# DEVELOPING WATER QUALITY CRITERIA FOR SUSPENDED AND BEDDED SEDIMENTS (SABS)

## Potential Approaches

A U.S. EPA Science Advisory Board Consultation

DRAFT

US EPA
Office of Water
Office of Science and Technology

August 2003

## TABLE OF CONTENTS:

**ACKNOWLEDGMENTS:**

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Acknowledgment goes to each of these individuals for the contributions they have made to this discussion paper and to the better understanding of SABS and possible approaches to developing water quality criteria.

Acknowledgment is also given to Michael Paul and Benjamin Jessup of Tetra Tech, Inc., Owings Mills, Maryland, (one of EPA's contractors) for their contributions.

## GLOSSARY OF TERMS:

**Aquatic Life Use**- a use designation in State/Tribal water quality standards that generally provides for survival and reproduction of desirable fish, shellfish, and other aquatic organisms; classifications specified in state water quality standards relating to the level of protection afforded to the resident biological community.

**Bedload**- Sediment which moves along and is in contact with stream or river bottom.

**Clean sediments**- Suspended and bedded sediments that are not contaminated with toxic chemicals.

**Contaminated sediments**- Deposited or accumulated sediments, typically on the bottom of a water body, that contain contaminants. These may or may not be toxic as revealed by a whole sediment toxicity test, or as predicted by equilibrium partitioning.

1**Criteria-** Under section 304(a) of the Clean Water Act, EPA publishes scientific information regarding concentrations of specific chemicals or levels of parameters in water that protect aquatic life and human health.

2**Criteria-** Levels of individual pollutants, or water quality characteristics, or descriptions of conditions of a water body, adopted into State water quality standards that, if met, will generally protect the designated use of the water. In many cases, States make use of the criteria developed by EPA under definition #1 above.

**Designated Uses**- those uses specified in State/Tribal water quality standards for each water body or segment whether or not they are being attained. Sometimes referred to as Beneficial Uses, i.e., desirable uses that water quality should support. Examples are drinking water supply, primary contact recreation (such as swimming), and aquatic life support.

**Embeddedness-** the amount of silt and sediment deposited in and around the larger gravel, cobble and boulders in the bottom of a stream or river.

**Fines**- fine particulate material such as silt and clay particles typically of less than .85 mm diameter.

**Jackson turbidity units (JTU)-** An alternative way (to NTU) to measure turbidity in water based on the length of a light path through a suspension that causes the image of a standard candle flame to disappear.

**Nephelometric turbidity units (NTU)-** The units of measurement for turbidity in water as determined by the degree light is scattered at right angles when compared to a standard reference solution.

**Reference Condition (Biological Integrity)-** the condition that approximates natural, un-impacted conditions (biological, chemical, physical, etc.) for a water body. Reference condition (Biological Integrity) is best determined by collecting measurements at a number of sites in a similar water body class or region under undisturbed or minimally disturbed conditions (by human activity), if they exist. Since undisturbed or minimally disturbed conditions may be difficult or impossible to find, least disturbed conditions, combined with historical information, models or other methods may be used to approximate reference condition as long as the departure from natural or ideal is understood. Reference condition is used as a benchmark to determine how much other water bodies depart from this condition due to human disturbance.

> **Minimally disturbed**- the physical, chemical, and biological conditions of a water body with very limited, or minimal, human disturbance in comparison to others within the water body class or region. Minimally disturbed conditions can change over time in response to natural processes.

> **Least Disturbed Condition**- the best available existing conditions with regard to physical, chemical, and biological characteristics or attributes of a water body within a class or region. These waters have the least amount of human disturbance in comparison to others within the water body class, region or basin. Least disturbed conditions can be readily found, but may depart significantly from natural, undisturbed conditions or minimally disturbed conditions. Least disturbed condition may change significantly over time as human disturbances change.

**Regional Reference Condition-** description of the chemical, physical, or biological condition based on an aggregation of data from reference sites that are representative of a water body type in an ecoregion, subecoregion, watershed, or political unit.

**Sediment-** Fragmented material that originates from weathering and erosion of rocks or unconsolidated deposits, and is transported by, suspended in, or deposited by water.

**Sedimentation-** The depositing of sediment.

**Settleable Solids-** Those solids that will settle to the bottom of a cone-shaped container, an Imhoff cone, in a 60-minute period.

**Silt –** Noncohesive soil whole individual particles are not visible to the unaided human eye (0.002 to 0.05 mm). Silt will crumble when rolled into a ball.

**Siltation–** The process by which a river, lake, or other water body becomes clogged with sediment.

**Suspended and bedded sediments**- particulate organic and inorganic matter that suspend in or are carried by the water, and/or accumulate in a loose, unconsolidated form on the bottom of natural water bodies.

**Suspended load-** Sediment which is derived from a river/streambed and is wholly or intermittently supported in the water column by turbulence.

**Suspended solids concentration (SSC)-** The amount of organic and inorganic particles suspended in water. SSC is determined by measuring the dry weight of all the sediment from a known volume of a water-sediment mixture.

**Total suspended solids (TSS)-** The entire amount of organic and inorganic particles dispersed in water. TSS is measured by several methods, most of which entail measuring the dry weight of sediment from a known volume of a subsample of the original.

1**Turbidity-** The scattering of light by fine, suspended particles which causes water to have a cloudy appearance. Turbidity is an optical property of water. More specifically, turbidity is the intensity of light scattered at one or more angles to an incident beam of light as measured by a turbidity meter or nephelometer.

2**Turbidity**- A principal characteristic of water and is an expression of the optical property that causes light to be scattered and absorbed by particles and molecules rather than be transmitted in straight lines through a water sample. It is caused by suspended matter or impurities that interfere with the clarity of water. These impurities may include clay, silt, finely divided inorganic and organic matter, soluble colored organic compounds, and plankton and other microscopic organisms.

**Washload-** Sediments smaller than 63 microns which are not from the bed but could be from bank erosion or upland sources.

**Water Quality Standards-** are provisions in State or Tribal law or regulations that define the water quality goals of a water body, or segment thereof, by designating the use or uses to be made of the water; setting criteria necessary to protect the uses; and protecting existing water quality through anti-degradation policies and implementation procedures.

## WHAT IS THE PURPOSE OF THIS DOCUMENT?

The Office of Water in EPA, with support from the Office of Research and Development, is preparing to develop and issue improved water quality criteria (either recommended values or methodologies) for use by the States to better manage Suspended and Bedded Sediments (SABS) in water bodies across the country. Before undertaking this effort, the Office of Water is undergoing a consultation with the EPA Science Advisory Board to gain their review and recommendations on the best scientific approaches to accomplish this. This paper is being prepared as the discussion paper for the Science Advisory Board to consider the key scientific questions regarding methods and approaches for developing water quality criteria for SABS.

This paper provides an introduction to SABS and water quality criteria and discusses the types and status of water quality criteria that have been or are currently being used by the States, Canada and elsewhere. The paper also proposes several new approaches or methods for developing SABS criteria for consideration by U.S. EPA Science Advisory Board. The consultation with the EPA Science Advisory Board is scheduled to take place October 2, 2003 in Washington, DC.

After the consultation, the Office of Water intends to prepare a comprehensive strategy for developing and implementing new SABS criteria, or methods, to be used by the States and Tribes in their water quality standards programs within the next few years as they adopt new and revised criteria to protect their waters.

## BACKGROUND:

### – What are Suspended and Bedded Sediments (SABS)?

Suspended and bedded sediments (SABS) are defined by EPA as particulate organic and inorganic matter that suspend in or are carried by the water, and/or accumulate in a loose, unconsolidated form on the bottom of natural water bodies. This includes the frequently used terms of clean sediment, suspended sediment, total suspended solids, bedload, turbidity, or in common terms, dirt, soils or eroded materials.

EPA's definition of SABS also includes organic solids such as algal material, particulate leaf detritus and other organic material. This initiative on SABS criteria intentionally does not look at contamination in sediments, another significant environmental issue, rather, EPA has dealt directly with the toxicity of chemicals in sediments through its work on Equilibrium Partitioning-Derived Sediment Benchmarks. EPA does recognize however, that managing SABS in the aquatic environment will have either direct or indirect consequences on the amount of contaminated sediments and may need to further examine these relationships in future efforts.

SABS can be further defined in regards to particle size which are related to the mode of action in the aquatic environment. SABS can be broken into two fractions based on size – fine sediment and coarse sediment. Fine sediment is typically considered to consist mostly of particles smaller than 0.85 mm and coarse sediment is defined as greater than 9.5 mm. Particles less than 0.063 mm (silt and clay) remain suspended in flowing water and are largely the cause of turbidity (IDEQ, 2003).

**– What are the impacts of SABS?**

SABS are a unique water quality problem when compared to toxic chemicals, in that suspended solids and bedded sediments (including the organic fraction) occur naturally in water bodies in natural or background amounts and are essential to the ecological function of a water body. Suspended solids and sediments transport nutrients, detritus, and other organic matter in natural amounts which are critical to the health of a water body. Suspended solids and sediment in natural quantities also replenish sediment bedloads and create valuable micro-habitats, such as pools and sand bars. Therefore, a basic premise for managing suspended and bedded sediments in water bodies to protect aquatic life uses may be the need to maintain natural or background levels of SABS in water bodies.

However, SABS in excessive amounts constitute a major ecosystem stressor. According to the EPA National Water Quality Inventory - 2000 Report, excessive sediment was the leading cause of impairment of the Nation's waters. The highest frequency of impairment was reported for rivers and streams, followed by lakes, reservoirs, ponds, and estuaries. In 1998, approximately 40% of assessed river miles in the U.S. were impaired or threatened from excessive SABS.

Suspended and bedded sediments have two major avenues of effect in aquatic systems; 1) direct effects on biota, and 2) direct effects on physical habitat, which result in effects on biota. In considering impacts, suspended sediment is the portion of SABS that exert a negative impact via suspension in the water column, such as shading of submerged macrophytes. Bedded sediments are those sediments that have a negative impact when they settle out on the bottom of the water body and smother spawning beds and other habitats. (An additional summary of the effects of SABS can be found in Appendix 1 and a comprehensive review can be found in Jha, 2003. The following discussion is excerpted from Jha, 2003.)

In streams and rivers, fine inorganic sediments, especially silts and clays, affect the habitat for macroinvertebrates and fish spawning, as well as fish rearing and feeding behavior. Larger sands and gravels can scour diatoms and cause burying of invertebrates, whereas suspended sediment affects the light available for photosynthesis by plants and visual capacity of animals. A potential problem with suspended sediment in reservoirs, coastal wetlands, estuaries, and near-shore zones is decreased light penetration, which often causes aquatic macrophytes to be replaced with algal communities, with resulting changes in both the invertebrate and fish communities. Increased sedimentation also may functionally shift the fish community from generalist feeding and spawning guilds to more bottom-oriented, silt tolerant fishes.

Sediment starvation caused by structures such as dams and levees is also a problem in some ecosystems, ranging from the loss of native fish species and native riparian ecosystem structure in many dammed Western rivers (e.g., Colorado River, Platte River, Missouri River), to the subsidence and loss of wetlands (e.g., Mississippi Delta in Louisiana).

Effects of excess suspended and bedded sediments on habitat structure include changes in refugia for biota (e.g., changes in macrophyte communities), increased fines (and embeddedness) and scouring in streams, aggradation and destabilization of stream channels, and filling in of wetlands and other receiving waters, and for sediment starvation, scouring and removal of riparian and pool habitat, and subsidence and disappearance of wetlands and lowering of the water table. Increased turbidity and concomitant changes in light regime may be considered to be aspects of altered habitat. Indirect effects on biota will occur as the fish, invertebrates, algae, amphibians, and birds that rely upon aquatic habitat for reproduction, feeding, and cover are adversely affected by habitat loss or degradation. Sea grasses and other submerged aquatic vegetation (SAV) are considered "keystone" species in temperate and tropical estuaries and coastal areas. These flora have a variety of beneficial attributes including providing food and shelter for many aquatic and terrestrial species. There has been a worldwide decline in sea grasses including dramatic regional losses in the Gulf of Mexico. When studied in detail, seagrass declines have always been linked to nutrient enrichment as the most important cause, but suspended sediment remains a suspected secondary cause in several cases.

SABS also affect fish populations. Three major effects of SABS on fishes include: 1) behavioral effects, such as inability to see prey or feed normally; 2) physiological effects, such as gill clogging; and 3) effects due to sediment deposition, such as burial and suffocation of eggs and larvae. Physiological effects of sedimentation can result in impaired growth, histological changes to gill tissue, alterations in blood chemistry, and an overall decrease in health and resistance to parasitism and disease. Lower doses or shorter duration of SABS will have transitory effects, while higher doses for longer periods can result in more lasting and severe effects.

Fish can also swallow large quantities of sediment, causing illness, reduced growth and eventual death, depending on other contaminants that may be adsorbed to the sediment. Some other physiological changes include; release of stress hormones (i.e., cortisol and epinephrine), a compensatory response to a decrease in gill function, and clogging gill mucus causing asphyxiation and traumatization of gill tissue. The severity of damage appears to be related to the dose of exposure as well as the size and angularity of the particles involved.

Certain fish populations may be severely impacted in their ability to feed by even small increases in SABS concentrations because of increased turbidity. Fish that need to see their prey to feed suffer from reduced visibility in turbid water and may be restricted from otherwise satisfactory habitat. Some fishes are able to hunt better as SABS concentrations increase up to a point because of increased contrast between the prey and the surrounding water.

Many species of fish may relocate when sediment load is increased, because fish can readily disperse. Other behavior responses include an increased frequency of the cough reflex and temporary disruption of territoriality. The severity of the behavioral response is associated with the timing of disturbance, the level of stress, decreased energy reserves, phagocytes, metabolic depletion, seasonal variation, and alteration of the habitat.

Severity of effect caused by suspended sediments is a function of many factors, which, in addition to sediment concentration, duration, particle size, and life history stage, may include temperature, physical and chemical characteristics of the particles, associated toxicants, acclimatization, other stressors, and interactions of these factors. Suspended sedimentation effects have been scored on a qualitative scale as "severity of ill effect" (SEV), that include everything from "no behavioral effects" (lowest on the scale) to behavioral effects (low on the scale); to sublethal effects (higher on the scale); to lethal effects (highest on the scale). According to Griffiths and Walton (1978), the upper tolerance level for suspended sediment is between 80-100 mg/l for fish, and as low as 10-15 mg/l for bottom invertebrates.

Many species of fish and macroinvertebrates use the interstitial spaces at the bottom of streams to lay their eggs. Reproductive success is severely affected by sediment deposition particularly in benthic spawning fishes. The primary mechanisms of action are through increased egg mortality, reduced egg hatch and a reduction in the successful emergence of larvae . The cause of egg survival rates and egg death are due to reduced permeability of streambed and from burial by settled particles. Thin coverings (a few mm) of fine particles are believed to disrupt the normal exchange of gases and metabolic wastes between the egg and water. Sediment deposition has caused a 94% reduction in numbers and standing crop biomass in large game fish, because of increased vulnerability of their eggs to predation in gravel and small rubble, reduction in oxygen supply to eggs, and increased embryo mortality. It can also cause reduced larval survival because of armoring of the sediment surface, which traps the larvae. Differences in sensitivity, egg mortality effects, early life stages (i.e., eggs, larvae) and magnitude of impact upon fish population are associated with amount of elevated sediment loads, size of the sediment particles involved, seasonal variation, and rates of sediment deposition. Even if intergravel flow is adequate for embryo development, sand that plugs the interstitial areas near the surface of the stream bed can prevent alevins from emerging from the gravel. For example, emergence success of cutthroat trout was reduced from 76% to 4% when fine sediment was added to redds (Weaver and Fraley, 1993).

There are also detrimental effects of SABS on aquatic invertebrates. SABSs impact the density, diversity and structure of invertebrate communities. High and sustained levels of sediment may cause permanent alterations in community structure including, diversity, density, biomass, growth, rates of reproduction, and mortality. Direct effects on invertebrates include abrasion, clogging of filtration mechanisms thereby interfering with ingestion and respiration, and in extreme cases, smothering and burial resulting in mortality. Indirect effects are primarily from light attenuation leading to changes in feeding efficiency, behavior (i.e., drift and avoidance), and alteration of habitat from changes in substrate composition, affecting the distribution of infaunal and epibenthic species. Three major relationships between benthic invertebrate communities and sediment deposition in streams have been reported, including correlation between abundance of micro-invertebrates and substrate particle size, embeddedness of substrate and loss of interstitial space, and change in species composition with change in substrate composition.

Sedimentation alters the structure of the invertebrate community by causing a shift in proportions from one functional group to another. Sedimentation can lead to embeddedness, which blocks critical macroinvertebrate habitat by filling in the interstices of the cobble and other hard substrate on the stream bottom. As deposited sediment increases, changes in invertebrate community structure and diversity occur.

Invertebrate drift is directly affected by increased suspended sediment load in freshwater streams. These changes generally involve a shift in dominance from ephemeroptera, plecoptera and trichoptera (EPT) taxa to other less pollution-sensitive species that can cope with sedimentation. Increases in sediment deposition that affect the growth, abundance, or species composition of the periphytic (attached) algal community will also have an effect on the macroinvertebrate grazers that feed predominantly on periphyton. For example in the Chattooga River watershed, accelerated sedimentation was identified as the leading cause of habitat loss and reduction in bed form diversity (Pruitt et. al., 2001). A significant correlation was observed between aquatic ecology and normalized total suspended solids (TSS) data. Effects on aquatic individuals, populations, and communities are expressed through alterations in local food webs and habitat. When sedimentation exceeds certain thresholds, ensuing effects will likely involve decline of the existing aquatic invertebrate community and subsequent colonization by pioneer species.

SABS also have a negative affect on the survival of freshwater mussels. Increased levels of SABS impair ingestion rates of freshwater mussels in laboratory studies. However, it has been suggested that survival may be species-specific. Mussels compensate for increased levels of suspended sediment by increasing filtration rates, increasing the proportion of filtered material that is rejected, and increasing the selection efficiency for organic matter. Species-specific responses to SABS are adaptations to sediment levels in the local environment, such that species inhabiting turbid environments are better able to select between organic and inorganic particles. Many of the endangered freshwater mussel species have evolved in fast flowing streams with historically low levels of suspended sediment. Such species may not be able to actively select between organic and inorganic particles in the water column. Therefore, even low levels of sediment may reduce feeding and, in turn, reduce growth and reproduction.

Corals differ greatly in their ability to resist SABS, with most species being highly intolerant of even small amounts while a minority are able to tolerate extremely embedded sediment conditions, and a few are even able to live directly in sedimented bottoms. Excessive sedimentation can adversely affect the structure and function of the coral reef ecosystem by altering physical and biological processes through a variety of mechanisms. These all require expenditure of metabolic energy and when sedimentation is excessive they eventually reach the point where they can no longer spare the energy to keep themselves clean, and the affected tissue dies back. Excess SABS cause reduced growth rates, temporary bleaching, and complex food web-associated effects with SABS killing not only corals but other reef dwelling organisms. Coral larvae will not settle and establish themselves in shifting sediments. Increases in sedimentation rates alter the distribution of corals and their associated reef constituents by influencing the ability of coral larvae to settle and survive.

Changes in the supply rate of sediment causes drastic changes in aquatic, wetland, and riparian vegetation. Undesirable changes in vegetation can be induced by both decreases and increases in SABS from natural levels. For example, in the Platte and Missouri Rivers, decreases in both sediment supply and scouring flows have resulted in the growth of stable riparian forests (including many exotic eastern tree species), and the loss of sandbar habitat for several wildlife species (e.g., cranes, piping plovers) (Johnson 1994). In the Colorado River, decreased sediment supply (but continuing scouring flow) has resulted in the loss of riparian wetland habitat dependent on sandbars (Stevens 1995). The magnitude and timing of sedimentation may influence structure and recolonization of aquatic plant communities. The effects of reduced primary production on aquatic invertebrates and fishes at higher trophic levels are compounded when SABS settles on remaining macrophytes. The macrophyte quality also is reduced as a food source. The periphyton communities are likely to be most susceptible to the scouring action of suspended particles or burial by sediments. For example, large-scale declines of submerged aquatic vegetation (SAV) in Chesapeake Bay is directly related to increasing amounts of nutrients, and secondarily to sediments entering the Bay (Staver et. al., 1996).

Indirect impacts of excess sediment on water quality can occur through its influence on aquatic plant communities, organic exchange substrates, and microbial populations. In environments with high concentrations of SABS, reductions in plant species density, biomass, and diversity throughout a trophic level are translated into reductions in energy input to the next trophic level. Decreases in plant populations may result in decreases in populations of zooplankton, insect abundance and overall biomass which may initiate reductions in herbivore, omnivore and predatory fish. SABS deposition may cover microbes, or organic matter needed for microbial processes, or alter redox profiles important in the performance of water quality processes.

For other uses of water bodies, excessive SABS can, among other things, affect water clarity and the aesthetic quality of swimming waters, increase pre-filtration efforts and expenses at drinking water purification facilities and lead to accelerated in-fill of dredged shipping channels, harbors and marinas.

In summary, the current literature suggests SABS are significant contributors to declines in populations of North American aquatic life and can impact other uses of waters. Improved SABS criteria are needed to properly manage the level of SABS in aquatic ecosystems to minimize or avoid these effects.

**– What Are Water Quality Standards?**

Water quality standards consist of a designated use(s) for a water body, ***water quality criteria*** to protect the designated use(s) and an antidegradation policy. States, and Tribes with authorization to conduct a water quality standards program, are required by section 303(c) of the Clean Water Act (CWA) to adopt water quality standards. States and Tribes adopt water quality standards to protect public health and welfare, protect designated uses, enhance the quality of water and serve the purposes of the CWA. Section 101(a) of the CWA specifies that water quality standards should provide, wherever attainable, “water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water”. Section 303(c) states that water quality standards should be established for water bodies taking into consideration their use and value for public water supplies; propagation of fish and wildlife, recreational, agricultural, industrial, navigation and other purposes.

**– What Are Water Quality Criteria?**

Water quality criteria are levels of individual pollutants, or water quality characteristics, or descriptions of conditions of a water body that, if met, will generally protect the designated use(s). EPA, under section 304(a) of the CWA, periodically publishes water quality criteria recommendation for use by States, Tribes and territories in setting water quality standards. Water quality criteria published pursuant to Section 304(a) of the CWA are based solely on data and scientific judgements on the relationship between (pollutant) concentrations and environmental (and human health) effects and do not reflect consideration of economic impacts or the technological feasibility of meeting the criteria values in ambient water.

When establishing numeric criteria, States and Tribes can 1) adopt EPA’s recommended criteria into their water quality standards, or 2) adopt EPA’s recommended water quality criteria modified to reflect site-specific conditions, or 3) adopt criteria derived using other scientifically defensible methods. EPA’s 304(a) criteria recommendations have been critical tools for the States, Tribes and territories for controlling many forms of pollution and improving water quality across the Nation.

There are also other types of designated uses of water bodies, other than aquatic life, which need to be protected from excess SABS. These include recreation in and on the water, shipping, drinking water sources, industrial water use, agricultural water use and others. Water bodies may have multiple use designations, including aquatic life, as well as those other uses listed above or may be limited to uses other than aquatic life if use attainability analyses have been performed by the State, Tribe or territories. There are human health criteria, and other criteria, that are most appropriate for these uses.

## WATER QUALITY CRITERIA FOR SABS– CURRENT STATUS:

During recent discussions between the States and EPA while developing a water quality standards and criteria strategy for the next decade (EPA 2003), the need for new/improved water quality criteria for SABS, or for methodologies for deriving SABS criteria on a regional or site-specific basis, was identified as one of the highest priorities for the EPA water quality criteria program. As a result, the EPA Office of Water has committed to do so.

At this time, EPA believes the biggest challenge will be to develop improved SABS criteria to protect aquatic life. Most other designated uses of water bodies (possibly with the exception of drinking water source uses) where aquatic life uses overlap, may be protected by the potentially more stringent aquatic life criteria. Drinking water uses may need more stringent criteria, but typically apply to few water bodies. Aquatic life uses typically apply to most all waters. However, EPA also believes at this time that other forms of criteria for protecting uses other than aquatic life may still be necessary, where aquatic life uses do not exist or where the other uses are affected differently by SABS.

The section below provides a description of the current status of criteria related to SABS in State and Tribal water quality standards, and elsewhere, primarily as background for considering new criteria development methodologies. However, some of these examples of past, current and future criteria approaches may hold promise as approaches that could be used on a national scale by EPA.

### – What Criteria Recommendations Has EPA Issued in the Past?

In 1976, EPA published a water quality criteria recommendation for solids and turbidity that is based on light reduction. This criterion is summarized in the 1986 EPA *Quality Criteria for Water* as:

> *"Solids (Suspended, Settleable) and Turbidity - Freshwater fish and other aquatic life: Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life."*

The criterion and a brief description of the rationale can be found at http://www.epa.gov/waterscience/criteria/goldbook.pdf. This criteria has not been frequently adopted or used by the States. However, in June 2003, Idaho DEQ proposed to use this criterion value as one component of their newly revised sediment TMDL targets (See description of Idaho below).

EPA also published a narrative "free from" aesthetic standard that States have since adopted into their water quality standards. This narrative states:

> *"Aesthetic Qualities - All waters shall be free from substances attributable to wastewater*

*or other discharges that: settle to form objectionable deposits; float as debris, scum, oil, or other matter to form nuisances; produce objectionable color, odor, taste or turbidity; injure or are toxic or produce adverse physiological response in humans, animals, or plants; produce undesirable or nuisance aquatic life."*

**– Other Recommended Values:**

Referenced in the 1986 *EPA Quality Criteria for Water* are two reports by the National Academy of Sciences (NAS, 1972) and the National Technical Advisory Committee (NTAC, 1968) which were predecessor documents on water quality criteria. In these reports, criteria recommendations related to drinking water and freshwater aquatic life were also provided. These are:

*"Raw Drinking Water with Treatment - Turbidity in water should be readily removable by coagulation, sedimentation and filtration; it should not be present to an extent that will overload the water treatment plant facilities, and should not cause unreasonable treatment costs. In addition, turbidity should not frequently change or vary in characteristics to the extent that such changes cause upsets in water treatment processes."*

*"Freshwater Aquatic Life - Combined effect of color and turbidity should not change the compensation point more than 10 percent from its seasonally established norm, nor should such a change take place in more than 10 percent of the biomass of photosynthetic organisms below the compensation point."*

For other types of designated uses such as boating, fishing, swimming, wading, aesthetics and hunting, a variety of factors contribute to the recreational quality of a water body (Parametrix, 2003). Visual factors such as color and clarity are important along with perceived changes in these factors. The ability to use water safely- to be able to see what is there- is also important. The National Academy of Sciences (NAS/NAE, 1973) recommended that waters used for bathing and swimming should have sufficient clarity to allow for the detection of subsurface hazards or submerged objects and for locating swimmers in danger of drowning. The National Technical Advisory Committee (NTAC) in 1968 recommended that clarity should be such that a secchi disk is visible at minimum depth of four feet given its conclusion that clarity in recreational waters is highly desirable from the standpoint of visual appeal, recreational opportunity, enjoyment and safety (Parametrix, 2003).

**– What Are States and Tribes Currently Doing?**

Most States currently have water quality criteria that can be applied to SABS. Two unpublished summary tables – one of State sediment criteria and the other, State sediment TMDLs, prepared by EPA in 2001, are provided in Appendices 3 and 4 for reference. A few States are developing new criteria for SABS and examples are described below.

Another summary of the current regulatory guidelines for SABS is in the Technical Appendix to the *Ambient Water Quality Guidelines (Criteria) for Turbidity, Suspended and Benthic Sediments* (Caux et al. 1997), prepared for the British Columbia Ministry of Environment, Land and Parks. Caux et al. (1997) built on an earlier review of available criteria by Singleton (1985). A third review of sediment targets used for TMDLs is provided in Idaho DEQ, 2003.

From these reviews it becomes clear there are a wide range of sediment criteria in current use in the United States. Some States use numerical criteria, some use narrative criteria, some use both, and some States have no criteria related to SABS at all. Many States have different criteria for different stream channel substrate types. When they are differentiated, States typically have more stringent criteria for streams with hard substrates (gravel, cobble, bedrock) and less stringent criteria for streams with soft substrates (sand, silt, clay). Hawaii has a separate criterion for reefs. Cold water fisheries typically have more rigorous criteria than do warm water fisheries in states that differentiate between the two uses. A few States use biocriteria (e.g., biotic indices), and at least one uses soil loss as a criterion. Several States provide criteria for an averaging period (e.g., 30 days) as well as an allowed daily maximum concentration. Some States set an absolute value, some set a value over a background level.

Most States with numerical criteria use turbidity as a surrogate measure. Some use exceedances over background (e.g., "Not greater than 50 NTU over background", or "not more than 10% above background" or "no more than 5 NTUs above background"), while some use absolute values (e.g., "Not greater than 100 NTU"). Some States have established numeric standards that are basin-specific while others vary with the presence of salmonids. In general, most States are concerned with the effects of water clarity and light scattering on aquatic life. The majority of States use EPA method 180.1 to measure turbidity and method 160.2 to measure total suspended solids (TSS). Most States use optical backscatter or optical transmission technology for turbidity either by measuring in situ or in the lab after collecting grab or single-point samples. Very few, if any States, attempt to correlate turbidity with TSS or biological impacts, and only a few States measure suspended solids concentration (SSC). Very few States measure particle size distribution and no States measure bedload.

Only a few States use suspended solids as a criterion. Suspended solids criterion values vary from 30 mg/L up to 158 mg/L. At least one State uses transparency ($\geq$ 90% of background) as a standard. A number of States have criteria based on sediment deposited over a time period, or during a storm event. Values are typically 5 mm during an individual event (e.g., during the 24 hours following a heavy rainstorm) for streams with hard substrates bottoms and 10 mm for streams with soft bottoms. Hawaii's reef criterion is 2 mm deposited sediment after an event.

The Chesapeake Bay Program (a multi-state effort) has a criterion based on clarity, including a measurement of the percent light through water (PLW) and secchi disk clarity. The criteria are stratified by depth and salinity regime and are adjusted by season. Water clarity criteria are used in the Chesapeake Bay because it is assumed that they will result in achievement of clarity/solids levels that would not impair other habitats and organisms (with the exception that the water clarity criteria may not fully protect smothering of soft or hard bottom habitats with large sized sediment particles from sources that by-pass (don't influence) shallow water habitats), since submerged aquatic vegetation represents one of the components of the Chesapeake Bay ecosystem that is most sensitive to increases in SABS. A detailed explanation of the derivation of the Chesapeake Bay water clarity criteria can be found in Appendix 1.

Many States have narrative criteria for SABS in addition to, or instead of, numerical criteria. These criteria most frequently pertain to turbidity or appearance of the water (e.g., "Free of substances that change color or turbidity"). Others refer to undesirable biological effects (e.g., "No adverse effects" or "No actions which will impair or alter the communities"). States that employ narrative sediment standards, typically also use a translator -- a numeric or quantifiable target for regulatory purposes (TMDLs, WLAs and permit limits).

Information from the EPA survey conducted in 2001 (Appendix 4) indicates that numeric sediment criteria of some type were identified in 32 of the 53 States. Narrative criteria were identified in13 of the States with no numeric criteria (and in 23 of the States with numeric criteria as well), leaving 8 States where no sediment criteria (either numeric or narrative) were identified. Of these 8 States without criteria, 5 listed an alternative method or guide for establishing sediment criteria such as effluent controls or regional criteria.

Of the 32 States with numeric criteria, 29 were for turbidity and 5 were for suspended solids, including three States listing criteria for both turbidity and suspended solids. Illinois listed criteria for upland erosion, using the soil loss statistic "T". Alaska and Hawaii are the only States that list numeric criteria for bedded sediments. The narrative criteria are broader than the numeric criteria, covering a large range of objectionable conditions that could affect aquatic life or other designated uses. Those related to sediments include water color (turbidity), floating and settleable solids, harmful deposits, and channel habitat measures.

In addition, biological and habitat measures are used to indicate suspended and bedded sediment conditions. Florida is the only State with a numeric criterion for benthic macroinvertebrates as an indicator of sediment conditions. In other States, biological and habitat criteria are narrative or nonexistent.

**– Turbidity Criteria:**

Turbidity criteria were variable among the States and can be categorized into three variations.

(1) Either thresholds in excess of background turbidity or absolute thresholds (independent of background) were established. The majority of States (15) set thresholds in comparison to background, 12 used absolute thresholds, and 2 used a combination of absolute thresholds and those based on a comparison to background (Figure 1).

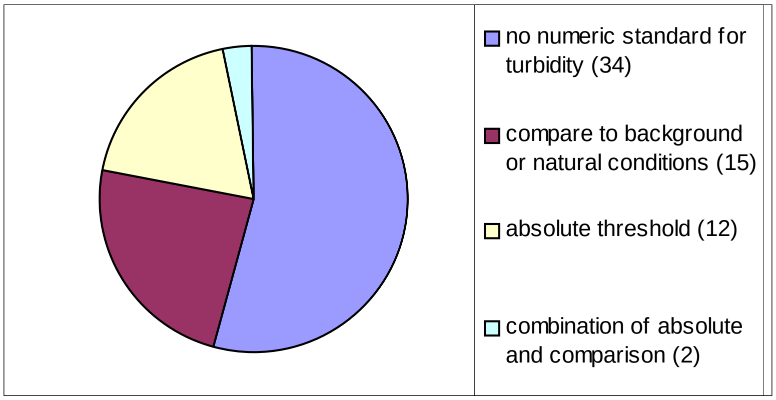


**Figure 1. Comparison of numeric criteria for turbidity, showing types of thresholds, among states**.

(2) Another variation regarded the frequency of exceedances - daily or monthly averages, percentage of readings above a threshold, or instantaneous readings. Instantaneous exceedances of absolute thresholds might be expected to result from rainfall events, though accounting for natural and periodic high turbidity was lacking in most of the criteria. Few States specified sampling during low flow only and Hawaii defined two criteria - one for the wet season and a lower threshold for the dry season.

(3) Within 17 States, thresholds vary based on designated uses, stream classes, fishery types, regions, or rivers (Figure 2). The other twelve of the 29 States with turbidity criteria have a single threshold that applies throughout the State. Most (14) of the States with varying thresholds have stricter criteria for streams that support cool water aquatic communities (trout) or are sources of potable water. These streams are identified by their designated use, stream class, or fishery type. Nevada and Louisiana describe criteria for specific water bodies. Criteria in Arkansas vary by region, probably based on underlying geologies.

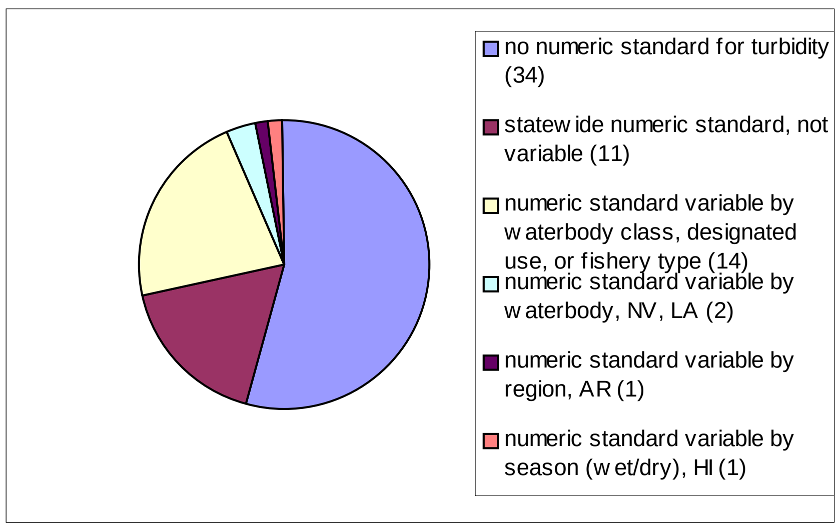


**Figure 2. Comparison of the application of turbidity thresholds by State-wide, water body or class, region and season among States.**

The strictest criteria for turbidity for all States are for highly protected streams in New Hampshire and in the dry season in Hawaii. These criteria require turbidity no greater than background (NH) and a mean value of 2 nephelometric turbidity units (NTU) in Hawaii.

Mountainous States with stable geology generally have stricter criteria than those in coastal or low gradient regions with sedimentary geology. The strictest thresholds within a State appear to be driven by aquatic life uses, whereas the more relaxed thresholds are driven by agricultural and non-aquatic life uses. In other words, where States have varying criteria, the strictest criteria are generally in trout streams or highly protected waters. The highest numeric thresholds (most relaxed criteria) are for large rivers in Louisiana and instantaneous readings in Maryland, both at 150 NTUs. The variability of turbidity criteria can be ascertained from Table 1, which enumerates the States by their strictest and most relaxed criteria. The most common criterion is an absolute threshold of 10 NTUs, which is among the stricter criteria.

**Table 1. Numeric turbidity criteria. The strictest criteria within each State may only apply to highly protected waterbodies and the most relaxed criteria may only apply to naturally turbid waterbodies. If States have uniform statewide criteria, they are tabulated in both sides of the table (as both strictest and most relaxed). Criteria are either NTUs above background levels or absolute thresholds.**

| Strictest of state's criteria | | | | Most relaxed of state's criteria | | | |
|---|---|---|---|---|---|---|---|
| NTUs above background | # states | NTU threshold | # states | NTUs above background | # states | NTU threshold | # states |
| 0 | 1 | 2 | 1 | 10 | 4 | 20 | 1 |
| 5 | 4 | 5 | 1 | 10% | 3 | 25 | 2 |
| 10 | 4 | 10 | 6 | 15 | 2 | 50 | 5 |
| 10% | 3 | 15 | 1 | 20% | 1 | 75 | 1 |
| 25 | 1 | 20 | 1 | 25 | 1 | 150 | 2 |
| 29 | 1 | 50 | 2 | 29 | 1 | qualitative | 1 |
| 50 | 2 | | | 50 | 4 | | |

**– Suspended Solids Criteria:**

Four States have criteria for total suspended solids (TSS), of which two also have turbidity criteria. However, it is not clear how these criteria are used in concert with each other. Hawaii has the strictest TSS criteria, which apply in their dry season, with a geometric mean of readings not to exceed 10 mg/L, less than 10% of readings to exceed 30 mg/L, and less than 2% of readings to exceed 55 mg/L. Utah, North Dakota, and South Dakota have similar criteria for their cold water streams; 35 mg/L, 30 mg/L, and 30 mg/L as a 30 day average or 58 mg/L daily maximum, respectively. Utah and South Dakota have higher thresholds for their warm water streams; 90 mg/L and 150 mg/L as a 30 day average or 263 mg/L daily maximum, respectively.

**– Biological and Other Criteria as Measures of SABS:**

Florida's biological criterion related to suspended sediments requires that the Shannon-Weaver index be reduced no more than 75% of a suitable background condition. New Mexico's matrix of aquatic life use attainment for sediment (NMED, 2002) uses three measures in comparison to reference conditions. Embeddedness and percent pebble-count fines are evaluated as percent increases above reference conditions. A biological index is evaluated as percent decrease below reference conditions. Final assessments of support are then based on the combination of physical and biological assessments. Other criteria based on biological community metrics are narrative (see below).

In Hawaii, criteria are described for episodic sediment deposits in hard-bottomed and soft-bottomed streams following storm events, allowing no more than 5 to 10 mm, respectively, of episodic deposition. In addition, criteria for oxidation-reduction potential and grain size distribution in pools are defined. In Alaska, the percent accumulation of fine sediment in spawning gravel may not be increased more than 5% by weight above natural conditions and in no case may the fine sediment in those gravel beds exceed a maximum of 30% by weight. Florida has a criterion for transparency, not to be reduced by more than 10%.

**– Narrative Criteria:**

Narrative criteria are general statements regarding protection of aquatic life or designated uses. They are mostly of the form: "Surface waters shall be free from pollutants in amounts that cause objectionable conditions or impairment of designated uses (including aquatic life uses)". Some specify the resources that should be protected and the pollutants that should be controlled, while others are general. Of the 36 States with narrative criteria, 32 specifically advocate control of suspended solids or turbidity and 23 specifically advocate control of bottom deposits or settleable solids (bedded sediments). While many narrative criteria have protection of aquatic life as a goal, only 8 recommend that the effects of sediments be determined by direct measurement of biological community integrity as evidenced by changes in community composition or reduction in diversity.

**--Recent Efforts by States to Develop New SABS Criteria:**

**Idaho:**

In Idaho, excessive fine sediment is the most common pollutant in impaired streams. Total Maximum Daily Load (TMDL) plans prepared by the State to address excessive fine sediment must comply with the existing narrative water quality standard for sediment, which states "*Sediment shall not exceed quantities ... which impair beneficial uses*" (IDAPA 58.01.02.200.08). While for the State, this aptly described a goal, it did not describe quantifiable objectives for TMDL plans and stream restorations. Because of this, the Idaho Department of Environmental Quality recently prepared a study suggesting appropriate water column and streambed measures for gauging attainment of the narrative sediment goal.

One of the important beneficial uses of Idaho streams is production of trout and salmon for ecological and recreational purposes. The effects of excessive fine sediment on the embryo, fry, juvenile, and adult life stages of salmonids are well studied by Idaho and others. Characteristics of the stream that change with increasing fine sediments and are known to affect salmonids and other aquatic biota are the best measures of sediment-caused impairment of beneficial uses. These characteristics, and the threshold values that describe minimal degradation, are the targets that are being contemplated for use by the State.

Water column and instream measures were determined to be the best indicators of sediment related impacts including decreased light penetration; increased turbidity, total suspended solids and sediments; increased embeddedness, increased extent of streambed coverage by surface fines and percent subsurface fines in potential spawning gravels, decreased riffle stability, and reduced intergravel dissolved oxygen. The relationships between these measures and the aquatic biota were considered by the State, with special attention given to growth, survival, reproductive success, and habitat suitability of salmonids. Target levels for most measures are recommended based on generalized relationships found in the scientific literature and specific background conditions that exist in Idaho streams. The targets for turbidity and intergravel dissolved oxygen were established based on existing Idaho Water Quality Standards. Where data to describe sediment-biota relationships were lacking or highly variable or background conditions are highly variable, statewide numeric thresholds were found to be inappropriate. For total suspended solids and sediments, embeddedness, and surface sediments, target levels could also be established for each individual stream based on local reference sediment conditions. To provide a regional perspective of the recommended SABS target levels, Idaho made comparisons to standards adopted in neighboring states and provinces. A table of these are included in the Idaho report (Idaho, 2003). The targets developed by Idaho were derived from literature values for studies primarily in the northwest U.S.

In Idaho, biological assessments and criteria are not used directly to manage sediments. Macroinvertebrate and fish community integrity is measured using the Stream Macroinvertebrate Index (SMI) and the Stream Fish Index (SFI), respectively. Reference conditions have been described for macroinvertebrates and fish after recognizing variability in natural stream types in Idaho. Departure from reference conditions indicates that the community is exposed to a stressor(s). Neither the Idaho SMI nor the SFI are specifically calibrated to sediments as a stressor, rather they are sensitive to a range of stressors, including sediments.

Idaho also considered other options for targets for SABS than those summarized in Table 2 below. These included measurements of channel and watershed characteristics. Channel characteristics considered included: width/depth ratio, sediment rating curves, pool frequency and quality, bank stability, and changes in peak flow. Watershed characteristics that were considered included: land area disturbed (especially in unstable areas), road crossings, length and hydrologic connectivity, or condition. Idaho concluded that numeric targets would be difficult to establish for channel and watershed characteristics and suggested that narrative targets or criteria would be more appropriate.

**Table 2: Idaho DEQ recommended instream sediment parameters and associated target levels.**

| Instream Sediment Parameter | Recommended Target Levels |
|---|---|
| Turbidity | Not greater than 50 NTU instantaneous or 25 NTU for more than 10 consecutive days above baseline background, per existing Idaho water quality standard. Chronic levels not to exceed 10 NTU at summer base flow |
| Light Penetration | Not to reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonally established norm for aquatic life |
| Total Suspended Solids and Suspended Sediment | No specific recommendation, establish site specific reference |
| Embeddedness | No specific recommendation, establish site specific reference |
| Surface Sediment | No specific recommendation, establish site specific reference |
| Subsurface Sediment in Riffles | For those streams with subsurface sediment less than 27% - do not exceed the existing fine sediment volume level. For streams that exceed the 27% threshold - reduce subsurface sediment to a 5-year mean not to exceed 27% with no individual year to exceed 29%. Percentage of subsurface sediment < 0.85 mm should not exceed 10% |
| Riffle Stability | Not to exceed a Riffle Stability Index of 70 |
| Intergravel Dissolved Oxygen | Not less than 5.0 mg/L for a 1-day minimum or not less than 6.0 mg/L for a 7-day average mean, per existing Idaho water quality standard |

**New Mexico:**

New Mexico recently developed a draft protocol to support an interpretation of their State Water Quality Standards narrative standard for stream bottom deposits (NMED, 2002). The current standard for the deposition of material on the bottom of a stream channel is listed in the *State Of New Mexico Standards for Interstate and Intrastate Surface Waters*, Section 1105.A General Standards: and states:

> "<u>*Bottom Deposits:*</u>
> *Surface waters of the State shall be free of water contaminants from other than natural causes that will settle and damage or impair the normal growth, function, or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom."*

The State's draft protocol for making use attainment decisions is a quantitative, three-step assessment procedure for determining whether the above narrative standard is being attained in a particular stream reach or segment by: 1) comparing changes or differences, if any, between the site of concern and a reference site; 2) directly evaluating instream habitat by measuring either of two stream bottom substrate parameters or indicators, namely substrate size (mainly fines, 2 mm or less) abundance or cobble embeddedness, and; 3) verifying or confirming results obtained in step 2 by assessing and comparing benthic macroinvertebrate communities (or fish) at the same sites.

New Mexico's step-by-step procedures are described below.

1. Select study site(s) along with a comparable reference site.

2. Perform a bioassessment on the benthic macroinvertebrate community at each reference in which a pebble count and/or embeddedness procedure is to be performed.

3. Do a pebble count and/or embeddedness evaluation at the reference sites. Pebble counts should be done in the same habitat unit(s) where the macroinvertebrates were collected. When doing pebble count evaluations, it is important to determine the necessary sample size (see page7) needed at each study site based on the evaluated sample size and determined percent fines at each reference site. This calculation should preferably be done streamside at the reference site using the pebble count analyzer software so that sufficient data can be collected with one visit. However, it is acceptable to do the calculations in the office, but realize that an additional visit to the stream may be required if the sample size is inadequate.

4. Perform a bioassessment of the benthic macroinvertebrate community at each study site, accompanied by collection of either pebble count and/or embeddedness data of sufficient size to be statistically significant.

5. Compare the physical and biological data between the study and reference sites by dividing the results obtained at the study site by that of the reference site to obtain percent "comparability."

6. Using the final assessment matrix (Table 4 below), locate the proper support cells for both the physical and biological percentages calculated in step 5, and determine the final degree of support for the aquatic life use that is affected by sediment.

**Table 4: New Mexico Final Assessment Matrix for Aquatic Life Use Attainment:**

| **Biological** ➡<br><br>**Physical** ⬇ | **Severely Impaired** 0-17% | **Moderately Impaired** 21-50% | **Slightly Impaired** 54-79% | **Non-impaired** 84-100% |
|---|---|---|---|---|
| **Non-Support** Fines or Embeddedness >40% increase | Non-Support | Partial Support Full | Support, Impacts Observed | Full Support, Impacts Observed |
| **Partial Support** Fines or Embeddedness 28-40%increase | Non-Support | Partial Support | Full Support, Impacts Observed | Full Support, Impacts Observed |
| **Supporting** Fines or Embeddedness 11-27% increase | Non-Support[1] | Partial support[1] | Full Support, Impacts Observed | Full Support |
| **Full Support** Fines or embeddedness <10% increase[2] | Non-Support[1] | Partial Support[1] | Full Support, Impacts Observed | Full Support |

1 Reduction in the relative support level for the aquatic life use in this particular matrix cell is probably not due to sediment. It is most likely the result of some other impairment (temperature, D.O., pH, toxicity, etc.), alone or in combination with sediment.

2 Raw percent values of =20% fines (pebble counts) and = 33% embeddedness at a study site should be evaluated as fully supporting regardless of the percent attained at the reference site.

The complete New Mexico stream bottom assessment protocol can be found at http://www.nmenv.state.nm.us/swqb/protocols/StreamBottomProtocol.pdf.

**– What Is Being Done Elsewhere in the World?**

**Canada:**

Environment Canada has narrative guidelines for deposited bedload sediment, streambed substrate, suspended sediment, and turbidity for aquatic life uses. The British Columbia Ministry of Water, Land and Air Protection released the Ambient Water Quality Guidelines (Criteria) for Turbidity, Suspended and Benthic Sediments which contains numeric thresholds in support of the national narrative guidelines. The BC guidelines are broken down by 5 water uses, 3 sediment parameters, and 2 flow conditions. The water use categories include untreated drinking water, treated drinking water, recreation and aesthetics, aquatic life, and the final catch-all, terrestrial life, irrigation, and industrial uses. Of the 3 sediment parameters, i.e., turbidity, suspended sediments, and streambed substrate composition, turbidity guidelines are defined for all water uses.

The strictest criterion is for untreated drinking water, allowing a turbidity increase of only 1 NTU above background. The most relaxed criterion is for terrestrial life, irrigation, and industrial uses, allowing 10 NTUs or 20% above background (whichever is greatest). Suspended sediments guidelines are defined for aquatic life, and terrestrial life, irrigation, and industrial uses. Streambed substrate composition guidelines are only defined for aquatic life uses and are only applied in actual and potential salmonid spawning areas. The criteria for aquatic life address all three parameters, with turbidity and suspended sediments thresholds varying for clear flow and turbid flow conditions. The thresholds for aquatic life uses are detailed below.

Turbidity:

Clear flow: Induced turbidity should not exceed background levels by more than 8 NTU during any 24-hour period (hourly sampling preferred). For sediment inputs that last between 24 hours and 30 days the mean turbidity should not exceed background by more than 2 NTU (daily sampling preferred).

Turbid flow: Induced turbidity should not exceed background levels by more than 8 NTU at any time when background turbidity is between 8 and 80 NTU. When background exceeds 80 NTU, turbidity should not be increased by more than 10% of the measured background level at any one time.

Suspended Sediments:

Clear flow: Induced suspended sediment concentrations should not exceed background levels by more than 25 mg/L during any 24-hour period (hourly sampling preferred). For sediment inputs that last between 24 hours and 30 days, the average suspended sediment concentration should not exceed background by more than 5 mg/L (daily sampling preferred).

Turbid Flow: Induced suspended sediment concentrations should not exceed background levels by more than 25 mg/L at any time when background levels are between 25 and 250 mg/L. When background exceeds 250 mg/L, suspended sediments should not be increased by more than 10% of the measured background level at any one time.

Stream substrate composition: These guidelines apply to actual and potential spawning sites in streams throughout the province. The composition of fine sediment in streambed substrates should not exceed 10% having a diameter of less than 2.00 mm, 19% having a diameter of less than 3.00 mm, and 25% having a diameter of less than 6.35 mm at potential salmonid spawning sites. The geometric mean diameter and Fredle number of streambed substrates should not be less than 12.0 mm and 5.0, respectively. The minimum and 30-day average guideline for intra-gravel dissolved oxygen levels are 6.0 and 8.0 mg/L, respectively. The British Columbia, Canada water quality standards for turbidity, suspended and benthic sediments are highlighted in Appendix 2.

A Summary of Existing Canadian Environmental Quality Guidelines is available at: www.ccme.ca/assets/pdf/e1_06.pdf. The British Columbia Ambient Water Quality Guidelines (Criteria) for Turbidity, Suspended and Benthic Sediments are available at: wlapwww.gov.bc.ca/wat/wq/BCguidelines/turbidity.html. A guideline on sampling for turbidity and suspended and benthic sediments can be found at http://wlapwww.gov.bc.ca/wat/wq/BCguidelines/sampstrat.html. As mentioned earlier, a detailed technical appendix to their criteria guidelines was prepared by Caux et. al., 1997 and is available at http://wlapwww.gov.bc.ca/wat/wq/BCguidelines/turbiditytech.pdf.

**Australia and New Zealand:**

In Australia and New Zealand, guidelines have been developed for recreational water quality and aesthetics (ANZECC, 2000). Turbidity is not addressed. The visual clarity guidelines are based on the objective that to protect visual clarity of waters used for swimming, the horizontal sighting of a 200mm diameter black disc should exceed 1.6 m. For protecting the aesthetic quality of recreational waters the natural visual clarity should not be reduced by more than 20 percent, the natural hue of water should not be changed by more than 10 points on the Munsell Scale and the natural reflectance of the water should not be changed by more than 50%.

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000) define an approach for defining trigger values which, when exceeded, indicate that a problem may be present due to the stressor of concern. To determine low-risk trigger values, measure the statistical distribution of water quality indicators either at a specific site (preferred), or an appropriate reference system, and also study the ecological and biological effects of physical and chemical stressors. Then define the trigger value as the level of key physical or chemical stressors below which ecologically or biologically meaningful changes do not occur, i.e. the acceptable level of change. Regarding sediments as pollutants, the guidelines address turbidity and suspended particulate matter.

To apply the guidelines where an appropriate reference system is available and there are sufficient resources to collect the necessary information for the reference system, the low-risk trigger concentrations for suspended particulate matter (suspended solids) or turbidity should be determined as the 80 percentile of the reference system distribution. Where possible the trigger values should be obtained for high flow conditions for rivers and streams and during inflow periods for other ecosystems, when most suspended particulate matter will be transported.

Default trigger values are provided for use where either an appropriate reference system is not available, or the scale of operation makes it difficult to justify the allocation of resources to collect the necessary information on a reference system. Ranges of low-risk default trigger values for turbidity indicative of slightly disturbed ecosystems in south-east Australia are as follows; upland rivers: 2-25 NTUs, lowland rivers: 6-50 NTUs, lakes and reservoirs: 1-20 NTUs, and estuaries and marine systems: 0.5-10 NTUs. For moderately or highly disturbed systems, more intensive study is recommended and trigger values may be established using some appropriate percentile of the reference distribution less than the 80$^{th}$ percentile.

The Australian and New Zealand guidelines are available at: www.mfe.govt.nz/publications/water/anzecc-water-quality-guide-02/anzecc-water-quality-guide-02-pdfs.html

**European Union (EU):**

The European Water Framework Directive (WFD) directs the member states to establish goals, basin plans, and monitoring of ecological quality. Assessment of ecological quality is based on a reference condition approach. Annex II of the Directive specifies methods for establishment of type-specific reference conditions for surface water body types.

For each water body type, type-specific hydromorphological, physicochemical and biological conditions shall be established representing the parameter values for that surface water body type at high ecological status. In applying the reference condition methods in heavily modified or artificial water bodies, high ecological status shall be construed as maximum ecological potential. The values for maximum ecological potential for a water body shall be reviewed every six years.

Type-specific reference conditions may be either spatially based or based on modeling, or may be derived using a combination of these methods. Where it is not possible to use these methods, expert judgement may be used to establish such conditions. A reference network for each water body type should be developed using a large enough reference data set to provide a sufficient level of confidence about the parameter values for the reference conditions, given the variability in the values and the modeling techniques. Type-specific biological reference conditions based on modeling may be derived using either predictive models or hindcasting methods. The methods should use historical, palaeological and other available data.

The Annex goes on to state that Member States should collect and maintain information on the type and magnitude of the significant anthropogenic pressures. The significant pressures include:

--Significant morphological alterations to water bodies.

--Other significant anthropogenic impacts on the status of surface waters.

--Land use patterns, including the main urban, industrial and agricultural areas and, where relevant, fisheries and forests.

In Annex VIII, a set of "main pollutants" are listed, among which is "Materials in suspension", but no specific references are made to sediments. The WFD is available at: europa.eu.int/comm/environment/water/water-framework/index_en.html

**POTENTIAL APPROACHES FOR IMPROVED SABS CRITERIA:**

When developing improved SABS criteria, EPA anticipates that the biggest challenge will be developing improved criteria to protect aquatic life. Other designated uses of water bodies where aquatic life uses overlap, most likely will be protected by the potentially more protective aquatic life criteria (with the exception possibly of some drinking water uses such as untreated water source). However, EPA anticipates that other forms of criteria for protecting uses other than aquatic life will still be necessary, where aquatic life uses do not exist or where the other uses are affected differently by the SABS. Therefore, the primary focus of this section is on new and improved SABS criteria methods aimed primarily at aquatic life protection.

Regardless, EPA expects that establishing appropriate criteria for SABS will follow much the same process used for establishing other water quality criteria. EPA, however, does not anticipate that issuance of a singular national recommended SABS criteria that would apply to all water bodies will be possible. Because water bodies vary from region to region with respect to natural SABS regime, it is anticipated that States and Tribes will need adaptable methodologies for deriving SABS on a water body-category basis or using a regional classification scheme.

Initially, EPA plans to produce a SABS criteria development strategy that outlines a general process that States and Tribes may follow when developing and adopting SABS criteria. As a part of this overall strategy, EPA anticipates laying out major goals and expectations, with key milestones and approximate time frames for each activity. EPA plans to prepare a series of technical and programmatic memoranda to assist the States and Tribes during each critical step.

EPA anticipates it will ask States, territories and authorized Tribes to develop plans for implementing new and improved SABS criteria in phases. The first phase, will likely include the development of individual State/Tribal/Territorial SABS adoption plans. The second phase will likely include the adoption of improved narrative standards for SABS, with implementation procedures where States do not currently have effective narrative standards. The third, and final phase, will likely be to adopt regional or water body-category numeric criteria using one or more EPA recommended procedures or methodologies, or scientifically defensible alternatives.

EPA also anticipates developing supporting technical information for the recommended procedures or methods. Potential methodologies that could be used by the States, Tribes and territories are described in this section and are the specific subject of the consultation with the EPA Science Advisory Board. While there may be several ways to develop SABS criteria for aquatic life protection, and each method has strengths and limitations, EPA's current thinking is the best approaches should be based on a correlation of SABS with effects on biota or aquatic life uses.

In general terms, an initial step in the process of developing aquatic life criteria for SABS is deciding which species, communities or designated aquatic life use to protect. The simplest approach is to protect everything, that is, to set the criteria at a level protective of the most sensitive aquatic organisms. This is roughly equivalent to making sure that SABS do not exceed the natural background levels for a particular region or class of water bodies.

Another approach is to protect most everything, as is done for the toxic chemical criteria, which attempt to be protective of 95% of the genera tested (Stephan et al, 1985) as a surrogate for the entire population or community. An alternative approach is to choose the most sensitive, or important of the biota and protect it.

Any approach, however, will be difficult because SABS are a natural component of the environment, and vary considerably within and among various habitats and regions. Biota in various habitats has evolved to tolerate or even require various levels of SABS.

The following generic steps may be useful to consider when developing a method for setting SABS criteria:

1) Develop a conceptual model outlining the ecological processes effected by SABS for a particular water body;

2) Choose the ecological processes, species or groups of species, and beneficial uses deemed desirable for protection; and

3) Develop numerical targets for protecting the ecological processes, species or groups of species, and beneficial uses deemed desirable for protection based on the correlations between SABS and the biota.

At this time, EPA is examining eight potential approaches to developing water quality criteria for SABS that need to be evaluated and then explained more thoroughly before any one is recommended for use by the States, Tribes or territories. These eight preliminary approaches include; 1) the Toxicological Dose-Response Approach, 2) the Relative Bed Stability and Sedimentation Approach, 3) the Conditional Probability Approach to Establishing Thresholds, 4) State-by-State Reference Condition Approach, 5) the Fluvial Geomorphic Approach, 6) the Water Body Use Functional Approach, 7) successful new State approaches and, 8) combinations of 1-7 or a synthesis of components of each. The first 5 approaches focus on aquatic life. These approaches are described in more detail below.

**Potential Options:**

**1. Toxicological Dose-Response Approach:**

Since the early 1980's, EPA has developed water quality criteria for specific pollutants to protect aquatic life under Section 304(a) of the Clean Water Act. The criteria provide recommendations to States and Tribes for adopting water quality standards which are the basis for water quality-based National Pollutant Discharge Elimination System (NPDES) permit limits for controlling point source discharges and for establishing total maximum daily loads (TMDLs) for water bodies. The majority of EPA's aquatic life criteria have been derived from two methodologies: the 1980 *Guidelines for Deriving Water Quality Criteria for the Protection of Aquatic Life and Its Uses*, and the 1985 *Guidelines for Deriving Numerical National Aquatic Life Criteria for Protection of Aquatic Organisms and Their Uses.* A third revision is currently underway at EPA to incorporate the science and technology advancements of the last 20 years.

When considering approaches for SABS criteria, it is useful to have an understanding of how the Guidelines are ordinarily applied. Under the Guidelines approach, acute toxicity test data must be available for species from a minimum of eight families with a minimum required taxonomic diversity. The diversity of tested species is intended to assure protection of various components of an aquatic ecosystem. The final acute value (FAV) is an estimate of the fifth percentile of a sensitivity distribution represented by the average LC50/EC50s of the tested genera. The Criterion Maximum Concentration (CMC) is set to one-half of the FAV to correspond to a lower level of effect than the LC50s/EC50s used to derive the FAV. Chronic toxicity test data (longer term survival, growth, or reproduction) must be available for at least three taxa to derive a final chronic value (FCV). A Criterion Continuous Concentration (CCC) can be established from a FCV calculated similarly to an FAV, if chronic toxicity data are available for eight genera with a minimum required taxonomic diversity; or most often the chronic criterion is set by determining an appropriate acute–chronic ratio (the ratio of acutely toxic concentrations to the chronically toxic concentrations) and applying that ratio to the FAV. When necessary, the acute and/or chronic criterion may be adjusted to protect locally important or sensitive species not considered during development of the criterion, or can be adjusted based on local water chemistry. Once developed, the CMC and CCC incorporate exposure duration and frequency factors, i.e; the CMC one-hour average should not be exceeded more than once in three years on average, or the CCC four-day average should not be exceeded more than once in three years.

SABS criteria based on toxicological and/or behavioral effects can be developed, in theory, much like other EPA toxic chemical criteria. However, EPA has concluded that sound data are lacking for most species, and standardized consensus-based test methods for determining sediment effects are generally unavailable. Therefore, it is unlikely that a list of genus mean acute and chronic values for sediment can be developed in the short-term and such an effort would require substantial resources. A second difficulty is that sediment can consist of many things depending on the site. Therefore, much like other "conglomerate" substances such as oil and grease or dissolved solids, it will be difficult to identify appropriate criteria for sediments without first determining the specific type of sediment (organic vs. inorganic; silt vs. clay, fine vs. coarse, etc.).

However, toxicological or behavioral-based criteria for SABS have the advantage of specifying appropriate management levels depending on the types of aquatic life present. Furthermore, this approach is explicitly causative; controlled laboratory or field analyses are used to determine threshold effect concentrations. In addition, it could be possible to specify the amount of reduction in suspended sediment or sedimentation needed to maintain desired aquatic resources using this approach. One modified way in which sediment thresholds can be reasonably implemented is through sediment criteria based on a few sensitive target indicator species for which some sediment effect levels are known (e.g., trout, certain corals, certain EPT taxa, or bluegills). Each indicator would represent certain types of beneficial uses, aquatic systems or regions of the U.S. This is similar to a risk assessment approach. If such thresholds could be developed, however, there would still be uncertainties due to synergistic interaction of the many other factors that influence sedimentation effects.

SABS have many impacts in aquatic ecosystems, and effects on the biota vary considerably among habitats. However, there are dose-response models for some species in some habitats, and criteria have been developed for their protection (e.g., British Columbia Guidelines in Caux et al., 1997, Chesapeake Bay Water Clarity Guidelines in U.S.EPA, 2000b). Using these approaches at a national level needs further investigation..

In summary, if the necessary data were available in the literature, the main strength of pursing a toxicological approach is that it employs a standardized methodology which has general acceptance by the scientific, regulatory and stakeholder communities. In addition, this approach would be more cost-effective and less burdensome on the States, as nationally recommended criteria values could be readily adopted without extensive data collection, analysis or water body-specific adjustments. This approach, however, would suffer from two additional key limitations. First is the absence of natural or background concentrations and organism acclimation being factored into the methodology. The second is the presumption applied to toxic chemicals that there is an absolute value above which effects are likely to occur for certain sensitive species, and below which they do not. SABS do not necessarily act on organisms in the environment in the same way as do toxicants. Also how would duration and frequency be defined for SABS, if at all? In principle, these limitations could be addressed through certain EPA-approved mechanisms to modify national criteria on a site-specific basis. The Recalculation Procedure (USEPA 1994), for example, could be used to refine the national SABS criteria based on the types of species that could occur in the region or waterbody classification, and their natural sensitivity to SABS. However, use of such a procedure assumes the availability of fairly large acute toxicity database (>20 genera, at a minimum), which may not be feasible in the short-term.

**2. Relative Bed Stability and Sedimentation Approach:**

Stream bed characteristics are often cited as major controls on the species composition of macroinvertebrate, periphyton, and fish assemblages in streams (e.g., Hynes, 1972; Cummins, 1974; Platts et al., 1983). Along with bedform (e.g., riffles and pools), substrate size influences the hydraulic roughness and consequently the range of water velocities in a stream channel. It also influences the size range of interstices that provide living space and cover for macroinvertebrates, salamanders, sculpins, and darters. Accumulations of fine substrate particles fill the interstices of coarser bed materials, reducing habitat space and its availability for benthic fish and macroinvertebrates (Platts et al. 1983; Hawkins et al., 1983; Rinne 1988). In addition, these fine particles impede circulation of oxygenated water into hyporheic habitats. Substrate characteristics are often sensitive indicators of the effects of human activities on streams (MacDonald et al., 1991). Decreases in the mean substrate size and increases in stream bed fine sediments can destabilize stream channels (Wilcock 1998) and may indicate increases in the rates of upland erosion and sediment supply (Lisle, 1982 Dietrich et al., 1989).

Although many human activities directly or indirectly alter stream substrates, streambed particle sizes also vary naturally in streams with different sizes, slopes, and surficial geology (Leopold et al., 1964; Morisawa, 1968). The size composition of a streambed depends on the rates of supply of various sediment sizes to the stream and the rate at which the flow takes them downstream (Mackin, 1948). Sediment supply to streams is influenced by topography, precipitation, and land cover, but the source of sediments is the basin soil and geology, and supplies are greater where these materials are inherently more erodible. Once sediments reach a channel and become part of the stream bed, their transport is largely a function of channel slope and discharge during floods (in turn, discharge is largely dependent upon drainage area, precipitation, and runoff rates). For streams that have the same rate of sediment input from watershed erosion, steeper streams tend to have coarser substrates than those with lower gradient, and larger streams (because they tend to be deeper) have coarser substrates than small ones flowing at the same slope. However, this transport capability can be greatly altered by the presence of such features as large woody debris and complexities in channel shape (sinuosity, pools, width/depth ratio, etc.). The combination of these factors determines the depth and velocity of streamflow and the shear stress (erosive force) that it exerts on the streambed. By comparing the actual particle sizes observed in a stream with a calculation of the sizes of particles that can be mobilized by that stream, the stream bed stability can be evaluated. Furthermore, it can be evaluated whether low values of bed stability are due to accumulation of fine sediments (“excess fining”), and may examine watershed data to infer whether the sediment supply to the stream may be augmented by upslope erosion from anthropogenic and natural disturbances.

**Quantifying Relative Bed Stability and Sedimentation**

***Relative Bed Stability (RBS)*** is calculated as the ratio of observed substrate diameter divided by the calculated “critical” or mobile diameter (Dingman, 1984). RBS is the inverse of the substrate “fining” measure calculated by Buffington and Montgomery (1999a, b), and is conceptually similar to the “Riffle Stability Index” of Kappesser (1995) and the bed stability ratio discussed by Dietrich et al., (1989).

***Bed Substrate Size****:* When evaluating the stability of whole streambeds (vs. individual bed particles), observed substrate is typically represented by the average diameter of surface substrate particles (e.g., $D_{50}$ or the geometric mean). To characterize the actual substrate particle size distribution in a stream channel, EMAP follows widely accepted procedures. The EMAP field protocols (Kaufmann and Robison, 1998) like those of most practitioners (e.g., Platts et al., 1983; Bauer and Burton, 1993) employ a systematic “pebble count," as described by Wolman (1954), to quantify the substrate size distribution.

***Critical Substrate Size:*** For calculating critical (mobile) substrate diameter in a natural stream, it is necessary to estimate average streambed tractive force, or shear stress, for some common reference flow conditions likely to mobilize the streambed. Bankfull discharge is typically chosen for this purpose, though it is more appropriate for gravel-bed streams than for "live-bed" streams such as naturally sand-bedded streams that transport bedload at lower flows. The EMAP approach for estimating the critical substrate particle diameter in a stream is based on sediment transport theory (e.g., Simons and Senturk, 1977), which allows an estimate of the average streambed shear stress or erosive tractive force on the bed during bankfull flow. Stream channels can be very complex, exhibiting a wide range in local bed shear stress due to small-scale spatial variation in slope, depth, and roughness within a channel reach (Lyle et al., 2000). When developing this approach, EMAP researchers (Kaufmann et al., 1999; Kaufmann and Larsen, in prep.) used physical habitat measurements collected in synoptic surveys (Kaufmann and Robison, 1998) to estimate the channel characteristics affecting bed shear stress at bankfull flows. These field measurements include bankfull channel dimensions, slope, channel complexity, and large woody debris. Using the channel and substrate data described in the two preceding paragraphs, EMAP researchers modified the Dingman (1984) RBS calculation to accommodate losses in shear stress resulting from large woody debris and channel complexity (Kaufmann et al., 1999). The reductions in shear stress, and therefore critical diameter, caused by these roughness elements allow fine particles to be more stable in a stream of a given slope and depth.

***RBS Range:*** RBS values in EMAP sample streams range from 0.0001 to 1000. A high positive value of RBS (e.g., 100-1000) indicates an extremely stable, immovable stream substrate like that in an armored canal, a tailwater reach below a dam, or other situations where the sediment supply is low, relative to the hydraulic competence of the stream to transport bedload sediments downstream (Dietrich et al., 1989). Very small RBS values (e.g., .01-.0001) describe a channel composed of substrates that are frequently moved by even small floods.

***RBS Expectations in Unaltered Streams:*** It is hypothesized that, given a natural disturbance regime, sediment supply in watersheds not altered by human disturbances will be in approximate long-term dynamic equilibrium with transport. For streams with sediment transport limited by competence (critical shear stress), rather than total capacity (stream power), the mean of RBS values in these relatively unaltered streams should approximate 1.0 (range from 0.3 to 3), and may have slight surface coarsening due to low hillslope erosion rates (Dietrich et al., 1989). Alternatively, RBS for streams draining watersheds relatively undisturbed by humans should tend towards values other than 1.0 that are characteristic of the region or specific classes of streams within a region, depending upon their natural lithology, soils, topography, climate, and vegetation. In addition, RBS in streams with minimal human disturbance might be expected to differ systematically across a geomorphic gradient from streams with transport dominated by bedload to those dominated by suspended load – generally this occurs in a downstream direction in the stream continuum. RBS values considerably lower than 1.0 may be expected in naturally fine-bedded alluvial streams where transport is limited by average stream power, rather than bankfull shear stress. Alternate hypotheses concerning the expected values of RBS using synoptic data from EMAP surveys are being evaluated. As the EMAP approach for assessing excess streambed sedimentation in low-gradient, fine-bedded streams and rivers, is refined, it may be necessary to modify the approach (currently based on the competence of bankfull floods to move given sizes of particles). For these waters, it may be useful to estimate bed stability in terms of the proportion of the year that the bed is in motion.

***Excess Sediment:*** In watersheds where sediment supplies are augmented relative to a stream's bedload transport competence, it is expected there will be evidence of excess fine sediments, or "textural fining" (Dietrich et al., 1989). Very small RBS values (e.g., .01-.0001) describe a channel composed of substrates that are frequently moved by even small floods, indicating excessive amounts of fine particles compared with expected values in most relatively undisturbed watersheds. Such evidence of textural fining of the stream bed (RBS<<1) typically occurs when land use activities increase hillslope erosion (Lisle, 1982; Dietrich et al., 1989; Lisle and Hilton 1992). It is further expected that, for streams draining basins of equal erodibility, RBS values should decrease in proportion to increases in sediment supply above that provided by the natural land disturbance regime. To the extent that human land use increases sediment supply by land erosion within regions of relatively uniform erodibility, RBS of streams in surveys should be inversely proportional to basin and riparian land use intensity and extent. This association of lower RBS with land use disturbances in several regions has been demonstrated (Kaufmann et al, 1999, Kaufmann and Larsen, in prep.) Finally, the more erodible the basin lithology within a geoclimatic region, the steeper the decline in RBS with progressive disturbance is expected. As demonstrated for streams in the Pacific Coastal region by Kaufmann and Larsen (in prep.), this means that any given amount of land use disturbance is expected to augment sediment supplies to a greater degree in basins underlain by erodible rocks than by more resistant rock.

**Evaluating Effects of Sediment on Biota**

Once the degree of sedimentation is estimated for sample sites, associations between biotic assemblages (algae, macroinvertebrates, fish, rooted aquatic plants), and/or key aquatic species or guilds, and deviations of sediment from expected values will be examined. In most cases, the data sets will include sites affected by multiple stressors besides sediment that could potentially act upon these aquatic biota. In such cases, a regional plot of sediment concentration versus some biotic assemblage characteristic (e.g., %EPT macroinvertebrates), will appear as a wedge-shaped pattern of points, where progressively higher fine sediment concentrations are sufficient to limit %EPT numbers, but low concentrations do not guarantee abundant EPT because of other habitat or chemical limitations. These patterns are consistent with a hypothesis that sediment is limiting biota. After demonstration of a plausible causal mechanism (from detailed experimental studies) and elimination of other plausible explanations for these observations, these kinds of associational data in a weight-of-evidence approach to support modeling of the effects of bedded sediments on aquatic biota will be used.

For suspended sediments in streams and rivers, the effort will focus initially on chronic levels of suspended sediments in streams and rivers, rather than those resulting from episodic events such as those accompanying storms. Expected natural levels of chronic suspended solids will be set on the basis of data from flowing waters in basins relatively undisturbed by human land uses and (in rivers) historic water clarity data to the extent possible. Regional reference areas could serve this purpose. Where no relatively undisturbed waters exist, as for large rivers, historic data or reconstructions of fish and/or macroinvertebrate assemblage composition will be used to infer (from published tolerance information) pre-disturbance suspended sediment characteristics. In an approach similar to that for bedded sediments, associations between biotic and/or key aquatic species or guilds and deviations of sediment from expected values in appropriate regional settings will be examined. As for bedded sediments, patterns will be sought that are consistent with biotic limitation by suspended sediment in a weight-of-evidence approach to support modeling the effects of bedded sediments on aquatic biota, supporting this information with controlled experimentation or literature reference to establish the suspended sediment levels that cause substantial impacts on assemblages, sensitive guilds, or key species.

**3. Conditional Probability Approach to Establishing Thresholds:**

A conditional probability approach using survey data is a third proposal for developing SABS criteria. This approach is consistent with the expression of numeric water quality criteria as likelihood of impacts when exceeding a value of a pollution metric. The approach uses survey data (sites selected with a probabilistic design) and determines the likelihood of impaired biology for varying levels of a stressor (in this case, some form of sediment). The use of probability-based survey data permits an unbiased extrapolation of results to the statistical population from which the probability sample was drawn (*e.g.*, the results would be applicable to all of the wadeable streams in a state if the sample was drawn from a sampling frame of all wadable streams in the state).

For application to numeric water quality criteria, a conditional probability statement provides the likelihood (probability) of impacts, if the value of the pollution metric is exceeded. The conditional probability is the probability of an event when it is known that some other event has occurred, and is denoted $P( Y \mid X^* )$, where $X^*$ is the other event that has occurred. For criterion development, $X^*$ is replaced with $X > X_C$, where $X_C$ is the specific threshold that is exceeded. Therefore, the conditional probability statement is $P ( Y \mid X > X_C)$. This approach is similar to the apparent effects threshold approach developed by Long and Morgan (1991) and MacDonald and Ingersoll (2002) to derive sediment quality guidelines.

Data on benthic communities in Mid-Atlantic wadable streams were collected by USEPA's Environmental Monitoring and Assessment Program (EMAP) in 1993-94 and are used to test and evaluate the approach. These data were part of a suite of indicators collected at sites selected with a probability-based design, and have been reported in the Mid-Atlantic Highlands Assessment State-of-the-Streams report (EPA-903-R-00-015). A stream sedimentation threshold of impacts was determined for a channel sedimentation index (CSI). The CSI expresses the deviation in the actual amount of substrate fines from that which would be normally expected to occur. EMAP stream benthic invertebrate survey data were used to determine the likelihood of impaired benthic community (EPT taxa < 9) as a function of the CSI.

This approach is implemented as a two-step process: first, subset the surveyed stream segments into those that exceed a specific CSI value, and second, determine the fraction of the subset with impaired biology. Since the sites were selected with a probabilistic design, the fraction of the stream segments that is impaired is the probability of observing impaired streams if a specific CSI value is exceeded. This process is then repeated for the entire range of observed CSI values. The result is an empirical curve for probability of impact for streams exceeding CSI values. Different analytical procedures are used to illustrate how thresholds of impact can be identified from this empirical curve.

To implement this approach, the following must be assumed or provided:

1. Some metric, X, that quantifies the pollution parameter for which criteria will be developed. In the example, the CSI is used.

2. It is not necessary that X be the only stressor affecting the aquatic community, but it must be a strong stressor, that is, aquatic community condition Y is clearly related to the stressor X for higher values of X. Thus, if the value of Xcis exceeded, it is likely an impact of the biological resource will be present, over and above what occurs naturally and from other stressors.

3. Some independent measure for determining biological impact must be available. In the example, EPT taxa < 9 defined biological impact.

4. Data from a probabilistic design must be available in order to establish the likelihood for impact across an entire geographic area. This is currently the only scientifically defensible means of extrapolation from sites with data to all the sites across an entire region.

Perhaps the biggest limitation of this approach is that it is correlative and not causative. If other factors (including unmeasured ones) are actually responsible for biological impact and not SABS at a given site, the model inaccurately represents SABS effects, and inappropriate SABS criteria may result. This may be sufficient for screening but is inappropriate for regulatory actions.

**4. State-by-State Reference Condition Criteria Derivation Approach:**

The reference condition approach for developing sediment criteria is derived from the regional reference approach for developing biocriteria (EPA 1996; 1998, 2000; Barbour et al. 1999). Analytical approaches 2 and 3 above (relative bed stability and conditional probability), and 5 below (fluvial geomorphological approach) are also compatible with examining and identifying reference conditions, and many of the same measurements would be used in all three approaches. In fact, the derivation of expectations for relative bed stability (RBS) in unaltered streams (Approach 2 above) is a specific reference condition predictive model. Described below is a more generic approach to deriving sediment criteria from reference site information.

There are well-established empirical and theoretical relationships describing the effects of landscape topography, climate, and geology (including soil properties) on channel morphology and sediment dynamics of streams (see Fig. 3 and examples in Knighton 1984 and Gordon et al. 1992). It seems reasonable, therefore, that empirical modeling of sediment characteristics based on these known relationships would be an appropriate method of developing criteria for SABS. The most defensible expectations would be built using relationships derived from non- or minimally disturbed streams (the desired condition).

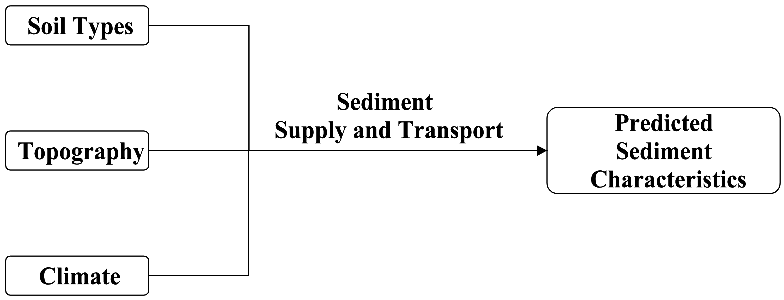


Figure 3 – Three major determinants of sediment characteristics in streams are catchment soil type, topography, and climate. The reference approach builds empirical models of sediment characteristics from minimally disturbed sites using factors related to these major landscape determinants.

The reference approach to developing biocriteria uses minimally disturbed reference streams to build predictive models of stream condition based on measurable characteristics (e.g. topography, geographic region, site and basin physical characteristics). Similar models can be constructed and confirmed to predict reference conditions with respect to sediment. They can then be used to predict acceptable ranges for specific streams based on the physical catchment characteristics of the stream. From this, a variety of criteria could be developed. For example, a certain deviation from prediction can be used (e.g. no more than 20 percent of predicted suspended solids) or models for different stream classes can be averaged to come up with class-specific criteria (e.g., the $75^{th}$ percentile for Piedmont streams with a watershed size less than 50 $km^2$). In addition, gradients or increases above reference condition associated with increasing levels of human disturbance can both be explored and related to human disturbance levels much as suggested for biological condition responses. In either case, the reference condition represents one point along the gradient. The approach also applies to both suspended and bedded sediment characteristics and should be applicable to other water body types other than streams and rivers, with some modification.

Although the models are empirical in that they require data analysis to develop them, the hypothesized relationships between climate, topography, soils, etc. are firmly based in theory and experiment from the body of hydrological knowledge. These models do not merely attempt to find the best statistical predictors, but the best measurable predictors that fit well in hydrological knowledge.

**Defining Reference**

An important step in the reference approach is selecting those streams that will make up the reference database (i.e., to build the model). Reference, in this sense, does not mean pristine; rather, it represents the desired stream state or what is "referred" to when evaluating the condition of any stream. Reference catchments are usually selected using a set of *a priori* designated reference criteria. In the case of model building for predicting sediment, it is important to include criteria that screen for minimally disturbed catchments. Since sediment supply and hydrology respond to most landscape modifications, the first reference criteria are derived from contemporary land use/land cover data and catchments with predominantly natural vegetation cover. A unique consideration for selecting sediment reference sites is also historic land use. The response time of stream channel equilibrium to landscape alteration is on the decades to centuries time scale, if not longer (Trimble 1974, Schumm 1977, Brunsden and Thornes 1979, Trimble 1999). Therefore, it is important to consider historic catchment land use when evaluating potential reference catchments. Those that have experienced historic anthropogenic landscape disturbance may likely still be undergoing geomorphic readjustment. Unless this is an acceptable "reference", these sites should be excluded from the reference database.

In addition to land use/land cover, instream modifications are also important. The presence of dams, channelization, dredging, and diversions will all affect instream sediment dynamics. Dams alter the sediment supply and hydrology of rivers, and therefore, have dramatic impacts on sediment dynamics, often for long distances downstream (Walker 1985, Reiser et al. 1989, Gregory and Madew 1982, Gordon et al. 1992). Channelization, dredging, and other channel modifications alter stream channel geometry. Because channel geometry is related to stream power and, therefore, sediment transport, readjustments such as knickpoint migrations occur following these channel impacts. These impacts often migrate downstream and upstream through a catchment causing long-term channel instability and altered sediment dynamics (Miller 1991, Simon and Hupp 1992). Water diversions alter the hydrology of receiving streams and the resulting reduction in flow can lead to channel destablization by sediment accretion. Therefore, it is important to identify present or historic instream modifications within the catchment when developing a reference database.

A list of criteria would be prepared such that all conditions must be met for a site to be designated as reference (Hughes 1995). The following list is an example of possible criteria for selecting reference sites for characterizing sediment benchmarks or natural background.

- Upwards of 95% of the watershed is in natural and undisturbed cover.
- Historical land uses did not disturb more than 10% of the land in the last 50 years or more than 25% of the land in the last 100 years.
- Activities in the portions of the watershed that are not in natural cover are not in sediment generating land uses such as mining, logging or cultivation on steep slopes, etc.
- Roads do not cross the stream more than once per mile. Road maintenance does not include excessive sanding.
- The stream channel is not altered by dams, channelization, dredging, or diversions within 10 miles upstream of the sampling location. The stream channel was not altered in the last 50 years.

These criteria might be considered too lenient in regions with extensive undisturbed land (e.g. Rocky Mountains) or too restrictive in regions with high population densities and few remote areas (e.g. Northeastern Coastal Plain). When application of a set of criteria result in too many or too few many reference sites, the criteria can be adjusted and re-applied until appropriate sample sizes are obtained. Five reference samples per discrete stream type is an absolute minimum reference data set. Thirty samples per stream type are desirable but often unobtainable (Elliott 1977). When reference stream types are not defined discretely *a priori*, then care must be taken to not exclude important unique natural stream conditions. Criteria may vary from one region to the next, or from one discrete stream class to the next (e.g. mountain streams or plains streams). By varying the criteria to allow for natural variation in sediment loads or ubiquitous land use patterns, all possible reference conditions are represented and models built upon the reference data will be applicable in all types of streams in the region.

**Data Requirements**

Since many state and federal biological monitoring programs (e.g., state biocriteria programs, EMAP, NAWQA) have identified reference sites and now have sizable reference databases, it may be possible to mine the existing reference data, augmented with basin-level data as necessary to examine preliminary models. It is highly likely that EMAP and NAWQA have sufficient data, including extensive sediment, physical and hydrologic data, to develop good predictive models of reference sediment conditions. Many of the state programs, however do not collect hydrologic or sediment data beyond RBP habitat assessment, and their reference sites may need to be revisited to collect the relevant data.

Once reference sites are identified, empirical models of suspended and bed sediment characteristics of those reference streams can be constructed. The models are built to predict the sediment characteristics of particular streams based on their soil, topographic, and climatic setting – the assumption is that these primary factors control the supply and transport of suspended and bed sediment. Several important sources of data are required to identify reference sites and build the models: land use, soil data, climate and hydrology, catchment geomorphology, and sediment data.

Current and historic land use data are necessary for reference site selection to estimate land use/land cover and the presence of any instream modifications. Current land use data are available for most of the contiguous US (e.g., LANDSAT), and the technology is advancing rapidly so that more current data are being made available rapidly. However, historic land use data are often harder to access due to the only relatively recent development of GIS technology (e.g., ArcView, ArcInfo, ArcGIS). Fortunately, historic land use information can often be reconstructed from tax data, historic photographs, historic diaries, etc. In addition, several techniques have been developed by fluvial geomorphologists to identify and/or infer past land use disturbance (e.g., dendrochronology, sediment profile dating, floodplain and terrace coring, etc., see Knighton 1984). These methods can be used to investigate past impacts within a potential reference catchment.

To build predictive models, data on soils, including factors such as soil type, texture, erodibility, porosity will be necessary. Fortunately, detailed soil maps are available for much of the US and are maintained by the Natural Resources Conservation Service (NRCS). Climate data, including precipitation and hydrology are also necessary for building these models. Climate data are available for most of the U.S. through NOAA and state climate offices, and are often accessible via the internet. Hydrologic data are maintained by several agencies, including the USGS and state geological surveys, and are, likewise, often accessible via the internet. However, hydrology is often only available for gauged catchments and may have to be modeled for others. A variety of hydrologic models exist and can be used as necessary (Gordon et al. 1992). Catchment geomorphology is also necessary, including data on topography, catchment size, etc. These data are readily extracted from surface topographic maps using a GIS. Ideally, the purpose of the models will be to predict reference sediment characteristics measurable in single "snapshot" data collections during routine stream monitoring. Nevertheless, it will probably be necessary to begin with models and data sets that include dynamics, including peak flows, stream power, sediment transport, etc. Initial modeling efforts should focus on accurately and reliably predicting the critical dynamic measures from catchment characteristics.

Lastly, and most importantly, suspended and bed sediment data for specified study reaches are necessary. The same measures and derived quantities relevant to approaches 2, 3, and 5 are also relevant here, e.g., relative bed stability (RBS), bed substrate size, critical substrate size, RBS range, channel sedimentation index (CSI), Rosgen class, etc. Total suspended sediment (TSS) data are ideal. Turbidity data using nephelometric turbidity units (NTU) can be converted in some cases, depending on the sediment composition, but the relationship between TSS and NTU is not always linear and can be difficult to convert. Bed transport data are less often collected due to the lack of robust methods, but bed texture data are often available from pebble count or core data.

**Analytical Approaches**

Once data have been assembled for a region, a number of analytical approaches can be used to build models to predict sediment characteristics for a stream. Empirical models are those built from the existing data. Continuous predictive empirical models predict the sediment characteristics for a specific stream reach based on its particular topography, soil type, and hydrology. The derivation of RBS expectations in unaltered streams described in (2) above is an example of a continuous predictive model for reference conditions. Much like the River Invertebrate Prediction and Classification System (RIVPACS)-type models (Wright et al. 1984, Hawkins et al. 2000, Wright 2000) build site-specific predictions of invertebrate communities based on reference site invertebrate data for biological assessment and biocriteria development, continuous predictive empirical sediment models would build a site-specific model for sediment characteristics at a particular site based on data from similar reference sites in the region. This can be done using a combination of multivariate and multiple regression techniques. Discrete predictive empirical models could also be used. Instead of building a site-specific model, these models predict sediment characteristics for discrete classes of streams. Streams would be explicitly classified from the outset, and then statistical models of sediment characteristics used to identify the expected sediment characteristics for each stream class. This has been the approach commonly used for building multimetric-type biological assessment models (e.g., IBI). The Fluvial geomorphological approach (option 5 below) is an example of a discrete classification.

In the absence of robust data for reference sites across the range of streams in a region, which is often the case, theoretical models are also an option. Theoretical models are built from theoretical principles and do not require field data. Theoretical models could be used to predict sediment characteristics for specific sites (continuous) or site classes (discrete). A combination of empirical and theoretical models could also be developed that uses theoretical estimates of predictor variables that can then be used in concert with empirical data to build predictive models. Likely, combined models will be most often used, since large spatial and temporal data gaps will exist for certain regions or for certain types of data.

Once the models are built and confirmed using validation datasets, criteria can be developed based on statistical properties of the predicted sediment values. For site specific predictions, deviations of the predicted values from observed values for reference sites can be used to construct an acceptable level of deviation based on natural reference site variability. For example, in RIVPACS models, the standard deviation of observed/expected scores at reference sites is used as an indicator of methodological and natural variability among reference sites. Any ratio outside that deviation is considered impaired. In a similar way, the predicted sediment to actual sediment value ratio from specific model building reference sites can be used as an indicator of acceptable variability and a ratio outside that range (e.g., 20% greater than expected) would be considered impaired. The criteria in that case would be a standard deviation or percentile above 1.0, where the expected value equals the observed value.

For discrete models, a percentile of the reference site values can be used as the criterion. In IBI models, the 25$^{th}$ percentile of IBI values for a specific class of streams is often used as the criterion for defining impairment where an IBI score below that is considered impaired. Similarly, the 75$^{th}$ percentile of reference site sediment values for a specific class of streams could be used as the impairment criterion. A TSS value above the 75$^{th}$ percentile for that class of streams would be considered impaired.

Values from either of these approaches can also be interpreted along disturbance gradients. Either predicted to actual sediment scores or the sediment values themselves can be related to human disturbance gradients. In either case, the reference condition would be placed along the gradient and other values interpreted appropriately.

**5. Fluvial Geomorphic Approach:**

Analytical methods that address within-channel and hillslope sediment sources and transport processes as well as sediment loads may be applicable to sediment criteria development and relevant to management actions that address impairments at the source. Fluvial geomorphology as a discipline offers theory, classification systems, and field measurement tools indicative of river or stream stability and changes relative to current and predicted sediment supply. A geomorphic approach to criteria development would likely have less measurement of effects on biota, but more emphasis on measuring erosional and depositional processes and rates that may affect a variety of designated uses.

An ongoing, EPA-funded study conducted by David L. Rosgen is developing a sediment assessment framework, called Watershed Assessment of River Stability and Sediment Supply (WARSSS), that is based on geomorphic analysis of the current sedimentary state of watersheds and stream systems. Although this study is directed more toward assessment to guide sediment management actions than to detect thresholds of adverse impact, as criteria do, the WARSSS framework merits examination for elements potentially useful to sediment criteria development.

The analysis separately considers hillslope and channel processes responsible for changes in erosion/sedimentation and related stream channel instability. Two hierarchical levels of assessment are included that provide: 1) an initial broad overview "screening level" to identify and prioritize potentially high risk sub-watersheds/river systems to be subjected to a more detailed prediction assessment for process-specific mitigation; and 2) a process-based, quantitative prediction of potential sediment source and magnitude, streamflow changes and river stability related to the nature, extent and location of a variety of land uses. WARSSS includes a bank erosion model for quantifying the relative contribution of bank erosion versus hillslope and other sources of sediment (Rosgen 2001). A monitoring methodology related to the prediction methods will provide for validation of the assessment methodology and track effectiveness of recommended mitigation to reduce existing excess sediment loading and improve channel stability. As an assessment framework rather than a rigid methodology, individual steps in a WARSSS assessment are amenable at the user's discretion to substitution of alternate models or measures that are better suited to the region or water body type being assessed.

Numerous authors (Rosgen 1994 and 1996, Montgomery and Buffington 1993, Meyers and Swanson 1992, Simon 1992) have observed the relationship between channel type classifications and differences in stability among channel types. This relationship has ramifications for determining appropriate strategies for sediment management. For example, an individual who hasn't considered channel type or stability could spend a great amount of time and effort running bedload transport equations and doing factor of safety analysis on streambanks, when the potential for instability and/or disproportionate sediment supply problems may be minimal. The channel type/stability relationship also may have value in determining appropriate differences in criteria among stable and unstable stream types. Channel evolution theory, which generally contrasts the structural properties of stable and unstable (or transitional) channels and identifies common sets of steps that transitional channels pass through in evolving toward a more stable state, further suggests that it may be possible to take into account the likely stable endpoint of unstable channels when setting waterbody-specific sediment criteria.

Moreover, a variation of the concept of reference condition discussed previously is applied by geomorphologists and hydrologists to characterize "reference reaches" of stable channel types. The channel type classes in the Rosgen classification system (Rosgen 1994) were developed and defined by recognizing consistent patterns in channel measurements from numerous reference reaches. Parameters commonly measured to document channel dimension, pattern and profile include bankfull width/depth ratio, channel slope, sinuosity, entrenchment ratio, and bedload particle size distribution. For a channel class that is typically stable, the physical traits of a reference reach would likely complement the biological traits documented in the same channel type's bioassessment of reference condition. Likewise, typically unstable classes' reference reach data may co-occur with and help explain sub-par bioassessments. The added value of structural reference reach data is their closer relationship to sediment supply and transport processes that play a part in determining stream disturbance by sediment.

Another element addressed in the WARSSS study that can be evaluated for application to sediment criteria involves sediment rating curves (SRCs) that plot, for a given channel, either suspended sediment or bedload against flow. Although general understanding of SRCs is limited, they may have some application potential related to criteria if reference relationships can be developed. Suspended sediment concentration, for example, is often found to be correlated with flow rate, and the literature does offer some evidence that sediment rating coefficients and flow are predictably interrelated within a given region (Hawkins 2002). In an examination of SRCs for suspended sediment and bedload of 160 Rocky Mountain rivers and streams, Troendle et al. (2001) were not able to show differences in dimensionless sediment transport attributable to stream type, but the analysis did reliably detect departure of generally unstable stream types as a group from values expected of stable channels. Ongoing work toward developing and testing reference SRCs continues mainly in the Rocky Mountain states with some investigations in other regions of the United States and Great Britain. Preliminary findings suggest that channel type plus stability may reveal a stronger relationship than channel type alone.

In conclusion, evaluating applicability of geomorphic approaches to EPA's sediment criteria development process should consider:

- What geomorphic measures associated with channel stability and instability would make suitable numeric criteria?

- Can water-column or bedload sediment measurements be paired with channel type classification, by developing different instream numeric criteria for different channel types?

- How can measures of hillslope, land use-related sediment loads best be integrated with measures of channel-derived sediment loads?

- What would be the cost and effort implications for state monitoring programs of using various geomorphic measurements to assess sediment impacts?

- Will other regions be able to develop and apply sediment rating curve relationships that are being developed in some regions of the US?

- Would integrating biotic with geomorphic reference data reduce variability in biotic measures within a given channel type and make biocriteria for sediment assessment consistent?

- As geomorphic measures are more closely related to sediment sources and sediment transport processes than are measures of water column effects or biological effects, would they be more useful for guiding sediment control and remediation activities implemented as a result of criteria non-attainment?

- Can this approach be used to develop classification schemes for use with other approaches?

**6. Water Body Use Functional Approach:**

The waterbody functional approach is proposed for developing SABS criteria for designated uses other than aquatic life. This is not necessarily a new method or approach, but is one that would examine the existing literature and focus criteria on non-aquatic life uses. This approach would primarily apply to recreational (swimming, boating, etc.), industrial, navigational, drinking water and agricultural uses, etc. Under this approach there would not be a need to determine toxic or harmful levels of SABS to aquatic life. Rather, benchmarks would be set based on data and information from the literature and State experiences, that would be protective of the functional use. For example, if shipping and navigational uses were the primary use of a water body, criteria would be established to prevent or minimize the depositional rates of sedimentation that would prevent accelerated filling of shipping channels thereby preventing frequent dredging to maintain those channels.

Likewise, for agricultural water usage, including irrigation and livestock watering, etc., benchmarks could be set based on data that illustrates the level of sediment that causes problems to pumps and piping or increases the need and expense for filtering. Similarly, benchmarks could be set to protect levels of clarity for swimming, drinking water and other functional uses where the literature indicates potential thresholds for protecting these non-aquatic life uses. Dose-response relationships for aquatic biota would not be a critical basis for these criteria.

Functional-based benchmarks for protecting uses other than aquatic life would apply primarily to waterbodies where aquatic life uses do not exist (historically not present, removed through a Use Attainability Analysis (UAA)), or where multiple designated uses have been assigned to a water body (such as a extensive river system) and SABS levels fluctuate substantially throughout the length of the system.

However, where multiple designated uses such as aquatic life and irrigation overlap in a water body or on a specific segment or portion of the water body, SABS criteria set to protect the aquatic life use most likely will be stringent enough to protect all other uses and additional functional criteria may not be necessary. This is a presumption that needs further investigation to confirm its validity.

Examples where "functional benchmarks" that have already been suggested or applied include NAS 1972, NAS/NAE 1993, NTAC 1968, ANZECC 2000, Parametrix 2003. Both narrative and numeric examples include:

> *Waters used for bathing and swimming should have sufficient clarity to allow for the detection of subsurface hazards or submerged objects and for locating swimmers in danger of drowning.*
>
> *Clarity should be such that a secchi disk is visible at minimum depth of four feet given its conclusion that clarity in recreational waters is highly desirable form the standpoint of visual appeal, recreational opportunity, enjoyment and safety.*
>
> *The visual clarity guidelines are based on the objective that to protect visual clarity of waters used for swimming, the horizontal sighting of a 200mm diameter black disc should exceed 1.6 m.*
>
> *Turbidity in water should be readily removable by coagulation, sedimentation and filtration; it should not be present to an extent that will overload the water treatment plant facilities, and should not cause unreasonable treatment costs. In addition, turbidity should not frequently change or vary in characteristics to the*

*extent that such changes cause upsets in water treatment processes.*

*No more than 15 NTUs over background will protect the visual aesthetic quality of a clear water stream.*

**7. Use of successful new State/International approaches:**

As summarized above, States under the pressure to develop and issue total maximum daily loads (TMDLs) for SABS impaired water bodies, are moving forward on their own to develop new and improved SABS criteria from which to implement these regulatory actions. In many cases, these efforts are being initiated under the pressure of legal actions and court ordered deadlines. EPA believes it is valuable to examine what States have done in the past, are currently doing, and are planning to do in the future for SABS criteria, to look for approaches and methods that may be useful, either directly, or with adaptation, to the entire nation. EPA also believes this same consideration should be given to the SABS criteria efforts of other countries. Where approaches and methods of States and other countries appear promising, EPA intends to carefully review these approaches and consider them for application nationwide. At this time, the efforts of Idaho, New Mexico and the province of British Columbia, Canada appear to be approaches that warrant further consideration.

**8. Combinations, or a synthesis of portions, of the above approaches.**

This option is suggested as a separate approach primarily for the purpose of stimulating consideration of a combination of the approaches described above, or a synthesis of components of the approaches. It may be possible that the best approach to developing SABS criteria would be the application of key concepts or components of all or some of the approaches above.

For example many possible synthesis approaches could be formulated from the following outline:

I. **Select Indicators That Should be Measured:**

--Suspended sediment: suspended sediment concentration, turbidity, clarity (use rating curves in flowing waters).
--Bedded sediment: systematic particle size tally ("Wolman pebble count"), embeddedness.
--Biota that indicate sediment problems: biological assemblage composition, "indicator taxa," anomalies, etc.

II. **Establish Expectations for Particular Water Bodies:**

A. Scale measurements by dominant local controlling factors:

1. Rating curves (scaling by discharge: suspended sediment, turbidity, clarity in streams and rivers).
2. Scale by bankfull shear stress (bedded sediments in streams and rivers). (*Relative Bed Stability and Sedimentation Approach*)
3. Scale by water depth and wave action (bedded sediment in lakes and estuaries.
4. Scale fish assemblage measures by stream or lake size.

5. Scale macrobenthos measures by stream or river shear stress.

B. Stratify waterbodies by type and landscape setting:

1. Waterbody type, size.
2. Ecoregion.
3. Further geomorphic classification- for lakes and wetlands *(Fluvial Geomorphic Classification Approach*), Rosgen classification for streams and rivers, Montgomery-Buffington classification for streams and rivers.

C. Identify minimally-disturbed reference sites: where measurements shall be made. (*State-by-State Reference Condition Approach*)

III. **Link Sediment Measures with Biotic Response:**

A. Use published literature: on tolerance and occurrence of biota.

B. Associational analysis: conduct an analysis on survey data where biota and sediment have been measured (*Evaluating Effects of Sediment on Biota -- Relative Bed Stability and Excess Sedimentation Approach*).

C. Experimental dose-response relationships: Establish supplemental relationships where needed. (*Toxicological Approach*).

D. Link relative risk: link sediment measures with biotic impacts that is independently defined. (*Toxicological Approach*).

IV. **Define Impacts:**

A. Rule-based quantification of impacts: TSS value above the 75th percentile of reference site, or 20% greater than expected, or more than 3 standard deviations above mean (*State-by-State Reference Condition Approach*) .

B. Link relative risk: link biologically-defined impacts with sediment levels. (*Toxicological Approach*).

C. Link impacts to uses other than aquatic life: *(Water-Body Use Functional Approach*).

**CONCLUSIONS:**

Developing and implementing improved water quality criteria for SABS will be a significant challenge for EPA, the States, Tribes and territories. The biggest challenge lies in improving criteria that are protective of aquatic life. The development of criteria for SABS may be complicated because of the need to be site-specific. Different water bodies have different processes involving SABS, and different tolerance levels depending on the species and the habitat. The amount of suspended sediment tolerated in a mountain stream is obviously much different from that tolerated in the Mississippi River. Even within habitats there may be great variation in the effect of SABS, thus EPA concludes there is a need for habitat classification in order to develop criteria.

EPA has examined the current status of SABS criteria throughout the country, and in specific locations across the globe, to identify existing or new approaches that may be useful. EPA has also proposed four new possible approaches to SABS criteria development (the Relative Bed Stability and Sedimentation Approach, the Conditional Probability Approach to Establishing Thresholds, the State-by-State Reference Condition Approach and the Fluvial Geomorphic Approach).

During preparation of this discussion paper, some common conclusions or concepts emerged that could be relevant to any criteria development methodology. A brief discussion of these concepts is presented below and are raised for consideration by the Science Advisory Board.

**Common Elements?**

**Two basic forms of criteria**- The States and Tribes need to protect all designated uses from the detrimental effects of suspended and bedded sediments. This includes aquatic life uses, human health related uses, industrial, agricultural and others. It appears however, that criteria to accomplish this will need to focus in two main areas; 1) criteria to protect aquatic life uses, and 2) criteria to protect other uses. The basic methods for deriving criteria in these two areas are fundamentally different.

**Aquatic Life Criteria - Most Stringent**- It appears that SABS criteria established for aquatic life would be the most protective or stringent of criteria for any other potential designated use (excluding some drinking water uses). By setting aquatic life criteria for water bodies with multiple uses in addition to aquatic life, most other uses (recreation, irrigation, navigation, industrial, etc.) would most likely be protected. Only where aquatic life uses do not exist, or in other special circumstances, such as untreated drinking water source uses, would other forms of criteria be needed.

**Natural or Background Levels-** Criteria methods for aquatic life should factor in background concentrations or possibly even natural levels of turbidity, suspended solids and embedded materials as these are valuable and natural components of aquatic ecosystems when in proper concentration and levels for the ecosystem. Although natural levels and background levels could be considered the same, it may provide more flexibility to develop these as two different concepts.

**Lotic vs. Lentic (lacustrine)-** Most likely, SABS criteria for aquatic life will need to be developed or stratified by water body type especially flowing versus pooled. Streams and small rivers have very different SABS background levels or natural regimes than do lakes, large rivers, estuaries, wetlands, coral reefs and other water bodies.

**Modes of action-** The effects of SABS on aquatic organisms are due primarily to impacts that can be grouped into two categories; 1) the effects of light scattering, in the case of excessive turbidity, and 2) the effects of particles, in the case of suspended solids, settleable solids and bed deposits.

**Lack of data**- There is inadequate data in the literature from which to develop toxicological-based thresholds for protecting all aquatic life from the effects of suspended and bedded sediments.

**Classification-** When developing SABS criteria using a reference condition approach, a conditional probability approach, or a habitat stability approach, the classification of water bodies into their natural groupings is critical and will be difficult, data-intensive, and time consuming.

**Programmatic needs of SABS criteria**- Once criteria are developed (whatever format they take) there are a number of programmatic considerations for the successful use of the criteria. They should relate to, and protect, designated uses. They need to be readily measurable and easily monitored by States and Tribes. They need to be readily implemented by EPA, the States and Tribes into their different water programs. They need to be a number(s), or quantifiable in some way, so they can be translated into TMDL targets, wasteload allocations and permit limits. They need to be able to indicate program effectiveness/success and they need to apply to all water body types, including streams, rivers, lakes, reservoirs, estuaries, wetlands, etc.

EPA is seeking advice on the information and conclusions/concepts raised in this paper and on the scientific viability of the proposed new approaches, a combination or synthesis of these approaches, or other approaches from it's Science Advisory Board as stated in the Charge and Specific Questions listed below.

**Overall Charge:**

While many questions and much research remain, EPA seeks the opportunity for a consultation with the Science Advisory Board to gain advice and recommendations on the best potential approaches to developing water quality criteria for suspended and bedded sediments as is described in this discussion paper. The Office of Water is also seeking recommendations on additional criteria development approaches for different types of water body uses, other than aquatic life, and is also seeking advice on any other scientifically defensible criteria derivation methodology not included in this paper.

**More Specific Consultation Questions:**

1. Is it a scientifically valid premise that SABS in natural amounts (or at background levels) are beneficial to ecosystems and therefore water quality criteria should attempt to simulate natural regimes or background levels? If so, how should natural levels or background be determined?

2. Can SABS criteria be stratified by water body type or by some other scheme? If by water body-type, by what level of classification? Lotic and lacustrine? Rivers and streams, wetlands, lakes/reservoirs and estuaries/coastal areas? Others? If some other classification scheme is necessary, what type and how much resolution must it have?

3. What indicators or components should a water quality criterion for SABS include- turbidity, suspended solids, and deposited solids? Others?

4. Can biological assessments and biocriteria play a role in SABS criteria? If so, what role?

5. Should EPA reconsider the inclusion of organic particulate material in its definition of suspended and bedded sediments?

6. Which of the EPA proposed criteria methods do you believe have the greatest potential? Why? Which ones should EPA not pursue further?

7. Can aspects of the different approaches described in the discussion paper be

combined into a synthesis approach?

8. Do any of the recent efforts of the States or other countries offer possibilities for a national criteria approach?

9. Does the Chesapeake Bay approach to light penetration (clarity) hold promise for a national scheme?

10. If SABS criteria are established to protect aquatic life in water bodies, is it reasonable to assume that these criteria will be stringent enough to also protect other uses of the water body (recreation, industrial water intake, drinking water source, etc.)?

With the feedback and recommendations from the EPA Science Advisory Board, the Office of Water anticipates proceeding forward to develop a strategy to be issued by the end of 2004 suggesting the best approaches, processes and schedules for EPA, States, Tribes and territories to pursue for developing and adopting improved SABS criteria.

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**APPENDICES:**

Appendix 1: Literature review on SABS– Berry et al., 2003.

Appendix 2: British Columbia, Canada, Ambient Water Quality Guidelines (Criteria) for Turbidity, Suspended and Bedded Sediments.

Appendix 3: EPA Summary Table of Current State Standards.

Appendix 4: EPA Summary Table of Sediment TMDLs.

Appendix 5: Idaho DEQ, Guide to Selection of Sediment Targets for Use in Idaho TMDLs. June 2003.