Chapter 6

Factors Associated with Diminished Biological Condition

Scientists and resource managers often become environmental detectives when assessments indicate that stream health is diminished. A major challenge to understanding why stream health is diminished is the ability to unravel the effects of many interacting natural and human-caused factors. Interdisciplinary scientific data on the physical, chemical, and biological conditions of streams can be used to improve our understanding of the relative importance of these factors in affecting biological communities—and ultimately, stream health.

U.S. Geological Survey photo by Daren Carlisle.

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

Factors Associated with Diminished Biological Condition—Summary

When assessments reveal that stream health is diminished, scientists and resource managers must determine which physical or chemical factors have been modified by human activities sufficiently to alter biological communities. This information is necessary so that remedial management strategies can be identified and implemented. A major challenge to understanding why biological communities are altered is unraveling the effects of many interacting natural and human-caused factors.

The findings and case studies presented in this chapter enhance our understanding of factors that influence stream health. Two general principles about these factors are briefly summarized here using findings from a national study of urban streams (Bryant and Carlisle, 2012; Coles and others, 2012). The remainder of the chapter describes more in-depth analyses of how, in a variety of land-use settings, different factors are related to biological alteration.
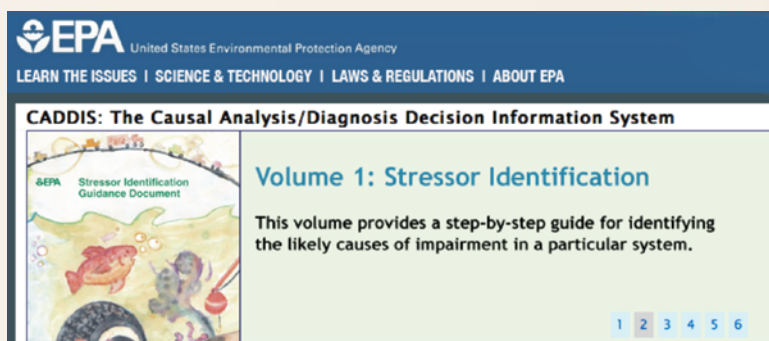
Biological alteration is often related to manmade modifications of multiple physical and chemical factors. For each biological community—algae, macroinvertebrates, and fish—in most geographic regions, biological alteration was generally associated with two or more physical or chemical factors. These findings reflect the fact that many physical and chemical factors are related or co-occur in watersheds influenced by human activities. These findings suggest that assessments and restoration efforts should take a multifactor approach, wherein a number of factors—and their possible interactions—are investigated and managed.

Factors associated with biological condition differ among environmental settings—there is no single physical or chemical factor that is universally associated with reduced stream health. None of the factors examined were associated with biological alteration in every geographic area. These findings suggest that management strategies aimed at restoring stream health are best developed and applied at the local scale, such as the watershed, where there is an understanding of how land- and water-management activities modify the physical, chemical, and biological attributes of streams. Nevertheless, the widespread importance of factors such as nutrients and streamflow suggest that regional and national priorities aimed at managing these factors can help restore and maintain stream health across the Nation.

## Tool for Diagnosing the Causes of Diminished Stream Health

Special tools are required to help identify the causes of diminished stream health. Experimentation is an important tool for understanding causality because it allows scientists to manipulate and measure the effect of one factor, while simultaneously controlling other factors. However, experimental manipulation of streams and their watersheds is rarely feasible or recommended, so a variety of other tools must be employed. In general, these tools integrate information from independent monitoring and other observational studies and examine whether this information provides evidence that alternative factors are responsible for declines in biological condition.

CADDIS (Causal Analysis/Diagnosis Decision Information System) is an online application developed by the U.S. Environmental Protection Agency that helps users organize and use information for identifying the causes of impaired stream health. It is designed for scientists involved in assessing causality, but resource managers, watershed groups, teachers, and others who are interested in factors reducing stream health may also find CADDIS useful. CADDIS features (1) advice on how to use specific data analysis methods and manage data for evaluating causality, (2) downloadable data analysis tools, and (3)other information sources such as databases of quantitative relations among specific environmental factors and biological communities. CADDIS can be accessed at http://www.epa.gov/caddis.

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CADDIS: The Causal Analysis/Diagnosis Decision Information System

Stressor Identification Guidance Document

Volume 1: Stressor Identification

This volume provides a step-by-step guide for identifying the likely causes of impairment in a particular system.

1 2 3 4 5 6

Physical and Chemical Factors Associated with Biological Alteration in Selected Urban Areas

Portland
Milwaukee
Denver
Raleigh
Dallas
Atlanta
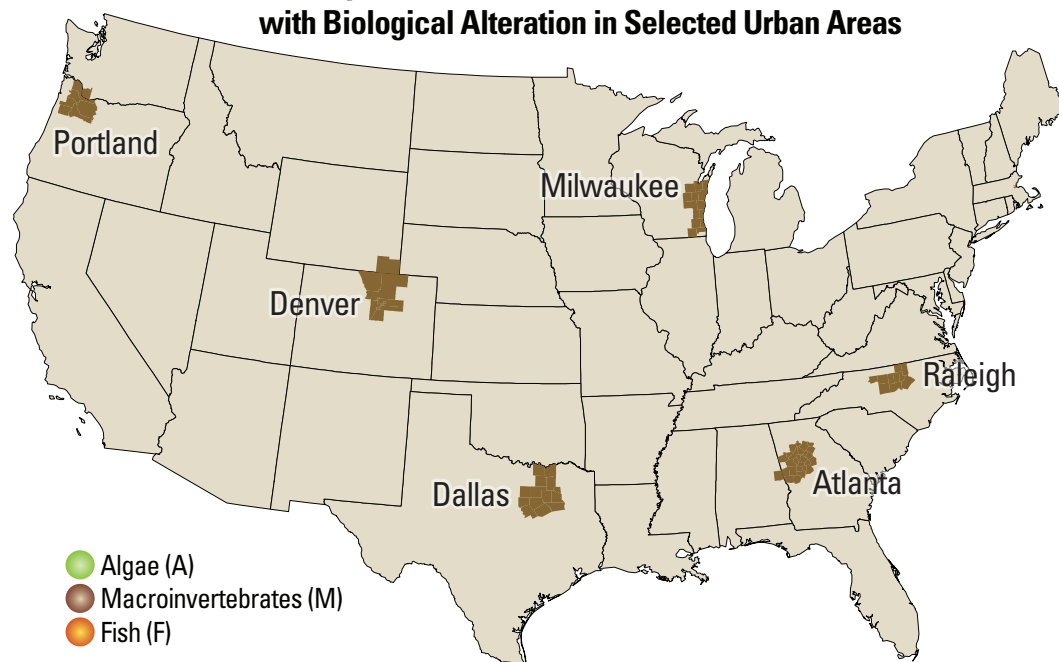
- 🟢 Algae (A)
- 🟤 Macroinvertebrates (M)
- 🟠 Fish (F)

Location	Portland			Denver			Dallas			Milwaukee			Atlanta			Raleigh		
Factor	A	M	F	A	M	F	A	M	F	A	M	F	A	M	F	A	M	F
Streamflow					M	F	A		F	A		F					M	F
Temperature		M				M-F				A	M	F		M				F
Sediment			F	A	M		A		M	A		F	A					F
Salinity	A				M	F	A			A						A		F
Nutrients	A			A		F	A	M		A			A	M	F	A		
Contaminants		M	F			F			F		M	F			F		M	F

NAWQA studies found that diminished biological condition in urban streams was associated with multiple physical and chemical factors. For example, in watersheds in six U.S. metropolitan areas (Portland, Oregon; Denver, Colorado; Dallas, Texas; Milwaukee, Wisconsin; Atlanta, Georgia; and Raleigh, North Carolina), associations of physical and chemical factors and biological condition were evaluated across 25 to 30 study sites in each of the areas (Bryant and Carlisle, 2012; Coles and others, 2012). This diagram shows these associations for algae, macroinvertebrate, and fish communities for each metropolitan area. Note that increases in all listed factors were associated with diminished biological condition. For example, increasing concentrations of contaminants were associated with reduced biological condition.

Cause-and-Effect Relations and the Role of Monitoring Data

Demonstrating that a specific physical or chemical factor is the cause of biological alteration is difficult when evidence is limited to monitoring data. This is largely because natural factors, such as stream size, and human-caused factors, such as streamflow alteration, may also vary with the factor of interest. For example, streams with elevated levels of insecticides may also have excess nutrients, which can also affect biological condition. As a result, attributing changes in biological condition to a single factor of interest can be misleading if other factors are not taken into account.

Ultimately, cause-and-effect relations must be established with the accumulation of evidence from rigorously designed observational studies and supporting laboratory experimentation (Clements and others, 2002). NAWQA is by design observational, relying on monitoring of current conditions rather than field or laboratory experimentation. Associations among biological condition and chemical and physical factors are presented in this report, but these do not alone prove causality. Rather, these findings provide evidence that these factors must be considered as likely contributors to biological alteration in more detailed studies.

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

Streamflow Modification

The natural timing, variability, and magnitudes of streamflow influence many key physical, chemical, and biological characteristics and processes of streams and are therefore crucial to maintaining stream health. Human-caused modification of natural streamflows occurs throughout the Nation and in all types of land uses (chapter 4).

NAWQA found that biological communities were more frequently altered in streams with increasingly modified flows. For example, with increasing manmade depletion of annual high flows, the incidence of altered communities increased from 16 to 45 percent for invertebrates 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 influence biological communities, such as nutrients, salinity, and land cover
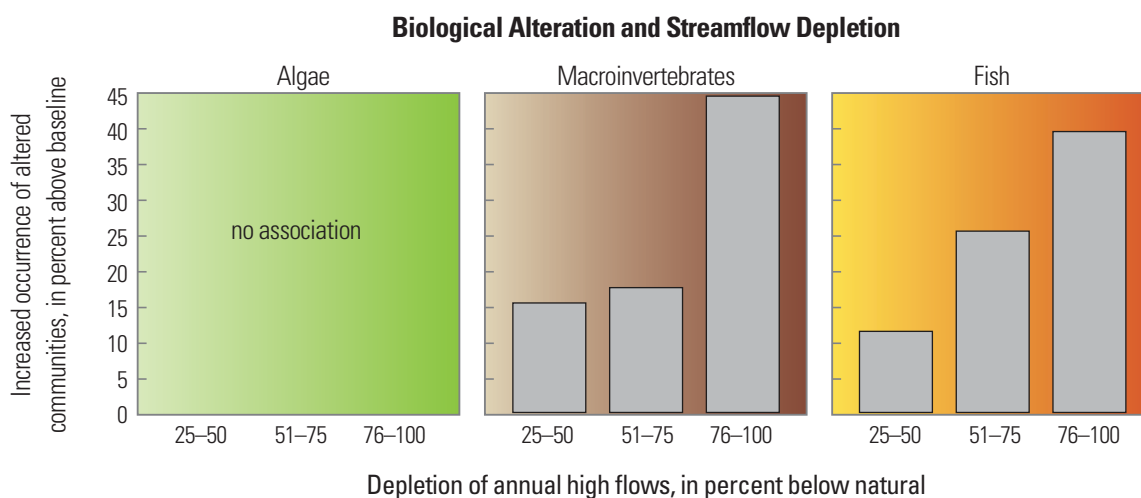
Biological Alteration and Streamflow Depletion

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). Algae were not affected by 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 highflow depletion less than 25 percent.

Understanding Biological Alteration

The biological condition of a community is expressed as the ratio of observed (O) community attributes (such as number of native species) to those expected (E) if the community was minimally disturbed by human activities. The resulting O:E ratio is multiplied by 100 and expressed as a "percentage of natural potential" (chapter 3). Increasing biological condition values indicate that a biological community is closer to its expected natural potential and, by inference, the stream is in better health. This continuous measure is used to describe the biological condition of individual sites.

A community was classified as "altered" by NAWQA if its biological condition was less than that of 90 percent of the reference sites within its region. Otherwise, a community was considered to be "unaltered." This classification is used to summarize biological condition across the diverse regions of the Nation. Increased occurrence of altered biological communities indicates that more stream sites have diminished biological condition and, by inference, diminished stream health.

(Carlisle and others, 2011). Algal community condition, in contrast, was unrelated to streamflow modification.

These national findings are similar to a large body of case studies that have documented negative ecological consequences of streamflow modifications (review by Bunn and Arthington, 2002), especially for macroinvertebrate and fish communities (review by Poff and Zimmerman, 2010). The life cycles of many aquatic species are highly synchronized with the variation and timing of natural streamflows. For example, the reproductive period of some fish species is triggered by the onset of spring runoff. Algal community responses to modified streamflows are less understood than other communities (Poff and Zimmerman, 2010). Although the incidence of altered algal communities was unrelated to streamflow modification, other attributes of these communities, such as total biomass, may be indicative of modified streamflows.

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

Diminished Biological Condition Related to Winter Flow Depletion in Utah Streams

A collaborative regional study done by the U.S. Geological Survey, Bureau of Reclamation, and Utah Division of Environmental Quality in 2010 found that the biological condition of macroinvertebrate communities declined in streams with increasing depletion of winter flows. In streams with more than 40 percent depletion of winter flows, macroinvertebrate community condition was below the threshold considered by the State to be protective of aquatic life (see graph). Results from this study provide a potentially important guideline for water-management strategies aimed at improving biological conditions in streams below dams and diversions (Carlisle and others, 2012).
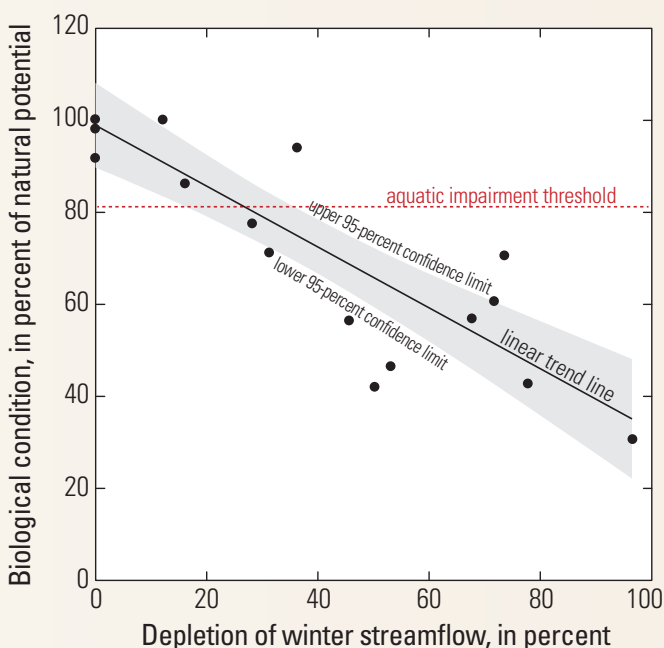

Streamflows are diverted from the South Fork of Rock Creek, Utah, for use in other river basins.
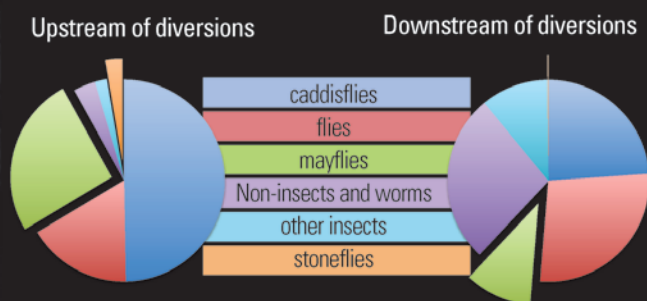
U.S. Geological Survey photo by Daren Carlisle.

Biological Communities are Influenced by Depleted Streamflows—The Example of Cache la Poudre River, Colorado

The Cache la Poudre River, Colorado, originates on the Continental Divide in the Rocky Mountains and flows through a rugged canyon popular with recreationists. Water is diverted at several locations for irrigation and other uses, which leaves some parts of the river with depleted flows during summer, fall, and winter.

Biological Condition
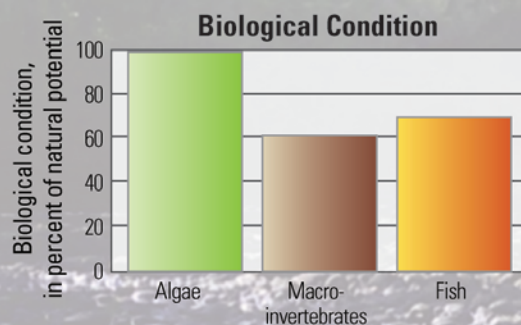
As shown in this graph, macroinvertebrate and fish communities in the Cache la Poudre River were more than 30 percent below their expected natural potential. In contrast, algal community condition was unrelated to streamflow depletion.

Macroinvertebrate Communities in the Cache la Poudre River

Upstream of diversions   Downstream of diversions

caddisflies
flies
mayflies
Non-insects and worms
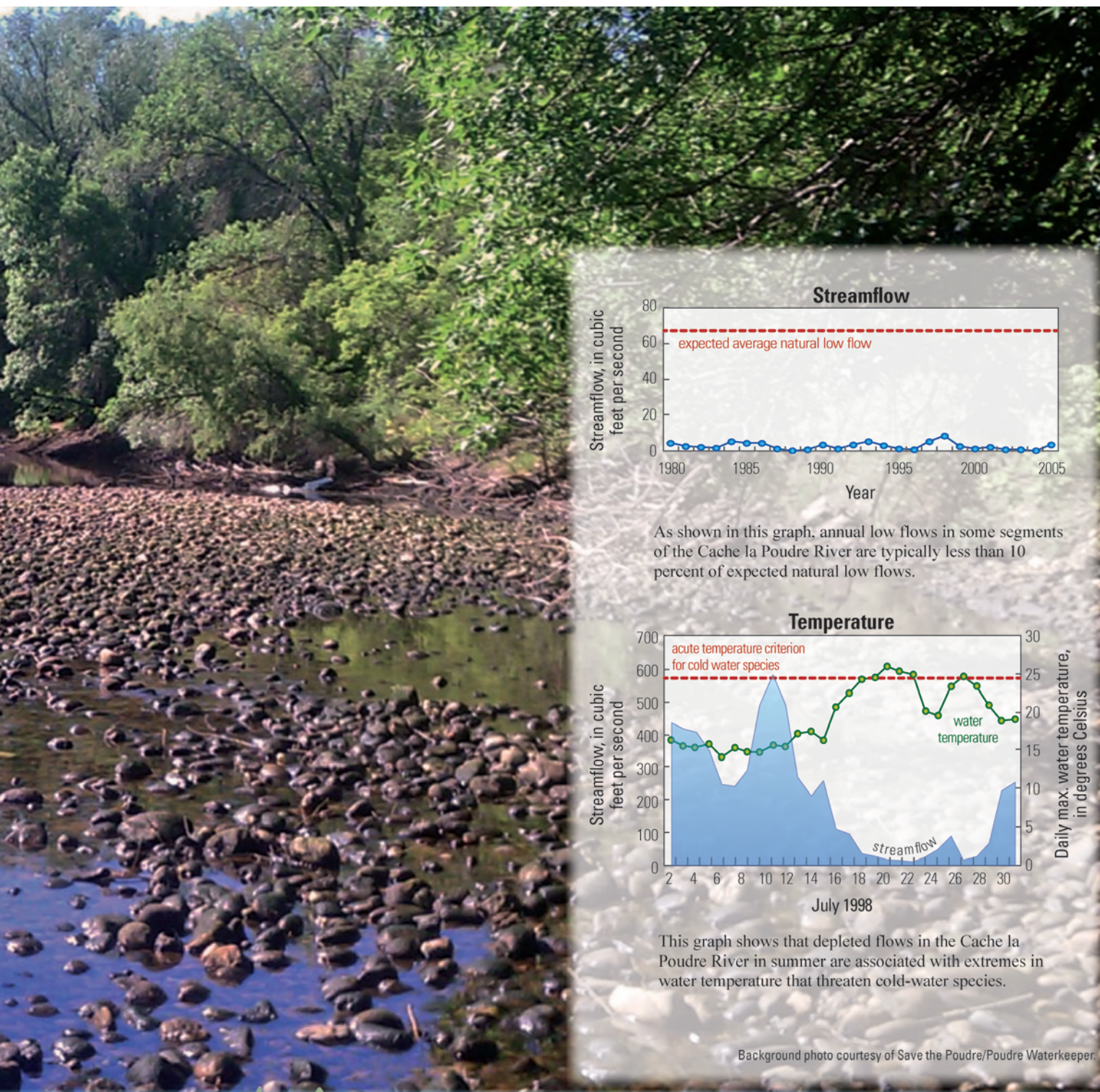other insects
stoneflies

Mayflies and stoneflies, which require cold and well-oxygenated water, are typically major components of macroinvertebrate communities in Rocky Mountain streams, as shown for the Cache la Poudre River upstream of diversions (left pie chart). However, the macroinvertebrate community in the Cache la Poudre River downstream of diversions (right pie chart) was dominated by flies, worms, and other organisms that are indicative of warm and stagnant water.

Fish Communities

Fish communities in naturally flowing Rocky Mountain streams typically include trout, suckers, and other species that require fast-flowing water. In the Cache la Poudre River, however, species adapted to intermittent or slow-flowing streams, such as green sunfish and fathead minnow, were most common.
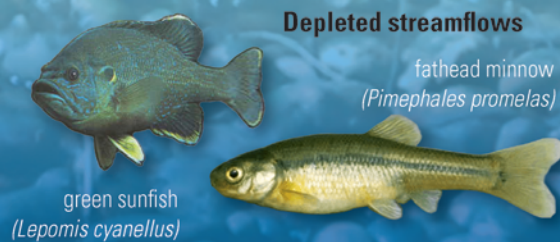
Streamflow

As shown in this graph, annual low flows in some segments of the Cache la Poudre River are typically less than 10 percent of expected natural low flows.

Temperature

This graph shows that depleted flows in the Cache la Poudre River in summer are associated with extremes in water temperature that threaten cold-water species.

Background photo courtesy of Save the Poudre/Poudre Waterkeeper.

Natural Streamflows

cutthroat trout
(Oncorhynchus clarkii)

longnose sucker
(Catostomus catostomus)

Depleted streamflows

fathead minnow
(Pimephales promelas)

green sunfish
(Lepomis cyanellus)

The incidence of altered biological communities increased with greater agricultural or urban land development within stream riparian zones.

Land Development within Stream Riparian Zones

Streamside trees and other vegetation, collectively known as riparian zones, are important to stream health because they influence the amount of shelter and food available to aquatic organisms, the amount of sunlight reaching the stream through the tree canopy, and the amount and quality of runoff that reaches the stream from surrounding uplands. However, agricultural and urban land development within riparian zones is pervasive, particularly in the eastern half of the Nation. The extent and severity of riparian-zone development in the Nation's watersheds suggests it may contribute to reduced stream health (U.S. Environmental Protection Agency, 2006a).

Biological communities were more frequently altered in streams with greater agricultural and urban development within the riparian zone. As the extent of development within the riparian zone increased, the incidence of altered biological communities increased from 5 to 61 percent for algae, 8 to 55 percent for macroinvertebrates, and 15 to 36 percent for fish communities.

Disturbance or removal of riparian vegetation, in any type of land-use setting, can have profound effects on stream biological communities. Increased exposure of the stream to sunlight can increase water temperature—for which many aquatic organisms have narrow requirements—and stimulate growth of nuisance algal species if nutrient levels are also excessive. Reduced inputs of leaves and woody debris from the riparian zone to the stream result in less food and living space for many invertebrate and fish species. Finally, disturbed riparian zones lose their ability to filter potentially harmful

Biological Alteration and Land Development in Stream Riparian Zones by Region
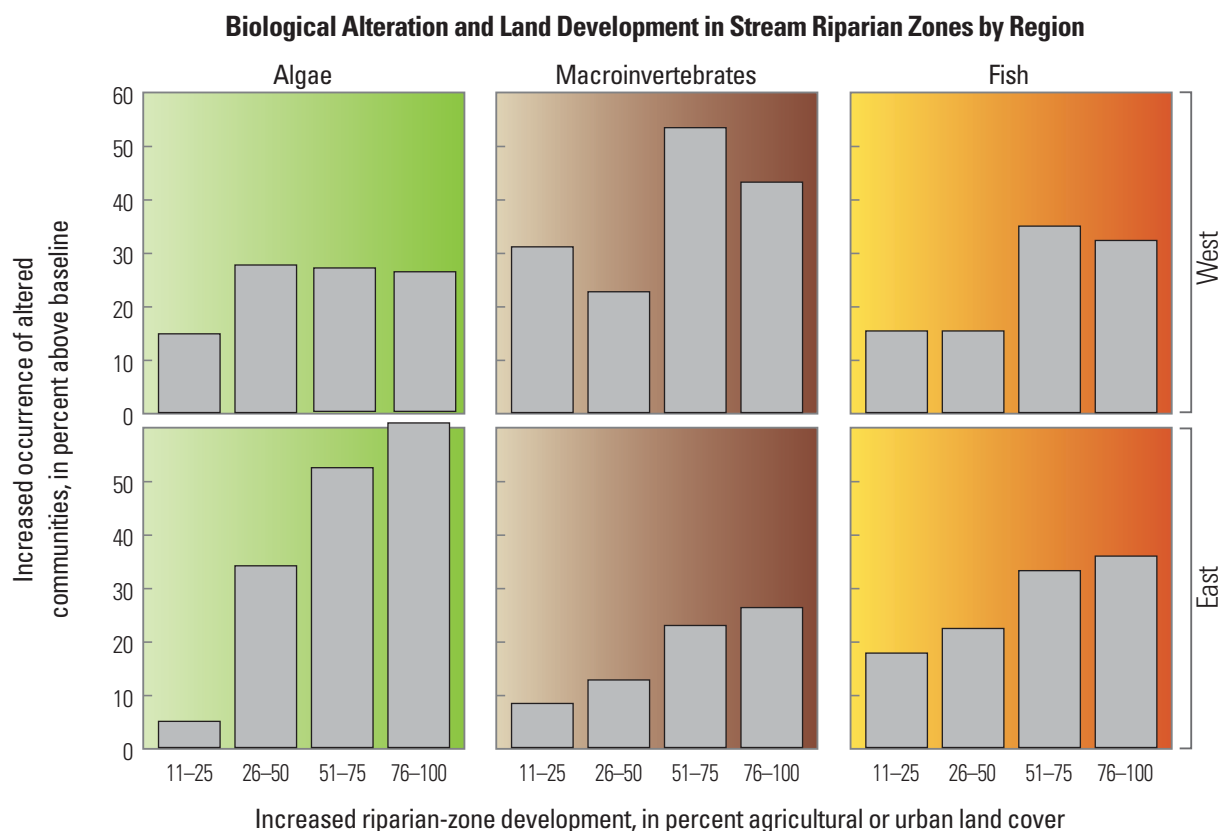
NAWQA studies found that algae, macroinvertebrate, and fish communities were more frequently altered in streams with increasing amounts of streamside development (defined as agricultural or urban land cover). These bar graphs show this relation for both the Eastern and Western United States. Disturbance or removal of streamside vegetation often leads to increased water temperature and inputs of sediment and other contaminants to a stream. Baseline is the occurrence of altered communities in approximately 250 streams with less than 10 percent agricultural or urban land cover in riparian zones.

contaminants in runoff from developed upland areas, thereby increasing the risk that sediments, nutrients, and harmful chemicals will enter the stream.

Findings were generally similar for streams in the Eastern and Western United States, which suggests the biological consequences of riparian-zone development are similar even though biological communities and the nature of riparian disturbance may differ from east to west. For example, many riparian zones of western streams with little agricultural or urban development may nevertheless be disturbed by rangeland livestock grazing and some forestry practices.

NAWQA's findings on a national scale corroborate many local and regional-scale studies showing that stream biological communities benefit from naturally vegetated riparian zones (for example, Moore and Palmer, 2005), even in intensively managed agricultural or urban watersheds. There is a great deal of evidence that the maintenance and restoration of vegetated stream riparian zones can improve stream health.

Before restoration

Photo courtesy of Wetland Studies and Solutions, Inc.

Photo courtesy of Kenneth Cole, Western Watersheds Project.

Even in areas with little agricultural or urban development, livestock management practices that allow animals to disturb streamside vegetation can lead to severe erosion and reduced stream health. This photograph shows such erosion along Basin Creek, Idaho.


After restoration

U.S. Geological Survey photo by Martin Gurtz.

Reestablishment of streamside vegetation is an important part of efforts to restore health to urban streams. These photographs show part of Snakeden Branch, Virginia, before restoration (top) and after restoration (bottom).
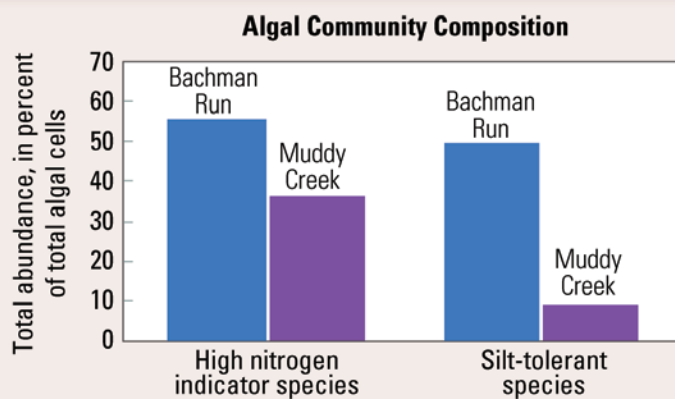
Vegetated Riparian Zones Influence Stream Health in Agricultural Settings—The Example of Bachman Run and Muddy Creek, Pennsylvania

Croplands are 75 percent of the land cover in the watersheds of Bachman Run and Muddy Creek, Pennsylvania. Land cover in the riparian zone, however, is dominated by cropland in Bachman Run (left) and trees and shrubs in Muddy Creek (right). Greater amounts of natural vegetation in the riparian zone correspond to less altered biological condition and lower nutrient concentrations in Muddy Creek than in Bachman Run. The ability of riparian vegetation to buffer the effects of land use are well known.
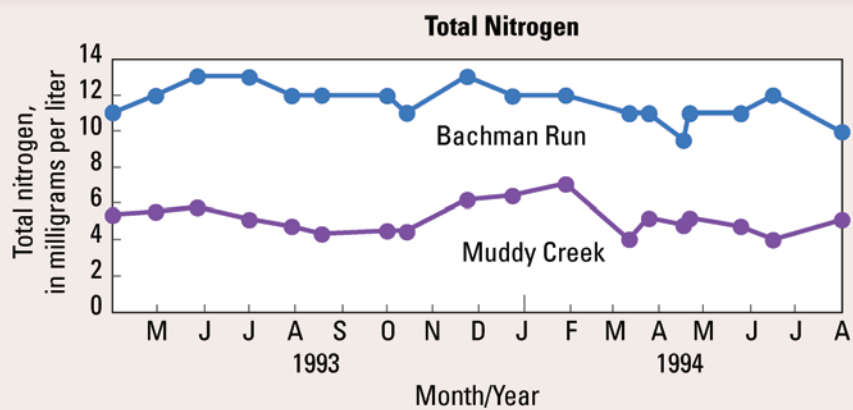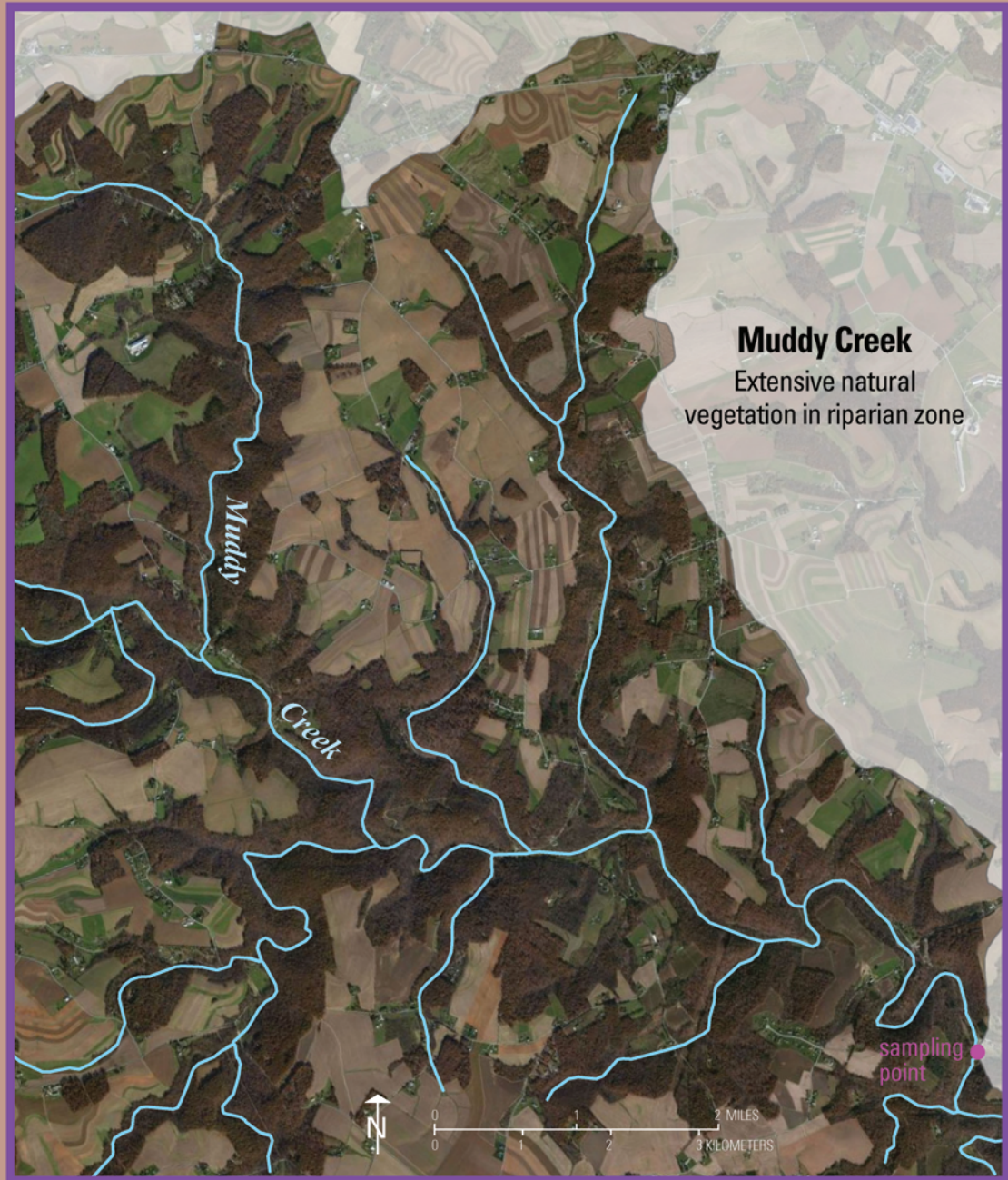
Biological Condition
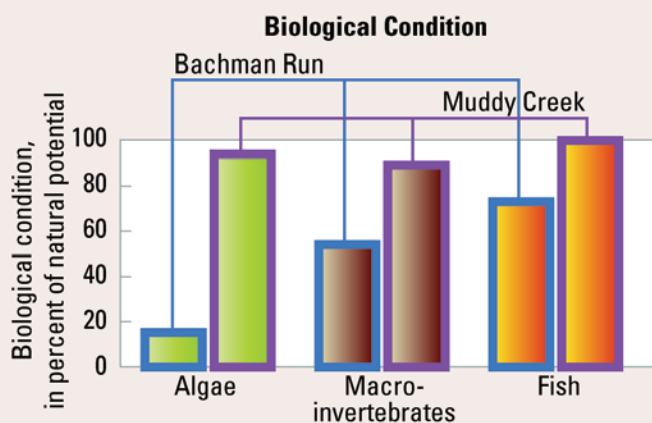
As shown on this bar graph, NAWQA studies found that algal, macroinvertebrate, and fish communities were 25 to 85 percent below their expected natural potential in Bachman Run and close to their expected natural potential in Muddy Creek.

Bachman Run
Little natural vegetation in riparian zone

The types and amounts of diatoms within the algal communities suggest that Bachman Run is affected by excess nutrients and sediments from the watershed. As this bar graph shows, species that require high nitrogen levels or that are adapted to silty conditions are 20 to 40 percent more common in Bachman Run than Muddy Creek.

Algal Community Composition

Muddy Creek
Extensive natural vegetation in riparian zone

sampling point

sampling point

0   1   2 MILES
0   1   2   3 KILOMETERS

N

Total Nitrogen

Bachman Run

Muddy Creek

Total nitrogen, in milligrams per liter

M J J A S O N D J F M A M J J A
1993   1994
Month/Year

This graph compares total nitrogen concentration in Bachman Run and Muddy Creek. NAWQA found that total nitrogen concentration in Bachman Run was consistently two times higher than that in Muddy Creek. (1 milligram per liter = 1 part per million.)

Images from U.S. Geological Survey National Land Cover Dataset 2006.

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

Elevated Salinity

Although geographic variation in natural salinity levels is high due to factors such as geology and soils, elevated salinity levels occur throughout the Nation, particularly in watersheds with substantial urban and agricultural land use. Recent studies have also documented increasing trends in salinity levels in streams and groundwater due to human activities (Kaushal and others, 2005; Mullaney and others, 2009).
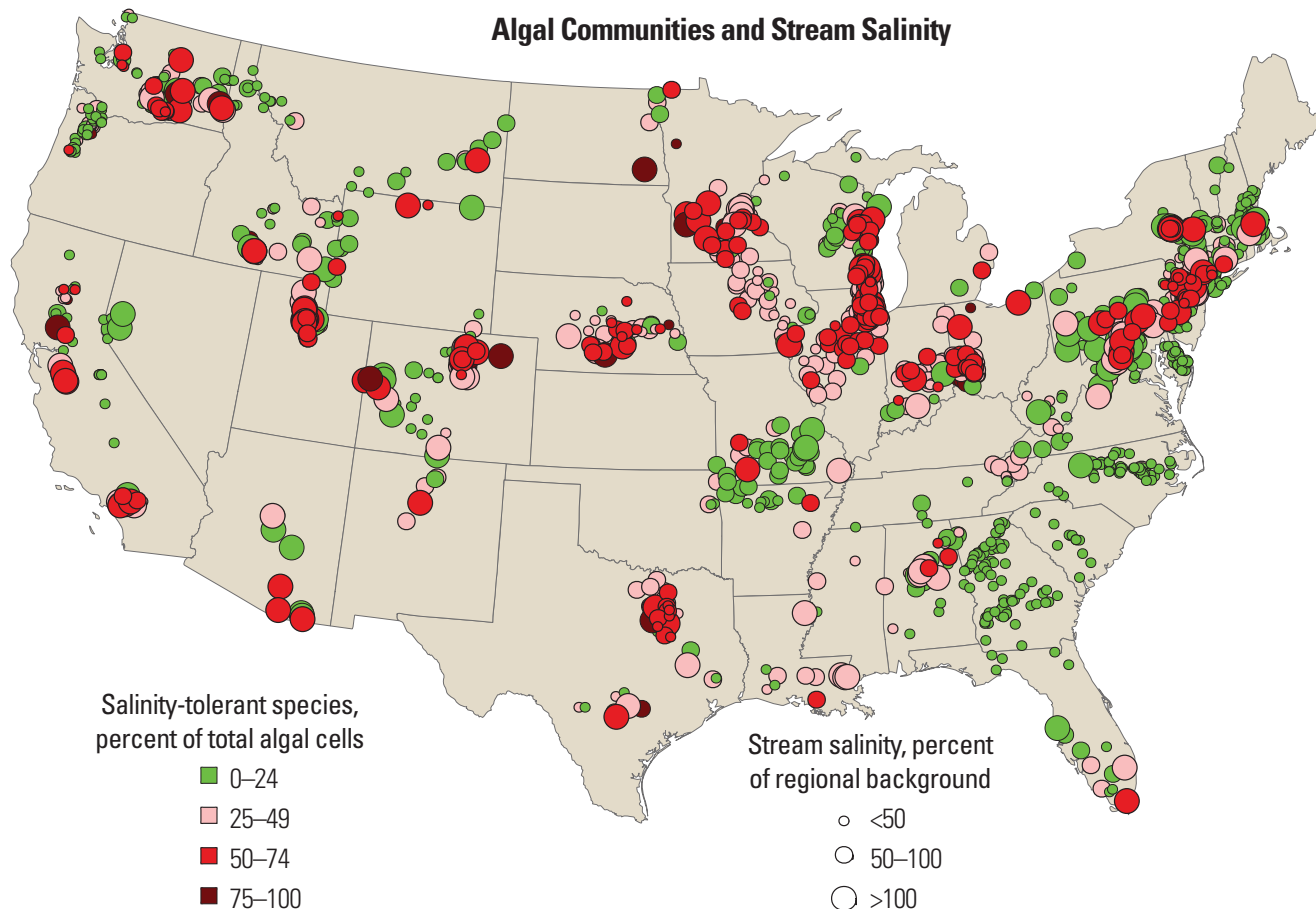
Biological communities were more frequently altered in streams with increasingly elevated salinity levels. In streams with increasingly elevated salinity relative to regional background levels (Van Sickle and Paulsen, 2008), the incidence of altered communities increased from 29 to 43 percent for algae, 7 to 25 percent for macroinvertebrates, 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. Many experimental studies have demonstrated that elevated salinity reduces growth, reproduction, and survival of aquatic organisms; young life stages appear to be particularly vulnerable (Findlay and Kelly, 2011). Toxic effects of salinity have been documented in fish, invertebrates, and amphibians. Algae, particularly diatoms, are also known to be highly sensitive to changes in salinity (for example, Bloom and others, 2003).
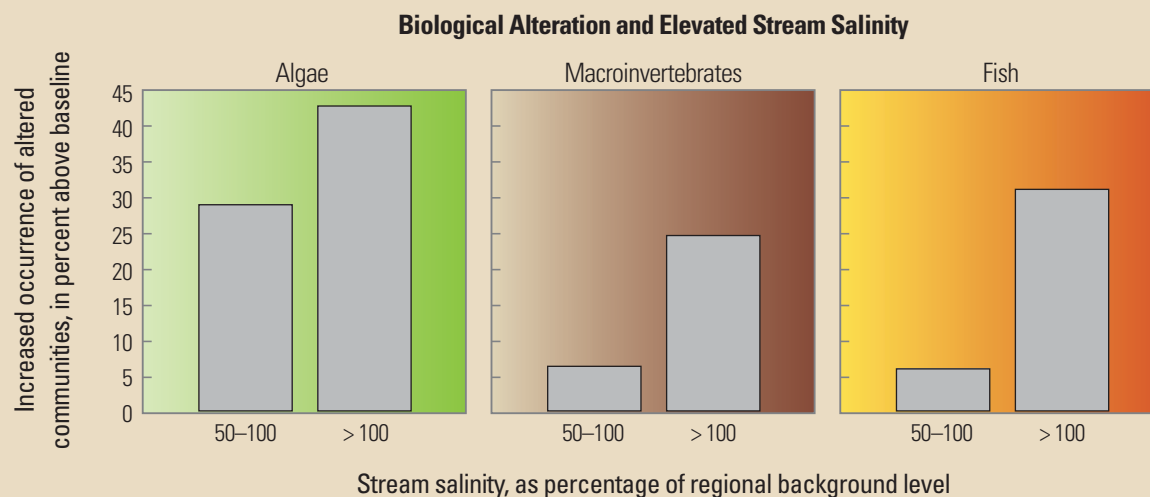
Biological Alteration and Elevated Stream Salinity

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.)

Diatom species that tolerate saline conditions were often the most common inhabitants of algal communities in streams with elevated salinity. Salinity-tolerant diatoms often accounted for more than two-thirds of all individuals in algal communities. This pattern occurs throughout the Nation and in all types of land-use settings and suggests that when salinity is excessive it is a likely cause of altered algal communities. These findings provide evidence that salinity is elevated—and a potential factor influencing biological condition—in streams throughout the Nation.

Algal Communities and Stream Salinity

Salinity-tolerant species, percent of total algal cells
- 0–24
- 25–49
- 50–74
- 75–100

Stream salinity, percent of regional background
- <50
- 50–100
- >100

Map of the conterminous United States showing salinity levels and the abundance of salinity-tolerant diatom species in streams. NAWQA found streams with elevated salinity levels throughout the Nation. Salinity-tolerant diatoms were often the most abundant species in streams with elevated salinity, which suggests that excess salinity has altered algal communities. (<, less than; >, greater than.)

Salinity is One of Several Factors That Contribute to Diminished Stream Health—The Example of Shingle Creek, Minnesota

Diminished stream health in Shingle Creek, an urban watershed in Minnesota, was originally thought to be caused by a single factor—elevated salinity. However, follow-up studies found evidence that streamflow alteration and consequent habitat modification and low dissolved oxygen levels were also likely contributing to biological alteration. As a result of NAWQA assessing multiple factors, resource managers now know that improving the health of Shingle Creek requires remediation of several important chemical and physical factors.

Biological Condition
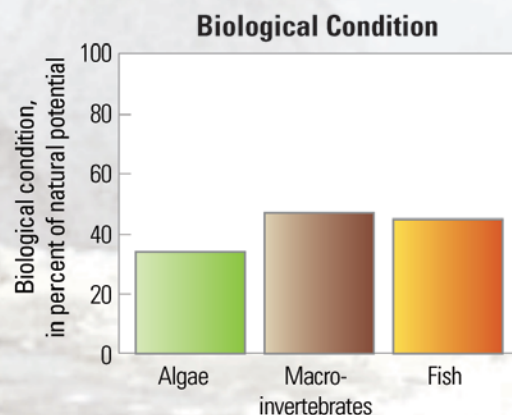
As shown in this bar graph, algal, macroinvertebrate, and fish communities were 40 to 70 percent below their expected natural potential in Shingle Creek.

Species Traits Provide Clues About the Causes of Biological Alteration

Human-caused changes to the physical and chemical properties of streams generally lead to the replacement of species whose traits are poorly suited to change with species whose traits are more suited to the change. If the sensitivities of species to chemical and physical factors are known, changes in the occurrence and abundance of species can provide clues about which factors contribute to alteration of biological communities.

The composition of biological communities in Shingle Creek suggests that several physical and chemical factors are responsible for diminished stream health. The number of species tolerant of elevated salinity and nutrients (algae), low dissolved oxygen (macroinvertebrates), and habitat alteration (fish) was nearly twice that of natural expectations. These clues from biological
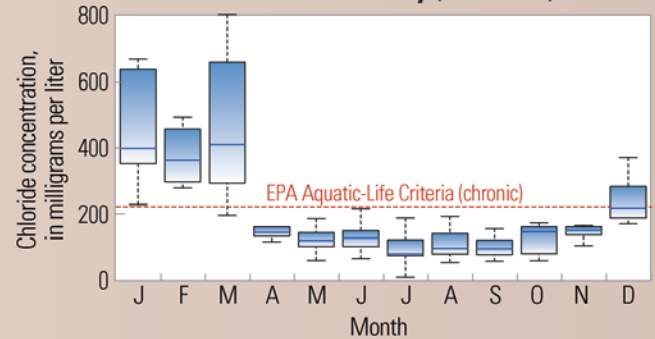
Background photo courtesy of Chris Meehan, Wenck Associates.

Stream-Water Salinity (Chloride)


EPA Aquatic-Life Criteria (chronic)

This graph shows that chloride concentrations (a measure of salinity) often exceed U.S. Environmental Protection Agency (EPA) Aquatic-Life Criteria during winter, when salt is applied to roadways in the Shingle Creek watershed. (1 milligram per liter = 1 part per million.)

Dissolved Oxygen

State benchmark for aquatic-life protection
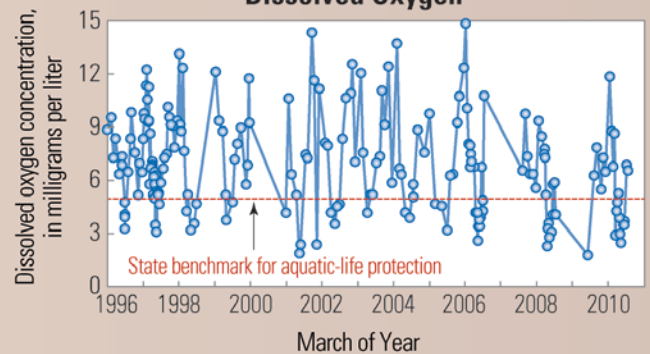
Dissolved oxygen concentrations in Shingle Creek often fall below State guidelines, particularly in summer months when algal and other plant growth is highest. (1 milligram per liter = 1 part per million.)

Variability of Streamflows

range of natural variability
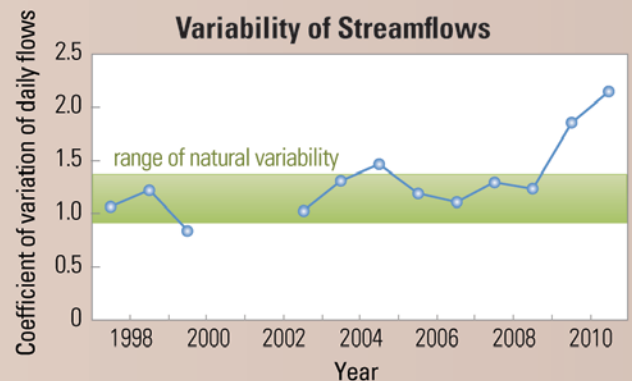
Streamflow in recent years in Shingle Creek (blue dots on graph) is more variable than would naturally occur, indicating the potential for degradation of habitat for many aquatic species.

communities, when combined with information from actual measurements of chemical and physical factors in Shingle Creek, suggest that low dissolved oxygen and streamflow modification—in addition to elevated salinity—were key factors in reducing stream health.

Biological communities, particularly algae, were more frequently altered in streams with elevated nutrients such as total nitrogen.

Elevated Nutrients

Although plant nutrients such as nitrogen and phosphorus are a basic need of aquatic ecosystems, excessive nutrients can have harmful effects on stream health (chapter 2). Nutrient levels in stream water are as much as six times greater than background levels in urban and agricultural lands across the Nation and are widely cited as a cause of diminished stream health (U.S. Environmental Protection Agency, 2006b; see http://ofmpub.epa.gov/tmdl_waters10/attains_nation_cy.control).

Biological communities, particularly algae, were more frequently altered in streams with elevated nutrients. 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. Alteration of algal communities was largely due to changes in the types of algae found in streams with elevated nutrients relative to streams with low nutrients. For example, one set of diatom species thrive in streams with elevated nutrients and are referred to as "eutrophic diatoms." These species were the largest part of algal communities in streams with elevated nutrients throughout the Nation (see sidebar, opposite page).

Relative to algal communities, associations between excess nutrients and macroinvertebrate and fish communities are less direct and often mitigated by other factors. Harmful effects to aquatic animals occur when elevated nutrients cause excessive growths of algae and aquatic plants, which consume oxygen in the water as they grow and decompose. However, these effects can vary from one stream to another as a result of differences in patterns of streamflow, amount of riparian shading, water temperature, water clarity, and the extent of groundwater and surface water exchange (Dubrovsky and others, 2010; Riseng and others, 2011). These results also serve as a reminder that many factors can adversely affect biological communities in urban and agricultural streams. Attributing causality to linkages between nutrient concentrations (or any other single factor) and biological alteration can be misleading because a single factor may not be responsible for all adverse biological effects. Instead, biological alteration is most often the result of multiple factors, each of which can have different effects and at different times of the year.

Biological Alteration and Elevated Nutrients
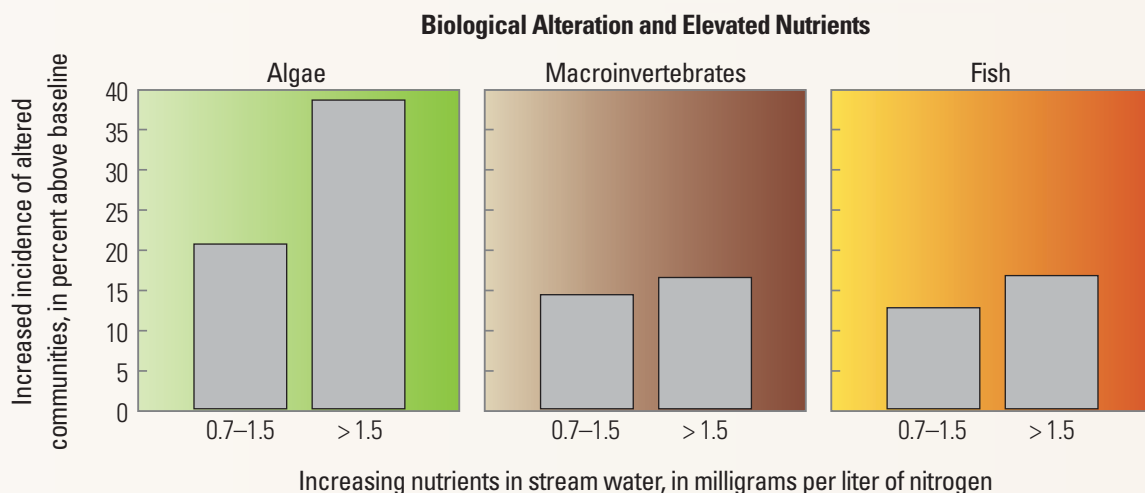
NAWQA studies found that biological communities, particularly algae, in the Nation's streams were more frequently altered in streams with elevated levels of the nutrient nitrogen (bar graphs above). Algae that flourish in streams with excess nutrients can become prolific and consume oxygen in the water, 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.)
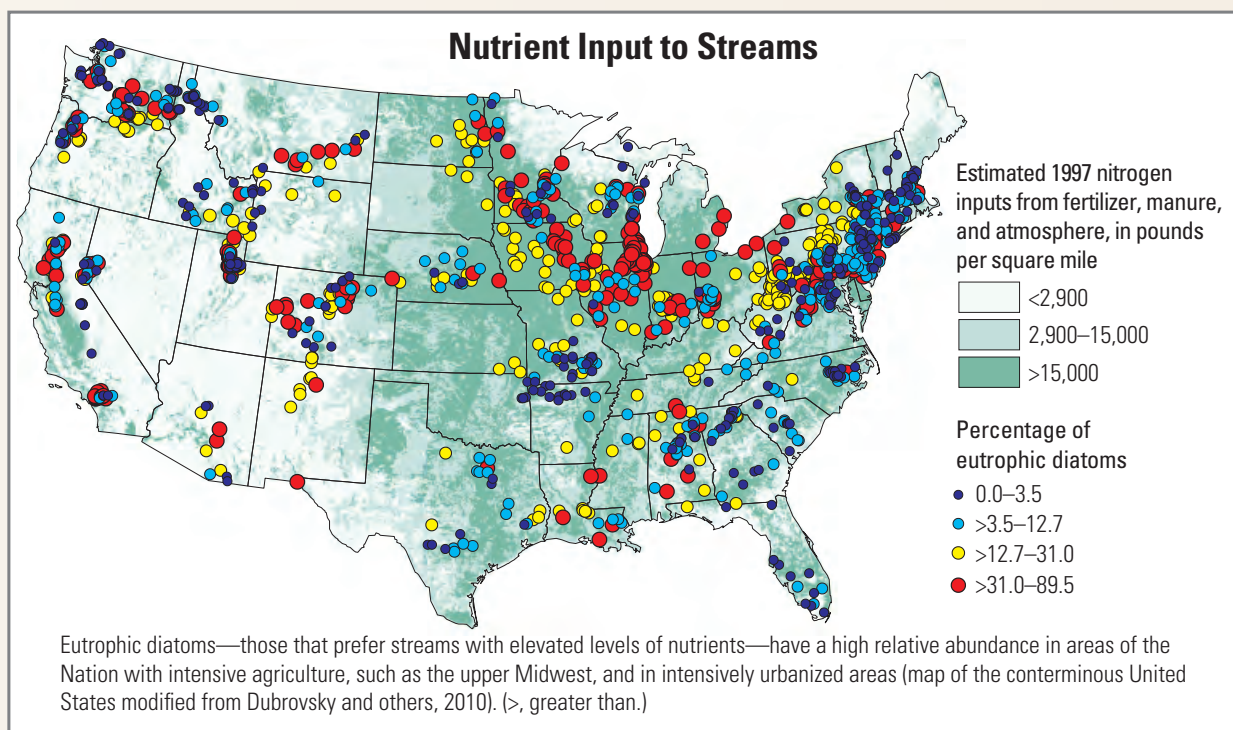
Algae as Indicators of Nutrient Enrichment

The biological condition of algal communities is an especially effective indicator of human-influenced changes in water and habitat quality because many algal species have specific environmental requirements for growth and development. These requirements—such as food and habitat preferences, reproductive behavior, and lifespan are all part of each species' life-history-strategy for survival. Because all algal species have unique combinations of life history strategies and environmental preferences, their presence in a stream indicates a specific—and sometimes narrow—range of environmental conditions. Species occurring in streams in which water and habitat quality are degraded generally are limited to those organisms that are tolerant of existing physical and chemical properties of the stream environment.

As an example, the relative abundance of eutrophic diatoms in algal communities increased as concentrations of nitrogen and phosphorus increased (Porter and others, 2008). Eutrophic diatoms, which are algal species that prefer streams with elevated levels of nutrients, had a higher relative abundance in areas of the Nation with intensive agriculture, such as the upper Midwest, and in heavily urbanized areas. The relative abundance of other algal species may reflect other important environmental conditions, such as the concentration of dissolved oxygen or salinity. Algal indices are increasingly being considered in State and tribal bioassessment programs (U.S. Environmental Protection Agency, 2002), as well as in development of nutrient criteria at the State level (Ponader and others, 2005; Belton and others, 2006).

Photos of eutrophic diatoms from the Academy of Natural Sciences of Drexel University, Patrick Center for Environmental Research, used with permission.

Nutrient Input to Streams

Estimated 1997 nitrogen inputs from fertilizer, manure, and atmosphere, in pounds per square mile

<2,900
2,900–15,000
>15,000

Percentage of eutrophic diatoms
- 0.0–3.5
- >3.5–12.7
- >12.7–31.0
- >31.0–89.5

Eutrophic diatoms—those that prefer streams with elevated levels of nutrients—have a high relative abundance in areas of the Nation with intensive agriculture, such as the upper Midwest, and in intensively urbanized areas (map of the conterminous United States modified from Dubrovsky and others, 2010). (>, greater than.)

Macroinvertebrate communities were more frequently altered in streams with elevated concentrations—and potential toxicity—of pesticides.
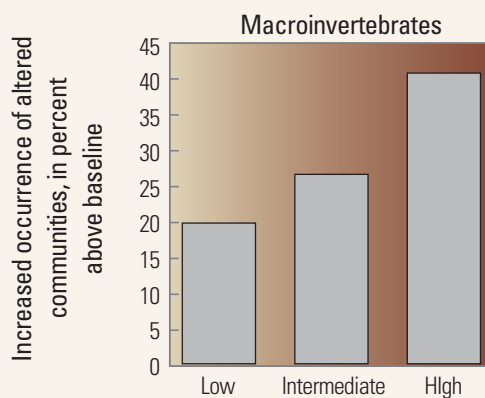
Pesticides in Stream Water

Pesticides frequently occur in stream water in all land-use settings and typically reflect patterns of use in the watershed (Gilliom and others, 2006). Although pesticide concentrations are highly variable seasonally and from year to year, they often reach levels that threaten aquatic organisms, particularly in agricultural and urban streams.

NAWQA studies found that macroinvertebrate communities were more frequently altered in streams with elevated concentrations—and potential toxicity—of pesticides. Specifically, the incidence of altered macroinvertebrate communities increased from 20 to 42 percent as the potential toxicity of pesticide mixtures increased. This association is predictable given that stream macroinvertebrate communities are mainly composed of insects and that the most frequently detected—and potentially toxic—pesticides were insecticides (chlorpyrifos, carbaryl, and diazinon). Substantially altered macroinvertebrate communities were associated with potentially toxic pesticides in urban settings throughout the Nation and in agricultural settings in the upper Midwest; Mississippi drainage basin south of Cairo, Illinois; and west coast States.

The effects of insecticides on macroinvertebrate communities were evident even after controlling for the influence of other factors. After controlling for nutrients, salinity, habitat, and land use, streams with insecticide levels that exceeded U.S. Environmental Protection Agency Aquatic-Life Benchmarks had 12 percent fewer macroinvertebrate taxa than streams without benchmark exceedances. These findings suggest that insecticides contribute to reduced stream health in agricultural and urban streams and support a growing body of scientific research documenting the ecological effects of pesticides on stream biological communities (Relyea, 2005; Macneale and others, 2010; review by Schulz and Liess, 1999).

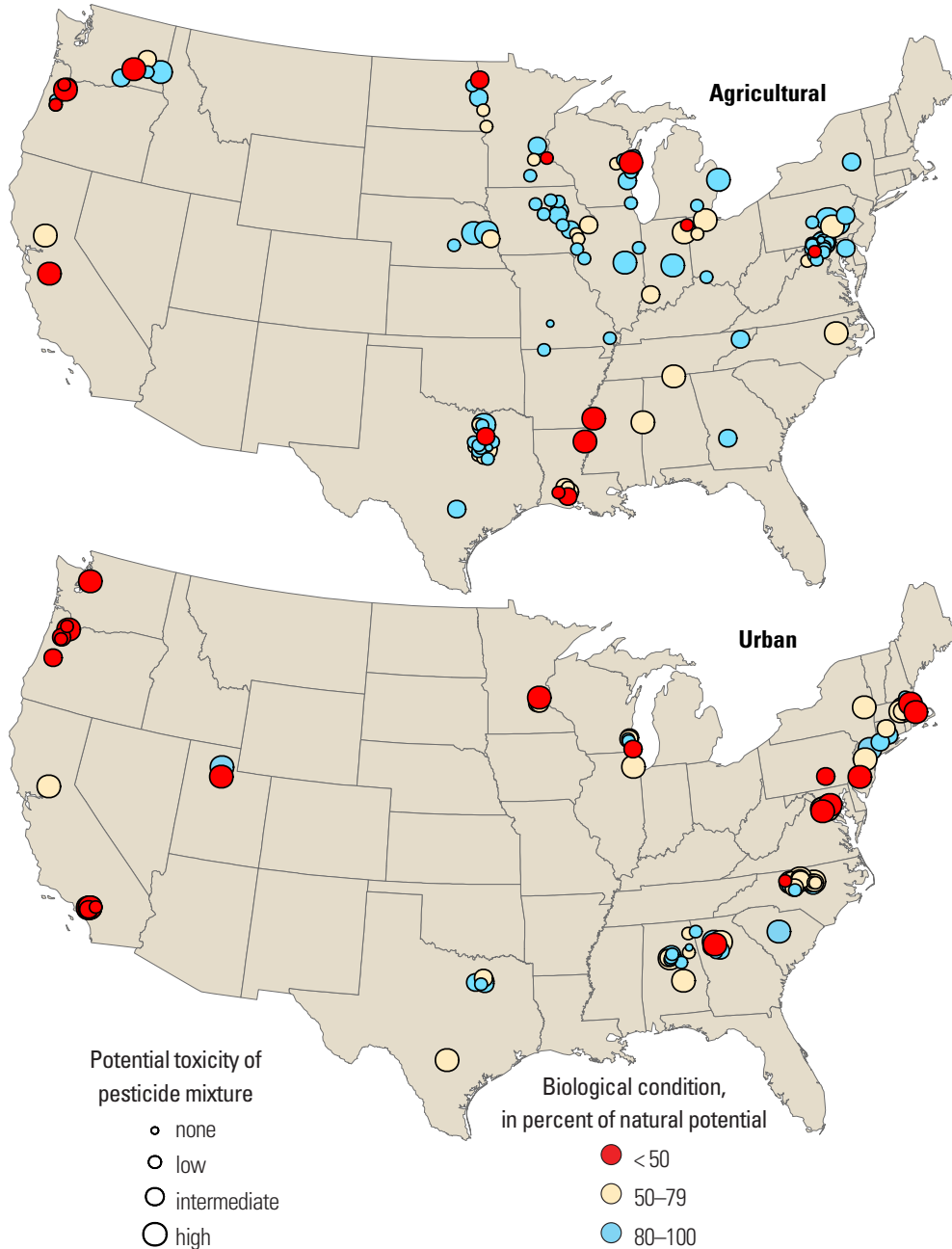**Macroinvertebrate Community Alteration and Potential Toxicity of Pesticides**

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.

Finally, it is important to note that two insecticides (diazinon and chlorpyrifos) found during the NAWQA study period have subsequently been discontinued, and concentrations in streams have declined (Gilliom and others, 2006). Indeed, pesticide use fluctuates over time, and these discontinued insecticides have been replaced with others (Spurlock and Lee, 2008) that may or may not pose a risk to stream health.

## Biological Condition and Potential Toxicity of Dissolved Pesticide Mixtures

NAWQA studies found that substantially altered macroinvertebrate communities were associated with potentially toxic pesticide mixtures in urban settings throughout the Nation and in agricultural settings in the upper Midwest; Mississippi drainage basin south of Cairo, Illinois; and west coast States. These maps show agricultural and urban sites in the conterminous United States at which pesticides were measured in water samples and macroinvertebrate communities were assessed. (<, less than.)

Elevated Pesticides and Nutrients Threaten Biological Communities—The Example of Zollner Creek, Oregon

Biological communities were highly altered in Zollner Creek, a predominantly agricultural watershed in Oregon. Forty-three pesticides were detected (1991–1995), some of which occurred at concentrations potentially harmful to aquatic life. Nutrient levels were also elevated—usually more than 10 times higher than expected background concentrations. Habitat conditions within the stream were also degraded.

Biological Condition
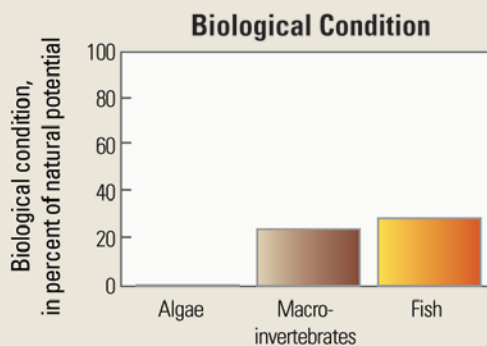
As this bar graph shows, macroinvertebrate and fish communities in Zollner Creek were 70 to 80 percent below their expected natural potential. Algal communities were almost 100 percent below their expected natural potential.

Algal Community Composition
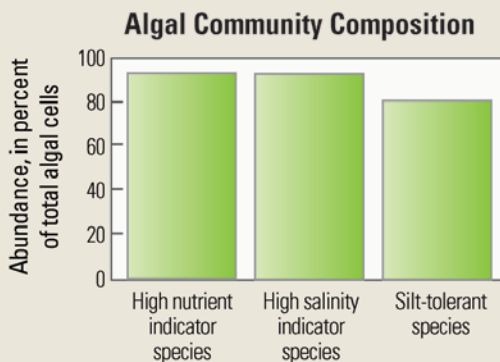
As this bar graph shows, species tolerant of elevated nutrients, salinity, and silt were 83 to 96 percent of the total algal community in Zollner Creek, which suggests that diminished biological condition was at least partially due to these factors.
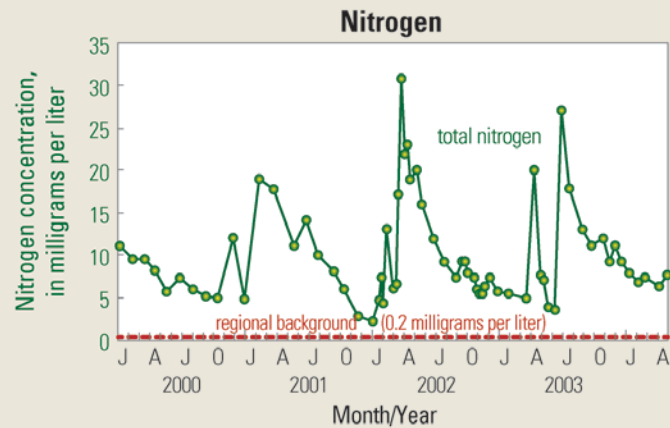

Zollner Creek, Oregon

Fish Communities

Native fish communities historically found in Zollner Creek and nearby rivers include more than 30 species, such as the torrent sculpin and cutthroat trout, as well as several minnow and salmon species. The present-day fish community in Zollner Creek is composed primarily of bullhead catfish (an introduced species) and largescale sucker—both species are tolerant of turbid (clouded with silt), sluggish streams.
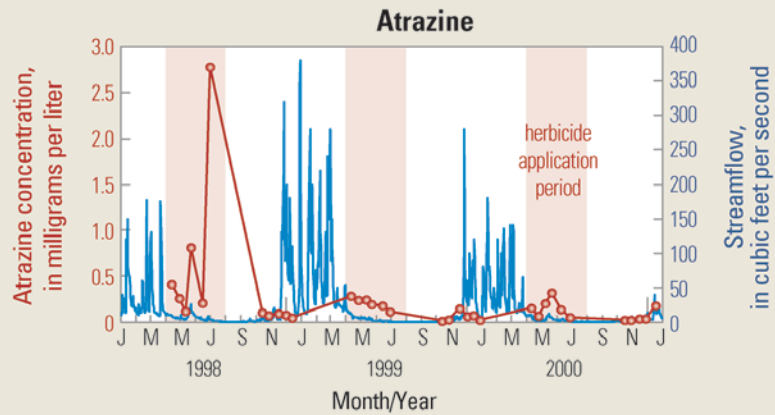
Atrazine

Concentrations of the herbicide atrazine in Zollner Creek (red dots on graph) were elevated during spring, which coincided with rainfall events during the pesticide application season. Elevated concentrations in the fall were associated with rainfall washing residual atrazine from croplands. (1 milligram per liter = 1 part per million.)

Nitrogen

Nitrogen concentrations in Zollner Creek (green dots on graphs) varied widely but were usually 10 to 100 times higher than regional background levels.
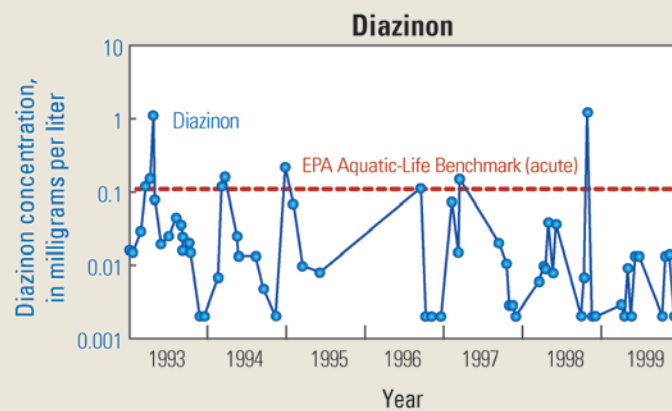
Diazinon

Concentrations of the pesticide diazinon in Zollner Creek (blue dots on graph) often exceeded the U.S. Environmental Protection Agency (EPA) Aquatic-Life Benchmark, although the frequency of exceedances declined through time.

Image from U.S. Geological Survey National Landcover Dataset.

Native

torrent sculpin
(Cottus rhotheus)

cutthroat trout
(Oncorhyncus clarkii)

Present day

black bullhead catfish
(Ameiurus melas)

largescale sucker
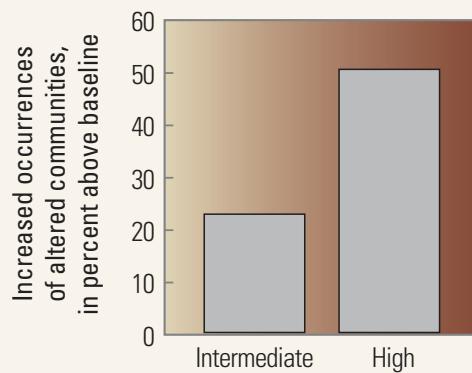(Catostomus macrocheilus)

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

Contaminants in Stream Sediments

NAWQA found contaminants in stream sediments throughout the Nation and at concentrations that may be toxic to aquatic species. Although present in all land-use settings, sediment contaminants had the greatest potential for toxicity in urban streams and were often various hydrocarbon chemicals known to be toxic to aquatic life. Because most macroinvertebrates live on the stream bottom, they are likely to be exposed to contaminants in sediments and therefore provide useful information about potential ecological effects (chapter 2).

Macroinvertebrate communities were more frequently altered in streams with greater potential toxicity of sediment contaminant mixtures. Specifically, the incidence of altered macroinvertebrates communities increased from 23 to 51 percent as the potential toxicity (based on Long and others, 2006) of sediment contaminants increased. Invertebrate species can be exposed to sediment compounds directly through their skin (through which many species respire), gills, or by consuming plants or animals that have already absorbed contaminants. These findings are corroborated by a wealth of field and laboratory studies documenting the toxic effects of sediment contaminants, such as metals and hydrocarbons, in aquatic invertebrates (for example, Scoggins and others, 2007) and suggest that sediment contaminants should be considered a potential cause of reduced stream health, especially in urban areas.

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.