LITERATURE REVIEW OF EFFECTS OF RESUSPENDED SEDIMENTS DUE TO DREDGING OPERATIONS

Prepared for

Los Angeles Contaminated Sediments Task Force
Los Angeles, California

Prepared by

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1 INTRODUCTION AND OBJECTIVES

To support the development of a Contaminated Sediment Management Strategy for southern California, the members of the Contaminated Sediments Task Force (CSTF) are evaluating the need for Best Management Practices (BMPs) for controlling sediment resuspension during dredging. To assist in that evaluation, an investigation of the potential impacts on the aquatic environment from turbidity and resuspended sediment caused by dredging operations was conducted and is presented in this document.

The focus of this evaluation is a discussion of the current understanding in the scientific community regarding the potential effects dredging clean and contaminated sediments may have on the aquatic environment. There have been numerous studies completed regarding this issue but many of these studies were completed over 20 years ago. This paper will summarize conclusions from prior key studies/reports and identify more recent pertinent studies.

The overall topic of turbidity/suspended sediment effects on the aquatic environment is very complex due to the many variables that exist (e.g., chemical concentrations and types of chemicals within the sediment, affected organisms, types of sediment, etc.). The conclusions of this document will be based on the overall consensus from reports referenced in this review, and will identify issues that are thought to be well understood and issues that may require future study.

The primary objectives for this document, as defined by the members of the CSTF, include answering the following four questions:

- Is there a potential for adverse impacts from sediment resuspension as a result of dredging?
- What is the magnitude of the potential impact, both spatially and by range of species affected?
- Assuming a significant impact exists, what management options could be implemented to reduce the impact?
- Based on the review of the sediment resuspension effects data, are the current Los Angeles Regional Water Board water quality monitoring procedures sufficient for assessing resuspension occurrences and impacts?

Many other aspects of the impacts of managing dredged material have been considered in the literature including: effects of in-water disposal, dewatering, upland disposal, etc. However, this paper exclusively reviews the issues associated with the dredging portion of sediment management activities as opposed to these other aspects of sediment management.

The layout of this paper first briefly presents the types of equipment commonly used during dredging. Next, a description of the mechanisms of sediment resuspension is provided as well as a presentation of typical dredging project sediment resuspension concentrations. Next, the literature pertaining to documented physical and chemical effects to the aquatic environment caused by resuspended sediments is presented, followed by a discussion on available best management practices. Lastly, a conclusions and recommendation section describes possible future data needs for the region.

It is anticipated that the information presented in this document will form the basis for ongoing discussions among the members of the CSTF regarding the adequacy of the current water quality monitoring practices for the region and any potential changes for future projects.

2 REVIEW OF DREDGE EQUIPMENT AND PROCEDURES

This section reviews the main types of dredge equipment and procedures that are commonly used in the United States and discusses typical uses and limitations. Understanding how different types of dredging equipment operate is essential to understanding how and why sediments are resuspended during dredging operations and what potential environmental impacts these sediments may create. The relative levels of resuspended sediments for any one dredging operation may be a factor of the type of dredge, how it is used (operational considerations), best management practices employed, and site-specific issues (e.g., sediment grain size, currents, etc.).

Dredging in the U.S. is typically conducted by two basic methods (hydraulic or mechanical) depending on the volume to be removed, disposal option selected, the nature of the sediments and site conditions. While hydraulic dredges are typically used for unconsolidated sediments, such as those typically found in waterway maintenance removal projects, some types of hydraulic dredges can be used to excavate more consolidated sediments. Sediments are directed into the suction end of a hydraulic pipeline by various methods (e.g., rotating cutterhead) and transported to the water surface inside a pipeline and then to a selected discharge point.

Mechanical dredges excavate material using some form of bucket to carry dredged material up through the water column and to a barge for off-site transport. Mechanical dredges are used for removing loose to hard, compacted materials. There are other types of dredges that combine mechanical and hydraulic capabilities or are designed for special purposes, but their use is fairly limited. Hydraulic and mechanical dredges are discussed further in the following subsections.

Another dredging technique that is occasionally used is called agitation dredging. Bottom materials are removed from a selected area with equipment that resuspends the sediment, allowing natural or generated currents to carry the sediment away (Stuber and Day 1994). This technique is generally not used extensively in the U.S. and is not discussed further in this paper.

2.1 Hydraulic Dredges

Hydraulically operated dredges can be classified into four main categories: pipeline (plain suction, cutterhead, dustpan, etc.), hopper (trailing suction), bucket wheel, and side casting (Herbich 2000). Hydraulic dredges are self-contained units that handle both the dredge and disposal phases of dredging operations. They not only dig the material up but also dispose of it either by pumping the material through a floating pipeline to a placement area, or by storing it in hoppers that can be subsequently emptied over the disposal area. In a hydraulic dredge the material to be removed is first loosened and mixed with water by cutterheads or by agitation with water jets and then pumped as a fluid (Herbich 2000).

2.1.1 Cutterhead Dredge

The hydraulic pipeline cutterhead suction dredge is the most common hydraulic dredge used in the United States and is generally the most efficient and versatile. With this type of dredge, a rotating cutter at the end of a ladder excavates the bottom sediment and guides it into the suction. The excavated material is picked up and pumped by a centrifugal pump to a designated disposal area through a 15 cm (6 in) to 112 cm (44 in) pipeline as slurry with a typical solids content of 10 to 20 percent by weight. The typical cutterhead dredge is swung in an arc from side to side by alternately pulling on port and starboard swing wires connected to anchors through pulleys mounted on the ladder just behind the cutter. Pivoting on one of two spuds at the stern, the dredge "steps" or "sets" forward (Herbich and Brahme 1991; Cleland 1997).

2.1.2 Hopper Dredge

Hopper dredges consist of a ship-type hull with an internal hopper to hold material dredged from the bottom. The material is brought to the surface through a suction pipe and draghead and discharged into hoppers built in the vessel. Suction pipes (drag arms) are hinged on each side of the vessel with the intake (drag) extending downward toward the stern of the vessel. The drag is moved along the channel bottom as the vessel moves forward at speeds up to 3 mph. The dredged material is sucked up the pipe and deposited and stored in the hoppers of the vessel. Typical hopper capacities range from several hundred cubic meters to 33,000 m^3 (43,000 yd^3) (Herbich 2000; CEM 1983; Cleland 1997).

Once fully loaded, hopper dredges move to the disposal site to unload before resuming dredging. Unloading is accomplished either by opening doors in the bottoms of the hoppers and allowing the dredged material to sink to the open-water disposal site or by pumping the dredged material to upland disposal sites. Hopper dredges are mainly used for maintenance dredging in exposed harbors and shipping channels where traffic and operating conditions rule out the use of stationary dredges. While specifically designed dragheads are available for use in raking and breaking up hard materials, hopper dredges are most efficient in excavating loose, unconsolidated materials (Herbich 2000; CEM 1983; Cleland 1997).

2.2 Mechanical Dredges

Mechanical dredges can be classified into ladder, dipper, or bucket dredges. Bucket dredges, specifically clamshell dredges, are the most common type of mechanical dredges. They are typically used in areas where hydraulic dredges cannot work because of the proximity of piers, docks, etc., or where the disposal area is too far from the dredge site for it to be feasible for a cutterhead dredge to pump the dredged material (Hayes and Engler 1986). They may be used to excavate most types of materials except for the most cohesive consolidated sediments and solid rock.

The most common type of mechanical dredge is the clamshell dredge. It consists of a clamshell bucket operated from a crane or derrick mounted on a barge. It is used extensively for removing relatively small volumes of material (i.e., a few tens or hundreds of thousands of cubic meters) particularly around docks and piers or within other restricted areas. The sediment is removed at nearly its in-situ density; however, production rates (relative to a cutterhead dredge) are low. The material is usually placed in barges or scows for transportation to the disposal area. Although the dredging depth is practically unlimited, because of production efficiency and accuracy clamshell dredges are usually used in water not deeper than 30 m (100 ft).

The clamshell dredge usually leaves an irregular, cratered bottom (Herbich and Brahme 1991; Cleland 1997).

Variations of the clamshell dredge have been developed in recent years in an attempt to minimize loss of sediment and allow better precision. One example, the cable arm bucket, works on a two-cable system. One cable is attached to four spreader cables, which control opening and closing of the bucket. The second cable draws the clams together and lifts, thus creating a level-cut in the sediment that is essential for precision dredging. Other features such as one-way vents in the top of the dredge to reduce downward pressure during deployment and rubber seals to prevent loss of sediments have been added to further reduce sediment resuspension. Other, similar designs have been developed to mimic these features and are collectively referred to as “environmental” buckets.

2.3 Key Studies and Reports

Key studies and reports cited in this section that are useful to understanding the different types of dredging equipment and how they operate include:

- Cleland, J., 1997. Advances in Dredging Contaminated Sediment-New Technologies and Experience Relevant to the Hudson River PCBs Site. Scenic Hudson, Poughkeepsie, NY 12601.
- Coastal Engineering Manual (CEM), March 1983. “Dredging and Dredged Material Disposal”, EM 1110-2-5025, Department of the Army U.S., Army Corps of Engineers, Washington, DC 20314-1000.
- Herbich, 2000. Handbook of Dredging Engineering, 2nd Ed., McGraw Hill, NY.
- Herbich, J.B., Brahme, S.B., 1991. “Literature Review and Technical evaluation of sediment resuspension during dredging”, Contract Report HL-91-1, prepared for the Department of the Army, U.S. Army Corps of Engineers, Washington, D.C.

3 REVIEW OF SEDIMENT RESUSPENSION MECHANISMS AND RATES

To understand the potential effects of dredging operations on water quality, a basic understanding of both the factors controlling sediment resuspension and the rates of resuspension to the water column is necessary. This section reviews the current state of knowledge about resuspension of sediments during dredging operations.

Sediment resuspension caused by dredging is defined as those sediment particles suspended into the water column during the dredging operation that do not rapidly settle out of the water column following resuspension (Hayes and Engler 1986). Sediment resuspension is unavoidable to some extent and occurs whenever materials are dredged, regardless of the dredge type or precautions that may be taken during dredging operations. However, the degree of sediment resuspension from dredging depends on many site and operation-specific variables (Herbich and Brahme 1991, Collins 1995, Johnson and Parchure 2000, Nakai 1978, Pennekamp et al. 1996, Hayes and Wu 2001) including:

Dredge site characteristics

- waterway shape
- water depth
- presence of structures (bridges, piers, docks, pilings, etc.)

Characteristics of the dredged material

- grain size distribution
- water content
- density
- specific gravity
- organic/detritus content
- debris content

Nature of dredging operation

- dredge type and size
- production rate
- dredge methods (dredge cut depth, swing of cutterhead, etc.)

Site hydrology, hydraulics, hydrodynamics

- currents
- tides

- vessel wakes
- waves

Site ambient water quality

- salinity (including haloclines)
- temperature (thermoclines)
- background suspended sediment concentrations
- background water chemistry.

Field studies (and modeling based on field studies) of sediment resuspension under a wide variety of dredge conditions have shown that in most cases (although there are exceptions) suspended sediment concentrations:

- Are greater near the bottom (i.e., the sediment bed being dredged) as compared to higher in the water column (Hayes 1986, Collins 1995)
- Rapidly decrease with distance from the dredge (Hayes 1986, Collins 1995, Herbich and Brahme 1991)
- Are greater when the particle size distribution is smaller (i.e., silt/clays rather than sand/gravels (Herbich and Brahme 1991, Collins 1995, Johnson and Parchure 2000, Nakai 1978, Pennekamp et al. 1996, Hayes and Wu 2001)
- Are greater when the ambient water currents are fast enough to mobilize the sediments being disturbed[1] (Johnson and Parchure 2000, Nakai 1978, Pennekamp et al. 1996, Hayes and Wu 2001).

These and similar studies have also shown that the shape and size of plumes of suspended sediment (or turbid water) are predominantly determined by the hydrodynamic (e.g., currents) conditions in the water body being dredged (Havis 1988). Consequently, water currents (whether river flow, tidal, or wind/wave generated) are important factors in determining not only the amount of suspended sediment generated but also how wide an area may be affected by suspended sediments. In almost all cases, the vast majority of resuspended sediments resettle close to the dredge within one hour,

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[1] Specifically, the suspended sediment concentrations increase when the fraction of sediment particles in the dredge material with a critical resupsension velocity less than the ambient current velocity increases.

and only a small fraction takes longer to resettle (Wright, 1978; Van Oostrum and Vroege, 1994; Grimwood, 1983).

Given the large number of variables that are important in determining suspended sediment (and associated turbidity) concentrations in any particular situation, generalizations about the rates of suspended sediment produced from dredging should be viewed with caution. However, even given these variables, a large number of dredging sediment resuspension rate and concentration observations are available from the scientific literature and dredging monitoring reports, which span a wide variety of site specific conditions. It is reasonable to expect that most dredging operations fall within the range of these extensive observations, but it should not be assumed that all new dredging operations will always fall inside these historically observed ranges at all times.

With this in mind, sediment resuspension rates and observed suspended sediment concentrations associated with particular types of dredging operations are discussed in the following subsections on hydraulic dredging and mechanical dredging.

3.1 Sediment Resuspension by Hydraulic Dredges

As discussed in Section 2.1, there are two predominant types of hydraulic dredges, those that dispose of sediments via pipeline and those that store the material in a hopper for later disposal.

For hydraulic dredges (with pipeline disposal) the vast majority of sediment resuspension occurs near the point of sediment removal (e.g., at the cutterhead) (Herbich and Brahme 1991). Because sediments are suctioned into the dredge and carried away via pipeline, they cannot directly enter the middle and upper water column (which is possible for mechanical dredges, see below). As noted in Section 2.1, the most common type of head on a hydraulic dredge is a cutterhead, but various other mechanisms exist for loosening the sediment before it is suctioned away. Hydraulic dredges (with various types of dredge heads) are treated as a group in the following discussion.

Hopper dredges are sometimes operated so that overflow of sediment-laden water is allowed, which increases the storage capacity of the hopper bins. In these cases, suspended sediment concentrations may be elevated near the overflow location, particularly in the upper water column (near surface)(Havis 1988, Johnson and Parchure 2000, Collins 1995, Barnard 1978). Several studies have shown that suspended sediment concentrations near overflowing hopper dredges are usually higher than non-hopper hydraulic dredges or hopper dredges operated without overflows in similar situations (Herbich and Brahme 1991, Hayes 1986, Pennekamp et al. 1996, Johnson and Parchure 2000, Havis 1988, Collins 1995). These greater suspended sediment concentrations appear to be attributable to the hopper overflow, as opposed to differences in the dredging mechanisms or site characteristics (Havis 1988, Collins 1995, Barnard 1978). Because hopper dredges are not widely used in the Los Angeles region for nearshore dredging, sediment resuspension caused by hopper dredges and their overflows are not further discussed in this paper.

3.1.1 Resuspension Rates

Johnson and Parchure (2000), Nakai (1978), Pennekamp et al. 1996, and Hayes and Wu (2001) have each independently developed approaches for estimating suspended sediment-source strength or resuspension rates associated with typical operation of hydraulic and mechanical dredges. These approaches use empirical measurements of suspended sediment concentrations very close (i.e., a few meters or less) to dredging operations to provide estimates of sediment resuspension that can be used for predictive modeling efforts. The resulting resuspension rates or source strength parameters are a measure of how much of the dredged sediment is available for movement and transport through the water column. In essence, they represent a “worst-case” suspended sediment condition extremely close to the point of dredging.

The suspended sediment concentrations observed by the various researchers were used to derive source strength parameters, defined either as a “turbidity generation unit” (TGU) (Nakai 1978), a “suspension parameter” (S) (Pennekamp et al. 1996), or a “resuspension factor” (R) (Hayes and Wu 2001). Johnson and

Pachure compiled the available project-specific "TGU" data (from 20 separate dredging projects) and "S" data (from an additional 23 dredging projects) for use in predictive modeling. Hayes and Wu (2001) recently published additional "R" data for 5 other dredging projects. In many of these cases, the researchers did not report the actual suspended sediment concentrations that were used to develop the source strength estimates. In some cases, however, these concentrations were reported and are discussed in Section 3.1.2.

Resuspension rates developed by these researchers provide a consistent measure of the amounts of sediment initially resuspended by dredging in the water column and allow a relative comparison of resuspension from hydraulic versus mechanical dredge types. Although conceptually equivalent, the various one-dimensional source strength parameters defined by different investigators (i.e., TGU, S, and R) are not directly interchangeable. The relationship between these parameters is generally as follows:

$$R = S/d_{sub} = TGU/(K \times d_{sub})$$

where:

R = resuspension factor (% dry weight basis) (Hayes and Wu 2001)

S = suspension parameter (kg dry/m^3 *in situ*) (Pennekamp et al. 1996)

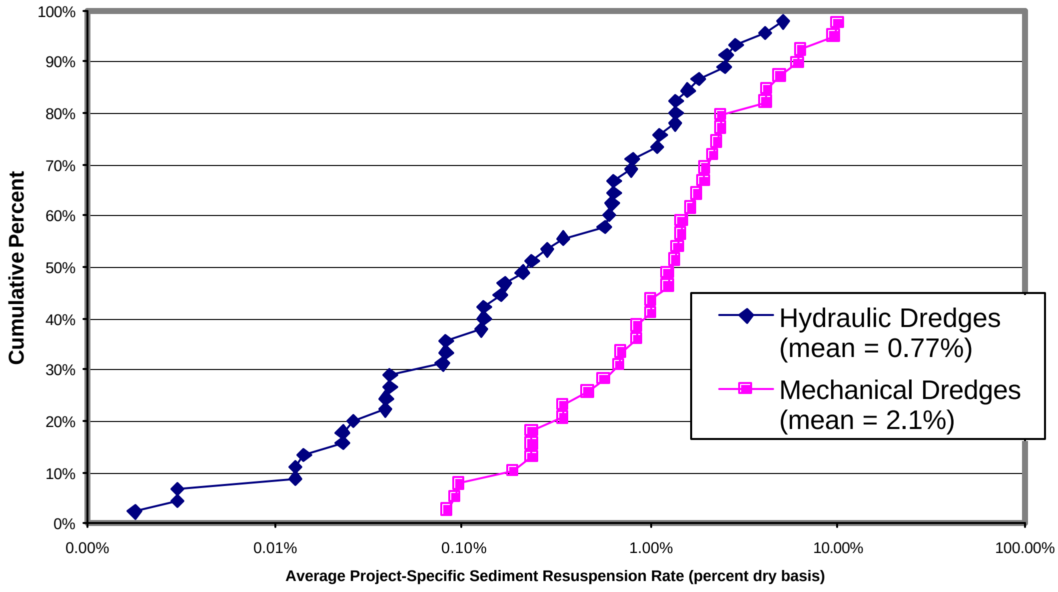
d_{sub} = *in situ* dry density (kg dry/m^3)

TGU = turbidity generation unit (kg dry/m^3 *in situ*) (Nakai 1978)

K = % of particles with diameter <74 um / % of particles too fine to settle in current.

The above equation was used to determine the resuspension rates in terms of "R" reported by each these researchers (Figure 1; see Appendix A for table of resuspension rates). The average resuspension rates (in terms of "R") from these data are 0.77% for hydraulic dredges and 2.1% for mechanical dredges. This indicates that, when all other factors are equivalent (e.g., the sediment sizes, hydrodynamic conditions, etc.) hydraulic dredges tend to resuspend less sediment into the water column than do mechanical dredges. However, it is important to note that the ranges of resuspension rates for hydraulic and mechanical methods overlap, and therefore, hydraulic dredging cannot always be assumed to create less sediment resuspension than mechanical dredging under all conditions.

Figure 1. Probability distribution of dredging resuspension rates for hydraulic and mechanical dredging equipment



3.1.2 Total Suspended Sediment Concentrations

Although resuspension rates are useful in terms of understanding the relative mass of dredged material lost to the water column, they do not provide a concentration of sediments present in the water. Measurements of resuspended sediment concentrations are useful when the relative effects of dredging on the environment are considered (as in Section 5). There are numerous studies in addition to the ones noted above that have measured suspended sediment concentrations extremely close to and at set distances (e.g., 100 feet) from dredge operations. The suspended sediment concentrations reported in these studies are summarized in Figure 2. (Appendix A contains the detailed data table used to create Figure 2.)

Figure 2. Cummulative percent total suspended sediments concentrations (above background conditions) for mechanical and hydraulic dredging

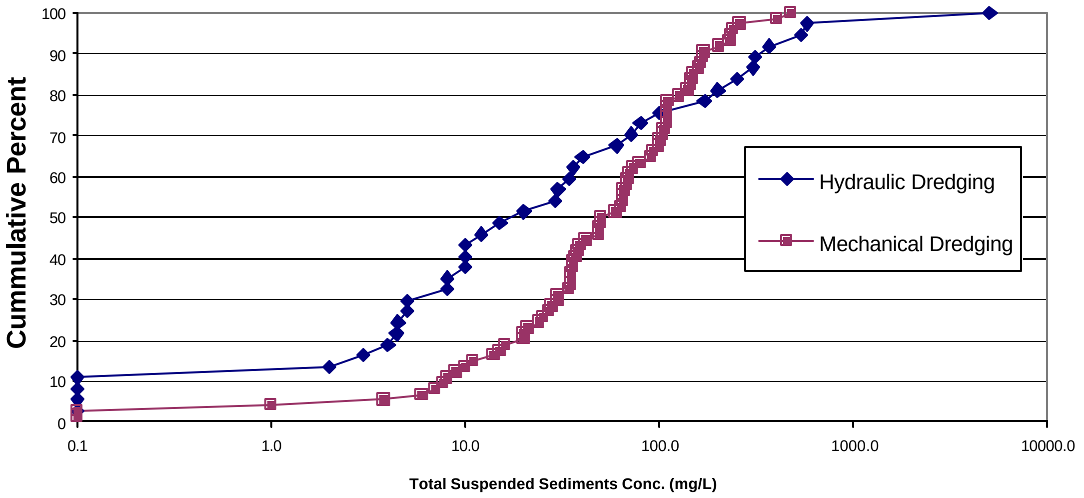


Figure 2 shows that suspended sediment concentrations (i.e., values above background concentrations) near hydraulic dredging are usually lower than those for mechanical dredging, with the 50th percentile for hydraulic dredging at 15 mg/L and the 50th percentile for mechanical dredging at 66 mg/L. The lower suspended sediment concentrations near hydraulic dredging are consistent with the lower resuspension rates for hydraulic dredges discussed above.

However, there are three observations for hydraulic dredges that are above the range of observations for mechanical dredges (Figure 2). One extreme observation (5000 mg/L) is for a hydraulic dredging project in Japan (Herbich and Brahme 1991). Because the dredge is described as a “drag head” it is possible that this extreme outlier represents a hopper dredge result, but this cannot be conclusively determined from the reference. Regardless of this one outlier, Figure 2 shows that it cannot always be assumed that hydraulic dredging will cause lower suspended sediment concentrations in the water column under all conditions.

3.2 Sediment Resuspension by Mechanical Dredges

As noted in Section 2.2 there are a variety of mechanical dredges, but all involve moving the sediment in some type of container (bucket, clamshell, ladder, etc.) to the surface. Unlike hydraulic dredges, this process allows for sediment resuspension at any vertical point in the water column from the bottom to above the water surface. The process of sediment resuspension from mechanical dredging has been broken down into several components (Herbich and Brahme 1991):

- Resuspension when the bucket impacts the sediment bed, closes, and is pulled off the bottom
- Sediment losses as the bucket is pulled through the water column (either raised from the bottom or lowered from the surface)
- Sediment losses when the bucket breaks the water surface
- Sediment/water spillage or leakage as the bucket is hoisted and swung from the water to the haul barge.

In addition, losses of sediment can occur if the barge is allowed to overflow. As with hopper dredges, such overflow of sediment-laden water is sometimes allowed to increase a barge's effective load and it is likely that this practice increases suspended sediment concentrations around the dredging operation. However, very little specific analysis or monitoring of the effects of barge overflow during mechanical dredging was found in the literature.

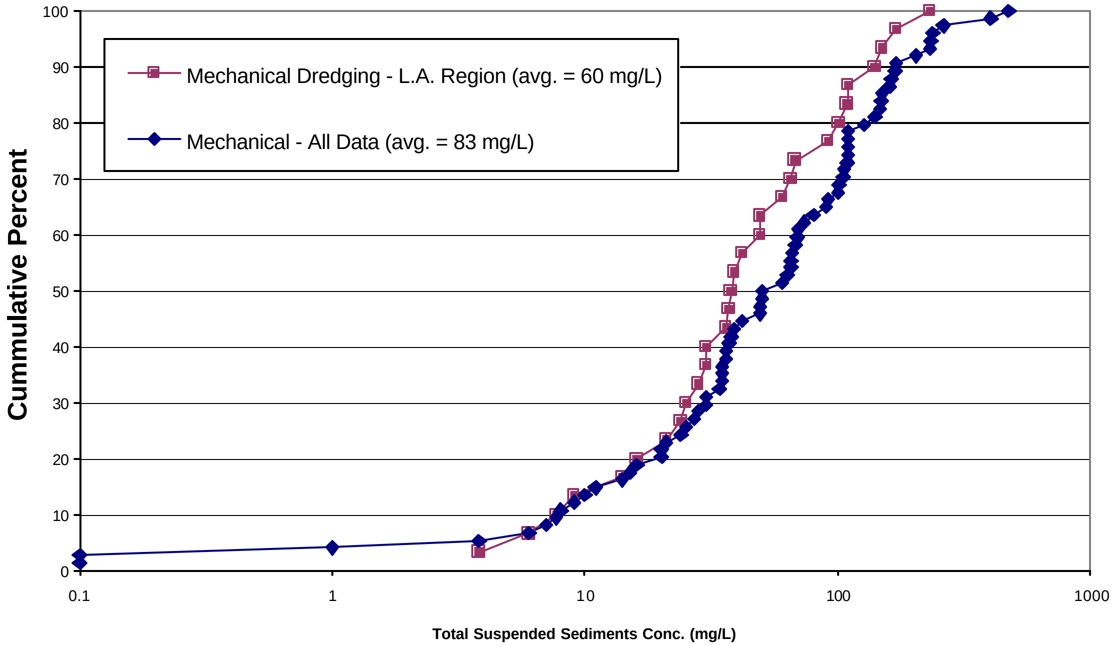
As discussed in the previous sections, the overall resuspension rates for mechanical dredging are generally higher but overlap with the range of rates found for hydraulic dredging (Figure 1). The same is true for suspended sediment concentrations observed near mechanical dredges (Figure 2), but the highest reported suspended sediment concentrations near dredges were for the hydraulic type.

3.3 Examples of Los Angeles Region Suspended Sediment Concentrations

Because this review is being conducted specifically to support monitoring decisions related to dredging in the Los Angeles region, it is worthwhile to consider how the international literature information on dredging induced sediment resuspension discussed above compares to available data from the Los Angeles region. For resuspension rates (in terms of % mass suspended sediment as described in Section 3.1.1), no specific studies of this nature have been conducted in the Los Angeles region. However, monitoring of suspended sediment concentrations near a number of dredging operations has been conducted recently and can be compared to suspended sediment concentrations discussed in Sections 3.1.2 and 3.2.

Available recent data on dredging in the Ports of Los Angeles and Long Beach were reviewed and compiled (MEC 2002 and MBC 2000, 2000b, 2001a, 2001b, 2001c, 2001d, 2001e, 2001f). In all cases, the available data were for mechanical dredging only. Figure 3 shows a comparison of these suspended sediment data to the international mechanical dredging data discussed above in Section 3.3 (detailed data are in Appendix A).

Figure 3. Cummulative percent total suspended sediments concentrations (above background conditions) for Los Angeles Region mechanical dredging compared to all available data



Generally, the resuspended sediment concentrations observed in the Los Angeles region near mechanical dredges is in the same range as those observed elsewhere in the U.S. and the world. Very approximately, both data sets range from several mg/L to several hundred mg/L, with the average for the Los Angeles region at 60 mg/L and the overall average at 83 mg/L. The slightly lower average for Los Angeles region data is likely because all of the regional observations were made between about 80 to 300 feet distant from the dredge (with most observations at 300 feet), while data from other parts of the world often include observations very close to the dredge (within a few meters).

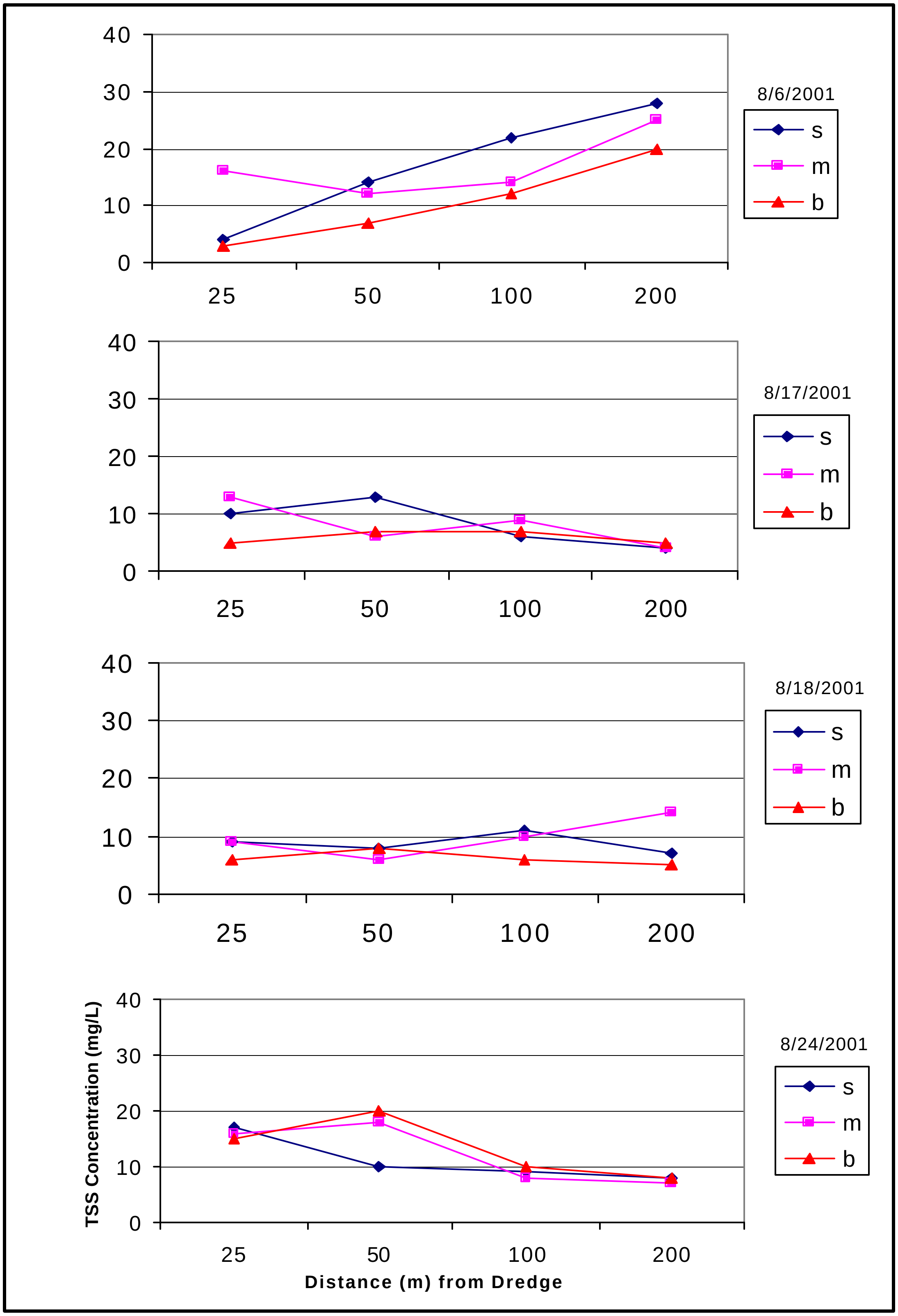
With respect to sediment resuspension distances, no real studies could be located that are specific to the Los Angeles region. Evaluation of water quality data collected on four separate occasions for the Los Angeles River Estuary during 2001 (MEC 2002) shows that the material settles very quickly, and in most cases within 50 meters from the point of dredging (Figure 4). In one example, however, the concentrations increased downstream from the dredge location suggesting a different source for the suspended materials. One explanation could be the presence of an algal bloom in the water moving upstream with a flooding tide. There was a flood tide at the time the samples were collected so this may have been the cause. As a point of reference, background concentrations of suspended solids for the examples presented in Figure 4 ranged from 8-19 mg/L.

3.4 Key Studies and Reports

Several key studies and reports cited in this section that are considered useful in understanding dredging induced sediment resuspension rates and suspended sediment concentrations include:

- Barnard, W.D., 1978. “Prediction and Control of Dredged Material Dispersion around Dredging and Open-Water Pipeline Disposal Operations”, Technical Report DS-78-13, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Collins, M.A. 1995. “Dredging-Induced Near-Field Resuspended Sediment Concentrations and Source Strengths”, Miscellaneous Paper D-95-2, US Army Engineer Waterways Experiment Station.

Figure 4. Example TSS settling distances for Los Angeles River Estuary Dredging 2001 (Note: s= surface, m= middle, b= bottom).



- Hayes, D., Wu, P-Y, 2001. Simple Approach to TSS Source Strength Estimates, Western Dredging Association Proceedings, WEDA XXI, Houston, TX, June 25-27, 2001. 11 pp
- Herbich, J.B., Brahme, S.B., 1991. "Literature Review and Technical evaluation of sediment resuspension during dredging", Contract Report HL-91-1, prepared for the Department of the Army, U.S. Army Corps of Engineers, Washington, D.C.
- Johnson, B.H., Parchure, T.M., 2000. "Estimating Dredging Sediment Resuspension Sources", DOER Technical Notes Collection, TN DOER-E6, U.S. Army Engineer Research and Development Center, Vicksburg, MS.
- Nakai, O., 1978. "Turbidity Generated by Dredging Projects, Management of Bottom Sediments Containing Toxic Substances", Proc. of the Third U.S.-Japan Experts Meetings, EPA-600/3-78-084, 1-47.
- Pennekamp, J.G.S., Eskamp, R.J.C., Rosenbrand, W.F., Mullie, A., Wessel, G.L., Arts, T., Decibel, I.K., 1996. "Turbidity caused by dredging; viewed in perspective", Terra et Aqua, 64, pp.10-17.

4 PROCEDURES FOR MEASURING WATER QUALITY IMPACTS ASSOCIATED WITH DREDGING

Numerous definitions, units of measures, and methods of measurement have been applied to the study of resuspended sediments and the related effects of turbidity, light attenuation, and water chemistry in aquatic environments. Three types of measures of resuspended sediment effects are most common (physical, chemical and biological) and can be further broken down into more specific parameters as follows:

- Physical Measurements
    - Turbidity (scattering and absorption of light in water)
    - Total Suspended Solids (TSS)
    - Reduced light transmission (light passing through water)
- Chemical Measurements
    - Total chemical concentrations (aqueous and particulate)
    - Dissolved chemical concentrations (partitioning from particulates to dissolved aqueous phase)
- Biological Measurements
    - Acute and chronic toxicity
    - Chemical bioaccumulation

Turbidity and light transmission are not direct measures of the amount of suspended sediments in water. Rather, they are measurements of the optical properties of water that change due to the presence of suspended sediment (as well as other factors unrelated to suspended sediment). These measures have been commonly used because of their ease of measurement in the field. Conversely, total suspended solids and chemical measurements are typically direct quantification of the concentrations of sediments and chemicals in the water, which require laboratory analyses. Biological measures involve the use of aquatic organisms either in the laboratory or field to measure the toxicity of the site water to the test organism. Each of these measures of effects is defined and described in more detail below.

4.1 Physical Measurements

Physical measurements of water quality are those aspects of suspended sediments that change the physical properties of the water and measurement of the suspended sediments themselves. There are other direct physical impacts of dredging such as noise impacts, destruction of benthic communities in the sediments, wave/wake creation, etc. However, only physical measurements of water quality are discussed in this paper.

4.1.1 Turbidity

Turbidity is a common standard method used to describe the cloudy or muddy appearance of water. Turbidity measurements have often been used for water quality studies because they are relatively quick and easy to perform in the field. The concept of turbidity involves optical properties of the water and is not a direct measure of the concentration of suspended sediments. Turbidity has been defined as an optical measurement of light that is scattered and absorbed, rather than directly transmitted, as it passes through water (APHA 1992). Primarily, suspended particulate matter in the water causes the scattering and absorption of light (i.e., turbidity). Dissolved materials in the water can also cause turbidity, but in most naturally occurring waters this effect is usually small in comparison to turbidity caused by particulate matter. Particulate matter can commonly include, but is not limited to, inorganic solids (sediment particles), organic solids or detritus (from activities of organisms), and living organisms (e.g., phytoplankton and zooplankton).

Turbidity is affected by the concentration of suspended particles as well as other factors such as particle shape, size distribution, refractive index, color, and absorption spectra (Thackston and Palermo 2000; Barnard 1978). Suspended particle concentrations are sometimes assumed to be the controlling factor in turbidity measurements, but the other factors of shape, size, etc. can cause considerable variability in turbidity (Thackston and Palermo 2000).

The standard unit of measurement for turbidity is the Nephelometric Turbidity Unit (NTU)[2] measured with a nephelometer. NTUs are based on a standard

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[2] Formerly, the Jackson Turbidity Unit (JTU) was a commonly used unit of measure, but is no longer the accepted standard (APHA 1992). JTU and NTU are not interchangeable and are based on different standardization solutions (Thackston and Palermo 2000).

suspension of formazin in water, which is used to calibrate nephelometers. According to this model, the lower the measured NTU value is, the clearer and less turbid the water will be.

Turbidity is extensively used as a measure of water quality for dredge monitoring as well as a variety of general water quality projects in freshwater, estuarine, and marine environments. When light penetration and water clarity are being studied, turbidity provides direct measurements of light properties that may be important to understanding photosynthetic production and sensory impacts to a variety of organisms (e.g., ability to see food, prey, predators, competitors, and mates)) (Nighingale and Simenstad 2001). Beyond this, turbidity has also been used as surrogate measurement of suspended sediments, fecal coliform, nutrients, and chemicals (Thackston and Palermo 2000; Christensen et al. 2000; WDOE 1997). In these cases, turbidity may be coupled with specific measurements of other parameters to determine their correlations with turbidity in a site-specific situation. More often, turbidity is used as a more qualitative guide to the potential effects of these other parameters, particularly TSS, based on general knowledge from scientific literature that there is usually some type of predictable relationship between the parameters (Thackston and Palermo 2000; Herbich and Brahme 1991). Researchers often use turbidity in lieu of more direct measurements of other parameters because turbidity is readily measured in the field with minimal expense.

4.1.2 Total Suspended Solids

Total suspended solids, sometimes referred to as suspended solids, is a simple measure of the dry-weight mass of non-dissolved solids suspended per unit volume of water (usually expressed in mg/L). TSS includes inorganic solids such as clay, silt, sand, etc. as well as organic solids such as algae, zooplankton, and detritus (APHA 1992). When direct measurement of the quantity of suspended particulate matter present in water is needed, TSS mass determination in a laboratory is the most common method. While turbidity and light transmission measure the presence of particles indirectly through their optical properties, TSS measurements directly quantify the mass of particulates present in the water.

TSS is commonly measured from a sample that is taken to a laboratory. Results are typically known no sooner than 24 to 48 hours after the sample is taken. Consequently, it is usually impossible to make real-time field decisions based on TSS measurements as is sometimes required for dredging projects. Although compared to chemical analyses the costs of TSS analyses are relatively low, they are still more expensive than typical turbidity and light transmission measurements.

TSS is a useful measurement when information on the mass or concentration of particulates or sediment present in the water is needed. TSS is directly related to physical health effects that some organisms may exhibit due to the presence of the sediment itself in the water including choking of gills, abrasion, smothering, etc. (Wilber and Clarke 2001; see Section 5 for more detail and references on effects of TSS). Further, because in most natural waters chemicals are highly associated (i.e., bound or absorbed) with particulates, TSS is often highly correlated with the total concentration of chemicals that may be of concern in resuspended sediment (Eisler 2000). Direct measurement of suspended solids can also provide information that may be related to more long-term issues such as mass estimates of sediment lost during dredging, the potential for sediment settling and transport to other areas, etc.

4.1.3 Reduced Light Transmission

Where turbidity is a measure of the scattering and absorption of light, light transmission is a measure of how much light passes directly through the water. Simply put, light transmission is the opposite of turbidity, because it measures the remaining directly transmitted light that is not scattered or absorbed. A transmissometer is used to measure the amount of light leaving a source and arriving at a receiver through a known distance in the water (typically 10 or 20 cm). Thus, 100% light transmittance represents clear water and 0% transmittance represents complete occlusion of all light or very cloudy water. Just like turbidity, the amount of light transmission observed can be affected by the shape, size distribution, and opacity of particles present in addition to the concentration of particles (MBC 2000). Like turbidity, light transmission can be easily measured in the field.

Light transmission (T) is related to a similar measurement known as light attenuation (A) that depends on the distance of the light path (x) and can be mathematically defined as (Hartman 1996):

$$A = \frac{-\ln T}{x}$$

Since light attenuation is a measurement of the light lost per distance, it is sometimes referred to as turbidity but should not be confused with turbidity measurements in NTU discussed in the previous section.

A Secchi disk is also sometimes used as general measure of water clarity or light transmission. It is a disk, usually 20-30 cm in diameter, with a bold black and white pattern that is lowered into the water to a depth where the sharp outline of the pattern cannot be perceived. This depth is recorded as a subjective measure of water clarity and can be imprecise (Thackston and Palermo 2000). Where quantitative measurements of water clarity are required, a transmissometer is commonly used.

Like turbidity measurements, transmissometers are commonly used in dredge monitoring as well as oceanographic and limnological studies to directly understand water clarity and light penetration. It can provide direct information that is relevant to photosynthetic production and organism sensory impacts. It can also provide indirect measurements of other water quality parameters and has been correlated with TSS (MBC 2000).

4.2 Chemical Measurements

Chemicals are often associated with bottom sediments in urban waterways. Consequently, when these sediments are dredged and some portion is resuspended in the water column, the chemicals associated with these sediments are also present in the water column at some concentration. At sufficiently high concentrations, chemicals in water can cause adverse effects to aquatic biota (direct toxicity or bioaccumulation) and people. As a result, the federal government and most states have established chemical water quality criteria, which are intended to protect aquatic life and human uses of natural water bodies. In the State of California there are several types of water quality standards and criteria that apply to Los Angeles regional waters where dredging occurs including the California Enclosed Bays and Estuaries Plan and California Toxics Rule.

Because of the potential for aquatic risks, measurements of chemicals in waters near dredging operations are often conducted. Typically, the measurements consist of water column sampling somewhere in the vicinity of the dredge operation for chemical and physical (i.e., suspended solids) analysis at a laboratory. For some chemical parameters, field tests also exist but their accuracy and precision is often inadequate for comparison to numeric criteria or guidelines, and they can only be used in as general indicators of a chemical's presence. In most cases, chemical analyses in a laboratory will require one or more weeks (typically 2-4 weeks) depending on the particular suite of chemicals analyzed and logistical considerations of the laboratory and sampling program. Thus, chemical measurements cannot be used to make daily decisions regarding dredging operations. Like suspended sediment measurements, almost every chemical analysis determines the mass of chemical present in the water sample and reports this as a concentration, usually in mg/L (parts per million) or ug/L (parts per billion), depending on the chemical in question.

4.2.1 Chemical Partitioning

Chemicals present in bottom sediments can exist in two basic forms: (1) adsorbed or otherwise bound to particulates and (2) dissolved in bottom sediment pore waters (the water between particulate grains in the sediment). When dredging of sediments occurs, these chemicals can be liberated to the water column and can either stay in their original forms (i.e., particulate associated or dissolved) or be transformed from one form to the other (Brannon 1978, DiGiano et al. 1995, EVS 1997). These transformations can be caused by a variety of processes including but not limited to physical agitation, changes in water chemistry (e.g., anoxic to oxic conditions), and dilution (Averett et al. 1999, Hirst and Aston 1983, DiGiano et al. 1995).

Consequently, chemical measurements near dredging operations fall into two general categories: those that measure dissolved forms (particularly metals), and those that measure total concentrations (dissolved and particulate forms combined). The relationship between dissolved and particulate phases of chemicals in resuspended dredge sediments is important because it has long been understood that for many chemicals (including most metals and organic compounds) it is the dissolved form that represents the most bioavailable portion of chemicals present in naturally occurring waters, and is therefore most important when discussing direct toxicity (Eisler 2000, Suter et al. 2000). For most metals, EPA's Office of Water recommends that the dissolved portion be analyzed for most water quality studies and comparison to water quality criteria (Prothro 1993). This is accomplished by filtering the water samples with 0.45 um filter to remove all particulates.

For organic chemicals, there is no indisputable federal guidance at this time on the interpretation of dissolved verses total organic chemicals in waters. One reason is that bioaccumulation of organic compounds and some metals species (e.g., mercury) in aquatic organisms can occur via exposure to both dissolved and particulate forms. More importantly, the behavior and toxicity of organic chemicals in water can vary widely depending on the specific structure of the organic compound in question. In addition, because many types of dissolved organics will adsorb to some extent onto most commercially available filters, there are also logistical difficulties in examining dissolved organics even when this is clearly desirable. Consequently, in most cases for organic chemicals, dredging studies (and many other types of water quality studies) focus on total organic chemicals (both dissolved and particulate form) and assume that this entire amount is bioavailable for both direct toxicity and bioaccumulation. This may result in conservative estimates of potential direct toxicity from organic chemicals dispersed during dredging operations.

4.3 Biological Measurements

Aquatic ecosystems can be complex and naturally varied in composition and character even within relatively small distances at a particular site depending on the types of habitats present and other factors. Consequently, quantifying the effects of dredging through biological measurements can be difficult. For this and logistical reasons, biological measurements of dredging effects typically focus on isolating some relevant component of the ecosystem (e.g., one species) and conducting a specific controlled test on that component.

These tests, broadly termed bioassays, are most commonly conducted in a laboratory, but can also occur in the field. The tests are often developed to understand water toxicity in a variety of situations (e.g., industrial effluent discharges) but have been used or adapted for the measurement of effects related to dredging. Two general types of bioassays are discussed below in more detail: acute and chronic bioassay toxicity tests and bioaccumulation tests.

4.3.1 Acute and Chronic Toxicity

Acute and/or chronic toxicity tests are frequently used to estimate or predict a biological impact resulting from a given event. As stated above, typical applications include monitoring effluent discharges and as a characterization step prior to dredging and disposal. In these instances, the tests are usually conducted in a laboratory under controlled conditions and the results are used to determine permit compliance or for suitability at a disposal location. For these specific applications, the use of toxicity tests and interpretation of the results is very well understood.

Conversely, acute and/or chronic toxicity tests used to monitor for potential adverse impacts during field or simulated dredging events can be difficult to interpret due to the complex physical and chemical processes at work and the inability to control all variables that may affect organism responses. For example, studies indicating toxicity might suggest that the adverse response was due to a physical effect from the suspended particles, a chemical effect resulting from the aqueous fraction of the chemical in the water, or even both.

4.3.2 *Chemical Bioaccumulation*

Bioaccumulation is a phenomenon by which chemicals are taken up by marine organisms from water directly or through consumption of food containing the chemicals (Rand and Petrocelli, 1985). For this paper, the term bioaccumulation is used as a general descriptor to include bioaccumulation, bioconcentration and biomagnification. Bioaccumulation of chemicals by marine organisms can occur via both the dissolved phase and the particulate bound phase of the chemicals of concern.

Organic compounds are generally less soluble than metals. Consequently, direct toxicity via organic compounds dissolved in the water column is often less likely. However, organic compounds tend to bioaccumulate in organisms. This can occur both through dissolved phase exposure through the water column and from organic compounds adsorbed to particulate matter. Bioaccumulation of most organic compounds occurs as a result of uptake by a receptor, followed by partitioning of the compounds into the receptor's organic carbon compartment—the lipids. Therefore, bioaccumulation is highly dependent upon an organism's lipid content and on the affinity of the compound to partition into the organic phase (ThermoRetec, 2001). Bioaccumulation most often occurs through sediment ingestion (e.g., filter feeders like molluscs).

4.4 Keys Studies and Reports

Several key studies and reports cited in this section that are considered useful in understanding measurements of dredging related water quality impacts include:

- APHA. 1992. Standard Methods for the Examination of Water and Wastewater. 18th ed. Washington, DC. American Public Health Association, American Water Works Association, Water Pollution Control Federation.
- Averett, D.E., Hayes, D.F., Schroeder, P.R., 1999. "Estimating Contaminant Losses During Dredging", Proc. of World Dredging Association, 19th Technical Conference.

- Brannon, J.M. 1978. "Evaluation of Dredge Material Pollution Potential", Technical Report DS-78-6, Synthesis of Research Results, Dredge Material Research Program, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
- EVS, 1997. "Release of Contaminants from Resuspended Particulate Matter", White Paper, EVS.
- MBC Applied Environmental Sciences (MBC), November 2000. "Turbidity Issues in Relationship to Dredging", Port of Los Angeles.
- Thackston, E.L., Palermo, M.R. (a), 2000. "Improved Methods for Correlating Turbidity and Suspended Solids for Monitoring", DOER Technical Notes Collection, ERDC TN-DOER-E8, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

5 PHYSICAL EFFECTS OF RESUSPENDED SEDIMENTS

Resuspended sediment effects can be broken down into two broad categories: (1) effects related to the physical properties of the sediment and (2) effects related to chemicals associated with the sediments. Resuspended sediments can also cause changes in the ambient water chemistry such as pH and dissolved oxygen content. This document does not address this issue at this time. This section addresses effects related to the physical properties of resuspended sediments. These effects may occur in either clean or contaminated sediments but are not related to the presence of any chemicals in the sediments. Section 6 addresses effects related to chemicals associated with resuspended sediments.

5.1 Biological Mechanisms for Physical Effects

Aquatic organisms' responses to suspended sediments are dependent on the aquatic ecosystem in question and the individual species and life stages affected. In very general terms, two types of physical effects to organisms have been noted in the literature:

1. Behavioral or physiological effects caused by the presence of suspended sediment particles and associated debris
    - Behavioral – alarm reaction, cover abandonment, avoidance, or attraction (as a potential food source or cover)
    - Physiological – changes in respiration rate, choking, coughing, abrasion and puncturing of structures (e.g., gills/epidermis), reduced feeding, reduced water filtration rates, smothering, delayed or reduced hatching of eggs, reduced larval growth/development, abnormal larval development, or reduced response to physical stimulus. These effects can in turn result in increased mortality and/or decreased growth and reproduction in general (Wilber and Clarke 2001, Newcomb and Jensen 1996; see Appendix A for additional references).

2. Behavioral effects caused by changes in light penetration/scattering[3] - alarm reaction, increased swimming, altered schooling behavior, avoidance, displacement, attraction, and changes in prey capture rates (Nightingale and Simenstad 2001, Benfield and Minello 1996, Lloyd 1987).

Both types of physical effects are discussed in more detail in the following subsections.

5.2 Literature Review - Sediment Particle Effects

A large number of mostly laboratory studies have been conducted in the last 30 to 40 years to understand the effects of suspended particulate matter on a variety of aquatic organisms. These studies have been conducted primarily on:

- Finfish – adult, subadult, and eggs
- Molluscs – adult, subadult, larvae, and eggs
- Crustaceans – adult and subadult.

Finfish studies have included marine, estuarine, freshwater, and anadromous species and span a variety of habitat types such as pelagic, bottom dwelling, and epibenthic feeders (e.g., herring, perch, bass, shad, minnow, and anchovy). Shellfish studies have included a variety of mostly filter feeders from the marine environment (e.g., clams, mussels, and oysters). Crustacean studies have included several kinds of marine shrimp, crabs, and lobster. Wilber and Clarke [2001] review many of these studies and Appendix A cites these references in detail.

5.2.1 Compilation of Effects Data Set

A large data set is available on the physical effects of sediment particles comprising a variety of aquatic organisms that reside in areas where dredging operations are likely to occur. Many of these species or closely related species can be found in the marine and estuarine environments of the Los Angeles region. This data set including the species, reported effects levels (in mg/L total

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[3] Changes in light penetration can also cause physiological effects in the case of phytoplankton and plants via reduced photosynthesis rates (Nightingale and Simenstad 2001).

suspended sediment), test duration, reported response, response type (e.g., lethal or sublethal), and type of sediment used in the studies is summarized in Appendix A.

The compiled effects data set was statistically summarized for both acute (less than 96 hours) and chronic (greater than 96 hours) effects levels that have been observed. Segregation of effects by duration of exposure is a common approach to studying the detrimental effects of chemicals and other materials in water (Suter et al. 2000).

The segregation of effects by duration is important when examining impacts from dredging operations (Wilber and Clarke 2001). Most dredging operations are not conducted on a continuous basis. That is, there are periods (e.g. at night) where dredging and resuspension of sediments is not occurring. Further, dredging operations often move from one area to another over time as sediments are removed. Currents may carry sediment plumes in various directions effecting different areas overtime. Consequently, continuous exposure of a particular aquatic community to resuspended sediments on a chronic basis (greater than 96 hours at a time) is less likely to occur near dredging operations as compared to more short-term acute exposures. It should not be inferred from this fact that chronic exposures never occur in any dredging situations. Rather, it is important to distinguish between the potential for chronic and acute exposures in any specific dredging situation so that the appropriate effects levels are being considered. Overall, several researchers have suggested that use of effects data of chronic durations is generally less appropriate for dredging operations (Wilber and Clarke 2001, Nightingale and Simenstad 2001).

The effects data set was further broken down between lethal effects (where the reported effect was mortality of the test organism) and sublethal effects (where the reported effect was some non-lethal response or the maximum level at which no effect was observed). Lethal versus sub-lethal effects is also an important distinction to consider when discussing the effects of dredging operations. For example, an aquatic community might be exposed to sublethal levels of resuspended sediments for a period of several days. This may cause some short-term detrimental effect on the organism, but it does not necessarily ensure long-term measurable impacts to survival, growth, and reproduction of the species. That is, many species may be able to recover without permanent injury from short-term sublethal effects. This is particularly important to consider when using no effects levels (which indicate the species was, in fact, not measurably affected by the test concentration) or sublethal effects such as "increased swimming behavior" or "decreased pumping rate". It is also important to recognize that, in most cases, measured sublethal effects were observed in controlled laboratory experiments where the test organism was forced to endure the suspended sediment without the opportunity to avoid the material. As such, some of these results may be conservative because in a field scenario some aquatic organisms (e.g., fish) will have the opportunity to avoid the sediment plume and reduce their impacts.

Where various mortality rates were provided for a particular study (e.g., 10%, 50%, 90% mortality), only the 50% mortality effect level was used. This value is also known as the Lethal Concentration 50 (LC50) and is a standard approach used for developing water quality standards and conducting risk assessments (Suter et al. 2000).

5.2.2 Effects Data Set Results

The data set for physical effects of suspended sediment particulates contained in Appendix A is summarized in Table 1 for chronic/acute and lethal/sublethal effects.

Table 1. Summary statistics for physical effects concentrations (mg/L total suspended sediments) for all species reported in Appendix A.

Endpoint	5th percentile	10th percentile	50th percentile	N	St. Dev.
Acute Lethal	500	760	7,000	67	69,262
Acute Sublethal	76	100	560	50	2,935
Chronic Lethal	50	142	2,150	59	28,725
Chronic Sublethal	22	45	500	68	3,402

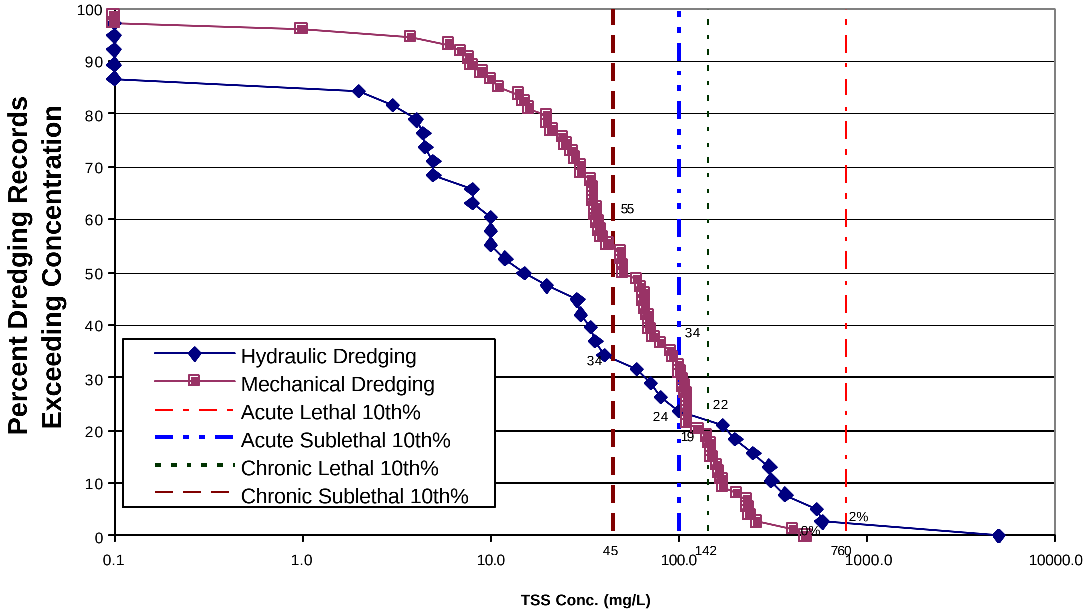
N = Sample size for each endpoint

St. Dev. = Standard deviation around the mean for each endpoint.

As Table 1 shows, there is a relatively wide range of effects levels reported and the effect level observed is highly dependent on both the duration (chronic versus acute) and type of effect (lethal versus sublethal) being studied.

The relative importance of these effects levels as compared to the suspended sediment concentrations typically observed near dredging operations is shown in Figure 5, where the 10th percentile results from Table 1 are compared to frequency curve of suspended sediment concentrations from dredge operations (discussed in Section 3.1). Essentially, Figure 5 shows the percent of dredging monitoring reports (given the data available) exceeding the effects levels depicted (i.e., acute lethal, chronic lethal, acute sublethal, and chronic sublethal). For example, based on the data available, suspended sediment concentrations from hydraulic dredging operations were reported to exceed the lower 10th percentile acute sublethal effects level about 24% of the time. Mechanical dredge operations were reported to exceed that same effects level 34% of the time.

Figure 5. Comparison of total suspended sediment data reported for various dredging operations to potential effects levels reported for a variety of marine and estuarine species



As noted above, the suspended sediment concentration data shown in Figure 5 include many values that are very close to the point of dredging (within a few meters) as well as values that are up to 300 feet from the dredge. Thus, it should not be assumed that this frequency of exceedance occurred at any particular set distance from these dredging operations.

Also, as noted above, it may not be appropriate to use either chronic or sublethal effects when considering the impacts of relatively short term and transient dredging operations. On this basis, it is noteworthy that Figure 5 indicates it would be very unlikely for any dredge type to exceed the 10th percentile acute lethal concentration (only one report exceeded this level). It should be also noted that the 10th percentile concentration is used in the above graph and may not be the most relevant statistic for comparison. It was chosen for the purpose summarizing the effects data set and represents a reasonably conservative value given the uncertainties of the data set and the variety of organisms tested in the literature. Choosing an appropriate effects level from a large data set for the purposes of determining likely environmental impact is a regulatory issue that is beyond the scope of this document.

5.2.3 Other Particle Related Effects

Another potential effect from suspended sediments can occur when suspended sediments resettle to the seabed, covering benthic organisms. This blanketing or smothering may cause stress or reduced rates of survival, growth or reproduction (Bray et al. 1997). The following are examples of observed effects to aquatic benthic organisms and lifestages due to siltation (UK Marine SAC 2002):

- Shellfish can have reduced growth or survival (ABP Research 1997).
- Maerl beds (calcified seaweed) are reported to be sensitive to siltation due to channel dredging (Birkett et al. 1998)
- In spawning or nursery areas for fish and other marine organisms, dredging can result in smothering of eggs and larvae (Reiser and Bjornn 1979)

- Siltation may also limit production of benthic invertebrates (Reiser and Bjornn, 1979).

Kiorbe et al. (1981) observed that suspended sediments might serve as an additional food source for blue mussels, which are suspension feeders that rely on suspended particulate matter as a primary food source. It is reasonable to assume that this effect could apply to other suspension feeders including other mollusks, tube worms, suspension feeding polychaetes, barnacles, etc. Finally, Stern and Stickle (1978) suggested that resuspension of sediments could cause the release of nutrients that would stimulate primary production in some situations.

5.3 Literature Review – Turbidity/Light Effects

This section reviews effects from resuspended sediments that are caused by increases in turbidity or reductions in water clarity (as opposed to the direct physical effects of the particles themselves in the water). Water turbidity or clarity is important to:

- primary production (photosynthesis) by phytoplankton and aquatic plants
- terrestrial organisms (such as sea birds) that rely on visual cues for foraging for food in water.
- any aquatic organism that has a visual sensory system

The focus of this section is on the latter of the three issues (discussed in Section 5.3.2). The other two, primary production and terrestrial animal foraging, are briefly discussed in Section 5.3.1. While they may be important, literature related to the specific effects of dredging generated turbidity primarily focus on aquatic organisms such as fish.

5.3.1 Primary Production and Other Effects

In general, it is known that primary production slows in waters where light penetration is limited by turbidity including production by both phytoplankton and aquatic plants (QEA et al. 2001, Parr et al. 1998, Wallen 1951). Likewise, it has been postulated in Southern California that sea bird foraging success may be affected by the presence of turbid waters (COE 1997). In fact, current dredge projects scheduled to occur in Southern California during known nesting periods (April 1 to September 15) for the visual feeder, the California Least Tern, are required to implement Best Management Practices (BMPs) for controlling turbidity as a precaution even though no specific studies have been conducted to document the link between dredging related turbidity and observed effects of these kinds (USFWS, 2002). What is known, however, is that the California Least Tern is a ground nesting species whose nests are highly susceptible to predators foraging along the shore. Typically, the terns feed within 2 miles of their nesting colony allowing them to alternate between feeding and protecting their nests. Even though a nearby dredging activity may not directly result in a documented adverse effect on the bird's foraging abilities, the mere presence of the equipment may force them to feed further away from their nests than they normally would. Consequently, the amount of time spent away from the nests might be longer and thus increase the risk of predation (USFWS, 2002).

5.3.2 Behavioral Effects in Finfish

The study of turbidity caused changes in behavior of aquatic organisms has focused mainly on finfish. Marine, estuarine, and riverine environments contain some natural levels of turbidity caused by phytoplankton, tidal flows, currents, storms, and runoff/ discharge from upland sites and rivers. Such levels can vary considerably depending on the conditions at any one time (e.g., during storms or periods of high runoff). Inland waters commonly exhibit a green color and relatively low light transmittance (50 to 60 percent) due to primary production by phytoplankton and coastal sediment sources (Nightingale and Simenstad 2001). The life history strategies of many fishes have evolved in the context of these variations in water clarity.

Consequently, not all of the effects observed in fish due to changes in water clarity are necessarily or clearly detrimental to the organisms in questions. It is known that many estuarine species prefer relatively turbid waters due to hunting strategies or as cover from predation (Wilber and Clarke 2001). Under laboratory conditions several species have been shown to actively prefer turbid over clear water conditions (Wilber and Clarke 2001). Depending on which species is being studied, turbidity as cover can either be interpreted as (1) protecting an organism (a theoretically beneficial effect) or (2) preventing predators from finding prey (a theoretically detrimental effect).

Boehlert and Morgan (1985) observed that turbid conditions might enhance the visual contrast of prey items and thus increase overall feeding rates of larval Pacific herring. Increased turbidity was observed to result in increase foraging rates in juvenile Chinook salmon, which was attributed to the increase in cover provided (Gregory and Northcote 1993). Turbidity has also been linked to the reductions in avoidance response of juvenile Chinook salmon to bird and fish models (Gregory and Northcote 1993). In Coho salmon increased turbidity has been observed to induce a surfacing response, which was postulated to increase their vulnerability to predation (Servizi, 1990, Servizi and Martens 1992).

Nightingale and Simenstad (2001) reviewed much of the available literature on behavioral changes triggered by patches of increased turbidity. They suggested that: “It is unknown what threshold of turbidity might exist that serves as a cue to a fish to avoid light reducing turbidity.” However, they concluded that the primary determinant of risk level from dredging would likely be a factor of the spatial and temporal overlap between the area of turbidity, the degree of turbidity elevation, the occurrence of fish, and the options available to the fish relative to conducting critical function of the relevant life-history stage. This conclusion suggests that straightforward or simplistic standards or guidance to protect fish from dredging induced turbidity would be difficult to derive.

Some specific studies have shown changes in behavior such as feeding success, foraging rates, reaction distances, schooling characteristics that can be linked to critical levels of turbidity. However, the link between these changes in behavior and potential adverse impacts to fish or their food web that should be of concern is unclear. With that caveat in mind, Table 2 summarizes finfish behavioral effects related to specific turbidity levels in studies detailed in Appendix A.

Table 2. Summary statistics for the cumulative distribution of turbidity levels (NTU) causing behavioral effects in finfish (n=27).

Summary Statistic	Value (NTU)
5th Percentile	7.1
10th Percentile	7.5
50th Percentile	40
Standard Deviation	62

The vast majority of the effects noted were for reduced feeding and reaction distance by fish in controlled laboratory experiments. In many cases, freshwater species that inhabit very clear waters (lakes and streams) were used in the experiments. Extrapolation of these values to marine and estuarine environments where dredging is likely to take place may be problematic, particularly if the dredge site is located in an estuary that frequently has high turbidity due to natural wind/wave conditions. In these instances, the organisms will have naturally adapted to thrive in that type of environment.

5.3.3 Relating Turbidity to Dredging Induced Suspended Sediment Concentrations

It would be useful to compare the effects levels for turbidity in Table 2 to the turbidity levels typically observed near dredging operations. Although direct measurements of turbidity are available for many sites, the vast majority of references reviewed in Section 3.1 report results in terms of suspended sediment concentrations. These studies were targeted because they provided the most recent data and have corresponding high quality (low detection limits) chemistry data to allow for additional data evaluations.

Thackston and Palermo (2000) state that turbidity can be correlated with suspended sediments on a site-specific basis and provide for specific sampling and analysis methods to obtain this correlation. They provide seven site-specific examples of the correlation between suspended sediment concentrations and NTU. In addition, several other researchers were reviewed who developed site-specific correlations between suspended sediment concentrations and NTU (MBC 2000, Hartman 1996, Malin et al. 1998, WDOE 1997, Christensen et al. 2000 and Herbich and Brahme 1991). These correlations were all developed to interpret readily collected field turbidity data in NTUs and convert the data to suspended sediment levels for that site.

The range of site-specific linear correlations reported by the researchers is summarized in Figure 6 below. The variability in the linear relationships derived for these sites emphasizes that it would be difficult or impossible to derive an overall correlation between turbidity and suspended sediment concentrations that would apply equally well to all Los Angeles regional sites. For this reason, Thackston and Palermo (2000) suggest specific procedures to develop a site-specific correlation where one is needed.

Despite this variability, the range of correlations in Figure 6 can be used to derive a range of potential turbidity estimates from the suspended sediment data summarized in Section 3.1. Figure 7 shows the range of estimates for mechanical dredging using correlations from Figure 6 that represent high, medium, and low range conversions from suspended sediment concentrations to NTU.

Figure 6. Linear regressions reported by various researchers between turbidity and total suspended sediments (TSS)

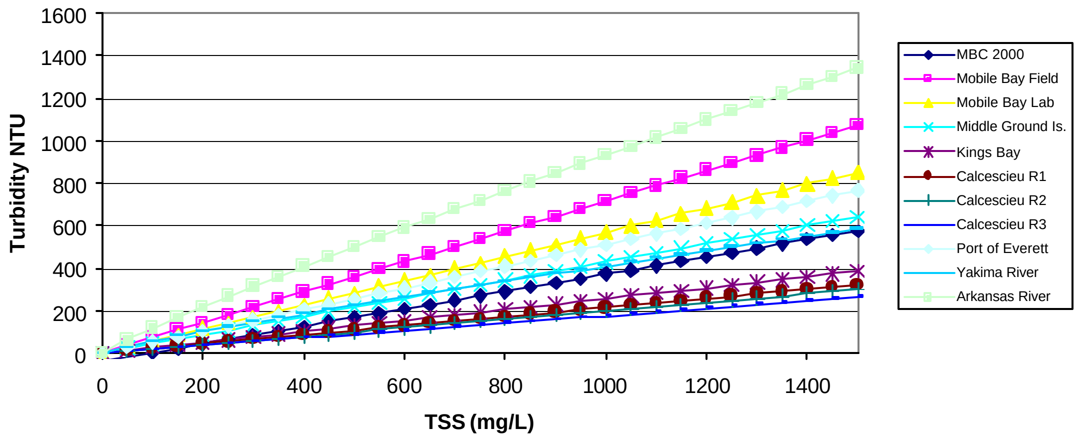
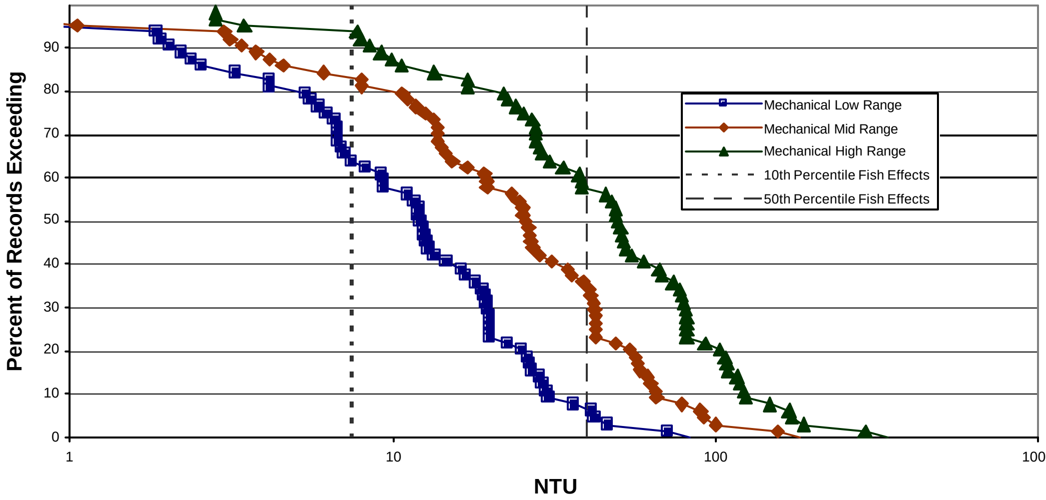


Figure 7 shows that the range of expected turbidities near dredging operations will have a considerable range, from close to 1 NTU to several hundred NTU, depending on the site-specific situation. Comparing this range of expected NTU values shows that between approximately 40 and 90% of the values are below the 50th percentile for sublethal finfish effects.

Figure 7. Predicted range of turbidities (NTU) using a range of correlation estimates from various sites and suspended sediment data from Section 3.1 for mechanical dredges



5.4 Discussion and Applicability to Los Angeles Region

Most of the data presented above comes from locations other than the Los Angeles region, which implies that it could be inapplicable to this region. The relative applicability of both the suspended sediment monitoring and effects data to the Los Angeles region are discussed below (Sections 5.4.1 and 5.4.2). In addition, the general issue of natural conditions and how this might apply to dredging water quality effects in the Los Angeles region is discussed in Section 5.4.3.

5.4.1 Applicability of Suspended Sediment and Turbidity Data From Dredges

As discussed in section 3.3, the suspended sediment data near dredging operations available from the Los Angeles region is comparable to those levels found internationally (at least for mechanical dredging). As would be expected, because the Los Angeles region data set contains a greater number of observations at a distance from the dredge, the average observed concentration in the Los Angeles region is slightly below the international average. This implies that neither the dredge operations nor the conditions of the waterways being dredged in the Los Angeles region are measurably different from elsewhere in terms of rates of resuspended sediment and dispersion of that sediment in the water column. There may indeed be particular situations within the Los Angeles region that are unique, but these situations were not observed in the data sets reviewed for this document.

The situation for turbidity is less clear. The vast majority of information from other regions is primarily in the form of suspended sediment concentrations and secondarily, turbidity (as NTU). Conversely, the most recently collected Los Angeles region information reviewed is primarily in the form of percent light transmission. These measures cannot be easily resolved into one comparable measurement. Consequently, it is unclear whether dredge induced turbidity conditions in the Los Angeles region differ from those observed elsewhere.

Thackston and Palermo (2000) suggest that the relationship between suspended sediment levels and turbidity is site-specific. That is, it varies not only by region but also by individual dredge sites. This is intuitively reasonable since it would not be expected that dredging of a sandy site and a muddy site would generate the same turbidity, regardless of their location relative to one another. Accordingly, correlations derived from various sites as shown in Figure 7, illustrate that the relationship between suspended sediment concentrations and turbidity can vary markedly from site to site.

It has been suggested that turbidity or light transmission could be used as a surrogate for TSS measurements (for dredge compliance purposes) in the Los Angeles region. The work by Thackston and Palermo (2000) and others cited above suggest that correlations can be developed, but only on a site-specific basis. This would mean that for turbidity to be used as a surrogate measure of the suspended sediment concentrations, a site specific correlation would have to be developed at the beginning of each dredge project. This could either be accomplished using the laboratory methods suggested by Thackston and Palermo (2000) or through a series of synoptic field measurements early in the dredging project. The site-specific correlation thus developed could then be used throughout the remainder of the project as a surrogate for suspended sediment concentrations. Depending on the size of the dredge project, there could be a measurable costs savings in monitoring using such an approach.

5.4.2 Applicability of Effects Data

Effects data were reviewed for both suspended sediment concentrations and turbidity. Each is discussed separately below.

Effects data for suspended sediments cover a wide range of species, primarily finfish, mollusks, and crustaceans. Many of these species are either found in Los Angeles region waters, have regional related species, or regional species filling similar niches. Almost 300 data points were compiled (Appendix A) and used in the effects summary discussed above. Consequently, this appears to be a reasonably good source of effects data for use in the Los Angeles region.

Newcombe and Jensen (1996) attempted to model impacts from dredging activities to marine organisms and they concluded that more information was needed on effects to various marine organisms due to the high variability associated with the data. Similarly, Nightingale and Simenstad (2001) and Wilber and Clarke (2001) also indicate that more research should be conducted on both lethal and sublethal effects. Thus, the effects database used in this paper could conceivably include a greater variety of species both within the represented taxonomic groups (i.e., finfish, mollusks, and crustaceans) as well as other taxonomic groups, such as echinoderms, polychaetes, plants, etc. Similarly, it could also include more species endemic to the Los Angeles region.

It is difficult to assess the relative importance of having more regional-specific data when compiling a particular effects database. At some point, data collection must stop and decisions must be made. However, it should be noted that many federally promulgated water quality standards are based on smaller and less regionally applicable data sets than those compiled for suspended sediments in this paper.

Effects data for turbidity cover a much smaller range of species than for suspended sediments (i.e. finfish). The majority of these species were either anadromous or freshwater species not endemic to the Los Angeles region (Appendix A). In many cases, these species typically inhabit relatively clear water environments such as northern lakes and streams. Only 34 effects data points were compiled.[4] Consequently, there must be much lower confidence in the applicability of these data to the Los Angeles region.

5.4.3 Ambient or Natural Conditions

As noted briefly above, marine, estuarine, and riverine environments contain some natural levels of suspended sediment and turbidity caused by phytoplankton, tidal flows, currents, storms, and runoff/ discharge from upland sites and rivers. These levels can vary considerably depending on the conditions at any one time (e.g., during storms or periods of high runoff). Thus, aquatic organisms are adapted to these suspended and sediment and turbidity levels as well as the variability in these levels caused by unusual events, such as storms (Nightingale and Simenstad 2001). Ambient background levels should be considered when any attempt is made to derive effects levels of these parameters that provide meaningful environmental protection. Since this document seeks to evaluate the effects of dredging on biological organisms as a single impact, the term ambient background is used to represent the conditions occurring in the absence of dredging. True background concentrations of suspended sediments cannot be determined for the Los Angeles/Long Beach Harbor because of the significant anthropogenic sources to the system.

Table 3 summarizes the ambient background suspended sediment data from Los Angeles regional monitoring efforts (Appendix A) and compares it to the effects database 10th percentile levels discussed in earlier sections. It is notable that the

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[4] Unlike the review of suspeneded sediment data, no comprehensive reviews of turbidity effects data were found. Consequently, it was more difficult to compile a large number of data points without a very time-consuming literature search.

average background suspended sediment concentration in the Los Angeles region is approximately equal to the 10th percentile chronic sublethal effects level.

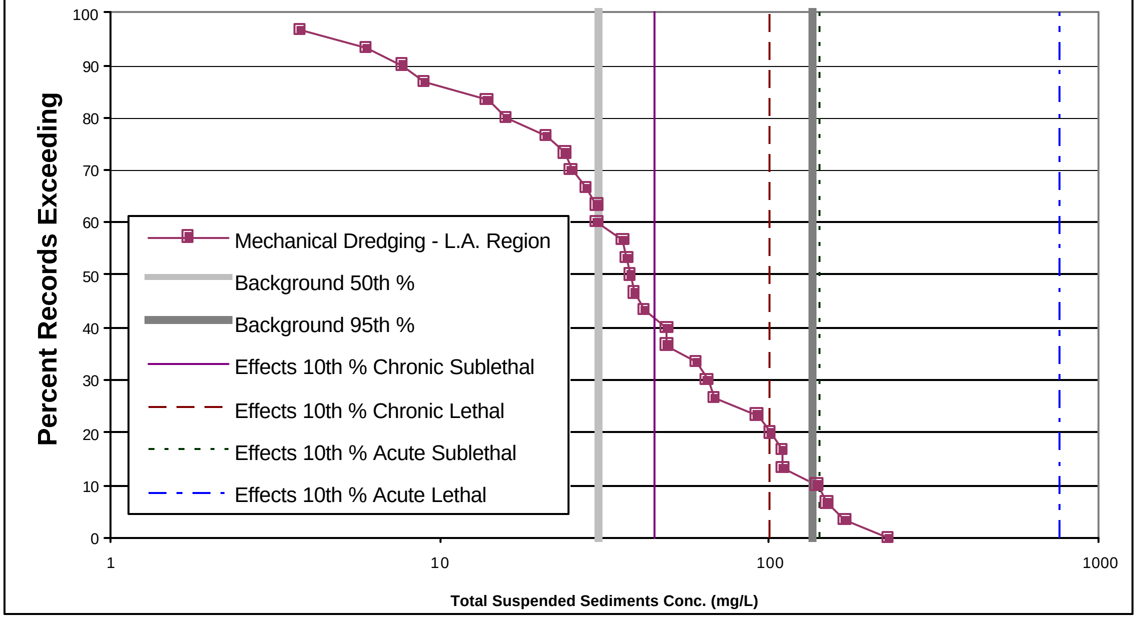
Table 3. Comparison of summary statistics for Los Angeles Regional suspended sediment background data to effects levels summary statistics (mg/L)

Cumulative distribution of background conc. (mg/L)		Cumulative distribution of effects database (10th percentile value by endpoint)	
5th Percentile	6	Chronic Sublethal	45
50th Percentile	31	Chronic Lethal	100
95th Percentile	135	Acute Sublethal	142
Std. Dev.	64	Acute Lethal	760

*Regional values from POLA, POLB, and LARE dredge monitoring events.

Closer examination of the background data set indicates that background concentrations exceeded the 10th percentile chronic sublethal level about 20% of the time and exceeded the 10th percentile chronic lethal level about 5% of the time. Figure 8 shows the significance of this information relative to the Los Angeles regional dredging induced TSS data. This figure supports the theory that re-suspended sediment concentrations resulting from dredging operations are generally well below significant effect thresholds.

Figure 8. Los Angeles Regional mechanical dredging total suspended sediment concentrations compared to background and effects levels



While many of the background suspended sediment concentrations presented in Table 3 are generally higher than the regional dredging induced concentrations, they do not appear to include extreme conditions that occasionally occur in any estuarine or marine environment. Although regional specific data for extreme weather conditions were not found for this review, Table 4 summarizes some naturally occurring suspended sediment values obtained for other sites in North America. It is likely that the Los Angeles region might occasionally be subject to suspended sediment concentrations in these ranges under extreme storm, runoff, current, or tidal conditions which adds an additional level of conservatism to this evaluation.

Table 4. Suspended sediment concentrations observed due to natural phenomena (mg/L).

Location	Max. Concentration
San Francisco Bay (tides) (Buchanan and Schoellhamer 1996; Schoellhamer 1996)	200
Indian River Bay, Delaware (Huntington and Miller 1998)	570
Chesapeake Bay (Brownlee et al 1988)	600
Bay of Fundy (Grant and Thorpe 1991)	3,000
Chesapeake Bay (hurricane) (Moore 1978)	10,000
False Bay, Washington (Miller and Sternberg 1988)	10,000

5.5 Key Studies and Reports

Several key studies and reports cited in this section that are considered useful to understanding the physical effects of resuspended sediments include:

- Newcombe, C. P. and J. O. T. Jensen, 1996. “Channel Suspended Sediment and Fisheries: a Synthesis for Quantitative Assessment of Risk and Impact”, North American Journal of Fisheries Management 16:693–727.
- Nightingale, B., Simenstad, C., July 2001. “Dredging Activities: Marine Issues”, White Paper, Washington Department of Fish and Wildlife, Washington Department of Ecology, Washington Department of Transportation.
- Lloyd, D.S., 1987. “Turbidity as a Water Quality Standard for Salmonid Habitats in Alaska. North Am. Journ. of Fish. Mang. 7:34-45.
- Wilber, D.H., Clark, D.G., 2001. “Biological Effects of Suspended Sediments: A Review of Suspended Sediment Impacts on Fish and Shellfish with

Relation to Dredging Activities in Estuaries", North American Journal of Fisheries Management 21:855–875.

5.6 Uncertainty and Data Needs

Throughout Section 5 it has been noted when data reviewed contain uncertainties. This section summarizes those uncertainties and the evaluations that could be conducted to reduce these uncertainties.

5.6.1 Regional Effects Data

As noted in the discussion of regional applicability, more data on local species effects to suspended sediments, and particularly turbidity, would increase the usefulness of the data sets compiled above by, hopefully, providing more data points and reducing the variability in the data. While not deemed a critical necessity, these data could be obtained through specific bioassays using local species of interest.

5.6.2 Background Levels

Some data were available from dredging projects on typical background levels of suspended sediments. However, these do not appear to encompass the total range of regional background conditions. Additional data collection (or literature reviews) on background suspended sediment and turbidity conditions would assist the realistic application of any effects data to dredging operations.

5.6.3 Use of Chronic and Sublethal Effects Levels

As noted above, many of the effects levels reviewed and compiled are for effects that are exhibited over longer terms (greater than 96 hours) and/or are based on sublethal endpoints. Some researchers have suggested that these effects are inappropriate for use in comparison to dredging induced suspended sediments (Wilber and Clarke 2000). That is, given changes in dredge location, current variations, the mobility of some organisms, etc. specific communities would not be expected to be exposed for durations greater than 96-hours. Further, many organisms may recover fully from sublethal effects of short durations with no apparent impact to overall survival, growth, or reproduction.

One potential way to better understand what effects levels and effects types are useful for dredging water quality evaluations would be to focus study on the durations of exceedances at any one location over time. This could include additional specific literature searches to determine if anyone has conducted this type of research and/or collection of point-specific (rather than relative to the dredge) data in the field at regional dredging projects.

In addition, the linkage between behavioral changes in fish caused by turbidity and adverse effects to those fish is unclear from the literature. We recommend caution when using sublethal behavioral effects in fish as a means to develop turbidity related guidelines. Identifying sublethal behavioral responses can be very subjective and allow for significant uncertainty in interpreting the results. Filling this data gap would require detailed fundamental research, which examines the link between these short-term behavioral changes and any long-term effects on survival, growth, and reproduction.

5.6.4 Monitoring Data Inconsistencies

Both local and international monitoring data has been collected at a variety of distances from the dredge. It is known that suspended sediment levels decrease rapidly with distance from a dredge (Hayes 1986, Collins 1995, Herbich and Brahme 1991). This introduces an increased uncertainty in any comparison between data sets. There are also other factors creating uncertainty such as methodology of background collection, depth of sample collection, etc.

Because it appears possible to model the decrease in suspended sediment concentrations with distance from the dredge with some accuracy (Hayes and Wu 2001), collection of more regional-specific data very close to the point of dredging (similar to efforts Hayes and Wu 2001, Pennekamp et al. 1996, and Nakai 1978) would help better determine whether Los Angeles regional dredge projects are unique in some aspects of sediment resuspension. Such data could also be used to determine regional-specific resuspension and settling rates (i.e., relative mass suspended per unit dredged).

In addition, no regional suspended sediment data for hydraulic dredges were evaluated for this review. Additional searches of literature and regulatory databases would be a reasonable first step in determining whether any useful hydraulic dredging monitoring data are available.

5.6.5 Other Effects

Very little information was found regarding the effects of dredging induced suspended sediments and turbidity to primary production rates, plants in general, and terrestrial animals that forage in water (e.g., birds). As noted above, considerable literature on the general effects of natural suspended sediment levels and turbidity on primary production, and possibly the foraging of various bird species, may exist. Resources could be collected through additional literature searches targeting this particular issue.

Lastly, the effects of changes to ambient pH and dissolved oxygen from dredging have not been addressed by this review. It appears that some information specifically related to dredging induced effects of this type does exist in the literature (e.g., Lunz 1987, Nightingale and Simenstad 2001) and could be collected.

6 CHEMICAL EFFECTS OF RESUSPENDED SEDIMENTS

Contaminated resuspended sediments have the potential to affect marine organisms through two processes: the physical impacts from the material itself and through toxic effects of the contaminants bound to the sediment. Physical impacts to aquatic organisms as a result of dredging have been discussed in the previous section; this section addresses the issue of chemical effects resulting from dredging operations. For the purpose of this discussion, chemical effects are defined as those occurring either in the form of direct toxicity to the organisms or bioaccumulation of chemicals in the organism's tissues, organs, etc.

The remainder of this section provides a description of the mechanisms for release of contaminants into the water column, followed by a discussion of the documented effects chemicals have on aquatic organisms under dredging scenarios.

6.1 Physiological Mechanisms for Chemical Effects

Potential chemical effects to aquatic organisms as a result of dredging are a function of the type of contaminant; it's concentration within the sediment, the environmental conditions at the time of dredging (e.g., low oxygen or reducing environments) and the duration of the exposure. As mentioned previously, the focus of Section 6 is to discuss the issue of direct toxicity (either acute or chronic) and bioaccumulation[5] resulting from resuspended contaminated sediments.

Contaminants of concern (COC) at impacted dredging sites can be numerous and usually depend on the site location and history of the site. The most common COCs include heavy metals such as lead, mercury or zinc and organic compounds such as pesticides, PCB's, PAH's.

It is generally assumed that metals associated with resuspended sediments become bioavailable to organisms when they are released in the dissolved state to the water

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[5] Bioaccumulation is a phenomenon by which chemicals are taken up by marine organisms from water directly or through consumption of food containing the chemicals (Rand and Petrocelli, 1985). For this paper, the term bioaccumulation will be used as a general descriptor to include bioaccumulation, bioconcentration and biomagnification. Bioaccumulation of chemicals by marine organisms can occur via both the dissolved phase and the particulate bound phase of the chemicals of concern.

column. As such, EPA's Office of Water has recommended that assessments of effects of aqueous metals on aquatic organisms be based on dissolved metal concentrations as determined by analysis of 0.45-µm-filtered water (Prothro, 1993). Total concentrations of metals are useful for screening assessments, but the dissolved form is appropriate for definitive risk assessments on aquatic organisms (Suter et al., 2000).

Organic compounds are generally less soluble. Consequently, direct toxicity via organic compounds dissolved in the water column is often less likely. However, organic compounds tend to bioaccumulate in organisms. This can occur both through dissolved phase exposure through the water column and from organic compounds adsorbed to particulate matter. Bioaccumulation of most organic compounds occurs as a result of uptake by a receptor, followed by partitioning of the compounds into the receptor's organic carbon compartment—the lipids. Therefore, bioaccumulation is highly dependent upon an organism's lipid content and on the affinity of the compound to partition into the organic phase (ThermoRetec, 2001). Bioaccumulation most often occurs through sediment ingestion (e.g., filter feeders like mollusks). For example, Guerrero et al. (2001) found that the uptake of pentachlorophenol by benthic bivalves may occur through the water phase and also by the ingestion of particles. Particulate bound contaminants can also be a problem when dealing with chemicals like mercury since they can be stripped from the particle in the organisms' gut and accumulate in tissues.

Contaminants become mobilized during dredging through the release of pore water containing dissolved chemicals, by desorption from sediment particles through a process known as equilibrium partitioning, and through loss of particulate bound contaminants (Averett et al., 1999). Once mobile, contaminants may become bioavailable through various mechanisms. As mentioned previously, metal contaminants are mostly bioavailable when in a dissolved phase; organics can be bioavailable in both dissolved and particulate bound phases. The dissolved form of chemicals can be toxic or can contribute to the bioaccumulation of chemicals in an organism's tissue. The concentration of dissolved contaminants released in the water is dependent on the chemical form and concentration and physical characteristics and volume of contaminated sediments resuspended, and also on the depth of water that the sediments are in and the duration of dredging operations (van Oostrum and Vroege, 1994).

Because chemical desorption from particulates to the dissolved phase can vary depending on many site factors and can range over periods from a few hours to 180 days, the length of time sediments are resuspended plays a key role in determining chemical impacts to the water column (Tomson et al. 2003). Some of the factors affecting chemical partitioning include particle geometry, chemical of concern and concentration, site water chemical concentrations, pH, salinity and fraction organic carbon of the sediment.

As noted in Section 3, the vast majority of resuspended sediment settles close to the dredge within one hour, and only a small fraction takes longer to resettle (Wright, 1978; Van Oostrum and Vroege, 1994; Grimwood, 1983). Consequently, the majority of contaminants in the particulate fraction resuspended by dredging may not have time to desorb before they resettle to the sediment bed.

The particulate bound portion of chemicals can also be toxic or contribute to the bioaccumulation of chemicals in an organism's tissue. The degree of dissociation of organic chemicals bound to sediments is correlated with the octanol-water coefficient of the chemical and the organic carbon content of the sediment. The dissociation of particulate bound contaminants can be modeled based on the equilibrium partitioning theory that is discussed below.

6.1.1 Metals

Desorption of metals from suspended sediments are a potential concern with dredging. Different studies have shown that while dry weight metal concentrations in sediments are not predictive of bioavailability, metal concentrations in interstitial (pore) water are correlated with observed biological effects (Ankley et al., 1996). Under natural conditions, most metals are bound to the sediment because they are associated with particulate matter which has co-precipitated or been scavenged by the iron/manganese oxyhydroxides and carbonates, associated with solid-phase natural organic matter, or are bound in the particles of the base mineral matrix. Only a small fraction of metals concentrations are dissolved and available under normal conditions. This description applies to surface sediments in contact with the overlying water and to the depth to which they are oxidized by diffusion or bioturbation (EVS, 1997; Hirst and Aston, 1983; Slotten and Reuter, 1995). On the other hand, deeper sediments are anoxic as a result of microbial action on natural organic matter and other oxidation reactions. Under anoxic conditions, the oxyhydroxides dissolve, releasing the metals, but these in turn are largely captured by sulfides formed by the reduction of sulfate. In most of these cases, the metals are also largely undissolved and unavailable (EVS, 1997). At the transition zone between anoxic and aerobic environments in the sediment, conditions may allow the formation and maintenance of sulfide phases. In this thin transition zone, neither the oxyhydroxides nor the sulfide phases exist and many metals are solubilized. During dredging operations, resuspension of sediments that are present in this transition zone may present potential risks from chemical release.

Based on laboratory results and field observations (Brannon et al., 1976; Lee et al., 1975; Wright, 1978; Hirst and Aston, 1983), EVS (1997) concluded that during dredging, releases of dissolved metals from the sediments, even in highly contaminated areas, were minimal. Even though release of total metals can be large, concentrations of dissolved metals are in general low and of short duration (CEM, 1983). Those results seem to indicate that resuspension of metal-contaminated sediments might only create a minimal potential for direct toxicity or bioaccumulation. Similar results are presented in Table 5 from a shipyard remediation site located in Southern California. Sediment elutriate tests using the Corps of Engineers' DRET test protocol where conducted to predict chemical partitioning as a result of dredging. Results showed very little metal partitioning despite sediment metal concentrations that exceeded probable effect screening criteria.

Table 5. Example Southern California shipyard bulk sediment/site water/elutriate sampling results

Analyte	Bulk Sediment (dry weight)	Site Water - Filtered	Site Water - Unfiltered	Elutriate - Filtered	Elutriate – Unfiltered	CTR Criteria[1]
TOC, mg/L	--	--	<5	--	<5	--
TSS, mg/L	--	--	1.2	--	160	--
Metals, ppm						
Copper	187	0.00909	0.0117	0.00475	0.068	0.0048
Lead	115	<.008	<.01	<.008	0.022	0.210
Zinc	288	0.0511	0.078	0.0246	0.665	0.090
PCBs, ppb						
Aroclor 1016	ND	<1	<1	<1	<1	--
Aroclor 1221	ND	<1	<1	<1	<1	--
Aroclor 1232	ND	<1	<1	<1	<1	--
Aroclor 1242	ND	<1	<1	<1	<1	--
Aroclor 1248	ND	<1	<1	<1	<1	--
Aroclor 1254	ND	<1	<1	<1	<1	--
Aroclor 1260	ND	<1	<1	<1	<1	--
Aroclor 1262	ND	<1	<1	<1	<1	--
Polynuclear Aromatic Hydrocarbons (PNAs), ppb						
Napththalene	ND	<10	<10	<10	<10	--
Acenaphthylene	ND	<10	<10	<10	<10	--
Acenaphthene	ND	<10	<10	<10	<10	--
Fluorene	ND	<10	<10	<10	<10	--
Phenanthrene	ND	<10	<10	<10	<10	--
Anthracene	ND	<10	<10	<10	<10	--
Fluoranthene	ND	<10	<10	<10	<10	--
Pyrene	ND	<10	<10	<10	<10	--
Benzo(a)anthracene	ND	<10	<10	<10	<10	--
Chrysene	ND	<10	<10	<10	<10	--
Benzo(k)fluoranthene	ND	<10	<10	<10	<10	--
Benzo(b)fluoranthene	ND	<10	<10	<10	<10	--
Benzo(a)pyrene	ND	<10	<10	<10	<10	--
Benzo(g,h,i) perylene	ND	<10	<10	<10	<10	--
Indeno(1,2,3-cd)pyrene	ND	<10	<10	<10	<10	--
Dibenzo(a,h)anthracene	ND	<10	<10	<10	<10	--
TPH (as diesel), ppm						
Total C7-C44	340	<0.001	**--**	**<0.001**	**<0.001**	**--**

1 California Toxics Rule Maximum Concentration (“---“ = no criteria)

6.1.2 Organics

Most organic compounds are hydrophobic, thus only slightly soluble in water. When organic-contaminated sediments are resuspended some of the organic compounds are desorbed and diffused into the water column. This process can be modeled using an equilibrium partitioning approach. Equilibrium partitioning theory assumes that a compound-specific process occurs that depends on the particular characteristics of the interaction of molecules of the compound with water molecules and with the surfaces of the particles, and also on the size of the molecules of the compounds (EVS, 1997).

Studies of organic contaminant releases to the water column during dredging have been conducted in the past (Ludwig and Sherrard, 1988; Brannon, 1978; Thomann and Connolly, 1984; Thomann, 1989; Hydroqual, 1994). Theoretically, the equilibrium exchange can allow for release during the dredging of contaminated sediments, and the concentrations of soluble, available organic compounds in water could therefore increase above ambient levels. However, observations made during field studies, indicated that the releases were small in comparison to the effective dilution of the receiving system, and any changes in the water quality were transient, even when grossly contaminated sediments were dredged (Ludwing and Sherrard, 1988; Brannon, 1978). Table 6 presents representative results of PCB concentrations gathered during water monitoring studies conducted during dredging projects. Based on a review of existing literature, the concentration of organics in the water column tends to be minimal and is often below detection limits.

Table 6. Example PCB concentrations observed in the water column during dredging

Site	Chemical	Method	Concentration in the water column (μg/L)
Black Rock Harbor (Ludwig and Sherrard, 1988)	PCB	On site	5.3
Black Rock Harbor (Ludwig and Sherrard, 1988)	PCB	Elutriate Test	2.0
Calumet River (Ludwig and Sherrard, 1988)	PCB	On site	Below detection limit
Calumet River (Ludwig and Sherrard, 1988)	PCB	Elutriate Test	Below detection limit
Duwamish River, WA (Hafferty et al., 1977)	PCB	On site	0.013 to 0.024
Grasse River, NY (Briot et al., 1999)	PCB	On site	13.3
Ruck Pond, WI (Briot et al., 1999)	PCB	On site	Below detection limit

Similar results have been observed for PAHs measured during dredging projects. Recent monitoring conducted at the ports of Los Angeles (Berths 167-169, 148-151, 261-265, and 212-215) and Long Beach (Pier T) show PAH concentrations in the water column that are a fraction of that observed in the sediments (MBC 2001a, 2001b, 2001c, 2001d, 2001e, and 2001f). For example, dredge monitoring at POLA Berths 261-265 showed PAH concentrations that were 4 to 6 orders of magnitude lower than the concentrations measured in the sediments. In sediment core samples, total PAH concentrations ranged from 9 to 52 ppm, while water column concentrations ranged from 0.098 to 1.5 ppb (MBC 2001e). To put these concentrations into perspective, the NOAA Effects Range Low (ERL) for PAHs is 4 ppm and the Effects Range Medium (ERM) is 35, suggesting that these sediment PAH concentrations exceed biological threshold levels for toxicity, While insufficient data exists to develop a water quality criterion for PAHs, EPA's Office of Water reports a suggested guideline value of 300 ppb based on the Lowest Observed Effect Level. This is an example where sediment concentrations exceed a biological threshold value, yet partitioning to water column is insignificant. Water column monitoring at other facilities within the POLA and POLB all show similar results, confirming the low probability for PAH releases during dredging.

In general, soluble phase releases of heavy metals and the majority of petroleum and chlorinated hydrocarbons associated with dredging activities are minimal (Herbich, 2000; EVS, 1997; Brannon et al., 1976, Engler, 1978). Adverse concentrations of heavy metals may be released from sediments when certain combinations of pH and oxidation-reduction potential are met (Burks and Engler, 1978), but those are rarely attained during typical dredging operations.

6.2 Literature Review

The direct effects of contaminated sediments on aquatic organisms under "in-situ" conditions have been recognized and evaluated in numerous biological and toxicological studies and observations. However, the acute and/or chronic toxicity and bioaccumulation effects of resuspended contaminated sediments due to dredging have not been evaluated thoroughly. This section discusses representative acute and chronic response to metals and organics, and summarizes laboratory and field study results. For the purpose of this discussion, the definitions of acute and chronic most closely follow U.S. EPA (1985) guidance for developing and applying water quality criteria. Whether an exposure is acute or chronic depends on both the duration of the exposure and the life stage and life span of the organism being exposed. For example, a 96-hour duration of exposure may be acute to an adult fish but chronic to a bivalve larvae or copepod. However, 96-hours is common benchmark between acute and chronic effects used for aquatic organisms.

6.2.1 Direct Chemical Effects

This section discusses the direct chemical effects (acute and chronic toxicity and bioaccumulation) of resuspended contaminated sediments to aquatic organisms.

6.2.1.1 Acute and Chronic Response to Metals

Acute exposure to metals is manifested in a wide range of effects, from slight reduction in growth rate to mortality. Comparison of concentration ranges of trace metals in surface waters with acute toxicity data for these metals shows that the concentration determined to be lethal in laboratory tests occur commonly in nature. The difficulty in assessing the toxicity of metals is due to differences in bioavailability. For example, metals may be complexed or uncomplexed, and aquatic organisms seem to be more sensitive to the latter form. Thus, laboratory predictions of field conditions are often uncertain. However, single-chemical acute toxicity test data are important since the U.S. Environmental Protection Agency (U.S. EPA) computes water quality criteria based on available acute toxicity data and laboratory exposures provide a controlled estimate of effects (U.S. EPA, 1985; Rand and Petrocelli, 1985). U.S. EPA’s ECOTOX database provides acute toxicity test data for different organisms and chemicals used by EPA for calculating water quality criteria.

Chronic responses by aquatic organisms to metals differ from species to species, from the exposure of one metal to another and from one life stage of biological development to another. Effects range from mortality to reduced growth rate to reproductive impacts. Chronic exposure can result in an organism developing physiological disturbances to vital organs and organ functions such as liver, kidney, blood composition, enzymes actions, etc. Any of these effects can sometimes lead to mortality, decrease growth or decreased reproduction (Rand and Petrocelli, 1985).

6.2.1.2 Acute and Chronic Response to Organics

Organic chemicals found in dredged sediment include pesticides, polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), phthalates, phenols, and chlorinated benzenes.

Pesticides may have a specific mode of action, such as acetylcholinesterase inhibition or act through a non-specific mechanism. Effects from pesticides included reduced rates of photosynthesis, inhibited oxygen evolution, reduced growth, paralysis, extension of the larval period, avoidance, and other effects. Chronic effects of pesticides are as varied as reduced growth rate, reduction in brain acetyl cholinesterase activity, mortality, etc. Scientists also found that some species developed resistance to pesticides while others developed unexpected reactions due to the combination of pesticides. However, Rand and Petrocelli (1985) noted that the effects described earlier and found in laboratories did not have as marked an impact on populations or communities of marine organisms in nature.

PCBs are highly lipophilic and, therefore, more readily bind to sediments or accumulate in tissues rather than remain in the water column (Eisler and Belisle, 1996). PCBs influence patterns of survival, reproduction, growth, enzyme activities, and accumulation in representative aquatic organisms. Chronic effects of PCB can be detected at total concentrations of 0.014 µg/L (US EPA, 1999). Although high PCB residue levels have been detected in fish, mammals, and birds worldwide (Eisler and Belisle, 1996), high concentrations alone may not be predictive of adverse effects. Some organisms are capable of storing extremely high concentrations of PCBs in their fat without any apparent detrimental effect (Olafsson et al., 1983), yet when fat stores are used for energy, mobilized PCBs may cause adverse effects (Landis and Yu, 1995).

Many organic compounds have non-specific modes of action. For example, PAHs have a narcotic mode of action involving interference with key membrane-mediated physiological and biochemical process. PAHs can be acutely toxic at concentrations of about 0.2-10 parts per million (ppm). Deleterious sublethal responses occur at concentrations of 5-100 parts per billion (ppb). They can cause growth or development anomalies or cancer (Rand and Petrocelli, 1985).

6.2.1.3 Laboratory Study Results

Different studies have been conducted to evaluate the effects of resuspended contaminated sediments on marine organisms, including bioaccumulation of the contaminants. Peddicord and McFarland (1978) found that most marine organisms presented a high tolerance to resuspended contaminated sediments. It appeared that, in general, the biological uptake of chemicals was low and short term, and most of the species tested were not very sensitive to metals, PCBs, pesticides or other contaminants. Peddicord and McFarland (1978) concluded that accumulation of contaminants in tissues, even from contaminated sediments, was the exception rather than the rule in their study. LaSalle and Clarke (1991) drew the same conclusions.

Wright (1978) did not observe any apparent trends in mean total PCB and lipid-normalized PCB concentrations in caged and resident fish with the exception of an apparent decreasing trend in total PCB concentrations in the some resident fish. Svavarsson et al. (2001) exposed common whelks to a simulation of harbor dredging, using suspended sediment containing levels of TBT and TPT. The study resulted in a low concentration of TPT and TBT in the tissues of these organisms, but did not seem to affect their reproduction capabilities. Common whelks seemed to receive the main part of TBT from the water column and the limited bioaccumulation in the experiment indicates that desorption of TBT from the sediment was slow.

In a biological evaluation of a dredging project for the Port of Oakland, EVS (1997) estimated that resuspension of contaminants could create the potential for biological uptake. However, this potential is expected to be low since the resuspension of contaminants would be localized and of sufficiently low concentration that acute and chronic effects would not be expected (EVS, 1997. Little information could be found concerning the effects on plants. However, Dee Davison Associates (1998) estimated that concentrations of heavy metals in most estuaries are too low to cause adverse effects on eelgrass Zostera.

While certain studies conclude that resuspended contaminated sediments have a relatively benign effect on marine organisms, other studies suggest more adverse effects. Pruell et al. (1986) exposed blue mussels to contaminated sediments containing PAHs and PCBs. They established that both organics were rapidly accumulated by the mussels and remained in the organisms for a long time. This study also suggested that organic contaminants in the dissolved phase might be the source of the compounds accumulated by the bivalves. Similar studies have been performed that support this theory (Roesijadi et al., 1978; Geyer et al., 1982).

6.2.1.4 Field Observations and Results

In addition to laboratory studies, scientists have conducted monitoring of marine organisms during several dredging projects. In Terry Creek, Georgia, Durant and Reimold (1972) noted that the dredging of sediments containing high levels of toxaphene did not lead to a significant increase in the tissues of oysters living near the site. In Savannah Harbor, Sturber and Day (1994) concluded that dredging of contaminated sediments did not cause adverse impacts to the marine species. In New Bedford, Massachusetts, Otis (1994) estimated that dredging of PCB contaminated sediments did not create significant sediment resuspension or water quality problems, thus minimizing potential harm to the environment. At a disposal site in Liverpool Bay, which receives substantial quantities of moderately contaminated silts, monitoring has revealed no evidence of any toxic effects on nearby benthic communities (Murray, 1994).

On the other hand, ThermoRetec (2001) reported an increase in liver tumors in brown bullhead during dredging of PAH contaminated sediments in Black

River, Ohio, in 1992. The incidence of tumors rose from values between 21 to 32% to values between 56 and 58%. Also during the dredging of the Sheboygan River and Harbor, in Wisconsin, monitoring reported that fish caged downstream exhibited higher PCB values than fish caged upstream. Alcoa (2000) also reported an increase in mercury tissue concentrations in caged oysters placed downstream during dredging operations of hot spots at a CERCLA site in Lavaca Bay, Texas. This study also monitored indices of organism health and did not show adverse impacts to the oysters other than increased tissue concentrations. At the conclusion of dredging, tissue mercury concentrations returned to near pre-dredge levels.

Few other significant results have been found concerning effects of resuspended contaminated sediments on marine organisms and the aquatic environment in general. Because of the ability of fishes to avoid dredge areas, data are lacking concerning the short and long-term effects of resuspended contaminated sediments (Nightingale and Simenstad, 2001).

6.3 Discussion and Applicability to Los Angeles Region

Previous investigations suggest there would not be a significant direct chemical effect (toxicity and/or bioaccumulation) to aquatic organisms resulting from resuspended contaminated sediments as a result of dredging. There are, however, very few studies that have been able to directly test this conclusion. The main difficulty in assessing the effects of resuspended contaminated sediments is the lack of information and research related to “real world” situations. Many studies addressed the issue of the exposure of marine organisms to contaminated sediments (mostly in undisturbed state), but few studies have addressed the issue of the exposure of marine organisms to resuspended contaminated sediments due to dredging. In other words, there are few studies that evaluated impacts from resuspended sediments at concentrations and durations typical of dredging projects. Conducting such a study in the field is very difficult because of the need to control variables such as concentration (exposure) and duration.

Laboratory studies could be developed using local test species and sediments to simulate actual field conditions. While there would be uncertainties in extrapolating these results to actual field conditions, this would provide an alternative for estimating potential impacts. What can be conducted with the local monitoring data is to evaluate the magnitude of chemical partitioning from resuspended sediment particles during dredging compared to regional water quality standards.

Results of water quality samples collected during the 1999/2000 Marina del Rey dredging event showed that resuspension of sediments during dredging did not result in significant releases of metals into the water column (Chambers Group 2001). In this case, samples were collected from the dredge-induced sediment plume down-current when turbidity concentrations exceeded 20% of the ambient concentration. Samples were collected from within and outside of the plume and compared to California Ocean Plan daily maximum limits. While there were occasional instances where the recorded concentrations exceeded the Ocean Plan limits, there was essentially no difference between the concentrations for the samples taken within and outside the plume.

Similar results were observed with water quality samples collected by the Port of Los Angeles during several water quality monitoring events associated with maintenance dredging along their berthing docks (MBC 2001b,c,d,e,f). As with the example from Marina del Rey, water samples were collected for chemical analysis when turbidity increased past a threshold compared to background (in this case, light transmittance). The results showed that most chemicals were not detected above the detection limit for most organics and metals. Organic chemicals that were detected were many magnitudes below associated sediment concentrations and available ecological screening values (MBC 2001b,c,d,e,f). Some metals were detected, but these were also mostly below screening values (e.g., California Ocean Plan). One exception was copper during some of the monitoring events.

Monitoring conducted by the Port of Long Beach for the Pier T Wharf Extension project (MBC 2001a) and by the U.S. Army Corps of Engineers for the Los Angeles River Estuary (MEC 2002) also showed similar results where very little chemical partitioning was observed. Organic chemicals were rarely detected in the water samples and metals concentrations were generally below Ocean Plan standards. These results all suggest that given the binding affinities of most organic chemicals and short suspension times for the sediment particulates associated with dredging, chemical partitioning from dredging projects in the Los Angeles region is generally not significant. When it does occur (most frequently with metals), the rates of partitioning are low and dissolved water column concentrations rarely exceed conservative ecological screening values.

6.4 Key Studies and Reports

Several studies and reports considered useful in understanding resuspended contaminated sediment effects are called out in this section.

- ABP Research, 1997. "Environmental Assessment of the deepening of Swansea Channel", ABP Research Report No. R701.
- Averett, D.E., Hayes, D.F., Schroeder, P.R., 1999. "Estimating Contaminant Losses during Dredging", World dredging Association, 19th Technical Conference.
- EVS, 1997. "Release of Contaminants from Resuspended Particulate Matter", White Paper.
- Nightingale, B., Simenstad, C., July 2001. "Dredging Activities: Marine Issues", White Paper, Washington Department of Fish and Wildlife, Washington Department of Ecology, Washington Department of Transportation.
- Port of Oakland EIS, U.S. Army Corps of Engineers, San Francisco District, January 2000. "Final Environmental Impact Statement, Oakland Harbor Navigation Improvement (-50 Foot) Project",
- U.S. EPA ECOTOX database: http://www.epa.gov/ecotox.
- Van Oostrum, R.W., Vroege, P., 1994. "Turbidity and Contaminant Release during Dredging of Contaminated Sediments", Proceedings of the Second International Conference on Dredging and Dredge Material Placement, Dredging '94.

6.5 Uncertainty and Data Needs

As mentioned above, there are very few studies that have been conducted specifically to monitor impacts to aquatic organisms during dredging. Field monitoring studies have been conducted to measure suspended sediment concentrations during dredge events as well as the resulting chemical partitioning associated with the resuspended sediments. Conversely, laboratory studies have been conducted to test potential effects from suspended sediments and from dissolved chemicals. To date, the best estimate for organism impacts resulting from dredging comes from estimating resuspension rates, durations, etc and chemical partitioning concentrations and comparing this to the literature of available toxicity tests to try and predict the potential for adverse impact. This approach, however, is very conservative because it assumes exposure durations that are typically not representative of field conditions and it does not take into account the presence of other water quality parameters than can influence chemical bioavailability. Additionally, data usually does not exist for many of the species that would potentially be affected during the dredge operation or at the suspended sediment levels that are routinely observed.

7 BEST MANAGEMENT PRACTICES FOR REDUCING SEDIMENT RESUSPENSION

Best Management Practices (BMP) are the actual practices, including the forms, procedures, charts, software references, etc, used by dredgers to minimize the consequences of dredging and disposal on water quality. The primary purpose for preparing this document is to assist the CSTF members in deciding the need for including BMPs as a part of Los Angeles regional dredge projects. This section provides an overview of the available dredging BMP technologies, a review of previous investigations regarding their effectiveness, and a brief discussion on the applicability of these options for Los Angeles regional projects.

7.1 Review of Available Technologies

Dredging BMPs can be separated into three main categories: silt curtains & gunderbooms, operation controls, and specialty dredging equipment (e.g., environmental buckets). The remainder of this section discusses each of these, along with the advantages and disadvantages for their use.

Silt Curtains and Gunderbooms: The objective when using silt curtains is to create a physical barrier around the dredge equipment to allow the suspended sediments to settle out of the water column in a controlled area. Silt curtains are typically constructed of flexible, reinforced, thermoplastic material with flotation material in the upper hem and ballast material in the lower hem. The curtain is placed in the water surrounding the dredge or disposal area, allowed to unfurl, and then anchored in place using anchor buoys. Silt curtains are most effective on projects where they are not opened and closed to allow equipment access to the dredging or disposal area. Because they are impermeable, silt curtains are easily affected by tides and currents and should not be used in areas with greater than 1-2 knot currents (Hartman Consulting Group 2001). Silt curtains can be deployed so that they extend to within 2 feet of the bottom, but this is seldom practical due to water currents. As such, most projects only use curtains that extend a maximum of 10-12 feet below the surface. Some of the key advantages of silt curtains are that, if they are deployed correctly, they can protect the adjacent resources and control surface turbidity. The main disadvantages for silt curtains are that they are not effective in high energy environments and they have no effect on bottom turbidity (where turbidity levels are highest as discussed in Section 3).

A gunderboom works in a similar way, except that the curtain is made of a permeable geotextile fabric which allows the water to pass through, but filters out the particulates. While silt curtains are typically deployed so that they extend downward through part of the water column, gunderbooms are designed to be installed from the water surface to the project bottom. The advantages with gunderbooms are that they allow unlimited curtain depth and permit unrestricted water flow while the disadvantages are that they are more expensive than silt curtains and can become clogged with silt.

Operational Controls: For dredging projects, operational controls are defined as modifications in the operation of the dredging equipment to minimize resuspension of materials. Operational controls can be employed with mechanical dredges, hydraulic dredges, hopper dredges or barges. Example operational control methods for mechanical dredges include:

- **Increasing cycle time** – Longer cycle time reduces the velocity of the ascending loaded bucket through the water column, which reduces potential to wash sediment from the bucket. However, limiting the velocity of the descending bucket reduces the volume of sediment that is picked up and requires more total bites to remove the project material. The majority of the sediment resuspension, for a clamshell dredge, occurs when the bucket hits the bottom.
- **Eliminating multiple bites** – When the clamshell bucket hits the bottom, an impact wave of suspended sediment travels along the bottom away from the dredge bucket. When the clamshell bucket takes multiple bites, the bucket loses sediment as it is reopened for subsequent bites. Sediment is also released higher in the water column, as the bucket is raised, opened, and lowered.
- **Eliminating bottom stockpiling**– Bottom stockpiling of the dredged sediment in silty sediment has a similar effect as multiple bite dredging; an increased volume of sediment is released into the water column from the operation.

Example operational controls for hydraulic dredges include:

- **Reducing cutterhead rotation speed** – Reducing cutterhead rotation speed reduces the potential for side casting the excavated sediment away from the suction entrance and resuspending sediment. This measure is typically effective only on maintenance or relatively loose, fine grain sediment.
- **Reducing swing speed** – Reducing the swing speed ensures that the dredge head does not move through the cut faster than it can hydraulically pump the sediment. Reducing swing speed reduces the volume of resuspended sediment. The goal is to swing the dredge head at a speed that allows as much of the disturbed sediment as possible to be removed with the hydraulic flow. Typical swing speeds are 5-30 feet/minute.
- **Eliminating the process of bank undercutting** – Dredgers should remove the sediment in maximum lifts equal to 80% or less of the cutterhead diameter.

Example operation controls for hopper dredges and barges include:

- **Eliminating or reducing hopper overflow** – Eliminating or reducing hopper overflow reduces the volume of fine material which flows from the hopper in the overflow. One caution is that this control may significantly reduce project production for hopper dredges or when hydraulic dredging into a barge.
- **Lowering the hopper fill level** – Lowering the hopper fill level in rough sea conditions can prevent material loss during transport.
- **Using a recirculation system** – Water from the hopper overflow can be recirculated to the draghead and used to transport more material into the hopper.

An operation control that can be effective with any type of dredge is to halt dredging during periods of extreme tidal fluctuation when currents are at their strongest point. Another, more generic, operational control is to only work with environmental work windows. Work windows are periods of time when listed species do not necessarily restrict dredging and disposal activities. Work proposed for times outside these windows requires consultation with the appropriate resource agencies. While this practice in itself will not reduce resuspension, it will reduce the potential for an environmental impact by eliminating the pathway for exposure with a sensitive species.

The main advantages with instituting operational controls are that they do not require installing additional equipment and they can be less costly than installing barriers. The major disadvantages are that they provide a lower regulatory comfort level because the control measure is not usually visual as with a physical barrier like a silt curtain, and that they typically slow the project down and increase costs.

Specialty Dredging Equipment:

The last category of dredging BMPs includes specialty dredging equipment and techniques designed to further reduce impacts from resuspended sediments. Examples include:

- **Pneuma Pump** - The Pneuma pump is used primarily for removal of fine-grained sediment. The Pneuma pump offers high solids concentration (up to 90%) in the dredge slurry, with minimal turbidity.
- **Closed or Environmental Bucket** - Specially constructed dredging buckets designed to reduce or eliminate increased turbidity of suspended solids from entering a waterway.
- **Large Capacity Dredges** - . Larger than normal dredges designed to carry larger loads. This allows less traffic and fewer dumps, thereby providing fewer disturbances at a disposal site.
- **Precision Dredging** - Dredging utilizing special tools and techniques to restrict the material dredged to that specifically identified. This may mean thin layers, either surficial or imbedded, or specific boundaries.

As with the operational controls described above, these specialty equipment options have the potential to reduce sediment resuspension, but also may increase costs.

7.2 Literature Review of Previous Investigations

For nearly twenty years, the Corps of Engineers has been conducting research to develop techniques for reducing the rate of sediment resuspension during dredging (Raymond 1984) through the development of new equipment and refinement of existing equipment. Numerous documents exist (Corps 1986, Corps 1988, Schroeder 2001, Herbich and Brahme 1991, Hayes 1986) that discuss methods for selecting the proper equipment to reduce sediment resuspension rates depending on site conditions and the resulting effectiveness in the field.

Work conducted by the Corps (2001b) in Boston Harbor on the effects of different bucket types concluded that "based on turbidity measurements, the Conventional bucket produced the highest amount of sediment resuspension spread throughout the water column. Use of the Cable Arm bucket appeared to reduce sediment resuspension in the water column as the observed depth-averaged turbidity was 46 percent less than observed for the Conventional bucket; insufficient TSS data were collected during the Cable Arm bucket operation to completely confirm this reduction, although the few data collected show an even higher reduction. The Enclosed bucket had the lowest overall turbidity and substantially less in the middle of the water column. Observed depth-averaged turbidity for the enclosed bucket was 79 percent less than observed for the Conventional bucket. This compared well with observed TSS which showed depth-averaged TSS concentrations for the enclosed bucket 76 percent less than for the Conventional bucket". However, if the appropriate type of sediment (e.g., soft) is not present, these reduction may not apply to other sites.

Several researchers (Schroeder 2001, Fort James Corporation et al. 2001, and Averett et al. 1999) have found that the use of silt curtains, when used properly, are effective in reducing off-site transport of resuspended sediment during dredging. Schroeder (2001) evaluated the differences in metal partitioning and losses with and without the use of silt curtains and predicted that dissolved metals concentrations would be less when the silt curtains were used. Other studies have shown that simply controlling resuspended sediments does not equate to reducing contaminant release during dredging. QEA and BBL (2001) found that even though silt curtains were very effective at reducing off-site transport of resuspended sediments, PCB concentrations downstream of the dredge location became elevated during the dredging of hot spots. Similar results were observed with mercury by Alcoa (2000).

These data suggest that dredging BMPs if properly applied and used in appropriate site-specific conditions can be effective at reducing suspended sediments in the water column and controlling losses of contaminants during dredging, but that with some chemicals, elevations in the water column can still occur.

7.3 Potential Applicability to Los Angeles Region

The data presented in this section shows that dredging BMPs are widely available and are effective under most conditions for reducing resuspended sediments in the water column. They are not, however, always effective at reducing contaminant losses as have been observed at some locations with high concentrations of mercury and PCBs. Some BMPs (e.g., silt curtains) are only effective in areas with currents less than 2 knots, which can be exceeded in some areas of the harbor (Corps of Engineers 1990). Typical current speeds under normal tidal patterns range from slack to 0.60 knots for the inner parts of the harbor, and up to over 2 knots for the outer portions of the harbor.

Depending on the location to be dredged, BMPs could be used to reduce suspended sediment levels around dredging projects in the Los Angeles Region, but doing so assumes that a risk is present as a result of the suspended sediments. Evaluating the potential for that risk is the goal of this paper.

7.4 Key Studies and Reports

Several key documents related to dredging BMPs are cited in this section, including the following:

- Corps 1988. Sediment Resuspension by Selected Dredges. Environmental Effects of Dredging Technical Notes. EEDP-09-2. March 1988.
- Corps 2001a. Long-Term Management Strategy for the Placement of Dredged Material in the San Francisco Bay Region, Management Plan. U.S. Army Corps of Engineers – San Francisco District.
- Corps 2001b. Coastal and Hydraulic Engineering Technical Note (CHETN) VI-35, March 2001, "Dredge Bucket Comparison Demonstration at Boston Harbor"
- Hartman Consulting Group. 2001. Long-Term Management Strategy for the Placement of Dredged Material in the San Francisco Bay Region, Management Plan- Appendix I, Best Management Practices. July 2001.

- Raymond, G.L. 1984. Techniques to reduce the sediment resuspension caused by dredging. Miscellaneous Paper HL-84-3. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi.
- Schroeder P.R. 2001. Environmental Processes and Engineering Division (U.S. Army Engineer Research and Development Center). Technical Memorandum to Russ Forba, USEPA Region 8 titled "Estimation of contaminant release from dredging of Clark Fork and Blackfoot River sediments in Milltown Reservoir". 10 August 2001.

7.5 Uncertainty and Data Needs

Most of the data presented in this paper are for studies conducted outside of the Los Angeles region. An additional data need might be to conduct a more extensive search of local contractors to identify projects where BMPs have been used and obtain field data (if available) regarding its effectiveness in reducing off-site transport of suspended sediments and chemical release.

8 CONCLUSIONS AND RECOMMENDATIONS FOR REGIONAL APPLICATION

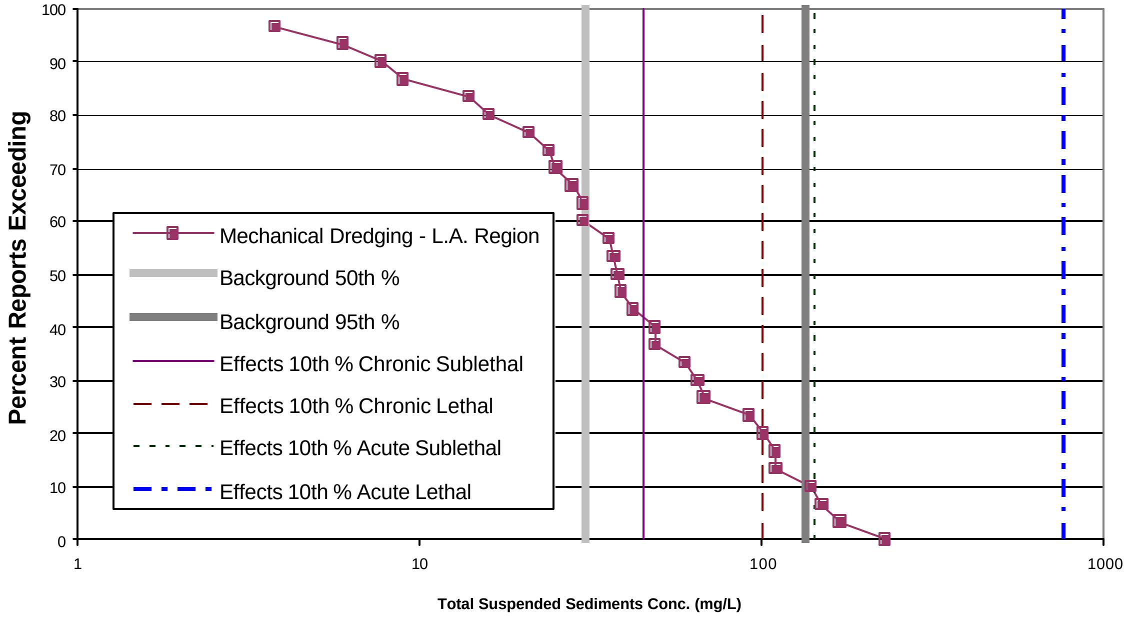
This paper presents relevant literature on the potential impacts to the aquatic environment from resuspended clean and contaminated sediments. Dredging operations will almost always resuspend sediments, but the level of resuspension and associated impacts depend upon the physical and chemical characteristics of the sediment, as well as the site conditions, type of equipment and manner of dredging employed.

A comparison of the dredging induced suspended sediment concentrations observed in the field and physical effects concentrations reported in the literature indicate that dredging is not likely to cause acute lethal effects in aquatic organisms (see summary presented in Figure 9). There is some overlap between potential acute sublethal and chronic effects ranges and observed suspended sediment concentrations. However, because of the transient nature of dredging induced sediment plumes, more long-term chronic and sublethal effects from resuspended clean sediments are not expected to occur around most dredging operations. Further, chronic and sublethal effects reported for clean sediments in the literature appear to overlap with naturally occurring background suspended sediment concentrations in the Los Angeles region indicating that regional aquatic life may be adapted to occasional exceedances of these chronic and sublethal effects levels. Very high levels of resuspended sediments and turbidity do have the potential to affect marine organisms; however, most of those impacts occur at resuspension levels and durations that are typically not present during dredging operations.

Potential impacts from dredging of contaminated sediments are more difficult to assess. Most of the information concerning the effects of contaminated sediments on marine organisms deals with the impacts of settled sediments. Few studies have dealt with resuspended contaminated sediments. Organisms exposed to resuspended contaminated sediments can develop physiological problems due to direct exposure to dissolved contaminants or bioaccumulation of metals and organic chemicals. However, much of the data suggests that significant adverse impacts do not occur at resuspension levels and durations typically associated with dredging projects. In general, previous studies indicate that potential effects from dredging are transient and not significant. There are, however, exceptions where highly elevated concentrations of specific chemicals (e.g., mercury and PCBs) have been shown to cause significant bioaccumulation in organisms down current from dredging operations. It should be noted that these instances are the exception rather than the norm.

In an attempt to investigate potential direct toxicity effects from contaminated suspended sediments using local data from the Los Angeles region, a series of additional evaluations were conducted with elutriate bioassay data contained in a regional database of sediments tested for off-shore disposal characterization. The specific goal for these additional investigations was to determine if a correlation existed between sediment chemical concentrations and toxicity. The results of this evaluation are presented as a supplement in Appendix B because some of the calculations required estimating suspended sediment concentrations for laboratory tests, resulting in some uncertainty in the resulting conclusions.

Figure 9. Los Angeles Regional mechanical dredging total suspended sediment concentrations compared to background and effects levels (Note, same as Figure 8)



To address CSTF regional concerns, additional studies to evaluate both clean and resuspended contaminated sediment effects could be performed to address specific local concerns and reduce uncertainty in the evaluations presented in the current paper and supplemental evaluations. Potential studies identified include:

- Collecting additional data on local species effects from suspended sediments, and particularly, turbidity. This data could be obtained through specific bioassays using local species.
- Collection of additional information on the range of typical regional background suspended sediment concentrations and turbidity levels for comparison to effects levels. This data could be obtained through additional targeted literature and regulatory report searches as well as additional field studies.
- Conducting studies to understand the duration of dredging induced resuspension effects in particular locations (rather than relative to the dredge) to determine proper application of acute versus chronic effects levels.
- Collecting monitoring data from immediately around (within a few meters) regional dredging operations to assist in the development of regional specific resuspension rates and suspended sediment concentrations that are comparable to data collected elsewhere.
- Conducting a more detailed evaluation of the potential effects of resuspended sediments to visual foragers like the California Least Tern.
- More extensive search of local contractors to identify projects where BMPs have been used and obtain field data (if available) regarding its effectiveness in reducing off-site transport of suspended sediments and chemical release.
- Conducting laboratory tests to validate resuspension rate formulas used to predict suspended sediment concentrations based on grain size and other physical parameters.

Other studies that may also be pertinent to the needs of the CSTF could be identified and expanded in the current evaluation. This paper was developed as a starting point for further discussion on the issue of water quality monitoring during dredging events in the Los Angeles region as it relates to suspended solids and the need for dredging BMPs.

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APPENDIX A

Table A-1. Summary of Reported Project-Specific Turbidity Generation Unit (TGU) and Resuspension Rate Values.

Dredge Type	Data Source	Classification	% fines	Reported TGU (kg/m3)	K (R74/R0,5)	S (kg/m3)	Submerged Density (psub; gms/cm3)	Resuspension Rate (R; % dry basis)
Hydraulic cutterhead	Nakai (1978)	Sand	2.5%	0.3	1.0 - 1.7	0.2 - 0.3	0.8 - 1.4	0.01% - 0.04%
Hydraulic cutterhead	Nakai (1978)	Sand	3.0%	0.2	1.0 - 1.0	0.2 - 0.2	0.8 - 1.4	0.01% - 0.03%
Hydraulic cutterhead	Nakai (1978)	Sand	8.0%	0.1	1.0 - 4.0	0.0 - 0.1	0.8 - 1.4	0.00% - 0.01%
Hydraulic cutterhead	Nakai (1978)	Sandy loam	31.8%	1.4	1.0 - 2.8	0.5 - 1.4	0.9 - 1.3	0.04% - 0.16%
Hydraulic cutterhead	Nakai (1978)	Clayey loam	69.2%	45.2	1.0 - 2.0	23.1 - 45.2	0.9 - 1.3	1.81% - 5.14%
Hydraulic cutterhead	Nakai (1978)	Sandy loam	74.5%	12.1	1.0 - 1.5	8.2 - 12.1	0.9 - 1.3	0.64% - 1.38%
Hydraulic cutterhead	Nakai (1978)	Silty clay	94.4%	9.9	1.0 - 2.7	3.6 - 9.9	0.9 - 1.3	0.28% - 1.13%
Hydraulic cutterhead	Nakai (1978)	Silty clay	98.5%	22.5	1.0 - 2.7	8.2 - 22.5	0.9 - 1.3	0.64% - 2.56%
Hydraulic cutterhead	Nakai (1978)	Silty clay	99.0%	5.3	1.0 - 2.5	2.1 - 5.3	0.9 - 1.3	0.17% - 0.60%
Hydraulic cutterhead	Nakai (1978)	Clay	99.0%	36.4	1.0 - 2.1	17.5 - 36.4	0.9 - 1.3	1.36% - 4.14%
Hydraulic cutterhead	Pennekamp et al. (1996)	N/A	N/A	N/A	N/A	0.0 - 0.1	0.9 - 1.3	0.00% - 0.01%
Hydraulic cutterhead	Hayes and Wu (2001)	Clay/silt	74.0%	N/A	N/A	N/A	0.8	0.08%
Hydraulic cutterhead	Hayes and Wu (2001)	Clay/silt	75.0%	N/A	N/A	N/A	1.5	0.13%
Hydraulic cutterhead	Hayes and Wu (2001)	Silty loam	83.0%	N/A	N/A	N/A	1.1	0.00%
Hydraulic cutterhead	Hayes and Wu (2001)	Clay/silt	98.0%	N/A	N/A	N/A	1.8	0.02%
Hydraulic cutterhead	Hayes and Wu (2001)	Clay/silt	99.0%	N/A	N/A	N/A	N/A	0.04%
Mechanical	Nakai (1978)	Sand	10.2%	17.6	1.0 - 6.8	2.6 - 17.6	0.8 - 1.4	0.18% - 2.29%
Mechanical	Nakai (1978)	Sandy loam	22.7%	55.8	1.0 - 2.2	25.2 - 55.8	0.9 - 1.3	1.97% - 6.34%
Mechanical	Nakai (1978)	Silty loam	45.0%	15.8	1.0 - 12.9	1.2 - 15.8	0.9 - 1.3	0.10% - 1.80%
Mechanical	Nakai (1978)	Clayey loam	54.8%	84.2	1.0 - 1.3	63.3 - 84.2	0.9 - 1.3	4.95% - 9.57%
Mechanical	Nakai (1978)	Silty clay	58.0%	89.0	1.0 - 1.7	53.1 - 89.0	0.9 - 1.3	4.15% - 10.11%
Mechanical	Nakai (1978)	Silty loam	62.0%	11.9	1.0 - 11.3	1.1 - 11.9	0.9 - 1.3	0.08% - 1.35%
Mechanical	Nakai (1978)	Silty loam	87.5%	17.1	1.0 - 14.6	1.2 - 17.1	0.9 - 1.3	0.09% - 1.94%
Mechanical	Pennekamp et al. (1996)	N/A	N/A	N/A	N/A	3.0	0.9 - 1.3	0.23% - 0.34%
Mechanical	Pennekamp et al. (1996)	N/A	N/A	N/A	N/A	3.0	0.9 - 1.3	0.23% - 0.34%
Mechanical	Pennekamp et al. (1996)	N/A	N/A	N/A	N/A	3.0 - 5.0	0.9 - 1.3	0.23% - 0.57%
Mechanical	Pennekamp et al. (1996)	N/A	N/A	N/A	N/A	6.0	0.9 - 1.3	0.47% - 0.68%
Mechanical	Pennekamp et al. (1996)	N/A	N/A	N/A	N/A	9.0	0.9 - 1.3	0.70% - 1.02%
Mechanical	Pennekamp et al. (1996)	N/A	N/A	N/A	N/A	11.0	0.9 - 1.3	0.86% - 1.25%
Mechanical	Pennekamp et al. (1996)	N/A	N/A	N/A	N/A	11.0	0.9 - 1.3	0.86% - 1.25%
Mechanical	Pennekamp et al. (1996)	N/A	N/A	N/A	N/A	13.0	0.9 - 1.3	1.02% - 1.48%
Mechanical	Pennekamp et al. (1996)	N/A	N/A	N/A	N/A	18.0 - 21.0	0.9 - 1.3	1.41% - 2.39%
Mechanical	Pennekamp et al. (1996)	N/A	N/A	N/A	N/A	19.0	0.9 - 1.3	1.48% - 2.16%
Mechanical	Pennekamp et al. (1996)	N/A	N/A	N/A	N/A	21.0	0.9 - 1.3	1.64% - 2.39%
Mechanical	Pennekamp et al. (1996)	N/A	N/A	N/A	N/A	54.0	0.9 - 1.3	4.22% - 6.14%

TGU - Tubidity Generation Unit (Nakai 1978)
R - Resuspension Factor (Hayes and Wu 1991)
K - % of particles too fine to settle in site currents
S - Suspension Parameter (Pennekamp et al. 1996)

Table A-2. Resuspended Sediment Concentrations Reported Near Dredges.

Study	Location	Distance From Dredge Feet	Dredge Type	Dredge TSS Mid-Range	Dredge TSS Max	Background TSS Mean/Min	Background Max	VAB Mean	VAB Max
Pennekamp et al. 1996	Delfzijl	Nearfield	Hopper	80	N/AV	65	N/AV	15	N/AV
Pennekamp et al. 1996	Rotterdam	Nearfield	Hopper	83	N/AV	23	N/AV	60	N/AV
Collins 1995	Grays Harbor	Nearfield	Hopper	146	N/AV	12	60	134	N/AV
Pennekamp et al. 1996	Rotterdam	Nearfield	Hopper	190	N/AV	40	N/AV	150	N/AV
Pennekamp et al. 1996	Rotterdam	Nearfield	Hopper	475	N/AV	75	N/AV	400	N/AV
Herbich and Brahme 1991	San Francisco Bay	N/AV	Hopper	3000	N/AV	38	28	2962	N/AV
Herbich and Brahme 1991	Yokkaichi Port Japan	96	Hydraulic	3	4	N/AV	N/AV	3	4
Herbich and Brahme 1991	Tokyo Bay Japan	N/AV	Hydraulic	4.5	N/AV	N/AV	N/AV	4.5	N/AV
Herbich and Brahme 1991	Osaka Japan	N/AV	Hydraulic	5	10	N/AV	N/AV	5	10
Collins 1995	Calumet Harbor	Nearfield	Hydraulic	5.4	N/AV	1	4	4	N/AV
Herbich and Brahme 1991	Yokkaichi Port Japan	96	Hydraulic	8	10	N/AV	N/AV	8	10
Herbich and Brahme 1991	Upper Mississippi	50	Hydraulic	12	N/AV	21	N/AV	0	N/AV
Herbich and Brahme 1991	Upper Mississippi	100	Hydraulic	16	N/AV	11	N/AV	5	N/AV
Herbich and Brahme 1991	Cape Fear River	N/AV	Hydraulic	20	36	N/AV	N/AV	20	36
Pennekamp et al. 1996	Hook of Holland	Nearfield	Hydraulic	25	N/AV	25	N/AV	0	N/AV
Pennekamp et al. 1996	Hook of Holland	Nearfield	Hydraulic	25	N/AV	25	N/AV	0	N/AV
Herbich and Brahme 1991	Upper Mississippi	Nearfield	Hydraulic	32	64	30	N/AV	2	34
Herbich and Brahme 1991	James River	Nearfield	Hydraulic	40	N/AV	N/AV	N/AV	40	N/AV
Pennekamp et al. 1996	Delfzijl	Nearfield	Hydraulic	50	N/AV	50	N/AV	0	N/AV
Pennekamp et al. 1996	Hellevoetsluis	Nearfield	Hydraulic	50	N/AV	20	N/AV	30	N/AV
Pennekamp et al. 1996	Heusden	Nearfield	Hydraulic	55	N/AV	45	N/AV	10	N/AV
Herbich and Brahme 1991	Ohio River	100	Hydraulic	55	N/AV	40	N/AV	15	N/AV
Herbich and Brahme 1991	James River	Nearfield	Hydraulic	71	N/AV	N/AV	N/AV	71	N/AV
Herbich and Brahme 1991	Osaka Japan	160	Hydraulic	80	N/AV	N/AV	N/AV	80	N/AV
Pennekamp et al. 1996	Rotterdam	Nearfield	Hydraulic	95	N/AV	35	N/AV	60	N/AV
Barnard 1978	Mobile Bay Ship Channel	96	Hydraulic	125	336	25	30	100	311
Herbich and Brahme 1991	Upper Mississippi	Nearfield	Hydraulic	150	N/AV	175	N/AV	0	N/AV
Herbich and Brahme 1991	Upper Mississippi	N/AV	Hydraulic	163	N/AV	155	N/AV	8	N/AV
Herbich and Brahme 1991	Tokyo Bay Japan	N/AV	Hydraulic	200	N/AV	N/AV	N/AV	200	N/AV
Barnard 1978	Corpus Cristi Channel	6	Hydraulic	209	580	39	N/AV	170	541
Pennekamp et al. 1996	Rotterdam	Nearfield	Hydraulic	295	N/AV	45	N/AV	250	N/AV
Collins 1995	James River	Nearfield	Hydraulic	411	N/AV	42	90	369	N/AV
Collins 1995	Savannah River	Nearfield	Hydraulic	594	N/AV	17	67	577	N/AV
Herbich and Brahme 1991	Tokyo Bay Japan	Nearfield	Hydraulic	5000	N/AV	N/AV	N/AV	5000	N/AV
Barnard 1978	Yokkaichi Harbor Japan	192	Hydraulic	N/AV	305	1	18	N/AV	304
Herbich and Brahme 1991	Yokkaichi Harbor Japan	3	Hydraulic	N/AV	30	1	18	12	29
MEC 2002	Los Angeles River	80	Mechanical	14	48	6	14	8	42
Herbich and Brahme 1991	Cumberland River	Nearfield	Mechanical	15	51	15	38	0	36
Herbich and Brahme 1991	Portland Harbor	Nearfield	Mechanical	15	23	8	N/AV	7	15

Table A-2. Resuspended Sediment Concentrations Reported Near Dredges.

Study	Location	Distance From Dredge Feet	Dredge Type	Dredge TSS Mid-Range	Dredge TSS Max	Background TSS Mean/Min	Background Max	VAB Mean	VAB Max
Herbich and Brahme 1991	Upper Mississippi	100	Mechanical	21	N/AV	21	N/AV	0	N/AV
Herbich and Brahme 1991	Upper Mississippi	100	Mechanical	22	N/AV	12	N/AV	10	N/AV
Herbich and Brahme 1991	Upper Mississippi	150	Mechanical	23	26	15	39	8	11
Herbich and Brahme 1991	Upper Mississippi	N/AV	Mechanical	25	58	24	52	1	34
Herbich and Brahme 1991	Jacksonville	Nearfield	Mechanical	27	N/AV	N/AV	N/AV	27	N/AV
MBC 2000	Long Beach Pier F	300	Mechanical	28	37	N/AV	N/AV	28	37
MBC 2000	Long Beach Pier D	300	Mechanical	30	39	N/AV	N/AV	30	39
MBC 2001f	Los Angeles Berth 212-21	100/300	Mechanical	30	44	13	38	4	6
Barnard 1978	Patapsco River, MD	70	Mechanical	30	N/AV	10	N/AV	20	N/AV
MBC 2001b	Los Angeles Berth 71	300	Mechanical	41.8	73	28	65	9	30
MBC 2001c	Los Angeles Berth 167-16	100/300	Mechanical	42	62	13	35	16	49
MBC 2001d	Los Angeles Berth 148-15	100/300	Mechanical	42	63	18	23	21	36
MBC 2001e	Los Angeles Berth 261-26	100/300	Mechanical	44	64	27	44	14	38
MBC 2000	Long Beach Pier B ('97)	300	Mechanical	49	92	N/AV	N/AV	49	92
Herbich and Brahme 1991	Pautuxent River	N/AV	Mechanical	50	70	N/AV	N/AV	50	70
Pennekamp et al. 1996	a/d Ijssel	Nearfield	Mechanical	55	N/AV	35	N/AV	20	N/AV
MBC 2000b	Long Beach Pier T Ph 1	300	Mechanical	57.8	140	17	330	24	101
MBC 2000	Long Beach Pier B ('99)	300	Mechanical	60	150	N/AV	N/AV	60	150
MBC 2000	Long Beach Pier A	300	Mechanical	65	170	N/AV	N/AV	65	170
Pennekamp et al. 1996	Rotterdam	Nearfield	Mechanical	65	N/AV	30	N/AV	35	N/AV
Herbich and Brahme 1991	Florida Keys	Nearfield	Mechanical	66	N/AV	1	N/AV	65	N/AV
MBC 2000	Long Beach Pier E	300	Mechanical	68	110	N/AV	N/AV	68	110
MBC 2001a	Long Beach Pier T Ph 2	300	Mechanical	68.4	230	10	330	25	230
Pennekamp et al. 1996	a/d Ijssel	Nearfield	Mechanical	70	N/AV	35	N/AV	35	N/AV
Collins 1995	Calumet River	Nearfield	Mechanical	72	75	9	18	63	66
Herbich and Brahme 1991	New York Harbor	N/AV	Mechanical	73.4	126.3	N/AV	N/AV	73.4	126.3
Collins 1995	Duwamish	Nearfield	Mechanical	80	N/AV	11	26	69	N/AV
Pennekamp et al. 1996	Scheverningen	Nearfield	Mechanical	83	N/AV	48	N/AV	35	N/AV
Barnard 1978	San Francisco Bay	160	Mechanical	90	200	40	N/AV	50	160
Pennekamp et al. 1996	Rotterdam	Nearfield	Mechanical	100	N/AV	20	N/AV	80	N/AV
MBC 2000	Long Beach Pier B ('00)	300	Mechanical	109	140	N/AV	N/AV	109	140
Herbich and Brahme 1991	Ohio River	100	Mechanical	115	N/AV	9	10	106	N/AV
Barnard 1978	Thames River CN	<320	Mechanical	115	168	5	N/AV	110	163
Pennekamp et al. 1996	Amsterdam	Nearfield	Mechanical	125	N/AV	15	N/AV	110	N/AV
Pennekamp et al. 1996	a/d Ijssel	Nearfield	Mechanical	135	N/AV	35	N/AV	100	N/AV
Pennekamp et al. 1996	Zierikzee	Nearfield	Mechanical	140	N/AV	50	N/AV	90	N/AV
Herbich and Brahme 1991	Jacksonville	Nearfield	Mechanical	146	N/AV	N/AV	N/AV	146	N/AV
Herbich and Brahme 1991	Hori River, Japan	22	Mechanical	150	300	40	N/AV	110	260
Collins 1995	Lake City	Nearfield	Mechanical	150	N/AV	2	27	148	N/AV

Table A-2. Resuspended Sediment Concentrations Reported Near Dredges.

Study	Location	Distance From Dredge Feet	Dredge Type	Dredge TSS Mid-Range	Dredge TSS Max	Background TSS Mean/Min	Background Max	VAB Mean	VAB Max
Pennekamp et al. 1996	Zierikzee	Nearfield	Mechanical	155	N/AV	50	N/AV	105	N/AV
Herbich and Brahme 1991	Lower Thames, CN	100	Mechanical	168	N/AV	N/AV	N/AV	168	N/AV
Herbich and Brahme 1991	Jacksonville	Nearfield	Mechanical	233	N/AV	N/AV	N/AV	233	N/AV
Collins 1995	St. Johns River	Nearfield	Mechanical	250	285	47	72	203	238
Collins 1995	Black Rock Harbor	Nearfield	Mechanical	449	520	45	69	404	475

VAB - Values shown are levels Values Above Background where background available - otherwise same as measured value

Mean used instead of minimum whereever possible for background concentration.

Mechanical = clamshells, buckets, but not excavators or backhoes

TSS - Total Suspended Solids

Table A-3. Resuspended Sediment Concentrations Report Near Dredges in the Los Angeles Region.

Study	Location	Distance From Dredge Feet	Dredge Type	Dredge TSS Mid-Range	Dredge TSS Max	Background TSS Min	Max	VAB Mean	VAB Max
MEC 2002	Los Angeles River	80	Mechanical	14	48	6	14	7.7	42
MBC 2000	Long Beach Pier F	300	Mechanical	28	37	N/AV	N/AV	28	37
MBC 2000	Long Beach Pier D	300	Mechanical	30	39	N/AV	N/AV	30	39
MBC 2000	Long Beach Pier B ('97)	300	Mechanical	49	92	N/AV	N/AV	49	92
MBC 2000	Long Beach Pier B ('99)	300	Mechanical	60	150	N/AV	N/AV	60	150
MBC 2000	Long Beach Pier A	300	Mechanical	65	170	N/AV	N/AV	65	170
MBC 2000	Long Beach Pier E	300	Mechanical	68	110	N/AV	N/AV	68	110
MBC 2000	Long Beach Pier B ('00)	300	Mechanical	109	140	N/AV	N/AV	109	140
MBC 2000b	Long Beach Pier T Ph 1	300	Mechanical	58	140	17	330	24	101
MBC 2001a	Long Beach Pier T Ph 2	300	Mechanical	68.4	230	10	330	25	230
MBC 2001b	Los Angeles Berth 71	300	Mechanical	41.8	73	28	65	9	30
MBC 2001c	Los Angeles Berth 167-169	100/300	Mechanical	42	62	13	35	16	49
MBC 2001d	Los Angeles Berth 148-151	100/300	Mechanical	42	63	18	23	21	36
MBC 2001e	Los Angeles Berth 261-265	100/300	Mechanical	44	64	27	44	14	38
MBC 2001f	Los Angeles Berth 212-215	100/300	Mechanical	30	44	13	38	4	6

VAB - Values shown are Values Above Background where background available - otherwise same as measured value

Actual paired project/background samples used in calculation of background means and maximums.

TSS - Total Suspended Solids

Table A-4. Reported Total Suspended Solids (TSS) Effects Concentrations and Relevant Test Variables for Aquatic Organisms.

Primary Reference	Secondary Reference	Species/ Lifestage	Reported Effects Conc. (mg/L TSS)	Test Duration (days)	Duration Category	Response	Response Type	Type of Sediment
Wilber and Clarke 2001	Huntington and Miller 1989	Northern Quahog larvae	56	0.5	Acute	No effect level	Sublethal	Not Reported
Wilber and Clarke 2001	Huntington and Miller 1989	Northern Quahog larvae	56	1	Acute	No effect level	Sublethal	Not Reported
Wilber and Clarke 2001	Huntington and Miller 1989	Northern Quahog larvae	56	2	Acute	No effect level	Sublethal	Not Reported
Clarke and Wilber 2000	Kiorboe et al. 1981	Striped bass eggs	100	1	Acute	Delayed hatching	Sublethal	Not Reported
Clarke and Wilber 2000	Kiorboe et al. 1981	White perch eggs	100	1	Acute	Delayed hatching	Sublethal	Not Reported
Wilber and Clarke 2001	Schubel and Wang 1973	White Perch eggs	100	1	Acute	Hatching delayed	Sublethal	Not Reported
Wilber and Clarke 2001	Robinson et al. 1984	Surf Clam	100	3	Acute	No effect level	Sublethal	Artificial
Wilber and Clarke 2001	Turner and Miller 1991	Northern Quahog	100	2	Acute	Reduced growth	Sublethal	Natural
Wilber and Clarke 2001	Huntington and Miller 1989	Northern Quahog larvae	110	1	Acute	No effect level	Sublethal	Not Reported
Wilber and Clarke 2001	Huntington and Miller 1989	Northern Quahog larvae	110	1	Acute	No effect level	Sublethal	Not Reported
Wilber and Clarke 2001	Huntington and Miller 1989	Northern Quahog larvae	110	2	Acute	No effect level	Sublethal	Not Reported
Wilber and Clarke 2001	Turner and Miller 1991	Northern Quahog	120	2	Acute	Reduced growth	Sublethal	Natural
Wilber and Clarke 2001	Morgan et al. 1973	White Perch larvae	155	2	Acute	50% mortality	Lethal	Not Reported
Wilber and Clarke 2001	Turner and Miller 1991	Northern Quahog	193	2	Acute	Reduced growth	Sublethal	Natural
Wilber and Clarke 2001	Cardwell et al. 1976	Pacific Oyster larvae	200	2	Acute	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Breitburg 1988	Striped Bass larvae	200	0.5	Acute	Reduced feeding rate	Sublethal	Artificial
Wilber and Clarke 2001	Huntington and Miller 1989	Northern Quahog larvae	220	0.5	Acute	No effect level	Sublethal	Not Reported
Wilber and Clarke 2001	Huntington and Miller 1989	Northern Quahog larvae	220	1	Acute	No effect level	Sublethal	Not Reported
Wilber and Clarke 2001	Huntington and Miller 1989	Northern Quahog larvae	220	2	Acute	No effect level	Sublethal	Not Reported
Wilber and Clarke 2001	Morgan et al. 1973	White Perch larvae	373	1	Acute	50% mortality	Lethal	Not Reported
Wilber and Clarke 2001	Morgan et al. 1973	Striped Bass larvae	485	1	Acute	50% mortality	Lethal	Not Reported
Clarke and Wilber 2000	Sherk et al. 1974 and 1975	Bluefish subadult	500	1	Acute	10% mortality	Lethal	Artificial
Wilber and Clarke 2001	Auld and Schubel 1978	Striped Bass larvae	500	3	Acute	Increased mortality	Lethal	Natural
Wilber and Clarke 2001	Cardwell et al. 1976	Pacific Oyster larvae	500	2	Acute	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Robinson et al. 1984	Surf Clam	500	3	Acute	No effect level	Sublethal	Artificial
Wilber and Clarke 2001	Kiorboe et al. 1981	Atlantic Herring eggs	500	0.5	Acute	Normal egg development level	Sublethal	Natural
Wilber and Clarke 2001	Breitburg 1988	Striped Bass larvae	500	0.5	Acute	Reduced feeding rate	Sublethal	Artificial
Clarke and Wilber 2000	Messieh et al 1981	Atlantic Herring larvae	540	2	Acute	Reduced growth	Sublethal	Not Reported
Wilber and Clarke 2001	Huntington and Miller 1989	Northern Quahog larvae	560	0.5	Acute	No effect level	Sublethal	Not Reported
Wilber and Clarke 2001	Huntington and Miller 1989	Northern Quahog larvae	560	1	Acute	No effect level	Sublethal	Not Reported
Wilber and Clarke 2001	Huntington and Miller 1989	Northern Quahog larvae	560	2	Acute	No effect level	Sublethal	Not Reported
Wilber and Clarke 2001	Sherk et al. 1974	Atlantic Silverside	580	1	Acute	10% mortality	Lethal	Artificial
Lunz 1987	Stern and Stickle 1978	Atlantic sliverside adult	580	1	Acute	Not reported	N/AV	Artificial
Wilber and Clarke 2001	Cardwell et al. 1976	Pacific Oyster larvae	600	2	Acute	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Sherk et al. 1974	White Perch	670	2	Acute	10% mortality	Lethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	White Perch subadult	750	1	Acute	100% mortality	Lethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	Atlantic Menhaden subadult	800	1	Acute	100% mortality	Lethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	Bluefish subadult	800	1	Acute	100% mortality	Lethal	Artificial
Wilber and Clarke 2001	Cardwell et al. 1976	Pacific Oyster larvae	800	2	Acute	50% mortality	Lethal	Natural
Wilber and Clarke 2001	Morgan et al. 1983	Striped Bass eggs	800	1	Acute	Development slowed	Sublethal	Natural
Clarke and Wilber 2000	Sherk et al. 1974 and 1975	Atlantic Croaker adult	1,000	1	Acute	10% mortality	Lethal	Artificial
Clarke and Wilber 2000	Sherk et al. 1974 and 1975	Bay Anchovy adult	1,000	1	Acute	10% mortality	Lethal	Artificial
Clarke and Wilber 2000	Sherk et al. 1974 and 1975	Menhaden subadult	1,000	1	Acute	10% mortality	Lethal	Artificial
Clarke and Wilber 2000	Sherk et al. 1974 and 1975	Striped Bass adult	1,000	1	Acute	10% mortality	Lethal	Artificial
Clarke and Wilber 2000	Sherk et al. 1974 and 1975	Weakfish	1,000	1	Acute	10% mortality	Lethal	Artificial
Wilber and Clarke 2001	Cardwell et al. 1976	Pacific Oyster larvae	1,000	2	Acute	50% mortality	Lethal	Natural
Wilber and Clarke 2001	Boehlert 1984	Pacific Herring larvae	1,000	1	Acute	Damage to epidermis	Sublethal	Natural
Wilber and Clarke 2001	Auld and Schubel 1978	Striped Bass larvae	1,000	3	Acute	Increased mortality	Lethal	Natural
Wilber and Clarke 2001	Cardwell et al. 1976	Pacific Oyster larvae	1,000	2	Acute	No effect level	Sublethal	Natural

Table A-4. Reported Total Suspended Solids (TSS) Effects Concentrations and Relevant Test Variables for Aquatic Organisms.

Primary Reference	Secondary Reference	Species/ Lifestage	Reported Effects Conc. (mg/L TSS)	Test Duration (days)	Duration Category	Response	Response Type	Type of Sediment
Wilber and Clarke 2001	Robinson et al. 1984	Surf Clam	1,000	3	Acute	No effect level	Sublethal	Artificial
Wilber and Clarke 2001	Loosanoff 1962	Eastern Oyster adult	1,000	2	Acute	Reduced pumping	Sublethal	Natural
Wilber and Clarke 2001	Sherk et al. 1974	Spot	1,140	2	Acute	10% mortality	Lethal	Artificial
Wilber and Clarke 2001	Cardwell et al. 1976	Pacific Oyster larvae	1,200	2	Acute	Abnormal shell development	Sublethal	Natural
Wilber and Clarke 2001	Cardwell et al. 1976	Pacific Oyster larvae	1,500	2	Acute	50% mortality	Lethal	Natural
Lunz 1987	Morton 1977	Striped Bass Larvae	1,557	3	Acute	Not reported	N/AV	Natural
Lunz 1987	Morton 1977	White Perch Larvae	1,626	3	Acute	Not reported	N/AV	Natural
Wilber and Clarke 2001	Cardwell et al. 1976	Pacific Oyster larvae	1,800	2	Acute	Abnormal shell development	Sublethal	Natural
Wilber and Clarke 2001	Cardwell et al. 1976	Pacific Oyster larvae	1,800	2	Acute	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Sherk et al. 1974	Spot	1,890	2	Acute	50% mortality	Lethal	Artificial
Wilber and Clarke 2001	Boehlert and Morgan 1985	Pacific Herring larvae	2,000	0.5	Acute	Reduced feeding rate	Sublethal	Not Reported
Wilber and Clarke 2001	Loosanoff 1962	Eastern Oyster adult	2,000	2	Acute	Reduced pumping	Sublethal	Natural
Wilber and Clarke 2001	Huntington and Miller 1989	Northern Quahog larvae	2,200	0.5	Acute	No effect level	Sublethal	Not Reported
Wilber and Clarke 2001	Huntington and Miller 1989	Northern Quahog larvae	2,200	1	Acute	No effect level	Sublethal	Not Reported
Wilber and Clarke 2001	Huntington and Miller 1989	Northern Quahog larvae	2,200	2	Acute	Reduced growth	Sublethal	Not Reported
Lunz 1987	Stern and Stickle 1978	Bay Anchovy adult	2,300	1	Acute	Not reported	N/AV	Artificial
Wilber and Clarke 2001	Sherk et al. 1975	Bay Anchovy	2,310	1	Acute	10% mortality	Lethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	Atlantic Silverside	2,500	1	Acute	50% mortality	Lethal	Artificial
Wilber and Clarke 2001	Cardwell et al. 1976	Pacific Oyster larvae	2,800	2	Acute	Abnormal shell development	Sublethal	Natural
Wilber and Clarke 2001	Sherk et al. 1974	White Perch	2,960	2	Acute	50% mortality	Lethal	Artificial
Wilber and Clarke 2001	Loosanoff 1962	Eastern Oyster adult	3,000	2	Acute	Reduced pumping	Sublethal	Natural
Wilber and Clarke 2001	Sherk et al. 1975	White Perch	3,050	1	Acute	10% mortality	Lethal	Artificial
Lunz 1987	Stern and Stickle 1978	White Perch adult	3,050	1	Acute	Not reported	N/AV	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	Spot	3,170	2	Acute	90% mortality	Lethal	Artificial
Wilber and Clarke 2001	Neumann et al. 1975	Oyster Toadfish	3,360	1	Acute	Oxygen consumption variable	Sublethal	Natural
Wilber and Clarke 2001	Boehlert 1984	Pacific Herring larvae	4,000	1	Acute	Punctured epidermis	Sublethal	Natural
Wilber and Clarke 2001	Loosanoff 1962	Eastern Oyster adult	4,000	2	Acute	Reduced pumping	Sublethal	Natural
Wilber and Clarke 2001	Peddicord 1980	Black-tailed Sand Shrimp	4,300	3	Acute	5% mortality	Lethal	Natural
Wilber and Clarke 2001	Cardwell et al. 1976	Pacific Oyster larvae	4,400	2	Acute	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Sherk et al. 1975	Bay Anchovy	4,710	1	Acute	50% mortality	Lethal	Artificial
Lunz 1987	Morton 1977	Striped Bass Larvae	5,210	3	Acute	Not reported	N/AV	Natural
Wilber and Clarke 2001	Cardwell et al. 1976	Pacific Oyster larvae	5,300	2	Acute	No effect level	Sublethal	Natural
Lunz 1987	Morton 1977	White Perch Larvae	5,380	3	Acute	Not reported	N/AV	Natural
Wilber and Clarke 2001	Cardwell et al. 1976	Pacific Oyster larvae	5,510	2	Acute	50% mortality	Lethal	Natural
Wilber and Clarke 2001	Cardwell et al. 1976	Pacific Oyster larvae	7,000	2	Acute	50% mortality	Lethal	Natural
Wilber and Clarke 2001	Cardwell et al. 1976	Pacific Oyster larvae	9,400	2	Acute	Abnormal shell development	Sublethal	Natural
Wilber and Clarke 2001	Sherk et al. 1974	Bay Anchovy	9,600	1	Acute	90% mortality	Lethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	White Perch	9,850	1	Acute	50% mortality	Lethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	White Perch	9,970	1	Acute	10% mortality	Lethal	Natural
Lunz 1987	Stern and Stickle 1978	White Perch adult	9,970	1	Acute	Not reported	N/AV	Natural
Clarke and Wilber 2000	Sherk et al. 1974 and 1975	Cusk eel adult	10,000	1	Acute	10% mortality	Lethal	Artificial
Clarke and Wilber 2000	Sherk et al. 1974 and 1975	Hogchoker adult	10,000	1	Acute	10% mortality	Lethal	Artificial
Clarke and Wilber 2000	Sherk et al. 1974 and 1975	Toadfish adult	10,000	1	Acute	10% mortality	Lethal	Artificial
Wilber and Clarke 2001	Rogers 1969	Cunner	10,000	1	Acute	50% mortality	Lethal	Natural
Wilber and Clarke 2001	Sherk et al. 1974	Atlantic Silverside	10,000	1	Acute	90% mortality	Lethal	Artificial
Wilber and Clarke 2001	Cardwell et al. 1976	Pacific Oyster larvae	11,700	2	Acute	Abnormal shell development	Sublethal	Natural
Wilber and Clarke 2001	Sherk et al. 1974	White Perch	13,060	2	Acute	90% mortality	Lethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	Spot	13,090	1	Acute	10% mortality	Lethal	Artificial
Wilber and Clarke 2001	Neumann et al. 1975	Oyster Toadfish	14,600	3	Acute	No effect level	Sublethal	Natural

Table A-4. Reported Total Suspended Solids (TSS) Effects Concentrations and Relevant Test Variables for Aquatic Organisms.

Primary Reference	Secondary Reference	Species/ Lifestage	Reported Effects Conc. (mg/L TSS)	Test Duration (days)	Duration Category	Response	Response Type	Type of Sediment
Lunz 1987	Stern and Stickle 1978	Spot adult	15,090	1	Acute	Not reported	N/AV	Artificial
Wilber and Clarke 2001	Rogers 1969	Fourspine Stickleback	18,000	1	Acute	50% mortality	Lethal	Natural
Clarke and Wilber 2000	Messieh et al 1981	Atlantic Herring larvae	19,000	2	Acute	100% Mortality	Lethal	Not Reported
Wilber and Clarke 2001	Sherk et al. 1974	White Perch	19,800	1	Acute	50% mortality	Lethal	Natural
Wilber and Clarke 2001	Sherk et al. 1974	Spot	20,340	1	Acute	50% mortality	Lethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	Striped Killifish	23,770	1	Acute	10% mortality	Lethal	Artificial
Lunz 1987	Stern and Stickle 1978	Striped Killfish adult	23,770	1	Acute	Not reported	N/AV	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	Mummichog	24,470	1	Acute	10% mortality	Lethal	Artificial
Lunz 1987	Stern and Stickle 1978	Mummichog adult	24,470	1	Acute	Not reported	N/AV	Artificial
Wilber and Clarke 2001	Rogers 1969	Cunner	28,000	1	Acute	50% mortality	Lethal	Natural
Wilber and Clarke 2001	Sherk et al. 1974	Spot	31,620	1	Acute	90% mortality	Lethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	White Perch	31,810	1	Acute	90% mortality	Lethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	Mummichog	35,860	2	Acute	10% mortality	Lethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	Striped Killifish	38,190	1	Acute	50% mortality	Lethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	Mummichog	39,000	1	Acute	50% mortality	Lethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	White Perch	39,400	1	Acute	90% mortality	Lethal	Natural
Wilber and Clarke 2001	Sherk et al. 1974	Mummichog	45,160	2	Acute	50% mortality	Lethal	Artificial
Lunz 1987	Saile et al. 1968	Stickleback adult	52,000	1	Acute	Not reported	N/AV	Natural
Wilber and Clarke 2001	Sherk et al. 1974	Mummichog	56,890	2	Acute	90% mortality	Lethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	Striped Killifish	61,360	1	Acute	90% mortality	Lethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	Mummichog	62,170	1	Acute	90% mortality	Lethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	Spot	68,750	1	Acute	10% mortality	Lethal	Natural
Lunz 1987	Stern and Stickle 1978	Spot adult	68,750	1	Acute	Not reported	N/AV	Natural
Lunz 1987	Saile et al. 1968	Cunner adult	72,000	2	Acute	Not reported	N/AV	Natural
Wilber and Clarke 2001	Sherk et al. 1974	Spot	88,000	1	Acute	50% mortality	Lethal	Natural
Wilber and Clarke 2001	Sherk et al. 1975	Striped Killifish	97,200	1	Acute	10% mortality	Lethal	Natural
Lunz 1987	Stern and Stickle 1978	Striped Killfish adult	97,200	1	Acute	Not reported	N/AV	Natural
Lunz 1987	Saile et al. 1968	Cunner adult	100,000	1	Acute	Not reported	N/AV	Natural
Lunz 1987	Saile et al. 1968	Cunner adult	100,000	1	Acute	Not reported	N/AV	Natural
Wilber and Clarke 2001	Sherk et al. 1974	Spot	112,630	1	Acute	90% mortality	Lethal	Natural
Wilber and Clarke 2001	Sherk et al. 1975	Striped Killifish	128,200	1	Acute	50% mortality	Lethal	Natural
Wilber and Clarke 2001	Rogers 1969	Cunner	133,000	0.5	Acute	50% mortality	Lethal	Natural
Lunz 1987	Saile et al. 1968	Cunner adult	133,000	0.5	Acute	Not reported	N/AV	Natural
Wilber and Clarke 2001	Sherk et al. 1974	Striped Killifish	169,300	1	Acute	90% mortality	Lethal	Natural
Wilber and Clarke 2001	Rogers 1969	Sheepshead Minnow	200,000	1	Acute	10% mortality	Lethal	Natural
Wilber and Clarke 2001	Rogers 1969	Fourspine Stickleback	200,000	1	Acute	95% mortality	Lethal	Natural
Wilber and Clarke 2001	Rogers 1969	Sheepshead Minnow	300,000	1	Acute	30% mortality	Lethal	Natural
Lunz 1987	Saile et al. 1968	Mummichog adult	300,000	1	Acute	Not reported	N/AV	Natural
Lunz 1987	Saile et al. 1968	Sheepshead Minnow adult	300,000	1	Acute	Not reported	N/AV	Natural
Wilber and Clarke 2001	Murphy 1985	Northern Quahog	6	14	Chronic	No effect level	Sublethal	Not Reported
Wilber and Clarke 2001	Bricelj et al. 1984	Northern Quahog subadult	10	21	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Bricelj et al. 1984	Northern Quahog subadult	25	21	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Murphy 1985	Northern Quahog	27	14	Chronic	Reduced growth	Sublethal	Not Reported
Wilber and Clarke 2001	Bricelj et al. 1984	Northern Quahog subadult	44	21	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Nimmo et al. 1982	Mysid Shrimp	45	4	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Nimmo et al. 1982	Mysid Shrimp	45	28	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Auld and Schubel 1978	American Shad larvae	100	4	Chronic	13% mortality	Lethal	Natural
Wilber and Clarke 2001	Grant and Thorpe 1991	Softshell Clam	100	14	Chronic	Amonia excretion increase	Sublethal	Natural
Clarke and Wilber 2000	Grant and Thorpe 1991	Softshell Clam	100	15	Chronic	Decreased stimulus response	Sublethal	Natural

Table A-4. Reported Total Suspended Solids (TSS) Effects Concentrations and Relevant Test Variables for Aquatic Organisms.

Primary Reference	Secondary Reference	Species/ Lifestage	Reported Effects Conc. (mg/L TSS)	Test Duration (days)	Duration Category	Response	Response Type	Type of Sediment
Wilber and Clarke 2001	Davis and Hidu 1969	Eastern Oyster larvae	100	12	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Davis and Hidu 1969	Northern Quahog larvae	100	10	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Mackin 1961	Eastern Oyster adult	100	21	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Robinson et al. 1984	Surf Clam	100	21	Chronic	No effect level	Sublethal	Artificial
Wilber and Clarke 2001	Grant and Thorpe 1991	Softshell Clam	100	21	Chronic	Oxygen use decrease	Sublethal	Natural
Wilber and Clarke 2001	Grant and Thorpe 1991	Softshell Clam	100	35	Chronic	Reduced growth	Sublethal	Natural
Wilber and Clarke 2001	Lin et al. 1992	Kuruma Shrimp subadult	180	21	Chronic	10% mortality	Lethal	Natural
Wilber and Clarke 2001	Davis and Hidu 1969	Eastern Oyster larvae	200	12	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Davis and Hidu 1969	Northern Quahog larvae	200	10	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Mackin 1961	Eastern Oyster adult	200	21	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Nimmo et al. 1982	Mysid Shrimp	230	4	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Nimmo et al. 1982	Mysid Shrimp	230	28	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Moore 1978	Bay Scallop	250	7	Chronic	No effect level	Sublethal	Artificial
Wilber and Clarke 2001	Moore 1978	Bay Scallop	250	14	Chronic	No effect level	Sublethal	Artificial
Wilber and Clarke 2001	Davis and Hidu 1969	Eastern Oyster larvae	300	12	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Davis and Hidu 1969	Northern Quahog larvae	300	10	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Mackin 1961	Eastern Oyster adult	300	21	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Kiorboe et al. 1981	Atlantic Herring eggs	300	11	Chronic	Normal egg development level	Sublethal	Natural
Wilber and Clarke 2001	Lin et al. 1992	Kuruma Shrimp subadult	370	21	Chronic	32% mortality	Lethal	Natural
Wilber and Clarke 2001	Davis and Hidu 1969	Eastern Oyster larvae	400	12	Chronic	10% mortality	Lethal	Natural
Wilber and Clarke 2001	Davis and Hidu 1969	Northern Quahog larvae	400	10	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Mackin 1961	Eastern Oyster adult	400	21	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Davis and Hidu 1969	Eastern Oyster larvae	500	12	Chronic	18% mortality	Lethal	Natural
Wilber and Clarke 2001	Auld and Schubel 1978	Yellow Perch larvae	500	4	Chronic	30% mortality	Lethal	Natural
Wilber and Clarke 2001	Auld and Schubel 1978	American Shad larvae	500	4	Chronic	32% mortality	Lethal	Natural
Wilber and Clarke 2001	Moore 1978	Bay Scallop	500	7	Chronic	Higher respiration	Sublethal	Artificial
Wilber and Clarke 2001	Moore 1978	Bay Scallop	500	14	Chronic	Higher respiration	Sublethal	Artificial
Clarke and Wilber 2000	Auld and Schubel 1978	White Perch larvae	500	4	Chronic	Increased mortality	Lethal	Not Reported
Wilber and Clarke 2001	Davis and Hidu 1969	Northern Quahog larvae	500	10	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Mackin 1961	Eastern Oyster adult	500	21	Chronic	No effect level	Sublethal	Natural
Priest 1981	Davis 1960	Hard clam larvae	500	12	Chronic	Not reported	N/AV	Artificial
Wilber and Clarke 2001	Robinson et al. 1984	Surf Clam	500	21	Chronic	Reduced growth	Sublethal	Artificial
Wilber and Clarke 2001	Mackin 1961	Eastern Oyster adult	590	20	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Sherk et al. 1974	Striped Bass	600	11	Chronic	No effect level	Sublethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1975	White Perch	650	5	Chronic	Increased hematocrit levels	Sublethal	Artificial
Wilber and Clarke 2001	Mackin 1961	Eastern Oyster adult	710	20	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Davis and Hidu 1969	Northern Quahog larvae	750	10	Chronic	10% mortality	Lethal	Natural
Wilber and Clarke 2001	Davis and Hidu 1969	Eastern Oyster larvae	750	12	Chronic	30% mortality	Lethal	Natural
Clarke and Wilber 2000	Davis 1960	Hard clam larvae	750	12	Chronic	Mortality	Lethal	Natural
Priest 1981	Davis and Hidu 1969	American Oyster larvae	750	12	Chronic	Mortality	Lethal	Natural
Wilber and Clarke 2001	Davis and Hidu 1969	Eastern Oyster larvae	750	12	Chronic	Reduced growth	Sublethal	Natural
Wilber and Clarke 2001	Sherk et al. 1974	Striped Killifish	960	5	Chronic	Increased hematocrit levels	Sublethal	Artificial
Wilber and Clarke 2001	Davis and Hidu 1969	Northern Quahog larvae	1,000	10	Chronic	10% mortality	Lethal	Natural
Wilber and Clarke 2001	McFarland and Peddicord 198	Shiner Perch	1,000	4	Chronic	10% mortality	Lethal	Not Reported
Wilber and Clarke 2001	Wakeman et al. 1975	Black-tailed Sand Shrimp	1,000	10	Chronic	10% mortality	Lethal	Artificial
Wilber and Clarke 2001	Auld and Schubel 1978	American Shad larvae	1,000	4	Chronic	29% mortality	Lethal	Natural
Wilber and Clarke 2001	Davis and Hidu 1969	Eastern Oyster larvae	1,000	12	Chronic	40% mortality	Lethal	Natural
Wilber and Clarke 2001	Moore 1978	Bay Scallop	1,000	7	Chronic	Higher respiration	Sublethal	Artificial
Wilber and Clarke 2001	Moore 1978	Bay Scallop	1,000	14	Chronic	Higher respiration	Sublethal	Artificial

Table A-4. Reported Total Suspended Solids (TSS) Effects Concentrations and Relevant Test Variables for Aquatic Organisms.

Primary Reference	Secondary Reference	Species/ Lifestage	Reported Effects Conc. (mg/L TSS)	Test Duration (days)	Duration Category	Response	Response Type	Type of Sediment
Wilber and Clarke 2001	Auld and Schubel 1978	Alewife eggs	1,000	4	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Auld and Schubel 1978	American Shad eggs	1,000	4	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Auld and Schubel 1978	Blueback Herring eggs	1,000	4	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Auld and Schubel 1978	Yellow Perch eggs	1,000	4	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Auld and Schubel 1978	Striped Bass eggs	1,000	7	Chronic	Reduced hatching success	Lethal	Natural
Wilber and Clarke 2001	Auld and Schubel 1978	White Perch eggs	1,000	7	Chronic	Reduced hatching success	Lethal	Natural
Wilber and Clarke 2001	Nimmo et al. 1982	Mysid Shrimp	1,020	4	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Nimmo et al. 1982	Mysid Shrimp	1,020	28	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Wakeman et al. 1975	Striped Bass larvae	1,200	10	Chronic	10% mortality	Lethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	Hogchoker	1,240	5	Chronic	Increased hematocrit levels	Sublethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	Spot	1,270	5	Chronic	No effect level	Sublethal	Artificial
Wilber and Clarke 2001	Davis and Hidu 1969	Northern Quahog larvae	1,500	10	Chronic	10% mortality	Lethal	Natural
Wilber and Clarke 2001	Davis and Hidu 1969	Eastern Oyster larvae	1,500	12	Chronic	58% mortality	Lethal	Natural
Wilber and Clarke 2001	Sherk et al. 1974	Striped Bass	1,500	14	Chronic	Increased hematocrit levels	Sublethal	Artificial
Wilber and Clarke 2001	Sherk et al. 1974	Mummichog	1,620	4	Chronic	Increased hematocrit levels	Sublethal	Artificial
Wilber and Clarke 2001	Peddicord 1980	Coast Mussel	1,900	20	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Davis and Hidu 1969	Northern Quahog larvae	2,000	10	Chronic	10% mortality	Lethal	Natural
Wilber and Clarke 2001	Wakeman et al. 1975	Blue Mussel	2,000	10	Chronic	10% mortality	Lethal	Artificial
Wilber and Clarke 2001	Davis and Hidu 1969	Eastern Oyster larvae	2,000	12	Chronic	75% mortality	Lethal	Natural
Wilber and Clarke 2001	Peddicord 1976	Blue Mussel	2,000	20	Chronic	No effect level	Sublethal	Artificial
Priest 1981	Davis and Hidu 1969	American Oyster larvae	2,000	12	Chronic	Not reported	N/AV	Artificial
Wilber and Clarke 2001	Peddicord 1980	Black-tailed Sand Shrimp	2,500	21	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Davis and Hidu 1969	Northern Quahog larvae	3,000	10	Chronic	15% mortality	Lethal	Natural
Wilber and Clarke 2001	Davis and Hidu 1969	Eastern Oyster larvae	3,000	12	Chronic	99% mortality	Lethal	Natural
Lunz 1987	Priest 1981	Dungeness Crab adult	3,500	21	Chronic	Not reported	N/AV	Natural
Wilber and Clarke 2001	McFarland and Peddicord 198	Shiner Perch	3,600	4	Chronic	20% mortality	Lethal	Not Reported
Wilber and Clarke 2001	Peddicord 1980	Coast Mussel	3,700	20	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Davis and Hidu 1969	Northern Quahog larvae	4,000	11	Chronic	30% mortality	Lethal	Natural
Wilber and Clarke 2001	Peddicord 1976	Blue Mussel	4,000	20	Chronic	No effect level	Sublethal	Artificial
Lunz 1987	Priest 1981	Striped Bass subadult	4,000	21	Chronic	Not reported	N/AV	Natural
Lunz 1987	Yagi et al. 1977	American Oyster adult	4,000	Extended	Chronic	Not reported	N/AV	Not Reported
Wilber and Clarke 2001	McFarland and Peddicord 198	Shiner Perch	6,000	4	Chronic	50% mortality	Lethal	Not Reported
Wilber and Clarke 2001	Peddicord 1976	Blue Mussel	8,000	20	Chronic	No effect level	Sublethal	Artificial
Wilber and Clarke 2001	Peddicord 1980	Coast Mussel	8,100	17	Chronic	10% mortality	Lethal	Natural
Wilber and Clarke 2001	Peddicord 1980	Black-tailed Sand Shrimp	8,400	21	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Wakeman et al. 1975	Black-tailed Sand Shrimp	9,000	10	Chronic	10% mortality	Lethal	Artificial
Wilber and Clarke 2001	McFarland and Peddicord 197	Dungeness Crab	9,200	8	Chronic	5% mortality	Lethal	Natural
Wilber and Clarke 2001	McFarland and Peddicord 198	Dungeness Crab	10,000	8	Chronic	10% mortality	Lethal	Artificial
Wilber and Clarke 2001	Wakeman et al. 1975	Blue Mussel	10,000	10	Chronic	10% mortality	Lethal	Artificial
Wilber and Clarke 2001	McFarland and Peddicord 198	Coast Mussel	10,000	10	Chronic	20-40% mortality	Lethal	Artificial
Clarke and Wilber 2000	Grant and Thorpe 1991	Bivalves adult	10,000	21	Chronic	Mortality	Lethal	Natural
Nightingale et al. 2001	Ross 1982	Chinook Salmon smolts	11,000	4	Chronic	50% mortality	Lethal	Not Reported
Wilber and Clarke 2001	Peddicord 1976	Blue Mussel	11,000	20	Chronic	No effect level	Sublethal	Artificial
Wilber and Clarke 2001	Peddicord 1980	Coast Mussel subadult	11,600	20	Chronic	10% mortality	Lethal	Natural
Wilber and Clarke 2001	McFarland and Peddicord 197	Dungeness Crab	11,700	7	Chronic	20% mortality	Lethal	Natural
Wilber and Clarke 2001	Peddicord 1980	Black-tailed Sand Shrimp	11,900	5	Chronic	10% mortality	Lethal	Natural
Wilber and Clarke 2001	Sherk et al. 1974	Spot	14,680	7	Chronic	No effect level	Sublethal	Natural
Wilber and Clarke 2001	Peddicord 1976	Blue Mussel	15,000	8	Chronic	0-20% mortality	Lethal	Artificial
Wilber and Clarke 2001	Peddicord 1980	Coast Mussel subadult	15,500	20	Chronic	10% mortality	Lethal	Natural

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Primary Reference	Secondary Reference	Species/ Lifestage	Reported Effects Conc. (mg/L TSS)	Test Duration (days)	Duration Category	Response	Response Type	Type of Sediment
Wilber and Clarke 2001	Peddicord 1980	Coast Mussel subadult	15,500	16	Chronic	20-40% mortality	Lethal	Natural
Wilber and Clarke 2001	McFarland and Peddicord 197	Dungeness Crab subadult	15,900	9	Chronic	15% mortality	Lethal	Natural
Wilber and Clarke 2001	McFarland and Peddicord 198	Spot-tailed Sand Shrimp	16,000	8	Chronic	10% mortality	Lethal	Artificial
Wilber and Clarke 2001	McFarland and Peddicord 197	Dungeness Crab subadult	18,900	4	Chronic	20% mortality	Lethal	Natural
Wilber and Clarke 2001	Peddicord 1976	Blue Mussel	19,000	20	Chronic	No effect level	Sublethal	Artificial
Wilber and Clarke 2001	Peddicord 1980	Coast Mussel subadult	19,500	20	Chronic	10% mortality	Lethal	Natural
Lunz 1987	Priest 1981	Black-tailed Shrimp subadul	21,500	21	Chronic	Not reported	N/AV	Natural
Wilber and Clarke 2001	McFarland and Peddicord 198	Grass Shrimp	24,000	10	Chronic	10% mortality	Lethal	Artificial
Wilber and Clarke 2001	McFarland and Peddicord 198	Dungeness Crab	32,000	8	Chronic	50% mortality	Lethal	Artificial
Lunz 1987	Yagi et al. 1977	American Oyster adult	32,000	Extended	Chronic	Not reported	N/AV	Not Reported
Wilber and Clarke 2001	McFarland and Peddicord 198	Spot-tailed Sand Shrimp	50,000	8	Chronic	50% mortality	Lethal	Artificial
Lunz 1987	Peddicord and McFarland 197	Spot-tailed Shrimp adult	50,000	8.33	Chronic	Not reported	N/AV	Artificial
Wilber and Clarke 2001	Wakeman et al. 1975	Blue Mussel	60,000	10	Chronic	10% mortality	Lethal	Artificial
Wilber and Clarke 2001	McFarland and Peddicord 198	Coast Mussel	75,000	6	Chronic	20-40% mortality	Lethal	Artificial
Wilber and Clarke 2001	McFarland and Peddicord 198	Grass Shrimp	77,000	8	Chronic	20% mortality	Lethal	Artificial
Wilber and Clarke 2001	McFarland and Peddicord 198	Coast Mussel	80,000	11	Chronic	50% mortality	Lethal	Artificial
Wilber and Clarke 2001	McFarland and Peddicord 198	Coast Mussel	85,000	9	Chronic	50% mortality	Lethal	Artificial
Lunz 1987	Peddicord and McFarland 197	Blue Mussel adult	96,000	8.33	Chronic	Not reported	N/AV	Artificial
Wilber and Clarke 2001	McFarland and Peddicord 198	Blue Mussel	100,000	11	Chronic	10% mortality	Lethal	Artificial
Wilber and Clarke 2001	McFarland and Peddicord 198	Blue Mussel subadult	100,000	5	Chronic	10% mortality	Lethal	Artificial
White Paper	Nightingale and Simenstad 20	Crustaceans	100,000	14	Chronic	Mortality	Lethal	Not Reported
Lunz 1987	Peddicord and McFarland 197	Blue Mussel adult	100,000	11	Chronic	Not reported	N/AV	Artificial
Lunz 1987	Peddicord and McFarland 197	Blue Mussel subadult	100,000	5	Chronic	Not reported	N/AV	Artificial
White Paper	Chiasson 1993	Rainbow Smelt	10	Not Reported	Chronic (assumed)	Increased swimming behaivor	Sublethal	Not Reported
Clarke and Wilber 2000	Urban and Kirchman 1992	American Oyster subadult	20	Not Reported	Chronic (assumed)	Feeding effected	Sublethal	Artificial
Lunz 1987	Morton 1977	Striped Bass Eggs	20	Not Reported	Chronic (assumed)	Not reported	N/AV	Natural
Lunz 1987	Morton 1977	White Perch Eggs	30	Not Reported	Chronic (assumed)	Not reported	N/AV	Natural
Lunz 1987	Schubel et al. 1977	Alewife eggs	50	Not Reported	Chronic (assumed)	Not reported	N/AV	Natural
Lunz 1987	Schubel et al. 1977	Striped Bass eggs	50	Not Reported	Chronic (assumed)	Not reported	N/AV	Natural
Lunz 1987	Schubel et al. 1977	White Perch eggs	50	Not Reported	Chronic (assumed)	Not reported	N/AV	Natural
Lunz 1987	Schubel et al. 1977	Yellow Perch eggs	50	Not Reported	Chronic (assumed)	Not reported	N/AV	Natural
Lunz 1987	Martin Marietta 1975	Eastern Oyster adult	100	Not Reported	Chronic (assumed)	Not reported	N/AV	Natural
Priest 1981	Davis 1960	Hard clam eggs	125	Not Reported	Chronic (assumed)	Not reported	N/AV	Artificial
Priest 1981	Davis 1960	Hard clam eggs	125	Not Reported	Chronic (assumed)	Not reported	N/AV	Artificial
Clarke and Wilber 2000	Davis and Hidu 1969	American Oyster eggs	188	Not Reported	Chronic (assumed)	Development effected	Sublethal	Natural
Priest 1981	Davis and Hidu 1969	American Oyster eggs	250	Not Reported	Chronic (assumed)	Not reported	N/AV	Natural
Priest 1981	Davis and Hidu 1969	American Oyster eggs	375	Not Reported	Chronic (assumed)	Not reported	N/AV	Natural
Priest 1981	Davis and Hidu 1969	American Oyster larvae	500	Not Reported	Chronic (assumed)	Not reported	N/AV	Artificial
Lunz 1987	Schubel et al. 1977	Alewife eggs	500	Not Reported	Chronic (assumed)	Not reported	N/AV	Natural
Lunz 1987	Schubel et al. 1977	Striped Bass eggs	500	Not Reported	Chronic (assumed)	Not reported	N/AV	Natural
Lunz 1987	Schubel et al. 1977	White Perch eggs	500	Not Reported	Chronic (assumed)	Not reported	N/AV	Natural
Lunz 1987	Schubel et al. 1977	Yellow Perch eggs	500	Not Reported	Chronic (assumed)	Not reported	N/AV	Natural
Lunz 1987	Martin Marietta 1975	Eastern Oyster adult	700	Not Reported	Chronic (assumed)	Not reported	N/AV	Natural
Priest 1981	Davis 1960	Hard clam eggs	750	Not Reported	Chronic (assumed)	Development effected	Sublethal	Natural
White Paper	Mulholland 1983	Hard clams eggs	1,000	Not Reported	Chronic (assumed)	Development effects	Sublethal	Not Reported
Priest 1981	Davis and Hidu 1969	American Oyster eggs	1,000	Not Reported	Chronic (assumed)	Not reported	N/AV	Artificial
Priest 1981	Davis 1960	Hard clam eggs	1,500	Not Reported	Chronic (assumed)	Not reported	N/AV	Natural
Priest 1981	Davis and Hidu 1969	American Oyster eggs	2,000	Not Reported	Chronic (assumed)	Not reported	N/AV	Artificial
Lunz 1987	Morton 1977	Striped Bass Eggs	2,300	Not Reported	Chronic (assumed)	Not reported	N/AV	Natural

Table A-4. Reported Total Suspended Solids (TSS) Effects Concentrations and Relevant Test Variables for Aquatic Organisms.

Primary Reference	Secondary Reference	Species/ Lifestage	Reported Effects Conc. (mg/L TSS)	Test Duration (days)	Duration Category	Response	Response Type	Type of Sediment
White Paper	Nightingale and Simenstad 20	Fish	4,000	Not Reported	Chronic (assumed)	Erosion at gill filament tips	Sublethal	Not Reported
Priest 1981	Davis and Hidu 1969	Hard clam eggs	4,000	Not Reported	Chronic (assumed)	Not reported	N/AV	Artificial
Lunz 1987	Morton 1977	White Perch Eggs	5,000	Not Reported	Chronic (assumed)	Not reported	N/AV	Natural
Clarke and Wilber 2000	Messieh et al 1981	Atlantic Herring eggs	7,000	Not Reported	Chronic (assumed)	No Effect	Sublethal	Not Reported
Lunz 1987	Schreck 1981	American Lobster adult	50,000	Not Reported	Chronic (assumed)	Not reported	N/AV	Artificial

Table A-5. Reported Behavioral Effects Levels from Turbidity (NTU) for Finfish.

Primary Reference	Secondary Reference	Species/Lifestage	Effects Level (NTU)	Duration Category	Response	Response Type	Comment
Lloyd 1987	Swenson 1978	Lake trout	6.0	Acute	Avoidance	Sublethal	
Lloyd 1987	Gradall and Swenson 1982	Brook trout	7.0	Acute	Altered feeding	Sublethal	
Vogel and Beauchamp 1999	Vogel and Beauchamp 1999	Lake trout	7.4	Acute	Altered reaction distance	Sublethal	
Lloyd 1987	Bachman 1984	Brown trout	7.5	Acute	Reduced feeding	Sublethal	Reported in JTU
Lloyd 1987	Berg 1982	Coho salmon juveniles	10	Acute	Reduced feeding	Sublethal	Reported in FTU
Benfield and Minello 1996	Grecay 1990	Weakfish juvenile	11	Acute	Reduced feeding	Sublethal	
Rowe and Dean 1998	Rowe and Dean 1998	Kokopu	20	Acute	Reduced feeding	Sublethal	
Lloyd 1987	Sigler 1980	Coho salmon juveniles	22	Acute	Avoidance	Sublethal	
Lloyd 1987	Bell 1984	N/AV	25	Acute	Altered feeding	Sublethal	
Lloyd 1987	Langer 1980	Trout	25	Acute	Altered feeding	Sublethal	
Nightingale and Simenstad	Berg and Northcote 1984	Coho salmon juveniles	30	Acute	Feeding behaivors et al.	Sublethal	
Sweka and Hartman 2000	Sweka and Hartman 2000	Brook trout	40	Acute	No effect in feeding rate	Sublethal	Reported in JTU
Lloyd 1987	Sigler 1980	Coho salmon juveniles	40	Acute	Displacement	Sublethal	Reported in FTU
Rowe and Dean 1998	Rowe and Dean 1998	Redfinned bullies	40	Acute	Reduced feeding	Sublethal	Reported in JTU
Sweka and Hartman 1999	Sweka and Hartman 1999	Brook trout	40	Acute	Reactive distance	Sublethal	
Sweka and Hartman 1999	Sweka and Hartman 1999	Smallmouth bass	40	Acute	Reactive distance	Sublethal	
Lloyd 1987	Sigler 1980	Coho salmon juveniles	50	Acute	Displacement	Sublethal	
Lloyd 1987	Berg 1982	Coho salmon juveniles	60	Acute	Reduced feeding	Sublethal	
Berg 1982	Berg 1982	Salmon	60	Acute	Feeding rate	Sublethal	
Lloyd 1987	Bisson and Bilby 1982	Coho salmon juveniles	70	Acute	Avoidance	Sublethal	
Reid et al. 1999	Reid et al. 1999	Largemouth Bass	70	Acute	Reduced feeding	Sublethal	
Lloyd 1987	Olson et al 1973	Rainbow trout	70	Acute	Reduced feeding	Sublethal	
Benfield and Minello 1996	Benfield and Minello 1996	Killifish	100	Acute	Reduced feeding	Sublethal	
Rowe and Dean 1998	Rowe and Dean 1998	Common bullies	160	Acute	Reduced feeding	Sublethal	
Rowe and Dean 1998	Rowe and Dean 1998	Inanga	160	Acute	Reduced feeding	Sublethal	
Rowe and Dean 1998	Rowe and Dean 1998	Smelt	160	Acute	Reduced feeding	Sublethal	
Lloyd 1987	Sigler 1980	Coho salmon juveniles	265	Acute	Avoidance	Sublethal	

NTU - Nephelometric Turbidity Units

JTU - Jackson Turbidity Units

FTU - Formazin Turbidity Units

Table A-6. Compilation of Los Angeles Regional Background Total Suspended Sediments (TSS) Data (see text for references)

Site	Date	Depth (m)	Distance	TSS (mg/L)
LARE	13-Aug-02	1	Background	2
LARE	13-Aug-02	1	Background	2
LARE	24-Aug-02	1	Background	6
LARE	24-Aug-02	1	Background	6
LARE	17-Aug-02	1	Background	8
LARE	24-Aug-02	8	Background	8
LARE	17-Aug-02	1	Background	8
LARE	24-Aug-02	8	Background	8
Pier T	23-Oct-00	5	Background	10
Berth 167-169	8-Oct-01	7	Background	13
Berth 212-215	8-Oct-01	7	Background	13
LARE	6-Aug-02	1	Background	14
LARE	6-Aug-02	1	Background	14
Pier T	10-Jan-01	7	Background	17
Berth 148-151	27-Aug-01	8	Background	18
Pier T	23-Nov-99	6	Background	19
Pier T	13-Jul-99	3	Background	21
Pier T	10-Aug-99	3	Background	21
Pier T	2-Mar-00	8	Background	23
Pier T	5-Feb-01	7	Background	23
Pier T	5-Feb-01	7	Background	23
Pier T	8-Dec-99	6	Background	24
Berth 148-151	8-Oct-01	8	Background	27
Berth 261-265	8-Oct-01	3	Background	27
Berth 71	20-Nov-01	8	Background	28
Pier T	29-Sep-99	6	Background	29
Berth 167-169	15-Aug-01	7	Background	30
Pier T	16-Jul-01	7	Background	31
Pier T	10-Jan-01	7	Background	33
Pier T	19-Oct-99	7	Background	34
Pier T	2-Aug-01	7	Background	34
Berth 167-169	29-Aug-01	7	Background	35
Pier T	29-May-01	6	Background	36
Berth 212-215	23-Aug-01	8	Background	38
Pier T	17-May-99	4	Background	39
Pier T	23-Jan-01	9	Background	39
Pier T	2-Jul-01	8	Background	39
Pier T	23-Jan-01	7	Background	39
Pier T	19-Mar-99	7	Background	41
Pier E	6-Apr-99	8	Background	41
Pier T	14-Sep-00	8	Background	41
Pier T	20-Apr-99	4	Background	42
Berth 71	25-Oct-01	8	Background	43
Pier T	24-Apr-01	7	Background	44
Pier T	24-Apr-01	7	Background	44
Berth 261-265	4-Sep-01	3	Background	44
Pier T	10-Jun-99	8	Background	45
Berth 71	15-Aug-01	8	Background	47
Berth 71	8-Oct-01	8	Background	65
Pier T	18-Jun-01	7	Background	91
Pier T	30-Jun-00	N/AV	Background	100
Pier T	4-Oct-00	4	Background	200
Pier T	18-Sep-00	7	Background	330
Pier T	18-Sep-00	8	Background	330

Table A-7. Calculated Turbidities (in NTU) from Reported Site-Specific Correlations with TSS (for a range of potential TSS concentrations). (see text for references)

Assumed TSS (mg/L)	MBC 2000 NTU	Mobile Bay Field NTU	Mobile Bay Lab NTU	Middle Ground Is. NTU	Kings Bay NTU	Calcescieu R1 NTU	Calcescieu R2 NTU	Calcescieu R3 NTU	Port of Everett NTU	Yakima River NTU	Arkansas River NTU
0	-37	3	3	2	1	2	1	1	3	1	2
50	-17	38	31	23	13	13	11	9	28	30	63
100	4	74	59	45	26	23	21	18	53	55	117
150	24	110	88	66	39	34	31	27	79	78	169
200	45	145	116	87	52	45	41	36	104	101	219
250	65	181	144	109	65	55	51	44	130	122	268
300	85	217	173	130	77	66	61	53	155	144	315
350	106	253	201	151	90	77	70	62	181	164	362
400	126	288	229	173	103	87	80	71	206	185	409
450	147	324	258	194	116	98	90	79	232	204	454
500	167	360	286	216	129	108	100	88	257	224	499
550	188	395	314	237	141	119	110	97	282	244	544
600	208	431	343	258	154	130	120	106	308	263	588
650	229	467	371	280	167	140	130	115	333	282	632
700	249	502	399	301	180	151	140	123	359	301	676
750	269	538	428	322	193	162	150	132	384	319	719
800	290	574	456	344	205	172	160	141	410	338	762
850	310	609	484	365	218	183	170	150	435	356	805
900	331	645	513	387	231	194	180	158	461	374	847
950	351	681	541	408	244	204	190	167	486	392	889
1,000	372	716	569	429	257	215	199	176	511	410	931
1,050	392	752	598	451	269	226	209	185	537	428	973
1,100	413	788	626	472	282	236	219	193	562	446	1,014
1,150	433	824	654	493	295	247	229	202	588	463	1,056
1,200	454	859	683	515	308	258	239	211	613	481	1,097
1,250	474	895	711	536	321	268	249	220	639	498	1,138
1,300	494	931	739	558	333	279	259	228	664	515	1,179
1,350	515	966	768	579	346	290	269	237	689	533	1,219
1,400	535	1,002	796	600	359	300	279	246	715	550	1,260
1,450	556	1,038	824	622	372	311	289	255	740	567	1,300
1,500	576	1,073	853	643	385	321	299	263	766	584	1,341

NTU - Nephelometric Turbidity Units
TSS - Total Suspended Solids

APPENDIX B

SUPPLEMENTAL DATA INVESTIGATION: EVALUATION OF ELUTRIATE BIOASSAY DATA

INTRODUCTION

Using the sediment quality database developed for the CSTF, a supplemental investigation was conducted to evaluate the potential for biological effects resulting from contaminated resuspended sediments. This bioassay database contains bulk sediment chemistry, grain size, and bioassay response results conducted on numerous dredge characterization elutriate samples from the Los Angeles region. These tests were conducted to evaluate dredge materials for suitability for open water disposal. Testing was conducted following the procedures outlined in the Inland Testing Manual (EPA and Army Corps 1998). Generally, the testing procedure is to mix sediments with sea water, allow the sediments to settle for a short time, then expose aquatic organisms to the resulting elutriate water, and finally, observe the level of response (e.g., percent mortality, normal growth, etc.) in those organisms.

An exploratory analysis was conducted with these data sets to determine whether bioassay responses could be related either to suspended sediments in the tests and/or the chemical concentrations in the bulk sediment being tested. It was hypothesized that this large database may contain information that is relevant to the expected suspended sediment or chemical levels that could be toxic to aquatic organisms affected by resuspended sediments during dredging operations. This appendix presents the methods and results of the exploratory data analysis and conclusions regarding the relevance of these data to determining potential toxic levels related to resuspension of dredge sediments.

METHODS

Determination of Suspended Sediment (TSS) Concentrations in Bioassay Tests

The testing procedures do not require that suspended sediments concentrations be directly measured in the test elutriates. Consequently, to assess the potential effects of suspended sediment, some method was needed to estimate the concentration of total suspended sediments (TSS) that might have been present in the test samples.

This was accomplished by reviewing the test procedures and making a mass balance estimate based on the settling rates that would be expected for various particle sizes in the sediments.

The elutriate test procedures (as defined in the Inland Testing Manual) are:

- Combine sediment and water in a 4:1 volumetric ratio
- Stir mixture vigorously for 30 minutes
- Allow mixture to settle for 1 hr
- Siphon off supernatant without disturbing settled material
- If sediment is very fine grained, centrifuge supernatant until organisms are visible in test chamber.
- Expose organisms to elutriate for 96 hours (4 days).

Assuming that the centrifuge step is not conducted, the mass of suspended sediment present in the elutriate (or supernatant) during the test can be calculated as follows:

For grain sizes that meet the condition: $\frac{Vg * Ts}{H} > 1$

$$TSS = \Sigma\ [Fg*R*Pb*DF]$$

where:

TSS = Total suspended sediments at Ts
Vg = Stokes settling velocity of particle grain size g (cm/sec)
Ts = Time that settling occurs during test (sec)
H = Height of test vessel (cm)
Fg = Fraction of particles of size g (by weight) in sediments
Pb = Bulk density of sediments (mg/L)
R = Volumetric ratio of sediments to water (unitless)
DF = Elutriate test dilution factor (unitless).

The time of settling was set equal to the mid-point of the test (48 hours) plus the time for the supernatant settling time (1 hr) for a total of 49 hours. The height of the test vessel was arbitrarily assumed to be 30 cm. The fraction of particles at each grain size was provided by the sediment grain size analysis in the database. The bulk density of the sediments was set equal to a typical value for silty sand (1.6 g/ml). Note that it is unclear whether the assumption of no centrifuging is applicable to the most of the tests, since information on centrifuging was not available from the database. This is a large source of uncertainty in the TSS estimate.

Determination of Total Sediments (TS) in Bioassay Tests

In addition to estimating the suspended sediment concentrations, the total amount of sediments initially used in the test was calculated. This estimate was made to investigate whether the total amount of sediment initially suspended in the test vessel was correlated with bioassay response. It was hypothesized that the total sediment present might be more related to the mass of contaminant desorption during the test (as compared to suspended sediments only). The total sediment concentration was estimated by multiplying the volume of sediment used in the test by the bulk density and dividing by the volume of water in the test including any elutriate dilution. A range of values was calculated assuming various bulk sediment densities ranging from 1.6 kg/L to 0.8 Kg/L.

Data Analysis

Linear regression correlations were calculated for values for TSS and TS vs. bioassay responses reported in the database. The general distributions of these values across the distribution of bioassay responses were also evaluated to see if there were any relationships between parameters.

The above exploratory analysis indicated a discernable relationship between TSS and bioassay response. From this information a “no effects” level was calculated by determining the TSS concentration at which less than 5% of the bioassays showed a substantial response. The 5th percentile of the distribution of bioassay responses was then used as a general guide for picking a no effects level, although selection of this value is arbitrary. A substantial bioassay response was defined as less than 80% normal/survivorship compared to control response. This statistic was calculated for all species combined as well as for individual species.

Finally, bulk sediment chemistry results associated with bioassay responses were examined to determine potential correlations. The chemical data set was reviewed and three "representative" chemicals were selected for further analysis. Chemicals were deemed representative when they were present in the data set across a wide range of sediment concentrations, were detected in a substantial percentage of the total sediment samples, and were characteristic of a larger group of commonly detected chemicals (i.e., metals, polycyclic aromatic hydrocarbons, and pesticides).

It was hypothesized based on general partitioning principles that bulk sediment chemical concentrations would be related to elutriate chemical concentrations, which in turn would be related to bioassay responses. This extrapolation was necessary because no direct measurement of elutriate test chemical concentrations was available for these samples. It was further assumed that the relationship between bulk sediment chemical concentrations and bioassay responses would also be heavily influenced by elutriate dilutions used for the bioassay tests. To allow for this variable, the bulk sediment chemistry concentrations were divided by the dilution factor of each test (e.g., 100, 10, 4, 2, or 1).

The dilution corrected sediment chemical concentrations were compared to bioassay responses using the same approach as described above for TSS. A "no effects" level was calculated based on a concentration at which less than 5% of the bioassays showed substantial responses. In addition, a similar calculation was also conducted using non-dilution corrected bulk sediment chemistry values. It was assumed that this later calculation might have some value for determination of when effects related to dredging might be expected based on bulk sediment chemistry alone.

RESULTS

Bioassay results related to physical measures (TS and TSS) are discussed first, followed by chemical measures.

TS and TSS Relationships to Bioassay Responses

The TS concentration in the elutriate tests was calculated to range between 200,000 to 400,000 mg/L (with the range created by different assumptions of the sediments bulk solids density). This relatively high value is obtained because the sediments are forced to completely suspend (at least initially) in the test vessel by shaking at the initiation of the test. Accounting for dilutions of this initial elutriate (from 1 to 0.01) used in the bioassay tests, the range of TS expands to 2,000 to 400,000 mg/L. For the remainder of the data analysis, calculated values associated with the higher bulk sediment density only were used. TSS concentrations including dilution factors were calculated to range approximately from 58 to 57,000 mg/L.

Exploratory Data Analysis

When all bioassay response data are plotted versus calculated TSS concentrations expected in the tests, a somewhat random pattern is observed as shown in Figure B-1. However, this pattern does not appear to be completely random because a relatively greater number of substantial responses (e.g., <80% normal survivorship) appear to occur in the high TSS tests. A comparison of this relationship to TS showed a similar pattern of results (Figure B-2).

The frequency with which negative responses are found at higher TS and TSS concentrations is better illustrated in Figures B-3 and B-4, where the number of substantial responses or “hits” (bioassay responses exhibiting <80% normal survivorship) is compared to the number of tests conducted at various TS or TSS concentrations. Clearly, the percentage of test results that are “hits” is greater in samples with higher TS or TSS concentrations. This pattern is illustrated in another way in Figures B-5 and B-6, where cumulative frequencies of bioassay responses are plotted for categories of TS and TSS concentrations. As the TS or TSS concentrations increase, the likelihood of negative responses also increases. For example, in Figure B-5, at TS concentrations of 400,000 mg/L, about 20% of the samples are “hits” (i.e., show <80% normal survivorship) while at 4,000 mg/L less than 5% of the samples are “hits”. Similarly, in Figure B-6, at TSS concentrations of 50,000 to 60,000 mg/L about 55% of the tests are “hits”, while at 10,000 mg/L or less TSS, less than 5% of the tests are “hits”.

TSS Effects Estimate for All Data

From these overall data distributions a type of "no effect level" for TSS can be approximately estimated. (This same estimate cannot be made for TS because there are only four values, based on the four dilution factors, in the distribution of TS.) Figure B-7 shows how the 5th percentile of the bioassay response distribution changes as each new elutriate test record is added (when they are sorted in order of ascending TSS concentrations). As Figure B-7 shows, the 5th percentile of the distribution of bioassays for all species falls permanently below 80% normal survivorship at 9,272 mg/L, which would be the approximate "no effects level". That is, substantial bioassay effects are observed in the data set in only about 5% of the reports at or below this TSS concentration.

TSS Effects Estimates by Species

Similar comparisons were made for each species and are summarized in Figures B-8 through B-11. The range of no effects levels, by the above definitions, was from 1,867 mg/L for *Mytilus edulis* to 15,067 mg/L for *Mysidopsis bahia*. For *Crassostrea gigas*, *Citharichthys stigmaeus*, and *Menidia beryllina* the 5th percentile was at or above the 80% normal survival level in all cases, so these species were not sensitive to TSS concentrations (at least in the ranges tested).

Chemistry Relationship to Bioassay Responses

Review of the database indicated that zinc, DDE, and pyrene were the most representative chemicals for further analysis, based on the criteria detailed in the methods section. Bulk sediment chemistry concentrations for these three chemicals were compared to bioassay responses. Attempted correlations via linear regression resulted in the same relatively scattered patterns observed for the TSS regression analyses. Consequently, further exploratory comparisons of the distributions of chemical concentrations as compared to bioassay responses were not attempted.

Instead, potential "no effects" levels were estimated for each chemical using the same statistical summarization approach as described for TSS. The results of this estimate are shown for dilution corrected sediment chemical concentrations in Figure B-12 and non-dilution corrected chemical concentration results are shown in

Figure B-13. As Figure B-12 depicts, the 5th percentile response falls below <80% normal/survivorship at very low concentrations for all three chemicals. This and the overall randomness of the 5th percentile distribution would indicate that there is often very little if any relationship between concentrations of these particular chemicals and observed bioassay responses.

However, for both zinc and pyrene, the 5th percentile bioassay response falls permanently below the 70% normal/survivorship level at about 104 mg/kg and 90 ug/kg. A similar relatively random pattern is also seen for non-dilution corrected samples in Figure B-13 for all three chemicals. In this case, the 5th percentile bioassay response falls permanently below the 70% normal/survivorship level at about 144 mg/kg for zinc and 210 ug/kg for pyrene. These values are comparable to the bulk sediment marine Threshold Effects Levels (TEL) for zinc of 124 mg/kg and pyrene of 153 ug/kg compiled by NOAA (1999), which are based on sediment bioassays. For DDE the 5th percentile bioassay response falls below the 80% normal survival level at very low concentrations. Consequently, a reasonable derivation of a DDE "no effects" level does not appear to be possible from this data set.

CONCLUSIONS

The above analysis contains many extrapolations to obtain very approximate "no effects" levels for TSS and two chemicals. These extrapolations could introduce large errors into the overall results, and further the level of potential error is difficult to judge. All conclusions should be reviewed with this context in mind.

Interestingly, the TSS "no effects" levels extrapolated above are 2 to 21 times greater than the 10th percentile acute lethal toxicity value derived in the Resuspension White Paper (700 mg/L). Assuming the extrapolations discussed above are somewhat accurate, the regional specific data suggest that acute lethal levels presented in the White Paper would be conservatively low for the species typically tested via bioassays in the region. Also, the values extrapolated here are well above the TSS concentrations normally observed near dredges in the region (as detailed in the White Paper).

The chemical “no effects” estimate process indicated that, overall, there was a poor relationship between the sediment chemical concentrations of the three chemicals examined and bioassay responses. The data analysis process did result in an approximate estimate of “no effects” levels for pyrene and zinc, but due to the many assumptions involved, these results should be viewed with great caution. Despite this, the levels obtained are not dissimilar to published TELs for these chemicals based on sediment bioassays. Although technically interesting, this conclusion does not provide a direct connection that could be used to estimate water column effects from chemicals resuspended during dredging of sediments. In order to make such a connection, concentrations in the actual elutriate water of the bioassay tests would need to be known. This information would in turn need to be related to the levels of dilution typical for dredge material operations.

REFERENCES

U.S. Army Corps of Engineers. 1998. Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. - Testing Manual, Inland Testing Manual. Washington, D.C. EPA 823-B-98-004

(NOAA) National Oceanic and Atmospheric Administration. 1999. Screening Quick Reference Tables. HAZMAT Report 99-1. Washington, D.C.

Figure B-1 Bioassay Response vs. Calculated TSS Concentration

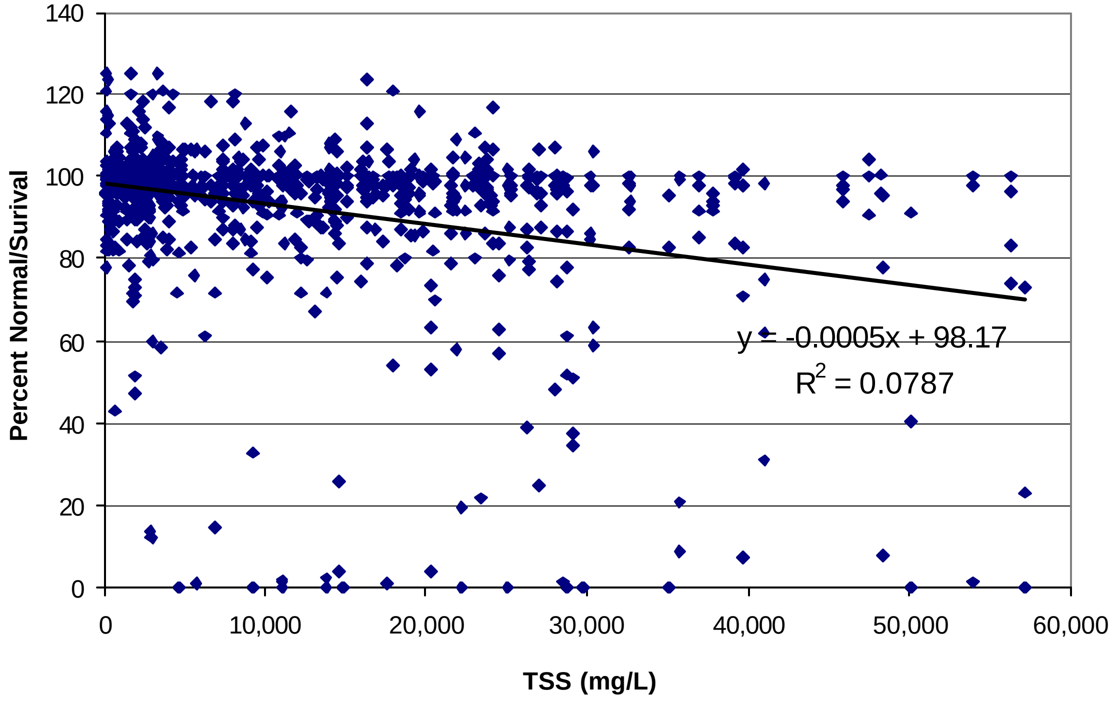


Figure B-2. All Samples TS vs. Response

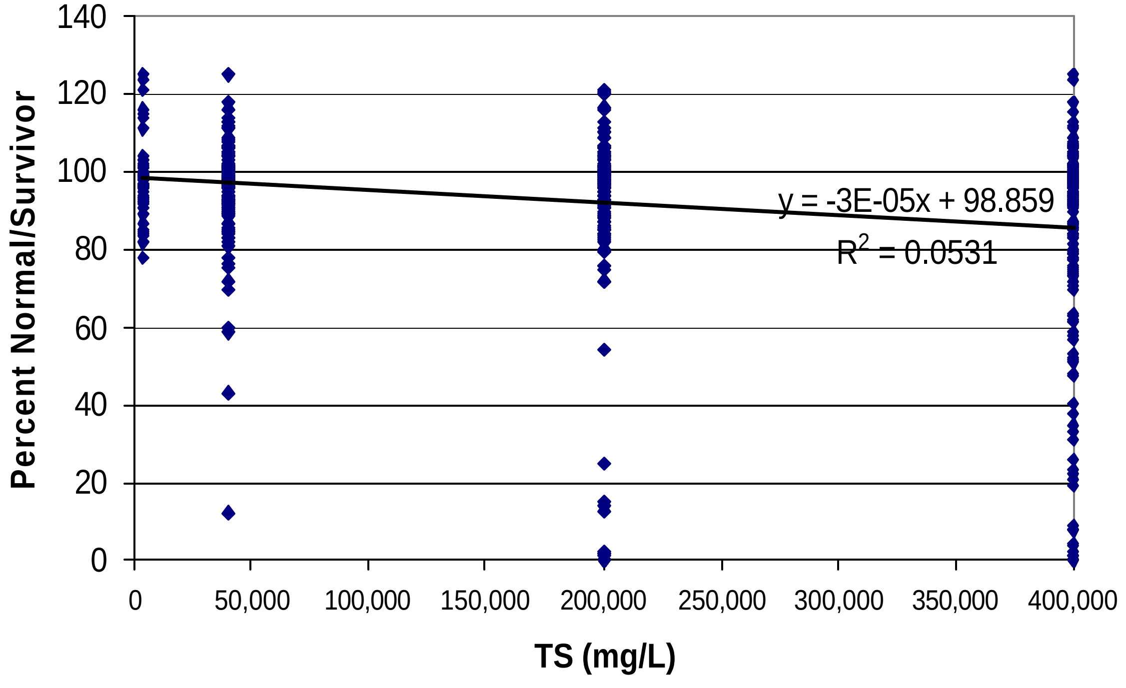


Figure B-3. Total Sediment (TS) and Percent Bioassay Hits

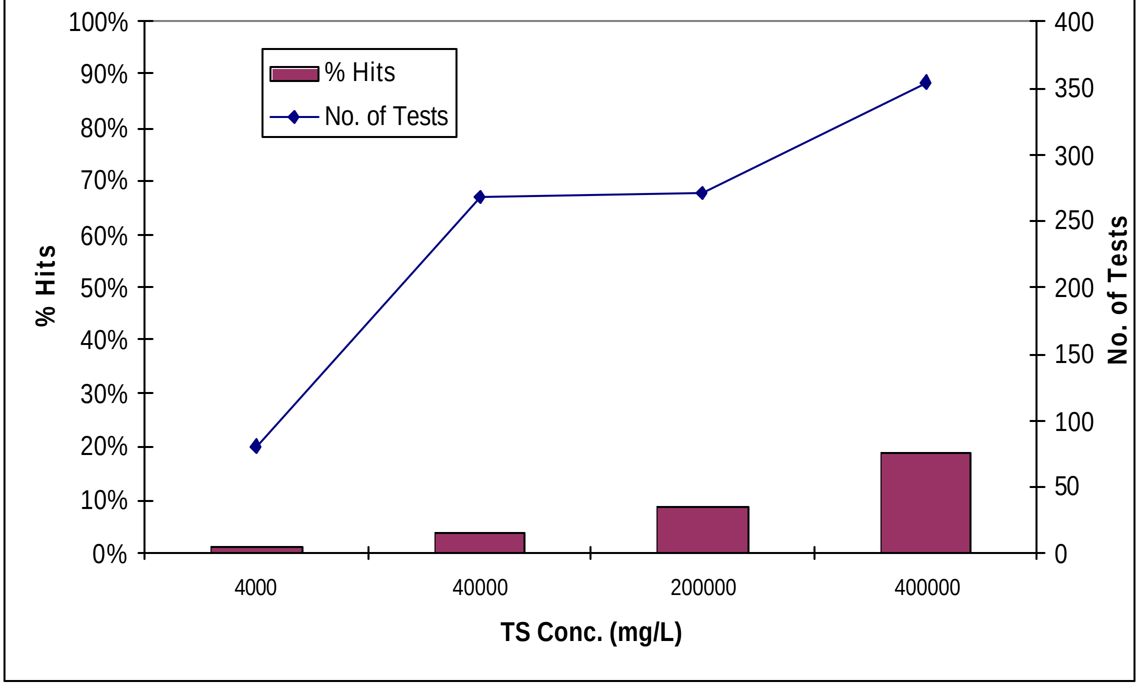


Figure B-4. Total Suspended Sediment (TSS) and Percent Bioassay Hits

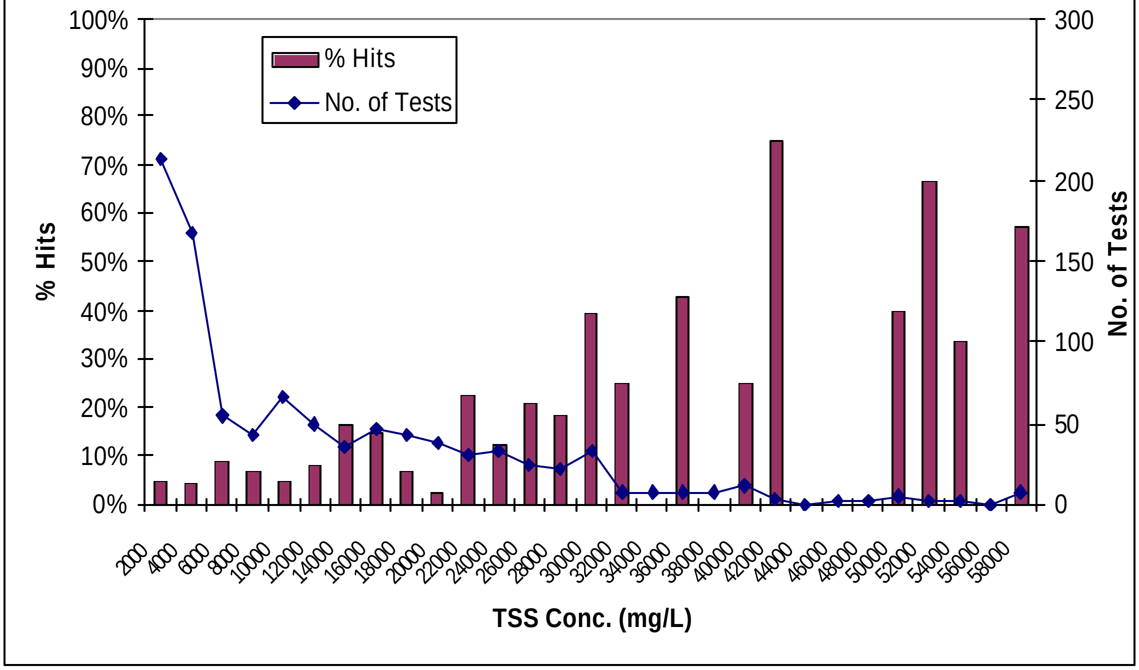


Figure B-5. Distributions of Responses by TS Category

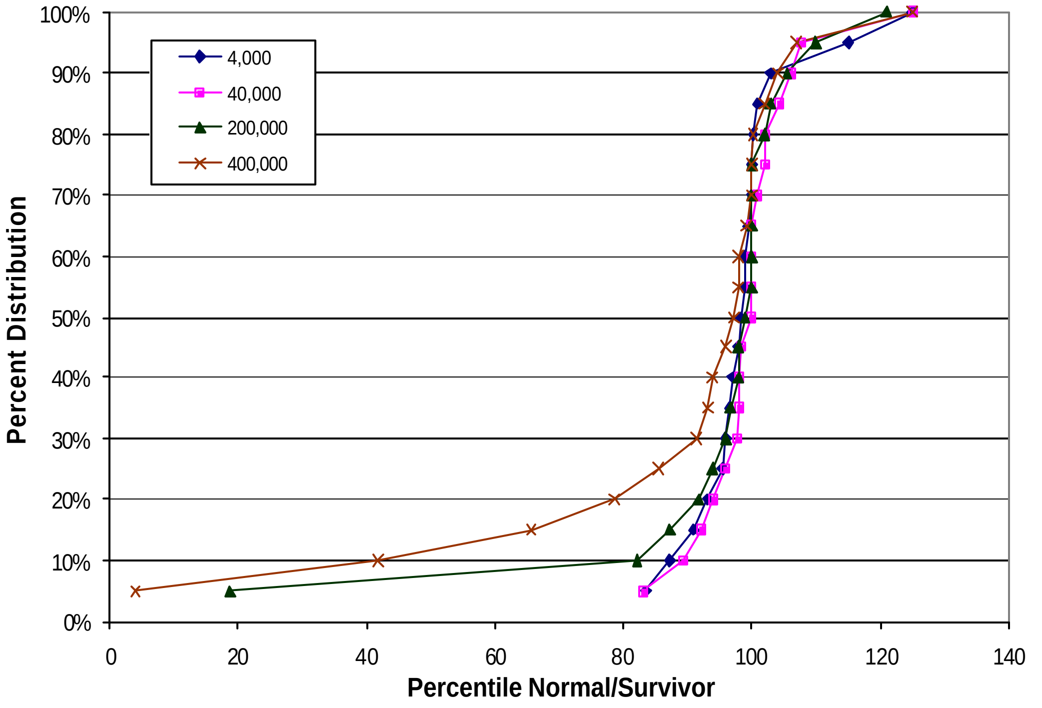


Figure B-6. Distributions of Responses by TSS Category

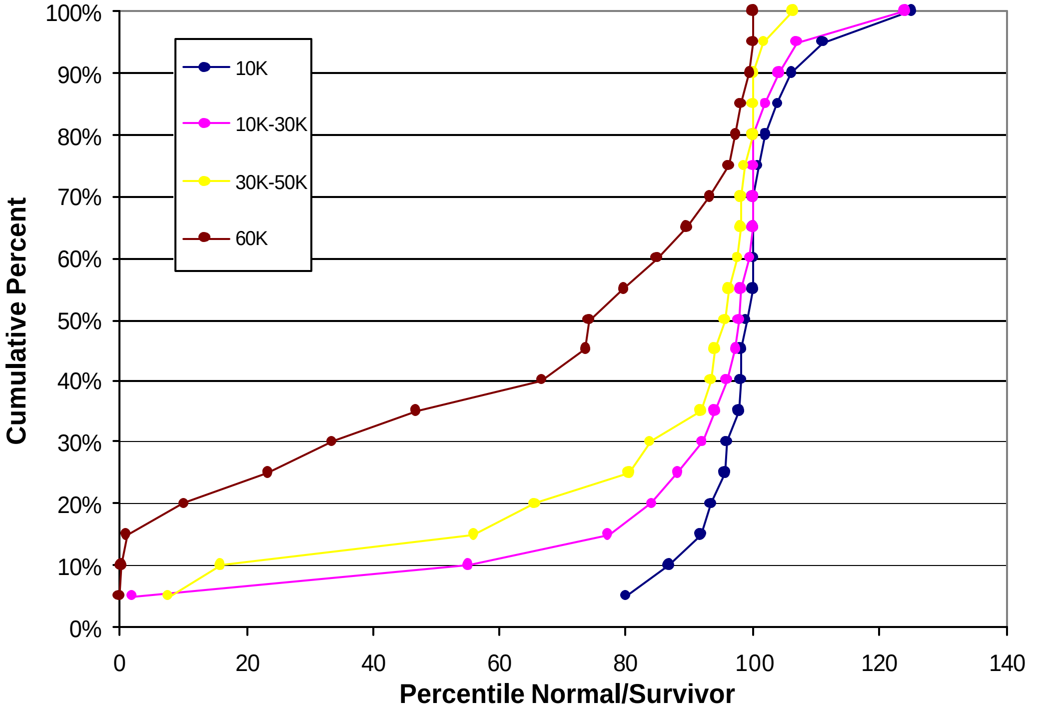


Figure B-7. 5th Percentile Distribution of All Bioassay Responses vs. TSS Concentraitons (n=971)

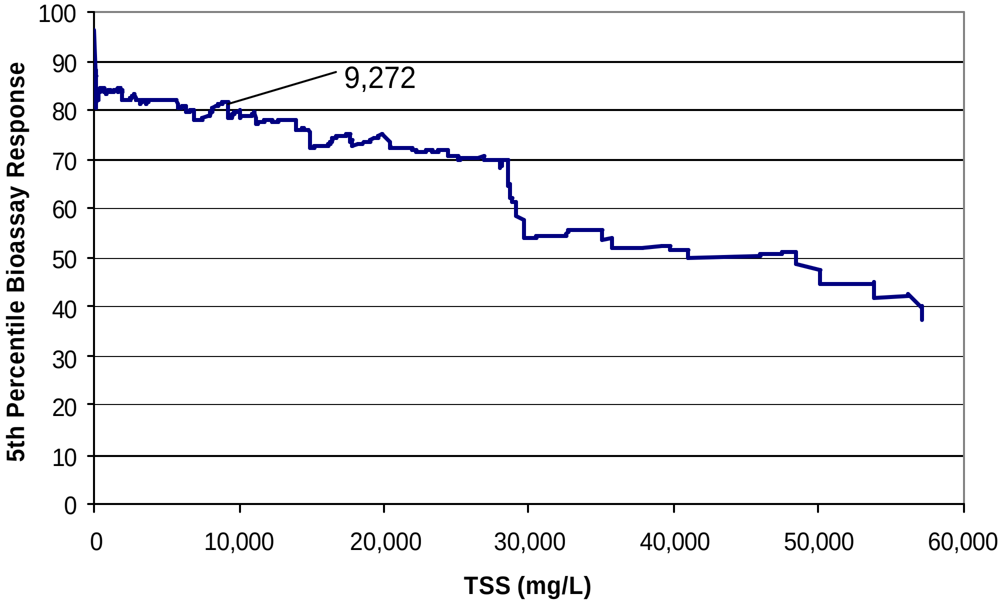


Figure B-8. 5th Percentile Distribution of Two Species Responses vs. TSS Concentraitons

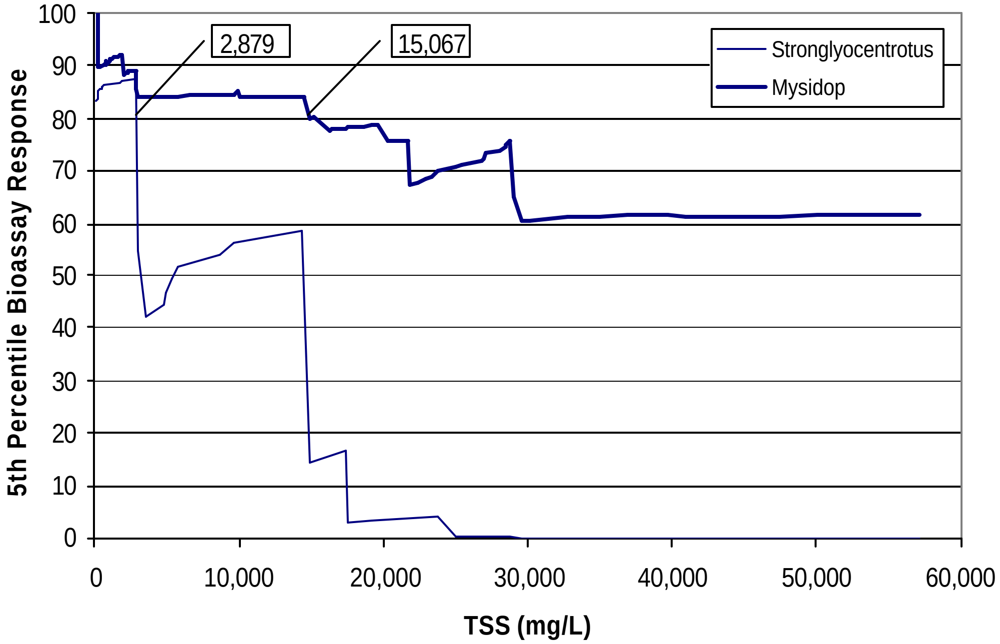


Figure B-9. 5th Percentile Distribution of Two Species Responses vs. TSS Concentraitons

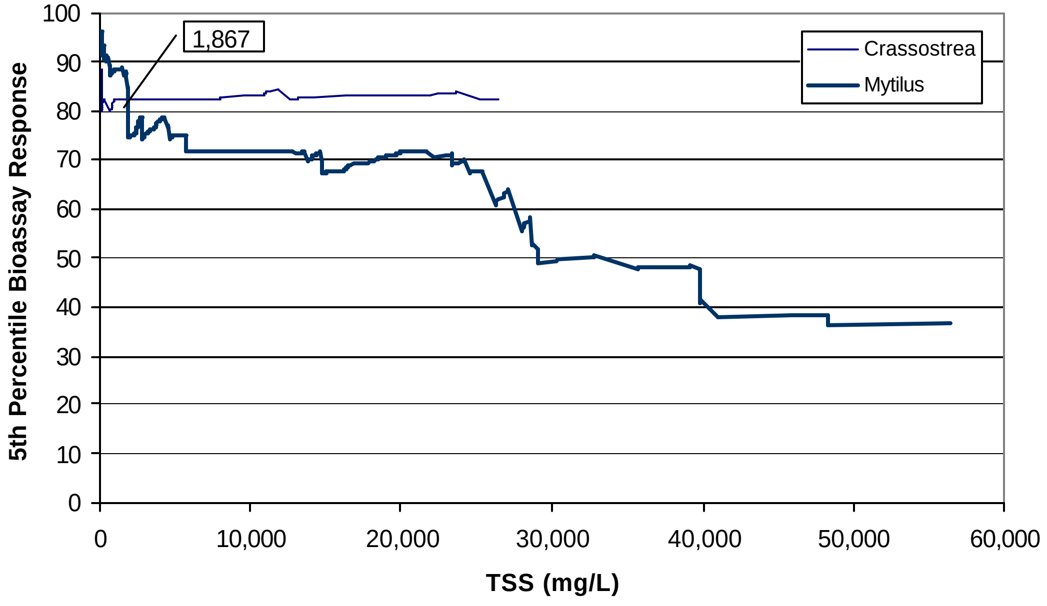


Figure B-10. 5th Percentile Distribution of Two Species Responses vs. TSS Concentraitons

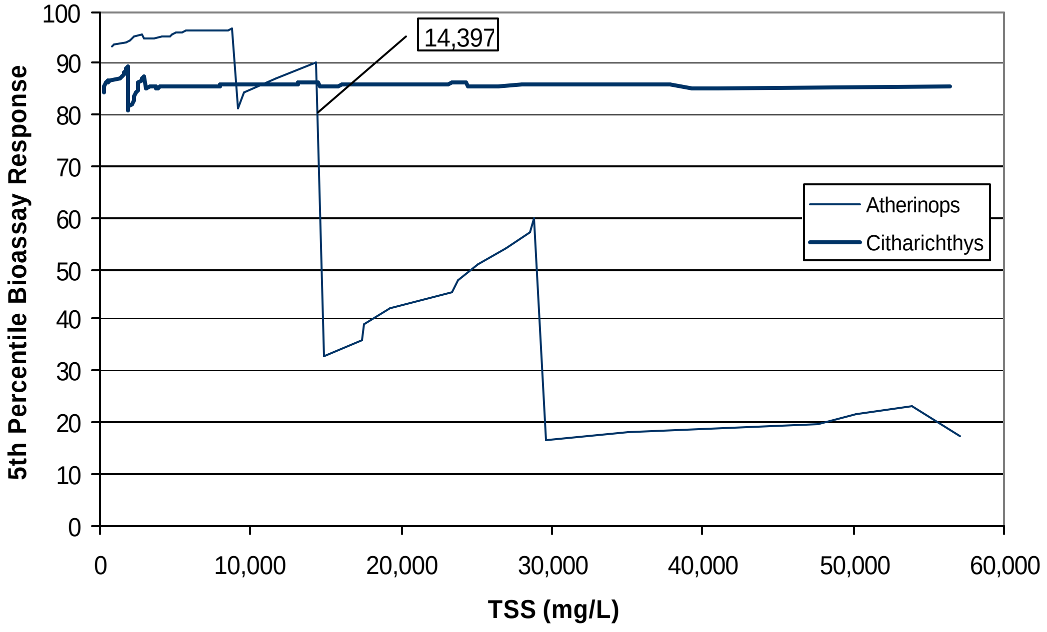


Figure B-11. 5th Percentile Distribution of Two Species Responses vs. TSS Concentraitons

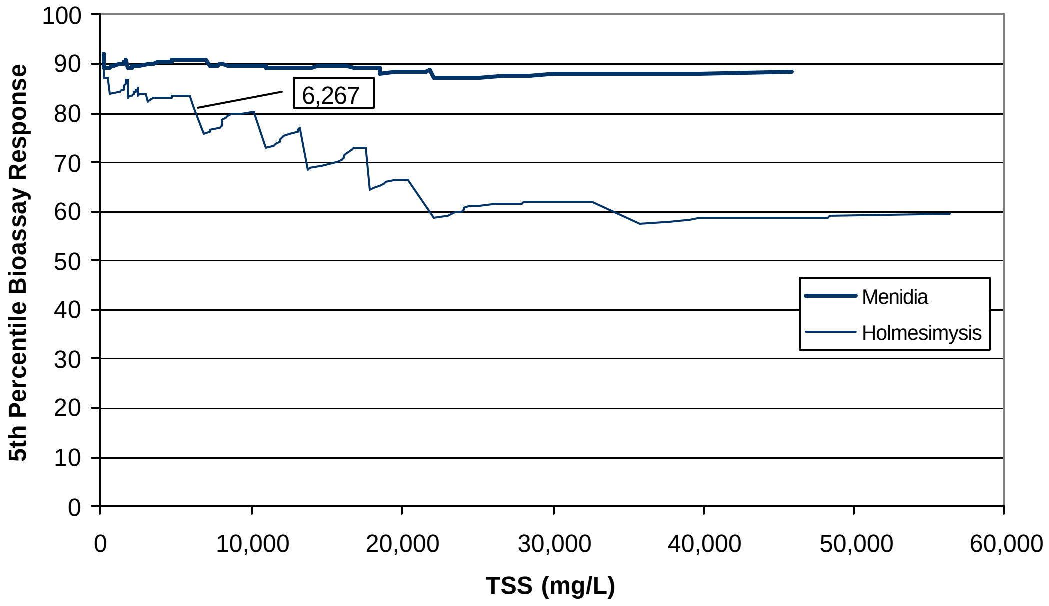


Figure B-12. 5th Percentile Response vs. Dilution Corrected Chemical Concentrations

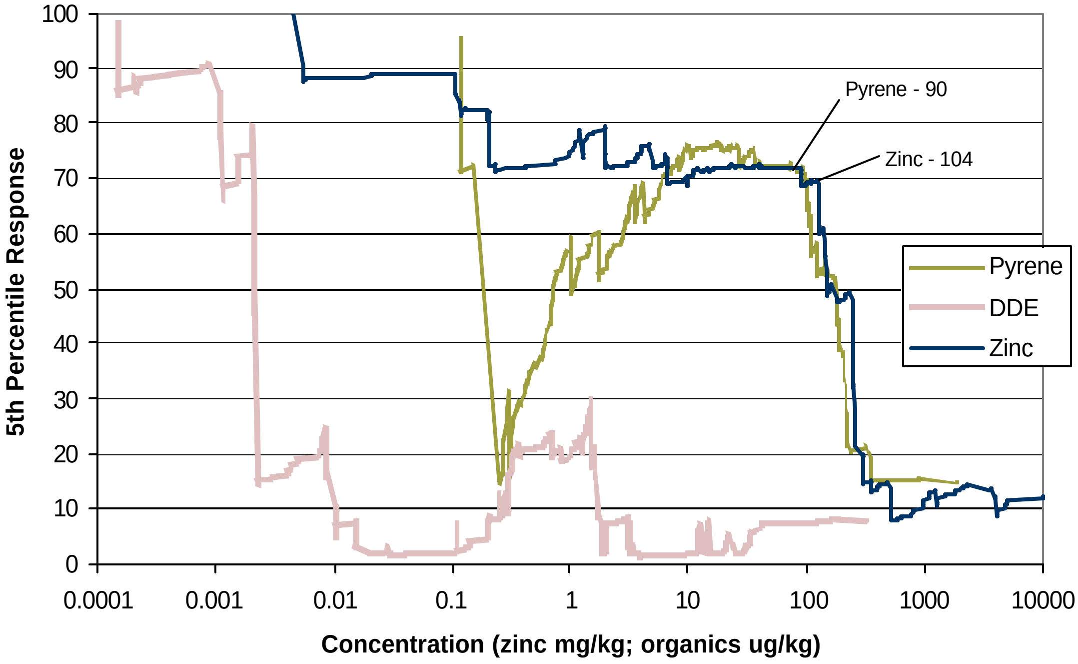
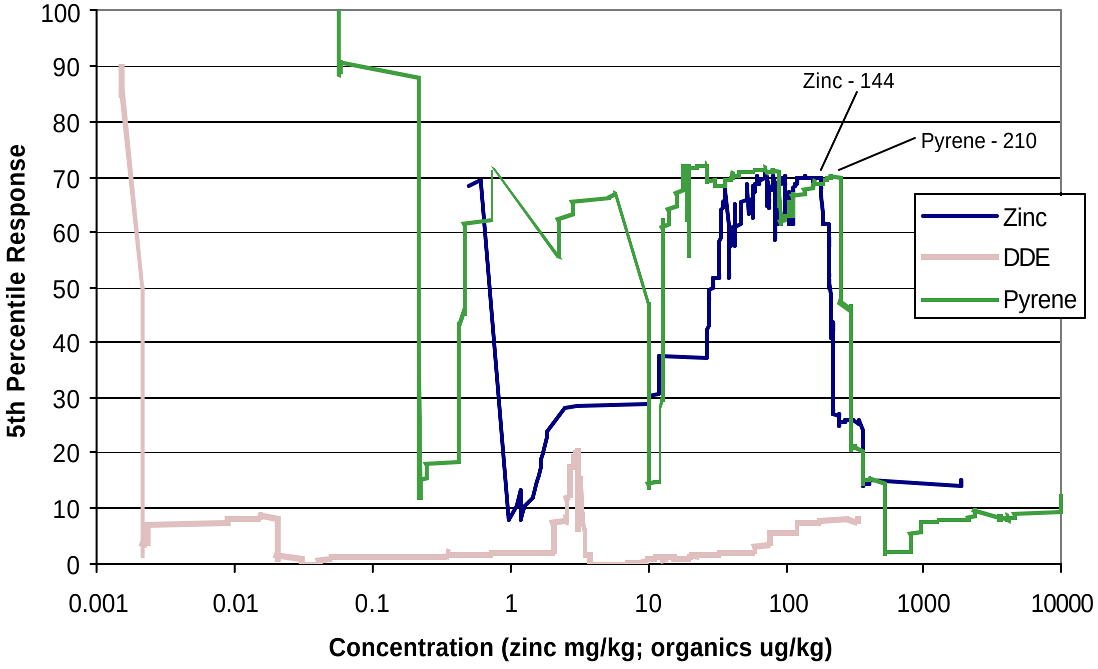


Figure B-13. 5th Percentile Response vs. Chemical Bulk Sediment Concentrations



APPENDIX C

EFFECTS OF RESUSPENDED SEDIMENTS – RESPONSE TO COMMENTS ON THE DRAFT REPORT

General Comments

General Comment 1: This report misses two key concerns related to dredging contaminated sediments: 1) mass loadings of contaminants that could change sediment chemistry in the area around the dredge site and 2) mass loadings of bioaccumulative contaminants that are unacceptable. Are there any studies that have quantified the mass loading of contaminants to the surrounding area during dredging? What about prediction based on models? What percentage of dredge material is lost to the surrounding area? What about mass loadings of bioaccumulative contaminants in areas that are already impaired for these contaminants?

Response to General Comment 1:
The concept that dredging causes a "mass loading" of contaminants to the ecosystem is misleading as the chemicals are already present in the system. Dredging can cause a release of a portion of those chemicals from one media (sediments) to another (water column) or a redistribution from one physical location to another, but does not result in a loading of additional contaminants to the system. Instead, this term should be referred to as "redistribution" or "removal efficiency" as is the case where the sediments are actually disposed of in a confined or upland facility.

The purpose of this project was to evaluate the issue of biological effects resulting from resuspended sediments from dredging. It is not within the scope of this project to evaluate losses of material from the targeted dredge area to surrounding areas. That issue will be addressed by the CSTF through collaborative discussions on the appropriateness and need for BMPs. The value of this document is to predict the range of suspended sediment concentrations that produce adverse biological responses so that information can be considered when setting larger management guidelines.

General Comment 2: Given the large amount of uncertainty in assessing the environmental impacts of dredging contaminated materials and the large number of data gaps identified in this report, Heal the Bay believes that basic BMPs to reduce loss of contaminants during dredging projects should be implemented. Employing basic pollution prevention techniques in the San Pedro Bay, the LA River Estuary and Marina Del Rey just makes sense given the fact that these waterbodies that are already heavily impacted waterways and listed for several impairments on the 303(d) list.

Response to General Comment 2:

The purpose of this study was an attempt to summarize the current literature related to biological effects of resuspended sediments and compare potential effects concentrations to documented ranges in regional dredge-related suspended sediment concentrations to assess the probability for impacts and to assist in modifying current dredge monitoring practices. It is beyond the scope of this report to comment or propose specific BMPs for regional use or any other regulatory change. Those discussions will occur through the CSTF Management Subcommittee process.

General Comment 3:

I would like to see you include a little more discussion on the relative applicability of the NTU and transmissivity measurements to dredging operations. MBC's Nov 2000 report has a discussion on this issue. We [The Port of Los Angeles] have argued against NTU measurements in dredge permit monitoring requirements and would like to see the pros and cons of these two methods reflected in this paper.

Response to General Comment 3:

The document attempts to provide an overview of each approach for measuring suspended sediment concentrations, including the pros and cons of each method, but does not seek to present a direct comparison of the two or to provide recommendations for use.

General Comment 4:

With regard to the suggested additional studies (p. 72), we need to keep in mind that the CSTF focus is solely on contaminated sediments, not clean sediments. I realize the Corps DMMP encompasses both, but I feel that any additional studies funded by the CSTF need to focus on contaminated sediment issues. For instance (and not that it wouldn't be good information), we would not support the CSTF funding additional studies related to turbidity and least tern foraging.

Response to General Comment 4:

We agree that the focus of the CSTF is to evaluate the effects of contaminated (vs. clean) sediments to biological organisms; however, doing so is complicated and difficult to quantify. Additionally, data presented in the revised white paper suggests that adverse effects resulting from suspended "clean" sediments may occur at similar sediment concentrations as tests conducted with "contaminated" sediments. This suggests a need to study both physical and chemical effects, rather than one component in isolation. Consequently, understanding the concentrations at which physical effects occur is critical to both the CSTF and DMMP program.

General Comment 5:

The Port [of Los Angeles] would support any additional studies needed to put the issue of contaminant resuspension to rest. More than one of the white paper recommendations relates to this and I think the committee as a whole needs to decide which additional studies would be most relevant to resolve this issue. Also related to this issue is the need to evaluate current permit monitoring requirements to determine what is meaningful and what is not necessary based on your literature evaluation and any additional studies conducted through the CSTF.

Response to General Comment 5:

We agree with all the statements made.

General Comment 6:

Evaluation of BMP effectiveness is also high on our [Port of Los Angeles] list of priorities. The Ports of LA and Long Beach have talked in the past about setting up a forum for dredging contractors operating in the LA region to discuss the use and effectiveness of various BMPs. Maybe this forum could be sponsored by the CSTF.

Response to General Comment 6:

We agree with these comments. The CSTF Management Subcommittee has recently directed the Aquatic Subcommittee chairperson (Jim Fields) to initiate the process of re-evaluating the current dredge monitoring programs to see if changes would be beneficial at this time.

Specific Comments

Specific Comment 1: Section 3

A review and discussion of studies conducted and data related to the distance from the dredge site impacted by resuspended sediment would help the CSTF develop better monitoring and BMP implementation protocols. A review of any data available on the area around the dredge impacted with resuspended sediments would greatly help the CSTF evaluate LA's existing dredge monitoring protocols and determine how to effectively implement BMPs (such as placement of silt curtains). At a minimum, this section should evaluate the historic monitoring completed in LA area which includes measuring turbidity at various distances from the dredge.

Response to Specific Comment 1:

Evaluations of dredge impacts and possible effects related to distance from the dredge equipment were attempted as part of the supplemental data evaluations performed by Anchor Environmental and the results were presented at three separate CSTF meetings. Copies of those presentations can be obtained from Anchor Environmental and the data is included in the revised report as Appendix B. Extensive information on dredge monitoring was reviewed. However, in the vast majority of cases the suspended sediment and chemistry data was very infrequent and taken at one distance from the dredge during any one monitoring event. We did not find any monitoring that included TSS and/or chemistry monitoring at multiple distances from a dredge for the same monitoring event.

Specific Comment 2: Section 3

A more comprehensive discussion on the specific mechanisms that cause resuspension during different types of mechanical dredging operations would greatly aid the CSTF in developing a BMP policy. Although some mechanisms of resuspension were mentioned in section 3.2, based on information briefly stated in section 7, it appears the authors have more information on mechanisms of resuspension than the information included in section 3.2. For example, section 7.1 contains the statement "The majority of the sediment resuspension, for a clamshell dredge, occurs when the bucket hits the bottom." This information and more generally, this type of discussion on the relative importance of different mechanisms was not included in Section 3. Have studies been completed on the primary mechanisms of resuspension for various types of mechanical dredges? The CSTF can develop a more effective BMP policy if the specific mechanisms that lead to resuspension are understood.

Response to Specific Comment 2:

The revised document includes additional information from the literature review, as available, on the specific mechanisms associated with resuspension during mechanical and hydraulic dredging.

Specific Comment 3: Section 3

Overflows can significantly contribute to resuspension in mechanical dredging projects and is an issue for dredging operations in the LA area. The report discusses overflow as it pertains to hopper dredges, but limits the discussion because hopper dredges are not used in the LA area. However, barge overflow does occur in mechanical dredging projects completed in this area. In fact, during past dredging projects completed at Marine Del Rey, the ACE has stated that overflow of the barge both during barge loading and transport can significantly increase resuspension. In addition, for some projects the ACE has specifically prohibited overflows during dredging and transport in the project contract. Clearly, prohibition of overflows is an operative BMP and should be emphasized.

Response to Specific Comment 3:

We agree that controlling barge overflow can be an important BMP for reducing sediment losses. The revised document includes additional discussions on this topic to clarify the issue. However, it should be noted that we found no specific monitoring work in the literature that addresses the impacts of barge overflows specifically. As far as we can determine, no one has done a study that clearly differentiates the impacts of barge overflows from the dredging itself. Consequently, we are not able to state exactly what additional impacts may be caused by overflows or how these may differ from the dredging itself. Rather, we mention that many researchers agree, based on general understanding and observations that overflows can contribute to losses of sediments.

Specific Comment 4: Section 3

A review of any information related to resettling times would help the CSTF evaluate current monitoring protocols. Since dredging is a sporadic operation, the timing of water quality sampling is an important factor to consider in the design of an effective monitoring program. For example, past monitoring requirements have specified the collection of turbidity measurements within an hour of active dredging. Is this an adequate time frame or should this be reduced?

Response to Specific Comment 4:

We agree that timing is an important factor in monitoring dredging. We have reviewed the information available and have added any available information on this subject into the revised document, where appropriate. However, a detailed review of the potential effects of sediment settling time on current dredge monitoring practices is beyond the scope of this document and will be addressed in more detail through the efforts of the CSTF Aquatic Subcommittee.

Specific Comment 5: Section 4

Section 4.1 should mention the Enclosed Bays and Estuaries Plan and the California Toxic Rule (CTR) in addition to the California Ocean Plan, particularly because the Ocean Plan doesn’t apply to San Pedro Bay and the Enclosed Bays and Estuaries Plan along with CTR specifically targets bays and other enclosed waterbodies.

Response to Specific Comment 5:

The revised document includes the suggested reference and comparisons to the water quality criteria values specified in the Enclosed Bays and Estuaries Plan and California Toxics Rule.

Specific Comment 6: Section 5

The total number of data points included in the effects database assembled for this report and the criteria used to determine that a data point could be included in the data set should be included in Section 5.2.1 (Compilation of Effects Data Set). In addition, the number of data points represented in the summary stats for each subcategory of toxicity should be included in Table 1. A discussion of the representativeness of the data in light of the number of data points should be included. These same comments also apply to the data presented in Table 2.

Response to Specific Comment 6:

The appendices currently contain all the data used in developing the tables. The revised document has been edited to clarify the linkage between these summary tables and complete data sets presented in the appendices.

Specific Comment 7: Section 5

The standard deviations reported in Table 1 for the physical effects concentrations are very high and should be explained. Is the data in each subcategory normally distributed? If not, how does this affect interpretation of the data? Are a few data points skewing the summary stats? These same comments also apply to data presented in table 2.

Response to Specific Comment 7:

As is common with toxicity data, the range of responses is large, hence the variability observed in the data. Because statistical tests were not being conducted, tests for normality were not conducted and all data points were included in the evaluations. The standard deviations were presented only as a general indication of this variability. We have added additional text about the general distributions of the data sets in the revised document.

Specific Comment 8: Section 5

Please explain "percent dredging reports". Is this the actual number of reports or the number of toxicity tests? Did some reports contain the results of multiple tests?

Response to Specific Comment 8:

This refers to the percent of reports of TSS concentrations from dredging operations. So, this means that for example, 55% of all the TSS data points for mechanical dredging in the L.A. Region exceeded the 10th percentile chronic effects level calculated from all of the toxicity data found. The toxicity data were not conducted specifically for any dredging projects, but are general laboratory bioassay tests that provide information on organism's general reactions to suspended sediments (what ever their source may be). The figures have been edited in the revised document to clarify the source of this information.

Specific Comment 9: Section 5

We disagree with the statement summarizing the NTU vs. finfish effect levels graph that states "…the *vast majority* of expected NTU values …. are below the 50th percentile effects levels reported for finfish."(page 39, italics added). Figure 7 shows that, when using the medium range turbidity/suspended sediment correlation, 30% of the reports exceeded the 50th percentile fish effect level. This is not a small or insignificant portion and, if accurately estimated, suggests unacceptable impacts to finfish occur due to dredging. Please delete the word "vast" and add further discussion to this section that points out that many (possibly 30% or more) dredging projects may impact finfish. In addition, this finding should be included in Section 8 of the report.

Response to Specific Comment 9:
The text has been edited accordingly in the revised document.

Specific Comment 10: Section 5
We believe the report inaccurately states that most turbidity measurements in the Los Angeles region are in the form of percent light transmission (page 41). The monitoring requirement for dredge projects per the RWQCB WDR was changed from turbidity to light transmission only in the last couple of years. Previously, our understanding is that most dredge monitoring measured turbidity in NTUs, as required by standard monitoring requirements of the RWQCB's WDRs. Thus, most of the historical monitoring data for dredge projects completed in the LA region is turbidity data.

Response to Specific Comment 10:
The text has been edited in the revised document to clarify that the majority of the available data which also has high quality (i.e., lab results with low detection limits) water column chemistry data at co-located stations is reported in the form of reduced light transmission. It is true that previous data exists in the form of turbidity and light transmission; however, for the majority of those data points either no water column chemistry data exists or it is not of sufficient quality for use in the document.

Specific Comment 11: Section 5
We believe the discussion on ambient concentrations of suspended sediment is somewhat misleading and incomplete. The report should include a discussion on the effect of the significant anthropogenic non-point sources of TSS that affect San Pedro Bay, the LA River Estuary and Marina Del Rey during both dry and wet weather, and therefore, affect any "ambient" measurements. The report does not consider the possibility that many of the "ambient" measurements of TSS are influenced by non-natural sources of TSS. San Pedro Bay, the LA River, and Marine Del Rey all receive large quantities of nuisance flows in dry weather and storm water in wet weather that are often heavily contaminated with TSS. Much of this sediment is originating from developed land uses and construction sites and is not naturally occurring. So, it may be misleading to compare the water quality impacts of dredging to water quality impacts from "ambient" measurements of TSS from waters impacted by urban runoff.

The discussion on ambient suspended solids concentrations should include a description of the data used to summarize ambient TSS concentrations for the LA region including the number of data points, what definition of ambient condition was used, and how Anchor determined that the measurements in the reports reviewed were not influenced by anthropogenic sources and do actually represent ambient conditions. For example, in this report, ambient is likely not the same as natural background because all the areas where dredging occurs in LA are impacted by anthropogenic sources of TSS. The conclusions summarized in Section 8 on this topic should also be modified, particularly the use of the term "naturally occurring background".

In addition, comparability of dredging-related TSS levels to "ambient" levels does not justify or make acceptable the generation of high TSS levels from dredging projects. Although the report does not explicitly state this, this section could be construed as suggesting such. We request that the report clearly state that comparability of dredging-related TSS levels to the ambient concentrations presented does not warrant the allowance of high TSS levels from dredging operations.

Response to Specific Comment 11:
Because the purpose of the document is to assess potential effects associated with resuspended sediments caused from dredging, the term "ambient" as referenced refers to existing conditions in the absence of dredging. Potential impacts associated with urban runoff and other anthropogenic sources are beyond the scope of this document and will be addressed by other facets of the CSTF. The revised document has been edited to clarify the definition of "ambient" and additional details are provided to explain the sources and calculations that resulted in the range of concentrations presented in the figures. All raw data used to generate the figures are contained in Appendix A for reference.

Specific Comment 12: Section 5
The report should point out that 60% of the dredging reports of suspended sediment concentrations exceed the median background concentrations for suspended solids. Figure 8 appears to show that 60% of all the dredging reports evaluated exceed the median background TSS concentration for LA, however, this point is not discussed. Instead, the report discusses at the length the fact that "ambient" TSS levels can sometimes exceed those measured around dredging sites. The emphasis on this point seems misleading.

Response to Specific Comment 12:
The intent of the document was to provide an unbiased statement of the facts related to the issue of resuspended sediment effects as a result of dredging. The text has been edited in the revised document to provide a more balanced discussion of all data available. Discussion of "ambient" background concentrations of suspended sediments was given more attention in the original document because this concentration range is based on actual data collected during local projects and shows the range of suspended sediment concentrations present during typical weather conditions in the area. Conversely, the biological effects data are based entirely on studies conducted at locations outside of the Los Angeles Region. It is possible that local aquatic species have become more adaptable to suspended sediments than some of the species used to develop the effects curve presented in Figure 8. As such, we believe that presenting the

range of concentrations that have been shown to produce adverse effects during controlled experiments in the context of the range of concentrations measured locally at background locations is important in evaluating the results.

Specific Comment 13: Section 5

The large amount of uncertainty associated with linking biological effects to turbidity levels could warrant conservative regulation of dredging operations. The report should offer this alternative perspective in section 5.6. The report states "we would recommend great caution in using the sublethal behavioral effects in fish as means to develop turbidity related guidelines." This is one management approach to dealing with the large amount of uncertainty; i.e., it is better to error on the side of setting TSS limits high to ensure that when the limit is exceeded, there is actually an impact. Another approach to dealing with the uncertainty is to set the limit lower, so that the preponderance of error is shifted to assuming there is an impact, when in fact there is not (Type I vs. Type II error). Heal the Bay believes this latter, environmentally protective approach is warranted because the purpose of regulating dredging projects is protection of biological resources, and the resources that exist in the areas commonly dredged in LA are already degraded and the water quality in these areas already impaired.

Response to Specific Comment 13:

The text has been edited in the revised document to remove the word "great" from the referenced text, but the overall position has not changed. The purpose of Section 5.6 is to discuss the level of certainty associated with the various measurement endpoints presented in the document. Measures of lethality are clear and have obvious detrimental impacts that must be protected. In contrast, some sub-lethal endpoints such as avoidance responses can be highly subjective and should be evaluated with caution. Making management decisions based solely on sub-lethal responses may be over-protective for short-term dredging projects. Regardless, these management decisions will be made by the CSTF as a whole and the regulators responsible for overseeing dredging activities, and are not within the scope of this report.

Specific Comment 14: Section 5.2.3:

Effects on eelgrass might be included, especially in areas where deposition of dredged sediments may result in turbidity plumes which impact eelgrass. The mechanism is the adherence of silt to eelgrass blades. A reference doesn't come to mind - would one be helpful?

Response to Specific Comment 14:

We agree that impacts to eelgrass could be important and have attempted to locate a source of information that could be summarized and included in the revised document. We were not able locate any new sources of final data before releasing document but are aware of new work that might be in progress for discussion at future CSTF meetings.

Specific Comment 15: Section 6

Please add a reference and some explanation to the statement "…desorption of chemicals from particulates to the dissolved phase tends to take place over time frames greater than one hour." (page 51). This statement seems to be a very broad generalization and could have important ramifications for evaluating the potential for release of contaminants during dredging. Thus, a reference and a discussion of the data that support this statement should be included in the report.

Response to Specific Comment 15:

A reference has been added to the revised document to support this statement.

Specific Comment 16: Section 6

The report should discuss the long-term fate of contaminants released from dredging projects that are associated with particles, and point out that the release of contaminants in any form could have long-term negative impacts on the environment. Total pollutant loading should be considered, particularly for large dredging projects and maintenance dredging. Metals associated with particles may not lead to immediate biological impacts because they are not immediately bioavailable, however, there is a potential that these contaminants can cause biological impacts in the long-term if they become bioavailable. Thus, any release of contaminants from the dredging process could be environmentally damaging even if they are not released in a bioavailable form.

Response to Specific Comment 16:

The scope of this document is to evaluate the effects of resuspended sediments on biological organisms. Issues related to potential chemical mass loading as a result of dredging reflect a larger policy decision that is better addressed through the CSTF as a whole. As stated in the response to general comment #1, dredging cannot be a source of "mass loading" of contaminants to the ecosystem as these chemicals are already present in the ecosystem. Dredging can, however, result in redistributing contaminants from one media to another. In these instances, chemicals have the potential to be released in a biologically available form (e.g., dissolved in the water column), meaning that they can be readily taken up by organisms and result in an adverse effects, or they may be re-distributed in an inert state. It is possible that chemicals bound to sediment particles and re-distributed in a relatively inert form can be made bioavailable in the future if environmental conditions change.

Specific Comment 17: Section 6

Table 5 should include the California Toxic Rule limits so that a comparison can be made between these standards, the detection limits, and the results of the analysis.

Response to Specific Comment 17:

The revised document includes a reference and comparisons to criteria presented in the California Toxics Rule.

Specific Comment 18: Section 6

Throughout section 6, summary statements of scientific reports are provided with descriptive, summary conclusions, but summary data from the studies that supports these conclusions are not provided. Please add quantitative information that supports the conclusions stated in section 6 or remove them from the report. As currently written, much of the summary of studies included in this section could be viewed as subjective because it is not adequately supported with the appropriate information from the studies. For example the phrase "changes in water quality were transient" (page 54) doesn't include a discussion on how long "transient" is – Is it minutes, hours, or days? Page 55 states "soluble releases of heavy metals and the majority of petroleum and chlorinated hydrocarbons associated with dredging activities are minimal" but does not quantify minimal. Were the amounts of chemicals releases not measurable, below CTR, or below some other biological effect level? How much data support this conclusion? Page 57 states "However, Rand and Petrocelli (1985) noted that the effects described earlier and found in laboratories did not have as marked an impact on populations or communities of marine organisms in nature." This is a sweeping statement that needs context in this report. Does this conclusion stand for all effects from all organic compounds? How many populations and communities "in nature" were studied? What types of populations and communities? This comment particularly applies to the summary of laboratory studies in section 6.2.1.3 and 6.2.1.4. These are just a few of many examples from this section.

Response to Specific Comment 18:

The purpose of the document was to review and summarize the available literature associated with biological effects of resuspended sediments. Complete and detailed references are provided for all statements of fact provided in the document. It is beyond the scope of this report to copy all the background information presented in the various studies referenced in the document. Comments requesting clarification on specific statements and quotations have been addressed in the revised document by expanding the discussion of the referenced sections.

Specific Comment 19: Section 6

Related to comment [18], throughout section 6, the reporting of water column concentrations should be accompanied with CTR standards and other appropriate biological effect levels for comparative purposes. Likewise, detection limits of the studies should be compared to CTR standards or biological effect levels when non-detects are reports. Concentrations of toxic pollutants in the water column can seem very low when reported without context, but may still be above biological effects levels.

Response to Specific Comment 19:

Comparisons to applicable water quality standards were conducted prior to reaching the conclusions stated in the document, but were not specifically presented in the document.

Specific Comment 20: Section 6:

The brief evaluation of the water column chemistry data collected in the LA region during dredging projects does not support the following statements: “These results all suggest….chemical partitioning from dredging projects in the Los Angeles region is generally not significant. When it does occur (most frequently with metals), the rates of partitioning are low and dissolved water column concentrations rarely exceed conservative ecological screening values.” A comparison of the water column testing results to CTR standards was not completed. Detection limits were not compared to CTR standards and other biological effects data. The number of data point that support this statement was not considered in the context of the number of variables that can affect water column concentrations associated with dredging (such as the types of sediments dredge and the sediment contaminant concentrations) and the high variability of TSS plumes associated with dredging. A summary table of the water column chemistry data collected over the past two years by CSTF members should be included. Without a much more thorough analysis of the data and thoughtful consideration of the issue, this report can not substantiate any conclusions about the potential for chemical partitioning during dredging.

Response to Specific Comment 20:

Comparisons to applicable water quality standards were conducted prior to reaching the conclusions stated in the document, but were not specifically presented in the document. The revised document includes a summary table showing water column chemistry data compared to CTR standards as suggested.

Specific Comment 21: Section 6:

The report fails to discuss the potential cumulative or synergistic biological effects associated with multiple pollutants and the biological stress associated with excessive TSS levels. A majority of contaminated sediments contain multiple pollutants. Cumulative or synergistic impacts to biological resources associated with exposure to multiple pollutants were not specifically discussed in the report. In addition, the combined exposure to multiple pollutants and stress related to excessive TSS levels of the dredging plume was not discussed.

Response to Specific Comment 21:

We recognize the importance of this issue and used the elutriate toxicity data from the CSTF database in an attempt to answer this question. The revised version of the document includes a supplemental appendix (Appendix B) that summarizes the results of additional calculations conducted since the original document was released, including an evaluation of direct toxicity measured during sediment elutriate bioassays compared to predicted resuspended sediment concentrations. The results of that evaluation failed to show a correlation between toxicity and increased suspended sediment concentrations or increased chemical concentrations. This information certainly can not be used to conclude that synergistic biological effects are not an important concern, just that a correlation was not observed using the available regional data.

Specific Comment 22: Section 6.3:

Reference to the Ocean Plan should be updated to the California Toxics Rule 7.1 - as an operational control, residence time of a dredging operation in a specific area can be reduced; also, you cite Pneuma pumps as a minimal turbidity approach - this has not been my experience, perhaps you could cite a specific situation?

Response to Specific Comment 22:

The revised document includes comparisons to the CTR instead of the Ocean Plan. The section on BMPs was updated/expanded with some additional details in the revised document.

Specific Comment 23: Section 7:

Halting dredging during large swings in tide height is an operational control that should be added to this section. This operational control was the only BMP that was effective during the most recent dredging activity at MDR, particularly because the area of concern was a small portion of the dredge footprint that contained fine materials. By directing the contractor to avoid dredging fine materials during spring tides, the ACE was able to avoid a dredge plume that exceeded acceptable levels as defined by the project.

Response to Specific Comment 23:

The revised document includes mention of controlling dredging operations during extreme tidal fluctuations and/or currents as an additional operational control.

Specific Comment 24: Section 7:

A major disadvantage to operational controls not discussed in the report is that they tend to slow down the dredging process, which impacts cost. In addition, dredging contractors often have incentives in their contracts to reduce the number of days of dredging and therefore, are not motivated to properly employ these techniques.

Response to Specific Comment 24:

We agree that employing some operational controls can result in longer dredging periods and have revised the document to include mention of this issue. As its purpose is to present technical and scientific facts, it is beyond the scope of this document to comment on specific details related to dredging contracts. Discussions related to this issue should occur directly with the organizations responsible for administering those contracts.

Specific Comment 25: Section 7:

Related to comment [#24], a major hurdle to implementation of BMPs of any type can be the contracting process, particularly for the ACE. The contracting process may need to be modified to accommodate adaptive implementation of BMPs during dredging projects. A brief discussion of this should be included in the report.

Response to Specific Comment 25:

See response to specific comment 24.

Specific Comment 26: Section 7:

The report states that silt curtains can not be used in areas with greater than 1-2 knots current. How does this limitation apply to the LA region? What are the average current speeds in various areas where dredging in commonly completed? Is there a similar current limit for gunderbooms?

Response to Specific Comment 26:

The revised document includes reference to the environmental conditions typical of the study area as a means of assessing feasibility of using silt curtains as a dredging BMP.

Specific Comment 27: Section 7:

The review of studies on BMPs is very limited. Heal the Bay was under the impression that the ACE had completed several studies on different types of dredging buckets, barge overflow, and silt curtains. Is the review complete?

Response to Specific Comment 27:

A review of dredging BMPs was conducted by Noble Consultants for the Los Angeles District Corps of Engineers in response to a request by the Coastal Commission on the Marina del Rey project. That review may be obtained directly from the Corps of Engineers, Los Angeles District.

Specific Comment 28: Section 7:

Please include a discussion in section 7.2 on the different types of buckets. The report discusses a cable arm bucket but gives no description. Also, how does an environmental bucket differ from a conventional bucket? Under what circumstances should an environmental bucket be employed?

Response to Specific Comment 28:

Comment noted. The revised document includes an expanded discussion of the various buckets available for dredging in Section 7.2.

Specific Comment 29: Section 8:

As currently written, we do not believe the report supports the following statement "Chronic and sublethal effects reported for clean sediments in the literature appear to significantly overlap with naturally occurring background suspended sediment concentrations in the Los Angeles region indicating that regional aquatic like is likely adapted to occasional exceedances of these chronic and sublethal effects levels."(page 71). Please see our comments #[11 and 12] which discuss our concerns related to this issue.

Response to Specific Comment 29:
For the purposes of the report, the term background was used to define ambient (without dredging) conditions. As such, these represent current conditions that aquatic organisms are exposed to on a frequent basis within the study area. It is important to acknowledge the range in these concentrations because one would assume that if the resident aquatic species present at the site were adversely impacted by the conditions occurring without the influence of dredging, they would not be present at the site and hence would not be impacted by future dredging events. The revised document has been edited to clarify the term "background" as it applies to this evaluation.

Specific Comment 30: Section 8:
In addition, we do not believe the report supports the following statement "In general, previous studies indicate that potential effects from dredging are transient and not significant." Please see our comments #[16, 17, 18, 19, and 21] related to this issue.

Response to Specific Comment 30:
Responses to the specific comments are provided in their respective sections.