DRAFT Science Synthesis Summary for Issue 7:
Predicting Pollutant Effects on the Biological Functioning of the South Bay

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What is the importance of the issue as it relates to the Project Objectives?

Contaminants have the potential to hinder the success of the Project through four principal mechanisms:

1. increases in wetland habitat may **increase mercury accumulation** in the food web;
2. **legacy sediment contamination** may impact specific restoration sites;
3. restoration may cause a regional increase in South Bay contamination through **accelerating erosion** of buried Bay sediment; and
4. **new inputs** could degrade restored habitat.

Three of the Project Objectives could be adversely impacted by contaminants through these mechanisms. There is a significant potential for contaminants to impact Objectives 1A and 1C, which relate to creation, restoration, or enhancement of habitat for special status species and native species. These objectives could specifically be affected by increased mercury accumulation, legacy sediment contamination, or new inputs. Increased mercury accumulation is the greatest threat, as one of the key special status species benefiting from the Project, the California clapper rail, is particularly vulnerable to mercury (Heinz 2003) and rail eggs in the region already have been found to contain enough mercury to cause embryo mortality (Schwarzbach and Adelsbach 2003) and be a significant factor limiting clapper rail reproductive success in the Bay (Schwarzbach et al. submitted). It is quite possible that increased mercury accumulation could jeopardize the success of the project with regard to restoring clapper rail populations. Risks also exist for other avian species that forage in the South Bay and its marshes and salt ponds, including Caspian and Forster's terns (Schwarzbach and Adelsbach 2003). Objectives 1A and 1C may also be impeded by the impacts of legacy sediment contamination at specific sites. Legacy contaminants that have been found at high concentrations in the sediment and food webs of marshes and salt ponds around the Bay include mercury, PCBs, and DDT (Hunt et al. 1998, Schwarzbach et al. 2001, Schwarzbach and Adelsbach 2003, BCDC 2004, Beutel and Abu-Saba 2004). Finally, new inputs of contaminants pose a potential threat to restored Bay marshes as chemical pollution in the local watersheds surrounding the Bay and in the atmosphere continues. Among the concerns are legacy contaminants such as mercury (which could be introduced via runoff or atmospheric deposition), chemicals in current use such as pyrethroid insecticides (carried by runoff) or polybrominated diphenyl ethers (PBDEs, potentially carried by runoff, wastewater treatment plant effluent, or atmospheric deposition), and contaminants such as PAHs that are still being emitted from combustion sources.

Project Objective 4, "protect or improve water and sediment quality and take into account ecological risks caused by restoration," could be adversely impacted by each of the four mechanisms. Both local and regional impacts of the Project on water and sediment quality are quite possible. Increased wetland habitat could lead to increased mercury accumulation that both affects specific marshes and leads to increased methylmercury export into the open waters of

South Bay, where mercury concentrations in fish are already high enough that a consumption advisory is in effect. Accelerated erosion of buried Bay sediment may occur as circulating sediments are drawn out of the Bay and into the restored marshes. Buried Bay sediment contains relatively high concentrations of mercury, PCBs, DDTs, polycyclic aromatic hydrocarbons (PAHs), and other contaminants that were deposited in the 1950s and 1960s prior to modern controls on pollution (van Geen and Luoma 1999). Erosion of this contaminated sediment could degrade water and sediment quality in the South Bay as a whole. Due to its limited flushing, extensive urbanization, and large volumes of wastewater discharge, the South Bay is already highly impacted by contaminants, so the potential adverse impacts of the Project on water quality would be particularly problematic.

Lastly, increased mercury accumulation or accelerating erosion could impact Project Objective 3 ("provide public access opportunities compatible with wildlife and habitat goals") by increasing contamination of sport fish in the South Bay. The consumption advisory for sport fish in the Bay was driven by concentrations of mercury, PCBs, organochlorine pesticides, and dioxins (OEHHA 1994). Concentrations of all of these contaminants could rise due to increased net methylmercury production in wetlands or contaminant remobilization from buried sediment. This could increase human health risks associated with sport fish consumption and prolong the existence of a fish consumption advisory for the region, contributing to limited public access to the Bay fishery.

While contaminant concerns must be seriously considered and addressed, they should not be viewed as a fatal flaw for the SBSP Project. The potential negative impacts of the Project on water quality must be weighed against the positive impacts on habitat, wildlife populations, and beneficial uses of the South Bay. With an adaptive management approach, it should be possible to accrue these benefits while minimizing the negative water quality impacts.

What do we know about this issue as it relates to the Project?

Our understanding of contaminants in the region has increased greatly in the past decade due to several major efforts: the Bay Protection and Toxic Cleanup Program, the Regional Monitoring Program, the Mercury and PCB TMDLs, the CALFED Mercury Project, USGS studies, and US Fish and Wildlife Service studies. Enough knowledge has been gained from these efforts to allow the Project to address contaminant issues in an intelligent manner. However, many questions still remain, especially with regard to mercury, which is probably the water quality topic of greatest concern to the Project. An adaptive management approach, as prescribed by the Mercury Strategy developed by CALFED (Wiener et al. 2003), will allow the Project to continue to gain understanding and better manage water and sediment quality as it proceeds. Enough information is available to support the plausibility of the four hypothesized mechanisms of contaminant impacts on the Project.

Increased Mercury Accumulation

The potential for increased mercury accumulation in the food web to occur and have a significant impact is well-established. Wetlands, especially newly created wetlands, can generally be expected to be sites of enhanced net production of methylmercury, the form which accumulates in the food web and poses risks to humans and wildlife (Davis et al. 2003, Wiener et al. 2003, Beutel and Abu-Saba 2004). Sulfur-reducing bacteria are abundant in wetlands due to the anaerobic conditions that prevail in these organic-rich environments, and these bacteria are the main methylators of mercury. Newly created wetlands have an even greater supply of organic material and exhibit even more net methylation.

While the general expectation is for increased mercury accumulation in restored wetlands, it is likely that distinct spatial variation on multiple spatial scales exists in net methylmercury production in Bay-Delta tidal wetlands, including variation within each tidal wetland, among tidal wetlands in the same region, and among tidal wetlands in different regions (Davis et al. 2003). Understanding this spatial variation and its underlying causes will allow managers to minimize the negative effects of mercury bioaccumulation as a result of restoration activities. Understanding this spatial variation is also a key to being able to accurately monitor tidal marshes and compare findings among marshes.

The potential impacts of increased mercury on the restoration of clapper rail populations is a serious concern. Recent research (Schwarzbach and Adelsbach 2003, Schwarzbach et al. submitted) indicates that mercury may be a significant mortality factor for Bay populations of the California clapper rail, due to a combination of its sensitivity and tendency to accumulate this toxic metal. The CALFED Mercury Project combined laboratory egg-injection studies (Heinz 2003) with field studies of mercury concentrations in eggs (Schwarzbach and Adelsbach 2003). The study examined clapper rails and many other bird species. Clapper rails were found to be one of the most sensitive species, significantly more sensitive than the mallard (which is the species that commonly accepted avian risk thresholds are derived from). This information, coupled with relatively high concentrations of mercury measured in the small number of clapper rail eggs that could be sampled (Figure 1), led Schwarzbach and Adelsbach to conclude that the mean mercury concentration observed in clapper rails of 0.82 ppm in fail-to-hatch clapper rail eggs in this study should be considered embryotoxic. Schwarzbach et al. (submitted) found clapper rail fecundity to be much reduced from rates typical of unimpacted populations. Mercury appeared to exert an adverse influence over clapper rail reproductive success as evidenced by the observation of a depressed rate of hatchability and the exceedance of avian embryotoxic threshold concentrations for mercury. In this study, contamination in the rail eggs (including South Bay marshes sampled in 1991 and 1992) was thought to be responsible for reducing hatchability by 15 to 30%, and mercury was the principal toxicant considered to be causing the reduction. Average mercury concentrations were higher in the South Bay than in the North Bay. Available evidence therefore supports the hypothesis that mercury has adversely impacted clapper rails at the population level in South Bay. Schwarzbach et al. (submitted) stated that a successful recovery strategy for rails will depend on achieving appropriately protective sediment and water quality objectives for mercury within rail habitat in San Francisco Bay.

Other bird species in the region were also found by Schwarzbach and Adelsbach (2003) to accumulate potentially deleterious mercury concentrations. Caspian terns and Forster's terns had mean concentrations above the mallard toxic threshold (Figure 1), with many high concentrations observed in eggs from the South Bay salt ponds. Data for the interpretation of tern eggs is limited to a non-systematic field study of common terns that suggested normal hatchability of tern eggs at mean concentrations of around 1 ppm but severe impairment by mercury to reproduction at concentrations of 3.65 ppm (Fimreite, 1974). Laboratory data are needed for better interpretation of the hazards posed by mercury concentrations found in Bay terns. Avocets, plovers and stilts had variable concentrations with some high eggs at salt pond sites in the South Bay that exceeded the threshold concentrations though means were just under 0.5 ppm. There are not yet data available to provide species specific interpretation of concentrations in the stilts, plovers, and terns but concentrations over 1 ppm in fish eating birds and over 0.5 ppm in nonpiscivorous species should be probably be considered elevated. Study of the potential impacts of mercury on Bay birds is continuing with a project being conducted by USFWS and USGS and funded by the California Bay-Delta Authority. This study will again combine egg injection studies with field collections, and will focus on terns, stilts, avocets, and surf scoters.

Other piscivorous wildlife species, such as harbor seals, are also highly exposed to mercury, though little is known about the potential impacts of this exposure. High mercury concentrations have been found in blood from harbor seals inhabiting San Francisco Bay (Kopec and Harvey 1995). A study by Moss Landing Marine Laboratory is currently underway examining mercury concentrations in blood and fur of harbor seals.

In addition to concerns about the impact of increased mercury concentrations on wildlife, such an increase would also exacerbate the existing problem of human exposure to methylmercury through consumption of sport fish from the South Bay. Increased methylmercury concentrations in the South Bay could lead to regional increases in mercury in sport fish, and even more acute local impacts near restored marshes that have elevated net production of methylmercury.

Legacy Sediment Contamination

Legacy sediment contamination is known to exist in the Bay, its marshes, and its watershed. Layers or patches of elevated concentrations of mercury in sediment are distributed widely due to past activities, especially mercury mining and hydraulic gold mining in the Sierra Nevada. Hydraulic gold mining in the Sierra Nevada resulted in the distribution of mercury-laden sediment throughout the North Bay, and deposits of hydraulic mining debris contaminated with mercury are likely present in many subtidal portions of the Bay-Delta, in some tidal wetlands and diked wetlands, and in the lower reaches of the attending watersheds, especially in the North Bay (Davis et al. 2003). Legacy mercury contamination on the margins of the South Bay are probably more influenced by mercury mining in the local Bay Area watersheds.

Mercury contamination of the South Bay salt ponds has been investigated in recent studies (Beutel and Abu-Saba 2004). Concentrations of total mercury in pond sediments have been found to be quite variable, with many samples well above average concentrations in Bay sediments (0.3 to 0.4 ppm) and even further above the TMDL target of 0.2 ppm (Figure 2). Runoff from the New Almaden mercury mining district probably had a particularly large influence on sediment quality in the salt ponds and the South Bay region historically (Conaway et al. 2004), and runoff from this watershed continues to be a principal source of mercury to the Bay today (SFBRWQCB 2004a). The distribution of legacy mercury in the salt ponds is probably related, among other factors, to the timing of salt pond establishment, which is known to have occurred over the course of nearly a century (Figure 3). An investigation of mercury concentrations in a sediment core from a marsh downstream of the historic New Almaden mining district indicated that mercury concentrations in sediments were greatest, peaking at greater than 1 ppm, between 1950 and 1980 (Conaway et al. 2004), suggesting that a considerable lag occurred between mercury operations at New Almaden and transport to the Bay. Conaway et al. hypothesized that this lag was due to a type of mining performed in the mid 1900s that mobilized greater amounts of mercury and the hydrological characteristics of the watershed.

Mercury from urban runoff and industrial activities also has contributed to the presence of mercury hotspots around the margin of the Bay (SFBRWQCB 2004a). The Bay Protection and Toxic Cleanup Program (Hunt et al. 1998), the RMP (SFEI 2004), and other studies have also documented the presence of hotspots of PCBs, legacy pesticides, and other contaminants in wetlands and other Bay margin habitats (SFBRWQCB 2004b). Tidal marshes adjacent to the U.C. Berkeley Richmond Field Station and Zeneca Corporation in Richmond, provide an example of extreme legacy contamination of Bay tidal marshes. Chemical production at the Zeneca site and local urban runoff have caused this marsh complex to have very high concentrations of mercury (averaging 16 ppm at the UCB site) and PCBs (maximum concentrations over 1,000,000 ppb).

In general, little information is available on contaminant concentrations in Bay marshes and salt ponds, but the existing examples of contaminated marshes suggest that marshes and salt ponds downstream of current or historical discharges of contaminated runoff or effluent are potentially sites of legacy contamination. Prior to initiating restoration projects it would be very important to screen the project site for potential legacy contamination, including mercury and other contaminants.

Accelerated Erosion of Bay Sediment

Accelerated erosion of buried Bay sediment is a potentially serious regional threat to South Bay water and sediment quality. Studies by USGS have shown that the South Bay (Foxgrover et al. 2004) and other parts of the Bay (Jaffe et al. 1998, Cappiella et al. 1999) are undergoing net erosion, largely due to a reduced supply of sediment coming in from the Central Valley (McKee et al. 2002). The Estuary is currently experiencing a sediment deficit (Williams 2003). Opening salt ponds to tidal action will create a new demand for sediment and increase the rate of erosion of buried sediment. This poses a significant problem with respect to recovery of the South Bay from mercury and PCB contamination because the layers of sediment that are being uncovered were originally laid down in earlier decades when the Bay was generally more contaminated (van Geen and Luoma 1999). Bathymetric surveys conducted in 1931, 1956, and 1983 are the basis for the recent analysis of South Bay erosion and deposition by Foxgrover et al. (Figure 4). From 1931 to 1956 (a period with rapid urbanization, industrialization, and little wastewater treatment), the South Bay had widespread deposition of relatively contaminated sediment. From 1956 to 1983 (a period including an era of peak contamination in the 1960s and marked improvements with the onset of wastewater treatment in the 1960s and 1970s), the South Bay experienced net erosion. The erosion and deposition varied by location, with erosion dominating in the northern part of South Bay and deposition dominating in southern South Bay. These long-term patterns of erosion and deposition are a critical piece of information needed to predict the rate of improvement of Bay water quality in decades to come. A new bathymetric survey of the South Bay is being conducted as part of the SBSP Project and will provide the information needed to evaluate the latest trends in erosion.

Like bottom sediments in the Bay, tidal marshes can also store large amounts of contaminants. Tidal marshes can also act as sources of contaminants, as contaminated marsh sediment erodes (Figure 5). An increase in the sediment deficit of the Bay may also accelerate erosion and contaminant remobilization from these marsh sediments. SFEI is currently studying the historical changes in the South Bay marshes and shoreline in the Historical Tidal Marsh Mapping project, funded by the Santa Clara Valley Water District, City of San Jose, Alameda County Flood Control and Water Conservation District, and others.

New Inputs of Contaminants

New inputs of contaminants from the watershed will pose a continuing concern for restored marshes, as they will for the South Bay as a whole. New inputs could enter restored habitat from either adjoining watersheds or the atmosphere. New inputs of a wide variety of contaminants from the watershed are possible, including legacy contaminants like mercury and PCBs, emerging contaminants such as PBDEs and pyrethroid insecticides, and contaminants such as PAHs that continue to be emitted from sources within the watersheds.

PBDEs are an example of an emerging contaminant that is persistent and biomagnifies, and could affect higher trophic level species in restored habitats. PBDE concentrations appear to be rising rapidly in the Bay (She et al. 2002), raising concern that another legacy contamination problem is developing. Virtually undetectable in samples during the 1980s, over the course of the past 10 years PBDEs have become common in the water, sediments, and food web of the Bay. Furthermore, studies of PBDE concentrations in seals, birds, and human blood, fat, and breast milk from the Bay Area have found some of the highest concentrations measured in the world (She et al. 2002, She et al. 2004). A Forster's tern egg from the Bay yielded the highest concentration yet reported in biota *in the world* (She et al. 2004). PBDEs appear to be potentially toxic to humans and wildlife, but the limited evidence available is not conclusive. Concerns about PBDEs led to legislation in 2003 that will ban two PBDE formulations ("penta" and "octa") in California starting in 2006. Another major formulation ("deca"), however, has not been banned. The loading pathways that lead to PBDE accumulation in the Bay include wastewater effluent, urban runoff, and atmospheric deposition. It is expected that PBDE loads will gradually decline once the ban is implemented, but there may be a significant lag between the drop in production and a drop in loads. In the meantime, concentrations will continue to rise and pose a potential health threat to terns and other higher trophic level species in the Project area. Food web monitoring is the best way to track trends in persistent, bioaccumulative contaminants such as PBDEs, mercury, PCBs, legacy pesticides, and dioxins.

Pyrethroids represent another type of emerging contaminant that could affect restored habitats by causing toxicity in fish or aquatic invertebrates and diminishing food resources for special status species and other species at higher trophic levels. The implementation of U.S.

EPA restrictions on the use of organophosphate (OP) insecticides has prompted pesticide manufacturers to turn to using alternatives insecticides to meet market demands. Pyrethroid insecticides are one of the primary replacements of the OPs, and their use has been increasing in recent years. Fish and aquatic arthropods are quite sensitive to pyrethroids, raising concern for possible non-target impacts on aquatic environments due to their use in agricultural, structural, and landscape maintenance applications. Toxicity testing, community assessments, and event-related chemical measurement is the best way to assess impacts of relatively non-persistent, water soluble contaminants such as pyrethroids.

Other contaminants, such as PAHs, have been a concern for many years but continue to be released into the environment and washed downstream into the Bay and its marshes. PAHs in the region primarily originate from motor vehicle exhaust. As population grows in the already densely populated and highly urbanized South Bay region, there is a potential for increases in loads of PAHs and other chemicals that are emitted in proportion to population. PAHs do not accumulate in higher trophic levels, but do pose a threat to aquatic invertebrates and fish. Chemical measurements, community assessments, and biomarker studies are the best way to assess the potential impacts of contaminants like PAHs that are persistent in water and sediment but metabolized by vertebrates (and therefore do not get passed up the vertebrate food chain).

New atmospheric inputs of contaminants, including mercury, into restored habitats are another concern. Recent research suggests that mercury derived from atmospheric deposition may make a disproportionately large contribution to mercury accumulation in the food web (Hintelmann et al. 2002). A hypothesis currently under consideration is that the mercury entering the Bay-Delta from atmospheric deposition alone may be enough to cause the degree of mercury contamination in the food web, as has been observed in other ecosystems (Wiener et al. 2003). A relatively small amount of mercury entering a habitat favoring net methylation may be enough to result in problematic amounts of food web accumulation. Other contaminants, such as PBDEs and PAHs, may also enter wetlands through atmospheric deposition.

Studies by the RMP and other programs are improving our understanding of contaminant inputs to the South Bay from local watersheds and atmospheric deposition. Restored tidal wetlands in the South Bay will be part of the Estuary, intimately connected to the open waters of the South Bay through the exchange of water and sediment. Consequently, the water quality concerns for the South Bay as a whole, which are being addressed by the RMP, will also apply to the SBSP Restoration Project. Conversely, the Project, through its potential regional impacts, may have impacts on the entire South Bay. Coordination of the Project with the RMP will be beneficial in evaluating the potential impacts of new inputs and other water quality threats on Project objectives.

What is the level of certainty of our knowledge?

While enough is known about the four principal mechanisms of contaminant impact on the Project to clearly warrant concern, considerable uncertainties remain. In the face of these uncertainties, an adaptive management approach, with careful monitoring of Project impacts, will be essential to reducing uncertainties and minimizing negative impacts as the Project proceeds. Major uncertainties include:

- many aspects of mercury cycling, including which restoration projects will cause increased methylmercury exposure;
- the present distribution of contaminants in the areas to be restored;
- recent trends in erosion and deposition in the South Bay and the potential influence of salt pond restoration;
- the sensitivity of key species to contaminants, especially with respect to mercury, but also other contaminants such as PBDEs and emerging contaminants; and
- the combined effects of multiple contaminants on local and regional scales.

Recommendations to address these uncertainties are presented in the last section of this report.

What predictive tools exist for gaining an understanding of this issue and what tools are needed to reduce uncertainty to an acceptable level?

In the past few years the first steps have been made to begin to develop a capacity to predict regional trends in contaminant concentrations in the South Bay for the next 50 to 100 years. Studies have also been performed or are planned that are beginning to delineate processes and patterns in the Estuary and its wetlands and provide the foundation for a predictive capacity. However, our present ability to predict the impacts of the Project on contaminant cycling in South Bay is weak due to a lack of information on contaminant cycling and distribution. Empirical monitoring and research guided by model development will be the way to continue to develop a predictive capacity and reduce uncertainty. Tools that are needed include:

- a conceptual understanding of cycling of mercury and other contaminants in Bay wetlands that allows prediction of accumulation in restored habitats, including different subhabitats within wetlands;
- a model and sediment budget that accurately describes sediment mixing and erosion in the South Bay; and
- a long term program of monitoring and research that assesses contaminants prior to, during, and after each restoration project.

Further discussion of the tools needed is provided in the recommendations section at the end of this report.

What are potential restoration targets and performance measures, linked to the Objectives, for evaluating the progress of the restoration project?

Restoration targets are the standards, based on scientific data, for successfully achieving Project Objectives. As no parts of the Estuary will be entirely free of contaminants, the reference condition for contaminants may be sites with relatively low concentrations. A review should be performed to determine whether restoration targets can be established based on existing data. If not, the Project should perform additional sampling of relatively clean habitats. The Regional Water Quality Control Board may establish restoration targets based on other criteria.

Performance measures are parameters or metrics used to assess progress toward the restoration targets. Food web monitoring is an essential performance measure for adaptive management of restoration in the Estuary, as prescribed by CALFED's Mercury Strategy

(Wiener et al. 2003). Fish monitoring is especially important for mercury. Other types of monitoring are important for determining the impacts of other contaminants. Performance measures would include:

- concentrations of mercury and other contaminants in the food web (fish, bird eggs, seals);
- general health assessments of key species and communities;
- toxicity testing would be a way of screening for potential effects of current use pesticides and emerging contaminants; and
- contaminant concentrations in water and sediment.

Management recommendations for addressing negative impacts will principally come out of the process of adaptive management and monitoring. Our understanding of mercury in the Estuary is too limited at present to predict which actions or habitats will be associated with increased methylmercury exposure. Recommendations that are clear at this stage are:

- avoid restoration in areas with problematic amounts of pre-existing sediment or food web contamination – detailed surveys should precede restoration projects;
- avoid restoration in areas with significant continuing inputs of contaminants from local watersheds;
- monitoring and research should be an ongoing part of SBSP restoration for the duration of the project; and
- SBSP monitoring should be closely coordinated with other contaminant work in the region being done by RMP, CALFED, and others.

What key questions essential to the success of the restoration need to be addressed through further studies, monitoring, or research?

The key questions relate to whether the four hypothesized mechanisms of contaminant impact on the Project actually occur, and include:

- the effect of different types of restoration on contaminant exposure in sensitive species;
- the effect of restoration on the South Bay sediment budget and long term trends in South Bay contamination;
- the sensitivity of target species, such as clapper rails and terns, to contaminants; and
- present levels of contamination in locations to be restored.

Recommendations to Address Uncertainties, Provide Needed Tools, and Answer Key Questions

A comprehensive body of work will be needed to understand whether and how restoration activities will affect water quality in the South Bay. The most prudent course of action will be to take an adaptive management approach, minimizing risk as much as possible based on existing knowledge while conducting the research needed to reduce the negative impacts of future restoration projects and the monitoring needed to assess regional and local impacts. The following recommendations for addressing uncertainties relating to the impacts of the SBSP on water quality are distilled from Davis et al. (2003), the CBDA Mercury Strategy (Wiener et al. 2003), and the SBSP Mercury Memo (Beutel and Abu-Saba 2004).

General Recommendations

A serious, multifaceted monitoring and research effort on mercury should be an on-going part of tidal wetland restoration in the South Bay and the rest of the Estuary. The SBSP should be a major participant in this effort. Mercury is the contaminant that poses the greatest threat to the success of the SBSP Project and that is likely to be most affected by the Project. The complexity of the mercury cycle and the rudimentary state of current understanding limit our present ability to predict which restoration projects will lead to unacceptable mercury bioaccumulation. These are challenging problems and it will take some time to find the necessary, creative solutions. The research program should include site-specific studies, but basic processes and broad questions must also be answered. A goal of the research program should be to develop numerical models that predict the extent of net mercury methylation, export to the Estuary, and food web accumulation in response to wetland restoration projects.

Effective coordination of SBSP studies with studies by other programs will be crucial to successfully and cost-effectively addressing contaminant concerns. Major investments are being made by the CBDA, the RMP, and others to improve understanding of mercury and other contaminants in the Bay-Delta. The SBSP has much to gain by being informed of findings from these other efforts and building on them, rather than duplicating them. Participation of the SBSP in the RMP would be an effective way to integrate the two programs and for the SBSP to leverage existing RMP efforts to evaluate contaminant sources and loadings, trends, fate, and effects in the South Bay.

Specific Recommendations

Long-term food web monitoring should be performed to ascertain the impact of restoration actions on water quality on both a regional and local scale. This monitoring should include sampling of concentrations in sport fish as an index of human exposure, and forage fish and avian eggs as an index of exposure of sensitive wildlife species. Monitoring of other food web or ecosystem components may also be useful in establishing long-term trends. Lower trophic level bioindicator organisms with high site fidelity may also be useful in differentiating relative mercury bioavailability at fine spatial and temporal scales. Long-term monitoring of individual restoration projects should be conducted until concentrations fall below thresholds of concern. Regional monitoring and assessment should be carefully coordinated with project-specific monitoring. Food web monitoring should be conducted in all of the habitat types (tidal marsh, tidal flats, and managed ponds) that are part of the restoration plan.

Long-term monitoring of other water quality indicators will also be needed to detect impacts of mercury and other contaminants on the Project. In order to ensure that contaminants do not interfere with the health of the species in restored habitats, the SBSP Project will need information on contaminant loads to the South Bay, the general health of key species and communities (needed to determine the possible impacts of some individual contaminants as well as contaminant mixtures), toxicity testing (to assess the potential effects of current use pesticides and other nonpersistent contaminants), and general trends in contaminant concentrations in the South Bay ecosystem. The RMP provides a mechanism for addressing all of these issues in an integrated manner, and coordinating with other related projects.

Detailed surveys should precede restoration projects to document existing concentrations of mercury and other contaminants in affected areas and to evaluate the potential for increased food web accumulation. Determining the impact of a restoration project will depend on the availability of information on conditions prior to the project. Pre-project contaminant concentrations in the local food web should be established. Preliminary studies of contaminant concentrations in sediments and cores of sediments should precede every engineering effort to restore a wetland or shallow water habitat. The presence and potential presence of contaminants in the water and sediment supply of restored wetlands should also be evaluated in the planning stages of each restoration project.

Process studies should be performed in a strategic way so that mechanisms of variation in mercury accumulation among tidal wetlands can be understood. This will provide the foundation needed by environmental managers and engineers to develop designs that minimize the impact of restoration activities. High priority should be given to examining effects of restoration on bioavailability and net methylation rates, as these processes have a great potential to significantly increase methylmercury exposure in this ecosystem.

Alternative restoration project designs should be evaluated for their potential to minimize methylmercury accumulation in the food web. The most promising alternatives should be implemented in an adaptive management context with careful monitoring and, where appropriate, process studies. The Mercury Memo should be used as a starting point for further discussion. A $1.2 million study funded by Prop 13 will begin soon to identify management options that could reduce methylmercury production in tidal wetlands of San Francisco Bay. The SBSP Project should benefit from this study.

An understanding of the role of tidal wetlands as net mercury importers from or exporters to the Estuary is needed. Restored wetlands in the SBSP Project could account for a significant fraction of the methylmercury production in the South Bay. Evaluation of this should include measurements of methylation and demethylation in water and sediment of different tidal wetland environments (channels, ponds, and marsh plains). Both laboratory and field measurements should be employed with an attempt to assess flux, methylation potential, and environmental covariates (e.g., total mercury concentration, sulfate reduction, suspended sediment concentrations of mercury, organic carbon content, and pH) that enhance or impair methylmercury formation on the local (i.e., wetland microhabitat) and regional (i.e., wetland export) scales.

Transfer of mercury and other contaminants through the food web to species at risk, including humans, must be understood. This should include an understanding of the factors controlling mercury accumulation in species involved in restoration, such as clapper rails. The link between food web contamination and human exposure also needs to be documented through study of fishing and fish consumption practices. This would provide information needed in development of monitoring strategies and in communicating risks to human populations with the highest mercury exposure. If the Project does increase mercury accumulation in South Bay sport fish, it will still be possible to reduce human exposure to methylmercury in the short term through outreach and education.

Better information is needed on the sensitivity of species facing the greatest exposure to methylmercury and other contaminants. Available information indicates that California clapper rails are highly exposed to methylmercury and highly sensitive – given the critical importance of these observations, they should be further defined and confirmed. The USFWS/USGS study funded by CBDA should provide needed information on the sensitivity of terns and stilts. Study of the possible impacts of mercury on seals is warranted. A small study by Moss Landing Marine Laboratory examining mercury concentrations in blood and fur of harbor seals is underway. Better information on the sensitivity of seals to mercury is needed. Piscivorous species are also highly exposed to PCBs, dioxins, PBDEs, and other persistent organic chemicals, and the sensitivity of these species to these chemicals individually and in combination is not well known.

Conceptual and numerical models of contaminant fate are needed on both regional and local scales. Conceptual models summarizing our understanding of mercury and other contaminants are being developed by the CEP, the CBDA, and the SBSP (Beutel and Abu-Saba 2004). These conceptual models provide a valuable framework for organizing and describing the current state of knowledge and defining uncertainties, and should continue to be updated with new information. Numerical models are needed to predict the regional impacts of the Project on accelerating erosion of sediment deposits. When the process studies have reached a stage of development that allows reliable predictions to be made, numerical models will also be applied in this context.

To allow for effective adaptive management decisions as the Project is implemented, the major uncertainties need to be further evaluated and prioritized. As part of the Project's Science Plan, key uncertainties regarding contaminant impacts on water quality should be developed and ranked. This ranking of uncertainties will act as a framework for the implementation of monitoring and experimental studies that will successfully inform adaptive management decisions.

LITERATURE CITED

BCDC. 2004. Draft Staff Report: Mercury, PCBs, and Other Legacy Contaminants in San Francisco Bay. San Francisco Bay Conservation and Development Commission, San Francisco, CA.

Beutel, M. and K. Abu-Saba. 2004. Mercury Technical Memorandum – Final Draft. South Bay Salt Pond Restoration Project. http://www.southbayrestoration.org/Documents.html#tr

Cappiella, K., C. Malzone, R. Smith, and B. Jaffe. 1999. Sedimentation and bathymetry changes in Suisun Bay: 1867-1990. U.S. Geological Survey Open-File Report 99-563. U.S. Geological Survey, Menlo Park, CA, USA.

Conaway, C.H., E.B. Watson, J.R. Flanders, and A.R. Flegal. 2004. Mercury deposition in a tidal marsh of south San Francisco Bay downstream of the historic New Almaden mining district, California. Marine Chemistry (in press).

Davis, J.A., J.N. Collins, D. Yee, S. Schwarzbach, and S.N. Luoma. 2003. Issues in San Francisco Estuary tidal wetlands restoration: Potential for increased mercury accumulation in the Estuary food web. San Francisco Estuary and Watershed Science 1: issue 1, article 4.

Foxgrover, A.C., Higgins, S.A., Ingraca, M.K., Jaffe, B.E., and Smith, R.E., 2004, Deposition, erosion, and bathymetric change in South San Francisco Bay: 1858-1983: U.S. Geological Survey Open-File Report 2004-1192, 25 p. [URL: http://pubs.usgs.gov/of/2004/1192]

Heinz, G.H. 2003. The use of egg-injections to rank the sensitivities of avian embryos to methylmercury. CALFED Bay-Delta Mercury Project. http://loer.tamug.tamu.edu/calfed/FinalReports.htm

Hintelmann, H., Harris, R., Heyes, A., Hurley, J.P., Kelly, C.A., Krabbenhoft, D.P., Lindberg, S., Rudd, J.W.M., Scott, K.J., and St. Louis, V.L. 2002. Reactivity and mobility of new and old mercury deposition in a boreal forest ecosystem during the first year of the METAALICUS study. Environmental Science and Technology 36: 5034-5040.

Hunt J.W., B.S. Anderson, B.M. Phillips, J. Newman, R.S. Tjeerdema, K. Taberski, C.J. Wilson, M. Stephenson, H.M. Puckett, R. Fairey, and J. Oakden. 1998. Sediment Quality and Biological Effects in San Francisco Bay: Bay Protection and Toxic Cleanup Program Final Technical Report. California State Water Resources Control Board, Sacramento, CA.

Jaffe BE, Smith RE, and Torresan LZ. 1998. Sedimentation and bathymetric change in San Pablo Bay, 1856-1983. U.S. Geological Survey Open-File Report 98-759. U.S. Geological Survey, Menlo Park, CA, USA.

Kopec, A.D. and J.T. Harvey. 1995. Toxic pollutants, health indices, and population dynamics of harbor seals in San Francisco Bay, 1989-1992. Moss Landing Marine Laboratories Technical Report 96-4. Moss Landing, CA. 168 pp.

McKee L.M., Ganju N., Schoellhamer D., Davis J.A., Leatherbarrow J., and Hoenicke R. 2002. Estimates of suspended sediment flux entering San Francisco Bay from the Sacramento and San Joaquin Delta. SFEI Contribution 65. San Francisco Estuary Institute, Oakland, CA, USA.

OEHHA. 1994. Health advisory on catching and eating fish: Interim sport fish advisory for San Francisco Bay. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, Sacramento, CA. (http://www/oehha.org/scientific/fish/int-ha.html)

Schwarzbach, S. and T. Adelsbach. 2003. CALFED Bay-Delta Mercury Project – Subtask 3B: Field Assessment of avian mercury exposure in the Bay-Delta ecosystem. http://loer.tamug.tamu.edu/calfed/FinalReports.htm

Schwarzbach, S.E., Henderson, J.D., Thomas, C.M. and J.D. Albertson. 2001. Organochlorine concentrations and eggshell thickness in failed eggs of the California clapper rail from South San Francisco Bay. *The Condor* 103: 620-624.

Schwarzbach, S.E., Albertson, J.D. and C. M. Thomas. Submitted. Impacts of predation, flooding and contamination on the reproductive success of the California clapper rail (*Rallus longirostris obsoletus)* in San Francisco Bay. *The Auk*.

SFBRWQCB. 2004a. Mercury in San Francisco Bay Total Maximum Daily Load (TMDL) Proposed Basin Plan Amendment and Staff Report. San Francisco Bay Regional Water Quality Control Board, Oakland, CA.

SFBRWQCB. 2004b. PCBs in San Francisco Bay: Total Maximum Daily Load Project Report. San Francisco Bay Regional Water Quality Control Board, Oakland, CA.

SFEI. 2004. The Pulse of the Estuary: Monitoring and Managing Water Quality in the San Francisco Estuary. SFEI Contribution 78. San Francisco Estuary Institute, Oakland, CA.

She, J.; Petreas, M.; Winkler, J.; Visita, P.; McKinney, M., and Kopec, D. PBDEs in the San Francisco Bay Area: measurements in harbor seal blubber and human breast adipose tissue. Chemosphere. 2002 Feb; 46(5):697-707.

She, J., A. Holden, M. Tanner, M. Sharp, T. Adelsback, and K. Hooper. 2004. Highest PBDE levels (max 63 ppm) yet found in biota measured in seabird eggs from San Francisco Bay. Organohalogen Compounds 66: 3939-3944.

Van Geen, A. and S.N. Luoma. 1999. The impact of human activities on sediments of San Francisco Bay, California: an overview. Marine Chemistry 64(1-2): 1-6.

Wiener, J.G., C.C. Gilmour, and D.P. Krabbenhoft. 2003. Mercury Strategy for the Bay-Delta Ecosystem: A Unifying Framework for Science, Adaptive Management, and Ecological Restoration. Report to the California Bay Delta Authority.

Williams, P.B. 2003. Predicting the future of San Francisco Bay. Presented at the State of the Estuary Conference, October 2003.

Figure 1. Mercury concentrations in eggs of aquatic birds from the Bay-Delta. WEGU – western gull; CAGU – California gull; GBHE – great blue heron; SNEG – snowy egret; BCNH – black-crowned night heron; GREG – great egret; AMAV – American avocet; BNST – black-necked stilt; BRCO – Brandt's cormorant; DCCO – double-crested cormorant; SNPL – snowy plover; CCRA - California clapper rail; CALT – California least tern; FOTE – Forster's tern; CATE – Caspian tern.

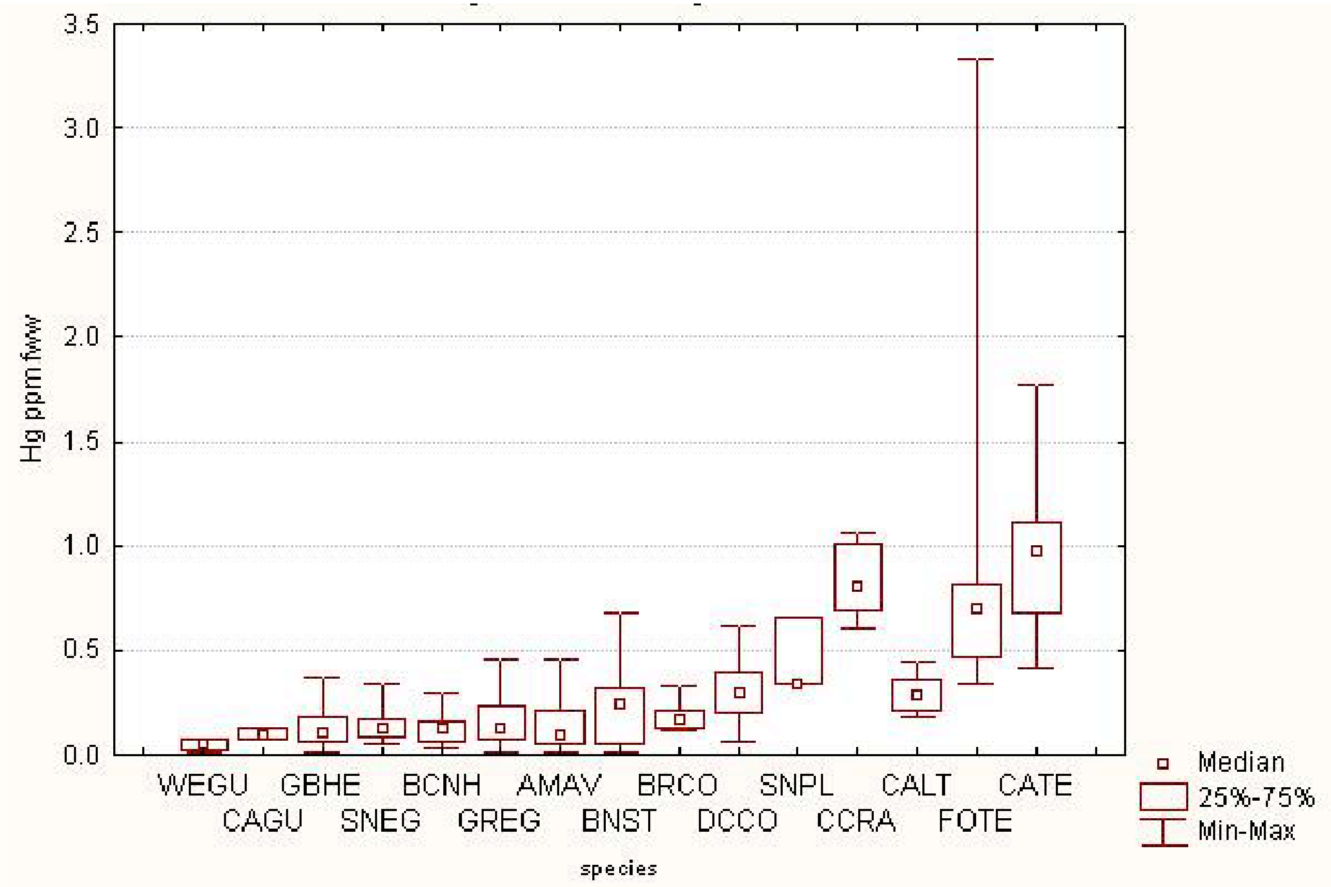
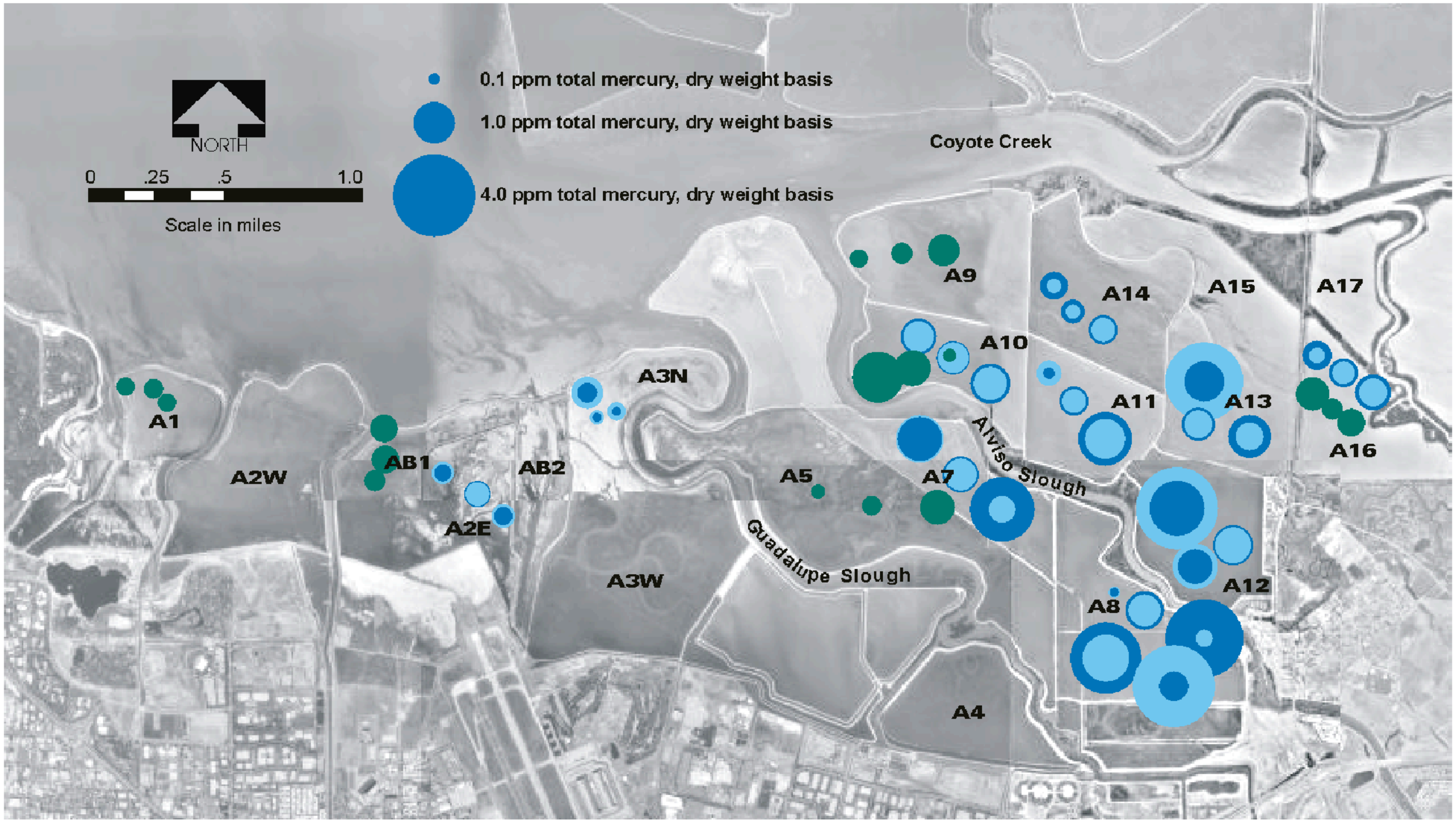


Figure 2. Spatial distribution of total mercury in Alviso salt ponds. From Beutel and Abu-Saba (2004).



Surface sediment samples (0 to 5 cm) collected during 2003 ISP monitoring. Location of circle does not correspond to location of sample.
Subsurface sediment samples (15 to 20 cm) collected during 2003 ISP monitoring. Location of circle does not correspond to location of sample.
Sediment sediment samples (0 to ~10 cm) reported by Maurer and Adlesbach (2002). Location of circle corresponds to location of sample.
Figure modified from Maurer and Adlesbach (2002)

Figure 3. Timing of salt pond establishment. From Collins et al. (2004).

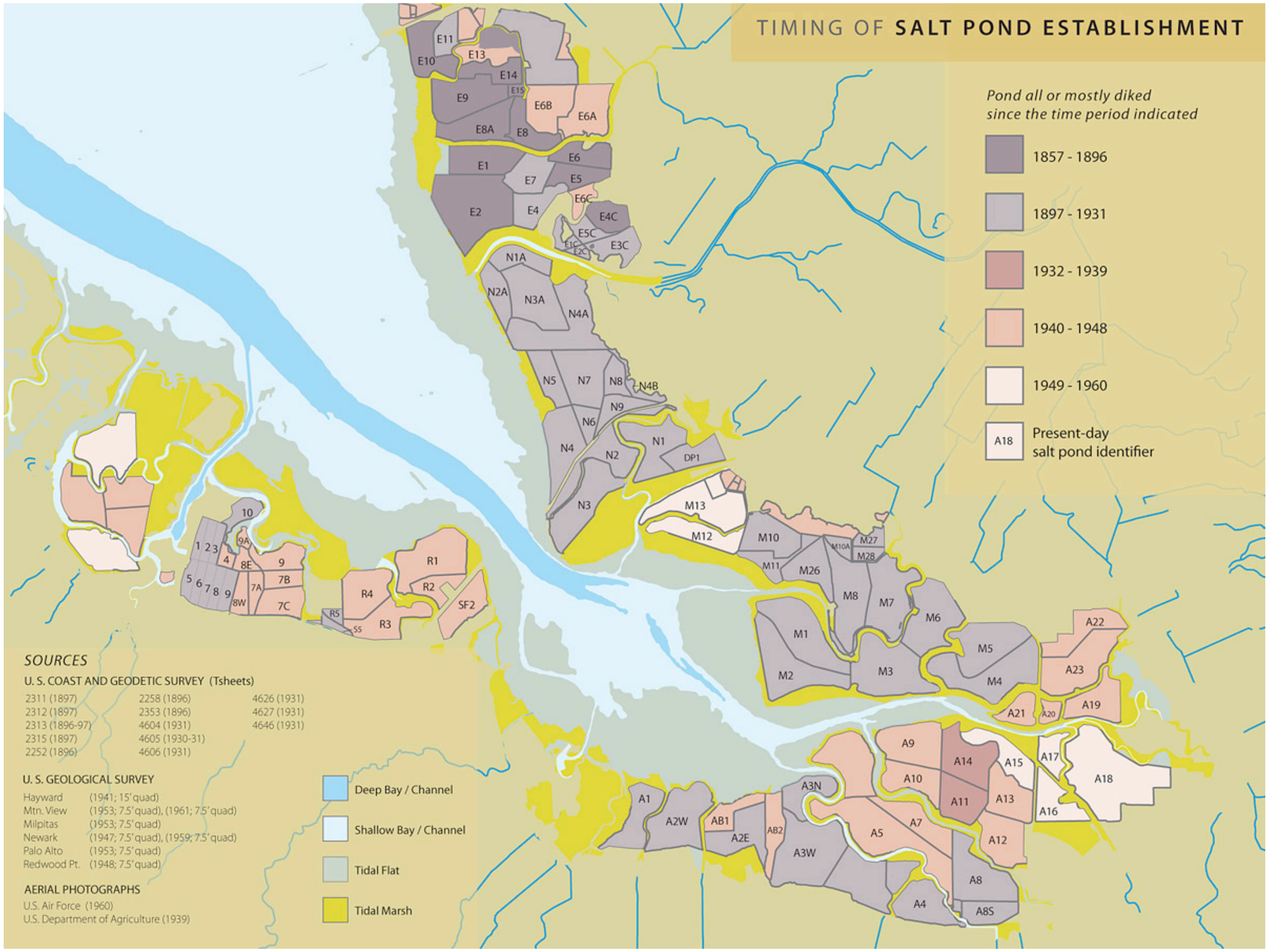


Figure 4. Deposition and erosion in the South Bay from 1931 to 1983. From Foxgrover et al. (2004).

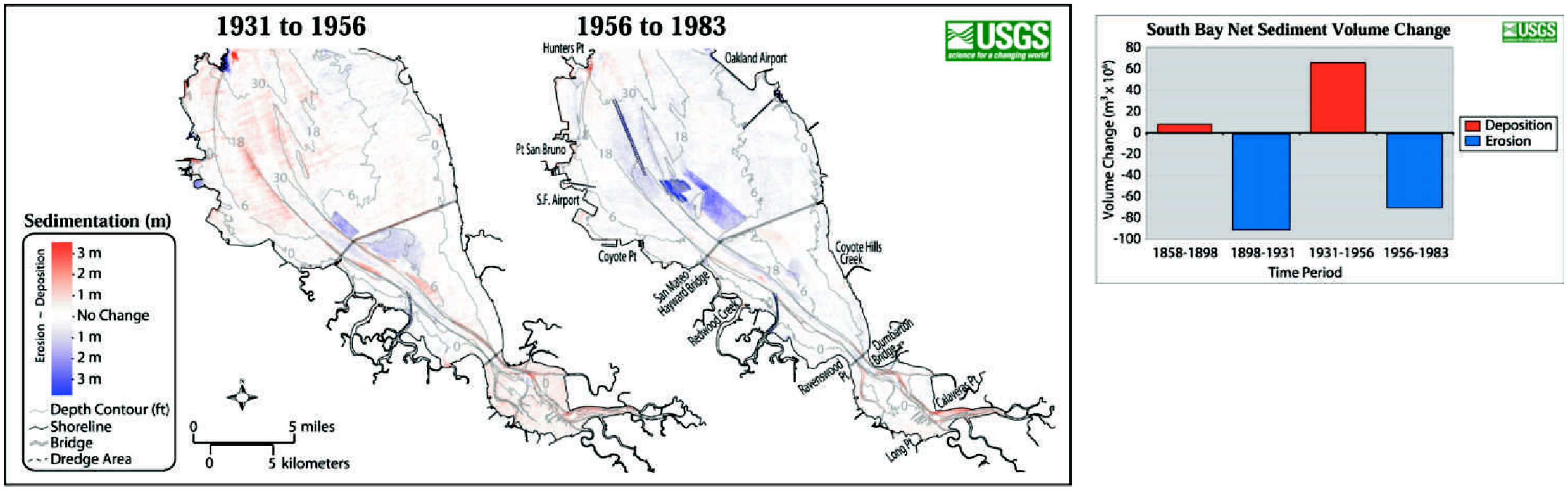
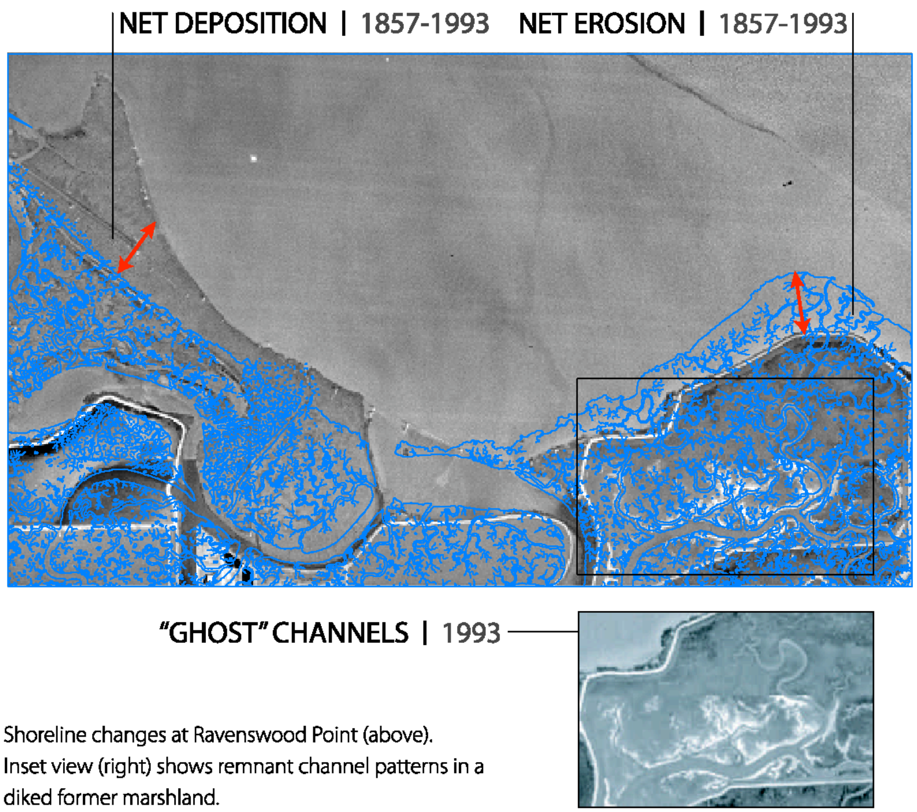


Figure 5. Like bottom sediments in the Bay, tidal marshes can store large amounts of contaminants. Tidal marshes can also act as sources of contaminants, as contaminated marsh sediment erodes. Shown is a figure overlaying marshland hydrography circa 1857 on modern marsh and diked baylands at Ravenswood Point. Shoreline change investigation can similarly help gauge patterns of contaminant storage and release in the Estuary's marshes. From SFEI (2004).



Shoreline changes at Ravenswood Point (above). Inset view (right) shows remnant channel patterns in a diked former marshland.