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ALASKA PARTICULATES CRITERIA REVIEW

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EXECUTIVE SUMMARY

1.0 INTRODUCTION

The Alaska Department of Environmental Conservation contracted L.A. Peterson & Associates, Inc. to conduct a study of Alaska's water quality particulates criteria. The comprehensive intent of the study was to:

(1) Review pertinent literature to determine state-of-the-art measurement technology, physical/chemical effects, and biological effects of particulates.

(2) Compile and assess particulates criteria from other states and Canadian provinces and territories and compile U.S. Environmental Protection Agency guidelines and requirements for particulates criteria.

(3) Evaluate the adequacy and scientific merit of existing Alaska criteria for particulates.

(4) Assess the potential for using parameters other than turbidity, suspended and settleable solids, and the percentage accumulation of fines in spawning gravels.

(5) Propose new particulates criteria if scientific evidence supports this action.

The investigation was limited to the problems of water pollution resulting from particulates and the direct and indirect methods for measuring particulates. A comprehensive literature review was performed to document the effects of particulates on various water uses. Background information regarding particulate measurement techniques, water quality, and aquatic ecology appears in Section 2.0. Section 3.0 summarizes particulates criteria used in water quality standards and guidelines throughout the United States and Canada. Alaska's particulates criteria are reviewed (Section 4.0) and the potential use of parameters other than turbidity, suspended and settleable solids, and percentage accumulation of fines in spawning gravels are discussed in Section 5.0. Recommended changes to Alaska's criteria to insure that Alaska's particulates criteria are supportable and based on the best available information are presented in Section 6.0.

2.0 COMPARISON OF ALASKA CRITERIA TO OTHER STATES AND CANADA

Other than Alaska, 33 states have quantitative turbidity criteria for at least some water uses. Among the 20 states having cold water systems similar to Alaska and numerical criteria for turbidity, the criteria are numerically equal to or more stringent than Alaska's. Turbidity criteria for lakes are comparable. Quantitative turbidity criteria in Canada are comparable to Alaska criteria for recreation and the propagation of fish and wildlife. The U.S. Environmental Protection Agency criterion for turbidity and solids pertains to the compensation point for photosynthetic activity. Of the 14 states with turbidity standards for marine water, seven employ quantitative criteria.

None of the states have quantitative criteria for settleable solids levels. Only four states other than Alaska currently have numeric criteria for suspended solids. Of the remaining states, 17 have general narrative statements addressing these parameters. Alaska is the only state with criteria controlling the accumulation of sediments as a maximum percentage by weight of spawning bed gravels. Currently, there are no water quality standards for suspended and settleable solids in Canadian provinces and territories.

3.0 PARTICULATES REQUIREMENTS FOR WATER SUPPLIES

The amount of particulates allowable in raw water supplies depends on the type and degree of treatment used to produce finished water. An excellent source of water requiring only disinfection would have a turbidity of 0 to 10 units. A good source of water supply requiring usual treatment would have a turbidity of 10 to 250 units. For disinfection purposes, raw drinking water sources should be limited to 5 turbidity units, and finished water should have a maximum limit of 1 turbidity unit where the water enters the distribution system. Most people find water with 5 or more turbidity units objectionable.

The water quality requirements for particulates varies among industrial uses. At one extreme, rayon manufacture requires water with only 0.3 turbidity units, whereas water used for cooling can have up to 50 turbidity units. Most other industrial uses require maximum turbidity levels within this range. Placer mining is one industry where water containing turbidity or suspended solids levels significantly higher than 50 units may be acceptable.

4.0 PARTICULATES REQUIREMENTS FOR RECREATION

The noticeable threshold for water contact recreation is 10 turbidity units and the limiting threshold is 50 units. The suggested maximum turbidity limit for Canadian contact recreational water quality is 50 turbidity units and the minimum Secchi disk visibility depth is 1.2 meters. The noticeable threshold for boating and aesthetic uses is 20 turbidity units. There is apparently no level found in surface water that is likely to impede these uses, although many people prefer clear water conditions. Fishing success is reduced where turbidity is greater than about 25 units.

5.0 PARTICULATES REQUIREMENTS FOR BIOTA

A large body of experimental data exist regarding the effects of fine sediment deposition on salmonid eggs in natural and laboratory stream gravels. By comparison, only limited numerical data are available regarding the effects of sediment on fish emergence time and population changes. The percentage of fines and level of spawning gravel embeddedness are critical factors to developing eggs and emerging fry. In general, salmon, trout, and char egg survival and emergence success are adversely affected when the fraction of fine sediment exceeds 20 percent. Although the critical particle size is highly variable among species, sediment smaller than 3 mm in diameter appears to be the most deleterious to fish egg survival, emergence success, and productivity. A number of investigators emphasize the deleterious effect of particles smaller than 1 mm in spawning gravels. In addition, it is generally recognized that deposited sediments smother fish eggs and benthic macroinvertebrates by blanketing the substrate.

The adverse impacts of a wide range of suspended solids and turbidity levels have been reported for a diversity of aquatic plants, macroinvertebrates, and various stages of fish development. Research has been conducted under a variety of environmental conditions for different lengths of time and the results are often expressed in different units of measure. In many instances, the data presented in one investigation either do not support or cannot be readily compared to the results of other investigations. An organism's level of sensitivity to suspended solids is dictated by its age, species, relative mobility, feeding and reproductive habits, the season, the size and nature of the sediment, the duration of exposure, the general health and stress level of the individual, and the degree and duration to which the individual was previously exposed. Furthermore, an individual's level of susceptibility depends to some degree upon its origin. For instance, one investigator indicates that hatchery-raised coho salmon are considerably more sensitive to suspended solids than are wild coho. Moreover, the results derived from laboratory experiments do not necessarily reflect field conditions because of the stress factors involved and because many organisms possess innate adaptation capabilities in response to changes in their environment. These variables are not always presented in the literature. It is relatively common to find the results from one particular study cited in three or more literature reviews. Upon reviewing the original document, it appears that some of the data have been presented without discussing other pertinent factors. Consequently, it is difficult to draw definitive conclusions concerning the impact of a specific suspended solids concentration or turbidity level on a particular species or age class of organism. With these limitations in mind, the following summary statements are made concerning the effects of suspended solids and turbidity on freshwater aquatic organisms.

Lethal suspended solids concentrations vary widely depending on the species and duration of exposure. Arctic grayling can survive high concentrations (10,000 mg/L) of suspended solids but not extremely high concentrations (250,000 mg/L) for a few days. High levels of turbidity (up to 8200 NTU) appear to have no adverse effect on grayling survival. Rainbow trout are capable of withstanding 30 to 90 ppm of certain types of suspended solids for several months but suffer significant mortality (50 percent) at levels greater than 100 mg/L for several weeks. At extremely high levels of suspended solids (160,000 mg/L), rainbow trout suffer total mortality in 1 day. Total egg mortality may occur at much lower concentrations (less than or equal to 2500 mg/L) in less than a week. The amount of sediment required to cause 50 percent mortality in juvenile coho salmon in 4 days is much higher in November (35,000 ppm) than in August (1200 ppm). Chum salmon egg survival is decreased by about half when suspended solids levels are increased from 97 to 111 mg/L.

In general, salmonid feeding, growth, reproduction, and behavior are not significantly affected by turbidity levels less than 25 NTU or suspended solids concentrations less than 50 mg/L. An exception is the cutthroat trout, which ceases feeding at 35 ppm suspended solids. With one exception, there is no indication that suspended solids concentrations less than 90 mg/L have any adverse effect on salmonid gill or fin tissues, or respiratory functions. In one instance, an _in situ_ concentration of 34 mg/L produced moderate to marked gill hypertrophy and hyperplasia in Arctic grayling in 5 days. Furthermore, suspended solids concentrations as low as 50 mg/L may be stressful to grayling, as indicated by blood glucose levels.

Algal-based productivity may begin to be reduced at turbidity levels greater than about 5 NTU in streams and lakes. Rooted aquatic plants may be absent at suspended solids concentrations greater than 200 mg/L. Benthic macroinvertebrate populations may be adversely affected by suspensions of 40 mg/L or more and zooplankton may be harmed by more than 82 mg/L suspended solids.

Lethal and sub-lethal effects of sediments have been determined for a diversity of marine organisms. Numerical data pertain primarily to the effects of suspended solids and turbidity as opposed to sediments deposited on the bottom. Much of the work done in the marine system involves estuarine invertebrates. With few exceptions, marine invertebrates are more tolerant of high suspended solids concentrations than are anadromous fish and freshwater invertebrates.

Primary production has been reduced at turbidity levels of 41 JTU near offshore mining activity. However, mixing and dilution limited the extent to which primary production was reduced by localized or temporary sediment increases. The lethal suspended solids concentration for adult bivalves, crustaceans, tunicates, and polychaetes is in all instances greater than 400 mg/L and in most cases greater than 1500 mg/L. The survival of a variety of estuarine fish eggs and larvae is not reduced by suspended solids concentrations less than 100 mg/L. However, the feeding rate of larval herring is significantly reduced at 20 mg/L.

The sub-lethal effects of suspended solids and turbidity on mollusks are quite variable. The feeding rate of some oysters is unaffected at 100 to 700 ppm turbidity. Some clams cease feeding at 1000 JTU. The water pumping rate of the American oyster is significantly reduced at concentrations greater than 100 mg/L. The feeding rate of the mollusk Crepidula sp. is significantly reduced at 200 mg/L. Clam eggs develop normally in silt suspensions of 3000 mg/L, whereas American oyster eggs are affected by silt concentrations as low as 188 mg/L. Seed scallops exhibit elevated respiration rates at 250 mg/L or greater. The mussel Mytilus sp. is well adapted to silt concentrations up to 50 mg/L. The shell growth of certain gastropods is decreased when natural suspended solids are increased to 250 mg/L.

6.0 CONCLUSIONS

1. The level of protection afforded by the existing Alaska particulates criteria for the designated water uses is generally supported by scientific data. However, a number of proposed modifications to the existing criteria have been made to attain the best criteria based on information presented in this report.

Use categories for which turbidity criteria have been retained include industrial water supply and contact and secondary recreation in fresh water. Under the proposed criteria, no distinction is made between lakes and streams for recreational uses. The turbidity criteria for drinking water supply, growth and propagation of aquatic organisms, and contact and secondary recreation in marine water are amended to allow variable increases in turbidity within specified ranges. It is proposed that the existing turbidity and sediment criteria be deleted for certain use categories because: (1) There is no evidence to support their validity, or (2) other criteria are judged to be more appropriate for the stated use category. It is proposed that the existing turbidity criteria be deleted for agriculture, seafood processing, industrial water supply in marine waters, harvesting for consumption of raw mollusks or other aquatic life, and aquaculture in both fresh and marine waters.

The sediment criteria for agriculture, seafood processing, drinking water supply, and industrial supplies (fresh and marine water) are amended to include statements addressing suspended and settleable solids. The existing sediment criteria for aquaculture and growth and propagation of aquatic biota have been rewritten to include numerical suspended solids and settleable solids criteria for both fresh and marine waters. Additionally, the allowable percentage accumulation of fines in spawning gravel is reduced for the growth and propagation of aquatic biota in fresh water. A new criterion for settleable solids is proposed for the harvesting of raw mollusks and other aquatic life. It is proposed that sediment criteria be deleted for contact and secondary recreation in both fresh and marine waters.

2. Alaska currently employs particulates criteria for two categories: turbidity and sediment. The sediment category includes criteria for total suspended solids, settleable solids, and the percentage accumulation of fines in spawning bed gravel. Criteria for these four parameters are adequate for the protection of all water use categories in Alaska. It was determined that the percentage accumulation of fines in spawning gravel is a difficult parameter to measure. Hence, it is recommended that settleable solids criteria be used as the

primary method to limit the accumulation of fines in spawning gravel. Actual measurement of the percentage accumulation of fines by weight can be used as a secondary method at the Department's discretion.

3. Settleable solids have direct and detrimental effects on aquatic biota and habitat by smothering fish eggs, alevins, and invertebrates, reducing intergravel flow, and by coating aquatic vegetation, thus reducing the potential for photosynthesis. Solids in suspension can cause invertebrate drift, cause fish to avoid previously usable habitat, prevent fish from seeing their prey, and cause physical damage such as gill irritation to fish. The lethal tolerance of salmonids and other aquatic organisms to suspended solids appears to be relatively high. In most instances, sublethal effects occur at much lower concentrations. Turbidity prevents the growth and photosynthesis of green plants and can also cause fish to avoid otherwise suitable habitat and prevent them from seeing their prey.

4. Gravimetric techniques represent a more accurate measure of the effects of suspended solids on aquatic biota while optical measurements may be more appropriate for photosynthetic or aesthetic purposes.

5. Sediment is, by volume, the greatest single pollutant of surface water. The transport and deposition of natural sediments is often related to local storm events and stage of hydrograph. The fate of man-induced sediments differs from natural sediments in that the former is not necessarily associated with or dependent upon fluctuations in runoff. In some instances man-caused sediment inputs are greater in magnitude, duration, and frequency than natural inputs. Furthermore, the timing of man-caused inputs may be out of phase with natural occurrences. Consequently, the ultimate fate of man-caused sediments may be different than natural sediments.

Also, the sequence of artificial sediment loading may induce abnormal behavioral responses in resident and anadromous fish.

6. Because many investigators have not adhered to the definition of turbidity and instrument design specification applied by Standard Methods for the Examination of Water and Wastewater, there is a significant amount of variability in the way turbidity is measured and reported. This factor makes it extremely difficult to assess and compare the effects of turbidity on various water uses. Common sources of error in turbidity measurements include the collection of representative samples in the field, extraction of subsamples, dilution technique, and reporting data to the correct number of significant figures. Although it is recognized that turbidity measurements may be difficult to evaluate, turbidity is the most applicable of the potential optical parameters for widespread use in Alaska.

7. The standard technique for measuring total suspended solids is routine to perform under laboratory conditions and the results are relatively exact. Common sources of error include those associated with field sampling techniques and the extraction of subsamples. Alternative methods for measuring suspensions of sediment possess limitations that preclude their widespread application.

8. Under limited conditions turbidity may be effectively used to estimate suspended solids concentrations. There is, however, no single expression which relates turbidity and suspended solids on a regional or universal basis. The development of any predictive relationship between these parameters should be on a drainage basin basis rather than a statewide basis. Any apparent correlation should be accompanied by a rigorous analysis of the data and include a statement of the error associated with the correlation. In addition to treating the

data collectively, regression analyses should include calculations of coefficients of determination and confidence limits for data in the low, medium, and high ranges.

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1.0 INTRODUCTION

The federal Water Pollution Control Act as amended in 1972, Public Law 92-500, was modified and renamed the Clean Water Act in 1977. This Act required all states to adopt standards of quality to protect their waters for specific uses. In Alaska, the water quality standards are the responsibility of the Department of Environmental Conservation (ADEC). Except in a few special cases, fresh and marine surface waters in Alaska must meet all standards designed to protect water quality for the uses shown below. The exceptions are noted in the 1985 water quality standards which indicate that all water bodies in Alaska except the lower Chena River and Nolan Creek and all its tributaries excluding Acme Creek are classified for all uses.

Freshwater Uses

+ Drinking, including cooking and food processing
+ Agriculture (irrigation and stock watering)
+ Aquaculture
+ Industry (mining, pulp milling, etc.)
+ Contact recreation (swimming, wading, bathing, etc.)
+ Secondary recreation (boating, hiking, camping, etc.)
+ Growth and propagation of fish, shellfish, and other aquatic life

Saltwater Uses

+ Seafood processing
+ Harvesting of clams or other aquatic life
+ Aquaculture
+ Industry (other than seafood processing)
+ Contact recreation (swimming, wading, bathing, etc.)
+ Secondary recreation (boating, hiking, camping, etc.)
+ Growth and propagation of fish, shellfish, and other aquatic life

Associated with each use are criteria for different water quality parameters. For example, drinking water quality criteria specify limits on bacterial contamination, color, temperature, turbidity, and sediment, as well as other parameters. The water quality standards consist of the set of most stringent criteria associated with each water use.

Particulates include the fine sediment in the water column and on the substrate. Typical measurements of particulate levels include total suspended solids, turbidity, settleable solids, and the percentage accumulation of fine sediment in gravel beds.

Particulate levels need to be controlled so that man-induced sediment loads do not significantly exceed or become out of phase with natural levels, thus adversely affecting the characteristics of the water column and substrate. The most obvious effect is often the aesthetic impact on recreational uses or visual evidence of particulate deposition. However, other water uses may be impacted, too. Heavy sediment loads in water used for drinking and food preparation, for agriculture, and for industry may render it unfit or unsafe. In addition, aquatic biota, waterfowl, and furbearers may be adversely affected by increased particulate levels. Impacts on biota may range from mortality to short-term effects on biotic processes and/or behavior; these effects may be direct or indirect. Increased sediment loads can affect aquatic biota directly through changes in their anatomy and physiology, and indirectly through changes in their habitat. Either of these broad classes of effects may induce a variety of behavioral responses, including inhibited movement and foraging, avoidance, modified feeding selection and rate, and modified reproductive behavior.

Controls on sediment are mandated by the Water Pollution Control Act and administered by the ADEC in Alaska. ADEC uses both numerical and narrative criteria for turbidity and sediment. These criteria are described in detail in Section 4.1. In general, the turbidity criteria for the various protected uses ranges from a 5 to 25 nephelometric turbidity unit (NTU) increase above natural conditions. The sediment standards are more subjective and include such statements as "No increase in concentration of sediment, including settleable solids, above natural conditions" and "No imposed sediment loads that will interfere with established water supply treatment levels."

Numerous methods for measuring particulates, including both direct and indirect methods, can be used to set criteria. These methods include measurement of turbidity, total suspended solids, settleable solids, transmissivity, Secchi disk depth, compensation point, and methods for measuring the amount of fine sediment in streambeds. These methods are discussed briefly in Section 2.0 and in detail in Section 5.0.

The purpose of this study is to evaluate the effectiveness of existing Alaska water quality criteria for particulates and to recommend necessary changes to these criteria. The specific objectives are:

(1) Review pertinent literature to determine state-of-the-art measurement technology, physical/chemical effects, and biological effects of particulates.

(2) Compile and assess particulates criteria from other states and Canadian provinces and territories and compile U.S. Environmental Protection Agency (EPA) guidelines and requirements for particulates criteria.

(3) Evaluate the adequacy and scientific merit of existing Alaska criteria for particulates.

(4) Assess the potential for using parameters other than turbidity, suspended and settleable solids, and the percentage accumulation of fines in spawning gravels.

(5) Propose new particulates criteria if scientific evidence supports this action.

This study is limited to the problems of water pollution resulting from particulates and the direct and indirect methods for measuring particulates. The report provides background information pertaining to measurement techniques of particulates, natural water quality, and aquatic ecology in Section 2.0. Section 3.0 summarizes particulates criteria used in the United States and Canada. The purpose of the project is to review Alaska's particulates criteria and the documented effects of particulates on beneficial water uses (Section 4.0); the potential use of parameters other than turbidity, suspended and settleable solids, and the percentage accumulation of fines in spawning gravels (Section 5.0); and to recommend necessary changes in Alaska'a criteria to assure that Alaska's particulates criteria are based on scientific information (Section 6.0).

2.0 BACKGROUND

This chapter summarizes pertinent background information regarding measurement techniques for particulates, natural water quality, and aquatic ecology. Quantitative data obtained during a comprehensive review of literature from a variety of sources regarding the effects of particulates on various water uses are presented in detail in Section 4.2, Demonstrated Effects of Particulates.

Literature reviewed appears in Appendices A, B, C, and D, which are organized as follows:

Appendix A: Annotated Bibliographies--Fresh Water
Appendix B: General Literature--Fresh Water
Appendix C: Annotated Bibliographies--Marine
Appendix D: General Literature--Marine

References listed in Appendices B and D addressed the subject of this study but were not considered to provide pertinent information due to the general nature of the data or availability of more detailed coverage in other references.

2.1 MEASUREMENT TECHNIQUES

Particulate levels in water are measured by numerous direct and indirect techniques, summarized below. A more detailed discussion of the techniques for measuring turbidity, suspended solids, and settleable solids appears in Section 5.0.

Direct measurements of particulates include parameters such as total suspended solids, settleable solids, and the amount of fine sediments on streambeds and lake bottoms. Four different techniques for measuring total suspended solids are reported in the literature. The most widely accepted technique involves filtering, drying, and weighing. Centrifugation has been used to concentrate samples followed by drying and weighing, but there are disadvantages to this technique. One disadvantage occurs with fine-grained material having organic matter associated with it since some organic matter can have a density similar to water, thereby making it very difficult to separate (Gibbs 1974). Centrifugation also has limitations for dilute water having less than about 10 mg/L suspended solids (Campbell and Elliott 1975). Radioactive absorption has also been used because the absorption of radiation is proportional to the mass present and therefore a direct measurement of the concentration of suspended sediment (Gibbs 1974). Fischer and Karabashev (1977) report that suspended organic matter can be determined in the marine environment by direct counting of particles under a microscope. However, this technique is time consuming.

Settleable solids are directly measured by securing a 1 liter sample and allowing 1 hour of settling before reading the volume of settled material.

The volume of fines in bedload samples are determined by obtaining a sample using a bedload sampler, such as a corer or a dredge. The sample is then subjected to a grain size analysis. Like other sampling techniques, different bedload samplers have advantages and disadvantages when sampling different sized bed material.

Indirect measurements of particulates are related to light penetration and are essentially an indication of the concentration of particulates. These measurements include turbidity and transmissivity, or its inverse, light extinction. Parameters calculated from light transmission measurements include compensation point (the depth at which 1 percent of available surface light is found in the water), light extinction coefficient, percent incident photosynthetically active radiation (PAR), and wave length analysis.

Indirect measurements quantify optical absorption and/or light scattering. Nephelometric turbidity measures the 90 degree scattering of light by suspended particles, whereas the beam transmittance meter measures the attenuation of light by scattering and absorption. The Secchi disk is a simple kind of irradiance meter whose values have been correlated with turbidity and light extinction coefficients (McCarthy et al. 1974).

An alternative method for directly counting suspended organic matter in the marine environment was employed by Fischer and Karabashev (1977). The volume concentration of particulate matter of different size was measured using a conductometric particle counter or Coulter counter and the abundance of particles was measured by a nephelometer. A fluorimetric determination of pigments (by luminescence) in phytoplankton cells was then used to determine the amount of organic matter.

2.2 WATER QUALITY

2.2.1 Fresh Water

Alaska aquatic environments encompass a variety of systems including wetlands, ponds, lakes, rivers, and intermittent streams. Although all are interrelated, each type of aquatic system has unique characteristics. This section provides a general description of the particulate levels common to these various aquatic systems.

Lakes are lentic, or non-flowing, aquatic environments. They may have inlet streams which contribute water and nutrients, but the level of the lake remains essentially the same and there are generally no permanent currents within the water body. Lakes can be miles in length and hundreds of feet in depth with numerous tributaries or they can be small tundra ponds an acre or less in size. Alaska has a diversity of lake types encompassing large, clear water systems like Lake Iliamna, silty lakes such as Tustumena Lake, and small, tea-colored melt ponds characteristic of the North Slope. Glacier-fed lakes are often naturally turbid.

Lakes generally contain distinct habitats. The littoral habitat, found along lake margins, is a relatively warm habitat where light penetrates to the bottom and where rooted aquatic plants grow. Many shallow lakes (ponds) can be described as littoral even at their deepest point. Very deep lakes have a profundal zone where it is too dark to allow green plants, including algae, to grow. The open water area above the profundal is known as the limnetic zone.

Sunlight and wind act upon lakes in ways which sometimes result in temperature stratification. In deep lakes in the summer, the upper layers receiving the most sun are the warmest, whereas those next to the profundal zone are the coldest. Winds can cause mixing currents, and temperature changes in the spring and fall can cause a lake to mix completely or "turn over." When a lake turns over, the cold, oxygen-poor water layer comes to the surface while the upper layer is forced to the bottom. Mixing currents can also bring bottom sediments up causing a normally clear lake to become temporarily turbid. In addition, turbidity can be introduced to a lake via its tributaries.

Clear water lakes seldom exceed 1 to 2 mg/L total suspended solids and turbidity is typically less than 1 to 2 NTU. Settleable solids are commonly unmeasurable and rarely exceed 0.1 ml/L.

Rivers and streams are lotic, or flowing water, systems. Water flow is continuous and in one direction, velocity changes with depth, and water depth and stream widths fluctuate with precipitation, runoff, and erosion. There is continual mixing within the water column with persistent or occasional turbidity, and the streambed is relatively unstable. Streams are considered "open systems" with respect to their interaction with and interdependence on the terrestrial environment.

In lakes, material brought in by tributaries or contributed by runoff usually is deposited on the lake bottom and remains in the system. In streams, material is carried downstream with heavier particles settling out fairly soon and lighter material remaining in suspension longer. Low density material may not settle at all and may be carried into lakes or estuaries. This is the case with glacial streams such as the Susitna River where glacial silt is carried into Cook Inlet. Particulates carried in the water column are referred to as wash load, whereas those moving along a streambed are bedload. The particles that bounce along the bed make up the saltation load.

Alaska has a wide variety of rivers and streams, most of which are important to water-dependent life. Stream types range from short, steep, clearwater systems in southeast Alaska to small, slow-moving tannic tundra streams, to enormous systems like the Yukon and Kuskokwim rivers. Streams can also be classified as clear, colored, and glacial. Colored or brown water streams drain boggy areas and have relatively high color values due to organic leachates.

Life forms in streams must either drift with the current or possess some mechanism to remain stationary within the channel. Clear streams usually are not deep enough to have a profundal zone; the whole stream is within the euphotic zone where light reaches all depths.

Undisturbed reaches of clear and colored streams typically exhibit low concentrations of solids. Total suspended solids concentrations are usually less than 5 mg/L but may increase to about 100 mg/L during spring breakup and summer floods. However, higher levels of sediment do occur in some systems during floods. Turbidity is generally less than 5 to 10 NTU, but may be 25 to 50 NTU during periods of high water. Settleable solids levels rarely exceed 0.1 ml/L. Glacial streams carry large suspended sediment loads during summer, but normally become clear water streams during winter. During summer, glacial streams and lakes may exceed 1000 mg/L total suspended solids and turbidity typically ranges between 50 and 1000 NTU.

Wetlands are a common and important type of aquatic habitat in Alaska. Many lakes are surrounded by both tundra bogs and marshes with emergent aquatic plants. These peripheral wetlands furnish energy to the lake system in the form of insects, plankton, and plant material. The same is true for many rivers. Streams often receive much of their water from surrounding wetlands. Wetlands also supply nutrients and furnish rearing areas for fish such as coho salmon and grayling. Nearly all wetlands in Alaska can be classified as clear water systems. Hence, they seldom exceed 1 to 2 mg/L total suspended solids and turbidity is typically less than 1 to 2 NTU.

2.2.2 Marine

Measurements of turbidity and/or suspended sediment load within the marine waters of Alaska are highly variable and dependent on several factors such as season, proximity to sediment sources (mainly rivers), distance from shore, current structure, depth, temperature, and salinity. Particulates data summarized herein are based on Burbank (1974) and Sharma (1979) except as otherwise noted.

Within Boca de Quadra and Smeaton Bay in southeast Alaska, the suspended sediment load is relatively low. The mean water column concentration in the central basins is less than 0.5 mg/L and less than 1.0 mg/L in the inner basins (Burrell 1984). Conversely, Taku Inlet, also in southeast Alaska, has extraordinarily high suspended sediment levels from discharge of the Taku River and subglacial streams. The suspended sediment load at the head of the inlet exceeds 10,000 mg/L in near-surface waters during summer months.

Concentrations of suspended sediment in continental shelf surface waters off Icy Bay in the northeast Gulf of Alaska generally decrease seaward (i.e., 1.3 mg/L nearshore and 0.1 mg/L at 65 km from shore in March). The particulate concentration is relatively constant with depth from the surface to within about 10 m above the bottom, and from shore to 30 km offshore at the 100 m depth. A steady increase in suspended solids levels within 10 m of the bottom suggests the presence of a nephloid or turbid layer along the bottom.

In the northern Gulf of Alaska during heavy runoff, the glacial streams typically carry 1000 to 2000 mg/L of suspended solids. Peak discharge in the Copper River in summer carries approximately 1700 mg/L of suspended material at the delta. Offshore from the Copper River during low discharge and minimal glacial melt, surface values as high as 30 mg/L are present. Coarse sediments rapidly settle out within the first few kilometers, depending on the energy of the environment. At distances greater than 10 km offshore, surface suspended solids levels of 2 to 10 mg/L are typical. The lowest concentrations indicated by ERTS imagery in waters greater than 50 km offshore generally range from 1 to 3 mg/L.

Suspended sediment concentrations in Cook Inlet vary from 2000 mg/L near Anchorage to 1.0 mg/L near the east side of the Inlet mouth. The Matanuska River, one of several sediment sources in the Inlet, has suspended sediment levels that approximate 3800 mg/L. The suspended load is mostly of glacial origin and maximum values occur at depths of approximately 10 m near the Inlet head. Concentrations increase with depth south of the Forelands, and concentrations in the lower Inlet generally vary between 1 and 100 mg/L.

In the western Gulf of Alaska from Resurrection Bay through Shelikof Strait to Unimak Pass, surface suspended solids vary from 0.5 to 2.0 mg/L in July and August. Values are generally higher to the east near the Kenai Peninsula and Shelikof Strait. On the shelf east, south, and southeast of Kodiak Island, there is an apparent absence of any input of suspended sediment.

In the Bristol Bay region of the southeastern Bering Sea, streams flowing from the Alaska Peninsula contribute as much as 500 to 2000 mg/L of suspended solids. The dominant sediment sources are the Kvichak and Nushagak Rivers at the head of the bay. The Kuskokwim and Yukon rivers to the north provide sediment input approximating 4 and 100 million metric tons per year, respectively, which equates to more than 90 percent of all river sediment input into the eastern Bering Sea. Suspended sediment levels for surface waters off the Yukon River and in Norton Sound are between 1 and 5 mg/L in July. Surface concentrations generally average between 0.5 and 2.0 mg/L in the northern Bering Sea. Concentrations increase with depth. The near-bottom sediment level from near Cape Romanzof to Nome ranges from 7.5 to greater than 20 mg/L, respectively.

Suspended solids levels in the Bering Strait and vicinity range from 1.2 to 4.1 mg/L for surface waters. The level decreases with increasing water depth immediately south of the Strait. As the water moves northward through the Strait, the distribution becomes almost uniform. North and northeast of the Strait, surface and sub-surface levels increase fourfold to nearly 10 mg/L. Surface water concentrations reach 5.3 mg/L near Point Hope while at depth, only about 1 mg/L is in suspension in July and August.

In the northern Chukchi Sea, the suspended load at the surface is low (less than 1 mg/L) and increases with depth. Nearshore loads in suspension are higher than offshore.

Measurements during two open-water seasons in the Beaufort Sea demonstrate the inter-annual variability of suspended solids levels. During 1972, inshore surface waters had concentrations averaging 1.0 mg/L with a range of 0.1 to 4.2 mg/L; however, in the following year, nearly a threefold increase was noted. Levels ranged from 0.5 to 31.0 mg/L and the average was 2.8 mg/L. Except during floods, waters low in suspended matter (about 1.0 mg/L) are commonly discharged in late summer from the major distributary mouths, while the presence of relatively turbid waters can be delineated at some distance from the mouths. These observations suggest that in mid- and late-summer, turbidity in coastal waters for the most part is associated with wave-induced resuspension from shallow water regions (U.S. Coast Guard 1972; 1974).

2.3 AQUATIC ECOLOGY

2.3.1 Fresh Water

In a broad sense, freshwater ecosystems are divided into two categories, lentic or standing water systems, and lotic or running water systems. All rivers, lakes, and wetlands support communities of aquatic organisms. As such, these communities are interrelated and interdependent, forming networks of distinctly different habitats with respect to flora and fauna, as well as the source of energy which drives the biological system. Freshwater aquatic communities derive carbon energy from terrestrial sources (allochthonous organic matter) or through instream (autochthonus) productivity or a combination of these sources. If one part of the community is disrupted, reverberations may be experienced throughout the entire system. Aquatic systems have been subdivided into subordinate communities and are discussed in this section.

Benthic organisms are those associated with lake beds and stream substrates. These organisms depend on the availability of suitable substrate materials for attachment, net building, concealment, movement, and burrowing. Stream benthos differs from that found in quiescent waters in the respect that stream organisms possess a variety of adaptations for withstanding stream currents.

The benthic stream community is extremely important to the health of the entire system. Many of these organisms provide food for other populations within the aquatic community in the form of invertebrate drift. Fish, in particular, are dependent on insect larvae and adult insects which originate in the benthic community.

Plankton are drifting organisms and can be either plants or animals (phytoplankton and zooplankton). Some plankters may actually have feeble powers of locomotion and in lakes may mill around and move up and down in the water column in response to light intensity. In streams, they are usually subject to transport by the water current.

Phytoplankton are composed primarily of algae which exist singly or as a collection of one-celled plants. In lakes, algae actively grow only in the euphotic zone. Zooplankters feed either on other species of zooplankton or on algae. Plankton is an extremely important food source for fish, especially juvenile fish. Physiological activities of zooplankton depend on water temperature, light, and oxygen content.

Phytoplankton production is important in many subarctic lakes and ponds, and perhaps in the lower reaches of a few large rivers; production is generally low in arctic ponds and lakes. Periphyton (attached algae) are dominant in high-velocity clear water streams where light penetration is sufficient for photosynthesis, and they can also be important in slow moving or standing shallow water. In certain lotic habitats, the evaluation of periphyton communities provides an accurate and reliable indicator of water quality. Macrophytes (rooted aquatic plants) are often abundant in shallow lakes and ponds, in the littoral zone of deep lakes, and along the edges of quiescent rivers. Zooplankton diversity, biomass, and production rates are low in arctic lakes and ponds but are often significant in subarctic lakes.

Fish are the most highly studied component of the fresh-water community. In Alaska, fish can be divided into resident and anadromous species. Resident fish live their entire lives in fresh water, often in the same water body. In many regions of Alaska, resident species such as Arctic grayling migrate upstream during spring to spawn, then return to deeper water downstream in the fall to overwinter. Anadromous fish spawn and hatch in fresh water, live the majority of their adult lives in saltwater and return to fresh water, usually their natal stream, to spawn. The five species of Pacific salmon which inhabit Alaska waters are the most obvious examples of anadromous fish. Several anadromous salmon species utilize silt-laden glacial rivers as migration corridors to reach clearwater tributary spawning and rearing habitat.

Fish occupy a variety of niches within aquatic systems. Some, like the slimy sculpin live at the bottom of lakes and swift-flowing streams and feed primarily on insects. Trout and grayling may hide under instream cover such as debris or log jams, or overhanging streambanks, coming to the surface to feed on zooplankton or insects which have fallen into the water or which have drifted down from upstream. These fish are primarily sight-feeders.

Diet and habitat requirements of fish vary with species and life stage. For example, adult salmon return from the sea to their natal stream to spawn often not feeding from the time they enter fresh water. The fish construct redds (spawning nests), in the gravel of the streambed and deposit their eggs. Other fish such as Arctic grayling and lake trout are broadcast spawners. The preferred size of the gravel in which the redds are constructed varies with the species. Salmon favor clear water streams but, in Alaska, often use turbid rivers as migratory corridors. In some cases, redds are dug in the turbid streams, but the newly hatched fish move to clearer backwater sloughs or tributaries to rear. This is the case with both the Kenai and Susitna rivers.

Fish are often used as "target" organisms in setting water quality criteria. The criteria for acceptable water quality standards are usually determined with bioassays, either in situ or in vitro using the relevant water and species.

Aquatic systems are also important to waterfowl, furbearers, and big game. Ducks, geese, and swans feed and nest near lakes and wetlands. Many species of waterfowl depend on emergent aquatic vegetation for food. Mallards, Canada geese, and brant are examples of waterfowl which primarily consume plants. Species such as mergansers feed on small fish and depend on their ability to see their prey under water.

Beaver, mink, and river otters are among the Alaska furbearers that inhabit riparian areas. Beavers construct lodges in stream courses and wetlands and feed on vegetation along stream banks. Otters live along stream banks and feed on fish within streams. They are highly dependent on their ability to see their prey.

Moose use lowland areas in the summer and feed on emergent vegetation in wetlands and along lake and stream margins. Both black and brown/grizzly bears consume salmon which move into Alaska rivers to spawn in the summer and late fall.

2.3.2 Marine

Variations in coastal topography, geology, climate, surface hydrology, and physical oceanographic factors influence the distribution and abundance of marine organisms along Alaska's 33,000 miles of tidal shoreline. The coastal ecosystem has been intensively studied in six geographical regions in Alaska including: (1) Arctic Alaska; (2) the Bering Sea coast; (3) Kodiak Island, the Alaska Peninsula, and the Aleutian Islands; (4) Cook Inlet; (5) the northern Gulf of Alaska; and, (6) southeastern Alaska. Characteristic ecosystems that have not been thoroughly studied by marine scientists have been described through information derived from similar habitats in other regions.

The lower trophic level organisms in marine and estuarine waters of Alaska are comprised of two groups: the producers and consumers. The primary producers are the phytoplankton, macrophytes, ice algae, and benthic microalgae. Lower level consumers include the zooplankton, ichthyoplankton, and intertidal and sub-tidal invertebrates. The degree of productivity and diversity among these organisms varies throughout Alaska's coastal waters. Important resource organisms such as king crab, herring, halibut, salmon, and whales depend either directly or indirectly on the lower level producers and consumers for their survival.

Phytoplankton undergo seasonal net increases and decreases in productivity, coincidental to ever changing levels of sunlight, nutrients, grazing pressure, wind mixing, and depth of light penetration. The major phytoplankton groups are the diatoms, dinoflagellates, and naked flagellates. These microscopic plants collectively represent the energy base for many higher forms of marine life such as fish, shellfish, marine birds, and marine mammals. Benthic microalgae are restricted to portions of the subtidal zone that receive sufficient light for photosynthesis.

Seaweeds and sea grasses (macrophytes) are common along the rocky shores of the intertidal zone and in shallow subtidal areas of Alaska. Seaweeds are primitive species that lack root systems and derive their nutrients exclusively from the water. Eelgrass is a common and important marine macrophyte that roots in sediment in protected bays, inlets, and lagoons along the Alaska coast. Eelgrass communities are often highly productive and serve as a major food source for waterfowl and as a nursery and feeding area for many marine vertebrates and invertebrates.

Zooplankton are the primary consumers in the pelagic ecosystem and serve as a large potential energy pool for fish and whales. Zooplankton are distributed in all Alaska waters with productivity being greatest in spring and early summer. Temperature and salinity have a major influence on the distribution of zooplankton; some prefer estuarine waters, whereas others prefer the open water environment. Physical factors such as light levels and sea ice affect their vertical distribution and productivity rates. Virtually all of Alaska's commercially-important shellfish have a zooplanktonic larval stage in their life history and spend up to three months in the near-surface layers feeding intensively on phytoplankton before settling on the bottom to mature.

The benthos is composed of bottom dwelling or attached invertebrates found in the intertidal and subtidal zone of the ocean. This important group may be divided into organisms living on the substrate surface (epifauna), and those living in the substrate (infauna). The distribution and richness of the subtidal benthos within a region is determined by a number of factors including sediment type, temperature, salinity, pressure, available food, species competition for space, and larval settling success. Factors influencing the distribution of intertidal invertebrates are substrate availability, competition, and ability to withstand surf and exposure to air. Food is supplied to bottom invertebrates through several mechanisms. A continuous flux of organic material to the bottom is provided by dead phytoplankton and zooplankton and the remains of higher organisms. A second important source of energy is provided by detritus entering the system through river runoff and ocean currents.

An obvious trend among the benthos in Alaska is that communities on the continental shelf are richer than those beyond the shelf break. This is probably due to the higher primary productivity of nearshore waters as compared to offshore waters, as well as the high detritus input from river systems.

Intertidal and subtidal benthic invertebrates serve several important functions. They represent a major source of food for shorebirds and waterfowl, as well as a variety of fish and marine mammals. Due to their relatively stationary nature, intertidal and subtidal species are one of the most susceptible groups of organisms to damage from water-borne sediments. Consequently, benthic organisms are useful indicators of changes in water quality.

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3.0 PARTICULATE CRITERIA

Existing particulates criteria for each state in the United States and for Canadian provinces are summarized in Sections 3.1 and 3.3, respectively. Information regarding the establishment of water quality parameters and criteria for particulates by the U.S. Environmental Protection Agency (EPA) is also summarized and appears in Section 3.2.

Telephone contacts to personnel in each state were made to determine particulates criteria currently used in regulations and guidelines by other states and in Canadian provinces and territories. During the initial telephone contact, each individual interviewed was apprised of the purpose of this study and questioned concerning his/her agency's water quality criteria for instream levels of particulates, specifically turbidity, suspended solids, and settleable solids. Inquiries were also made concerning recent or proposed changes to regulations, protected uses of water bodies, availability of separate standards for marine waters (where appropriate), and the basis for any quantitative standards or limitations identified in pertinent regulations. Where particulate standards existed, the interviewee was also questioned as to recognized problems associated with compliance, field sampling, or enforcement of the standards. A copy of pertinent regulations was requested for review from each agency.

3.1 STATES

Based on information received during telephone interviews and the water quality standards and beneficial water uses identified in individual state regulations, a summary of the designated water uses and associated criteria for turbidity was compiled for the 50 states and District of Columbia (Table 3-1). To the extent possible, water use categories are similar to the Alaska criteria for ease of comparison. Where

TABLE 3-1

TURBIDITY CRITERIA FOR UNITED STATES AND CANADA

State	Designated Water Use[1]	Turbidity Criteria
Alabama (Feb 81)	A, B, D, E, G, M	NTE[2] 50 NTU above ambient
Alaska (Apr 84)	A	NTE 5 NTU above ambient when the natural turbidity is 50 NTU or less; limit of 10% increase when natural exceeds 50 NTU; maximum increase of 25 NTU
	B	narrative
	C	NTE 25 NTU above ambient for streams; NTE 5 NTU for lakes
	D	narrative
	E	NTE 5 NTU above ambient when natural turbidity is 50 NTU or less; limit of 10% increase when ambient exceeds 50 NTU, NTE 15 NTU increase; NTE 5 NTU over ambient for lakes
	F	NTE 10 NTU above ambient when natural turbidity is 50 NTU or less; limit of 20% increase when ambient exceeds 50 NTU, NTE 50 NTU increase; NTE 5 NTU over ambient for lakes
	G	NTE 25 NTU above ambient; NTE 5 NTU over ambient for lakes
	H	NTE 25 NTU
	I	narrative
	J	narrative
	K	NTE 25 NTU
	L	NTE 25 NTU
	M	compensation depth reduction limit of 10%; Secchi disk depth reduction limit of 10%
	N	same as M
Arizona (Feb 85)	E, F	NTE 50 NTU in streams; NTE 25 NTU in lakes
	G	NTE 10 NTU for cold water fishery in streams and lakes
		special standards for "unique" waters as low as 3 NTU change limit
		***basin specific standards or use classification
Arkansas (Nov 84)	A, B, D-G	NTE 10 NTU for trout or coolwater streams
		***basin specific standards or use classification
California (Nov 83)	A-G	turbidity standards by basin Example: NTE 20% increase where ambient is less than 50 JTU; NTE 10 JTU increase where ambient is between 50-100 JTU; NTE 10% increase where ambient exceeds 100 JTU
	J-M	narrative
		***basin specific standards or use classification
Canada (Provinces, Territories, and Federal Government) (Feb 85)		
Federal Government	E, F	NTE 50 JTU
International Joint Comm. (Great Lakes)	G	NTE 10% decrease in Secchi disk depth
Alberta	Unknown	NTE 25 JTU over ambient (objective only)
British Columbia	Unknown	guidelines of other agencies are used and amended as applicable
Manitoba	A	5 NTU (draft regulation)
	G	NTE 10 JTU for cold water fisheries; NTE 25 JTU for warm water fisheries; narrative proposed as replacement for numeric criteria in draft revisions

State	Designated Water Use[1]	Turbidity Criteria
Manitoba	E, F	NTE 10 "turbidity units" for cold water fisheries; NTE 25 "turbidity units" for warm water fisheries; draft revision proposes change to 50 JTU for both uses
New Brunswick	Unknown	guidelines of other agencies are used and amended as applicable
Newfoundland	Unknown	guidelines of other agencies are used and amended as applicable
Northwest Territories	Unknown	guidelines of other agencies are used and amended as applicable
Nova Scotia	Unknown	guidelines of other agencies are used and amended as applicable
Ontario	G	NTE 10% increase in Secchi disk reading above ambient
Prince Edward Island	Unknown	guidelines of other agencies are used and amended as applicable
Quebec	A	NTE 5 "turbidity units" (guideline only)
	E, F	NTE 10% increase in nonfilterable residue or less than 3 mg/l absolute (draft regulation)
Saskatchewan	Unknown	NTE 25 "turbidity units" over ambient (objective only)
Yukon	Unknown	guidelines of other agencies are used and amended as applicable
Colorado (Jan 84)	A	NTE 1.0 turbidity unit
		***basin specific standards or use classification
Connecticut (Sep 80)	A, E	NTE 10 JTU above ambient
	B, D, F, G	NTE 10 JTU above ambient or more than 25 JTU total
	H-N	narr; Secchi disk transparency mid-summer from 0-6 meters depth
		***basin specific standards for lakes
Delaware (Jul 83)	A-G	NTE 10 NTU above ambient or 25 NTU total
	H-N	NTE 150 NTU in tidal areas of stream basins
		***basin specific standards or use classification
District of Columbia (Mar 84)	A, E-G	NTE 20 NTU above ambient
	A, D-G	narrative
Florida (Feb 83)	A, E-G	NTE 29 NTU above ambient; depth of compensation point not reduced more than 10% from ambient
	B	narrative
		***basin specific standards or use classification
Georgia (Oct 80)	A-G	narrative
	A	NTE 1 turbidity unit
	G (special case)	streams designated as wild or scenic shall have no alteration of ambient water quality
		***basin specific standards or use classification
Hawaii (Oct 84)	A-G, K-N	streams: 2-15 NTU, NTE 25 NTU estuaries: 1.5-3.0 NTU, NTE 5.0 NTU embayments: 0.4-3.0 NTU, NTE 5.0 NTU oceanic waters: 0.03-0.10 NTU, NTE 0.20 NTU
		***basin specific standards or use classification
Idaho (Oct 83)	A, B, E-G	narrative; also stream water quality requirements for point source discharges outside the mixing zone: NTE 5 NTU above ambient when background is 50 NTU or less; NTE 10% increase when background is more than 50 NTU, up to a maximum increase of 25 NTU
Illinois (Apr 84)	A, B, D-G	narrative
		***basin specific standards or use classification

State	Designated Water Use[1]	Turbidity Criteria
Indiana (Mar 84)	A, B, D-G	identified spawning, rearing, or imprinting areas for salmonids NTE 10 JTU total; identified salmonid migration routes NTE 25 JTU total
		***basin specific standards or use classification
Iowa (Dec 83)	A, B, D-G	NTE 25 NTU above ambient from any point source discharge
		***basin specific standards or use classification
Kansas (Sep 83)	A, B, D-G	narrative
		***basin specific standards or use classification
Kentucky (Mar 83)	A, E-G	narrative
		***basin specific standards or use classification
Louisiana (Oct 84)	A, B, E-G	freshwater lakes, reservoirs, and oxbows which are not naturally turbid and designated scenic streams and outstanding resource waters NTE 25 NTU total; other waters NTE 10% increase above ambient
		***basin specific standards or use classification
Maine (Sept 79)	A, D-G	narrative; "great ponds" NLT 2 meters Secchi disk transparency or as naturally occurs
	H, J-N	narrative
		***basin specific standards or use classification
Maryland (no date)	E-G	NTE 150 NTU at any time or 50 NTU as a monthly average
		***basin specific standards or use classification
Massachusetts (no date)	A, E-H, L-N	narrative; for public water supplies, no increase above ambient
Michigan (Jun 84)	A, D-G	narrative
		***basin specific standards or use classification
Minnesota (Feb 81)	A	NTE 5 as "turbidity value"
	E, G	NTE 10 as "turbidity value"
	F, G	NTE 25 as "turbidity value"
		***drainage specific standards or use classification
Mississippi (Jan 85)	A, E-G	narrative; NTE 50 NTU above ambient in proposed amendments ***drainage specific standards or use classification
Missouri	Unknown	narrative
Montana (Mar 82)	A	NTE ambient conditions
	B, D-G	NTE 5-10 NTU above ambient
		***drainage specific standards or use classification
Nebraska (Feb 83)	A, B, D-G	NTE 10% increase above ambient
		***drainage specific standards or use classification
Nevada (Nov 84)	A, B, D-G	none as general criteria; stream/reach specific criteria NTE 10-50 NTU, based on location
		***drainage specific standards or use classification
New Hampshire (May 84)	A	NTE 5 "turbidity units"
	D-G	NTE 10 "turbidity units" in cold water fisheries nor 25 "turbidity units" in warm water fisheries
New Jersey (Oct 84)	E-G	NTE 15 NTU for 30-day average; NTE 50 NTU max. at any time
	K-N (estuarine)	NTE 10 NTU for 30-day average; NTE 30 NTU max. at any time
	K-N (marine)	NTE 10 NTU
		***basin specific standards or use classification

State	Designated Water Use[1]	Turbidity Criteria
New Mexico (Feb 85)	E-G	narrative
		***basin specific standards or use classification
New York (Sep 74)	A, E-G	narrative
	I, K-N	narrative
North Carolina (Jan 85)	A, E-G	NTE 50 NTU in streams other than trout waters; NTE 10 NTU in streams, lakes, or reservoirs designated as trout waters
	K-M	NTE 25 NTU; if ambient exceeds this level, no increase is allowed
North Dakota (Apr 85)	A, B, E-G	narrative
Ohio	Unknown	narrative
Oklahoma (1982)	A, B, D-G	NTE 50 NTU in warm water streams; NTE 25 NTU in warm water lakes; NTE 10 NTU in cold water streams.
		***basin specific standards or use classification
Oregon (Aug 84)	E-G	NTE 10% increase over ambient
		***basin specific standards or use classification
Pennsylvania (Feb 85)	Unknown	effluent standards only; do not attempt to control in-stream water quality
		***basin specific criteria for Delaware River Commission
Rhode Island (Dec 84)	A	NTE 5 JTU; none of other than natural origin
	B, E, G	NTE 10 JTU
	D, F, G	NTE 15 JTU
	J-M	narrative
		***basin specific standards or use classification
South Carolina (Feb 85)	A	natural conditions maintained
	G	NTE 10% above ambient
	E	none
	B, D, F	none
	K, M (high quality)	natural conditions maintained
		***basin specific standards or use classification
South Dakota (Aug 84)	A, B, D-G	narrative
		***basin specific standards or use classification; also seasonal criteria
Tennessee (no date)	A, B, D-G	narrative
Texas	A, B, D-G J-M	narrative narrative
Utah (Oct 78)	A	none; case by case determination
	B	none; case by case determination
	D	none
	E-G	NTE 10 NTU above ambient for natural conditions less than 100 NTU; NTE 10% increase when ambient conditions exceed 100 NTU
	G(non-game)	NTE 15 NTU above ambient with provisions for case by case determination
		***basin specific standards or use classification
Vermont (Jan 85)	A	NTE 10 NTU or ambient, whichever is lower
	B, E, G	NTE 10 NTU for cold water fish habitat; NTE 25 NTU for warm water fish habitat
		***basin specific standards or use classification; provision for seasonal criteria for fish habitats

State	Designated Water Use[1]	Turbidity Criteria
Virginia (Oct 84)	A, E-G	narrative
		***basin specific standards or use classification
Washington (Jun 82)	A, E, G, K, M, N	NTE 5 NTU over ambient when background is 50 NTU or less; NTE 10% increase when background is more than 50 NTU
	B, D, G, J, L	NTE 10 NTU over ambient when background is 50 NTU or less; NTE 20% increase when background is more than 50 NTU.
	A, B, D-G (lakes)	NTE 5 NTU over ambient
		***basin specific standards or use classification
West Virginia (1983)	Unknown	NTE 10 NTU over ambient
Wisconsin (Nov 79)	A, B, D-G	narrative
		***basin specific standards or use classification
Wyoming (Sep 83)	A, B, D-G	NTE 10/15 NTU increase over ambient, depending on water class

(1) Designated Water Uses Comparable to Alaska Categories

Designated Water Uses: Fresh Water

A	Water Supply:	drinking, culinary, food processing
B	Water Supply:	agriculture, irrigation, stock watering
C	Water Supply:	aquaculture
D	Water Supply:	industrial
E	Water Recreation:	contact
F	Water Recreation:	secondary
G	Growth and Propagation of Fish, Shellfish, and Wildlife	

Designated Water Uses: Marine Water

H	Water Supply:	aquaculture
I	Water Supply:	seafood processing
J	Water Supply:	industrial
K	Water Recreation:	contact
L	Water Recreation:	secondary
M	Growth and Propagation of Fish, Shellfish, and Wildlife	
N	Harvesting for Consumption of Raw Mollusks or Other Raw Aquatics	

(2) NTE = Not to Exceed
NLT = Not Less Than

appropriate, turbidity criteria for marine waters are also presented.

Although many states identify beneficial or protected water uses similar to those in the Alaska criteria, it is apparent that water quality concerns associated with particulates are approached differently by other state agencies. As a result of interviews and review of individual state standards, it was evident that turbidity and sediment concerns differ among agencies because of:

(1) The presence of naturally turbid systems carrying high sediment loads;
(2) Difficulties of addressing seasonal fluctuations in particulate concentrations;
(3) Aquatic flora and fauna adapted to warm water systems versus cold water ecosystems;
(4) Philosophical approach to turbidity control (instream water quality standards versus control of point source effluents);
(5) Lack of specific studies which document the threshold for adverse impacts to aquatic resources or water uses; and,
(6) Lack of basin-specific information on the natural occurrence of particulate loads.

None of the water resource agencies contacted were able to provide specific information to document the background information for setting quantitative criteria in their water quality regulations. In general, most respondents were unaware of their state's basis for turbidity, suspended solids, or settleable solids criteria except in reference to "generally accepted" standards or the "Red Book" (EPA 1976). West Virginia currently has studies in progress on trout streams and heavily industrialized waterways that will attempt to correlate particulate standards with identifiable impacts to biota. Idaho is currently involved with a "serious injury" task force which is attempting to define thresholds of impact and acceptable levels of injury to stream systems and biota.

Personnel in several states acknowledged that the implementation of turbidity criteria was not aggressively pursued because their standards do not address natural or seasonal turbidity and/or the differences between cold and warm water aquatic systems. Some individuals interviewed felt that the standards were unreasonably low or did not have a scientific basis. Other agencies focus their concerns on effluent standards for point source discharges and best management practices from non-point source discharges, essentially avoiding regulation of instream water quality.

Approximately 30 percent of the states (17) only have general narrative criteria defining turbidity limits. These narrative criteria range from general "antidegradation" statements to broad guidelines that prohibit turbidity levels which would impact other uses. The remaining 70 percent (33 states) have at least some protected water uses with quantitative criteria for instream turbidity. Very few states have established quantitative turbidity criteria for all water uses.

Evaluation of 20 states which have quantitative turbidity criteria and cold-water systems similar to Alaska revealed that their turbidity standards for recreation and fish and wildlife propagation are numerically equal to or, in most cases, more stringent than Alaska criteria for these same uses. The turbidity standards for lakes are also comparable.

Of the 22 states with marine or estuarine waters along their borders, 14 have specific criteria for turbidity in marine or tidal waters. Of these 14 states, seven employ quantitative criteria.

A summary of states with narrative or quantitative criteria for instream water quality pertaining to suspended and settleable solids is presented in Table 3-2. None of the states have quantitative criteria for settleable solids levels. Only four states other than Alaska, Nevada, New Jersey, South Dakota, and West Virginia, currently have numeric standards for suspended solids in the water column. Nevada employs specific limits for some stream reaches. The existing or higher quality is to be maintained where the natural suspended solids concentration is equal to or less than 15 mg/L. The limit for the protection of all beneficial uses in the upper reaches of a watershed is 25 mg/L and 80 mg/L in the lower reaches. New Jersey limits suspended solids concentrations to 25 to 40 mg/L on specific streams while South Dakota has a 30 mg/L maximum limit for coldwater fisheries. West Virginia employs a 30 mg/L maximum suspended solids concentration in receiving waters. Of the remaining states, 17 have general narrative statements addressing these parameters. The balance of the states do not consider suspended or settleable solids in their general water quality criteria. Hawaii is the only state which has established standards for maximum allowable depth of deposition for settleable solids. Alaska is the only state with standards addressing the accumulation of sediments as a maximum percent by weight of spawning bed gravels.

Most states have approached the problems of suspended and settleable solids by regulating the maximum concentration allowable in effluents discharged from point sources. Control of non-point sources are generally addressed by best management practices or special conditions attached to project authorizations.

3.2 U.S. ENVIRONMENTAL PROTECTION AGENCY

This section summarizes information used by EPA to establish water quality parameters and criteria for particulates.

TABLE 3-2

SUSPENDED AND SETTLEABLE SOLIDS CRITERIA
FOR THE UNITED STATES AND CANADA

State	Suspended/Settleable Solids Criteria[1]
Alabama	none
Alaska	narratives for most water uses sprinkler irrigation: no particles 0.074 or coarser; NTE 200 mg/l for an extended period; fish, shellfish, & wildlife: % accumulation of sediment 0.1 mm to 4.0 mm in the gravel bed of spawning waters NTE 5% increase by weight over natural conditions; in no case may sediments in the 0.1 mm to 4.0 mm range exceed 30% by weight in the gravel of spawning beds
Arizona	none
Arkansas	none
California	narrative
Canada (Provinces, Territories, and Federal Government)	
Federal Government	narra.; regulations for effluents for some industrial processing and mining (other than gold) are limits of 25 mg/l maximum monthly arithmetic mean
International Joint Commission (Great Lakes)	narrative
Alberta	NTE 10 mg/l over ambient (objective only)
British Columbia	none
Manitoba	narrative (draft regulations)
New Brunswick	none
Newfoundland	none
Northwest Territories	none
Nova Scotia	none
Ontario	none
Prince Edward Island	none
Quebec	none
Saskatchewan	NTE 10 mg/l over ambient (objective only)
Yukon	none; proposed effluent standards for stream classes based on biological productivity[2] high biological importance - no suspended solids effluent discharge moderate biological importance - NTE 100 mg/l suspended solids in effluent low biological importance - NTE 1000 mg/l suspended solids unless it is tributary to a higher class stream (then it must meet 100 mg/l effluent standard) designated placer mining areas - NTE 1000 mg/l suspended solids unless it is tributary to a higher class stream (then it must meet 100 mg/l effluent standard)
Colorado	narrative; also use effluent limitations and best management practices
Connecticut	none
Delaware	narrative; also use effluent limits
District of Columbia	none
Florida	none
Georgia	none
Hawaii	standards for maximum depth of deposition

State	Suspended/Settleable Solids Criteria[1]
Idaho	narrative
Illinois	none
Indiana	narrative for salmonid waters
Iowa	none
Kansas	narrative
Kentucky	narrative for aquatic life waters
Louisiana	narrative
Maine	narrative
Maryland	effluent limits on suspended solids in treated sewage
Massachusetts	none
Michigan	narrative
Minnesota	narrative; also effluent standard of 30 mg/l for treated sewage
Mississippi	none
Missouri	none
Montana	none
Nebraska	narrative
Nevada	narrative; specific mg/l limits for some stream reaches
New Hampshire	none
New Jersey	narrative and 25-40 mg/l limits on specific streams
New Mexico	none
New York	narrative
North Carolina	narrative
North Dakota	none
Ohio	narrative
Oklahoma	narrative
Oregon	narrative
Pennsylvania	narrative
Rhode Island	narrative
South Carolina	narrative
South Dakota	narrative and 30 mg/l limit for coldwater fisheries
Tennessee	narrative
Texas	narrative
Utah	narrative
Vermont	narrative
Virginia	narrative
Washington	none
West Virginia	30 mg/l maximum
Wisconsin	narrative; also effluent limit of 30 mg/l
Wyoming	narrative; also effluent limit of 30 mg/l

(1) NTE = Not to Exceed

(2) Source: Department of Fisheries and Oceans, 1983. A rationale for standards relating to discharge of sediments into Yukon streams for placer mines. Environment Canada, New Westminster, British Columbia. 24 pp.

According to Keup (1985), there are eight reports of primary interest to this subject: the "Blue Book" (NAS 1973), "Red Book" (EPA 1976), "Green Book" (Sorensen et al. 1977), three EPA funded projects completed in 1978 and 1979 (Iwamoto et al. 1978; Farnworth et al. 1979; Muncy et al. 1979), and two current reports by Camp, Dresser & McKee (George and Lehnig 1984; Clarkson et al. 1985).

The Blue Book, or Water Quality Criteria 1972, presents discussions of turbidity and sediment only in relation to drinking water and agricultural uses of water. Recommendations regarding turbidity and suspended solids concentrations in water used for these purposes were not made, apparently because of the lack of information regarding the effects of particulates.

The Red Book, or Quality Criteria for Water, established the first EPA criterion for solids (suspended, settleable) and turbidity to protect freshwater fish and other aquatic life. The criterion is: "Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more then 10 percent from the seasonally established norm for aquatic life." This criterion, as well as all others in the Red Book, was reviewed by the American Fisheries Society (Thurston et al. 1979), who state that the criterion is difficult to apply under most conditions and impossible to apply in others. According to the reviewers, "it attempts to make solids and turbidity synonymous, which they are not, and no method is proposed for measuring the compensation point." Other problems noted by the reviewers include: (1) The use of a compensation point is meaningless in shallow water bodies where the photic zone extends to the bottom; and, (2) It is unrealistic to expect adequate data to be available for all points to determine a "seasonally established norm" for the compensation point. The reviewers recommended that the criterion be rewritten with solids and turbidity considered separately.

The Green Book by Sorensen et al. (1977) is a literature review of the effects of dissolved and suspended solids on freshwater biota. Included are the effects of suspended solids on aquatic photosynthetic systems, zooplankton and macroinvertebrates, salmonid fishes, other fishes, aesthetic preference, and public and industrial water supply. Major conclusions derived from this review concerning the biological effects of suspended solids include: (1) Acute effects on specific organisms were difficult to demonstrate; (2) Suspended solids have significant effects on community dynamics due to turbidity; (3) Suspended solids may have significant effects on community succession, community stability, and fish avoidance reactions; (4) Sediments may serve as a reservoir of toxic chemicals; and, (5) Relatively high suspended solids were needed to cause behavioral reactions (20,000 mg/L) or death (200,000 mg/L) in fish over the short term.

Of the three EPA funded projects completed in 1978 and 1979, Iwamoto et al. (1978) is the most applicable to this study since it presents an extensive literature review emphasizing freshwater salmonid habitats. Farnworth et al. (1979) reviewed literature dealing with impacts of sediment, nitrogen, and phosphorus on aquatic biota in order to suggest future research and management schemes for freshwater systems. Muncy et al. (1979) reviewed literature regarding the effects of suspended solids and sediment on the reproduction and early life of warmwater fishes. Their review cites literature that provides evidence of detrimental effects of sediment on reproductive behavior, embryonic development, larval development, and juveniles.

The Camp, Dresser & McKee reports are the most recent EPA funded literature reviews. Turbidity and Solids by George and Lehnig (1984) summarizes recent literature pertaining to the impacts of turbidity and sediment on primary production and on the survival, growth, and propagation of zooplankton, macroinvertebrates, and fish. Numerical data from several key investigations are presented including results from bioassay studies, state water quality standards, and Alaska and Canada placer mining studies. In addition, the report examines Canadian water quality objectives for turbidity, supporting rationale, guidelines for setting turbidity and sediment standards, and recommended levels for the protection of a variety of water uses in Canada.

The Hydrologic Basis for Suspended Solids Criteria by Clarkson et al. (1985) discusses several factors that are important to the development of a water quality criterion for suspended solids/turbidity for the protection of aquatic biota. These factors include regional, physiographic, and seasonal considerations, and related hydrologic phenomena. The natural solids loading to a waterbody will vary from site to site, depending upon physiographic factors (including slope, soil type, and type of ground cover) and upon rainfall and runoff. Hence, seasonal and regional criteria need to be developed that take into account the significance of natural and other nonpoint source loadings. Water quality criteria should be developed for suspended solids in the water column as well as for settled sediment, and these criteria need to address the complex situation of toxics sorbed to suspended and settled solids. Additionally, the effects of sustained exposure to suspended solids versus short-term storm-related pulses need to be quantified. Although the report does not recommend criteria to protect aquatic life, it does establish a framework for consideration of regional, seasonal, and biological factors.

3.3 CANADIAN PROVINCES AND TERRITORIES

The Canadian federal government, through the offices of Environment Canada and the Canadian Council of Resource and Environment Ministers (CCREM), establishes guidelines and objectives for water quality parameters for the provinces and territories. They also prepare guidelines and regulations which address specific activities (e.g., Metal Mining Liquid Effluent Regulations and Guidelines; Potato Processing Plant Liquid Effluent Regulations and Guidelines; Fish Processing Operations Liquid Effluent Guidelines; Pulp and Paper Effluent Regulations). The CCREM Task Force on Water Quality Guidelines has prepared an Inventory of Water Quality Guidelines and Objectives 1984 which contains a compilation of guidelines and objectives currently used in Canada (CCREM 1985). From these guidelines, the governments of the provinces and territories develop specific water quality criteria.

The current standards for turbidity in Canadian provinces and territories appear in Table 3-1. In addition to provincial regulations, the federal government has established standards for certain water uses and has promulgated standards for boundary waters with the United States (International Joint Commission--Great Lakes). Only Manitoba and Ontario have developed enforceable regulations for some water uses. The remaining provincial governments only have objectives, guidelines, or draft regulations at this time. British Columbia, New Brunswick, Newfoundland, Northwest Territories, Nova Scotia, Prince Edward Island, and the Yukon Territory use the guidelines of other agencies on a case by case basis. Quantitative turbidity criteria for recreation and for fish and wildlife propagation are comparable to Alaska criteria for these same water uses.

Water quality standards for suspended and settleable solids in Canadian provinces and territories appear in Table 3-2. There are no regulations for water column standards currently in effect. Quantitative criteria for Alberta and Saskatchewan are objectives only. The Yukon Territory has proposed effluent standards for suspended and settleable solids based on classes of biological productivity of the receiving water.

3.4 REFERENCES

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4.0 ADEQUACY AND SCIENTIFIC MERIT OF ALASKA CRITERIA

This section summarizes Alaska criteria for water supply, recreation, and protection of biota for both fresh and marine waters; summarizes scientifically documented levels of turbidity, suspended solids, settleable solids, and fine particles in streambeds that have demonstrated effects on various water uses; and, presents suggested criteria from the literature.

4.1 ALASKA CRITERIA

The purpose of this section is to describe protected water uses for both fresh and marine water, and existing turbidity and sediment criteria for the various protected uses. Before describing the protected water uses and particulates criteria, however, four points are made to enhance the reader's understanding of the standards. First, the standards apply only to human activities which result in alterations to waters within the state. In this context, the standards constitute the level of degradation which may not be exceeded in a water body. Second, sediment refers to particulates in the water column as well as particulates that settle to the bottom. Sediment in the water column may be measured as total suspended solids or settleable solids (Easton 1985). Third, the methods of analysis used to determine water quality are in accordance with _Standard Methods for the Examination of Water and Wastewater_ (APHA 1980) and _Methods for Chemical Analysis of Water and Wastes_ (EPA 1979). This requirement insures that accepted methods are used for measuring turbidity, total suspended solids, and settleable solids. Fourth, if a water is classified for more than one use, the most stringent water quality criteria of all the included uses applies. All waters in Alaska except the lower Chena River and Nolan Creek and all its tributaries, excluding Acme Creek, are classified for all uses. Therefore, the most stringent criteria applies to all waters except those noted above. The criteria for protection of drinking water sources and contact recreation are the most stringent for particulates, but are not necessarily the most stringent for all other water quality parameters.

Existing turbidity and sediment standards for the protection of identified water uses in both fresh and marine waters appear below (ADEC 1985):

FRESH WATER

1. WATER SUPPLY: DRINKING, CULINARY, AND FOOD PROCESSING

   Turbidity: Shall not exceed 5 NTU above natural conditions when the natural turbidity is 50 NTU or less, and not have more than 10 percent increase in turbidity when the natural condition is more than 50 NTU, not to exceed a maximum increase of 25 NTU.

   Sediment: No increase in concentrations of sediment, including settleable solids, above natural conditions.

2. WATER SUPPLY: AGRICULTURE, INCLUDING IRRIGATION AND STOCK WATERING

   Turbidity: Shall not cause detrimental effects on indicated use.

   Sediment: For sprinkler irrigation, water shall be free of particles of 0.074 mm or coarser. For irrigation or water spreading, shall not exceed 200 mg/L for an extended period of time.

3. WATER SUPPLY: AQUACULTURE

   Turbidity: Shall not exceed 25 NTU above natural condition level. For all lake waters, shall not exceed 5 NTU over natural conditions.

   Sediment: No imposed loads that will interfere with established water supply treatment levels.

4. WATER SUPPLY: INDUSTRIAL

   Turbidity: Shall not cause detrimental effects on established water supply treatment levels.

Sediment: No imposed loads that will interfere with established water supply treatment levels.

5. WATER RECREATION: CONTACT RECREATION

Turbidity: Shall not exceed 5 NTU above natural conditions when the natural turbidity is 50 NTU or less, and not have more than 10 percent increase in turbidity when the natural condition is more than 50 NTU, not to exceed a maximum increase of 15 NTU. Shall not exceed 5 NTU over the natural condition for all lake waters.

Sediment: No increase in concentrations of sediment, including settleable solids, above natural conditions.

6. WATER RECREATION: SECONDARY RECREATION

Turbidity: Shall not exceed 10 NTU over natural conditions when natural turbidity is 50 NTU or less, and not have more than 20 percent increase in turbidity when the natural condition is more than 50 NTU, not to exceed a maximum increase of 50 NTU. For all lake waters turbidity shall not exceed 5 NTU over natural conditions.

Sediment: Shall not pose hazards to incidental human contact or cause interference with the use.

7. GROWTH AND PROPAGATION OF FISH, SHELLFISH, AND OTHER AQUATIC LIFE

Turbidity: Shall not exceed 25 NTU above natural condition level. For all lake waters, shall not exceed 5 NTU over natural conditions.

Sediment: The percent accumulation of fine sediment in the range of 0.1 mm to 4.0 mm in the gravel bed of waters utilized by anadramous or resident fish for spawning may not be increased more than 5 percent by weight over natural condition (as shown from grain size accumulation graph). In no case may the 0.1 mm to 4.0 mm fine sediment range in the gravel bed of waters utilized by anadramous or resident fish for spawning exceed a maximum of 30 percent by weight (as shown from grain size accumulation graph). In all other surface waters no sediment loads (suspended or deposited) which can cause adverse effects on aquatic animal or plant life, their reproduction, or habitat.

MARINE WATER

1. WATER SUPPLY: AQUACULTURE

   Turbidity: Shall not exceed 25 NTU.

   Sediment: No imposed loads that will interfere with established water supply treatment levels.

2. WATER SUPPLY: SEAFOOD PROCESSING

   Turbidity: Shall not interfere with disinfection.

   Sediment: Below normally detectable amounts.

3. WATER SUPPLY: INDUSTRIAL

   Turbidity: Shall not cause detrimental effects on established levels of water supply treatment.

   Sediment: No imposed loads that will interfere with established water supply treatment levels.

4. WATER RECREATION: CONTACT RECREATION

   Turbidity: Shall not exceed 25 NTU.

   Sediment: No measureable increase in concentration above natural conditions.

5. WATER RECREATION: SECONDARY RECREATION

   Turbidity: Shall not exceed 25 NTU.

   Sediment: Shall not pose hazards to incidental human contact or cause interference with the use.

6. GROWTH AND PROPAGATION OF FISH, SHELLFISH, AND OTHER AQUATIC LIFE

   Turbidity: Shall not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent. In addition, shall not reduce the maximum Secchi disk depth by more than 10 percent.

   Sediment: No measureable increase in concentrations above natural conditions.

7. HARVESTING FOR CONSUMPTION OF RAW MOLLUSKS OR OTHER RAW AQUATIC LIFE

   Turbidity: Shall not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent.

In addition, shall not reduce the maximum Secchi disk depth by more than 10 percent.

Sediment: Not applicable.

4.2 DEMONSTRATED EFFECTS OF PARTICULATES

4.2.1 Water Supply

The effects of particulates on water supply summarized in this section include information pertaining to both fresh and marine waters. Fresh water uses include drinking, culinary, and food processing; agriculture; aquaculture; and industrial. Marine uses include aquaculture, seafood processing, and industrial. The effects of particulates on these various water uses are quantified in this section where possible.

The extent to which suspended solids can be tolerated in water supplies varies widely. Solids in water used for drinking, culinary, and food processing can support growth of harmful microorganisms and reduce the effectiveness of chlorination, resulting in health hazards. For most water supplies, high levels of suspended solids are objectionable for aesthetic reasons and can interfere with treatment processes and chemical and biological tests. Suspended solids may also transport nutrients and toxic substances, such as pesticides, herbicides, and certain metals.

The amount of particulates allowable in raw water supplies depends on the type and degree of treatment used to produce finished water. Sorensen et al. (1977) note that an excellent source of water supply, requiring only disinfection as treatment, would have a turbidity range of 0 to 10 units. A good source of water supply, requiring usual treatment such as filtration and disinfection would have a turbidity range of 10 to 250 units. Waters with turbidities over 250 units are poor sources of water supply requiring special or auxiliary treatment and disinfection. The ability of common water treatment processes (i.e., coagulation, sedimentation, filtration, and chlorination) to remove suspended matter to achieve water with acceptably low turbidity is a function of the composition of the material as well as its concentration (EPA 1976). The type of plankton, clay, or earth particles, their size, and electrical charges, influence coagulation more than the number of turbidity units (NAS 1973). For example, a water with 30 turbidity units may coagulate more rapidly than one with 5 to 10 units and water with 30 turbidity units sometimes may be more difficult to coagulate than water with 100 units (NAS 1973).

Although the Alaska criteria for drinking water refer to a 5 NTU increase in turbidity above background in raw water, the following information pertaining to turbidity levels in finished drinking water is provided to give the reader a feeling for the importance of low turbidity levels. It should be noted that raw water at a low turbidity level is the same as finished drinking water with respect to the following information. Bruvold (1975), reporting the results of a consumer acceptance survey of finished tap water conducted by Harris, notes that 11 percent of the respondents judged 5 turbidity units to be acceptable for drinking water. This water also had 15 color units and a threshold odor number of 3. For drinking water, 5 units of turbidity become objectionable to a considerable number of people, and many people turn to alternate supplies which may be less safe. Symons and Hoff (1975) discuss the relationship between particulates in water and the presence of disease-causing organisms. Low levels of particulates interfere with disinfection and can prevent maintenance of an effective disinfectant agent (e.g., chlorine) throughout the distribution system. Indications are that bacteria and viruses can be protected by certain kinds of particles from inactivation by chlorine. Inorganic particles can cause turbidity and probably have no bearing on the potential protection of pathogens. Small organic particles, however, may protect pathogens. Therefore, in evaluating water supplies, the nature of the particles in the water should be taken into account. Hence, if only disinfection is applied, the raw water source should be limited to low levels of particulates. George and Lehnig (1984) note that a level of 5 turbidity units should not be exceeded for drinking water. EPA (1976) notes that finished drinking water should have a maximum limit of 1 turbidity unit where the water enters the distribution system.

Agricultural uses of water containing suspended solids may be adversely affected in many ways. Deposition of suspended sediments reduces the capacity of irrigation structures and systems and decrease reservoir storage capacity (King et al. 1978). Deposition on land can produce crusts that inhibit water infiltration and plant emergence, impedes soil aeration, and can contribute to salinity problems by hindering leaching of saline soils (King et al. 1978). High colloidal content in water used for sprinkler irrigation may result in deposition of films on leaf surfaces that may reduce photosynthetic activity and, therefore, growth. The films may also affect marketability of leafy vegetable crops such as lettuce (NAS 1973).

Quality requirements regarding the amount of particulates vary among different industrial uses. For example, rayon manufacture requires water with only 0.3 turbidity units, whereas water used for cooling can have up to 50 turbidity units (McGauhey 1968). Although industrial cooling water can tolerate relatively high levels of suspended solids without significant problems, modern high pressure boilers require water that is virtually free of all impurities (Hach 1983). The quality requirements even vary within some industries, such as the pulp and paper industry. Different processes within this industry require different levels of turbidity. The groundwood process is the least sensitive to particulates and can tolerate up to 50 turbidity units, the kraft process up to 25 units, the soda and sulfite process up to 15 units, and light paper production tolerates up to 5 turbidity units (McGauhey 1968).

Criteria established for evaluating and identifying water treatment needs for fish hatcheries by Sigma Resource Consultants (1979) include limits on suspended solids. The suggested limit for suspended solids for incubating eggs is 3 mg/L and for rearing and holding the limit is 25 mg/L in the absence of other pollutants.

4.3.2 Recreation

Contact recreation refers to activities where there is direct and intimate contact with water and includes wading, swimming, diving, water skiing, surfing, and any other intimate contact with water directly associated with shoreline activities. Secondary recreation refers to activities where water use is incidental, accidental, or visual, and includes fishing, boating, camping, hunting, hiking, and vacationing. The effects of particulates on contact and secondary recreation summarized in this section include information pertaining to both fresh and marine waters.

Water quality is rarely defined by the public in terms of chemistry, physics, or bacteriology because public perceptions of quality are attuned to the senses (Wolman 1974) such as sight. The public perceives water quality in terms such as algae, foam, and turbidity. Contact and secondary recreational uses of water vary widely with respect to the amount of particulates that are acceptable. Water contact uses such as wading, swimming, and diving require clear to moderately clear water for safety. The less turbid the water the more desireable it becomes for swimming and other water contact sports (EPA 1976). McGauhey (1968) notes that the noticeable threshold is 10 turbidity units and the limiting threshold is 50 units for water contact recreation. The guidelines for Canadian recreational water quality (National Health and Welfare 1983) note that the maximum limit for turbidity is suggested as 50 turbidity units and the water should be sufficiently clear so that a Secchi disk is visible at a minimum of 1.2 meters (4 feet). These objectives insure the protection of waters suitable for contact recreation, including wading, swimming, diving, water skiing, and surfing.

Fishermen tend not to fish in areas of turbid water because game fishes are not found there in as great abundance as in clear waters (Bartsch 1960). Fishing success is reduced where turbidity is greater than 25 ppm (Phillips 1971) to 30 JTU (Grundy 1976). According to Townsend (1983), one of the most popular recreational activities on the Chatanika River is sport fishing for Arctic grayling. He notes that numerous complaints from the public were received about muddy water conditions in the Chatanika drainage in 1979, the first season of increased placer mining activity in this drainage. Townsend states that fishermen probably refrained from fishing because of turbid conditions. He also notes that in 1977 and 1978 the Chatanika was the second most popular waterbody for sport fishing in the Interior but it fell to seventh place in 1979.

Boating, canoeing, and kayaking are enjoyed in Alaska in a variety of clear and turbid systems. There is really no upper limit to the amount of turbidity for these activities. For example, river boating (for pleasure and transportation) is popular on the Tanana and Yukon rivers and kayaking and rafting are popular on the Nenana River; all are turbid systems. According to McGauhey (1968), the noticeable threshold is 20 turbidity units for boating and aesthetic uses but "no level [is] likely to be found in surface waters [that] would impede [these] use[s]." That is, high turbidity levels do not eliminate boating and aesthetic uses. However, given a choice, most people prefer clear water conditions for these uses.

4.2.3 Biota

Fresh Water

Scientific data describe many ways in which turbidity and excessive concentrations of sediment may adversely affect aquatic organisms. In general, these effects include:

(1) Direct actions which either kill or reduce growth rate and resistence to disease;
(2) Prevention of the successful development of eggs and/or larvae;
(3) Modification of natural movements and migration; and,
(4) Reduction in the abundance of available food items.

A substantial amount of information exists regarding the general effects of suspended solids, settleable solids, turbidity, and the accumulation of fines in spawning gravel on freshwater aquatic organisms. A large percentage of the published literature summarizes the results of investigations undertaken by other authors, and relatively few present original data that quantify the levels which cause deleterious effects. Furthermore, many of the frequently cited publications address the effects of particulates on organisms not found in Alaska waters. Difficulties arise in deriving conclusions about the effects of particulates on specific organisms as a result of the wide range of tolerance among different species, among individuals of different ages and stages of development, and among individuals of the same species which have adapted to different natural conditions. For example, salmonid egg incubation is adversely affected by suspended solids concentrations greater than 3 mg/L, but some adult salmonids are not adversely affected by short-term exposure to concentrations greater than 100,000 mg/L. There is a wide range of effects on individuals, their age class, and habitat over a wide range of particulate types and levels. Furthermore, the various units of measure and methods of measuring turbidity and suspended matter make it difficult to compare results.

Particulates have direct and indirect effects on aquatic biota. Direct effects include anatomical and physiological influences on the organisms themselves, whereas indirect effects involve impacts such as a reduction in prey species or habitat alteration. Additionally, the biological effects of particulates are interactive in that a change in natural levels may affect the structure of an entire aquatic community, as opposed to only one functional group of organisms.

Data from early field studies indicate that it is often difficult to assess the effects of suspended solids independent of factors such as sorbed toxic metals and pesticides, biochemical oxygen demand, and nutrient content. Consequently, the objective of more recent studies has been to identify the biological effects of inert particulate material, similar in size and composition to those found in natural waters. Another problem with early studies is that investigators used a variety of units for turbidity. Hence, there are a variety of units, ppm, mg/L, JTU, FTU, NTU (not directly translated one to another), making it appear that there are inconsistencies in the reported data. The actual units reported in the literature appear in the following discussion of the effects of particulates on biota.

Particulates, especially turbidity, are considered to have a deleterious effect on plant communities within waterbodies. Few quantitative results are reported in the literature. Bell (1973) reported that algal-based food production for juvenile salmonids was reduced at turbidities above 25 JTU. In Great Britain, Nuttall and Bilby (1973) stated that rooted aquatic vegetation was absent at stations where suspended solids levels exceeded 2000 ppm in a river polluted with china-clay wastes. Reed et al. (1983) found in experimental ponds in North

Carolina, that a reduction of turbidity from 12 to 6 NTU allowed submerged plants to grow in deeper water areas because of the corresponding increase in light at depth. In Ya-Ya Lake, NWT, phytoplankton productivity was lowest in the region where turbidity and suspended solids were highest (McCart et al. 1980). Van Nieuwenhuyse (1983) observed a strong correlation between incident photosynthetically active radiation (PAR) and gross productivity which lead to development of a model by Van Nieuwenhuyse (LaPerriere 1985) to predict algal productivity at different turbidity levels.

Benthic organisms and other invertebrates are also adversely affected by particulates. Gammon (1970) reported a 25 percent reduction in macroinvertebrate populations downstream from a limestone quarry where sediment loads were less than 40 mg/L. Population reductions of 40 percent were noted in stretches of the river where the sediment load was 80 to 120 mg/L and, in areas where 120 mg/L was exceeded, the macroinvertebrate population reduction was 60 percent. Sediment which settled out caused a reduction of 40 percent in population density regardless of suspended sediment concentration. Invertebrate drift increased immediately when introductions of 160 mg/L sediment were made to the stream.

Wilber (1983), citing Herbert et al. (1961), reported that macroinvertebrate populations are reduced at turbidity levels of 261 to 390 ppm and that density is reduced at 1000 to 6000 ppm. Reduced numbers were reported for turbidities of 40 to 200 JTU (Sorensen et al. 1977). In McCart et al. (1980), a discernible effect on the species composition and relative abundance of zooplankton was noted in the silty south end of Ya-Ya Lake, NWT. Species diversity, equitability, and taxonomic diversity appeared to be negatively correlated to siltation. Mortality of Daphnia sp. occurred at 82 ppm suspended solids according to EIFAC (1965).

McCart et al. (1980) also discussed the effects of siltation on various fish species within Ya-Ya Lake, including two species of sculpins, lake trout, northern pike, trout-perch, lake chub, inconnu (sheefish) and several other whitefish species. The study focused on the distribution of the species in the lake. They concluded that lake trout and slimy sculpin were characteristic species of clearwater conditions, whereas the trout-perch and spoonhead sculpin appeared in turbid parts of the lake. Many species which were tolerant of turbid conditions preferred to feed in the clearwater end of the lake. These species included northern pike and humpback and broad whitefish.

In laboratory tests, the torrent sculpin appeared to be fairly tolerant of suspended sediments, and no effect on feeding behavior was evident at levels ranging from 0 to 1250 mg/L (Brusven and Rose 1981). McLeay et al. (1983) conducted laboratory tests on Arctic grayling and reported that, when acclimated to 15 degrees C, they survived a 4-day exposure to sediment suspensions of more than 250,000 mg/L and a 16-day exposure to 50,000 mg/L. Grayling which were acclimated to 5 degrees C survived 4 days in suspensions of less than 10,000 mg/L. Suspensions greater than 10,000 mg/L caused grayling to surface. Although gill histologies appeared normal in the fish held for 4 days, acute stress responses such as elevated and/or varied blood glucose levels, were noted. Gill hypertrophy and hyperplasia were reported for grayling captured in the field in water with low suspended solids and then held in water with suspended solids levels of approximately 1210 mg/L and 35 mg/L. It was concluded that grayling subjected to short-term sublethal amounts of suspended solids can exhibit various responses including acute stress.

A relatively large body of literature exists dealing with the effects of particulates on trout and salmon. The effects on adult fish, juveniles, and embryos are considered separately. Bell (1973) reports that relatively large quantities (500 to

1000 ppm) of sediment load can be carried in a stream without any apparent detriment to adult salmon and trout for short periods of time. Concentrations of 4000 ppm can cause salmon to cease instream movements, however. Herbert et al. (1961) concluded that brown trout populations in the rivers Fal and Par in Cornwall were reduced in areas having suspended sediment concentrations of 1000 ppm but were unaffected at 60 ppm. Reductions in the standing crop of brook trout in a British Columbia stream appeared to be the result of decreased spawning and destruction of hiding places due to siltation (Saunders and Smith 1965). Bachmann (1958) revealed that cutthroat trout cease feeding at 35 ppm suspended solids and that cutthroat may abandon redds if silt is present. Rainbow trout exhibited the following responses to varying amounts of suspended solids: (1) 50 ppm--reduced growth; (2) 90 ppm--20 percent mortality in 2 to 6 months; (3) 100 to 270 ppm--fin rot; (4) 200 ppm--50 percent mortality in 16 weeks; (5) 1000 to 2500 ppm--100 percent mortality in 20 days; (6) 1000 ppm--20 percent mortality in 37 days; (7) 4250 ppm--50 percent mortality in 28 days; and, (8) 160,000 ppm--100 percent mortality in 1 day.

Results of acute (4 days or less) exposure to suspended sediments indicate that juvenile salmonids exhibit seasonal changes in their tolerance to suspended sediments (Noggle 1978). Bioassays conducted in summer produced LC50's less than 1500 mg/L, while autumn bioassays showed LC50's in excess of 30,000 mg/L. The tolerance of wild coho salmon to suspended solids was higher than hatchery produced cohos, apparently because of prior exposure to suspended sediments.

Langer (1980) reported reduced feeding among salmonids at turbidities greater than 25 JTU. Brook trout exhibited increased ventilatory response (a stress reaction) at 231 NTU clay in water (Carlson 1984). Pacific salmon survived 3 to 4 weeks in 300 to 750 ppm suspended solids and avoided muddy waters during migrations according to the literature review by Wilber (1983).

The effects of particulates on salmonid juveniles and eggs have been studied more extensively than those on adults. In laboratory tests, Bisson and Bilby (1982) found that turbidities of 70 to 100 NTU caused reduced feeding among coho juveniles. Crouse et al. (1981) found that 26 to 31 percent sediment in laboratory stream gravels increased mortality among emerging coho fry. Noggle (1978) found that feeding by coho juveniles was reduced at 100 mg/L and ceased at concentrations greater than 200 mg/L. Mortality (LC50) occurred at 1198 mg/L in August and at 35,000 mg/L suspended solids in November indicating perhaps a seasonal tolerance of juvenile coho salmon or the affect of increased maturity of individuals. NCASI (1984b) conducted a literature review pertaining to the effects of sediments on salmon habitat. It was discovered that the time necessary for coho fry to emerge from the gravel in which they were hatched increased from 10 to 47 days when the amount of fines (less than 3.327 mm in diameter) was increased from 36.6 to 42.3 percent (Koski 1966). Success of emergence decreased as sediment levels increased from 27 to 51 percent. Coho biomass decreased 65 percent when sediment smaller than 0.8 mm increased from 20 to 31 percent as a result of road construction (Burns 1972). Juvenile coho productivity was reduced from 8.8 grams per square meter to 5.0 grams per square meter as sediment embeddedness was increased from 0 to 100 percent in a laboratory stream (Crouse et al. 1981; NCASI 1984a). Sigler et al. (1984) reported that coho and steelhead fry showed a reduction in growth at 25 NTU turbidity.

Work by Herbert and Merkens (1961) indicated that suspensions of 30 ppm kaolin and diatomaceous earth caused negligible damage to juvenile rainbow trout over a 6 month period in laboratory tests. Some mortality occurred at 90 ppm and more than half the trout died at 270 ppm and 810 ppm. Fish exposed to 30 to 90 ppm suspended solids exhibited normal gills, but those exposed to concentrations of 270 to 810 ppm displayed thickening or fusing of gill lamellae. Caudal fin damage was also evident after exposure for 57 days to 270 ppm suspended solids.

Salmon eggs are usually laid in depressions excavated in the gravel of stream bottoms and then covered over with more gravel. Development of the eggs depends on water flowing through the gravel, bringing oxygen to the eggs and removing metabolic products. When gravel interstices are covered or clogged with fine material, successful development of the eggs is impaired. Bjornn et al. (1977) reported reduced survival of salmon eggs in an Idaho stream when there was 20 to 30 percent sand in the gravel. Increased mortality of brook trout eggs in laboratory streams was noted by Hausle and Coble (1976) when there was more than 20 percent fines in gravel. A literature review by Iwamoto et al. (1978) revealed that coho eggs suffered increased mortality when the fines content of gravel was greater than 15 percent. The same was true of steelhead eggs when the fines content was greater than 20 percent. The size of bottom material in streams utilized for spawning by pink salmon varies considerably. According to McNeil and Ahnell (1964), escapement was very high when the percentage of solids passing through a 0.833-mm sieve was about 5 percent, medium to high at 10 percent, and low to fair at about 20 percent.

Bjornn (1969) reported that chinook fry had difficulty during emergence when sand (0.25 mm) in the gravel was increased 20 to 40 percent. Mortality of chinook embryos approached 50 percent as a result of 30 to 40 percent sand in the gravel. Langer (1980) reported an increase in steelhead fry mortality when gravels contained more than 10 percent sediments. Survival of steelhead declined to 3.3 percent when fine sediment (6.4 mm) reached 39.4 percent in gravel (NCASI 1984b). Approximately 18 percent survival was achieved with 70 percent 1 to 3 mm sediment (Phillips et al. 1975) and 10 percent survival occurred when 0.85 mm sediment reached 19.5 percent (Tappel and Bjornn 1983) in gravel. Only 6 percent survival occurred when there was 50 percent fine sediment (9.5 mm) present (Tappel and Bjornn 1983). Steelhead fry survival decreased from 49 to 52 percent to 3 to 9 percent when 20 percent fines (0.25 mm) were introduced in the gravel (NCASI 1984b). Steelhead populations declined by 85 percent when sediment smaller than 0.8 mm increased from 20.6 percent to 34.2 percent after road construction (Burns 1972).

Rainbow trout alevins and eggs showed reduced survival of 1 to 1.3 percent for every 1 percent increase in 0.8 mm fines in gravel (NCASI 1984a). Phillips (1971) reported a 57 percent decrease in the population of juvenile rainbow trout in 20 days in an area 1 1/2 miles downstream from a gold dredge where the suspended sediment concentration in the water ranged from 1000 to 2500 ppm.

Hausle and Coble (1976) reported that emergence time for brook trout embryos was increased and their survival decreased when 2.0 mm sediment in gravel greater than 20 percent. Chum salmon eggs exhibited a decrease in survival of 1.26 percent for every 1 percent increase in sand (Koski 1975). For coho eggs, the ratio was 3.1 percent decrease in survival for every 1 percent increase in sand (Cederholm et al. 1980). Sockeye salmon eggs showed a 40 percent decrease in survival when fines of less than 0.336 cm were introduced into gravel. The survival of chinook eggs decreased from 88 to 18 percent when 39 percent fines (6.4 mm) were in the gravel. Coho eggs showed a reduced survival from 96 to 8 percent with a 0 to 70 percent increase in fine (1 to 3 mm) sediment (Phillips et al. 1975).

In laboratory tests, Phillips et al. (1975) found that the survival of coho eggs correlated negatively with the addition of sand to the substrate with the following results. There was 96 percent survival in the control mixture, 82 percent survival in 10 percent sand, 64 percent survival in 20 percent sand, 38 percent survival in 30 percent sand, 20 percent survival in 40 percent sand, 22 percent survival in 50 percent sand, and 8 to 10 percent survival in 60 to 70 percent sand. Steelhead eggs showed a similar response; survival was reduced from 99 to 18 percent when sand was increased to 70 percent.

In other studies, Shelton and Pollack (1966) found that 15 percent of chinook salmon eggs survived when 15 to 30 percent of the gravel voids were filled with sediment in laboratory streams. Tagart (1976) observed that survival of coho eggs in the Clearwater River in Washington was negatively correlated with the percent of "poor" (fines less than 0.85 mm in diameter) gravel present in the stream. In Great Britain, Turnpenny and Williams (1980) found that rainbow trout eggs suffered 98 to 100 percent mortality in 2 to 2481 mg/L suspended solids where the permeability of the gravel was 5 to 74 cm/hr and dissolved oxygen in the water was 2.4 to 7.8 mg/L. At suspended sediment concentrations of 3 to 1810 mg/L, where the permeability was 7 to 2950 cm/hr and dissolved oxygen was 3.8 to 8.6 mg/L, survival of the eggs ranged from 24 to 98 percent. Witzel and MacCrimmon (1981) found that only 1 percent of the rainbow eggs survived when the gravel was 2 mm in diameter but that 76 percent survival was achieved when the gravel diameter was 26.5 mm.

The main concern with regard to the protection of aquatic fauna from lethal sediment concentrations is the amount of solids in suspension that can potentially settle out (settleable solids) as flow decreases (Duckrow and Everhart 1971). It is the sessile, immobile forms in or on the streambed which are the most susceptible to being smothered. Sedimentation of the stream substrate, particularly the gravel used for spawning, produces significant detrimental effects on salmonid resources (Iwamoto et al. 1978). Iwamoto et al. (1978) note that there are substantial data describing the deleterious effects of particles of sizes less than 0.850 mm in diameter when they exceed approximately 20 percent of the total. They also note that sediments ranging between 0.1 and 3.3 mm appear to cause the most significant impact.

Sediment deposited on the streambed surface or within the gravel can reduce the exchange of water between the stream and the gravel (Cooper 1965). Three factors affect the magnitude and direction of water interchange in spawning beds: (1) The surface profile of the streambed; (2) depth of the streambed; and (3) streambed permeability. Water exchange occurs in stream gravels as either downwelling or upwelling. Downwelling is predominant in convex streambed surfaces, whereas upwelling occurs where the streambed is concave. Furthermore, increased stream gravel permeability induces downwelling, whereas decreased permeability induces upwelling (Vaux 1968). Substantial reductions in flow through the gravel may result from a reduction in the size of particles in the gravel bed (Cooper 1965). Permeability may be increased by removing fine material from the stream gravels (McNeil and Ahnell 1964) such as during flood events that wash fines out of the gravel.

The intrusion of fines into stream gravels is a complicated and not fully understood process (Beschta and Jackson 1979). Presently there is little known about the mechanisms and rates of sediment interchange between the water column and the interstitial environment (Carling 1984). Sediment intrusion involves the transport and deposition of particles into gravel voids at the surface, and the settling of particles into deeper gravel voids under the influence of gravity, assisted by turbulent pulses at the gravel surface (Beschta and Jackson 1979). Since there is often an exchange of flow between a stream and the gravel bed of a stream, it is logical to expect that suspended sediments might be carried into the gravel and deposited even if they are not deposited on the streambed. While conducting bedload experiments with gravel, Einstein (1968) noticed that murky water gradually cleared up at low bedload rates, and postulated that the deposition of suspended silt particles must occur in the pores of the gravel bed. Subsequent experiments showed that the deposition rate of suspended silt particles begin to fill the pores of the gravel from the bottom up. The concentration of silt ranging from 3.5 to 30 microns decreased exponentially downstream as sediment was deposited in the stream gravels. As a result of these experiments, Einstein (1968) concluded that the deposition of silt is primarily a function of the sediment concentration close to the sediment-water interface and that hydraulic controls are of secondary importance. Carling (1984) notes a similar experiment in which low concentrations of silty clay (less than 300 mg/L) decreased exponentially downstream although high concentrations decreased logarithmically.

A series of experiments conducted by Beschta and Jackson (1979) demonstrate that flow conditions, as indexed by Froude numbers, significantly influenced the degree of gravel intrusion by sand. Other flow indicators such as shear velocity and Reynold's number did not significantly affect the amount of intrusion. At low Froude numbers, 0.5 mm sand quickly established a sand "seal" within the upper 5 cm of the gravel. Once the sand seal had formed and the intergravel spaces had filled with fines, the downward movement of additional sediment was prevented and the intrusion process stopped. In comparison with 0.5 mm sand, the intrusion of 0.2 mm sand was more extensive suggesting that particle size is an important variable affecting the intrusion of stable gravels. Instead of forming a sand seal in the upper gravels, the finer sands generally migrated down through the test gravels by gravity and began to fill them from the bottom up. The amount of intrusion of 0.2 mm sand decreased as the Froude number increased from 0.6 to 1.1. These observations support the findings of Einstein (1968) that intrusion by fine sediments fills stream gravels from the bottom up.

Experiments were conducted by Cooper (1965) using 0.5 to 74 micron silt in concentrations of 200 and 2000 ppm to determine the rate and magnitude of fine sediment deposition. Data show that stream gravels act as a filter in removing suspended sediments from the water flowing through the gravel. The rate of silt accumulation in the gravel varied in proportion to the flow through the gravel.

Carling (1984) found that porous gravels could physically entrap particles in the dead zones on the lee side of gravel grains and prevent resuspension. In base level flow conditions and low concentrations of sediment, the grain size of particles settling onto the gravel bed is similar to particles filling the gravel void spaces. For all concentrations, the deposition rate was strongly linearly correlated with the suspended sediment concentration. Results indicate that open-work gravels will rapidly become silted even with water containing low concentrations of suspended solids.

Thus, the amount of silt and larger particles transported in suspension may have a pronounced affect on the natural quality and composition of gravel substrates in streams. However, McNeil and Ahnell (1964) report that fines in the gravel can be locally removed by salmon during spawning. Nevertheless, additional sediment deposition and infiltration after spawning may reduce the rate and magnitude of water exchange in spawning gravels, to the detriment of developing eggs.

Although it is well documented that silt and larger particles in suspension may fill streambed gravels, the effects of clay-sized and other non-settleable particles on streambed embeddedness are not reported in the literature reviewed for this project.

In summary, numerous field and laboratory investigations have documented lethal and sub-lethal effects of suspended and deposited sediments on freshwater aquatic organisms. These effects are summarized in Tables 4-1 through 4-4. Most of the numerical data appearing in these tables pertain to salmonids and their habitat. The impacts of a wide range of sediment and turbidity levels have been documented for all stages of salmonid

TABLE 4-3

EFFECTS OF SUSPENDED SOLIDS AND TURBIDITY ON SALMONID SURVIVAL AND MORTALITY

Organism	Nature and Extent of Effect	Level or Conc.	Duration	Comments	Reference
Grayling	Mortality	250,000 mg/L	4 days	Suspended solids	McLeay et al. 1983
	Mortality	50,000 mg/L	16 days	Suspended solids	McLeay et al. 1983
	Survived	10,000 mg/L	5 days	Suspended solids	McLeay et al. 1983
	No mortality	950 to 8200 NTU	9 days	Turbidity	Simmons 1984
	No mortality	880 to 6600 mg/L	9 days	Total solids	Simmons 1984
Rainbow Trout	<20% mortality	90 ppm	2-6 months	Diatomaceous earth	Herbert and Merkens 1961
	20% mortality	1000 ppm	37 days	Cellulose fiber	EIFAC 1965
	50% mortality	200 ppm	16 weeks	Spruce fiber	Herbert and Richards 1963
	50% mortality	4250 ppm	28 days	Suspended gypsum	Herbert and Wakeford 1962
	Greater than 50% mortality	Greater than 270 ppm	1-6 months	Suspended kaolin & diatomaceous earth	Herbert and Merkens 1961
	No mortality	30 ppm	2-6 months	Suspended kaolin & diatomaceous earth	Herbert and Merkens 1961
	100% mortality	160,000 ppm	1 day	Suspended solids	EIFAC 1965
	98-100% egg mortality	2 to 2481 mg/L	—	Suspended solids	Turnpenny and Williams 1980
	24-98% egg mortality	3 to 1810 mg/L	—	Suspended solids	Turnpenny and Williams 1980
	Mortality occurred	1000 to 2500 ppm	20 days	Suspended solids	Campbell 1954
	No mortality	50 and 100 ppm	8 months	Coal-washery waste	Herbert and Richards 1963
	No mortality	200 ppm	9-10 months	Coal-washery waste	Herbert and Richards 1963
	No mortality	553 ppm	4 weeks	Suspended gypsum	Herbert and Wakeford 1962
Coho Salmon	50% mortality	1200 in August 35,000 ppm in November	4 days	Suspended solids	Noggle 1978
Chum Salmon	egg survival decreased by 55%	Increased by 12%	—	Suspended solids	Langer 1980

TABLE 4-2

MISCELLANEOUS EFFECTS OF SETTLED SOLIDS AND FINES ON SALMONIDS

Organism	Nature and Extent of Effect	Sediment Level	Sediment Size	Comments	Reference
Pink Salmon	Low escapement success	About 20%	0.833 mm	---	McNeil and Ahnell 1964
	Medium escapment success	About 10%	0.833 mm	---	McNeil and Ahnell 1964
	High escapement success	About 5%	0.833 mm	---	McNeil and Ahnell 1964
Coho Salmon	Fry emergence time increased	Increased from 37 to 42%	<3.327 mm	---	Koski 1966
	Emergence success decreased	Increased from 27 to 51%	Fines	---	NCASI 1984b
	Juvenile productivity decreased 44%	Increased from 0 to 100%	<2.0 mm	Embeddedness	Crouse et al. 1981
	Biomass decreased 65%	Increased from 20 to 31%	<0.8 mm	---	Burns 1972
Chinook Salmon	Emergence impaired	Increased from 20 to 40%	Sand	---	Bjornn 1969
Brook Trout	Embryo emergence time increased	Increased from 0 to >20%	<2 mm sand	---	Hausle and Coble 1976
Steelhead Trout	Population decreased by 65%	Increased from 21 to 34%	0.8 mm	---	Burns 1972
	Biomass decreased by 42%	Increased from 20 to 31%	0.8 mm	---	Burns 1972
Salmonids	Deleterious effects	Greater than 20%	<0.850 mm	---	Iwamoto et al. 1978
	Most significant impact	Not stated	Between 0.1 and 3.3 mm	---	Iwamoto et al. 1978

TABLE 4-1

EFFECTS OF SETTLED SOLIDS AND FINES ON SALMONID MORTALITY AND SURVIVAL

Organism	Nature and Extent of Effect	Sediment Level	Sediment Size	Comments	Reference
Brook Trout	Survival to emergence	Greater than 20%	2 mm sand	---	Hausle and Coble 1976
Salmon	Egg survival decreased	20 to 30% range	Fines	In gravel	Bjornn et al. 1974
Chum Salmon	Egg survival decreased 1.26%	Each 1% increase	Sand	---	Koski 1975
Chinook Salmon	Egg survival decreased from 54 to 18%	Increased from 28 to 39%	6.4 mm	---	NCASI 1984b
	Embryo mortality approached 50%	30 to 40%	Sand	---	Bjornn 1969
	Up to 85% mortality	15 to 30% of gravel voids	Silt	Filled gravel voids	Shelton and Pollack 1966
Coho Salmon	Egg survival decreased from 96 to 8%	Increased from 0 to 70%	1 to 3 mm	---	Phillips et al. 1975
	Egg survival decreased 3.1%	Each 1% increase	Sand	---	Cederholm et al. 1980
	Egg survival decreased from 96 to 10%	Increased from 0 to 70%	Sand	---	Phillips et al 1975
	Egg survival averaged 22.1%	---	0.85 mm	---	Tagart 1976
	Egg mortality increased	Greater than 15%	Fines	In gravel	Iwamoto et al. 1978
	Fry mortality increased	Increased from 26 to 31%	Fines	In gravel	Crouse et al. 1981
	Egg mortality averaged 27.1%	27 to 51% fines	3.327 mm	In gravel	Koski 1966
Rainbow Trout	Egg survival decreased 1.1 to 1.3%	Each 1% increase	0.8 mm fines	---	NCASI 1984a
	Egg survival decreased by 0.8%	Each 1% increase	6.4 mm fines	---	NCASI 1984a
	Egg survival ranged from 1 to 76%	Not stated	2 to 26.5 mm	---	Witzel and MacCrimmon 1981
Steelhead Trout	Egg mortality increased	Greater than 20%	Fines	In gravel	Iwamoto et al. 1978
	Egg survival decreased from 99 to 18%	Increased to 70%	Sand	---	Phillips et al. 1975
	Egg survival decreased to 3.3%	Increased to 39.4%	6.4 mm fines	---	NCASI 1984b
	Egg survival decreased to 18%	Increased to 70%	1 to 3 mm fines	---	Phillips et al. 1975
	Egg survival decreased to 10%	Increased to 19.5%	0.085 mm fines	--	Tappel and Bjornn 1983
	Egg survival decreased to 6%	Increased to 50%	9.5 mm fines	---	Tappel and Bjornn 1983
	Egg survival decreased from 52 to 3-9%	Increased to 20%	0.25 mm fines	---	NCASI 1984b
	Mean egg survival was 17.7%	Exceeded 30%	0.85 mm	---	Cederholm et al. 1980
	Egg survival decreased 3.4%	Each 1% increase	0.85 mm	---	Cederholm et al. 1980

TABLE 4-4

MISCELLANEOUS EFFECTS OF SUSPENDED SOLIDS AND TURBIDITY ON AQUATIC BIOTA

Organism	Nature and Extent of Effects	Level or Conc.	Duration	Comments	Reference
Salmonids in general	Cease instream movements	4000 ppm	---	Sediment load	Bell 1973
	No apparent detriment	500 to 1000 ppm	---	Sediment load	Bell 1973
	Reduced feeding	Greater than 25 NTU	---	Turbidity	Langer 1980
	Production reduced	Greater than 25 JTU	---	Turbidity	NCASI 1984b
Rainbow Trout	Production increased 35%	Reduced by 85%	---	Sand	Alexander and Hansen 1983
	Slight effect on growth	50 to 60 ppm	---	Coal washery waste	Herbert and Richards 1963
	Reduced growth rate	270 ppm	4.5 months	Suspended matter	Herbert and Merkens 1961
	Juvenile population decreased 57%	1000 to 2000 ppm	20 days	Suspended solids	Phillips et al. 1975
	Normal gills	30 ppm kaolin & diatomaceous earth	2 months	Suspended solids	Herbert and Merkens 1961
	Normal gill histology	30 to 90 ppm kaolin & diatomaceous earth	>5 months	Suspended solids	Herbert and Merkens 1961
	Gill thickening or fusing	270 and 810 ppm	>5 months	Suspended solids	Herbert and Merkens 1961
	No sign of disease	50 ppm	8 months	Wood fiber	Herbert and Merkens 1961
	Caudal fin disease	270 ppm	57 days	Diatomaceous earth	Herbert and Merkens 1961
	Some fin disease	200 ppm	8 months	Wood fiber	Herbert and Merkens 1961
Steelhead Trout	Avoidance	>167 NTU	---	Turbidity	Sigler et al. 1984
	Reduced growth	25 NTU	---	Turbidity	Sigler et al. 1984
	Displacement	40 to 50 NTU	---	Turbidity	Sigler et al. 1984
Coho Salmon	Avoidance	>167 NTU	---	Turbidity	Sigler et al. 1984
	Feeding reduced	100 mg/L	---	Suspended solids	Noggle 1978
	Feeding reduced	70 to 100 NTU	---	Turbidity	Alabaster 1972; Sykora et al. 1972
	Feeding ceased	200 mg/L	---	Suspended solids	Noggle 1978
	Reduced growth	25 NTU	---	Turbidity	Sigler et al. 1984
	Avoidance by juveniles	70 NTU	---	Turbidity	Bisson and Bilby 1982
	Displacement	40 to 50 NTU	---	Turbidity	Sigler 1981
Algal Based Productivity	Reduced	25 NTU	---	Turbidity	Bell 1973
Rooted Plants	Absent	>2000 ppm	---	China clay wastes	Nuttall and Bilby 1973
Submerged Plants	Grew in deeper water	Reduced from 12 to 6 NTU	---	Turbidity	Reed et al. 1983
Aquatic Plants	Reduced production	0 to 1500 NTU	---	Turbidity	VanNieuwenhuyse 1983

TABLE 4-4 Continued

MISCELLANEOUS EFFECTS OF SUSPENDED SEDIMENT AND TURBIDITY ON AQUATIC BIOTA

Organism	Nature and Extent of Effect	Level or Conc.	Duration	Comments	Reference
Benthic Invertebrates	Population reduced by 25%	40 mg/L	---	Suspended solids	Gammon 1970
	Population reduced by 40%	80 to 120 mg/L	---	Suspended solids	Gammon 1970
	Populations reduced by 60%	) 120 mg/L	---	Suspended solids	Gammon 1970
	Population reduced to 25%	261 to 390 ppm	---	Suspended solids	Sorensen et al. 1977
	Bottom fauna absent	250 ppm	---	Suspended solids	EIFAC 1965
	Population numbers reduced	40 to 200 JTU	---	Turbidity	Sorensen et al. 1977
	Density reduced to 11%	1000 to 6000 JTU	---	Suspended solids	Herbert et al. 1961
	Abundance unaffected	60 ppm	---	Suspended solids	Herbert et al. 1961
	25% increase in drift	40 mg/L increase	---	Suspended solids	Gammon 1970
	90% increase in drift	80 mg/L increase	---	Suspended solids	Gammon 1970
	Reduced abundance	0 to)2250 NTU	---	Turbidity	LaPerriere et al. 1983
Torrent Sculpin	Impaired Feeding	0 to 1250 mg/L	---	Suspended solids	Brusven and Rose 1981
Grayling	Elevated blood glucose, reduced leucocrit	10,000 mg/L	4 days	Suspended solids	McLeay et al. 1983
	Gill hypertrophy and hyperplasia	34 and 1210 mg/L	---	Suspended solids	McLeay et al. 1983
	Swam to surface	)10,000 mg/L	---	Suspended solids	McLeay et al. 1983
	Normal gill histologies	170 mg/L	4 days	Total solids	Simmons 1984
	Moderate gill tissue damage	1205 mg/L	2 days	Total solids	Simmons 1984
	Extensive gill damage	1388 mg/L	4 days	Total solids	Simmons 1984
	Limited food intake	1150 to 4825 NTU	6 days	Turbidity	Simmons 1984
	Limited food intake	1340 to 6280 mg/L	6 days	Total solids	Simmons 1984
Brown Trout	Population unaffected	60 ppm	---	Suspended solids	Herbert et al. 1961
	Reduced abundance	1000 ppm	---	Suspended solids	Herbert et al. 1961
	Density reduced by 86%	1000 to 6000 ppm	---	Suspended solids	EIFAC 1965
	Production increased by 41%	Reduced by 86%	---	Sand	Alexander and Hansen 1983
Cutthroat Trout	Cease Feeding	35 ppm	---	Suspended solids	Bachmann 1958
Brook Trout	Increased ventilatory response	231 NTU	---	Clay	Carlson 1984
Daphnia magna	Harmful effects	82 to 102 ppm	---	Kaolinite and montmorillonite	EIFAC 1965

development including eggs and embryos, alevins, fry, juveniles, and adult fish. Furthermore, quantitative analyses have been performed to determine the effects of sediment on feeding, growth, productivity, biomass, abundance, anatomy, physiology, and behavior. Nonetheless, a number of data gaps exist with regard to threshold levels having a specific effect on a particular species.

The above discussion demonstrates that particulates have detrimental effects on freshwater aquatic biota.

(1) Turbidity reduces the amount of light available for green plant growth and photosynthesis within water bodies, can inhibit instream movements of fish, and may inhibit the ability of fish to see their prey.

(2) Turbidity and settled solids can cause reductions in invertebrate populations and can cause an increase in invertebrate drift.

(3) Ability of fish to withstand various concentrations of settled and/or suspended solids depends on their life stage. Adult fish can withstand relatively high concentrations of suspended solids for limited amounts of time without suffering mortality, although other physiological effects such as fin and gill damage and stress reactions may result.

(4) Survival of fish eggs and juveniles may be significantly reduced by settled solids in spawning and rearing areas.

(5) Settled solids have direct effects on aquatic biota and habitat by smothering fish eggs, alevins, and invertebrates, reducing intergravel flow, and by coating aquatic vegetation, thus reducing the potential for photosynthesis.

(6) Solids in suspension can cause invertebrate drift, cause fish to avoid previously usable habitat, prevent fish from seeing their prey, and cause physical damage, such as gill irritation, to fish.

(7) Silt and larger particles in the water column can fill open-work gravels even when the concentration of suspended solids in the water is low.

Marine

The biological effects of inorganic suspended solids on marine communities are complex and extremely difficult to quantify. The effects on zooplankton and higher aquatic organisms are more difficult to evaluate than the effects on phytoplankton (Brehmer 1965). With the exception of a few commercially important species, little is known about the effects of turbidity and suspended material on marine invertebrates (Stern and Stickle 1978). Different species of marine organisms are affected to different degrees by the same concentrations of turbidity-causing sediments (Loosanoff 1961; Moore 1977; McFarland and Peddicord 1980). Many species of marine shellfish and finfish are sensitive to increases in suspended solids, which undoubtedly have an injurious effect on the estuarine community as a whole (Brehmer 1965). Filter feeders and early-life stages of estuarine fish are more sensitive to suspended sediments than bottom dwelling organisms and adult fish (Sherk et al. 1975). As filter feeders, bivalves are particularly susceptible to the mechanical or abrasive action of suspended sediments (Cairns 1967; Moore 1977). Other filter-feeding invertebrates at risk from inorganic suspensions include mollusks, certain crustaceans, sponges, ascidians, and *Amphioxus* (Moore 1977).

The effects of particulates on marine biota are divided into discussions of plankton, egg development and hatching success, larvae survival and development, and adult survival. This is followed by a discussion of feeding and growth and finally distribution.

Carbon assimilation rates by four species of phytoplankton were significantly reduced by the light attenuating properties of fine silicon dioxide suspensions. A concentration of 1000 mg/L caused a 50 to 90 percent reduction in carbon uptake among the four species tested. A concentration of 2500 mg/L caused an 80 percent reduction in one of the species tested (Sherk et al. 1976).

The presence of an open-ocean turbidity plume in the North Equatorial Pacific, having an average suspended sediment concentration of 440 ug/L, reduced primary productivity by 40 percent over the entire euphotic zone. However, because particulate concentrations return to ambient within a few days, it is believed that species composition changes would not take place (Ozturgut et al. 1981). The results of two sets of plankton tows indicated there was no major decrease in the abundance of neustonic macrozooplankton or sufficient amounts of particulates ingested to cause alteration in their chemical composition at turbidity concentrations of less than 1 mg/L.

The relationship between gastropod eggs and suspended solids concentrations is discussed in a literature review by Stern and Stickle (1978). One species of planorbid snail showed normal egg development at 190 to 360 ppm, while another species experienced high mortality at the same concentrations. A third species did not lay eggs in the 360 ppm water but did so in water containing 190 ppm suspended solids.

Loosanoff and Davis (1963) report that silt is considerably more harmful to oyster eggs than to clam eggs. at concentrations of 250 mg/L silt, only 73 percent of oyster eggs survived, while more than 95 percent of clam eggs developed normally. Practically all clam eggs developed in concentrations of 500 mg/L silt, while only 31 percent of oyster eggs survived. In a 1000 mg/L suspension of kaolin and Fuller's earth, on the other hand, practically all oyster eggs developed normally, while only 37 to 57 percent of clam eggs survived. Davis (1960) showed that the normal development of clam (Venus mercenaria) eggs decreased as concentrations of clay, chalk, and Fuller's earth increased up to 4000 mg/L. The same was true for silt concentrations exceeding 750 mg/L. Furthermore, no clam eggs developed normally in silt concentrations of 3000 or 4000 mg/L. In a subsequent paper, Davis and Hidu (1969), report that 188 mg/L silt, 3000 mg/L kaolin, or 4000 mg/L Fuller's earth significantly reduced the normal development of American oyster eggs. Oyster eggs were not, however, affected by 4000 mg/L silicon dioxide, regardless of the particle size. These findings suggest that the composition, as well as the concentration of different sediments may be critical to the normal development of bivalve eggs.

Auld and Schubel (1978) note that suspended sediment concentrations up to 1000 mg/L did not significantly affect the hatching success of a variety of non-salmonid anadromous and estuarine fish. The same concentrations did, however, reduce the hatching success of white perch and striped bass. Kiorboe et al. (1981) report that herring eggs are unaffected by suspended silt. They note that the embryonic development of herring is unaffected by either short-term exposure to 500 mg/L, or long-term exposure to 5 to 300 mg/L suspended silt.

With respect to larval survival and development, experimental results indicate that suspended sediment concentrations of 500 mg/L significantly reduced the survival of striped bass and white perch larvae, whereas short-term exposure to 100 mg/L reduced the survival of American shad larvae (Auld and Schubel 1978). As in the case of clam and oyster eggs, Loosanoff and Davis (1963) found silt to be more harmful to oyster larvae than to clam larvae. At a concentration of 750 mg/L silt, oyster larvae growth was markedly decreased, while clam larvae grew normally in 1000 mg/L silt. Moreover, clam larvae survived for 12 days in 3000 to 4000 mg/L silt. In contrast to silt, 1000 mg/L kaolin caused total mortality in clam larvae in 12 days, while the growth of oyster larvae was not affected by 1000 mg/L kaolin. Silicon dioxide particles ranging from 5 to 50 microns had little effect on the survival of either clam or American oyster larvae. The smallest particles (<5 microns) had the greatest effect on the larvae of both species. Growth of American oyster larvae decreased progressively as the size of silicon dioxide particles decreased (Davis and Hidu 1969). From these studies, it was concluded that bivalve larvae grew faster in low concentrations of suspended solids than in clear sea water (Davis and Hidu 1969).

With respect to adult survival, McFarland and Peddicord (1980) observed a wide range of sensitivities to suspended kaolin among the 16 marine species they studied. Eight species exhibited less than 10 percent mortality after exposure to 100 g/L suspended sediment. Several other species were found to be more sensitive. The 200-hr LC50 for the mussel _M. californianus_ was 96 g/L. Two species of tunicates were relatively tolerant of suspended solids with a 12-day LC50 of 100 g/L. The 200-hr LC50 for the spot-tailed sand shrimp was 50 g/L. The 400-hr LC50 for the same species was 40 g/L indicating a high tolerance to suspended clay. The euryhaline grass shrimp was even less sensitive to suspended kaolin. The Dungeness crab, _Cancer magister_, was found to be more sensitive than any of the shrimp species, with a 200-hr LC50 of 32 g/L. The amphipod, _Anisogammarus confervicolus_, demonstrated an intermediate sensitivity to suspended sediment with a 100-hr LC50 of 78 g/L. The kaolin concentration which caused 50 percent mortality in the polychaete _Neanthes succinea_ was 48 g/L in 200 hours. The English sole, _Parophrys vetulus_, experienced no mortalities in 10 days at a concentration of 70 g/L or less. However, 80 percent mortality occurred after 10 days at 117 g/L. The shiner perch, _C. aggregata_, was the most sensitive species tested with only one fish alive after 26 hours in 14 g/L suspended kaolin (McFarland and Peddicord 1980). In a similar publication, Peddicord (1980) states that marine and estuarine invertebrates were able to tolerate continuous exposure to suspensions of kaolin and bentonite in the grams/liter range for several days to several weeks without substantial mortality. Fish tolerated similar concentrations for similar periods under similar conditions. Even at high temperatures and low dissolved oxygen concentrations, most invertebrates tolerated continuous exposure to 60 g/L suspended bentonite for several days before mortality occurred. An exception is noted for juvenile Dungeness crabs which were affected to a greater degree by kaolin suspensions than other species. Moore (1977) notes an experiment in which shrimp (Crangon sp.) survived immersion for 14 days in a clay suspension of 3000 mg/L. In another experiment, Crangon crangon survived red mud suspensions up to 33 g/L for 72 hours, but were heavily coated on the gills. Experiments using seed scallops showed elevated respiration rates at kaolin concentrations of 250 to 1000 mg/L. Adult bivalves (Argopecten irradians) also showed higher respiration rates at 500 and 1000 mg/L kaolin. The bivalve Mya arenaria survived for only 11 days at 1220 mg/L suspended mud and 15 days at 1520 mg/L chalk (Moore 1977). In their literature review, Stern and Stickle (1978) report that suspended sediment concentrations from 4 to 32 g/L can be detrimental to oysters. Furthermore, they note that scallop and quahog (clam) reproduction may be impaired by high concentrations of suspended solids.

Peddicord et al. (1975) note several investigations in which deposited sediments increased the mortality rate of bottom dwelling marine invertebrates. Oysters (Crassostrea virginica) suffered 57 percent mortality where they were covered with 2 to 15 cm of sediment near a dredge spoil site. This compared to 17 percent mortality in the same oyster bed where little sedimentation had occurred. Cumaceans and harpacticoid copepods were killed by deposition of 15 cm of sediment. The same amount of deposition reduced the number of large bivalves by 50 percent. In experiments conducted by Peddicord et al. (1975), the mortality of mussels (M. edulis) was 10 percent under 4 cm and 60 percent under 6 and 8 cm of sediment deposited on the mussels.

Static bioassays conducted by Sherk et al. (1975) established the lethal concentration of Fuller's earth on a variety of non-salmonid estuarine fish. Species were classified as tolerant (>10 g/L), sensitive (1.0 to 10 g/L), or highly sensitive (<1.0 g/L), based on a 24-hour LC10. Lethal concentrations ranged from 0.58 to 24.5 g/L, depending on the species. Exposure to sublethal concentrations of Fuller's earth significantly increased the hematocrit value, hemoglobin concentration, and erythrocyte numbers among the species tested.

With respect to feeding and growth, Johnston and Wildish (1980) conducted an investigation to determine if increased levels of suspended sediment reduced the feeding rate of larval herring. Larvae fed in water containing 4 and 8 mg/L consumed the same quantity of zooplankters as those fed in clear water. However, larvae fed at 20 mg/L consumed significantly fewer zooplankters than did the controls. They concluded that decreased light intensity at the lower sediment concentrations (4 and 8 mg/L), is not sufficient to depress larval feeding rates. At greater suspended sediment concentrations (20 mg/L), light intensity and visibility of prey are reduced sufficiently to cause depressed feeding rates. Brehmer (1965) reports that the feeding activity of certain filter-feeding shellfish is inhibited by high suspended solids levels. An example is noted by Moore (1977) in which the filtration rate of a mollusk (Crepidula sp.) was significantly reduced as turbidity increased from 140 to 200 mg/L. Likewise, Johnson (1971) found that the filtration rates of C. fornicata decreased as natural suspended solids levels increased from 2 to 250 mg/L. He also found that the filtration rate decreased significantly as the concentration of silt, Fuller's earth, and kaolin was increased up to 6 g/L under experimental conditions. It is interesting to note the difference between natural and experimental sediment concentrations which produced the same reported effect. The presence of 0 to 500 mg/L suspended kaolin reduced the filtering rate of the scallop Placopecten magellanicus and the mahogany quahog Arctica islandica (Peddicord et al. 1975).

In the lower sediment concentration range, Kiorboe et al. (1980) indicate that the blue mussel Mytilus edulis is well adapted to feeding in silt suspensions up to 55 mg/L, and even benefits from concentrations up to 25 mg/L. Furthermore, Stern and Stickle (1978) cite a report in which the pumping rate of M. edulis was not reduced by bentonite suspensions of 1000 mg/L. In an experiment conducted by Loosanoff and Tommers (1948), as little as 100 mg/L silt significantly reduced the water pumping rate and shell movements of adult oysters. At concentrations of 3000 to 4000 mg/L the pumping rate was reduced by 94 percent. In another experiment, oysters failed to resume normal pumping rates or shell movements after being subjected to water containing 1000 to 4000 mg/L suspended sediment for 48 hours (Loosanoff 1961). It as apparent that suspended sediments adversely affect adult oysters by damaging their gills and palps. Furthermore, it was apparent that oysters and clams feed most effectively in relatively clean water. In contrast, Stern and Stickle (1978) cite a report which states that oyster feeding rates were not impaired by 100 to 700 ppm of suspended mud.

The ingestion rate of two calanoid copepods was significantly reduced during exposure to a 250 mg/L mixture of Fuller's earth, fine silicon dioxide, and river silt (Sherk et al. 1975; 1976). At a concentration of 500 mg/L river silt, the ingestion rate was reduced by 77.5 percent (Sherk et al. 1976).

The distribution of marine organisms may be affected by turbid conditions. Resulting from an investigation of the filtration and shell growth rate of the filter feeding gastropod

C. fornicata, Johnson (1971) suggests that sustained high turbidity levels may have a limiting effect on its distribution. Moore (1977) notes that an inshore cephalopod, Lolliguncula brevis, preferred intermediate turbidities (70 to 90 percent light transmission) and was limited seaward by higher turbidities.

Several anadromous salmonid investigations performed in fresh water are cited in the marine literature. The results of such studies apply to both fresh water and marine systems and are presented above in Tables 4-1 through 4-4. The quantitative effects of suspended solids and turbidity on marine plankton and macroinvertebrates are summarized in Tables 4-5 and 4-6.

The above discussion demonstrates that particulates may have detrimental effects on marine biota. These effects are summarized below.

(1) The biological effects of particulates on marine biota are similar to the effects on freshwater aquatic biota. Particulates in the water column reduce the amount of light available for photosynthesis, can inhibit movements of fish, and may inhibit the ability of fish and other sight-feeders to see their prey. Filter feeders, which are particularly susceptible to the mechanical or abrasive action of suspended sediments, and early-life stages of estuarine fish are more sensitive to suspended sediments than bottom dwelling organisms and adult fish.

(2) Much of the marine literature refers to the effects caused by clay, silt, chalk, Fuller's earth, and kaolin. It appears that the composition and/or particle size, as well as the concentration of different sediments may be critical to predicting the effects of particles on marine organisms.

(3) The difference between natural and experimental sediment concentrations producing the same reported effect should

TABLE 4-5

SURVIVAL AND MORTALITY OF MARINE ORGANISMS

Organism	Nature and Extent of Effect	Level or Conc.	Duration	Comments	Reference
Alewife, Yellow Perch, American Shad, Blueback Herring	Hatching success unaffected	1000 mg/L	—	Suspended solids	Auld and Schubel 1978
White Perch, Striped Bass	Hatching success affected	1000 mg/L	—	Suspended solids	Auld and Schubel 1978
Yellow Perch, Striped Bass	Reduced survival of larvae	>500 mg/L	—	Suspended solids	Auld and Schubel 1978
American Shad	Reduced survival of larvae	>100 mg/L	4 days	Suspended solids	Auld and Schubel 1978
Five Species	10% mortality	580 to 24,500 mg/L	24 hours	Suspended solids	Sherk et al. 1975
Herring Eggs	Survival reduced to 40-50%	1 to 10 ml/L	—	Suspended red mud	Rosenthal 1971
and Larvae	Survival reduced to 0-22%	1.25 to 12.5 ml/L	—	Suspended red mud	Rosenthal 1971
8 Species of Estuarine Macrofauna	10% mortality	100,000 mg/L	5-12 days	Suspended kaolin	McFarland and Peddicord 1980
Shiner Perch	Near 100% mortality	14,000 mg/L	26 hours	Suspended kaolin	McFarland and Peddicord 1980
English Sole	No mortality	>70,000 mg/L	10 days	Suspended kaolin	McFarland and Peddicord 1980
	80% mortality	117,000 mg/L	10 days	Suspended kaolin	McFarland and Peddicord 1980
Adult Bivalve (*M. arenaria*)	Mortality increased from 0 to 100%	Increased from 440 to 1520 mg/L	15 days	Suspended chalk	Moore 1977
Blue mussel	10% mortality	100,000 mg/L	11 days	Suspended kaolin	Peddicord et al. 1975
Coast mussel	50% mortality	96,000 mg/L	200 hours	Suspended clay	McFarland and Peddicord 1980
Polychaete	50% mortality	48,000 mg/L	200 hours	Suspended kaolin	McFarland and Peddicord 1980
Clam larvae	<90% mortality	250-500 mg/L	—	Mixed suspension	Davis 1960
	No appreciable mortality	4000 mg/L	—	Silt	Davis 1960
Clam & oyster larvae	Severe mortality	500 mg/L	—	Silicon dioxide	Davis and Hidu 1969
Sea Urchin	No mortality	100,000 mg/L	9 days	—	Peddicord et al. 1975
Oysters	57% mortality	2 to 15 cm	—	Deposited sediment	Peddicord et al. 1975
Cumaceans & copepods	Mortality	15 cm	—	Deposited sediment	Peddicord et al. 1975
Bivalves	Mortality	15 cm	—	Deposited sediment	Peddicord et al. 1975
Mussel	10% mortality	4 cm	—	Deposited sediment	Peddicord et al. 1975
(*M. edulis*)	60% mortality	6 and 8 cm	—	Deposited sediment	Peddicord et al. 1975

TABLE 4-5 Continued

SURVIVAL AND MORTALITY OF MARINE ORGANISMS

Organism	Nature and Extent of Effect	Level or Conc.	Duration	Comment	Reference
Tunicates (2)	50% mortality	100,000 mg/L	12 days	Suspended clay	McFarland and Peddicord 1980
Amphipod	50% mortality	55,000 mg/L	200 hours	Suspended kaolin	Peddicord et al. 1975
	50% mortality	78,000 mg/L	100 hours	Suspended clay	McFarland and Peddicord 1980
	20% mortality	35,000 mg/L	200 hours	Suspended kaolin	Peddicord et al. 1975
Eurynaline Grass Shrimp	20% mortality	77,000 mg/L	200 hours	Suspended kaolin	Peddicord et al. 1975
Spot-tailed Sand Shrimp	50% mortality	50,000 mg/L	200 hours	Suspended clay	McFarland and Peddicord 1980
Shrimp	Survived clay concentrations	3000 mg/L	14 days	Suspended clay	Moore 1977
(*Crangon* sp.)	Survived red mud	Up to 33,000 mg/L	72 hours	Suspended clay	Moore 1977
Lobster	No mortality	50,000 mg/L	—	Suspended kaolin	Stern and Stickle 1978
	No mortality	1600 ppm	—	Turbidity	Stern and Stickle 1978
Dungeness Crab	50% mortality	32,000 mg/L	200 hours	Suspended clay	McFarland and Peddicord 1980
Estuarine Invertebrates	No substantial mortality	Up to 60,000 mg/L	Several days	Suspended kaolin and bentonite	Peddicord 1980

TABLE 4-6

MISCELLANEOUS EFFECTS ON MARINE ORGANISMS

Organism	Nature and Extent of Effect	Level or Conc.	Duration	Comments	Reference
American Oyster	>22% decrease in normal egg development	188-4000 mg/L	---	Suspended silt	Davis and Hidu 1969
	Normal egg development	To 1000-2000 mg/L	---	Mixed suspensions	Davis and Hidu 1969
	Reduced average pumping rate by 57%	100 mg/L	---	Silt	Loosanoff and Tommers 1948
	Reduced average pumping rate by 94%	3000-4000 mg/L	---	Silt	Loosanoff and Tommers 1948
	Failed to resume normal functions	1000-4000 mg/L	48 hours	Silt suspensions	Loosanoff 1961
Oysters	No effect on feeding	100-700 ppm	---	Suspended solids	Stern and Stickle 1978
Seed Scallops	Elevated respiration rate	250-1000 mg/L	---	Kaolin suspensions	Moore 1977
Clams	No eggs developed normally	3000-4000 mg/L	---	Silt suspensions	Davis 1960
	Decreased development	Up to 4000 mg/L	---	Mixed suspensions	Davis 1960
	Ceased feeding	1000 JTU average	5 days	Turbidity	Stern and Stickle 1978
Quahog	Reduced filtration rate	0 to 500 mg/L	---	Suspended kaolin	Peddicord et al. 1975
Mollusk (*Crepidula* sp.)	Filtration rate significantly reduced	Increased from 140-200 mg/L	---	Suspended solids	Moore 1977
Mussel	Well adapted to silt conc.	Up to 55 mg/L	---	Silt	Kiorboe et al. 1980
(*Mytilus* sp.)	Benefits from silt conc.	Up to 25 mg/L	---	Silt	Kiorboe et al. 1980
	Increased respiration rates	500-1000 mg/L	7-14 days	Kaolin suspensions	Moore 1977
	No reduction in pumping rates	1000 mg/L	---	Bentonite Suspensions	Stern and Stickle 1978
Phytoplankton	Production reduced to 40%	0.440 mg/L	Temporary	Mining plume	Ozturgut et al. 1981
	Carbon assimilation decreased by 50-90%	1000 mg/L	---	Silicon dioxide suspension	Sherk et al. 1976
	Carbon assimilation decreased by 80%	2500 mg/L	---	Silicon dioxide suspension	Sherk et al. 1976
Primary Production	Reduced by 50%	41-43 JTU average	---	Turbidity	Stern and Stickle 1978
Zooplankton	No significant decrease in abundance	1 mg/L	Temporary	Mining plume	Ozturgut et al. 1981
Calanoid Copepods	Ingestion rate reduced 77%	500 mg/L	---	Suspended silt	Sherk et al. 1976
	Ingestion rate reduced signficantly	250 mg/L	---	Mixed suspension	Sherk et al. 1975; 1976
Cephalopod	Preferred intermediate turbidities	70-90% light transmission	---	---	Moore 1977
Gastropod	Decreased filtration rate	Increased from 2 to 250 mg/L	---	Natural sediment	Johnson 1971
	Decreased shell growth rate	Increased from 80 to 1560 mg/L	---	Mixed suspension	Johnson 1971
	Filtration rate decreased	Up to 6000 mg/L	---	Mixed suspension	Johnson 1971
Herring	Embryonic development unaffected by continuous exposure	Up to 300 mg/L	Long-term	Suspended silt	Kiorboe et al. 1981
	Larval feeding significantly reduced	20 mg/L	---	Suspended solids	Johnston and Wildish 1982

be noted. Laboratory experiments often do not duplicate natural conditions or reflect natural levels of organism tolerance to turbidity and suspended material.

4.3 SUGGESTED CRITERIA FROM THE LITERATURE

Various authors suggest different criteria for the protection of water used for supply, recreation, and biota. This section presents these suggested criteria. It should be noted that there is general agreement on the criteria for water supply and recreation, but the criteria for the protection of aquatic biota are varied.

4.3.1 Water Supply

For drinking water, the raw water source should be limited to 5 turbidity units if only disinfection is applied (George and Lehnig 1984). Higher levels of particulates are acceptable if the source water is adequately treated (coagulation, sedimentation, filtration) prior to chlorination or other means of disinfection. EPA (1976) notes that finished drinking water should have a maximum limit of 1 turbidity unit where the water enters the distribution system.

The water quality criteria for particulates varies among industrial uses. At one extreme, rayon manufacture requires water with only 0.3 turbidity units, whereas water used for cooling can have up to 50 turbidity units (McGauhey 1968). Other industrial uses require maximum turbidity levels within this range.

Criteria established for evaluating and identifying water treatment needs for fish hatcheries by Sigma Resource Consultants (1979) include limits on suspended solids. The suggested limit for suspended solids for incubating eggs is 3 mg/L and for rearing and holding the limit is 25 mg/L in the absence of other pollutants.

4.3.2 Recreation

The noticeable threshold for water contact recreation is 10 turbidity units, and the limiting threshold is 50 units (McGauhey 1968). The suggested maximum turbidity limit for Canadian contact recreational water quality is 50 turbidity units and the minimum Secchi disk visibility depth is 1.2 meters (National Health and Welfare 1983). Fishing success is reduced where turbidity is greater than 25 (Phillips 1971) to 30 NTU (Grundy 1976). According to McGauhey (1968), the noticeable threshold for boating and aesthetic uses is 20 turbidity units. However, there is no evidence that boating and aesthetic uses are precluded at higher turbidities.

4.3.3 Biota

Sugested particulates criteria from the literature are divided into two categories in the following discussion: (1) Criteria for sediment in the water column (suspended solids and turbidity); and, (2) Criteria for sediment deposited on the substrate (settleable solids and substrate measurements).

<u>Criteria for Sediment in the Water Column</u>

General suspended sediment criteria were initially proposed by Ellis (1937; 1944) with respect to light penetration and aquatic life. For the restoration of streams, Ellis (1937) suggested the silt load should not reduce the light intensity at 5 meters by more than one millionth of its intensity at the surface. Ellis (1944) restated this criterion for the prevention of direct damage to the gills and delicate exposed structures of fish, mollusks, and insects. For the protection of fish, Berger (1977) suggests that turbidity shall not average more than 27 times the natural level during any 8-hour period, or more than 9 times the natural level during any 96-hour period, or more than 3 times the natural level during any 30-day period. These suspended sediment standards shall apply during construction activities and for 2 years after they have ceased. Berger's criteria for turbidity and macroinvertebrates during the post-construction period were stated as follows. In the year that starts 12 months after completion of a construction activity, turbidity should not exceed one-half of the levels recommended above and the Shannon Diversity Index for bottom-living aquatic macroinvertebrates shall not be changed more than 25 percent from the natural value as a result of finely-divided solids.

The first definite suspended solids criteria for fresh water were proposed by the European Inland Fisheries Advisory Commission (EIFAC) in 1965. According to the commission, there is no evidence that suspended solids levels less than 25 ppm have any harmful effects on fish; suspended solids in the range of 25 to 80 ppm will maintain good to moderate fisheries; 80 to 400 ppm suspended solids are unlikely to support good freshwater fisheries; and, at best only poor fisheries are present in waters containing greater than 400 ppm suspended solids. These tentative criteria proposed by EIFAC were based on a survey of existing literature, and were presented as a basis for discussions of criteria necessary for the maintenance of freshwater fish. They are by far the most frequently cited criteria. Not all authors, however, indicate if they simply concur with the criteria suggested by EIFAC or are suggesting identical criteria based on conclusions derived independently. Those who suggest or state criteria similar to EIFAC include Gammon (1970), Alabaster (1972), Bell (1973), NAS (1973), Sorensen et al. (1977), Alabaster and Lloyd (1982), Wilber (1983), and George and Lehnig (1984). In addition, Van Nieuwenhuyse (1983) and Simmons (1984) suggest turbidity criteria levels (NTU) similar to the EIFAC criteria for suspended solids (ppm).

In their review of the EPA Red Book, Thurston et al. (1979) support a limit of 100 mg/L of suspended solids to prevent the mortality of fresh and marine organisms. However, one of the reviewers felt that 100 mg/L is too restrictive and that concentrations could be much higher without causing adverse effects. These values are higher than those suggested by EIFAC (1965) to maintain a good fishery, but do not account for the sublethal effects discussed by several authors and presented in this literature review. Thurston et al. (1979) state that no universal agreement exists as to the level of turbidity to be allowed. Herbert and Richards (1963) note that there is a fairly distinct separation at 100 mg/L, between rivers containing fish and those devoid of fish, thus supporting the recommendation of Thurston et al. (1979) regarding lethal concentrations.

The most conservative recommended turbidity standard is 25 NTU above natural conditions in streams and 5 NTU above natural conditions in lakes for moderate protection, and 5 NTU in both lakes and streams for a high level of protection (Lloyd 1985). With regard to incubating eggs, Sigma Resource Consultants (1979) propose an acceptable limit of 3 mg/L suspended solids and 25 mg/L would be acceptable for fish rearing and holding in the absence of other pollutants.

DFO (1983) has proposed sediment discharge standards, as opposed to receiving water standards, for five different classes of streams. For streams which are important as salmon and trout spawning habitat (A classifications), the recommended sediment standard is 0 mg/L. Streams which are rearing areas for salmon and trout (B classifications) and those which provide habitat for grayling, whitefish, and burbot (C classifications) would have a discharge limit of 100 mg/L. In streams having low or no use by any of the above fish except as migration routes, the recommended standard is 100 or 1000 mg/L. The same is true for all streams having a reduced biological capacity due to past placer mining activities (X classification).

Sherk et al. (1975) state that the use of lethal concentrations (LC50) to establish suspended solids criteria ignores biologically significant sublethal effects on estuarine organisms. Therefore, in establishing criteria for the protection of estuarine organisms, the sublethal effects of suspended sediment on the most sensitive biological components (important species and life stages) must be considered. Adequate knowledge of local conditions, such as life-history stages, sediment types, sediment concentrations, species, duration of exposure, and habitat preference, is required.

Criteria for Sediment Deposited on the Substrate

Tarzwell (1957) states that it is not possible to establish numerical criteria for settleable solids which are applicable over wide areas. The criteria should be established to protect environmental conditions but will vary from stream to stream, depending on local concditions. With regard to deposited sediment, EIFAC (1965) concluded that spawning grounds for salmon and trout should be kept as free as possible from finely divided solids. Bjornn et al. (1974) suggested that the amount of sediments that should be allowed to enter a stream before detrimental effects will occur on the aquatic habitat will depend on the amount of fines already contained within the stream channel. The amount that can enter the stream is the difference between the present level and the allowable, plus the amount transported. Bjornn et al. (1977) state that fine sediment should not be allowed to fill pools or fully embed the larger substrate rocks, to avoid reducing the salmonid production capacity. They advocate using the percentage of fine sediment in selected riffle areas as the primary index for monitoring fine sediment deposition in streams. Along these same lines, Iwamoto et al. (1978) indicate that the best alternative appears to be the establishment of criteria which limits the percentage of fines in the streambed, and suggest a limit of 10 to 20 percent for sediment less than 0.85 mm in diameter. In an earlier report, Ellis (1944) thought that fine sediment should be controlled to the extent that it does not blanket the bottom to a depth of more than one-quarter of an inch.

Van Nieuwenhuyse (1983) and Simmons (1984) propose a settleable solids standard of <0.1 ml/L for a high level of protection in receiving waters. Simmons (1984) goes a step further and suggests settleable solids levels of 0.1 to 0.2 ml/L for a moderate level, and >0.2 ml/L for a low level of protection.

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5.0 POTENTIAL USE OF OTHER PARAMETERS

This section presents a discussion of potential alternatives to the parameters currently used by Alaska for defining particulates criteria for the various protected water uses. Parameters currently employed include turbidity, total suspended solids, settleable solids, and the percentage accumulation of fine particles in the substrate. This discussion is divided into water column measurements and substrate measurements. The settleable solids test, although a water column measurement, is discussed with substrate measurements because settleable solids frequently become part of the substrate. A discussion of the relationship between turbidity and suspended solids appears before the discussion of water column and substrate measurements.

5.1 RELATIONSHIP BETWEEN TURBIDITY AND SUSPENDED SOLIDS

The accepted technique for measuring suspended solids (APHA 1985) is time consuming, costly, and normally performed in a laboratory. Due to these constraints, many field investigators have used turbidity as an indirect measurement of the concentration of suspended solids. In order to adequately assess the potential for a relationship, if one exists, one must understand the principles of turbidity and suspended solids measurement, be familiar with the various methods of measurement and analysis, and be aware of the potential variability inherent in each of these methods.

In simple terms, turbidity may be interpreted as a measure of the relative clarity of water (Hach et al. 1984). However, turbidity is not as precisely defined as dissolved oxygen, pH, alkalinity or many other water quality parameters. It must be recognized that turbidity, like color, is a visual or optical property. Consequently, the word means different things to different people. Pickering (1976) notes that turbidity should be treated as a non-quantitative term similar to the term "warmth," in the respect that one measures temperature and not warmth.

With respect to measuring particulates, turbidity has received the most attention. Some water quality experts believe that the turbidity measurement is subject to great uncertainty and variability as a unit of measurement. This belief primarily originates from a number of studies related to placer mining where exceedingly high levels of turbidity have been measured. Turbidity measurements are less precise at high levels.

Attempts to quantify turbidity have led to the development of several methods, instruments, standards, and units of measure. Consequently, there is a great deal of confusion over which methods, instruments, standards, and units of measure are the most appropriate. McCluney (1975) has summarized the various definitions of turbidity. These include the intensity of light transmitted (unscattered) through the sample, ratio of the intensity of light scattered by a sample to the intensity of the light source, the amount of light scattered and absorbed rather than transmitted in straight lines through the sample, and a reduction in transparency of a sample due to the presence of particulate matter. Turbidity has also been defined as the amount of suspended matter, in ppm, as ascertained by optical observation, and in terms of different measurement techniques (e.g., Jackson Candle and nephelometric turbidity). The units of measure for turbidity have included mg/L, ppm, Jackson turbidity units (JTU), formazin turbidity units (FTU), and nephelometric turbidity units (NTU). Because of the variety of different methods, instruments, standards, and units of measure, many of the supposed equivalent measurements presented in the literature are actually expressions of different properties of natural water (McCarthy et al. 1974). Today, however, most investigators use nephelometers and report results in NTU rather than the older units. Hence, recent data are more comparable.

Comparability of turbidity measurements may not only be affected by the numerous ways of measuring it, but may also be influenced by the variability among instruments (Beschta 1980). Even among nephelometers, there is a variety of different physical designs. This situation makes it difficult to compare turbidity levels. Even using the same standard suspension for calibrating different instruments does not insure that turbidity values will be the same. Pickering (1976) reports that different types of instruments were calibrated with the same formazin standard and then used to measure various natural water samples. This resulted in a variety of turbidity values for the same sample.

The only means for reducing the confusion surrounding turbidity measurements is to standardize the definition of turbidity and the instrument design specifications. This has been accomplished according to Standard Methods (APHA 1985) and the EPA (1983) methods manual. Standard Methods is jointly published by the American Water Works Association, a drinking water group, the Water Pollution Control Federation, a waste and sewage group, and the American Public Health Association, a public health group. The EPA methods manual is used by many among these groups as well as scientists interested in streams, lakes, wetlands, estuaries, and coastal areas. Hence, much of the confusion could, and should, be avoided by adhering to the definition of turbidity and instrument design specified by APHA (1985).

APHA (1985) defines turbidity as an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the samples. Turbidity in water is caused by suspended matter, such as clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, and plankton and other microscopic organisms.

According to APHA (1985), the standard instrument for measuring low turbidities is the nephelometer, for which a formazin polymer is used as the standard reference suspension. The light source is a tungsten-filament lamp operated at a color temperature between 2,200 and 3,000 K, where the angle of light acceptance by the detector is 90 degrees plus or minus 30 degrees. The distance traversed by incident light and scattered light within the sample tube is not to exceed 10 cm. Turbidity measurements less than 40 NTU can be read directly from the instrument. Turbidities above 40 NTU need to be diluted with turbidity-free water until turbidity falls between 30 and 40 NTU.

The precision and accuracy of nephelometric turbidity measurements are highest at lower levels, the levels at which criteria are currently set. This statement is supported by the proper reporting of significant figures according to APHA (1985), which is:

Turbidity Range NTU	Report to the Nearest NTU
0-1.0	0.05
1-10	0.1
10-40	1
40-100	5
100-400	10
400-1000	50
>1000	100

There are fewer direct methods for measuring total suspended solids than there are for turbidity. Hence, there is less variability in suspended solids determinations. Total suspended solids represent the material retained on a standard glass-fiber filter after a well-mixed sample is filtered, then dried at 103 to 105 degrees C (APHA 1985). Some investigators have inappropriately used 0.45 micron filters. Some marine scientists have used centrifugation for concentrating suspended particulates followed by drying and weighing. However, this method is imprecise for dilute waters having less than 10 mg/L suspended solids (Campbell and Elliott 1975).

A major source of variability in both turbidity and total suspended solids measurements is obtaining a sample that is representative of the water being sampled. It is difficult to collect representative samples for suspended solids and turbidity. Many investigators simply collect grab samples, which may or may not be representative of the stream water being sampled. This depends on the amount of variability in the sampled stream. In determining the suitability of the water for various uses, it is essential that a sample represent the total or average discharge, as opposed to an isolated cell of water. Hence, some investigators obtain composite samples over time by manually collecting grab samples across a cross-section or by the use of automatic samplers. Automatic samplers, however, are usually set to sample only one location at a cross-section and may not collect all particle sizes. Composite samples can be time-weighted by combining equal volumes of individual samples at a specified time interval, or discharge-weighted where the volume of each individual sample is proportional to the stream discharge. Each type of composite can result in different reported particulates levels.

The difficulty in obtaining representative and reliable particulates data from automatic samplers has been documented for municipal wastewater treatment plants. Reed (1977) reported the results of Harris and Keffer who note that the suspended solids data for a raw municipal wastewater treatment stream, monitored concurrently with more than one commercial automatic sampler, can vary by as much as 300 percent depending on the type of automatic sampler used.

The most reliable suspended solids data are those collected using depth-integrated samplers. These samplers are lowered at a uniform rate with water being admitted throughout the vertical profile. The number of verticals collected across a stream depends on the accuracy being sought and on the the variation of sediment concentrations across the stream. Variability typically increases as the concentration of sediment increases.

Another source of variability in turbidity and suspended solids analyses occurs in the analytical process. Subsampling a relatively small sample for analysis is difficult when the particulates concentration is moderate to high, and when the particle size is equivalent to small sand or larger. This situation arises when relatively large samples (typically 250 ml to 1 liter) are collected in the field but the volume required for turbidity and total suspended solids analyses is small. Turbidity requires about 25 ml and suspended solids requires a few to 100 ml or more depending on the concentration of particulates. Consequently, the analyst must thoroughly mix the sample and then obtain a representative subsample by decanting, pipetting, or other appropriate means. This process is exceedingly difficult and is a source of significant variability among samples containing high particulates concentrations and/or samples containing sand-sized particles. Sand settles too fast to enable an analyst to obtain a representative subsample.

Assessment of the relationship between turbidity and total suspended solids must consider the sources of variability discussed above: (1) Variability in the turbidity analysis; (2) variability in the suspended solids analysis; (3) sample variability; and (4) subsample variability. These sources produce variability in the relationship between turbidity and suspended solids. Many authors (Black and Hannah 1965; Duckrow and Everhart 1971; Peterson 1973; McGirr 1974; Carlson 1976; Pickering 1976; Stern and Stickle 1978; Langer 1980; McCart et al. 1980; LaPerriere 1983; Wilber 1983; George and Lehnig 1984; Hach et al. 1984) recognize that turbidity is not necessarily a good quantitative indicator of the concentration of suspended solids because of the inconsistent correlation between these parameters. Table 5-1 and Figure 5-1 present numerous correlations, both linear and logarithmic, between turbidity and suspended solids concentrations reported by many authors. This information clearly demonstrates that there is no single equation relating these two parameters. Furthermore, most of the authors listed in Table 5-1 failed to consider percentage error. Kunkle and Comer (1971) reported a percentage error for their correlation ranging from -69 to +333 percent. Allen (1979) studied a turbidimeter to determine its accuracy in predicting suspended sediment concentrations. His results showed maximum errors of -184 percent at one gaging station, +261 percent at another, and average prediction errors of 31 and 25 percent. Allen attributed the poor correlation to changes in the particle-size distribution of the sediment.

Turbidity, an optical property, must be recognized as being entirely different from a weight concentration of suspended matter. This occurs because the size, shape, and refractive index of suspended particles which influence turbidity measurements are not directly related to the concentration and specific gravity of the suspended matter. Particle size and particle size distribution are two key factors required in comparing suspended solids measurements to the actual turbidity present in a sample (Booth 1974). McCarthy et al. (1974) found that the same FTU reading could be obtained from a given concentration of kaolinite and twice that concentration of calcium montmorillonite. They concluded that because twice as much material is in suspension, the resulting siltation problem would be significantly greater for a calcium montmorillonite discharge than for a kaolinite discharge.

The majority of turbidity is due to the scattering of light by particles having diameters less than about 10 microns (King et al. 1978). Although turbidity is often unsuitable for determining suspended solids concentrations, findings indicate

TABLE 5-1

CORRELATIONS BETWEEN TURBIDITY AND SUSPENDED SOLIDS CONCENTRATIONS

Logarithmic Correlations	R^2	Reference	Note
$TBD = 3.20\ (TSS)^{0.84}$	0.77	Weagle 1984	1
$TBD = 6.00\ (TSS)^{0.631}$	0.80	R&M 1985	2
$TBD = 1.78\ (TSS)^{0.863}$	0.87	R&M 1985	3
$TBD = 0.44\ (TSS)^{0.858}$	0.83	Lloyd 1985	4
$TBD = 0.185\ (TSS)^{0.998}$	0.92	Lloyd 1985	5
$TBD = 1.103\ (TSS)^{0.968}$	0.92	Lloyd 1985	6
$TBD = 13.49\ (TSS)^{0.68}$	0.89	R&M 1982	7
$TSS = 5.32\ (TBD)^{1.32}$	0.82	Kunkle and Comer 1971	8
$TSS = 3.92\ (TBD)^{1.41}$	0.89	Kunkle and Comer 1971	9
$TSS = 2\ (TBD)^{1.25}$	----	King et al. 1978	10a
$TSS = 4.2\ (TBD)^{1.09}$	----	King et al. 1978	10b
$TSS = 2.34\ (TBD)^{1.0}$	0.88	King et al. 1978	10c
$TSS = 0.63\ (TBD)^{1.19}$	0.95	King et al. 1978	10d
$TSS = 21.1\ (TBD)^{0.7}$	----	King et al. 1978	10e
Linear Correlations			
$TBD = 15.65 + 0.861(TSS)$	0.49	R&M 1985	11
$TBD = 8.69 + 0.904(TSS)$	0.8739	Toland 1983	12
$TBD = 0.18 + 0.41\ (TSS)$	0.47	Peterson 1973	13
$TBD = 8.78 + 0.26\ (TSS)$	0.42	Peterson 1973	14

TBD: Turbidity, NTU

TSS: Total Suspended Solids, mg/L

Notes

1. Correlation applied to placer mining effluent samples.
2. Glacier Fork, tributary to Eklutna Lake, Alaska--30 to 40 percent of the basin is covered by glaciers.
3. East Fork, tributary to Eklutna Lake, Alaska--5 to 10 percent of the basin is covered by glaciers.
4. Data provided by USGS for 229 samples of Alaska streams, many of which are glacial or glacially influenced.

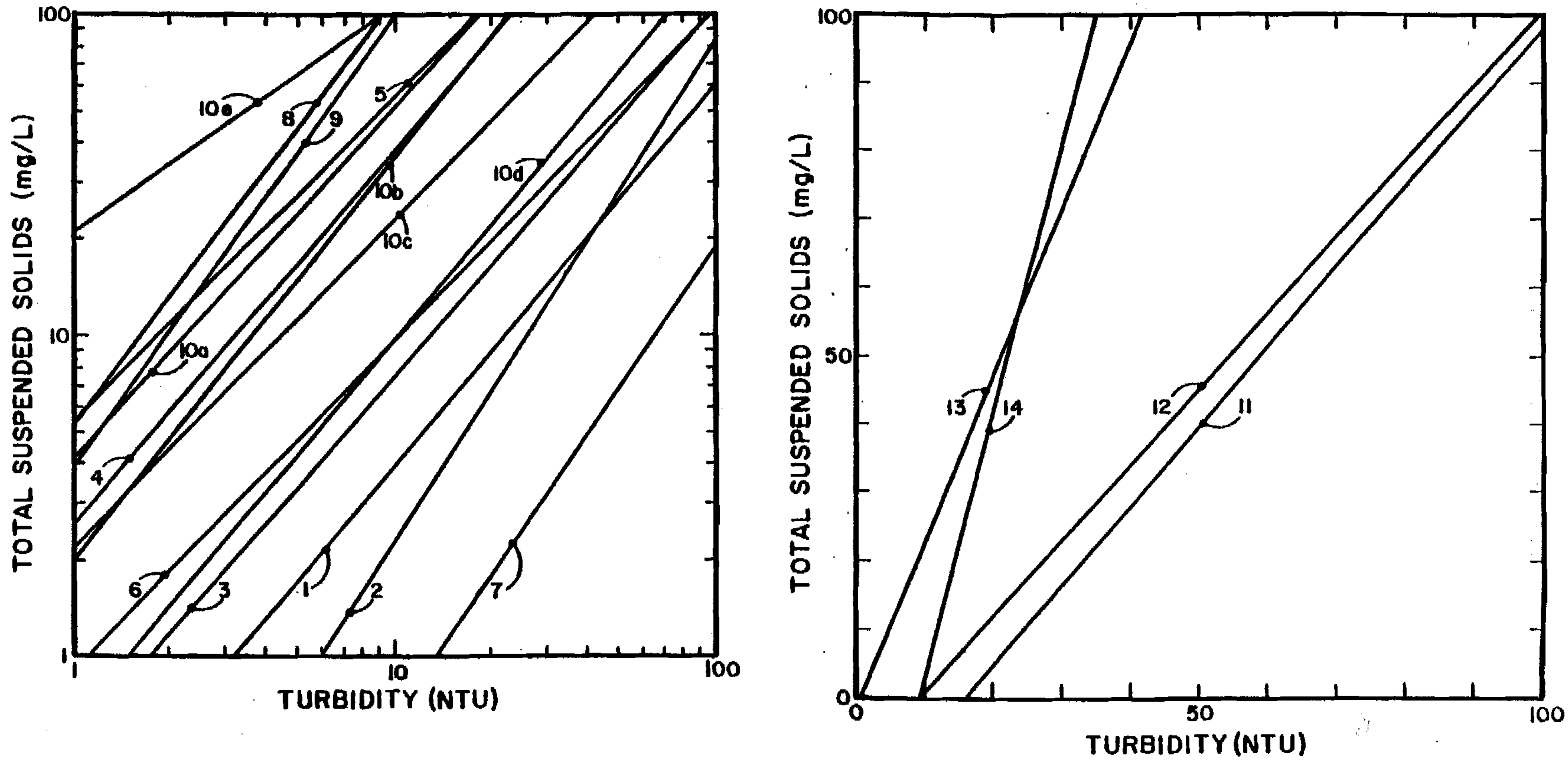
TABLE 5-1 Continued

CORRELATIONS BETWEEN TURBIDITY AND
SUSPENDED SOLIDS CONCENTRATIONS

5. Cited Peratrovich, Nottingham & Drage, Inc. data from the Susitna River, Alaska.
6. Data for 279 samples collected from unmined and placer mined streams in interior Alaska by the Alaska Department of Fish and Game and Toland (1983).
7. Data from settling column tests performed on Alaska placer mining sluice box discharges.
8. The correlation represents 2 years of data collected from an agricultural area. The percentage error ranged from -69 to +333 percent and the high percentage errors generally were associated with the low turbidities (less than 500 mg/L sediment.
9. The correlation represents the first year of data for the above equation.
10. Correlations from other authors presented by King et al. (1978) for drainage from sandy to silty, silt loam, fine silt loam, and fine silt plus clay soils in agricultural areas (10a-10e correspond to equations in Figure 5-1).
11. Five combined Eklutna Lake, Alaska sample stations.
12. Chatanika River, Alaska. The correlation appears to hold up to about 250 mg/L and NTU. Above this range, the curve flattens showing higher suspended solids values in relation to turbidity. Other variables appear to affect this correlation so that uniform application cannot be assured.
13. Correlation for data collected from the Chatanika River, Alaska in 1970 and 1971 when placer mining had no measureable affect on water quality.
14. Correlation for data collected from Goldstream Creek, Alaska in 1970 and 1971.

FIGURE 5-1

CORRELATIONS BETWEEN TURBIDITY ANS SUSPENDED SOLIDS CONCENTRATIONS



Note: See Table 5-1 for references to the various equations.

that a correlation may be useful in cases involving fine sediments (Allen 1979). Turbidimeters respond less to larger sediment sizes.

Turbidity measurements yield results that are roughly proportional to the amount of suspended material only under certain circumstances. Turbidity instrumentation relies on optical properties of particulates such as their shape, refractive index, particle size distribution, particle concentration, and the absorption spectra (McCluney 1975). Hence, turbidity is proportional to mass or volume concentration only when all other parameters are constant. However, the sediment in natural waters exhibit considerable variability in these parameters, which makes the establishment of the desired relationship difficult. This variability in natural water severely restricts the usefulness of using turbidity for routine measurement of the amount of suspended material (McCluney 1975).

Although turbidity and suspended sediment concentration are not synonymous, they are related in some instances, and turbidity can be used to help define the level of sediment concentration (Ritter and Ott 1974). Within certain size and concentration ranges, and with certain types of suspended material, it is possible to estimate sediment concentrations based on turbidity (Pickering 1976). Hence, any predictive relationships between these parameters must be developed on a drainage basin basis (Kunkle and Comer 1971; Beschta 1980; Beschta et al. 1981). Once a correlation between turbidity and suspended solids has been established for a given water body, one parameter can be used to give an estimate of the other, although each of the measurements has independent significance (McGirr 1974). Truhlar (1976) found a good correlation between daily mean discharge-weighted turbidity and daily mean discharge-weighted suspended solids concentration. This approach considers the variability in particulates concentrations with discharge.

Based on the above information, it is clear that there is no one consistent correlation between turbidity and suspended solids concentrations. However, these parameters may be correlated under certain circumstances. Consequently, using turbidity to predict suspended solids concentrations may be useful but the investigator needs to recognize all the potential variables, calculate the correlation including periodic updates, and calculate the percentage error associated with the correlation. In addition to treating the data collectively, regression analyses should include calculations of coefficients of determination and confidence limits for data in the low, medium, and high ranges.

Since the relationship between turbidity and suspended solids concentration is dependent on local geological and hydrological characteristics, any correlation between these parameters needs to consider drainage, season, and discharge. There are natural and man-made sources of particulates that improve the correlation between these parameters, such as glacial streams and placer mining. Particle sizes and shapes and particle-size distributions from these sources probably exhibit less variability than in natural clear water systems.

5.2 WATER COLUMN MEASUREMENTS

Particulate levels in water have been measured by numerous direct and indirect techniques. Direct measurements of the number or weight of particles include total suspended solids, microscopic analysis, electronmicroprobe analysis, use of a Coulter counter, X-ray methods, and radioactive absorption. The most widely accepted technique, the total suspended solids test described above in Section 5.1, involves filtering a known volume of water through a glass-fiber filter followed by drying and weighing. Centrifugation has been used to concentrate samples followed by drying and weighing, but there are disadvantages to this technique. One disadvantage occurs when fine-grained sediment has organic material associated with it. Some organic material can have a density close to that of water, making it very difficult to separate (Gibbs 1974). Another disadvantage is that centrifuging is not good for dilute water having less than about 10 mg/L suspended solids (Campbell and Elliott 1975). Radioactive absorption has been used because the absorption of radiation is proportional to the mass present and therefore directly measures the concentration of suspended sediment (Gibbs 1974). However, this method is impractical because of its expense. Microscopic analysis and the Coulter counter rely on counting the number of particles present, both of which are time consuming. Additionally, conversion of the number of particles to weight per unit volume requires assessment of particle size and specific gravity. Electronmicroprobe analysis and X-ray methods require expensive equipment and a relatively high level of expertise. Therefore, of the direct methods for measuring particulates in the water column, the gravimetric method for total suspended solids as described by APHA (1985) is the most acceptable. This is the method specified in the Alaska water quality standards (ADEC 1985).

Measurements related to light penetration may, under certain circumstances, be an indication of the concentration of particulates. These measurements include turbidity (described above in Section 5.1) and transmissivity, or its inverse, light extinction. Microspectrophotometry, Secchi disk depths, and remote sensing using color infrared photography are also indirect measurement techniques.

These optical methods rely on absorption and/or scattering. Nephelometric turbidity measures the scattering of light by suspended particles, whereas the beam transmittance meter measures the attenuation of light by scattering and absorption. The Secchi disk is a simple kind of irradiance meter which is less precise than other indirect methods. Additionally, use of the Secchi disk is inapplicable in shallow, clear to moderately turbid areas. Measures of light penetration, such as compensation point, light extinction coefficient, wave length analysis, and transmissivity have been related to primary production. Furthermore, extrapolations have been made from these measures to other effects of particulates on aquatic biota.

A chief concern in estimating suspended solids concentrations in water by remote sensing is obtaining adequate ground truth data (Shelley 1976). Two aspects that must be considered in obtaining ground truth data are timing actual sample collection with the remote sensor pass, and standardizing sampling equipment and techniques. It appears that remote sensing is less precise than nephelometric turbidity measurements.

Although no single optical measurement technique stands out as being the most accurate and precise, the nephelometric turbidity measurement as defined by APHA (1985) is the most acceptable indirect technique for measuring particulates for a number of reasons. First, the instrument specifications are well defined, leading to improved accuracy and precision. Second, turbidity is more widely accepted than many of the other indirect methods. Third, turbidity measurements have been applied to many different water uses including water supply, recreation, and the protection of aquatic biota. Fourth, turbidity levels may be highly correlated with total suspended solids concentrations under certain circumstances. Therefore, nephelometric turbidity measurements are the most applicable indirect measurement technique for particulates. The existing Alaska water quality standards (ADEC 1985) specify that turbidity measurements are to be performed in accordance with APHA (1985).

5.3 SUBSTRATE MEASUREMENTS

The measurement of settleable solids is typically a volumetric test that measures the volume of material that will settle under quiescent conditions in one hour. An Imhoff cone is filled to the 1-liter mark with a thoroughly mixed sample and allowed to settle for 45 minutes. The sample is gently stirred along the sides of the cone with a rod or by spinning, and allowed to settle 15 additional minutes (APHA 1985). The volume of settleable matter in the cone is recorded as milliliters per liter (ml/L). A gravimetric technique for settleable solids can be employed. However, this technique is time consuming and employs all the equipment required in the suspended solids test. The volumetric test can be performed easily in the field. Hence, it is the recommended procedure for settleable solids.

Substrate conditions in spawning areas are typically determined by measuring the percentage of various particle sizes, the permeability of gravels, or the dissolved oxygen concentration in the gravel. The most widely used and accepted technique is measuring the percentage of various particle sizes. This technique is specified by the Alaska water quality standards (ADEC 1985).

The volume of fines in substrate samples is determined by first securing a sample using a substrate sampler such as a corer or dredge. The sample is then subjected to grain size analysis. Like other sampling techniques, different samplers have advantages and disadvantages when sampling different size bed material. To minimize loss of fine-grained sediment, the Alaska water quality standards specify that a technique for freeze sampling streambed sediments be followed. A major disadvantage of this technique is that it requires additional and heavy equipment, making it difficult to use in remote areas. Furthermore, variability is relatively high with this technique, as it is with other substrate sampling devices.

Measurements of bedload, although technically valid, are too complicated as a criterion (Iwamoto et al. 1978). Iwamoto et al. (1978) suggest that it may be possible to relate suspended solids in the water column to the bedload by the use of sediment rating curves. The use of suspended solids as the basis for bedload criteria may hold promise if difficulties with estimation, prediction, and determination of the relationship with streambed sediments, and long- and short-term effects on aquatic biota are clarified to the extent that reproducible results are obtainable. However, until this is accomplished, the accepted technique of freeze core sampling to determine the percentage of various particle sizes in streambed sediments is recommended.

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6.0 PROPOSED PARTICULATES CRITERIA

6.1 INTRODUCTION

A criterion is a designated concentration or limit of a parameter that, when not exceeded, will protect a prescribed water use with a reasonable degree of safety. In some cases, a criterion may be a narrative statement instead of a numerical limit.

The water quality standards for a particular water body consist of those criteria associated with the uses for which that water body is protected. Water bodies are classified by the uses for which they are protected. In Alaska, all water bodies except the lower Chena River and Nolan Creek (and most of its tributaries) are classified for protection of all uses.

Ideally, parameters used for defining criteria should be able to be measured relatively simply and be inexpensive, fast, precise, and accurate. It is desirable to use techniques that can be performed in the field without compromising the precision or accuracy of the measurement. Additionally, standards should include only the most applicable parameters for each water use. For example, turbidity criteria are sufficient to protect secondary recreational uses, so there is no need to have suspended or settleable solids criteria. Standards must be stated in clear, understandable terms so that confusion does not arise over their interpretation. Ideally, they should be appropriate for all types of aquatic systems and should consider seasonal, geographical, and flow differences in natural particulate concentrations.

Criteria should be periodically reviewed and updated as new data or techniques for obtaining fast and accurate measurements become available. The particulates criteria should not be viewed as permanent fixtures but as essential parts of an evolving system to safeguard the current and future uses of Alaska's waters.

6.2 PROPOSED CRITERIA

This section outlines suggested changes to the Alaska water quality criteria for particulates. The current wording, proposed wording, and supporting rationale are presented for each criteria. The rationale for retaining, changing, or deleting each criterion is based on the literature reviewed for this document. That literature has been used to formulate the discussions in Chapters 1 through 5. Therefore, the rationale sections are necessarily summaries of the preceding discussions. The reader is referred to the earlier chapters for more detailed overviews of literature relating to the effects of particulates on water supply, recreation, and biota.

Given the status of knowledge, there are probably as many defensible sediment and turbidity criteria for certain use categories as there are informed agencies or individuals interested in proposing them. In reality, there is probably no one definitive level or concentration that is detrimental to each use in all systems under all circumstances. In some instances, the existing criteria have been refined or modified to reflect the findings of a variety of researchers. With regard to aquaculture, definitive maximum suspended solids concentrations for egg incubation and rearing have been identified in the literature. In other instances an absolute maximum turbidity level or suspended solids concentration may not be appropriate. Such is the case for growth and propagation of freshwater and marine organisms. The proposed standards for these categories reflect seasonal fluctuations and site-specific differences in natural turbidity and sediment levels. They limit any appreciable increase above natural levels in systems which normally carry low particulate loads while allowing for some increase in systems which periodically exhibit moderate to high natural levels.

The proposed particulates criteria presented below are made with two caveats from the Alaska Department of Environmental Conservation. First, the Department does not want to assess revisions to the existing water use categories as part of this study. Second, since it is the Department's responsibility to fully protect the various water uses, in setting criteria the Department prescribes limits be set on the most sensitive use in each water use category. For aquatic biota, this means setting criteria for the most sensitive life stage of the most sensitive species in the most sensitive season. This approach is prescribed by the EPA.

Table 6-1 lists water uses and the parameters that are essential to each. Parameters not appearing in a particular category are considered unnecessary for the protection of that use.

<u>Fresh Water</u>

1. Water supply: drinking, culinary and food processing
   a. Turbidity

      <u>Existing</u>: Shall not exceed 5 NTU above natural conditions when the natural turbidity is 50 NTU or less, and not have more than 10% increase in turbidity when the natural condition is more than 50 NTU, not to exceed a maximum increase of 25 NTU.

      <u>Proposed</u>: There shall be no increase in turbidity when the natural condition is 5 NTU or less, increase shall not cause turbidity to exceed 10 NTU when the natural condition is between 5 and 10 NTU, shall not cause more than a 5 NTU increase when the natural condition is 10 to 25 NTU, and shall not cause turbidity to exceed 250 NTU when the natural condition is 50 to 250 NTU.

TABLE 6-1

WATER USES AND PARAMETERS FOR WHICH CRITERIA MUST BE ESTABLISHED TO MEET WATER QUALITY OBJECTIVES

Water Use	Particulate Parameters			
	Turbidity	TSS	Settleable Solids	% Accum. Fines
Fresh Water				
Drinking, culinary, and food processing	X	X	X	
Agriculture		X	X	
Aquaculture		X	X	
Industrial	X	X	X	
Contact recreation	X			
Secondary recreation	X			
Growth of aquatic organisms	X	X	X	X
Marine Water				
Aquaculture		X	X	
Seafood Processing		X	X	
Industrial		X	X	
Contact recreation	X			
Secondary recreation	X			
Growth of aquatic organisms	X	X	X	
Harvest of raw shellfish			X	

TSS = Total Suspended Solids

b. Sediment

Existing: No measurable increase above natural conditions.

Proposed: No increase in settleable solids or volatile suspended solids above natural conditions.

Although light attenuation is not an issue related to the acceptability of drinking water, most people find water with 5 or more turbidity units objectionable (Bruvold 1975). Sorensen et al. (1977) state that 0 to 10 turbidity units provide an excellent source of water supply requiring only disinfection. They also state that 10 to 250 units provide good sources requiring only usual treatment, and that waters with turbidities greater than 250 units are poor sources requiring special or auxiliary treatment. Therefore, the existing criteria has been modified to protect naturally clear sources of drinking water. At the same time, the proposed standard allows for a greater increase where water contains higher natural turbidity levels which would require usual treatment or would otherwise be unacceptable as a water supply. With regard to sediment, the primary concern is that sediment not interfere with disinfection. Interference with disinfection is directly related to the type and amount of organic sediment (volatile suspended solids) present in the water (Symons and Hoff 1975). An increase in inorganic suspended sediment above natural conditions does not necessarily impede the clarification process, and in some instances may enhance it (NAS 1973) Therefore, the suspended sediment criterion has been modified to limit only volatile suspended solids. The rationale for the proposed settleable solids criterion is: (1) Natural waters which are otherwise suitable as a water supply normally contain low levels of settleable solids; and (2) settleable solids may significantly decrease the effective life of sedimentation basins or filtration systems, thereby increasing treatment costs.

2. Water supply: agriculture, including irrigation and stock watering

a. Turbidity

Existing: Shall not cause detrimental effects on indicated water use.

Proposed: Delete criterion for this use category.

b. Sediment

Existing: For sprinkler irrigation, water shall be free of particles of 0.074 mm or coarser. For irrigation or water spreading, shall not exceed 200 mg/l for an extended period of time.

Proposed: Retain the existing criteria and add the following. Increase in total suspended solids shall not interfere with the treatment of agricultural water supply. No increase in settleable solids above natural conditions allowed.

The concern is for particulate matter which may block pumping and spraying equipment and cause formation of crusts on land or coat vegetables which have been irrigated. The solids criteria should be measured directly. Turbidity should be deleted because the concern is for the physical presence of particles and not light scattering and absorption. The term "extended period of time" is vague, but there was no information in the literature reviewed that would improve this term and be defensible. The particle size criterion appears to be adequate because it limits the particle size to silt and smaller material.

3. Water supply: aquaculture

a. Turbidity

Existing: Shall not exceed 25 NTU above natural condition level. For all lake water, shall not exceed 5 NTU over natural conditions.

<u>Proposed</u>: Delete criteria for this use category.

b. Sediment

<u>Existing</u>: No imposed loads that will interfere with established water supply treatment levels.

<u>Proposed</u>: Where the natural condition is less than 3 mg/L, suspended solids shall not exceed 3 mg/L. Where the natural condition is greater than 3 mg/L, suspended solids shall not increase by more than 20%. There shall be no increase in settleable solids above natural conditions.

A definitive maximum concentration of 3 mg/L for incubating salmonid eggs and 25 mg/L for salmonid rearing is presented in the literature (Sigma Resource Consultants 1979). Thus, the maximum concentration should be limited in order to facilitate adequate water supply treatment and ensure successful incubation and rearing. The 3 mg/L level is important because most hatcheries support egg incubation and use of this level is the most conservative. There is no apparent reason for a turbidity criterion as such. The proposed suspended solids criteria would insure that turbidity-causing sediments are kept to a minimum. It should be noted that ultraviolet disinfection may be inhibited by turbidity-causing sediments. However, there are no data in the literature reviewed regarding specific turbidity levels that inhibit ultraviolet disinfection. A low level increase in suspended solids (3 mg/L) will limit the volume of turbidity-causing particles. The rationale for limiting settleable solids include the well documented adverse impacts of sediment accumulation on egg incubation and fry development (see Tables 4-1 and 4-2).

4. Water supply: industrial

a. Turbidity

<u>Existing</u>: Shall not cause detrimental effects on

established water supply treatment levels.

Proposed: Retain criterion for this use category.

b. Sediment

Existing: No imposed loads that will interfere with established water supply treatment levels.

Proposed: No increase in total suspended solids and settleable solids levels above natural conditions that would adversely affect established water supply treatment.

Turbidity is retained for those industries which use turbidity as the established parameter in treatment systems, such as the brewing industry. As pointed out in Section 4.2, industries vary considerably with regard to the amount of particulates which can be tolerated. Some industries can tolerate only low particulate levels. Because the range of acceptable water quality varies widely, a narrative criteria is probably the best available. The proposed sediment criterion is designed to protect established treatment techniques.

5. Water recreation: contact recreation

a. Turbidity

Existing: Shall not exceed 5 NTU above natural conditions when the natural turbidity is 50 NTU or less and not have more than 10% increase in turbidity when the natural condition is more than 50 NTU, not to exceed a maximum increase of 15 NTU. Shall not exceed 5 NTU over natural conditions in all lake waters.

Proposed: Shall not exceed 5 NTU above natural conditions when the natural turbidity is 50 NTU or less and not have more than 10% increase in turbidity when the natural condition is more than 50 NTU.

b. Sediment

Existing: No increase in concentrations above natural conditions.

__Proposed__: Delete criterion for this use category.

Aesthetics and safety are the primary considerations for contact recreation such as diving, swimming, and wading. Data show that people prefer to recreate in clear rather than turbid water. A 5 NTU change in turbidity levels is noticed by most people. Cloudy water can also obscure dangerous rocks or other underwater obstructions. The upper limit for achieving these goals is 50 NTU (McGauhey 1968). There is no basis for having different standards for lakes and streams. Therefore, this part of the standard is deleted. There is no information that warrants changing the turbidity levels in the existing criteria, which afford a high level of protection, other than the amount of maximum increase.

Sediment is not a direct consideration for contact recreation and this standard is deleted. Suspended sediments may need to be limited only if the particles are organic or are associated with pathogenic microorganisms. The presence of pathogenic organisms are covered in water quality criteria not addressed in this document.

6. Water recreation: secondary recreation

   a. Turbidity

      __Existing__: Shall not exceed 10 NTU over natural conditions when natural turbidity is 50 NTU or less, and not have more than 20% increase in turbidity when the natural condition is more than 50 NTU, not to exceed a maximum increase of 50 NTU. For all lake waters, turbidity shall not exceed 5 NTU over natural condi tions.

      __Proposed__: Shall not exceed 10 NTU over natural conditions when natural turbidity is 50 NTU or less, and not have more than 20% increase in turbidity when the natural condition is more than 50 NTU.

b. Sediment

Existing: Shall not pose hazards to incidental human contact or cause interference with the use.

Proposed: Delete criterion for this use category.

Based on McGauhey (1968), the current turbidity criteria afford a high level of protection for boating and other non-contact water recreation. Fishing may require more stringent standards in order to maintain a suitable sport fishery. However, in this case, the turbidity criteria for the growth and propagation of fish, shellfish, and other aquatic organisms would apply. There is no apparent reason for lake and stream standards to differ. Furthermore, there is no defensible reason for retaining the sediment criterion for this use based on the literature reviewed.

7. Growth and propagation of fish, shellfish, and other aquatic life

a. Turbidity

Existing: Shall not exceed 25 NTU above natural condition level. For all lake waters, shall not exceed 5 NTU over natural conditions.

Proposed: Shall not exceed 5 NTU increase above natural conditions up to 25 NTU and shall not exceed 20% increase above natural conditions (measured in NTU) when the natural condition is 25 NTU or greater.

b. Sediment

Existing: The percent accumulation of fine sediment in the range of 0.1 to 4.0 mm in the gravel bed of waters utilized by anadromous or resident fish for spawning may not be increased more than 5% by weight over natural conditions (as shown from grain size accumulation graph). In no case may the 0.1 to 4.0 mm fine sediment range in the gravel bed of waters used by anadromous and resident fish for spawning exceed a maximum of 30% by weight (as shown from grain size accumulation graph). (See note 3 and 4) In all other surface waters no sediment loads (suspended or deposited) which can cause adverse effects on aquatic animal or plant life, their reproduction or habitat.

Proposed: Suspended and/or settleable solids content of surface waters shall not adversely affect aquatic plants and animals, their reproduction or habitat. In natural conditions less than 25 mg/L, suspended solids shall not have more than a 10% increase. In waters where the natural condition is greater than 25 mg/L, suspended solids shall not have more than a 20% increase. No increase in settleable solids above natural conditions. The percent accumulation of fine sediment in the range of 0.1 to 4.0 mm in the gravel bed of waters used by anadromous or resident fish for spawning may not be increased more than 5% by weight over natural conditions, not to exceed 20% by weight over natural conditions.

The existing turbidity criteria afford a moderate to high level of protection for aquatic organisms as evidenced by data from Herbert et al. (1961), Alabaster (1972), Sykora et al. (1972), Sorensen et al. (1977), Langer (1980), Sigler (1981), Bisson and Bilby (1982), NCASI (1984b), Sigler et al. (1984), and Simmons (1984). Although, the current state of knowledge in Alaska is inadequate to describe the energy base of more than a few streams and lakes, it should be assumed that many systems depend on primary productivity to at least some extent. Quantitative information presented by Bell (1973), Nuttall and Bilby (1973), McCart et al. (1980), Van Nieuwenhuyse (1983), and

LaPerriere et al. (1983) indicate that turbidity criteria are necessary for the protection of aquatic systems which depend on in-stream primary productivity. Furthermore, there is substantial evidence that turbidity has a negative impact on salmonid feeding (Alabaster 1972; Sykora et al. 1972; Langer 1980; Simmons 1984), salmonid growth (NCASI 1984b; Sigler et al. 1984), salmonid distribution (Sigler 1981; Bisson and Bilby 1982; Sigler et al. 1984), and benthic macroinvertebrate populations (Herbert et al. 1961; Sorensen 1977; LaPerriere et al. 1983). The suggested changes in the turbidity standard address the fact that increases in very clear water are likely to have a greater effect on aquatic organisms and primary productivity than the same magnitude of increase in naturally turbid water.

The reason for limiting fines in spawning gravels is to avoid smothering eggs and alevins by filling interstices in the gravel. This is a volumetric, not a gravimetric concern. Depending on the type of fine material, weight may vary widely for particles of the same dimensions, but both would occupy the same volume of space and reduce the oxygen-carrying capacity in water flowing through the gravel to the same degree. However, because the accepted technique is to weigh the fines, the proposed criteria are expressed in terms of weight. Although, the percentage accumulation of fine sediment in a gravel bed is difficult to evaluate, the Department has found it to be a useful criterion. With regard to substrate characteristics of spawning beds, the size range stated in the existing criteria are adequate and based on information in the literature (McNeil and Ahnell 1964; Koski 1966; Burns 1972; Phillips et al. 1975; Hausle and Coble 1976; Tagart 1976; Iwamoto et al. 1978; Cederholm et al. 1980; Crouse et al. 1981; Tappel and Bjornn 1983). The criterion allowing a maximum of 30 percent fine sediment is not supported by the literature; this maximum should be lowered to 20 percent as a maximum (McNeil and Ahnell 1964; Koski 1966; Shelton and Pollack 1966; Bjornn 1969; Burns 1972;

Bjornn et al. 1974; Hausle and Coble 1976; Iwamoto et al. 1978; Cederholm et al. 1980; Crouse et al. 1981; Tappel and Bjornn 1983; NCASI 1984a; NCASI 1984b). The settleable solids measurement is relatively simple and reliable and can be used in place of the percentage accumulation of fine sediment at the Department's discretion. EIFAC (1965) concluded that spawning gravels should be kept as free as possible from finely dividied solids. Van Nieuwenhuyse (1983) and Simmons (1984) suggest a settleable solids criterion of less than 0.1 ml/L for a high level of protection. Thus, the proposed criteria afford a high level of protection for salmonid spawning gravels.

Suspended solids are also detrimental to aquatic organisms and, since suspended solids can not be correlated with turbidity on a state-wide basis, it is necessary to have a standard for total suspended solids. The proposed criterion is restrictive for naturally clear water but less restrictive for waters containing naturally high suspended solids concentrations. It is in agreement with the 25 mg/L criteria suggested by several authors (EIFAC 1965; Gammon 1970); Alabaster 1972; Bell 1973; NAS 1973; Sorensen et al. 1977; Alabaster and Lloyd 1982; Wilber 1983; and George and Lehnig 1984) to maintain optimal fisheries and prevent harmful effects on fish. This criterion offers a high level of protection for sediment-free spawning and rearing waters while allowing some increase in streams and lakes which receive natural sediment loads. It also accounts for the high degree of seasonal suspended sediment variability in Alaska's many streams and lakes.

Marine_Water

1. Water supply: aquaculture
   a. Turbidity
      Existing: Shall not exceed 25 NTU.
      Proposed: Delete standard for this use category.

b. Sediment

Existing: No imposed loads that will interfere with established water supply treatment levels.

Proposed: Where the natural condition is less than 3 mg/L, suspended solids shall not exceed 3 mg/L. Where the natural condition is greater than 3 mg/L, suspended solids shall not increase by more than 20%. There shall be no increase in settleable solids above natural conditions.

The rationale is the same as cited above for aquaculture in fresh water.

2. Water supply: seafood processing

a. Turbidity

Existing: Shall not interfere with disinfection.

Proposed: Delete criterion for this use category.

b. Sediment

Existing: Below normally detectable amounts.

Proposed: Shall not increase levels of suspended and settleable solids above natural condition or shall not interfere with disinfection or established water treatment processes.

The turbidity standard was deleted because the concern with seafood processing is the amount of suspended and settleable solids in the water rather than light scattering. The sediment criterion, "below normally detectable amounts," is somewhat ambiguous and was redefined in terms of an increase in suspended and settleable solids above natural conditions, thereby making the criterion easier to enforce.

3. Water supply: industrial

a. Turbidity

Existing: Shall not cause detrimental effects on established levels of water supply treatment.

Proposed: Delete criterion for this use category.

b. Sediment

Existing: No imposed loads that will interfere with established water supply treatment levels.

Proposed: No increase in total suspended and settleable solids levels above natural conditions that would adversely affect established water supply treatment.

Turbidity was deleted because light scattering is not a concern for industrial use of marine water; suspended and settleable solids levels are the concern. Industries vary in their water quality requirements. Some require water virtually free of particulates. This standard encompasses all potential uses so that opportunities for future economic development in Alaska are not precluded.

4. Water recreation: contact recreation

a. Turbidity

Existing: Shall not exceed 25 NTU.

Proposed: Shall not exceed 5 NTU above natural conditions when the natural turbidity is 50 NTU or less and not have more than 10% increase in turbidity when the natural condition is more than 50 NTU.

b. Sediment

Existing: No measureable increase in concentrations above natural conditions.

Proposed: Delete criterion for this use category.

Aesthetics and safety are the primary considerations for contact recreation such as diving, swimming, and wading. Data show that people prefer to swim in clear rather than turbid waters. Cloudy water can also obscure dangerous underwater obstructions. The upper limit for achieving these goals is 50 NTU. Therefore, the turbidity standard is limited to that level. The turbidity criteria afford a high level of protection, but are lower than natural conditions in some areas of Alaska marine waters.

Sediment is not a consideration for contact recreation and this criterion should be deleted.

5. Water recreation: secondary recreation

   a. Turbidity

      Existing: Shall not exceed 25 NTU.

      Proposed: Shall not exceed 10 NTU over natural conditions when natural turbidity is 50 NTU or less and not have more than 20% increase in turbidity when the natural condition is more than 50 NTU.

b. Sediment

      Existing: Shall not pose hazards to incidental human contact or cause interference with the use.

      Proposed: Delete criterion for this use category.

The current standards afford a high level of protection for boating and other non-contact water recreation. Fishing may require more stringent standards in order to maintain a suitable sport fishery. However, the standards for the growth and propagation of fish, shellfish, and other aquatic organisms would cover the concerns.

6. Growth and propagation of fish, shellfish, and other aquatic life

   a. Turbidity

      Existing: Shall not reduce the depth of the compensation point for photosynthetic activity by more than 10%. In addition, shall not reduce the maximum Secchi disk depth by more than 10%.

<u>Proposed</u>: Within the photic zone, shall not exceed 5 NTU increase above natural condition up to 25 NTU and shall not exceed a 20% increase above natural condition (measured in NTU) when the natural condition is 25 NTU or greater. Shall not reduce the depth of the compensation point (depth at which 1% of the incident light is available) for photosynthetic activity by more than 10%.

b. Sediment

<u>Existing</u>: No measureable increase in concentrations above natural conditions.

<u>Proposed</u>: Total suspended solids shall not have more than a 20% increase above natural conditions. There shall be no increase in settleable solids levels above natural conditions.

The existing criteria using compensation point and Secchi disk depth may be adequate. However, there are few data in the literature reporting compensation point and Secchi disk depth in Alaska marine waters. Most of the data are reported as turbidity and suspended solids. Hence, turbidity levels should be used as the primary criterion limiting the amount of particulates where light penetration is of paramount interest with compensation point as a secondary criterion. The suggested changes in the turbidity standard address the fact that increases in turbidity in clear waters are likely to have a greater affect on primary productivity and depth of the euphotic zone than the same magnitude of increase in turbid waters.

The existing sediment criterion (no measurable increase in concentration above natural conditions) certainly affords a high level of protection. This criterion is restated in terms of suspended and settleable solids, allowing for some increase in total suspended solids above natural conditions. The suspended solids criterion reflects marine organisms' generally greater tolerance of sediment than that of freshwater organisms as evidenced by higher concentrations (100 to 6000 mg/L) at which adverse affects have been reported (see Tables 4-5 and 4-6). Furthermore, increases in suspended marine sediments are likely to be localized and periodic (Ozturgut et al. 1981) in this high dilution environment. Although no specific settleable solids criteria are presented in the literature, the proposed criterion is conservative and restricts any increase for the following reasons: (1) The natural variability in settleable solids levels with verticle depth in the water column; (2) the potential difficulty in establishing natural levels of inorganic sediment which will eventually settle under quiescent conditions; (3) the potential difficulty in monitoring and enforcing a definitive criterion in the marine environment; (4) the variability in distribution of infaunal and epifaunal organisms which may be sensitive to additional sediment accumulations; and, (5) the lack of scientific data regarding the demonstrated effects of settleable solids on marine benthos.

7. Harvesting for consumption of raw mollusks or other raw aquatic life
   a. Turbidity
      Existing: Shall not reduce the depth of the compensation point for photosynthetic activity by more than 10%. In addition, shall not reduce the maximum Secchi disk depth by more than 10%.
      Proposed: Delete criteria for this use category.
   b. Sediment
      Existing: No existing standard.
      Proposed: No increase in settleable solids above natural conditions.

There is no evidence to support the necessity of having turbidity or suspended solids criteria for this use category. Concerns relating to toxic materials and/or microbial contamination of raw shellfish are covered in other water quality standards outside the scope of the particulate standards. The proposed settleable solids criterion protects the consumer from undesirable deposits of particulate matter on edible organisms.

6.3 REFERENCES

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APPENDIX A

ANNOTATED BIBLIOGRAPHIES--FRESH WATER

REFERENCE: ADEC, 1985. Water quality standards. Alaska Dept. of Environmental Conservation, Juneau, Alaska. 27 pp.

REFERENCE LOCATION: L.A. Peterson & Associates, Inc.

IMPORTANT PAGES: 3-13

KEY WORDS: Standards, Turbidity, Sediment

ANNOTATION

The water quality standards, 18 AAC 70, are described by various sections which include a general section and discussion of short-term variance, protected water uses and criteria, procedure for applying water quality criteria, mixing zones, zones of deposit, thermal discharges, classification of state waters, procedure for reclassification, classification criteria, enforcement discretion, and definitions.

REFERENCE: Alabaster, J. S., and R. Lloyd, 1982. Water quality criteria for freshwater fish. Second Edition, Butterworth Scientific, Boston. 361 pp.

REFERENCE LOCATION: University of Alaska Library, Fairbanks

IMPORTANT PAGES: 1-3, 15-17

KEY WORDS: Sediment, Turbidity, Suspended Solids, Fish, Water Quality

ANNOTATION

Excessive concentrations of finely divided solids may be harmful to a fishery by: acting directly on fish swimming in water containing suspended solids, and either killing them or reducing their growth rate and resistance to disease; by preventing the successful development of fish eggs and larvae; by modifying natural movements and migrations of fish; by reducing the abundance of food available to the fish; or by affecting the efficiency of methods for catching fish. The spawning grounds of trout and salmon are particularly susceptable to finely divided solids, and a small amount of turbidity or deposited solids may cause fish to avoid them or prevent successful development of their eggs. There is no evidence that suspended solids concentrations below 25 mg/L have any effect on fish. Concentrations above 25 mg/L have, in some instances, reduced fish yield; 35 mg/L have reduced feeding intensity; 50 mg/L have reduced the growth rate of trout; 82 mg/L charcoal have killed Daphnia. The lowest concentration known to have reduced fish life expectation is 90 mg/L, and the lowest concentration known to have increased susceptibility to disease is 100 mg/L. In some waters fish are few in number, or absent in the 100-400 mg/L range. Similar concentrations increase susceptibility to disease, mortality rates, reduce growth rates, kill Daphnia, and drastically reduce invertebrate fauna in stream beds. There is no reliable evidence to indicate that fish faunas exist in waters normally containing greater than 400 mg/L suspended solids. Fish may survive concentrations of several thousand mg/L for short periods but may damage their gills. This may subsequently affect their survival.

Tentative criteria for suspended solids in freshwater are as follows: <25 mg/L have no harmful effects on fishes; 25-80 mg/L will provide for good or moderate fisheries; 80-400 mg/L are unlikely to support good fisheries; at best, only poor fisheries are likely to be contained in waters normally containing >400 mg/L.

REFERENCE: Arruda, J. A., G. R. Marzolf, and R. T. Faulk. 1983. The role of suspended sediments in the nutrition of zooplankton in turbid reservoirs. Ecology, 64(5): 1225-1235.

REFERENCE LOCATION: Alaska Resources Library, Anchorage (microfilm)

IMPORTANT PAGES: 1225-1235

KEY WORDS: Daphnia, Suspended Sediment, Algae

ANNOTATION:

Daphnia were tested to discover: (1) The physical effects of suspended sediments on ingestion and incorporation rates of algae; (2) Ingestion rates of two sizes of clay mineral sediment particles; and (3) Growth and survival when fed yeast and sediments with and without organic material adsorbed onto particles. Increases of suspended sediment from 0.0 to 2451 mg/L decreased ingestion rates of algae by 95 percent and decreased incorporation rates by 99 percent. Nutrients can be adsorbed onto sediment particles and provide food for Daphnia but not as well as directly ingesting nutrients. The threshold of suspended solids for efficient feeding appeared to be 100 mg/L.

REFERENCE: Bell, M.C., 1973. Silt and turbidity. In: Fisheries Handbook of Engineering Requirements and Biological Criteria. U. S. Army Corps of Engineering Division, Corps of Engineers, North Pacific Division, Portland, Oregon.

REFERENCE LOCATION: L. A. Peterson & Associates, Inc.

IMPORTANT PAGES: 1-7

KEY WORDS: Sediment, Silt, Bed-load, Turbidity, Trout, Salmon, Eggs, Alevins, Production, Mortality, Smothering, Infection

ANNOTATION

Relatively large quantities (500-1000 ppm) of suspended water-borne material can be carried for short periods of time in streams without detriment to fish. The catch of fish is affected above levels of 30 JTU, as visual references are lost. Primary food production is lowered above levels of 25 JTU. The presence of bed load material can kill buried eggs or alevins by restricting water interchange and can smother food organisms. Studies conducted in the Chilcotin River in British Columbia indicate that salmonid fish will not move in streams where the silt content is above 4,000 ppm. Streams with average silt loads between 80 and 400 ppm are not desirable for supporting fresh-water fisheries. Streams with less than 25 ppm may be expected to support good freshwater fisheries. When an excess amount of silt is deposited throughout salmon and trout redds after spawning is completed, there is a resultant interference with the proper percolation of water upward through the redd, a loss of dissolved oxygen, and a lack of proper removal of catabolic products. This "smothering" of eggs also promotes the growth of fungi which may spread throughout the entire redd. The extent to which siltation is harmful to salmon and trout spawning and egg incubation depends upon the amount and type of material deposited, as well as the time of occurrence. When sediment contains clay particles, it may form a hard, compact crust over the stream bed and render the spawning area unusable. Generally, salmonid eggs will suffer a mortality of 85 percent when 15 to 20 percent of the gravel voids are filled with sediment. Prolonged exposure to some types of sediment results in thickening of cells of the respiratory epithelium and the eventual fusion of adjacent gill lamellae. Evidence of gill irritation in trout and salmon fingerlings held in turbid water has been noted frequently by fish culturists, and considered a common avenue of infection for fungi and pathogenic bacteria. It is apparent that salmonids suffer more physical distress in turbid water than do other species.

REFERENCE: Beschta, R. L. 1980. Turbidity and suspended sediment relationships. In: Proc. Symp. on Watershed Management '80, Boise, Idaho. pp. 271-282.

REFERENCE LOCATION: Alaska Department of Fish and Game, Anchorage

IMPORTANT PAGES:

KEY WORDS: Suspended Sediment, Turbidity

ANNOTATION

The Oak Creek and Flynn Creek watersheds in western Oregon were analyzed for turbidity and suspended sediment. Suspended sediment concentration and turbidity correlated significantly at the 90 percent confidence limit for 24 of 26 storm events. The relationships differed significantly between drainages, however, so prediction equations must be worked out for each watershed. Turbidity may be useful in evaluating sediment transport in small mountain drainages where suspended sediment concentrations and water discharges can change quickly. Turbidity measurements, though, are ambiguous partly because there are so many ways of measuring it and each instrument used influences the resultant turbidity values. On this project, the Hach 2100A turbidimeter calibrated in NTU was used. Formulae and curves showing the relationships between suspended sediment and turbidity are presented.

REFERENCE: Bisson, P. A. and R. E. Bilby. 1982. Avoidance of suspended sediment by juvenile coho salmon. No. Amer. Jour. of Fish. Manage., 2(4):371-374.

REFERENCE LOCATION: Alaska Resources Library, Anchorage

IMPORTANT PAGES:

KEY WORDS: Turbidity, Coho Salmon

ANNOTATION

Juvenile salmon were tested under laboratory conditions to determine threshold levels eliciting avoidance and modification of behavioral response by acclimation to chronic low levels of fine sediment. Sediment was introduced into a divided chamber and fish were observed to see which half they preferred. Suspended sediment levels avoided by coho juveniles were below lethal levels. Feeding effectiveness may be impaired in the 70 to 100 NTU range. Fish may have avoided waters in that range so they could see prey. Fish did not select slightly turbid (10 to 20 NTU) water but water of slightly higher turbidity appeared to be used for cover. The authors conclude that fish should not be stocked into highly turbid water. Also, moderate increases over low background levels are apparently not avoided by the fish.

REFERENCE: Bjornn, T. C., M. A. Brusven, M. P. Molnau, and J. H. Milligan, 1977. Transport of granitic sediment in streams and its effects on insects and fish. University of Idaho, Forest Wildlife and Range Experiment Station Bulletin No. 17, Moscow, Idaho. 47 pp.

REFERENCE LOCATION: Cooperative Fish Unit, University of Alaska, Fairbanks

IMPORTANT PAGES: 40, 41

KEY WORDS: Salmonids, Aquatic Insects, Abundance, Drift, Sediment, Embeddedness

ANNOTATION

The effects of <6.35 mm diameter sediment on juvenile salmonids and aquatic insects was assessed in two Idaho streams. In a natural stream riffle, benthic insects were 1.5 times more abundant in a plot cleaned of sediment, with mayflies and stoneflies 4 to 8 times more abundant, respectively. In small natural pools, additions of sediment resulted in a proportional decrease in fish numbers. The amounts of sediment in the two streams studied did not have an obvious adverse effect on the abundance of fish or the insect drift on which they feed. In artificial stream channels, benthic insect density in fully sedimented riffles (>2/3 cobble embeddedness) was 1/2 that in unsedimented riffles. However insect drift was essentially the same in both. Fish in sedimented channels exhibited hierarchical behavior, while those in unsedimented channels were territorial in behavior.

Conclusions derived from experimental data are that sediments can affect aquatic insect populations when deposited in riffles, reduce the summer rearing capacity of streams when deposited in pools, and reduce the winter fish capacity of streams when deposited in the larger interstitial spaces of stream substrate. If the percentage of fine sediment exceeds 20 to 30 percent in spawning riffles, survival and emergence of salmonid embryos begins to decline. When riffles are fully embedded with fine sediment, insect species composition and abundance changes. The abundance of juvenile salmon in pools of small rearing streams declines in almost direct proportion to the amount of pool area or volume lost to fine sediment deposited in the pool. The number of salmonid fish a stream can support in winter is much reduced when the interstices in the stream substrate are filled with fine sediment. The percentage of fine sediment in riffles not only provides a measure of the suitability of the riffles for embryo survival, but is also an index of the amount of fine sediment being deposited in pools or substrate interstices.

REFERENCE: Clarkson, C.C., D. E. Lehnig, S.V. Plante, R. S. Taylor, and W. M. Williams, 1985. Hydrologic basis for suspended solids criteria. Prepared for Environmental Protection Agency by Camp, Dresser & McKee, Annandale, Virginia.

REFERENCE LOCATION: Alaska Department of Environmental Conservation

IMPORTANT PAGES: v-vii, 2-34--2-37, 4-1--4-25

KEY WORDS: Sedimentation, Suspended Solids, Turbidity, Primary Production, Zooplankton, Macroinvertebrates, Salmonid, Fish, Hydrology

ANNOTATION

The report discusses several factors that are important to the development of a water quality criterion for suspended solids/turbidity for the protection of aquatic biota. These factors include regional, physiographic, and seasonal considerations, and related hydrologic phenomena.

The natural solids loading to a waterbody will vary from site to site, depending upon physiographic factors (including slope, soil type, type of ground cover) and upon rainfall and runoff. Hence, seasonal and regional criteria need to be developed that take into account the significance of natural and other nonpoint source loadings. Water quality criteria should be developed for suspended solids in the water column as well as for settled sediment and these criteria need to address the complex situation of toxics sorbed to suspended and settled solids. Additionally, the effects of sustained exposure to suspended solids versus short-term storm related pulses need to be quantified. Although the report does not recommend criteria to protect aquatic life, it does establish a framework for consideration of regional, seasonal, and biological factors.

REFERENCE; Crouse, M. R., C. A. Callahan, K. W. Malueg, and S. E. Dominguez, 1981. Effects of fine sediment on growth of juvenile coho salmon in laboratory streams. Trans. Amer. Fish. Soc., 110(2):281-286.

REFERENCE LOCATION: Alaska Resources Library, Anchorage (microfilm)

IMPORTANT PAGES:

KEY WORDS: Coho Salmon, Benthos, Sedimentation

ANNOTATION

Juvenile coho salmon production expressed as tissue elaboration was measured in laboratory streams under six levels of fine sedimentation. Levels of sediment embeddedness were 20, 40, 60, 80, and 100 percent as cumulative weight. Production of coho salmon was inversely related to the quantity of fine sediment. Significant decreases in fish production occurred in the 80 to 100 percent embeddedness streams when fine (2.0 mm or less) sediments were 26 and 31 percent by volume. Benthic organisms were covered by the sediment. Authors conclude that rearing habitat for juvenile salmon as well as spawning habitat should be protected from sedimentation.

REFERENCE: DFO, 1983. A rationale for standards relating to the discharge of sediments into Yukon streams from placer mines. Department of Fisheries and Oceans, Field Services Branch, Environment Canada, Environmental Protection Service, New Westminister, B.C. 24 pp.

REFERENCE LOCATION: Alaska Department of Fish and Game, Habitat Division, Fairbanks

IMPORTANT PAGES: ii, 1-3, 13-18

KEY WORDS: Sediment Discharge, Plants, Invertebrates, Fish, Production, Mortality, Stream Classifications, Standards

ANNOTATION

Guidelines are proposed for an administrative/regulatory framework to manage placer mining sediment discharge. This approach is based on an extensive review and discussion of literature regarding the sensitivity of biologically important aquatic resources. Five classifications (A, B, C, D, and X) have been proposed based on the biological sensitivity of resources and past mining activity in each waterbody. "A" classifications are associated only with high importance - Schedule I (salmon, trout, or char) spawning habitat. "B" classifications would serve as rearing areas for Schedule I fish. "C" classifications are good habitat areas for Schedule II fish such as grayling, whitefish, or burbot. "D" classifications would exhibit low or no use by any of the above fish or be used only as migration corridors, and "X" classifications are for previously designated placer mining areas. Sediment discharge standards to the waters of the above classifications are proposed to be 0 mg/L for all "A" waterbodies, 100 mg/L for all "B" and "C" streams, 100 or 1000 mg/L for all "D" streams and 100 or 1000 mg/L for "X" streams. These standards are upper limits of acceptable levels and are defined for effluents from the operation as opposed to receiving water standards.

The impact of a sediment release on stream production will depend on the organisms present, streambed composition, the season, stream flow, stream velocity, background sediment levels, the volume of release, the duration of the release and the composition of the sediment. The obvious effects of sediment on fish production will be most noticeable on certain stages of fish life cycles which varies among species. Sediment causes the greatest reduction in fish production by causing mortality in the egg and alevin stages of development and in the degradation of the habitat. Since primary producers, invertebrates, and fish are linked together in aquatic food chains, any deleterious effect on algae will affect aquatic invertebrates and fish that depend on energy produced in the stream.

REFERENCE: European Inland Fisheries Advisory Commission, 1965. Water quality criteria for European freshwater fish, report on finely divided solids and inland fisheries. EIFAC Technical Paper No. 1. International Journal of Air and Water Pollution, 9(3):151-168.

REFERENCE LOCATION: University of Alaska, Fairbanks

IMPORTANT PAGES: 165-167

KEY WORDS: Suspended Solids, Turbidity, Fish, Water Quality Criteria

ANNOTATION

A literature survey addresses the direct effects of suspended solids on fish-growth, death, resistance to disease, reproduction, behavior, and food supply. Evidence indicates that fish species are not equally susceptible to suspended solids and that solids are not equally harmful. Minimal turbidity may cause fish to avoid spawning grounds or prevent successful egg development. There is no evidence that suspended solids concentrations below 25 ppm harms fish or fisheries. Concentrations above 25 ppm have reduced fish, 50 ppm have reduced growth rate of trout, and 82 ppm of charcoal have killed *Daphnia*. The lowest reported concentration for a stretch of stream containing few or no fish is 85 ppm. There are several other streams with slightly lower concentrations where the fishery is not noticeably harmed. In laboratory tests the lowest concentration known to reduce fish life expectations is 90 ppm and the lowest concentration known to have increased susceptability to disease is 100 ppm. Waters containing 100 to 400 ppm suspended solids increase susceptibility to disease, increase mortality rates and reduce growth rates. *Daphnia* have been killed by a variety of solids in this concentration range. There is no evidence that waters normally carrying solids greater than 400 ppm support varied or plentiful fish faunas. Many kinds of solids can be present in concentrations of several thousand ppm for short periods without killing fish, but may damage their gills.

Tentative suspended solids criteria are proposed as follows: <25 ppm will not have any harmful effects on fisheries; 25 to 80 ppm will maintain good or moderate fisheries; 80 to 400 ppm are unlikely to support good freshwater fisheries; at best only poor fisheries are likely to be found in waters containing >400 ppm suspended solids.

REFERENCE: Gammon, J. R., 1970. The effect of inorganic sediment on stream biota. Prepared for the Water Quality Office of the Environmental Protection Agency, Grant No. 18050DWC, U.S. Gov. Printing Office, Washington, D.C. 141 pp.

REFERENCE LOCATION: Cooperative Fish Unit, University of Alaska, Fairbanks

IMPORTANT PAGES: i, ii, 1-3, 7, 8

KEY WORDS: Fish, Macroinvertebrates, Suspended Sediment, Population Density, Diversity

ANNOTATION

Fish and macroinvertebrate populations fluctuated in response to varying quantities of sediment produced by a crushed limestone quarry. Suspended solids loads <40 mg/L resulted in a 25 percent reduction in macroinvertebrate density below the quarry. Inputs of 80 to 120 mg/1 caused a 40 percent reduction and inputs of more than 120 mg/L resulted in a 60 percent reduction in macroinvertebrate population density. Sediment which settled out in riffles caused a 40 percent decrease in population density regardless of the suspended solids concentration. Macroinvertebrate population diversity remained unchanged because most taxa responded to the same degree. Introductions of sediment up to 160 mg/L causes immediate increases in the rate of invertebrate drift proportional to the concentration of additional suspended solids. The standing crop of fish decreased drastically when heavy suspended sediment (150 mg/L) occurred in spring. Fish remained in pools during the summer when sediment input was very heavy but vacated as sediment accumulated. After winter floods removed sediment deposits, fish returned to the pools during spring and achieved 50 percent normal standing crop levels by early June. It is concluded that significant reductions in fish and macroinverterbate population densities will definitely occur at suspended solids concentrations as low as 50 to 80 mg/L.

REFERENCE: George, T.S., and D. E. Lehnig, 1984. Turbidity and solids. Prepared for U. S. Environmental Protection Agency by Camp, Dresser & McKee, Annandale, Virginia.

REFERENCE LOCATION: L. A. Peterson & Associates, Inc.

IMPORTANT PAGES: 2-2 - 4-11

KEY WORDS: Turbidity, Sediment, Aquatic Biota, Impacts, Standards, Criteria, Water Quality Objectives

ANNOTATION

Summarizes recent literature pertaining to the impacts of turbidity and sediment on primary production, and on the survival, growth and propagation of zooplankton, macroinvertebrates, and fish. In addition, it examines Canadian water quality objectives for turbidity, and the supporting rationale. Numerical data from several key investigations are presented including results from bioassay studies, state water quality standards, placer mining studies in Alaska, guidelines for setting turbidity and sediment standards, and recommended levels for the protection of a variety of water uses.

REFERENCE: Hausle, D. A., and D. W. Coble, 1976. Influence of sand in redds on survival and emergence of brook trout (Salvelinus fontinalis). Transactions American Fisheries Society, No. 1, pp. 57-63.

REFERENCE LOCATION: University of Alaska Library, Fairbanks

IMPORTANT PAGES: 59-62

KEY WORDS: Brook Trout, Spawning Gravel, Sand Concentration, Emergence, Survival, Mortality

ANNOTATION

Alevins of brook trout were buried in laboratory troughs in spawning gravel containing 0 to 25 percent sand. Sand slowed emergence and reduced the number of fry emerging. Although the percentages of fry emerging in laboratory studies were high (>82 percent), they decreased significantly with increasing sand composition. Emergence of brook trout from this study, and steelhead, chinook salmon, and coho salmon in other investigations declined when spawning gravel concentration of sand exceeded about 20 percent. The brook trout survival rate from hatching to emergence was estimated at 70 percent in Lawrence Creek, Wisconsin where natural spawning redds contained 31 percent sand. Total emergence was 59 percent from egg deposition to emergence. Mortality of 41 percent or more of deposited ova in Lawrence Creek may have been caused by low concentrations of dissolved oxygen and/or the effects of sand.

REFERENCE: Herbert, D. W. M., and J. C. Merkens, 1961. The effect of suspended mineral solids on the survival of trout. International Journal of Air and Water Pollution, Vol. 4, No. 1, pp. 46-55.

REFERENCE LOCATION: University of Alaska, Fairbanks

IMPORTANT PAGES: 51-54

KEY WORDS: Suspended Solids, Trout, Lethal Effects, Gill Damage, Fin Rot

ANNOTATION

Suspensions of kaolin and diatomaceous earth were used to test the effects of suspended solids on trout. From the data available there appears to be no great difference in the lethal effect of kaolin and diatomaceous earth. Suspensions of 30 ppm caused negligible damage to fish over a 6 month period. A few deaths occurred in suspensions of 90 ppm indicating that this level may have an adverse effect. More than half the trout died in suspensions of 270 and 810 ppm, frequently from the effects of disease. Fish exposed to suspended solids concentrations of 30 to 90 ppm exhibited normal gills but fish exposed to concentrations of 270 to 810 ppm displayed a thickening and/or fusing of gill lamellae. After 57 days of exposure to 270 ppm diatomaceous earth trout showed signs of caudal fin damage.

REFERENCE: Herbert, D. W. M., and J. M. Richards, 1963. The growth and survival of fish in some suspensions of solids of industrial origin. International Journal of Air and Water Pollution, Vol. 7, pp. 297-302

REFERENCE LOCATION: University of Alaska, Fairbanks

IMPORTANT PAGES: 302

KEY WORDS: Suspended Solids, Trout, Survival, Disease, Growth

ANNOTATION

A fishery is likely to be seriously harmed if the average concentration of suspended solids in the water is greater than about 600 ppm. At concentrations of 90 and 300 ppm the effect is more doubtful. This study has shown that trout can be kept in good health for 9 months in 200 ppm coal-washery waste solids. The extent to which concentrations in this range will be harmful depends on the nature of the solids and other environmental factors. There is no indication that 30 ppm kaolin and diatomaceous earth make trout more susceptible to disease or reduce their chances for survival. In one experiment 50 ppm wood fiber and coal-washery solids reduced the growth of rainbow trout in the laboratory. In practice, it is unlikely that 50 to 60 ppm solids will have a serious effect on growth.

REFERENCE: Hynes, H. B. N. 1973. The effects of sediment on the biota in running water. In: Fluvial processes and sedimentation. Proc. of Hydrology Symp., Univ. of Alberta, Edmonton, Alberta.

REFERENCE LOCATION: Alaska Department of Fish and Game, Anchorage

IMPORTANT PAGES:

KEY WORDS: Sedimentation, Standards

ANNOTATION

The status of knowledge of the effects of turbidity and siltation by inert solids on plants, benthos, fish, and fish eggs is reviewed. It is concluded that the upper limit for suspended sediments is 80 mg/L of inert silt, sand, or clay. This level will not seriously damage a fishery but may reduce growth rates and abundance. The allowable amount should not, however, result in siltation. If so, the level should be adjusted. Streams must always be allowed to remove the silt.

REFERENCE: Iwamoto, R. N., E. O. Salo, M. A. Madej, and R. L. McComas, 1978. Sediment and water quality: a review of the literature including a suggested approach for water quality criteria. Fisheries Research Institute, College of Fisheries, University of Washington, Seattle, Washington. Prepared for the U. S. Environmental Protection Agency, Seattle, EPA 910/9-78-048. 46 pp. + Appendices.

REFERENCE LOCATION: Falls Creek Environmental, Anchorage

IMPORTANT PAGES: 1-5, 8-12, 43-46, Appendix A, Appendix C

KEY WORDS: Sediment Criteria, Suspended Sediment, Turbidity, Bedload, Streambed, Measurement Techniques, Algae, Phytoplankton, Invertebrates, Insects, Fish, Salmonids

ANNOTATION

Conclusions and recommendations regarding sediment criteria are based on an analysis of the literature and the proceedings of a one-day sediment workshop. Among the conclusions drawn by the technical panel at the sediment workshop, the following points are most pertinent: (1) Sedimentation of spawning gravels produces significant detrimental effects on salmonids; (2) Fine bed material appears to have a significant impact on primary and secondary productivity; (3) Turbidity measurements are useful indicators of general suspended sediment levels but are difficult to relate to any biological significance; (4) The establishment of sediment criteria on the basis of measurements other than turbidity may be difficult but not impractical; (5) Alternative approaches to turbidity as a criterion include composition of bed material, behavioral aspects of aquatic fauna, and clinical measurements of physiological functions as a measure of stress; (6) A set of sediment criteria is needed rather than one numerical standard; (7) If a criterion is chosen, it should be streambed material and it should be associated with the amount of fines in the spawning bed; (8) Bedload measurements are too complicated to use as a criterion; (9) Streambed composition reflects the overall condition of a stream in relation to sediments; (10) The best alternative appears to be establishment of criteria limiting the percentage of fines in streambeds; and, (11) A need exists to develop a measurable relationship between suspended sediments and streambed composition.

REFERENCE: King, L. G., D. L. Bassett, and J. M. Ebeling, 1978. Significance of turbidity for quality assessment of agricultural runoff and irrigation return flow. Agricultural Engineering Department, Washington State University, Pullman, Washington. 36 pp. + Appendices.

REFERENCE LOCATION: Nichols Environmental Consulting

IMPORTANT PAGES: 1, 7-11, 28-33

KEY WORDS: Sediment, Turbidity, Runoff, Irrigation, Erosion

ANNOTATION

Turbidity and suspended sediment concentration were measured for both agricultural runoff and irrigation return flow. Extensive statistical analysis showed only minimal correlation. Mie scattering theory was explored to determine the significance of such factors as particle size, index of refraction, concentration and angle of scatter for both the nephelometer and the transmissiometer. It was found that only particles of less than 10 microns in diameter contribute significantly to the measurement of turbidity. The researchers recommend direct measurement of suspended sediment for agricultural runoff and irrigation return flow.

REFERENCE: Langer, O. E., 1980. Effects of sedimentation on salmonoid stream life. Paper presented at the Technical Workshop on Suspended Solids in the Aquatic Environment, June 17-18, Whitehorse, Yukon Territory, Canada. Environmental Protection Service, Vancouver, B. C.. 20 pp.

REFERENCE LOCATION: Alaska Department of Fish and Game, Habitat Division, Fairbanks

IMPORTANT PAGES: 1-20

KEY WORDS: Sediment, Salmonid, Turbidity, Periphyton, Primary Production, Algae, Macrophytes, Invertebrates

ANNOTATION

Available data from several investigators indicate that sediment can affect all forms of stream life. The greater the increase in sediment in a salmonid stream, the greater will be the adverse effects on plant and animal life present in the stream. The addition of sediment to a stream increases turbidity, causes scouring, smothers periphyton, and produces unstable substrates. These conditions have an adverse impact on primary production, photosynthetic activity of algae and macrophytes, and invertebrate populations. Since lower trophic levels produce most of the food required for salmonid production, any decrease in their quantity or quality will affect fish growth and survival. Sediments may directly affect fish through abrasion and/or clogging of gills, reducing feeding efficiency, and destruction of eggs in spawning grounds.

The British Columbia Pollution Control Branch accepts 50 mg/L as an acceptable sediment release level, while Federal Fisheries accepts releases of 25 mg/L or background levels, whichever is greater. The state of Oregon insists that releases be no higher than background levels up to 30 JTU. When background levels exceed 30 JTU, the release may elevate background levels by 10 percent. Unfortunately, turbidity does not necessarily correlate with the amount of suspended sediment present.

REFERENCE: Lenat, D.R., D. L. Penrose, and K. W. Eagleson, 1981. Variable effects of sediment addition on stream benthos. Hydrobiologia, 79:187-197.

REFERENCE LOCATION: Biomedical Library, University of Alaska, Fairbanks

IMPORTANT PAGES: 187, 188, 192, 193

KEY WORDS: Sediment, Invertebrates, Benthos, Stream

ANNOTATION

The effects of sediment inputs from road construction on two streams were studied. Data suggest that the benthic stream community responded to sediment additions in the following ways. As sediment was added to a stream, the area of available rock habitat decreased with a corresponding decrease in benthic density. During low flow conditions a stable sand community develops which is qualitatively different from the rocky substrate community. During periods of high flow, sand substrates are an unsuitable habitat for benthic organisms. As available habitat decreases, the benthic community has a markedly lower density. Both streams exhibited downstream increases in mean suspended solids concentrations in the range of 17 to 105 mg/L, and in the percentage of substrate sand and gravel.

REFERENCE: Lloyd, D. S., 1985. Turbidity in freshwater habitats of Alaska: a review of published and unpublished literature relevant to the use of turbidity as a water quality standard. Report No. 85-1, Alaska Dept. of Fish and Game, Habitat Division, Juneau, Alaska. 101 pp.

REFERENCE LOCATION: Alaska Department of Fish and Game, Anchorage

IMPORTANT PAGES: 39-46, 51-70

KEY WORDS: Turbidity, Suspended Sediment, Water Quality Standards, Aquatic Habitat

ANNOTATION

This report is a review and interpretation of information provided by numerous investigators on turbidity as it relates to freshwater aquatic habitats in Alaska. A summary of information from Alaska and elsewhere addressing the effects of turbidity on freshwater aquatic habitats is presented. A specific discussion is presented concerning turbidity as it affects light penetration, primary production, secondary production, and human use of freshwater habitats. This information provides a basis for establishing turbidity water quality standards. Relationships between turbidity and suspended sediment are also discussed. Summary tables present documented effects or relationships of turbidity and suspended sediment ranges on a variety of systems and organisms. It is concluded that turbidity is a reasonable water quality standard for use in Alaska. Based on current information, the present standards provide a moderate level of protection for the propagation of fish and wildlife in clear water aquatic habitats. This paper also presents a model predicting the effects of turbidity on primary productivity.

REFERENCE: McCabe, G. D., and W. J. O'Brien, 1983. The effects of suspended silt on feeding and reproduction of Daphnia pulex. American Midland Naturalist, Vol. 110, No. 2, pp. 324-337.

REFERENCE LOCATION: University of Alaska Library, Fairbanks

IMPORTANT PAGES: 329-335

KEY WORDS: Daphnia pulex, Zooplankton, Suspended Silt, Filtering Efficiency, Assimilation Rate, Growth, Size, Reproduction

ANNOTATION

The effects of suspended silt and clay on the filtering and assimilation rates of Daphnia pulex were determined using a Carbon 14 radiotracer method. The filtering rate for all observations at turbidity less than 10 NTU is 2.03 ml/animal/hr. At a turbidity of 10 NTU the filtering rate significantly declines. The decrease in filtering rates above turbidities of 10 NTU is probably due to increased gut-loading of ingested silt. In addition, with an increase in suspended silt concentration from 0 to 10 NTU, the assimilation rate of algae by D. pulex decreased to below 55 percent in all cases. It was shown that the greatest effect of turbidity on assimilation efficiency occurs at low turbidity values. Results from a life table experiment show that even low suspended silt levels impaired healthy Daphnia population growth. Fecundity levels were also greatly influenced by increased levels of suspended silt. The filtering rates for turbidities used in the life table experiment were 2.5 ml/animal/hr at 2 NTU, but declined to 0.4 ml/animal/hr at 33 NTU. When assimilation efficiencies are factored in, animals feeding at 2 NTU would obtain 16 times more energy than animals feeding at 33 NTU. The mean body length for control animals was significantly smaller than the mean body length of D pulex raised in both low and high silt environments. The most likely reason for this discrepancy is that animals growing in the suspended silt environment channel more energy into increasing body size than into reproduction. Although the animals raised in suspended silt were larger, they were not as healthy as those raised in the absence of silt. Specifically, the individuals raised in silty water lacked carapace strength and resiliency. It was concluded that both filtering efficiency and assimilation rates are severly depressed at even low concentrations of suspended silt and clay. Furthermore, the population growth rate of zooplankton was significantly diminished by suspended silts and clays.

REFERENCE: McCart, P. J., P. M. R. Green, D. W. Mayhood, and P. T. P. Tsui, 1980. Environmental studies No. 13 effects of siltation on the ecology of Ya-Ya Lake, N. W. T. Prepared for Minister of Indian and Northern Affairs by Aquatic Environments, Limited, Calgary, Alberta. 286 pp.

REFERENCE LOCATION: Nichols Environmental Consulting

IMPORTANT PAGES: 85-141, 144-162, 231-235, 250-274

KEY WORDS: Suspended Sediment, Turbidity, Secchi Disk, Chlorophyll-a

ANNOTATION

The report provides a detailed discussion of a variety of water quality parameters and the ecology of Ya-Ya Lake, Northwest Territories. Water quality parameters discussed include suspended sediment, Secchi disk transparency, turbidity, temperature, dissolved oxygen, pH, alkalinity, and nutrients. Biological functional groups discussed include phytoplankton, zooplankton, zoobenthos, and fish. The report also addresses the problem of quantitative standards for suspended solids, including the relationship between turbidity and suspended solids.

REFERENCE: McCluney, W. R., 1975. Radiometry of water turbidity measurements. Journal Water Pollution Control Federation, 47(2):252-266.

REFERENCE LOCATION: L. A. Peterson & Associates, Inc.

IMPORTANT PAGES: 252, 253, 256-264

KEY WORDS: Turbidity, Transmittance, Scatter, Nephelometric

ANNOTATION

A number of optical measurement techniques for particulates have been developed that are easy and quick and can be performed *in situ*. However, these methods are applicable only if a proper relationship between the optical property being measured and the amount of suspended sediment can be found. Some of these techniques yield results that are roughly proportional to the amount of suspended material under certain circumstances. However, the optical properties of these techniques rely on the shape, refractive index, particle size distribution, particle concentration, and the absorption spectra. Hence, optical properties are proportional to mass or volume concentration only when all other parameters are constant. However, natural waters exhibit considerable variability in these parameters, which makes the establishment of the desired relationship difficult. This variability in natural water severly restricts the usefulness of using optical techniques for routine measurement of the amount of suspended material.

Of the various techniques for measuring optical properties, turbidity and transparency are the most widespread.

A variety of definitions of turbidity exist. These include the intensity of light transmitted (unscattered) through the sample, a ratio of the intensity of light scattered by a sample to the intensity of the light source, the amount of light scattered and absorbed rather than transmitted in straight lines through the sample, and a reduction in transparency of a sample due to the presence of particular matter. Turbidity has also been defined as the amount of suspended matter, in ppm, as ascertained by optical observation, and in terms of different measurement techniques (e.g., Jackson Candle and Nephelometric turbidity).

REFERENCE: McLeay, A. J., A. J. Knox, J. G. Malick, I.K. Birtwell, G. Hartman, and G. L. Ennis, 1983. Effects on Arctic grayling (Thymallus arcticus) of short-term exposure to Yukon placer mining sediments: laboratory and field studies. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1171. 40 pp. + Appendices.

REFERENCE LOCATION: Alaska Department of Fish and Game, Habitat Division, Fairbanks

IMPORTANT PAGES: xiii, xiv, 34, 35

KEY WORDS: Grayling, Suspended Sediment, Mortality, Sub-lethal Effects, Blood Glucose Levels, Gill Histologies

ANNOTATION

In a laboratory study, laboratory-reared grayling which were acclimated to 15 degrees C survived a 4-day exposure to sediment suspensions of <250,000 mg/L, and a 16-day exposure to 50,000 mg/L. Fish which were acclimated to 5 degrees C and held in pay dirt suspensions of <10,000 mg/L survived for 4 days, whereas 10 to 20 percent mortality occurred at the higher concentrations. Inorganic sediment levels of >10,000 mg/L caused fish to surface, a direct response to elevated sediment levels. The gill histologies of fish surviving these 4-day exposures was normal. Suspensions of sediment caused acute stress responses (elevated and/or more varied blood glucose levels, depressed leucocrit levels) in grayling acclimated to either temperature. Hematocrit values for these fish were not affected by sediments.

During summer field bioassay studies, all grayling held in <20 mg/L and <100 mg/L streams survived with no overt signs of distress or physical damage. Subsequently, fish captured in low suspended solids water were exposed to levels of <1210 mg/L and <34 mg/L for 5 days in two separate streams. Although all of these fish survived, gill tissues from specimens at each site showed moderate-to-marked hypertrophy and hyperplasia of lamellar epithelium, along with a proliferative number of gill ectoparasites. It was concluded that short-term exposure of Arctic grayling to sublethal concentrations of suspended sediment can cause a number of effects including acute stress responses.

REFERENCE: NCASI, 1984a. A laboratory study of the effects of sediments of two different size characteristics on survival of rainbow trout (Salmo gairdneri) embryos to fry emergence. National Council of the Paper Industry for Air and Stream Improvement, Technical Bulletin No. 429, April, 1984. 49 pp. + Appendices.

REFERENCE LOCATION: University of Alaska Library, Fairbanks

IMPORTANT PAGES: 45, 46

KEY WORDS: Fine Sediment, Rainbow Trout, Embryos, Fry Emergence, Entrapment, Mortality, Survival

ANNOTATION

This technical bulletin describes the findings of a continuing laboratory study of the effects of selected fine sediments on the survival of rainbow trout embryos to fry emergence. The presence of fine sediment was observed to be beneficial as well as detrimental depending on the size of the sediment. Physical entrapment was indicated to be the principle cause of mortality while there was no discernable difference in fish sizes or times of fry emergence under the conditions studied. Conclusions from this study are as follows. Major differences were observed in the survival of rainbow eggs to the time of emergence, between <0.88 mm and <6.4 mm diameter sediment. Fines <0.8 mm were found to reduce survival by 1.1 percent for each percent increase in fines over the range of 10 to 40 percent. This compares to a 1.8 percent mean reduction in survival for each percent increase in fines, determined from a large number of literature references. The presence of coarse fines <6.4 mm diameter reduced survival by approximately 0.8 percent for each percent increase in fine sediment over the range of 0 to 40 percent fines.

REFERENCE: NCASI, 1984b. The effects of fine sediment on salmonid spawning gravel and juvenile rearing habitat - a literature review. National Council of the Industry for Air and Stream Improvement, Technical Bulletin No. 428, New York. 66 pp.

REFERENCE LOCATION: University of Alaska, Fairbanks

IMPORTANT PAGES: 12-21, 30-61

KEY WORDS: Fine Sediment, Salmonids, Survival, Mortality, Emergence, Production, Turbidity, Avoidance, Feeding, Measurement Techniques

ANNOTATION

A literature review is presented on the effects fine sediments may have on salmonid habitats, primarily with reference to spawning gravel and juvenile rearing habitat. Life history and habitat characteristics of eight species are summarized. Fine sediments in spawning gravel have been defined as particles being anywhere from 0.8 mm to 9.51 mm diameter, depending on the author. It has been shown that an increase in fine sediment decreases gravel permeability, intragravel water flow, and oxygen concentrations in the gravel, decreases embryonic survival, impairs normal embryo development, and affects timing, size, and success of fry emergence. Documented effects on salmonids are presented for the eight species.

Documented effects of fine sediment in the water column and streambed on juvenile salmonids pertain to growth, survival, movement, density, size, biomass, and production. Catchability of fish was reduced when turbidity exceeded 30 JTU due to reduced visibility. Algal-based food production is reduced when turbidities exceed 25 JTU. Fish movement was impaired in streams where silt exceeded 4,000 ppm. Juvenile coho salmon which were preacclimated to turbidity exhibited an avoidance reaction at threshold levels of 100 NTU.

Fine sediment measurement techniques include the McNeil bottom sampler, a device for measuring gravel size constituents by volumetric development, a liquid carbon dioxide freeze core sample device, and a tritube freeze core sampler.

REFERENCE: Noggle, C.C., 1978. Behavioral, physiological and lethal effects of suspended sediment on juvenile salmonids. M.S. Thesis, College of Fisheries, Univ. of Washington, Seattle, WA. 87 pp.

REFERENCE LOCATION: University of Alaska, Fairbanks (Interlibrary loan)

IMPORTANT PAGES: 2-7, 59-75

KEY WORDS: Suspended Sediment, Salmonids, Bioassay, Turbid

ANNOTATION

Studies were conducted to assess the effects of suspended sediment on juvenile salmonids in the stream environment. Static bioassay tanks were used to determine 96 hour LC50's, changes in gill histology, and changes in blood physiology. Two experimental stream designs were used to relate sediment concentrations to avoidance behavior.

Results, involving acute (4 days or less) rather than chronic exposure to suspended sediments, indicate seasonal changes in the tolerance of salmonids to suspended sediment. Bioassays conducted in summer produced LC50's less than 1500 mg/L, while autumn bioassays showed LC50's in excess of 30,000 mg/L. The tolerance of wild coho salmon to suspended solids was higher than hatchery produced coho's, apparently because of prior exposure to suspended sediments. Histological examination of gills revealed structural damage by suspended sediment. Blood chemistry showed elevated blood glucose levels at sublethal suspended sediment concentrations. Experiments conducted with a turbid artificial stream and clear tributary indicated a reluctance by the fish to leave their established territories. Studies conducted with a Y-shaped stream showed a preference for turbid water at low to medium concentrations and slight avoidance at high concentrations.

REFERENCE: Nuttall, P.M., and G. H. Bilby, 1973. The effect of china-clay wastes on stream invertebrates. Environmental Pollution, (5):77-86.

REFERENCE LOCATION: University of Alaska Library, Fairbanks

IMPORTANT PAGES: 77, 79, 81, 83

KEY WORDS: Clay Wastes, Suspended Solids, Deposited Solids, Aquatic Plants, Macroinvertebrates, Population, Density, Abundance

ANNOTATION

Rivers polluted with clay wastes supported a sparse population of few species. Rooted aquatic vegetation was absent at stations where the suspended solids concentration was high (>2000 ppm), whereas unpolluted reaches supported a rich community of aquatic plants. Control streams supported 36 times the density of animals found at clay-polluted stations. Species composition was greater in unpolluted rivers and at stations downstream of sewage outfalls compared with clay-polluted reaches. Clay pollution either eliminated or reduced the abundance of several macroinvertebrate species frequent in control streams. The absence of plants and macroinvertebrates in rivers receiving clay waste was associated with the deposition of fine inert solids rather than turbidity or abrasion by particles in suspension.

REFERENCE: Phillips, R. W. 1971. Effects of sediments on the gravel environment and fish production. In: Proc. of Symp. Forest Land Uses and Stream Erosion, Oregon St. Univ.

REFERENCE LOCATION: Alaska Department of Fish and Game, Anchorage

IMPORTANT PAGES:

KEY WORDS: Rainbow Trout, Gold Mining, Logging, Turbidity

ANNOTATION

Sediment influences fish in many ways: (1) Blocks transmission of light, reducing algae production; (2) Damages gill membranes and can cause death where concentrations are high and exposures are long; (3) Harms spawning by filling interstices and reducing oxygen exchange; (4) Interferes with removal of metabolites; (5) Makes barriers preventing fry from emerging; and, (6) Reduces cover on stream bottom. Sediment is defined as particles less than 4 mm in size. Fishing success is reduced where turbidity is greater than 25 ppm. Concentrations of kaolin and diatomaceous earth of 270 to 810 ppm for 10 days killed rainbow trout. Mortality of 57 percent in rainbow fingerlings one and a half mile downstream of a gold dredge producing 1000 to 2500 ppm solids occurred in 20 days versus 9.5 percent mortality in a control stream. Other fish species such as sunfish and bass appear to be more tolerance of turbidity. Turbidity is produced from erosion as a result of logging, road building, mining, and other activities.

REFERENCE? Phillips, R. W., R. C. Lantz, E. W. Claire, and J. R. Moring, 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Trans. Amer. Fish. Soc., 104(3):461-466.

REFERENCE LOCATION: Alaska Resources Library, Anchorage (microfilm)

IMPORTANT PAGES:

KEY WORDS: Coho Salmon, Steelhead Trout, Sedimentation

ANNOTATION

Eight mixtures of sand and gravel were tested in incubation troughs using coho salmon and steelhead eggs. Survival for coho eggs was 96 percent in control mixture, 82 percent in 10 percent sand, 64 percent in 20 percent sand, 38 percent in 30 percent sand, 20 percent in 40 percent sand, 22 percent in 50 percent sand, and 8 to 10 percent in 60 to 70 percent sand. Sand was 1 to 3 mm in diameter. For steelhead, the relationship was similar, ranging from 99 percent in the control mixture to 18 percent in 70 percent sand. Emergence of fry appeared to be earlier than normal. This study appears to support previous studies which have shown the inverse relationship between the amount of fines and egg survival.

REFERENCE: Pickering, R. J., 1976. Measurement of "turbidity" and related characteristics of natural waters. Open-File Report 76-153, U.S. Geological Survey. 13 pp.

REFERENCE LOCATION: L. A. Peterson & Associates, Inc.

IMPORTANT PAGES: 1, 2

KEY WORDS: Turbidity, Jackson Candle, Formazin, Nephelometric

ANNOTATION

Attempts to quantify turbidity have led to a proliferation of definitions, methods of measurement, instruments, standards, and units of measure. Turbidity data for natural waters are applied to several uses, including: (1) Determination of the depth to which photosynthesis can occur; (2) Aesthetic evaluation of water used for recreation; and, (3) Estimation of concentration of suspended sediment. Lack of standardization of the measurement often has resulted unwittingly in correlations between unrelated numbers. There is a strong feeling within the hydrologic profession that more precise and definitive sets of methods and terminology are required. Turbidity generally is measured as an optical phenomenon and should be reported in optical units.

The U. S. Geological Survey has adopted the following principles: (1) Standard instruments and methods should be adopted to measure and report the light transmitting characteristics of natural waters in optical units, thus avoiding the use of "turbidity" as a quantitative measure; (2) Reporting of "turbidity" in Jackson Turbidity Units, Hellige Units, severity, or Nephelometric Turbidity Units should be phased out; (3) The basis for estimations of sediment concentrations using light measurements should be documented adequately; and, (4) The use of transparency measurements by Secchi disk is considered to be acceptable, although light transmittance may prove to be a more precise means of obtaining the same information.

REFERENCE: Shelton, J. M., and R. D. Pollock, 1966. Siltation and egg survival in incubation channels. Trans. Amer. Fish. Soc., 95(2):183-189.

REFERENCE LOCATION: Alaska Resources Library, Anchorage (microfilm)

IMPORTANT PAGES:

KEY WORDS: Chinook Salmon, Chum Salmon, Siltation

ANNOTATION

Chinook and chum salmon eggs in incubation channels were subjected to siltation. In the first season, 180,000 chinook eggs were planted and no siltation control measures were implemented. Survival of eggs was 50 percent. In the succeeding two seasons, chum salmon eggs were planted and silt control measures were implemented. Survival was 92 and 95 percent, respectively. Silt was cleaned from the channel after the first season. Deposition was primarily silts and clays and accounted for 0.5-10.4 percent of total substrate sample weight. In the first season, siltation was so heavy that an estimated 35.3 percent of intergravel voids were filled. The upper portion of the channel was used as a settling basin in seasons 2 and 3 and most of the material settled out. Mortality of eggs in the first season ranged from 85 percent in the heaviest silt to 32 percent in the lightest silt.

REFERENCE: Sigler, J. W., T. C. Bjornn, and F. H. Everest, 1984. Effects of chronic turbidity on density and growth of steelheads and coho salmon. Trans. Amer. Fish. Soc., 113(2):142-150.

REFERENCE LOCATION: Alaska Resources Library, Anchorage

IMPORTANT PAGES:

KEY WORDS Coho Salmon, Steelhead, Turbidity

ANNOTATION

Yearlong and older salmon can survive high concentrations of suspended sediment for considerable lengths of time. Mortality occurs above 20,000 mg/L. This paper considers the effects of suspended sediments on newly emerged young. Tests done in laboratory streams used clay, fireclay and bentonite. Significant differences were seen between the growth rate of fish in clear versus turbid streams. Fish tended to move out of turbid channels. In natural systems, newly emerged fish encountering turbidity would likely move out of the area. Gill tissue damage was observed after 3 to 5 days in turbid water. As little as 25 NTU caused reduction in fish growth, probably from reduced ability to feed. It is not known if this is due to inability to see prey or interceptions of appropriate light wavelengths by particles. At turbidities of 100 to 300 NTU, fish left the channels or died. The tests were conducted primarily with turbidities of 25-50 NTU.

REFERENCE: Sigma Resource Consultants, 1979. Summary of water quality criteria for salmonid hatcheries. Dept. of Fisheries and Oceans.

REFERENCE LOCATION: Alaska Department of Fish and Game, Anchorage

IMPORTANT PAGES:

KEY WORDS: Salmon, Suspended Solids

ANNOTATION

Criteria are established to allow evaluation of new water sources and identify water treatment needs when establishing a hatchery. Primary fish culture parameters such as dissolved oxygen, pH, ammonia, dissolved carbon dioxide, hydrogen sulfide, nitrite, and suspended solids are considered. Suspended solids are either organic or inorganic. Inorganic solids can transport adsorbed pollutants such as pesticides. Coating of fish eggs with silt can inhibit gas transfer of carbon dioxide, oxygen, and ammonia. It can also affect juvenile fish by reducing growth rate, reducing dissolved oxygen, disrupt feeding, transportation of adsorbed pollutants, and damage to gills. It is suggested that an acceptable limit of suspended solids for incubating eggs is 3 mg/L and for rearing and holding the limit would be 25 mg/L in the absence of other pollutants.

REFERENCE: Simmons, R. C., 1984. Effects of placer mining sedimentation on Arctic grayling of interior Alaska. M.S. Thesis, University of Alaska, Fairbanks, Alaska. 75 pp.

REFERENCE LOCATION: L. A. Peterson & Associates, Inc.

IMPORTANT PAGES: 3, 52-65

KEY WORDS: Turbidity, Settleable Solids, Total Residue

ANNOTATION

The effects of placer mining sedimentation on Arctic grayling were assessed by comparing data collected in mined and unmined streams. Although many young-of-the-year and adult grayling used unmined streams for summer habitat, no grayling were found in the mined streams except during periods of migration. Grayling apparently selected clear water streams for summer residence.

Caged fish studies demonstrated that if grayling could not escape from streams carrying mining sediments, they would suffer direct, chronic effects, including gill damage, dietary deficiencies, and slowed maturation. The indirect effects of sedimentation on grayling populations, through loss of summer habitat for feeding and reproduction, are more severe than the direct ones.

Based on this study, the following water quality guidelines and corresponding levels of protection expected in receiving waters were suggested:

Level of Protection	Total Residue, mg/L	Settleable Solids, ml/L	Turbidity, NTU
High	< 150	< 0.1	< 25
Moderate	150-300	0.1-0.2	25-100
Low	> 300	> 0.2	> 300

REFERENCE: Sorensen, D. L., M. M. McCarthy, E. J. Middlebrooks, and D. B. Porcella, 1977. Suspended and dissolved solids effects on freshwater biota: a review. EPA-600/3-77-042, Corvallis Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Corvallis, Oregon. 65 pp.

REFERENCE LOCATION: L. A. Peterson & Associates, Inc.

IMPORTANT PAGES: 1, 2, 21,22, 32-42

KEY WORDS: Suspendedanisms were difficult to demonstrate; Suspended solids have significant effects on community dynamics due to turbidity; Suspended solids may have significant effects on community succession, community stability, and fish avoidance reactions; Sediments may serve as a reservoir of toxic chemicals; and, Relatively high suspended solids were needed to cause behavioral reactions (20,000 mg/L) or death (200,000 mg/L) in fish over the short term.
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REFERENCE: Symons, J. M., and J.C. Hoff, 1975. Rationale for turbidity maximum contaminant level. Presented at Third Water Quality Technology Conference, American Water Works Association, Atlanta, Georgia, December 8-10, 1975. Water Supply Research Division, Environmental Protection Agency, Cincinnati, Ohio. 18 pp.

REFERENCE LOCATION: Alaska Department of Environmental Conservation

IMPORTANT PAGES: 1-4, 15, 17

KEY WORDS: Turbidity

ANNOTATION

For drinking water, 5 units of turbidity became objectionable to a considerable number of people, and many people turn to alternate supplies which may be less safe. The relationship between particulates in the water and the presence of disease causing organisms was documented from literature. Turbidity even at low levels, above 1 turbidity unit, interferes with disinfection and prevents maintenance of an effective disinfectant agent (e.g., chlorine) throughout the distribution system. Indications are that bacteria and viruses can be protected by certain kinds of particles from inactivation by chlorine. Inorganic particles can cause turbidity and probably have no bearing on the potential protection of pathogens. Small organic particles, on the other hand, may protect pathogens. Therefore, in evaluating turbidity, the nature of the particles in the water must be taken into account.

REFERENCE: Tappel, P. D., and T. C. Bjornn, 1983. A new method of relating size of spawning gravel to salmonid embryo size. North American Journal Fisheries Management, 3:123-135.

REFERENCE LOCATION" University of Alaska Library, Fairbanks

IMPORTANT PAGES: 129-131

KEY WORDS: Salmonid, Survival, Size, Emergence, Spawning Gravel, Fine Sediment

ANNOTATION

A new method for describing the size composition of salmonid spawning gravel was developed. Salmonid embryo survival was related to two particle size groups, 9.50 mm and 0.85 mm, in laboratory tests. In these tests, >90 percent of the variability in embryo survival was correlated with changes in subtrate size composition. Gravel mixtures containing high percentages of the fine sediment produced slightly smaller steelhead fry than gravels containing low percentages of fine sediment. There was no relationship between changes in gravel size composition and the size of chinook salmon emergents. In gravels containing large amounts of fine sediment, many of the steelhead and chinook salmon fry emerged before yolk sac absorption was complete.

REFERENCE: Thurston, R. V., R. C. Russo, C. M. Fetterolf, Jr., T. A. Edsall, Y. M. Barber, Jr., (eds.), 1979. A review of the EPA Red Book: quality criteria for water. Water Quality Section, American Fisheries Society, Bethesda, MD. 313 pp.

REFERENCE LOCATION: L.A. Peterson & Associates, Inc.

IMPORTANT PAGES: 1, 2, 266-270

KEY WORDS: Suspended Solids, Settleable Solids, Turbidity, Residue, Criteria, Aesthetics, Freshwater Aquatic Life, Protection

ANNOTATION

This is a review and discussion of EPA criteria for suspended solids, settleable solids, and turbidity with regard to aesthetic water quality, freshwater fish and other aquatic life. The aesthetics criteria are generally satisfactory as stated in the Red Book. Recommendations for improvement of aesthetics criteria include definition of nuisance organisms, and recognition and discussion of the aesthetic value of biological components of aquatic systems. The criterion for freshwater and other aquatic life is difficult to apply under most conditions and impossible to apply in others. Turbidity and solids are not synonymous as suggested in the Red Book, and no method is proposed for measuring the compensation point. There is no correlation made between sedimentation effects and the criterion or with compensation depth. The recommended maximum concentrations of suspended solids for various levels of protection are oversimplified in the Red Book to the extent that they are no longer scientifically sound. The application of reduced photo-synthetic activity as a criterion for freshwater fish appears to be an indirect measurement of the effects of sediment and turbidity, at best. Residues (turbidity and solids) should be considered separately with each parameter measured in standard units. The criterion for solids should be defined in mg/L of residues (solids), turbidity in NTU, and terminology should be consistent with Standard Methods. Future EPA criteria should take into account the criteria developed by a number of authors. Many of these data would support a limit of 100 mg/L non-filterable residue for fresh and estuarine waters to prevent mortality. However, one reviewer of the Red Book thought that 100 mg/L is too restrictive and that concentrations could be much higher without causing adverse effects. There is no universal agreement as to levels of turbidity to be allowed nor is there agreement upon units to be used.

REFERENCE: Truhlar, J. F., 1976. Determining suspended sediment loads from turbidity records. In: Proc. Third Inter-Agency Sedimentation Conf., 1976. Water Resources Council, Denver, CO.

REFERENCE LOCATION: Alaska Department of Fish and Game, Anchorage

IMPORTANT PAGES:

KEY WORDS: Turbidity, Suspended Solids

ANNOTATION

Methods of evaluating sediment-control measures are considered. Field data shows a good correlation between mean daily discharge-weighted turbidity and mean daily discharge-weighted suspended solids concentration. Digital and graphic recorders were employed to measure turbidity. Although there appears to be no universal relationship between turbidity and suspended sediments, there appears to be a good correlation for individual streams. Turbidity could be taken and suspended solids computed using water discharge records. Actual measurement must be made to establish the correlation and then periodically to verify it.

REFERENCE: Turnpenny, A. W. H., and R. Williams, 1980. Effects of sedimentation on the gravels of an industrial river system. Journal Fish Biology, 17:681-693.

REFERENCE LOCATION: University of Alaska Biomedical Library, Fairbanks

IMPORTANT PAGES: 684, 686-691

KEY WORDS: Trout, Mortality Rate, Eggs, Alevins, Suspended Solids, Dissolved Oxygen, Permeability

ANNOTATION

Rainbow trout eggs were planted in river gravels to assess the effects of siltation on salmonid spawning success. In reaches where siltation due to the coal industry has occurred, 98 to 100 percent of eggs died during incubation in the gravels. This high mortality rate corresponds to suspended solids concentrations of 2 to 2481 mg/L, gravel permeabilities in the range of 5 to 74 cm/h, and dissolved oxygen concentrations of 2.4 to 7.8 mg/L. In another river egg mortality ranged from 24 to 98 percent corresponding to suspended solids levels of 3 to 1810 mg/L, gravel permeabilities ranging from 7 to 2950 cm/h, and dissolved oxygen of 3.8 to 8.6 mg/L. The lower mortality rate in the later river is probably a reflection of the lower suspended solids levels. Alevin survival threshold values for dissolved oxygen and permeability are around 4.9 mg/L and 40 cm/h, respectively. It was calculated that a 50 percent alevin mortality rate corresponds to a dissolved oxygen concentration of 6.5 mg/L. Alevin size also showed a strong positive correlation with the dissolved oxygen supply rate.

REFERENCE: Van Nieuwenhuyse, E. E., 1983. The effects of placer mining on the primary productivity of interior Alaska streams. M.S. Thesis, University of Alaska, Fairbanks, Alaska. 120 pp.

REFERENCE LOCATION: L. A. Peterson & Associates, Inc.

IMPORTANT PAGES: 58-66

KEY WORDS: Turbidity, Settleable Solids, PAR, Gross Productivity, Algal Productivity, Recreational Activities, Criteria

ANNOTATION

A strong positive correlation was observed between incident PAR and gross productivity, attesting to the importance of light in regulating primary production. This relationship provides the partial basis for a model which could be used to predict algal productivity at different turbidity levels.

Recreational activities such as canoeing and fishing would probably be popular on Birch Creek if the channel were rehabilitated to allow fish passage, and if turbidity could be maintained below 200 to 300 NTU. The results of this study support the contention that a settleable solids standard of <0.1 ml/L for receiving waters could be reasonable. With regard to turbidity, the following tentative criteria are suggested: 6 to 25 NTU high level of protection, 25 to 100 NTU moderate, 100 to 300 NTU low, 300 to 500 NTU very low.

REFEREBCE: Vanous, R. D., P. E. Larson, and C. C. Hach, 1982. The theory and measurement of turbidity and residue. *In:* Water Analysis Volume 1 inorganic species, Part I, Academic Press, New York, N.Y. pp. 164-234

REFERENCE LOCATION: L. A. Peterson & Associates, Inc.

IMPORTANT PAGES: 167-221

KEY WORDS: Turbidity, Nephelometric, Residue, Suspended and Dissolved Solids

ANNOTATION

The theory of light scattering is presented by a review of terminology, Rayleigh scattering and theory, and Mie scattering. The discussion of the measurement of turbidity includes the effects of sample and instrument parameters on turbidity measurement, a history of turbidimetric methods, modern nephelometric instrumentation, commercial instrument responses, process instruments, specifications for nephelometric instrumentation, methods of instrumental turbidity measurement, and the potential of future nephelometric developments.

REFERENCE Wilber, C. G., 1983. Turbidity in the aquatic environment, an environmental factor in fresh and oceanic waters. Charles C. Thomas, Publisher, Springfield, Illinois. 133 pp.

REFERENCE LOCATION: Nichols Environmental Consulting

IMPORTANT PAGES: 25-36, 41-108, 112-116

KEY WORDS: Turbidity, Suspended Solids, Freshwater, Marine Water, Effects

ANNOTATION

A review of key literature quantifies the effects of turbidity and suspended solids on fresh and marine water uses. Included are effects on chemical and physical water quality, water supply, freshwater and marine organisms and aesthetics. Biological effects on a wide variety of organisms include physiological, feeding efficiency, feeding selection, feeding rates, filter-feeder feeding, reproductive behavior, population numbers and densities, growth and development, resistance to disease, and habitat utilization. Specific groups of organisms discussed are warm water fishes, salmonid fishes, freshwater macroinvertebrates, and a number of marine organisms including coral, filter feeding organisms, and marine mammals.

Streams may be classified according to suspended solids concentrations. A concentration of 25 to 30 ppm is optimal, 30 to 85 ppm is good, 85 to 400 ppm is poor, and >400 ppm is extremely bad.

REFERENCE: Witzel, L. D., and H. R. MacCrimmon, 1981. Role of gravel substrate on ova survival and alevin emergence of rainbow trout, Salmo gairdneri. Canadian Journal of Zoology, Vol. 59. pp. 629-636.

REFERENCE LOCATION: Cooperative Fish Unit, University of Alaska, Fairbanks

IMPORTANT PAGES: 629, 632-635

KEY WORDS: Gravel Size, Trout, Ova, Alevins, Survival, Emergence

ANNOTATION

A verticle flow incubation apparatus was used to determine the role of various gravel sizes on ova survival and emergence of rainbow trout alevins. Survival to emergence, time of emergence, and alevin condition at emergence were significantly influenced by gravel size. Mean percent survival to emergence increased from 1 percent in 2-mm gravel to 76 percent in 26.5-mm gravel. Survival of ova to swim-up stage in a gravel free incubator was 88 percent. Differences in percent survival were most significant within the 2 to 8 mm gravel range. Poor survival of trout alevins in the 2 to 4 mm gravel was the result of entrapment. The time to emergence also increased with gravel size. Larger alevins, which emerged later from coarser gravels had the least yolk reserve. Premature emergence of free embryos and shortening of the alevin emergence period in 2.0-mm gravel was identified as a stress response.

APPENDIX B

GENERAL LITERATURE--FRESH WATER

The references listed herein were reviewed by project team members and judged to be: (1) Too general; (2) Inapplicable to the scope of this project (e.g., related topics such as biological life history); (3) The information contained in a specific reference was explained in more detail in one or more of the references appearing above in Appendix A; or, (4) Only a portion of the reference was applicable and this information is cited in the text of the report.

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APPENDIX C

ANNOTATED BIBLIOGRAPHIES--MARINE

REFERENCE: Auld, A. H., and J. R. Schubel, 1978. Effects of suspended sediment on fish eggs and larvae: a laboratory assessment. Estuarine and Coastal Marine Science, (6)153-164.

REFERENCE LOCATION: University of Alaska Library, Fairbanks

IMPORTANT PAGES: 153

KEY WORDS: Suspended Sediments, Laboratory, Fish Eggs, Fish Larvae, Hatching, Survival

ANNOTATION

Eggs and larvae of six species of anadromous and estuarine fish were exposed to concentrations of suspended sediment up to 100 mg/L to determine the effects of different concentrations on hatching success and short term survival. Egg experiments indicate that concentrations of up to 1000 mg/L did not significantly affect the hatching success of yellow perch, blueback herring, alewife or American shad eggs. The same concentrations did however significantly reduce the hatching success of white perch and striped bass, whereas lower concentrations did not. Experiments with larvae indicated that concentrations above 500 mg/L significantly reduced the survival of striped bass and yellow perch. Concentrations above 100 mg/l significantly reduced the survival of American shad larvae continously exposed for 96 hours. The significance of these results are discussed in relation to changes in sediment loading in estuaries.

REFERENCE: Brehmer, M. L., 1965. Turbidity and siltation as forms of pollution. Journal of Soil and Water Conservation, July-August, 1965. pp. 132-133.

REFERENCE LOCATION: University of Alaska, Fairbanks. (Interlibrary loan)

IMPORTANT PAGES: 132-133

KEY WORDS: Suspended Solids, Sediment Deposition, Effects, Estuarine Systems, Aesthetic Quality, Recreational Uses, Phytoplankton, Zooplankton, Infauna, Benthos

ANNOTATION:

The role of suspended solids and sediment depositions in estuarine systems is discussed in this paper. The destruction of recreational beaches and aquatic habitats is well documented. Grounds made suitable for oyster culture suffer heavily from siltation. Dredge spoil disposal studies indicate that infaunal forms are destroyed by smothering. Siltation can also smother epifaunal forms, and the unstable characteristics of silt deposits could prevent re-establishment of populations. Suspended solids in water have a definite effect on the water's aesthetic quality and its value for recreational purposes. The concentration at which water becomes objectionable to the user is a matter of individual conditioning. The biological effects of inorganic suspended solids to estuarine communities are complex and extremely difficult to quantify. The effects of inorganic sediments on zooplankton and higher aquatic life are even more difficult to evaluate than the effects on phytoplankton. Man-made levels of turbidity undoubtedly exert injurious effects on the estuarine community. Shellfish and finfish are especially vulnerable to damage by inorganic suspended solids. The feeding activity of certain filter-feeding shellfish is inhibited by high suspended solids levels.

REFERENCE: Davis, H. C., and H. Hidu, 1969. Effects of turbidity-producing substances in sea water on eggs and larvae of three genera of bivalve mollusks. The Veliger, Vol. II, No. 4. pp. 316-323

REFERENCE LOCATION: University of Alaska, Fairbanks

IMPORTANT PAGES: 320

KEY WORDS: Clams, Oysters, Silt, Kaolin, Fuller's Earth, Concentration, Particle Size, Growth, Development, Survival

ANNOTATION

A series of experiments were run to compare the effects of different-sized particles on embryos and larvae of hard clams and American oysters. As little as 0.188 g/L silt, 3 g/L kaolin, and 4 g/L Fuller's earth caused a significant decrease in the percentage of oyster eggs developing normally. American oyster eggs were not affected by 4 g/L silicon dioxide, regardless of particle size. The smallest particles (<5 microns) of silicon dioxide had the greatest effect on survival and growth of clam and oyster larvae. Particles in the range of 5 to 25 microns and 25 to 50 microns had little effect on survival of either species or on growth of clam larvae. Growth of American oyster larvae decreased progressively as the size of silicon dioxide particles decreased. Bivalve larvae grew faster in low concentrations of suspended particles than in clear sea water.

REFERENCE: Johnson, J. K., 1971. Effect of turbidity on the rate of filtration and growth of the slipper limpet, *Crepidula fornicata* Lamarck, 1799. The Veliger, Vol. 14, No. 3. pp. 315-320.

REFERENCE LOCATION: University of Alaska, Fairbanks

IMPORTANT PAGES: 318-320

KEY WORDS: Turbidity, Silt, Kaolin, Fuller's Earth, Effects, Filter Feeding, Shell Growth, Gastropod

ANNOTATION

The purpose of this investigation was to determine how the shell growth of the filter feeding gastropod *Crepidula fornicata* is affected by prolonged exposure to various levels of turbidity (0.002 to 0.25 g/L) in nature, and to examine the experimental effects of increasing concentrations (0.08 to 1.56 g/L) of silt, kaolin, and Fuller's earth on the filtration rates of *C. fornicata*. Results showed that the shell growth rate decreased as the level of natural turbidity increased. Likewise, shell growth was found to be greatest in a transplantation environment of low turbidity as compared to a high turbidity environment. The filtration rates of *C. fornicata* decreased as the level of turbidity increased. Low concentrations of silt equivalent to natural levels of turbidity in nature produced significant reductions in filtration rates. Silt, Fuller's earth, and kaolin each caused a significant reduction in the filtration rate as the concentration increased up to 6 g/L. Reduced shell growth rate may be the result of inadequate food intake due to clogging of the filtering mechanism by turbidity. Sustained high turbidity may have a limiting effect on the distribution of *C. fornicata*.

REFERENCE: Johnston, D. D., and D. J. Wildish, 1982. Effect of suspended sediment on feeding by larval herring (*Clupea harengus harengus* L.). Bulletin Environmental Contamination Toxicology, (29):261-267.

REFERENCE LOCATION: University of Alaska Library, Fairbanks

IMPORTANT PAGES: 261, 264-267

KEY WORDS: Suspended Sediments, Light Intensity, Herring, Larvae, Feeding Rate, Zooplankters, Visibility

ANNOTATION

The purpose of this study was to determine if increased levels of suspended sediment occurring after dredging, and resultant decreases in light intensity, reduce prey visibility for larval herring to the extent that the feeding rate is affected. The effect of suspended sediment on larvae of different ages was also investigated. Larvae fed in water containing 4 and 8 mg/L did not consume significantly fewer zooplankters than did control larvae. However, larvae fed at 20 mg/L did consume significantly fewer zooplankters than did the controls. Similarly, larvae fed at 65 and 105 phototopic lux consumed significantly fewer zooplankters than those fed at 300 lux in the control tanks. There were significantly fewer larvae in the bottom section of the tanks containing suspended sediment than in the controls. As the concentration of suspended sediment was increased, light intensity and visibility of prey decreases. As a result, the larvae move into the better illuminated surface layers to feed. The decrease in light intensity at lower sediment concentrations (4 and 8 mg/L) is not sufficient to result in a depression of feeding rates. At greater concentrations of suspended sediment (20 mg/L), the visibility of prey and light intensity are significantly decreased and the feeding rate is depressed. The level of suspended sediment resulting in a depression of feeding rate by herring larvae is also a function of larval age and size.

REFERENCE: Kiorboe, T., E. Frantsen, C. Jensen, and G. Sorensen, 1981. Effects of suspended sediment on development and hatching of herring (Clupea harengus) eggs. Estuarine, Coastal and Shelf Science, (13):107-111.

REFERENCE LOCATION: University of Alaska Library, Fairbanks

IMPORTANT PAGES: 107

KEY WORDS: Eggs, Herring, Suspended Sediments, Hatching, Development

ANNOTATION

Herring (Clupea harengus) eggs artifically fertilized in the laboratory were constantly exposed at 5 to 300 mg/L suspended silt and to short term concentrations of 500 mg/L at different times during embryonic development. Results indicate that embryonic development was unaffected by suspended silt. Mortality rates varied significantly between aquaria, but the variation was not related to silt concentrations. It was concluded that no harmful effects are likely to occur to herring spawning grounds as a result of suspended particle inputs from dredging and similar operations.

REFERENCE: Kiorboe, T., F. Mohlenberg, and O. Nohr, 1980. Feeding, particle selection and carbon absorption in *Mytilus edulis* in different mixtures of algae and resuspended bottom material. Ophelia, 19(2):193-205.

REFERENCE LOCATION: University of Alaska Library, Fairbanks

IMPORTANT PAGES: 193

KEY WORDS: Silt Concentration, Algae Suspensions, *Mytilus edulis*, Filtration, Food Uptake, Carbon Budget

ANNOTATION

The effects of silt concentration on filtration behavior, food uptake, and carbon budget of the mussel *Mytilus edulis* were studied. Increasing amounts of material were retained by the gills with increasing silt concentrations, but an increasing proportion of this was rejected as pseudofaeces. Pseudofaeces was produced at silt concentrations above 1 mg/L. The amount increased linearally with the amount of material retained. Dry matter ingestion increased with increasing concentration of silt. At a silt concentration of 2 mg/L, algae were concentrated by a factor of 3, and at 55 mg/L by a factor of about 30. The carbon ingestion rate increased considerably at a low concentration of silt compared to a suspension of pure algae, and decreased at high concentrations (55 mg/L). Carbon absorption efficiencies were high (59 to 65 percent) up to a silt concentration of 25 mg/L, and decreased slightly at higher concentrations (52 to 55 mg/L). It was concluded that *Mytilus* is well adapted to silt concentrations up to 55 mg/L, and even benefits from concentrations up to 25 mg/L.

REFERENCE: Loosanoff, V. L., 1961. Effects of turbidity on some larval and adult bivalves. Proceedings Gulf and Caribbean Fish Institute, Fourteenth Annual Session, November. pp. 80-95.

REFERENCE LOCATION: University of Alaska, Fairbanks (Interlibrary Loan)

IMPORTANT PAGES: 80, 83-91

KEY WORDS: Bivalves, Oysters, Turbidity, Silt. Kaolin, Pumping Rate, Shell Movement

ANNOTATION

An analysis of the effects of turbidity upon larval and adult bivalves is presented. Studies of the American oyster, *Crassostrea virginica*, and of *Venus mercenaria* are emphasized although several other species are also presented. Different species of mollusks, their eggs and their larvae were affected to different degrees by the same concentrations of turbidity-causing sediments. Very small quantities of silt and kaolin sometimes stimulated normal activities of adult and larval mollusks. However, concentrations as small as 0.1 g/L significantly reduced the water pumping rate by an average of 57 percent and strongly affected the character of shell movements of the adult oysters. At concentrations of 3.0 to 4.0 g/L, the average reduction in pumping rate was over 90 percent. The shell movements of oysters kept in turbid waters were associated with frequent ejections of large quantities of silt and mucus accumulating on the gills and palps. In another experiment, oysters were exposed to silt concentrations of 1.0, 2.0, 3.0, and 4.0 g/L for 48 hours. When the oysters were again subjected to normal sea water, they failed to show the usual recovery-type of shell movement nor did they resume a rapid rate of pumping, as is normally observed after exposure to sediment for relatively short periods. Apparently longer exposures affect them adversely by injuring the ciliary mechanisms of their gills and palps. Data indicated that lamellibranchs (oysters and clams) feed most effectively in relatively clear water.

REFERENCE: McFarland, V. A., and R. K. Peddicord, 1980. Lethality of a suspended clay to a diverse selection of marine and estuarine macrofauna. Archives Environmental Contamination Toxicology, (9):733-741.

REFERENCE LOCATION: University of Alaska, Fairbanks

IMPORTANT PAGES: 637-640

KEY WORDS: Marine Macrofauna, Suspended Kaolin, Sensitivity, Tolerance, Mortality

ANNOTATION

An evaluation was made of the lethality of a suspended clay mineral on a phylogenetically diverse selection of marine and estuarine macrofauna. A very wide range of sensitivities to suspended kaolin was observed among the 16 species studied. Eight had <10 percent mortality after exposure to 100 g/L suspended kaolin for 5 to 12 days. A variety of other species were found to be more sensitive. The 200-hr LC50 for the mussel M. Californianus was 96 g/L. An experiment using the tunicate Ascidia ceratodes was terminated at 136 hr because of the high mortality reached at that time. Two other tunicates were much more tolerant to suspended kaolin with a 12 day LC50 of 100 g/L. The 200-hr LC50 for the spot-tailed sand shrimp was 50 g/L, and the 400-hr LC50 was 50 g/L for the same species, indicating a high tolerance to suspended clay. The euryhaline grass shrimp was even less sensitive to suspended kaolin. The Dungeness crab Cancer magister was tested for 10 days and found to be more sensitive than any of the shrimp species, with a 200-hr LC50 of 32 g/L. The 100-hr LC50 for the amphipod Anisogammarus confervicolus was 78 g/L, indicating an intermediate sensitivity to suspended kaolin. The concentration causing 50 percent mortality of the polychaete Neanthes succinea in 200 hr was estimated to be 48 g/L. The English sole Parophrys vetulus exhibited no mortalities in 10 days at a concentration of 70 g/L or less, but 80 percent mortality occurred after 10 days at 117 g/L. The shiner perch C. aggregata was the most sensitive species tested with only one fish alive after 26 hr in 14 g/L suspended kaolin. The relative sensitivity of the species tested may be a function of the frequency to which they are subjected to high suspended sediment in their environment.

REFERENCE: Moore, P. G., 1977. Inorganic particulate suspensions in the sea and their effects on marine animals. Oceanography and Marine Biology Annual Review, (15):225-363.

REFERENCE LOCATION: University of Alaska, Fairbanks

IMPORTANT PAGES: 225-337

KEY WORDS: Turbidity, Suspended Solids, Marine Animals, Direct Effects, Indirect Effects, Measurement Techniques, Economic Effects

ANNOTATION

An overall synthesis of available literature pertaining to saline aquatic habitats is presented and discussed along with measurement techniques for total particulate matter. These techniques include gravimetric, centrifugation, and *in situ* measurements of the absorption of radioactive energy or the absorption of scattered light. Optical methods are by far the most popular techniques for studying suspended material, and involve the use of devices ranging from the simple Secchi disk to a variety of transmittance scattering and depolarization meters. Several investigators have established a relationship between Secchi depth and seston content, Secchi depth and attenuation coefficients, and the attenuation coefficient and particulate concentrations in sea water. More recently, turbid conditions have been recorded by *in situ* photography, remote sensing, and shipborne acoustic systems. Four methods available for particle size analysis of suspended sediments include microscopic analysis, optical sedimentation analysis, direct optical analysis, and the electronic (Coulter Counter) method.

Legal turbidity standards should ultimately be defined in terms of the light requirements of silt tolerance of the organisms requiring protection. It may be more realistic to re-define allowable turbidity increases in terms of the percentage above background rather than any arbitrary numerical value.

Numerous laboratory and field experiments have been accomplished to determine the effects of inorganic suspensions on marine animals. General effects are presented for a variety of marine animal groups including: protozoa, porifera, coelenterata, ctenophora, polycheata, crustacea, mollusca, echinodermata, bryozoa, phoronidea, brachiopoda, ascidiacea, hemichordata, and cephalochordata. In addition, a brief discussion is presented regarding fish, birds, marine mammals, and man.

REFERENCE: Ozturgut, E., J. W. Lavelle, and R. E. Burns, 1981. Impacts of manganese nodule mining on the environment: results from pilot-scale mining tests in the North Equatorial Pacific. In: R.A. Geyer, (ed.), Marine Environmental Pollution, 2: Dumping and Mining. Elsevier Scientific Publishing Co., New York. 574 pp.

REFERENCE LOCATION: University of Alaska Library, Fairbanks

IMPORTANT PAGES: 451-474

KEY WORDS: Mining Plume, Turbidity, Particulate Concentration, Photosynthetically Active Radiation (PAR), Light Attenuation, Primary Productivity, Macrozooplankton, Abundance, Mortality

ANNOTATION

Pilot-scale mining tests were conducted to evaluate environmental concerns and develop environmental guidelines prior to full scale mining in the North Equatorial Pacific. Particulate concentrations were recorded as light scattering intensities with a nephelometer. Particle sizes were measured with a Coulter counter. PAR measurements confirmed the presence of a particulate plume with an average concentration of 440 ug/L in the upper 25 m. Mining particulates increase light attenuation and thereby directly affect primary production in the mining area. A comparison was made between ambient production rates measured *in situ* and the estimated production rate at a point along the axis of the plume. The total reduction in productivity over the entire euphotic zone at this point amounted to 40 percent. The direct effects of mining-related particulate matter on macrozooplankton include mortality, changes in ingestion rates and the production of fecal pellets, changes in the elemental composition of whole organisms, and short-term affects on spatial distribution, abundance, and species composition. The results of two sets of tows indicate that there was no major decrease in the abundance of neustonic macrozooplankton, or sufficient amounts of mining particulates ingested to cause alteration in their chemical composition, at plume concentrations less than 1 mg/L.

It is concluded that the effect of mining discharge on phytoplankton is limited to that caused by turbidity. Increased light attenuation due to increased turbidity reduced the primary production rate in the plume. Because particulate concentrations return to ambient levels within a few days, it is believed that species composition changes will not take place. Based on both mining tests and laboratory experiments, it is concluded that the abundance and mortality of macrozooplankton will also be unaffected by the mining plume.

REFERENCE: Peddicord, R. K., 1980. Direct effects of suspended sediments on aquatic organisms. In: R.A. Baker (ed.), Contaminants and Sediments, Vol. 1, Ann Arbor Science Publishers, Inc., Ann Arbor, MI. pp. 501-536.

REFERENCE LOCATION: University of Alaska Library, Fairbanks

IMPORTANT PAGES: 501, 502, 511-515, 526-533

KEY WORDS: Suspended Sediment, Kaolin, Bentonite, Aquatic Organisms, Mortality

ANNOTATION

Marine and estuarine invertebrates were able to tolerate continuous exposure to suspensions of kaolin and bentonite clays in the range of grams/liter for several days to several weeks without substantial mortality. Fish tolerated similar concentrations for similar periods under similar conditions. As temperature increased or dissolved oxygen decreased, tolerance decreased. Even at higher temperatures and 2 ppm dissolved oxygen, most invertebrates tolerated continuous exposure to 60 g/L suspended bentonite for several days before mortality occurred. Juvenile Dungeness crabs were affected to a greater degree by kaolin suspensions than other species. Juvenile American lobsters suffered no mortalities in 20 g/L contaminated sediment for 25 days and only one molting abnormality occurred. Uncontaminated fluid muds have the potential for producing high suspended sediment concentrations and low dissolved oxygen for periods sufficient to cause mortality of a variety of organisms. Contaminated sediment suspensions are potentially more harmful than suspensions of uncontaminated sediment.

REFERENCE: Sherk, J.A., J.M. O'Connor, and D. A. Neumann, 1975. Effects of suspended and deposited sediments on estuarine environments. In: L. E. Cronin, (ed.), Estuarine Research, Volume II, Geology and Engineering. Academic Press Inc., New York. pp. 541-558.

REFERENCE LOCATION: University of Alaska, Fairbanks

IMPORTANT PAGES: 541-556

KEY WORDS: Bioassays, Fuller's Earth, Mortality, Estuarine Organisms, Sublethal Effects

ANNOTATION

Static bioassays conducted with Fuller's earth showed significant mortality among five of the seven species tested in suspended concentrations typically found in estuarine systems during flooding, dredging, and spoil disposal. Lethal concentrations ranged from a low of 0.58 g/L for silversides to 24.5 g/L for mummichogs (24 hr LC10). Fishes were classified as either tolerant (>10 g/L), sensitive (1.0 to 10 g/L), or highly sensitive (<1.0 g/L), based on a 24 hr LC10 using Fuller's earth. Generally, filter feeders and early-life stages were more sensitive than bottom dwellers and adults. Exposure to sublethal concentrations significantly increased the hematocrit value, hemoglobin concentration, and erythrocyte numbers in the blood of a variety of fish. In addition, Fuller's earth, fine sand, and river silt (>250 mg/L) caused significant reductions in the ingestion rate by copepods.

REFERENCE: Sherk, J. A., Jr., J. M. O'Connor, and D. A. Neumann, 1976. Effects of suspended solids on selected estuarine plankton. Miscellaneous Report No. 76-1, U. S. Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, VA. 50 pp.

REFERENCE LOCATION: University of Alaska, Fairbanks (Interlibrary Loan)

IMPORTANT PAGES: 10, 11, 15, 23, 26, 32, 35, 36

KEY WORDS: Suspended Sediments, Fuller's Earth, Silicon Dioxide, River Silt, Effects, Carbon Assimilation, Phytoplankton, Ingestion Rate, Copepods

ANNOTATION

This report provides baseline data on the effects of different suspended sediments on selected typical estuarine plankton. Carbon assimilation by four species of phytoplankton was significantly reduced by the light attenuating properties of fine silicon dioxide suspensions. A concentration of 1000 mg/L caused a 50 to 90 percent reduction in carbon uptake among the four species of phytoplankton tested. A concentration of 2500 mg/L caused an 80 percent reduction in one of the species. The ingestion rate by two species of calanoid copepods was significantly reduced during exposure to a 250 mg/L mixture of Fuller's earth, fine silicon dioxide, and natural river silt. At a concentration of 500 mg/L river silt, the ingestion rate was reduced by 77.5 percent.

REFERENCE: Stern, E.M., and W.B. Stickle, 1978. Effects of turbidity and suspended material in aquatic environments. Dredged Material Research Program, Technical Report D-78-21, Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. 117 pp.

REFERENCE LOCATION: Doug Clarke, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

KEY WORDS: Aquatic Environment, Dredged Material Disposal, Environmental Effects, Suspended Load, Suspended Solids, Turbidity

IMPORTANT PAGES: 2-10

ANNOTATION

This literature review includes discussions of definitions, units of measure, methods of measurement, and effects of turbidity and suspended material in the aquatic environment. There is common agreement that optical instruments provide an inferred rather than a direct measurement of suspended solids and that it is almost impossible to relate sediment concentrations and optical characteristics from one turbidimeter, standard suspension, or unit of measure to another. Relatively few studies relate animal responses to the actual weight per volume concentration of particles in suspension. Rather, they correlate response with turbidity. It is unlikely that the light absorbing and scattering properties of suspended particles directly affect animals. Because turbidity involves optical properties that cannot be correlated with the weight/volume concentration of suspended material, which directly affects aquatic biota, several investigators suggest that turbidity only be used as a nontechnical descriptor. Gravimetric techniques probably represent a more accurate measure of the effects of suspended solids on aquatic biota while optical measurements may be preferable for photosynthetic or aesthetic purposes. Laboratory experiments often do not duplicate natural conditions or reflect natural levels of organism tolerance to turbidity and suspended material.

The review also discusses the effects of suspended material and turbidity on corals, bivalves (clams, oysters, mussels) copepods, and fishes. The discussion includes information about effects on eggs, juveniles, and adult organisms.

APPENDIX D

GENERAL LITERATURE--MARINE

The references listed herein were reviewed by project team members and judged to be: (1) Too general; (2) Inapplicable to the scope of this project (e.g., related topics such as biological life history); (3) The information contained in a specific reference was explained in more detail in one or more of the references appearing above in Appendix C; or, (4) Only a small of the reference was applicable and this information is cited in the text of the report. Additionally, references pertaining to measurements of particulates applying to both fresh and marine water are not reprinted here as they appear in Appendix B.

Adams, C.E., and G.L. Weatherly, 1981. Suspended sediment transport and benthic boundary layer dynamics. In: C.A. Nittrouer (ed.), Sedimentary Dynamics of Continental Shelves. Elsevier, Amsterdam.

Austin, R.W., 1974a. Instrumentation used in turbidity measurement. In: Proceedings of National Oceanographic Instrumentation Center Workshop held at Washington, D.C. on May 6-8, 1974. National Oceanographic Instrumentation Center, Washington, D.C. pp. 45-74.

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Baker, E.T., G.A. Cannon, and H.C. Curl, Jr., 1983. Particle transport processes in a small marine bay. Journal of Geophysical Research, 88(C14):9661-9669.

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Burbank, D.C., 1974. Suspended sediment transport and deposition in Alaskan coastal waters with special emphasis on remote sensing by the ERTS-1 satellite. M.S. Thesis, Univ. of Alaska, Fairbanks, Alaska. 222 pp.

Burrell, D.C., 1972. Suspended sediment distribution patterns within an active turbid-outwash fjord. In: S.S. Wetteland and P. Bruun (eds.), Proceedings of the International Conf. of Port and Ocean Engineering. University of Norway, Trondheim. pp. 227-245.

Burrell, D.C., 1984. Seasonal turbidity patterns in Boca de Quadra and Smeaton Bay. Interim Report Prepared for U.S. Borax and Chemical Corp. and Pacific Coast Molybdenum Co. 54 pp.

Carder, K.L., P.R. Betzer, and D.W. Eggimann, 1974. Physical, chemical, and optical measures of suspended-particle concentrations: their intercomparison and application to the West African Shelf. In: R.J. Gibbs (ed.), Suspended Solids in Water. Plenum Press, New York, NY. pp. 173-193.

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Chase, R.R.P., 1979. Settling behavior of natural aquatic particulates. Limnology and Oceanography, 24(3):417-426.

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