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# AN ANALYSIS OF THE LITERATURE ON THE EFFECTS OF DREDGING ON JUVENILE SALMONIDS

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# PREFACE

This literature survey was undertaken at the request of the Department of the Navy in order to help determine the effects of dredging operations associated with the construction of the Trident drydock and refit pier in the Devil's Hole area of Hood Canal.

# INTRODUCTION

It is accepted that dredging and spoil disposal operations create higher suspended sediment concentrations than normally found under natural conditions. It is also accepted that the impacts of dredging are variable, often temporary and localized, and usually have a severe influence upon the benthos. Thus, most of the studies have been conducted on the effects of siltation on benthic organisms and little information is available concerning the effects of suspended sediments on fin fish, especially juvenile salmonids. Therefore, predictions of tolerance levels of specific stocks of fish in their natural environment become difficult. Without qualitative and quantitative data, the biologist is obligated to use conservative standards as a safety factor.

This literature survey was conducted in an attempt to establish the tolerance levels of juvenile salmonids to various levels of suspended solids. The information will then be analyzed for the assessment of the impact upon the outmigrating salmonids of the proposed dredging operations in the Devil's Hole area of the Trident project. The citations in the text refer to the number of the article in the Annotated Bibliography.

# DESCRIPTION OF THE DREDGING SITE

The proposed Trident drydock-refit pier will be located in the Devil's Hole area of the Keyport, Bangor Annex. The dredging of the drydock is scheduled to begin in February 1977 and will continue for approximately 6 months. The drydock basin will be located 400 to 700 ft from shore and will be approximately 90 ft wide, 700 ft long, and have a floor level at El. -43 mean lower low water (MLLW). Existing bottom elevations in the area range from El. -20 to El. -65 MLLW. The total amount of material to be excavated is unknown at the present time.

## Soil Types in Dredging Area

The following information is taken from Volume 2, Parts A and B, of the Trident Drydock Preliminary Engineering Study Site Investigation by Haley and Aldrich, Inc., October 1975.

There are four distinct layers of deposited soil types in the Bangor-Hood Canal area: recent alluvium, glacial till, aquifer sands and gravels, and lower silts. The lower silt is too deep to be involved in the dredging (El. -300 ft) and will not be discussed.

### Recent Alluvium

The top layer of soil consists of loose-to-compact gray sands and gravels with small amounts of shell fragments, silt, decomposed wood, and small cobbles. The thickness of this layer in the dredging area is 10 ft or less.

### Glacial Till

Directly below the recent alluvium there is a layer of silty sand with a trace of gravel and clay. Pockets of silt and gravel are frequently found. This layer is 20 to 40 ft thick in the proposed drydock area.

### Aquifer Sands and Gravel

Directly below glacial till there are very compact sands and gravels with some layering of silt, organic matter, clay, shell fragments, and cobbles. It is relatively pervious and contains water with high artesian pressures. This layer is approximately 200 to 250 ft thick.

## Size Distribution of Suspendable Sediments

Suspendable sediments in the Trident drydock area can be defined as fine sand, silt, and clay. Based upon the Corps of Engineers unified soil classification system, fine sand ranges from approximately 0.40 mm to 0.063 mm, while silt or clay is any particle which is less than 0.063 mm.

Communications with Navy personnel and analysis of grain size distribution charts, composed by Haley and Aldrich, Inc. (See Additional References p. 37) from soil cores obtained from the drydock site, show the upper 50 ft of soil in the drydock area to contain 20% to 30% silt or clay or a mixture of the two, and approximately 20% fine sand. The silt and clay components appear to have a median grain size of approximately 0.011 mm. Since the fine sand will tend to settle rapidly due to its larger size, the silt and clay will be the primary particles in suspension.

Four samples of the top 4 inches of bottom sediment were analyze Two samples taken at a water depth of 80 ft show an average of 48.7% fine sand (0.50 to 0.063 mm) and 48.8% silt and clay (<0.063 mm). The other two samples were taken in the intertidal zone. They averaged 37.0% fine sand and 17.9% silt and clay. Other analytical results are listed in Tables 1 and 2.

Table 1. Bottom sediment analysis of samples taken from the Devil's Hole area[1]

| | Sample Number | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| | Reported as percent, as received basis | | | | | |
| Total solids | 75.6 | 75.2 | 71.7 | 61.8 | 52.8 | 71.2 |
| | Reported as percent, dry basis | | | | | |
| Volatile solids | 2.6 | 3.1 | 2.6 | 2.8 | 3.7 | 2.0 |
| Chemical Oxygen Demand | 1.3 | 1.2 | 1.3 | 1.5 | 1.8 | 1.1 |
| Oil and Grease | 0.13 | 0.04 | 0.04 | 0.03 | 0.04 | 0.02 |
| Mercury | ND<br>(None detected) | ND | ND | ND | ND | ND |
| Lead | 0.001 | ND | ND | ND | ND | ND |
| Zinc | 0.003 | 0.002 | 0.002 | 0.002 | 0.002 | 0.001 |
| Copper | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Arsenic | ND | ND | 0.0002 | ND | ND | 0.0002 |
| Sulfide | 0.005 | ND | 0.001 | 0.001 | 0.002 | 0.001 |

Lower limit of detection

Mercury - 0.0001 Arsenic - 0.0001
Lead - 0.001 Sulfide - 0.001

| Sample station | Water depth (ft) |
|---|---|
| 1 | 40 |
| 2 | 55 |
| 3 | 45 |
| 4 | 60 |
| 5 | 55 |
| 6 | 65 |

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[1] Laucks Testing Laboratories report on spoil analysis, January 22, 1976, Seattle, Washington.

Table 2. Results of elutriant test on bottom sediment and receiving water from the Devil's Hole area[2]

| | | Sample Number | | | | | |
|---|---|---|---|---|---|---|---|
| | Receiving water | 1 | 2 | 3 | 4 | 5 | 6 |
| Mercury | ND<br>(None detected) | ND | ND | ND | ND | ND | ND |
| Lead | ND | ND | ND | ND | ND | ND | 0.009 |
| Zinc | ND | 0.006 | 0.003 | ND | 0.001 | 0.005 | 0.003 |
| Copper | 0.001 | 0.004 | 0.002 | 0.002 | 0.002 | 0.004 | 0.003 |
| Arsenic | 0.01 | ND | ND | 0.03 | 0.01 | ND | ND |
| Oil sheen Yes/No | | No | No | No | No | No | No |

Lower limits of detection

Mercury - 0.001
Lead - 0.003
Arsenic - 0.01
Zinc - 0.001

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[2] Laucks Testing Laboratories report on spoil analysis, January 22, 1976, Seattle, Washington.

The possible suspended sediment loads, resulting from the dredging operations, have not been calculated; nor have the settling rates and particle shape of sediment by size fraction been determined.

## HOOD CANAL SALMONID OUTMIGRATION

The information in this section was taken from a report submitted to the Navy by Schreiner et al. (22). This report contains information on the salmonid species found in the canal, the times of migration, and the routes of the juvenile salmonids in the Bangor Annex shoreline area.

### Species

Chum (*Oncorhynchus keta*), chinook (*O. tshawytscha*), pink (*O. gorbuscha*), and coho (*O. kisutch*) salmon, as well as steelhead (*Salmo gairdneri*) and cutthroat (*S. clarki*) trout use this area of Hood Canal as a rearing area and passageway. Chum salmon were most abundant throughout the study period (March through July 1975). No data on juvenile pink salmon were obtained as outmigrants occur only during even years.

### Migration Characteristics

#### Times and Routes

Juvenile chum salmon appear to be the most abundant species of salmonids using the Bangor Annex area as a migration route. Migrations through the Devil's Hole area start about late February or early March, peak in late May, and end in mid- to late July. At the present time (1976), chum salmon are present in the Bangor Annex area in mid-January. In 1975, chinook salmon appeared in mid-May, but the capture of insufficient numbers prevented an estimate of peaks of migration.

Coho salmon were also caught in small numbers. Big Beef Creek data show migrations from freshwater begin in mid-March and end in mid-May. In the Bangor Annex area, coho were observed in early May and catch data show a peak in late May.

In 1975, migration duration and peaks could not be determined for steelhead and cutthroat trout due to extremely small catches; however, the patterns are expected to be similar to those determined at Minter Creek, Big Beef Creek, and other stations. A spring migration peaking in May is the general pattern. The townetting surveys in mid-July showed a definite downward trend for all species. This indicates that the salmonid populations had moved out of the area.

Concentrations of salmonids were more common along the Bangor Annex or eastern shoreline than along the western shoreline (22).

## Notes on Life Histories of Salmonids Common to Hood Canal

### Pink Salmon (O. gorbuscha)

During early fall (September through October) of odd-numbered years, mature pinks spawn in the lower portions of the watershed, but some do spawn in the upper watershed. The eggs hatch in late winter and early spring of the even years. The fry (young fish which have just absorbed their yolk sacs, about 25 mm in length) emerge from the gravel in January and migrate downstream to salt water from January through March. The young pinks, after leaving freshwater, stay close to shore during their first summer.

### Chum Salmon (O. keta)

Mature chum salmon enter streams to spawn in September and may continue into late January. They frequently spawn in the lower reaches of the streams, but occasionally move farther upstream. Fry start moving downstream as early as January. Their migration routes follow the shore and they are usually found in large schools in shallow water until June or July, when they move offshore.

### Coho Salmon (O. kisutch)

In Hood Canal, the mature coho spawn (for the most part) in October, November, and December. Fry emerge in early March and April, and remain in freshwater streams for about 1 year. The yearling coho (smolts) are approximately 70 mm when they begin their downstream migration to salt water in April and May.

### Chinook Salmon (O. tshawytscha)

Chinook salmon spawn mainly in the larger rivers in Septemeber and October. Most of the juveniles migrate to sea after a stream residence of about 90 days, but some may stay in freshwater for up to a year. Migrations to salt water begin in late April when the fish are approximately 50 mm in length. By July, they may reach lengths to 130 mm.

### Rainbow Trout (*S. gairdneri*) - Steelhead

Rainbow trout spawn in winter and spring. Most of the young remain in freshwater for 2 years before migrating to sea. Size of rainbow trout in salt water varies widely, as do their migration characteristics.

### Cutthroat Trout (*S. clarki*)

Mature cutthroat trout usually spawn in small streams from February to March. The young remain in freshwater for a year or two and downstream migration to salt water takes place in April and May. Although their salt-water life histories are not known precisely, it is thought that most cutthroat trout stay near, or in, the estuaries at the mouths of streams. Thus, Hood Canal is an ideal environment for cutthroat trout.

## SUMMARY OF THE LITERATURE ON THE EFFECTS OF DREDGING AS IT MAY RELATE TO SALMONIDS

Dredging operations remove and redeposit large quantities of bottom sediment. This material can range from clean sand to organic mud and sludge. The adverse effects of this material on fish and aquatic life in general are of great concern but as yet little has been done to study this situation in the Pacific Northwest. The literature emphasizes some of the more obvious effects on fish which may result from dredging or spoil disposal and these include:

1. Direct effects of suspended sediments
    a. suffocations
        1) gill clogging
        2) clubbing of gills, through abrasion
    b. breakdown of resistance to disease by
        1) initial stress
        2) continued abrasive action of the sediments
    c. behavior of fish
        1) avoidance of polluted areas
        2) methods and tendencies to escape from polluted areas after varying exposures

   d. toxic substances which may be included in the suspended sediments

      1) ionic metals
      2) other toxicants

2. Indirect effects of suspended sediments

   a. demand upon the dissolved oxygen in the water

      1) increased surface area of particles which may create an increased oxygen demand
      2) light penetration which influences primary productivity and consequently, the oxygen balance

## Direct Effects

The direct effects of dredging-related suspension of sediments on fish could range from death to total avoidance of the area. It should be noted that many of the reviewed articles used lab-bioassay methods with suspended sediment concentrations much greater than those normally occurring in the natural environment, but these levels could possibly be reached during dredging.

### Suffocation

Suffocation can occur in several ways. Fine particles can coat and isolate the gill surfaces from contact with the water, thereby preventing gas exchange. The larger particles lodge in the gill lamellae blocking water circulation and creating "dead" spaces at the sites of gas exchange. Injury to the lamellae due to abrasion also prevents sufficient gas exchange. If the injury is severe or the abrasive action prolonged, the fish can suffocate (1, 4, 7, 10, 11, 13, 20, 25).

White perch (*Morone americana*), spot (*Leiostomus xanthurus*), menhaden (*Brevoortia tyrannus*), striped killifish (*Fundulus majalis*), and mummichog (*F. heteroclitus*) in static bioassays were tested in suspensions of mineral solids and natural sediments. These fish represent the broad ecological types likely to be found in typical East Coast estuarine areas, thereby providing a tolerance range of these types of estuarine fishes to suspended sediment.

White perch, spot, mummichog, and menhaden exposed to the mineral solid kaolinite (Hydrite -10) in concentrations of 140 g/liter for 48 hr showed no mortality, but when exposed to suspensions of fuller's earth, mortality did occur. The lowest concentrations which produced 100%

mortality in 0- and 1-year-old menhaden were 1.2 and 0.8 g/liter respectively. Lethal concentrations (fuller's earth) for 10, 50, and 90% mortality in 24-hr bioassays were made on striped killifish, white perch, spot, and mummichog. The lethal concentrations (g/liter) are given in Table 3.

Table 3. $LC_{10}$, $LC_{50}$, and $LC_{90}$ values determined for 24-hr exposure of estuarine fishes to fuller's earth (Sherk et al., 1974) (25)

| | g/liter of fuller's earth | | |
|---|---|---|---|
| Species | $LC_{10}$* | $LC_{50}$* | $LC_{90}$* |
| White perch | 3.05 | 9.85 | 31.81 |
| Spot | 13.08 | 20.34 | 31.62 |
| Striped killifish | 23.77 | 38.18 | 61.36 |
| Mummichog | 24.47 | 39.00 | 62.17 |

*$LC_X$ - concentration of suspended sediments able to produce 10%, 50%, or 90% mortality in a given population.

In 24-hr lethality tests using resuspended natural sediments, lethal concentrations for 10%, 50%, and 90% mortalities for white perch, spot, mummichog, and striped killifish are given in Table 4.

Table 4. $LC_{10}$, $LC_{50}$, $LC_{90}$ values determined for 24-hr exposure of estuarine fish to natural sediment (Sherk et al., 1974) (25)

| | g/liter suspended natural sediment | | |
|---|---|---|---|
| Species | $LC_{10}$ | $LC_{50}$ | $LC_{90}$ |
| White perch | 9.97 | 19.80 | 39.40 |
| Spot | 68.75 | 88.00 | 112.63 |
| Mummichog | Unable to produce sufficient mortalities at any concentration | | |
| Striped killifish | 97.10 | 128.20 | 169.30 |

Natural sediments were shown to be less "toxic" than suspensions of mineral solids such as fuller's earth. The lethal effect of fuller's earth is attributed to a coating effect on the gill filaments due to the finer composition and angularity of the particles, whereas natural sediment clogs gill spaces due to a high content of larger-size, less-angular particles. Rogers (1966), cited by Sherk (25), concluded that particle shape and angularity were the primary reasons for the lethal effect of a suspended mineral solid.

It was suggested that juvenile fish may trap more particles due to their smaller gill openings. Since their increased metabolic rate requires more oxygen, suspended sediments could have a lethal effect with lower concentrations or in less time at the same concentration (25).

Studies of the effects of coal washings on 6-inch steelhead trout (S. gairdneri) and 1- to 2-inch cutthroat trout (S. clarki) showed sand, coal, and slate particles to be lethal in 1-1/2 and 1/2 hr respectively. No suspended sediment concentrations were given. Examination of mortalities showed copious amounts of mucous covering the gills and extrememly heavy concentrations of coal and slate particles adhering to the mucous (20).

Lethality tests were run on several species of estuarine fish using montmorillonite clay. Lethal concentrations of suspended sediment ranged from 38,000 ppm for A. rupestris to 175,000 ppm for F. notatus. Salmonids were not included in the species studied. Examination of the mortalities showed the opercular cavity to be matted with soil, but no damage to gill epithelia was observed. Generally, fish survived 100,000 ppm turbidity for a week, but died within 2 hr when turbidity reached 175,000 ppm (29).

Histological changes in gill epithelium, such as cell thickening and fusion of adjacent lamellae, occurred in 9 to 18-month-old fingerling rainbow trout held in 270 ppm kaolin (median particle size = 2.2μ) and 810 ppm diatomaceous earth (median particle size = 0.46μ). These studies with diatomaceous earth and kaoline produced 50% mortality in as few as 10 days at concentrations of 810 ppm and 270 ppm respectively (11).

Herbert revealed, in a personal communication to the EIFA, that 160,000 ppm gravel washings were the minimum concentration needed to kill rainbow trout (unknown size or age) in one day. Subsequent death resulted from suffocation due to lack of water circulation (10).

Suspensions of kaolin (median particle size = 4.5μ) produced 100% mortality of a test group of shiner surfperch (Cymatogaster aggregata) after only 26 hr at a concentration of 14 g/liter. A 200-hr $LC_{50}$ determined a non-lethal tolerable concentration to be 3 g/liter (21).

## Resistance to Disease

Suspended sediments act on fish by either causing direct mortality or by reducing their resistance to disease. Disease entry is facilitated when fish are placed into stressful situations such as abnormal suspensions of particulate matter. Mechanical abrasion of body epithelium also permits disease organisms to infect the fish and further reduce its resistance.

Angularity, particle size, and concentration are factors which determine the degree of abrasion suffered by the fish exposed to suspended matter. The larger and more angular the particle, the more abrasion it creates, thereby causing existing wounds (if any) to heal more slowly and creating new sores. Chances of infection by bacteria and fungus are greatly increased (1, 4, 7, 10, 11, 13, 25).

Fingerling rainbow trout held for 5 days in 270 ppm diatomaceous earth showed more incidence of fin rot than controls under the same conditions except for the absence of suspended sediments (11).

Rainbow trout yearlings held in suspensions of 200-ppm wood fibers for less than 30 weeks showed a steady mortality. Most of the dead fish showed signs of fin rot. Trout held in 100-ppm concentrations of wood fibers suffered less mortality, but still showed some signs of fin rot (13).

Fuller's earth at concentrations of 0.65 g/liter caused increases in sublethal effects in white perch. Significant increases in hematocrit, RBC count, and hemoglobin occurred while blood osmolality did not change (25).

## Fish Behavior

In most instances, fish will tend to avoid areas which maintain conditions that may be harmful to them. Suspended sediment, in excessive concentrations, may modify the natural movements and migrations of fish by causing avoidance reactions to turbidity and oxygen reduction (1, 10).

Population densities of rainbow trout and other fish in freshwater streams showed an inverse relationship with suspended solid concentrations. Trout fry were also lacking in turbid areas of the streams studied. The fish were either eliminated, or they migrated from the area (downstream) to escape the siltation and suspended sediment (2, 12).

Various freshwater fish other than salmonids exhibited displays of stress-initiated behavior due to high levels of suspended solids (maximum turbidity of 225,000 ppm). At lower concentrations (measurement impossible due to experimental method), the fish surfaced and gulped air and water. As turbidities increased, the fish would surface and lose equilibrium. Further turbidity increases produced a cessation of activity and death (29).

Turbidity caused by disposal of outer harbor sediments from Bellingham Bay may divert salmon (sockeye were the salmon of concern), both adult and juvenile, from their migration routes. Bioassay showed the fish to become disoriented in the turbid water. This particular sediment caused dissolved oxygen levels as low as 0.1 ppm in 2 hr with 5% suspensions, which also may divert salmon from their normal migration routes (23).

Chinook and coho salmon will avoid areas with dissolved oxygen levels of 6 mg/liter or less, but avoidance is not always complete, and, therefore, some fish may die from asphyxiation (31).

Chinook and coho salmon (63 mm to 110 mm) showed avoidance of oxygen concentrations of 1.5, 3.0, and 4.5 mg/liter at 17°C and 24°C. The chinook showed little avoidance of oxygen concentrations of 4.5 mg/liter at 9°C to 17°C, and no avoidance of oxygen concentrations of 6.0 mg/liter at any temperature. Coho exhibited erratic behavior but showed avoidance of concentrations of 1.5, 3.0, 4.5, and 6.0 at 17°C and 24°C (31).

Mass fish migrations occur in Mobile Bay as a result of depressed dissolved oxygen levels due to activities such as dredging and spoil disposal from the construction of the Mobile ship canal. Fish, trapped between shore and oxygen-depleted water, avoid this periodically deoxygenated water and are driven ashore (18).

## Toxic Substances

Suspensions of bottom sediments may release a variety of toxic substances in quantities which may be harmful to fish. Test core samples of the bottom sediments in the proposed dredging area appear to contain no abnormal concentrations of toxic materials, but these toxic substances can be lethal at very low levels.

Representative compounds which could affect fish in the dredging area are discussed below.

The following information is taken from Bell (1), Holland (14), California State Water Resources Control Board (4), and Committee on Water Quality Criteria (7).

Cadmium - The lowest concentration lethal to fish is 0.01 mg/liter. Salmon fry have been killed by 0.03 mg/liter of cadmium when combined with 0.15 mg/liter of zinc.

Chromium - Using coho salmon of an average length of 107 mm, it was found that 10.0 ppm was a critical tolerance level. The chromium content was determined by use of a standard colometric involving dephenyl carbozide (color intensity accurate to 0.005 ppm of chromium).

Copper - Effects of copper can be magnified by symbiotic associations with a number of materials. Copper concentrations as low as 0.015 mg/liter have been toxic. The maxium concentration allowable of copper sulfate for trout is 0.014 mg/liter. Tests using pink salmon (*O. gorbuscha*) with an average length of 41 mm in salt water produced significant kills at 0.563 ppm copper ions. In 66 hr, loss of equilibrium and initial mortalities occurred at 0.178 ppm copper ions.

Lead - Toxic effects on fish have been reported at 0.01 mg/liter.

Mercury - Mercury ions are extremely harmful to aquatic life. Lethal concentrations of Hg for stickleback (*Gasterosteus aculeatus*) have been found to be 0.008 µg. On the basis of experiements on other marine organisms, 0.10 µg/liter constitutes a hazard to the marine environment.

Zinc - Concentrations as low as 0.01 mg/liter have been lethal. It is recommended that a level below 0.02 mg/liter be observed as a minimal risk and that con centrations exceeding 0.01 mg/liter may constitute a hazard to marine life.

Arsenic - Using weighed amounts of arsenic trioxide dissolved in salt water, a tolerance limit for pink salmon ranging in weight from 0.3 g to 8.4 g of 2.65 ppm was obtained Arsenic is a cumulative poison and has long-term effects on aquatic organisms. Trivalent arsenic is much more toxic than the pentavalent forms. Recommendations state that 0.05 mg/liter constitutes a hazard in the marine environment.

Nickel - It has been proposed that 0.1 mg/liter concentrations would pose hazards to marine organisms.

Sulfides - Chinook salmon have survived hydrogen sulfide concentrations of 0.3 mg/liter, cutthroat trout 0.5 mg/liter, and coho salmon at 0.7 mg/liter. Concentrations of 10 mg/liter have been toxic to salmon and trout within 24 hr. Ten mg/liter is toxic to trout within 15 min, and concentrations of 0.05 mg/liter have proved fatal to trout. Chinook and coho salmon and cutthroat trout were affected by concentrations of 1.0 mg/liter, but survived concentrations of 0.3 mg/liter. The eggs and juveniles are more sensitive than adults.

Petroleum and related products - The water-soluble principles (emulsification, primarily) of petroleum products produce direct toxic effects on fish and fish food organisms. These toxic actions may be acute or chronic, depending upon the type and weight of the petroleum product. The lethal concentrations of jet fuel and gasoline for salmon fingerlings were 500 and 100 mg/liter, respectively. Hydrocarbons from petroleum may also lower dissolved oxygen concentrations in the water (4, 7).

## Indirect Effects

The indirect effects of suspended sediments could range from a lower dissolved oxygen content of the water to a reduction in food organisms. In some instances, the subtle effect of marginal environments can stress the fish during an early life stage and cause delayed mortalities.

### Oxygen Demand of Suspended Sediments

Sediments, when suspended, generally exert an increased biochemical oxygen demand on the order of eight times that of the same material in bottom deposits. This is due to the increased exposure of particulate surface area to bacteria, increased nutrient suspension, and increased decomposition of organic matter. As a result, dissolved oxygen levels can be significantly reduced (1, 3, 4, 7, 15, 19, 23).

Results of experiments testing the oxygen demand of inner and outer harbor sediments from Bellingham Bay show that after 1 hr, 2% concentrations of inner harbor sediment contained 3.1 ppm oxygen, while outer harbor sediment contained 5.1 ppm oxygen. A 5% concentration of outer harbor sediments contained 0.1 ppm oxygen after 2 hr. It was stated that the oxygen demand of the inner harbor sediment was probably due to the presence of high concentrations of hydrogen sulfide (23).

Reductions in dissolved oxygen content ranging from 16 to 83% from normal concentrations of 6 to 8 g/liter oxygen were noted during maintenance dredging in Arthur Kill (a tidal waterway in New York harbor). These reductions were attributed to an oxygen demand from suspended sediments and a lack of photosynthetic oxygen production resulting from reduced light penetration (3).

Disturbance of bottom sediments by pipeline and grapple dredging can reduce dissolved oxygen concentrations significantly. In a study of maintenance dredging of Whatcom Waterway in Bellingham by a pipeline dredge, little or no change in surface water quality was noted, but water near the bottom proved to be highly turbid within a large area from the dredge. The bottom at 1,000 ft from the dredge was covered with 2 ft of thin spoil slurry which was completely deoxygenated. Samples taken at 400 ft from the dredge showed a 7-ft thick slurry layer along the bottom.

The primary water quality problems associated with dredging in the Pacific Northwest are dissolved oxygen depressions and the release of turbidity-producing and toxic materials. It is also noted that dredge spoil disposal may be of more harm to the aquatic environment than the actual dredging activity (19).

Carbonaceous pollutants such as oil can cause serious oxygen depletions when introduced into the aquatic environment through sewage sludge and dredge spoil disposal. A work by Thorpey (1967)(15) in the New York Bight showed that pollution loading levels requiring a rate of 20 lb $O_2$ per acre per day cause oxygen levels to drop sharply, thereby causing fish migrations from the area. Loading levels requiring a rate of 20 to 132 lb $O_2$ per acre per day produced constant dissolved oxygen levels at 25% to 50% saturation. Symbiotic algae and bacteria are responsible for this "homeostatic plateau." Rates exceeding 132 lb $O_2$ per acre per day produced anaerobic conditions. Pearce (1969) (15) showed an organic matter content of 4.4 to 81.0 mg/liter was present in sediments of the New York Bight.

A study of the effects of hopper dredging in Coos Bay, Oregon noted two occasions when dissolved oxygen concentrations dropped to less than 2 mg/liter at the dredging site. This is a significant reduction from the background levels of 6.4 to 7.4 mg/liter (26).

Cleveland harbor bottom sediments contain high amounts of pollutants. During hopper dredging, oxygen levels were depressed as much as 25%. In the dump area, 35% oxygen reductions were noted (19).

## Turbidity and Its Relation to Primary Productivity

Turbidity created by dredging and spoil disposal can have various effects on the aquatic environment. These changes may indirectly harm fish, such as salmonids, by reducing the ability of the environment to support food organisms. Suspended solids have been shown to attenuate light and to inhibit food uptake by filter feeders. Turbidity, by reducing the depth of the photic zone, indirectly decreases oxygen production by limiting photosynthesis (7, 1, 3, 25, 4, 7, 5, 10, 24). However, primary production and photosynthesis can, in some cases, be stimulated by the suspension of inorganic nutrients (24).

Turbidity Increases Noted During Dredging and Dredge Spoil Deposition. Observations of a pipeline-dredging operation in Portland Harbor showed no visual effects at the dredge site, but runoff from the spoil deposition area increased turbidity levels from a background of 12 to 18 Jackson Turbidity Units (JTU) to levels of 35 JTU at a distance of up to 100 ft (19).

The Depot Slough, Toledo, Oregon, project involved maintenance dredging with a pipeline dredge and resultant spoil pumped to a diked basin. Background turbidity levels were 6 JTU. During dredging, surface turbidities remained at 6 JTU while turbidities near the bottom increased to 11 JTU. The runoff from the settling pond produced an obvious increase in turbidity 20 ft to 30 ft offshore and 100 ft downstream. The turbidity of the effluent averaged 28 JTU (19).

Primary Productivity - Phytoplankton and Zooplankton. A final report on the effects of dredging and spoil disposal in Upper Chesapeake Bay (6) entails various environmental and geological studies pertaining to sediment deposition, sediment dispersion, and biological changes. The waters of Chesapeake Bay are naturally very turbid. Secchi disc values fall between 0.5 and 1.7 m, as compared with typical values of 1 m to 5 m for Long Island Sound.

Light transmission, in relation to turbidity and particle size, decreased as particle size decreased (increase of surface area) and the effects of turbidity on phytoplankton were measured in terms of transparency and chlorophyll *a*. Transparencies were measured by Secchi disc, marine photometer, and transmissometer. Chlorophyll *a* was at a maximum during late summer and early fall (50 to 60 $mg/m^3$) and winter and spring values averaged 2 to 5 $mg/m^3$. Primary production in the upper Chesapeake Bay averaged 1,300 lb per acre per year of dry organic matter, a relatively low production. This is probably due to high turbidity and reduced light penetration.

It was observed that suspension of fine material from the spoil disposal did not affect phytoplankton in any gross manner, but it was noted that primary production was reduced for short periods due to increased turbidity. Problems in sampling procedures prevented any conclusions concerning the effects of turbidity and suspended sediments on zooplankton and ichthyofauna (6).

Estuary characteristics such as tidal prisms and flushing rates affect size and composition of zooplankton populations, and suspended sediments and other side effects of dredging may be encountered only for a short time or for weeks (27). Monitoring of turbidity and chlorophyll *a* during clamshell dredging in Budd Inlet in Puget Sound showed no definite change from normal conditions except during one instance of disposal of dredge spoil when chloropyll *a* concentrations dropped from 56 mg/m$^3$ to 6 mg/m$^3$ (30), but natural changes in phytoplankton abundance and production masked any changes due to clamshell dredging. In fact, changes in turbidity due to clamshell dredging could not be detected because of the masking effect of phytoplankton blooms caused by the introduction of sewage. Increases in turbidity were noticed during spoil disposal in the deeper waters.

During pipeline dredging, the greatest phytoplankton concentrations were found in the turbidity plume, where in turn the turbidity was greatly affected by phytoplankton abundance, but it was noted that water transparency decreased as much as 49% near the pipeline disposal zone (30).

Absorption of light in natural waters is affected by the concentration of suspended solids. The growth of fixed and suspended aquatic plants can be limited by the light intensity. The Committee on Water Quality Criteria (7) cited calculations by Krone (1963) in which he showed a definite relation between photic zone depth and suspended solid concentrations.

Water with increased suspended solids will absorb more heat and light and will therefore warm more quickly than clearer water. This warming reduces vertical mixing and dissolved oxygen capabilities of the water, especially when water is still or slow-moving. Therefore, an increase of turbidity could change stratification patterns, temperature distribution, dissolved oxygen, and composition of aquatic communities (7).

Turbidity and dissolved oxygen in relation to clamshell dredging in Arthur Kill were studied (3). Background dissolved oxygen averaged between 6 and 8 mg/liter while during dredging, dissolved oxygen at two sampling stations dropped to approximately 1 mg/liter. At the same time, Secchi disc values were 1.5 ft, the lowest value of the day. In the slow-moving Arthur Kill, reduction of incidental light available for photosynthesis as well as the oxygen demand of suspended sediments may cause a lowering of dissolved oxygen concentrations especially during the warmer months. "Resuspension (bottom sediments) during warm months would certainly be harmful to aquatic life, especially if it occurred during a period of maximum fish migration" (3).

The effects of suspended particles of silicone dioxide (median particle size = 17 µm and 6.2 µm) on carbon assimilation by monospecific cultures of phytoplankton in "typical" estuarine salinities of 5.5 ppt to 7.5 ppt at approximately 20°C were determined by Sherk (25). Cell concentrations in storage flasks were kept between 0.5 x $10^5$ to 5 x $10^6$ cells/ml. At the start of an experiment, approximately 10 ml of stock were mixed with 1.5 liters of fresh sterile enriched water. Increases in cell number under a light intensity of 1.45 x $10^4$ ergs per $cm^2$ per sec were monitored until a cell concentration of 50,000 cells/ml was reached (representative of cell concentrations found in areas of Chesapeake Bay). At this concentration experimentation was initiated and standard saturation curves were determined.

Experimentation involved four species of phytoplankton exposed to graded concentrations of silicone dioxide ($SiO_2$). Monochrysis lutheri was exposed to 100, 250, 500, 1,000, 2,250 mg/liter concentrations of $SiO_2$ of median grain size 17 µm. Nanochloris sp., Stichococcus sp., and Chlorella sp. were exposed to 50, 100, 500, and 1,000 mg/liter of $SiO_2$ with a median size of 6.2 µm. Concentrations of $SiO_2$ by weight were determined by dry weight difference between oven-dried aliquots of $SiO_2$ slurry mixture and dried aliquots of the enriched river water to reduce error due to salt content of the water.

No form of submarine light resembles the spectral distribution of unfiltered sunlight or light from fluorescent lamps because of the spectral distribution and light attenuating properties of sea water. However, these experiments using black plastic screen to reduce incidental light provided a geometric decrease in radiation reaching the sample.

Results of increasing suspended solids concentrations were determined and the carbon-14 uptake of M. lutheri decreased as concentrations of suspended sediments increased. A concentration of 2,250 mg/liter $SiO_2$ caused an 80% reduction in carbon uptake. A 50% reduction in carbon uptake was noted at 1,000 mg/liter. The other species showed a 90% reduction at 1,000 mg/liter. The lessening effect on carbon uptake of M. lutheri was attributed to lesser light attenuation by the larger particles (median particle size = 17 µm) and the mobility of the organisms which enabled them to obtain full benefit of incidental light at the sides of the bottle.

Significant reductions of carbon uptake were demonstrated for concentrations of $SiO_2$ between 100 and 500 mg/liter. Typical suspended sediment particles, of similar size distributions to those used in these experiments, occur during dredging and spoil disposal operations and are significant in reducing the energy available to filter feeders.

Nonselective filter feeding copepods Eurytemora affinis and Acartia tonsa were studied in respect to the effects of suspended sediment on feeding activities. It was found that 250 mg/liter concentrations of fuller's earth (median particle size = <0.5 µm), fine sand (median particle size = 1.7 µm and 6.2 µm), and natural silt (median particle size = 0.8 µm) caused significant reductions in the ingestion of phytoplankton due to increased uptake of silt particles (25).

These studies show that suspended sediments do interfere with the natural energy flow by light attenuation and dilution of food cell concentrations. The food supply to secondary consumers (juvenile stages of vertebrates and invertebrates) could be greatly reduced.

## Dicussion

Few literature sources on the effects of dredging on fish existed prior to the 1930's. Since then, most studies have dealt with the more sediment-resistant species such as sunfish, bass, mummichog, and white perch. Only within the last 15 to 20 years have valid environmental studies dealt with salmonids, and of these published studies, very few are specifically concerned with dredging and disposal of dredged materials. The problems of dredging and related spoil disposal can be considered very site-specific, varying greatly with the nature of the material dredged, the quantity, and the hydrographic characteristics of the area.

The scientific literature on the quantitative effects of suspended solids on salmonids is limited. Most of these studies used large (110 mm) fingerling or yearling salmonids as test animals.

General criteria for suspended sediments concentrations in relation to fisheries are presented by the E.I.F.A.C. (10). They state:

"(a) there is no evidence that concentration of suspended solids less than 25 ppm (parts per million) have any harmful effects on fisheries:

"(b) it should usually be possible to maintain good or moderate fisheries in waters which normally contain 25 to 80 ppm suspended solids. Other factors being equal, however, the yield of fish from such waters might be somewhat lower than from those in category (a):

"(c) waters normally containing from 80 to 400 ppm suspended solids are unlikely to support good freshwater fisheries, although fisheries may sometimes be found at the lower concentrations within this range: and

"(d) at the best, only poor fisheries are likely to be found in waters which normally contain more than 400 ppm suspended solids.

"In addition, although several thousand parts per million solids may not kill fish during several hours or days exposure such temporary high concentrations should be prevented in rivers where good fisheries are to be maintained.

"The spawning grounds of salmon and trout require special consideration and should be kept as free as possible from finely divided solids."

The formulation of these criteria are based on studies of species much more tolerant to sedimentation and other stresses than the small (38 mm) chum salmon fry.

It is impossible to generalize on the effects of dredging, and prediction of the effects is hazardous. Pilot or trial studies, including bioassays, appear to be the most logical solution to any large or complex environmental dredging problems.

## Summary of Literature Review

1) In November 1975, the Department of the Navy contracted the Fisheries Research Institute to conduct a literature search on the effects of dredging on juvenile salmonids.

2) Dredging activities for the Trident drydock facility, located in the Devil's Hole area of Hood Canal, are due to commence in February of 1977 and will continue through August 1977.

3) Preliminary studies show the Devil's Hole area to be a primary feeding and rearing area for pink, chum, coho, and chinook salmon juveniles during their outmigration from Hood Canal. The outmigration of salmonids through this area takes place from January through July with a peak in May.

4) Since dredging activities and the salmonid outmigration will occur at the same time, possible damage to Hood Canal salmonid populations may occur.

5) Turbidity and suspended sediments resulting from dredging-related activities can have varying effects on fish and their habitats.

6) Directly, suspended solids harm and may even kill fish by clogging and coating gill filaments; by causing abrasive injuries; by releasing toxic compounds into the surrounding water; and by lowering the fishes' resistance to disease.

7) Indirectly, suspended solids screen out light, thus limiting oxygen production through photosynthesis; reduce the dissolved oxygen level by exposing nutrients to bacterial breakdown; limit primary production by increases in turbidity and reduction of the photic zone; and release toxic substances into the surrounding waters.

8) The effects of suspended sediment depend largely upon characteristics such as size, shape, and concentration of the particles as well as the amount of organic and toxic materials released by the suspension of these sediments.

9) Size, age, and species are also factors which affect the tolerance levels of marine organisms to suspended solids.

## PROBABLE EFFECTS OF DREDGING ON SALMONIDS IN THE DEVIL'S HOLE AREA

The dredging operations are tentatively scheduled from February through July 1977; thus, there will undoubtedly be an impact on the juvenile salmonid outmigrations simply because the entire migration coincides with this time period. At this time, the degree of impact is unknown; however, it may be possible to predict whether it will be significant, moderate, or insignificant.

The dredging site is located on the outer edge of the Devil's Hole tideflats just south of the existing Marginal Wharf. Studies by Schreiner conducted in May 1975 (22) showed this area to have high densities of salmonids. Studies currently in progress will attempt to determine the cause (i.e., piling food organisms, water currents, wharf lighting, etc.) of this attraction of salmonids to this area. To further complicate the situation, the proposed refit pier will be constructed this spring (1976) on the south side of the dredging area, 1,400 ft into Hood Canal. This structure will probably have an additional influence upon the salmonid migration patterns. The concentration of salmonids in the Marginal Wharf area indicates that there are some beneficial factors involved, but this develops a potential hazard if unforeseen events occur (high turbidities, oil spills, pollution, toxic substances, etc.).

The effects of dredging on salmonids in the Devil's Hole area will be very complex. The dredging method and hours of duration of dredging per day will largely determine the magnitude of the effect. Most important will be the suspended solids in shallow water zones or on the tideflats of Devil's Hole. In this area, reduction of dissolved oxygen or increase in suspended sediments to lethal levels may occur during times of calm waters and minimal tidal cycles. Without doubt, water turbidities will reduce the primary productivity of the immediate area. Therefore, a reduction, or actual elimination, of food organisms utilized by salmonids will occur. This may cause the salmonids either to avoid the area or to be stressed somewhat while migrating through the area. The probabilities of either event occurring are unknown at this time.

Particular emphasis should be placed on any toxic substances that may be present (Tables 1 and 2).

Other possible stimuli that may affect salmonid migration patterns are 1) construction and personnel movements in the area, 2) lighting of the area, and 3) artesian water currents.

## RECOMMENDATIONS

1) Any benefits to salmonid migration patterns that may be realized by the use of a small-meshed barrier net are very problematical and, at best, limited. It is our considered opinion that any possible benefits are not worth the risks and costs involved in the use of such large nets.

2) We suggest that, as a more realistic approach, field studies (1976) including on-site bioassay tests be conducted. These bioassays should be run in static and flow-through (dilution and concentration) conditions. The avoidance reactions could then be determined by observations of behavior by offering choices of concentrations and escape routes for the fish. These data could then be applied to conditions expected from the dredging operations. Perhaps the impact can be minimized.

It is our present opinion that the fish will partially avoid and partially migrate through the dredging site with a probable minimum loss; however, the effects of the loss of feeding area and change in "customary" migration routes are unknown. Therefore, a monitoring of the dredging operation should be conduted as follows: a) south of the site, b) at the site, and c) north of the site, to determine catch per unit of effort, growth rates, and stomach content data which can be used to assess the total impact of dredging and permit reasonable levels of mitigation of the fisheries resource, if deemed necessary. At the present time, if well-documented, we do not anticipate such mitigation, but it cannot be completely ruled out.

## ANNOTATED BIBLIOGRAPHY

(1) Bell, M. C.
1973. Fisheries handbook of engineering requirements and biolcgical criteria. Fisheries Engineering Research Program, U.S. Army Engineers Division, North Pacific Corps of Engineers, Portland, Oregon.

A 34-chapter handbook outlining various engineering and biological criteria for use in design of facilities which may have a potential impact on the aquatic environment. Criteria set forth in this publication are compiled from many sources and are valuable for developing "workable limits" but may be subject to change under varying conditions.

(2) Branson, B. A. and D. L. Batch
1972. Effects of strip mining on small stream fishes in east-central Kentucky. Proc. Biol. Soc. Wash. 84(59): 505-517.

In this study the authors observed the effects of siltation from strip mining on the fish populations of two streams.

Results show that fish are eliminated or forced to move downstream due to high turbidity and siltation. Benthic organisms were reduced in number and species by 90 percent and reproduction in darters and minnows was reduced.

(3) Brown, C. L. and R. Clark
1968. Observations on dredging and dissolved oxygen in a tidal waterway. Water Res. Research 4(6): 1381-1384.

Evidence indicates that resuspension of oxidizable bottom sediments in a tidal waterway caused significant reductions in the dissolved oxygen (D. O.) concentration of the water. During dredging, D. O. was reduced between 16-83 percent below normal.

(4) California State Water Resources Control Board, 1963. Water quality criteria. Pub. 3-A, 543 p. McKes and Wolf (eds.), (Reprint June 1, 1974).

This report is a survey and evaluation of the literature and compendium of data on water quality criteria. Conclusions and recommendations are presented on various topics which include water quality criteria of state and interstate agencies; judicial expression; quality criteria for the major beneficial uses of water; potential and biological pollutants; radioactivity; pesticides and surface active agents.

(5) Chandler, D. C.
1942. Limnological studies of western Lake Erie. II. Light penetration and its relation to turbidity. Ecology 23(1): 41-52.

"The present report is concerned with variations in turbidity of the waters of western Lake Erie and the effect of these variations on the depth to which 1% of the surface light penetrates. In this investigation year-round observations were made of: (1) turbidity, (2) light penetration, (3) amount of organic and inorganic suspended matter, and (4) quantity of phytoplankton. The study extended from Sept. 1939 through Oct. 1940, during which time several observations were made each month."

(6) Chesapeake Biological Laboratory
1970. Gross physical and biological effects of overboard spoil disposal in upper Chesapeake Bay. Final Report to the U.S. Bureau of Sport Fisheries and Wildlife (Contract 14-16-0005-0296). Ref. No. 70-3.

This report is a compilation of the results of six research projects, conducted independently, on the effects of spoil disposal on the biological and physical parameters of Chesapeake Bay. Hydrography and geology, phytoplankton, benthos, zooplankton, fish eggs and larvae and fish were studied and guidelines for dredging and spoil dumping were proposed. It was found that as the result of spoil disposal turbidity increased, suspended sediments extended to a distance of 3.1 miles, nitrogen and phosphate levels were increased significantly, benthic individuals were reduced by about 70 percent along with a 65 percent reduction in benthic biomass and the number of species present. However, no gross effect on phytoplankton, zooplankton, fish eggs and larvae, or fish was observed. It should be noted that problems related to sampling methods did occur in some of the studies.

(7) Committee on Water Quality Criteria
1972. Water Quality Criteria 1972. Environmental Studies Board, National Academy of Sciences, National Academy of Engineering, 594 p. Wash. D. C.

A report written for the U.S.E.P.A. concerning various aspects of water quality. This material is organized into six sections:

1. Recreation and Aesthetics,
2. Public Water Supplies,
3. Freshwater Aquatic Life and Wildlife,
4. Marine Aquatic Life and Wildlife,
5. Agricultural Uses of Water, and
6. Industrial Water Supplies.

Each of the sections are thoroughly discussed and water quality standards and guidelines, as established by the National Academy of Sciences - National Academy of Engineering, are presented.

(8) Cordone, Almo J. and D. W. Kelley
1960. The influences of inorganic sediment on the aquatic life of streams. Cal. Fish. and Game 47(2): 189-228.

This report discusses the effects of inorganic sediment on fishes; fish eggs and alevins; bottom organisms; aquatic plants; physical habitat and populations. Discussion of sediment standards and research was included.

(9) Ellis, M. M.
1936. Erosion silt as a factor in aquatic environments. Ecology 17: 29-42.

The aquatic environment is affected by silt by 1) reducing light penetration, 2) changing heat radiation, 3) covering the stream bottom, and 4) retaining organic and other material. Each of these effects is discussed.

(10) European Inland Fisheries Advisory Commission
1965. Water quality criteria for European freshwater fish. Report on finely divided solids and inland fisheries. Int. J. Air and Water Poll. 9: 151-168.

"This is the first of a series of reports on water quality criteria for European freshwater fish prepared for and approved by the European Inland Fisheries Advisory Commission. The background of the project is described and reasons for establishing water quality criteria for fish explained. This is followed by a literature survey of: the direct effects of solids in suspension on death or survival of fish, their growth, and resistance to disease; suspended solids and reproduction; effects on behaviour; effect on food supply; and total effect of suspended solids on freshwater fisheries. Finally tentative water quality criteria are suggested."

(11) Herbert, D. W. and J. C. Merkens
1961. The effect of suspended mineral solids on the survival of trout. Int. J. Air and Water Poll., 5: 46-55.

A study on the effects of mineral solids, kaolin and diatomaceous earth, suspensions on young rainbow trout. Results show that 270 ppm kaolin and diatomaceous earth produced significant mortalities (50% or more). Suspended sediments in concentrations up to 270 ppm had no apparent effect on growth of the test fish after 4-1/2 months. However, concentrations of 270 and 810 ppm kaolin and diatomaceous earth did produce pathological changes in gill tissue and some instances of fin rot.

(12) Herbert, D. W., J. S. Alabaster, M. C. Dart, and R. Lloyd
1961. The effect of china-clay wastes on trout streams. Int. J. of Air and Water Poll. 5(1): 56-74.

"In some Cornish rivers suspended matter from china-clay workings is the only important polluting material, and such streams provide good sites for investigating the effect of chemically inert suspended solids on fisheries, since there are other non-polluted streams of similar size nearby. This paper describes a survey made during May 1960 to determine the status of the brown trout (Salmo trutta L.) in both clean and polluted parts of the Rivers Par, Fal, and Camel, and also in two umpolluted streams, the Subulyan, which is a tributary of the Par, and the Tresillian. The concentrations of suspended matter, the numbers, size and age of the trout, and the amount of food available to them in these streams were investigated."

(13) Herbert, D. W. and J. M. Richards
1963. The growth and survival of fish in some suspensions of solids of industrial origin. Int. J. Air and Water Poll. 7: 297-302.

Suspensions of coal-washery solids and spruce fibers were used in tests of the effects of suspended solids on rainbow trout. It was found that concentrations of up to 200 ppm coal-washery solids produced no moralities. Concentrations of 200 ppm wood fiber produced a slow-steady mortality in test fish populations. The dead fish showed signs of fin rot. Wood fiber in concentrations of 100 ppm also produced fin rot in test fish. The results of a questionnaire inquiring into the effects of discharges of china-clay solids on fisheries in streams of the United Kingdom are also presented.

(14) Holland, G. A., J. E. Lasater, E. D. Neumann,and W. E. Edlridge
1964. Toxic effects of organic and inorganic pollutants on young salmon and trout. State of Washington Dep. of Fisheries, Res. Bull. No. 5, second printing, 264 p.

Industrial and municipal pollution are a threat to Washington's fishery resources. This study investigated the toxic properties of some industrial wastes and by-products, both organic and inorganic, which are known to be discharged into estuaries and rivers of the Pacific Northwest. Because of their importance to the fishing industry of the state, young salmon and trout were used as study animals.

(15) Horne, R. A., A. J. Mahler, and R. C. Rossello
1971. The marine disposal of sewage sludge and dredge spoil in the waters of the New York Bight. Woods Hole Oceanographic Institution. 163 p. Woods Hole Massachusetts.

"The dumping of sewer sludge and dredge spoil in the waters of the New York Bight and the effect of this waste disposal practice on the marine environment is reviewed. The quantities and composition of these wastes is described together with their physical, chemical and biological effects on the environment. At the center of the sludge dump the bearing capacity of the waters has been exceeded and an anoxic bottom area devoid of life formed. Both spoil and sludge contain large quantities of toxic heavy metals and the spoil also contains large quantities of petrochemicals and pesticides."

(16) Institute For Water Resources
1972. U.S. deepwater port study; The environmental and ecological

aspects of deepwater ports. Dept. of the Army Corps of Engineers, Rept. 72-8, Vol IV, 298 p.

A report which includes discussions of dredging, spoil disposal, ship operations, shore development and offshore development in relation to the development of port facilities.

A discussion of the environmental effects of certain shippable commodities is included.

Analysis and evaluation procedures for deepwater port development are discussed and several alternative plans are reviewed and evaluated.

(17) Legore, R. S. and D. M. Des Voigne
1973. Absence of acute effects on threespine sticklebacks (*Gasterosteus aculeatus*) and coho salmon (*Oncorhynchus kisutch*) exposed to resuspended harbor sediment contaminants. J. Fish. Res. Bd. Can. 30(8): 1240-1242.

"Threespine sticklebacks (*Gasterosteus aculeatus*) and coho salmon fry (*Oncorhynchus kisutch*) were challenged in static 96-hr bioassays with suspensions of sediment from the Duwamish Waterway, Seattle, Wash. Doses of up to 5% wet weight (28.8 g/liter dry weight basis) were used. No observable effect on the fish of contaminants released from the sediment was elicited, although high levels of these contaminants, such as volatile solids, COD, organic nitrogen, oil and grease, zinc, and lead, were present."

(18) May, E. B.
1973. Extensive oxygen depletion in Mobile Bay, Alabama. Alabama Dept. of Cons. and Nat. Res., 17 p. Montgomery.

"Extensive areas of bottom water in Mobile Bay, Alabama, one of the largest estuaries on the Gulf of Mexico, suffer oxygen depletion in summer because of salinity stratification in sinks created by shoals in the lower bay and by spoil from construction of the Mobile Ship Channel. When these water masses low in dissolved oxygen are occasionally forced against the beach demersal fishes and crustaceans migrate shoreward in a depressed or moribund state. In the absence of technical data these popular occurrences called "jubilees" provide over a century of historical evidence of oxygen depletion. Oxygen depletion and jubilees occurred in the bay before man physically modified the basin but the conditions responsible for oxygen depletion are worse than in the past. Because of bathymetric changes and modifications which have restricted water circulation, Mobile Bay has exceeded its capacity to assimilate its oxygen demand in summer, which has severely affected the biota of the estuary."

(19) O'Neal, G. and J. Sceva
1971. Effects of dredging on water quality in the northwest United States. Environmental Protection Agency - Region X, 158 p.

A comprehensive study of various effects of dredging and dredge spoil disposal methods. This project involved the study or development of:

1. Methods used in dredging and spoil disposal.
2. Sediment characteristics in dredging areas of Pacific Northwest.
3. Effects of dredging and spoil disposal on the aquatic environment.
4. The criteria for evaluation and monitoring a dredging project.
5. Measures for reduction or elimination of adverse environmental effects due to dredging.

Major findings and conclusions are:

1. Planning of spoil disposal is limited and long-term plans have received very little attention.
2. Pipeline and grapple dredging and spoil discharge can reduce dissolved oxygen, smother bottom organisms and release toxic compounds.
3. Spoil disposal from a pipeline dredge in Bellingham harbor created submarine mudflows with 0.0 mg/l D.O. and total solids of 75,000 mg/l above background levels.
4. Hopper dredges used in maintenance projects do not create adverse water quality effects.
5. Dredging or disposing of spoil behind dikes or breakwaters is effective in reducing movement of turbid water.
6. Pacific Northwest harbor sediments settle more rapidly in salt than in freshwater.
7. Volatile solids content of 10% or greater inhibit biological populations.

Recommendations are also developed concerning regulations of dredging in respect to water quality.

(20) Pautzke, C. F.
1938. Studies on the effect of coal washings on steelhead and cutthroat trout. Trans. Amer. Fish. Soc. 67: 232-234.

Young steelhead and cutthroat trout were held in an area of the Cedar polluted with wastes from coal mining operations. Mortalities occurred in 1-1/2 to 2-1/2 hours. Dead fish showed extended heart and liver, pale gills, and heavy mucous secretions. It was concluded that coal washings were deleterious to fish.

(21) Peddicord, R. K., V. A. McFarland, D. P. Belfiori, and T. C. Byrd
1975. Effects of suspended solids on San Francisco Bay organisms. Appendix G, Physical Impact Study, Dredge Disposal Study San Francisco Bay and Estuary. U.S. Army Engineering District, San Francisco Corps of Engineers. 158 p.

"This research evaluated the impact of the presence of fine mineral particles in the water column on the macrofauna of San

Francisco Bay. A unique laboratory facility providing large aquaria with open, once-through flow of water with the desired suspended solids concentrations was employed. The initial research determined the 200-hour LC$_{10}$, LC$_{20}$ and LC$_{50}$ of suspended kaolin for 18 species of fish and invertebrates. The more sensitive species, including *Mytilus edulis*, *Crangon nigricauda*, *Morone saxatilis* and *Cymatogaster aggregata*, were selected for study of the influence of temperature and dissolved oxygen on the 10-day LC$_x$ of suspended bentonite, which approximated the fine sediments of San Francisco Bay in mineralogy and particle size distribution. Increasing suspended bentonite concentrations reduced the survival of all species, and tolerance decreased as dissolved oxygen content was lowered. Tolerance of the invertebrates to suspended bentonite varied inversely with temperature, while the survival of fish increased at higher temperatures. Changes in oxygen consumption of *Mytilus edulis* and *Morone saxatilis* were noted with increasing suspended bentonite concentrations. In burial experiments only *Mytilus edulis* and *Synidotea laticauda* had significant mortalities within 4 days after rapid deposition of up to 8 cm of bentonite. No species occurring primarily on muddy bottoms was found to be sensitive to high suspended bentonite concentrations. The sensitive species were all fish not intimately associated with the bottom, sandy bottom epifauna or fouling organisms, none of which normally encounter high suspended solids concentrations for extended periods of time. The results indicate that the impact of high suspended solids would be less in winter than in summer due to higher dissolved oxygen levels and lower temperatures."

(22) Schreiner, J. U., A. Didier, E. O. Salo, and B. P. Snyder
1975. Salmonid outmigration studies in Hood Canal. First progress report, March 1975 to July 1975. Fish. Res. Inst., College of Fisheries, U. of Wash. 26 p. Seattle, Wash.

"Beach seine and townetting surveys were conducted in this area of Hood Canal adjacent to the Bangor Annex. Juvenile chum, coho, chinook salmon and rainbow and cutthroat trout were found in this area with the majority migrating along the Bangor Annex shoreline. Chum were the most abundant species with a peak outmigration occurring from mid to late May. No peak migrations could be determined for the other species encountered. Preliminary data show that piers and wharfs, existing along the Bangor Annex shoreline, appear 'to attract salmonids during their migration.'"

(23) Servizi, J. A., R. W. Gordon, and D. W. Martens
1969. Marine disposal of sediments from Bellingham Harbor as related to sockeye and pink salmon fisheries. Int. Pac. Sal. Comm., Prog. Rept. 23, 38 p.

"A recent proposal for dredging and marine disposal of sediment from Whatcom Waterway, Bellingham was of concern to fisheries agencies since the proposed disposal area was utilized by several fish stocks, including migrating Fraser River sockeye and pink salmon. Laboratory study indicated that two types of sediment were involved. Sediment from the inner harbor consisted primarily of putrefying pulp fibers which exerted a significant oxygen demand, created substantial turbidity, and were toxic to juvenile sockeye salmon because of their hydrogen sulfide content. Hydrogen sulfide was readily dissipated from inner harbor sediment by diffused air but was not removed by exposure for a few hours to the atmosphere. Various methods of widespread dispersal to dilute the sediment appeared impractical, and it was concluded that land disposal of inner harbor sediment would be necessary to protect fish stocks. Sediment from the outer harbor was a natural silt, not containing hydrogen sulfide, but exerted an oxygen demand and created a highly turbid mixture which settled very slowly. Because dumping of this sediment at the proposed site could also prove harmful to fisheries, hydraulic dredging and local disposal adjacent to the outer harbor was recommended."

(24) Sherk, J. A. Jr.
1971. The effects of suspended and deposited sediments on estuarine organisms, literature summary and research needs. Nat. Res. Inst. of the Univ. of Maryland, Chesapeake Biological Laboratory. Contribution no. 443, 73 p. Solomons, Maryland.

An extensive summary and discussion of literature related to the effects of sediment on biological systems, filter-feeding organisms, and offshore waste disposal are presented. Research needs on the effects of suspended and deposited silt are proposed.

In the section of sediment effects on biological organisms the author discusses: Loss of habitat, decrease in euphotic zone depth, oxygen demand, nutrient sorption and release, primary production, community disruption, mortality and other gross effects.

The section involving sediment effects on filter-feeding organisms includes: pumping and feeding, character of the bottom and larval metamorphosis, and larval and egg development. The problems and biological effects resulting from offshore disposal of particulate wastes are discussed and information from some studies related to these effects is presented.

Research needs in the area of suspended and deposited sediments are fairly extensive. A standardization of study methods and a need for quantitative knowledge of the physical aspects of suspended matter is indicated as well as complete studies incorporating the total interaction of environmental change to the lethal effects on <u>all</u> life stages of the organisms studied. These aspects are important "in order to provide complete predictability of the effects of environmental change."

(25) Sherk, J. A., J. M. O'Connor, D. A. Neumann, R. D. Prince, and K. V. Wood

1974. Effects of suspended and deposited sediments on estuarine organisms - Phase II. Final Report, Natural Res. Inst., University of Maryland, 299 p. College Park, Maryland.

"A three-year laboratory study identified biological components of selected populations of estuarine organisms which were most sensitive to the effects of particle size and concentration of (1) suspended mineral solids similar in size to sediments likely to be found in, or added to, estuarine systems in concentrations typically found during flooding, dredging, and disposal of dredged material, and (2) natural sediments in identical experiments. Significant mortality of estuarine fishes was demonstrated at these suspended solids concentrations. Estuarine fishes were classified using the results of static bioassays as tolerant (24 hr $LC_{10}$ $> 10$ g $l^{-1}$), sensitive (24 hr $LC_{10}$ $< 10 > 1.0$ g $l^{-1}$), or highly sensitive (24 hr $LC_{10}$ $< 1.0$ g $l^{-1}$) to fuller's earth suspensions. Generally, bottom-dwelling fish species were most tolerant to suspended solids; filter feeders were most sensitive. Early life stages were more sensitive to suspended solids than adults. Bioassays with natural sediments indicated that suspensions of natural muds affect fishes in the same way as fuller's earth, but higher concentrations of natural material were required to produce the same level of response. The effect of finely divided solids on fishes was dependent on several characteristics of suspended particles with different mechanisms operative in producing mortality in fishes, although the cause of death was the same: anoxia. Sublethal solids effects on fishes were identified: hematological compensation for reduction in gas exchange across the gill surface, abrasion of the body epithelium, packing of the gut with large quantities of ingested solids, disruption of gill tissue, increased activity, and reduction in stored metabolic reserves. Oxygen consumption of striped bass and white perch swimming at controlled levels of activity was generally reduced during exposure to suspensions of fuller;s earth and natural Patuxent River sediments. Carbon assimilation by foud species of phytoplankton was significantly reduced by the light attenuating properties of fine silicon dioxide suspensions. Ingestion of radioactive food cells by two species of calanoid isopods was significantly reduced during exposure to suspensions of fuller's earth, fine silicon dioxide, and natural Patuxent River silt. With adequate knowledge of local conditions (life history stages, sediment types, sediment concentrations, seasonal and resident species, duration of exposure, and habitat preference) at estuarine sites selected for environmental modification, our efforts provide baseline data for pre-project decision making based upon concentration effects of different types of suspended sediments."

(26) Slotta, L. S., C. K. Sollitt, D. A. Bella, D. H. Hancock, J. E. McCauley, and R. Parr
1973. Effects of hopper dredging and in channel spoiling in Coos Bay, Oregon. Interdisciplinary Studies of the School of

Engineering and School of Oceanography, Oregon State University. 133 p. Corvallis, Oregon.

"An integrated study was conducted to gain insight on actual chemical, physical and biological effects associated with the dredging and disposal methods of a hopper dredge. Field investigations and subsequent laboratory analyses were organized to evaluate the nature and magnitude of environmental changes resulting from dredging activities on October 4, 1972, at Coos Bay, Oregon, over miles 13+00 to 13+40. Methods and evaluation techniques for proper assessment are discussed and post-dredging conditions compared to a pre-dredging baseline.

"Following dredging, sediments were found to: (1) decrease in median grain size at the dredge site due to exposure of fine subsurface material; (2) increase in median grain size and decrease in uniformity at the spoil site due to loss of fines; (3) decrease in porosity at the spoil site due to the ability of the coarse sediments to resist resuspension, and (4) decrease in volitile solids at the spoil site due to loss of light organics (that surface spoils were high in volatile solids immediately after spoiling before the wood chips were washed away).

"Bottom sediment instability was pronounced; frequent resuspension of the surface sediments was in evidence as sediment profiles revealed coarse material near the surface and finer material settled at depth. Destabilizing forces such as dredge spoiling or frequent marine traffic in the navigation channels resuspend sediments allowing fines to be washed away by currents. Natural deposition provided more fines in bottom deposits than dredge spoiling. Chronic environmental impacts caused by continuous marine traffic may be more significant than the acute impacts caused by singular dredging operations.

"Free sulfides were not detected in interstitial waters of the sediments at the dredging site, nor overlying waters. The absence of free sulfides may have been due to frequent overturning of the bottom materials by marine traffic. Before dredging, turbidity levels exceed 80 JTU (Jackson Turbidity Units); but rose to over 500 JTU in the wake of the dredge during dredging and spoiling exceeding Environmental Protection Agency recommended levels. Debris increased in bottom sediments as a result of spoiling.

"The benthic fauna in the study area on Coos Bay were representative of a moderately polluted environment. Significant reduction of infaunal abundance was observed following dredging and spoiling. Increased diversity immediately following dredging and spoiling may be due to increased homogenization of patchiness. Incomplete dredging left submerged hummocks which might be important in subsequent re-establishment of biota. Biological sampling on board the dredge was not as satisfactory as benthic sampling.

"The physical, chemical and biological sampling techniques employed were found to be quite useful for describing acute effects of dredge spoil distribution and estuarine impacts, but more efficient techniques are needed to gain spatial and temporal resolution of chronic, long-term effects."

(27) Slotta, L. S., D. R. Hancock, J. E. McCauley, C. K. Sollitt, J. M. Sander, and K. J. Williamson

1974. An examination of some physical and biological impacts of dredging in estuaries. Interim Progress Report to the Division of Environmental Systems and Resources (RANN). Interdisciplinary Studies of the Schools of Engineering and Oceanography, Oregon State University. 257 p., Corvallis, Oregon.

This is an interdisciplinary study of the effects of dredging in estuaries. It covers both biological and physical aspects and presents studies of dredging in relation to physical changes in the estuary and effects on zooplankton and benthic fauna. A draft of applied interdisciplinary research and environmental management is included.

(28) Van Oosten, J.

1945. Turbidity as a factor in the decline of Great Lakes fishes with a special reference to Lake Erie. Trans. Amer. Fish. Soc. 75: 281-322.

"Fish live and thrive in waters with turbidities that range above 400 ppm and average 200 ppm. The waters of the Great Lakes usually are clear except in Lake Erie where the turbidities of the inshore areas averaged 37 ppm; the turbidities of the offshore waters averaged less. Lake Erie waters were no clearer 50 years ago than they are now. In fact, the turbidity values are less now than they were in earlier years; the annual average of the inshore waters dropped from 44 ppm before 1930 to 32 ppm in 1930 and later, and the April-May values decreased from 72 ppm to 46 ppm. Any general decline in the Lake Erie fishes cannot be attributed to increased turbidities. Furthermore, these turbidities averaged well below 100 ppm and, therefore, were too low to affect fishes adversely.

"Turbidity in the open waters of Lake Erie is primarily the result of wave action induced by winds. River discharge is a minor factor even in the western end of the lake. Other probable factors are plankton, the eastward movement of the water mass, currents, seiches, and possibly bacteria. Wave action is undoubtedly the dominant agency in soil erosion along the shores of all of the Great Lakes.

"No evidence exists that fluctuations in the abundance of zooplankton, the basic food of fishes, and of the fishes themselves are positively correlated in Lake Erie or that the plankton crop in this lake is ever in short supply. On the contrary, all available evidence shows that Lake Erie is comparatively rich in plankton and that the western end in spite of its turbidity is richer than the eastern. Some factor other than turbidity dominates the basic productivity of western Lake Erie.

"With respect to turbidity Lake Erie has not become less suitable for fishes. This conclusion also receives support from the study of the fishes themselves. It was demonstrated that the growth of the western Lake Erie fishes compared very favorably with that of fishes in the other Great Lakes or similar waters. It was shown further that the known occurrence of relatively strong year classes in this lake was not consistently associated with low turbidities and conversely that the known low turbidities of the Lake Erie waters were not always accompanied by the large year classes. Also, contrary to the "turbidity theory," certain clean-water varieties, such as the walleye, have increased tremendously in recent years in Lake Erie, whereas the supposedly turbid-water forms, such as the sauger, have decreased in abundance. Reference was made to Doan's work, wherein he attempted to show correlation between turbidity and abundance for several species of Lake Erie fish but failed to do so except for the sauger where he reported a positive correlation. With respect to the productivity of fishes Lake Erie ranks first among the Great Lakes, and the western end in spite of its greater turbidity surpasses the eastern. As judged by certain accepted standards of water suitability, Lake Erie ranks high, and the western end again surpasses the eastern. Finally, it was pointed out that fishes which inhabit the clear waters of the Great Lakes declined as well as those which live in the more turbid waters and that turbidity, therefore, cannot be a factor in the depletion of all Great Lakes fishes. Furthermore, the reduction in abundance repeatedly has been associated with increased fishing intensity.

"All of the evidence indicates, then, that soil erosion on farms and the turbidity of the water were not major factors, if operative at all, in the decline of Great Lakes fishes and that they did not make Lake Erie unsuitable for fish life."

(29) Wallen, E. I.
1951. The direct effect of turbidity on fishes. Bull. Okla. Agr. and Mech. Coll. Arts and Sciences Studies, Biological Series No. 2, 48: no 2, 27 p. Stillwater.

Concentrations of montmorillonite clay killed most testfish (16 species) at 175,000 to 225,000 ppm in 15 to 120 minutes. Most fish survived concentrations up to 100,000 ppm. Behavior patterns elicited by increasing turbidity concentrations (20,000 ppm to 225,000 ppm) had 4 stages:

1. Surfacing for short periods and gulping air and water,
2. Surfacing for several minutes and losing equilibrium,
3. Floating on side at surface for up to 30 minutes and occasionally trying to swim,
4. Floating on side at surface with attempts at opurcular and pectoral movement followed by death.

Mortalities showed gills clogged with silt and clay particles. Montmorillonite clay at naturally occurring turbidities was not shown to be lethal to juvenile or adult fish as concluded by the author.

(30) Westley, R. D., E. Finn, M. Carr, M. Tarr, A. Scholz, L. Goodwin, R. W. Sternberg, and E. E. Collins
1973. Evaluation of effects of channel maintenance dredging and disposal on the marine environment in southern Puget Sound, Washington. Management and Research Division, State of Washington Dept. of Fish., 308 p.

A compilation of studies of the effects of dredging and spoil disposal on physical and biological parameters in 3 areas of southern Puget Sound; and comparison of 3 methods of disposal. General salmon, as well as oysten and clam larvae bioassays revealed no toxicity associated with dredging or spoil dumping. Phytoplankton was also apparently not inhibited. Silt distribution varied in each of the study sites and was attributed to tidal action, current patterns, and dredging and dumping methods.

Water quality was not shown to be affected significantly by dredging or barge dumping except for a small decrease in oxygen and increase in BOD during pipeline dredging on Olympia Harbor.

It was noted that phytoplankton bloom during the study caused toxic water conditions and rendered the oyster and clam larvae bioassay inconclusive. Also, sewage discharge from the city of Olympia caused some difficulties in interpreting results.

Of the methods of spoil disposal studied in this report, pipeline disposal distributes silt much more extensively than barge dumping, but was noted to be a much faster method than barge dumping.

General problems to be encountered in studies of this type are:

1. Lack of techniques for evaluation of environment conditions.

2. Lack of biological and oceanographical background information of the area under study.

3. Separation of dredging effects from pre-existing water quality problems.

4. Incomplete assessment evaluation of field information due to the short duration of dredging operations.

(31) Whitmore, C. M., C. E. Warren, and P. Doudoroff
1960. Avoidance reactions of salmonid and centrarchid fishes to low oxygen concentrations. Trans. Amer. Fish. Soc. 89(1): 17-26.

"All four fish species used in 174 laboratory experiments with a "channeled avoidance tank" avoided some low oxygen concentrations, the degree of avoidance generally decreasing with increasing concentration. Avoidance indices computed were based on numbers of entries into two experimental channels with reduced oxygen concentrations and two control channels, on numbers of crossings of a transverse line located well inside each channel, and on numbers of fish observed in the channels at 60-second intervals. Juvenile chinook salmon showed marked avoidance of oxygen concentrations near 1.5, 3.0, and 4.5 mg/l. in summer at high temperatures. A decrease of the avoidance observed in the fall is ascribable to lower temperatures. The chinook salmon showed little avoidance of concentrations near 4.5 mg/l. in the fall, and no avoidance of concentrations near 6.9 mg/l. at any time. At summer temperatures juvenile coho salmon showed some avoidance of all of the above oxygen concentrations, including 6 mg/l., but their behavior was erratic and their avoidance of concentrations near 4.5 mg/l. and less was not as pronounced as that of chinook salmon at corresponding temperatures. Largemouth bass and bluegill markedly avoided concentrations near 1.5 mg/l. but showed little or no avoidance of the higher concentrations, only the bass showing any avoidance of concentrations near 4.5 mg/l. The nature and significance of the observed avoidance reactions are not quite clear. The prompt avoidance by some fish of oxygen concentrations well above those known to be lethal cannot be ascribed entirely to mere stimulation or increase of activity due to oxygen deficiency. It may not be assumed, however, that oxygen concentrations avoided under the experimental conditions are usually avoided likewise under natural conditions."

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1938. Experiments on tolerance of young trout and salmon for suspended sediment in water. In H. B. Ward, Placer mining on the Rogue River, Oregon in its relation to the fish and fishing in that stream. Appendix B, Oregon Dep. Geol. and Min. Indust., Bull. No. 10, p. 28-31.

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1973. Pacific fishes of Canada. Fish. Res. Bd. Can. Bull. 180, 740 p. Ottawa.

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