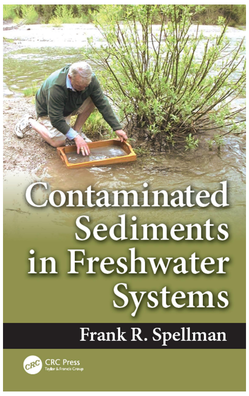

Contaminated Sediments in Freshwater Systems

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Setting the Stage

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2 Setting the Stage

Probably the best way to understand where this book is headed, to get a really good feel for it, to get to the heart of what the message is all about is to read the following by Rachel Carson (1962):

> We poison the caddis flies in a stream and the salmon runs dwindle and die. We poison the gnats in a lake and the poison travels from link to link of the food chain and soon the birds of the lake margins become victims. We spray our elms and the following springs are silent of robin song, not because we sprayed the robins directly but because the poison traveled, step by step, through the now familiar elm leaf–earthworm–robin cycle. These are matters of record, observable, part of the visible world around us. They reflect the web of life—or death—that scientists know as ecology.

As Carson pointed out, what we do to any part of our environment has an impact on other parts. In other words, there is an interrelationship between the parts that make up our environment. Probably the best way to state this interrelationship is to point out that on Earth it is all about specific interactions that exist between organisms and their living and nonliving environment.

BENTHIC HABITAT

Before setting the stage for the discussion that follows, a brief look at the benthic habitat is called for. The benthic habitat is found in a streambed, or benthos. A streambed is comprised of various physical and organic materials where erosion and deposition are continuous characteristics. Erosion and deposition may occur simultaneously and alternately at different locations in the same streambed. Where channels are exceptionally deep and taper slowly to meet the relatively flattened streambed, habitats may form on the slopes of the channel. These habitats are referred to as *littoral habitats*. Shallow channels may dry up periodically in accordance with weather changes. The streambed is then exposed to open air and may take on the characteristics of a wetland.

Silt and organic materials settle and accumulate in the streambed of slowly flowing streams. These materials decay and become the primary food resource for the invertebrates inhabiting the streambed. Productivity in this habitat depends on the breakdown of these organic materials by herbivores. Bottom-dwelling organisms do not use all of the organic materials; a substantial amount becomes part of the streambed in the form of peat.

In faster moving streams, organic materials do not accumulate so easily. Primary production occurs in a different type of habitat found in the riffle regions with shoals and rocky regions for organisms to adhere to. Plants that can root themselves into the streambed dominate these regions. By plants, we are referring mostly to forms of algae, often microscopic and filamentous, that can cover rocks and debris that have settled into the streambed during summer months.

> ***Note:*** If you have ever stepped into a stream, the green, slippery slime on the rocks you encountered in the streambed is representative of this type of algae.

Although the filamentous algae seem well anchored, strong currents can easily lift the algae from the streambed and carry it downstream, where it becomes a food resource for low-level consumers. One factor that greatly influences the productivity of a stream is the width of the channel; a direct relationship exists between stream width and richness of bottom organisms. Bottom-dwelling organisms are very important to the ecosystem, as they provide food for other, larger benthic organisms through consuming detritus.

BENTHIC PLANTS AND ANIMALS

Vegetation is not common in the streambed of slow-moving streams; however, vegetation may anchor along the banks. Algae (mainly green and blue–green) as well as common types of water moss attach themselves to rocks in fast-moving streams. Mosses and liverworts often climb up the sides of the channel onto the banks, as well. Some plants similar to the reeds of wetlands with long stems and narrow leaves are able to maintain roots and withstand the current. Aquatic insects and invertebrates dominate slow-moving streams. Most aquatic insects are in their larval and nymph forms such as the blackfly, caddisfly, and stonefly. Adult water beetles and waterbugs are also abundant. Insect larvae and nymphs provide the primary food source for many fish species, including American eel and brown bullhead catfish. Representatives of crustaceans, rotifers, and nematodes (flat worms) are sometimes present. The abundance of leeches, worms, and mollusks (especially freshwater mussels) varies with stream conditions but generally favors low-phosphate conditions. Larger animals found in slow-moving streams and rivers include newts, tadpoles, and frogs. The important characteristic of all life in streams is adaptability to withstand currents.

BENTHIC MACROINVERTEBRATES

The emphasis on aquatic insect studies, which have expanded exponentially in the last several decades, has been largely ecological. Freshwater macroinvertebrates are ubiquitous; even polluted waters contain some representative of this diverse and ecologically important group of organisms. Benthic macroinvertebrates are aquatic organisms without backbones that spend at least a part of their life cycle on the stream bottom. Examples include aquatic insects, such as stoneflies, mayflies, caddisflies, midges, and beetles, as well as crayfish, worms, clams, and snails. Most hatch from eggs and mature from larvae to adults. The majority of the insects spend their larval phase on the river bottom and, after a few weeks to several years, emerge as winged adults. The aquatic beetles, true bugs, and other groups remain in the water as adults. Macroinvertebrates typically collected from the stream substrate are either aquatic larvae or adults. In practice, stream ecologists observe indicator organisms and their responses to determine the quality of the stream environment. A number of methods can be used for determining water quality based on biologic characteristics. A wide variety of indicator organisms (biotic groups) are used for biomonitoring. The most often used include algae, bacteria, fish, and macroinvertebrates.

In stream ecology studies, benthic macroinvertebrates are studied for a number of reasons. Simply, they offer a number of advantages:

1. They are ubiquitous, so they are affected by perturbations in many different habitats.
2. They are species rich, so the large number of species produces a range of responses.
3. They are sedentary, so they stay put, which allows determination of the spatial extent of a perturbation.
4. They are long-lived, which allows temporal changes in abundance and age structure to be followed.
5. They integrate conditions temporally, so like any biotic group they provide evidence of conditions over long periods.

In addition, benthic macroinvertebrates are preferred as bioindicators because they are easily collected and handled by samplers; they require no special culture protocols. They are visible to the naked eye and samplers easily distinguish their characteristics. They have a variety of fascinating adaptations to stream life. Certain benthic macroinvertebrates have very special tolerances and thus are excellent specific indicators of water quality. Useful benthic macroinvertebrate data are easy to collect without expensive equipment. The data obtained by macroinvertebrate sampling can serve to indicate the need for additional data collection, possibly including water analysis and fish sampling.

WATER QUALITY AND SEDIMENTS

Traditionally, concerns relative to the management of aquatic resources in freshwater systems have focused primarily on water quality. The focus has been on questions or concerns related to, for example, what was in the water that you just drank? Was it only hydrogen and oxygen atoms? More importantly, was it safe for drinking? All water is of a certain quality, which we cannot determine solely by looking at it. The real question is what does "water quality" really mean? Water loaded with sediments such as dirt and grime might work fine for a lettuce plant but would you want to drink it? Some would think this question relative—relative to whether or not you are dying of thirst. Anyway, water quality can be thought of as a measure of the suitability of water for a particular use based on selected physical, chemical, and biological characteristics. The bottom line on water quality—that is, on the quality of water you are about to drink or use—is a matter of judgment. Like pollution, water quality, in many instances, can be a judgment call.

Early aquatic resource management efforts were often directed toward ensuring the potability of surface water sources. Subsequently, the scope of these management initiatives expanded to include protection of instream (i.e., fish and aquatic life), agricultural, industrial, and recreational water uses. Although initiatives undertaken in the past several decades have unquestionably improved water quality conditions, a growing body of evidence indicates that management efforts directed solely at the attainment of surface water quality criteria may not provide an adequate basis for protecting the designated uses of aquatic ecosystems (USEPA, 2002).

In recent years, concerns relative to the health and vitality of aquatic ecosystems have begun to surface in North America. One of the principal reasons why is that many toxic and bioaccumulative chemicals can accumulate to elevated levels in sediments; these chemicals include metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), chlorophenols, organochlorine (OC) pesticides, and polybrominated diphenyl ethers (PBDEs), which are found in only trace amounts in water. Some of these pollutants, such as OC pesticides and PCBs, were released into the environment long ago. The use of many of these substances has been banned in North America for more than 40 years; nevertheless, these chemicals continue to persist in the environment. Other contaminants enter our waters every day from industrial and municipal discharges, urban and agricultural runoff, and atmospheric deposition from remote sources. Due to their physical and chemical properties, many of these substances tend to accumulate in sediments. In addition to providing sinks for many chemicals, sediments can also serve as potential sources of pollutants to the water column when conditions change in the receiving water system (e.g., during periods of anoxia, after severe storms).

Information from a variety of sources indicates that sediments in aquatic ecosystems throughout North America are contaminated by a wide range of toxic and bioaccumulative substances, including metals, PAHs, PCBs, OC pesticides, a variety of semivolatile organic chemicals (SVOCs), and polychlorinated dibenzo-*p*-dioxins and furans (PCDDs and PCDFs). Contaminated sediments pose a major risk, for example, to the beneficial uses of aquatic ecosystems throughout the Great Lakes. The imposition of fish consumption advisories has adversely affected commercial, sport, and food fisheries in many areas. In addition, degradation of the benthic community and other factors have adversely affected fish and wildlife populations. Furthermore, fish in many of these areas often have higher levels of tumors and other abnormalities than fish from reference areas. Contaminated sediments have also threatened the viability of many commercial ports because of restrictions placed on dredging navigational channels and the disposal of dredged materials. Overall, contaminated sediments have been linked to beneficial use impairments in Canada and the United States (USEPA, 2002).

KEY TERMS AND DEFINITIONS

Although a glossary of terms and definitions is included at the end of the book, experience has shown that defining basic, fundamental, and important terms at the beginning of a technical presentation is paramount to understanding the technical information that follows. Many of the terms used in the text that follows are presented here first to provide a map to understanding:

Activity—A dimensionless quantity expressing the escaping tendency of a component in a system relative to that in a pure state of the same component at the same temperature and total pressure. It is the ratio of the partial pressures (or, more precisely, the fugacities) of the dissolved component in the system to that of the component at standard state.

Activity coefficient—A dimensionless quantity that corrects for the deviation of the partial pressure (or fugacity) of a component in solution from that value defined by Raoult's law. If the observed partial pressure is greater than that predicted by Raoult's law, the activity coefficient is less than one. Most organic solutes in water show positive deviation from ideality; that is, the activity coefficient is greater than one. This term provides an approximation of how much interaction exists between molecules at higher concentrations.

Adsorption—The interphase accumulation or concentration of substances at a surface or interface. The process can occur at an interface between any two phases, such as liquid–liquid, gas–liquid, gas–solid, or liquid–solid interfaces. The material being concentrated or adsorbed is the adsorbate, and the adsorbing phase is termed the adsorbent.

Advection—The transport of particles due to the motion or velocity of the fluid.

Anthropogenic compounds—Compounds that are produced as a result of the activities of humans as contrasted with compounds formed by the actions of natural forces and events.

Bedload—Sediment that is transported in a stream by rolling, sliding, or skipping along the bed and very close to it (i.e., within the bedlayer).

Bedload layer—A thin layer through which the bedload discharges, commonly assumed to be only a few grain diameters thick.

Benthic—Of the seafloor, or pertaining to organisms living on or in the seafloor.

Bioturbation—Mixing processes in sediment layer caused by the activity of biological organisms.

Boundary layer—The thin layer of fluid next to a solid boundary (e.g., bottom of an estuary) where friction is very important.

Bulk density—The total mass density of sediment and water in a given volume of sediment bed material.

Coagulation—A process where charge neutralization of discrete colloids occurs through interactions with available counterions (i.e., the mobile ions in ion exchange).

Cohesive—Description of sediments, generally less than 200 μm in diameter, that tend to stick together and resist separation.

Colloids—Operationally defined as discrete particles with at least one characteristic dimension in the micrometer to nanometer range.

Critical shear stress—The shear stress at which sediments begin to exhibit a measurable amount of motion.

Diagenesis—The gradual and successive chemical and physical changes that take place in sediment previous to or during its consolidation.

Dissolved—Operationally defined as discrete particles less than 0.45 μm in their maximum dimension.

Epibenthic—Pertaining to organisms living near the seafloor.

Fetch—Distance of water over which the wind blows in essentially a constant direction.

Flocculation—Aggregation of natural discrete colloids into larger masses by the mixing action of water.

Fluvial—Pertaining to rivers or streams.

Flux—The rate of flow of a physical substance (e.g., water or sediments) through a given area.

Fulvic acids—The fraction of organic matter that remains dissolved in solution after sequential extraction of the sample with alkali and then acid.

Humic acids—The fraction of organic matter that remains dissolved in solution after extraction with alkali but that precipitates from solution upon further extraction with acid.

Humins—The fraction of organic matter that is not soluble in either alkali or acid.

Interstitial water—Water occurring in the small openings, spaces, and voids between particles of unconsolidated materials in that portion of the vadose water zone between the root zone and the water table. The water is held in place by entrapment, ionic attraction, and capillary or adhesive forces, rather than from upward pressure components of saturation.

Lipophilic—The characteristic of solutes or solvents that are readily miscible in other organic solvents such as lipids. Lipids as a heterogeneous group of substances include fatty acids, neutral fats, phosphatides, glycolipids, aliphatic alcohols and waxes, terpenes, and steroids. Lipids are categorized by their extractability in nonpolar organic solvents such as chloroform carbon tetrachloride, benzene, ether, carbon disulfide, and petroleum ether.

Miscible—The ability of two or more substances to mix and to form a single, homogeneous phase.

Noncohesive—Description of sediments, generally more than 200 μm in diameter, that exhibit no tendency toward resisting separation.

Particulate—Operationally defined as discrete particles greater than 0.45 μm in their maximum dimension.

Partition—The distribution of a compound between two different bulk phases, usually by a solubilization process.

Polarity—Local charge groupings occurring as a result of geometric asymmetries between atoms of a given molecule. This chemical characteristic can lead to incompatibilities between liquids of different polarities. The relative polarity of large macromolecules, such as the humic and fulvic acids, is measured by comparing the oxygen-to-carbon ratios of the molecules. The larger the magnitude of the ratio, the greater the relative polarity of the compound.

Porewater (or interstitial water)—Subsurface water in an interstice, or pore (Bates and Jackson, 1984). Sediment interstitial water, or porewater, is defined as the water occupying the spaces between sediment particles. Contaminants in the interstitial water and in the solid phase are expected to be at thermodynamic equilibrium. This makes interstitial waters useful for assessing contaminant levels and associated toxicity (USEPA, 2001).

Porosity—The ratio of openings (voids or pores) to the total volume of a soil or rock. Porosity is expressed either as a decimal fraction or as a percentage (Heath, 1983). The porosity of a rock is its property of containing interstices (Meinzer, 1923).

Sediment—Fragmented material that originates from the disintegration of rocks and is transported by, suspended in, or deposited by water or air or is accumulated in beds by other natural processes; it is detached fragmental matter that originates from either chemical or physical weathering of rocks and minerals and is transported by, suspended in, or deposited by water or air or is accumulated in beds by other natural agencies (Osterkamp, 2008).

Shear stress—The force due to friction exerted on a unit area of the sediment bed due to a moving water mass.

Solute—The compound dissolved in solution.

Sorption—General expression for a process in which a component moves from one phase to be accumulated in another. The material being sorbed is the sorbate, and the sorbing phase is termed the sorbent. Sorption is used when it is not certain if the accumulating mechanism is a partitioning, an adsorption, or an absorption process.

Surface microlayer—Upper, very thin layer of a surface water body characterized by high surface tension and some physical and chemical properties distinguishable from the bulk solution.

Surficial sediment layer—Upper sediment layer with a thickness that fluctuates depending on the disposition rates of new sediment and the degrees of resuspension generated by boundary layer turbulence. In this book, the surficial sediment layer is always considered to be submerged.

Suspended load—Sediment particles maintained in the water column by turbulence and carried with the flow of water.

Turbulent diffusion—The movement and dispersal of a mass in the water column due to random turbulent motions in the flow.

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