,3,7,8-TCDD concentrations in these species (NJDEP 2013). Providing additional opportunities for migratory game fish (such as striped bass American eel, bluefish and summer flounder to forage in these contaminated habitats prior to being caught for consumption in other areas could put the public at increased risk of harm.

Conclusions

Preliminary post-construction monitoring data from mitigation bank sites in the Meadowlands indicate that those sites are becoming re-contaminated. This re-contamination appears to be primarily a function of re-establishing hydrological connections of project sites with contaminated waterbodies. The conversion of *Phragmites*- to *Spartina*-dominated wetlands may also increase bioavailability of mercury by both modifying sediment methylation rates and increasing plant uptake through the conversion of *Phragmites* marshes to *Spartina* marshes. Finally, the attractiveness of restored habitats may increase exposure of biological resources to all contaminants prevalent in the Meadowlands, including mercury, PCDD/Fs, and PCBs.

Until the sources of mercury contaminants are remediated, broad scale conversion of mercury-contaminated *Phragmites*-dominated marshes to *Spartina* marshes should be avoided.

Based on the concerns listed above, the Service offers the following recommendations for potential restoration actions in the Meadowlands and surrounding waterbodies, in order of preference:

1. In-watershed restoration in areas where there is negligible/discountable risk to natural resources from contamination or recontamination.
2. Preservation of wetlands that provides substantive ecological services without mobilizing mercury or other contaminants. However, mitigation crediting would need to be adjusted accordingly.
3. Out-of-watershed (but within the Hudson-Raritan Estuary), in-kind restoration with negligible/discountable contamination/recontamination risk.
4. Out-of-watershed and out-of-kind restoration projects that can be considered on a case-by-case basis.

In addition, as a condition of project permitting, a robust site monitoring program should be implemented. This monitoring should include the following methods to evaluate mitigation success criteria:

1. Quantitative measurements of the nature, extent and rate of contamination or recontamination in the appropriate and relevant abiotic and biotic matrices that can be used to evaluate contaminant bioaccumulation, and trophic transfer.
2. Qualitative measurements of restoration effectiveness that evaluate the project’s ability achieve and maintain success criteria.
3. Digital photo documentation of the restoration progress and habitat sustainability.

FIGURES

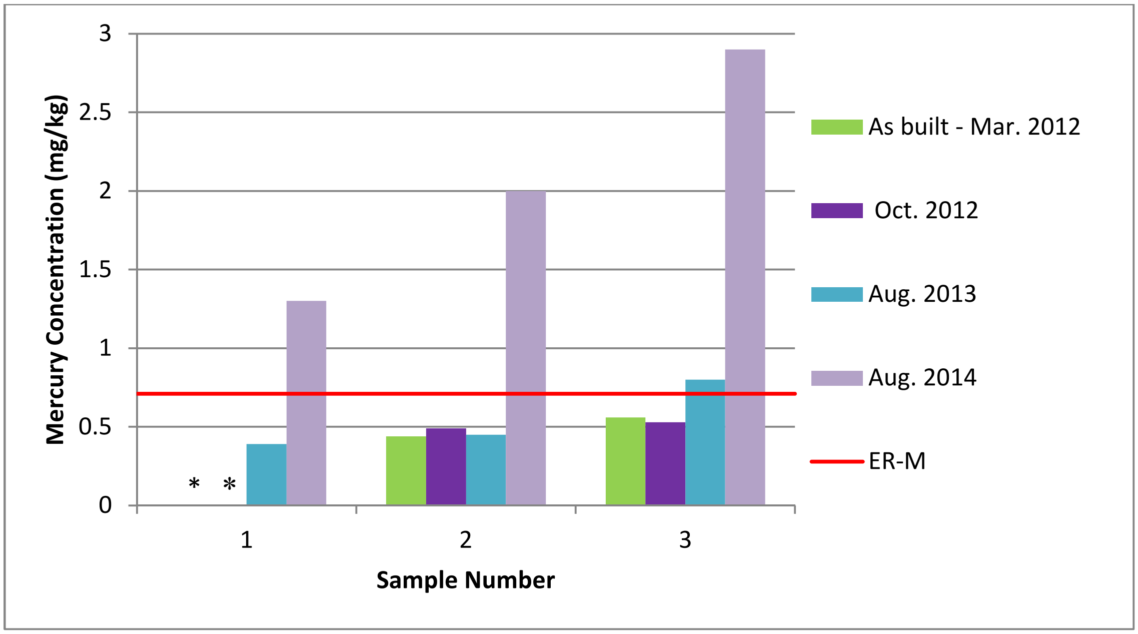

Figure 1. Mercury concentrations in surface sediment at Global Terminal Mitigation Site. ER-M=Effects Range Median; mg/kg = milligrams per kilogram; * = non-detect. The ER-M is the median of reported values in marine and estuarine sediments associated with adverse biological effects (Long *et al.* 1995).

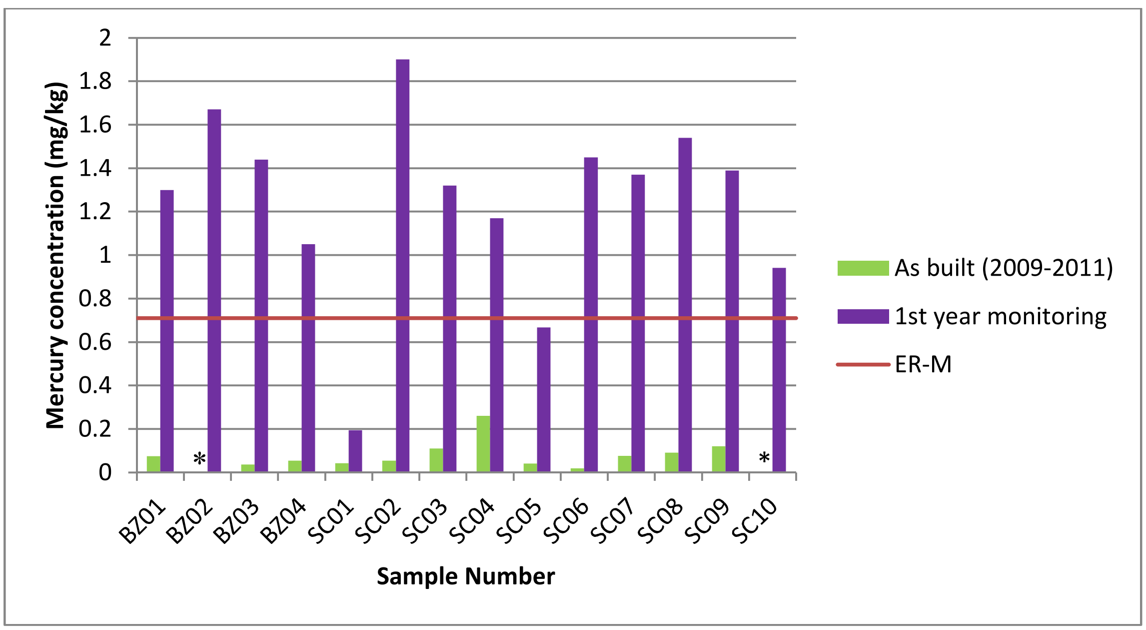

Figure 2. Mercury concentrations in surface sediment at Kane Mitigation Bank. ER-M = Effects Range Median; mg/kg = milligrams per kilogram; * = non-detect. The ER-M is the median of reported values in marine and estuarine sediments associated with adverse biological effects (Long *et al.* 1995).

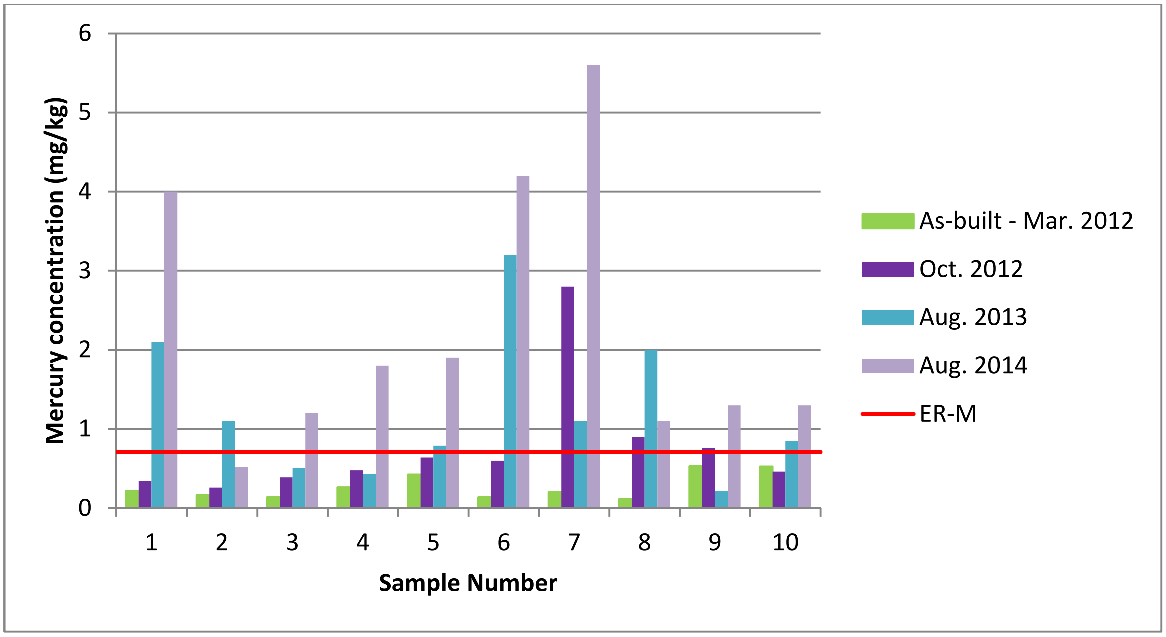

Figure 3. Mercury concentrations in surface sediment at MRI-3 Mitigation Bank. ER-M = Effects Range Median; mg/kg = milligrams per kilogram. The ER-M is the median of reported values in marine and estuarine sediments associated with adverse biological effects (Long *et al.* 1995).

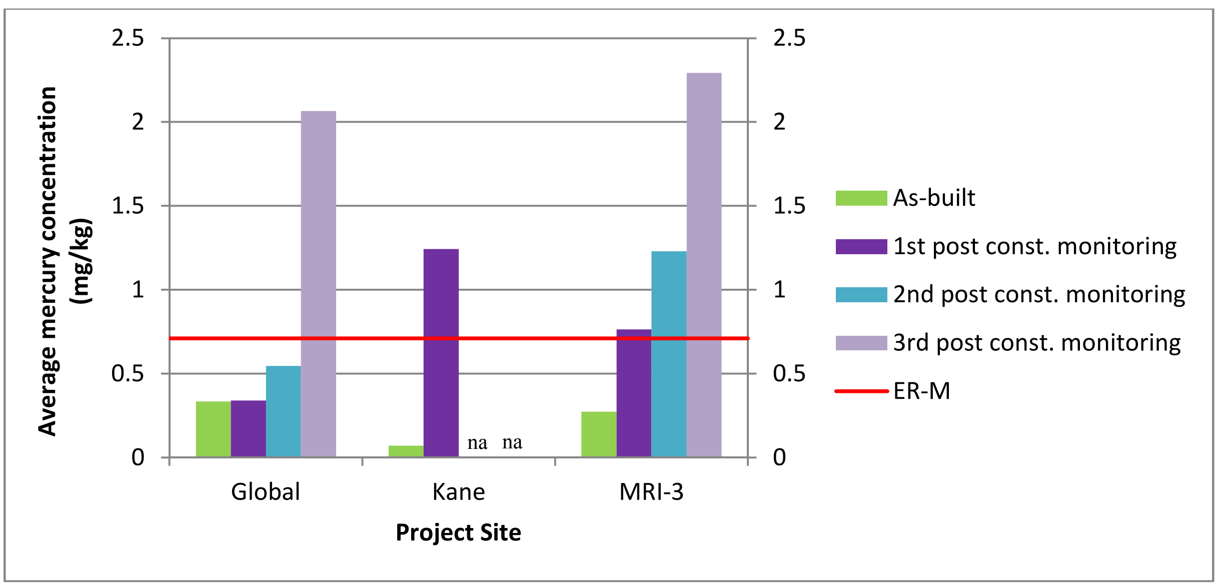

Figure 4. Average mercury concentrations across surface sediment sampling locations at the Global Terminal, MRI-3, and Kane Mitigation Banks. ER-M = Effects Range Median; mg/kg = milligrams per kilogram; const. = construction; na = data not available. The ER-M is the median of reported values in marine and estuarine sediments associated with adverse biological effects (Long *et al.* 1995).

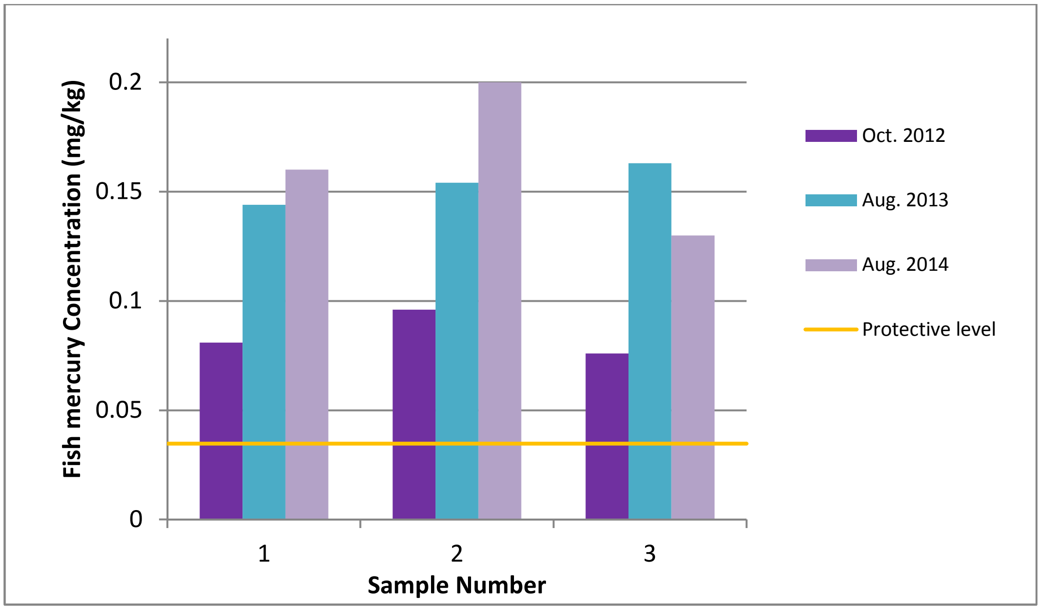

Figure 5. Total mercury concentrations in fish at the Global Terminal Mitigation site. mg/kg = milligrams per kilogram. Note: as-built concentrations not available. Protective level is for wildlife consumers of aquatic biota, based on the value for methylmercury presented in CCME 2001 and converted to a total mercury tissue concentration using a methylmercury:total mercury ratio in prey fish of 0.95 (Weiner and Spry 1996).

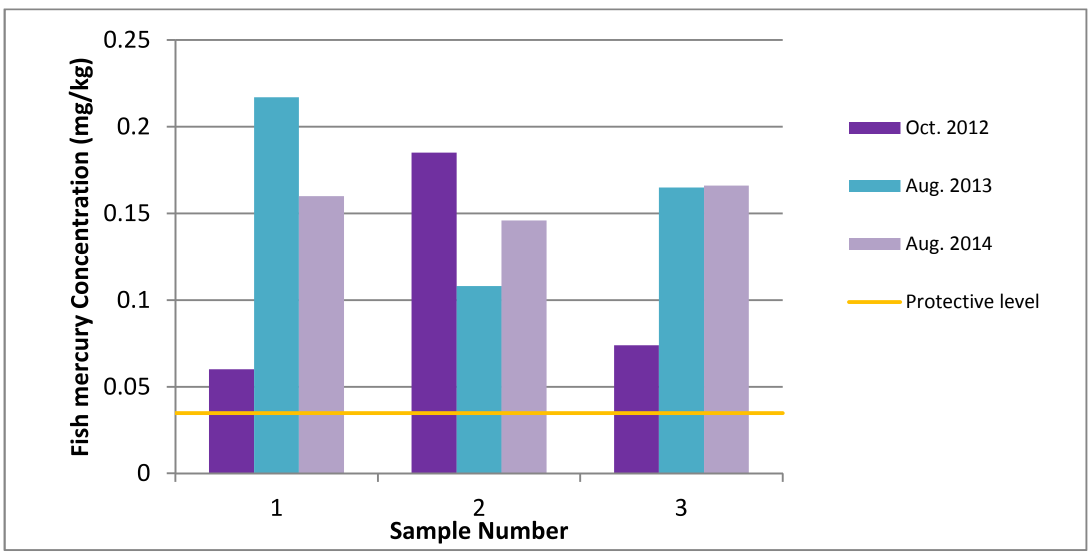

Figure 6. Mercury concentrations in fish at the MRI-3 Mitigation Bank. mg/kg = milligrams per kilogram. Protective level is for wildlife consumers of aquatic biota, based on the value for methylmercury presented in CCME 2001 and converted to a total mercury tissue concentration using a methylmercury:total mercury ratio in prey fish of 0.95 (Weiner and Spry 1996).

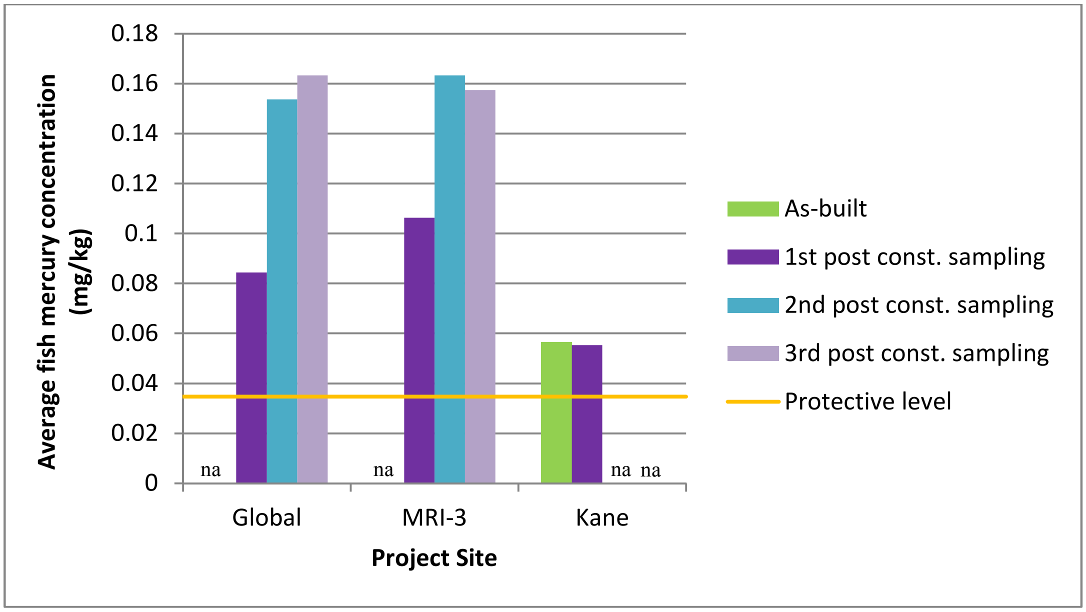

Figure 7. Average mercury concentrations in fish at the Global Terminal and MRI-3 Mitigation sites. mg/kg = milligrams per kilogram; const. = construction; na = data not available. Protective level is for wildlife consumers of aquatic biota, based on the value for methylmercury presented in CCME 2001 and converted to a total mercury tissue concentration using a methylmercury:total mercury ratio in prey fish of 0.95 (Weiner and Spry 1996).

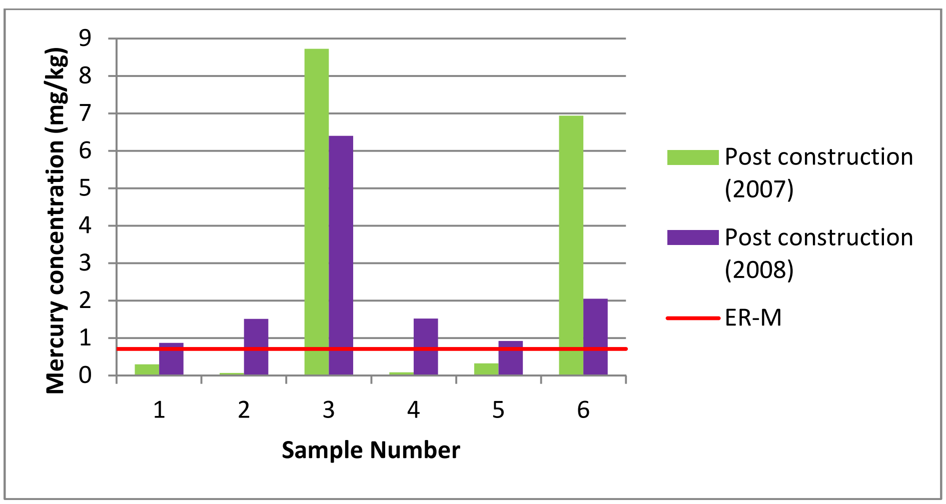

Figure 8. Mercury concentrations at Secaucus High School Restoration Site. ER-M = Effects Range Median; mg/kg = milligrams per kilogram. The ER-M is the median of reported values in marine and estuarine sediments associated with adverse biological effects (Long *et al.* 1995).

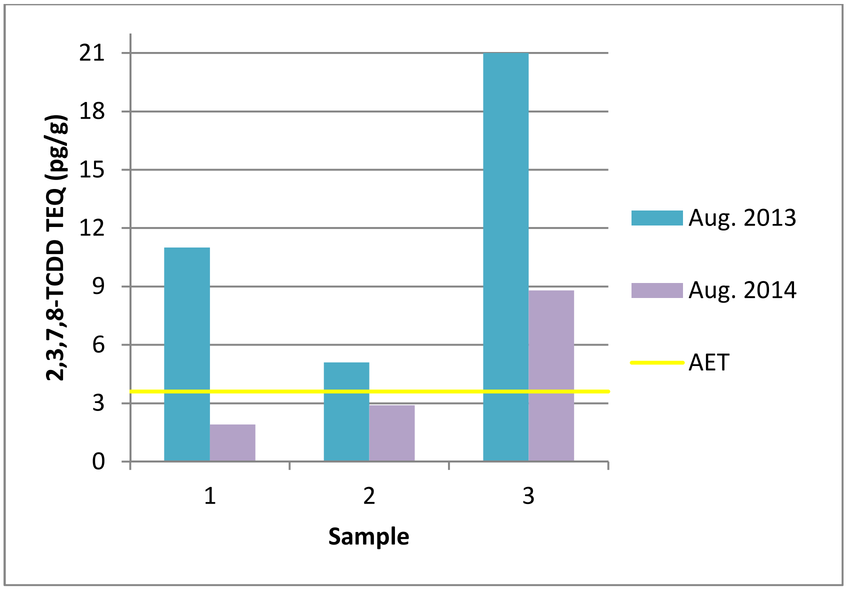

Figure 9. 2,3,7,8-TCDD toxic equivalent concentrations in surface sediment at Global Terminal Mitigation Site. TEQ = toxic equivalents; pg/g = picograms per gram; AET = Apparent Effects Threshold (Buchman 2008). The AET is the highest concentration associated with a nontoxic sample; thus concentrations above the AET are predictive of adverse impacts (NOAA 2014). Note: Values for 2012 are not included because they were obtained using a different analytical method and are therefore not comparable to data for other sampling events (M. Rena, pers. comm. 2014). As-built concentrations are not available.

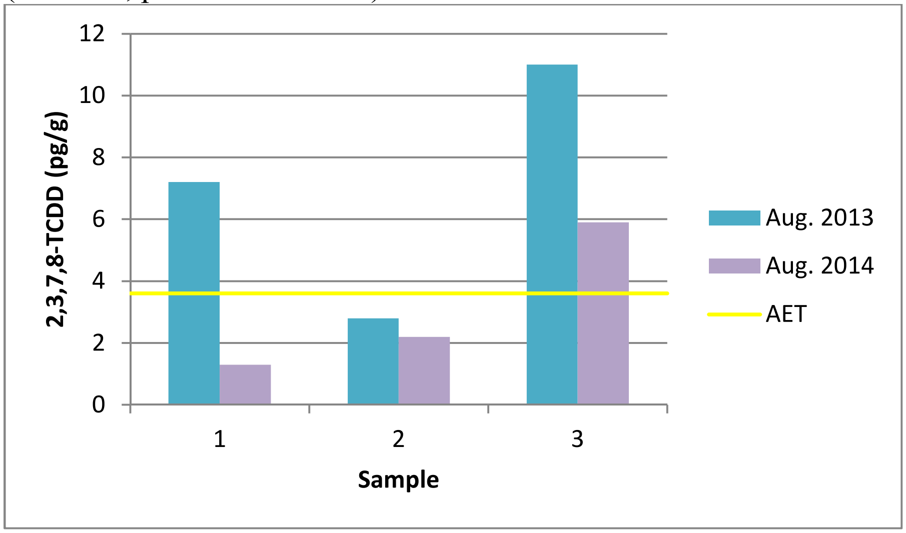

Figure 10. 2,3,7,8-TCDD concentrations in surface sediment at Global Terminal Mitigation Site. pg/g = picograms per gram; AET = Apparent Effects Threshold (Buchman 2008). The AET is the highest concentration associated with a nontoxic sample; thus concentrations above the AET are predictive of adverse impacts (NOAA 2014). Note: Values for 2012 are not included because they were obtained using a different analytical method and are therefore not comparable to data for other sampling events (M. Rena, pers. comm. 2014). As-built concentrations are not available.

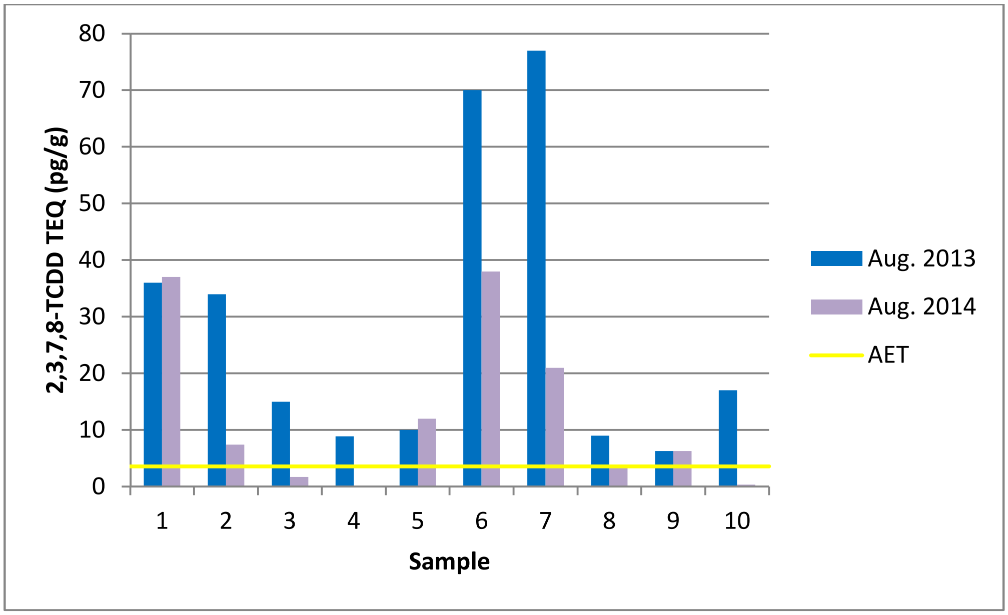

Figure 11. 2,3,7,8-TCDD toxic equivalents in surface sediment at MRI-3 Mitigation Bank. TEQ = toxic equivalents; pg/g = picograms per gram; AET = Apparent Effects Threshold (Buchman 2008). The AET is the highest concentration associated with a nontoxic sample; thus concentrations above the AET are predictive of adverse impacts (NOAA 2014). Note: Values for 2012 are not included because they were obtained using a different analytical method and are therefore not comparable to data for other sampling events (M. Rena, pers. comm. 2014). As-built concentrations are not available.

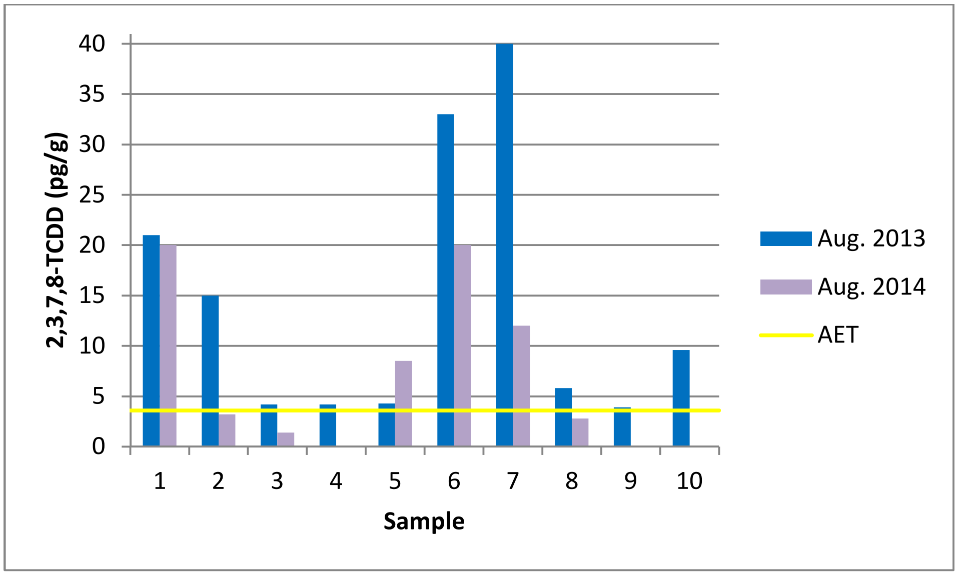

Figure 12. 2,3,7,8-TCDD concentrations in surface sediment at MRI-3 Mitigation Site. pg/g = picograms per gram; AET = Apparent Effects Threshold (Buchman 2008). The AET is the highest concentration associated with a nontoxic sample; thus concentrations above the AET are predictive of adverse impacts (NOAA 2014). Note: Values for 2012 are not included because they were obtained using a different analytical method and are therefore not comparable to data for other sampling events (M. Rena, pers. comm. 2014). As-built concentrations are not available.

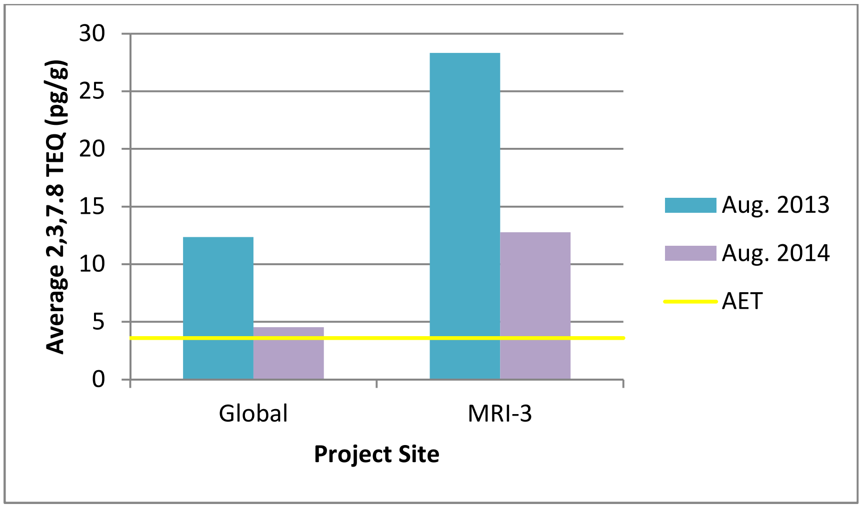

Figure 13. Average 2,3,7,8-TCDD toxic equivalent concentrations in surface sediment at MRI-3 and Global Mitigation Banks. TEQ = toxic equivalents; pg/g = picograms per gram; AET = Apparent Effects Threshold (Buchman 2008). The AET is the highest concentration associated with a nontoxic sample; thus concentrations above the AET are predictive of adverse impacts (NOAA 2014). Note: Values for 2012 are not included because they were obtained using a different analytical method and are therefore not comparable to data for other sampling events (M. Rena, pers. comm. 2014). As-built concentrations are not available.

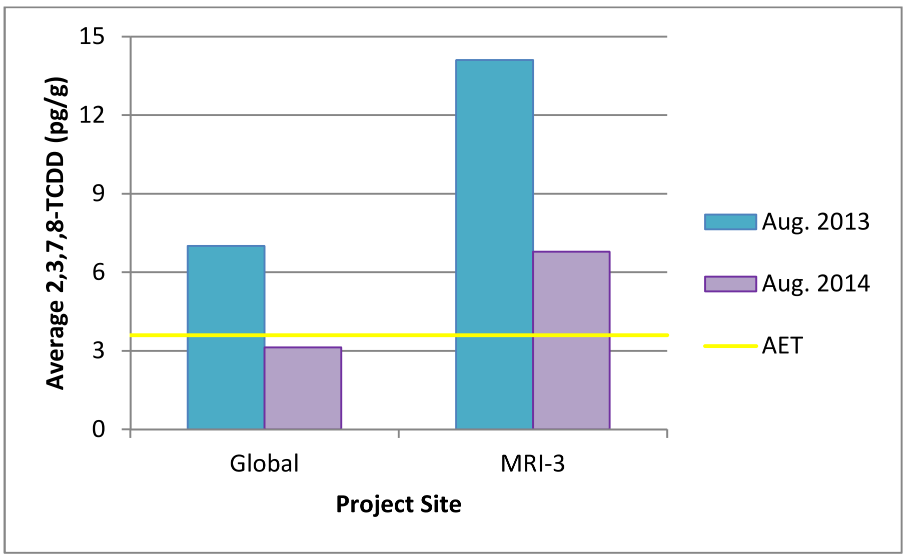

Figure 14. Average 2,3,7,8-TCDD concentrations in surface sediment at MRI-3 and Global Mitigation Banks. pg/g = picograms per gram; AET = Apparent Effects Threshold (Buchman 2008). The AET is the highest concentration associated with a nontoxic sample; thus concentrations above the AET are predictive of adverse impacts (NOAA 2014). Note: Values for 2012 are not included because they were obtained using a different analytical method and are therefore not comparable to data for other sampling events (M. Rena, pers. comm. 2014). As-built concentrations are not available.

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