Chapter 1 Overview of Findings and Implications

Nearly 4 million miles of streams and rivers are woven through the landscape of the United States. This immense natural resource provides many societal benefits. Streams and rivers provide water for cities and farms; they provide recreational, cultural, and aesthetic benefits valued by many people; and they nourish a diverse array of plant and animal species. Changes in land use and increasing demands for freshwater pose risks to the health of streams and rivers and to the benefits they provide to society.

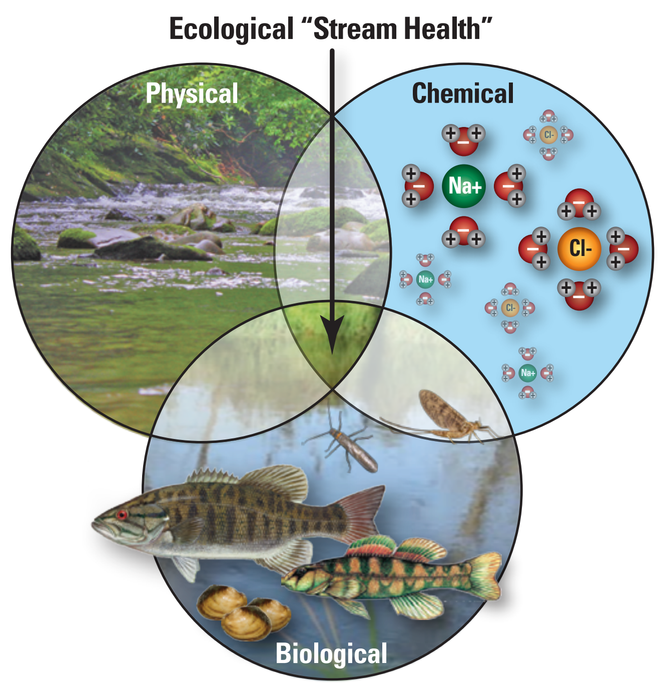
U.S. Geological Survey photo by Daren Carlisle.

The condition of biological communities—which are collections of aquatic organisms—provides a direct measure of stream health.

Introduction

This report summarizes a national assessment of the ecological health of streams done by the U.S. Geological Survey's (USGS) National Water-Quality Assessment Program (NAWQA). Healthy functioning stream ecosystems provide society with many benefits, including water purification, flood control, nutrient recycling, waste decomposition, fisheries, and aesthetics. The value to society of many of these benefits is substantial; for example, sportfishing in the United States generates an estimated annual economic output of $125 billion, including more than 1 million jobs (National Research Council, 2005; American Sportfishing Association, 2008). Continued monitoring and assessment of the Nation's streams is needed to support informed decisions that will safeguard this important natural and economic resource.

The quality of streams and rivers is often assessed with measures of the chemical or physical properties of water. However, a more comprehensive perspective is obtained if resident biological communities are also assessed. Guidelines to protect human health and aquatic life have been established for specific physical and chemical properties of water and have become useful yardsticks with which to assess water quality. Biological communities provide additional crucial information because they live within streams for weeks to years and therefore integrate through time the effects of changes to their chemical or physical environment. In addition, biological communities are a direct measure of stream health—an indicator of the ability of a stream to support aquatic life. Thus, the condition of biological communities, integrated with key physical and chemical properties, provides a comprehensive assessment of stream health.



As this simple diagram shows, a stream's ecological health (or "stream health") is the result of the interaction of its biological, physical, and chemical components. Stream health is intact if (1) its biological communities (such as algae, macroinvertebrates, and fish) are similar to what is expected in streams under minimal human influence and (2) the stream's physical attributes (such as streamflow) and chemical attributes (such as salinity) are within the bounds of natural variation. Although the condition of biological communities is a crucial indicator of stream health, a more holistic approach includes assessments of key physical and chemical characteristics of streams. This is NAWQA's approach to assessing stream health.

Highlights of Major Findings and Implications

- The presence of healthy streams in watersheds with substantial human influence indicates that it is possible to maintain and restore healthy stream ecosystems. Such streams can also offer insights into how stream health can be maintained amid anticipated changes in land use or restored when stream health has deteriorated as a result of human actions.
- Assessments that are limited to a single biological community are likely to underestimate the effects of land and water use on stream health. Assessments of multiple biological communities increase our ability to detect streams with diminished health and provide a more complete understanding of how land and water use influence stream health.
- Water quality is not independent of water quantity because flows are a fundamental part of stream health. Because flows are modified in so many streams and rivers, there are many opportunities to enhance stream health with targeted adjustments to flow management.
- Efforts to understand the causes of reduced stream health should consider the possible effects of nutrients and pesticides, in addition to modified flows, particularly in agricultural and urban settings.
- Stream health is often reduced due to multiple physical and chemical factors. Assessments and restoration efforts should therefore take a multifactor approach, wherein a number of factors—and their possible interactions—are considered. Understanding how these multiple factors influence biological communities is essential in developing effective management strategies aimed at restoring stream health.

U.S. Geological Survey photo by John Wilson.

This photograph of stream runoff going through a cornfield in Hancock County, Indiana, illustrates that stream health can be influenced by multiple factors. For example, runoff from some land-use practices may contain nutrients, sediments, and pesticides, which can be transported to local streams and potentially affect biological communities.

U.S. Geological Survey photo by Daren Carlisle.

Extreme low-water conditions shown in this photograph of a California stream illustrate the necessity to balance societal needs for water withdrawal with the needs to maintain stream health. Understanding relations among biological communities and manmade modification to streamflow is essential to informing decisions needed to achieve this balance.

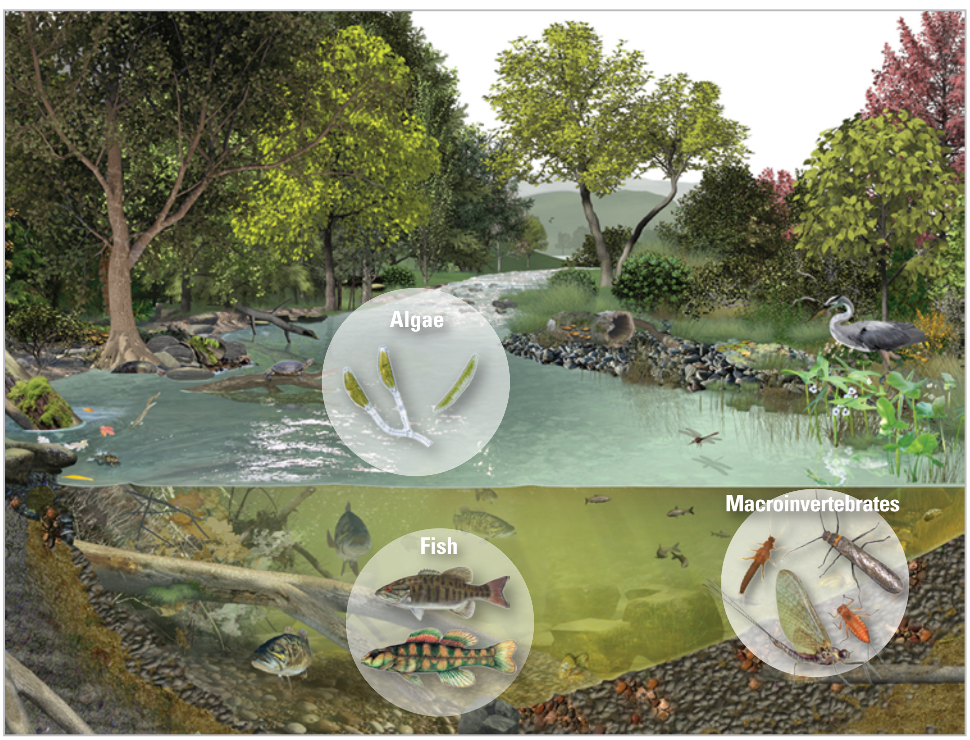
At least one biological community—algae, macroinvertebrates, or fish—was altered in 83 percent of assessed streams.

Biological Condition and Land Use

Across all land-use settings at least one biological community—algae, macroinvertebrates, or fish—was altered in 83 percent of assessed streams. In urban settings, 89 percent of sites assessed by NAWQA had at least one altered biological community, compared with 79 percent of sites in agricultural settings and 83 percent of sites in mixed-use settings. All three biological communities were altered in 22 percent of assessed streams. A community was classified as altered if the numbers and types of organisms in it were substantially different from its natural potential, as estimated from regional reference sites (chapter 3). This high incidence of altered biological communities suggests that stream health is threatened by a wide variety of land- and water-management activities across the Nation (chapter 5).

Unaltered biological communities were present in 17 percent of assessed streams. The presence of unaltered biological communities in agricultural and urban watersheds suggests that it is possible to maintain stream health in the midst of substantial human influence. In addition, a wide range in the severity of biological alteration was found among streams within each land-use setting (chapter 5), which indicates that the influences of land and water management on stream health differ widely across the Nation.

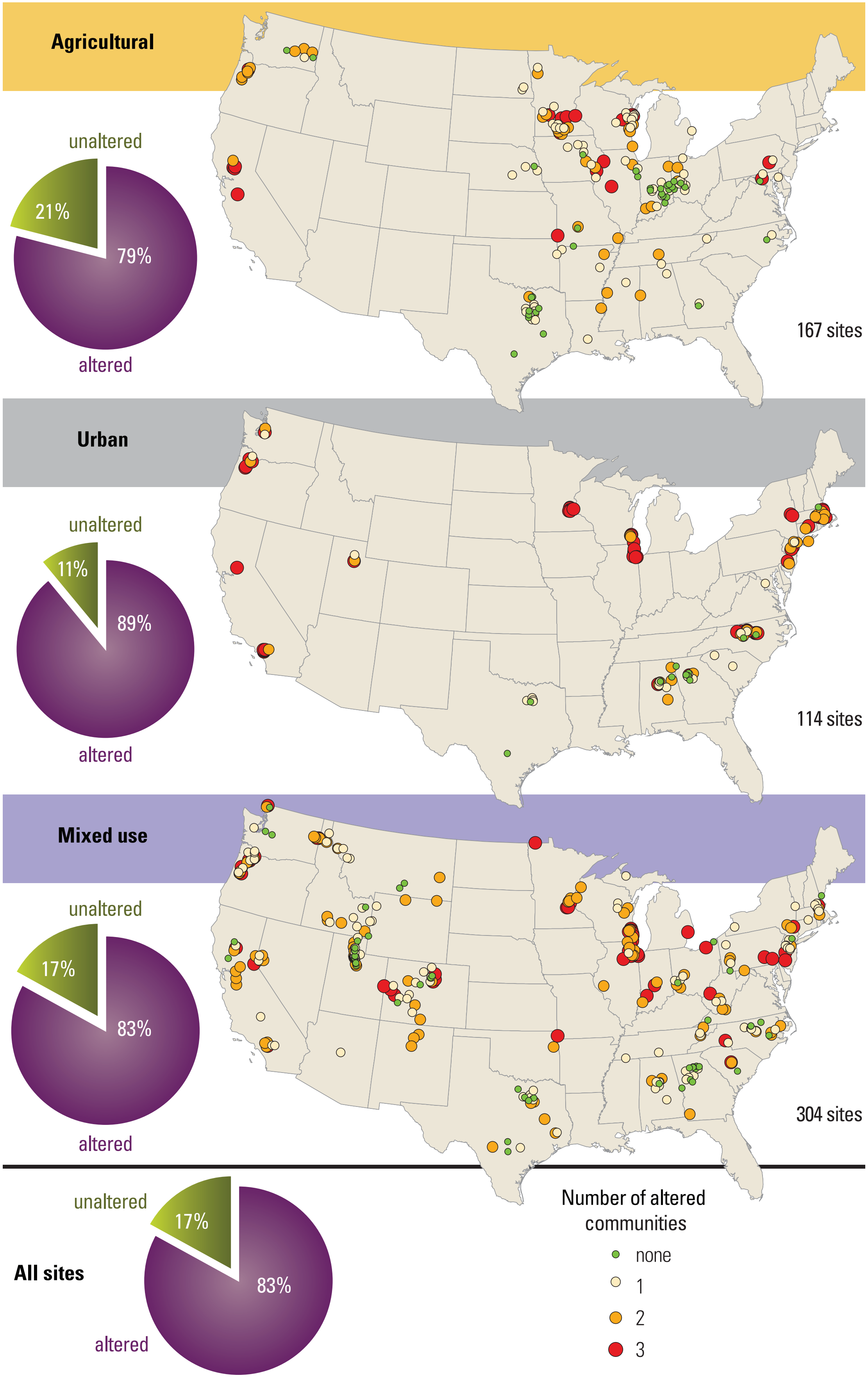
Integrated assessments of algal, macroinvertebrate (such as insects and snails and clams), and fish communities revealed twice as many altered streams in some land-use settings compared to single-community assessments (chapter 5). Multicommunity assessments increase the likelihood of detecting reduced stream health because species in different communities have unique vulnerabilities to manmade changes in their physical and chemical surroundings. This finding suggests that assessments limited to a single biological community are likely to underestimate the influence of land and water management on stream health.



Background illustration by Frank Ippolito/www.productionpost.com.

As shown in this illustration, living components of stream ecosystems include a complex and varied array of biological communities, including algae, macroinvertebrates (such as aquatic insects and snails and clams), and fish.

Integrated Condition Assessment of Algal, Macroinvertebrate, and Fish Communities



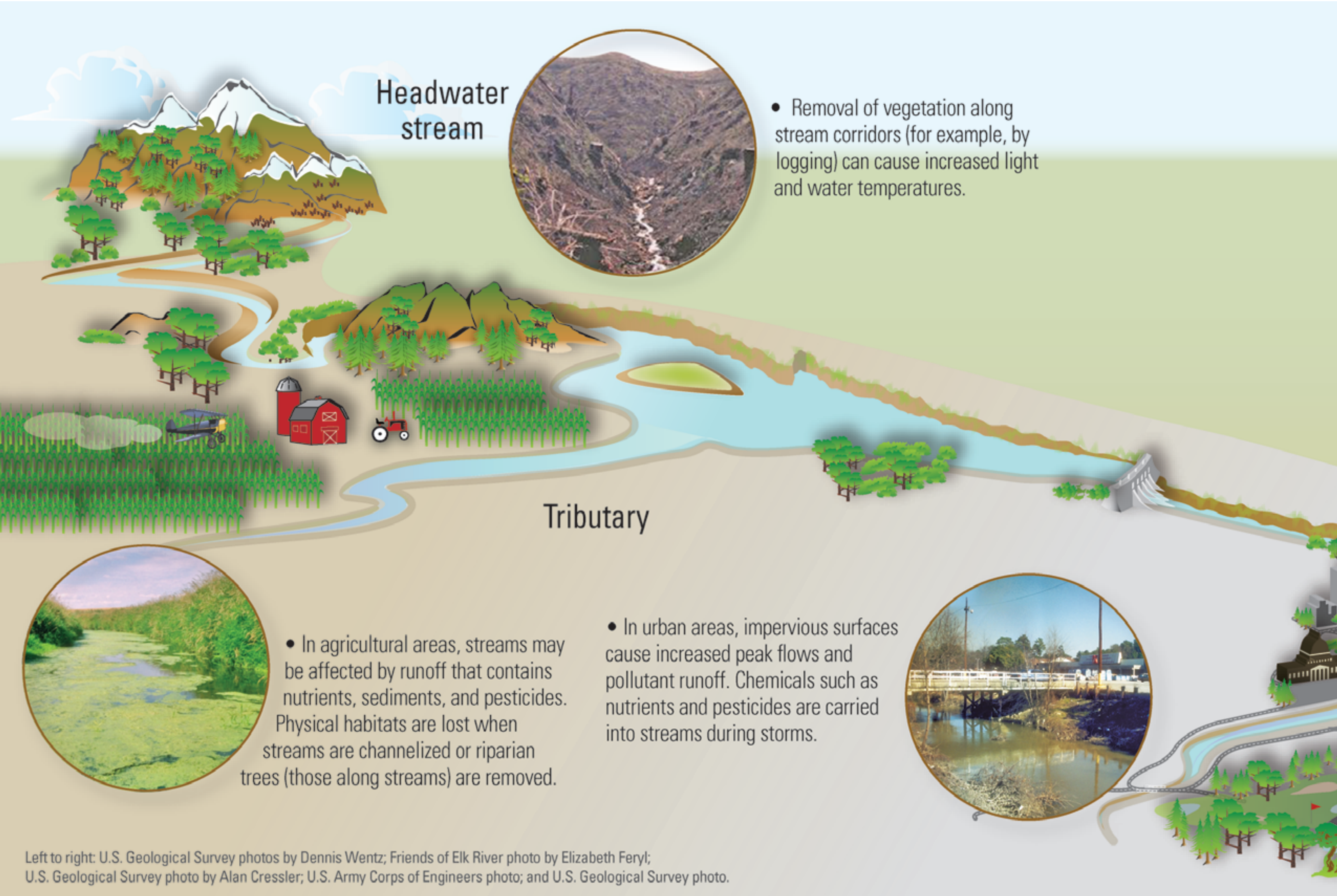
As shown in this diagram, regardless of land-use setting, at least one biological community (algae, macroinvertebrates, or fish) was altered, relative to regional reference conditions, at 83 percent of the 585 streams in the conterminous United States where NAWQA performed integrated assessments of multiple biological communities. (%, percent. Labels for individual States are shown on the map on page 22.)

Reduced stream health was associated with manmade modifications to physical and chemical factors that often result from land and water management.

Factors Associated with Stream Health

When assessments reveal that biological communities are altered—which indicates that stream health is diminished—scientists and managers must determine which physical or chemical factors have been modified by human activities sufficiently to alter biological communities. This information is essential to identifying and implementing appropriate management practices aimed at restoring stream health (chapter 6).

Reduced stream health is associated with manmade modifications to the physical and chemical properties of streams, which are a consequence of land and water management. Maintenance of stream health requires that physical and chemical properties of streams remain within the bounds of natural variation. When manmade disturbances push these characteristics beyond natural ranges, such as might occur from increased fluctuation in streamflows or excess nutrients, vulnerable aquatic species are eliminated—ultimately reducing stream health. Manmade modifications to key physical and chemical factors that control stream health are extensive, occurring in all types of land-use settings (chapter 4).

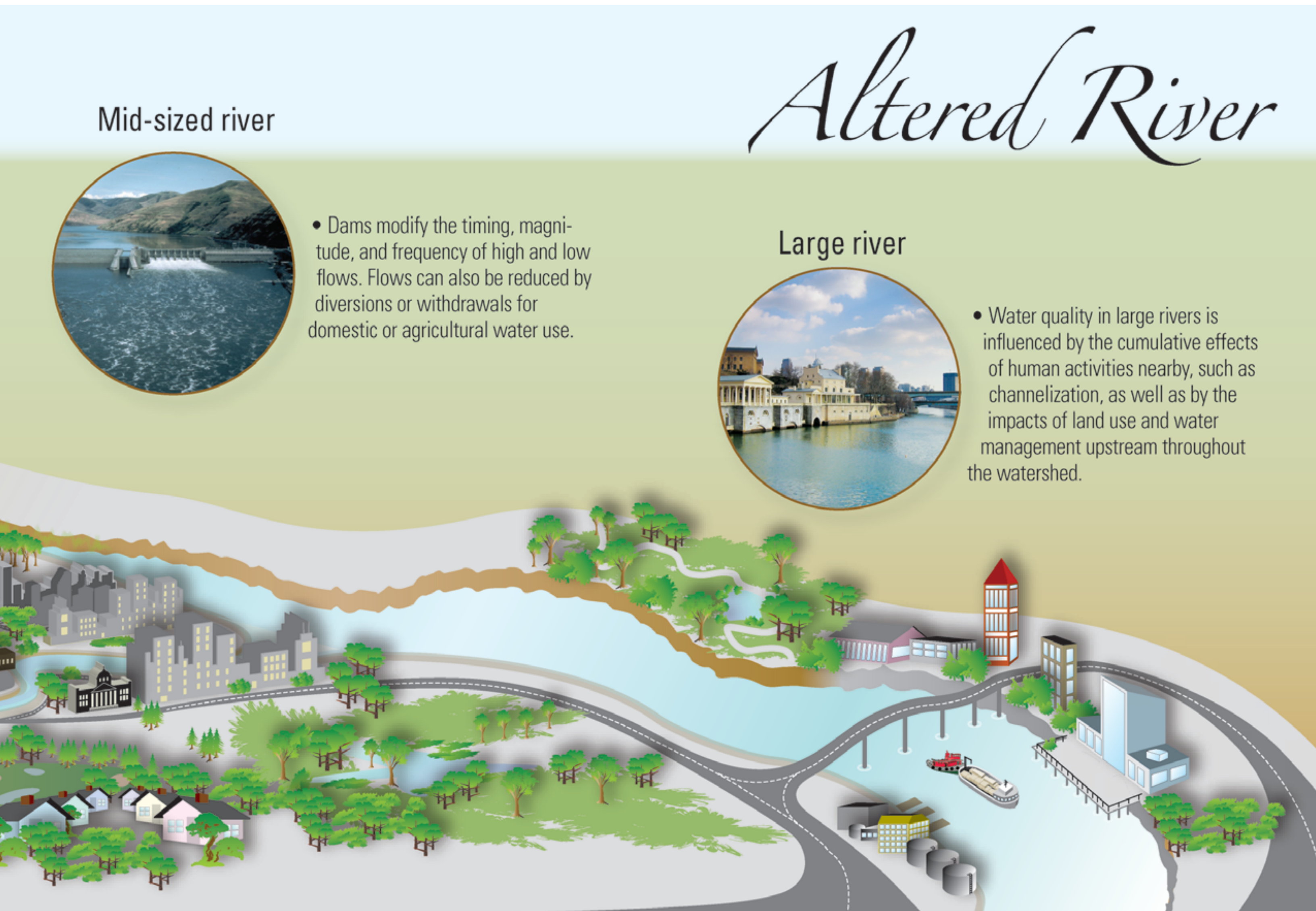


Left to right: U.S. Geological Survey photos by Dennis Wentz; Friends of Elk River photo by Elizabeth Feryl; U.S. Geological Survey photo by Alan Cressler; U.S. Army Corps of Engineers photo; and U.S. Geological Survey photo.

Alteration of biological communities and reduced stream health in a given stream are often related to modifications of multiple physical and chemical factors. A major challenge to understanding why stream health is reduced is unraveling the effects of many interacting natural and human-caused factors (chapter 6). In addition, factors associated with altered biological communities often differ among algal, macroinvertebrate, and fish communities, because each has unique requirements for survival and vulnerability to changes in their environment (chapters 5 and 6). Finally, factors associated with reduced stream health often differ among geographic regions (chapter 6). These findings suggest that management strategies aimed at restoring stream health should take a multifactor approach that is tailored to the geographic setting and the biological communities that have been altered.

Several physical and chemical factors that are known to be widely altered as a result of land and water management have the potential to alter stream health. These are briefly summarized in the pages that follow but do not represent all the possible factors that contribute to reduced stream health across the Nation.

No single physical or chemical factor was universally associated with reduced stream health across the Nation.

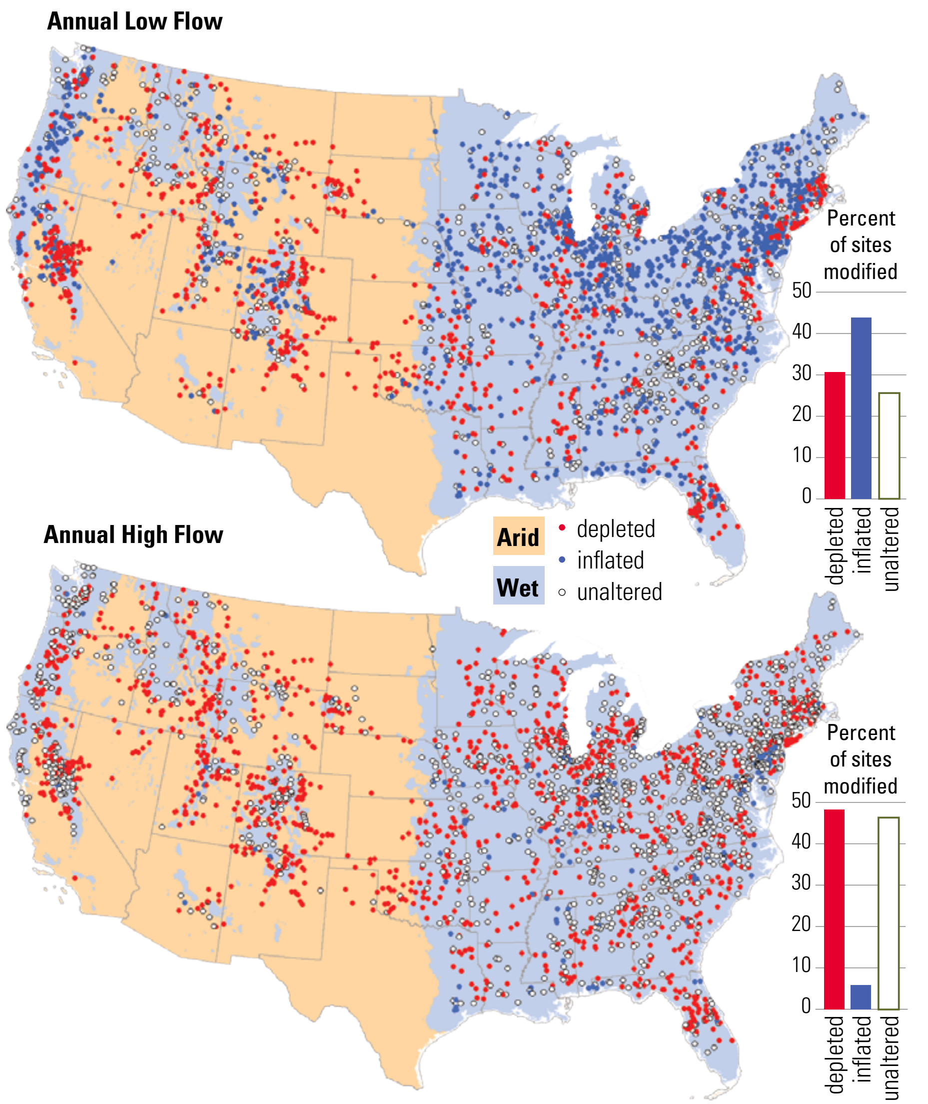


Annual low or high flows were modified in 86 percent of the almost 3,000 assessed streams.

Streamflow Modification

Flowing water is the defining feature of streams, yet streamflows across the Nation have been modified by land and water management, leading to reduced stream health. Annual high or low flows were modified in 86 percent of the almost 3,000 streams assessed by NAWQA across the Nation (chapter 4). Streamflows are modified by a variety of land- and water-management activities, including reservoirs, diversions, subsurface tile drains, groundwater withdrawals, wastewater inputs, and removal of vegetated land cover in the watershed.

Differences in streamflow modification are especially large between arid and wet climates. In wet climates, watershed management is often focused on flood control, which can result in depleted high flows and inflated low flows. In contrast, extremely low flows are a larger concern in arid climates, in part due to groundwater withdrawals and high water use for irrigation.

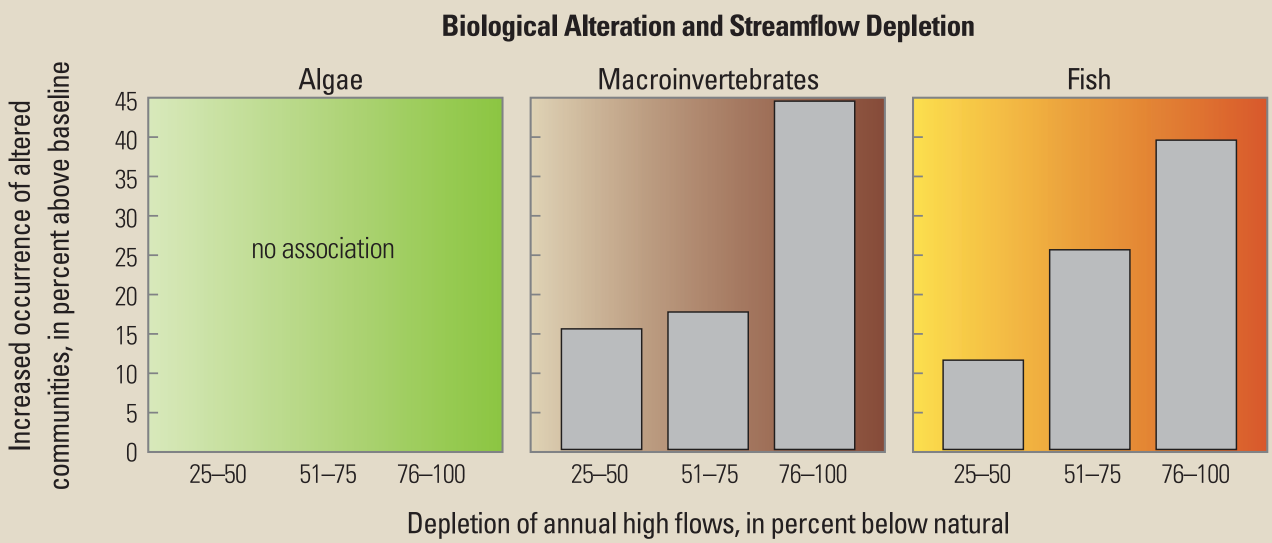


As shown in this diagram, annual high or low streamflows were modified in 86 percent of stream sites assessed across the Nation by NAWQA. Streamflow modification was depleted (less than), inflated (more than), or unaltered relative to expected natural magnitudes. Although high flows were depleted throughout the United States, low flows tended to be depleted in arid regions and inflated in wet regions. These results highlight the value of long-term streamflow data collected by the U.S. Geological Survey in cooperation with numerous local, State, and Federal partners.

Biological communities were more frequently altered in streams with modified flows (chapter 6). With increasing manmade depletion of annual high flows, the incidence of altered communities increased from 16 to 45 percent for macroinvertebrates and from 12 to 40 percent for fish. Similar patterns were observed for depletion of annual low flows. These associations between biological alteration and streamflow modification were evident even after controlling for the influence of other factors that affect biological communities such as nutrients, salinity, and land cover (Carlisle and others, 2011). Algal community condition, in contrast, was unrelated to streamflow modification.

Understanding the relations between streamflow modification and biological condition is essential to make informed decisions about tradeoffs between water use and the maintenance of stream health (Postel and Richter, 2003; Poff and others, 2010). NAWQA findings provide a national-scale perspective on the importance of natural streamflow to the maintenance of biological communities and stream health and provide water managers a much-needed perspective on the pervasiveness and severity of streamflow modification.

Macroinvertebrate and fish communities were frequently altered as streamflow modification increased.



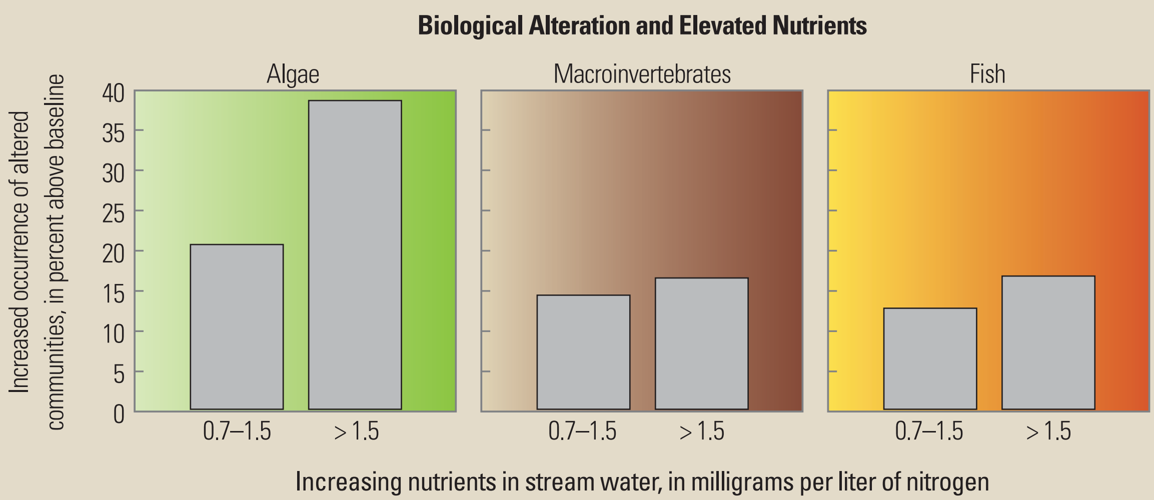
NAWQA studies found that macroinvertebrate and fish communities in the Nation's streams were more frequently altered in streams with increasingly severe flow depletion (bar graphs above). Algal community alteration was not related to flow depletion. Reservoirs, diversions, and other manmade changes to streams and their watersheds modify natural streamflows that are crucial to the life cycles of aquatic organisms. Baseline is the occurrence of altered communities in approximately 60 streams with annual high-flow depletion less than 25 percent.

Biological communities, particularly algae, were more frequently altered in streams with elevated nutrients.

Elevated Nutrients

Excess concentrations of nutrients are widespread in the Nation's streams and rivers and are associated with altered biological communities (U.S. Environmental Protection Agency, 2006a). A national NAWQA assessment of nutrients (Dubrovsky and others, 2010) reported that concentrations of nitrogen and phosphorus—important plant nutrients—exceeded predicted natural levels in streams and rivers and in all types of land-use settings throughout the Nation. A variety of sources can contribute nutrients to streams, including wastewater and industrial discharges, fertilizer applications to agricultural and urban lands, and atmospheric deposition.

Biological communities, particularly algae, were more frequently altered in streams with elevated nutrients (chapter 6). With increasing nutrient concentrations in stream water, the incidence of altered biological communities increased from 21 to 39 percent for algae, from 15 to 17 percent for macroinvertebrates, and 13 to 17 percent for fish. Changes in biological alteration associated with nutrient levels were most pronounced for algal communities, likely because of the direct link between nutrient availability and algal growth and reproduction.



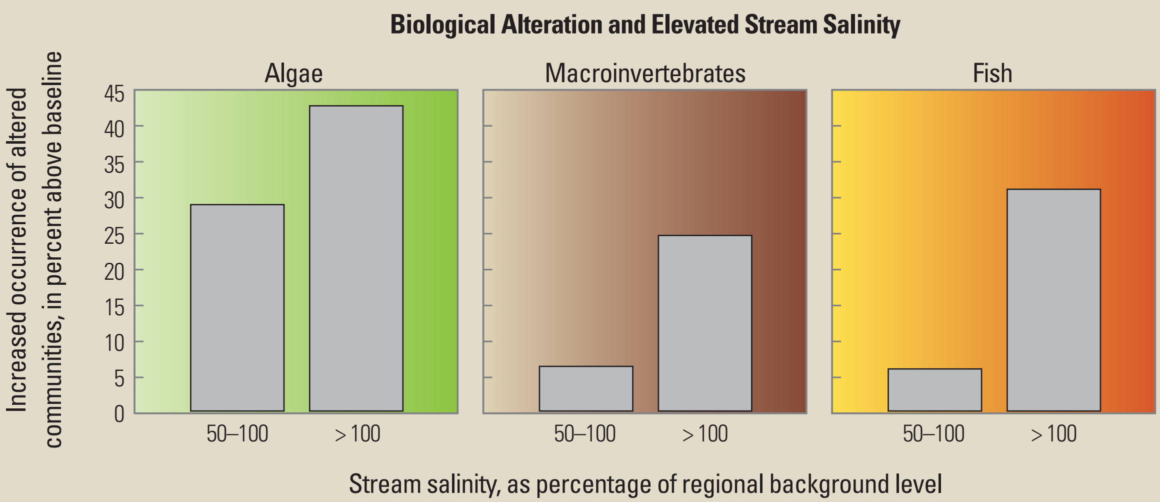
NAWQA studies found that biological communities, particularly algae, in the Nation's streams were more frequently altered in streams with elevated levels of the nutrient nitrogen (bar graphs above). Algae that flourish in streams with excess nutrients can become prolific and consume the oxygen in water, often leading to the death of aquatic animals. Baseline is the occurrence of altered communities in approximately 400 streams with total nitrogen concentrations less than 0.7 milligram per liter. (>, greater than; 1 milligram per liter = 1 part per million.)

Elevated Salinity

Streams with elevated salinity occur in urban and agricultural land-use settings throughout the Nation (Mullaney and others, 2009). Elevated salinity in urban settings is most prevalent in northern States that receive relatively high snowfall, which suggests that road de-icing is a major salt source (chapter 4). Other sources of salinity in urban streams include wastewater effluent and faulty septic systems. Elevated salinity in agricultural streams occurs throughout the Nation. The largest sources of excess salinity in agricultural streams include fertilizer applications and irrigation wastewater (Mullaney and others, 2009).

Biological communities were more frequently altered in streams with increasingly elevated salinity levels (chapter 6). In streams with increasingly elevated salinity above regional background levels, the incidence of altered communities increased from 29 to 43 percent for algae, 7 to 25 percent for invertebrates, and 6 to 31 percent for fish. Excess salinity in stream water disrupts the balance of salts and fluids between the tissues of aquatic organisms and the surrounding water, which often leads to death and, ultimately, the loss of vulnerable species.

Biological communities were more frequently altered in streams with increasingly elevated salinity relative to background levels.



NAWQA studies found that algal, macroinvertebrate, and fish communities in the Nation's streams were more frequently altered in streams with increased salinity over natural background levels (bar graphs above). Land-use practices such as irrigation and road-salt application can lead to excess salinity in stream water, which disrupts the balance of salts and fluids in aquatic organisms, often leading to death. Baseline is the occurrence of altered communities in approximately 500 streams with salinity levels less than 50 percent of regional background levels. (>, greater than.)

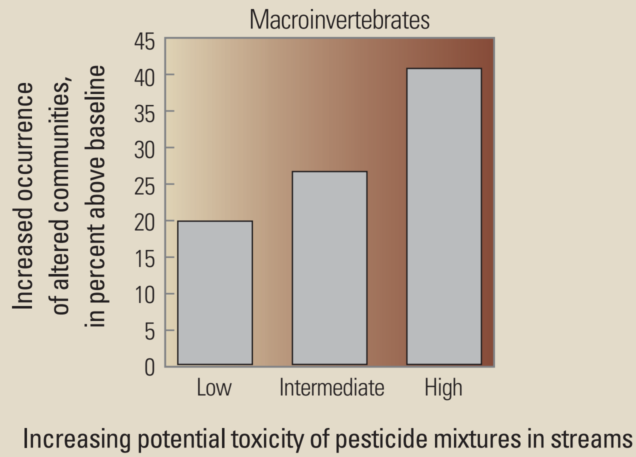
Macroinvertebrate communities were more frequently altered in streams containing pesticide mixtures with higher potential toxicity.

Contaminant Toxicity in Stream Water and Sediments

Across the Nation, contaminant mixtures in stream water and sediments contribute to diminished stream health. A national NAWQA assessment of pesticides (Gilliom and others, 2006) reported that dissolved pesticide concentrations were greater than benchmarks established for aquatic life by the U.S. Environmental Protection Agency in more than half of assessed streams in agricultural and urban settings and therefore have the potential to adversely affect aquatic organisms. Importantly, pesticides commonly occur as mixtures of multiple chemical compounds, rather than individually. As a consequence, aquatic organisms are typically exposed to complex mixtures of multiple compounds, and the total combined toxicity of these mixtures may be greater than that of any single compound present.

Macroinvertebrate communities were more frequently altered in streams with elevated concentrations—and potential toxicity—of pesticides (chapter 6). Specifically, the incidence of altered macroinvertebrate communities increased from 20 to 42 percent as the potential toxicity of pesticide mixtures increased. Insecticides commonly used in agricultural and urban areas (chlorpyrifos, carbaryl, and diazinon) were among the most frequently detected—and potentially toxic—pesticides in stream water and were associated with the alteration of macroinvertebrate communities across the Nation, even after controlling for other natural and manmade factors (chapter 6). These findings indicate that nationwide some of the reduction in stream health in agricultural and urban areas can be attributed to elevated levels of dissolved insecticides. Diazinon

Macroinvertebrate Community Alteration and Potential Toxicity of Pesticides



NAWQA studies found that macroinvertebrate communities in the Nation's streams were more frequently altered in streams with increasing levels of pesticides, as measured by the potential toxicity of pesticide mixtures (bar graph above). Insecticides, which are designed to kill insects, were the most frequently detected and potentially toxic pesticides and were found in stream water in agricultural and urban settings. Baseline is the occurrence of altered communities in 132 streams with no pesticide detections.

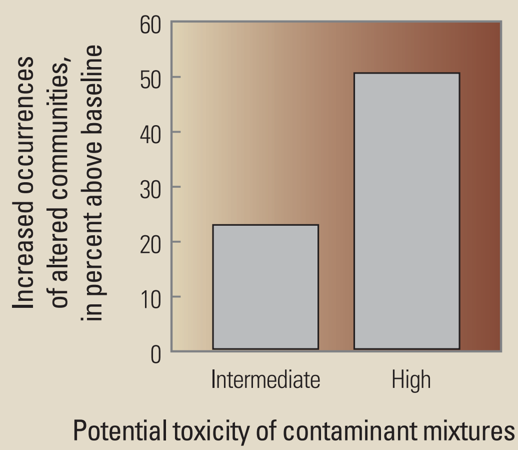
sales for residential use were phased out beginning in 2000, and it has since been replaced by other products.

Contaminants associated with streambed sediments also were frequently present at concentrations that may adversely affect stream health. A national NAWQA assessment of the occurrence and distribution of contaminants in streambed sediments reported that U.S. Environmental Protection Agency Aquatic-Life Benchmarks for pesticide compounds were exceeded at 70 percent of assessed streams in urban settings and 30 percent of streams in agricultural settings (Gilliom and others, 2006). As with dissolved pesticides, sediment contaminants generally occurred in complex mixtures of multiple compounds.

Macroinvertebrate communities were more frequently altered in streams with greater potential toxicity of sediment contaminant mixtures (chapter 6). Specifically, the incidence of altered macroinvertebrate communities increased from 23 to 51 percent as the potential toxicity of sediment contaminants increased. The sediment contaminant mixtures examined in this report include organochlorine pesticides such as dichlorodiphenyltrichloroethane (DDT), polycyclic aromatic hydrocarbons (PAHs) such as benzene, and trace metals such as mercury. In urban areas, high potential toxicity was mostly the result of elevated concentrations of PAHs, many of which are known to be highly toxic to aquatic life (Albers, 2003). In agricultural areas, high potential toxicity was largely the result of elevated concentrations of legacy organochlorine compounds, such as DDT. Collectively, these findings show evidence that elevated concentrations of dissolved pesticide mixtures in stream water and contaminant mixtures in stream sediments have a high potential to diminish stream health across the Nation.

Macroinvertebrate communities were more frequently altered in streams with greater potential toxicity of sediment contaminant mixtures.

Macroinvertebrate Community Alteration and Potential Toxicity of Sediment Contaminants



NAWQA studies found that macroinvertebrate communities in the Nation's streams were more frequently altered in streams with increasing concentrations and potential toxicity of contaminants in streambed sediments (bar graph above). Sediment-bound contaminants in streams typically include polycyclic aromatic hydrocarbons in urban settings and persistent pesticides in agricultural settings. Baseline is the occurrence of altered communities in 132 streams within the lowest category of potential toxicity.

Priorities for Filling Information Gaps for Understanding the Ecological Health of Streams

As present-day knowledge is brought to bear on decision making, there is a continuing need to improve the data and scientific understanding required for future decisions on the biological health of the Nation's streams. Some of the most important steps needed to fill these information gaps are outlined below:

- **Reference sites—**Improve understanding of natural variability in physical, chemical, and biological characteristics at streams with minimal human influences. The ability to quantify manmade modifications requires an understanding of the natural variability in physical, chemical and biological characteristics of streams. An expanded network of reference sites, particularly in regions that have widespread landscape modification, will be necessary to improve understanding of natural variability.

- **Predicting baseline conditions—**Synthesize existing State and Federal monitoring data to develop models that predict expected baseline conditions of key physical and chemical factors in streams, such as salinity, sediment, and water temperature. Greater use of the water-quality data portal (http://waterqualitydata.us) would increase access to State and Federal monitoring data and enhance the ability to synthesize large amounts of data for model development.

- **Understanding multiple factors—**Improve assessment and understanding of the effects of the interactions of multiple manmade factors on biological communities. A major challenge to understanding why biological communities are altered is the ability to unravel the effects of many interacting natural and manmade factors. New studies are needed to specifically assess the interactions of multiple factors on stream health.

- **Tools for decision making—**Improve the availability of tools useful for decision making. Increased understanding of the ways in which land and water management modify key physical and chemical characteristics of streams—and in turn influence stream health—should be accompanied by decision-support tools that allow predictions of the effects of alternative management actions.

- **Long-term monitoring—**Sustain and expand long-term monitoring for trends in the ecological health of streams. Long-term, consistent data for assessing trends is essential for tracking biological responses to management practices, as well as to natural and human-influenced variation in climate.

Society benefits in many ways from healthy streams and rivers, including recreational fishing, as shown in this photograph on the White River, Indiana.

U.S. Geological Survey photo by Joe Fenelon.