Effects of Short-term Water Quality Impacts Due to Dredging and Disposal on Sensitive Fish Species in San Francisco Bay

Prepared by

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1. Summary

This document summarizes the short-term water quality impacts of dredging operations (dredging and dredged material placement) on sensitive fish species in San Francisco Bay. The review considered five fish species: chinook salmon, coho salmon, delta smelt, steelhead trout, and green sturgeon. As directed by stakeholders of the San Francisco Bay Long-Term Management Study (LTMS) Framework, the review focused specifically on the potential short-term effects of chemical contaminants that may be introduced in the water column with plumes. Water quality impacts of concern include dissolved oxygen (DO) reduction, pH decrease, and releases of toxic components such as heavy metals, hydrogen sulfide (H_2S), ammonia, and organic contaminants The latter include polyaromatic hydrocarbons (PAHs), polychlorinated biphenyl (PCBs), and pesticides. Potential short-term effects include acute toxicity, subacute toxicity, and biological and other indirect effects such as avoidance.

Work for this project consisted of a literature review of potential short-term water quality impacts and possible effects on fish species of concern and an evaluation of available environmental data. Relevant literature is presented as an annotated bibliography (Appendix A) and summarized in Section 3 Review Findings and Conceptual Models. The review is topically divided into Short-term Water Quality Impacts (Section 3.1) and Possible Short-Term Effects on Sensitive Species (Section 3.2). The data evaluation is summarized in synthesis tables (Appendix B) and the findings are discussed in Section 5 Data Evaluation and Synthesis.

Since few water column chemistry data were collected during dredging operations in the San Francisco Estuary or elsewhere, data evaluation relied on indirect estimation methods to calculate potential water quality changes and effects based on available sediment concentration data from dredging studies. The data evaluation consisted of three parts:

1) Sediment concentrations from the California Sediment Quality Objectives (SQO) database (SCCRWP 2006) were screened against effects range-medium (ERM) and effects range-low (ERL) thresholds (Long et al. 1995);
2) The sediment concentrations were also used to calculate dissolved water concentrations in plumes, which were then compared with toxicity and effects thresholds for fish species of concern obtained from the ECOTOX (USEPA 2007) database or extrapolated by Interspecies Correlation Estimations (ICE) (Asfaw et al. 2003; Mayer et al. 2004); and
3) Contaminant concentrations from chemical elutriate tests for the evaluation of John R. Baldwin Ship Channel sediments were also compared with the effects thresholds.

Based on the data evaluation, most contaminants likely remain below any known impact levels of serious concern for sensitive fish species during dredging or disposal of dredged material. Of those considered, ammonia emerged as the only contaminant to exceed a biological threshold, based on a calculated concentration in a model plume using average Bay sediment concentrations. Findings from the literature and data evaluation for specific contaminant groups or issues can be summarized as follows:

Dissolved oxygen

The potential impacts of reduced dissolved oxygen (DO) concentrations due to sediment resuspension were previously evaluated. It was concluded that DO reductions would be localized and short term, with minimal impacts (US Navy 1990). In the LTMS review, the possibility was raised that more extensive water quality impacts may occur at disposal areas where DO levels are already depressed

(such as in the South Bay or in Richardson Bay) and/or during disposal at high dumping frequencies.(LFR 2004). Site-specific studies and modeling exercise may be required to address this concern.

H_2S

H_2S, although a potent metabolic poison in fish, occurs in lethal concentrations presumably only in association with hypoxic conditions that are also lethal to fish. Thus, H_2S would also not be expected to have a significant impact on sensitive species in San Francisco Bay.

Heavy Metals

Possible risks from heavy metals released during dredging are primarily related to changes in conditions promoting the shift of heavy metals from the particulate into the dissolved state (Goosens and Zwolsman 1996). Reviewed studies suggest that resuspension of metal-contaminated sediments may create only minimal potential for direct toxicity, because dissolved concentrations are in general low, even though releases of total metals can be large, and most of the releases to the dissolved phase may in fact be largely due to the resuspension of fine colloidal particles (Tomson et al. 2003). Thus, the concentration of freely dissolved metal ions that would be released and available for gill uptake by fish is expected to be fairly minor. The same is true for organic contaminants, which are expected to stay mainly bound to particulate organic matter (POM) and would thus not be available for gill uptake. In model calculations using available sediment concentrations of heavy metals from monitoring studies and making simplified and conservative modeling assumptions (i.e. worst-case scenarios), only one contaminant, nickel (Ni), exceeded the ERM threshold in more than 10% of samples. Sediments in San Francisco Bay are naturally high in nickel due to a geological signature (Yee et al. 2007). Calculated dissolved concentrations in plumes for nickel and three other metals—cadmium (Cd), Copper (Cu), and zinc (Zn), which were selected for these calculations based on the availability of field partitioning constants—also indicated no exceedance of threshold toxicity values. Reported elutriate test data from the John R. Baldwin Ship Channel were also safely above reported and calculated effects threshold values. Based on conservative estimates of this study, short-term water quality impacts due to metal and organic contaminant releases from dredging activities do not emerge as a major issue.

Organic Contaminants

The results were similar for organic contaminants: PAHs, PCBs, and other organic contaminants of concern are generally less soluble and direct toxicity by exposure to dissolved concentrations in the water column is not very likely. Conservative model calculations with two PAHs—fluoranthene and phenanthrene—did not indicate a concern based on available sediment concentration data and effects thresholds.

Ammonia

Magnitude and extent of changes in ammonia levels as a result of dredged material has not been extensively monitored in San Francisco Bay (LFR 2004). The calculated ammonia concentration in a hypothetical scenario, using a baywide average concentration and a model dredged material plume of 0.001 km^3, was calculated as 0.77 mg/L. This concentration is 2-3 magnitudes smaller than ammonia levels reported to induce mortality in toxicity tests, but an order of magnitude greater than concentrations that were observed to affect swimming performance of coho salmon in freshwater. In general, there has been little direct work on the toxicity of ammonia to estuarine fish, albeit the fact that estuarine fish may be more at risk than marine and freshwater species (Eddy 2005).

In summary, the presented review indicates that direct short-term effects on sensitive fish by contaminants associated with dredging plumes are probably fairly minor, especially in comparison with other potential impacts, such as long-term effects due to bioaccumulation or immediate physical effects of suspended solids on fish health and habitat (Connor et al. 2004; LFR 2004). There appears to be a need to better study the potential of ammonia releases during dredging in San Francisco Bay, and to examine possible subacute effects with respect to the fish species under consideration. In general, there are significant data and knowledge gaps concerning the release, bioavailability, and effects of contaminants during dredging on sensitive fish. An improved knowledge and data base would reduce remaining uncertainties about potential adverse short-term impacts of contaminants on sensitive fish species.

2. Introduction

In San Francisco Bay, one approach to reduce potential adverse impacts from dredging on marine life has been the implementation of environmental work windows; periods in the year when specific marine organisms are presumed to be least vulnerable to possible impacts. The goal of environmental work windows is to provide a high degree of protection to resources, but they can also cause difficulties in scheduling needed dredging projects.

The *Framework for Assessment of Potential Effects of Dredging on Sensitive Fish Species in San Francisco Bay* (LTMS Framework), developed as a guidance document by/for the Environmental Windows Committee of the San Francisco Bay Long-Term Management Strategy (LTMS), addresses the potential effects of dredging on fish and identifies stakeholder concerns regarding environmental work windows. One of the concerns is that localized changes in water quality within plumes resulting from dredging and dredged material placement may have an adverse effect on sensitive species of fish in the San Francisco Estuary, particularly those which may be considered under Essential Fish Habitat (EFH) and Endangered Species Act (ESA) regulations and policy (LFR 2004).

This document summarizes the short-term water quality impacts of dredging operations (dredging and dredged material placement) on sensitive fish species in San Francisco Bay. Short-term effects were identified by stakeholders in the *LTMS Framework* (p. 62) as one of the "existing data gaps and remaining uncertainties that if better resolved could result in more informed and effective protection of sensitive fish species":

One of the concerns of the resource agencies (given that the work windows are in effect) involves indirect, sublethal or subtle potential effects that could significantly affect species populations in a variety of ways, but which may not be easily detected. Many of these concerns are associated with environmental parameters where there are ambient (i.e., non-dredging induced) levels present in the San Francisco Bay.

The preparation of this document included a literature review and an evaluation of relevant environmental data from the San Francisco Estuary.

Per request, the literature review was focused specifically on potential short-term effects due to chemical contaminants that may be associated with plumes and thus introduced in the water column. Potential short-term effects include acute toxicity, subacute toxicity, and biological and other indirect effects, such as avoidance. The review does not address long-term effects, such as bioaccumulative effects or chronic toxicity, or sublethal impacts on individual organisms or populations. It also does not address other physical effects of resuspended sediments, which are discussed in a parallel review.

The review considered five fish species: chinook salmon, coho salmon, delta smelt, steelhead trout[1], and green sturgeon (Table B-1). The five species of interest for this study were identified in a kick-off conference by the participants: Bill Brostoff, US Army Corps of Engineers (USACE), Beth Christian, San Francisco Bay Regional Water Quality Control Board (SFBRWQCB), Brenda Goeden, Bay Conservation and Development Commission (BCDC), and David Woodbury, National Marine Fisheries Service (NFMS).

[1] Both steelhead and steelhead trout are being issued interchangeably as common names for the anadromous (ocean-going) forms of *Oncorhynchus mykiss*. We used "steelhead trout" to be consistent with the terminology used in the LTMS Science Framework (2004).

Chinook salmon, coho salmon, delta smelt, and steelhead trout are four of the five sensitive fish species for which there are currently environmental work windows in the Bay. Short-term water quality effects on Pacific herring, the fifth fish window species, were evaluated in a previous white paper that looked at a wide range of potential impacts of dredging and disposal activities in San Francisco Bay on that particular species (Connor et al. 2004). Green sturgeon, the fifth species added to this study, is of more recent concern to the LTMS, since it has recently received threatened status for its population segment south of the Eel River, including those in San Francisco Bay (NFMS 2005).

The review considered (1) the potential presence of chemicals associated with plumes resulting from dredging and dredged material placement (Table B-2), (2) chemical processes affecting their potential short-term impacts on fish (e.g. reduced dissolved oxygen, decreased pH, chemical transformation reactions, changes in bioavailability), and (3) potential for acute toxicity or subacute biological effects on sensitive fish species resulting from short-term exposure to dredging-related water quality impacts.

3. Literature Review: Findings and Conceptual Models

Water quality effects of dredging activities are variable depending on increases in turbidity, suspended solids, and noise; reduced light transmittance; changes in salinity, temperature, and pH; reduced dissolved oxygen (DO); and releases of nutrients, heavy metals and organic contaminants (Connor et al. 2004; US Navy 1990). This review focuses on contaminants associated with elevated levels of suspended sediments in dredging plumes which could have direct health effects on fish. It provides a reference for priority concerns identified by the LTMS Science Assessment and Data Gaps Work Group for chinook salmon, coho salmon, delta smelt, and steelhead trout regarding water quality, bioavailability, and acute toxicity (LTMS 1996). Green sturgeon was also included in the review. There are no environmental windows for green sturgeon, but the species has been listed as threatened in San Francisco Bay (NFMS 2005). Potential water quality impacts of dredging activities on Pacific herring in San Francisco Bay were addressed previously (Connor et al. 2004).

This section provides an overview of literature and conceptual models describing short-term water quality impacts and possible effects on the specified fish window species of concern, with a focus on contaminant pathways for plumes associated with dredging or open-water disposal. It complements the annotated bibliography featured in Appendix A, which provides a comprehensive documentation and access resource on the subject matter.

3.1 Short-term Water Quality Impacts

Conceptually, the water quality impact of dredging activities is two-fold: 1) suspended sediment plumes resulting from dredging or disposal activities, and associated water quality changes in the water column (LFR 2004), and 2), sediment disturbance, and associated changes in the chemical properties of the dredged sediment (Eggleton and Thomas 2004). This overview addresses the first, short-term water quality impacts in the water column associated with plumes, which include chemical transformations, release of oxygen-demanding substances/reductions in DO, decreased pH, release of contaminants, and changes in bioavailability.

The focus of the literature review presented here was on changes in the physical and chemical properties of sediment during dredging that stimulate the mobilisation of contaminants. A broader discussion of more fundamental topics, such as the distribution of contaminants within undisturbed sediment, their affinities to the various solid-phase fractions of sediment (clay, sand, silt, particulate organic matter, detrital aggregates), or the interaction of contaminants between sediment and porewater, is outside of the scope of this project. However, many published data have focused on these fundamental topics. For example, Dong et al. (2000) studied the role of natural particle surfaces in metal adsorption, with an emphasis on iron and manganese oxides. Langstone and Pope (1995) describe determinants affecting the sorption of tributyltin in estuarine sediments, and Moore et al. (1988) discuss the partitioning of arsenic and trace metals in sulfidic estuarine sediments. Several studies describe the general distribution and trends, partitioning, and trends for various contaminants in San Francisco Bay sediments, including the trace metals Cd, Cu, and Zn (Wood et al. 1995) , mercury and methylmercury (Conaway et al. 2003; Kim et al. 2004), pesticides and other organic contaminants (Domagalski and Kuivila 1993), and PAHs (Oros and Ross 2006).

Chemical transformations

The most significant chemical transformation processes in dredging plumes are probably the releases of ferrous iron (Fe^{2+}) and sulfides from oxygen-depleted resuspended sediments and their subsequent oxidation with the DO in the aerated water column (Jones-Lee and Lee 2005). The oxidation of sulfides to sulfate and of Fe^{2+} to iron oxides/hydroxides are the primary chemical processes driving DO reductions in sediment plumes (Lee 2007; Stumm and Morgan 1996). In addition, they control the release of ionic metals and their short-term speciation and bioavailability during resuspension (Allen et al. 1993; Balistrieri 1981; Caetano and Vale 2003; Davies-Colley et al. 1985; Delaune and Smith 1985; Goosens and Zwolsman 1996; Hirst and Aston, 1983; Moore et al. 1988; Morse 1995; Petersen et al. 1997; Prause et al. 1985; Simpson et al. 2000; see Figure 3-1).

In anoxic (oxygen-free) sediments, sulfur occurs in the form of sulfide species (S^{2-}, S^{2-}/S^{-}, H_2S, and HS^{-} species), and iron occurs as Fe^{2+}. During resuspension of the anoxic sediment in the oxic water column, both Fe^{2+} and sulfides react with DO. Sulfides are oxidized by DO to form the highly acidic sulfate (SO_4^{2-}) species. Thus, the reaction of sulfides with oxygen can both reduce DO and also contribute to pH decreases in the water column. Fe^{2+} is oxidized by DO to form ferric ($Fe3^{+}$) hydroxide [$Fe(OH)_3$], which is exceedingly insoluble within the normal pH range of oxygenated waters and rapidly precipitates (Stumm and Morgan 1996).

Heavy metals occur mostly as sulfides (CdS, CuS, PbS, etc) in anoxic sediments. The low solubility of metal sulfides results in low porewater concentrations. Upon resuspension of anoxic sediment into the oxic conditions of the overlying water, Fe and also Manganese (Mn) are rapidly oxidized (first few minutes following sediment resuspension) to insoluble oxides/hydroxides. The insoluble Fe and Mn oxides/hydroxides precipitate again from the water column and are subsequently deposited, thus contributing to the formation of fresh sediment layers. Compared to the rapid oxidation of iron sulfides (FeS) and manganese sulfides (MnS), the oxidation kinetics for heavy metal sulfides are much slower. Laboratory studies showed that oxidation of CuS, CdS, and PbS takes more than 8 hrs. Once oxidized, however, they are quickly scavenged by, or coprecipitated with, the iron and manganese hydroxides or complexed by organic matter (Balistrieri et al; 1981; Caetano and Vale 2003; Davies-Colley et al. 1985; Engel et al. 1981; Goosens and Zwolsman 1996; Hirst and Aston, 1983; Maddock et al., 2007; Moore et al. 1988; Morse 1995; Petersen et al. 1997; Prause et al. 1985; Simpson et al. 1998, 2000).

Releases of oxygen-demanding substances/reductions in dissolved oxygen

Dissolved oxygen (DO) concentrations in the water column may be reduced when oxygen-demanding substances (for example, organic material) are mixed into the water column by dredging or disposal activities (LFR 2004). Lee et al. (1978) monitored changes in DO and other physical and chemical parameters in the water column during more than 10 open-water disposal operations before, during and after passage of the sediment plumes, and observed that oxygen demand follows a pattern of an initial, rapid rate of oxygen demand lasting 5-10 minutes, followed by a five to ten time slower rate of

DO consumption. Based on sediment analyses from about 100 locations throughout the US, Lee et al. conclude that sediments have a substantial reservoir of inorganic oxygen demand, with the potential to cause significant water quality problems when the sediment is resuspended in the water column. Inorganic oxygen demand is caused by abiotic (non-biological—inorganic)-based reactions consuming DO in waterbodies (Borglin et al. 1996). The most important inorganic constituents responsible for DO reductions in aquatic systems are sulfides and reduced iron. When released from the reducing anoxic sediments into the oxidative conditions of the water column, they will be oxidized in reactions with the oxygen present in the water column (Stumm and Morgan 1996). Therefore, anoxic sediments containing reduced substances such as Fe^{2+} and sulfides that react with DO would cause the greatest temporary depression in DO at the disposal site (LFR 2004).

In comparison with these inorganic abiotic reactions with DO that occur in aquatic sediments, typical biochemical oxygen demand (BOD) reactions (i.e. oxygen consumption by bacterial degradation processes) are relatively slow: typical domestic wastewater and dead algal BOD reactions proceed on a time scale of days (Baird and Smith 2000; Johnson et al. 1985). Inorganic abiotic reactions with DO, on the other hand, take place in a few minutes to a few hours (Chen and Morris 1972; Stumm and Lee 1961).

Studies of dredging-induced reduction of DO yielded different results for different dredging locations. For example, Brown and Clark observed 16-83% reductions in DO upon resuspension of dredged sediments in Arthur Kill and Kill Van Kull, Staten Island, New York (Brown and Clark 1968), whereas a study of dredging-induced DO reduction at Haverstraw Bay on the Hudson River did not reveal any statistical differences between dredging and non-dredging periods (LaSalle 1989). In a study of more than ten open-water disposal operations in US waterways, Lee et al. (1978) found that there was, in some instances, some decrease in DO, as well as some increase in some chemical constituents. However, they concluded that ammonia was the only constituent of concern that was released. Factors affecting the extent of DO decreases include the extent of the sediment release, the chemical composition and initial oxygen demand of the dredged material, its exposed surface area, aeration resulting from water column hydrodynamics and mechanical perturbations during dredging, and the contact time between sediment and water (Lee 2007; USACE 1976).

Water quality impacts due to dredging are more likely in situations where DO levels are already reduced (LFR 2004). In general, DO issues are less likely in well oxygenated waters, and waters in San Francisco Bay are generally well oxygenated. Typical concentrations of DO in most of San Francisco Bay range from 9 to 10 milligrams per liter (mg/L) during high periods of river flow, 7 to 9 mg/L during moderate river flow, and 6 to 9 mg/L during the late summer months when flows are lowest (SFEI 1994). Thus, DO issues in San Francisco Bay due to dredging impacts are likely limited. Reduced DO situations can occur during the summer in the extreme southern end of the South Bay or semi-enclosed embayments such as Richardson Bay, where DO concentrations are reduced by poor tidal mixing and high water temperature (SFEI 1994). There are generally no dredging activities in the extreme southern part of the bay, but some marinas located in Richardson Bay require dredging (see Figure 3-2). Compared to other areas in the Bay, these specific dredging sites are more likely to be affected by dredging-induced DO reductions than others.

Decreased pH

The extent of pH decreases during sediment resuspension is mainly a function of the oxidization of sulfides to highly acidic sulfate (SO_4^{2-}). The formation of sulfate depends on the amount of sulfide in the sediment and how much it is oxidized during the release (Delaune and Smith 1985). However, the buffering capacity of seawater (Duxbury and Duxbury 1991) makes drastic and sudden pH changes unlikely in San Francisco Bay. This conclusion is supported by a laboratory study with anoxic sediments taken from heavily polluted waters near Rio de Janeiro, Brazil. In a resuspension experiment with freshwater sediment samples (less buffering capacity) from the River Iguaçu.(Brazil), the pH decreased from 7.5 to 4.4 after five hours of resuspension, accompanying the oxidation of sulfides to sulfate. In a parallel experiment with a brackish sediment sample (more buffering capacity) from Sepetiba Bay (Brazil), no decreases in pH were observed (Maddock et al. 2007), presumably due to the higher buffering capacity of the brackish water. Thus, drastic pH drops due to sulfate formation are not expected during dredging activities in San Francisco Bay.

Release of sediment contaminants

Dredging and dredged material disposal can release sediment-associated metals and other pollutants by dispersion within the resulting sediment plume (Eggleton and Thomas 2004, LFR 2004). The dispersion of pollutants can occur in the dissolved or in the particulate state (Goosens and Zwolsman 1996, LFR 2004). A number of studies have examined the release of contaminants into the water column (for example, Bloom and Lasora 1999; Pieters et al. 2002; Vale et al. 1998), but general conclusions are difficult to draw, because of the complex and specific nature of the physiochemical processes in each case. While the processes and mechanisms are well known, the exact results are dependent on numerous conditions that regulate them. Examples are the influence of ambient water concentrations on sorption and desorption from sediment particles, the role of dissolved organic carbon (DOC) and particulate organic carbon (POC) vs. mineral particles per se (e.g. bi- and tri-partite clay minerals), and how these processes are controlled by changes in redox potential and other factors (Eggleton and Thomas 2004).

Heavy Metals of concern, due to their potential toxicity to fish, include cadmium (Cd), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), zinc (Zn), silver, (Ag), chromium (Cr), and arsenic (As). Research to date has investigated the effect of dredging-induced sediment resuspension on many potentially toxic metals. However, despite the many comprehensive studies, there is very little consensus on the release of metals and their effects.

Heavy metals occur in different modes in aquatic systems: as free ions in the water; complexed with organic or inorganic anionic ligands; adsorbed to particulate organic matter or minerals, or as solid precipitates. Central in terms of potential bioavailability and toxicity is the free mode of occurrence (see Figure 3-3). In this mode, Cd, Cu, Hg, Ni, Pb, Zn, and Ag occur as single, positively charged ions in the water. As and Cr occur in negatively charged forms (Goosens and Zwolsman 1996, Stumm and Morgan 1996).

Following the six hour resuspension of a polluted anoxic sediment into seawater, Hirst and Aston (1983) observed significant release of Fe and Mn but not of Cu or Zn. Their results actually showed small, but measurable, net losses of Cu and Zn from the aqueous phase to the reoxidized sediment. Upon resuspension of contaminated dredged material into an estuarine water, Prause et al. (1985) observed that neither Pb nor Cd were released within ten hours and only Cd was observed to be released over 50 days. In a case study in the lower delta of the Rhine and Meuse rivers in the Netherlands, the investigators (Van den Berg et al. 2001) observed that the mixing of dredged material with riverine suspended matter resulted in increasing levels of trace metals in the suspended fraction. However, dissolved trace metal concentrations in the water column were not significantly influenced by dredging activities. They interpreted this finding as an indication of a strong binding mechanism of trace metals to the solid phase or a fast redistribution over different sorptive phases in response to oxidation of trace metal sulfides. They propose that dissolved metal concentrations reflect the availability and reactivity of different carrier phases (iron and manganese hydroxides, sulfides, and organic matter) available to metals and the competing kinetics of release and removal mechanisms. Given the variable proportions of sorptive phases available to metals between the ambient suspended matter and the resuspended sediments, changes in these parameters upon dredging show one possible behavior of trace metals during dredging operations.

Overall, the literature suggests that only a small fraction of the total amount of heavy metals is dissolved, because of their general tendency to be bound to Fe and Mn oxyhydroxides. In anoxic pore waters the dissolved heavy metal fraction that occur as single, positively charged ions in water (e.g., Cd, Cu, Hg, Ni, Pb, and Zn, see Figure 3-3) is reduced further by precipitation with sulfide Thus, the direct contribution of these metals from anoxic sediments is considered to be negligible (Goosens and Zwolsman 1996). For example, a study from the Netherlands found that less than 0.1% of the amount of heavy metal (Cd, Cu and Zinc) in the sediment was in the dissolved phase (Van den Berg et al. 2001).

Similar conclusions were reached for As, which occurs as a negatively charged ion in the free state. In resuspension experiments on sediment samples taken in Saguenay Fjord, Canada, Saulnier and Mucci (Saulnier and Mucci 2000) observed a strong correlation between the acid volatile sulfide (AVS) and the amount of As released to the solution. However, the released As was subsequently scavenged by newly precipitated Fe and Mn oxyhydroxides (Saulnier and Mucci 2000). No studies were found pertaining specifically to potential releases of chromium.

Ammonia. The *LTMS Framework* background document raises the possibility of short-term changes in unionized ammonia in conjunction with near-bottom turbidity plumes caused by disposal (LFR 2004). Ammonia toxicity is known as a confounding factor in toxicity tests with benthic organisms, which are part of sediment evaluations in San Francisco Bay according to the Inland Testing Manual and the Ocean Testing Manual (DMMO 2001; SWRCB 2006; USEPA and USACE 1991, 1998)

Organic contaminants are mostly particle-bound due to their hydrophobic ("oily") nature. Thus, direct contribution from pore water is low, unless it contains high concentrations of dissolved organic matter (DOM). In this case, pore water may contribute substantial amounts of DOM-bound pollutants: organic contaminants may adsorb to DOM, forming a complexed fraction which is included in the operationally defined dissolved state (particles <0.45 μm), although the micropollutants occur in bound form. Then, a substantial amount of apparently dissolved, yet DOM-bound pollutants may enter the water column during dredging. (Goosens and Zwolsman 1996).

During dredging, several changes occur when sedimentary material is dispersed into the water column:

1. the POM concentration in the water increases;
2. DOM-bound pollutant concentration in the water column increases;
3. the total concentration of pollutant in the water increases;
4. and POM with different pollutant concentrations are mixed.

According to the partition theory, a new equilibrium will be established (Figure 3-4). The concentrations in this newly equilibrated situation can be estimated using partition theory, which says that, for a given compound, the ratio of the concentration associated with POM (μg/g) and the dissolved concentration in the water (in μg/L) is a constant, characteristic for that compound (Brown and Neff 1993; Goosens and Zwolsman 1996). .In many cases, the concentration on the sediment POM can be expected to be higher than the concentration on suspended POM already in the water column. In that case, mixing of sediment particles will cause desorption, according to the partition theory, to restore the equilibrium. However, for organic contaminants, desorption rates tend to be quite slow, and it may take months to years for these chemicals to desorb and reach equilibrium partitioning between the solid and dissolved phase (Borglin et al. 1996; NRC 2001; Shorten et al. 1990; Vale et al. 1998; Zhang et al. 2000).

Changes in bioavailability

Contaminants are available to fish via gill uptake or ingestion with food. Branchial uptake of dissolved contaminants in the water column is presumably the most significant route of exposure for short-term acute toxicity in fish (Figure 3-5)(Rand and Petrocelli 1985). Eggleton and Thomas (Eggleton and Thomas 2004) provided a fairly recent review of factors affecting the bioavailability of sediment contaminants during dredging and other disturbance events. In general, dredging and resuspension result in the exposure of anoxic sediment to DO, which results in a positive change in the redox potential (Eh), which can accelerate desorption, oxidation, complexation, and the bacterial degradation of sediment contaminants (Figure 3-6). An example is the mobilization and transfer of metals from sulfide minerals (FeS/MnS) to the dissolved phase during the initial exposure of reduced sediments to DO (Calmano et al. 1993). However, these processes are sediment, compound, and animal specific. Dredging related bioavailability is mainly site-specific and dependent on the degree of contamination, the amount of suspended sediment, the duration of the disturbance, and the organism. Few studies have examined this phenomenon and there are major information gaps, for example, regarding the kinetic processes that regulate metal and organic contaminant release during changes in redox potential, the release of organometallic compounds from sediments during resuspension, and the short-term partitioning of organic and organometallic compounds between the different phases of the plume (particles of different size and origin, colloidal matter, etc).

3.2 Possible Short-term Effects on Sensitive Species

In general, relatively little is known about pollutant effects on estuarine species, compared to freshwater and marine species. However, estuaries represent an ever-changing environment with respect to salinity, pH, temperature, oxygen, and if present, pollutants. Resident fish, such as the delta smelt, may have evolved mechanisms to accommodate or avoid stressful aspects of an estuarine habitat. In migrating species such as salmon, steelhead, and sturgeon, successful navigation of the estuary may involve changes in physiological and behavioral systems as an adaptation to the stressful effects of ammonia and other pollutants (Eddy 2005). Potential short-term effects on sensitive fish species are a function of the type of contaminant, its concentration in the sediment, environmental conditions at the time of dredging (e.g, low oxygen or reducing environments), and the duration of the exposure. Although there are numerous studies on the direct effects contaminated sediments may have on fish, there are few studies that look specifically at the acute toxicity of suspended contaminated sediments due to dredging (Anchor Environmental CA2003). There are even fewer studies that look specifically at the species of concern for this review. Although there are a number of studies on rainbow/steelhead trout, most involve rainbow trout residing in freshwater, and only a few look at saltwater-adapted rainbow trout or ocean-migrating steelhead trout. Some limited ecotoxicological information relevant to this review was found on chinook and coho salmon, but, to our knowledge, there have been no relevant studies on delta smelt or green sturgeon.

Heavy metals. Branchial uptake of dissolved metals is presumably the most significant exposure route for short-term acute toxicity in fish (Figure 3-5)(Rand and Petrocelli 1985)[2]. Bioavailability and toxicity of waterborne metals is very speciation dependent (3-3). Chemical speciation concerns the nature and quantity of the various forms in which a chemical element occurs. Typically, the free metal ion is the most toxic form, and metals complexed with dissolved organics and inorganic anions show lower degrees of bioavailability and toxicity (Kramer et al. 1997). This general rule, however, is not always valid. Notable exceptions are organometallic compounds such as the very toxic methyl mercury and tributyl tin. In any case, risks from heavy metals released during dredging would be primarily related to

[2] The reviewed literature does not suggest a significant role of metal-laden prey for short-term acute toxicity in fish.

changes in conditions promoting the shift of heavy metals from the particulate into the dissolved state (Goosens and Zwolsman 1996).

Most metals in sediments are present in the particulate phase; the amount of metals dissolved in the porewater is typically less than 0.1% of the total metal in sediments (Van den Berg 2001). Therefore, in most scenarios, resuspension of metal-contaminated sediments might only create minimal potential for direct toxicity, unless there is a significant transfer of metals into the dissolved phase.

Most available studies suggest that there is no significant transfer of metal concentrations into the dissolved phase during dredging, even though release of total metals associated with the suspended matter may be large (Caetano and Vale 2003; Goosens and Zwolsman 1996; Maddock et al. 2007; Van den Berg 2001; Simpson et al. 2000). This is documented, for example, by a case study from a riverine dredging site in the Netherlands. During dredging, the authors observed an increase in particulate trace metal concentrations (Cd, Cu, Ni, Pb, and Zn) in the water column. The total metal increases during resuspension ranged between 26 and 135%, but there were no differences in dissolved metal concentrations before and during resuspension. Initial sediment concentrations of the metals ranged between 19 milligrams per kilogram (mg/kg) for Cd and 1527 mg/kg for Zn (Van den Berg et al. 2001), a range that is 1,000 – 10,000 times higher than average concentrations in San Francisco Bay (Table B-3). In a Portuguese study, levels of trace metals measured during dredging operations varied randomly in both dissolved and particulate phase, even though results from laboratory slurry experiments published in the same study suggest significant releases of Cd, Cu, and Cd within the first hour of the experiment (Saulnier and Mucci 2000).

Organic contaminants such as pesticides, polychlorinated biphenyls (PCBs), and polyaromatic hydrocarbons (PAHs) are generally not very soluble in water and direct toxicity by exposure to dissolved concentrations in the water column is not very likely. Nevertheless, the particulate bound portion of chemicals can also be toxic (Anchor Environmental CA2003)(Figure 3-7). Various acute toxicity and biological effects have been attributed to organic contaminants based on laboratory studies: pesticides may cause paralysis or avoidance; PCBs may influence enzyme activities, and PAHs have a narcotic mode of action involving interference with key membrane-mediated physiological and biochemical processes (Rand and Petrocelli 1985). PAHs can be acutely toxic in the parts per million (ppm) range. The lethal concentration for 50% of the population (LC50) values for acenaphthene and pyrene determined in short-term freshwater toxicity studies (exposure 1 day) with rainbow trout were 1.6 mg/L and 2.0 mg/L (USEPA 2007). Deleterious sublethal responses include growth and development anomalies (Meador et al. 2006), cancer (Rand and Petrocelli 1985), or susceptibility to infectious disease (Arkoosh et al. 2000), but these are only known to occur due to long-term exposure. For example, rainbow trout fed diets containing 1006 mg/kg of benzo[a]pyrene for 12 months developed liver tumors (Couch 1993). A dose-response feeding study indicated adverse effects on fish growth and alterations in whole-body lipids and several blood chemistry parameters when juvenile ocean-type chinook salmon were fed PAHs in their diet for 53 days (Arkoosh et al. 2000) .

Low dissolved oxygen (Figure 3-8). The United States Environmental Protection Agency (USEPA) adult/juvenile aquatic life survival criterion for DO[3] is 2.3 mg/L (USEPA 2000a) and the DO water quality objectives (WQO) for San Francisco Bay are 7 mg/L downstream of Carquinez Bridge and 5 mg/L upstream of Carquinez Bridge (Kapahi et al. 2006). DO concentrations between the aquatic life criterion and several mg/L below the WQO would be expected to slow fish growth rate; the amount of impact is proportional to the amount of depletion below the WQO. If the DO would remain at or below a critical DO level of about 2 to 3 mg/L, significant mortality is expected in fish populations

[3] i.e., twice the Final Acute Value, which is the lowest level of DO that does not allow the mortality of aquatic organisms (both juveniles and adults) to exceed 50% when exposed for 96 hours (Stephan et al. 1985).

(Lee 2007). Generally, reduced DO concentrations due to sediment resuspension would be expected to be localized and short term, with minimal impacts (US Navy 1990).

Hydrogen sulfide (H_2S) is a metabolic poison that is lethal to most fish at less than 1 mg/L (USEPA 1976). Effects on fish are difficult to determine because H_2S usually occurs only in association with hypoxic conditions; that is, situations with extremely low DO below the aquatic life criterion that are also lethal to fish (Figure 3-9). Aside from ephemeral releases of H_2S, risks to fish may be of greatest concern when dredging operations result in depressed DO concentrations near the bottom (LFR 2004). Risks of H_2S to fish are dependent on temperature, pH, and DO. In general, fish exhibit a strong avoidance reaction to H_2S. Ortiz et al. (1993) studied rainbow trout mortalities after eight hours of flow-through exposure to combinations of sulfides and low pH. A concentration of 0.4 mg/L sulfide at pH 5.5 led to 100% mortality. The mortality rate for 0.45 mg/L sulfide at pH 6.5 was 20% mortality, and for 0 mg/L and pH 5.5 40%. No local data were found to further evaluate the likelihood of H_2S exposure and effects in San Francisco Bay

Ammonia toxicity studies have been done on freshwater fish but there has been little direct work on the toxicity of ammonia to estuarine fish. From studies of other species, the toxicity of ammonia is strongly influenced by differences between species and pH. Salinity and temperature also influence ammonia toxicity, but the effect is comparatively minor compared to pH (USEPA 1989, 1999; Wicks et al. 2002). In general, ammonia toxicity is based on the presence of unionized ammonia (NH_3). In estuarine fish, the toxicity of ionized ammonia (NH_4^+) may also occur, since the gills show some permeability to this ion. In experimental studies, the gills of saltwater-adapted rainbow trout were more permeable to NH_4^+ than in freshwater. This also implies that ammonia toxicity is greater in sea water-adapted or estuarine species, since their ammonia uptake results from the exposure to both the ionized as well as unionized species in the surrounding water. These findings also imply that ammonia toxicity to estuarine fish may be underestimated, if it is measured as a function of the unionized ammonia concentration (USEPA 1989, 1999; Wicks et al. 2002; Wilson and Taylor 1992). During ammonia exposure, estuarine fish are most likely to be at risk during larvae or juveniles stages if the temperature is elevated, if salinity is near the sea water value, and if the pH value decreases below pH 7. They are also likely to be more at risk in waters of low salinity, high pH and high ammonia levels. These conditions favor transfer of ammonia from the environment into the fish, as both ionized and unionized ammonia, and retention of ammonia by the fish is likely. Since ammonia interferes with nervous function, there may be impairment of activity and behavior. Fish will be further at risk from ammonia toxicity if they are not feeding, if they are stressed, and if they are active and swimming (Eddy 2005; Randall and Tsui 2002; Shingles et al. 2001; Wicks and Randall 2002; Wicks et al. 2002). Episodic exposures to ammonia, as would be the case for dredging-related exposure, should be considered in relation to the rate at which the animal is able to accumulate and excrete ammonia, and the effects of ammonia ionic regulatory and acid-base processes in the gill. The rate of unloading the accumulated ammonia from the body will be of critical importance in determining response to the next episode. If the next episode occurs before ammonia unloading is substantially complete, then a larger and potentially more damaging burden of ammonia may accumulate, with possible disruption of ionic regulatory processes. Bioenergetic modeling of ammonia uptake and excretion taking both physiological and chemical processes into account may be useful in developing an understanding of these aspects of ammonia toxicity to fish. An appropriate model is not available and would have to be developed. It is not clear whether ammonia exposed fish at higher temperatures accumulate more ammonia than those at lower temperatures. The permeability of biological membranes increases by a factor of between 2 and 3 for a 10º C increase in temperature (Prosser 1991), but there are no studies available to address whether fish exposed to ammonia at higher temperatures accumulate more ammonia than those at lower temperatures (Randall and Tsui 2002). It is also uncertain how far estuarine fish are able to detect and avoid affected areas, and the difference in how estuarine residents and migrants respond to ammonia. If entry to an ammonia polluted area is unavoidable, then responses will be determined by the fish's developmental stage, condition, activity level and its physiological capacity to respond to ammonia levels during the exposure (Eddy 2005). Table B-4 provides a summary of toxicity and biological effects thresholds found in the literature. Figure 3-10 depicts a conceptual model of potential short-term toxicity of ammonia during dredging.

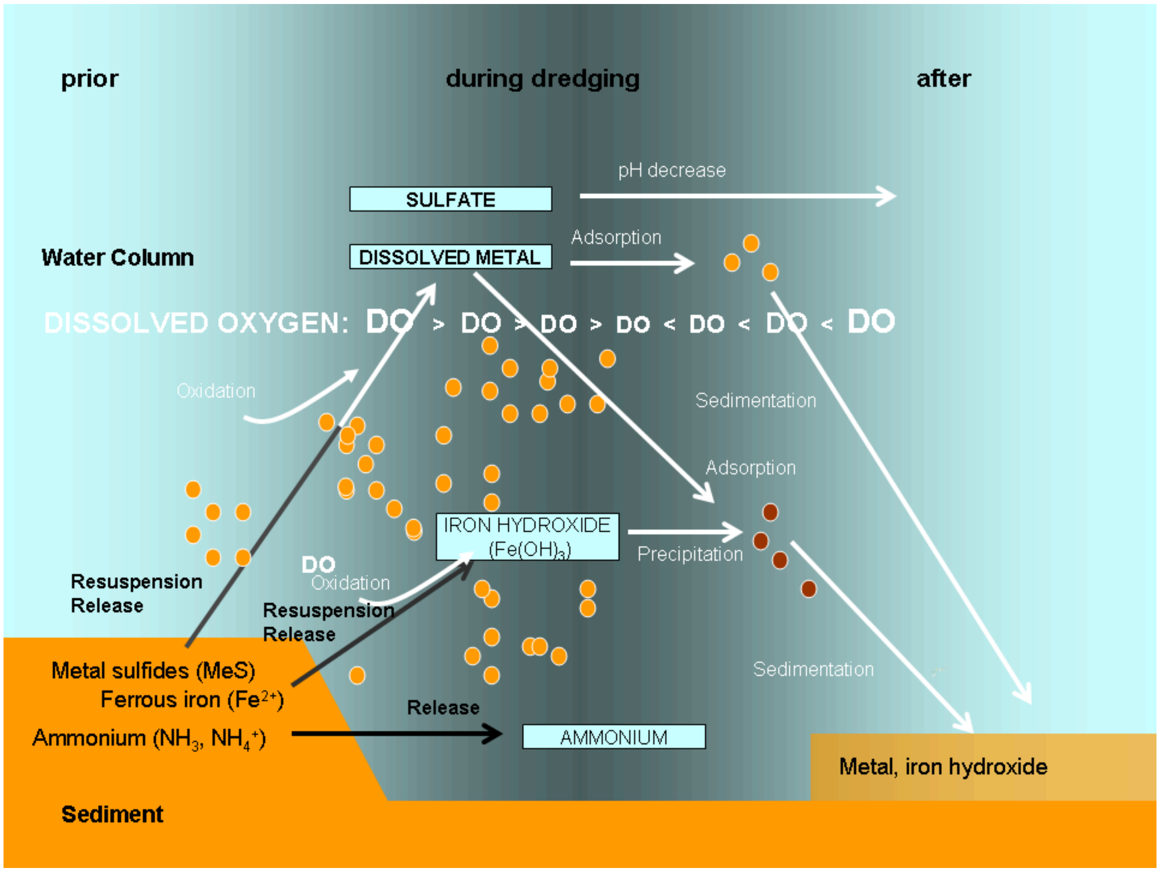

Figure 3-1. Chemical processes upon resuspension caused by dredging.

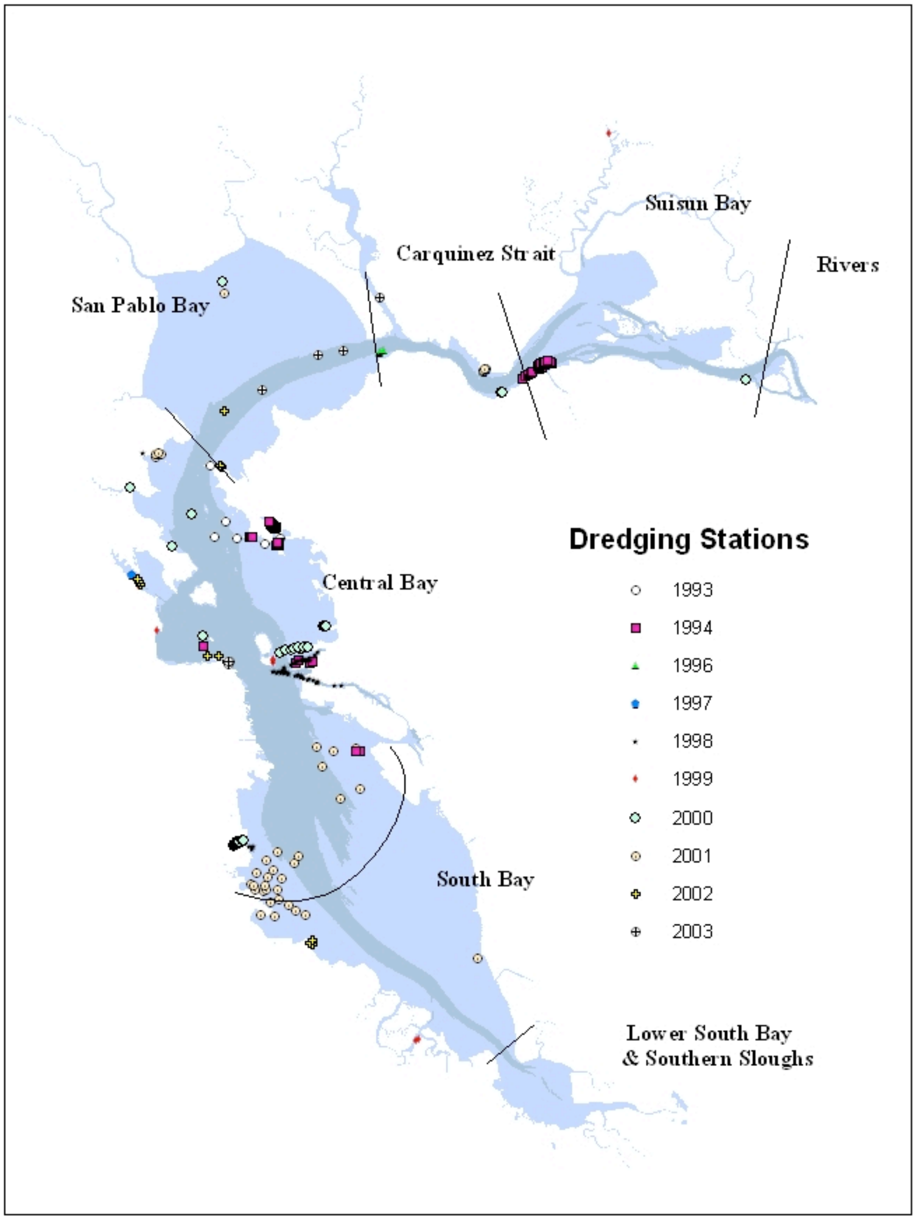

Figure 3-2. Location of sediment sampling stations of dredging studies in the San Francisco Estuary (1993 – 2003).

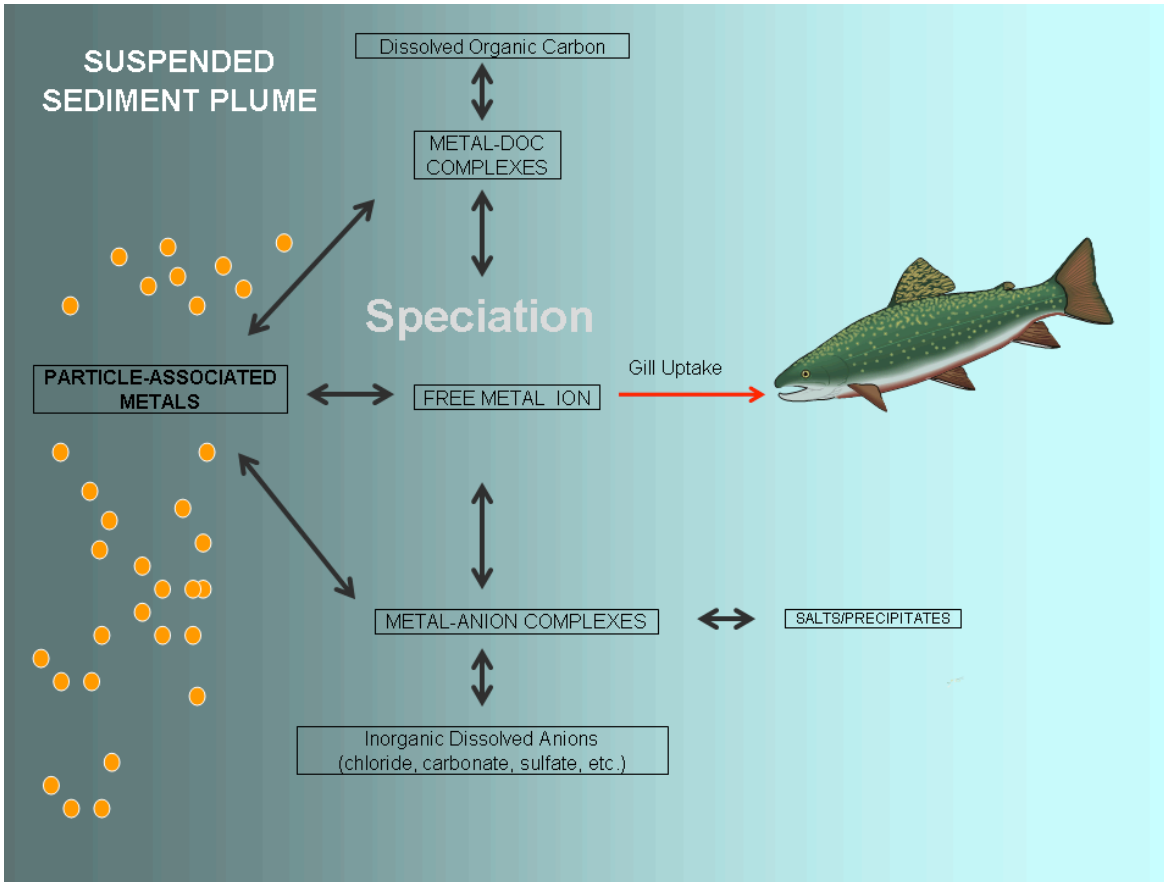

Figure 3-3. Bioavailability and toxicity of waterborne metals is very speciation dependent.

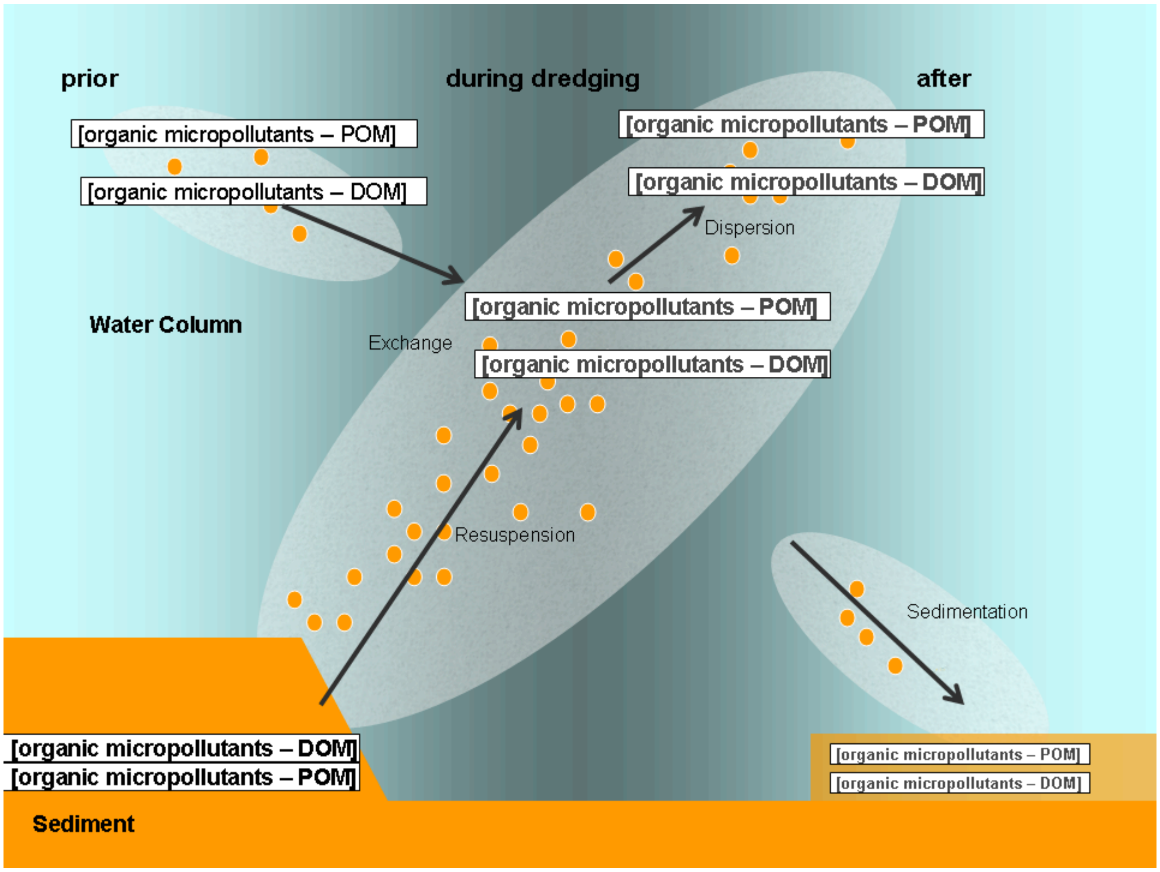

Figure 3-4. Schematic representation of the processes controlling the chemical and biological availability of organic contaminants (such as PAHs) upon resuspension caused by dredging (adapted from Goosens and Zwolsman 1996).

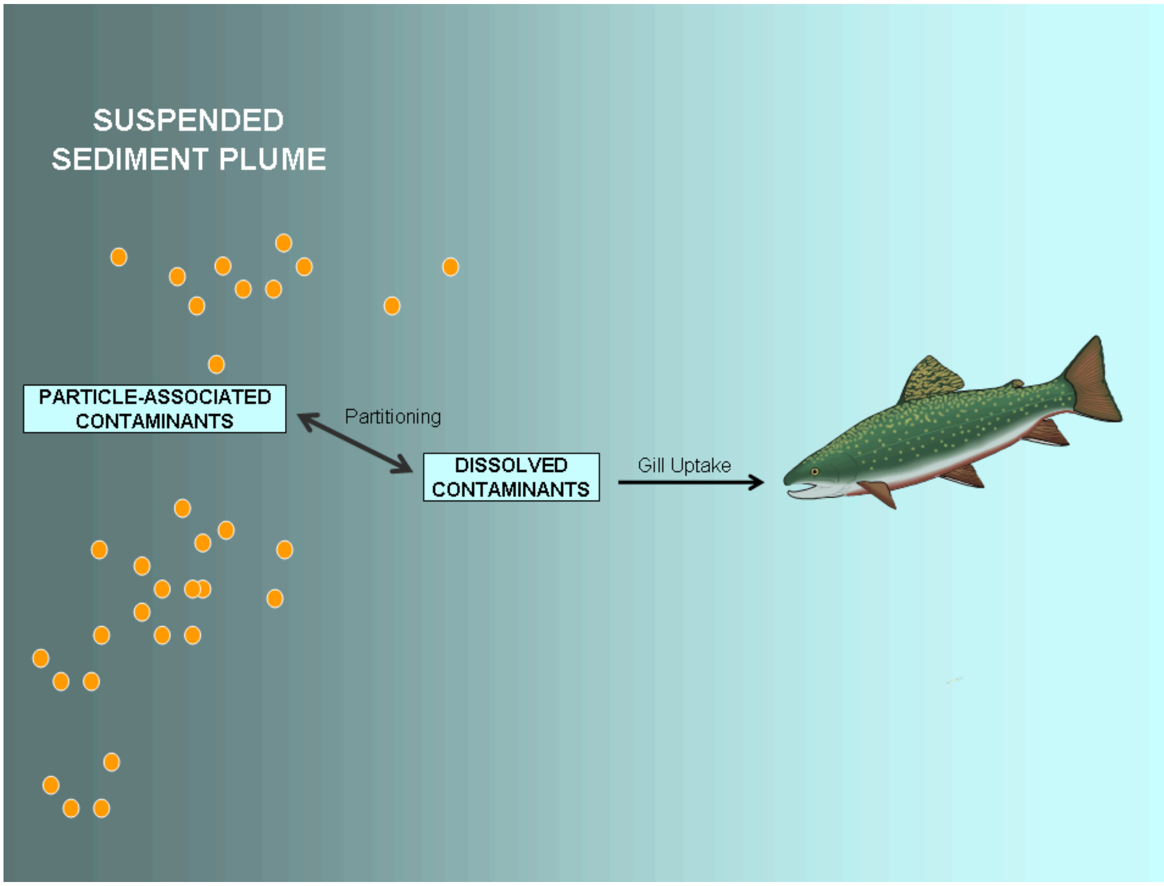

Figure 3-5. Simplified conceptual model of dredging-related contaminant exposure of fish. Branchial uptake of dissolved contaminants in the water column is presumably the most significant route of exposure for short-term acute toxicity in fish.

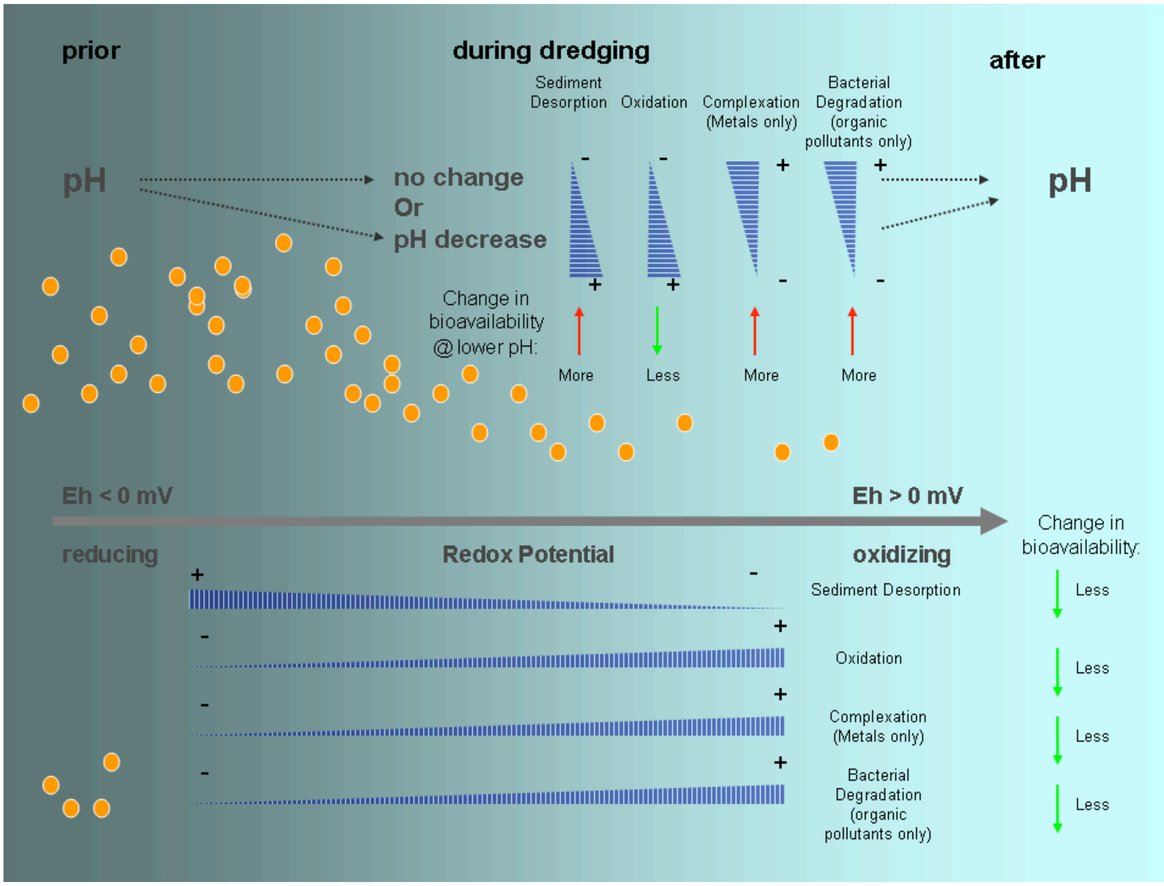

Figure 3-6. Generalized schematic representation of the direction of changes in bioavailability as impacted by changes in pH and redox potential during dredging.

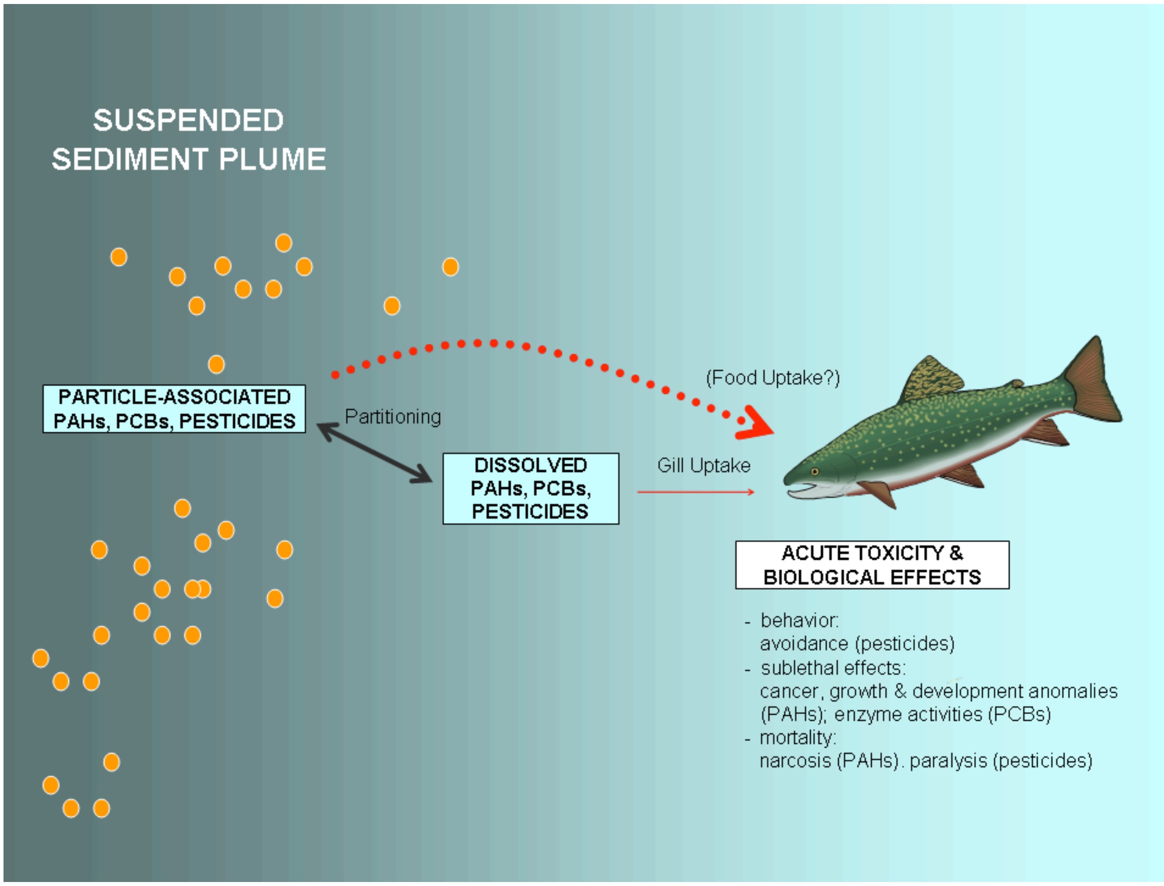

Figure 3-7. Conceptual model of direct short-term toxicity due to exposure to organic contaminants in resuspended sediments.

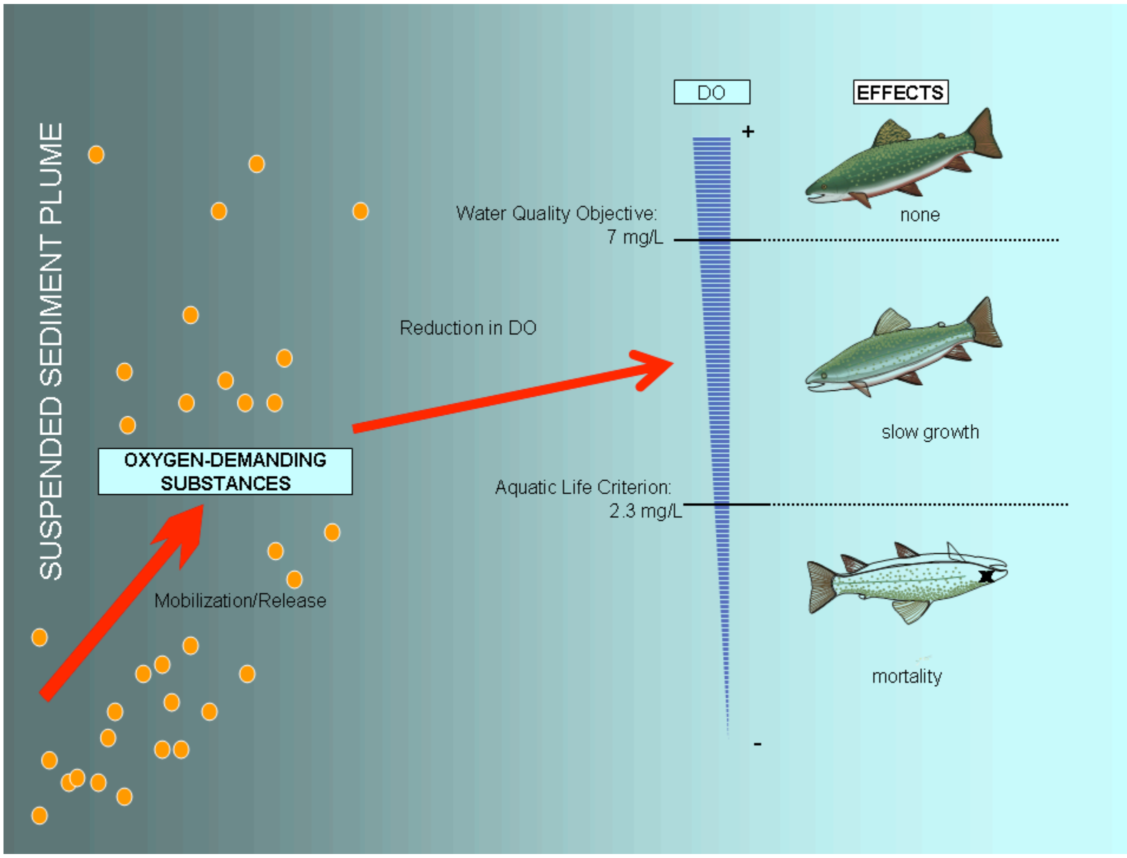

Figure **3-8**. *Conceptual model of reduced DO impacts on fish.*

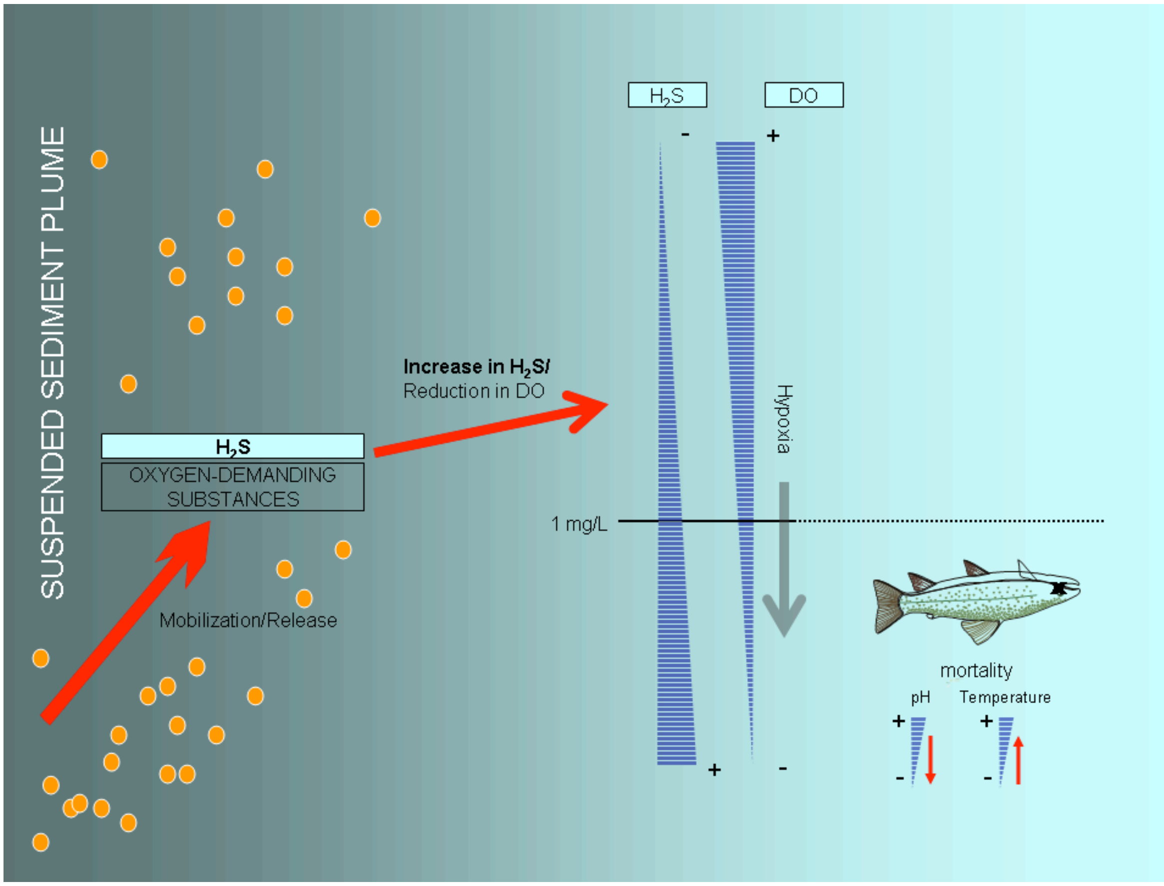

Figure 3-9. Conceptual model of potential acute H_2S toxicity to fish during dredging. H_2S toxicity is associated with hypoxic (low DO) conditions that are also toxic to fish.

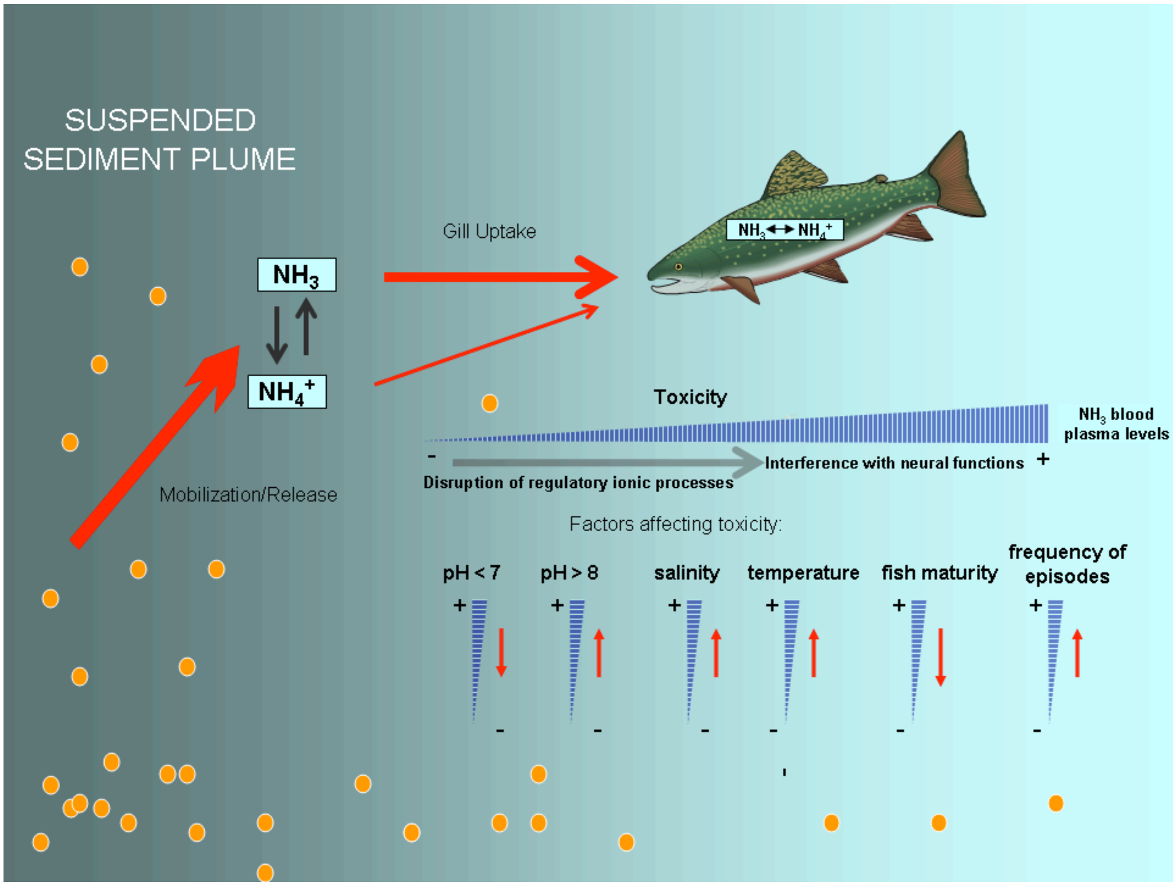

Figure 3-10. Conceptual model of potential ammonia toxicity to estuarine fish during dredging.

4. Methods

Short list of fish species and contaminants

The scope of work for this project, in terms of fish species and contaminants, was defined through discussions with USACE, SFBRWQCB, BCDC, and NFMS staff. The initial list of contaminants (Table B-2) was based on the U.S. Fish and Wildlife Service (USFWS) biological opinion on the proposed wetland restoration project at the former Hamilton Army Airfield in Marin County (Goude 2005). Several contaminants listed in the biological opinion were not included, either due to their propensity to affect fish only after bioaccumulation, for a lack of available information on their toxicity potential effects, low acute toxicity, lack of available data, or a combination thereof[4]. Several conventional water quality constituents were added for their potential effects on sensitive fish (see Table B-2). This initial list of potential contaminants of concern provided focus for a literature review of potential short-term water quality impacts and possible effects on the fish species of concern, as well as for the evaluation of available environmental data.

Toxicity and biological effects thresholds for the five fish species of concern

Toxicity and biological effects thresholds for the five fish species of concern (Table B-1) were retrieved from ECOTOX (USEPA 2007) or extrapolated by means of Interspecies Correlation Estimations (ICE), which were calculated based on available toxicity data from closely related species (Asfaw et al. 2003; Mayer et al. 2004). Only the information most ecologically relevant to this study was used. This includes selection of data only on acute effects (e.g., behavior and mortality) and selection of the lowest available effect level (i.e., NOEC > LOEC > LC50[5]) or the minimum test duration. For the species and contaminants of interest to this project, information was only available for freshwater toxicity, not for saltwater toxicity. For Cd, Cu, Ni, and Zn, the minimum effect thresholds used in our calculations are below the respective water quality criteria for the San Francisco Estuary (see Table B-5).

Two species of concern were not present in the ECOTOX database at all: green sturgeon and delta smelt. There were also no general data on other sturgeon or smelt species. Data on steelhead trout was also sparse. However, there are numerous toxicological studies using its freshwater-adapted counter-part, rainbow trout. Toxicity studies with rainbow trout have shown that its response to contamination and other environmental influences are more sensitive than similar species (e.g., Hansen et al. 2002; Svecevicius 2005).

Evaluation of sediment contaminants for acute toxicity and short-term sublethal effects on the five fish species of concern

The major limitation of the environmental data evaluation was the lack of water column chemistry data collected during dredging operations in the San Francisco Estuary or elsewhere. Therefore, indirect methods were used to estimate potential water quality changes and the potential for effects based on available sediment concentration data from dredging studies (see below).

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[4] Chlordanes, Cobalt, Dioxin (total TCDD TEQ), Endrin Aldehyde, Heptachlor-epoxide, MCPP, TPH-diesel/motor oil, TPH-gasoline/JP-4

[5]NOEC = No observed effects concentration; LOEC = lowest observed effects concentration; LC50 = lethal concentration for 50% of the population.

The following approach was followed for assessing potential short-term effects:

1. Sediment concentrations were screened against effects range-medium (ERM) and effects range-low (ERL) values to narrow the initial list of contaminants (Long et al. 1995). *ERL and ERM* are proposed guideline values to define total sediment concentrations ranges that are rarely (below ERL), occasionally (above ERL and below ERM), and frequently (above ERM) associated with adverse biological effects (Long et al. 1995). The possible effects ranges are based on available data on biological effects of sediment-associated chemicals in coastal sediments. The two guideline values, ERL and ERM, are based on percentiles: ERL represents the lower 10th percentile of the effects data, and ERM represents the 50th percentile, or median, of the effects data. This screening method is extremely conservative, since it bases any risk for adverse effects on the assumption that all sediment-bound metal resuspended during dredging would be readily dissolved and bioavailable in the water column (see Section 3.1. for a discussion of contaminant bioavailability in plumes).
2. Available elutriate concentrations of contaminants from dredged material testing in San Francisco Bay were compared with thresholds for species of concern (see below); and
3. Dissolved concentrations in sediment plumes resulting from dredging and disposal operations were estimated with model calculations based on average sediment concentrations from dredging studies in San Francisco Bay and compared with toxicity and biological effects thresholds for the species of concern.

Dissolved plume concentrations of contaminants that are predominantly particle-bound (e.g., organic pollutants and trace metals) were estimated based on sediment-water equilibrium partitioning, and those for sediment contaminants that occur mostly dissolved in porewater (e.g. ammonia, sulfides) were based on simple mass dilution. Equations (1) and (2) were used to make the conversion from sediment to dissolved water column concentrations for organic pollutants (e.g. PAHs, polyaromatic hydrocarbons, Schwarzenbach et al. 1993):

$$M_{dissplume} = \left(C_{dissambient} \times V_{plume}\right) + \left(V_{pore} \times C_{pore}\right) + \left(\left(C_{sed} / Kd \times Foc\right) \times V_{sed}\right) \quad (1)$$

$$C_{dissplume} = M_{dissplum} / V_{plume} \quad (2)$$

where $M_{diss, plumes}$ is the mass of dissolved contaminant in the dredged sediment plume, $C_{diss, plumes}$ is the ambient dissolved contaminant concentration, V_{plumes} is the volume of the dredged sediment plume, V_{pore} is the volume of pore-water in dredged sediment, C_{pore} is the contaminant concentration in pore-water of dredged sediment, C_{sed} is the contaminant concentration in dredged sediment, K_d is the equilibrium partition constant for the contaminant of interest, F_{OC} is the fraction of organic carbon in dredged sediment, V_{sed} is the volume of dredged sediment, and $C_{diss/plume}$ is the contaminant concentration dissolved in the dredged sediment plume. The definition and estimation of mixing zones was beyond the scope of this project.

Environmental data sources

The SQO database provided contaminant concentrations (C_{sed}), OC contents, and volumes of dredged sediments (V_{sed}) for calculations using Equation (1). K_{OC} values for organic compounds were obtained from Schwarzenbach et al. (1993), and dissociation constants for metals (K_d) were estimated based on field data collected by SFEI and the U.S. Geological Survey in San Francisco Bay (Kuwabara et al. 1989; SFEI 1994, 1997) (Table B-6). Calculations of dissolved contaminant concentrations in plumes also required assumptions concerning the size and extent of plumes and of ambient water concentrations prior to dredging. Sediment plume volumes were estimated based on available information about the size of disposal sites in the Bay (LTMS 1996). The plume volumes used were 0.001 km^3, 0.002 km^3, and 0.004 km^3 to provide a range in dredging scenarios for evaluation. Ambient contaminant concentrations prior to dredging were calculated using data collected by the RMP between 1993 and 2006 (e.g., SFEI 2006). Dissolved water concentrations were averaged by Bay segment across all years of available data to obtain an estimate of ambient status for contamination. The direct porewater contribution of metals and organic pollutants was unknown and was assumed to be negligible in terms of quantity (Goosens and Zwolsman 1996) and was therefore not estimated.

Sediment concentrations for contaminants of concern were gleaned from the California Sediment Quality Objectives (SQO) database (SCCWRP 2006). The database contains records of studies conducted for various purposes, and includes data from ambient monitoring programs and dredging projects. There are 286 records of sediment sampling station visits from dredging projects in the San Francisco Estuary, but the database is not an exhaustive compilation of all dredging projects. The SQO database includes sediment data from San Francisco Estuary dredging projects between 1991 and 2003, with the majority of data being from 1996 to 2003 (Table B-7). Most of these samples were collected and analyzed by private contractors for the port authorities, marinas, civil works and maintenance units of local governments, refineries and other industrial terminal operations, homeowner associations, federal agencies (Army Corps of Engineers and Coast Guard), and other dredging interests. The recorded stations are either at the site of a dredging project, at a disposal site, or at reference sites inside the estuary. Most dredging samples (68%) are from stations in the Central Bay, the region that is most heavily used for navigation and contains the largest ports in the Bay (i.e., San Francisco, Oakland, and Richmond). There are no sampling sites in the database for dredging projects in the Rivers and Lower South Bay regions, which have less navigational and shipping infrastructure and therefore fewer dredging needs (Jabusch and Yee 2006).

In total, the SQO database includes measurements for 303 different chemical parameters including trace metals, polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), dioxins, furans, organotins, pesticides, phenols, phthalates, and various semivolatile organic contaminants. However, for the bulk of these contaminants (including PCBs, pesticides, dioxins and furans, organotins, phenols, phthalates, and semivolatile organic compounds), dredging studies do not collect data or there were high proportions of non-detect concentrations. These factors, as well as different reporting conventions (for example, reporting individual PCBs vs. Aroclors vs. total PCBs), are confounding factors limiting the direct comparison of sediment contamination data from dredging projects and other monitoring studies (Jabusch and Yee 2006). Therefore, the present study was limited to an analysis of data obtained from dredging projects. An exception was made for ammonia. Since there were no ammonia data for dredging projects available in the database, data collected by the Regional Monitoring Program (RMP) for Water Quality in San Francisco Bay were used.

Supporting information on each dredging study was a prerequisite for inclusion in our data analysis. This included Quality Assurance (QA) information, qualifiers for non-detectable contaminants, and volumes of dredged sediment at each site.

5. Data Evaluation and Synthesis

Heavy metals. Acute heavy metal toxicity is related to the concentration of free metal ion species dissolved in the water. As discussed, it is difficult to quantify actual releases into the dissolved phase during resuspension, and, even more so, the resulting bioavailable free ion fraction. Also, toxicological data for the species of interest are sparse, and where available, from studies that do not represent estuarine conditions during dredging (see Section 5.1). Considering the paucity of useable data, the evaluation of potential effects was limited to an approximation, making simplified and conservative modeling assumptions (i.e. worst-case scenarios).

As described in Section 4, potential contaminants of concern were initially screened by comparing total contaminant concentrations in sediments (Table B-3) against effects range-low (ERL) and effects range-medium (ERM) values (Table B-8).

Of the 22 screened contaminants, only Ni exceeded the ERM threshold in more than 10% of samples (Table B-8). Sediments in San Francisco Bay are naturally high in nickel due to a geological signature (Yee et al. 2007). Three additional metals—Cd, Cu, and Zn—were selected for further screening to obtain a more complete picture of potential short-term metal toxicity, even though the initial ERM screening did not indicate a concern. Subsequently, dissolved water column concentrations of Cd, Cu, Ni, and Zn in plumes were calculated as described in Section 4. The estimated dissolved concentrations were then compared to toxicity and biological effects thresholds. This second screening step is also conservative, assuming that all released dissolved metal is readily bioavailable. Based on the estimated concentrations, there were no threshold exceedances in any sample for any of the four metals, i.e. no indication of a toxicity or biological effects risk (Table B-9). The calculated average estimated dissolved water column concentrations of Cu, Cd, and Zn in model plumes were 5x, 22x, and 322x less than the lowest documented NOEC values. The average estimated Ni concentration was 29x less than the lowest documented LC50 value. This implies that even if the total dissolved fraction of these metals should become bioavailable; there is a safety margin of a factor of five to several hundreds between estimated concentrations of remobilized metals and the lowest reported effects thresholds.

We also compared the available toxicity and biological effects thresholds (Table B-5) with chemical elutriate test data from a sediment evaluation study for the John F. Baldwin Ship Channel sediment dredging project (Lee et al. 1993). The standard elutriate test is the method of choice for assessing potential water column impacts and associated biological effects of dredging activities (USEPA and USACE 1998). The 1993 study results for the John F. Baldwin Ship Channel sediment dredging project (Lee et al. 1993) were the only available elutriate chemistry data for all of San Francisco Bay. Comparison of these data with available threshold values support the previous conclusion that there is no indication for acute toxicity or biological effects on the species of concern due to dredging activities in San Francisco Bay (Table B-10).

In summary, based on our evaluation, there is little likelihood of an immediate concern for acute toxicity or biological effects of the metals considered, on the species of concern, at the locations examined in San Francisco Bay, based on available threshold values (Tables B-9 and B-10). A note of caution should be added for the hypothetical case that a sediment to be dredged is more heavily contaminated than what the available data indicate, and that the fishes of concern were present at the time of dredging such a sediment, and would be more sensitive to metal toxicity than the tested species, or that testing conditions would grossly underestimate field toxicity. Also, there are remaining uncertainties due to 1) the sparsity of representative ecotoxicological data and 2) basic scientific information gaps and limited modeling capabilities concerning the behavior and bioavailability of metals during resuspension of dredged sediments. If more certainty is desired, chemical elutriate tests of sediments may be a feasible alternative and reasonable first approximation to evaluate the potential release of bioavailable metals and adverse effects on fish species of concern for any particular dredging project or situation. More complete and ecologically relevant toxicological information, and a better basic understanding of the processes controlling the fate and bioavailability of heavy metals under local conditions, would further reduce uncertainties.

Organic contaminants. As with heavy metals, the acute short-term toxicity of organic contaminants is mainly attributed to the fraction that become available in dissolved form in the water column during release, even though the particle-bound fraction may also play a role (Anchor Environmental CA2003). However, the possible contribution of particle-bound organic contaminants to acute fish toxicity is not well understood, and relevant toxicological information for the species of concern was not available. Twelve PAHs that are of potential concern to the five sensitive fish species were screened against threshold values as described above under heavy metals. There were no exceedances of effects range values (Tables B-8). Two PAHs, fluoranthene and phenanthrene, were also screened against water column concentration-based toxicological and biological effects thresholds with negative results (Table B-9). Elutriate test concentrations of PAHs from John F. Baldwin Ship Channel sediments did not exceed any ecologically relevant effects thresholds (Table B-10).

Conclusions for PAHs are similar to those for heavy metals: based on the available data, there is little reason for concern for adverse effects to the five species of concern due to exposure from dredging and disposal activities, but there are remaining uncertainties since there is only a smattering of relevant toxicological data and there are basic scientific information gaps, in this case mainly concerning the release kinetics and bioavailability of organic contaminants and the role of particle-bound organic contaminants for acute toxicity. If reducing uncertainties about potential effects is desired, chemical elutriate testing of sediments is recommended.

DO: The potential for DO to exert adverse effects on sensitive fish species was summarized and evaluated previously (LFR 2004), based on studies that were conducted between 1972 and 1975 by the U.S. Army Corps of Engineers' San Francisco District (USACE 1976). Our literature and data review did not reveal any new information of relevance. Disposal of dredged sediment has the potential to affect levels of DO at any disposal site, particularly in waters near the Bay floor. The effects are usually short-term, generally limited to the plume associated with each dump, and confined to the disposal area and immediately adjacent waters (LFR 2004). The overall risk to fish species of concern due to temporary oxygen depletion appears low: although, in several instances, reductions temporarily resulted in concentrations below the aquatic life protection threshold of 2.3 mg/L, these low DO conditions lasted for less than a minute in each recorded instance, which would not be expected to cause any major risk to fish that may be present in the vicinity (see Section 3.1).

In the LTMS review, the possibility was raised that more extensive water quality impacts may occur at disposal areas where DO levels are already depressed (such as in the South Bay or in Richardson Bay) and/or during disposal at high dumping frequencies.(LFR 2004). Site-specific studies and modeling exercises may be required to address this concern.

H_2S. No data were found concerning the release of H_2S during dredging activities in San Francisco Bay. There is a general lack of knowledge on whether, and if, to what extent, H_2S contributes to adverse effects on fish during resuspension of anoxic sediments. Effects on fish are difficult to determine because H_2S is often associated with hypoxic conditions caused by other factors. Hypoxia may also be lethal to fish (LFR 2004). In general, fish exhibit a strong avoidance reaction to H_2S (Ortiz et al. 1993).

Ammonia. Magnitude and extent of changes in ammonia levels as a result of dredged material has not been extensively monitored in SFB (LFR 2004). In general, there has been little direct work on the toxicity of ammonia to estuarine fish, despite the fact that estuarine fish may be more at risk than marine and freshwater species (Eddy 2005). Based on the reviewed literature, there is a possibility of adverse short-term effects on sensitive species by ammonia upon release by dredging; however, there has been little direct work to address this issue. The average calculated dissolved water column concentration for unionized ammonia in the Bay in a hypothetical scenario, using a baywide average concentration and a model dredged material plume of 0.001 km^3, was calculated as 0.77 mg/L (Table B-11). This concentration is 2 to 3 magnitudes smaller than ammonia levels inducing mortality in toxicity tests, but an order of magnitude greater than concentrations that were observed to affect swimming performance of coho salmon in freshwater (Table B-10). This estimated concentration also exceeds the water quality criteria of 0.16 mg/L for the Central Bay[6]. These preliminary results need to be treated with extreme caution, because they are based on many assumptions, e.g. concerning the homogeneity of ammonia concentrations within a bay segment, the dredged sediment volume and plume size, and resulting concentrations within the plume. There appears to be a need to better study the potential of ammonia releases during dredging in San Francisco Bay, and quantify possible risks due to subacute effects with respect to fish window species.

[6] A more stringent criteria is planned for the northern reaches of the San Francisco Estuary (KAPAHI ET AL. 2006)

6. Conclusions

The goal of this paper is to synthesize and summarize knowledge of short-term water quality impacts due to dredging operations (dredging and dredged material placement) on sensitive fish species in San Francisco Bay. It serves several purposes:

a. Provide the San Francisco Bay LTMS with a technical basis for predicting and managing potential impacts of dredging activities on fish;
b. Identify data and knowledge gaps; and
c. Provide a bibliography of written and electronic material.

The presented review indicates that direct short-term effects on sensitive fish by contaminants associated with dredging plumes are probably fairly minor, especially in comparison with other potential impacts, such as long-term effects due to bioaccumulation, sublethal effects, or immediate physical effects of suspended solids on fish health and habitat (Connor et al. 2004; LFR 2004). Based on our review and data evaluation, the most likely contaminant of concern to exert short-term effects, if any, is ammonia. In general, there are significant data and knowledge gaps concerning the release, bioavailability, and effects of contaminants during dredging on sensitive fish. An improved understanding based on sound scientific study and data base would reduce remaining uncertainties about potential adverse short-term impacts of contaminants on sensitive fish species.

6.1 Short-term Water Quality Impacts

Dredging and dredged material disposal can remobilize sediment-associated pollutants by dispersion with the resulting sediment plume (Eggleton and Thomas 2004; LFR 2004). Pollutants of concern include heavy metals (Cd, Cu, Hg, Ni, Pb, Zn, Ag, Cr, As), organic contaminants (PAHs, PCBs, pesticides), and oxygen-consuming processes involving H_2S and ammonia. The dispersion of pollutants can occur in the dissolved or in the particulate state (Goosens and Zwolsman 1996; LFR 2004). In sediments, only a small fraction of the total amount of heavy metals and organic contaminants is dissolved. In case of heavy metals, releases during dredging may be largely due to the resuspension of fine particles from which the contaminants may be desorbed (Lee et al. 1993), and in case of organic contaminants, most of the chemical released into the dissolved phase would be expected to be bound to DOM. Thus, the concentration of freely dissolved metal ions and organic contaminants that would be released and available for gill uptake by fish is presumably fairly minor. In model calculations using available sediment concentrations of heavy metals and PAHs from monitoring studies, and making simplified and conservative modeling assumptions (i.e. worst-case scenarios), only one contaminant, Ni, exceeded the ERM threshold in more than 10% of samples. Thus, the resulting short-term water quality impacts due to metal and organic contaminant releases from dredging activities do not appear to be a major issue.

Short-term changes in DO, pH, H_2S, and ammonia may occur in connection with sediment plumes caused by dredging and disposal activities. DO and pH effects are expected to be minimal in most San Francisco Bay conditions. H_2S would only become released in significant amounts from anoxic sediments that, if resuspended, would also cause DO depletion (or hypoxia). Releases of ammonia have the potential to result in toxicity.

6.2 Short-term Effects on Sensitive Species

Potential short-term effects on sensitive fish species are a function of the type of contaminant, its concentration in the sediment, the environmental conditions at the time of dredging (.e.g, low oxygen or reducing environments), and the duration of the exposure. Gill uptake is presumably the most significant exposure route for short-term acute toxicity in fish. Bioavailability and toxicity of waterborne metals is very speciation dependent. Typically, the free metal ion is the most toxic form, and metals complexed with dissolved organics and inorganic anions show lower degrees of bioavailability and toxicity (Kramer et al. 1997). This general rule, however, is not always valid. Exceptions are organometallic compounds such as methyl mercury and tributyl tin. In any case, risks from heavy metals released during dredging would be primarily related to changes in conditions promoting the shift of heavy metals from the particulate into the dissolved state (Goosens and Zwolsman 1996). However, reviewed studies suggest that resuspension of metal-contaminated sediments might create only minimal potential for direct toxicity, because dissolved concentrations are in general low, even though release of total metals can be large. Our model calculations show that even if total sediment concentrations were assumed to be dissolved, critical threshold toxicity values would not be exceeded. The results were similar for organic contaminants: PAHs, PCBs, and other organic contaminants of concern are generally less soluble, and direct toxicity by exposure to dissolved concentrations in the water column is not very likely. Model calculations with PAHs did not indicate a concern based on available sediment concentration data and effects thresholds.

The potential impacts of reduced DO concentrations due to sediment resuspension were evaluated previously and it was concluded that DO reductions would be localized and short term, with minimal impacts (US Navy 1990). H_2S, although a potent metabolic poison in fish, occurs in lethal concentrations presumably only in association with hypoxic conditions that are also lethal to fish. Thus, H_2S would not be expected to have a significant impact on sensitive species in San Francisco Bay.

Although there have been no specific studies, the literature review indicates that there is considerable potential for ammonia to have adverse short-term effects during dredging: ammonia concentrations in plumes fall within in a range that was shown to affect swimming performance of coho salmon in freshwater (Table B-5). Ammonia sensitivity is considered to be very species-specific and is strongly dependent on pH. In general, sea water-adapted or estuarine species are believed to be more susceptible to ammonia than freshwater fish, since their gills are more permeable to NH_4^+. Thus, both unionized and ionized ammonia concentrations should be taken into consideration when evaluating potential ammonia effects on fish species in San Francisco Bay (Eddy 2005; USEPA 1989, 1999; Wilson and Taylor 1992). During ammonia exposure, sensitive fish in San Francisco Bay would most likely be affected when they are larvae or juveniles, if the temperature is elevated, if salinity is near the sea water value, and if the pH value decreases below pH 7. They are also more likely to be affected in waters of low salinity, high pH and high ammonia levels. If entry to an area with high ammonia is unavoidable, then the responses of the fish would be determined by its developmental stage, condition, activity level, and its physiological capacity to respond to ammonia levels during the exposure (Eddy 2005).

6.3 Information and Data Gaps

Information and data gaps are summarized in Table 6-1. With regard to changes in pollutant chemistry upon resuspension, there is a need to better characterize the geochemical and kinetic processes regulating contaminant release and bioavailability. To better characterize the release and potential, and actual bioavailability of metals, the short-term speciation of metals during resuspension needs to be better characterized. Cr appears as the least studied toxic metal of concern and may merit more emphasis in future studies. For organic contaminants, partitioning needs to be better characterized. This includes a need for more realistic desorption and resorption rates during resuspension events. Additionally, chemical elutriate data are not usually part of sediment evaluations, even though they are considered to provide a reasonable estimate for potential contaminant releases. The exposure risk of sensitive species during dredging activities is not well characterized, partially because of uncertainties concerning the bioavailability during dredging, and partially because the species distribution is not always known in relation to dredging activities. Most laboratory toxicity studies do not simulate conditions representative of those during sediment resuspension, and there is a universal lack of fish toxicity data for estuarine fish or saltwater-adapted migrant species, such as steelhead trout. Contaminant effects on the fish species of concern under representative conditions are largely unknown. Also, the contribution of particle-bound organic contaminants to acute toxicity needs to be evaluated. Little is known about the potential release of organic contaminants that have not been routinely monitored and studied, such as pyrethroid pesticides.

There are wide knowledge gaps regarding ammonia toxicity to estuarine fish, including the influence of temperature and intermittent exposure, as for example, during multiple dredging events. Relevant information on ammonia toxicity in sensitive fish species and physiological and behavioral responses is scant. Thompson et al (1997) measured total ammonia on interstitial or overlaying water samples in bioassays with amphipods to determine relationships of sediment toxicity with contamination in San Francisco Bay. However, to our knowledge there are no studies that have specifically assessed the potential for ammonia releases during dredging associated with concentration changes in the water column, and resulting exposure risks for sensitive fish in San Francisco Bay. There were also no ammonia data from elutriate tests available for review. Concerning DO, it has not been established whether DO dredging activities are in fact aggravating existing low DO situations, as for example, during summer conditions in the South Bay or Richardson Bay. There are no data to assess H_2S releases during dredging, and the contribution of H_2S to fish toxicity during resuspension of anoxic sediments is unknown.

6.4 General Recommendations for Filling Data Gaps and Further Investigation

The available information suggests that the risk of short-term effects to sensitive fish during dredging due to contaminant exposure is generally low for most contaminants. Filling some of the information gaps identified here would reduce remaining uncertainties surrounding the low risk predictions. Ammonia seems to be the exception. Based on the review information, there is a possibility for subacute effects due to ammonia exposure, but there are no data available for San Francisco Bay to sufficiently evaluate a possible risk to sensitive fish during dredging. Therefore, we suggest putting a focus on ammonia in further investigations. This focus may include a) monitoring changes of ammonia levels in the water column (near bottom) during dredging studies, b) characterizing bioavailability and toxicity of ammonia in relation to pH, salinity, temperature, and intermittent exposure; and c) performing ecologically relevant studies of ammonia toxicity and effects with estuarine and/or seawater-adapted species; including the characterization of behavioral and physiological responses and whether or not these are of ecological significance.

Table 6-1. Summary of information and data gaps concerning short-term water quality impacts due to dredging operations (dredging and dredged material placement) on chinook salmon, coho salmon, delta smelt, green sturgeon, and steelhead trout in San Francisco Bay.

Water Quality Impacts	**Data and information gaps**			
	General	*SF Bay-specific*	*Dredging-specific*	*Species-specific*
Ammonia		Effect of dredging and disposal activities on changes of ammonia levels in the water column (monitoring studies at dredging sites before, during, and after dredging)		
	Ammonia toxicity in saltwater-adapted salmonids and sturgeon, incl. effects of intermittent exposure, temperature, role of NH_4^+ (experimental toxicity studies in the laboratory)			
				Physiological and behavioral response of saltwater adapted salmonids (chinook salmon, rainbow trout) to ammonia exposure, incl. bioenergetic model (experimental toxicity studies in the laboratory combined with field sampling and mathematical modeling)
		Risk assessment of dredging-related exposure based on field data collections at dredging sites and during dredging and disposal activities		
DO reductions		Monitoring studies of DO changes during dredging and disposal at sites with an increased likelihood of low DO conditions, e.g marinas in Richardson Bay		

Table 6-1 (continued). Summary of information and data gaps concerning short-term water quality impacts due to dredging operations (dredging and dredged material placement) on chinook salmon, coho salmon, delta smelt, green sturgeon, and steelhead trout in San Francisco Bay.

Water Quality Impacts	**Data and information gaps**			
	General	*SF Bay-specific*	*Dredging-specific*	*Species-specific*
Heavy metals	Geochemical processes regulating metal releases and short-term speciation, particularly Cr (laboratory studies combined with field data collection at dredging projects before, during, and after dredging and natural resuspension events)			
			▶ Release of methyl mercury and organotins during resuspension (laboratory studies combined with field data collection at dredging projects before, during, and after dredging and natural resuspension events) ▶ Role of fine colloidal particles (field data collection at dredging projects before, during, and after dredging and natural resuspension events	
Organic contaminants	Experimental toxicity studies of the short-term acute toxicity of particle-bound PAHs (laboratory studies)		▶ Desorption rates of organic contaminants in model systems simulating estuarine conditions, particularly PAHs (batch equilibrium studies in the lab using representative sediment samples)	

Table 6-1 (continued). Summary of information and data gaps concerning short-term water quality impacts due to dredging operations (dredging and dredged material placement) on chinook salmon, coho salmon, delta smelt, green sturgeon, and steelhead trout in San Francisco Bay.

Water Quality Impacts	**Data and information gaps**			
	General	*SF Bay-specific*	*Dredging-specific*	*Species-specific*
H_2S	Experimental toxicity studies in the laboratory (using saltwater adapted salmonids) combined with chemical monitoring during dredging to study the role and significance of H_2S toxicity to fish during resuspension of anoxic sediments	Monitor H_2S releases due to dredging activities		

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City: San Francisco, CA
Relevance to Short-term Water Quality Impacts of Dredging: dissolved oxygen, pH, total suspended solids, turbidity, ammonia, hydrogen sulfide, cadmium, chromium, cobalt, copper, lead, mercury, nickel, selenium, silver, zinc, PAHs, PCBs, pesticides, Chinook Salmon (Oncorhynchus tshawytscha), Coho Salmon (Oncorhynchus kisutch), Steelhead Trout (Oncorhynchus mykiss irideus), Delta Smelt (Hypomesus transpacificus),
URL: http://www.spn.usace.army.mil/ltms/rpt-USACE-SciencePlan-Final-Aug04-09170.pdf

Dredged Sediment Management

16: Long-term management strategy (LTMS) for the placement of dredged material in the San Francisco Bay region
Author: LTMS
Year: 1996
Project Sponsor: Army Corps of Engineers, LTMS Management Committee
Volume: Report Number: Volume I
Relevance to Short-term Water Quality Impacts of Dredging: Environmental impact assessment of dredging and disposal in San Francisco Bay. Review of LTMS.
URL: http://www.spn.usace.army.mil/ltms/toc.html

17: A risk management strategy for PCB-contaminated sediments
Author: National Research Council
Year: 2001
Publisher: National Academy of Sciences
City: Washington, DC
URL: http://www.nap.edu/catalog.php?record_id=10041

Dredging and Dredged Material Disposal Evaluation

18: Guidelines for Implementing the Inland Testing Manual in the San Francisco Bay Region
Author: Dredged Material Management Office
Year: 2001
Project Sponsor: DMMO agencies (USEPA, BCDC, USACE, SFBRWQCB, SLC)

Relevance to Short-term Water Quality Impacts of Dredging: Guidelines for DMMO agencies when determining the dredged material testing that will be required for dredging projects proposing disposal at designated sites in waters of the U.S. within San Francisco Bay.
URL: http://www.spn.usace.army.mil/conops/sfitm092101.pdf

19: Port of San Francisco Dredging Support Program Review of Sediment Evaluations at Pier 35
Author: Anchor Environmental CA
Year: 2007
Project Sponsor: Port of San Francisco
Relevance to Short-term Water Quality Impacts of Dredging: Bioavailability of PAHs at Pier 35 in San Francisco Estuary

20: Framework for assessing the need for seasonal restrictions on dredging and disposal operations
Author: M. W. LaSalle, and D. G. Clarke
Year: 1991
Publisher: U.S. Army Corps of Engineers
City: Washington, DC
Report Number: Technical Report D-91-1

21: Evaluation of Upland Disposal of John F. Baldwin Ship Channel Sediment
Author: C. R. Lee, D. L. Brandon, H. E. Tatem, J. W. Simmers, J. G. Skogerboe, R. A. Price, J. M. Brannon, T. E. Myers, and M. R. Palermo
Year: 1993
Publisher: U.S. Army Corps of Engineers
City: San Francisco, CA
Report Number: EL-93-17
URL (abstract):
http://stinet.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA270425

22: Evaluation of the elutriate test as a method of predicting contaminant release during open water disposal of dredged sediment and environmental impact of open water dredged materials disposal, Vol II: data report
Author: G. F. Lee, R. A. Jones, F. Y. Saleh, G. M. Mariani, D. H. Homer, J. S. Butler, and P. Bandyapadhyay
Year: 1978
Publisher: US Army Engineer Waterways Experiment Station
City: Vicksburg, MS
Report Number: Technical Report D-78-45
Relevance to Short-term Water Quality Impacts of Dredging: If the DO remains at or below 2 to 3 mg/L for a period of time, significant mortality will occur in most fish populations. Other than that, mostly review of how DO changes in waterways due to dredging, but not specific to any fish species or estuarine waters.
URL (abstract):
http://stinet.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA061710

23: Regulations and techniques for dredging and dredged material disposal evaluation (Rhode Island Sea Grant White Paper Series)
Author: N. I. Rubenstein
Year: 1991
Project Sponsor: Rhode Island Sea Grant

Relevance to Short-term Water Quality Impacts of Dredging: outlines dredged material disposal options and evaluation process

24: A Preliminary assessment of the environmental impacts of dredged material dumping a the Alcatraz dumpsite, San Francisco Bay, California (Tech. Report #10)
Author: D. A. Segar
Year: 1988
Project Sponsor: Romberg Tiburon Center
Link: Relevance to Short-term Water Quality Impacts of Dredging: Discusses potential for contaminants to become bioavailable to biota after dumping at in-bay disposal site of Alcatraz Island. Table 5 includes estimates of bioavailable metals and organics in dredged material (tons/year). 20% of material dumped settles to bottom while the rest becomes part of suspended sediment of the bay, and can mix throughout and even go out to the Ocean. Main vector for contamination of invertebrates and vertebrates would be contaminants binding to sediment and other particle and being ingested by fish; however affects would take some time and bioaccumulation to show up in most species.

25: An assessment of certain aspects of the environmental impacts of dredged material dumping in San Francisco Bay: a technical report
Author: D. A. Segar
Year: 1989
Project Sponsor: U.S. Department of the Interior, Fish and Wildlife Service, Division of Ecological Services
Relevance to Short-term Water Quality Impacts of Dredging: Compares potential toxicity of dredged material dumped at Alcatraz to studies done in Long Island Sound. Concludes that potential toxicity of suspended sediments is "seriously underestimated" since most comparable sites are non-dispersive, whereas SF Bay is a dispersive environment. Dredged material for the Alcatraz disposal site failed the Ocean Dumping Criteria since concentrations of suspended sediments were toxic to 50% of test species after 4 hours of mixing. Multiple exposures due to continuous dumping ("at busy times the average time between successive dumps is 1 hour" p. 17) exacerbate the problem for most species and expose them continuously to the toxic sediments. In addition tidal action can bring some sediments back to the dumping site that would otherwise be carried away in currents. "In summary...studies in Long Island Sound have established evidence that toxic contaminants in dredged material suspended particulates are significantly bioaccumulated by various species of marine organisms, and substantial evidence that this bioaccumulation or other effects of dredged material suspended particulates causes a variety of sublethal detrimental biological effects on these species" (p. 21). Tests were performed on shrimp, mussels, amphipods, and polychaete worms.

26: Predicting water-quality during dredging and disposal of contaminated sediments from the Sitcum Waterway in Commencement Bay, Washington, USA
Author: P. A. Spadaro, D. W. Templeton, G. L. Hartman, and T. S. Wang
Year: 1993
Journal: Water Science and Technology
Volume: 28
Number: 8-9
Pages: 237-254

27: Development of Sediment Quality Objectives for Enclosed Bays and Estuaries – CEQA Scoping Meeting Informational Document
Author: State Water Resources Control Board, Division of Water Quality
Year: 2006
Publisher: State Water Resources Control Board
City: Sacramento, CA

Relevance to Short-term Water Quality Impacts of Dredging: summarizes SWRCB staff's method for developing sediment quality objectives (SQOs) and a preliminary process that could be used to apply and implement the objectives. SQOs would provide a mechanism to differentiate sediments impacted by toxic pollutants from those that are not.
URL:
http://www.waterboards.ca.gov/water_issues/programs/bptcp/docs/draft_sqo_scopingdoc081706.pdf

28: Evaluation of Dredged Material Proposed for Ocean Disposal - Testing Manual (Ocean Testing Manual)
Author: USEPA and USACE
Year: 1991
Project Sponsor: U.S. Environmental Protection Agency
Report Number: EPA-503/8-91/001
Relevance to Short-term Water Quality Impacts of Dredging: This manual, commonly referred to as the Green Book, contains technical guidance to determining the suitability of dredged material for ocean disposal through chemical, physical, and biological evaluations. The technical guidance is intended for use by dredging applicants, laboratory scientists, and regulators in evaluating dredged-material compliance with the United States Ocean Dumping Regulations. Integral to the manual is a tiered-testing procedure for evaluating compliance with the limiting permissible concentration (LPC) as defined by the ocean- dumping regulations. The procedure comprises four levels (tiers) of increasing investigative intensity that generate information and apply relatively inexpensive and rapid tests to predict environmental effects. Tiers III and IV contain biological evaluations that are more intensive and require field sampling, laboratory testing, and rigorous data analysis.
URL: http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA269382&Location=U2&doc=GetTRDoc.pdf

29: Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. - Testing Manual (Inland Testing Manual)
Author: USEPA and USACE
Year: 1998
Project Sponsor: U.S. Environmental Protection Agency
Report Number: EPA 823-B-98-004
Relevance to Short-term Water Quality Impacts of Dredging: Guide commonly used to test of dredged material to assess the potential for contaminant-related impacts of dredged material disposal that could affect water quality
URL: http://www.epa.gov/waterscience/itm/ITM/

30: Final environmental impact statement for proposed new dredging. U.S. Navy Military Construction Projects P-202 (Naval Air Station Alameda) and P-082 (Naval Supply Center Oakland)
Author: US Navy
Year: 1990
Project Sponsor: U.S. Navy, Western Division Naval Facility Engineering Command

Water Quality Aspects of Dredged Sediment Management

31: Environmental monitoring of dredging operations in the Belgian nearshore zone
Author: J. De Groote, G. Dumon, M. Vangheluwe, and C. Jansen
Year: 1998
Journal: Terra et Aqua

Volume: 70
Pages: 21-25
Relevance to Short-term Water Quality Impacts of Dredging: As part of the larger Mobag 2000 project, physical, chemical and ecotoxicological studies of dredging effects in the harbour at Nieuwpoort were conducted and compared.
URL: http://www.terra-et-aqua.com/dmdocuments/Terra-et-Aqua_nr70_04.pdf

32: An evaluation of the behaviour of pollutants during dredging activities
Author: H. Goosens, and J. J. G. Zwolsman
Year: 1996
Journal: Terra et Aqua
Volume: 62
Number: Pages: 20-28
Relevance to Short-term Water Quality Impacts of Dredging: Two main classes of pollutants, heavy metals and organic micropollutants, are evaluated to determine the extent of environmental risks when dredging and how these can be controlled.
URL: http://www.terra-et-aqua.com/dmdocuments/Terra-et-Aqua_nr62_03.pdf

33: Water quality aspects of dredged sediment management
Author: A. Jones-Lee and G. F. Lee
Year: 2005
Book Title: Water Encyclopedia: Water Quality and Resource Development
Pages: 122-127
Publisher: Wiley
City: Hoboken, NJ
Relevance to Short-term Water Quality Impacts of Dredging: Overview of environmental impacts of dredging. In most cases, ammonia is only contaminant of concern though DO dips in the plume initially but returns to pre-dredging levels after 10 minutes or less.
URL: http://www.members.aol.com/annejlee/WileyDredging.pdf

34: Physical and chemical alterations associated with dredging: an overview
Author: M. W. LaSalle
Year: 1988
Conference: Effects of Dredging on Anadromous Pacific Coast Fishes
City: Seattle, WA
Editor: C. Simenstad
Relevance to Short-term Water Quality Impacts of Dredging: Summarizes what is known about dredging: only turbidity has acute affect and only in immediate vicinity of dredging while metals have undetected effects.

35: Stormwater Runoff Water Quality Newsletter
Author: G. F. Lee
Year: 2007
Volume: 10
Number: 4
Date: April 30, 2007
Relevance to Short-term Water Quality Impacts of Dredging: If the DO remains at or below 2 to 3 mg/L for a period of time, significant mortality will occur in most fish populations. Other than that, mostly review of how DO changes in waterways due to dredging, but not specific to any fish species or estuarine waters.
URL: http://www.members.aol.com/LFandWQ/swnews104.pdf

36: Chemical monitoring of maintenance dredging operations at Zeebrugge
Author: A. Pieters, M. Van Parys, G. Dumon, and L. Speleers
Year: 2002
Journal: Terra et Aqua
Volume: 86
Pages: 3-10
Relevance to Short-term Water Quality Impacts of Dredging: As part of an intensive research project to evaluate the ecological impact of dredging and relocation of material, two different techniques were compared.
URL: http://www.terra-et-aqua.com/dmdocuments/Terra-et-Aqua_nr86_01.pdf

37: Chemical transformations of contaminants in dredged material and implications for bioavailability
Author: T. H. Wakeman, V. A. McFarland and S. K. Lemlich
Year: 1988
Conference: The Bioavailability of Toxic Contaminants in the San Francisco Bay-Delta, Berkeley, CA
Editor: A. J. Gunther
Relevance to Short-term Water Quality Impacts of Dredging: Overview of a variety of contaminants and how/if they become bioavailable after dredging. Concentrations were studied in the lab in invertebrates and mussels but no significant changes were observed.

Short-term Water Quality Impacts

Ecotoxicology

38: Relationship between sediment toxicity and contamination in San Francisco Bay
Authors: B. Thompson, B. Anderson, J. Hunt, K. Taberski, and B. Phillips
Year: 1997
Journal: Marine Environmental Research
Volume: 48
Number: 4-5
Pages: 285-309

Ecotoxicology: Heavy Metals

39: Ecotoxicology of metals in aquatic sediments: binding and release, bioavailability, risk assessment, and remediation
Author: P. M. Chapman, F. Y. Wang, C. Janssen, G. Persoone, and H. E. Allen
Year: 1998
Journal: Canadian Journal of Fisheries and Aquatic Sciences
Volume: 55
Number: 10
Pages: 2221-2243
Relevance to Short-term Water Quality Impacts of Dredging: Metal binding and bioavailability. Different models are discussed for release of metals from sediment to water.
URL (abstract): http://rparticle.web-p.cisti.nrc.ca/rparticle/AbstractTemplateServlet?journal=cjfas&volume=55&year=&issue=&msno=f98-145&calyLang=fra

40: A computer simulation of water quality change due to dredging of heavy metals contaminated sediments in the Old Harbour of Montreal
Author: A. Degtiareva and M. Elektorowicz
Year: 2001
Journal: Water Quality Research Journal of Canada
Volume: 36
Number: 1
Pages: 1-19
Relevance to Short-term Water Quality Impacts of Dredging: available at UCB
Cadmium, Nickel, Zinc and Lead
URL: http://digital.library.mcgill.ca/wqrj/search/issue.php?issue=WQRJ_Vol_36_No_1

41: Toward a better understanding of the bioavailability, physiology and toxicity of silver in fish: implications for water quality criteria
Author: C. Hogstrand and C. M. Wood
Year: 1998
Journal: Environmental Toxicology and Chemistry
Volume: 17
Number: 4
Pages: 547-561
Relevance to Short-term Water Quality Impacts of Dredging: Silver toxicity to fish. Silver ion is most toxic compared to associations with thiosulfate or chlorides. Saltwater fish are affected in the intestine, while freshwater fish are affected in the blood plasma. Bioavailability of silver is discussed.
URL (abstract): http://www.setacjournals.org/perlserv/?request=get-abstract&doi=10.1897%2F1551-5028(1998)017%3C0547:TABUOT%3E2.3.CO%3B2

42: Chemical speciation and metal toxicity in surface freshwaters
Author: J. R. Kramer, H. E. Allen, W. Davison, K. L. Godfredsen, J. S. Meyer, E. M. Perdue, E. Tipping, D. van de Meent, and J. C. Westall
Year: 1997
Book Title: Reassessment of Metals Criteria for Aquatic Life Protection
Pages: 57-70
Editor: H. L. Bergman and E. J. Dorward-King
City: Pensacola, FL

Ecotoxicology: Ammonia

43: Ammonia in estuaries and effects on fish
Author: F. B. Eddy
Year: 2005
Journal: Journal of Fish Biology
Volume: 67
Number: 6
Pages: 1495-1513
Relevance to Short-term Water Quality Impacts of Dredging: Review of ammonia and its affect on estuarine, freshwater, and marine fish species. Toxicity (LC 50 in 96 hours) at 068-2.0 mg/L in freshwater. Acute toxicity for marine species is in the range 0.09–3.35 mg/l NH3–N depending on species, temperature and pH. Estuarine fish toxicity is probably in the same range as fresh- and saltwater. The pH has huge effect on toxicity threshold in estuarine environments: 1 unit of pH decrease can increase total ammonia concentration 10-fold. Salmonids tend to be some of the most

sensitive species to ammonia, with toxicity at less than 1 mg/l in both fresh and saltwater. Generally stressed fish (due to dredging?) are more sensitive to external ammonia. Estuarine species are also more sensitive when they are not feeding, and when they are swimming.
URL (abstract):
http://www.ingentaconnect.com/content/bsc/jfb/2005/00000067/00000006/art00002

Chemistry and Fate

44: Rates, Constants, and Kinetic Formulations in Surface Water Modeling, 2nd ed.
Authors: G. L. Bowie, W. B. Mills, D. B. Porcella., C. L. Campbell, J. R. Pagenkopf, G. L. Rupp, K. M. Johnson, P. W. Chan, and S. A. Gherini
Year: 1985
Publisher: USEPA
City: Athens, GA
Report Number: EPA/600/3-85/040

45: Kinetics of Oxidation of Aqueous Sulfide by Oxygen
Authors: K. Y. Chen and J. C. Morris
Year: 1972
Journal: Environmental Science & Technology
Volume: 6
Pages: 529-537

46: A review of factors affecting the release and bioavailability of contaminants during sediment disturbance events
Author: J. Eggleton and K. V. Thomas
Year: 2004
Journal: Environment International
Volume: 30
Number: 7
Pages: 973-980
Relevance to Short-term Water Quality Impacts of Dredging: Cd and Cr are particularly soluble in oxic conditions and can easily desorb from FeS and MnS precipitates. "Acute water column toxicity from the release of sediment-bound contaminants [is] unlikely" (p. 978).

47: Partition coefficients and their uses
Author: A. Leo, C. Hansch, and D. Elkins
Year: 1971
Journal: Chemical Reviews
Volume: 76
Number: 6
Pages: 525-616

48: Environmental Organic Chemistry
Author: R. P. Schwarzenbach, P. M. Gschwend., and D. M. Imboden
Year: 1993
Edition: 1st
Publisher: John Wiley & Sons
City: New York, NY
Pages: 681 p.
URL (TOC): http://www3.interscience.wiley.com/cgi-bin/bookhome/110474149?CRETRY=1&SRETRY=0

49: Oxygenation of Ferrous Iron
Authors: W. Stumm and G. F. Lee
Year: 1961
Journal: Industrial and Engineering Chemistry
Volume: 53
Pages: 143-146
URL: http://www.members.aol.com/annejlee/StummOxygenFerrous.pdf

50: Aquatic Chemistry
Author: W. Stumm and J. J. Morgan
Year: 1996
Edition: 3rdt
Publisher: Wiley Interscience
City: New York, NY
Pages: 1022 p.

Chemistry and Fate: Heavy Metals

51: Scavenging residence times of trace metals and surface chemistry of sinking particles in the deep ocean
Author: L. Balistrieri, P. G. Brewer, and J. W. Murray
Year: 1981
Journal: Deep Sea Research Part A. Oceanographic Research Papers
Volume: 28A
Number: 2
Pages: 101-121
Relevance to Short-term Water Quality Impacts of Dredging: Equilibrium constants that define metal interactions with deep-ocean particles

52: Changes in mercury speciation and the release of methyl mercury as a result of marine sediment dredging activities
Author: N. S. Bloom, and B. K. Lasora
Year: 1999
Journal: The Science of the Total Environment
Volume: 237-238
Pages: 379-385
Relevance to Short-term Water Quality Impacts of Dredging: MeHg was high in the first 10cm of sediment cores from an estuary in Texas, however laboratory attempts to duplicate the results failed. Re-suspension of sediments will increase methylation locally, but in a large open bay, the dredging will only be a minor source of MeHg compared to other sources (air deposition, urban runoff, etc.).

53: Mercury speciation in the San Francisco bay estuary
Authors: C. H. Conaway, S. Squire, S., R. P. Mason, and A. R. Flegal
Year: 2003
Journal: Marine Chemistry
Volume: 80
Pages: 199-225

54: Adsorption of Pb and Cd onto metal oxides and organic material in natural surface coatings as determined by selective extractions: new evidence for the importance of Mn and Fe oxides.
Authors: D. Dong, D. Y. M. Nelson, L. W. Lion, M. L. W. Shuler, and W. C. Ghiorse

Year: 2000
Journal: Water Research
Volume: 34
Pages: 427-36

55: Partitioning of arsenic and metals in reducing sulfidic sediments
Author: J. N. Moore, W. H. Ficklin, and C. Johns
Year: 1988
Journal: Environmental Science & Technology
Volume: 22
Pages: 432-437

56: Dynamics of trace metal interactions with anthigenic sulfide minerals in anoxic sediments
Author: J. W. Morse
Year: 1995
Book Title: Metal Contaminated Aquatic Sediments
Pages: 187-189
Editor: H. E. Allen
City: Ann Arbor, MI

57: Diagnostic modeling of trace-metal partitioning in South San Francisco Bay
Author: T. M. Wood, A. M. Baptista, J. S. Kuwabara and A. R. Flegal
Year: 1995
Journal: Limnology and Oceanography
Volume: 40
Number: 2
Pages: 345-358
Relevance to Short-term Water Quality Impacts of Dredging: Partitioning coefficients for Zn, Cd and Cu in the bay exhibit spatial and temporal variability depending on the location of metals coming into the system and the distribution of aqueous vs. solid phase of the metals. Also has reported coefficients for the 3 metals from the literature.

Chemistry and Fate: Hydrogen Sulfide

58: Oxidation of H_2S in seawater as a function of temperature, pH and ionic strength
Author: F. Millero, S. Hubinger, M. Fernandez, and S. Garnett
Year: 1987
Journal: Environmental Science & Technology
Volume: 21
Number: Pages: 439-443

Distribution

59: Spatial and seasonal patterns in sediment nitrogen remineralization and ammonium concentrations in San-Francisco Bay, California
Author: J. M. Caffrey
Year: 1995
Journal: Estuaries
Volume: 18
Number: 1B
Pages: 219-233

Relevance to Short-term Water Quality Impacts of Dredging: Differences in ammonia, nitrogen, and carbon content of sediments in North/South Bay.
URL: http://estuariesandcoasts.org/cdrom/ESTU1995_18_1B_219_233.pdf

60: Vertical distribution of acid volatile sulfide and simultaneously extracted metals in a recent sedimentation area in the River Meuse in The Netherlands
Author: G. A. Van den Berg, J. P. G Loch, L. M. Van der Heijdt, and J. J. G. Zwolsman
Year: 1998
Journal: Environmental Toxicology and Chemistry
Volume: 17
Number: 4
Pages: 758-763
Relevance to Short-term Water Quality Impacts of Dredging: SEM/AVS ratios in mixed homogenized sediment samples are generally not suited for the assessment of potential metal toxicity of sediments.
URL (abstract): http://www.setacjournals.org/perlserv/?request=get-abstract&doi=10.1897%2F1551-5028(1998)017%3C0758:VDOAVS%3E2.3.CO%3B2&ct=1

Distribution: Trace Metals

61: Review of selected metals in dredged sediments and implications for uplands disposal
Author: L. Antrim, Battelle (unpublished white paper)
Year: 1994

62: Trace metal associations in the water column of South San Francisco Bay, California
Author: J. S. Kuwabara, C. C. Y. Chang, J. E. Cloern, T. L. Fries, J. A. Davis, and S. N. Luoma
Year: 1989
Journal: Estuarine, Coastal, and Shelf Science
Volume: 28
Pages: 307-325
Relevance to Short-term Water Quality Impacts of Dredging: Spatial patterns in Cu, Cd, Zn. Partition coefficients estimated. Correlations to salinity and POC.
URL: http://sfbay.wr.usgs.gov/publications/pdf/kuwabara_1989_trace.pdf

63: Processes affecting the benthic flux of trace metals into the water column of San Francisco Bay
Author: J. S. Kuwabara, B. R. Topping, K. H. Coale, and W. M. Berelson
Year: 1999
Book Title: U.S. Geological Survey Toxic Substances Hydrology Program--Proceedings of the Technical Meeting, Charleston, South Carolina, March 8-12, 1999--Volume 2--Contamination of Hydrologic Systems and Related Ecosystems.
Report Number: U.S. Geological Survey Water-Resources Investigations Report99-4018B
Relevance to Short-term Water Quality Impacts of Dredging: Pore-water sulfide increases with sediment depth (lowest at the sediment-water interface). Suggests a source of sulfide to the water column (positive flux). DOC-complexation with certain metals influences benthic flux. Bioturbation/irrigation at sediment-water interface also likely contributes to the advection of trace metals to the water column.
URL: http://toxics.usgs.gov/pubs/wri99-4018/Volume2/sectionA/2214_Kuwabara/pdf/2214_Kuwabara.pdf

64: Benthic flux of dissolved nickel into the water column of South San Francisco Bay
Author: B. R. Topping, J. S. Kuwabara, S. W. Parchaso, A. J. Hager, and F. M. Arnsberg

Year: 1999
Publisher: US Department of the Interior
City: Washington, DC
Report Number: Open File Report 01-89
Relevance to Short-term Water Quality Impacts of Dredging: Significant because it points out that natural processes, in addition to dredging can cause the re-mobilization of metals, nutrients, and other contaminants into the water column.
URL: http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA442930&Location=U2&doc=GetTRDoc.pdf

65: Synthesis of long-term nickel monitoring in San Francisco Bay
Author: D. Yee, T. Grieb, W. Mills, and M. Sedlak
Year: 2007
Journal: Environmental Research
Volume: 105
Pages: 20-33
URL: http://www.sfei.org/EnvironResearch2007/Yee_EnvironRes2007.pdf

Distribution: Organic Contaminants

66: Distributions of pesticides and organic contaminants between water and suspended sediment, San-Francisco Bay, California
Author: J. L. Domagalski and K. M. Kuivila
Year: 1993
Journal: Estuaries
Volume: 16
Number: 3A
Pages: 416-426
Relevance to Short-term Water Quality Impacts of Dredging: PAHs were most common contaminant in suspended sediment. Log Koc's for pesticides provided although most dissolved concentrations were so low they were not detected. Diazinon was the only Koc they were able to measure.
URL: http://estuariesandcoasts.org/cdrom/ESTU1993_16_3A_416_426.pdf

67: Polycyclic aromatic hydrocarbons in San Francisco Estuary sediments.
Authors: D. R. Oros and J. R. M. Ross
Year: 2006
Journal: Marine Chemistry
Volume: 86
Pages: 169-184

Distribution: Sulfides

68: Dissolved sulfides in the oxic water column of San-Francisco Bay, California
Author: J. S. Kuwabara and G. W. Luther
Year: 1993
Journal: Estuaries
Volume: 16
Number: 3A
Pages: 567-573

Relevance to Short-term Water Quality Impacts of Dredging: Influence of dissolved sulfides on the speciation of metals (esp. Cu, Zn, Cd). Link to bioavailability of metals is indicated. Vertical but not horizontal gradients in sulfide were evident.
URL: http://www.springerlink.com/content/f7w8g82w63n36076/fulltext.pdf

Remobilization:

69: Monitoring of organic compounds and trace metals during a dredging episode in the Gota Alv Estuary (SW Sweden) using caged mussels
Author: J. Bellas, R. Ekelund, H. P. Halldorsson, M. Berggren, and A. Granmo
Year: 2007
Journal: Water Air and Soil Pollution
Volume: 181
Number: 1-4
Pages: 265-279
Relevance to Short-term Water Quality Impacts of Dredging: Organics and metals were monitored in mussels before and during dredging in a Swedish Estuary. Metals and PCBs were low before and during dredging. Organotins and PAHs were elevated during dredging.

70: Release of nutrients and metals following oxidation of freshwater and saline sediment
Author: Delaune, R. D., and C. J. Smith.
Year: 1985
Journal: Journal of Environmental Quality
Volume: 14
Number: 2
Pages: 164-168
Relevance to Short-term Water Quality Impacts of Dredging:
Mississippi River deltaic sediments were collected from freshwater and adjacent saline environments along Louisiana's Gulf Coast to evaluate chemical changes that may develop when bottom sediment from different salinity regimes with contrasting levels of reduced S are exposed to anoxic environment. Chemical transformations of the dredged sediments were influenced by changes in the sediment-water pH and oxidation-reduction status. Sediment pH decreased as the redox potential (Eh) was increased in both the freshwater and saline sediment. Both sediments had near-neutral pH when maintained under anoxic conditions and the minimum pH developed under oxic conditions was 5.1 and 3.0 for the freshwater and saline sediment resulted in the release of the potentially toxic metals Pb, Cu, Ni, Cr, Cd, and Sb into the solution. There was also an increase in the solution concentration of Fe, Mn, Al, and Se. The solution concentration of these elements was inversely proportional to Eh (p less than or equal to 0.05).
URL (abstract): http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=5710493

71: Release of contaminants from resuspended particulate matter, white paper
Author: EVS Consultants
Year: 1997

72: A preliminary evaluation of contaminant release at the point of dredging
Author: R. N. Havis
Year: 1988
Publisher: US Army Engineer Waterways Experiment Station, Environmental Laboratory
City: Vicksburg, MS
Volume: Environmental Effects of Dredging Technical Notes
Report Number: EEDP-09-3

Relevance to Short-term Water Quality Impacts of Dredging: Elutriate tests for four dredged harbors in VA, RI, IL, and CT. Useful for a preliminary evaluation, for predicting within an order of magnitude. In many cases, the detection level was not reached.
URL: http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA382114&Location=U2&doc=GetTRDoc.pdf
.

73: Contaminant release during removal and resuspension
Investigators: M. Tomson, A. T. Kan, and L. J. Thibodeaux
Year: 2003
Project Sponsor: Hazardous Substance Research Center South & Southwest
Report: Fate of heavy metals and inorganic compounds during sediment resuspension (Research Brief #23: http://www.hsrc-ssw.org/pdf/RB26.pdf)
City: Athens, GA
URL: http://www.hsrc-ssw.org/ssw-abstracts.html

74: Mobility of contaminants in relation to dredging operations in a mesotidal estuary (Tagus estuary, Portugal)
Author: C. Vale, A. M. Ferreira, C. Micaelo, M. Caetano, E. Pereira, M. J. Madureira. and E. Ramalhosa
Year: 1998
Journal: Water Science and Technology
Volume: 37
Number: 6-7
Pages: 25-31
Relevance to Short-term Water Quality Impacts of Dredging: Resuspended material didn't cause higher than normal concentrations of Pb, Hg or PCBs but in a lab simulation these contaminants were accumulated in mussels. No acute toxicity affects mentioned.

75: Release of trace constituents from sediments resuspended during dredging operations
Author: T. H. Wakeman
Year: 1977
Book Title: Chemistry of Marine Sediments
Pages: 173-180
Editor: T. F. Yen
City: Ann Arbor, MI

76: Contaminants in sediments: remobilisation and demobilisation
Author: T. Zoumis, A. Schmidt, L. Grigorova, and W. Calmano
Year: 2001
Journal: Science of the Total Environment
Volume: 266
Number: 1-3
Pages: 195-202
Relevance to Short-term Water Quality Impacts of Dredging: Warns about the oxidization of anoxic sediments due to dredging because it makes metals such as Zn more bioavailable. No effects on fish are noted. This is also a reservoir of freshwater, mostly from groundwater sources so not entirely comparable to the bay/estuary.
URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/11258817

Remobilization: Trace Metals

77: Metal remobilisation during resuspension of anoxic contaminated sediment: short term laboratory study
Author: M. Caetano and C. Vale
Year: 2003
Journal: Water, Air and Soil Pollution
Volume: 143
Number: 1-4
Pages: 23-40
Relevance to Short-term Water Quality Impacts of Dredging: Metal concentrations increased 20-40 minutes after resuspension but then decreased rapidly. Resuspension of rich acid-volatile sulfide (AVS) sediments in oxygenated water column can induce a significant release of Fe, Mn, Cd, Pb and Cu. 50% of Cd released to water.
URL (abstract): http://www.springerlink.com/content/txl33t10m73g2122/

78: Binding and mobilisation of heavy metals in contaminated sediments affected by pH and redox potential
Authors: W. Calmano, J. Hong, and U. Forstner
Year: 1993
Journal: Water Science & Technology
Volume: 28(8-9)
Pages: 223-35

79: Sulfide control of cadmium and copper concentrations in anaerobic estuarine sediments
Author: R. J. Davies-Colley, P. O. Nelson, and K. J. Willamson
Year: 1985
Journal: Marine Chemistry
Volume: 16
Pages: 173-186
Relevance to Short-term Water Quality Impacts of Dredging: Equilibrium concentrations of the trace metals copper and cadmium

80: Studies on the transfer of heavy metals between sedimentary phases with a multi-chamber device: combined effects of salinity and redox potential
Authors: U. Forstner, W. Ahlf, and W. Calmano, W.
Year: 1989
Journal: Marine Chemistry
Volume: 28
Pages: 145-58

81: Physicochemical parameters that regulate mobilization and immobilization of toxic heavy metals
Author: R. P. Gambrell, R. A. Khalid, and W. H. Patrick, Jr.
Year: 1976
Conference: Specialty Conference on Dredging and its Environmental Effects.
City: New York , NY
Editor: P. A. Krenkel, J. Harrison and J. C. I. Burdick
Relevance to Short-term Water Quality Impacts of Dredging: Herring, dredging effects, suspended solids and sedimentation, reduced dissolved oxygen, noise, PCB, DDT, mercury, chromium, cadmium

82: Scavenging of dissolved Zn and Cu by resuspended harboursludge in oxic seawater
Author: W. Hegeman, T. Jansen, and C. van der Weijden
Year: 1991
Project Sponsor: Institute of Earth Science, University of Utrecht

83: Behaviour of copper, zinc, iron and manganese during experimental resuspension and reoxidation of polluted anoxic sediments
Author: J. M. Hirst and S. R. Aston
Year: 1983
Journal: Estuarine, Coastal and Shelf Science
Volume: 16
Number: 5
Pages: 549-558
Relevance to Short-term Water Quality Impacts of Dredging: Rates and extents of Cu, Zn, Fe, and Mn releases during resuspension and reoxidation in an English estuary

84: The effect of resuspension on the fate of total mercury and methyl mercury in a shallow estuarine ecosystem: a mesocosm study
Author: E.-H. Kim, R. P. Mason, E. T. Porter and H. L. Soulen
Year: 2004
Journal: Marine Chemistry
Volume: 86
Number: Pages: 121-137
Relevance to Short-term Water Quality Impacts of Dredging: Distribution coefficient for total and methyl-Hg.

85: Determinants of TBT adsorption and desorption in estuarine sediments
Authors: W. J. Langstone and N. D. Pope
Year: 1995
Journal: Marine Pollution Bulletin
Volume: 31 (1-3)
Pages: 32-43

86: Contaminant metal behaviour during re-suspension of sulphidic estuarine sediments
Author: J. E. L. Maddock, M. F. Carvalho, R. E. Santelli, and W. Machado
Year: 2007
Journal: Water Air And Soil Pollution
Volume: 181
Number: 1-4
Pages: 193-200
Relevance to Short-term Water Quality Impacts of Dredging: Dissolved sulphide concentrations in re-suspension waters were always less than 2 mg/l and decreased to below the detection limit (<0.05 mg l^{-1}) during resuspension experiments. Heavy metals appeared in solution only upon acidification due to sulphate formation. This means that they were only released after a delay and, in a real estuarine system, would only be released if the system were confined so that acid was not dispersed or diluted. This implies that substantial metal release into solution would be unlikely in a real case of sediment re-suspension: in a flood flow situation, dilution and dispersion would prevent pH lowering. Like the other metals, dissolved Pb concentrations only increased after a considerable re-suspension time (>36 h) and, like [Fe], decreased at the end of the experiment

87: Remobilization of trace elements from polluted anoxic sediments after resuspension in oxic water
Author: W. Petersen, E. Willer, and C. Willamowski
Year: 1997
Journal: Water Air and Soil Pollution
Volume: 99
Number: 1-4
Pages: 515-522
Relevance to Short-term Water Quality Impacts of Dredging: This experiment tested the release of trace metals Cd, Zn, and Cu from sediments from two river systems in Germany in order to understand their release after disturbance from both natural and human-induced activities like dredging. The results show that Cd has a delayed release (>10 days) while zinc and copper have quicker releases, particularly in warmer water. In a tank of 20C Zn and Cu steadily increased, while in 5C the release was delayed for 150 hrs. The release of these trace metals is strongly influenced by microbial activity in the sediments (in addition to temperature and substrate composition) as Zn and Cd in particular released more in artificial river water which likely has lower microbial activity. Overall the significance of dredged material that is released back into a river is pretty low, though no conclusions were made about it once it settles back into the substrate.
URL (abstract): http://www.springerlink.com/content/j6521160654613322/

88: The remobilization of Pb and Cd from contaminated dredge spoil after dumping in the marine environment
Author: B. Prause, E. Rehm, and M. Schulzbaldes
Year: 1985
Journal: Environmental Technology Letters
Volume: 6
Number: 6
Pages: 261-266

89: Trace metal remobilization following the resuspension of estuarine sediments: Saguenay Fjord, Canada
Author: I. Saulnier and A. Mucci
Year: 2000
Journal: Applied Geochemistry
Volume: 15
Pages: 191-210

90: Effect of short term resuspension events on trace metal speciation in polluted anoxic sediments
Author: S. L. Simpson, S. C. Apte, and G. E. Batley
Year: 1998
Journal: Environmental Science & Technology
Volume: 32
Number: 5
Pages: 620-625
Relevance to Short-term Water Quality Impacts of Dredging: Iron and manganese sulfides were oxidized in model resuspension experiments quickly, while zinc, copper, lead, and cadmium complexes were stable. In prolonged resuspension events, significant amounts of many trace metal sulfides may be oxidized.
URL (abstract): http://pubs.acs.org/cgi-bin/abstract.cgi/esthag/1998/32/i05/abs/es970568g.html

91: Effect of short-term resuspension events on the oxidation of cadmium, lead, and zinc sulfide phases in anoxic estuarine sediments
Author: S. L. Simpson, S. C. Apte, and G. E. Batley

Year: 2000
Journal: Environmental Science & Technology
Volume: 34
Number: 21
Pages: 4533-4537
Relevance to Short-term Water Quality Impacts of Dredging: Resuspension experiments with sulfides of zinc, cadmium, and lead. Oxidation was resisted by sulfide complex in 24 hr experiments. In resuspended, anoxic, contaminated sediments, rapid oxidation occurred. Results suggest that metals in these sediments are not sulfide complexes, and that the original form of these metals is most important in determining oxidation.
URL (abstract): http://pubs.acs.org/cgi-bin/abstract.cgi/esthag/2000/34/i21/abs/es991440x.html

92: Dredging-related mobilisation of trace metals: a case study in the Netherlands
Author: G. A. Van den Berg, G. G. A. Meijers, L. M. Van der Heijdt, and J. J. G. Zwolsman
Year: 2001
Journal: Water Research
Volume: 35
Number: 8
Pages: 1979-1986
Relevance to Short-term Water Quality Impacts of Dredging: Concentrations of soluble metals did not increase significantly from before to during dredging activities and settled out quickly.
URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/11337844

Remobilization: Organic Chemicals

93: Parameters affecting the desorption of hydrophobic organic chemicals from suspended sediments
Author: S. Borglin, A. Wilke, R. Jepsen, and W. Lick
Year: 1996
Journal: Environmental Toxicology and Chemistry
Volume: 15
Number: 10
Pages: 2254-2262
Relevance to Short-term Water Quality Impacts of Dredging: Desorption times of hydrophobic organic chemicals in sediments and soils.
URL (abstract): http://www.setacjournals.org/perlserv/?request=get-abstract&doi=10.1897%2F1551-5028(1996)015%3C2254:PATDOH%3E2.3.CO%3B2

94: Desorption kinetics for selected PCB congeners from river sediments
Author: J. T. Coates and A. W. Elzerman
Year: 1986
Journal: Journal of Contaminant Hydrology
Volume: 1
Pages: 191-210

95: Assessment of sediment resuspension and PCB release during dredging activities
Author: P. H. Israelsson, J. P. Connolly, C. R. Barnes, and L. K. Brussel
Year: 2001
Publisher: General Electric Company
City: Albany, New York

Relevance to Short-term Water Quality Impacts of Dredging: Monitored PCB release and TSS at 3 sites of historic PCB contamination that are being dredged to remove the contaminated sediments in order to guide GE for what to do in the Hudson River. The most comparable site, Fox River indicated a release to the water column of 2.2-9.1% of the total PCB mass removed over two years of dredging operations. Concentrations of PCBs in fish were predicted through 2068 to spike within the first few years then die off. No acute toxicity information discussed.

96: Mobilization of PAHS and PCBs from in-place contaminated marine resuspension events
Author: J. S. Latimer, W. R. Davis, and D. J. Keith
Year: 1999
Journal: Estuarine Coastal and Shelf Science
Volume: 49
Number: 4
Pages: 577-595
Relevance to Short-term Water Quality Impacts of Dredging: Water column concentrations of PAHs and PCBs increased by as much as 21-69 times when shear stress was applied to bottom sediments taken from estuaries in CT and RI, demonstrating that in calm conditions, water quality criteria may be met but under turbulent conditions it could be very different. "due to the less cohesive nature of the dredged material [from Black Rock Harbor, RI] it is more susceptible to resuspension at lower shear than typical estuarine deposits." (p. 583). The average log Kd value for all of the individual PAHs was 3·99 +/- 0·99 Kd=foc Koc p. 591-2 has tables of log Kd values for PAHs and PCBs and distribution coefficients.

97: Methods for the determination of PAH desorption kinetics in coal fines and coal contaminated sediments
Author: C. V. Shorten, A. W. Elzerman, and G. L. Mills
Year: 1990
Journal: Chemosphere
Volume: 20
Pages: 137-159

98: Field study on desorption rates of polynuclear aromatic hydrocarbons from contaminated marine sediment
Author: Y. Zhang, R. S. S. Wu, H.-S. Hong, K.-F. Poon, and M. H. W. Lam
Year: 2000
Journal: Environmental Toxicology and Chemistry
Volume: 19
Number: 10
Pages: 2431-2435
URL (abstract): http://www.setacjournals.org/perlserv/?request=get-abstract&doi=10.1897%2F1551-5028(2000)019%3C2431:FSODRO%3E2.3.CO%3B2

Bioavailability

99: Bioavailability of Sediment-Bound Contaminants to Marine Organisms
Author: B. Brown and J. Neff
Year: 1993
Publisher: NOAA National Ocean Pollution Program Office and DOE
City: Washington, DC
Relevance to Short-term Water Quality Impacts of Dredging: Cadmium in pore waters is unstable and particularly mobile in reducing environments. Copper's bioavailability reduced in the presence of sediment in a study with polychaete worms. In a study with clams, 50% of the copper became bound

to sediments and was unavailable to the clams that fed on suspended sediments, but was available to deposit-feeding clams. Everything else in the study focused on bioaccumulation and where metals and organics are stored in fish. No discussion of acute toxicity.
URL: http://www.osti.gov/bridge/purl.cover.jsp?purl=/10103045-Xb4rIt/webviewable/

Bioavailability: Organic Chemicals

100: PCB bioavailability assessment of river dredging using caged clams and fish
Author: C. P. Rice and D. S. White
Year: 1987
Journal: Environmental Toxicology and Chemistry
Volume: 6
Pages: 259-274
URL (abstract): http://www.setacjournals.org/perlserv/?request=get-abstract&doi=10.1897%2F1552-8618(1987)6%5B259%3APAAORD%5D2.0.CO%3B2

DO Reduction

101: Third Century of Biochemical Oxygen Demand
Authors: R. B. Baird and R. Smith
Year: 2002
Publisher: Water Environment Foundation
City: Alexandria, VA

102: Observations on dredging and dissolved oxygen in a tidal waterway
Author: C. L. Brown and R. Clark
Year: 1968
Journal: Water Resources Research
Volume: 4
Number: Pages: 1381-1384
Relevance to Short-term Water Quality Impacts of Dredging: Dissolved oxygen reduction during dredging in Staten Island

103: Predicting and monitoring dredge-induced dissolved oxygen reduction
Author: M. W. LaSalle
Year: 1989
Project Sponsor: U.S. Army Engineer Waterways Experiment Station
Relevance to Short-term Water Quality Impacts of Dredging: Summarizes the results of research into the potential for dissolved oxygen (DO) reduction associated with dredging operations. Efforts toward development of a simple computational model for predicting the degree of dredging-induced DO reduction are described along with results of a monitoring program around a bucket dredge operation.
URL: http://libweb.wes.army.mil/uhtbin/cgisirsi/20071227183053/SIRSI/0/518/0/EEDP-06-9.pdf/Content/1?new_gateway_db=HYPERION

Short-term effects on sensitive fish species

Water Quality Criteria

104: Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary
Authors: G. Kapahi, I. Baehr, J. Farwell, D. Riddle, and G. Wilson
Year: 2006
Publisher: State Water Resources Control Board, Division of Water Rights
City: Sacramento, CA
URL: http://www.waterrights.ca.gov/baydelta/docs/2006_plan_final.pdf

105: Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and their Uses
Authors: C. E. Stephen, D. I. Mount, D. J. Hansen, J. R. Gentile, G. A. Chapman, and W. A. Brungs
Year: 1985
Publisher: U.S. EPA Office of Research and Development, Environmental Research Laboratories.
City: Duluth, MN
Relevance to Short-term Water Quality Impacts of Dredging: Derivation of numerical national water quality criteria for the protection of aquatic organisms and their uses.
URL: http://www.epa.gov/waterscience/criteria/85guidelines.pdf

106: Site-specific objectives for copper in San Francisco Bay
Agency: State Water Resources Control Board
Year: 2007
Relevance to Short-term Water Quality Impacts of Dredging: Basin Plan Amendments adopted by the Water Board. Status: Approved by the Regional Water Board on June 13, 2007. Pending approval by the State Water Board, the Office of Administrative Law, and the U.S. Environmental Protection Agency.

107: Quality Criteria for Water
Author: USEPA
Year: 1976
Publisher: U.S. Environmental Protection Agency
City: Washington, DC
URL: http://www.epa.gov/waterscience/criteria/redbook.pdf

108: 40 CFR Part 131. Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants for the State of California
Agency: USEPA
Year: 2000
Journal: Federal Register
Volume: 65
Number: 97
Pages: 31682 - 31719
Relevance to Short-term Water Quality Impacts of Dredging: California Toxics Rule (CTR), final rule.
URL: http://www.epa.gov/waterscience/standards/ctr/index.html

Water Quality Criteria: Ammonia

109: Ambient Water Quality Criteria for Ammonia (Saltwater) - 1989
Author: USEPA
Publisher: USEPA Office of Water, Regulations and Standards, Criteria and Standards Division
City: Washington, DC
Report Number: EPA 440/5-88-004
URL: http://www.epa.gov/waterscience/pc/ambientwqc/ammoniasalt1989.pdf

110: 1999 Update of Ambient Water Quality Criteria for Ammonia
Author: US EPA
Year: 1999
Publisher: USEPA Office of Water
City: Washington, DC
Report Number: EPA-822-R-99-014
URL: http://www.epa.gov/waterscience/criteria/ammonia/99update.pdf

Water Quality Criteria: Dissolved Oxygen

111: Aquatic Life Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Cape Hatteras
Author: USEPA
Year: 2000
URL: http://www.epa.gov/waterscience/criteria/dissolved/index.html

Sediment Toxicity

112: Analysis of acid-volatile sulfide (AVS) and simultaneously extracted metals (SEM) for the estimation of potential toxicity in aquatic sediments
Author: H. E. Allen, G. Fu, and B. Deng
Year: 1993
Journal: Environmental Toxicology and Chemistry
Volume: 12
Pages: 1441– 53
URL (abstract): http://www.setacjournals.org/perlserv/?request=get-abstract&doi=10.1897%2F1552-8618(1993)12%5B1441%3AAOASAA%5D2.0.CO%3B2

113: Assessing the potential toxicity of resuspended sediment
Author: C. Bonnet, M. Babut, J. F. Ferard, L. Martel, and J. Garric
Year: 2000
Journal: Environmental Toxicology and Chemistry
Volume: 19
Number: 5
Pages: 1290-1296
Relevance to Short-term Water Quality Impacts of Dredging: Freshwater sediment toxicity examined in mesocosms (Canada). Ammonia, chromium, copper, and zinc released during resuspension of sediments. DO dropped during first 24 hrs. After 24hrs metals were not detected in water. After 96h, hardness, DO, ammonia were at reference values.

URL (abstract): http://www.setacjournals.org/perlserv/?request=get-abstract&doi=10.1897%2F1551-5028(2000)019%3C1290:ATPTOR%3E2.3.CO%3B2

114: Determinants of sediment toxicity in San Francisco Bay: final report
Author: E. Hoffman, S. Anderson, and J. Knezovich
Year: 1994
Publisher: LBL Energy and Environment Division, University of California
City: Berkeley, CA
Report Number: LBL-36592, UC-000
Relevance to Short-term Water Quality Impacts of Dredging: Areas of sediment toxicity in the bay (in order of decreasing toxicity): Marshes, mid-bay, harbors, navigation channels.

115: Incidence of adverse biological effects within ranges of chemical concentrations in marine and estuarine sediments
Author: E. R. Long, D. D. Macdonald, S. L. Smith, and F. D. Calder
Year: 1995
Journal: Environmental Management
Volume: 19
Number: 1
Pages: 81-97
URL (abstract): http://www.springerlink.com/content/976912025h384lj7/

Toxicity and Biological Effects

116: Impacts of navigational dredging on fish and wildlife: a literature review
Author: K. O. Allen and J. W. Hardy
Year: 1980
Publisher: National Technical Information Service
City: Washington, DC

117: Literature review of effects of resuspended sediments due to dredging operations
Author: Anchor Environmental CA
Year: 2003
Publisher: Los Angeles Contaminated Sediments Task Force
City: Los Angeles, CA
URL: http://www.coastal.ca.gov/sediment/Lit-ResuspendedSediments.pdf

118: Fundamentals of Aquatic Toxicology, Methods and Applications
Author: G. M. Rand and S. R. Petrocelli
Year: 1985
Publisher: Hemisphere Publishing Corporation
City: Washington, DC
URL (abstract): http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=5014403

119: Potential long-term ecological impacts caused by disturbance of contaminated sediments: a case study
Author: S. H. Su, L. C. Pearlman, J. A. Rothrock, T. J. Ianuzzi, and B. L. Finley
Year: 2002
Journal: Environmental Management
Volume: 29
Number: 2
Pages: 370-376

Relevance to Short-term Water Quality Impacts of Dredging: Evaluation of sediments for PCDD/Fs, metals, and turbidity after removal of large barges in New Jersey River.
URL (abstract): http://www.springerlink.com/content/c9xfkwm0pfh78e4k/

Toxicity and Biological Effects: Trace Metals

120: Complexation and time-dependent accumulation of copper by larval fathead minnows (Pimephales promelas): implications for modeling toxicity
Author: M. L. Brooks, C. J. Boese, and J. S. Meyer
Year: 2006
Journal: Aquatic Toxicology
Volume: 78
Number: 1
Pages: 42-49
Relevance to Short-term Water Quality Impacts of Dredging: Copper ligand model. 24 hr exposure experiments. Copper bioavailability in juvenile fathead minnows.
URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/16546273

121: Effects of lead on the growth and delta-aminolevulinic acid dehydratase activity of juvenile rainbow trout, *Oncorhynchus mykiss*
Author: V. M. Burden, M. B. Sandheinrich, and C. A. Caldwell
Year: 1998
Journal: Environmental Pollution
Volume: 101
Number: 2
Pages: 285-289
Relevance to Short-term Water Quality Impacts of Dredging: Biomarker used to estimate lead uptake in juvenile rainbow trout. Biomarker activity significantly reduced at two highest lead exposures. At high lead concentration, lower feeding rate and lethargy noted after 12 days.
URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/15093090

122: Selenium - A potential time bomb or just another contaminant?
Author: P. M. Chapman
Year: 1999
Journal: Human and Ecological Risk Assessment
Volume: 5
Number: 6
Pages: 1123-1138
Relevance to Short-term Water Quality Impacts of Dredging: Summary of selenium. No established thresholds of biological effect. Need to continue monitoring for selenium since current concentrations of selenium in water suggest a hazard exists - further investigation needed.

123: Toxicity of cadmium in sediments: the role of acid volatile sulfide
Author: D. M. Di Toro, J. D. Mahony, D. J. Hansen, K. J. Scott, M. B. Hicks, and S. M. Mayr
Year: 1990
Journal: Environmental Toxicology and Chemistry
Volume: 9
Pages: 1487–502
Relevance to Short-term Water Quality Impacts of Dredging: Role of AVS in determining LC50 for cadmium

URL (abstract): http://www.setacjournals.org/perlserv/?request=get-abstract&doi=10.1897%2F1552-8618(1990)9%5B1487%3ATOCIST%5D2.0.CO%3B2

124: Factors affecting trace metal uptake and toxicity to estuarine organisms: I. environmental parameters
Author: D. W. Engel, W. G. Sunda and B. A. Fowler
Year: 1981
Conference: Biological Monitoring of Marine Pollutants, New York, NY
Editor: F. J. Vernberg, F. D. Calabrese, F. D. Thurberg and W. B. Vernberg
Relevance to Short-term Water Quality Impacts of Dredging: Cd and Cr are particularly soluble in oxic conditions and can easily desorb from FeS and MnS precipitates. "Acute water column toxicity from the release of sediment-bound contaminants [is] unlikely" (p. 978).

125: Toxicity of metal-contaminated sediments from Keswick Reservoir, California, USA
Author: B. Finlayson, R. Fujimura, and Z. Z. Huang
Year: 2000
Journal: Environmental Toxicology and Chemistry
Volume: 19
Number: 2
Pages: 485-494
Relevance to Short-term Water Quality Impacts of Dredging: Investigation of site of hydroelectric power generation which scours bottom sediments and can affects metal mobilization. Toxicity results were associated with zinc and copper in sediments and elutriate tests. Concentrations in sediments would exceed probable effects levels in freshwater.
URL (abstract): http://www.setacjournals.org/perlserv/?request=get-abstract&doi=10.1897%2F1551-5028(2000)019%3C0485:TOMCSF%3E2.3.CO%3B2

126: Zinc binding to the gills of rainbow trout: the effect of long-term exposure to sublethal zinc
Author: F. Galvez, N. Webb, C. Hogstrand, and C. M. Wood
Year: 1998
Journal: Journal of Fish Biology
Volume: 52
Number: 6
Pages: 1089-1104
Relevance to Short-term Water Quality Impacts of Dredging: "Acute toxicity caused by very high environmental Zn exposure (i.e. mg/l range) is manifested primarily as an inflammatory oedema resulting in suffocation due to an increased diffusion distance across the gills" (p. 1089). "Except for highly polluted sites near industrial inputs, waterborne Zn concentrations rarely reach acute lethal levels. At more environmentally realistic, sublethal concentrations of the metal (microgram/l range), Zn exerts a much more specific response of plasma hypocalcaemia, produced by an impairment of branchial Ca uptake" (p. 1090). The tissue readily repairs itself after damage by Zinc. Also the experiment was conducted in hard water which inhibits Ca influx. The results may be different in softer water.
URL (abstract): http://www.blackwell-synergy.com/doi/abs/10.1111/j.1095-8649.1998.tb00957.x

127: Avoidance of copper and nickel by rainbow trout as monitored by a computer-based data acquisition system
Author: J. D. Giattina, R. R. Garton, and D. G. Stevens
Year: 1982
Journal: Transactions of the American Fisheries Society
Volume: 111
Number: 4

Pages: 491-504
Relevance to Short-term Water Quality Impacts of Dredging: avoidance responses of rainbow trout to copper and nickel solutions
URL (abstract): http://afs.allenpress.com/perlserv/?request=get-abstract&doi=10.1577%2F1548-8659(1982)111%3C491%3AAOCANB%3E2.0.CO%3B2&ct=1

128: Cu uptake and turnover in both Cu-acclimated and non-acclimated rainbow trout (Oncorhynchus mykiss)
Author: M. H. Grosell, C. Hogstrand, and C. M. Wood
Year: 1997
Journal: Aquatic Toxicology
Volume: 38
Number: 4
Pages: 257-276
Relevance to Short-term Water Quality Impacts of Dredging: Uptake of copper by rainbow trout. Uptake was to blood plasma in first 3 hours, then clearing to liver within 12 hours. After 24 hours, copper levels return to pre-experiment levels.
URL: http://www.rsmas.miami.edu/groups/grosell/PDFs/1997%20Grosell%20et%20al.pdf

129: Acute toxicity of boron, molybdenum, and selenium to fry of chinook salmon and coho salmon
Author: S. J. Hamilton and K. J. Buhl
Year: 1990
Journal: Archives of Environmental Contamination And Toxicology
Volume: 19
Number: 3
Pages: 366-373
URL (abstract): http://www.springerlink.com/content/k15366jw62x49466/

130: Chinook salmon (*Oncorhynchus tshawytscha*) and rainbow trout (*Oncorhynchus mykiss*) exposed to copper: neurophysiological and histological effects on the olfactory system
Author: J. A. Hansen, J. D. Rose, R. A. Jenkins, K. G. Gerow, and H. L. Bergman
Year: 1999
Journal: Environmental Toxicology and Chemistry
Volume: 18
Number: 9
Pages: 1979-1991
Relevance to Short-term Water Quality Impacts of Dredging: Chinook more sensitive to copper than rainbow trout. Cu-induced histological damage and neurophysiological impairment indicated. Results parallel behavioral avoidance experiments.
URL (abstract): http://www.setacjournals.org/perlserv/?request=get-abstract&doi=10.1897%2F1551-5028(1999)018%3C1979:CSOTAR%3E2.3.CO%3B2

131: Relative sensitivity of bull trout (*Salvelinus confluentus*) and rainbow trout (*Oncorhynchus mykiss*) to acute exposures of cadmium and zinc
Author: J. A. Hansen, P. G. Welsh, J. Lipton, D. Cacela, and A. D. Dailey
Year: 2002
Journal: Environmental Toxicology and Chemistry
Volume: 21
Number: 1
Pages: 67-75

Relevance to Short-term Water Quality Impacts of Dredging: Cadmium and zinc toxicity in bull trout and rainbow trout. Rainbow more sensitive than bull trout for both metals. Higher hardness and lower pH reduced toxicity response.
URL (abstract): http://www.setacjournals.org/perlserv/?request=get-abstract&doi=10.1897%2F1551-5028(2002)021%3C0067:RSOBTS%3E2.0.CO%3B2

132: Relative sensitivity of bull trout (*Salvelinus confluentus*) and rainbow trout (*Oncorhynchus mykiss*) to acute copper toxicity
Author: J. A. Hansen, J. Lipton, and P. G. Welsh
Year: 2002
Journal: Environmental Toxicology and Chemistry
Volume: 21
Number: 3
Pages: 633-639
Relevance to Short-term Water Quality Impacts of Dredging: Copper toxicity tests in bull trout and rainbow trout. In lower temperature experiment, both species were more sensitive. Rainbow trout appeared to be more sensitive than bull trout in some experiments.
URL (abstract): http://www.setacjournals.org/perlserv/?request=get-abstract&doi=10.1897%2F1551-5028(2002)021%3C0633:RSOBTS%3E2.0.CO%3B2

133: A review of boron effects in the environment
Author: P. D. Howe
Year: 1998
Journal: Biological Trace Element Research
Volume: 66
Number: 1-3
Pages: 153-166
Relevance to Short-term Water Quality Impacts of Dredging: Acute toxicity for boron to chinook salmon fry 725 mg/l in freshwater and 600 mg/l in brackish water (more advanced fry). coho salmon: 447 mg/l in freshwater and 600 mg/l in brackish water (more advanced fry). Toxicity thresholds given for rainbow trout embryo/larval stage but probably not relevant to bay since too young and freshwater conditions only. At concentrations of 1mg/l no effects were observed in fish in "natural waters".
URL (abstract): http://www.springerlink.com/content/w24548q735821566/

134: A lead-gill binding model to predict acute lead toxicity to rainbow trout (*Oncorhynchus mykiss*)
Author: A. Macdonald, L. Silk, M. Schwartz, and R. C. Playle
Year: 2002
Journal: Comparative Biochemistry and Physiology C-Toxicology & Pharmacology
Volume: 133
Number: 1-2
Pages: 227-242
Relevance to Short-term Water Quality Impacts of Dredging: Relationship between LT50 for lead toxicity and lead in gills of rainbow trout calculated from exposure was established.
URL (abstract): http://lib.bioinfo.pl/pmid:12356530

135: Renal responses to acute lead waterborne exposure in the freshwater rainbow trout (*Oncorhynchus mykiss*)
Author: M. Patel, J. T. Rogers, E. F. Pane, and C. M. Wood
Year: 2006
Journal: Aquatic Toxicology
Volume: 80
Number: 4

Pages: 362-371
Relevance to Short-term Water Quality Impacts of Dredging: Kidney function in adult rainbow trout from a lake system exhibited no decreased kidney function in first 96 hours of being exposed to lead in the water (concentration was close to LC50), however, excess ammonia was excreted. The kidneys act as a lead "sink".

136: Bioaccumulation and toxicity of silver compounds: a review
Author: H. T. Ratte
Year: 1999
Journal: Environmental Toxicology and Chemistry
Volume: 18
Number: 1
Pages: 89-108
Relevance to Short-term Water Quality Impacts of Dredging: Silver does not bioaccumulate rapidly and exposure is usually linked to contact with soil, especially soil contaminated from industrial wastewater sludge where silver is prevalent. Many water characteristics reduce silver toxicity, reducing the availability of free silver ions by binding free silver ions. Also, competing cations (e.g., Ca^{2+}) prevent binding of free silver ions to the reactive surfaces of organisms. Silver sulfide has low toxicity and is the most common form found in soil, sewage sludge, and sediments.
URL (abstract): http://www.setacjournals.org/perlserv/?request=get-abstract&doi=10.1897%2F1551-5028(1999)018%3C0089:BATOSC%3E2.3.CO%3B2

137: Toxicity of silver to the marine teleost (*Oligocottus maculosus*): effects of salinity and ammonia
Author: J. R. Shaw, C. M. Wood, W. J. Birge, and C. Hogstrand
Year: 1998
Journal: Environmental Toxicology and Chemistry
Volume: 17
Number: Pages: 594-600
Relevance to Short-term Water Quality Impacts of Dredging: Effects of silver on tidepool sculpin in varying salinities and ammonia concentrations.
URL (abstract): http://www.setacjournals.org/perlserv/?request=get-abstract&doi=10.1897%2F1551-5028(1998)017%3C0594:TOSTTM%3E2.3.CO%3B2

138: Behavioral responses of rainbow trout *Oncorhynchus mykiss* to sublethal toxicity of a model mixture of heavy metals
Author: G. Svecevicius
Year: 2005
Journal: Bulletin of Environmental Contamination and Toxicology
Volume: 74
Number: 5
Pages: 845-852
Relevance to Short-term Water Quality Impacts of Dredging: Behavioral responses of rainbow trout to heavy metals were investigated. Significant relationship between various behavioral responses and metal mixture concentration. Behavioral tests in rainbow trout useful for detecting pollution, even at low/background levels.

139: Physiology and modeling of mechanisms of silver uptake and toxicity in fish
Author: C. M. Wood, R. C. Playle, and C. Hogstrand
Year: 1999
Journal: Environmental Toxicology and Chemistry
Volume: 18
Number: 1

Pages: 71-83
Relevance to Short-term Water Quality Impacts of Dredging: The acute toxicity of ionic Ag to fish is much lower in seawater than in freshwater (up to three orders of magnitude less) because of the presence of Cl and Na in seawater, the latter of which competes for Ag uptake binding sites. Waterborne silver (non-ionic) can enter fish and accumulate in blood, then the kidneys, but is not acutely toxic. 50% inhibition of trout gill Na1,K1- ATPase activity (IC50) at 48 h exposure in vivo occurs at a calculated Ag1 concentration of about 16 nM (1.7 mg/L) but most toxic effects take several days to show up.
URL (abstract): http://www.setacjournals.org/perlserv/?request=get-abstract&doi=10.1897%2F1551-5028(1999)018%3C0071:PAMOMO%3E2.3.CO%3B2

Toxicity and Biological Effects: Organic Contaminants

140: The relevance of aquatic organisms lipid-content to the toxicity of lipophilic chemicals - toxicity of lindane to different fish species
Author: H. J. Geyer, I. Scheunert, R. Bruggemann, M. Matthies, C. E. W. Steinberg, V. Zitko, A. Kettrup, and W. Garrison
Year: 1994
Journal: Ecotoxicology and Environmental Safety
Volume: 28
Number: 1
Pages: 53-70
Relevance to Short-term Water Quality Impacts of Dredging: Toxicity of lindane. Relationship to lipid content. Higher lipid = higher toxicity threshold. Therefore, the more lipid in a fish, less likely to see effects.
URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/7523068

141: Altered growth and related physiological responses in juvenile chinook salmon (*Oncorhynchus tshawytscha*) from dietary exposure to polycyclic aromatic hydrocarbons (PAHs)
Authors: J. P. Meador, F. C. Sommers, G. M. Ylitalo, and C. A. Sloan
Year: 2006
Journal: Canadian Journal of Fisheries and Aquatic Sciences
Volume: 63
Pages: 2364-2376
URL (abstract): http://rparticle.web-p.cisti.nrc.ca/rparticle/AbstractTemplateServlet?journal=cjfas&volume=63&year=&issue=&msno=f06-127&calyLang=eng

142: Biomarker responses and chemical analyses in fish indicate leakage of polycyclic aromatic hydrocarbons and other compounds from car tire rubber
Author: E. Stephensen, M. Adolfsson-Erici, M. Celander, M. Hulander, J. Parkkonen, T. Hegelund, J. Sturve, L. Hasselberg, M. Bengtsson and L. Forlin
Year: 2003
Journal: Environmental Toxicology and Chemistry
Volume: 22
Number: 12
Pages: 2926-2931
Relevance to Short-term Water Quality Impacts of Dredging: Uptake of PAHs by rainbow trout exposed to tire rubber. Biomarker responses were higher in fish exposed to PAHs in tires vs. tires with no PAHs.
URL (abstract): http://www.setacjournals.org/perlserv/?request=get-document&doi=10.1897%2F02-444

Toxicity and Biological Effects: Ammonia

143: Low levels of environmental ammonia increase susceptibility to disease in Chinook salmon smolts
Author: P. A. Ackerman, B. J. Wicks, G. K. Iwama, and D. J. Randall
Year: 2006
Journal: Physiological and Biochemical Zoology
Volume: 79
Number: 4
Pages: 695-707
Relevance to Short-term Water Quality Impacts of Dredging: Effects of ammonia toxicity show up around 96 hours after exposure and can limit immunological responses, especially when fish are under stress from noise/turbidity and other things surrounding dredging operations or other stressful events like predation. Smolts are particularly vulnerable since their smolting takes up so much energy that would otherwise be used for fighting off pathogens, though they only tested the juvenile salmon with one pathogen. More investigation needed to determine reaction to other diseases.
URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/16826496

144: Sub-lethal plasma ammonia accumulation and the exercise performance of salmonids
Author: D. J. McKenzie, A. Shingles, and E. W. Taylor
Year: 2003
Journal: Comparative Biochemistry and Physiology A. Molecular & Integrative Physiology
Volume: 135
Number: 4
Pages: 515-526
Relevance to Short-term Water Quality Impacts of Dredging: Ammonia toxicity in blood plasma of brown trout, rainbow trout, and coho salmon. Species-specific differences. Impairment of swimming ability. Tissues affected include brain and white muscle. Depuration of ammonia also discussed.
URL (abstract): http://www.ncbi.nlm.nih.gov/pubmed/12890542

145: Ammonia toxicity in fish
Author: D. J. Randall and T. K. N. Tsui
Year: 2002
Journal: Marine Pollution Bulletin
Volume: 45
Number: 1-12
Pages: 17-23
Relevance to Short-term Water Quality Impacts of Dredging: During exhaustive exercise and stress, fish increase ammonia production and are more sensitive to external ammonia.

146: Effects of sublethal ammonia exposure on swimming performance in rainbow trout (*Oncorhynchus mykiss*)
Author: A. Shingles, D. J. McKenzie, E. W. Taylor, A. Moretti, P. J. Butler, and S. Ceradini
Year: 2001
Journal: Journal of Experimental Biology
Volume: 204
Number: 15
Pages: 2691-2698
URL: http://jeb.biologists.org/cgi/content/full/204/15/2691

147: The effect of feeding and fasting on ammonia toxicity in juvenile rainbow trout, *Oncorhynchus mykiss*
Author: B. J. Wicks and D. J. Randall
Year: 2002
Journal: Aquatic Toxicology
Volume: 59
Number: 1-2
Pages: 71-82

148: Swimming and ammonia toxicity in salmonids: the effect of sub lethal ammonia exposure on the swimming performance of coho salmon and the acute toxicity of ammonia in swimming and resting rainbow trout
Author: B. J. Wicks, R. Joensen, Q. Tang, and D. J. Randall
Year: 2002
Journal: Aquatic Toxicology
Volume: 59
Number: 1-2
Pages: 55-69
Relevance to Short-term Water Quality Impacts of Dredging: Swimming performance of coho salmon was significantly reduced at 0.04 and 0.08 mg per l NH_3. Mortality rate of rainbow trout increased much more quickly with increasing ammonia (starting at 0.04 mg/l NH_3) in swimming fish than in resting fish because they produce ammonia naturally as a metabolic waste product when exercising. Exposure to ammonia greater than 0.04 mg/l also impedes their ability to naturally excrete ammonia. Significant for juveniles who particularly need strong swimming to escape predators.

149: Transbranchial ammonia gradients and acid-base responses to high external ammonia concentration in rainbow trout (*Oncorhynchus mykiss*) acclimated to different salinities
Author: R. W. Wilson and E. W. Taylor
Year: 1992
Journal: Journal of Experimental Biology
Volume: 166
Number: 1
Pages: 95-112
URL: http://jeb.biologists.org/cgi/reprint/166/1/95

Toxicity and Biological Effects: pH

150: Effect of pH on trout blood vessels and gill vascular resistance
Author: M. P. Smith, R. A. Dombkowski, J. T. Wincko, and K. R. Olson
Year: 2006
Journal: Journal of Experimental Biology
Volume: 209
Number: 13
Pages: 2586-2594
Relevance to Short-term Water Quality Impacts of Dredging: Various gills, muscle, and vascular responses found in pH experiments with steelhead and rainbow trout.
URL: http://jeb.biologists.org/cgi/content/full/209/13/2586

Responses and Endpoints

151: Light and electron microscopical comparisons of normal hepatocytes and neoplastic hepatocytes of well-differentiated hepatocellular carcinomas in a teleost fish
Authors: J. A. Couch
Year: 1993
Journal: Diseases of Aquatic Organisms
Volume: 16
Pages: 1-14
URL: http://www.int-res.com/articles/dao/16/d016p001.pdf

152: A comprehensive assessment of the impacts of contaminants on fish from an urban waterway
Author: T. K. Collier, L. L. Johnson, C. M. Stehr, M. S. Myers, and J. E. Stein
Year: 1998
Journal: Marine Environmental Research
Volume: 46
Number: 1-5
Pages: 243-247
Relevance to Short-term Water Quality Impacts of Dredging: Flatfish, juvenile chinook and chum salmon investigated for organic contaminants in waterway of Puget Sound. Concentrations in salmon similar to levels previously shown to have biological effects to juvenile chinook. PAHs, PCBs, and pesticides are of particular concern.

153: Physiology is pivotal for interactions between salinity and acute copper toxicity to fish and invertebrates
Author: M. Grosell, J. Blanchard, K. V. Brix, and R. Gerdes
Year: 2007
Journal: Aquatic Toxicology
Volume: 84
Number: 2
Pages: 162-172
Relevance to Short-term Water Quality Impacts of Dredging: Fish at intermediate salinities were most tolerant to copper toxicity. Although, juveniles are most sensitive, physiology and size account for species differences.

154: Acute toxicity of sulfide and lower pH in cultured rainbow trout, Atlantic salmon, and coho salmon
Author: J. A. Ortiz, A. Rueda, G. Carbonell, J. A. Camargo, F. Nieto, M. J. Reoyo, and J. V. Tarazona
Year: 1993
Journal: Bulletin of Environmental Contamination and Toxicology
Volume: 50
Number: 1
Pages: 164-170
Relevance to Short-term Water Quality Impacts of Dredging: 100% mortality for rainbow trout at 0.4 mg/l H_2S exposure for 8 hours in a freshwater system in Spain.

155: Environmental and metabolic animal physiology
Author: C. L. Prosser
Year: 1991
Publisher: Wiley-Liss
City: New York, NY

Responses and Endpoints: Steelhead/Rainbow Trout: 152

156: Effects of copper, pH and hardness on the critical swimming performance of rainbow trout (*Salmo gairdnieri* Richardson)
Author: K. G. Waiwood and F. W. H. Beamish
Year: 1978
Journal: Water Research
Volume: 12
Pages: 611-619

Responses and Endpoints: Coho Salmon: 152

157: Physiological and behavioral effects of zinc and temperature on coho salmon (Oncorhynchus kisutch)
Author: L. Bowen, I. Werner, and M. L. Johnson
Year: 2006
Journal: Hydrobiologia
Volume: 559
Pages: 161-168
Relevance to Short-term Water Quality Impacts of Dredging: Experimental mesocosms used to examine zinc and temperature effects on hatchery raised coho salmon. Results were compared to wild populations of coho and steelhead in Navarro River, CA. Zinc in liver increased in hatchery fish when exposed to high zinc. Iron in liver increased when exposed to high temp/high zinc. Growth reduced in this treatment. Feeding rate increased when exposed to high zinc. Experimental fish had lower zinc, iron, hsp-70, than wild coho or steelhead from Navarro River.
URL (abstract): http://www.springerlink.com/content/w65271757242r553/

Responses and Endpoints: Chinook Salmon

158: Increased susceptibility of juvenile chinook salmon to infectious disease after exposure to chlorinated and aromatic compounds found in contaminated urban estuaries
Authors: M. Arkoosh, E. Casillas, E. Clemons, P. Huffman, A. Kagley, T. Collier, and J. Stein
Year: 2000
Journal: Marine Environmental Research
Volume: 50(1-5)
Pages: 470-471

Data Sources

Sediment Chemistry

159: Evaluation of Dredged Material Testing Data For Monitoring Contaminants in the San Francisco Estuary.
Author: T. Jabusch and D. Yee
Year: 2006
Publisher: SFEI (unpublished data evaluation: data summaries available by request)
City: Oakland, CA

160: California Sediment Quality Objectives Database
Author: SCCWRP
Year: 2006

URL: http://www.sccwrp.org/data/2006_sqo.html

161: Characterization of San Francisco Bay dredged sediments - crystalline matrix study. Dredge Disposal Study, Appendix F
Author: R. J. Serne and B. W. Mercer
Year: 1975
Publisher: US Army Engineer District, San Francisco
City: San Francisco, CA

162: 1993 Annual Monitoring Results. The San Francisco Estuary Regional Monitoring Program for Trace Substances (RMP)
Author: SFEI
Year: 1994
Publisher: San Francisco Estuary Institute
City: Oakland, CA
URL: http://www.sfei.org/rmp/RMP_Annual_Reports/1993_RMP_Annual_Report.pdf

163: 1995 Annual Monitoring Results. The San Francisco Estuary Regional Monitoring Program for Trace Substances (RMP)
Author: SFEI
Year: 1997
Project Sponsor: San Francisco Estuary Institute (SFEI)
URL: http://www.sfei.org/rmp/RMP_Annual_Reports/1995_RMP_Annual_Report.pdf

164: 2005 Annual Monitoring Results. The San Francisco Estuary Regional Monitoring Program for Trace Substances (RMP)
Author: SFEI
Year: 2006
Publisher: San Francisco Estuary Institute
City: Oakland, CA
URL: http://www.sfei.org/rmp/2004to05/2004to05_Annual_Results.htm

165: Dredge Disposal Study, San Francisco Bay and Estuary, Appendix C: Water Column
Author: USACE
Year: 1976
Publisher: US Army Engineer District, San Francisco
City: San Francisco, CA
Relevance to Short-term Water Quality Impacts of Dredging: Study conducted to assess impacts to water column after both dredging and disposal. Only constituent influenced was dissolved oxygen concentration, and effect was much larger after disposal than for dredging.

166: Dredge Disposal Study, San Francisco Bay and Estuary: Appendix I, Pollutant Availability Study
Author: USACE
Year: 1976
Publisher: US Army Engineer District, San Francisco
City: San Francisco, CA
Relevance to Short-term Water Quality Impacts of Dredging: An integrated investigation of the effects of a dredge hopper disposal operation on pollutant availability to local invertebrate fauna and of the pathways (water, sediment, and suspended particulates) by which pollutants may be accumulated by invertebrates was undertaken in San Francisco Bay.
URL (abstract):
http://stinet.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA038312

Toxicity and Biological Effects

167: Interspecies correlation estimations (ICE) for acute toxicity to aquatic organisms and wildlife. II. User manual and software
Author: A. Asfaw, M. R. Ellersieck ,and F. L. Mayer
Year: 2003
Publisher: US Environmental Protection Agency, Office of Research and Development
City: Washington, DC
Report number: EPA/600/R-03/106

168: Interspecies correlation estimations (ICE) for acute toxicity to aquatic organisms and wildlife. I. Technical basis
Author: F. L. Mayer, M. R. Ellersieck, and A. Asfaw
Year: 2004
Publisher: US Environmental Protection Agency, Office of Research and Development
City: Washington, DC
Report number: EPA/600/R-03/105

169: ECOTOXicology Database System, Version 4.0
Author: USEPA
Year: 2007
Relevance to Short-term Water Quality Impacts of Dredging: Source for locating single chemical toxicity data for aquatic life, terrestrial plants and wildlife. Toxicity thresholds in the database were used to determine toxicity of current SF Bay contaminant concentrations.
Link: http:/www.epa.gov/ecotox/

Appendix B. Synthesis Tables

Table B-1. Sensitive fish species in San Francisco Bay

Common Name	Species Name
Chinook Salmon	*Oncorhynchus tshawytscha*
Coho Salmon	*Oncorhynchus kisutch*
Steelhead Trout	*Oncorhynchus mykiss*
Delta Smelt	*Hypomesus transpacificus*
Green Sturgeon	*Acipenser medirostris*

Table B-2. List of constituents considered for short term effects on sensitive fish species, based on the Hamilton BO (Whitlock 1999).

Conventional Parameters

Ammonia

DO

pH

Sulfides

Heavy Metals/Trace Elements

Arsenic

Barium

Beryllium

Boron

Cadmium

Chromium

Copper

Lead

Manganese

Mercury

Nickel

Lead

Selenium

Silver

Vanadium

Zinc

Organic Contaminants

PAHs

PCBs

Pesticides

Dichloroprop, DDTs, Dieldrin, Heptachlor, Lindane, MCPA, MCPP, Methoxychlor, PCBs, Pentachlorophenol

Others

Phenol

Table B-3. Summary of sediment chemistry data from SQO database (SCCWRP 2006).

Chemical Name	Average Concentration	Standard Deviation	Units
2-Methylnaphthalene	15.74	38.9	µg/kg
Acenaphthene	16.54	133.0	µg/kg
Acenaphthylene	19.44	105.0	µg/kg
Ammonia	110.87	62.3	µg/kg
Anthracene	41.96	110.6	µg/kg
Arsenic	10.67	4.1	µg/kg
Barium	159.36	48.4	µg/kg
Benz(a)anthracene	95.96	178.7	µg/kg
Benzo(a)pyrene	170.85	315.1	µg/kg
Beryllium	0.83	0.4	µg/kg
BHCs, total	0.62	n/a	µg/kg
Cadmium	0.30	0.2	µg/kg
Chromium	214.85	106.0	µg/kg
Chrysene	118.26	236.7	µg/kg
Copper	48.80	28.8	µg/kg
DDTs	7.26	8.9	µg/kg
Dibenz(a,h)anthracene	29.45	129.8	µg/kg
Dieldrin	1.31	3.4	µg/kg
Fluoranthene	215.49	451.8	µg/kg
Fluorene	31.42	183.8	µg/kg
Heptachlor	0.35	1.0	µg/kg
Lead	26.37	24.3	µg/kg
Manganese	632.31	313.8	µg/kg
Mercury	0.32	0.4	µg/kg
Methoxychlor	4.43	6.9	µg/kg
Naphthalene	32.96	166.7	µg/kg
Nickel	92.71	21.5	µg/kg
PCBs	37.01	60.2	µg/kg
Pentachlorophenol	40.71	110.0	µg/kg
Phenanthrene	112.66	375.6	µg/kg
Phenols	15.40	28.1	µg/kg
Pyrene	302.64	586.8	µg/kg
Selenium	0.34	0.4	µg/kg
Silver	0.31	0.3	µg/kg
Sulfides	381.66	493.6	µg/kg
Sulfides (dissolved)	0.03	0.1	µg/kg
Vanadium	115.65	29.2	µg/kg
Zinc	114.81	48.6	µg/kg

Table B-4. Ammonia toxicity and biological effects values from the literature.

Species	Temperature (°C)	pH	Salt/fresh water	NH_3 (mg N/L)	LC_{50}[a] (mg N/L)	Comments	Source (no. in annotated bibliography)
Rainbow Trout	17	7	100% freshwater	0 – 58 (swimming) 0 – 378 (resting)	32 (swimming) 207 (resting) *(96 hr LC50)*	- Mortality rate increased more quickly in swimming vs. resting fish	Wicks et al. 2002
Rainbow Trout	10	7.2	100% freshwater	20 – 80	177 (fed) 135 (5-day fast) *(24 hr LC50)*	- Feeding rate decreased with increasing ammonia, after 48 hrs feeding increased except at 80 mg/l NH_3 exposure concentration - - Mortality only observed above 80 mg/l NH3; mortality rate increased more quickly in fasting fish vs. fed fish	Wicks and Randall 2002
Rainbow Trout	15	7.9	33% seawater	17.03	Not calculated	Significant Increase in plasma ammonia after 24 hrs	Wilson and Taylor 1992
Coho Salmon	9 - 12	6	100% freshwater	0.02 - 0.08	Not calculated	- Linear decrease in swimming performance with increasing water ammonia. - Significant increase in plasma ammonia correlated to ambient ammonia - Elevated plasma ammonia in swimming vs. resting fish	Wicks et al. 2002

[a]The reported LC_{50} values were extrapolated based on the observed mortality.

Table B-5. Selected toxicity thresholds from the ECOTOX database (USEPA 2007) and California Toxics Rule (CTR) criteria (USEPA 2000B).

Contaminant	Species	Threshold/ Test Type[c]	Duration	Threshold Value (µg/L)	Water Quality Objectives (all values in µg/L)				
					Saltwater			Freshwater	
					1-hr	24-hr	4-day	1-hr	4-day
Cadmium	Chinook Salmon	NOEC	4d	1.3	43.0		9.3	4.3	2.2
		LOEC		1.9					
		LC50		10					
	Rainbow Trout	NOEC	4d	0.7					
		LOEC		1.5					
		LC50		2.1					
Copper	Chinook Salmon	NOEC	4d	11.7	9.4[b]		6.0[b]	13.4	9
		LOEC		15.5					
		LC50	2d	20					
	Coho Salmon	NOEC	8d	28					
	Rainbow Trout	NOEC	4d	24	9.4[b]		6.0[b]	13.4	9
Nickel	Rainbow Trout	LC50	4d	60	74		8.2	470	52
Zinc	Chinook Salmon	NOEC	4d	280	90		81	120	120
	Rainbow Trout	NOEC	30d	36					
		LOEC	4d	130					
		LC50	4d	240					
Fluoranthene	Rainbow Trout	LC50	4d	7.7		15[a]			
Phenanthrene	Rainbow Trout	NOEC	60d	19		15[a]			

[a]Total PAHs; [b]copper guidelines are from the Proposed Basin Plan Amendment (SWRCB 2007);.[c] all threshold values are from freshwater toxicity tests.

Table B-6. San Francisco Estuary dredged sediment data from the SQO Database (SCCWRP 2006).

WaterBody	Agency Lead	Project Name	Year	Number of Stations
Carquinez	City of Benicia	Benicia 1997	1997	3
Carquinez	City of Benicia	Benicia 2000	2000	4
Carquinez	City of Vallejo	Vallejo Ferry	2003	2
Carquinez	UNOCAL Corporation	UNOCAL Corporation Loading Terminal	1996	4
Central SF Bay	Advanced Biological Testing, Inc. (ABT)	Loch Lomond Marina San Rafael	2001	7
Central SF Bay	Army Corps of Engineers	Richmond Harbor Deepening Project/Turning Basin	1994	7
Central SF Bay	Arques Shipyard and Marina	Arques Shipyard and Marina Maintenance Dredging	1998	2
Central SF Bay	Battelle Pacific Northwest Laboratories	Richmond Harbor Dredging October	1991	93
Central SF Bay	California Department of Transportation (CalTrans)	SFOBB East Span Project	1999	12
Central SF Bay	Emery Cove Marina	Emery Cove Marina Dredging	2000	3
Central SF Bay	Golden Gate Bridge Highway and Transportation District	Golden Gate Ferry	2000	2
Central SF Bay	Kappas Marina	Kappas	1997	2
Central SF Bay	Marina Vista	Marina Vista Homeowners Assoc San Rafael	1998	1
Central SF Bay	Oyster Point Marina	Oyster Point Marina	1998	4
Central SF Bay	Pacific EcoRisk	Clipper	2002	3
Central SF Bay	Port of Oakland	Port of Oakland Berths 26, 30, and Outer Harbor	1994	4
Central SF Bay	Port of San Francisco	Port of San Francisco Pier 35 West	2002	1
Central SF Bay	Port of San Francisco	Port of San Francisco Berth 35 East	2003	3
Central SF Bay	RMC Lonestar Cement Terminals Operations	RMC Lonestar Redwood City	1999	2
Central SF Bay	US Coast Guard	USCG Baker East Facility	1999	1
Central SF Bay	US Coast Guard	USCG Yerba Buena Island	1999	3
San Pablo Bay	Army Corps of Engineers	Pinole Shoals Navigation Channel	2003	3
San Pablo Bay South	Point San Pablo Yacht Harbor	Point San Pablo Yacht Harbor	2002	2
San Francisco Bay	County of San Mateo	Coyote Point Marina	2002	3
Suisun Bay	Army Corps of Engineers	Bulls Head Channel Dredging	1994	9
Suisun Bay	Blue Water Design Group	Martinez	2000	3
Suisun Bay	City of Suisun	Suisun City Launch Ramp	1999	1
Suisun Bay	Southern Energy Company	Pittsburg Power Plant	2000	1

Table B-7 Equilibrium partitioning constants used in conversion of sediment to dissolved water concentrations

Contaminant	Constant Type	Constant Value
Cadmium	Kd	2500
Copper	Kd	19953
Nickel	Kd	50118
Zinc	Kd	316228
Fluoranthene	Koc	35662
Phenanthrene	Koc	7865

Table B-8 Effects range – low (ERL) and effects range – medium (ERM) values of sediment contaminants. Average ERL and ERM values are from Long et al. (1995).

Parameter	Unit	ERL	ERM	Number of Samples > ERL (%)	Number of Samples > ERM (%)
Heavy Metals					
Arsenic	µg/g	8.2	70	103 of 138 (75%)	0 of 138 (0%)
Cadmium	µg/g	1.2	9.6	6 of 138 (4%)	0 of 138 (0%)
Chromium	µg/g	81	370	122 of 138 (88%)	0 of 138 (0%)
Copper	µg/g	34	270	105 of 138 (76%)	1 of 138 (1%)
Lead	µg/g	46.7	218	13 of 138 (9%)	1 of 138 (1%)
Mercury	µg/g	0.15	0.71	98 of 138 (71%)	12 of 138 (9%)
Nickel	µg/g	20.9	51.6	137 of 138 (99%)	130 of 138 (94%)
Silver	µg/g	1	3.7	5 of 138 (4%)	1 of 138 (1%)
Zinc	µg/g	150	410	34 of 138 (25%)	0 of 138 (0%)
PAHs					
Benzo(a)anthracene	µg/kg	261	1600	6 of 135 (4%)	2 of 135 (1%)
Benzo(a)pyrene	µg/kg	430	1600	8 of 135 (8%)	2 of 135 (1%)
Chrysene	µg/kg	384	2800	7 of 135 (5%)	2 of 135 (1%)
Dibenz(a,h)anthracene	µg/kg	63.4	260	6 of 135 (4%)	1 of 135 (1%)
Fluoranthene	µg/kg	600	5100	6 of 135 (4%)	0 of 135 (0%)
Pyrene	µg/kg	665	2600	9 of 135 (7%)	2 of 135 (1%)
2-Methylnaphthalene	µg/kg	70	670	1 of 29 (3%)	0 of 29 (0%)
Acenaphthene	µg/kg	16	500	15 of 135 (11%)	1 of 135 (1%)
Acenaphthylene	µg/kg	44	640	8 of 135 (6%)	0 of 135 (0%)
Anthracene	µg/kg	85.3	1100	12 of 135 (9%)	1 of 135 (1%)
Fluorene	µg/kg	19	540	13 of 135 (10%)	2 of 135 (1%)
Naphthalene	µg/kg	160	2100	4 of 135 (3%)	1 of 135 (1%)
Phenanthrene	µg/kg	240	1500	8 of 135 (6%)	4 of 135 (3%)

Table B-9. Evaluation of estimated water column concentrations at dredging sites in San Francisco Estuary.

Contaminant	Average Dissolved Water Column Concentration in Dredged material Plume of 0.001 km^3 (ug/l)	Number of Samples Above Minimum Threshold Value
Cadmium	0.06	0 of 138
Copper	2.59	0 of 138
Nickel	2.31	0 of 138
Zinc	0.87	0 of 138
Fluoranthene	0.16	0 of 126
Phenanthrene	0.47	0 of 127

Table B-10. Comparison of John F. Baldwin Ship Channel Sediment Evaluation –Chemical Elutriate Data (Lee et al. 1993) and toxicity and biological effects thresholds retrieved from ECOTOX (USEPA 2007). All concentrations in µg/L.

Parameter	Elutriate, dissolved		Chinook Salmon			Coho Salmon			Rainbow Trout		
	Pinole Shoal	West Richmond	NOEC	LC50	LOEC	NOEC	LC50	LOEC	NOEC	LC50	LOEC
Conventional Parameters											
DO	10	9.8									
pH	7.4	8.4									
Salinity	26	27									
Heavy Metals											
Arsenic	8.49	8.27									170
Cadmium	0.137	1.3	1.33 - 1.88	1.88	1.41	0.65[ICE]			0.7 - 14.8	1.5 - 26	2.1 - 4200
Chromium	0.56	1.26			179 [ICE]			151[ICE]			170
Copper	2.92	2.8	11.7	7.4 - 15.5	20 - 200	18 - 51		39 - 164	24 - 51	12 - 80	52 - 150
Mercury	0.014	0.004				· 10[a]					5
Nickel	3.15	1.53									50 - 90
Lead	1.48	0.72								0.007 – 54 · 10^4	0.02 - 54· 10^4
Selenium	ND	ND			4.7 – 9.6 · 10^4			1.7 – 3.8 · 10^4	0.2 · 10^4	0.3 - 1 · 10^4	0.02 – 4.8 · 10^4
Silver	0.001	0.003								1.8 - 11	6.2 - 51.4
Zinc	18.77	9.73	280 -500	49 - 500	182	32[ICE]			36	0.34 - 3600	170 - 9800
Organotins											
Dibutyltin	0.008	0.006									
Monobutyltin	0.004	0.004									
Tributyltin	0.014	0.011									

[ICE]Interspecies Correlation Estimations (ICE)(Asfaw et al. 2003; Mayer et al. 2004); [a]0% mortality

Table B-10 (continued). Comparison of John F. Baldwin Ship Channel Sediment Evaluation –Chemical Elutriate Data (Lee et al. 1993) and toxicity and biological effects thresholds retrieved from ECOTOX (USEPA 2007). All concentrations in µg/L.

Parameter	Elutriate, dissolved		Chinook Salmon			Coho Salmon			Rainbow Trout		
	Pinole Shoal	West Richmond	NOEC	LOEC	LC50	NOEC	LOEC	LC50	NOEC	LOEC	LC50
PAHS											
Acenaphthylene	ND	ND									
Acenapthene	0.008	ND									670 - 1570
Anthracene	ND	ND									
Benzo[a]anthracene	ND	ND									
Benzo[a]pyrene	ND	0.019									
Benzo[b]fluoranthene	ND	ND									
Benzo[g,h,i]perylene	ND	0.052									
Benzo[k]fluoranthene	ND	ND									
Chrysene	ND	ND									
Dibenzo[a,h]anthracene	ND	ND									
Fluoranthene	ND	0.015									7.7 - 187
Fluorene	ND	ND									
Indeno[1,2,3-c,d]anthracene	ND	ND									
Naphthalene	0.05	0.027				1.8 – 3.2 · 10^4	3.2 – 5.6 · 10^4	0.7 – 11.8 · 10^4	10^4	10^4	0.01 – 0.61 ·10^4
Phenanthrene	ND	ND							19 - 44	38 - 88	0.0002 - 3200
Pyrene	ND	0.025									2000

Table B-11. Comparison of ambient ammonia concentrations between San Francisco Bay segments. Concentrations based on SFEI's Regional Monitoring Program data (1993 – 2006). South Bay includes South Bay and Extreme South Bay segments. North Bay includes Carquinez Strait, San Pablo Bay and Suisun Bay segments. The Bay-wide average is the combined average of these segments. Calculated average dissolved water column concentration of ammonia in a hypothetical model dredged material plume of 0.001 km3 (mg/l). The dissolved ammonia concentrations is calculated as the sum of the average water column concentrations plus the total ammonia released from the sediment diluted by the plume volume (see Section 4. Methods).

Segment	Average Sediment Concentration (mg/l)	Average Dissolved Water Concentration (mg/l)	Average Dissolved Water Column Concentration in Dredged Material Plume of 0.001 km^3 (mg/l)
Central Bay	1.14	0.09	0.73
South Bay	2.23	0.10	0.16
North Bay	1.55	0.09	0.20
Bay-wide	1.53	0.09	0.77

Table B-12. Comparison of sediment concentrations by Bay segment. ND indicates concentration below detection. "-" denotes parameters not measured. North Bay included data collected in Carquinez Strait, San Pablo Bay, and Suisun Bay.

Parameter	South Bay		Central Bay		North Bay	
	Avg. Concentration	Std Dev.	Avg. Concentration	Std Dev.	Avg. Concentration	Std Dev.
2-Methylnaphthalene	ND		23.56	56.2	-	
Acenaphthene	3.27	2.9	19.83	146.4	7.80	6.6
Acenaphthylene	10.27	3.3	23.47	115.3	4.50	1.0
Ammonia	-		110.87	62.3	-	
Anthracene	22.33	11.4	50.07	120.3	18.35	7.6
Arsenic	7.27	1.2	10.97	4.2	10.35	0.5
Barium			163.50	42.0	--	
Benz(a)anthracene	74.67	23.0	113.76	192.0	31.05	3.0
Benzo(a)pyrene	150.00	26.5	204.46	337.5	41.10	11.5
Beryllium	-		0.94	0.3	-	
BHCs, total	-		0.62		-	
Cadmium	0.25	0.0	0.33	0.2	0.20	0.0
Chromium	80.77	7.0	221.39	111.1	143.50	0.7
Chrysene	92.33	24.2	140.56	254.9	47.90	4.9
Copper	43.73	18.4	50.67	29.8	65.00	1.4
DDTs	-		7.60	9.0	-	
Dibenz(a,h)anthracene	13.33	2.5	35.66	142.3	4.65	3.6
Dieldrin	ND		1.60	3.7	ND	
Fluoranthene	173.33	51.3	254.83	488.0	86.60	28.8
Fluorene	6.70	2.7	37.33	202.0	8.15	2.5
Heptachlor	ND		0.43	1.1	ND	
Lead	30.33	7.9	29.15	25.6	24.45	0.1
Manganese	-		452.18	134.4	-	
Mercury	0.37	0.2	0.37	0.4	0.36	0.0
Methoxychlor	ND		4.89	7.0	-	
Naphthalene	10.87	1.2	38.78	183.2	9.75	0.4
Nickel	67.63	14.9	91.71	21.9	99.10	0.8
PCBs	22.00	8.7	40.50	62.4	ND	
Pentachlorophenol	-		40.71	110.0	-	
Phenanthrene	65.00	31.4	132.62	410.9	40.75	18.5
Phenols	-		15.40	28.1	-	
Pyrene	220.00	55.7	359.48	630.9	125.80	39.9
Selenium	0.04	0.0	0.37	0.4	ND	
Silver	0.61	0.1	0.33	0.2	0.51	0.1
Sulfides	-		634.45	507.0	-	
Sulfides dissolved	-		0.04	0.1	-	
Vanadium	-		121.07	19.9	-	
Zinc	105.73	35.5	119.95	50.6	124.50	2.1