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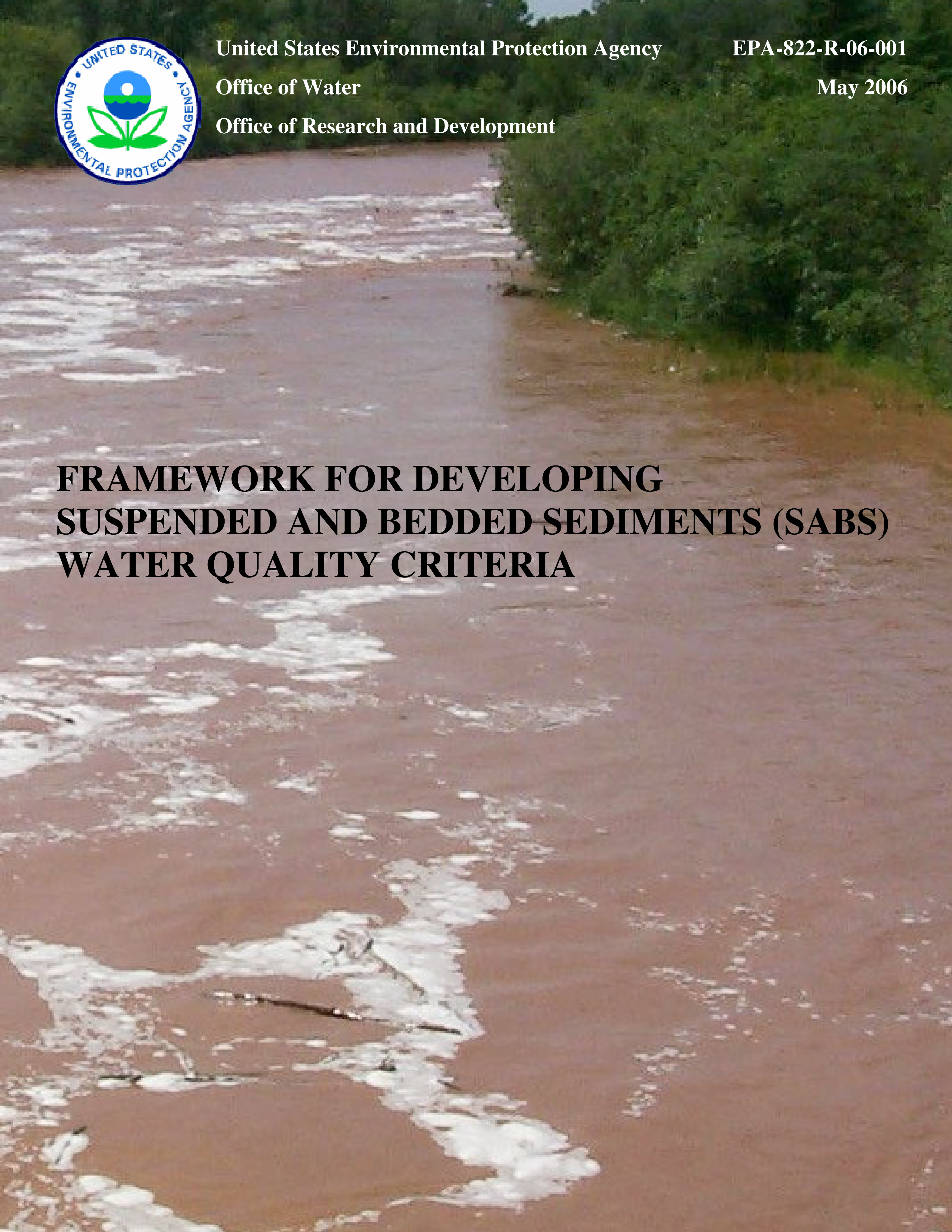
FRAMEWORK FOR DEVELOPING SUSPENDED AND BEDDED SEDIMENTS (SABS) WATER QUALITY CRITERIA



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Framework for Developing Suspended and Bedded Sediments (SABS) Water Quality Criteria

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NOTE TO READER

This document is designed as a framework with a recommended process and methods for developing suspended and bedded sediment criteria. It is not a substitute for the CWA or U.S. EPA's regulations; nor is it a regulation itself. The *Framework* does not impose legally binding requirements on U.S. EPA, states, tribes, territories or the regulated community, and the recommendations may not apply to some particular situations. U.S EPA, state, tribal, and territorial decision-makers retain the discretion to adopt methods on a case-by-case basis that are appropriate to their SABS needs. As research results and new information become available, U.S. EPA expects to revise this document.

LIST OF ACRONYMS

BPJ	Best Professional Judgment
BMP	Best Management Practice
CCC	Criterion Continuous Concentration
CCDF	Conditional cumulative distribution function
CDF	Cumulative distribution function
CI	Confidence interval
CMC	Criterion Maximum Concentration
CPA	Conditional probability analysis
CSREES	Cooperative State Research, Education, and Extension Service
CWA	Clean Water Act
DIN	Dissolved inorganic nitrogen
DIP	Dissolved inorganic phosphorus
EMAP	U.S. EPA Environmental Monitoring and Assessment Program
U.S. EPA	U.S. Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, and Trichoptera metric of mayflies, stoneflies, and caddisflies
GIS	Geographic Information System
HDI	Human Disturbance Index
HQ	U.S. EPA Headquarters
IBI	Index of Biotic Integrity
LA	Load Allocations for non-point sources of pollution
LANDSAT	Land Remote-Sensing Satellite
MPRSA	Marine Protection, Research, and Sanctuaries Act
NAWQA	USGS National Water Quality Assessment Program
NMFS	NOAA National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NTU	Nephelometric turbidity units

ODEQ	Oregon Department of Environmental Quality
ORD	U.S. EPA Office of Research and Development
OST	U.S. EPA Office of Science and Technology
OWOW	U.S. EPA Office of Wetlands, Oceans, and Watersheds
PLL	Percent Light-at-the-Leaf
PLW	Percent Light-through-Water
RBS	Relative Bed Stability
RIVPACS	River Invertebrate Prediction and Classification System
RTAG	Regional Technical Advisory Groups
SABS	Suspended and Bedded Sediments
SAV	Submerged Aquatic Vegetation
SRI	Sediment Risk Index
SSC	Suspended-sediment concentration
STC	Sediment Transport Curves
TMDL	Total Maximum Daily Load
TSS	Total suspended solids
UAA	Use Attainability Analysis
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WARSSS	Watershed Assessment of River Stability and Sediment Supply
WLA	Waste Load Allocation for point sources of pollution
WQC	Water quality criteria
WQS	Water quality standard

ACKNOWLEDGMENTS

The U.S. EPA Science Advisory Board is acknowledged for valuable input during an October 2003 consultation. The Board consisted of scientists and technical experts that met to review and discuss potential methods for developing water quality criteria for suspended and bedded sediment (SABS) as described in a discussion paper prepared and presented by U.S. EPA staff. We greatly appreciated states and staff who responded to a survey of states' needs regarding SABS criteria. GLEC, Inc. and Tetra Tech, Inc. provided contractual support for this document. Ben Jessup of Tetra Tech was responsible for much of the editing and document compilation. All inquiries about this document should be directed to Robert Cantilli by e-mail at Cantilli.Robert@epamail.epa.gov.

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Cover Photograph
Iron River, WI, (1999) near its confluence with Lake Superior
Courtesy of Anett Trebitz and John Morrice
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EXECUTIVE SUMMARY

Suspended and bedded sediments (SABS) occur naturally in all types of waterbodies. In appropriate amounts, sediments are essential to aquatic ecosystems (e.g., in appropriate amounts, SABS can contribute to essential habitat for aquatic species' growth and reproduction). However, imbalanced sediment supply has repeatedly ranked high as a *major cause* of waterbody impairment (U.S. EPA 2003a). The quantity and characteristics of SABS can affect the physical, chemical, and biological integrity of streams, lakes, rivers, estuaries, wetlands, and coastal waters. Excessive SABS (and in some cases, insufficient SABS) can impair waterbody uses such as navigation, recreation, and drinking water filtration. An imbalanced sediment supply resulting from human activities impacts ecological integrity at several scales and trophic levels.

In 2003, the U.S. EPA Office of Science and Technology (OST) within the Office of Water (OW) issued a document titled "Strategy for water quality standards and criteria: setting priorities to strengthen the foundation for protecting and restoring the Nation's waters" (U.S. EPA 2003a). After a wide-ranging review of the existing water quality standards and criteria programs within the context of all clean water programs and after extensive discussions with Water Quality Standards stakeholders, U.S. EPA identified 10 priorities for improving the quality of the Nation's waters. Development of SABS criteria was among the top priorities. The U.S. EPA developed this document in support of states, tribes and territories' efforts to establish SABS criteria that protect the ecological integrity and beneficial uses of water resources, which are major goals of the Clean Water Act (CWA).

This *Framework* describes a process that states, tribes, and territories can use to develop SABS criteria to support water quality standards and protect designated uses. The *Framework* is intended to provide a consistent, defensible process for developing SABS criteria that also allows flexibility for regional and local application and interpretation. The major chapters of the *Framework* include both programmatic and technical elements. The programmatic elements section contains discussions of resources, integration with state programs, and implementation of criteria and standards. The technical elements section provides analytical methods for SABS criteria development. Examples are provided to illustrate how the *Framework* can be applied. Neither the process nor the methods are meant to be mandatory.

Purpose of Document

The U.S. EPA understands that states, tribes, and territories have an interest in adopting consistent scientifically defensible SABS criteria. Towards this goal, the U.S. EPA is providing this *Framework*, with possible methods that states, tribes, and territories can use to develop SABS criteria to support water quality standards and protect designated uses. This *Framework* describes what is known and what can be done relative to developing SABS criteria and will evolve as research results and new information become available.

This *Framework* does not intend to prescribe a priority of activities that should be undertaken for developing SABS criteria. Nor does this *Framework* intend to suggest that states, tribes, territories, or other water resource managers need to change their existing priorities (e.g., switching priorities from one program area to SABS). U.S. EPA is providing information that water resource mangers could use in developing their SABS criteria.

How Can States, Tribes, and Territories Use this Document?

States, tribes, and territories that desire to develop and implement SABS criteria may use the process and methods described in this *Framework*. The *Framework* is flexible, allowing many variations in the combination of indicators, classifications, and analytical methods. This flexibility allows resource managers to customize the criteria development approach to specific needs and capacities. It also encourages justification for the choices made in customizing the process. While these methods and processes are explained individually, in practice they will be applied simultaneously or in combination.

With this *Framework*, states, tribes, and territories are presented with scientifically valid tools and technical elements needed for developing criteria, adopting criteria into standards, and managing and evaluating performance management actions to support attainment of SABS standards. Adopting criteria into standards could proceed in phases (i.e., going from a planning phase, to adoption of improved narrative criteria, and then to adoption of improved numeric criteria). Management for acceptable SABS conditions and evaluation of SABS criteria performance are complimentary processes that can be accomplished by monitoring SABS conditions and designated use attainment.

The *Framework* for SABS Criteria Development

The *Framework* for SABS criteria development can be expressed as a seven-step process, described as follows.

1. Review current designated uses and criteria for a set of waterbodies.
2. Describe SABS effects on the waterbodies' designated uses.
3. Select specific SABS criteria and biological response indicators.
4. Define potential ranges in values of the SABS and biological response indicators.
5. Identify a response indicator value that protects the designated use.
6. Analyze and characterize SABS/response associations.
7. Explain decisions that justify criteria selection.

The most significant aspect of the *Framework* is that it ties SABS criteria to levels that protect the many uses of waterbodies (e.g., fishing, recreation, swimming, navigation, agricultural uses, drinking water supply, and aquatic life). The *Framework* recognizes that SABS are naturally occurring and are often altered by human activities that are not necessarily well managed but could be. It recognizes that the level of SABS that is appropriate for one waterbody type, say a lake, may not be appropriate for the Mississippi River. To accommodate the range of variability in waterbodies, their uses, and natural sediment regimes, the *Framework* describes methods for classification of waterbodies, measurement of SABS, and measurement of effects. Then criteria are selected in an analytical fashion that is scientifically defensible. The criteria are linked to human values and are readily understood by a lay audience. No single study or analytical method is used or recommended. Rather, the *Framework* consists of a step-wise process that allows for the integration of information from different data sets and different perspectives, thereby increasing confidence in the criteria.

Several appropriate technical aspects to the *Framework* are discussed, including measures taken within the water column (e.g., Secchi depth, turbidity, suspended sediment concentration, and total suspended solids), within bedded sediments (e.g., percent of fine sediments by extent or composition at depth), and within the waterbody environment (channel, shoreline, and bathymetric measures). Indicators of designated use impairment (biological response indicators) are also discussed, especially biological indicators of SABS impairment. Key determinants of appropriateness for indicators are their variability and relative distinction between impaired and unimpaired waterbodies and their demonstrated relationship to desirable characteristics and uses for those waterbodies.

Classification of Waterbodies

SABS conditions vary naturally among broad types of waterbodies such as lakes, rivers, wetlands, estuaries, and coastal waters. Furthermore, within each type of waterbody, the supply and movement of sediment varies with physiographic, climatic, and geologic characteristics. To establish appropriate criteria for sediment, these naturally occurring processes should be characterized in as much detail as possible. Natural features such as geology, watershed topography, stream gradient, waterbody morphology, vegetative land cover, climate, soil erodibility and other landscape characteristics contribute to the variability in sediment supply and transport. Development of SABS criteria should take into account the natural conditions and variability of the water. Regardless of the method used to derive criteria, the outcome should not be beyond the natural expectations. In addition, criteria must protect designated uses. However, SABS conditions that reflect pristine conditions may not be necessary to fully protect designated uses (i.e., aquatic life and recreation goals may be fully supported by SABS conditions that are different than pristine conditions). Criteria will vary with waterbody type and with other natural waterbody features with respect to designated uses. The *Framework* recognizes the potential need for different criteria based on classification of waterbodies and natural sediment regimes. In fact, the need for classification is addressed in the first step in the *Framework* and is evaluated again in steps 4 and 6, with iteration back to step 1 when refinement is necessary.

Illustration of Methods for Use in Criteria Development

The *Framework* suggests methods that can be used for SABS criteria development. These methods are presented to illustrate how states, tribes, and territories may identify appropriate indicators, link sediment measures with biotic responses, establish expectations for specific waterbodies, define impairment, and evaluate adequacy of SABS models. The methods that are presented in this *Framework* are listed below:

(1) Measurement of Suspended and Bedded Sediment
- Readily Available Measures
- Sediment Transport Curves
- Relative Bed Stability

(2) Waterbody Classification
- Empirical Classification of Reference Sites
- Fluvial Geomorphology

(3) Associating Suspended and Bedded Sediment with Response Indicators
- Controlled Experiment
- Field Observational Studies
  - Percentile Analysis (including Reference Condition Methods)
  - Exposures and Effects Analysis
  - Conditional Probability Analysis
- Waterbody Use Functionality

While each of these methods can be described separately, U.S. EPA recommends that they be used together in the *Framework* to take advantage of the strengths of each. In some cases, a method is only useful for one step in the *Framework*. For instance, basic statistical methods for classification of streams are essential for step 1 of the *Framework* but inadequate to select protective criteria. Fluvial geomorphology will alert a resource manager to potential impairment and reveal the evolution of changing stream morphology, but will not necessarily provide a measure of sediment or impacts to a designated use. Likewise, indicators of the physical processes moving sediment supply, such as the Relative Bed Stability method, provide an understanding of the deviation from natural conditions but do not tell if the designated use is impaired when there is 5% or 50% more sediment. Similarly, whereas the Controlled Experiment, Field Observational Studies, and Waterbody Use Functionality methods have the potential to link desired designated uses with sediment regimes, they do not automatically enable classification.

During an October 3, 2003 consultation on setting SABS criteria, the U.S. EPA Science Advisory Board recommended that the U.S. EPA develop a synthesized approach. This synthesis has become the *Framework*. The *Framework* includes examples of criteria development illustrating the potential synthesis of methods that could be applied to various waterbody types and with different designated uses.

Chapter I. INTRODUCTION

I.A. Purpose of this Document

Suspended and bedded sediments (SABS) occur naturally in all types of waterbodies. In appropriate amounts, they are essential to aquatic ecosystems. However, imbalanced sediment supplies have repeatedly ranked high as a major cause of waterbody impairment (U.S. EPA 2003a). The quantity and characteristics of SABS may affect the physical, chemical, and biological integrity of streams, lakes, rivers, estuaries, wetlands, and coastal waters. Excessive SABS (and in some cases, insufficient SABS) can impair waterbody uses such as aquatic life navigation, recreation, and filterable sources of drinking water.

In response to evidence that imbalanced sediment supplies have negatively affected water resources throughout the United States (U.S. EPA 2000a), the U.S. Environmental Protection Agency (U.S. EPA) is providing the tools that could support the states, tribes, and territories in their efforts to establish SABS criteria in water quality standards that protect the ecological integrity and beneficial uses of water resources.

> *The Agency is providing the tools that could support the states, tribes and territories efforts to establish SABS standards that protect the ecological integrity and beneficial uses of water resources.*

This document describes a scientific process for establishing SABS criteria that are protective of national water resources and their designated uses. This *Framework* includes (1) an introduction to SABS criteria issues, (2) programmatic elements for the SABS criteria development effort, and (3) technical elements for developing SABS criteria. The *Framework* can be implemented by states, tribes, and territories at the local and regional levels to meet their specific requirements.

While preparing this document, U.S. EPA consulted various resources, including U.S. EPA Water Quality Reports and current state and U.S. EPA criteria for SABS-related measures as well as the U.S. EPA Science Advisory Board and state water quality resource managers. The results of this preliminary work, along with background on SABS criteria issues, are contained in Chapter I (Introduction). Chapter II covers the programmatic elements of the *Framework*, including the actions U.S. EPA may take towards providing additional information and implementing the *Framework*. Chapter III focuses on the technical elements of SABS criteria development. This chapter illustrates the direction that the scientific research is taking, or could take. The *Framework* is described as a process that includes distinct activities and steps, concepts inherent to the *Framework*, and methods that can be used within the *Framework*. The *Framework* is illustrated with actual and hypothetical examples for SABS criteria development.

I.B. The Need for SABS Criteria

The imbalanced loading of SABS to aquatic systems is considered one of the major causes of water quality impairment in the Nation (U.S. EPA 2003a). The 305(b) Water Quality Reports have consistently listed turbidity, suspended solids, sediment, and siltation as dominant polluting factors in rivers and streams, lakes, reservoirs, ponds, wetlands, and ocean shoreline waters (Table 1). In 1998, approximately 40% of assessed river miles in the U.S. had problems arising from sediment stress (U.S. EPA 2000a).

We use the term 'SABS imbalance' to connote significant changes in normal SABS loading to aquatic systems (i.e., changes in comparison to natural patterns that typically result in increases or reductions in sedimentation).

Table 1. Ranks of SABS stressors among all stressor types[a] (Modified from Berry et al. 2003).

Waterbody Type	Pollutant/Stressor	1994	1996	1998	2000
Rivers & Streams	Siltation[b]	2[c] of 7[d]	1 of 8	1 of 8	2 of 8
	Suspended Solids	7 of 7	7 of 8		
Lakes, Ponds, & Reservoirs	Siltation	2 of 7	3 of 7	3 of 7	3 of 7
	Suspended Solids	5 of 7	6 of 7	5 of 7	
Wetlands	Sediment	1 of 9			
	Sedimentation & Siltation		1 of 8	1 of 7	1 of 6
Estuaries[e]	Siltation, Suspended Solids, Sediment, or Turbidity	0 of 7	0 of 7	0 of 7	0 of 7
Ocean Shoreline Waters	Turbidity	4 of 7	2 of 8	2 of 7	3 of 7
	Siltation	5 of 7			
	Suspended Solids		5 of 8	4 of 7	4 of 7

[a] Comparisons of 305(b) National Water Quality Inventory Reports by year and waterbody type.
[b] For streams, siltation is synonymous with increased embeddedness and percent fines.
[c] Rank among Pollutants/Stressors
[d] Total number of Pollutants/Stressors. As an example, Siltation was ranked second out of the seven Pollutants/Stressors found on the table for Rivers & Streams in the 1994 Report.
[e] Note that Siltation, Suspended Solids, Sediment, and Turbidity were not on the estuary lists for the 1994, 1996, 1998, and the 2000 305(b) Reports.

Effects of sediment loading in natural, pristine ecosystems are complex, multi-dimensional and not fully understood. Changes in sediment loading caused by human activity – SABS imbalance – add further complexity. We use the term 'SABS imbalance' to connote significant changes in normal SABS levels in aquatic systems (i.e., changes in comparison to natural patterns that typically result in increases or reductions in sedimentation). SABS stresses result from changes in sediment loads originating from within the watershed that ultimately compromise the ecological integrity of the aquatic environment (Nietch et al. 2005). Waterbody impairment due to SABS is commonly recognized when aquatic life is impaired. While the biotic effects are the focus of much of the criteria development effort, other designated uses such as navigation, drinking water sources, recreation, and agriculture are also vulnerable to impairment by SABS and are addressed by this *Framework*.

I.B.1. Suspended and Bedded Sediments (SABS)

SABS are defined as organic and inorganic particles that are suspended in, are carried by, or accumulate in waterbodies. This definition includes the frequently used terms *clean sediment*, *suspended sediment*, *total suspended solids*, *turbidity*, *bedload*, *fines*, *deposits*, or, in common terms, soils or *eroded materials*. This definition of SABS includes organic solids such as algal material, particulate detritus, and other organic material. SABS are natural parts of aquatic systems and are not considered harmful until they are out of balance, that is, excessive or deficient. SABS may be a cause of impairment if this material diminishes the quality or quantity of the aquatic resource by altering the behavior, health, or survival of biota, the availability of habitat, the stability of channels and banks, the natural amount and size distribution of particles in the water column and on the bottom and banks of waterbodies, or by otherwise impairing designated uses of waterbodies.

SABS are defined as organic and inorganic particles that are suspended in, are carried by, or accumulate in waterbodies. … SABS are natural parts of aquatic systems and are not considered harmful until they are out of balance, that is, excessive or deficient.

SABS are further defined in terms of particle sizes, which are related to the mode of action in the aquatic environment. They can be defined as fine sediment and coarse sediment. Fine sediment is typically (though not rigidly) considered to consist mostly of particles smaller than 0.85 mm and coarse sediment is between 0.85 and 9.5 mm. Particles less than 0.063 mm (silt and clay) remain suspended in flowing freshwater and are largely the cause of turbidity but may settle during low flow in low gradient streams (Idaho DEQ 2003).

This *Framework* addresses the physical properties of SABS and intentionally does not address the effects of co-occurring contaminants or nutrients. Nutrient criteria have been developed by an U.S. EPA supported effort (see National Nutrient Strategy, U.S. EPA 1998). U.S. EPA has dealt directly with the toxicity of chemicals in sediments through its work on Equilibrium Partitioning-Derived Sediment Benchmarks (U.S. EPA 2003b, 2005a). U.S. EPA does recognize, however, that managing SABS in the aquatic environment will have consequences on the amount of toxicants and nutrients associated with SABS and these relationships may need to be examined further in future efforts. An example of the integrated assessment of sediments and nutrients is described in the technical section using criteria development for the Chesapeake Bay (Section III.D.3).

I.B.2. Summary of the Ecological Effects of SABS

The Nation's waters have many designated uses, including drinking water, navigation, recreation, agriculture (such as irrigation), aquatic life, and fishing for sport and food. While SABS can affect all of these uses, U.S. EPA is currently focused on SABS effects on aquatic life for several reasons. First, when SABS diminish the quality of aquatic life by degrading habitat, other uses such as recreational or commercial fishing may also be diminished. Second, there is evidence that aquatic-life uses are one of the most sensitive endpoints of altered sediment supply. Therefore, measuring and monitoring aquatic organisms may provide an early warning that SABS may become problematic for a wide range of uses. Early action may prevent other uses from being impacted. This premise influenced water clarity criteria development for the Chesapeake Bay, where protection of the vegetative habitat was considered equivalent to protection of the species that used that habitat and the larger ecosystem (U.S. EPA 2003c). For these reasons, this *Framework* addresses waterbody designated uses but has a strong focus on aquatic life uses (e.g., habitat, foraging, refugia). Because of their importance in ecosystem functions, the imbalance of SABS can have an impact on ecological integrity at several scales and trophic levels as depicted in the conceptual model (Figure 1). Therefore, a basic premise for managing SABS in waterbodies is the need to maintain SABS at levels that are protective of the ecological integrity of aquatic systems.

SABS differ from toxic pollutants in that SABS, including the organic fraction, occur in waterbodies in natural or background amounts and are essential to the ecological functioning of a waterbody. In addition, SABS transport toxicants, nutrients, detritus, and other organic matter at levels that are critical to the health of a waterbody. SABS in natural quantities also replenish intermittently mobile bottom sediments and create valuable micro-habitats, such as pools and sand bars.

Sediments can enter waterways through a wide variety of transport mechanisms, including surface water transport, bank erosion, and atmospheric deposition. Once in the system, re-suspension and deposition can "recycle" sediments so that they exert water column and benthic effects repeatedly over time and in multiple locations. Human activities that increase soil erosion or alter rates of sediment transport in waterways (e.g., forestry, mining, urban development, agriculture, dredging, channel alteration, and dam construction) are among the most pervasive causes of sediment imbalance in aquatic systems (Waters 1995; Nietch et al. 2005). Activities that decrease sediment to aquatic systems are numerous and varied. A major cause is man-made reservoirs that trap sediment that normally would be carried downstream. Excessive sediment is a more common cause of sediment imbalance than is sediment deficiency though both can impair ecosystems.

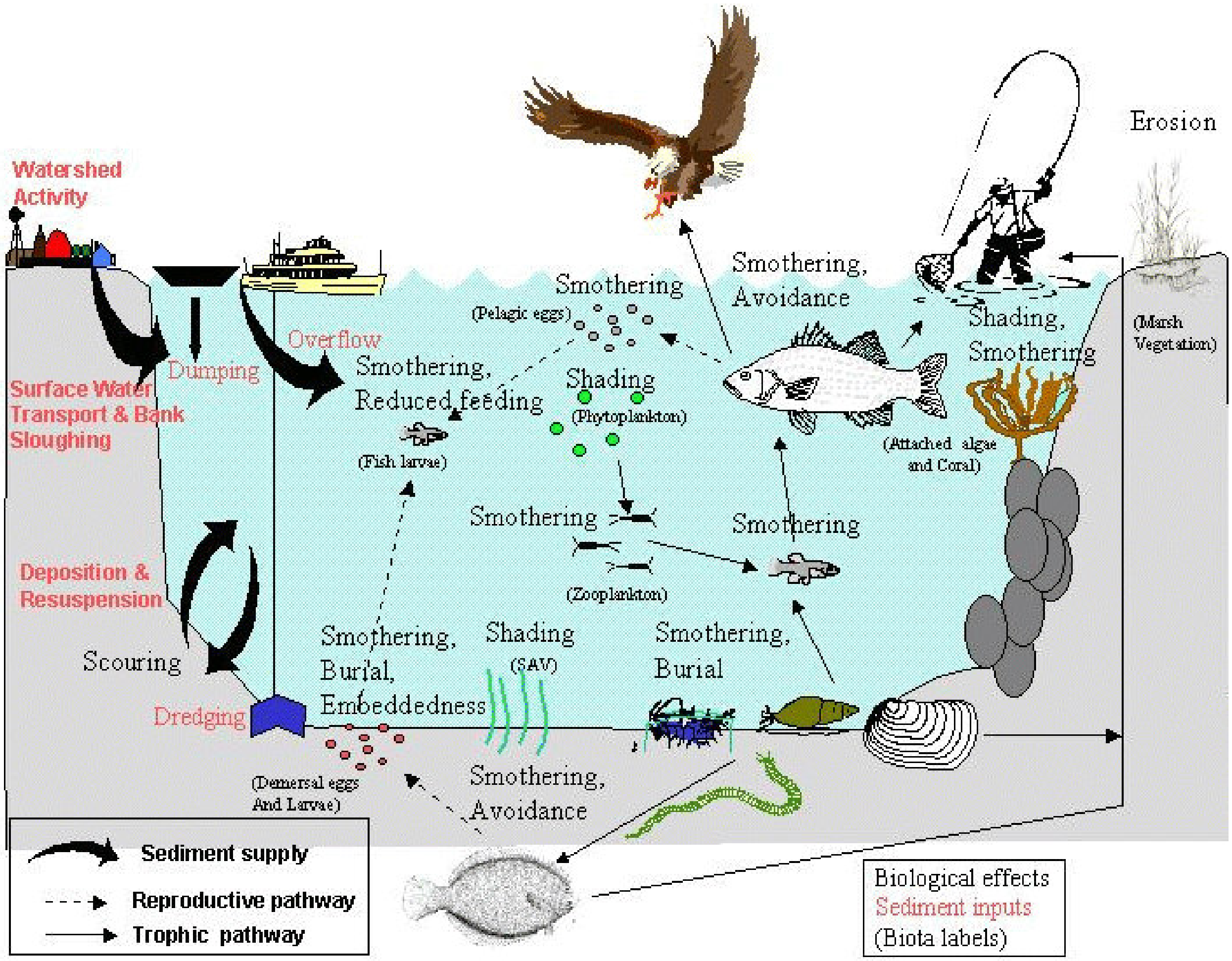

Figure 1. Conceptual diagram of SABS effects in estuaries (courtesy of W. Munns, U.S. EPA).

Excessive suspended sediment in aquatic systems decrease light penetration, directly impacting productivity that is especially important in estuarine and marine habitats, where trophic interrelationships tend to be more complex and marginal when compared to freshwater aquatic systems. Decreased water clarity impairs visibility and associated behaviors such as prey capture and predator avoidance, recognition of reproductive cues, and other behaviors that alter reproduction and survival. At very high levels, suspended sediments can cause physical abrasion and clogging of filtration and respiratory organs.

In flowing waters, bedded sediments are likely to have a more significant impact on habitat and biota than suspended sediments; while most organisms can tolerate episodic occurrences of increased levels of suspended sediments, impacts can become chronic once the sediment is settled. When sediments are deposited or shift longitudinally along the streambed, infaunal or epibenthic organisms and demersal eggs are vulnerable to smothering and entrapment. In smaller amounts, excess fine sediments can fill in gaps between larger substrate particles, embedding the larger particles, and eliminating interstitial spaces that could otherwise be used as habitat for reproduction, feeding, and cover for invertebrates and fish. A noteworthy example of effects of bedded sediments in streams and rivers is the loss of spawning habitat for salmonid fishes due to increased embeddedness. Increased sedimentation can limit the amount of oxygen in the spawning beds, which can reduce hatching success, trap the fry in the sediment after hatching, or reduce the area of habitat suitable for development. Appendix B details many other direct and indirect effects of SABS.

I.B.3. State Needs Survey

In September 2004, a survey was conducted to solicit input from nine states on the status of SABS-related impairment and monitoring in their state, as well as technical, budgetary, and other needs for developing numeric SABS criteria. Details of the survey are included in Appendix C. The results presented below pertain only to those states surveyed and cannot be extrapolated to the entire Nation. Three states (Delaware, New Hampshire, and New York) consider SABS a minor or lower priority problem, while states in other parts of the country consider SABS a major problem. SABS criteria appear to be partially established for most of the states surveyed and are a mix of narrative and numeric criteria and standards.

Wyoming, for example, has numeric criteria for turbidity but narrative criteria for suspended and settleable solids. The programs under which states apply SABS criteria/standards include Total Maximum Daily Load (TMDL) reporting, National Pollutant Discharge Elimination System (NPDES), surface water monitoring programs and various state-level programs. The majority of states surveyed use turbidity and total suspended solids (TSS) as indicators for suspended sediments; North Carolina also uses Secchi depth and Michigan uses light penetration. Bedded sediments are most commonly measured with embeddedness, followed by percent fines, Wolman pebble counts, substrate stability, best professional judgment using photos, and intergravel dissolved oxygen.

Most respondents felt the need to improve water quality criteria for SABS in their state. The Wyoming respondent suggested that there is a greater need for bedded sediment criteria than suspended sediment criteria, which already exist in many places (as criteria for turbidity or TSS). All designated uses, except agricultural uses, were considered vulnerable to SABS impairment.

Each of the states surveyed envision technical and scientific obstacles to SABS criteria development. Some pointed out that, in most waterbodies, SABS occur naturally and with significant variability, making the development and application of strict numeric criteria difficult. Others mentioned the lack of sound scientific data that could lead to numeric criteria for threatened and endangered species. In addition to technical and scientific obstacles, states may also face political obstacles where SABS sources are mostly non-point, such as from agricultural lands. Louisiana was unique in that sediment starvation in their coastal wetlands was the primary concern; their criteria should be sensitive to the state's efforts at arresting wetland subsidence. Program elements considered most useful for SABS criteria development include personnel/expertise, money/grants and access to data on SABS effects from scientific literature as well as from other states. Some elements of the *Framework* were considered less useful by a minority of respondents.

I.B.4. Application of this *Framework* for Developing SABS Water Quality Criteria and Standards

Water Quality Criteria

Water quality criteria (WQC) describe the quality of water that will generally support designated use(s). U.S. EPA, under Section 304(a) of the CWA, periodically publishes WQC recommendations for use by states, tribes, and territories in developing and adopting water quality standards. Water quality criteria published pursuant to Section 304(a) of the CWA are based solely on data and scientific judgments on the relationship between pollutant concentrations and environmental (and human health) effects and do not consider economic impacts or the technological feasibility of meeting the criteria values in ambient water.

When establishing SABS numeric criteria, states, tribes, and territories can use the process described in this document or other scientifically defensible approaches for deriving criteria. U.S. EPA's 304(a) criteria recommendations have been instrumental for states, tribes, and territories to control many forms of pollution and improve water quality across the Nation.

As mentioned previously, in addition to aquatic life uses, waterbodies have other designated uses that need to be protected from stressors such as excess SABS. These include recreation in and on the water, navigation, drinking water sources, industrial water use, and agricultural water use. Waterbodies may have multiple use designations, including those just listed and aquatic life.

Water Quality Standards

Water quality standards (WQS) consist of three elements: (1) one or more designated uses for a waterbody, (2) WQC to protect the designated use(s), and (3) an antidegradation policy. States, tribes, and territories adopt WQS 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 WQS 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 WQS should be established taking into consideration waterbody use and value for public water supplies, propagation of fish and wildlife, recreation, agriculture, industry, navigation, and other purposes.

Antidegradation provisions specify that all existing uses of a waterbody, that have occurred since November 28, 1975, should be maintained, regardless of whether they are specified as designated uses. If the water is of a higher quality than necessary to support fishable/swimmable uses, then that water quality must be maintained unless important economic and social goals dictate otherwise. A three-tiered antidegradation policy is part of each state's WQS:

Tier 1 Maintain existing beneficial uses of surface waters and prevent degradation that could interfere with those uses.

Tier 2 Protect water quality in "fishable/swimmable" waters (bodies of water in which water meets or exceeds the levels necessary to support the propagation of fish, shellfish, and wildlife as well as recreation on and in the water).

Tier 3 Provide special protection for "Outstanding Natural Resource Waters," such as waters of national or state parks, wildlife refuges, or other waters of exceptional recreational or ecological significance.

I.B.5. U.S. EPA-OW/OST Standards and Criteria Strategy

Recently, U.S. EPA's Office of Science and Technology (OST) within the Office of Water (OW) issued a document titled "Strategy for Water Quality Standards and Criteria: Setting Priorities to Strengthen the Foundation for Protecting and Restoring the Nation's Waters" (U.S. EPA, 2003a). Working with stakeholders and considering a wide-ranging review of the existing WQS and criteria program within the context of all CWA programs, U.S. EPA identified 10 priorities for achieving higher WQS on a national basis. These include providing guidance, strategies, or approaches for criteria development for several stressors. Producing and implementing a *Framework* for the development of SABS criteria was among the top priorities and is the basis for the present work. OST and the Office of Wetlands, Oceans, and Watersheds (OWOW) are coordinating efforts with the Office of Research and Development (ORD) to design research and develop methods that can be used to support SABS criteria development.

One of the milestones of the Standards and Criteria Strategy discussed above was a consultation with the Science Advisory Board regarding development of SABS criteria. This consultation took place on October 2, 2003 and resulted in generally agreed-upon recommendations that are presented in Section I.D.

I.C. Current Water Quality Criteria Related to SABS

I.C.1. Existing/Current U.S. EPA Criteria

In "*Quality Criteria for Water*" (U.S. EPA 1986), the Agency published the following recommendations for developing a numeric criterion for suspended solids and turbidity:

> *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.*

This criterion has not been frequently adopted or used by states, perhaps because certain methods are somewhat difficult to perform. A narrative "free from" aesthetic standard that states have occasionally adopted into their water quality standards was published in the same document (U.S. EPA 1986), stating:

> *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; [or] produce undesirable or nuisance aquatic life.*

I.C.2. Current State Criteria

In addition to the more recent needs survey discussed in section I.B.3 above, U.S. EPA conducted a study of published SABS criteria in all states in 2001 (Appendix D). Based on the study, some form of numeric SABS criteria existed in 32 of the 53 states, tribes, and territories, and the District of Columbia. Narrative criteria were identified in 13 states with no numeric criteria (and in 23 of the states with numeric criteria as well), leaving eight states with neither numeric nor narrative sediment criteria identified. Of these eight states without criteria, five listed an alternative or guide for establishing sediment criteria such as effluent controls or regional criteria. Additional reviews of state criteria have been compiled by Caux et al. (1997a), Singleton (1985), Idaho DEQ (2003), and Rosetta (2005).

Of the 32 states with numeric criteria, 30 had criteria for turbidity and seven for suspended solids. Five of these 32 states listed criteria for both turbidity and suspended solids. Criteria were in the form of exceedances over background (e.g., "not more than 10% above background" or "no more than 10 NTUs above background") or absolute values (e.g., "not greater than 100 NTU"). States have established statewide and/or basin-specific criteria depending on the presence of salmonids. In general, concerns are the effects of water clarity and light scattering on aquatic life. The majority of states use U.S. EPA method 180.1 to measure turbidity and U.S. EPA method 160.2 (40 CFR Part 136) to measure TSS. For example, suspended solids criteria vary from 30 mg/L up to 263 mg/L for aquatic life uses and up to 500 mg/L for storm water pollution control in North Carolina. Florida uses transparency as a criterion (not to be reduced by more than 10%).

States, under pressure to develop and issue total maximum daily loads (TMDLs) for SABS-impaired waterbodies, are moving forward on their own to develop new-and-improved SABS criteria from which to develop TMDLs. U.S. EPA believes it is valuable to examine what states have done in the past, are currently doing, and plan to do in the future in developing SABS criteria as a way to identify methods that may be useful, either directly or with adaptation, for the entire Nation. U.S. EPA also believes this same consideration should be given to the SABS criteria efforts in other countries. Therefore, promising methods used by some states and other countries have been reviewed by U.S. EPA and are included in the *Framework*. As new methods become available, U.S. EPA may review and consider them either for application nationwide or for updating this document. Criteria have recently been developed by Idaho, Oregon, and New Mexico (United States), British Columbia (Canada), Australia, New Zealand, and the European Union (Appendix D).

I.D. Recommendations of the U.S. EPA Science Advisory Board

As part of the current effort to develop national SABS criteria, the U.S. EPA Science Advisory Board met on October 2, 2003 to discuss various methods for establishing criteria. This meeting resulted in several generally agreed-upon recommendations. It is important to note, however, that the Science Advisory Board did not reach consensus and votes were not taken. The general recommendations are summarized here and detailed in Appendix E. The specific approaches mentioned here are discussed in detail in Section III.D.

Overall Recommendations

- Consideration should be given to setting criteria from the management perspective, classifying by waterbody function and designated uses, while ensuring that resource managers know what natural levels of SABS are expected for any given waterbody.

- Criteria should be developed for each major waterbody type (lakes, estuaries, wetlands, rivers, streams, headwaters, etc.) and then tiered by classes of similar waterbody types within each of these major categories (e.g., high-gradient vs. low-gradient mountain streams).

- As no single criterion or indicator will work for each major waterbody type and class, several different criteria or indicators should be developed to address key distinctions in SABS among waterbody types and classes.

- Criteria should be based on a synthesis of methods that demonstrate the relationship between the measurements of SABS and aquatic life or a valued ecological resource. The conditional probability and reference condition approaches could be used to meet this requirement.

- The strengths and weaknesses of each method should be clearly explained for states, tribes, and territories.

- Any uncertainty with respect to ecological theory or statistical model development should be clearly documented and considered during criteria selection and implementation.

- The problem of SABS imbalance resulting from too little sediment should not be overlooked.

- Recommended methods should be clear and understandable.

- Work should continue that develops methods and other approaches for establishing SABS criteria. Real data should be used in creating examples of a synthesized process.

- Recommended that there is national consistency in assessment, management, and evaluation.

It has been and will continue to be the intention of the U.S. EPA to consider all of these recommendations during the development and implementation of this *Framework*. For instance, the recommendation that actual or available data should be used in creating examples of a synthesized approach (or combination of approaches) was interpreted as a need for case studies. U.S. EPA initiated a case study that is included as a draft using hypothetical examples (see Section III.E). Case studies, using actual state data, are now under development and may be included in U.S. EPA SABS documents in the future. The Board did not suggest any new, unique, or "silver bullet" methods that would solve all problems or be quickly and easily implemented.

However, U.S. EPA is not taking a supervisory role in defining criteria near jurisdictional boundaries but will support the efforts of bordering states and act as a mediator if needed. This document is designed to provide a *Framework* for developing SABS criteria. It is not a substitute for the CWA or U.S. EPA's regulations nor is it a regulation itself. The *Framework* does not impose legally binding requirements on U.S. EPA, states, tribes, territories or the regulated community and may not apply to some particular situations. U.S. EPA, state, tribal, and territorial decision-makers retain the discretion to adopt methods and approaches on a case-by-case basis that are appropriate to their SABS needs.

Chapter II. PROGRAMMATIC ELEMENTS OF SABS CRITERIA DEVELOPMENT

II.A. Possible Uses of this Framework

Using this *Framework*, states, tribes, and territories could develop new, or review existing, SABS criteria (narrative and numeric criteria). These criteria could then be incorporated into WQS and implemented in various water quality programs. Criteria development could follow the process as described in Chapter III, proceeding first in regions and watersheds where applicable data are currently available. Where states have existing SABS criteria, these criteria could be reviewed in the context of the overall *Framework*.

II.B. Resources for Framework Implementation

For those states developing SABS criteria or beginning the process of addressing SABS, this *Framework* provides several resource elements. For example, components of the *Framework* include techniques for sampling, data management, and analysis. The resources include professional contacts for technical and administrative issues and communication vehicles. These tools and resources are yet to be developed, and the following list is a sampling of possibilities. The final list of tools and resources may differ as needs are identified, tools are developed and U.S. EPA support evolves.

U.S. EPA Expertise

U.S. EPA Headquarters, ORD, and Regional staff will be interested in how state, tribal, and territorial officials, and other interested parties develop SABS criteria.

Internet Resources

In support of SABS criteria development, U.S. EPA plans to build and maintain a Web site devoted to SABS information and knowledge exchange. This Web site could serve at least three functions: (1) as a portal for communication among states, tribes, and territories (2) as a source of data on SABS exposures and biotic responses and (3) as a center for distribution of tools for SABS criteria development.

Communication

SABS criteria development will benefit from dialogue among all parties involved, including state, tribe, and territorial water resource managers, scientists, National and Regional SABS Teams, and U.S. EPA. Moreover, parties will benefit and learn from third-party communication. For example, exchange of information between a state scientist and Regional SABS Team members may be useful to a scientist in another state in the same region. A SABS Web site may help facilitate this type of communication, where frequently asked questions can be answered, problems and solutions can be posted, virtual brainstorming can occur, and innovative ideas can be shared.

SABS Datasets
As datasets with sufficient data for analysis are identified, they should be made available, for example, via a Web site. These datasets may include state monitoring records, academic studies, or federal agency research. Perhaps the biggest challenge of SABS criteria development will be establishing links between SABS exposures and biotic responses so that effect levels can be identified. Reviewing the existing data in the primary scientific literature will help this process (e.g., Berry et al. 2003). These reviews may be the starting point for quantifying relationships between SABS and biotic responses, which may assist in both setting criteria and monitoring management actions.

Data Management: Storage and Processing
States, tribes, and territories will benefit from consistent and compatible data storage, retrieval, and assessment systems to help interpret data so that it is meaningful for management decisions. Convenient data storage and modeling programs will enhance data assessment, and also, if consistent throughout a region, promote coordinated inter-state surveys and data sharing. The U.S. EPA Storage and Retrieval database (STORET) or the U.S. Geologic Survey may be an appropriate starting point for data management though other alternatives may exist or be developed.

II.C. Integration of the SABS Framework with Existing State Programs

The SABS *Framework* provides a scientifically defensible process and the necessary methods and analytical tools for states, tribes, and territories to develop or adjust numeric SABS criteria into their WQS. This *Framework* could help water quality resource managers support efforts to achieve and maintain protective water quality conditions as well as identify impaired waters and their causes. Some state, tribal and territorial efforts that may be supported by SABS *Framework* implementation and WQS revisions include

- Total maximum daily loads (TMDLs), waste load allocations (WLAs) for point sources of pollution and load allocations (LAs) for non-point sources of pollution
- Water quality management plans which prescribe the regulatory, construction and management activities necessary to meet the waterbody goals
- NPDES water quality-based effluent limitations for point source discharges
- Water quality certifications under CWA § 401 for activities that may affect water quality and that require a federal license or permit
- Reports, such as those required under CWA § 305(b), that document current water quality conditions and CWA § 303(d) that list impaired waters and
- CWA § 319 management plans for the control of non-point sources of pollution.

Protection of waterbodies from SABS imbalances may require management actions. SABS management is a process that should integrate a number of programs and management approaches, including but not limited to

- Non-point and Watershed programs
- NPDES Permitting programs
- Nutrient and Contaminated Sediment Management
- Marine Protection, Research, and Sanctuaries Act (MPRSA) permits for ocean dumping
- CWA permitting for dredge and fill activities
- Biosolids Management programs

As the process and methods outlined in this *Framework* are implemented or utilized, we will informally gather and evaluate feedback and experiences from states, tribes, territories, and other water resource managers to ensure the SABS *Framework* works well. Suggestions, comments, and input may include data sets, existing analysis or insights into the interactions between SABS sources and waterbody conditions and knowledge of SABS conditions and designated use attainment. If necessary, we will revise the document accordingly and issue another edition.

II.D. Implementation of SABS Criteria and Standards

As stated previously, the primary goal of this *Framework* is to provide useful tools for developing SABS criteria. This *Framework* could also help water quality resource managers manage and evaluate SABS through application of criteria and standards. There are some fundamental management concepts that should apply in most situations. The SABS program needs to consider what activities will be needed once SABS criteria have been established. Possible sequential steps are outlined in Table 2.

This *Framework* incorporates all the key elements essential to good management planning, but the user might find that some steps can be consolidated or that circumstances necessitate a different sequence. With a good database predicated on reliable indicators and the comparable analytical methods for development of regional SABS criteria, states, tribes, and territories will be capable of assessing the SABS status of their waters, and establishing their criteria as well as planning, prioritizing, and evaluating their management responses.

Table 2. Sequential elements of a SABS management program.

Step	Description
1 Identify Problem	Identify waterbodies where SABS may contribute to non-attainment of aquatic life and other designated uses based on landscape or mechanistic screening. Collect SABS indicator measurements from the sites to confirm exceedance of protective SABS criteria. If possible, collect biological data or other indicators of designated uses to confirm loss or reduction of the designated use. If the designated use is not impaired, the level of SABS may be tolerated at the location and the site need not be listed as impaired. If there is reduction or loss of a designated use, the impairment should be addressed. The problem should be defined in terms that make it possible to seek a solution. Be aware that if the designated uses are fully supported but sediment is exported to other waterbodies, these sites may be a source for sediment that is impairing a different waterbody.
2 Investigate Background	Use literature searches, questionnaires, interviews, and other background investigations to describe the lost designated use due to exceedance of SABS criteria. Compile and analyze available data and other information. Develop list of possible sediment loading sources and/or other factors leading to SABS imbalance. At this and the following two stages, identify and characterize fully supported biological and physical reference conditions or reference sites.
3 Gather Data	Design and conduct a field study to sample physical, chemical, and biological parameters and sediment loading sources in the watersheds. This step should be of sufficient duration to accommodate seasonal and annual variation and possible storm events.
4 Confirm Problem	Conduct a thorough causal assessment of all of the above information. Consider the other possible causes for the impairment. If SABS are identified among the probable cause(s), estimate sediment loading from all identified sources.
5 Develop Alternative Management Options	Develop a list of management alternatives to address each sediment source. Evaluate risk associated with each alternative and its impact on present uses with respect to the likelihood of restoring the designated use, scientific validity, cost-effectiveness, and sociopolitical feasibility. Involve local and state-level governments, property owners, citizen groups, and public and business interests in discussions about the optimal approach. Potential management options for SABS in different waterbodies are presented in Table 3.
6 Detail Management Plan	Prepare a plan that discusses how to address each key element of the SABS problem in the most effective sequence. Indicate the rationale for selecting a particular course of action. Include a stepwise sequence of coordinated activities in detail. Management plans are typically written for a five-year period. Changes in SABS ought to be detected in this time frame, which is short enough to be accommodated within most budgets. Longer projects might require sequential management plans and will be more apt to detect biological recovery.
7 Implement and Communicate	Initiate the management program, including consideration of SABS water quality criteria (WQC) and other WQS. Where appropriate, establish SABS limitations in NPDES permits and develop TMDLs as elements of the program. Maintain community, interest group, and other agency involvement through regular updates on the process. Communications may begin at step 4 or sooner but should be emphasized here.
8 Monitor and Review	Incorporate water quality monitoring before, during, and after the project to demonstrate relative response of the system to management efforts. Build in specific intervals for management review to allow response to changing circumstances, modifications of approaches and schedules, and changes in emphasis.
9 Complete and Evaluate	Determine if the water resource has been protected or improved. Give credit to the community and other participants. Report on successes and failures for future applications and on lessons that are learned.
10 Monitor and Maintain Controls	Water resource monitoring stations and parameters continue on a reduced scale (e.g., fewer sampling stations, fewer parameters, less frequent sampling). Ensure regular maintenance of management efforts to preserve the effects achieved. Monitoring provides warning of any future degradation, allowing resource managers to intervene in a timely, cost-effective manner. Close the cycle by returning to step 1.

II.D.1. Management Options

The management of SABS imbalance involves a sequential investigation and decision-making process, including a multidisciplinary evaluation of possible mitigating, remedial or other alternative actions to address SABS problems and prioritize them and their possible solutions. Although not intended to be exhaustive, Table 3 summarizes remediation, protection, and management approaches by waterbody type. It is an introductory presentation of some of the readily evident options that states, tribes, territories and other responsible parties can use to make a positive response to the situations with imbalanced SABS regimes.

Another management resource is the "Draft Handbook for Developing Watershed Plans to Restore and Protect Our Waters" (U.S. EPA 2005b), which is available at http://www.epa.gov/owow/nps/watershed_handbook/. The handbook contains in-depth guidance on quantifying existing pollutant loads including SABS, developing estimates of the load reductions required to meet water quality standards, developing effective management measures, and tracking progress once the plan is implemented. As indicated previously, during this pilot phase we will informally gather and evaluate feedback and experiences from states, tribes, territories, and other water resource managers to ensure the SABS *Framework* works well. If necessary, we will revise the document accordingly and issue another edition.

In considering the various management options for controlling SABS imbalances (Table 3), the resource manager should keep in mind that the different waterbody types described here may often be interrelated (e.g., streams draining to and from lakes and rivers entering estuaries and coastal waters). Under these circumstances, the resource manager would select management plan practices that are protective of downstream resources. For example, biota in high gradient streams may tolerate spates of high sediment loads during storms, whereas reservoirs and low gradient streams may be overwhelmed as these materials settle.

It should be noted that activity in upland portions of the watershed could affect all waterbody types in the drainage system. Management in upland areas should proceed with consideration of the connectivity between land disturbance anywhere in the watershed and effects on the SABS loadings to aquatic systems. Watershed approaches to management provide options that consider sources and controls for SABS for all connected waterbodies. They offer the advantages of allowing communities to focus resources on the most serious sources of excess sediment in the watershed. Additional basic management actions can be found in other U.S. EPA documents such as *Protocol for Developing Sediment TMDLs* (1999) and *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters* (1993).

An example of an assessment framework to guide sediment management actions for streams is the U.S. EPA-funded study called the Watershed Assessment of River Stability and Sediment Supply (WARSSS). It is based on geomorphic analysis of current sedimentary states of watersheds and stream systems and pertains to development of a sediment assessment framework (http://www.epa.gov/warsss). WARSSS is based on modeled associations between SABS sources and channel conditions and the models are calibrated on field observations.

Table 3. Issues and management options for addressing SABS imbalances by waterbody type.

	Issue Area	Management Option
STREAMS AND RIVERS	Land use	Include land use as a separate early warning indicator (i.e., if development is proposed in a watershed, an environmental impact study should be done to assess the potential impact on the surrounding watershed).
	Hydrology, hydraulics (flow regime, storm water management, stream regulation)	Identify natural hydrologic regimes and use such information in addressing runoff control or dam operations to better replicate natural conditions in the waterbodies while allowing development, generating power, or preserving intended reservoir levels.
	Impoundment removal	Remove man-made impoundments that have lost their utility and are now causes of flow interruption and sources of downstream sediment imbalance.
	Restoration of riparian and flood plain wetlands	Implement programs designed to restore riparian and flood plain wetlands.
	Storm water management	Implement storm water BMPs such as constructing ponds, wetlands, infiltration and detention basins, and diversions.
LAKES AND RESERVOIRS	Vegetative buffer zones	Preserve or reestablish natural, indigenous vegetation (groundcover, shrubs, and trees) in the riparian zone to intercept sediment runoff before the runoff reaches the waterbody.
	Watershed land use changes	Identify critical loading sources and promote changes of these land use practices. Examples of practices to promote are implementation of conservation farming; use of road, commercial and municipal runoff diversions and detentions; restoration of woodlots in critical drainage areas; and land use planning to avoid excessive tiers of lake residences.
	Habitat restoration	Improve lake nursery and spawning areas to restore a diverse aquatic community and food chain.
	Water level control	Initiate winter or other episodic draughts of lake/reservoir waters to augment sediment removal or consolidation.
	Restoration and protection of strategic wetlands	Restore and protect wetlands located in areas critical to water quality concerns.
	Storm water management	Implement storm water BMPs such as constructing ponds, wetlands, infiltration and detention basins, and diversions.
WETLANDS	Wetland protection and restoration	Preserve and restore wetlands through the implementation of voluntary and regulatory programs.
	Vegetative buffer zones	Preserve or reestablish natural, indigenous vegetation (ground cover, shrubs, and trees) as buffer zones adjacent to wetlands to intercept sediment runoff before the runoff reaches the wetland.
	Watershed land use changes	Identify critical land loading sources and promote changes of these land practices. Examples of changes that could be made include the implementation of conservation farming techniques; runoff diversions and detentions, filter strips, and vegetated drainage ways; the implementation of forestry BMPS; and the implementation of controls on urbanization and industrial development.
	Land use planning	Protect wetlands by limiting amounts of impervious surfaces, limiting development near waterbodies or steep slopes, and minimizing discharges from storm water, sewer, and septic systems.
	Protect and restore streams entering wetland	Stabilize stream channels and establish riparian buffers to reduce the amount of sediment entering a wetland.
ESTUARIES AND COASTAL WATERS	Land use and development controls	Promote natural vegetative cover in shore areas and zoning restrictions on dense residential or commercial/industrial development along shoreline areas.
	Restricted estuaries/coastal areas	Protect sensitive waters such as endangered shellfish beds, spawning and nursery areas, and recovering weed beds.
	Shoreline erosion controls	Implement erosion controls on banks subject to wave or ice damage. Restrict access to sensitive shorelines, dune restoration areas, and shorelines susceptible to erosion.
	Sea grass replenishment	Restore submerged and emergent aquatic vegetation in estuaries, including wetland areas. Plant and protect emergent and terrestrial riparian vegetation as further protection of tidal zone wetlands from runoff.

The study considers hillslope and channel processes responsible for changes in erosion and 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 watersheds or river systems that require a more detailed predictive assessment for process-specific mitigation and (2) a process-based, quantitative prediction of potential sediment sources, magnitude of sediment delivery, 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 process allows validation of the assessment approach and tracks the 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 better suited to the region or waterbody type being assessed.

II.D.2. Evaluation

When appropriate indicators and criteria have been established, states, tribes, or territories may be able to evaluate the effectiveness of management and regulatory approaches. Progress in management of SABS imbalance and designated use impairment should be assessed by comparing changes in sediment flux from the land, SABS indicators, and designated uses through the state's water quality monitoring programs. Timely evaluation of program effectiveness allows for successful management approaches and techniques to be shared and repeated in similar circumstances elsewhere. Where success has not been achieved, the knowledge gained is valuable in developing alternative approaches and in avoiding repetition of the same unproductive activity. This information could be shared through correspondence and national meetings to enhance management effectiveness.

Chapter III. TECHNICAL ELEMENTS OF SABS CRITERIA DEVELOPMENT

III.A. Need for a Technical Discussion in This Framework

This chapter is an introduction to the scientific process, potential methods, and current research regarding development of SABS criteria. Inclusion of a technical section is intended to provide as much clarity as is possible to those looking for a defensible, transparent approach toward setting SABS criteria. The SABS technical workgroup decided that issuing workable scientific methods, along with the intent to develop SABS criteria, would expedite implementation. The workgroup committee is aware that this technical information does not cover all possibilities but believes that these methods provide a starting point to initiate SABS criteria development. The *Framework* may encourage research that could further improve the methods.

While all the material has been reviewed by the workgroup, which consist of experts in various aspects of SABS policy and science and knowledgeable peer reviewers, some of the material may still be in an exploratory or developmental stage. This applies especially to some of the analytical methods (Section III.D) and the hypothetical example that illustrates how these methods can be combined to develop SABS criteria (Section III.E).

III.B. Process for SABS Criteria Development

The basic process for developing SABS criteria, outlined in Figure 2, consists of four types of activities: (1) gathering information, (2) synthesizing the state of knowledge, (3) analyzing available data, and (4) selecting criteria values. The process begins by gathering information from the literature, regulations and stakeholders about data sources and possible classifications for waterbodies. The information is then synthesized, depicted in a conceptual model, and described in text format. From the conceptual model, measurements are selected and the rationale for the selection is recorded. Next, available data sets are assembled and analyzed. The details of some possible analyses are presented in Sections III.D and III.E. Outputs from the data analysis phase may include analysis designs, evaluated classifications, exposure-response profiles, background SABS regimes, ranges of protective responses, and probabilities of adverse effects. Finally, the outputs from the analysis phase are considered in the decision analysis phase where SABS criteria values are selected and the rationale for the selection is described. SABS criteria can then be implemented within a comprehensive management plan as described in Table 2.

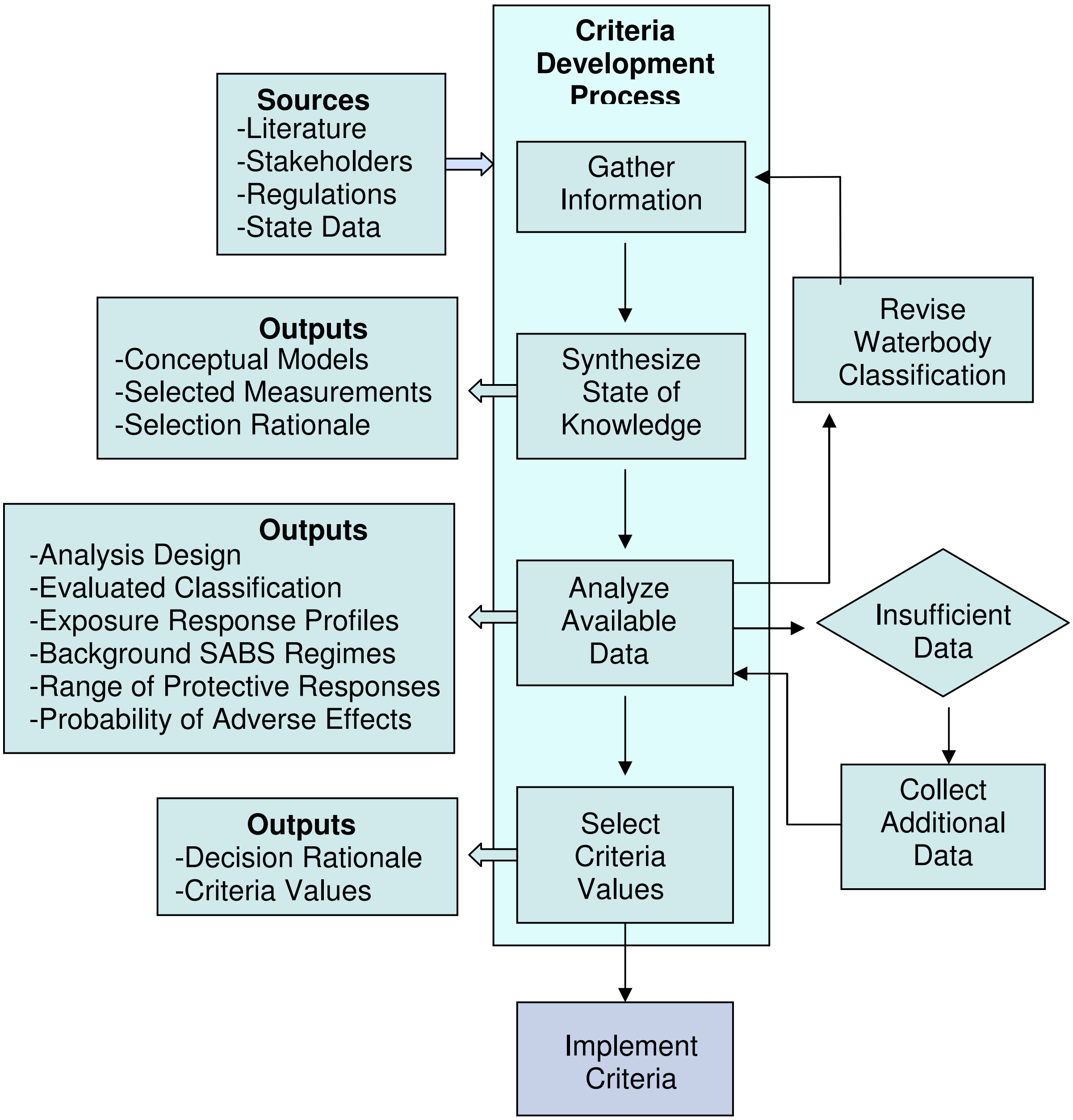

Figure 2. Activities and outputs of the SABS criteria development process.

Although presented as a sequence of steps, iteration may be necessary. For instance, a set of waterbodies may be classified as a group at the beginning of the process, but new information may arise and require waterbody types to be assigned to more specific categories. Available data may be insufficient and require additional data collection. In all cases, analysis that develops SABS associations with response indicators should take advantage of the benefits of comparing results from several methods using different data sets, thereby, allowing criteria selection to be supported by the strength-of-evidence.

The four activities can be expanded to reveal the greater detail shown in Figure 3 that presents the elements of the SABS Criteria Development Framework (in seven steps). Each of the seven steps is described briefly below. In addition, hypothetical examples that illustrate how one could implement the seven steps are presented in Section III.E as a synthesis of the methods. The methods for classification, analysis, and characterization of SABS/response associations are presented in Section III.D along with specific examples.

III.B.1. Step 1. Review Current Designated Uses and Criteria for a Set of Waterbodies

The development of SABS criteria begins by selecting and characterizing a type of waterbody and identifying the specific designated uses for which the local authority desires to set protective criteria. Although waterbody type (streams, rivers, estuaries, coastal areas, lakes, or wetlands) may be sufficient as a classification variable, more refined classification relevant to SABS is usually necessary during this step or in step 4.

Existing designated uses and associated narrative or numeric criteria should be reviewed and an initial determination should be made as to whether these are protective of the valued resources. Uses are designated to support and protect navigable waterways, industrial, and agricultural uses, recreational activities, drinking water sources, and aquatic life. Designated uses may be very general (e.g., biotic integrity) or more specific (e.g., high-energy, cold-water streams that supports salmonid fisheries). Extremely vulnerable or highly valued waterbody types may have their own specific designated uses that provide special protection for valued, threatened and endangered species or important ecological functions. With a more specific designated use, the SABS criteria will be more defensible. However, it is important to balance the desire for defensibility against the need to avoid proliferation of so many specific standards that SABS criteria become impractical to implement. Davies and Jackson (2006) discuss the appropriate use of biological information to tier designated aquatic life uses in WQS.

Criteria should be identified for all current designated uses. If these criteria need refinement, or if a new criterion is needed for a new designated use, then a general description is required of the point of transition between support and non-support of the designated use for a group of waterbodies. Initially, the criteria should be described in narrative terms and then quantified in subsequent steps. It is important to note that premature declaration of a specific threshold may introduce bias into the criteria development process.

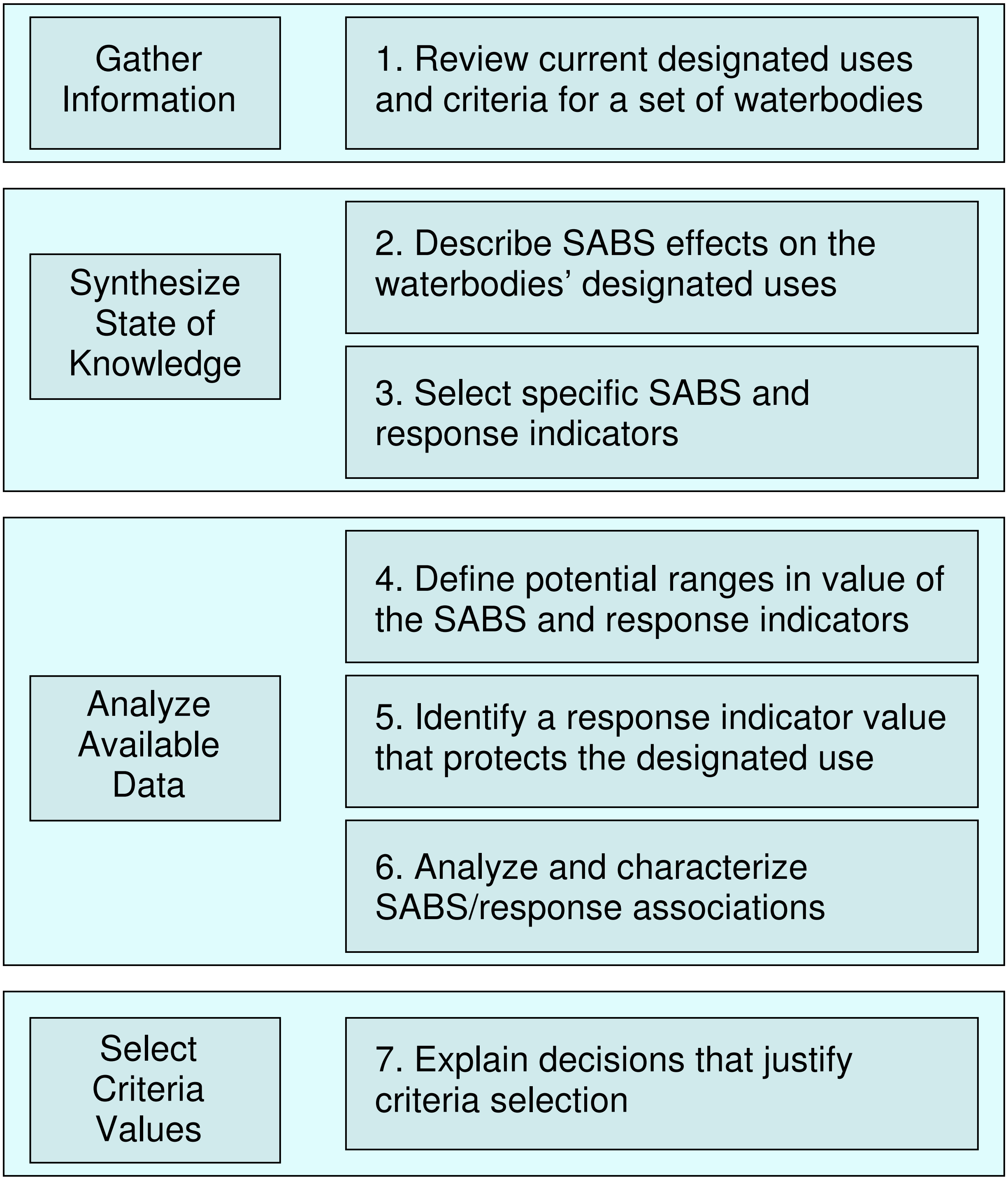

Figure 3. Seven steps of the SABS criteria development process and relationship to four activities in Figure 2.

III.B.2. Step 2. Describe SABS Effects on the Waterbodies' Designated Uses

SABS criteria should have a strong scientific basis, including both a causal mechanism and empirical evidence of association between SABS and the designated use, described in either positive terms or in the form of use impairment. A literature review is critical to identify evidence of causal mechanisms and the current state of knowledge related to the SABS criterion under consideration, including examples of exposure-response relationships. An additional review of relevant and available data sets would reveal both potential data sources and significant data gaps that may affect the course of SABS criteria development.

The current scientific understanding of the ways that SABS impair the designated use may be described in text and conceptual diagrams (Figure 4). The use of both of these communication tools helps ensure clarity of thought and consistent logic while developing the SABS criteria. Their use also enables easier identification of appropriate indicators (see step 3) and ultimately enables the defense of the selected criteria and standards. Most importantly, the underlying scientific basis linking SABS with designated uses should be articulated. Sections I.B.2 and Appendix B provide some useful documentation of how SABS can impair waterbody types. Additional examples of conceptual models can be found in Appendix F and Section III.E.1. Associations between SABS and designated use in terms of impairment (through the response indicator) should be supported by peer-reviewed literature or confirmed with data sets that the state, tribe or territory has compiled and analyzed. For instance, associational analysis (correlation, regression) of survey data including measurements of both biota and SABS might show the strength of exposure-response relationships. A combination of mechanistic studies and correlative associations provide the most defensible rationale for selection of SABS and response indicators in step 3.

III.B.3. Step 3. Select Specific SABS and Response Indicators

Selecting specific SABS and response indicators sets the stage for data analysis in steps 4, 5, and 6 through selection of the quantitative measurements for SABS (exposure indicators) that are believed to reduce the support of a designated use as described in the conceptual model (step 2). For example some typical measurements are *Secchi distance* to measure clarity, *suspended sediment concentration* to measure inorganic particles and *percent fines* to measure settled particles. Composite indicators of sediment movement are calculated from more than one measurement (See Relative Bed Stability, Section III.D.1). SABS exposure indicators should represent levels of intensity, frequency and duration as well as quantify the attributes of SABS that are responsible for impairment as evaluated in step 7. A mechanistic connection between the SABS indicator and the response indicator, as described in step 2, is also necessary to support the analyses described in step 6.

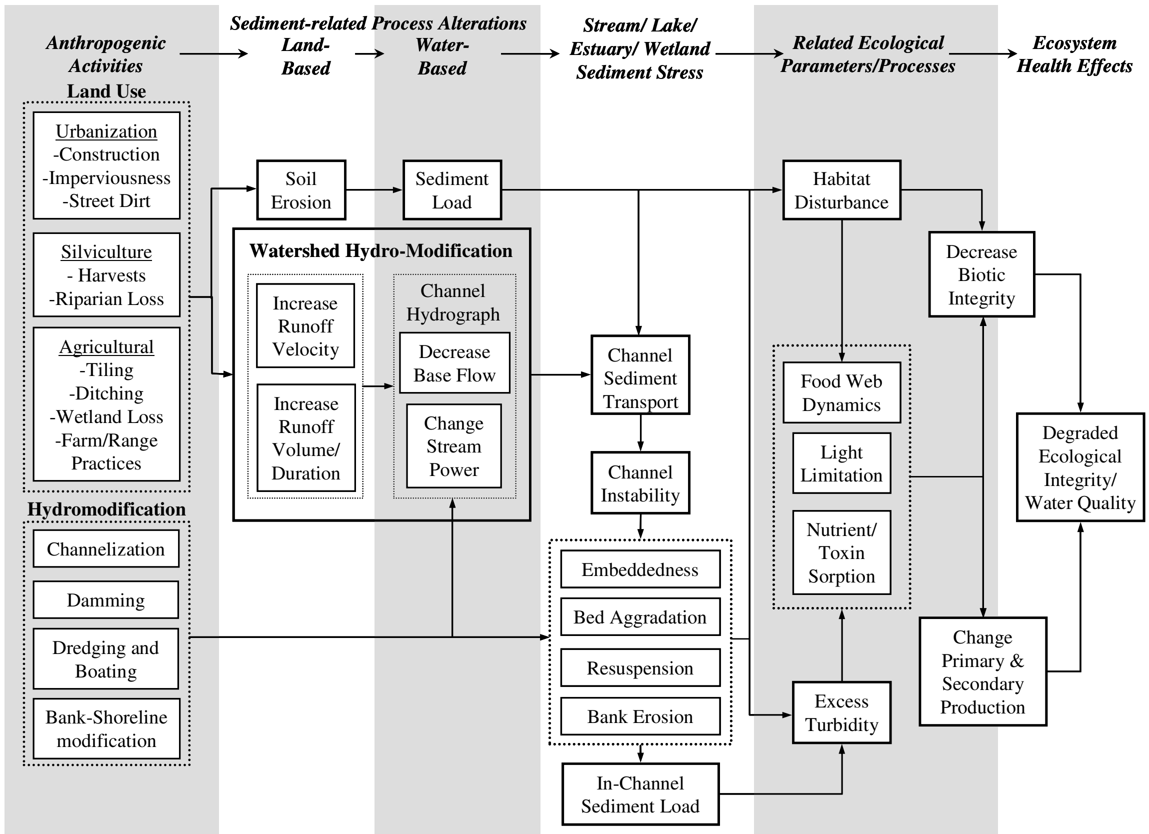

Figure 4. Conceptual linkages among sources of sediment stress and aquatic ecosystem health (Nietch et al. 2005).

III. Technical Elements

Also in step 3, the response measures that will be used to define impairment are selected. Examples of response measures include abundance of a species, presence or absence of a species, and clogging rate of drinking water filters due to source water impurities. In some cases the distinction between the SABS and the response indicator can be confusing. For instance, rate of stream bank erosion may be a measure of sediment to a stream, a SABS indicator, or it can be a measure of aquatic habitat loss or damage to adjacent real estate, a response indicator as described for the Waterbody Use Functionality method (Section III.D.3). Care should be taken to recognize how the indicator is being used.

Indicators should be selected that are appropriate for the waterbody type, classification, region, and designated use. Furthermore, indicators should be selected that have the following characteristics: (1) association with the designated uses, (2) quantifiable with available or accessible data, (3) dependable measurement characteristics, (4) appropriate for the specific analytical method, and (5) valued by stakeholders. Response indicators should relate directly to the designated use and quantify how well the waterbody type is meeting expectations for that use. If the designated use is the support of aquatic life, biocriteria such as an index of biotic integrity may be the appropriate indicator of response. The best response indicator would have a robust relationship with SABS levels. Existing biocriteria probably address general impairment, not SABS-specific impairment, and metrics that are more responsive to SABS levels should be selected as response indicators if they are available and the responsiveness can be documented. For designated uses more specific than “aquatic life” other appropriate entities and attributes may be used for defining attainment (U.S. EPA 2003d).

After the response indicator is selected, the level of protection is defined. This is a value judgment. For chemical criteria, the U.S. EPA has defined that level as protecting 95% of the tested species. Identifying the level for sediment is challenging. Current knowledge of SABS effects does not permit the same type of rigorous calculation for SABS. In the meantime, alternative standards can be used. A protective level may be pre-determined if criteria already exist in state standards for the designated use selected in step 1. Otherwise, impairment thresholds can be determined in step 5.

Data availability and accessibility may be significant factors in the selection of indicators. Many state programs are currently collecting and compiling monitoring data for purposes other than SABS criteria development. If these monitoring data are sufficient and relevant to the SABS criteria development effort, they should certainly be used, eliminating the need for a new and specifically designed monitoring program. Sufficiency of existing data should be determined through consideration of the program sampling design, sample size, sample frequency and timing, performance characteristics of the data (precision, bias, accuracy, representativeness, and completeness) and whether the indicators already sampled represent relevant SABS and response measures. Existing multi-purpose data would be valuable for preliminary analyses of potential value ranges (step 4), protective response indicator levels (step 5), and exposure-response relationships (step 6).

If existing data are found to be insufficient or irrelevant in steps 3-6, then a new and specifically designed SABS monitoring program should be implemented. New study designs that incorporate sampling of biological assemblages or individual taxa should target the biota that have measurable responses to the SABS indicators of interest over the expected range of values as recorded in the scientific literature (step 2). The sampling design used to collect the data is very important. Data sources and sampling designs can introduce bias and imprecision. Imprecision adds noise that limits the ability to reach sound conclusions. Bias clouds our understanding of mechanisms but its uniform nature still allows trends to be detected. Interpretation of data should assume that both processes are acting to increase uncertainty and that attempts to minimize their effects will be necessary. A probability-based design is ideal for quantifying status and trends and allows extrapolation of analytical results throughout the geographic area of interest. However, a targeted design, including the highest and lowest quality sites, is typically required to assure that the full range of exposure and response is represented to develop a complete exposure-response model. A hybrid design, a probability-based design augmented with targeted sites, combines the advantages of both methods and improves the overall analysis.

Frequency and timing of sample collection may also be an important consideration in the selection of indicators. For instance, some suspended sediment indicators vary with climatic as well as geographical variation. Data for such indicators may need to be collected more frequently or with prescribed timing in relation to storm events. Both data collection and adjustment of expectations can be more complex for some indicators, and investigators should be confident that they can collect sufficient data to account for multiple sources of spatial and temporal variability.

III.B.4. Step 4. Define Potential Ranges in Value of the SABS and Response Indicators

Once the ecology of the waterbody type is reviewed and SABS and response indicators are selected, then it is time to begin the analysis phase. The first step is to analyze the natural and altered waterbody characteristics that affect SABS regimes. For instance, SABS regimes may be affected by natural differences in responses to SABS variables by region, waterbody size, geomorphology, hydrology, lithology, soils, and so on. They may also be affected by land uses or modifications to the waterbody itself such as dams, channelization, and water diversion, to name a few (see Cross-Cutting Concepts, Section III.C.1, for a more extensive description.). Characterization of the natural and disturbed SABS regimes and response indicator values is dependent on waterbodies selected in step 1 and the appropriate classification within that waterbody type. Classification is typically based on expected, not observed, natural indicator levels. Waterbody classifications are evaluated in light of the potential and observed responses at step 6.

The process of classification or stratification identifies waterbody types with shared SABS regimens so that variability within a class is minimized compared to the variability among classes or variability caused by disturbance. For instance, high gradient streams would be expected to have less deposited sediments than low gradient systems where stream power is less and, therefore, particles settle. Properly recognizing natural supply regimes is particularly important for wetlands, where alteration of sediment supply could mean the difference between wetland loss due to accelerated subsidence or loss due to filling. Analytical methods that may be used to classify streams for SABS include most statistical tests that allow comparison among two or more potential populations. For example, if the central tendencies or distributions for measured suspended sediment concentration are different for undisturbed streams from two different ecoregions, these two types of streams should be analyzed separately and may require different sediment criteria. Issues associated with classification are more fully described in Section III.D.2. The sub-classes of waterbody types are then evaluated for existing and nearly natural levels of SABS.

Sediment supply and redistribution are natural processes that can be disrupted, leading to impairment of the designated uses of waterbodies. When impairment relates to rates of habitat loss or other non-aquatic biological endpoints, natural levels of SABS should be estimated to determine appropriate levels that will maintain or restore the designated use. Natural levels of SABS can be modeled using site and landscape characteristics or observed within groups of reference sites with similar characteristics. The potential natural range of a SABS indicator for a set of waterbodies is usually not the same as the observed range of the indicator for the same set of waterbodies. Examining the discrepancy between the potential and the observed is an instructive exercise in determining the extent and magnitude of SABS imbalances. Like the analysis of SABS indicator value ranges, the natural potential and observed ranges of response indicator values should also be examined in this step. This exercise will illustrate the extent and magnitude of response indicator imbalances. These values may prove useful in determining a threshold of non-attainment of designated use in step 5.

III.B.5. Step 5. Identify a Response Indicator Value that Protects the Designated Use

If there is a preexisting criterion for the designated use, for instance, a defined score from a benthic invertebrate index, and this criterion is used as the response indicator, then the criterion level for attainment identified in step 1 is the value used in subsequent analysis steps. If there is no preexisting criterion that is acceptable or if a more specific response indicator is preferred, then a response level that protects the designated use should be selected.

An appropriate transition point may be selected as a threshold of impairment by analysis of available data. Because natural systems are characterized as responding incrementally to changes in exposures, response indicators rarely exhibit an unambiguous inflection between unimpaired (or minimally impaired) and impaired conditions. Therefore, threshold levels of impairment should be supported with a detailed description of the procedure used to determine the threshold, preferably documented with peer-reviewed literature. There are three general ways to set thresholds for a given set of analyses on a data set:

(1) Ad hoc - A subjective approach in which thresholds are arbitrarily set at a specific percentile of reference sites, all sites, or some other subset of the data. The result may be biased because it depends on how the sites and percentile were selected. In explaining the selected threshold, this potential bias and subjective process should be recognized.

(2) Resource Managers decision – A resource manager sets a threshold that she/he is comfortable with - for example, at 90% probability of identifying a degraded resource. Rationale for threshold selections can include considerations of costs associated with false positive and false

negative results. It can also include the resource manager's preferences regarding acceptable uncertainties, tolerable sacrifices, and desirable resource protection.

(3) Statistical significance – An objective approach that is dependent on the sample size and variability. However, subjective decisions must be made in defining a difference to check for, perhaps in biomarkers, and the level of significance to use.

III.B.6. Step 6. Analyze and Characterize SABS/Response Associations

A specific body of water is impaired when it is not attaining its designated uses. Step 6 describes the procedure for identification of the level of SABS that is likely to cause failure to attain a designated use. First, it is necessary to show a relationship between the SABS and response indicators using one or more of the available quantitative analysis techniques. Analytical methods to establish an exposure-response relationship are of two types, based on either controlled experiments in the laboratory or field or descriptive analyses of biological and SABS indicators as they normally occur in the region, often termed "field observations." Field observations can be analyzed as a continuous or categorical relationship. Next, SABS levels that are either detrimental to or protective of the designated use must be identified. This may be accomplished by relating SABS indicator values with the transition point for the response indicator identified in step 5.

There is always uncertainty when trying to link exposure levels to an effect, in this case, linking SABS levels with use attainment. Awareness of the sources of these uncertainties and recognition of assumptions made during study design, data collection, and analysis are paramount. Some key issues to consider for dealing with uncertainty are mentioned here. Detailed guidance may be more fully described in future technical manuals.

Imbalanced SABS regimes may occur concurrently with other stressors, such as elevated nutrients or temperature. In such cases of multiple, simultaneous stressors, it is possible that the SABS indicator may be a causal agent of use impairment at only some of the sites used to develop the relationship. It is also possible that SABS may indirectly cause effects through an intermediate cause, such as settled particles restricting the flow through interstitial spaces in the bedded sediments thus reducing food availability, gas exchange, temperature maintenance, and waste removal (see Appendix F, Model 2). The SABS would then be considered part of a causal pathway that results in a deleterious effect. Controlling for multiple stressors and accounting for complex secondary effects is sometimes possible when using controlled experiments (see Section III.D.3). However, any correlative association may be confounded and may not be causal. These caveats must be considered when applying any of the methods. Nevertheless, the SABS indicators should be shown to be associated with a biological response. A SABS criterion can then be determined that is likely to result in biological conditions that permit a body of water to either attain or not attain its designated use(s).

Finally, the waterbody classification identified in step 1 and refined in step 4 needs to be reevaluated to see if it remains defensible. If further refinement of the classification scheme is needed, then the process is reiterated until defensible associations are developed. For example, if classification of streams by size results in similar levels of SABS for non-attainment in each size class, then the classification would be unnecessary. However, if classification indicated that different levels or measures of SABS would indicate non-attainment, then the classification was important in the criteria development process. At this point, a level of the SABS indicator that separates attainment from non-attainment for a designated use and waterbody class (the SABS criterion) should be established.

III.B.2. Step 7. Explain Decisions that Justify Criteria Selection

The scientific basis for setting any SABS criterion should be documented, including the actual criterion, magnitude, duration, and frequency variations (if necessary). All the steps used to establish this criterion should be recorded as well (including description of the data used). Different methods or studies will often indicate different SABS levels. The rationale for resolving these differences must be clear, reasonable, and scientifically defensible. Factors that may influence the decision may include choosing the most conservative method, selecting the method that enables the use of the highest quality data, averaging the results of several methods, or incorporating the weight of evidence in other ways. See Linkov et al. (2004) and Stahl et al. (2002) for various decisional analysis approaches.

One way to illustrate options that have been considered is to model expected impacts using simulations that reflect various potential SABS criteria. Building models that link criteria with impacts for evaluating potential criteria offers a number of advantages. For example, accurate predictive models require a thorough working knowledge of a system. If the output of such a model does not reflect field observations (e.g., relationships among causes, stressors, and responses are not consistent), this might indicate that more information about a system is needed to make effective management decisions or that the model needs refinement. Conversely, models that accurately reflect the relationships seen in field data may be useful for making management decisions. Models also allow virtual manipulation of systems beyond what is typically possible via experimentation, and without exorbitant time or cost commitment. For instance, what is the effect of setting a criterion at 30% versus 10% fines? If a researcher has developed a model of SABS effects on low-gradient streams in forested watersheds with aquatic life designated use, then the model could be used to compare the effect on benthic macroinvertebrate assemblages.

Furthermore, if the indicators were collected with a probability-based design, a cumulative distribution function can be constructed for the entire resource, known impaired resources, known unimpaired resources, and best conditions. Then, various SABS indicator levels can be overlaid on these distributions to evaluate the trade-offs of varying criteria levels, giving an estimate of error rates associated with the proposed criterion. False positives (identifying a waterbody as impaired when it is not) and false negatives (failure to detect truly impaired waterbodies) are valuable quantitative indications of uncertainties associated with an established criterion. Models can also be used to estimate the costs of remediation to specific criterion levels. For instance, what will be the cost of being more protective? What are the accrued societal benefits at the more protective level? And, what is the cost of having to remediate to a greater level as more waterbodies fall within the category not meeting the criterion?

III.C. Cross-Cutting Concepts

III.C.1. Classification of Waterbodies

As discussed earlier, SABS conditions vary naturally among waterbody types and geographic regions because of differences in supply and transport properties. Natural features such as geology, watershed topography, waterbody morphology, vegetative land cover, climate, soil erodibility and other landscape characteristics contribute to the variability in sediment supply and transport (Appendix F, Model 3). Expectations of sediment conditions must be established in the context of natural variability before impairment can be assessed. Moreover, certain indicators may be much more effective in certain regions or waterbody types than others. The waterbody types that form the basic strata are

- Rivers and streams
- Lakes, ponds, and reservoirs
- Wetlands
- Estuaries
- Coastal marine waters.

Further classification to account for more complex natural variability in sediment conditions may also be needed. Classification to account for natural variability was strongly recommended by the U.S. EPA Science Advisory Board.

Waterbody types

WQS are typically tailored for different waterbody types. A number of factors, such as flow regime, water (and sediment) retention time, sediment input sources, indicator biota, and many others make different types of waterbodies distinct. These natural differences imply SABS imbalances, and the way that those imbalances are measured and managed, are specific to each waterbody type.

For SABS criteria development, states, tribes, and territories may consider stratifying, at a minimum, by the five major waterbody types listed above. Stratifying waterbodies in this way will lend organizational and scientific plausibility to the overall criteria development process. Approaches for assessing SABS should consider that although waterbody types can be addressed separately, they are not independent of one another, but rather, are part of interconnected and larger basins or watersheds. The interconnectedness of systems highlights the need for integrated assessment and control of SABS for all waterbody types.

Regions

Stratification by region may be essential for discerning major locational differences in waterbodies (e.g., ecoregions, biogeographic provinces, physiographic/geologic regions, climatic regions). For instance, Simon et al. (2004) used ecoregional stratification to produce suspended-sediment ‘reference’ values using the flow that occurs, on average, every one and a half years as a measure of effective discharge for suspended-sediment transport. Regional stratification may also serve to simplify the criteria development process by limiting the waterbody types, analytical data to be reviewed, and range of classes within waterbody.

The well-documented "ecoregion" system (Omernik 1995; Omernik et al. 1988) may be a useful framework to stratify regions for SABS assessment because it has been used successfully to develop biological criteria. If it is found to be appropriate for the development of regional SABS criteria, it is encouraged that the scale of ecoregion aggregation and division be determined. The degree of variability within each of the ecoregions would determine the final regional scheme. Ecoregional stratification does not preclude the use of other classification schemes if they are judged to be more appropriate.

Classification beyond Waterbody Types and Regions

Even after stratifying by waterbody type and region, the variation of natural SABS levels within these strata may require finer levels of classification or classification based on other factors. For example, streams within one region may have low-gradient and high-gradient classes. A measurement of waterbody size (e.g., stream order, lake area, catchment area, discharge) may also be used to classify waters. Lakes may be classified by size or retention time. These different classes within waterbody types have different levels of naturally occurring SABS and may respond differently to an imbalance of SABS. The actual number of classes recognized within a stratum depends on a number of factors, including variation among classes in natural levels of SABS, similarities and differences among classes in effective response indicators, and data available for development of criteria.

The goal of defining classes within strata is to achieve a balance between accounting for the natural differences in SABS among individual waterbodies and finding some commonalities among waterbodies so that each river or lake does not become a class. One option is to identify the waterbody type in the watershed or basin that is less tolerant to shifts in sediment supply. Criteria developed for this waterbody type may automatically set the criteria for upstream waterbodies, which may be sources of sediment but resilient in the face of episodic spates of increased sediment loads. Taking this tact may reduce the number of classes and customized criteria. It may also enable remediation plans on a basin or watershed scale (see the example for the Chesapeake Bay, Section III.D.3).

Classification requires defining likely classes and describing indicator ranges among proposed classes. Classification should progress using data from waterbodies that are unimpaired. Splitting into more refined classes has possible drawbacks. There may not be enough sites to perform a statistical evaluation or enough resources to collect data from the field. Too many classes may make it difficult to know which criteria to apply in a particular case. Classification using stochastic or deterministic models does not require as many data points per class as classification methods based exclusively on statistical analysis of field data. However, the cost (in terms of dollars and time) of initiating a new model development effort may be excessive.

III.C.2. Indicators - Exposure and Response Measurements

The selection of indicators is a major element within the *Framework* and is a key step in defining impairment and monitoring management actions. When attempting to meet WQS, resource managers rely upon narrative or numeric criteria to determine whether a designated use is being protected. In many cases, resource managers select specific, measurable variables, or indicators, to express a narrative standard in terms of the pollutant of concern. A numeric target value for the variable is a threshold between the impaired and unimpaired designated use of the waterbody. The most effective indicators are quantitative measures that can be used to establish the relationship between pollutant sources and their impact on water quality.

> *An ideal indicator is measurable, quantifiable, reproducible, and comparable.*

There are many indicators of SABS-caused impairment. Most fall into one of five discrete categories: (1) water column measures, (2) substrate measures, (3) channel/bathymetric characteristics, (4) biotic response measures, and (5) functional measures. The first three categories are types of exposure measures; the last two are measures related to effects and designated uses. Indicators should be appropriate to the waterbody type (Table 4) and allow analysts to efficiently discriminate impaired from unimpaired conditions.

When adopting a particular indicator or suite of indicators, it is important to consider various technical, practical, and socioeconomic considerations. An ideal indicator is measurable, quantifiable, reproducible, and comparable. In addition, it is important to weigh the costs of obtaining data compared against the value of the information produced. Each potential indicator has specific measurement methods, appropriate applications, precedent uses as indicators, and ranges of possible criterion values. When applied properly and judiciously, indicators can provide the requisite understanding of SABS processes to show the link to biological resources or designated uses and to identify the management actions with the highest likelihood of success. In practice, selection of appropriate indicators will require investigation into measurement techniques, specific applicability, and performance characteristics that cannot be completely reviewed in this *Framework*.

Exposure Measures

There are three main classes of sediment-exposure indicators: (1) water-column measures, (2) substrate measures (including bedload), and (3) channel/bathymetric characteristics. Each can be characterized by one or more metrics tailored to the specific indicator. For example, metrics associated with suspended sediment and turbidity tend to be more effective in identifying water-column impairments in still or slow-moving water, such as in lakes, estuaries, and some coastal areas, and some rivers at sluggish flows. In faster-moving waters, bedded sediments and bedload may have relatively greater impacts on habitat and biota than water column impairments. This is in part due to the episodic nature of suspended sediment flux in faster-moving waters, in which most aquatic organisms have adaptive characteristics for withstanding short-term exposures to turbid waters.

Table 4. Suitability of SABS indicators by waterbody type. ● = appropriate application, ⦿ = limited applicability, ○ = not appropriate

	Rivers and Streams	Lakes, Ponds, and Reservoirs	Wetlands	Estuaries	Coastal Marine Waters
Suspended Sediment					
Turbidity	●	⦿	⦿	⦿	⦿
Total Suspended Solids	●	⦿	⦿	⦿	⦿
Suspended Sediment Concentration	●	●	●	⦿	⦿
Light Penetration	⦿	●	⦿	●	⦿
Water Clarity	●	●	⦿	●	●
Bedded Sediment					
Bedload Sediment	●	○	○	⦿	○
Percent fine sediment at surface	●	●	●	●	○
Percent fine sediment at depth	●	⦿	●	●	○
Sedimentation rate	●	●	●	●	⦿
Embeddedness	●	●	○	⦿	○
Suspendable Solids	●	●	⦿	●	○
Particle size distribution	●	●	●	⦿	○
Particle size geometric mean	●	●	●	⦿	○
Substrate Stability	●	⦿	○	⦿	⦿
Relative Bed Stability	●	○	○	○	○
Bottom Deposit Depth	⦿	●	●	●	●
Residual Pool Volume	●	○	●	⦿	○
Bank Stability	●	●	●	●	○
Waterbody Dimensions	●	●	●	●	○
Bathymetry	●	●	●	●	●
Riffle/Pool ratios	●	○	○	○	○
Gradient	●	○	⦿	○	○
Sinuosity	●	○	○	○	○
Incision	●	○	●	○	○
Response Indicators					
Biological Measures	●	●	●	●	●
Eroding Banks	●	●	○	●	●
Reservoir Filling Rate	●	●	●	●	○
Filter Clogging	●	●	○	○	○

Suspended sediments reduce water clarity and light penetration. The particles can be abrasive, clogging biological and man-made filters. If the particles are organic or algal, they may also alter water quality via decomposition and shift in community structure (such as an altered food source). Suspended sediments also have the potential to settle. No single indicator measures exposures that would be adequate to reflect all of these effects. Therefore, it may be judicious to measure a suite of indicators.

Physical measures associated with substrate or bedded sediments include embeddedness, percent coverage or percent volume of fine sediments, and substrate stability indices. Bedload transport is largely responsible for changes in channel morphology and habitat.

Channel/bathymetric characteristics are measures associated with the morphological stability that change near-shore or wetted basin physical characteristics. They can reveal effects of erosion, transport, and deposition on channel morphology and habitat conditions. Channel/bathymetric characteristics can be used to infer past, present, and potential future erosional and depositional processes. A process-based understanding of the fluvial system can lead to development of causative links to management practices aimed at remediation of sediment problems.

Biotic Response Measures

The existing biomonitoring programs in many states, tribes, and territories sample aquatic life that may be sensitive to SABS. Biological metrics can provide discriminating indicators for SABS associated with impairment of the aquatic conditions. Aquatic organisms may be measured in the water column as well as in or near the sediment or substrate. Because the presence, diversity, and productivity of aquatic organisms can be used to infer habitat suitability, biological indicators can complement physical exposure indicators in SABS criteria development as well as provide information on overall biological integrity. Biotic responses may be measured or calculated in numerous ways, including metrics of taxa assemblages or presence and abundance of specific taxa such as threatened, endangered, invasive, or exotic species. For example, researchers have assigned sediment tolerance values to specific organisms in stream environments, allowing calculation of metrics that may prove uniquely responsive to SABS effects (Relyea et al. 2000; Yuan 2006).

Biological metrics can be discriminating indicators for SABS associated with impairment of the aquatic conditions though they may not be sufficiently specific for diagnosis of SABS impairment.

It is important to note that biological measures may not always indicate or diagnose SABS impairment. An excess of SABS may result in a predictable change in the biota. However, any given change in the biota may not be attributable definitively to SABS. SABS is only one of many stressors in aquatic systems that can cause similar responses in the biota.

III.C.3. Integration and Synthesis of Multiple Methods

One conclusion of the U.S. EPA Science Advisory Board was that no single method would suffice for complete criteria development in every situation and that multiple methods applied simultaneously (synthesized) may be more appropriate for criteria development. This conclusion recognizes the complexity of natural SABS settings, the variable applicability of methods in those settings and the flexibility required by states, tribes, and territories to use their SABS data to their best advantage. Various methods are described in Section III.D, organized by groupings that are appropriate for measuring and calculating SABS indicators, for classifying waterbodies, and for developing associations between indicators of SABS with indicators of designated uses. A key element is that the methods and resulting evidence are best used in combination. Results from different methods can provide independent collaboration of scientific findings. They are best applied when interpreted in terms of a watershed or interconnected waterbodies. In other words, the evidence should be evaluated in such a way that upstream criteria protect not only the immediate waterbody but downstream designated uses as well. Examples of how these methods could be used in combination (a synthesis of methods) are described in Section III.E.

III.D. Methods Applicable within the Framework

At this time, U.S. EPA has been examining various methods for use in developing water quality criteria for SABS that are applicable within this *Framework*. Some of these methods are presented here as they relate to three activities: (1) measuring suspended and bedded sediments, (2) evaluating water body classification, and (3) associating suspended and bedded sediments with designated uses. These methods are generally applicable in steps 3, 4, and 6 of the *Framework*, respectively. The presented statistical methods can often be applied to more than one activity. Some methods are well developed, whereas, others may have been tested in only certain classes of waterbodies. All these methods need to be evaluated and applied to local situations. The *Framework* is flexible, allowing many variations in the combination of indicators, classifications, and analytical methods. This flexibility allows resource managers to customize the criteria development process to specific needs and capacities. It also encourages justification for the choices made in customizing the process. While these methods are explained individually, in practice they will be applied simultaneously or in combination.

(1) Measurement of Suspended and Bedded Sediment (Step 3)
- Readily Available Measures
- Sediment Transport Curves
- Relative Bed Stability

(2) Waterbody Classification (Step 4)
- Empirical Classification (Reference Condition)
- Fluvial Geomorphology

(3) Associating Suspended and Bedded Sediment with Response Indicators (Step 6)
- Controlled Experiment
- Field Observational Studies
  - Percentile Analysis (including Reference Condition Methods)
  - Exposures and Effects Analysis
  - Conditional Probability Analysis
- Waterbody Use Functionality

Brief examples of some of these methods are included with the descriptions below. The examples use data sets generously provided by the state of Oregon, the Chesapeake Bay Program, and the U.S. EPA Environmental and Monitoring Assessment Program (EMAP). These example analyses demonstrate that acceptable data sets may be already available or can be developed within a few years.

To select a SABS indicator value that is protective of a designated use, common sense and clear thinking are indispensable. This section will provide some analytical methods and a few tips, but the investigators should provide the clear thinking and rationale for each of their choices. Choices of indicators and thresholds require reliance on assumptions regarding mechanisms, modeled relationships, bias, measurement precision, and other analytical elements. Selection of a protective response level requires a trade-off between full protection and what the public will support and implement. These assumptions and compromises should be examined transparently and often during the criteria development process. The four elements that have the strongest impact on criteria development include selection of endpoints and measurements, classification, methods for demonstrating associations, and selection of criteria values.

Selection of endpoints and measurements should support the goal of showing a causal relationship between SABS and an impaired designated use. The most mechanistically plausible relationships are those that are specific rather than general, rely on few classifications, and make direct association with few intervening steps.

- *Specific indicators are better than general ones*. The association of stoneflies, a type of benthic invertebrate, and silt free substrates is more definitive than an invertebrate index or even the number of ephemeroptera, plecoptera, and trichoptera (EPT) taxa with silt free substrates. This is because most stoneflies have very narrow habitat and water quality requirements, whereas benthic macroinvertebrates occupy many niches. EPT, a metric of mayflies, stoneflies and caddisflies, includes mayflies that burrow in sediment and caddisflies that thrive on fine particulate matter. Indices are designed to detect a wide range of causes rather than impacts of SABS alone.

- *Indicators are better if they rely on few classifications*. Relative Bed Stability is a measure that inherently uses channel characteristics in calculation of the metric. Because the channel characteristics incorporate the same determinants that might be used to classify sites, more sites can be lumped into a single class, with individual site differences accounted for in the metric. This reduces the chances of a categorical error in site classification, though some gross and easily recognized class may still be needed (e.g., wadeable streams within a single ecoregion).

- *Indicators with direct associations are better than those with indirect pathways.* An association of suspended sediment concentration (SSC) and extent of eelgrass bed is more readily demonstrated than SSC and blue crab catch. This is because the catch is dependent on effort as well as abundance, and sediment does not directly affect the crab as much as it affects eelgrass beds. Therefore, there is an indirect association rather than a direct one. In a conceptual model there would be multiple boxes and arrows to make the connection.

Classification is a statistical method for removing variation due to factors other than SABS that affect the SABS and response indicators. It is most appropriate and necessary for observational field survey data. Classification may be unnecessary if assessment endpoints are specific. If field data are plotted for the presence of brook trout and total suspended solids, the classification is *de facto* for those streams with brook trout. Classification is explicit in controlled experiments, where the laboratory conditions or experimental setting defines the class. Classification is looking as much for similarities as it is for differences. No two sites are the same. However, by placing different sites in the same class, we are recognizing their relative similarity among all sites in the data set. In doing so, we allow for potential bias and error (some sites are not as similar as others) and simplify criteria application (by not expecting definition of site-specific criteria).

Methods for demonstrating associations between the SABS measurement and the response measurement can show that an adverse effect is likely to occur given some level of SABS. To demonstrate an association, it is recommended that one use at least two methods that rely on different assumptions, different data sets, and different statistical methods. For instance, results from controlled experiments can be compared with characterizations based on independent field observations.

When SABS are characterized with respect to reference sites or acceptable physical conditions, it is possible to describe deviation from the reference conditions in terms of SABS measurements alone. These deviations may be interesting and perhaps even indicate increased human activity in the watershed, but it is possible that they are also insignificant to the function and attainment of the designated use. Until the SABS indicators are linked to the response indicator (selected because it represents the designated use), changes in the SABS indicator cannot be interpreted in the criteria setting context.

Selection of a criterion value is often a value judgment that can be somewhat distanced from scientific methods, especially when clear inflection points are not evident in stressor-response curves. Despite the many uncertainties, one can determine defensible criteria when different data sets and different types of associations support or corroborate one another. Examples of different types of evidence include:

- Plausible effects based on laboratory and field exposures
- The interactions among gradient, flow, substrate, and other variables
- The connectedness of abiotic and biotic components in ecosystems
- Characteristics of chronic and episodic exposures to SABS
- Levels of SABS in upstream locations and how they relate to downstream resources with different tolerances to SABS.

III.D.1. Measurements of SABS; Applicable in Step 3 of the *Framework*

Measurements are usually required for sources, exposures, and responses of SABS. The mechanistic pathways through which sediment can affect biological assemblages can be depicted in conceptual models. Associations between indicators that are close together in the conceptual model (only one arrow connecting) are easy to demonstrate because there are few unmeasured variables that will affect the interaction. Keep in mind that the measurements that are selected will need to be associated with a designated use so that an effect level can be demonstrated.

Readily Available Measures

Some of the technical issues and considerations for selecting measurements of SABS were described as part of steps 2, 3, 4 and 5 and in Section III.C.2. Table 4 lists possible indicators sorted by their usefulness in measuring suspended or bedded sediment and their applicability to waterbody type. Naming conventions are listed in ASTM's Terminology for Fluvial Sediment, D 4410-98 (2005), which contains the widely accepted definitions for riverine and most other freshwater environments. Of the five fundamental sedimentation methods listed by ASTM D 4410-98, erosion, transportation, and deposition are relevant to the SABS guidelines. Approaches are also reviewed and published by ASTM (2005), for example, turbidity (ASTM D 1889-00) and suspended sediment concentration (ASTM D 3977-97). The USGS has been a leader in the development of reliable measures of the fluvial-sediment method and their Web site is a good place to find useful methods for measuring SABS (http://water.usgs.gov/osw/techniques/sediment.html).

The mechanistic pathways through which sediment can affect biological assemblages are depicted in several conceptual models (Appendix F). For suspended (Model 1) and bedded sediments (Model 2), boxes are highlighted in grey that directly measure characteristics of sediment that affect aquatic life. For instance, Secchi distance could be selected to measure light penetration. Substrate stability and substrate movement and scouring are more dynamic processes that can be inferred, measured, or modeled. Land cover/land use and in-stream factors that alter sediment supply are depicted in Model 3. Whichever SABS measurements are selected should be associated with a response variable so that an effect level can be estimated. Associations between indicators that are directly connected conceptual model are easier to confirm because there are fewer unmeasured variables that will affect the interaction. The following two sections describe two methods, sediment transport curves and Relative Bed Stability (RBS), that may be less well known than more commonly used measures of SABS.

Sediment Transport Curves

Sediment transport curves (STC) are graphics for displaying the relationship between measured sediment values (either bedload or suspended sediment load) and measured or expected flow or discharge. Departure of measured sediment values at a given flow from expected sediment loads may help indicate the type and magnitude of impairment and may help a resource manager identify targets for reestablishing more stable sediment conditions for the waterbody.

Stream stability shifts are reflected in STCs, also termed sediment rating curves, where measured sediment values are regressed against measured discharge. The upward shift in the slope or intercept values of the STC are due to increased sediment supply resulting from a variety of sources. The upward shift in the STC exponentially increases the sediment yield for selected increments of stream-flow. Land uses that increase stream-flow magnitude and duration can be instrumental in accelerating "flow related" increases in sediment. Figure 5, below, provides an example of STCs for two rivers of different channel type, sediment budget, and stability.

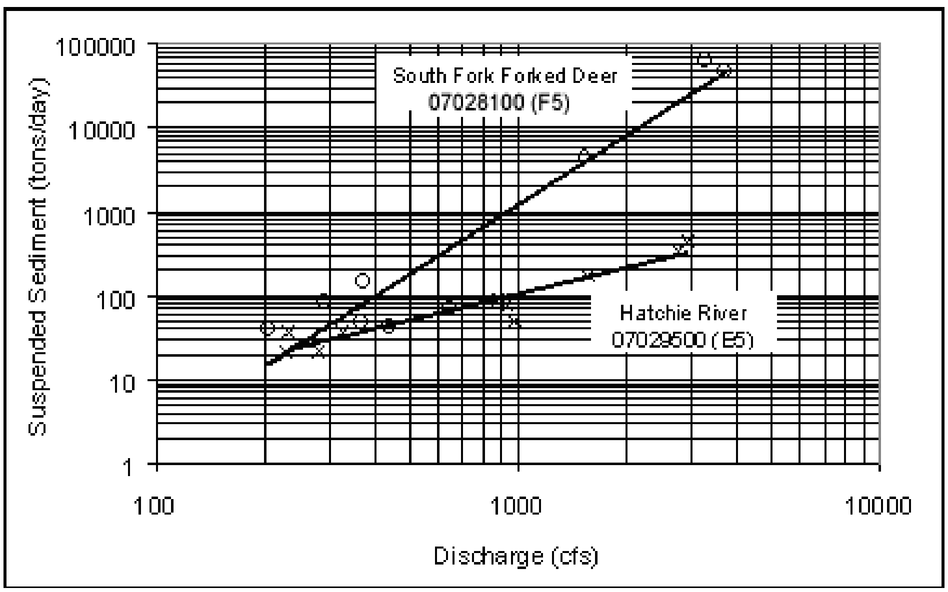

Figure 5: Suspended sediment transport curves for South Fork, Forked Deer and Hatchie River (from Simon, 1989).

Although understanding of STCs is limited, they may have some application potential related to criteria if reference relationships can be developed. Suspended sediment concentration, for example, is often correlated with flow rate, and the literature offers some evidence that sediment transport coefficients and flow are predictably interrelated within a given region (Hawkins 2002). In an examination of STCs 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 geomorphic channel type, but the analysis did reliably detect departure of generally unstable stream types as a group from values expected of stable channels. Ongoing work in developing and testing reference STCs 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.

Relative Bed Stability

Relative bed stability (RBS) is a comparison of bed substrate size divided by the mobile diameter at bankfull flow, which is proportional to the estimated shear stress at bankfull flow. 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). Topography, precipitation, and land cover influence sediment supply to streams, but the source of sediments is the basin soil and geology, and supplies are greater where these materials are inherently more erodible.

> *Relative Bed Stability is an index of substrate mobility with respect to physical characteristics of the waterbody. Substrates are expected to move a calculable degree for each natural hydrologic and geomorphic condition. When observed substrate mobility is considerably greater or less than the predicted, human-induced SABS stresses are indicated.*

Once sediments reach a channel and become part of the streambed, 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 streambed stability can be evaluated. Furthermore, the degree to which streambed instability is due to accumulation of fine sediments can be evaluated, and watershed data can be examined to infer whether the sediment supply to the stream may be augmented by upslope erosion from human activities and natural disturbances.

RBS is calculated as the ratio of observed bed substrate particle diameter divided by the calculated “critical” or mobile particle diameter (Dingman 1984; Gordon et al. 1992). RBS is the inverse of the substrate “fining” measure calculated by Buffington and Montgomery (1999a,b) The RBS is conceptually similar to the “Riffle Stability Index” of Kappesser (2002), the bed stability ratio discussed by Dietrich et al. (1989), and the ratio of critical near-bed water velocity to actual near-bed velocity defined by Jowett (1989).

When evaluating the stability of whole streambeds (vs. individual bed particles), observed-bed substrate is typically represented by the average diameter of surface substrate particles (e.g., D_{50} or the geometric mean). The widely accepted procedures for measuring substrate particle size distribution in a stream channel typically employ a systematic “pebble count" as described by Wolman (1954). 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 although this is more appropriate for gravel-bed streams than for “live-bed” streams such as naturally sand-bedded streams that transport bedload at lower flows.

One method 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. When developing this method, EMAP researchers (Kaufmann et al. 1999; Kaufmann and Larsen 2006) 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 channel and substrate data as described above, EMAP researchers modified the Dingman (1984) critical diameter 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 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., 0.0001-0.01) describe a channel composed of substrates that are frequently moved by even small floods.

Scientists hypothesize 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. Kaufmann et al. (1999) argued that, on a regional scale, streams will adjust sediment transport over time to match supply from natural weathering and delivery mechanisms driven by the natural disturbance regime. Consequently, for streams with sediment transport limited by competence (critical shear stress) rather than total capacity (stream power), RBS in appropriately stratified regional reference sites should tend towards a range characteristic of the climate, lithology, and natural disturbance regime (Kaufmann and Hughes 2006).

In support of this assertion, Stoddard et al. (2005) found that Log_{10} (RBS) in reference sites differed among aggregated ecoregions of the Western U.S.A., where, for example, the 25th percentiles of reference sites in mountain ecoregions ranged from -0.6 to -1.1 compared with -1.7 for plains ecoregions. RBS values considerably lower than 1.0 (Log_{10} RBS <<0} may be the norm in streams draining watersheds relatively undisturbed by humans if those streams are characterized by natural features (lithology, soils, topography, climate, and vegetation) that are conducive to high rates of sediment supply and transport.

In particular, naturally fine-bedded streams with unstable beds (i.e., Log_{10} RBS <<0), would be expected to drain relatively undisturbed watersheds where streambed textural responses are constrained by a lack of coarse particle sizes in sediment inputs from the drainage area. 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. Log_{10} (RBS) values considerably lower than zero may be expected in these examples of 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 method (currently based on the competence of bankfull floods to move given sizes of particles). For these waters, it is useful to estimate bed stability in terms of the proportion of the year that the bed is in motion.

In watersheds where sediment supplies are augmented relative to a stream's bedload transport competence, evidence will likely show an excess of fine sediments (Dietrich et al. 1989). Very small RBS values (e.g., 0.0001- 0.01) indicate excessive amounts of fine particles compared with expected values in most relatively undisturbed watersheds. Such evidence of excess fine sediments in the stream bed (RBS<<1) typically occurs when land use activities increase hillslope erosion (Lisle 1982; Dietrich et al. 1989; Lisle and Hilton 1992), especially when there is also damage to riparian vegetation.

In 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 (Kaufmann et al. 1999; Kaufmann and Larsen 2006). Finally, as the basin lithology within a geoclimatic region becomes more erodible, the RBS steeply declines with progressive disturbance (Kaufmann and Hughes 2006). As demonstrated for streams in the Pacific coastal region by Kaufmann and Larsen (2006), 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 (Figure 6).

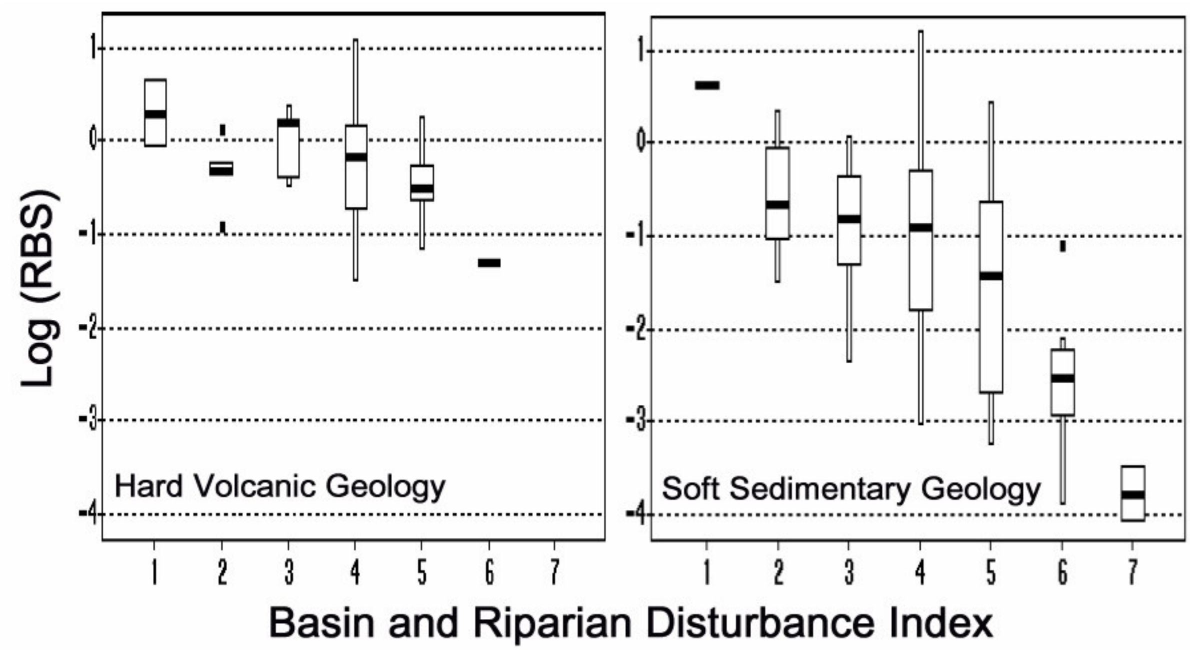

Figure 6. RBS in streams of the Coast Range ecoregion of Oregon and Washington as a function of a relative disturbance gradient in hard volcanic and soft sedimentary geologies (Kaufmann et al. 2004).

Once the degree of sedimentation is estimated for sample sites, deviations from expected values can be examined in relation to key aquatic species, guilds, or biotic assemblages (algae, macroinvertebrates, fish, rooted aquatic plants). A relationship observed between RBS and the biotic metric is positive evidence that excessive fine sediments are affecting aquatic life uses (Figure 7) and that the RBS indicator may be a reliable basis for establishing SABS criteria. Scatter at the low end of the plot may be due to poor biological conditions that are attributable to stressors other than RBS. These patterns are consistent with the hypothesis that sediment is limiting biota when the upper limits of the plot are showing a response. In large, representative surveys of sites from across an ecoregion, the upper limits represent the best biological conditions that can be expected for the corresponding RBS values.

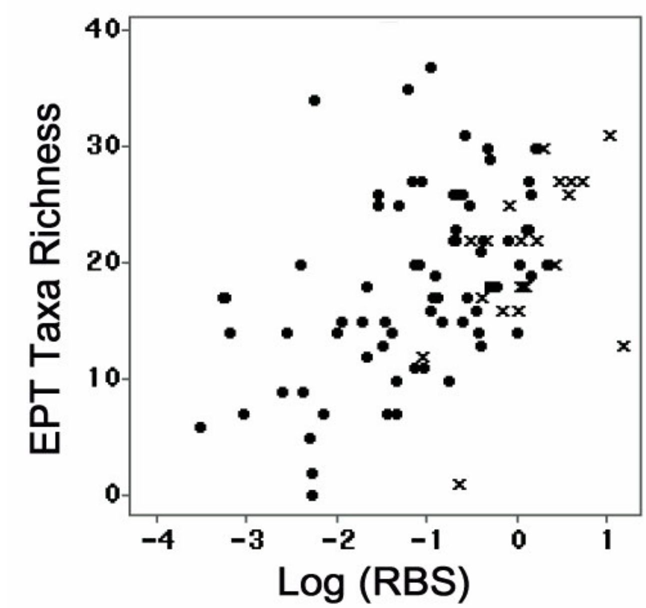

Figure 7. RBS in streams of the Coast Range ecoregion in relation to EPT taxa richness (Kaufmann et al. 2004). Data points represented with an "x" have 20% or more bedrock at the site. Circles are sites with less than 20% bedrock.

III.D.2. Waterbody Classification: Applicable in Step 4 of the Framework

Sediment is a natural component of aquatic ecosystems. Some ecosystems, by their very nature, have evolved under conditions of extremely low sediment supply and others with a lot. Some systems evolved with unstable substrates and others with stable substrates. Some experience a steady supply of sediment and others have periods of sediment starvation and periods of sediment inundation. It doesn't make sense to apply very low sediment criteria to a system that would naturally experience a heavier supply of sediment. Similarly, it would be inappropriate to permit high levels of fine sediments in a system that is normally characterized by cobbles or bedrock substrate. Therefore, aquatic systems with similar sediment regimes need to be classified and sorted into similar categories or arranged along a predictable continuum so that appropriate sediment criteria can be developed and applied.

The natural sediment regime for a waterbody can be estimated based on geographical, geomorphic, and climatic characteristics of waterbodies in a nearly natural state (reference conditions). We refer to this method as the *Empirical Classification Method*. The *Fluvial Geomorphology Method* is based on model building and field observation and is useful for selecting stable sites and avoiding those in successional states.

Empirical Classification

Empirical classification refers to an investigation of SABS conditions that can be expected in systems that are functioning in pristine or minimally disturbed watersheds. The expectations are not uniform across all systems. Rather, they vary according to variations in underlying geology, soil characteristics, climate, vegetative types, and other natural determinants. At the heart of empirical classification is the identification of the natural determinants that are most influential to variations in SABS conditions. Once determinants are identified, they can be used to describe distinct site classes or a continuum of classes. The SABS conditions observed in those sites with minimal landscape disturbance become the standard to which any other site within the class can be compared.

> *At the heart of empirical classification is the identification of the natural determinants that are most influential to variations in SABS conditions.*

Classification techniques could be used to identify degraded site classes with respect to SABS. However, if the differences attributable to natural variation were not first identified, it would be difficult to distinguish true degradation from acceptable natural differences. For this reason, the classification techniques are best applied in sites with no known impacts or few impacts if non-impacted sites are nonexistent. Sites with few or no impacts are generally termed reference sites as these are the sites to which we refer when defining unaltered (or best observable) SABS conditions.

The first step in empirical classification is identifying wholly natural or minimally disturbed reference sites. After removing sites with known impacts, it is assumed that any observed variation in SABS conditions is due to natural factors. The next step is to explain the observed variation in SABS conditions in terms of natural determinants. The step described above regarding definition of reference SABS conditions and comparison to those conditions for determination of imbalances is really beyond the scope of the classification exercise but is addressed in subsequent sections. If analytical anomalies are discovered as indicated in step 6 of the *Framework*, it may be necessary to return to this step and reclassify.

Identifying Reference Sites. Sediment supply and hydrology respond to most landscape modifications. Thus, contemporary land use data are important in identifying reference sites. Current land use data are available for most of the contiguous U.S. (e.g., LANDSAT), and the technology is advancing rapidly so that more contemporary data are being made available rapidly. Historic land uses should also be considered when selecting sites with nearly natural sediment regimes, especially for bedded sediments. The time required for stream channels to return to equilibrium after landscape alteration is on a scale of decades to centuries, if not longer (Trimble 1974; Schumm 1977; Brunsden and Thornes 1979; Trimble 1999).

Streams in catchments that have experienced historic landscape disturbance by human activities for an extended time or intensity may still be undergoing geomorphic readjustment. Unless this is an acceptable class in itself, these sites should be excluded from the reference data set. Other waterbody types may also require considerable time to reach equilibrium after disturbance in the watershed. Historic land use data can often be reconstructed from tax data, historic photographs, and historic diaries. Techniques have been developed by fluvial geomorphologists to identify or infer past land use disturbance (e.g., dendrochronology, sediment profile dating, floodplain and terrace coring, etc.) (Knighton 1984). These can be used to investigate past impacts within a potential reference catchment though they may be prohibitive in terms of cost, time, and expertise.

Modifications within the channel or waterbody are also important for defining sites with nearly natural sediment regimes. The presence of dams, channelization, dredging, and diversions will all affect in-stream 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, sediment and channel features can migrate downstream and upstream following channel impacts, 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 destabilization by sediment accretion.

A deliberative process for identifying reference sites includes listing all conditions that should be met for a site to be designated as reference. Criteria should address measures that are independent of the SABS and response indicators for which criteria are being developed. Persons familiar to the region are most knowledgeable about what factors might be used.

The following are examples of possible criteria for selecting reference streams based on information about land use/land cover and stream morphology. Obviously, criteria would be differently customized for other waterbody types and prevailing regional stressors.

- 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 are not in natural cover or are not in sediment generating land uses, such as mining, clear-cut logging, or cultivation on steep slopes.
- Roads cross the stream once per kilometer or less and do not dominate riparian areas.
- 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.
- Stream channel is not in an erosive successional stage.

Reference Site Identification in Oregon

The Oregon Department of Environmental Quality (ODEQ) is in the process of establishing SABS criteria in wadeable streams. As a first step in the process, reference sites were identified using multiple types of quantitative and qualitative information (Drake 2004). To identify reference sites, ODEQ used GIS analysis and aerial photos or thematic mapping data, or both, to pre-screen areas and find watersheds with minimal human disturbance. Using best professional judgment (BPJ), resource specialists edited the list of potential sites within unimpaired areas. A Human Disturbance Index (HDI) was developed for the candidate reference reaches and watersheds based on reach level observations and watershed-scale geographic information. The HDI score was used to help select and rank reference sites in a basin or region. Verification of reference sites includes evaluating physical habitat and biological and water quality data. Outlying data may indicate problems that would exclude sites from the reference set. After identifying reference sites, ODEQ went on to investigate differences in SABS indicators among potential site classes. The studies revealed that ecoregions are reasonable determinants of natural SABS variations.

Identify Potential Class Determinants. The naturally occurring factors that can potentially affect SABS supply make a lengthy list. Well established empirical and theoretical relationships describe the effects of landscape topography, climate, and geology (including soil properties) on sediment dynamics (examples in Knighton 1984 and Gordon et al. 1992). Classification determinants may include underlying geology, soil type, gradient, hydrology, climate, topography, and catchment geomorphology. Determinants that are substantially influenced by human activities, such as land use or vegetative cover, should be avoided because their use would introduce the risk of defining classes based on degrees of impact, not natural variation.

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 regional reference data, augmented with basin-level data as necessary, to examine preliminary models. In some cases, 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 other than that necessary to conduct qualitative habitat assessments, and their reference sites may need to be revisited to collect the relevant data.

Data on soils, including factors such as soil type, texture, erodibility, and porosity, would be ideal for determining classes. Soil maps containing such information are available for much of the U.S. and are maintained by the Natural Resources Conservation Service (NRCS). Climate data, including precipitation and hydrology are also desirable for building predictive 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. However, detailed hydrology is only available for gauged catchments and may have to be modeled for others. A variety of hydrologic models can be used as necessary (Gordon et al. 1992), those predicting base-flow and peak-flow perhaps being most useful. Catchment geomorphology is necessary, including data on topography and catchment size. These data are readily extracted from surface topographic maps using GIS software.

If there is an absence of a robust data set for reference sites across the range of waterbodies in a region, then the suspended sediment regime may be modeled from theoretical principles that do not require detailed field data. Some validation would be necessary for acceptable uncertainty in the results. Theoretical models could be used to predict sediment characteristics for specific sites or site classes and then used to classify streams based on the modeled sediment regimes. Classification using existing stochastic or deterministic modeling does not require as many data points per class as classification methods based exclusively on field data. However, the cost (in terms of dollars and time) of initiating a new model development effort may be prohibitive.

Establish Meaningful Classes. The challenge of defining classes is to achieve a balance between accounting for the natural variation in SABS among individual waterbodies and finding some commonalities among waterbodies. If this is not done, each waterbody will have its own SABS criteria, which can become cumbersome and costly. Too many classes may make it difficult to know which criteria to apply in a particular case. These types and amounts of relevant data may limit classification analysis. There may not be enough sites to define multiple classes or enough resources to collect additional data from the field. Five reference samples per discrete waterbody type is an absolute minimum reference data set; however, the small sample set will have low statistical power to detect differences. A data set of 30 samples per waterbody class is desirable but often unobtainable (Elliott 1977).

The impacts and behavior of suspended and settled particles have different modes of action and may require separate classification analyses. For that matter, each SABS indicator may require a separate analysis although multivariate analysis would allow consideration of multiple SABS signals in a single analysis. If discrete classes are to be defined (as opposed to a continuum), then the investigator should define the categorical parameters for each grouping of sites, based on one determinant or a combination of determinants. Exploration of potential groupings is difficult to automate, so *a priori* hypotheses of reasonable classes should be tested first, and further exploration should be guided by the preliminary results.

The full range of conditions can be evaluated rather than categorically defining classes. For instance, basin size as a classification variable need not have arbitrarily sized bins to define distinct classes. Rather a continuous range of stream sizes can be modeled if there is sufficient power to predict SABS conditions relative to stream size. Often, several variables have more predictive power than a single variable, in which case multivariate analysis is required.

If identifiable groups of sites are found to be different then a decision must be made whether to separate the groups or retain a single group. The example in Figure 8 illustrates that groups can appear different but closer examination suggests that they should remain a single classification. The magnitude of difference between groups, sample sizes, and uncertainty will affect the decision. Serious consideration should be given to the possibility that any statistical difference is due to difference in disturbance between the groups rather than different sediment supply and transport regimes. For example, reference streams with erodible soils and resistant soils may appear to be reasonable classes of streams; however, both groups have similar levels of turbidity under least disturbed conditions (Figure 8). This similarity could be misinterpreted if the criteria for reference sites are less stringent; thereby allowing a few disturbed sites into the "reference" group.

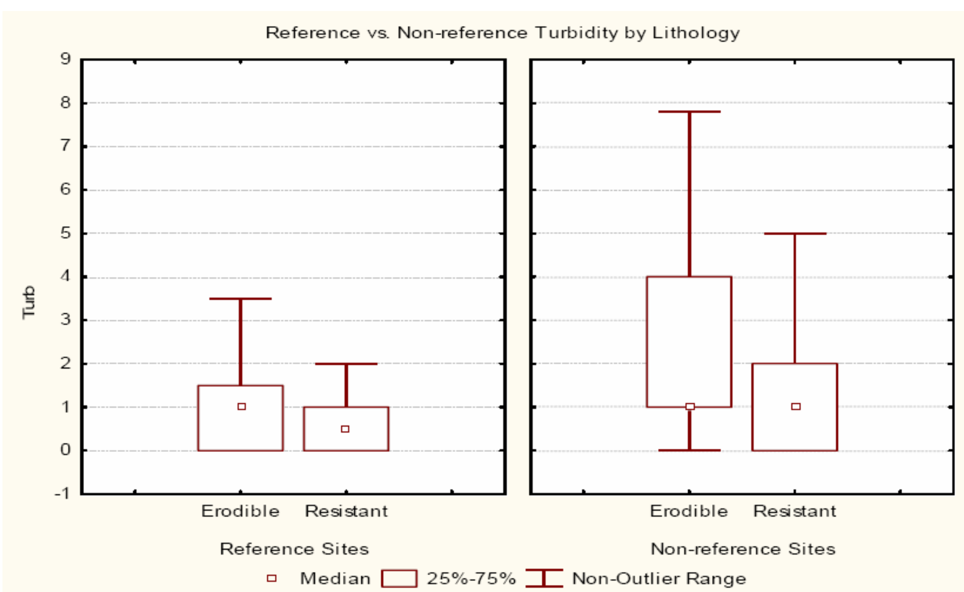

Figure 8. Turbidity in Oregon streams by reference status and erodibility (Rosetta 2005).

III. Technical Elements

Empirical classification is based on appropriately applied statistical methods that test whether two or more groups are likely to be similar or different. The basic premise is that the sediment indicator of interest will behave similarly in similar systems and differently in different systems. Within sites of the same class, SABS indicators are expected to have similar natural levels. Therefore, a single criterion can be defined to illustrate the natural expectations within each distinct class. Characteristics of the reference indicator distribution such as central tendencies (mean, mode, median) and shape of the distribution (skewness and kurtosis) are compared among classes. Most statistical texts and statistical software packages are available that describe commonly used techniques.

The selection of statistical methods will vary depending on the assumed underlying statistical distribution of the data, whether discrete or continuous relationships are analyzed, and whether single or multivariate comparisons are analyzed. Various statistical methods have been described for classification in developing biological criteria (Barbour et al. 1999; Hughes 1995). One rather simple visual is to construct box-and-whisker plots of the sediment indicator of interest and to compare overlapping confidence intervals. Another is to construct a series of cumulative distribution functions (CDFs) and compare differences using the Kolmorogorv-Smirnov Test.

Fluvial Geomorphology

Fluvial geomorphology involves the study of the primary physical processes in streams and rivers that erode, transport and deposit sediment, thereby influencing channel form, stability, and changes over time. Geomorphology is relevant to criteria development as a source of measurable parameters that can indicate departure from a sediment regime needed to support the designated uses of a given waterbody. Further, classification of different waterbody types based on geomorphic principles can be used to stratify waterbodies into more homogeneous clusters for which more specific and appropriate sediment criteria can be developed.

Numerous authors (Rosgen 1994, 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 selecting reference streams and for determining appropriate strategies for sediment management. 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 predict the type of stable channel that will evolve from a given type of transitional, unstable channel. This could be valuable when setting waterbody-specific sediment criteria.

Several decades ago, Pfankuch (1975) developed a system to rate channel stability. This rating system has been widely used by hydrologists to quantify stream erosion potential and by fish biologists to measure potential stresses to littoral habitat. Channel instability measures that are not sensitive to natural expectations for the channel type and evolution may give a false sense of impairment. Instability of a stream channel might be acceptable and, in some cases, might be considered a reference condition because for short time intervals, all self-adjusting (alluvial) channels, whether natural or altered, can be viewed as being unstable because the fluxes of water and sediment are always changing. Rosgen (1996) has proposed a channel stability rating scale that combines Pfankuch stability ratings and stream geomorphology.

Streamflow changes, sediment budget changes, and many other causes lead to channel change that result in stability shifts. These shifts and adjustments lead to stream channel morphological changes culminating in a stream type change. Stream type succession sequences were first described as stages of channel evolution by Schumm et al. (1984) and Simon and Hupp (1986). The nine successional sequences (Figure 9) show progressions through different stream classes from the Rosgen system and indicate a larger range of possible morphological shifts and their tendency toward a stable end-point (Rosgen 1999, 2001). The stream successional theory suggests that streams depicted in the first and last frames of Figure 9 are morphologically stable and would be appropriate reference sites. The intermediate stages are inappropriate reference conditions because sediment is either being eroded or deposited at unnatural rates.

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 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.

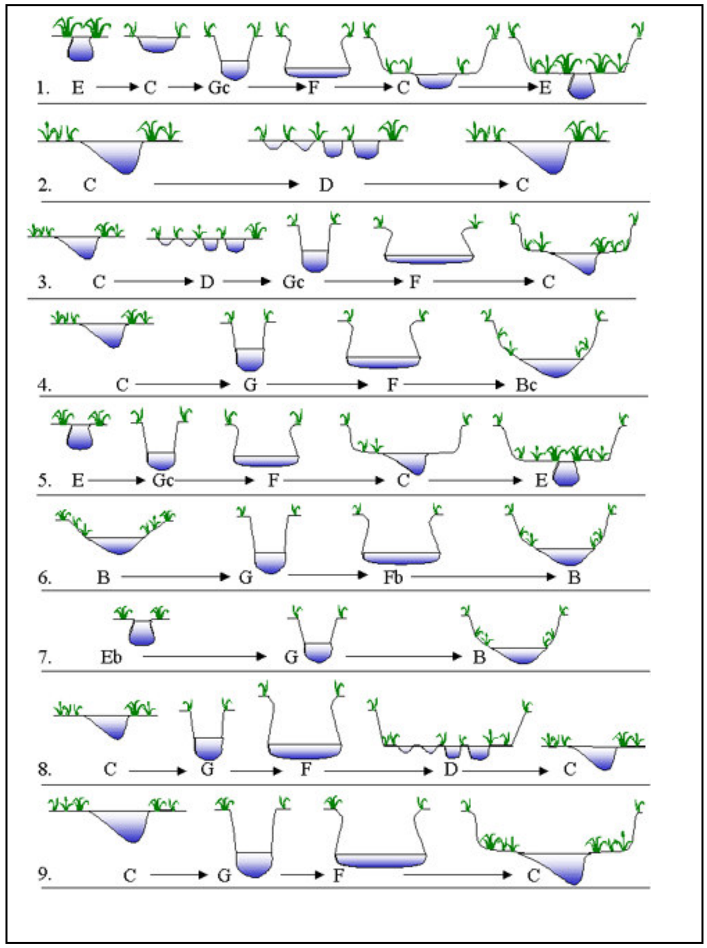

Figure 9: Various stream type succession scenarios (after Rosgen 2001).

III.D.3. Associating Suspended and Bedded Sediments with Response Indicators Applicable in Step 6 of the *Framework*

There are two general categories of methods for establishing quantitative associations between a relevant measure of SABS and a response measurement that are relevant to the designated use (see Section III.B step 4). The first method has the potential to reduce uncertainty regarding the cause of changes in the biological response by controlling experimental conditions. This is referred to as the *Controlled Experiment* method and may be performed in the laboratory or in field mesocosms. The second method embodies all the complexity of waterbodies as they occur in the region of interest and is based on field sampling but cannot control other variables in the same way as in controlled experiments. This is referred to as the *Field Observational* method. Using evidence from both controlled experiments and field observational analysis provides a powerful duo of experimental rigor and a characterization of actual SABS and biological conditions in a waterbody class. Furthermore, when both controlled experimental findings and associations derived from in-stream measurements result in similar values, there is greater confidence in setting the SABS criterion.

The Chesapeake Bay Criteria (Batiuk et al. 2000) and the *Draft Technical Basis for Revising Turbidity Criteria* (Rosetta 2005) are excellent examples of criteria development programs that benefit from the combination of mechanistic knowledge, controlled experiments, and field observations for setting criteria for different designated uses. The Chesapeake Bay project is described as an example of integration of many types of evidence and the complexity of biological endpoints that can be affected. The *Draft Technical Basis for Revising Turbidity Criteria* is concerned with water clarity and uses NTU as the measurement endpoint and considers NTU as a surrogate that is somewhat protective of sedimentation and loss of habitat. The U.S. EPA Science Advisory Board identified the conditional probability approach as particularly useful for evaluating field observation data, which assigns probabilities of impairments based on SABS measurements. Our example uses EMAP data from the mid-Atlantic Region.

Controlled Experiments

The controlled experiment is one in which aquatic organisms are tested under controlled conditions for behavioral or physical responses to stressors. The stressors are varied during the experiments so that responses can be quantified with respect to the level of exposure.

Since the early 1980's, under Section 304(a) of the CWA, U.S. EPA has been developing WQC for toxic chemicals to protect aquatic life. The majority of U.S. EPA's aquatic life criteria have been derived from two methods: (1) the 1980 *Guidelines for Deriving Water Quality Criteria for the Protection of Aquatic Life and Its Uses* (U.S. EPA 1980, Appendix B), and (2) the 1985 *Guidelines for Deriving Numerical National Aquatic Life Criteria for Protection of Aquatic Organisms and Their Uses* (Stephan et al. 1985). The U.S. EPA is preparing a third revision that will incorporate the scientific and technological advancements of the last 20 years. Current chemical criteria incorporate magnitude, duration, and frequency endpoints. These are developed according to strict guidelines using a species sensitivity distribution method (Stephan et al. 1985). SABS criteria based on exposure-response data can be developed, in theory, much like chemical criteria. However, achieving this goal – development of SABS criteria using the exposure-response – will be a challenge because suitable methods, relevant data requirements, and accepted “endpoints” for SABS currently do not exist.

Thresholds for SABS can be developed using the exposure-response if exposure-response relationship(s) can be developed for selected groups of organisms. This method involves testing aquatic organisms for adverse effects using suspended sediment (e.g. water cloudiness) or bedded sediment (e.g., spatial extent) to quantify the character and severity of response as a function of level of exposure. Experiments can be conducted either in the laboratory or field and the results can be used in conjunction with other SABS measurements to determine impairment in a waterbody. Results can also be used to develop exposure-response models which may be useful at similar sites.

Exposure-response models currently exist for some species in some habitats, and criteria have been developed for their protection (e.g., British Columbia Guidelines in Caux et al. (1997a), Chesapeake Bay Water Clarity Guidelines in U.S. EPA 2003c). The Chesapeake Bay Water Clarity Guidelines, for example, use a model that predicts the effect of reduced water clarity, due in part to suspended sediments, on submerged aquatic vegetation (U.S. EPA 2003c).

Similar constructs are available in some commercially available modeling software packages as well as in the U.S. EPA-supported ecosystem model AQUATOX (freely available at http://www.epa.gov/ost/models/aquatox/). Currently, AQUATOX is able to simulate the impacts of suspended sediment on light penetration in the water column and associated impacts on primary productivity and ecosystem structure and function. It also can simulate the effects of the organic portion of the sediments on the nutrient dynamics of the system. Future versions of the model may include the ability to simulate other effects, including physical smothering of spawned fish eggs by deposited sediment.

Guidelines for water quality criteria presented in Stephan et al. (1985) promote an approach based on data from at least eight families from a diverse group of taxa. The diversity of tested species is intended to assure protection of various components of an aquatic ecosystem. A Criterion Maximum Concentration (CMC) is determined using average effects levels. Chronic toxicity test data (longer term survival, growth, or reproduction) should be available for at least three taxa to derive a Criterion Continuous Concentration (CCC). The chronic criterion can be 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 criteria. When necessary, the criteria – acute or chronic or both – can be adjusted to protect locally important or sensitive species that were not considered during development of the criterion, or it can be adjusted based on local water chemistry.

Sediment criteria may be based on experimental studies for a few sensitive indicator species (e.g., salmonids, certain corals, certain mayfly, stonefly and caddisfly taxa, or bluegills). Each indicator species could represent certain types of beneficial uses, aquatic systems, or regions of the country. This is similar to a risk assessment approach.

The main strength of the controlled experiment method is that it employs techniques that are used in standardized toxicity test methodologies and that are generally accepted by the scientific, regulatory and stakeholder communities. The method is explicitly causative; controlled laboratory or field mesocosm analyses address a single SABS indicator in relation to one or a few response indicator(s). SABS criteria can be customized to the types of aquatic life present at each site and may be adjustable to account for field conditions that are not simulated in the laboratory. Moreover, it may be possible, using this method, to specify the amount of reduction in SABS needed to maintain desired aquatic resources.

U.S. EPA has concluded that sound exposure-response, SABS data are lacking for most species, and standardized consensus-based test methods for determining SABS effects are generally unavailable. Therefore, it is unlikely that a list of acute and chronic values for SABS can be developed in the short-term and such an effort would require substantial resources. A second difficulty is that SABS can consist of many substances 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 SABS without first determining the specific type of SABS (organic vs. inorganic; silt vs. clay, fine vs. coarse, etc.).

For bedded sediments, the substrate surrounding the fine sediments is an additional variable. The lack of standard endpoints for determining the effects of either suspended or bedded sediments on specific organisms and the need for the development of minimum data requirements are additional drawbacks. If thresholds could be developed through controlled experimentation, there would still be uncertainties due to interactions of the many other factors that influence SABS effects and that are not generally tested during controlled experiments.

The controlled experiment method has two characteristics that result in uncertainty. Firstly, it is difficult to account for natural or background conditions and organisms' acclimation to dynamic environmental changes in SABS. Secondly, SABS do not necessarily act on organisms in the environment in the same way as toxicants. The change point between a detrimental level of SABS and a beneficial one is a function of amount, duration, and distribution rather than of concentration and duration. In principle, these limitations could be addressed through certain U.S. EPA-approved mechanisms to modify national criteria on a site-specific basis. The Recalculation Procedure (U.S. EPA 1994), for example, could be used in lieu of 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.

Field Observations

As bioassessment and biocriteria have become common tools for assessing the status of aquatic life, rich data sets have been generated that include measures of physical, chemical, biological, and landscape characteristics. These data sets provide an opportunity to examine relationships between SABS and other variables. This Section focuses only on the relationship between SABS and biological indicators, but the analytical methods and study design concepts are also relevant to other physical and chemical attributes of aquatic systems and is essentially the basis of the Waterbody Use Functionality (Section III.D.3). The strength of using field observational methods is that they enable analysis of SABS and their potential effect on biota as they occur in a defined region or class of waterbody type. This strength is also its weakness because variability among field samples might reflect natural variability, or SABS, or some other stressor linked to human activity. Therefore, analysis must take into account that a lower than expected measurement of a biological indicator may be due to other causes besides the one of interest, in this case SABS. Any analysis must consider these other sources of variation when developing stressor/response relationships using field sampling.

Percentile Analysis (Including Reference Condition Methods). One method is to attempt to remove sites with known stressors from the data set that is analyzed. This is the basis for some types of reference condition analyses more specifically termed here as *Percentile Analysis*. Percentile Analysis method for developing sediment criteria follows the example of the regional reference condition method for developing biological criteria (Barbour et al. 1999; Hughes 1995). It is based on the *a priori* selection of a population of sites with a similar SABS regime (Section III.D.2.). From the population of sites with similar sediment regimes, a subset of sites are selected that meet designated uses (e.g., supports cold water fishery), represent best attained conditions for a specific assessment endpoint (e.g., presence of threatened species) or represent nearly natural SABS conditions (as described in Section III.D.2). Some factors should be kept in mind when using a Percentile Analysis method.

(1) Using a population of sites that meets designated uses is defensible, but may put valued resources at risk if the sites do not protect downstream uses, if the designated uses are somewhat lax, or if waterbody sub-types were too broadly defined.

(2) Best attained condition as an approach to select sites can demonstrate that the standards will be achievable but may underestimate impacts in classes of waterbodies that are generally highly altered. Even the best available conditions might not really meet the expectations of the CWA. However, using the best sites can point management in the right direction and clearly help to define highly degraded sites.

(3) Using sites with nearly natural SABS regimes is sensitive to errors in selecting criteria for defining natural sites. This does not directly demonstrate how SABS affects the response indicator or designated use.

In all three cases, distributions of SABS for the population of sites is described, usually as a cumulative distribution function or box plot, a value from within that distribution is selected as the SABS criterion. More than one designated use can be defined for a class of streams. For instance, a different criterion might be selected for exceptional waterbodies and another selected criterion that enables streams to meet state water quality standards for aquatic life. Typically, the criterion is set at the 75th percentile of sites attaining their designated use or characterized as best attainable conditions. The selection of the percentile is also influenced by the desired level of protection, which is dependent on the designated use. Therefore, criteria for designated uses of "exceptional biodiversity" or "irrigation supply" may be based on different percentiles.

Exposure and Effects Analysis. Another method assumes that SABS is a limiting stressor on biological communities and that the upper limit of biological measurements is an estimate of the best possible performance expected for a system given any point along a range of exposures. This assumption may be violated if the biological measurement is influenced in a positive direction by another stressor, for instance, moderate organic enrichment increasing fish biomass. There are a number of statistical methods that can be used to analyze these data sets. For continuous variables they include, but are not limited to, conditional probability analysis, regression, quantile regression, maximum response curves, and several different multivariate statistical analyses. With quantile regression, the likely biological conditions in the absence of any other stressors are described by estimating changes in the response variable relative to a measurement of SABS near the upper range of the response distribution (i.e., 90th or 95th percentile; Figure 10). Regular regression models the median (i.e., 50th percentile) relationship. These same statistical methods can also be applied to data sets in which SABS is reduced as a part of mitigation. Specifically, if the response indicator is measured before and several times after intervention at a single site, the level of SABS that is present when the designated use is met represents a threshold, which may be considered when setting criteria. The combination of field observations and controlled experiments is illustrated in the Chesapeake Bay Case.

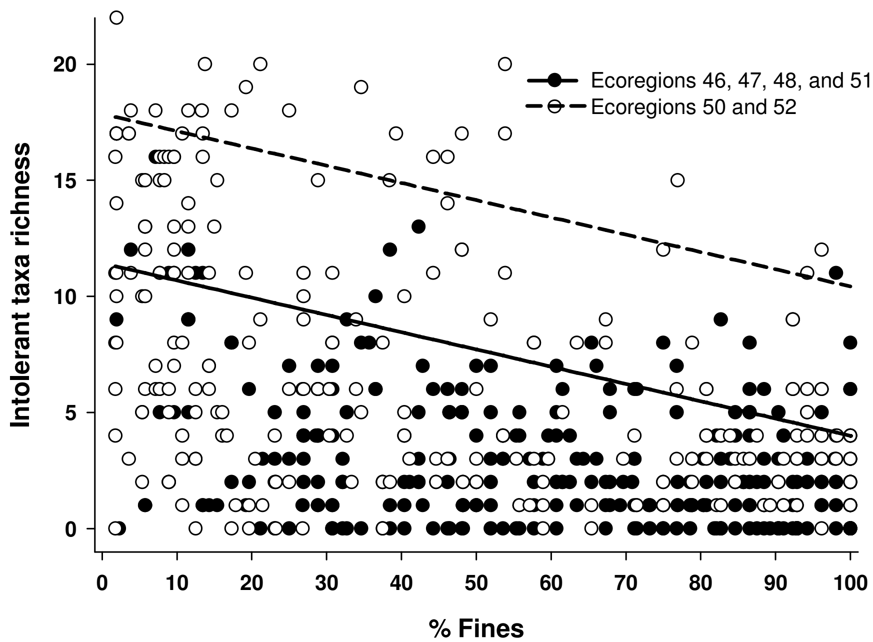

Figure 10. Quantile regression of the 90th percentile of intolerant invertebrate taxa over a full range of percent fines in Minnesota streams in two groups of ecoregions. The Northern Lakes and Forests and the Driftless Plains (Ecoregions 50 and 52) appear to support more intolerant taxa than streams with the same percentage of fines in the other ecoregions, Northern Glaciated Plains, Western Corn Belt Plains, Lake Agassiz Plain, and North Central Hardwoods (Ecoregions 46, 47, 48, and 51) (figure from Michael Griffith with U.S. EPA, unpublished data).

Synthesis of Controlled Experiments and Field Observations in the Chesapeake Bay

The Chesapeake Bay-specific water clarity criteria constitute one of the best examples of the use of exposure-response methods for development of SABS criteria. The criteria are based on a conceptual model of the effects of reduced light to the leaves of submerged aquatic vegetation (Figure 11). This model was developed using knowledge from both controlled experiments and field observations.

The loss of underwater bay grasses from the shallow waters of the Chesapeake Bay is a widespread, well-documented problem caused by decreased light intensity. Also certain wavelengths of light may not be transmitted through the water. The loss of underwater bay grass beds is of particular concern because these plants create rich animal habitats that support the growth of diverse fish and invertebrate populations and provide food for waterfowl. The primary causes of losses are nutrient over-enrichment and increased suspended sediments in the water and the associated reduction of light. The key to restoring the bay grass beds is to provide the necessary levels of light penetration in shallow waters to support their survival, growth, and reproduction. The Chesapeake Bay Water Clarity Guidelines employ a model to predict the effect of reduced water clarity, due in part to suspended sediments, on underwater bay grasses (U.S. EPA 2003c). This model is based on associations derived from both controlled experiments and field observations that link changes in valued attributes of the Bay with different exposures to nutrient enrichment and suspended sediment.

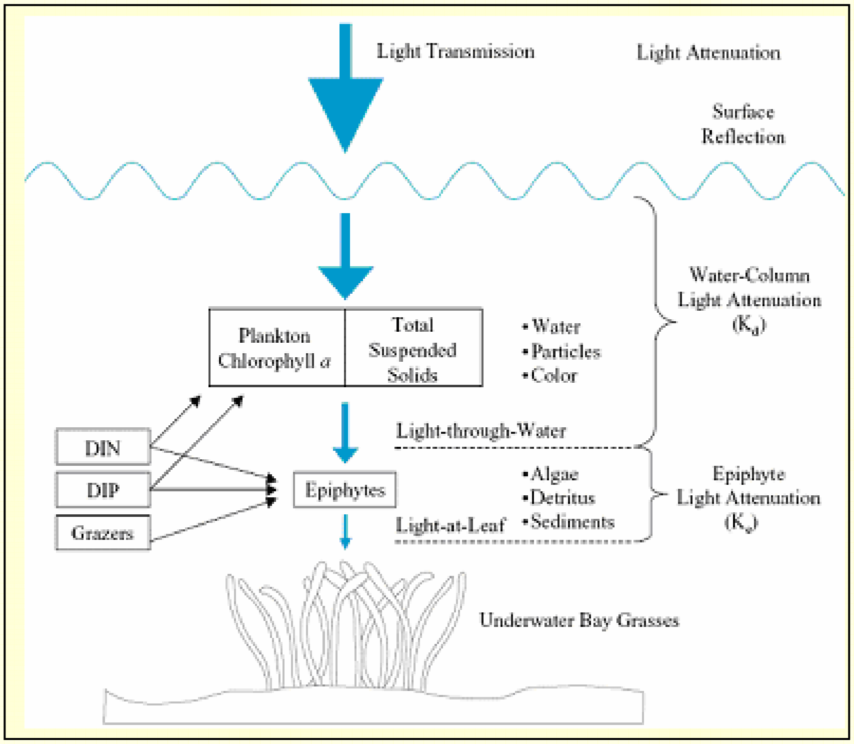

Figure 11. Availability of light for underwater grasses is influenced by water column and at-the-leaf surface light attenuation. DIN = dissolved inorganic nitrogen, DIP = dissolved inorganic phosphorus.

The Chesapeake Bay-specific water clarity criteria were derived in four stages: (1) water column-based light requirements for bay grass survival and growth were determined, (2) factors contributing to water-column light attenuation were quantified, (3) contributions from epiphytes to light attenuation at the leaf surface were factored into analyses for estimating total light

Synthesis of Controlled Experiments and Field Observations in the Chesapeake Bay (continued)

attenuation and (4) a set of minimal requirements for light penetration through the water and at the leaf surface were determined to give the water clarity criteria values.

The principal relationships between water quality conditions and light regimes for the growth of underwater bay grasses are illustrated in a conceptual diagram (Figure 11). Incident light is attenuated through the water column above the bay grasses by particulate matter (chlorophyll-*a* and total suspended solids), by dissolved organic matter and by water itself. The water-column light attenuation coefficient (K_d) is dominated by contributions from chlorophyll-*a* and total suspended solids. Light that actually reaches the underwater bay grass leaves also is attenuated by the epiphytic material (i.e., algae, bacteria, detritus and sediment) that accumulates on the leaves. This epiphytic light attenuation coefficient (K_e) increases exponentially with epiphyte biomass. Dissolved inorganic nitrogen (DIN) and phosphorous (DIP) in the water column stimulate the growth of epiphytic (and water-column) algae. Suspended solids also can settle onto bay grass leaves. Because epiphytic algae also require light to grow, water depth and water-column light attenuation constrain epiphyte accumulation on bay grass leaves, and light attenuation by epiphytic material depends on the mass of both algae and total suspended solids settling on the leaves.

An algorithm was developed to estimate light attenuation at the leaf due to the biomass of epiphytic algae and other materials attached to bay grass leaves (Kemp et al. 2004; Batiuk et al. 2000). The algorithm was verified by applying it to Chesapeake Bay water quality monitoring data. It uses monitoring data for the water-column light attenuation coefficient (or Secchi depth), total suspended solids, DIN and DIP concentrations to calculate the potential contribution of epiphytic materials to total light attenuation for bay grasses at a particular depth. Using a set of commonly monitored water quality parameters, attainment of the percent light-through-water (PLW) water clarity criteria and percent light-at-the-leaf (PLL) diagnostic parameter can be readily determined for any established restoration depth.

To determine the Chesapeake Bay water clarity criteria necessary to ensure that sufficient light reaches bay grass leaves at a defined restoration depth, three lines of evidence were compared:

- Application of bay grasses habitat requirement parameter values to the new algorithm for calculating percent light-at-the-leaf.
- Evaluation of results of light requirement studies in areas with few or no epiphytes.
- Comparison of median field measurements of the amount of light reaching plants' leaves (estimated through the percent light-at-the-leaf algorithm) along gradients of underwater bay grasses growth observed in the Chesapeake Bay and its tidal tributaries.

Based on a thorough review of controlled shading experiments and model findings published in the scientific literature, a PLW value of greater than 20 percent is needed for the minimum light requirement of Chesapeake Bay mesohaline and polyhaline species (Batiuk et al. 2000).

Synthesis of Controlled Experiments and Field Observations in the Chesapeake Bay (continued)

Consistent with the literature-derived value, the PLW requirement of 22 percent was determined for mesohaline and polyhaline regions of the Chesapeake Bay and its tidal tributaries using the algorithm for calculating percent light-at-the-leaf. This PLW requirement was confirmed by almost two decades of field observations in the Potomac and York Rivers (Batiuk et al. 1992, 2000; Moore 1996; Moore et al. 2001).

Based on published model findings reviewed in Batiuk et al. (2000) and confirmed by a review of recent tidal Potomac and Patuxent River research and monitoring studies, a PLW requirement of 13 percent was determined to apply to Chesapeake Bay tidal-fresh and oligohaline species. This light requirement was calculated using the algorithm for calculating percent light-at-the-leaf and the appropriate SAV habitat requirements for K_d. The PLW requirement is consistent with the 13.5 percent value published by Dennison et al. (1993). The PLW requirements in both salinity regimes were validated through an ecoepidemiological analysis of 14 years (1985-1998) of Chesapeake Bay water quality monitoring data.

The Chesapeake Bay water clarity criteria are summarized in Table 5 as PLW and Secchi depth equivalents over a range of application depths. They reflect a set of minimum light requirements to protect underwater bay grass species. The Secchi depth criteria vary across salinity regimes and through the seasons because of differing light requirements, growth potential, and reproductive strategies.

Table 5. Summary of Chesapeake Bay water clarity criteria for application to shallow-water bay grass designated use habitats (U.S. EPA 2003c).*

Salinity Regime	Criteria as Percent Light Through Water	Water Clarity Criteria as Secchi Depth								Temporal Application
		Water Clarity Criteria Application Depths								
		0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.0	
		Secchi Depth (meters) for *a*bove Criteria Application Depth								
Tidal-fresh	13%	0.2	0.4	0.5	0.7	0.9	1.1	1.2	1.4	Apr 1 - Oct 31
Oligohaline	13%	0.2	0.4	0.5	0.7	0.9	1.1	1.2	1.4	Apr 1 - Oct 31
Mesohaline	22%	0.2	0.5	0.7	1.0	1.2	1.4	1.7	1.9	Apr 1 - Oct 31
Polyhaline	22%	0.2	0.5	0.7	1.0	1.2	1.4	1.7	1.9	Mar 1 - May 31 Sep 1 - Nov 30

*Based on application of the equation, PLW = 100exp(-K_d*Z). The appropriate PLW criterion value and the selected application depth (Z) are inserted and the equation is solved for the light attenuation coefficient (K_d). The generated K_d value is then converted to Secchi depth (in meters) using the conversion factor K_d = 1.45/Secchi depth.

Conditional Probability Analysis. This detailed section is devoted to the Conditional Probability Analysis (CPA) method because the Science Advisory Board found this to be one of the more useful methods for showing the relationships between the SABS indicator and the desired condition of the waterbodies, conveying the impacts of selecting different SABS criteria and ability to inherently incorporate uncertainty into the analyses. The CPA method is illustrated in the mid-Atlantic stream case. This case also introduces some methods for evaluating change-points (thresholds or transition points) that may be helpful for identifying reasonable criteria values. Refer to Paul and McDonald (2005) for details of the CPA method and the application to mid-Atlantic streams.

The application of the CPA method for criteria development describes the association between the SABS indicator and the designated use indicator as a probability of observing impairment (or not observing impairment) when a particular level of SABS indicator is exceeded. The CPA method communicates the outcome in terms that are relatively easy to understand. A hypothetical outcome might include sites with more than 60% fines, where there is a 90% probability that the biota will be impaired. The analysis provides the user with the ability to evaluate the probability of impact across the full range of observed SABS levels.

Conditional probability analysis quantifies the likelihood that biotic impacts will occur when a given level of SABS exposure is exceeded. Probabilities are based on the likelihood of observing an undesirable response indicator. Judgments as to acceptable SABS indicator levels can be made based on desired probability of impact.

The following are recommended for application for criteria development to take advantage of the full capability of CPA: (1) monitoring data should be acquired using a probability-based sampling design, (2) some metric must quantify SABS levels, (3) a response metric must be sufficiently sensitive to respond to the extant levels of the SABS metric, (4) independent studies should identify the characteristics of an impacted response metric; and (5) the SABS metric must be capable of exerting a strong effect on the response metric.

Probability-based design data can provide estimates of the probability of occurrence for a sampled variable in the statistical population. The statistical population is the desired resource for which various statistical parameters will be estimated and from which samples will be drawn for data acquisition. For example, consider the statistical population of all stream segments in a state. If 75% of the stream segments sampled exhibit impacted benthic communities, then the probability of observing benthic impairment in any of the stream segments in the state was 0.75 during the sampling period. When data are collected from a targeted set of sites and are not probability-based, then the bias introduced by site selection factors must be accounted for if the results are to have any reasonable meaning beyond the locations actually sampled.

The probability of observing a certain event, y, is denoted as P (y). A conditional probability is the probability of an event y occurring given that some other event x also has occurred. It is denoted P (y | x). The vertical line means "conditioned on," not "divided by." Thus, a conditional probability describes the likelihood of observing an event of interest in a subset of samples drawn from the original statistical population. These subsets are defined by conditions when x has occurred, in addition to those used to define the entire statistical population. Conditional probability can be calculated as the ratio of the joint probability that y and x occur simultaneously in a given sample (P (y, x)) from the original statistical population, to the probability of x in the original population

$$P(y \mid x) = P(y, x) / P(x) \quad (1)$$

This is considered a definition of conditional probability (Hogg and Ledolter, 1992). An example of a conditional probability statement would be the probability of benthic community impact if total copper levels in the sediments exceed 10 ppm. The events y and x are considered statistically independent if, and only if, their conditional probabilities (of one another) are equal to their (unconditional) probabilities in the original statistical population. Conditional probabilities differ from joint probabilities, which are often used in risk assessment (e.g., Verdonck et al. 2003). Joint probability, when the two variables are statistically independent, is calculated simply as the product of P (y) and P (x). So, P (y, x) = P (y) * P (x). If two variables are statistically independent, then the conditional probability is equal to the unconditional probability (see Paul and McDonald (2005) for additional information).

Application of Conditional Probability Analysis for Criteria Development. Our application of the CPA method for criteria development starts with a two-step procedure to calculate the conditional probabilities (Paul and McDonald 2005). We let y represent the dichotomous response variable (1 for impaired conditions, 0 for good conditions) and assume it to be a random variable. We let x be the SABS indicator, which is also a random variable. We let x_C be the conditioning value for the SABS indicator. In the first step, we identify subsets of the sampled resource (e.g., stream segments) for which $x \geq x_C$ (i.e., we order the samples based on the value of SABS indicator). In the second step, we determine which of the SABS indicator values also have impaired response indicator values. This allows us to determine, for example, the fraction of the stream miles in which SABS indicator values are greater than or equal to a specific value (x_C) and also had impaired biological response. This two-step procedure is applied over the range of observed SABS indicator values. This produces an empirical curve for the conditional probability, the probability of expecting an impaired biological response when observed SABS indicator values are greater than or equal to x_C.

This empirical curve provides the probability of impairment of the ecological system (e.g., benthic community structure degradation) for an exposure to high levels of SABS indicator. Confidence intervals (CIs) for this empirical curve are estimated for each value of x_C by assuming that the individual values that go into determining $P(y = 1 \mid x < x_C)$ can be treated as a simple random sample when at least two individual values are available.

Identifying Thresholds of Impact. Threshold levels for pollutants or pollution, such as SABS, that elicit different levels of biological impact in waterbody elements of a region need to be identified for eventual use in developing criteria. A threshold of impact is identified as a changepoint separating the empirical conditional probability curve into two parts: the part of the curve above the changepoint and the part below it. For those samples that are above the changepoint, the probability of impact is different than what one would expect for the entire geographic area. A confounding factor in the identification of a changepoint is that these two groups created by the changepoint are not independent (i.e., the numbers used to create the points above the changepoint are a subset of the numbers used to create the points below the changepoint). Thus, a traditional t-test cannot be used in the determination of the changepoint since the data are not independent (Venables and Ripley 1997). Using a weight-of-evidence approach with different techniques will identify the change point. Three examples of these techniques are (1) non-overlapping confidence intervals, (2) change in curvature of fitted curve, and (3) nonparametric deviance reduction. Other possible techniques could be used to identify a changepoint. In this demonstration, specific values for factors and confidence intervals were selected only as examples. Values used in an actual application of this approach would depend on the particular management requirements and objectives.

The use of non-overlapping confidence intervals (CI) to determine a changepoint involves determining when the lower CI of the empirical curve no longer overlaps the upper CI of the unconditional value (Cherry 1996, 1998; Austin and Hux 2002; Rahlfs 1997). This procedure is a conservative estimate for significant difference since the CIs could overlap when the values are significantly different (Austin and Hux 2002). The bootstrap percentile confidence intervals, based on a bootstrap distribution of 1000 samples, were used for this evaluation. The α-level for the non-overlapping confidence interval must be adjusted to account for the one-sided nature of this test, whereas the α-level for developing the confidence intervals for the curves was based on a two-sided test (i.e., a factor of 2 in the α-level).

The second technique used for selecting a threshold of impact through changepoint identification is to fit an equation to the empirical curve for conditional probability. The following constraints are used: the conditional probability approaches the unconditional value, P (y = 1) as x goes to the minimum x-value; the conditional probability approaches 1 as x goes to the maximum value; and there is a curvature change at the inflection point of the curve. The following functional form satisfies these constraints:

$$P(y = 1 | x > x_C) = \begin{cases} 1 + (D_0 - 1) / \left(1 + \exp(B_0 (x_C - x_0))\right), \text{ for } x_C > x_0 \\ 1 + (D_0 - 1) / \left(1 + \exp(B_1 (x_C - x_0))\right), \text{ for } x_C \le x_0 \end{cases} \quad (2)$$

where:

exp is the exponential function to base e,
D_0 is unconditional probability value P(y = 1),
x_0 is the changepoint where curvature changes,
B_0 is curvature for values of $x_C > x_0$, and
B_1 is curvature for values of $x_C < x_0$.

The parameters x_0, B_0, and B_1 are determined from a nonlinear least squares regression (Venables and Ripley 1997). Uncertainty in the parameters is estimated from the standard errors generated by the regression software and, where possible, by computing asymmetric confidence intervals (Venables and Ripley 1997). The residuals from the regression are checked for normality. While it may be generally possible to fit equation (4) to the empirical curve, the curvature values (B_0 and B_1) may not be significantly different, and a threshold would not be identified with this technique.

The third technique uses nonparametric deviance reduction to determine the changepoint. This determines the dividing point for splitting the data into two groups resulting in the largest reduction in the deviance in the data (Qian et al. 2003). The deviance is defined as

$$D = \sum_{i=1}^{N} (P_i - P^*)^2 \quad (3)$$

where:

D is the deviance,
N is the sample size,
P_i is the conditional probability P (y = 1 | x > x_i), and
P* is the mean of P_i based on a sample size of N.

When the data are divided into two groups, the sum of the deviance for the two subgroups is always less than or equal to the deviance for the entire data set. When the split in the data minimizes the deviance, the threshold is identified. This has been used to detect ecological changes along an environmental gradient (Qian et al. 2003). Qian et al. (2003) compared results of deviance reduction with a Bayesian hierarchical modeling and found that the nonparametric provides similar results with the Bayesian analysis.

The deviance reduction point generally can be determined, but it may or may not be of biological significance. Uncertainty in the deviance reduction changepoint (90% and 95% confidence intervals) is estimated from the empirical percentiles for the bootstrap distribution from resampling 1000 times (Manly 1997). An approximate χ^2 test was used to determine the significance of the changepoint. The test assumes that the deviance reduction divided by the scale parameter is approximately χ^2 distributed with 1 degree of freedom (Venables and Ripley 1997). A large deviance reduction will result in a small p-value, and the consequent rejection of the null hypothesis (H_0: no changepoint).

Biological Importance of Identified Thresholds. For use in criteria development, some level of biological importance needs to be associated with the threshold of impact value that is identified. The changepoint value determined by each technique must separate the samples so that the probability of impact for samples above the threshold would be different than what one would expect for the entire geographic area. As an example, a summary of literature values on the response of fish and benthic invertebrates at low reported levels of percent fines in the substrate (Newcombe and Jensen 1996; Berry et al. 2003; Bash et al. 2001) was used to identify biological importance for the mid-Atlantic streams case.

Statistical Analysis of Data. Several statistical analyses are useful in addition to the conditional probability determination. The cumulative distribution function (CDF), the conditional cumulative distribution function (CCDF), and their reverses were used to complement the conditional probability calculation. The CDF gives probability that x is less than or equal to x_C:

$$P(x \le x_c) \approx F(x_c) = \sum_{x_i \le x_c} f_i(x_i) \tag{4}$$

The reverse CDF is the probability that x is greater than x_C, which is the complement of equation (5) or,

$$P(x > x_c) \approx 1 - F(x_c) = 1 - \sum_{x_i \le x_c} f_i(x_i) = \sum_{x_i > x_c} f_i(x_i) \tag{5}$$

The conditional cumulative distribution function (CCDF) is the distribution for a subset of the total data, conditioned on a second variable [F(y | x)]. The reverse CCDF uses 1-F(y | x). The reverse functions are consistent with the CPA results, which are expressed as a threshold (i.e., exceeding some value x_C).

Application of Conditional Probability Analysis to Mid-Atlantic Wadeable Streams

CPA was used to establish realistic thresholds for impacts to stream biotic condition from non-point source pollution in the mid-Atlantic region of the U.S. (Paul and McDonald 2005). The mid-Atlantic was selected because of the extensive amount of research and monitoring of streams that has been done in this region (see example in Boward et al. 1999; U.S. EPA 2000b), which provided the information base needed to satisfy conditions for application of CPA.

These data were collected from mid-Atlantic streams in 1993 and 1994 and include 102 stream segments in 1st to 3rd (Strahler) order wadeable streams as part of EMAP (Herlihy et al. 2000) (Figure 12). These segments were selected for sampling using a spatially balanced probability design. Inclusion probabilities for each sampled stream segment were determined using the sample sizes for each Strahler order and the total length of streams within each order in the region. Sampling locations within stream segments were chosen randomly. Quantitative data for stream macroinvertebrates, habitat, and water quality were collected at each site. Sampling took place during a yearly, two-month sampling window from April through mid-June.

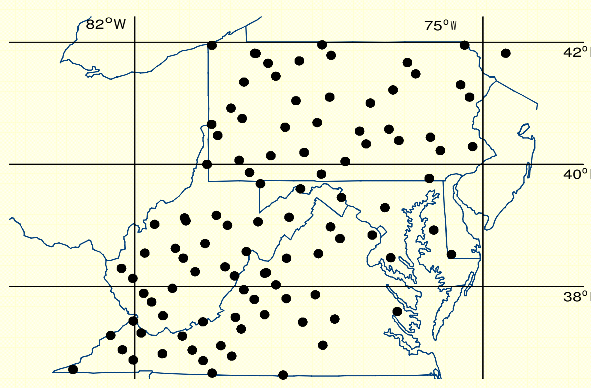

Figure 12. Mid-Atlantic region of the U.S. with EMAP wadeable stream sampling sites.

Application of Conditional Probability Analysis to Mid-Atlantic Wadeable Streams **(continued)**

Stream benthic macroinvertebrates are a robust measure of stream condition, integrating temporal pollutant exposure. They are responsive to in-stream changes to sediment levels. Benthic stream community taxa in the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) (collectively known as EPT) are considered reasonably sensitive indicator organisms since they exhibit a decrease in taxa richness with increased degradation of stream conditions. EPT taxa were used to identify SABS-related impacts in stream segments in the mid-Atlantic. When EPT taxa were < 9 in these stream segments, the streams were considered impaired (Davis and Scott 2000).

For the purpose of this study, percent fines in the substrate were used as a surrogate indicator for sedimentation in streams. Percent fines (silt/clay fraction, < 0.06 mm) represent a direct measure of the smallest class of sediments. Percent fines are strongly correlated with sediment embeddedness, a source of the most-likely-to-be resuspended sediment, and an indirect measure of suspended sediment levels in the water column. Streams containing a larger fraction of fine sediment would be expected to have a benthic community at greater risk for impact.

The reverse cumulative distribution function (CDF) and reverse conditional CDFs for percent fines in the substrate are expressed as proportion of stream miles (Figure 13). The sampled stream segment values are weighted by inclusion probabilities to convert to stream miles. The distribution for impacted benthic communities is displaced to the right of the distribution for benthic communities in good condition as should be expected. The distribution for reference conditions (the best conditions) is shifted to the left (towards lower percent fines) of that for unimpacted streams.

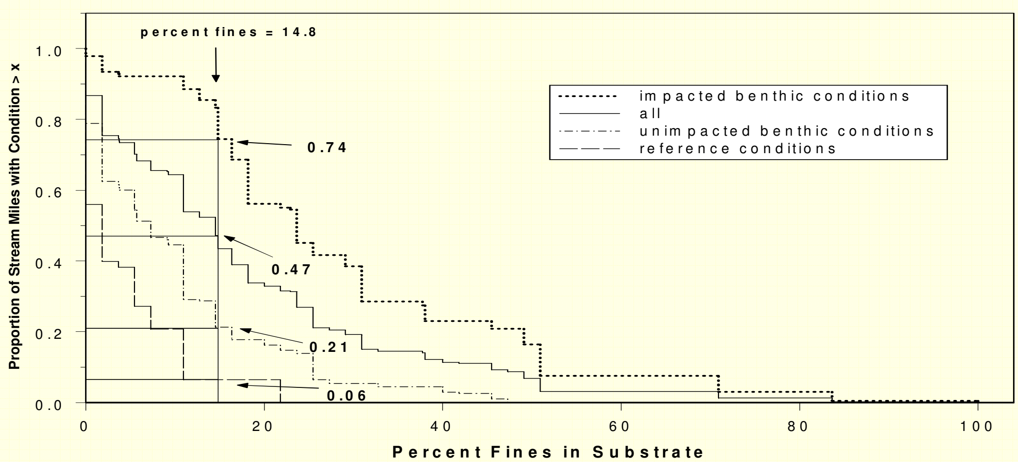

Figure 13. Reverse cumulative distribution function (CDF) for percent fines in the substrate (silt/clay fraction, < 0.06 mm) for stream miles across entire area (all), and reverse conditional CDFs of stream miles for impacted benthic conditions (EPT taxa richness < 9), unimpacted benthic conditions (EPT taxa richness > 9) and reference conditions. Vertical line is where the threshold of 15 percent fines intersects the curves.

***Application of Conditional Probability Analysis to Mid-Atlantic Wadeable Streams** (continued)*

The outcome of the CPA application suggests that when percent fines in the substrate is greater than 49%, there is a 100% probability that the benthic communities are impacted (Figure 14). All sites with percent fines in the substrate in excess of 49% had EPT taxa richness less than 9. As the percent fines approach zero, there is a background level of impact on EPT taxa richness from all sources of stress in the region (mean = 42%, 95% confidence interval of 30-56%). Thus, irrespective of the level of percent fines in the substrate, approximately 42% of the stream-miles in the region will likely exhibit an impact on EPT taxa richness, Therefore, to detect a significant signal due to percent fines in the substrate affecting the U.S. EPA taxa richness, the upper confidence limit on our estimate of the background impairment (e.g., 56%, Figure 14) must not overlap with the lower confidence limit on the probability of benthic impact. This occurs when the percent fines in the substrate is 15%. It could be argued that this is the initial threshold of impact that is distinguishable from background within this geographic area. The mean probability of observing impacted EPT taxa richness associated with this threshold is 67%.

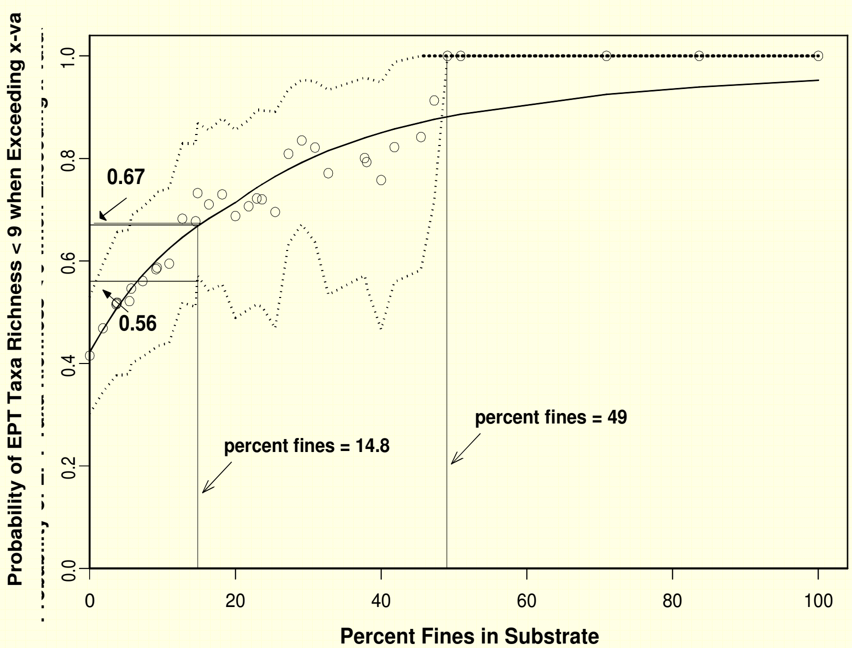

Figure 14. Probability of observing EPT taxa richness < 9 (benthic impact) in mid-Atlantic streams (open circles) if specified value of percent fines in the substrate (silt/clay fraction, < 0.06 mm) is exceeded. Solid line is fit to data using equation (2).

The CPA method identified a threshold of 15% fines (from non-overlapping confidence intervals) would translate into approximately 47% of the total stream miles in the geographic area exceeding the threshold (from Figure 13). Similarly, only a small percentage of streams with reference condition characteristics (6%) or good benthic conditions (21%) would exceed the 15% fines threshold, but a much larger percentage of streams where impacts are occurring (74%) would exceed it. These values provide an estimate of the number of "false positives" for this value of a threshold for percent fines as the indicator of sedimentation. Because multiple stressors often impact stream communities, we cannot estimate the "false negatives." A community not stressed by the stressor of interest might be stressed in some other way.

Waterbody Use Functionality

The waterbody use functionality method is proposed for developing SABS criteria for designated uses other than aquatic life. This method examines the existing literature and focuses criteria on non-aquatic life uses such as recreational (swimming, boating, etc.), industrial, navigational, drinking water, and agricultural uses, among others. Although not emphasized in the CWA, economic impacts from poor stewardship of sediment supply can also have costly repercussions. Some impaired functional uses related to sediment management include flooding, bank erosion with collapsing infrastructure, and loss of coastal wetlands and protection from storm surges among others. As costs continue to rise, these functions can no longer be overlooked.

Functional-based benchmarks for protecting uses other than aquatic life apply primarily to waterbodies where aquatic life uses do not exist (historically, not present or removed through a Use Attainability Analysis (UAA), or where multiple designated uses have been assigned to a waterbody (such as a large river system) and SABS levels fluctuate substantially throughout the extent of the system. However, where multiple designated uses (such as aquatic life and irrigation) overlap in a waterbody or on a specific segment or portion of the waterbody, SABS criteria established to protect the aquatic life use most likely will be stringent enough to protect all other uses except perhaps drinking water uses. In such cases, additional functional criteria may not be necessary. This is a presumption that needs further investigation.

The waterbody use functionality approach focuses the process of SABS criteria development on the desired outcome: attainment of all the designated uses of the waterbody. This approach is proposed in cases where uses other than aquatic life uses must be attained.

Benchmarks protective of the functional use would be based on data and information from the literature, field observations, and state experiences. For example, if shipping and navigational uses were the primary use of a waterbody, criteria would be established to prevent or minimize the depositional rates of sediments that would prevent accelerated filling of shipping channels thereby preventing frequent dredging to maintain those channels.

For agricultural water usage, including irrigation and livestock watering, benchmarks could be established based on data that illustrate 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, sources of drinking water and other functional uses where the literature indicates potential thresholds for protecting these non-aquatic life uses. Exposure-response relationships for aquatic biota would not be a critical basis for these criteria.

Examples where functional benchmarks have already been suggested or applied include National Academy of Sciences (NAS)/National Academy of Engineering (NAE) (1973), National Technical Advisory Committee (NTAC) (1968), Australian and New Zealand Environment and Conservation Council (ANZECC 2000; Parametrix 2003). Some 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 from 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 generally protect the visual aesthetic quality of a clear water stream.

Advantages and Disadvantages of the Methods

The U.S. EPA Science Advisory Board recommended that the distinct advantages and disadvantages of each method should be considered when deciding how to apply them in specific criteria development situations. Table 6 summarizes this information.

III.E. Hypothetical Examples of the Synthesis of Methods Within the Framework

The following hypothetical examples illustrate the process for developing SABS criteria in representative waterbody types. The first scenario describes the sequence of SABS criteria development steps for a statewide set of high gradient, 2nd to 3rd order headwater streams. This hypothetical scenario includes (1) the decision process for the selection of measurements for SABS and response variables that are appropriate to the waterbody type and designated uses; (2) the possible rationales for selecting analytical methods for linking SABS to impacts; and (3) the importance of using a logical and transparent decision analysis to select SABS criteria. Fewer detailed example scenarios are also provided for several other waterbody types, including large rivers, regulated rivers, wetlands, lakes, ponds and reservoirs, estuaries, estuarine wetlands, and coastal waters. Different designated uses and types of criteria are also mentioned to give the reader a sense of the range of situations in which SABS criteria development might occur. Actual data analysis is not included in these hypothetical cases. Efforts are ongoing to prepare one or more case studies based on actual data sets.

Table 6. Advantages and disadvantages of methods used in SABS criteria development.

	Advantages	Disadvantages
Measurement of SABS		
Readily Available Measures (e.g., SSC, Percent fines, Secchi distance)	• Published methods with known performance • Often measured by state, tribal, territorial, and federal monitoring programs • Good body of published literature linking direct measures to biological effects and to land cover/land use	• Often not easily tracked to sources
Sediment Transport Curves	• Can reveal channel stability's effects on within-channel sediment loads, and explain past, present, and predicted erosional and depositional processes that may affect restoration	• Applies only in flowing waters (though similar systems may be developed for slow and still waterbody types) • Requires extensive field sampling under specific field conditions. • Not vetted for all waterbody types.
Relative Bed Stability	• Accounts for local environmental conditions (standardized to the reference condition) • Measures both excessive and deficient sediments	• Not as effective in sand bedded rivers and streams where fine sediments are transported frequently and where SABS impairment is not closely related to sediment transport competence • Current formulation only useful for flowing waterbodies though analogous methods may be developed to evaluate stability of sediments in lakes and coastal waters as influenced by wave action.
Classification		
Empirical Classification	• Many states are familiar with this method, having used it in biological assessment programs • May be cost effective because the framework is in place in many states	• Reference site selection can be subjective. • Large data sets are preferred and not always available for all classes that should be compared.
Fluvial Geomorph-ology	• Good for stratification before assessment or for diagnostics after identifying impairment • Can reveal channel stability's effects on within-channel sediment loads and explain past, present, and predicted erosional and depositional processes that may affect restoration	• May be more indicative of sediment effects some distance from the observed geomorphology rather that at the location • Measurements are local rather than based on landscape scale parameters, and therefore, require field sampling. • Not verified for all waterbody types. • Inferring mechanisms from form has not been demonstrated to be technically supportable

Table 6. (continued)

	Advantages	Disadvantages
Associating SABS to Response Indicators		
Controlled Experiments	• Cause and effect relationships supported • Familiar derivation and application • Criteria can be tailored to biotic types in the system • Thresholds can be identified for individual species • Standard development is independent of setting so that states could adopt standards after development in any region (more cost effective to states)	• Data are lacking for many species and development of criteria would take time and money (if only sensitive species were addressed, investment could be reduced) • Sediment criteria may not be specific to site conditions (because sediment character and site context are variable) • SABS do not act in the environment as do toxicants • Difficult to factor in background levels
Field Observations: Percentile of a Distribution of Exposures and Full Range of Exposures and Effects	• Familiar derivation and application • Criteria can be tailored to biotic types in the system • Thresholds can be identified for individual species • Field conditions and background levels are taken into account • Many states are familiar with this , having used it in biological assessment programs • May be cost effective because the framework is in place in many states	• Other stressors confound the association. • When least disturbed sites are compared, there is an assumption that these will meet designated uses and that may not be true • The reference condition may represent an unattainable condition
Field Observations: Conditional Probability of a Selected Effect	• Provides likelihood of impact for exceeding pollutant or pollution level • Incorporates statements of uncertainty • Use of probability-based survey data permits an unbiased extrapolation of results to the statistical population from which the sample was drawn	• Other stressors confound the association. • Traditionally, a single-factor (although it could be modified to include multiple factors)
Waterbody Use Functionality	• Applies in waterbodies where aquatic life is not a primary concern • Explicit stratification by designated use	• Does not protect ecological integrity in waterbodies that are not designated as having an aquatic life use

The detailed scenario and other examples illustrate how some of the proposed methods might be used together to establish SABS criteria (Table 7). Each of these cases is based on activities and steps within the process that is described in Section III.B of this *Framework*:

1. Review current designated uses and criteria for a set of waterbodies
2. Describe SABS effects on the waterbodies' designated uses
3. Select specific SABS and response indicators
4. Define potential ranges in value of the SABS and response indicators
5. Identify a response indicator value that protects the designated use
6. Analyze and characterize SABS - response associations
7. Explain decisions that justify criteria selection

Table 7. Specific applications of the methods used in the hypothetical model for criteria development and application.

	Application/Use
Empirical Classification	To characterize range of biological, physical, or chemical conditions
	To verify stream type classification
Fluvial Geomorphology	To classify waterbodies with similar sediment dynamics
Relative Bed Stability	To evaluate observed against expected stream bed particle size characteristics
Controlled Experiments Field Observations	To evaluate threshold of impact
	To confirm a plausible effect given the exposure frequency, duration and magnitude
Conditional Probability Analysis	To establish thresholds and criteria
Waterbody Use Functionality	Possibly to classify waterbodies
	To establish thresholds and criteria

The examples below illustrate how several methods are used together to develop independent response ranges and identify criteria based on thresholds of effects. That is, a combination of classification, controlled laboratory findings, departure from reference condition, and associations derived from in-stream measurements all play a part. When different quantitative methods result in values that are similar, there is greater confidence the criteria will be protective of the designated use. Different methods are ***italicized*** and ***bolded*** at each appearance to emphasize the roles they play individually and together in the development process. Note that all numbers are hypothetical and are included, not to recommend criteria values but rather to more clearly demonstrate the decision process.

III.E.1. Example: Northeastern Headwater Streams

In this scenario, we assume that a resource manager is developing criteria for a statewide set of 2nd or 3rd order, high gradient headwater streams. These streams had been grouped by similarity in form and function during a statewide classification of all waterbodies, based on a ***fluvial geomorphology*** method. The headwaters class contained high gradient systems that move substrates of widely varying sizes during storm events. These were small streams with mostly cobble/gravel bed materials and sediment transport that were limited by competence (critical shear stress). Despite the high gradient of the streams and the predominantly coarse bed materials and natural tendency to export rather than accumulate sediment, substantial sources of fine sediment may exist in the watershed, banks and bed. Moreover, in- and near-channel disturbances combined with 'flashy' high-flow patterns were capable of mobilizing excessive fine sediment loads thereby causing channel alterations, bank instability, and subsequent biotic impairments in these streams.

Step 1. Review current designated uses and criteria for a set of waterbodies:
The major designated use of these streams is a cold-water fishery. No specific criteria existed for SABS indicators. The designated use was stated in very general terms and the resource manager decided to refine it as 'support of spawning populations of native brook trout' to distinguish it from 'seasonal survival of stocked trout'. Continuing to meet this designated use is dependent on many attributes of stream condition, such as sufficient depth, flow, clarity, and oxygenation; clean gravels for spawning; sufficient habitat and cover for invertebrates and small fish, as well as the trout themselves; an appropriate water temperature regime; and the absence of other conflicting or incompatible uses. Excessive sediment loads can affect several of these attributes at sensitive life stages.

Step 2. Describe SABS effects on the waterbodies' designated uses:
To begin the process, the resource manager considered the potential ways that excess sediment could adversely affect the brook trout fishery. The resource manager identified several mechanisms that could reduce trout survival: (1) physical abrasion by suspended particles, (2) decreased visibility reducing successful sight-feeding, (3) reduced prey capture due to low abundance of prey from the lack of suitable habitat for invertebrates, (4) poor reproduction/recruitment through the loss of spawning habitat or damage to the eggs or sac fry, (5) increased width/depth ratio, lower pool frequency and depth due to sediment deposition, reducing the abundance and quality of territory for adult and juvenile trout; and (6) increased maximum water temperatures associated with the deposition-driven increased width/depth ratio, causing decreased DO and lethal or sub-lethal effects (e.g., disease, crowding at cool seeps) on adult fish. These mechanisms were depicted in a conceptual model, which was useful for illustrating the relationships among the SABS, designated uses, and potential measurements to quantify the associations (Figure 15). The resource manager conducted a literature review to support the linkages described in the conceptual model and discovered a variety of observed sub-lethal effects for brook trout including inhibition of prey capture, growth, and egg survival. A review of available data sets revealed that these exact measurements were not monitored in the state's own studies though reasonable surrogates were noted. As a result, our hypothetical resource manager considered what types of data were available to use or what could reasonably be developed in the context of a variety of possible methods for criteria development.

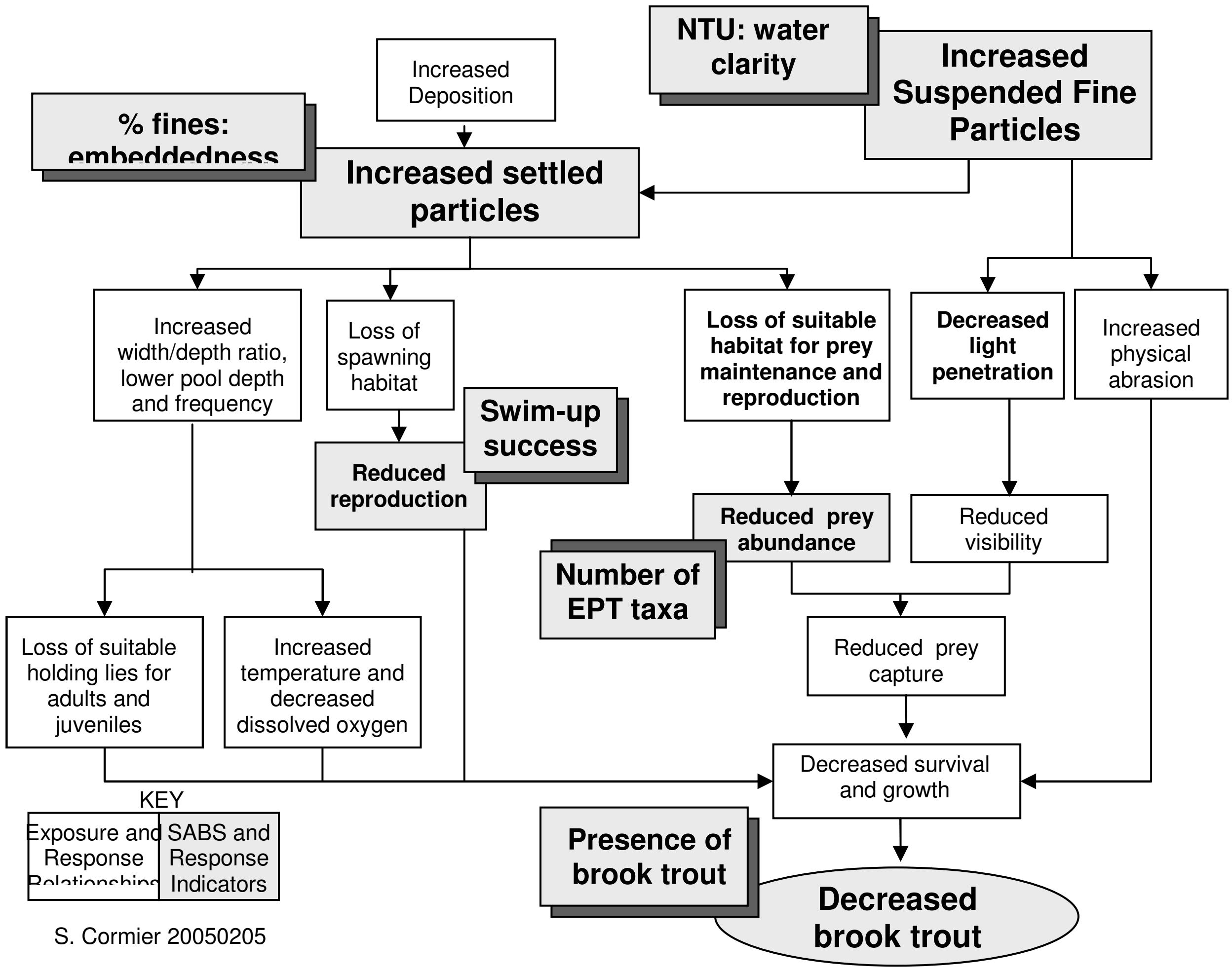

Figure 15. Conceptual model for the northeastern headwater stream example.

Step 3. Select specific SABS and response indicators:

In this step the resource manager selected measurements that defined the impairment as well as the suspended or bedded sediment measurements. The resource manager knew that selection could be based either on previously established designated use criteria or could be independently established. The resource manager recognized that the absence of brook trout would be the most definitive threshold, but significantly reduced populations could also be documented and defended as impairments.

In this hypothetical case, the conceptual model illustrates that three response indicators were identified: (1) the presence of brook trout, (2) reproductive success, and (3) available prey. The resource manager needed to select appropriate measurements for these response indicators. The resource manager selected density of adult brook trout as a direct measure of the designated use. For assessing reproductive success, the resource manager chose the percent survival to swim-up stage because this addresses a life stage of the brook trout that is sensitive to SABS and is feasible to measure. For prey availability, the number of Ephemeroptera, Trichoptera, and Plecoptera (EPT) insect taxa was considered a reasonable surrogate although some of these species are not normally brook trout prey and the number of species may not necessarily represent either abundance or availability as prey for trout. These uncertainties were noted in the decision record.

Likewise, data for prey capture and abundance may be unavailable or too costly to measure, and we assume that this is the case for our hypothetical case. Inspection of the conceptual model suggested that, at a minimum, there should be one SABS indicator for suspended sediments as well as an indicator for bedded sediments. The resource manager selected turbidity (NTU) for water clarity and percent fines for settled particles, based on the availability of data in the region and based on reported mechanistic and exposure/response associations between turbidity and percent fines and effects to salmonids and invertebrates. The resource manager documented two reasons for his decision to use these SABS indicators: (1) based on the literature, low levels of turbidity and percent fines were linked with trout spawning success and macroinvertebrate prey productivity, and (2) data for analysis regarding turbidity, percent fines, density of trout and the macroinvertebrate assemblage were readily available from both state studies and EMAP.

Step 4. Define potential ranges in value of the SABS and response indicators

In our case, we will assume that the EMAP data set had more than 100 sample locations in cold, headwater streams where fish surveys were conducted along with benthic macroinvertebrate sampling, water quality analysis, and characterization of physical habitat. To determine the range of indicator values that are possible for the waterbody class, the ***empirical classification*** method was used. First, non-SABS parameters were selected to identify high quality reference streams. The resource manager used both land cover (high percent natural) and water quality (low conductivity and metals concentrations) criteria. Through GIS analysis and database queries, the resource manager identified 25 sites with more than 95% natural land cover, specific conductance less than 100 µS/cm, and no exceedances of U.S.

> *All numbers used in these examples are hypothetical and are included not to recommend criteria values but rather to more clearly demonstrate the decision process.*

EPA hardness adjusted metals criteria. These 25 sites were considered to be minimally impacted and were representative of as nearly natural conditions as was available. Additional parameters were examined in the reference sites to confirm the classification and to minimize the influence of other potential stressor sources. The resource manager sought evidence of cold water temperatures throughout the year, suitable hydrologic conditions, the absence of point sources or development, excellent water quality including low levels of contaminants, high concentrations of dissolved oxygen, and a forested riparian zone. No further classification was deemed necessary after examining the reference data.

Natural indicator ranges were plotted for these 25 sites and were compared to ranges of the same indicators in the 75+ remaining sites. For most of the indicators plotted, the reference distribution overlapped partially with the non-reference distribution, with the ranges of non-reference values showing a greater percentage of sites with "worse" SABS and biological conditions. These findings suggested that some sites had conditions that were closer to the natural potential than others and that the tested indicators may be reasonable measurements for assessing SABS and biological conditions. There were consistently three to four reference sites that had poorer indicator values than the remaining data and the resource managers decided to use the 75th percentile of SABS data and the 25th percentile of biological data to describe reasonable expectations for the natural potential. The few sites with poorer indicator values could not be associated with a consistent source of variability.

Step 5. Identify a response indicator value that protects the designated use

Three biological measures were selected as response indicators: (1) The 25th percentiles of the distributions were 4.3 adult brook trout per 100 square meters, (2) 15 EPT taxa, and (3) percent survival to swim-up stage. In this hypothetical example, percent survival to swim-up stage was not measured in the field because it would require destructive sampling. For this response indicator, literature suggested that 86% survival was adequate for sustained reproduction. Additional literature review supported the state's findings regarding adult trout densities, with a mean value of 6.2 fish/100 square meters in productive trout streams averaged over three studies. The EPT richness values in reference sites were found to be similar in cold water streams of neighboring states.

These numbers are for illustration purposes only and are not meant to represent actual targets. The 25th percentile of reference values were therefore established as response indicator transition points between attainment and non-attainment of the designated use (i.e., support of spawning populations of native brook trout). Below, the completion of the hypothetical case using the multi-step process is discussed separately for suspended sediments and for bedded sediments, with reference to the individual methods used to develop the criteria for each.

Suspended Sediment Criterion Development

In this case, two ***exposure-response*** techniques (***controlled experiments*** and ***field observations***) are used in combination to complete the development of a criterion for suspended sediment.

Step 6. Analyze and characterize SABS - response associations

To use the ***controlled experiment*** method to define the association between SABS indicators and biological responses, the resource manager carefully reviewed the scientific literature for independent reviews, reports, and peer-reviewed publications linking specific levels of turbidity and suspended solids to adverse responses of salmonids including brook trout. In the tradition of criteria-setting based on controlled laboratory tests of chemicals, the most sensitive life stage of the brook trout was selected as the specific response measurement whenever possible.

Fortunately for our resource manager, studies that extended from fertilization to the swim-up stage for brook trout were available. The resource manager identified three high quality studies that were based on (1) high percentage of survival in controls, (2) appropriate statistical analysis, and (3) clear documentation. Since the thresholds for significant effects for 86% survival from the three studies were within the same order of magnitude, the geometric mean was calculated and, for illustrative purposes, it was assumed to be 8 NTU. In addition, physiological condition studies were examined and assumed effects were reported between 3 and 10 NTUs. Although this might be sufficient to set a suspended sediment criterion and thereby define impairment, additional evidence would strengthen the confidence in the decision. Thus, in our hypothetical case, the resource manager decided to use another analytical method to confirm the exposure/response analysis.

There are several ways that the ***field observational*** methods can be used to partially characterize SABS-response indicator associations. For the sake of brevity, we only illustrate one here, the ***conditional probability analysis (CPA)*** method. The analysis depended on multiple field-collected samples that should include a measure of SABS and a measurement of the designated use. In our hypothetical case, the resource manager wanted to determine the turbidity level at which adult brook trout density is reduced below 4.3 fish/100m^2, the transition point identified in step 5. So, the resource manager plotted turbidity on the *x*-axis and brook trout density on the *y*-axis, performed a quantile regression analysis, and recorded the maximal trout abundance given an observed level of turbidity.

For our hypothetical case using the data set of more than 100 sample locations in headwater streams, the analysis indicated that during low flow conditions adult brook trout only occurred in streams with less than 20 NTUs. Furthermore, a strong association between turbidity and brook trout density was found using the state's own data with a reduction to 4.3 fish/100m^2 occurring between 12 and 15 NTUs. The greatest densities were observed between 3 and 10 NTU. These turbidity levels were compared with results of the ***controlled experiment*** method described previously.

An additional method was applied based on a separate data set: creel surveys of fly fishermen. The survey showed that most fishing on popular trout streams occurred only when stream turbidity was less than 5 NTU. Results from the questionnaire of fly fisherman revealed that their decision to fish or not to fish was based on perceived fishing success attributed to the visibility of their trout flies to the brook trout.

Step 7. Explain decisions that justify criteria selection

In this hypothetical case, two response indicators were evaluated, survival to swim-up stage from controlled experiments reported in the scientific literature and density of brook trout based on exposure/response analysis of ***field observations***. Based on these two different types of information presented in the scenario, our hypothetical resource manager drafted his decision as well as the rationale for that decision. A decision table (Table 8) is valuable for illustrating the benefits and drawbacks of alternative criteria levels. The turbidity levels associated with the transition points of the response indicators were 8 NTU for 86% survival of swim-up fry and 12-15 NTU for adult densities of 4.3 fish/100 square meters. The resource manager decided that 15 NTU was not sufficiently protective since adverse effects appeared to have occurred in streams in the state at or near that level. The resource manager might also consider that although 5 NTU may have an economic benefit on recreational fisheries, this level of water clarity may be difficult to achieve and was lower than necessary to protect the fishery because the state's own data clearly showed that brook trout could thrive in waters as high as 10 NTU. Since the duration and frequency of the exposures in the field was uncertain, the resource manager decided to adopt 8 NTU as a reasonably protective criterion based on controlled laboratory studies on the most sensitive life stage and because this value was within the range in which high quality trout fisheries were reported for the state. Additional site specific testing for extent and duration would be addressed on a site-by-site basis.

Table 8. Decision rationale for selecting a suspended sediment criterion.

Potential criterion (NTU)	Advantages	Disadvantages
15		Value was not sufficiently protective since adverse effects occurred at or near that level in the state's streams.
10	Brook trout were present at this value based on the state's monitoring data.	
8	Value is the geometric mean threshold in controlled laboratory exposures.	
5	Value may have an economic benefit.	Value may be lower than necessary to protect the fishery. Value may be difficult to achieve.

This hypothetical scenario illustrates the approach and reasoning for indicator selection, data analysis and suspended sediment criterion selection. Another alternative might be to use species sensitivity distribution curves to derive a criterion that is protective of 95% of species; and there are still other alternatives. What is essential is that the scientific analysis be sound and the rationale for decision-making transparent, logical, and defensible. Remember that this is a hypothetical example and values are not based an actual analysis of the literature or data sets.

Bedded Sediment Criterion Development

In this case, the ***conditional probability analysis (CPA), fluvial geomorphology, and relative bed stability (RBS)*** methods were used to complete the development of a criterion for bedded sediment.

Step 6. Analyze and characterize SABS - response associations

The resource manager used the ***CPA*** method to determine the probability of observing reduction below acceptable levels of EPT taxa (15 taxa). Percent fines was selected as the SABS measurement for bedded sediment (Step 3). The resource manager could confidently apply the ***CPA*** method because data were available from an EMAP study where sampling locations were randomly selected. Results from the ***CPA*** indicated an 80% chance for the presence of fewer than 15 species of EPT when the percentage of fine sediments (<0.06mm) exceeded 20%. There was a 60% chance of fewer than 15 species of EPT when the percentage of sediments exceeded 10% fines. In a similar analysis using density of brook trout, there was an 80% chance of less than 4.3 fish/m^2 in cold water streams with less than 25% fine sediments and a 60% chance at 12% fine sediments.

The resource manager also knew that in a neighboring state restoration efforts were already underway in two streams that had originally only supported stocked brook trout. The resource manager of the study had used the ***fluvial geomorphology*** method to evaluate SABS in the two streams and designed controls including stabilization of stream banks consistent with the on-going adjustment of the channel toward a more stable form and the creation of in-stream complexity by adding large boulders to the stream. Before implementing the controls, SABS and biological response indicators were measured. After implementation, sampling continued at regular intervals. Year-old trout were observed in one stream two years after intervention; the percent fines had declined to 5%.

No recovery was seen in the second stream where percent fines were reduced but were measured at 12%. The resource manager was unsure of the reason(s) why the second stream had not recovered. Stressor(s) could include insufficient recovery to permit areas of down-welling and up-welling, which are necessary for spawning, or insufficient recovery time to reduce the levels of percent fines. Although this was not enough information to use in development of alternative criteria, the resource manager recognized its value in providing some quantitative response data consistent with the results from other methods, providing SABS measures that were more closely related to problematic SABS source locations (e.g., the unstable banks) and thereby helping him target restoration actions more effectively, and providing valuable post-project monitoring information.

The resource manager also recognized that he could apply the ***RBS*** method because ***fluvial geomorphology*** data were also collected by a state agency and by EMAP. These measures included ongoing channel adjustment, bank instability, and dominant bed particle size along with channel gradient and other measures to help classify the waterbody type. The channel morphology data provide an opportunity to characterize a range of values for headwaters streams for percent fines and ***RBS*** measures. In particular, the ***RBS*** data set provided him with information on the abiotic sediment regime in its characterization of expected bed composition and particle sizes, and a range of departures from reference exemplified by the observed bed composition.

As a comparison with the other methods that analyze associations with percent fines, the resource manager determined whether thresholds occurred at a relatively consistent ***RBS*** ratio value. The resource manager also noted that results from such an analysis might demonstrate suitability of a selected ***RBS*** value associated with an effects threshold as an alternative criterion for percent fines. Further, the resource manager planned to look for associations among the ***RBS*** values, embeddedness, and geomorphic indicators of ongoing channel instability and adjustment, in the possibility that these can either cross-validate or provide additional criteria alternatives in the future.

Step 7. Explain decisions that justify criteria selection

The resource manager knew from the adjacent state's experience that a reduction to 5% fines could restore a fishery, but the exact threshold was still very uncertain and based on only one stream that had recovered and one that did not. The resource manager also knew that the choice of a probable effect level was critical to a decision. A decision table (Table 9) is valuable for illustrating the benefits and drawbacks of alternative criteria levels. If the resource manager chose the 80% level (20 – 25% fines) he/she would have a high probability of losing the trout fishery. The resource manager believed that he/she could demonstrate to the water director the economic and political efficacy of setting the threshold at a 60% effect level (10-12% fines), which would be more protective. Percent fines at this level still posed some risk to the fishery, so the resource manager recommended that the lower end of the range (10%) be selected as a provisional criterion and that the criterion should be revisited after data were collected from several streams in his state that he/she knew would require TMDLs and restoration. The resource manager recommended careful monitoring of streams during the provisional period and after the criterion was implemented. The 10% fine sediment provisional criterion was selected as a reasonably protective level for the support of brook trout.

Table 9. Decision rationale for selecting a bedded sediments criterion

Potential Criterion (percent fines)	Advantages	Disadvantages
20-25%		80% chance of loss invertebrate food base and reduced fishery, may require costly stocking due to lack of survival of early life stages
10-12%		60% chance of loss of fishery. No recovery in similar fishery at 12% fines.
10%	More likely to be protective	More difficult to achieve than a more relaxed criterion.
5%	Unstocked, juvenile trout observed in similar fishery after 5% fines were achieved	More difficult to achieve than a more relaxed criterion.

Scenario Summary

In this hypothetical scenario, the SABS criteria established for headwater streams were developed and confirmed using statewide and regional data sets. We could imagine that a limited statewide analysis validated the regional study and that the criteria of 8 NTUs for suspended sediments and 10% fines for bedded sediments were adopted as standards for headwater streams with the native cold-water fisheries designation throughout the state.

This scenario illustrated a variety of applications of the methods discussed throughout this *Framework* but these do not constitute all the roles each might potentially play. For more detailed examples of applications of the individual methods, see Section III.D.

III.E.2. Abbreviated Examples

SABS criteria can be developed using the multi-step process and these same general methods for any waterbody type. To avoid redundancy, other waterbody types are presented in a much shorter format than for headwater streams.

Large Rivers

Large rivers (e.g., fifth order or greater) collect and transport SABS in ways inherently different than the smaller headwater streams. Sediments may reach the larger and lower gradient watercourses through upstream sources as well as erosion from the intensive land uses (agriculture and urban development) that are prevalent in wide, gently sloping valleys. The predominant bed material would be composed of gravel and smaller size particles that could be suspended or moved with small flow increases. Deep pools and large quantities of water allow for designated uses such as drinking water supply and primary contact recreation (swimming and boating). Aquatic life uses shift to warm water species (e.g., bass fisheries) and the benthic macroinvertebrate community is fundamentally different compared to upstream.

Resource managers will be faced with a separate SABS criteria development effort for the large river waterbody type or class to address unique designated uses and different expectations for SABS indicators and the biotic assemblages. This separate effort will follow the same multiple steps described in Section III.B of this *Framework*. SABS indicators and criteria development approaches for large rivers may differ from the scenario above. Indicators pertaining to suspended sediments (TSS, turbidity, clarity) may be more universally applicable than measures of bedded sediments. However, some large rivers may have a certain degree of cobble and larger substrates that should be preserved or restored as important habitat. All the previously described methods for SABS criteria development could be applied to large rivers, including the ***waterbody use functionality*** method, which has limited applicability in headwater streams. ***Waterbody use functionality*** drives criteria development efforts for the uses not pertaining to aquatic life (e.g., navigation, drinking water source, and recreation). Turbidity/suspended sediments should be low enough to allow efficient water filtration for drinking water, and water clarity must allow visibility that is safe for swimmers and boaters.

Regulated Rivers

Dams that disrupt river flow to create reservoirs also block the flow of sediments. Cobble, heavy gravel, and sands can build up behind dams, causing channel armoring and a deficiency of sediments below dams. While these changes can result in alterations to water quality, the major impacts are on habitat for fish and benthic macroinvertebrates as measured by the composition of the substrate. The ***RBS*** method can yield effective indicators of substrate changes below dams.

After examining ***RBS*** values in areas unaffected by dams (***empirical classification***) as well as scientific literature regarding sediment alterations caused by dams, a SABS criterion based on ***RBS*** could be established, above which altered sediment supplies and channel armoring would be indicated.

Wetlands

Riparian wetlands in side channels and floodplains are critical habitat for fish spawning and for amphibians that lay egg masses on stable substrates. Because wetlands are natural deposition zones for sediments, bedded sediment criteria for stream channels would not be appropriate for the adjacent wetlands. Instead, the Sediment Risk Index (SRI, U.S. EPA 2002) could be used as an indicator. The indicator, based on predicted soil erosion and delivery from agricultural lands, could be correlated with metrics from amphibian surveys. A criterion could be established based on ***field observation*** methods that demonstrate associations between the SRI and the presence of sensitive frog species. Turbidity criteria that might be applied in the main channel would not be applicable in the wetlands because water turnover rates are generally slower and fine clays can remain in suspension for longer periods.

Lakes, Ponds, and Reservoirs

Natural lakes and ponds would likely be designated for aquatic life use such that naturally occurring species could survive and reproduce, providing opportunities for recreational fisheries and wildlife observations. These waterbodies would vary considerably in SABS conditions and might require classification based on size and substrate type.

For aesthetic purposes related to aquatic life and recreational uses, Secchi depth was selected as an indicator of water clarity. This measure is easy to understand from an aesthetic perspective; it is a visual estimate of the depth of water through which a black and white disk can be seen. A criterion was established such that the Secchi disk must be visible at a minimum depth of four feet. This allows sufficient clarity in recreational waters to provide visual appeal, recreational opportunity, enjoyment, and safety (Smith and Davies-Colley 1992). Secchi depth also indicates planktonic density. This aspect of the measure needs consideration when management options are recommended because both excess sediment supply and high nutrient concentrations can cause shallower Secchi depth readings.

Many lakes and ponds are actually reservoirs created to provide hydropower, drinking water supply, and agricultural water supply. Secondary uses include non-contact recreational use. Low turbidity is required for efficient operation of pumps, turbines, filters, and treatments; and water clarity can be desirable for aesthetic reasons. Therefore, the ***waterbody use functionality*** method can be used for setting criteria for these designated uses. Criteria for bedded sediments may not be required if reservoir capacities are not threatened by excessive sedimentation and lakebeds are naturally composed of fine materials.

Estuaries

Bass fisheries, shellfish, and submerged aquatic vegetation (SAV) beds that provide critical habitat are valued resources in estuaries. SAVs represent one of the components of the estuarine ecosystem that is most sensitive to increases in SABS. A criterion based on water clarity would (if attained) provide conditions for optimal growth and reproduction of SAVs and would not impair other habitats and organisms.

Criteria could be developed using the ***field observations*** method. In an example from the Potomac estuary and the Chesapeake Bay, existing studies were compiled in a worldwide literature synthesis. The criteria derived from the literature were evaluated with site-specific field studies, model simulation, and diagnostic tools (see example in Section III.D.3). The criteria were stratified by depth and salinity regime and adjusted by season. The final criteria used percent light through water (PLW) as the indicator and had a range of 13-22 PLW.

Estuarine Wetlands

Emergent wetlands that line estuaries and bays may also be subject to excessive SABS effects. Water clarity may not be an issue in these generally shallow waterbodies, but sediment accumulation as it affects anadromous fish spawning may require establishment of criteria for bedded sediments. If the majority of sediments settling in the wetlands come from upland sources, as opposed to suspended sources flowing in from the deeper estuary, then an indicator of sediment supply (such as the Sediment Risk Index) may be appropriate for the estuarine wetlands as it was for the wetlands in the upper parts of the watershed.

Coastal Waters

Natural marine sediment supplies as well as discharge from the estuary and other smaller rivers and streams heavily influence SABS conditions at the mouth of the estuaries and in other coastal waters. Criteria established in the contributing waterbodies may be considered sufficient for protecting designated uses for coastal waters and beaches. Some states may have sensitive aquatic life (corals), ecologically significant coastal wetlands, and economically important recreational uses (beaches) that merit protection that is not provided through criteria applied to the contributing waterbodies. Classification could be guided using the *Classical Framework for Coastal Systems* (U.S. EPA 2004). This framework includes conceptual models of SABS impacts in coastal areas that would be a good starting point for criteria development.

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Appendix A
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 that moves along and is in contact with the stream or river bottom.

Clean sediments- Suspended and bedded sediments that are not contaminated with toxicants.

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

Controlled experiment- An experiment in which replicate experimental units (e.g., organisms, sediment microbial communities, or colonized rock baskets) are randomly assigned to treatment groups that receive controlled levels of exposure to an agent and responses of interest are observed.

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

[2]**Criteria**- Levels of individual pollutants, water quality characteristics, or descriptions of conditions of a waterbody, 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 U.S. EPA as described in the first definition of criteria.

Designated Uses- Those uses specified in state/tribal water quality standards for each waterbody or segment, whether or not they are being attained. The term is 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 degree to which larger substrate particles (gravel, cobble and boulders) in the bottom of a stream or river are surrounded by deposited sediment.

Erodibility- A soils sensitivity to the effects of wind and water on the soil structure.

Fines- Fine particulate material such as silt and clay particles typically of less than 0.85 mm diameter though other diameters can be specified.

Fluvial Geomorphology- The study of the influence of flowing surface water on the Earth's surficial sediments through the processes of erosion and deposition.

Kurtosis- Kurtosis is the degree of peakedness of a distribution.

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- The condition that approximates a natural, unimpacted condition (biological, chemical, physical, etc.) for a waterbody. Reference condition is best determined by collecting measurements at a number of sites in a similar waterbody class or region under undisturbed or minimally disturbed conditions (by human activity), if they exist.

Secchi disk- A black and white quadrant disk, typically 20cm in diameter, used to determine water clarity by measuring the distance through the water column at which the disk disappears and appears.

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

Sedimentation- The deposition of sediment.

Settleable solids- Solids that will settle to the bottom of a cone-shaped container in a standard time interval (e.g., an Imhoff cone in a 60-minute period).

Silt- Non-cohesive inorganic particles. 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 waterbody becomes clogged with sediment.

Suspended and Bedded Sediments (SABS)- Organic and inorganic particles that are suspended in, are carried by, or accumulate in waterbodies. SABS are natural parts of aquatic systems and cannot be considered as pollutants until they are out of balance, in excess or deficient.

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

Suspended sediment- Very fine soil particles that remain in suspension in water for a considerable period of time without contact with the bottom. Such material remains in suspension due to the upward components of turbulence and currents and/or by colloidal suspension.

Suspended-sediment concentration (SSC)- The dry weight of sediment from a know volume of water-sediment mixture, typically expressed in milligrams per liter. Primarily fine inorganic clay, silt, and sand, but also includes the well-decomposed organic matter typically found in soils.

Total Suspended Solids (TSS)- Suspended organic and inorganic solids that are not in solution and can be removed by filtration. Suspended solids usually contribute directly to turbidity.

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.

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

Water Quality Standards- Are provisions in state, tribal, or territorial law or regulations that define the water quality goals of a waterbody, or segment thereof by (1) designating the use or uses to be made of the water, (2) setting criteria necessary to protect the uses, and (3) protecting existing water quality through anti-degradation policies and implementation procedures.

Appendix B
Impacts of Suspended and Bedded Sediments (SABS)

SABS are a unique water quality problem when compared to most 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 that 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 *U.S. 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 three major avenues of effect in aquatic systems: (1) direct effects on aquatic life, (2) direct effects on physical habitat, which result in indirect effects on aquatic life, and 3) effects on uses other than aquatic life, such as recreation or drinking water.

SABS can be broken down into suspended sediments and bedded sediments. 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. In discussions within the *Framework*, thresholds of effects on biota are omitted because of high variability found in the literature, specificity of application that cannot be explained in brief, and intentions to avoid bias in future criteria development exercises. The following discussion is excerpted from Jha (2003). Comprehensive reviews of the effects of SABS can be found in the scientific literature (e.g., Jha 2003; Berry et al. 2003;Wilber and Clarke 2001; Waters 1995; Chapman 1988; Wood and Armitage 1997; Newcombe and Jensen 1996; Nalepa and Quigley 1980).

<u>Suspended sediments</u>

-Direct effects on aquatic life

Suspended sediments can directly affect many components of the biota, including algae and macrophytes, invertebrates, and fish. The increased turbidity associated with suspended sediments can reduce primary productivity of algae as well as the growth and reproduction of submerged vegetation. In some systems, increased sediment can lead to a shift from macrophyte-dominated productivity to algal-dominated productivity.

The direct effects of suspended sediments on invertebrates and fish are complex, ranging from behavioral to physiological to toxicological. The severity of effect caused by suspended sediments is a function of many factors, including sediment concentration, duration, organism life history stage, temperature, physical and chemical characteristics of the particles, associated toxicants, acclimatization, other stressors, and interactions of these factors. Suspended sediment effects have been scored on a qualitative scale as severity of ill effect (SEV), and they 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) (Newcombe and Jensen 1996).

Invertebrates may show behavioral, physiological, or toxicological responses to excess suspended sediment. For example, invertebrate drift is a behavior that is directly affected by increased suspended sediment load in freshwater streams. These changes may be associated with a shift in dominance from Ephemeroptera, Plecoptera, and Trichoptera (EPT) insect taxa to other less sediment-sensitive taxa of the benthic assemblage.

Suspended sediments also have a negative affect on the survival of freshwater mussels. Increased levels of SABS impair ingestion rates of freshwater mussels. Laboratory studies have shown 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.

Suspended sediments also affect fish populations. Two major effects of SABS on fish include (1) behavioral effects, such as inability to see prey or feed normally and (2) physiological effects, such as gill clogging. 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.

Many species of fish may relocate when sediment load is increased because fish can readily disperse. Other behavioral 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.

Physiological effects of gill clogging 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 (e.g., cortisol and epinephrine), compensatory response to 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.

-Indirect effects on aquatic life
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. A loss of macrophytes can represent a loss of habitat for certain species that use them as protective refugia. Reduced light availability can also limit the feeding efficiency of macroinvertebrates and fish. Invertebrates and fish may avoid areas of high turbidity or low light, affecting community structure and dynamics.

-Effects on other designated uses
Excessive suspended sediments can affect designated uses other than aquatic life. Recreation can be impacted if swimmers prefer clear water to turbid water, or if highly turbid water makes swimming hazardous by hiding submerged objects. Anglers may be less able to see fish in turbid water. Finally, excess sediments in waterbodies used for drinking water necessitate the use of expensive filtration systems to make the water suitable for human consumption.

Bedded sediments

-Direct effects on aquatic life
Excessive bedded sediment can affect aquatic life in several ways. 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. 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. For example, large-scale declines of submerged aquatic vegetation (SAV) in Chesapeake Bay are directly related to increasing amounts of nutrients, and secondarily to sediments entering the Bay (Staver et al. 1996). There also 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.

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 the streambed and to burial by settled particles. Thin coverings (a few millimeters) of fine particles are believed to disrupt the normal exchange of gases and metabolic wastes between the egg and water.

Sediment deposition has caused significant 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. 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.

High and sustained levels of bedded sediment may cause permanent alterations in macroinvertebrate community structure, including diversity, density, biomass, growth, rates of reproduction, and mortality. 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. Specific 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.

In marine environments, corals differ greatly in their ability to resist SABS, with most species being highly sensitive to 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, organisms eventually reach the point where they can no longer spare the energy to keep themselves clean, and the affected tissues die back. Excess SABS cause reduced growth rates, temporary bleaching, and complex food web-associated effects to reef dwelling organisms other than corals. 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.

-Indirect effects on aquatic life

Some of the indirect effects of bedded sediments stem from the feeding mechanisms of aquatic animals. 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). 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.

Increased sedimentation also may functionally shift the fish community from generalist feeding and spawning guilds to more bottom-oriented, sediment tolerant fishes.

-Effects on other designated uses
The build-up of deposited sediment can interfere with other designated uses besides aquatic life. Sedimentation can interfere with habitat quality in all waterbody types, but particularly in wetlands, where the water filtering capabilities may be affected. Over time, the deposition of sediment can alter water tables and channel depths, affecting drinking water, agriculture, and recreational and commercial boating and navigation. The removal of deposited sediments via dredging is costly and may cause detrimental re-suspension of sediments.

Other SABS Effects

Effects of SABS on waterbodies result not only from excess SABS but also from SABS starvation and changes in supply. Sediment starvation caused by structures such as dams and levees is 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). Changes in the supply rate of sediment can cause 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 and 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.

In summary, the current literature suggests that imbalanced SABS contribute significantly to detrimental effects on 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.

Appendix C
State Needs Survey
Conducted in 2004

In September, 2004, a survey was conducted to solicit input from states on the status of SABS related impairment and monitoring in their state, as well as technical, budgetary, and other needs for developing numeric SABS criteria. One state was randomly chosen from each of the 10 U.S. EPA regions. States initially contacted included New Hampshire (NH), New York (NY), Delaware (DE), Louisiana (LA), North Carolina (NC), Michigan (MI), Kansas (KS), Wyoming (WY), Oregon (OR), and California (CA). In each state, a person working with water quality standards was contacted and sent the survey, which was often completed with the aid of people working directly with water quality monitoring. In one case (Kansas), two state employees responded with similar answers. The staff in Louisiana chose not to respond to the survey *per se*, but provided written responses that were modified into survey answers. The responses summarized below are from the following states: NH, NY, DE, NC, MI, KS, WY, OR. California did not respond.

STATE NEEDS SURVEY

Name
Telephone Number
Job position
Date

The U.S. EPA intends to publish a draft *Framework for Developing Suspended and Bedded Sediment (SABS) Water Quality Criteria*. This survey is being conducted to summarize issues regarding SABS criteria development that are important to the states. Please answer to the best of your knowledge. If you cannot answer confidently, provide a reference to another state employee that would be more qualified to answer. Though some questions are categorical, additional comments are invited.

1. **How would you characterize suspended and bedded sediment (SABS) related water body impairment in your state?**

   (5) Major problem
   (3) Minor problem
   (0) Not a problem at all

2. **What is the current status of criteria/standards for SABS in your state? Are they fully implemented or under development?**

Existing	Under Development	
(1)	(0)	No criteria or standards
(1)	(0)	Narrative criteria
(1)	(1)	Numeric criteria

(5)	(0)	Standards with narrative criteria
(3)	(0)	Standards with numeric criteria

3. Are you applying SABS criteria now? In what capacity or which programs (e.g., requirements of the Clean Water Act, TMDLs, upstream/downstream monitoring for discharges)?

KS: Kansas 305(b) reports and 303(d) lists have long recognized SABS-related impairments in streams and reservoirs, but the extent of the problem has not been accurately reflected in these documents. Most of the reported problems in streams have been identified through biological monitoring efforts rather than through the state's more extensive stream chemistry monitoring program. An expansion of the state's biological monitoring program would undoubtedly paint a bleaker picture. (Historically, a TSS criterion of 100 mg/L was applied to streams in Kansas for diagnostic and 305(b) reporting purposes. This BPJ-based criterion was ultimately abandoned owing to a general lack of supporting scientific evidence.)

MI: Yes, Michigan is currently applying SAB type criteria under the NPDES program and the surface water monitoring program.

NH: Not for benthic deposits. Streams: Photo documentation or BPJ for assessing impairment. Yes, for turbidity. Primarily for episodic events related to construction. Ad hoc.

NC: Yes- CWA requirements, TMDL (turbidity –TSS); monitoring (NPDES and ambient)- Lakes and Streams; Storm water

DE*:* No

NY: Yes, we are applying narrative sediment standards currently.

OR: We have done TMDLs for sediment. We require turbidity monitoring for some sources.

WY: Turbidity limits and monitoring are routinely required when appropriate on construction sites. Limits for suspended solids (TSS) are also place on various industrial and municipal discharge permits e.g., (coal mines, municipalities).

4. Do you feel there is a need for improving your water quality criteria for SABS?

KS: Definitely

MI: The current approach is working, however other options would be considered.

NH: I guess so for benthic deposits, no further development for turbidity

NC: Yes

DE: Not sure

NY: Numeric standards are preferable to narrative, but development of numeric standards is not a high priority for NYS. We believe that our assessments done for aquatic life use are appropriate and adequate. To protect the aesthetic quality of the waters, and recreation and other best uses, the standards might be useful, but there are other higher priorities for standards development in the state.

OR: Yes

WY: There is always a need for improving WQ standards.

5. If you have SABS criteria/standards, what is/are your indicator(s) for:

a. Suspended sediments:

(6) turbidity
(5) total suspended solids
(1) light penetration
(1) other- secchi depth

b. Bedded sediments:

(1) Wolman pebble counts
(3) embeddedness
( ) percent fines by volume
(2) percent fines by area
( ) silt depth
(1) substrate stability
( ) residual pool volume
(2) other – best personal judgement & photos; intergravel dissolved oxygen

c. Biology

(7) benthic macroinvertebrates
(4) fish
(3) periphyton
(1) other - mussels

6. What designated uses other than aquatic life uses do you feel are vulnerable to SABS impairment in your state?

(3) Fish consumption
(5) Primary contact recreation
(3) Secondary contact recreation
(7) Drinking water supply
(0) Agriculture use
(2) Industrial use
(1) Navigation

7. Do you foresee specific technical/scientific problems with development or application of SABS criteria in your state? If yes, please explain.

(5) Yes
(0) No
(3) Not sure

KS: Money and other resource issues may pose a far greater concern. In agricultural regions, political opposition may pose an even greater challenge (technical and scientific difficulties may seem minor by comparison). U.S. EPA will need to convince the states that it is serious about tackling this issue.

NH: No expert on staff, what parameters, bedload, rate of erosion, deposition, embeddedness tough to hang your hat on, for streams: rock baskets – if impaired – then pursue sedimentation measure.
NC: Analytical techniques, background issues
NY: For bedded sediments, there will some difficulties
OR: Yes how to deal with natural variability; which are the best measures; what levels are needed to protect threatened and endangered species, particularly salmonids
WY: The largest problem with sediment in Wyoming is clean sediment rather than contaminated sediment and its effects on habitat. The issue is keeping sediment transport in balance which is different for each stream system. This makes every decision site-specific and usually requires more data than we can get to do it right.

8. The following elements/resources are potentially part of the draft Framework for Developing SABS Criteria that is being considered. Please rate their utility for your criteria development process as: very useful, somewhat useful, unknown, not very useful, not at all useful.

Elements	Very useful	Somewhat useful	Unknown	Not very useful	Not at all useful
a. Personnel/expertise	8				
b. Money/grants	6	1	1		
c. Existing criteria/standards	3	5			
d. Technical documentation/manuals	3	5			
e. Access to data on SABS effects from scientific literature	6	2			
f. SABS data for your State	5	2	1		
g. Analytical methods for converting narrative to numeric criteria	4	3	1		
h. Example case studies	1	5	1	1	
i. Web-based communication with U.S. EPA and others in criteria development process	2	3	1	2	
j. Data management tools	1	4	1	2	

9. What other information, in addition to what is listed in the above table, would you find useful for improving or deriving better numeric SABS criteria?

KS: In the assessment of aquatic life support, we would benefit from a clearer knowledge of the sensitivity of different taxa and assemblages to SABS exposure, that is, from the application of more widely accepted biological indicators
MI: U.S. EPA derived SAB criteria and standards that included state involvement.

NH: Workshops
NC: Data specific to bedded sediments
OR: Clarity about what uses we're trying to protect at what level and which measures/criteria are best suited to each purpose. A way to do this with as few criteria/measures as possible and as simply as possible. Something that is implementable technically and from a resource perspective. Assistance with how to deal with uncertainty and sublethal impacts. How to deal with systems that are dynamic and with natural disturbance.
WY: I don't know.

Survey Respondents:
Delaware: Hassan Mirsajadi, Environmental Engineer, Watershed assessment, Department of Natural Resource and Environmental Control
Kansas: Robert T. Angelo, Chief, Technical Services Section, Bureau of Environmental Field Services, Kansas Department of Health and Environment; and Bret Holman, Kansas Water Quality Standards Coordinator, Kansas Department of Health and Environment
Louisiana: Kristine Pintado, Environmental Scientist, Office of Environmental Assessment, Department of Environmental Quality
Michigan: Sylvia Heaton, Senior Aquatic Biologist, Water Quality Standards Coordinator, Department of Environmental Quality
New Hampshire: David Neils, Biologist, Department of Environmental Services
New York: Margaret Novak, Chief, Statewide Waters Monitoring Section, Department of Environmental Conservation
North Carolina: Dianne Reid, Environmental Biologist, Supervisor, Intensive Survey Unit, Department of Environment and Natural Resources; and Connie Brower, Environmental Chemist, Classifications and Standards Unit, Department of Environment and Natural Resources
Oregon: Debra Studevant, Water quality standards coordinator, Department of Environmental Quality
Wyoming: Bill DiRienzo, Watershed Program Supervisor, Department of Environmental Quality

Appendix D
SABS-Related Criteria for Surface Water Quality

D.1 Examples of Approaches Currently in Use or Under Development in States and Internationally

Idaho:
In Idaho, as in many states, new numeric criteria must comply with existing narrative WQS, such as: "*Sediment shall not exceed quantities ... which impair beneficial uses*" (IDAPA 58.01.02.200.08). One of the important beneficial uses of Idaho streams is production of trout and salmon for ecological and recreational purposes. Although macroinvertebrate and fish community integrity are measured in Idaho (using the Stream Macroinvertebrate Index and the Stream Fish Index), these measures are not currently used as indicators of SABS impairment. Rather, the state considers as indicators water column and instream measures that change with increasing fine sediments and are known to affect growth, survival, reproductive success, and habitat suitability of salmonids and other aquatic. These include decreases in light penetration, riffle stability, and intergravel dissolved oxygen, and increases in turbidity, total suspended solids, embeddedness, extent of streambed covered by surface fines, and percent subsurface fines in potential spawning gravels. Target levels for these measures are based on relationships in the scientific literature (primarily from studies in the Northwestern U.S.), background conditions in Idaho streams, and existing Idaho WQS (Idaho DEQ 2003).

New Mexico:
New Mexico recently developed a draft protocol to support an interpretation of their state WQS stream bottom deposits narrative standard (New Mexico Environment Department 2002), which states:

> *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.*

Unlike Idaho, New Mexico's draft protocol calls for making use attainment decisions based on both biological and non-biological indicators. The approach is based on reference condition sites. Specifically, the protocol 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 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.

British Columbia, Canada:
Environment Canada has narrative guidelines for deposited bedload sediment, streambed substrate, suspended sediment, and turbidity for aquatic life uses. The British Columbia (BC) Ministry of Water, Land and Air Protection released the Ambient Water Quality Guidelines (Criteria) for Turbidity and Suspended and Benthic Sediments that contain numeric thresholds

compliant with the national narrative guidelines (Singleton 2001, technical appendices; Caux et al. 1997a,b).

The BC guidelines are broken down by five water uses (untreated drinking water, treated drinking water, recreation and aesthetics, aquatic life, and the final catch-all, terrestrial life, irrigation, and industrial uses), three sediment indicators (turbidity, suspended sediments, and stream substrate composition), and two flow conditions (clear flow and turbid flow). Numeric criteria, based on background conditions, exist for each indicator and flow condition for aquatic life use.

Australia and New Zealand:

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000) define criteria for visual clarity and aesthetics, and outline an approach for defining trigger values which, when exceeded, indicate that a problem may be present due to the stressor of concern. 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 percent.

The trigger values approach mirrors the reference condition method using biological or ecological indicators. The trigger value is defined 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, and the 80th percentile of the reference system distribution is chosen. 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.

European Union (EU):

The European Water Framework Directive (WFD) directs the member states to establish goals, basin plans, and monitoring of ecological quality (The European Parliament and the Council of the European Union 2000). Assessment of ecological quality is based on a reference condition method. Annex II of the Directive specifies methods for establishing type-specific reference conditions for surface waterbody types. Reference conditions may be based on field data, modeling, or professional judgment. Member states are also directed to collect and maintain information on the type and magnitude of significant anthropogenic pressures such as urban development, forestry, and fisheries.

Table D.1. Suspended and Bedded Sediments (SABS)-Related Criteria for Surface Water Quality by state (U.S. EPA 2001).

State	Numeric	Narrative
Alabama	**TURBIDITY:** **Public Water Supply**: There shall be no turbidity of other than natural origin that will cause substantial visible contrast with the natural appearance of waters or interfere with any beneficial uses they serve. Furthermore, in no case shall turbidity exceed 50 Nephelometric units above background. Background will be interpreted as the natural condition of the receiving waters, without the influence of man-made or man-induced causes. Turbidity levels caused by natural runoff will be included in establishing background levels. The following uses require the same turbidity criteria as described above: swimming and other whole body water-contact sports; shellfish harvesting; fish and wildlife; agricultural and industrial water supply; industrial operations; and navigation.	
Alaska	**FRESH WATER USES:** **Drinking Water Supply and Culinary Food Processing, Contact Recreation**: Nephelometric turbidity units (NTU) may not exceed 5 Nephelometric units above natural conditions when the natural turbidity is 50 NTU or less, and may not have more than 10% increase in turbidity when the natural turbidity is more than 50, not to exceed a maximum increase of 25 NTU. No measurable increase in concentration of **settleable solids** above natural conditions, measured by the volumetric Imhoff cone. **Secondary Contact Recreation**: Shall not exceed 5 NTU above natural conditions when natural turbidity is 50 NTU or less, and not have more than 20% increase in turbidity when the natural condition is more than 50 NTU, not to exceed a maximum increase of 50 NTU. For all lake waters, shall not exceed 5 NTU over natural conditions. **Aquaculture**: May not exceed 25 NTU above natural conditions. For all lake waters, may not exceed 5 NTU above natural conditions.	**Water Supply**: aquaculture, industrial: No imposed loads that will interfere with established water supply treatment levels. **Agriculture**: may not cause detrimental effects on indicated use. **In other surface waters:** no sediment loads (suspended or deposited) that may cause adverse effects on aquatic animal or plant life, their reproduction, or habitat may be present.

Table D.1. cont.

State	Numeric	Narrative
Alaska (cont.)	**Growth and Propagation of Fish, Shellfish, and Other Aquatic Life**: The percent accumulation of fine sediment in the range of 0.1 mm to 4.0 mm in the gravel bed of waters used by anadromous or resident fish for spawning may not be increased more than 5% by weight above natural conditions (as shown from grain size accumulation graph). In no case may the 0.1 mm to 4.0 mm fine sediment range in those gravel beds exceed a maximum of 30% by weight (as shown from grain size accumulation graph). **Water Supply Agriculture, including Irrigation and Stock Watering**: For sprinkler irrigation, water must be free of particles of 0.074 mm or coarser. For irrigation or water spreading, may not exceed 200 mg/l for an extended period of time.	
Arizona	Designated uses of a surface water may include full body contact, partial body contact, domestic water source, fish consumption, aquatic and wildlife (cold water fishery), aquatic and wildlife (warm water fishery), aquatic and wildlife (ephemeral), aquatic and wildlife (effluent dependent water), agricultural irrigation, and agricultural livestock watering. The following water quality standards for **turbidity**, expressed as a maximum concentration in Nephelometric Turbidity Units (NTU), shall not be exceeded: **Full body contact and incidental human contact**: Not to exceed 50 NTU in streams, or 25 NTU in lakes. **Aquatic and Wildlife (cold water fishery)**: Not to exceed 10 NTU in rivers, streams, other flowing waters, lakes, reservoirs, tanks and ponds. **Aquatic and Wildlife (warm water fishery)**: Not to exceed 50 NTU in rivers, streams, and other flowing waters. Not to exceed 25 NTU in lakes, reservoirs, tanks and ponds.	A surface water shall be free from pollutants in amounts or combinations that: 1. Settle to form bottom deposits that inhibit or prohibit the habitation, growth, or propagation of aquatic life or that impair recreational uses. 2. Cause objectionable odor in the area in which the surface water is located. 3. Cause off-taste or odor in drinking water. 4. Cause off-flavor in aquatic organisms or waterfowl. 5. Are toxic to humans, animals, plants, or other organisms. 6. Cause the growth of algae or aquatic plants that inhibit or prohibit the habitation, growth, or propagation of other aquatic life or that impair recreational uses. 7. Cause or contribute to a violation of an aquifer water quality standard. 8. Change the color of the surface water from natural background levels of color.

Table D.1. cont.

State	Numeric	Narrative
Arkansas	In establishing these standards, the Commission has taken into consideration the use and value of the streams for public water supplies, commercial, industrial and agricultural uses, aesthetics, recreational purposes, propagation of fish and wildlife, other beneficial uses, and views expressed at public hearings. There shall be no distinctly visible increase in **turbidity** of receiving waters attributable to municipal, industrial, agricultural, other waste discharges or instream activities. **Water bodies/Streams** — **Limit (NTU)** Ozark Highlands — 10 Boston Mountains — 10 Arkansas River Valley — 21 Ouachita Mountains — 10 Springwater-influenced Gulf Coastal — 21 Typical Gulf Coastal — 45 Channel-Altered Delta — 75 Arkansas River — 50 Mississippi River — 50 Red River — 50 St. Francis River — 75 Trout — 10 Lakes and Reservoirs — 25	Significant physical alterations of the habitat within extraordinary resource waters, ecologically sensitive waterbodies or natural and scenic waterways are not allowed.
California	None listed in state regulations. U.S. EPA provides some (from California Water Quality Standards by River Basins, Ca. 1975).	

Table D.1. cont.

State	Numeric	Narrative
Colorado	Provide some numeric standards by major river systems, although no turbidity or other sediment-related criteria are specified.	The Commission recognizes that excessive salinity and suspended solids levels can be detrimental to the water use classifications. The Commission has established salinity standards for the Colorado River Basin ("Water Quality Standards for Salinity including Numeric Criteria and Plan of Implementation of Salinity Control", Commission Regulation No. 39) but has not established or assigned other standards for salinity or suspended solids control practices to be developed through 208 plans, coordination with agricultural agencies, and further studies of existing water quality.
Connecticut	Could not identify any sediment-related criteria for non-point source (U.S. EPA document lists upper turbidity limits for streams classed)	
Delaware	**For all Fresh Waters**: Turbidity shall not exceed natural levels by more than 10 Nephelometric or Formazin Turbidity Units. For mixing zones, there is a limit of 10 NTU above natural background.	
Florida	**Turbidity**: Shall not exceed 29 NTUs above natural background conditions. **Biological Integrity**: No more than a 75% reduction of benthic macro-invertebrates using the Shannon-Weaver Index relative to established background levels measured using organisms retained by a U.S. Standard No. 30 sieve collected and composited from a minimum of three natural mini-Dendy type artificial substrate samples of 0.1 to 0.15 m^2, incubated for 4 weeks. **Transparency:** Shall not be reduced by more than 10%.	

Table D.1. cont.

<table>
<tr><th>State</th><th>Numeric</th><th>Narrative</th></tr>
<tr><td>Georgia</td><td>All waters shall be free from turbidity which results in a substantial visual contrast in a water body due to a man-made activity. The upstream appearance of a body of water shall be as observed at a point immediately upstream of a turbidity-causing man-made activity. That upstream appearance shall be compared to a point which is located sufficiently downstream from the activity so as to provide an appropriate mixing zone.</td><td>All waters shall be free from material related to municipal, industrial or other discharges which produce turbidity, color, odor or other objectionable conditions which interfere with legitimate water uses.</td></tr>
<tr><td>Hawaii</td><td>Streams: Not to exceed the given value:
<table>
<tr><th></th><th></th><th colspan="2">More Than:</th></tr>
<tr><th>Parameter</th><th>Geometric Mean</th><th>10% of the Time</th><th>2% of the Time</th></tr>
<tr><td>Suspended Solids (mg/L)</td><td>10.0**</td><td>30.0**</td><td>55.0**</td></tr>
<tr><td>Turbidity (N.T.U)</td><td>5.0*</td><td>15.0*</td><td>25.0*</td></tr>
<tr><td></td><td>2.0**</td><td>5.5**</td><td>10.0**</td></tr>
</table>
*Wet Season- November 1 through April 30
**Dry Season- May 1 through October 31

Bottom criteria for streams:
(A) Episodic deposits of flood-borne soil sediment shall not occur in quantities exceeding an equivalent thickness of five millimeters (0.20 inch) over hard bottoms twenty-four hours after a heavy rainstorm.
(B) Episodic deposits of flood-borne soil sediment shall not occur in quantities exceeding an equivalent thickness of ten millimeters (0.40 inch) over soft bottoms twenty-four hours after a heavy rainstorm.
(C) In soft bottom material in pool sections of streams, oxidation-reduction potential (EH) in the top ten centimeters (four inches) shall not be less than +100 millivolts.
(D) In soft bottom material in pool sections of streams, no more than fifty per cent of the grain size distribution of sediment shall be smaller than 0.125 millimeter (0.005 inch) in diameter.</td><td>All waters shall be free of substances attributable to domestic, industrial, or other controllable sources of pollutants, including:
(1) Materials that will settle to form objectionable sludge or bottom deposits.
(2) Floating debris, oil, grease, scum, or other floating materials.
(3) Substances in amounts sufficient to produce taste in the water or detectable off-flavor in the flesh of fish, or in amounts sufficient to produce objectionable color, turbidity or other conditions in the receiving waters.
(4) High or low temperatures; biocides; pathogenic organisms; toxic, radioactive, corrosive, or other deleterious substances at levels or in combinations sufficient to be toxic or harmful to human, animal, plant, or aquatic life, or in amounts sufficient to interfere with any beneficial use of the water.
(5) Substances or conditions or combinations thereof in concentrations which produce undesirable aquatic life.
(6) Soil particles resulting from erosion on land involved in earthwork, such as the construction of public works; highways; subdivisions; recreational, commercial, or industrial developments; or the cultivation and management of agricultural lands.</td></tr>
</table>

Table D.1. cont.

<table>
<tr><th>State</th><th>Numeric</th><th>Narrative</th></tr>
<tr><td>Hawaii (cont.)</td><td>Biological criteria for streams:
The director shall prescribe the appropriate parameters, measures, and criteria for monitoring stream bottom biological communities including their habitat, which may be affected by proposed actions. Permanent benchmark stations may be required where necessary for monitoring purposes. The water quality criteria for this subsection shall be deemed to be met if time series surveys of benchmark stations indicate no relative changes in the relevant biological communities, as noted by biological community indicators or by indicator organisms which may be applicable to the specific site.

Coastal and Marine

Turbidity (NTU) not to exceed the given value:
<table>
<tr><th></th><th></th><th colspan="2">More Than</th></tr>
<tr><th>Location</th><th>Geometric Mean</th><th>10% of the Time</th><th>2% of the Time</th></tr>
<tr><td>All Estuaries</td><td>1.5</td><td>3.0</td><td>5.0</td></tr>
<tr><td>Pearl Harbor</td><td>4.0</td><td>8.0</td><td>15.0</td></tr>
<tr><td>Embayments</td><td>0.4</td><td>1.0</td><td>1.5</td></tr>
<tr><td>Open Coastal Waters</td><td>0.5*
0.02**</td><td>1.25*
0.05**</td><td>2.0*
1.0**</td></tr>
<tr><td>Oceanic Waters</td><td>0.03</td><td>0.1</td><td>0.2</td></tr>
<tr><td>Marine</td><td>0.1</td><td></td><td></td></tr>
</table>
* Wet season - November 1 through April 30.
** Dry season - May 1 through October 31.

Marine Bottom Types:
Sand beaches: No more than fifty per cent of the grain size distribution of sediment shall be smaller than 0.125 millimeters in diameter.
Lava rock shorelines: Episodic deposits of flood-borne sediment shall not occur in quantities exceeding an equivalent thickness of five millimeters (0.20 inch) for longer than twenty-four hours after a heavy rainstorm.
Marine pools and protected coves: No more than fifty per cent of the grain size distribution of the sediment shall be smaller than 0.125 millimeters in diameter.
Hard bottoms: No thicker than an equivalent of five millimeters (0.2 inch).
Soft bottoms: No thicker than an equivalent of ten millimeters (0.4 inch).</td><td>The water quality standards (for most subsections) shall be deemed to be met if time series surveys of benchmark station indicate no relative changes in the relevant biological communities, as noted by biological community indicators or by indicator organisms which may be applicable to the specific site.

Specific criteria to be applied to all reef flats and reef communities: No action shall be undertaken which would substantially risk damage, impairment, or alteration of the biological characteristics of the areas named herein.

"Soft bottom communities" means poorly described and "patchy" communities, mostly of burrowing organisms, living in deposits at depths between two to forty meters (approximately six to one hundred thirty feet). The particle size of sediment, depth below sea level, and degree of water movement and associated sediment turnover dictate the composition of animals which rework the bottom with burrows, trails, tracks, ripples, hummocks, and depressions.</td></tr>
</table>

Table D.1. cont.

State	Numeric	Narrative
Hawaii (cont.)	***Reef Flats and Reef Communities:*** No more than fifty per cent of the grain size distribution of sand patches shall be smaller than 0.125 millimeters in diameter; Episodic deposits of flood-borne soil sediment shall not occur in quantities exceeding equivalent thicknesses for longer than twenty-four hours after a heavy rainstorm as follows: **Living coral surfaces**: No thicker than an equivalent of two millimeters (0.08 inch).	
Idaho	**Aquatic Habitat Parameters**: These parameters may include, but are not limited to, stream width, stream depth, stream shade, measurements of sediment impacts, bank stability, water flows, and other physical characteristics of the stream that affect habitat for fish, macroinvertebrates or other aquatic life; and (3-20-97). **Biological Parameters**: These parameters may include, but are not limited to, evaluation of aquatic macroinvertebrates including Ephemeroptera, Plecoptera and Trichoptera (EPT), Hilsenhoff Biotic Index, measures of functional feeding groups, and the variety and number of fish or other aquatic life to determine biological community diversity and functionality.	In determining whether a water body fully supports designated and existing beneficial uses, the Department shall determine whether all of the applicable water quality standards are being achieved, including any criteria developed pursuant to these rules, and whether a healthy, balanced biological community is present. The Department shall utilize biological and aquatic habitat parameters listed below and in the current version of the "Water Body Assessment Guidance", as published by the Idaho Department of Environmental Quality, as a guide to assist in the assessment of beneficial use status. These parameters are not to be considered or treated as individual water quality criteria or otherwise interpreted or applied as water quality standards.
Illinois	**Soil Loss**: Effective January 1, 1994 to January 1, 2000, all land greater than 5% slope subject to this program shall be considered in compliance with the state program if the long term annual soil losses are kept at or below one and one-half "T" value. Effective January 1, 2000, and thereafter, all land subject to the Act shall meet "T" value. The soil loss tolerance as established by the Soil Conservation Service and as published in the Soil Conservation Service Technical Guide (United States Department of Agriculture, Soil Conservation Service, Field Offices in Illinois) are adopted as the official "T" values for soils of Illinois.	Studies have not yet been able to accurately determine what part of the stream sediment load is attributable to stream bank erosion and what part comes from non-point sources of erosion. While the Department will encourage all conservation measures and practices to minimize stream bank erosion, more research needs to be done before the feasibility of and the responsibility for controlling stream bank erosion can be determined.

Table D.1. cont.

State	Numeric	Narrative
Indiana	No sediment-related criteria identified.	(1) All waters at all times and at all places, including the mixing zone, shall meet the minimum conditions of being free from substances, materials, floating debris, oil, or scum attributable to municipal, industrial, agricultural, and other land use practices, or other discharges that: (A) Will settle to form putrescent or otherwise objectionable deposits. (B) Are in amounts sufficient to be unsightly or deleterious. (C) Produce color, visible oil sheen, odor, or other conditions in such degree as to create a nuisance. (D) Are in amounts sufficient to be acutely toxic to, or to otherwise severely injure or kill aquatic life, other animals, plants, or humans.
Iowa	Criteria applicable to all surface waters including general use and designated use waters, at all places and at all times to protect livestock and wildlife watering, aquatic life, noncontact recreation, crop irrigation, and industrial, domestic, agricultural and other incidental water withdrawal uses not protected by the specific numerical criteria. **Turbidity**: The turbidity of the receiving water shall not be increased by more than 25 Nephelometric Turbidity Units (N.T.U.) by any point source discharge.	**Physical and biological integrity**: The waters designated as high-quality resource waters will receive protection of existing uses through maintaining water quality levels necessary to fully protect existing uses or improve water quality to levels necessary to meet the designated use criterion. This involves the protection of such features of the water body as channel alignment, bed characteristics, water velocity, aquatic habitat, and the type, distribution and abundance of existing aquatic species.
Kansas		Surface waters shall be free, at all times, from the harmful effects of substances that originate from artificial sources of pollution and that produce any public health hazard, nuisance condition, or impairment of a designated use. Suspended solids added to surface waters by artificial sources shall not interfere with the behavior, reproduction, physical habitat, or other factors related to the survival and propagation of aquatic or semi-aquatic life or terrestrial wildlife.

Table D.1. cont.

State	Numeric	Narrative
Kentucky	**AQUATIC LIFE:** **Warm water aquatic habitat**: The following parameters and associated criteria shall apply for the protection of productive warm water aquatic communities, fowl, animal wildlife, arboreous growth, agricultural, and industrial uses: **Total suspended solids**: Total suspended solids shall not be changed to the extent that the indigenous aquatic community is adversely affected. **Settleable solids**: The addition of settleable solids that may alter the stream bottom so as to adversely affect productive aquatic communities is prohibited.	Surface waters shall not be aesthetically or otherwise degraded by substances that: (a) Settle to form objectionable deposits. (b) Float as debris, scum, oil, or other matter to form a nuisance. (c) Produce objectionable color, odor, taste, or turbidity. (d) Injure, are chronically or acutely toxic to or produce adverse physiological or behavioral responses in humans, animals, fish and other aquatic life. (e) Produce undesirable aquatic life or result in the dominance of nuisance species. (f) Cause fish flesh tainting. The concentration of all phenolic compounds which cause fish flesh tainting shall not exceed five (5) µg/L as an instream value.
Louisiana	**Turbidity** other than that of natural origin shall not cause substantial visual contrast with the natural appearance of the waters of the state or impair any designated water use. Turbidity shall not significantly exceed background; background is defined as the natural condition of the water. Determination of background will be on a case-by-case basis. As a guideline, maximum turbidity levels, expressed as Nephelometric Turbidity Units (NTU), are established and shall apply for the following named waterbodies and major aquatic habitat types of the state: i. Red, Mermentau, Atchafalaya, Mississippi, and Vermilion Rivers and Bayou Teche-150 NTU; ii. estuarine lakes, bays, bayous, and canals-50 NTU; iii. Amite, Pearl, Ouachita, Sabine, Calcasieu, Tangipahoa, Tickfaw, and Tchefuncte Rivers—50 NTU; iv. freshwater lakes, reservoirs, and oxbows-25 NTU; v. designated scenic streams and outstanding natural resource waters not specifically listed in Subsection B.9.b.i-iv of this Section—25 NTU; and vi. other state waters and waterbody segments where natural background turbidity exceeds the values specified in these clauses, turbidity in NTU caused by any discharges shall be restricted to the appropriate background value plus 10 percent. This shall not apply to designated intermittent streams.	All waters shall be free from such concentrations of substances attributable to wastewater or other discharges sufficient to: a. Settle to form objectionable deposits. b. Float as debris, scum, oil, or other matter to form nuisances or to negatively impact the aesthetics. c. Result in objectionable color, odor, taste, or turbidity.

Table D.1. cont.

State	Numeric	Narrative
Louisiana (cont.)	**Biological and Aquatic Community Integrity**: The biological and community structure and function in state waters shall be maintained, protected, and restored except where not attainable and feasible as defined in LAC 33:IX.1109.B.3. This is the ideal condition of the aquatic community inhabiting the unimpaired water bodies of a specified habitat and region as measured by community structure and function. The biological integrity will be guided by the fish and wildlife propagation use designated for that particular water body. Fish and wildlife propagation uses are defined in LAC 33:IX.1111.C. The condition of these aquatic communities shall be determined from the measures of physical, chemical, and biological characteristics of each surface water body type, according to its designated use (LAC 33:IX.1123). Reference site conditions will represent naturally attainable conditions. These sites should be the least impacted and most representative of water body types. Such reference sites or segments of water bodies shall be those observed to support the greatest variety and abundance of aquatic life in the region as is expected to be or has been recorded during past surveys in natural settings essentially undisturbed by human impacts, development, or discharges. This condition shall be determined by consistent sampling and reliable measures of selected, indicative communities of animals and/or invertebrates as established by the department and may be used in conjunction with acceptable chemical, physical, and microbial water quality measurements and records as deemed for this purpose.	
Maine	No sediment-related criteria identified.	
Maryland	**Turbidity** (All streams): Turbidity in the surface water resulting from any discharge may not exceed 150 units at any time or 50 units as a monthly average. Units shall be measured in NTU.	Turbidity may not exceed level detrimental to aquatic life.

Table D.1. cont.

State	Numeric	Narrative
Massachusetts	**Water Body Classification** Class A - These waters are designated as a source of public water supply. Class B - These waters are designated as a habitat for fish, other aquatic life, and wildlife, and for primary and secondary contact recreation. (c) Class C - These waters are designated as a habitat for fish, other aquatic life and wildlife, and for secondary contact recreation. Class SA - These waters are designated as an excellent habitat for fish, other aquatic life and wildlife and for primary and secondary contact recreation. In approved areas they shall be suitable for shellfish harvesting without depuration (Open Shellfish Areas). These waters shall have excellent aesthetic value. Class SB - These waters are designated as a habitat for fish, other aquatic life and wildlife and for primary and secondary contact recreation. In approved areas they shall be suitable for shellfish harvesting with depuration (Restricted Shellfish Areas). These waters shall have consistently good aesthetic value. No sediment-related numeric criteria are specified.	**CLASS A, B, C, SA, SB** **Solids**: These waters shall be free from floating, suspended and settleable solids in concentrations or combinations that would impair any use assigned to this class, that would cause aesthetically objectionable conditions, or that would impair the benthic biota or degrade the chemical composition of the bottom. **Color and Turbidity**: These waters shall be free from color and turbidity in concentrations or combinations that are aesthetically objectionable or would impair any use assigned to this class.
Michigan	Uses an effluent limitation system. No numeric criteria were identified.	
Minnesota	**Turbidity:** Domestic consumption Class A–5 Class B–5 Class C–24 Fisheries and recreation Class A–10 Class B–25 Class C–25 Industrial consumption Class A–5	

Table D.1. cont.

State	Numeric	Narrative
Mississippi	The turbidity outside the limits of a 750-foot mixing zone shall not exceed the background turbidity at the time of discharge by more than 50 NTU.	Waters shall be free from materials attributable to municipal, industrial, agricultural or other discharges producing color, odor, taste, total suspended solids, or other conditions in such degree as to create a nuisance, render the waters injurious to public health, recreation or to aquatic life and wildlife or adversely affect the palatability of fish, aesthetic quality, or impair the waters for any designated uses.
Missouri		**Turbidity and Color**: Water contaminants shall not cause or contribute to turbidity or color that will cause substantial visible contrast with the natural appearance of the stream or lake or interfere with beneficial uses. **Solids**: Water contaminants shall not cause or contribute to solids in excess of a level that will interfere with beneficial uses. The stream or lake bottom shall be free of materials which will adversely alter the composition of the benthos, interfere with the spawning of fish or development of their eggs or adversely change the physical or chemical nature of the bottom. **Biocriteria**: The biological integrity of waters, as measured by lists or numeric diversity indices of benthic invertebrates, fish, algae or other appropriate biological indicators, shall not be significantly different from reference waters. Waters shall be compared with reference waters of similar size within an ecoregion. Reference water locations are listed in a Table.
Montana	**Turbidity** B-1 Streams: The maximum allowable increase above naturally occurring turbidity is 5 NTU. B-2 and B-3 Streams: The maximum allowable increase above naturally occurring turbidity is 10 NTU. C-1 Streams: The maximum allowable increase above naturally occurring turbidity is 5 NTU. C-2 Streams: The maximum allowable increase above naturally occurring turbidity is 10 NTU.	B1 B2 B-3 C-1 C-2 water bodies No increases are allowed above naturally occurring concentrations of sediment, settleable solids, oils, or floating solids, which will or are likely to create a nuisance or render the waters harmful, detrimental, or injurious to public health, recreation, safety, welfare, livestock, wild animals, birds, fish, or other wildlife.

Table D.1. cont.

State	Numeric	Narrative
Nebraska	No sediment-related criteria identified.	
Nevada	Class A waters include waters or portions of waters located in areas of little human habitation, no industrial development or intensive agriculture and where the watershed is relatively undisturbed by man's activity: **Settleable solids**: Only amounts attributable to man's activities which will not make the waters unsafe or unsuitable as a drinking water source or which will not be detrimental to aquatic life or for any other beneficial use established for this class. Specific **turbidity** (NTU) and **suspended solids** (mg/l) values are given for specific rivers in the state. **Aquatic life**: The water must be suitable as a habitat for fish and other aquatic life existing in a body of water. This does not preclude the reestablishment of other fish or aquatic life.	For some waters (not all), turbidity is included in the following statement: Waters must be free from high temperature, biocides, organisms pathogenic to human beings, toxic, corrosive or other deleterious substances attributable to domestic or industrial waste or other controllable sources at levels or combinations sufficient to be toxic to human, animal, plant or aquatic life or in amounts sufficient to interfere with any beneficial use of the water. Compliance with the provisions of this subsection may be determined in accordance with methods of testing prescribed by the department. If used as an indicator, survival of test organisms must not be significantly less in test water than in control water.

Table D.1. cont.

State	Numeric	Narrative
New Hampshire	**Deposits** (a) Class A waters shall contain no benthic deposits, unless naturally occurring. (b) Class B waters shall contain no benthic deposits that have a detrimental impact on the benthic community, unless naturally occurring. **Turbidity** (a) Class A waters shall contain no turbidity, unless naturally occurring. (b) Class B waters shall not exceed naturally occurring conditioning by more than 10 NTUs. (c) Waters identified in RSA 485-A:8, III shall contain no turbidity of unreasonable kind or quality. (d) Class C is the same as class B. **Aquatic Life** (a) The surface waters shall support and maintain a balanced, integrated, and adaptive community of organisms having a species composition, diversity, and functional organizational comparable to that of similar natural habitats of a region. (b) Differences from naturally occurring conditions shall be limited to non-detrimental differences in community structure and function.	(1) All surface waters shall be free from substances in kind or quantity that: a. Settle to form harmful deposits. b. Float as foam, debris, scum or other visible substances. c. Produce odor, color, taste or turbidity which is not naturally occurring and d. Would render it unsuitable for its designated uses. e. Result in the dominance of nuisance species, or f. Interfere with recreational activities.
New Jersey	**SOLIDS, SUSPENDED** 25.0 (mg/L) **Turbidity**: Fresh waters that are not designated as FW1(those fresh waters, as designated in N.J.A.C. 7:9B-1.15(h) Table 6, that are to be maintained in their natural state of quality (set aside for posterity) and not subjected to any man-made wastewater discharges or increases in runoff from anthropogenic activities) or Pinelands Waters: Maximum 30-day average of 15 NTU, a maximum of 50 NTU at any time. **Coastal saline waters**: Levels shall not exceed 10.0 NTU. **Saline Estuaries**: Maximum 30-day average of 10 NTU, a maximum of 30 NTU at any time.	

Table D.1. cont.

State	Numeric	Narrative
New Mexico		**Turbidity**: Turbidity attributable to other than natural causes shall not reduce light transmission to the point that the normal growth, function, or reproduction of aquatic life is impaired or that will cause substantial visible contrast with the natural appearance of the water. **Bottom Deposits:** 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.
New York	**TURBIDITY** **Water Body Types AA, A, B, C, D, SA, SB, SC, SD, I**: No increase except from natural sources that will cause a substantial visible contrast to natural conditions. In water body type GA, turbidity shall not exceed 5 NTU.	**Suspended, Colloidal and Settleable Solids** AA, A, B, C, D, SA, SB, SC, I, SD, A-Special None from sewage, industrial colloidal and wastes or other wastes that will cause deposition or impair the waters for their best usages.
North Carolina	**Turbidity**: the turbidity in the receiving water shall not exceed: 50 Nephelometric Turbidity Units (NTU) in streams not designated as trout waters. 10 NTU in streams, lakes or reservoirs designated as trout waters. 25 NTU for lakes and reservoirs not designated as trout waters. If turbidity exceeds these levels compared to natural background conditions, the existing turbidity level cannot be increased. Compliance with this turbidity standard can be met when land management activities that employ Best Management Practices (BMPs) [as defined by Rule .0202(6) of this Section] recommended by the Designated Nonpoint Source Agency [as defined by Rule .0202 of this Section]. BMPs must be in full compliance with all specifications governing the proper design, installation, operation and maintenance of such BMPs.	**Water Body Classification** **Class C:** freshwaters protected for secondary recreation, fishing, and aquatic life including propagation and survival, and wildlife. All freshwaters shall be classified to protect these uses at a minimum. **Class B:** freshwaters protected for primary recreation which includes swimming on a frequent or organized basis and all Class C uses.

Table D.1. cont.

State	Numeric	Narrative
North Carolina (cont.)	**Nonpoint Source and Storm water Pollution Control Criteria For Entire Watershed** WS-II Waters (i) Nonpoint **Source and Storm water Pollution Control Criteria For Entire Watershed**: (A) Low Density Option: Development density must be limited to either no more than one dwelling unit per acre of single family detached residential development (or 40,000 square foot lot excluding roadway right-of-way) or 12 percent built-upon area for all other residential and non-residential development in the watershed outside of the critical area; Storm water runoff from the development shall be transported by vegetated conveyances to the maximum extent practicable. (B) High Density Option: If new development exceeds the low density option requirements as stated in Sub-Item (3)(b)(i)(A) of this Rule, then engineered storm water controls must be used to control runoff from the first inch of rainfall; new residential and non-residential development shall not exceed 30 percent built-upon area. (C) Land within the watershed shall be deemed compliant with the density requirements if the following condition is met: The density of all existing development at the time of reclassification does not exceed the density requirement when densities are averaged throughout the entire watershed area at the time of classification. (D) Cluster development is allowed on a project-by-project basis. (E) Minimum 100 foot vegetative buffer is required for all new development activities that exceed the low density option requirements as specified in Sub-Items (3)(b)(i)(A) and Sub-Item (3)(b)(ii)(A) of this Rule; otherwise a minimum 30 foot vegetative buffer for development activities is required along all perennial waters indicated on the most recent versions of U.S.G.S. 1:24,000 (7.5 minute) scale topographic maps or as determined by local government studies; nothing in this Section shall stand as a bar to desirable artificial stream bank or shoreline stabilization.	**Class WS:** waters protected as water supplies. (There are five sub-categories depending on degree of development in the watershed.) The following are supplemental classifications: (A) **Trout waters (Tr)**: freshwaters protected for natural trout propagation and survival of stocked trout. (B) **Swamp waters (Sw)**: waters which have low velocities and other natural characteristics which are different from adjacent streams. (C) **Nutrient Sensitive Waters (NSW)**: waters subject to growths of microscopic or macroscopic vegetation requiring limitations on nutrient inputs. (D) **Outstanding Resource Waters (ORW)**: unique and special waters of exceptional state or national recreational or ecological significance that require special protection to maintain existing uses.

Table D.1. cont.

State	Numeric	Narrative
North Carolina (cont.)	(F) No new development is allowed in the buffer; water dependent structures, or other structures such as flag poles, signs and security lights, which result in only diminimus increases in impervious area and public projects such as road crossings and greenways may be allowed where no practicable alternative exists; these activities shall minimize built-upon surface area, direct runoff away from the surface waters and maximize the utilization of BMPs. Other water classes have similar BMP type rules with some of the numbers changed slightly. **Critical Area Nonpoint Source and Storm water Pollution Control Criteria**: Total dissolved solids not greater than 500 mg/l.	
North Dakota	Class I streams: **Suspended solids-** Thirty milligrams per liter consecutive thirty-day average. Class II: none	
Ohio	Water quality standards are specified as deviation from **biotic indices** for each ecoregion. Values of the index are specified in detail by waterbody or ecoregion [not reproduced here].	
Oklahoma	**Classification**: The narrative and numerical criteria in this section are designated to promote fish and wildlife propagation for the fishery classifications of Habitat Limited Aquatic Community, Warm Water Aquatic Community, Cool Water Aquatic Community (Excluding Lake Waters), and Trout Fishery (Put and Take). (c) Cool Water Aquatic Community subcategory. Cool Water Aquatic Community means a subcategory of the beneficial use category "Fish and Wildlife Propagation" where the water quality, water temperature, and habitat are adequate to support warm water intolerant climax fish communities and includes an environment suitable for the full range of cool water benthos. Typical species may include smallmouth bass, certain darters and stoneflies.	

Table D.1. cont.

State	Numeric	Narrative
Oklahoma (cont.)	**Turbidity** from other than natural sources shall be restricted to not exceed the following numerical limits: **Cool Water Aquatic Community/Trout Fisheries**: 10 NTU. Lakes: 25 NTU Other surface waters: 50 NTU. In waters where background turbidity exceeds these values, turbidity from point sources shall be restricted to not exceed ambient levels. Numerical criteria listed above apply only to normal stream flow conditions. Elevated turbidity levels may be expected during, and for several days after, a runoff event. **Biological Criteria** Aquatic life in all waterbodies designated Fish and Wildlife Propagation (excluding waters designated "Trout, put-and-take") shall not exhibit degraded conditions as indicated by one or both of the following: (i) comparative regional reference data from a station of reasonably similar watershed size or flow, habitat type and Fish and Wildlife beneficial use subcategory designation or (ii) by comparison with historical data from the waterbody being evaluated.	
Oregon	**Turbidity** (Nephelometric Turbidity Units, NTU): No more than a ten percent cumulative increase in natural stream turbidities shall be allowed, as measured relative to a control point immediately upstream of the turbidity causing activity. However, limited duration activities necessary to address an emergency or to accommodate essential dredging, construction or other legitimate activities and which cause the standard to be exceeded may be authorized provided all practicable turbidity control techniques have been applied and one of the following has been granted. The formation of appreciable bottom or sludge deposits or the formation of any organic or inorganic deposits deleterious to fish or other aquatic life or injurious to public health, recreation, or industry shall not be allowed [some modifications to standards for specific rivers].	Notwithstanding the water quality standards contained below, the highest and best practicable treatment and/or control of wastes, activities, and flows shall in every case be provided so as to maintain dissolved oxygen and overall water quality at the highest possible levels and water temperatures, coliform bacteria concentrations, dissolved chemical substances, toxic materials, radioactivity, turbidities, color, odor, and other deleterious factors at the lowest possible levels.

Table D.1. cont.

State	Numeric	Narrative
Pennsylvania	No statewide criteria. The following turbidity criteria are specific to waters in the Neshaminy Creek Basin where indicated, based on special studies: Potable water supply, warm water fishes, migratory fish: Not more than 100 NTU. Potable water supply and Cold Water Fishes (Maintenance or propagation, or both, of fish species including the family Salmonidae and additional flora and fauna which are indigenous to a cold water habitat.): For the period May 15—September 15 of any year, not more than 40 NTU. Warm Water Fish, Migratory fish: for the period September 16—May 14 of any year, not more than 100 NTU.	(a) Water may not contain substances attributable to point or nonpoint source discharges in concentration or amounts sufficient to be inimical or harmful to the water uses to be protected or to human, animal, plant or aquatic life. (b) In addition to other substances listed within or addressed by this chapter, specific substances to be controlled include, but are not limited to, floating materials, oil, grease, scum and substances which produce color, tastes, orders, turbidity or settle to form deposits.
Rhode Island	Class A (Potable water supply highest use): **Turbidity** not to exceed 5 NTU over background. Class B and C (fish and wildlife habitat and primary and secondary contact recreational activities. They shall be suitable for compatible industrial processes and cooling, hydropower, aquacultural uses, navigation, and irrigation and other agricultural uses: **Turbidity** not to exceed 10 NTU over background.	

Table D.1. cont.

State	Numeric	Narrative
South Carolina	Biological assessment methods may be employed in appropriate situations to determine abnormal nutrient enrichment, median tolerance limits (TLm), concentration of toxic substances, acceptable instream concentrations, or acceptable effluent concentrations for maintenance of a balanced indigenous aquatic community. Put, Grow, and Take (TPGT) are freshwaters suitable for supporting growth of stocked trout populations and a balanced indigenous aquatic community of fauna and flora. Suitable also for uses listed in Freshwaters. For this class: **Turbidity**: Not to exceed 10% above natural conditions, provided existing uses are maintained. Other water classes do not have specific criteria for turbidity.	4. All ground waters and surface waters of the state shall at all times, regardless of flow, be free from: a. Sewage, industrial waste, or other waste that will settle to form sludge deposits that are unsightly, putrescent, or odorous to such degree as to create a nuisance, or interfere with classified water uses or existing water uses. b. Floating debris, oil, grease, scum, and other floating material attributable to sewage, industrial waste, or other waste in amounts sufficient to be unsightly to such a degree as to create a nuisance or interfere with classified water uses or existing water uses. c. Sewage, industrial, or other waste which produce taste or odor or change the existing color or physical, chemical, or biological conditions in the receiving waters or aquifers to such a degree as to create a nuisance, or interfere with classified water uses (except classified uses within mixing zones as described in this regulation) or existing water uses. d. High temperature, toxic, corrosive, or deleterious substances attributable to sewage, industrial waste, or other waste in concentrations or combinations which interfere with classified water. b. uses (except classified uses within mixing zones as described in this regulation), existing water uses, or which are harmful to human, animal, plant or aquatic life.

Table D.1. cont.

State	Numeric	Narrative
South Dakota	**Coldwater permanent fish life propagation waters**: Total suspended solids (TSS) less than 30 mg/L as a 30 day average and 53 mg/L as a daily maximum. **Coldwater semi-permanent fish life propagation waters**: TSS less than 90 mg/L as a 30 day average and 158 mg/L as a daily maximum. **Warm water permanent and semi-permanent fish life propagation waters**: TSS less than 90 mg/L as a 30 day average and 158 mg/L as a daily maximum. **Warm water marginal fish life propagation waters**: TSS less than 150 mg/L as a 30 day average and 263 mg/L as a daily maximum. **Effluent Criteria**: Effluents discharged from water pollution control facilities into waters classified for the beneficial use of coldwater permanent fish life propagation and coldwater marginal fish life propagation must be of high quality. In order to protect these uses, the effluent may not exceed 10 mg/L of suspended solids and 10 mg/L of 5-day biochemical oxygen demand.	Raw or treated sewage, garbage, rubble, unpermitted fill materials, municipal wastes, industrial wastes, or agricultural wastes which produce floating solids, scum, oil slicks, material discoloration, visible gassing, sludge deposits, sediments, slimes, algal blooms, fungus growths, or other offensive effects may not be discharged or caused to be discharged into surface waters of the state. All waters of the state must be free from substances, whether attributable to human-induced point source discharges or nonpoint source activities, in concentrations or combinations which will adversely impact the structure and function of indigenous or intentionally introduced aquatic communities.
Tennessee	Turbidity or Color - There shall be no turbidity or color in amounts or characteristics that cannot be reduced to acceptable concentrations by conventional water treatment processes.	For all beneficial uses: Solids, Floating Materials and Deposits - There shall be no distinctly visible solids, scum, foam, oily slick, or the formation of slimes, bottom deposits or sludge banks of such size or character as may impair the usefulness of the water as a source of domestic water supply.

Table D.1. cont.

State	Numeric	Narrative
Texas	Five subcategories of aquatic life use are established. They include limited, intermediate, high, and exceptional aquatic life and oyster waters. No specific criteria for a sediment-related number.	Surface water shall be essentially free of floating debris and **suspended solids** that are conducive to producing adverse responses in aquatic organisms or putrescible sludge deposits or sediment layers which adversely affect benthic biota or any lawful uses. Surface waters shall be essentially free of **settleable solids** conducive to changes in flow characteristics of stream channels or the untimely filling of surface water in the state. Waste discharges shall not cause substantial and persistent changes from ambient conditions of turbidity or color. Waste discharges shall not cause substantial and persistent changes from ambient conditions of **turbidity** or color. **Aquatic life uses**. Vegetative and physical components of the aquatic environment will be maintained or mitigated to protect aquatic life uses.
Utah	**Turbidity Increase**: 10 NTU for coldwater and warm water game fish and other cold water aquatic life, including the necessary aquatic organisms in their food chain: 15 NTU for non-game fish and waterfowl, shore birds and other water-oriented wildlife. **Total Suspended Solids**: 35 mg/L for coldwater game fish and other cold water aquatic life, including the necessary aquatic organisms in their food chain; 90 mg/L for warm water game and non-game fish.	It shall be unlawful, and a violation of these regulations, for any person to discharge or place any waste or other substance in such a way as will be or may become offensive such as unnatural deposits, floating debris, oil, scum or other nuisances such as color, odor or taste; or cause conditions which produce undesirable aquatic life or which produce objectionable tastes in edible aquatic organisms; or result in concentrations or combinations of substances which produce undesirable physiological responses in desirable resident fish, or other desirable aquatic life, or undesirable human health effects, as determined by bioassay or other tests performed in accordance with standard procedures.

Table D.1. cont.

State	Numeric	Narrative
Vermont	The following water quality criteria shall be achieved in all Class A(1) ecological waters. **Turbidity** - Not to exceed 10 NTU (Nepholometric Turbidity Units). **Aquatic Biota, Wildlife, and Aquatic Habitat** - Change from the natural condition is limited to minimal impacts from human activity. Measures of biological integrity for aquatic macroinvertebrates and fish assemblages are within the range of the natural condition. Uses related to either the physical, chemical, or biological integrity of the aquatic habitat or the composition or life cycle functions of aquatic biota or wildlife are fully supported. All life cycle functions, including over wintering and reproductive requirements are maintained and protected. Water Quality Criteria for Class B waters for **Turbidity** - The following criteria shall be achieved: a. In Cold Water Fish Habitat waters - Not to exceed 10 NTU. b. In Warm Water Fish Habitat waters - Not to exceed 25 NTU. In addition, the Secretary may determine whether there is full support of aquatic biota and aquatic habitat uses through other appropriate methods of evaluation, including habitat assessments. **Aquatic Biota, Wildlife and Aquatic Habitat** - No change from the reference condition that would prevent the full support of aquatic biota, wildlife, or aquatic habitat uses. Biological integrity is maintained and all expected functional groups are present in a high quality habitat. All life-cycle functions, including over wintering and reproductive requirements are maintained and protected. In addition, the following criteria shall be achieved: Water Management Type One waters - change from the reference condition for aquatic macroinvertebrate and fish assemblages shall be limited to minor changes in the relative proportions of taxonomic and functional components; relative proportions of tolerant and intolerant components are within the range of the reference condition. Changes in the aquatic habitat shall be limited to minimal differences from the reference condition consistent with the full support of all aquatic biota and wildlife uses.	Settleable solids, floating solids, oil, grease, scum, or total suspended solids: None in such concentrations or combinations that would prevent the full support of uses. In addition to other applicable provisions of these rules and other appropriate methods of evaluation, the Secretary may establish and apply numeric biological indices to determine whether there is full support of aquatic biota and aquatic habitat uses. These numeric biological indices shall be derived from measures of the biological integrity of the reference condition for different water body types. In establishing numeric biological indices, the Secretary shall establish procedures that employ standard sampling and analytical methods to characterize the biological integrity of the appropriate reference condition. Characteristic measures of biological integrity include but are not limited to community level measurements such as: species richness, diversity, relative abundance of tolerant and intolerant species, density, and functional composition.

Table D.1. cont.

State	Numeric	Narrative
Vermont (cont.)	Water Management Type Two waters - change from the reference condition for aquatic macroinvertebrate and fish assemblages shall be limited to moderate changes in the relative proportions of tolerant, intolerant, taxonomic, and functional components. Changes in the aquatic habitat shall be limited to minor differences from the reference condition consistent with the full support of all aquatic biota and wildlife uses. Water Management Type Three waters - change from the reference condition for aquatic macroinvertebrate and fish assemblages shall be limited to moderate changes in the relative proportions of tolerant, intolerant, taxonomic, and functional components. Changes in the aquatic habitat shall be limited to moderate differences from the reference condition consistent with the full support of all aquatic biota and wildlife uses. When such habitat changes are a result of hydrological modification or water level fluctuation, compliance may be determined on the basis of aquatic habitat studies.	
Virginia	None identified for standards. Turbidity and suspended solid criteria provided as effluent limits on specific water bodies.	All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life. Specific substances to be controlled include, but are not limited to: floating debris, oil, scum, and other floating materials; toxic substances (including those which bioaccumulate); substances that produce color, tastes, turbidity, odors, or settle to form sludge deposits; and substances which nourish undesirable or nuisance aquatic plant life. Effluents which tend to raise the temperature of the receiving water will also be controlled.

Table D.1. cont.

State	Numeric	Narrative
Washington	Class AA (Extraordinary), Class A (Excellent): **Turbidity** shall not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10 percent increase in turbidity when the background turbidity is more than 50 NTU. Class B (Good) and C (Fair) **Turbidity** shall not exceed 10 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 20 percent increase in turbidity when the background turbidity is more than 50 NTU. Lake Class: Turbidity shall not exceed 5 NTU over background conditions.	
West Virginia	Categories A, B, and C: No point or non-point source to West Virginia's waters shall contribute a net load of suspended matter such that the turbidity exceeds 10 NTU's over background turbidity when the background is 50 NTU or less, or have more than a 10% increase in turbidity (plus 10 NTU minimum) when the background turbidity is more than 50 NTUs. This limitation shall apply to all earth disturbance activities and shall be determined by measuring stream quality directly above and below the area where drainage from such activity enters the affected stream. Any earth disturbing activity continuously or intermittently carried on by the same or associated persons on the same stream or tributary segment shall be allowed a single net loading increase.	

Table D.1. cont.

State	Numeric	Narrative
Wisconsin		Practices attributable to municipal, industrial, commercial, domestic, agricultural, land development or other activities shall be controlled so that all waters including the mixing zone and the effluent channel meet the following conditions at all times and under all flow conditions: (a) Substances that will cause objectionable deposits on the shore or in the bed of a body of water shall not be present in such amounts as to interfere with public rights in waters of the state. (b) Floating or submerged debris, oil, scum or other material shall not be present in such amounts as to interfere with public rights in waters of the state. (c) Materials producing color, odor, taste or unsightliness shall not be present in such amounts as to interfere with public rights in waters of the state. (d) Substances in concentrations or combinations which are toxic or harmful to humans shall not be present in amounts found to be of public health significance, nor shall substances be present in amounts which are acutely harmful to animal, plant or aquatic life.
Wyoming	(a) In all Class 1 and 2 waters which are cold-water fisheries, the discharge of substances attributable to or influenced by the activities of man shall not be present in quantities which would result in a **turbidity** increase of more than 10 Nephelometric Turbidity Units (NTUs). (b) In all Class 3 waters and in Class 1 and 2 waters which are warm-water fisheries, the discharge of substances attributable to or influenced by the activities of man shall not be present in quantities which would result in a turbidity increase of more than 15 NTUs.	In all Wyoming surface waters, substances attributable to or influenced by the activities of man that will settle to form sludge, bank or bottom deposits shall not be present in quantities which could result in significant aesthetic degradation, significant degradation of habitat for aquatic life or adversely affect public water supplies, agricultural or industrial water use, plant life or wildlife. In all Wyoming surface waters, floating and suspended solids attributable to or influenced by the activities of man shall not be present in quantities which could result in significant aesthetic degradation, significant degradation of habitat for aquatic life, or adversely affect public water supplies, agricultural or industrial water use, plant life or wildlife.

Table D.1. cont.

State	Numeric	Narrative
District of Columbia	No turbidity increase over 20 NTU for waterbody classes A, B, and C.	The surface waters of the District shall be free from substances attributable to point or nonpoint sources discharged in amounts that do any one of the following: (a) Settle to form objectionable deposits. (b) Float as debris, scum, oil or other matter to form nuisances. (c) Produce objectionable odor, color, taste or turbidity. (d) Cause injury to, are toxic to or produce adverse physiological or behavioral changes in humans, plants or animals. (e) Produce undesirable aquatic life or result in the dominance of nuisance species. (f) Impair the biological community which naturally occurs in the waters or depends on the waters for their survival and propagation.
Puerto Rico	Coastal waters and estuarine waters of high quality and/or exceptional ecological or recreational value whose existing characteristics shall not be altered, except by natural causes, in order to preserve the existing natural phenomena. Coastal waters and estuarine waters intended for use in primary and secondary contact recreation, and for propagation and preservation of desirable species Turbidity shall not exceed 10 NTU, except by natural causes. Surface waters intended for use as a raw source of public water supply, propagation and preservation of desirable species as well as primary and secondary contact recreation: Turbidity shall not exceed 50 (NTU, except when due to natural phenomena.	The waters of Puerto Rico shall not contain floating debris, scum and other floating materials attributable to discharges in amounts sufficient to be unsightly or deleterious to the existing or designated uses of the waterbody. The waters of Puerto Rico shall be free from color, odor, taste and turbidity attributable to discharges in such a degree as to create a nuisance to the enjoyment of the existing or designated uses of the waterbody.
Virgin Islands	None	

Appendix E
Summary of the October 2, 2003
Consultation with the Science Advisory Board

The Ecological Processes and Effects Committee (EPEC) of the Science Advisory Board met October 2, 2003 in an informal consultation to review and discuss potential approaches to developing water quality criteria for suspended and bedded sediments as described in a discussion paper prepared and presented by U.S. EPA staff. The following summary includes additional information that was not detailed in Section I.D of the *Framework*. This summary does not represent Committee consensus or majority opinions since votes were not taken and no attempt was made to reach consensus under the consultation process.

EPEC Science Advisory Board Members

Chair:	Dr. Virginia Dale
Panel Members:	Dr. Gregory Biddinger
	Dr. Ivan Fernandez
	Dr. Cynthia Gilmour
	Dr. Charles Hawkins
	Dr. Lawrence Master
	Dr. Judy Meyer
	Dr. Michael Newman
	Dr. Charles Pettinger
Consultants:	Dr. Brian Bledsoe
	Mr. Charles Rabeni
	Mr. Timothy Thompson
SAB Staff:	Dr. L. Joseph Bachman
	Dr. Vanessa Vu

Need to Focus on Both Flowing Waters as Well as Slow Waters

A couple of Committee members indicated that the focus of the U.S. EPA discussion paper and the U.S. EPA staff presentations was primarily on running water habitats. Some of the Committee members wanted to emphasize that slow or still water habitats (large rivers, lakes, estuaries, and oceans) were as important. Members suggested that Idaho, California, Washington, and British Columbia have criteria/guidelines that would be a good starting point for developing criteria for running water habitats. The Chesapeake Bay methods may be a good starting point for large rivers and estuaries, especially where water column conditions are less variable in space and time.

Some members of the Committee felt that because the two types of habitats are so different (running water and slow or still water), there may be a need to stratify using this division, use different biological endpoints in the two types, and develop different criteria. Some members suggested that bedded sediment criteria may be more appropriate for running water habitats and suspended measures would be more appropriate for slow or still water habitats. Pelagic target organisms may be important in slow water habitats, whereas benthic organisms may be critical in running waters.

Too Little Sediment is a Problem

The focus of the discussion was on excess sediments, but some members of the Committee also pointed out that lack of sediments is sometimes a problem in regulated rivers and in bedrock channels. There was feedback that both extremes of sediment conditions should and could be addressed using some of the methods under discussion.

Appropriate Focus of Criteria

There were different opinions voiced regarding the starting point of any assessment or criteria. Some thought that the criterion should reflect a water body's ecological potential given the intended use of the water body, focusing on the question of "How should we manage given what's here?" as opposed to "How does this compare to reference condition?" This would preclude any stratification based on natural waterbody types, using the intended use as the stratifying factor. This would also simplify the modeling processes; the endpoints would be selected to work within management models, and there would be no need to define reference conditions (which are sometimes difficult to identify).

An opposing view was that reference condition is important to define, even if it is not attainable. Society should know what it is giving up in terms of natural waterbodies. When reference conditions are not attainable or can not be identified, then the natural conditions can be estimated and a Use Attainability Analysis can be performed. It was also suggested that designated uses of a waterbody may overlap and be in conflict with each other. Also, the intent is to protect aquatic life; by focusing only on designated uses, some systems may be written off as not being biologically valuable.

Reference conditions were differentiated from background conditions, as being natural conditions found in unimpacted settings similar to the assessed water body, whereas background conditions are detected upstream of a suspected inducement of sediment pollution. Some Committee members were concerned about finding sufficient reference conditions, especially for large rivers. Expectations for reference conditions should not be set using estimates of pre-colonial conditions. It was not clear that any Committee member was advocating the use of background conditions.

Build In Uncertainty in Methods/Approaches

Some Committee members stated more than once that uncertainty is an important component of any assessment and it should be inherent to any methods developed for setting or applying sediment criteria. Criteria could be set while recognizing and accounting for uncertainty before triggering management action. The Conditional Probability was attractive because it is inherently based on uncertainty. Variability also needs to be addressed in terms of flow because suspended sediment measures are associated with flow conditions. The time when a measurement is taken may be as important as how it is taken; base flow may be best for comparison with biological conditions.

Work Towards National Consistency

The Committee discussed maintaining consistency of sediment assessments among states. Obvious differences in sediment assessments across state borders should be eliminated. How this is to be done was not spelled out though coordination at the watershed or regional level was implied. The State-by-State Reference Condition Method implies that each state would be autonomous in setting criteria and that the state border issue could be a problem unless the U.S. EPA has some hand in maintaining consistency.

Reaction to the Staff's Criteria Development Methods

Pros and cons of each criteria development approach were discussed by the Committee first in isolation, then as a synthesis of methods. The Committee concluded that there was no one single method that could do everything, but features of each one were valuable and should be combined into a synthesized framework.

Toxicological Method

The first method discussed was the Toxicological Method. It was thought to be very different from the other method with some merits and some detractions. One advantage is that it canidentify thresholds for specific species. Also, the laboratory experiments may help define the nature of the response curve for single species and provide a basis for dose-response experiments in the field. Some Committee members thought that the Toxicological Method could complement another method, at least as an additional line of evidence, but that it was not a valid stand-alone method primarily because impacts are context dependent and are not reproducible in the laboratory.

A concern that came up in relation to the toxicological method, but that is of general concern regardless of method, is that the endpoint of the experiments must be translatable into loads for management purposes. Managers may typically model in terms of turbidity or TSS and they are not accustomed to using LD_{50} concentrations, other explicitly toxicological measures, or other measures associated with other methods. For management purposes, the criteria must be in units that can be modeled. Other Committee members commented that methods must be "doable," that is, able to be implemented.

Conditional Probability Analysis (CPA) Method

The CPA method was attractive to some Committee members because it inherently includes statements of uncertainty (variability) and because it could lead to powerful causal analysis. When the question came up about whether this method is essentially single factor ecology, it was suggested that multiple conditions could be used in the models, but that it would be data intensive to do so.

Relative Bed Stability (RBS) Method

The RBS method was viewed as best for use in running water habitats and seemed, to some Committee members, as difficult to use in fine bedded systems such as large rivers. In large rivers, sediment analysis may require sieving techniques and assessment of stream power as opposed to stream competence. The limited applicability in slow or still waters was a detractor for the method. On the positive side, some members said the method showed promise if it used a classification scheme that truly adjusts expectations for natural erosional inputs. The comparison of observed conditions to expected conditions automatically puts the RBS value on a relative scale, which could be standardized across state lines and would be easier to interpret than a table of different criteria for different water body classes. There was considerable technical discussion regarding this method.

One concern expressed by some members with the method was that the biological response to the RBS parameter did not seem to be linear; responses were only obvious with the very worst conditions. This was explained as evidence of a possible threshold. Members suggested that any method needs to show a strong link between the measurement and biological conditions.

Reference Condition Method

Many Committee members seemed to express that the Reference Condition Method was a good method but not a stand-alone approach. It was noted that many states have already invested in this method during biological assessments, and additional costs for developing sediment criteria would, therefore, be marginal. There was some concern about using single number thresholds, and some solutions included using observed/expected ratios, using sediment rating curves to incorporate variable flow conditions, and the Conditional Probability Analysis as part of the Reference Condition Method.

Fluvial Geomorphological Method

Some Committee members considered the Fluvial Geomorphological Method a good screening level method because sediment budgeting already uses such a method. Committee members noted that natural sediment regimes characteristic of particular stream types show some consistency, and channel evolution theory explains the changes of unstable channels in ways that may help clarify thresholds of impairment and aid efforts to restore impaired streams. Sediment Rating Curves were recognized as potentially useful but not sufficiently developed, and they are difficult to apply. Some committee members called channel type classification useful to some degree but advised that U.S. EPA be aware of and consider the different schools of thought about classifying based on different channel parameters.

The Committee indicated that the Fluvial Geomorphological Method focused on the sediment sources and exposure without considering biotic effects which were considered essential for criteria development. Despite this point, one member did state that abiotic, in-channel measurements would be useful as a component of ecological condition. Some members viewed Hydrogeomorphic classification as a good method for stratification after identifying impairment and before assessment and diagnosis.

Synthesis of Methods

Some members proposed a synthesis of methods that would take advantage of the strengths of several methods. The Reference Condition and Conditional Probability Approach methods were suggested as central to a framework that could be supported with elements from all of the other methods. In terms of the process that was presented by staff in the briefing materials, it was suggested that selection of indicators might not be the first step, but should come later. The Committee considered this a work in progress and suggested continued work on the synthesis of methods using real data.

Key Feedback by the Committee on the Methods:

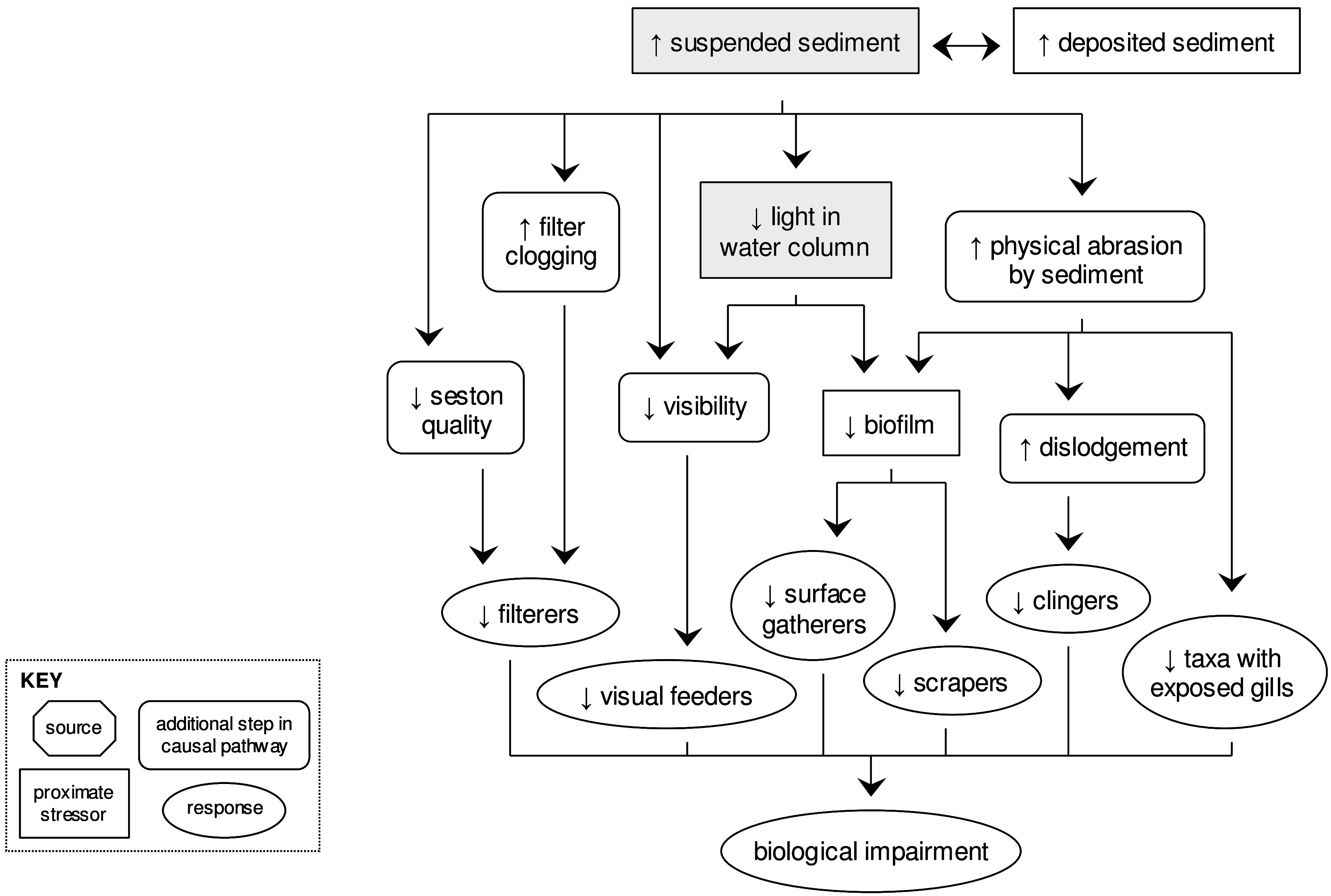
- A synthesis of the methods for setting sediment criteria would be optimal.
- The Toxicological Method would be best used to support other methods, but should not be pursued as a primary method.
- The CPA Method has merit because it inherently included measures of uncertainty.
- The RBS Method has merit in running water systems.
- The Reference Condition Method has merit and could be used as the core or backbone of a synthesized process.
- The Fluvial Geomorphological Method would be best used for classification or diagnosis/causal assessment but not for effects assessment because it is not closely related to biological integrity.

Key Differences of Opinion

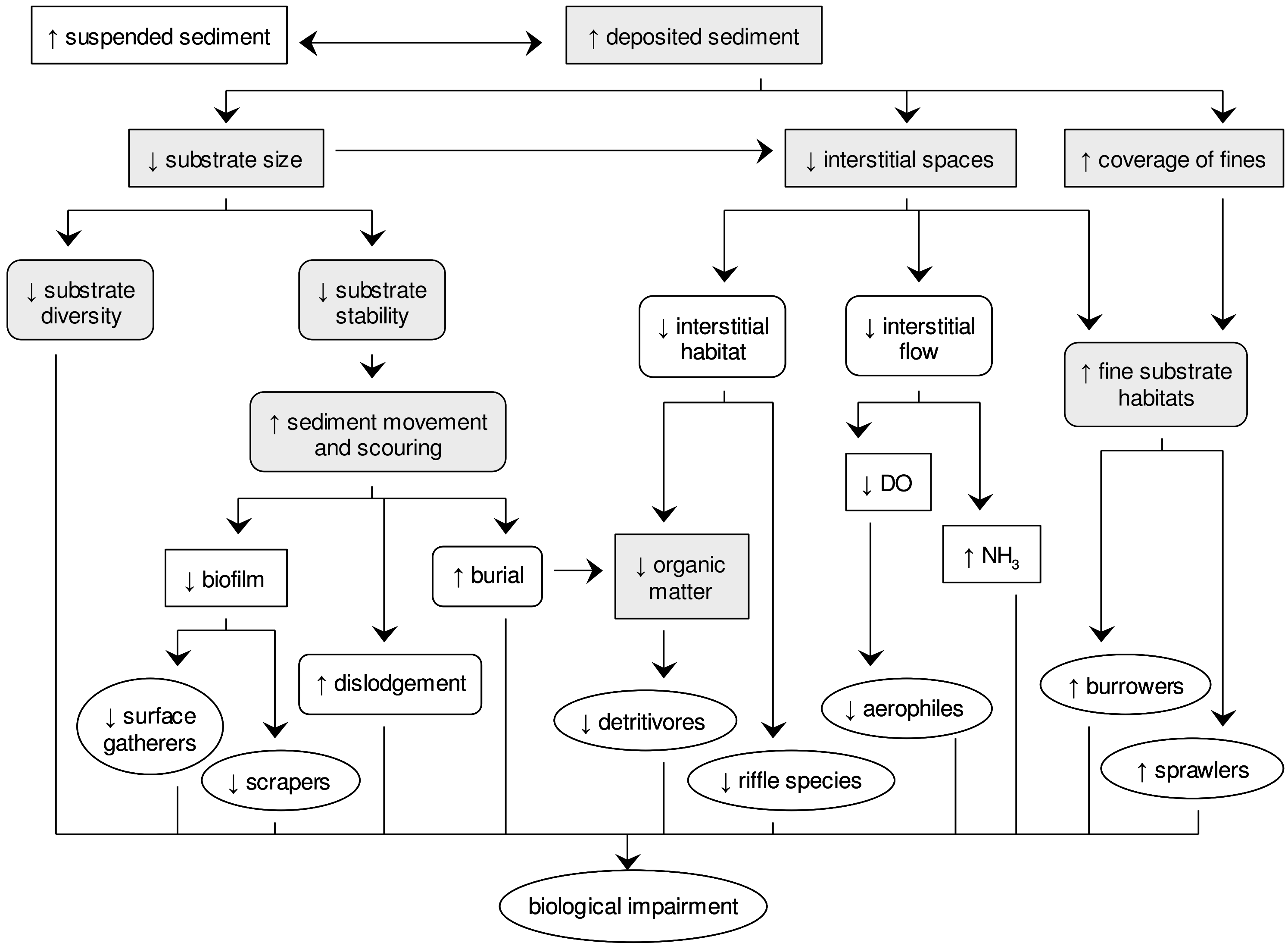
The Committee was divided on the definition and use of reference conditions. Some advocated description of reference conditions and classification by natural types, estimating reference conditions in cases where appropriate unimpaired systems could not be identified and sampled. Other members suggested that management objectives (water body function and designated uses) should be the primary classification scheme, especially for systems with no pristine reference examples (e.g., large rivers).

Appendix F
Conceptual Models of SABS Sources and Effects

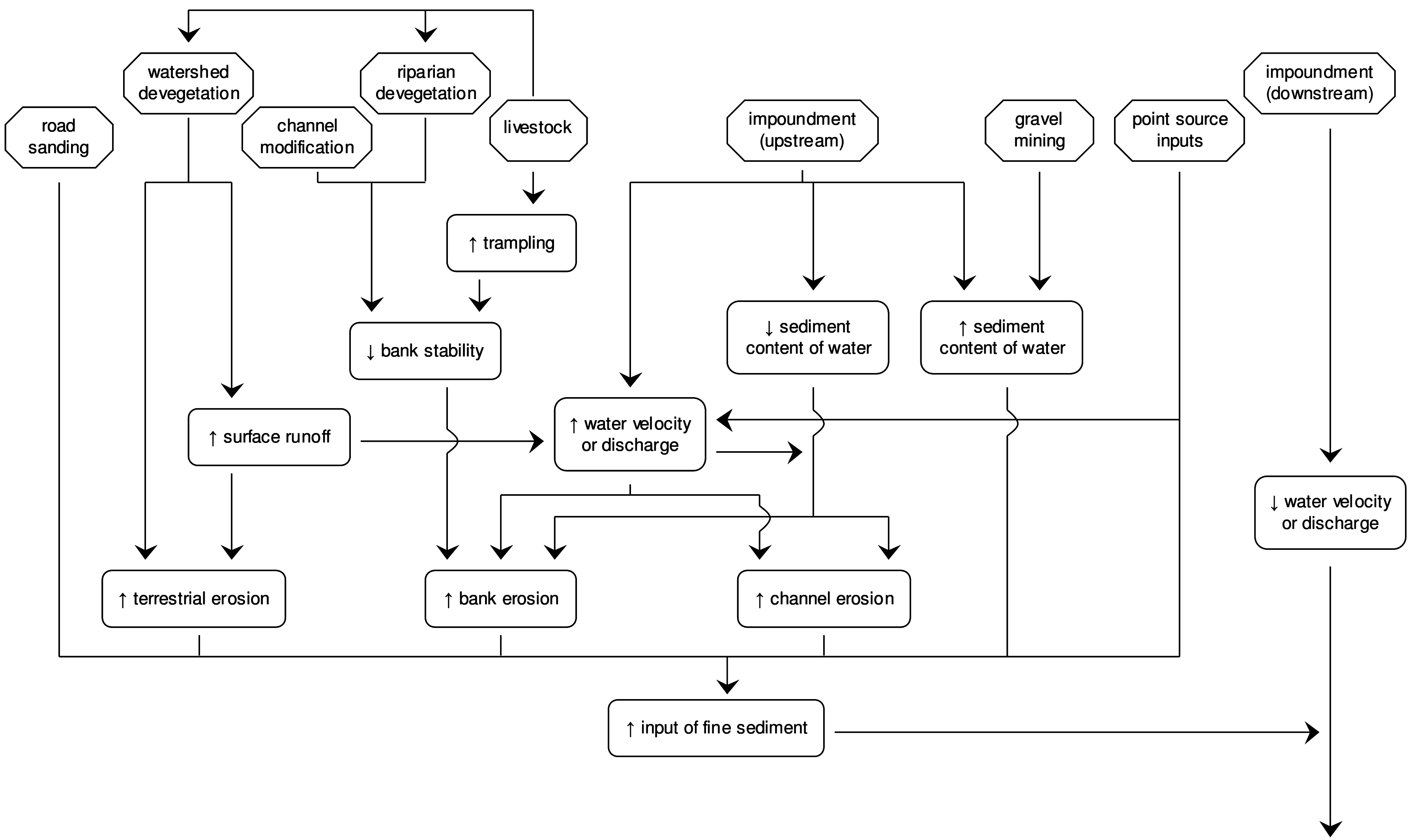
The following conceptual model depicts relationships from sources of increased erosion of sediments from terrestrial environments to their effects on benthic invertebrates. The model can be viewed as three subunits (1) Increased suspended sediment supply through various mechanisms to their effect on the biota, (2) Increased deposited sediments and their effects on biota, and (3) Terrestrial environments to increased transport of sediment. Both suspended and deposited sediment can affect aquatic biota, and these effects have been examined in numerous review documents (e.g., Waters 1995; Wood and Armitage 1997). Models were prepared by Kate Schoffield, U.S. EPA, NCEA.



Model 1. Suspended sediments.



Model 2. Deposited sediments.



Model 3. Sources and processes.