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Clear as Mud

The challenge of sediment criteria and TMDLs

Matthew T. Moore, Sam Testa III, Charles M. Cooper, Sammie Smith, Jr., Scott S. Knight, and Richard E. Lizotte, Jr.

Even though sediments are natural aquatic ecosystem components (due to weathering of parent material), excessive amounts of sediment may impair a waterbody. In fact, according to J.M. Fowler and E.O. Heady, the largest water pollutants in the United States, by volume, are instream suspended sediment and bed load.

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To mitigate such problems, Sec. 304(a) of the Clean Water Act requires the U.S. Environmental Protection Agency (EPA) to develop and implement sediment quality criteria. According to P. Chapman, sediment quality criteria are needed to supplement water quality criteria because

- trace amounts of potential contaminants in water may accumulate to dangerous levels in sediments;
- sediments can integrate contaminant concentrations over time, while water-column contamination is more vari able; and
- sediments are essential components in aquatic ecosystems, providing habitat, substrate, feeding, and rearing areas for aquatic biota.

Much debate has occurred about the practicality and purpose of sediment criteria. Criteria proponents are concerned about sediment quality because of the possible detrimental effects of contaminated dredge material. Some opponents of sediment criteria feel too much uncertainty is involved. Nevertheless, sediment effects on aquatic ecosystems must be addressed.

Clean or Contaminated?

Sediments include sand, clay, silt, and other particles deposited at the bottom of waterbodies. Such particles can come from stream banks, stream and river channels, or upland areas used for farming, forestry, mining, and urban development.

Each waterbody has natural concentrations of suspended and deposited sediments, which depend on natural waterbody conditions and may or may not be similar at national, regional, or local scales. Sediment loads may be divided into three types: bed load, suspended load, and wash load. Bed load refers to sediment that moves along and is in contact with the river or stream bottom. Suspended load is sediment derived from a river or streambed that is either intermittently or wholly supported in the water column by turbulence. Sediments smaller than about 63 microns, which are not from the bed but could be from bank erosion or upland areas, typically are referred to as a wash load. Each load can be difficult to quantify because of the inherent flux of sediment between the bottom and the water column due to various natural and anthropogenic causes.

So, how can researchers determine whether sediment is truly the cause of an aquatic ecosystem's impairment? Unlike most aquatic ecosystem impairments, sediments may be a contaminant source ("clean") or a contaminant sink ("contaminated"). Clean sediment particles can scour or smother habitat, scour an organism's body, and partially or totally occlude an organism's breathing, feeding, or sensory mechanisms. Sediment turbidity and siltation have been linked to declines in fisheries since the 1930s.

Contaminated sediments can kill aquatic organisms (primarily the benthic community) or reduce their survival, vigor, or reproductive success. Sometimes the contaminant concentrations may lead authorities to issue swimming advisories to decrease human risk. Besides such direct effects, contaminated sediments may affect more organisms indirectly through the food chain, as the organisms directly in contact with contaminated sediments are eaten by semi-aquatic and terrestrial organisms. Bioaccumulation and biomagnification of such contaminants in various species often lead authorities to issue consumption advisories to limit human risk.

Is it possible, then, to detect sediment problems through measures of adjacent suspended sediment? This is a primary concern among scientists attempting to develop sediment criteria and TMDLs. Obviously, the presence of excessive sediment often indicates a deeper underlying problem needing attention, such as local or regional stream bed destabilization, riparian zone disturbance, or excessive impermeability of the watershed landscape.

When J.F. Fairchild, T. Boyle, W.R. English, and C. Rabeni studied the effects of clean and contaminated sediments on functional components of aquatic ecosystems in the mid-1980s, they found that both types of sediment

- altered drift dynamics of benthic invertebrates,
- decreased the percent similarity of benthic invertebrates,
- decreased the drift of filamentous algae,
- increased the production of rooted flora, and
- increased net nutrient retention.

They also found that clean sediment altered benthic invertebrate drift dynamics, including delaying nocturnal drift, but contaminated sediment caused immediate nocturnal drift. However, neither type of sediment altered leaf decomposition rates or insect emergence.

Sediment Criteria Development

More emphasis has been placed on developing criteria for contaminated sediment, partially because in waterbodies where sediment is one of several impairment causes, reducing sediment load also may alleviate other potential impairments, such as metals, pesticides, and phosphorus. While contaminated sediment criteria are, in some ways, easier to establish because the associated contaminant is often the suspected cause for biological impairment, the process is not simple. For example, variability in sediment particle size and structure poses a challenge for national sediment quality criteria development, according to B.C. Suedel and J.H. Rodgers Jr.

Some states have established sediment quality criteria, and EPA currently is developing sediment quality criteria for contaminated sediments, based on situations where, among other conditions, total organic carbon is at least 0.2% of sediment dry weight. Unfortunately, much like water quality criteria, hundreds of potential contaminants exist, making it virtually impossible to propose sweeping sediment criteria for all contaminants.

Many scientists use the sediment quality triad (SQT) approach to examine the dangers contaminated sediments could cause an aquatic ecosystem. This approach involves assessing sediments based on chemical contaminant con-

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centrations, benthic assessments, and experimental bioassays. Unfortunately, the SQT approach is expensive, and many states may lack sufficient funding to use this method to test all listed impaired waterbodies.

Also, some researchers caution against overemphasizing bioassay results. To better understand sediment toxicity, according to S.N. Luoma and J.L. Carter, researchers must accept complexity, incorporate uncertainty, study toxicity mechanisms, and consider the specific ecosystem involved.

One of the biggest challenges to establishing sediment criteria and TMDLs is that sediment naturally often resuspends and transports within waterbodies repeatedly. Such resuspension may occur for many reasons, ranging from the natural movement of benthic-zone organisms to dredging for navigational or flood control projects. Sediment transport varies over a range of temporal and spatial scales, and such variations can be autocyclic or allocyclic (the result of heavy rainfall, for example), according to R.A. Kuhnle, S.J. Bennett, C.V. Alonso, R.L. Bingner, and E. Langendoen. So, when developing clean sediment TMDLs, timing, seasonality, and temporal scale (episodic or cumulative) are critical. Transient storms, for example, can cause catastrophic ecological damage. R.A. Kuhnle and A. Simon recently reported on sediment transport data and how they may be used for development of clean sediment TMDLs.

So, proposed approaches to developing clean sediment criteria include adopting suspended solids limits, basing criteria on "light extinction," and identifying proportions of fines in substrates that cause biological impairment, according to C. Richards. Richards notes that while adopting suspended solids limits may be the oldest proposed approach, it is probably the least effective, because many freshwater fish have high suspended solids tolerances.

The light extinction approach, in which suspended solids decrease primary productivity, worked well in Alaska (where it was developed by D.S. Lloyd, J.P. Koenings, and J.D. LaPerriere), but it has yet to be validated in other parts of the United States, Richards notes.

The best approach, Richards notes, may be identifying the proportion of fines causing biological impairment. Developed from attempts by D.W. Chapman and K.P. McLeod to derive criteria based on salmonid spawning habitat, this approach relates directly to a measurable ecosystem response.

Research Directions and Pertinent Questions

Much research is needed to provide solutions for the challenge of developing sediment criteria and TMDLs. Researchers cannot simply establish a sediment point threshold concentration for ecosystem viability because of all the variables associated with sediments. However, by combining knowledge in such areas as ecotoxicology, fluvial geomorphology, hydrology, and aquatic ecology, appropriate questions may be asked and potentially answered.

First, existing research on the ecological effects of sediments needs to be consolidated and interpreted appropriately, so stakeholders can see what work remains to be done and which existing methods best address the issue of sediment effect on water quality and the biological community.

Next, better methods of determining biological impairment are needed. While many advances have been made recently, existing methods are expensive because of the wide range of natural and artificial conditions existing nationwide. Also, they only determine the presence or absence of organisms and indicate the severity of impairment. Rarely do they provide any estimate of the impairment's cause.

Following are some of the remaining questions that future sediment research should address:

- At what depth should contamination be evaluated in deposited sediments?
- Does this depth differ among ecosystems (such as small streams, large rivers, lakes, and estuaries)?
- At what depth (within deposited sediments) do contaminants cease being a problem, especially if "capped"?
- At what concentration do sediment-associated nutrient, metal, or synthetic compounds become a "contaminant," rendering a given sediment no longer "clean"?
- What are the links between ecological impairment at a site and clean sediment (in other words, what qualitative or quantitative sediment measures or appropriate habitat measures should be used to set clean sediment criteria)?
- How do we address the underlying problem causing clean sediment impairment? Is it land use, land alteration, or stream or waterbody destabilization?
- Can we focus toxicology efforts to determine which regional indicator organisms will point out clean sediment problems, or do contaminants and other factors affect natural systems so much that only SQT and related approaches can elucidate which effects are caused by clean sediment and which are caused by contaminated sediment?
- Should we strive for further work with fish or invertebrate metrics (looking at abundance or percent composition of communities, especially in reference to certain indicator organisms, such as tolerant, erosional-frequenting dragonfly larvae or nontolerant, soft-body mayflies)?

Regardless of the methods, the ultimate goal should be remembered: to protect the aquatic resources of our nation and limit risk to humans. Because we currently have more questions than answers, open communication is needed among scientists, regulators, and stakeholders because informed, involved parties are more likely to solve the seemingly endless string of questions related to sediment criteria and TMDLs than would isolated individuals.

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