SEDIMENT: DETAILED CONCEPTUAL MODEL NARRATIVE

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Although sediments are natural components of aquatic ecosystems, human activities have greatly altered sediment budgets (i.e., the supply, movement, and retention of mineral and organic particles of all sizes) in many watersheds. The following conceptual model depicts how either excess or insufficient sediments in streams can affect benthic invertebrates, fish, and plants (e.g., see Waters 1995; Wood and Armitage 1997).

Model Format

The sediment conceptual model diagram depicts sources and land use and channel alterations that alter stream sediment budgets near the top of the figure, leading down the diagram to steps in the causal pathway, proximate stressors, modes of action, and eventually biological responses at the bottom. This model is most applicable to eastern cobble-bottomed streams, but can be easily modified for other stream or waterbody types.

The top half of the model describes how the three sources of soil (land, bank, and channel) plus direct or point sources of inorganic or organic material are moved by water leading to a change in in-stream sediment (Δ sediment). The far left portion of the model shows what happens when soil is eroded from land within the watershed to waterbodies. Situations that move sediments from the banks and channel are described in the center of the model and direct deposits of material and impoundments (e.g., dams) are shown on the right side of the model.

The lower half of the model depicts mechanisms by which a change in sediments can cause changes in the biological community. Reading from left to right, the model depicts modes of action and effects of suspended sediments (SS), deposited and bedded sediments (DBS) and insufficient sediments (IS).

This narrative generally follows the diagram from top to bottom, left to right. For more information on interpreting CADDIS conceptual model diagrams, see the Conceptual Model Library homepage.

Linking Sources to Proximate Stressors

Sources of sediments are soils from land in the watershed or from the channel, streambank, or shore (top left). These may be natural or from anthropogenic sources. Natural sources can include landslides and glacial deposits. Some soils are more susceptible to movement, such as volcanic ash. Generally, smaller, lighter particles move more readily and stay in suspension longer. Organic particles also are directly discharged into waterbodies, especially from combined sewer overflows during storms or from wastewater treatment plants (WWTPs) during treatment failures. Construction soils, mining spoils, and sand-laden snow can be directly dumped into waterbodies. Gravel mining, dredging, and trawling directly resuspend bedded sediments. In contrast, watercourses that are lined with concrete or rock generally do not erode, and reduce normal sediment inputs.

Overland flow and in-stream flow, wave action, and currents move sediments. When the volume, discharge, and pattern of water movement are altered, the increased force of moving water transports sediments; when the force lessens, sediments are deposited. Slope, gradient, channel morphology, watershed alterations, channel alterations, and other factors affect water velocity and discharge, and therefore the ability of water to move soil and sediments (see CC.7 Flow Alteration for a more detailed description).

Watershed land cover alterations may increase watershed erosion by increasing overland flow and by increasing soil susceptibility to movement (upper left). Soils on unpaved roads are easily eroded. Disturbance of soils and removal of vegetation (e.g., due to tilled crops or residential development, fires, logging, and mining) increase erosion, leading to increased inputs of sediments to streams and other waterbodies. Infiltration of water is impeded or eliminated by compaction and impervious land surfaces (e.g., rooftops, paved roads, parking lots). For example, during construction vegetation is removed and soils are compacted, reducing permeability and increasing overland flow that erodes disturbed soils from uncompacted areas.

Many types of channel alteration cause increased water velocity and discharge that forcefully mobilize streambed sediments, resulting in stream channels that lack stable geometries and leading to increased bank erosion (center). The increase in flows during storms is exacerbated by reduced infiltration on adjacent landscapes. The force of the water is stronger when it is restricted to a straightened channel rather than dissipated over a floodplain. When this happens, the channel is carved deeper (incision) and the water undercuts the banks, which can cause the banks to collapse. As the process repeats itself, the stream channel is widened and a new floodplain is created, or the incision stops because particles are too large for the water to move. In addition, until a new floodplain is established, the full burden of sediments is carried rather than being deposited on land, which increases sediment delivery downstream.

Various land use practices involve devegetation (top right) of riparian areas, which reduces streambank stability and increases bank erosion. Livestock trample riparian vegetation and directly collapse streambanks and resuspend sediment in the channel. In developed landscapes, trees are often removed and small streams are rerouted, thereby eroding soil until a more stable stream channel is formed.

Decreased slopes dissipate the force of water. Water withdrawals (e.g., for irrigation or trans-basin export) reduce flow and increase deposition because the force of the water can no longer suspend sediments. Also, impounded areas reduce water velocity, leading to increased deposition of sediments which collect behind the dam. These sediments change the habitat making it unsuitable for the original inhabitants. The retention of sediments behind dams reduces downstream sediment supply. In addition, forceful releases from a dam can strip the downstream channel of all small and moderately-sized particles, further reducing sediments in that portion of the stream. In contrast, dam failures and intentional releases of water from dams can release sediments to downstream areas. Suspended fine organic particles such as algal cells or leaf fragments may collect in impounded areas during low flow, and be discharged at higher flows. At road crossings, constrained channels (e.g., culverts, concrete waterways) increase the force of the water resulting in erosion and the deposition of sediments downstream.

Linking Proximate Stressors to Biological Impairment

At high flows, increased sediment supplies move with flowing water as suspended sediments or are pushed across the streambed, creating unstable habitats or scouring the bed. When flow lessens sediments are deposited, changing the type of substrate, filling interstitial spaces, and covering plants, animals, and geologic substrates with material.

Increases in suspended and deposited and bedded sediments can lead to biological impairment by numerous pathways. As **suspended sediments** increase, filterer-feeding organisms may be affected by (1) changes in food quality of suspended material (i.e., depending on whether organic or inorganic particles increase); or (2) increased clogging of their filtering apparatuses. Suspended sediments can reduce the amount of light penetrating the water column, which can reduce submerged aquatic plants and habitat for some animals, and decrease available periphyton or biofilm, which are important foods for herbivores and omnivores. Lower visibility may interfere with behaviors dependent on visual cues, including feeding, predator avoidance, and spawning. Some suspended sediments are abrasive and can directly damage fish and invertebrate gills. Suspended sediments also can increase heat absorption, contributing to increases in water temperature.

Increased **deposited and bedded sediments** may affect organisms by leading to three potential proximate stressors: increased cover by fines, decreased interstitial spaces, or decreased substrate size. As the coverage of fine sediment increases on the streambed (lower center), fine substrate habitats increase, which may benefit taxa adapted to these habitats (e.g., burrowing or sprawling invertebrates, nest-cleaning fishes) while adversely affecting gravel spawners and other riffle-obligate organisms. Coverage by fines may lead to burial of taxa or life stages with limited mobility (e.g., fish eggs), or may lead to the infilling of pools with sediment and subsequent declines in pool depth, adversely affecting pool-dependent taxa and potentially reducing cool water habitats during low flow.

Decreased interstitial spaces (lower right) may lead to decreases in both interstitial habitat and water flow through these spaces. As sediment fills interstitial spaces, refugia are lost. As interstitial habitat decreases, interstitial taxa or life stages can decrease. In addition, decreased flushing of ammonia waste products increases the potential for toxicity affecting ammonia-sensitive taxa or life stages. With reduced interstitial flow, dissolved oxygen often decreases, adversely affecting aerophiles, which can further increase ammonia concentrations by decreasing nitrification. When organic matter is a large component of the sediment, ammonia production and sediment oxygen demand may be even greater.

As substrate size decreases, substrate diversity decreases and substrate movement and scouring both increase (lower right). Decreased substrate diversity alters the potential for diversity in the biotic community, potentially leading to biological impairment. Accumulations of rooted plants, periphyton, and biofilms can be reduced by physical abrasion as fine bedload scours the streambed surface, which may lead to a decrease in herbivores and omnivores. Moving sediments also may dislodge organisms such as clingers, eggs, and alevins from substrates, or cause increased gill damage in taxa with exposed respiratory structures.

Insufficient sediments generally make the stream habitat less hospitable (far right). Stream channels that are reduced to bedrock and boulders are unsuitable habitats for many benthic taxa, because the diversity of substrate niches is limited and food diversity and resources may be reduced.

References

Waters, TF. (1995) Sediment in streams: sources, biological effects and control. American Fisheries Society Monograph 7. Bethesda, MD: American Fisheries Society.

Wood, PJ; Armitage, PD. (1997) Biological effects of fine sediment in the lotic environment. Environ Manage 21(2):203-217.