# Technical Memorandum

## Investigation of Best Management Practices to Limit Loadings of Methyl Mercury Associated with Planned Dredging Activities in Sacramento and San Joaquin River Deep Water Ship Channels

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**Prepared for:**

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# 1. Introduction

In 2009, Applied Marine Sciences, Inc. (AMS) conducted water quality sampling within dredge spoil ponds associated with maintenance dredging conducted by Ross Island Sand and Gravel Company (Ross Island) in the Sacramento and San Joaquin River Deep Water Ship Channels (DWSCs). The monitoring was designed to answer two basic questions: (1) Is methyl mercury (MeHg) being produced within the dredge ponds; and (2) Do MeHg concentrations in pond water decrease over time. Results of this investigation suggested that the concentration of MeHg within DMP ponds increased rapidly within the first two weeks after pumping began. There was typically a slight decrease in MeHg after reaching a maximum concentration, but water MeHg concentrations did not return to the initial concentrations measured at the start of pumping.

On February 23, 2010, representatives of the Central Valley Regional Water Quality Control Board (Water Board), Port of West Sacramento, Port of Stockton, US Army Corps of Engineers (USACE), Ross Island, and AMS met at the Water Board offices in Rancho Cordova to discuss the results of the 2009 investigations and implications for future dredging activities. At that time, USACE representatives asked AMS and Ross Island personnel to coordinate development of a proposed monitoring framework with the goal of identifying and testing Best Management Practices (BMPs) to minimize new loadings of MeHg to ship channels associated with discharge from DMP site ponds.

This memorandum provides a general summary of mercury methylation processes and identifies possible BMPs that may be considered for testing purposes associated with dredging activities in 2010 and beyond. We have researched and attempted to list the full spectrum of ideas in order to start a comprehensive list and initiate discussions. It is our goal that this process will identify some BMPs that warrant investigation, others that can be disregarded immediately, and others that show promise but require further review. It should be noted that the plan of study discussed herein does not contain the goal of determining the environmental fate of mercury associated with dredging activities and is limited to minimizing direct loadings of MeHg to the Delta.

### 2. Mercury Methylation

In aquatic environments, inorganic mercury is typically transformed to the biologically available form, MeHg, by sulfate-reducing bacteria (SRB) within the oxic-anoxic boundary zone in sediments (Tetra Tech, Inc., 2006). These conditions in San Francisco Bay are typically found within organic-rich sediments, where oxygen consumed by bacterial respiration outstrips its replenishment via pore water diffusion and active mixing (e.g., by bioturbating organisms). The upper 2 to 10 cm of shallow water sediments typically represent a mosaic of oxic and anoxic microhabitats as a result of microbial degradation and benthic bioturbation (Fenchel, 1996). The chemical conditions that influence the process and rate of mercury methylation are complex, and depend on numerous factors, including redox (Eh) and pH, the concentration of inorganic mercury, available organic carbon, and concentrations of organic and inorganic complexing agents (Ullrich et al., 2001).

### 3. BMPS for Addressing Potential Loads

The study of mercury methylation processes has received a great deal of recent attention and investigation. As a result, many of the potential BMPs that may be considered for use associated with DWSC dredging operations have been previously studied. By and large, these investigations have taken the form of laboratory experimentation and have not encompassed the complexity associated with large-scale field investigations.

The following sections survey the relevant literature to present BMP options available for consideration. BMPs can be broadly grouped into three main categories: (1) those that prevent or limit methylation within the ponds themselves, (2) those that treat outflow to remove / transform MeHg before rejoining the Delta system, and (3) other BMPs, or those that involve no actual treatment, but rather rely upon management actions to achieve pre-defined goals. The descriptions below contain information on each individual BMP, its mechanism for action, relevant references for previous investigations, likelihood of effectiveness, and implications for implementation. This information is also summarized in a table at the end of this document.

We have attempted to incorporate all BMPs that we are aware of at this time, even those with little opportunity for success, with the idea of generating a broad spectrum of alternatives for consideration by the cooperating organizations. It is our hope that this document will foster discussions that will lay out a feasible strategy for moving forward over the next few years to better understand potential BMPs and identify those with best likelihood for success.

## 4. BMPs That Limit Methylation Within Dredge Ponds

The following BMPs share the common goal of affecting chemistry within the dredge ponds as a means of inhibiting the mercury methylation process prior to discharge.

### *4.1. Discharge site water early*

The purpose of the DMP ponds is to allow suspended sediment to settle out of the dredged sediment/water slurry so that any discharge from the ponds would not negatively impact relevant water quality objectives for suspended material. Monitoring during 2009 found that SSC in the DMP site ponds decreased significantly in the first three days of inflow and MeHg production increased rapidly during the first 1-2 weeks. Therefore, it may be possible to find a point in time after which suspended sediment concentration (SSC) has decreased enough in the ponds and before MeHg has increased significantly, when the water can be discharged without affecting the water quality of the river. This strategy requires monitoring of SSC and water MeHg to verify that water quality targets are achieved before discharging water. It is possible that a single monitoring effort might establish an optimal timeframe common to all sites when SSC and MeHg are within established limits.

### *4.2. Remove vegetation*

The vegetation growing within DMP sites before flooding provides organic carbon required by sulfate reducing bacteria (SRB) to methylate mercury in the ponds. Removing the vegetation could reduce the methylating potential at a site due to the available organic carbon. In addition, this would remove Hg adsorbed by the plant material during previous seasons, as well as the potential anoxia due to decomposition of the vegetation. This strategy would involve scraping the vegetation from the soil with a bulldozer before a site is flooded. Scraping is preferable, because disking or turning the vegetation into the soil would require specialized equipment and would likely enhance the availability of organic carbon by mechanically breaking up the vegetation. Scraping would also remove existing animal waste on the site before flooding, like that of cows and sheep found at the S-31 and Scour Pond sites during the 2009 monitoring. A limitation of this approach is that it would not reduce the inorganic mercury and organic matter pumped onto a site during dredging. It is possible that scraping could expose buried organic matter and Hg in the underlying soil, which could counter the purpose of this strategy. Additionally, because vegetation acts as a baffle to drop out suspended sediment from the water, sites with no vegetation might be expected to take longer for SSC to decrease. A key consideration for this strategy would be determining the appropriate reuse of the removed soil and plant biomass. We recommend that this strategy be considered a strong candidate for testing during 2010 monitoring.

### *4.3. Cap site soil*

Capping the existing DMP site soil with clay could isolate the organic carbon and inorganic Hg, and reduce the MeHg that diffuses during methylation in sediments. However, this would decrease the holding capacity of ponds, require a relatively large amount of effort and expense, and would not affect the Hg and organic carbon pumped onto a site from the DWSCs during dredging. We do not recommend investigating this BMP.

### *4.4. Remove site soil*

Removing the soil at a given DMP site could reduce the amount of inorganic Hg and organic carbon available for methylation. However, this approach, like capping, does not address the Hg and carbon pumped onto a site during dredging. We do not recommend this BMP for 2010, but suggest that it might provide a useful test in future years to address the contribution of Hg and TOC from existing soil versus river sediments and algal productivity.

### *4.5. Burn soil and vegetation*

Burning the soil and vegetation at a DMP site before it is flooded could reduce MeHg production by removing Hg and organic carbon used by SRB. Mineralizing the soil organic matter (including existing animal waste) through combustion could minimize the potential anoxia in site waters resulting from its decomposition when water is added. Additionally, the charcoal created during burning may bind aqueous Hg and MeHg to remove it from the water column. This strategy is similar to removing vegetation with a bulldozer as discussed above, but is likely more effective and does not require considering reuse issues of soil and biomass. However, burning has some potentially significant drawbacks. Specifically, the particulate matter and Hg emitted during a controlled burn may be prohibited due to air quality restrictions. Also, controlled burns may be costly to manage and there is a risk of damage to the surrounding area. Additionally, although the total amount of Hg and MeHg may be reduced using this strategy, there is evidence suggesting that remaining carbon fractions in the water may increase the uptake of MeHg by biota if the water were discharged into rivers. Because of its potential effectiveness, we recommend that this BMP be considered further to determine its feasibility in the face of its potential drawbacks.

### *4.6. Demethylate via photodegradation*

Breakdown of MeHg in water via sunlight is a natural process. Monitoring during 2009 suggested that photodemethylation does not reduce water MeHg concentrations to baseline levels, even in very shallow (< 3 cm) ponds. This BMP is passive and does not require additional effort. However, it is unlikely that the effect can be enhanced, because light penetration in the DMP site ponds is restricted due to high SSC and TOC.

### *4.7. Aerate ponds*

Aerating the DMP ponds could alter the redox conditions of anoxic bottom sediment, which could decrease the methylation rate. However, aerating extensive, shallow ponds could be difficult, and would likely result in increased SSC. In addition, dissolved oxygen measurements during 2009 found large fluctuations, with concentrations that were often above atmospheric saturation (~ 8 mg/L), despite elevated MeHg. Therefore, the effectiveness of this strategy is questionable in DMP ponds.

### *4.8. "Pre-wet" soils*

We were unable to identify supporting documentation, or a mechanism for action, that would suggest this as an effective BMP. We therefore do not recommend it for further investigation.

### *4.9. Maintain permanent ponds*

Permanent ponds may remove MeHg from other water sources through sedimentation of MeHg-associated particles and burial of plants that adsorb MeHg (Stephenson et al., 2009). However, this approach has not been tested in situations similar to those at DMP sites, and would involve maintaining water depth at all DMP sites year-round, which would require water additional water rights not currently allocated. Additionally, keeping the ponds partially filled would reduce the capacity of dredged material that they could hold, so more DMP sites would be required. For these reasons, we do not recommend further review of this BMP.

### *4.10. Phytoremediation*

Phytoremediation is the use of plants to remove hazardous materials from the environment through uptake of a bioavailable form. This approach is typically used in applications for hazardous waste sites, so it has been applied at landscape scales, but removal efficiencies at lower concentrations are unknown. Phytoremediation is a promising technology, but background information is lacking that would make this a likely candidate for implementing in 2010. For example, King et al. (2002) found that the submerged macrophyte *Potamogeton pusillus* helped to reduce dissolved mercury concentrations and enhance demethylation potential in wetland mesocosms, but landscape-scale application of such a technique in shallow, short-lived ponds similar to the DMP sites has not been tested. If there is interest in pursuing this as a BMP, we can conduct further research into possible applications of the technology. Additionally, a few soil total mercury samples could be incorporated into the sampling scheme for 2010 to determine the potential usefulness of this approach by establishing baseline conditions.

### *4.11. Mix bottom sediments*

It is possible that resuspending the bottom sediments in DMP site ponds could decrease water MeHg concentrations by increasing the Hg binding sites provided by clay particles (e.g., Hecky et al., 1987 as cited in Mailman et al., 2006). However, this approach has not been investigated in shallow ponds like the DMP sites. Additionally, resuspending the sediments would result in increased SSC, which is opposite of the effect desired if the water is to be discharged. Moreover, it would take considerable effort to mix the sediments using construction equipment. We therefore do not recommend investigating this BMP further.

### *4.12. Add selenium*

Amending the soil of DMP sites with 2.5-5.0 μg/g sodium selenite (Na2SeO3) before pumping water onto the site may significantly reduce the methylation rate of Hg and increase demethylation (Jin et al., 1997, 1999). However, the effect on methylation varies considerably with soil oxygenation and selenium concentration. Lower selenium concentrations (0.25 μg/g) may stimulate methylation in anaerobic sediments, whereas water concentrations above 2 μg/L can be toxic to aquatic biota. Because selenium is another TMDL pollutant within the Central Valley, this option is not recommended for further study.

### *4.13. Add iron*

Adding ferrous iron (3.9 mg/g) to site soil has been shown to reduce Hg methylation rates in anoxic wetland sediments by decreasing Hg-sulfide complexes used by bacteria during methylation (e.g., Mehrotra and Sedlak, 2005). However, the effectiveness of this approach in the shallow, short-lived ponds on DMP sites in unknown. The amount of iron to add is important, because a lower Fe(II) dose may have the undesired effect of stimulating methylation. Additionally, pyrite is expected to build up in the amended sediments. We recommend against this BMP for 2010 and future investigation efforts.

### *4.14. Add nitrate*

Adding 1-10 mg/L nitrate to DMP ponds when dissolved oxygen becomes depleted may reduce the flux of MeHg from sediments into the pond water by providing additional electron acceptors to microbial reactions (Auer et al., 2008). However, this approach has not been tested on the scale of the DMP ponds. Additionally, nitrate in the pond waters may stimulate algal growth in receiving waters if the water is discharged. We recommend against investigating this approach.

### *4.15. Add lime*

In acidic systems ($pH < 5$), less Hg is transported from the water to the atmosphere during equilibrium conditions (Mailman et al., 2006 and references therein). Adding lime can neutralize the water pH to allow more Hg to escape in gaseous form, thereby reducing the Hg available for methylation. The DMP site waters are not acidic, so this BMP does not apply. We do not recommend investigating this BMP.

### *4.16. Add sulfate*

Although adding sulfate (CaSO4) to DMP site soil may remove inorganic Hg through precipitation, this has been shown to increase the methylation of remaining mercury (e.g., King et al., 2002). This BMP would likely have the opposite effect desired, so we recommend against it.

## 5. BMPs That Treat Outflow

The following BMPs ignore the mercury methylation processes occurring within the dredge ponds and attempt treatment of discharge from the ponds themselves. As such, they are reliant on mechanical processes that could be installed at the pond outfall areas.

### *5.1. Centrifuge discharge water*

Centrifuging discharge water would likely reduce MeHg concentrations by removing particles within the discharge to which mercury particles are adsorbed. We were unable to locate documentation of this treatment being applied in similar applications to the DMP sites, but understand there has been some discussion of its use associated with suction dredge mining in the Sacramento River system. For this reason, we recommend against investigating centrifuging during 2010, but suggest gathering more information on its applicability as a BMP for future years.

### *5.2. Treat discharge water with activated carbon*

Previous investigations have shown that treatment systems incorporating activated carbon are able to decrease total mercury concentrations in wastewater (e.g., Tonini et al., 2003). We were unable to locate any investigations attempting a similar type of MeHg removal as under discussion for the DMP sites, but would recommend contacting an industry representative to better understand what current technologies exist and whether they show promise for this application. As such, we would recommend eliminating this BMP for consideration in 2010, with possible follow-up in future years.

## 6. Other BMPs

### *6.1. Retain site water*

Perhaps the most effective strategy with the least amount of effort would be to avoid discharging water from DMP site ponds to receiving waters, as was done during maintenance dredging of the Sacramento and San Joaquin DWSCs in 2009. Regardless of the MeHg generated in pond waters, if the water does not enter the rivers, it is not an issue at this time. Water in the ponds would be allowed to evaporate or percolate into the soil. This strategy would be effective when existing DMP capacity can accommodate the amount of material dredged within a given reach. However, additional capacity will likely be needed in some years, especially associated with future DWSC deepening activities. This may prove an effective BMP in some cases where additional storage capacity can be arranged through, for example, identification of additional DMP sites adjacent to current sites or by periodic sediment removal from within existing ponds.

### *6.2. Discharge site water to beneficial uses*

Rather than discharge DMP site elutriate containing MeHg concentrations above targets back into the Sacramento and San Joaquin Rivers, this water could instead be discharged to a beneficial use. Examples of such beneficial uses could include agricultural fields or landscape irrigation for which Hg concentrations were not deemed an important consideration. Such beneficial uses that are unaffected by the MeHg concentration in discharged water would first need to be identified. The water would need to be discharged to a nearby location (e.g., adjacent agricultural fields), but the water must not be allowed to reenter receiving waters (e.g., via agricultural irrigation ditches). Alternatively, the water could be pumped into a barge or truck for transportation offsite, although transportation costs may be prohibitive. We do not recommend investigating this BMP for 2010, but could work to identify possible beneficial uses in future years if requested by the DMP dredging partners.

### *6.3. Mercury offsets*

Depending on the feasibility of other BMPs for controlling MeHg and Hg loadings associated with discharge from DMP sites, the best option may be to assist in controlling system-wide loadings of mercury to the Delta by participating in a mercury offset program in which greater reductions in loading / methylation can be achieved through funding projects unrelated to dredging. This is similar in concept to a process started by Sacramento Regional County Sanitation District (SRCSD) within its NPDES permit. If this type of process is deemed a high priority, better understanding of loadings of MeHg / Hg within DMP discharge would be required to gauge the type and effort associated with offset actions.

## 7. CONCLUSIONS

The above strategies discuss possible approaches to reduce the MeHg discharged from DMP site ponds back into the Sacramento and San Joaquin Rivers. To properly evaluate the strategies discussed, target concentrations of MeHg and SSC within discharge should be identified as part of the BMP review process.

In general, strategies that require adding chemicals to a site are less likely to be feasible in reducing MeHg concentrations. The chemistry involved is complex, and getting the stoichiometry right in these dynamic systems could be difficult. Additionally, applying chemicals could have very different results at different sites and potentially result in unintended consequences (e.g., lime additions at Roberts Island I in previous years). Soil and water amendment strategies are better studied under controlled conditions in a laboratory before gradually expanding to a landscape scale project like the DMP sites.

Based upon the above discussion, we have identified the following BMPs for consideration by the workgroup. It is not our intent that all be investigated during 2010 field operations, but rather that an orderly process be initiated to identify BMPs of potential interest, those best for implementation in 2010, and any data gaps that may be filled by further review or through potential collaboration with partner organizations.

**Discharge site water early** – This BMP is a likely candidate for 2010. Implementation would involve more frequent collections and analysis of MeHg and SSC in site water over the first two weeks of dredging, with the goal of identifying the optimal timing for discharge. Also, the workgroup would need to determine the target concentrations for MeHg, SSC, and total Hg (if applicable) in discharge water, but not necessarily before field investigation.

**Remove vegetation** - Because this BMP strategy is relatively low-effort and the 2009 monitoring effort identified organic carbon as an important influence on MeHg, we recommend this BMP strategy as a potential BMP for investigation in 2010. Depending on the constraints of DMP sites for 2010, it may be necessary to identify reuse / disposal options for the material removed prior to implementation.

**Burn soil and vegetation** – We do not recommend this BMP for implementation in 2010. However, as a potentially more effective version of removing vegetation, this strategy warrants further review.

**Aerate ponds** - We do not recommend this BMP for 2010, but suggest that more information be gathered to evaluate the potential for creating and aerating a smaller treatment/holding pond from which to discharge water. This would require investigating several facets of its implementation, including how such a holding pond would be constructed at the DMP sites and the treatment capacity of available aerators.

**Phytoremediation** – We do not recommend this BMP for implementation in 2010. However, if this is a BMP of interest to the workgroup, we could solicit information from qualified firms that would address areas of uncertainty for future consideration. This may also involve sampling and analysis of sediment from within dry DMP ponds to better understand site conditions and associated pollutant removal efficiencies.

**Centrifuge discharge water** – We do not recommend this BMP for implementation in 2010. However, if it is of interest to the workgroup, we can review available / promising technologies to gauge their feasibility and effectiveness for future years.

**Treat discharge water with activated carbon** - We do not recommend this BMP for implementation in 2010. However, if this approach is of interest to the workgroup, we can review the technology to gauge its feasibility and effectiveness for future years.

**Retain site water** – There are no fieldwork implications for this BMP. As appropriate, the workgroup can investigate options for extending storage capacity of DMP sites.

**Discharge site water to beneficial uses** - There are no fieldwork implications for this BMP. As appropriate, the workgroup can investigate options for collecting and reusing site water rather than discharging it back to the rivers.

**Develop mercury offset program** - Water Board staff can update the workgroup on the mercury offset program currently under consideration for SRCSD. If that program is determined feasible, these efforts may be able to piggyback off of previous work conducted by SRCSD and its partners. There would likely be some small fieldwork component to better understand loadings of MeHg and Hg within the discharge, but not an immediate need.

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**Table 1. Strategies to minimize MeHg discharged from DMP site ponds to receiving waters.**

| Strategy | Effectiveness | Effort | Process Affected | Actions | Mechanism | Discussion |
|---|---|---|---|---|---|---|
| Discharge site water early | Unknown | Low | Discharge timing | Discharge elutriate back into river at optimal time, after SSC has decreased and MeHg has not yet increased greatly. | Limits methylation. | SSC and MeHg will likely increase when sediments are suspended during the discharge process, so water quality in settled ponds may not be representative of discharged water. |
| Remove vegetation | Unknown | Moderate | Hg source; methylation | Grade soil past root depth to remove existing vegetation from DMP site before flooding. | Removes source Hg retained in soil and vegetation from previous years. Reduces methylation potential by decreasing organic carbon used by SRB. | Soil disturbance during grading may expose buried organic carbon and Hg, thus countering the purpose of the strategy. Must determine what to do with removed (potentially MeHg-contaminated) vegetation. |
| Cap site soil | Unknown | High | Hg source; methylation | Deposit clean clay (low Hg and organic content) on top of DMP site soils. Possible additional amendment with zeolite minerals. | Isolates pre-existing source Hg and organic carbon in surface soils at a site. Minimizes MeHg diffusion from sediment pore water into the water column by creating a barrier at the sediment- water interface. May decrease methylation by binding aqueous Hg to clay particles or zeolite minerals. | Does not address new source Hg and organic carbon pumped on top of the clean capping sediments during dredging. Application potentially costly - must find, transport, and place clean clay and zeolite material at a site. |

| Strategy | Effectiveness | Effort | Process Affected | Actions | Mechanism | Discussion |
|---|---|---|---|---|---|---|
| Remove site soil | Unknown | High | Hg source; methylation | Excavate soil from DMP sites, which contain source Hg and organic carbon deposited during previous use. | Removes existing source Hg and organic carbon at site. | Does not address new source Hg and organic carbon pumped on top of the underlying soil during dredging. Must transport removed soil to a suitable disposal site. |
| Burn soil and vegetation | Unknown | High | Hg source; methylation; MeHg removal | Burn soil and vegetation at DMP sites before flooding | Removes source Hg (reduced to gaseous elemental Hg). Reduces methylation potential by removing organic carbon used by SRB. Minimizes potential anoxia in site waters by mineralizing organic matter that would otherwise decompose. Resulting charcoal may remove Hg and MeHg from the system through binding. | Hg and particulates emitted to atmosphere affect air quality standards, and may not be allowed. Costly and risks damage to surrounding area from losing control of fire. May increase MeHg uptake by biota if water released. Does not affect the source Hg and organic carbon added by dredged material. |
| Demethylate via photo-degradation | Low | Low | MeHg removal | None - Allow site water to be exposed to sunlight. | Converts MeHg to gaseous Hg that would volatilize | 2009 monitoring suggested that photodegradation does not reduce MeHg to starting concentrations, despite shallow, relatively clear water. Light penetration limited by SSC, high productivity, and dark water color (high TOC). |

| Strategy | Effectiveness | Effort | Process Affected | Actions | Mechanism | Discussion |
|---|---|---|---|---|---|---|
| Aerate ponds | Low | High | Methylation | Pump site water into the air with aerator/sprayer to maximize contact with oxygen in the atmosphere. | Alters the redox conditions of anoxic bottom sediment to lower MeHg methylation. | Based on 2009 monitoring results, it seems unlikely that oxygenation of the water would extend into sediment porewater where methylation occurs. May alter redox boundary without affecting methylation. Difficult to aerate ponds, because they are very shallow and this would likely increase turbidity (SSC) of water. Requires maintenance and powering of equipment at each site. |
| "Pre-wet" soils | Low | Low | Methylation | Wet DMP site soils briefly before flooding during dredging operations. Allow MeHg to increase while water evaporates. Then flood sites. | Unknown | No literature references were found to describe this strategy, so it is likely untested. Requires a source of water to apply to sites. Unknown how much water to add and how long to wait after wetting before flooding can begin. |
| Maintain permanent ponds | High | High | Methylation | Pump water into DMP ponds to keep them wet year-round | Sedimentation of MeHg-associated particles and burial of MeHg removed by plant biomass. | Requires constant addition of water (permits). Poorly tested. Decreases amount of dredged material that can be added. Increases risk of discharge to rivers. |
| Phyto-remediation | Unknown | Low | Hg source; methylation | Select and plant appropriate crops. | Adsorbs MeHg from soil and water. | Science in early stages, so effectiveness is unknown. Must harvest and dispose of vegetation after ponds are dry. |

| Strategy | Effectiveness | Effort | Process Affected | Actions | Mechanism | Discussion |
|---|---|---|---|---|---|---|
| Mix bottom sediments | Unknown | High | Methylation; Hg removal | Mix bottom sediments in pond with a bulldozer or by dragging a rake attachment. | May oxygenate bottom sediments to reduce methylating potential. Potentially exposes more Hg-binding sites on suspended clay particles to remove Hg from system. | Untested in shallow ponds. Difficult and time-consuming. Unclear how often to mix sediments. Increases SSC of pond waters, which restricts discharge. |
| Add selenium | Moderate | High | Methylation, demethylation | Add selenium to DMP site soil (2.5- 5.0 ug/g Na2SeO3) before flooding. | May significantly lower rate of methylation and increase the rate of demethylation. | Effect on methylation varies based on sediment oxygen conditions and selenium concentration, with the possibility of stimulating methylation at low selenium concentrations (0.25 ug/g) in anaerobic sediments. Discharge of elevated selenium concentrations in site water (2 ug/L) could cause toxic effects downstream if discharged. Accumulates in sediment. |
| Add iron | Moderate | High | Methylation | Add Fe(II) (3.9 mg/g) to DMP site soil | Reduces methylation by decreasing the bioavailable complexes between Hg and sulfide. | Unknown effectiveness in short-lived DMP ponds. Potentially increased methylation at low iron dose. Formation of pyrite in amended sediment. |
| Add nitrate | High | High | MeHg flux out of sediments | Add nitrate (1-10 mg/L) to DMP site water when oxygen depleted | Provides additional electron acceptors that inhibit MeHg flux out of sediments to the water column. | Untested. Nitrate may stimulate algal blooms in receiving waters if water discharged. |

| Strategy | Effectiveness | Effort | Process Affected | Actions | Mechanism | Discussion |
|---|---|---|---|---|---|---|
| Add lime (low pH systems) | Low | High | Hg source; methylation | Add lime to DMP site soil before flooding. | Transport of elemental Hg across the air-water boundary decreases at lower pH (< 5), leaving more Hg in the water for potential methylation. Lime neutralizes pH so that Hg isn't retained in the water as much. | DMP waters are not acidic (pH = 6.5 to 9.5), so no expected effect. Contradictory information exists regarding the effect of pH on Hg methylation. Fluctuating water levels in DMP sites would make estimating the amount of lime to add complicated. Previous application of lime at Roberts Island I indicates that this could result in unintended consequences. |
| Add sulfate | Low | High | Hg source | Add sulfate to DMP site soil. | Removes inorganic Hg from system via precipitation. | Increases methylation of remaining Hg by forming bioavailable sulfur-Hg complexes. |
| Centrifuge discharge water | Unknown | Unknown | Hg source | Install treatment system at outflow | Physical removal of high-density compounds. | Untested. Unknown flow rate supported. |
| Add activated carbon | Unknown | Unknown | Hg source | Install treatment system at outflow | Adsorbs Hg and MeHg to remove it from water. | Potentially high cost. Unknown flow rate supported. |
| Retain site water | High | High | Discharge location | Allow site water to evaporate or percolate into soil, rather than discharging to the river. Pump dredged material into additional DMP sites when a site's holding capacity is reached. | MeHg in water does not enter rivers. | Requires additional DMP site capacity along dredged reaches. |

| Strategy | Effectiveness | Effort | Process Affected | Actions | Mechanism | Discussion |
|---|---|---|---|---|---|---|
| Discharge site water to beneficial uses | High | Moderate | Discharge location | Discharge elutriate to agricultural fields or other beneficial uses, instead of back into the river. | MeHg in water does not enter rivers. | Must identify beneficial uses unaffected by elevated water MeHg. Alternate discharge locations must be geographically close to DMP site to minimize costs of transporting water. |
| Offsets | High | Unknown | Not applicable | Fund mercury reduction efforts undertaken elsewhere | Not applicable | Need an update from Water Board on status of Sacramento Regional County Sanitation District offset program. If this strategy is a possibility, we may be able to piggyback upon their efforts. Need better understanding of Hg and MeHg loadings in discharge. |