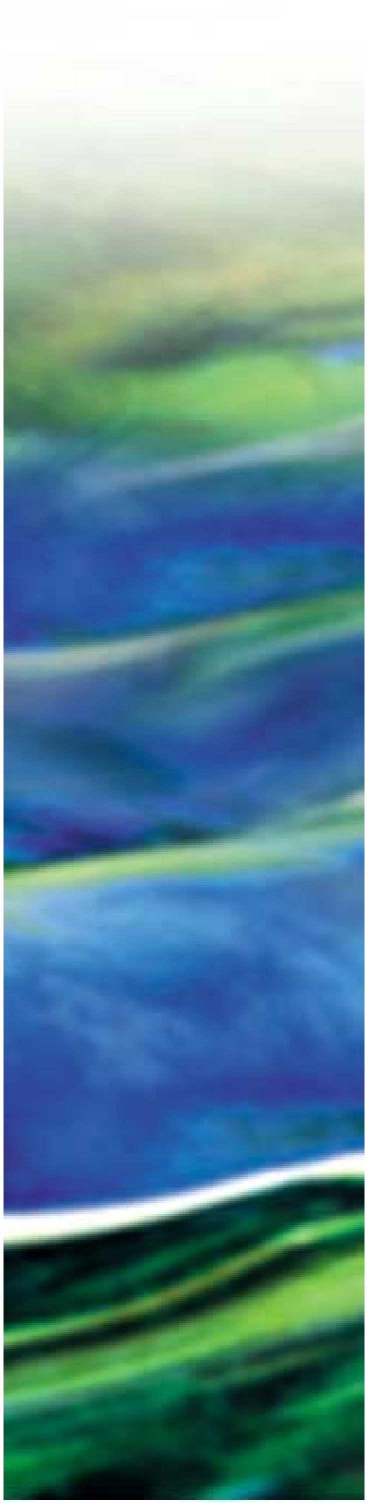

Technical Memorandum

Suspended Solids and Turbidity Requirements of Freshwater Aquatic Life and Example Relationship Between TSS (mg/L) and Turbidity (NTUs) for a Treated Municipal Effluent

Prepared by:

Robertson - Bryan, Inc.
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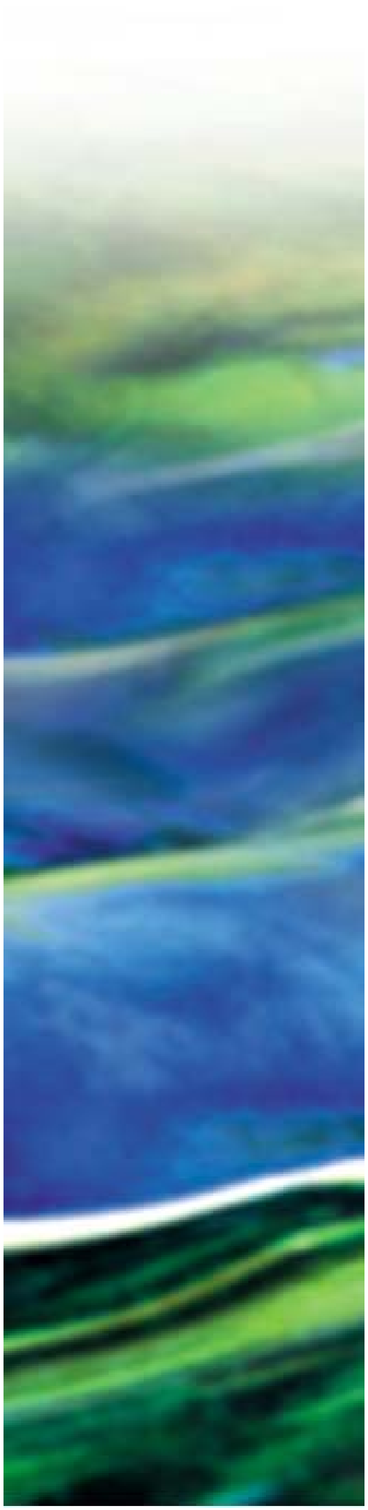
March 2006



Technical Memorandum

SUSPENDED SOLIDS AND TURBIDITY REQUIREMENTS OF FRESHWATER AQUATIC LIFE AND EXAMPLE RELATIONSHIP BETWEEN TSS (MG/L) AND TURBIDITY (NTUS) FOR A TREATED MUNICIPAL EFFLUENT

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REQUIREMENTS OF FRESHWATER AQUATIC LIFE

Background Information and Definitions

Turbidity is the optical property of a suspension that causes light to be scattered and absorbed rather than transmitted through the water column. The scattering and absorption of light is caused by: 1) water; 2) suspended particulate matter ranging in size from colloidal to coarse dispersions; and 3) dissolved chemicals (Wetzel 1983; Boyd 1990). Suspended materials may include suspended sediments, finely divided organic and inorganic compounds, plankton, and other microscopic organisms (APHA 1985).

Because primarily suspended solids cause turbidity, these two parameters are often discussed together. Suspended solids concentration in water is quantified by filtering a known volume of water through a weighed standard glass-fiber filter, and drying the residue retained on the filter to a constant weight at 103-105^{o}C (APHA 1985). The "total suspended solids" (TSS) concentration within the sample is then reported as milligrams of dried residue per liter of water filtered (mg/l).

Although the terms "suspended solids" and "turbidity" are sometimes used synonymously, the degree of turbidity is not equal to the suspended solids concentration; rather, turbidity is an expression of only one effect of suspended solids upon the character of water (i.e., the ability of light to penetrate through the water column). Because the particle size and nature (e.g., organic vs. inorganic) of the suspended solids affect the light scattering, different turbidities can be measured for waters having the same TSS concentration (McKee and Wolf 1963).

Early researchers used a variety of approaches to quantify turbidity, including the "millionth intensity depth" of light penetration into the water column (Ellis 1937) and suspended solids concentration in mg/l (Wallen 1951). Early work by Ellis (1937) contributed to an understanding that turbidity largely affects primary production within water bodies. The concept of the "compensation point" was later developed to define the water column depth where oxygen production from photosynthesis and oxygen consumption due to respiration is equal. Above the compensation point, net oxygen production occurs throughout the daylight hours because photosynthetic oxygen production by macrophytes and algae exceed total oxygen consumption due to respiration. The compensation point is an attempt to establish the lower limit of the occurrence of plankton populations (AFS 1979). In general, photosynthesis cannot proceed at rates exceeding respiration at depths where light intensity is less than 1% of its value at the water surface (Boyd 1990). The stratum of water receiving 1% or more of the incident light is termed the “euphotic” or “photic” zone. Hence, compensation point depth is directly related to turbidity, and indirectly related TSS concentration.

More recently, researchers have developed the standard methods for determination of turbidity based on the Jackson candle turbidimeter. However, the lowest turbidity value that can be measured directly using this instrument is 25 “Jackson Turbidity Units” or JTU. Because many natural and treated waters are less than 25 JTU, indirect secondary methods of measurement are required. These methods employ instruments that measure the intensity of light scattered at a 90-degree angle to the light entering the sample. These turbidimeters called “nephelometers” are relatively unaffected by small changes in design parameters and, therefore, are specified as the standard instrument for the measurement of low turbidities. These instruments measure turbidity in “Nephelometric Turbidity Units” or NTUs (APHA 1985).

Nephelometers compare the intensity of light scattered by a sample to the intensity of light scattered by a standard reference suspension. The reference nephelometer standard is a suspension of the polymer Formazin. NTUs based on Formazin are approximately equal to JTUs measured with the Jackson Candle Turbidimeter (i.e., JTU) (APHA 1985).

All surface water bodies have quantifiable levels of suspended solids and turbidity. The numerous scientific studies conducted over the past 50–60 years indicate that there is no sharply defined concentration of suspended solids and associated turbidity level above which aquatic communities are harmed. Rather, the magnitude and type of impact(s) on aquatic life are species-specific and determined by concentration and type of suspended solids and turbidity, as well as the duration of exposure.

In general suspended solids influence plant and algal communities through their effects on turbidity. The influence (both positive and negative) of turbidity on plant communities can be measured in the clearest and the most turbid of waters. Suspended solids, particularly when at high levels, directly affect fish and macroinvertebrates, whereas turbidity acts indirectly through its effects on primary production, food availability, and risk of predation. Direct injury to fully developed fish by nontoxic suspended matter has been demonstrated in numerous studies, but only at concentrations that are much higher than the concentrations that would exist in water bodies characterized by turbidity levels of 2 NTUs or less. A technical discussion of the impacts of suspended solids and associated turbidity is provided below.

Turbidity and Suspended Solid Levels of Ambient Waters

Turbidities of fresh waters vary greatly with location and season (see Ellis 1937). The headwaters of streams and rivers generally have low turbidities (e.g., often below 5 NTUs) throughout the year. Larger rivers, located at lower elevations, typically have higher turbidities (e.g., <10 to over 100 NTUs). In 1945, it was reported that, among inland waters of the United States supporting a varied fish fauna, about 5% had a suspended solids concentration under 72 mg/l; about 50% under 169 mg/l; and about 95% under 400 mg/l (McKee and Wolf 1963). The turbidity of all water bodies increases during and following precipitation events that result in highly turbid runoff. Hence, turbidities of most riverine systems are lowest at times furthest removed from runoff events, and highest during and immediately following large storms that result in high rates of runoff. Total suspended solid levels in natural waters seldom exceed 20,000 mg/l for more than a few days (Boyd 1990).

Relationship Between TSS and Turbidity for Treated Municipal Effluent

It has been determined that a significant positive relationship exists between effluent TSS (mg/l) and turbidity (NTUs) levels for the El Dorado Irrigation District's Deer Creek WWTP (SWRI 1996), which discharges to Deer Creek, a seasonally effluent-dominated water body (EDW). The relationship established for this plant's effluent indicates that the effluent concentration of TSS (in mg/l) is generally about 1.8–2 times the level of turbidity, as expressed as NTU. Hence, on the average, an effluent TSS level of 10 mg/l would correspond to an effluent turbidity of about 5-6 NTUs. It should be noted that this is an average relationship and, therefore, the relationship can vary at specific points in time for this WWTP, and also would be expected to vary among WWTPs. Nevertheless, the TSS-NTU relationship is presented here for the Deer Creek WWTP simply to provide a perspective for interpreting the scientific literature on suspended solids levels, and their effects on aquatic life.

EFFECTS OF TURBIDITY AND SUSPENDED SOLIDS ON AQUATIC LIFE

Aquatic Plants and Primary Production

The growth and photosynthetic rates of fixed and suspended aquatic plants is directly affected by the light intensity reaching them. In most aquatic systems, suspended solids and turbidity levels are important in defining the composition, structure, and photosynthetic activity of the aquatic plant and algal communities. Boyd (1990) reported that macrophyte growth increases with increasing concentrations of key nutrients, and often with increasing alkalinity, but probably the most critical factor regulating macrophyte growth is turbidity. Reactions of plant communities (both “positive” and “negative”) can be measured across the entire spectrum of suspended solids and turbidity levels encountered in ambient waters. Increasingly high levels of suspended solids and turbidity can adversely affect aquatic systems by limiting the depth to which light can penetrate into the water column, thereby limiting the depth of the “photic zone” and primary production.

Lloyd et al. (1987) studied the effects of turbidity on light penetration and primary productivity in Alaska streams and lakes. These researchers evaluated the relationship between the 1% light depth (i.e., depth to which 1% of available subsurface light penetrates) and turbidity by measurements made in 14 lakes. The data evaluated showed that the 1% light depth varied little among four lakes having turbidities below 2 NTUs, but showed a notable decrease between turbidities >2 to 10 NTUs. Based on their study findings, these authors concluded that a high level and moderate level of protection to aquatic ecology, based on effects on primary production, would be provided for streams and lakes, respectively, by limiting turbidity increases to 5 NTUs above natural conditions. Relative to lakes, streams show lesser effects on primary production due to increases in turbidity because of their shallower depths (where light often reaches the channel bottom) and a lesser reliance of the invertebrate community on phytoplankton production.

Fish

Low-Level Turbidity and Suspended Solids Studies

Bash et al. (2001) prepared a review article on the effects of turbidity and suspended solids on salmonids. Of the scores of scientific articles/reports reviewed, none reported adverse effects on fish at turbidity levels addressed by the proposed amendment (i.e., background turbidity <1.0 NTU not to exceed 2 NTUs). Low-level turbidity effects on fish tend to be related to visually oriented fishes’ ability to capture prey and/or avoid predation. Sufficiently high degree of effects on these key behaviors can lead to effects on growth and survival of certain species that, in turn, can lead to population or community level effects. Nevertheless, as shown by Bash et al. (2001), turbidities well above 2 NTUs are required to produce sufficient behavioral effects that would lead to reduced growth or population or community effects. Even subtle behavioral effects (e.g., reaction distance to prey, avoidance responses) were not reported at turbidity levels below 2 NTUs.

Sweka and Hartman (2001) evaluated reaction distance in brook trout under various turbidity levels. Data from this study show a statistically significant decline in reaction distance with increasing turbidity when all data are analyzed for turbidity levels between about 1 NTU and >40 NTUs. However, there was no statistically significant relationship between reaction distance and turbidity for turbidity levels <5 NTU. Servizi and Martens (1992) estimated that the threshold for avoidance behavior by juvenile coho salmon was 37 NTUs. Berg (1982, as cited in Bash et al. 2001) found that juvenile coho exposed to a short-term pulse of 60 NTU left the water column and congregated at the bottom of the test tank. When turbidity was reduced to 20 NTU, the fish returned to the water column. Similarly, Bisson and Bilby (1982) exposed juvenile coho salmon to elevated suspended sediment. Juveniles did not avoid moderate increases in turbidity when background turbidity levels were low. In this study, significant avoidance required a turbidity of 70 NTUs.

Most of the studies identified in the above literature did not evaluate turbidity increases as small as 2 NTUs. Waters having turbidities around 2 NTUs were typically part of the "control" or "clear water" test group, not an "elevated turbidity" treatment group. A good example of this is provided by Lloyd et al. (1987), who reported that arctic grayling were absent from reaches below mines, where average turbidities ranged from 75 to 727 NTUs, but that un-mined reaches, having average turbidities from 1.3 to 2.7 NTUs, had 0.5 to 8.7 grayling per haul. In tests conducted by Gradall and Swenson (1982) to examine behavioral effects associated with elevated turbidity, clear water control turbidities ranged from approximately 1.0 to 3.5 (mean = 2.4) NTUs for brook trout (*Salvelinus fontinalis*) and 2.0 to 3.0 (mean = 2.3) NTUs for creek chubs (*Semotilus atromaculatus*).

A key exception to the general trend in the scientific literature described above is provided by Newcombe (2003). This review article did evaluate effects down to the 2-3 NTU turbidity level. Newcombe (2003) evaluated the severity of effects (e.g., fish reactive distance, predatory prey dynamics, egg and larval growth rates, and habitat effects) for clear water fishes exposed to 2-10 NTU turbidity increases for exposure periods ranging from 1 hour to > 10 weeks. According to the model presented in Newcombe (2003), 3 NTUs would be protective of clear water fishes for long-term exposures.

Regarding macroinvertebrates, Quinn et al. (1992) evaluated the effects of long-term exposure to elevated turbidity on macroinvertebrate densities and taxonomic richness. Quinn et al. (1992)

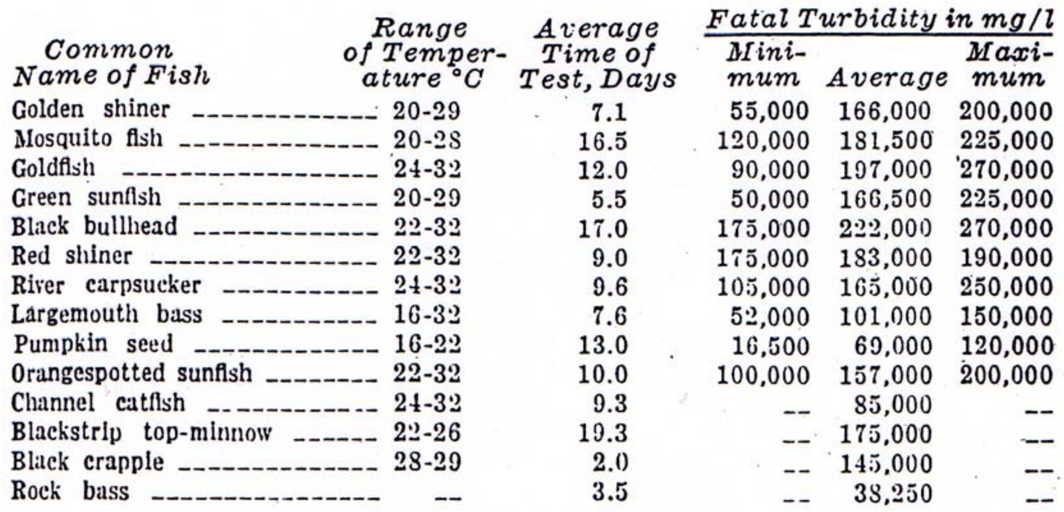
determined that both densities and taxonomic richness decreased at downstream sites having higher turbidities compared to lower turbidity sites upstream. Invertebrate density decreased significantly at downstream sites that had median turbidity levels from 7 to 154 NTUs higher than upstream sites, which had median turbidities of 0.9 to 4 NTUs. Invertebrate taxonomic richness decreased significantly between all but two downstream sites having median turbidities 23-154 NTUs higher than upstream sites. The authors concluded that turbidity related effects on primary production and thus food supply for the invertebrates was the cause of the above-cited effects. It should be noted that the lowest turbidity increase documented by this study to decrease macroinvertebrate density was 7 NTUs, and to decrease taxonomic richness was a 23 NTU increase. It is equally revealing that the upstream, low turbidity "reference sites" used in this study were characterized by median turbidities of 0.9 to 4 NTUs.

Higher Level Turbidity and Suspended Solids Studies

Fish (and benthic macroinvertebrates) are generally not directly affected by suspended solids and turbidity, unless they reach relatively high levels. When the levels of suspended solids (and thus turbidity) become extremely high, they can adversely impact fish and macroinvertebrates by making it difficult for sight feeders to locate prey, causing abrasive injuries, clogging gills and respiratory passages, and/or by blanketing the streambed, thereby killing incubating fish eggs/larvae and benthic macroinvertebrates (McKee and Wolf 1963; EIFAC 1965; NAS 1972; Alabaster and Lloyd 1980). Moreover, high suspended solids and turbidity levels can indirectly impact fish and macroinvertebrates through reductions in primary production that, in turn, may limit food supplies and thus reduce growth rates, and by carrying down and trapping bacteria and organic wastes on the bottom, which can lead to noxious conditions and oxygen depletion (McKee and Wolf 1963; EIFAC 1965; Alabaster and Lloyd 1980). Decreased visibility in waters having moderately high turbidities can benefit the early life stages of fish and other prey organisms by providing visual protection from predators.

Mortality Resulting from Short-term Exposures

Numerous studies have been conducted over the years on the acute lethality of suspended solids. A brief review of findings from key studies is presented here. Griffin (1938) stated that Pacific salmon and trout fingerlings lived for 3-4 weeks at suspended solids levels of 300-750 mg/l with short daily increases to 2,300-6,500 mg/l caused by stirring up sediments. Wallen (1951) conducted a study that investigated the direct short-term effects of suspended montmorillonite clay on 14 species of warmwater fishes. In this study, suspended solids levels were increased for a short time each day by stirring the sediment.



Common Name of Fish	Range of Temperature °C	Average Time of Test, Days	Fatal Turbidity in mg/l Minimum	Fatal Turbidity in mg/l Average	Fatal Turbidity in mg/l Maximum
Golden shiner	20-29	7.1	55,000	166,000	200,000
Mosquito fish	20-28	16.5	120,000	181,500	225,000
Goldfish	24-32	12.0	90,000	197,000	270,000
Green sunfish	20-29	5.5	50,000	166,500	225,000
Black bullhead	22-32	17.0	175,000	222,000	270,000
Red shiner	22-32	9.0	175,000	183,000	190,000
River carpsucker	24-32	9.6	105,000	165,000	250,000
Largemouth bass	16-32	7.6	52,000	101,000	150,000
Pumpkin seed	16-22	13.0	16,500	69,000	120,000
Orangespotted sunfish	22-32	10.0	100,000	157,000	200,000
Channel catfish	24-32	9.3	--	85,000	--
Blackstrip top-minnow	22-26	19.3	--	175,000	--
Black crapple	28-29	2.0	--	145,000	--
Rock bass	--	3.5	--	38,250	--

Source: Wallen (1951, as summarized by McKee and Wolf 1963).

A summary of his findings was presented by McKee and Wolf (1963), and is provided below. The lowest concentration of suspended solids for which mortality was observed was with pumpkinseed sunfish (Lepomis gibbosus) exposed to 16,500 mg/l daily for an average of 13 days. Rock bass (Ambloplites rupestris) was the species for which the lowest reported suspended solids level (38,250 mg/l) consistently caused mortality due to daily exposures of less than one week. Some level of mortality was observed for all species tested when exposed daily to 100,000 to 175,000 mg/l montmorillonite clay suspensions over a 1- to 2-week period. At suspended solids levels causing mortality, the opercular cavities of test fish were matted with clay, and the gills were covered with a layer of clay. Harmful non-lethal effects were first observed when suspended solids levels approached 20,000 mg/l.

This study clearly demonstrated that the tolerance of various fish species can differ widely. Kramer and McLeod (1965, as cited in Alabaster and Lloyd 1980) found that walleye *(Stizostedion vitreum vitreum*) experienced mortality within 72 hours of exposure to 100 mg/l of various wood pulps, but that 20,000 mg/l did not kill fathead minnows (*Pimephales promelas*) exposed for 96 hours.

Mortality Resulting from Long-term Exposures

Other studies have investigated chronic or long-term effects of suspended solids levels on fish. Van Oosten (1945) concluded from a literature review that average suspended solids levels of up to 200 mg/l are harmless to fish, and that they can thrive in waters having TSS levels over 400 mg/l and averaging 200 mg/l. Similarly, Ward (1938, cited in McKee and Wolf 1963) reported that turbidity as high as 245 mg/l is not harmful to fish. Herbert and Merkens (1961) conducted experiments on the survival of rainbow trout in suspensions of inert solids (kaolin and diatomaceous earth). Results showed that concentrations of 30 mg/l caused no increase in mortality over control fish; mortality increased slightly at 90 mg/l, and substantial additional mortality occurred in 2-12 weeks when test fish were continuously exposed to 270 mg/l and higher levels of these solids. Herbert and Wakeford (1962) observed no mortality in rainbow trout exposed to a suspension of 553 mg/l gypsum for a 4-week period. Similarly, there was no mortality of rainbow trout exposed for 9-10 months to 200 mg/l of suspended solids from a coal washery (Herbert and Richards 1963). These later studies indicate that the *general* conclusions regarding the effects of suspended solids on fish reached by early investigators, such as those cited above, may hold for certain types of suspended solids, but not others. In fact, these studies suggest that the effects of suspended solids on a given species of fish can vary widely, depending upon the type or nature of suspended solids to which fish are exposed. From a literature review, Newcombe and Jensen (1996) indicated that long-term exposure (e.g., 4 months or more) to suspended sediment concentrations of 20-55 mg/l or more would be required before mortality would occur in juvenile and adult salmonids and adult non-salmonids.

Growth, Production, Risk of Predation and Population-level Effects

The growth (and survival) of larval lake herring was not affected by exposure for 62 days to red clay concentrations of up to 28 mg/l (Swenson and Matson 1976, cited in Alabaster and Lloyd 1980). Laboratory experiments in which the amount of food made available to trout was limited showed that 50 mg/l wood fiber and coal washery waste suspended solids reduced growth rates. These impacts increased with increasing suspended solids concentrations. However, growth impacts were less evident when there was abundant food supply (Herbert and Richards 1963). Sigler et al. (1984) reported that turbidities (caused by clay) as low as 25 NTUs caused a reduction in growth in young steelhead (*Oncorhynchus mykiss*) and coho salmon (*Oncorhynchus* *kisutch*). Turbidities at this level correspond to suspended solids concentrations well above 25 mg/l, regardless of the site-specific turbidity-suspended solids relationship. Feeding tests conducted by Breitburg (1988) showed no significant reduction in the number of copepods or daphnids eaten by striped bass larvae per 25-min feeding period between suspended solids levels from 0 to 75 mg/l. An increase in the prey capture rate at 75 mg/l compared to 0 mg/l occurred when Daphnia pulex were used as prey.

Buck (1956) studied the growth of fish over a 2-year period in 39 farm ponds that were cleared of fish and then restocked with largemouth bass, bluegill, and red ear sunfish (*Lepomis microlophus*). He observed maximum production (161.5 lb/acre) in farm ponds where average suspended solids was less than 25 mg/l. Production dropped to 94 lb/acre (a relative reduction of about 42%) in ponds having suspended solids levels of between 25 and 100 mg/l, and to 29.3 lb/acre (a relative reduction of about 82%) in ponds where the suspended solids often exceeded 100 mg/l. Differences were attributed to the greater availability of prey organisms in the "clear" ponds. The rate of reproduction of all of these species was reduced at suspended solids levels of about 75-100 mg/l or greater. Lower growth rates for largemouth bass, crappies (*Pomoxis spp.*) and channel catfish (*Ictalurus punctatus*) also were found in a reservoir having an average suspended solids level of 130 mg/l, relative to another reservoir where the water was always substantially clearer. In a stream where suspended solids levels increased from a range of 13-52 mg/l upstream of a limestone quarry to a range of 21-250 mg/l downstream, Gammon (1970) found that most fish numbers were lower downstream.

Schubel et al. (1974) showed that laboratory suspensions of natural, fine-grained sediments from Chesapeake Bay up to 500 mg/l had no measurable effect on the success of egg hatching for yellow perch (*Perca flavescens*) or striped bass (*Morone saxatilis*). However, this study did document significantly lower hatching success for both species at concentrations of 1,000 mg/l. Based on literature review, Alabaster and Lloyd (1980) concluded that impacts on incubating fish eggs is less a function of the suspended solids levels or turbidity levels, than it is the amount of material that will settle out of suspension, thereby covering incubating eggs and reducing gas exchange with the surrounding water. Hence, suspended solids and turbidity levels that cause little to no deposition of finely divided solids tended not to adversely affect the reproductive success of bottom-spawning fishes.

Field tests in England, showed that a stream containing 60 mg/l of suspended solids had just as many trout and invertebrates as a "clear" control stream (Alabaster and Lloyd 1980). Similarly, Herbert et al. (1961) found that 1,000 to 6,000 mg/l of suspended solids from china-clay wastes reduced the density of brown trout to about one-seventh of that found in clear streams, but that a normal trout population was present in a river having suspended solids levels of 60 mg/l. Liepolt (1961) (cited in Alabaster and Lloyd 1980) reported that a trout fishery existed in a stream having suspended solids levels typically between 19 and 23 mg/l, and that the fishery was not harmed by dredging operations that raised the suspended solids levels to 160 mg/l for short periods. In a concurrent field test in the River Fal that had 1,000 mg/l suspended matter, trout were observed to be at densities one-seventh and invertebrates one-third those in control streams (McKee and Wolf 1963).

Gradall and Swenson (1982) studied the responses of brook trout (*Salvelinus fontinalis* – a predator) and creek chub (*Semotilus atromaculatus* – prey species) to red-clay turbidity in the laboratory. Creek chub preferred highly turbid water (57 NTUs) to moderately turbid water (6 NTUs), but brook trout did not show a preference for either. In moderately turbid water, both species were more active and used overhead cover less than in clear water. The results from this study indicate that turbidity may represent an important isolating mechanism that promoted production of the prey species. These findings further demonstrate that turbidity increases are not necessarily adverse to fish communities; rather, low to moderate turbidities (e.g. <10 NTUs) may provide as many or more positive compared to negative effects. The negative effects outweigh the positive influences when turbidities become significantly higher than normal levels.

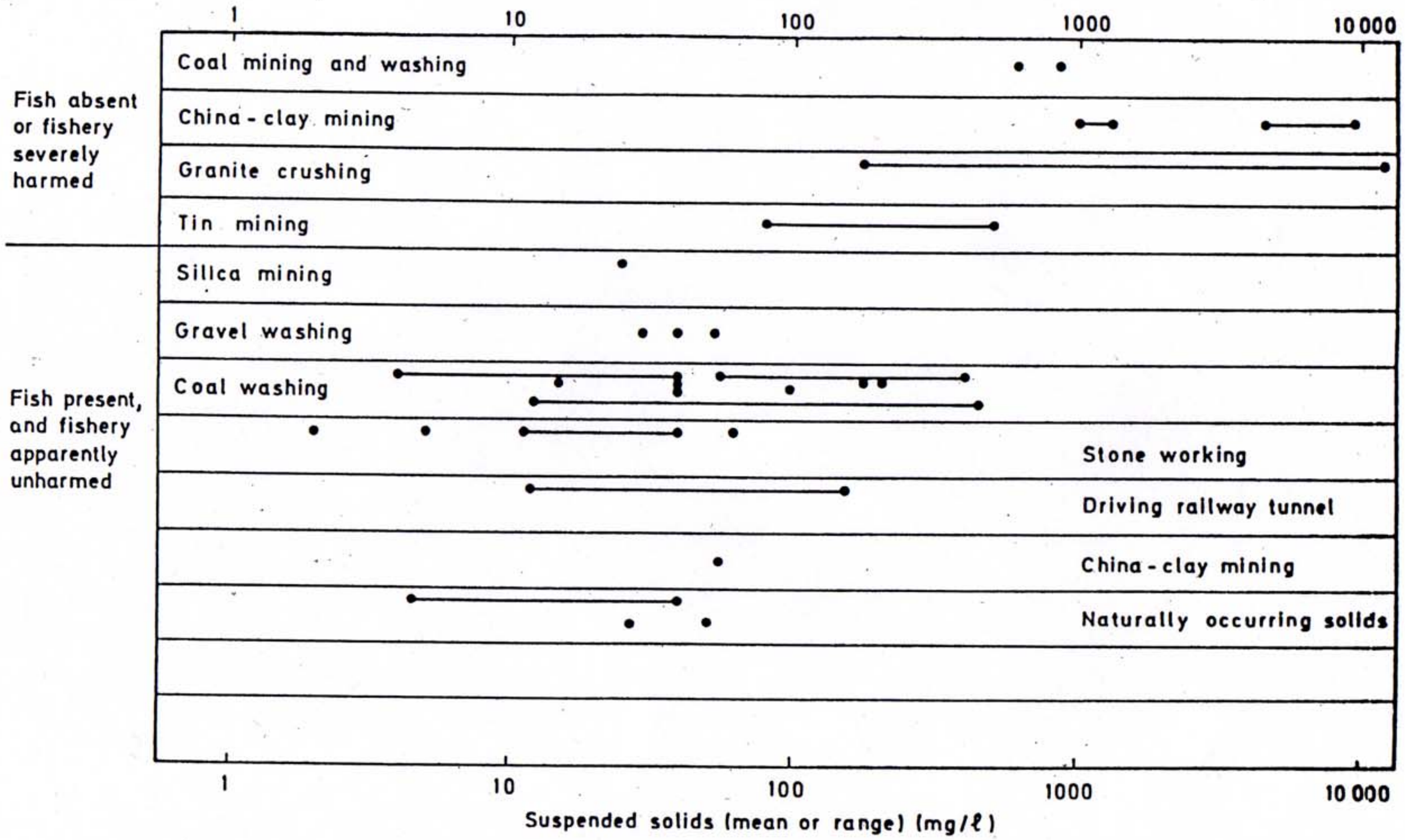
MINIMUM EFFECT LEVELS

Fish

Alabaster and Lloyd (1980) cited several studies that reported the loss of fish communities in rivers downstream from the discharge of large quantities of suspended solids. However, the affected fish reappeared downstream of where suspended solids levels were reduced to 100-200 mg/l. Moreover, Alabaster and Lloyd (1980) presented results of a questionnaire sent to River Boards in Great Britain regarding the effects of suspended solids of industrial origin on fish populations. With few exceptions, fisheries in streams having suspended solids above 100 mg/l were either severely harmed or absent, whereas fisheries in streams with suspended solids concentrations below 80-100 mg/l were in good condition. Care was taken in this review to not include data for streams that were polluted with materials other than inert suspended solids.

Based on available literature regarding chemically inert suspended solids in waters that are otherwise satisfactory for the maintenance of freshwater fisheries, the EIFAC (1965) concluded the following (as presented in NAS 1972):

- there was no evidence that concentrations of suspended solids less than 25 mg/l have any harmful effects on fisheries;
- it should usually be possible to maintain good or moderate fisheries in waters that normally contain 25-80 mg/l suspended solids; other factors being equal; however, the yield of fish from such waters might be somewhat lower than from those in the preceding category;
- waters normally containing from 80-400 mg/l suspended solids are unlikely to support good freshwater fisheries, although fisheries may sometimes be found at the lower concentrations within this range; and
- only poor fisheries are likely to be found in waters that normally contain more than 400 mg/l suspended solids.



Reported status of freshwater fisheries related to the suspended solids content of the water

Source: Herbert and Richards (1963, as presented by Alabaster and Lloyd 1980).

The USEPA's 1972 water quality criteria document (NAS 1972) quotes findings from EIFAC (1965). Since the EIFAC issued its report on suspended solids in 1965, numerous additional research articles and technical reports have become available on the topic, including review articles by Hollis et al. (1964), Gammon (1970), Ritchie (1972), Sorensen et al. (1977) and Alabaster and Lloyd (1980). The data provided in these articles support the conclusions drawn in the original EIFAC report (EIFAC 1965). Based on their review of the literature, Alabaster and Lloyd (1980) reiterated the above bulleted statements initially presented by EIFAC (1965) as tentative water quality criteria for suspended solids.

Newcombe and Jensen (1996) performed a "meta-analysis" of 80 published reports on fish responses to suspended sediments, and developed empirical relationships between observed biological response and duration of exposure and suspended sediment concentration. These relationships indicated that long-term exposures (e.g., 4 months or more) to suspended sediment concentrations of approximately 20 mg/l or more would be required before fish growth rates or density would be reduced for juvenile and adult salmonids and freshwater non-salmonids.

Based on the literature reviewed, and with the exception of minor behavioral responses that would not be expected to result in adverse population-level effects, it is concluded that suspended solids concentrations below 20-25 mg/l (and resulting turbidity) would result in little, if any, measurable affects on fish populations and communities. Possible exceptions include egg and larvae mortality and reduced growth rates in salmonids (Newcombe and Jenson 1996). It should be noted that the 20-25 mg/l suspended solids concentrations discussed above, and the somewhat lower levels (i.e., 10-20 mg/l) noted by Newcombe and Jenson (1996) where certain effects have been noted from specific studies, all correspond to turbidity levels that are substantially higher than the 0-1 NTU level to which the proposed turbidity amendment applies. Although the relationship between turbidity (NTUs) and TSS (mg/l) varies somewhat by site, water having a turbidity between 0 and 1 NTU would be expected to have a corresponding TSS level in the range of 0-3 mg/l – well below any effect levels discussed above. Moreover, and as stated above, more recent research (Newcombe 2003) found that 3 NTUs would be protective of clear water fishes for long-term exposures.

Benthic Macroinvertebrates

The effects of suspended solids and associated turbidity on macroinvertebrates partially depend on the nature of the suspended particles present. A study conducted by Robinson (1959) found that pond sediment had no measurable adverse effects on *Daphnia magna* at concentrations as high as 1,458 mg/l, but that charcoal and montmorillonite clay caused adverse impacts at 100 mg/l, ground glass at 98 mg/l, chlorite at 120 mg/l, and illite at 264 mg/l. Adverse effects can occur at relatively low turbidity when contaminants (e.g., pesticides) are adsorbed to suspended particles. Alabaster and Lloyd (1980) discussed results from two similar studies conducted with cladocerans and copepods. Pooling the information from both studies, harmful effects were reported for these organisms at suspended solids (clay, charcoal, soil, and sand) concentrations ranging from 82-500 mg/l. Much lower concentrations (e.g., 39 mg/l kaolinite and 73 mg/l pond sediment) appeared to increase the reproductive rate of *Daphnia*.

Although they are important fish food items in lakes, *Daphnia* are less important in rivers than benthic macroinvertebrates. Benthic macroinvertebrates are not only at risk from suspended solids, but also from the accumulation of particles that settle on the stream bottom (Alabaster and Lloyd 1980). In a 4-year study of a stream receiving sediment input from a limestone quarry, Gammon (1970) reported that suspended solids concentration increases of up to 40 mg/l above normal resulted in increased drift and reduced macroinvertebrate density in affected riffles below the quarry. When the concentration of suspended solids increased from 13-52 mg/l upstream of the quarry to 21-250 mg/l downstream, benthic macroinvertebrates preferring silt or mud substrate increased in abundance while others such as the net-spinning species (e.g., *Cheumatopsyche* spp.) were reduced in number.

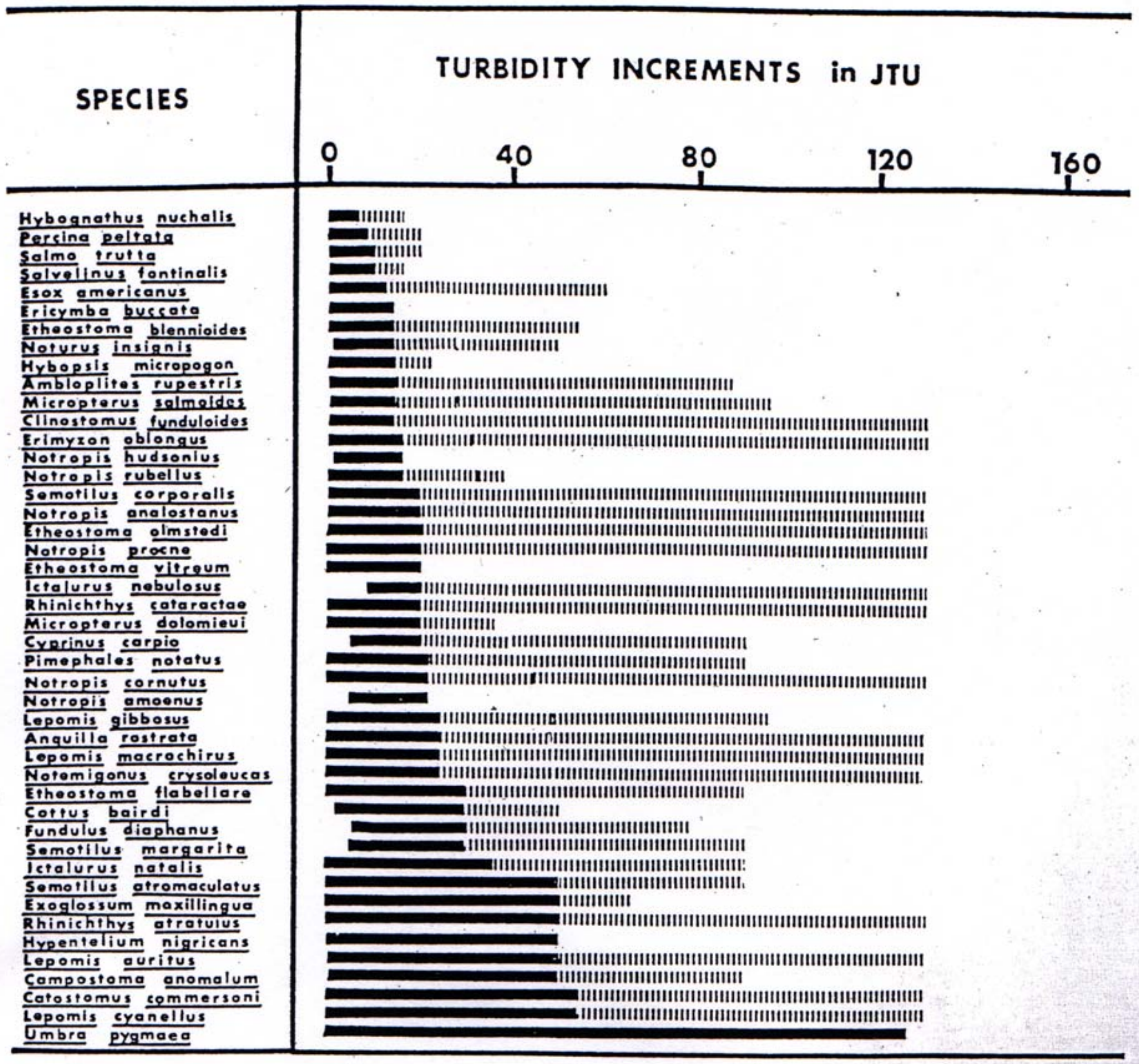
Alabaster and Lloyd (1980) discussed findings from a study conducted in France regarding increased suspended solids loading to a river from a sand-washing plant. The downstream benthic macroinvertebrate community essentially disappeared from the point of discharge, but reappeared in a condition closely approximating that of the upstream community 4 kilometers downstream where suspended solids levels had fallen to 29 mg/l. A similar study reported that downstream of a coal mining operation, a sparse fauna reappeared where suspended solids levels had fallen to approximately 100 mg/l.

Finally, although benthic macroinvertebrates numbers may be reduced by finely divided chemically inert solids, light deposits of some kinds of organic solids (e.g., humus from wastewater treatment plants) can support dense populations of some bottom-dwelling invertebrates, such as *Chironomus riparius* and *Asellus aquaticus*, which provide an abundant food supply for fish.

As with all ecosystems, the benthic macroinvertebrates that occur in rivers and streams are in balance with the physical, chemical, and biological factors that define the system. Low-level changes (e.g., changes in waters having suspended solids levels less than 25 mg/l) in suspended solids concentrations (be they inert inorganic or organic in nature) may result in subtle changes in the structure of macroinvertebrate communities, but should not cause significant adverse impacts to community composition, structure, or function. It should again be noted that the 20-25 mg/l suspended solids “no observed effect concentration” derived from the literature discussed above relates to turbidity levels well above 1 NTU, which is the upper end of turbidity for which the amendment proposes a modification, relative to the existing Basin Plan 0-5 NTU turbidity objective.

EFFECTS OF TURBIDITY ASSOCIATED WITH WASTEWATER DISCHARGES

As stated above, the nature of the suspended matter plays a significant role in its effects on fish for a given suspended solid concentration. Tsai (1973) studied fish populations downstream from the point of discharge of more than 100 wastewater treatment plants. Upstream turbidity averaged 12 ± 11 JTU and downstream turbidity averaged 34 ± 22 JTU. Because of the wide seasonal variability in background turbidity, turbidity “increment” was used to assess its effects on downstream fish communities. Statistical analyses revealed that a 50% reduction in a species diversity index occurred at a turbidity increment of 20 JTU, with a 25% reduction occurring at 8 JTU. The presence of 45 fish species upstream and downstream of the wastewater plants was assessed in relation to turbidity. For most fish species, occurrence was detected over a narrow range of turbidities downstream compared to upstream. This may indicate that they were less tolerant of the suspended organic matter discharged from wastewater plants, than to the more inert upstream sediment-derived turbidity. However, these data also could be caused by confounding factors such as oxygen depletion due to organic loading above certain turbidity levels and/or the presence of materials such as chlorine and ammonia. These same considerations of confounding factors associated with this study’s analyses must also be considered when interpreting the relationships discussed between incremental increases in turbidity and reduced diversity, reported above. Regardless, all 45 fish species were present downstream when the incremental increase in downstream turbidity due to wastewater discharges was in the range of 0 to 10 JTU.



Occurrence range, at 135 Type I sewage treatment plants, of 45 species of fish at upstream stations (hatched column) and downstream stations (solid column) with respect to turbidity increment at downstream stations.

PERSPECTIVE ON TURBIDITY EFFECTS ON AQUATIC LIFE FROM THE AFS, AND TURBIDITY CRITERIA CURRENTLY IN EFFECT FOR OTHER WESTERN STATES AND IN CANADA

In its review of the USEPA's Red Book, the American Fisheries Society (AFS) stated that Oregon and Washington State Water Quality Standards "… *are especially strict when applied to* *turbidity*" (AFS 1979). For example, AFS (1979) defined the State of Washington's turbidity standard [in 1979] as follows:

> *"Turbidity shall not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10 percent increase in turbidity when the background turbidity is more than 50 NTU."*

The State of Washington maintains this turbidity criterion today for protection of its highest quality rivers and streams (M. Hicks, Washington State Department of Ecology, pers. comm., 1998). AFS (1979) further reported that the State of Wyoming's turbidity standard [in the late 1970s] was established as a maximum increase of 10 JTU for game fish and 15 JTU for non-game fish. Wyoming's current turbidity criteria read as follows:

> *"(a) In all Class 1 and 2 waters which are coldwater fisheries, the discharge of substances attributable to or influenced by the activities of man shall not be present in quantities which would result in a turbidity increase of more than 10 nephelometric turbidity units (NTUs).*
>
> *(b) In all Class 3 waters and in Class 1 and 2 waters which are warmwater fisheries, the discharge of substances attributable to or influenced by the activities of man shall not be present in quantities which would result in a turbidity increase of more than 15 NTUs.*

The Ministry of Environment for the Province of British Columbia published a document titled: *Water Quality Criteria for Particulate Matter* (Singleton 1985). The recommended turbidity criteria for the protection of aquatic life (freshwater, estuarine, and marine) published in this document read as follows: "*Induced turbidity should not exceed 5 NTU when background turbidity is ≤50 NTU, nor should induced turbidity be more than 10% of background when background is >50 NTU.*"

In short, the scientific literature compiled and discussed in this appendix, as well as turbidity criteria discussed above for the states of Oregon and Washington and the Province of British Columbia, demonstrate that the turbidity levels being addressed by the proposed amendment are far below levels that would have demonstrable effects on freshwater aquatic life.

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