Chapter 2

Photo courtesy of the Georgia Department of Natural Resources

Condition of the Nation's Streams

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Background

The CWA explicitly aims "to restore and maintain the chemical, physical, and biological integrity of the nation's waters." The WSA examines these three aspects of water quality through a small set of commonly used and widely accepted indicators. Although this WSA report does not include all aspects of biological integrity or review all possible chemical, physical, or biological stressors known to affect water quality, it does present the results of important indicators for an entire class of water resources—wadeable, perennial streams.

This chapter describes the results of the WSA and is organized as follows:

- **Indicators of Biological Condition** – Provides a description of the indicators or attributes of biological condition that were measured by the WSA survey and the results of the data analysis.
- **Aquatic Indicators of Stress** – Presents findings on the stressors evaluated for the study.
- **Ranking of Stressors** – Presents an analysis of the relative importance of the stressors in affecting biological condition.

Results for each indicator are shown for the nation's streams and for the three major regions (Eastern Highlands, Plains and Lowlands, and West). Chapter 3 of this report presents indicator results for each of the nine WSA ecoregions.

Indicators of Biological Condition

Ecologists evaluate the biological condition of water resources, including wadeable streams, by analyzing key characteristics of the communities of organisms that live in these waterbodies. These characteristics include the composition and relative abundance of key groups of animals (e.g., fish and invertebrates) and plants (e.g., periphyton, or algae that attach themselves to stream bottoms, rocks, and woody debris)

Jellison Meadow Brook, ME, in the Eastern Highlands region (Photo courtesy of Colin Hill, Tetra Tech, Inc.).

found in streams. The WSA focused on just one assemblage, benthic macroinvertebrates (e.g., aquatic insects, crustaceans, worms and mollusks); however, some WSA participants also researched other assemblages.

Why focus on macroinvertebrates? Macroinvertebrates are key organisms that reflect the quality of their environment and respond to human disturbance in fairly predictable ways. As all fly-fishermen know, the insects emerging from streams and rivers are good indicators of the water quality and serve as an important food source for both game and non-game fish. Given the wide geographic distribution of macroinvertebrates, as well as their abundance and link to fish and other aquatic vertebrates, these organisms serve as excellent indicators of the quality of flowing waters and the human stressors that affect these systems.

WSA researchers collected samples of these organisms and sent them to laboratories for analysis, yielding a data set that provided the types and number of taxa (i.e., classifications or groupings of organisms) found at each site. To interpret this data set, the WSA used two indicators of biological condition: the Macroinvertebrate Index of Biotic Condition and the Observed/Expected (O/E) Ratio of Taxa Loss.

Macroinvertebrate Index of Biotic Condition

The Macroinvertebrate Index of Biotic Condition (henceforth referred to as the Macroinvertebrate Index) is similar in concept to the economic Consumer Confidence Index (or the Leading Index of Economic Indicators) in that the total index score is the sum of scores for a variety of individual measures, also called indicators or metrics. To determine the Leading Index, economists look at a number of metrics, including manufacturers' new orders for consumer goods, building permits, money supply, and other aspects of the economy that reflect economic growth. To determine the Macroinvertebrate Index, ecologists look at such metrics as taxonomic richness, habit and trophic composition, sensitivity to human disturbance, and other biotic aspects that reflect "naturalness." Originally developed as an Index of Biotic Integrity for fish in Midwestern streams, the Macroinvertebrate Index has been modified and applied to other regions, taxonomic groups, and ecosystems.

What are Taxa?

Taxa (plural of taxon) are groupings of living organisms, such as phylum, class, order, family, genus, or species. Biologists scientifically describe and organize organisms into taxa in order to better identify and understand them.

The metrics used to develop the Macroinvertebrate Index for the WSA covered six different characteristics of macroinvertebrate assemblages that are commonly used to evaluate biological condition:

- **Taxonomic richness** – This characteristic represents the number of distinct taxa, or groups of organisms, identified within a sample. Many different kinds of distinct taxa, particularly those that belong to pollution-sensitive insect groups, indicate a variety of physical habitats and food sources and an environment exposed to generally lower levels of stress.

Using Multiple Biological Assemblages to Determine Biological Condition

EPA's guidance on developing biological assessment and criteria programs recommends the use of multiple biological assemblages to determine biological condition. The term "multiple biological assemblages" simply refers to the three main categories of life found in a waterbody: plants (e.g., algae), macroinvertebrates, and vertebrates (e.g., fish). The purpose of examining multiple biological assemblages is to generate a broader perspective of the condition of the aquatic resource of interest.

Each assemblage plays a different role in the way that rivers and streams function. Algae and macroinvertebrates occur throughout all types and sizes of streams, whereas very small streams may be naturally devoid of fish. Algae are the base of the food chain and capture light and nutrients to generate energy. They are sensitive to changes in shading, turbidity, and increases or decreases in nutrient levels. Macroinvertebrates feed on algae and other organic material that enters the aquatic system from the surrounding watershed. Macroinvertebrates also form the base of the food chain for many aquatic vertebrates. Fish are an example of these aquatic vertebrates and also serve as an important food source for people and wildlife. Each of these groups of aquatic organisms is sensitive in its own way to different human-induced disturbances.

The WSA collaboration began as a partnership among 12 western states; EPA Regions 8, 9, and 10; and EPA's Western Ecology Division (Environmental Monitoring and Assessment Program [EMAP] West) before it was expanded to include the entire United States. The original EMAP West program addressed fish, macroinvertebrates, and algae; future WSA reports will also address multiple assemblages.

To learn more about EMAP West and its use of multiple biological assemblages, visit www.epa.gov/emap/west/index.html.

- **Taxonomic composition** – Ecologists calculate composition metrics by identifying the different taxa groups, determining which taxa in the sample are ecologically important, and comparing the relative abundance of organisms in those taxa to the whole sample. Healthy stream systems have organisms from across many different taxa groups, whereas unhealthy stream systems are often dominated by a high abundance of organisms in a small number of taxa that are tolerant of pollution.
- **Taxonomic diversity** – Diversity metrics look at all the taxa groups and the distribution of organisms among those groups. Healthy streams should have a high level of diversity throughout the assemblage.
- **Feeding groups** – Many macroinvertebrates have specialized strategies to capture and process food from their aquatic environment. As a stream degrades from its natural condition, the distribution of animals among the different feeding groups will change. For example, as a stream loses its canopy (a source of leaves and shading), the aquatic community will shift from a more diverse food chain to one of predominantly algal-feeding animals that are tolerant of warm water.
- **Habits** – Just like other organisms, benthic macroinvertebrates are characterized by certain habits, including how they move and where they live. These habits are captured in the habit metrics. For example, some taxa burrow under the streambed sediment, whereas others cling to rocks and debris within the stream channel. A stream that naturally includes a diversity of habitat types will support animals with diverse habits; however, if a stream becomes laden with silt, the macroinvertebrates that cling, crawl, and swim will be replaced by those that burrow.
- **Pollution tolerance** – Each macroinvertebrate taxa can tolerate a specific range of stream contamination, which is referred to as their pollution tolerance. Once this level is exceeded, the taxa are no longer present in that area of the stream. Highly sensitive taxa, or those with a low pollution tolerance, are found only in streams with good water quality.

The specific metrics chosen for each of these categories varied among the nine ecoregions used in the analysis. Each metric was scored and then combined to create an overall Macroinvertebrate Index for each region, with values ranging from 0 to 100. For the WSA, analysts calculated a Macroinvertebrate Index score for each site, factored in the stream length represented by the site, and then generated an estimate of the stream length in a region, and nationally, with a given Macroinvertebrate Index score.

Six different characteristics of macroinvertebrate assemblages are commonly used to evaluate biological condition in wadeable streams (Photo courtesy of Lauren Holbrook, IAN Image Library).

Findings for the Macroinvertebrate Index of Biotic Condition

As illustrated in Figure 13, the Macroinvertebrate Index indicator results show that 42% of the nation's stream length (281,170 miles) is in poor condition, 25% (167,092 miles) is in fair condition, and 28% (189,236 miles) is in good condition compared to the least-disturbed reference condition in each of the nine WSA ecoregions. The 28% of stream length in good condition has conditions most similar to the reference distribution derived from the best-available (least-disturbed) sites in each ecoregion. The 5% (33,553 miles) of unassessed stream length results from the fact that 1st-order streams in New England were not sampled for the WSA.

Macroinvertebrate Index results show that the Eastern Highlands region has the highest proportion of stream length (52%, or 143,170 miles) in poor condition, followed by the Plains and Lowlands (40%, or 96,905 miles) and the West (27%, or 41,754 miles).

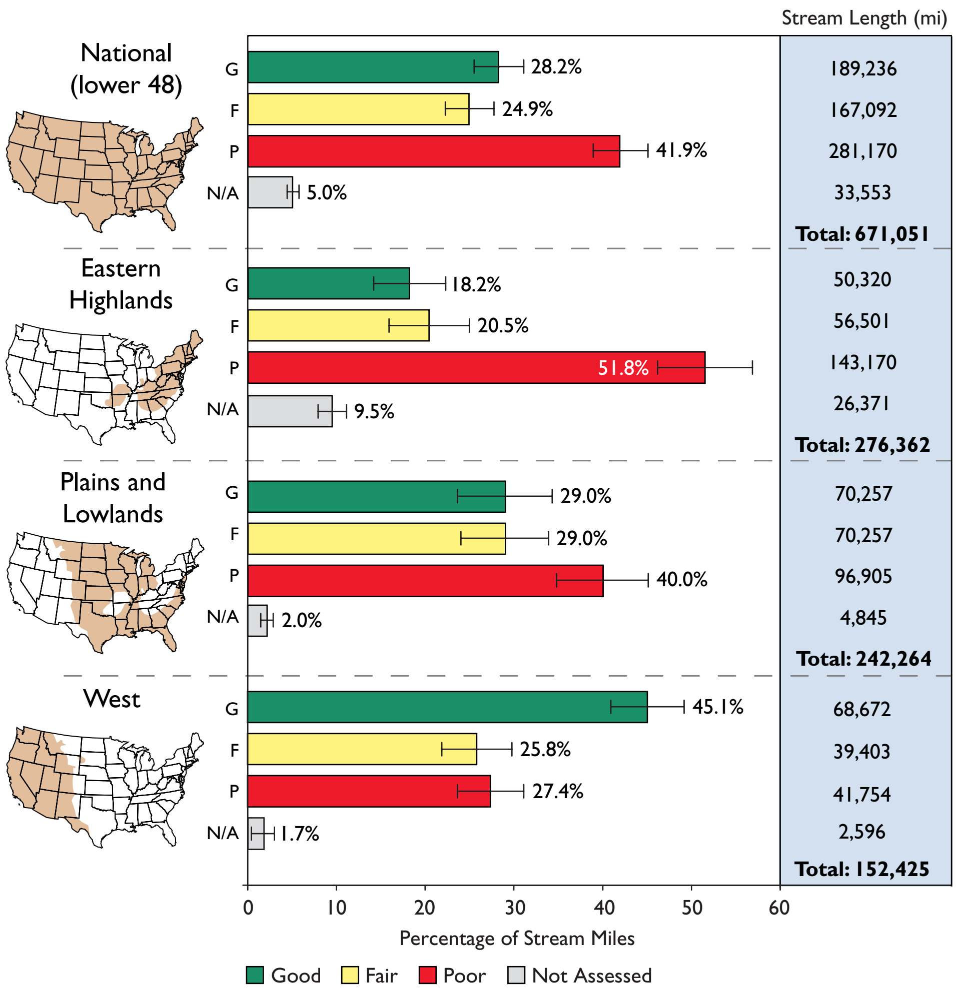

Figure 13. Biological condition of streams based on Macroinvertebrate Index of Biotic Condition (U.S. EPA/WSA). The Macroinvertebrate Index combines metrics of benthic community structure and function into a single index for each region. The thresholds for defining good, fair, and poor condition were developed for each of the nine WSA ecoregions based on condition at the least-disturbed reference sites. Stream length in good condition is most similar to least-disturbed reference condition; in fair condition has Macroinvertebrate Index scores worse than 75% of reference condition; and in poor condition has Macroinvertebrate Index scores worse than 95% of reference condition.

What are Confidence Intervals?

Confidence intervals (i.e., the small lines at the end of the bars in this report's charts) are provided to convey the level of certainty or confidence that can be placed in the information presented in this report. For example, for the national Macroinvertebrate Index, the WSA finds that 28.2% of the nation's stream length is in good condition, and the confidence is +/- 2.8%, which means that there is a 95% certainty that the real value is between 25.4% and 31%. The confidence interval depends primarily on the number of sites sampled; as more streams are sampled, the confidence interval becomes narrower, meaning there is more confidence in the findings. When fewer streams are sampled, the confidence interval become broader, meaning there is less certainty in the findings. Figure 13 shows an example of this pattern, in which the confidence interval for the national results (the largest sample size) is narrowest, whereas the confidence intervals for the major regions, where a smaller number of streams were sampled, are generally broader. Ultimately the breadth of the confidence interval is a tradeoff between the need for increased certainty to support decisions and the money and resources dedicated to monitoring.

Macroinvertebrate Observed/ Expected (O/E) Ratio of Taxa Loss

The Macroinvertebrate O/E Ratio of Taxa Loss (henceforth referred to as O/E Taxa Loss) measures a specific aspect of biological health: taxa that have been lost at a site. The taxa expected (E) at individual sites are predicted from a model developed from data collected at least-disturbed reference sites; thus, the model allows a precise matching of sampled taxa with those that should occur under specific, natural environmental conditions. By comparing the list of taxa observed (O) at a site with those expected to occur, the proportion of expected taxa that have been lost can be quantified as the ratio of O/E. Originally developed for streams in the United Kingdom, O/E Taxa Loss models are modified for the specific natural conditions in each area for which they are used. The O/E Taxa Loss indicator is currently used by several countries and numerous states in the United States.

O/E Taxa Loss values range from 0 (none of the expected taxa are present) to slightly greater than 1 (more taxa are present than expected). These values are interpreted as the percentage of the expected taxa present. Each tenth of a point less than 1 represents a 10% loss of taxa at a site; thus, an O/E Taxa Loss score of 0.9 indicates that 90% of the expected taxa are present and 10% are missing. O/E Taxa Loss values must be interpreted in the context of the quality of reference sites used to build the predictive models, because the quality of reference sites available in a region sets the bar for what is expected (i.e., regions with lower-quality reference sites will have a lower bar). Although an O/E Taxa Loss value of 0.8 means the same thing regardless of a region (i.e., 20% of taxa have been lost relative to reference conditions in each region), the true amount of taxa loss will be underestimated if reference sites are of low quality.

The WSA developed three O/E Taxa Loss models to predict the extent of taxa loss across streams of the United States, one model for each of the three major regions outlined in this report (Eastern Highlands, Plains and Lowlands, West). Analysts used the O/E Taxa Loss scores observed at each site to generate estimates of the nation's stream length estimated to fall into four categories of taxa loss.

Although in many cases the results of O/E Taxa Loss analysis are similar to the results of the Macroinvertebrate Index, such agreement will not always occur. The O/E Taxa Loss indicator examines a specific aspect of biological condition (biodiversity loss), whereas the Macroinvertebrate Index combines multiple characteristics. For the WSA, the two indicators provided similar results in those WSA ecoregions that had a lower disturbance signal among their reference sites.

Findings for O/E Taxa Loss

Figure 14 displays the national and regional O/E Taxa Loss summary. These data are presented in four categories: (1) less than 10% taxa loss, (2) 10–20% taxa loss, (3) 20–50% taxa loss, and (4) more than 50% taxa loss. Forty-two percent of the nation's stream length retained more than 90% of expected taxa; 13% lost 10–20% of taxa; 26% lost 20–50% of taxa; and 13% lost more than 50% of taxa.

Within the three regions, stream length in the Eastern Highlands experienced the greatest loss of expected taxa, with 17% experiencing a loss of 50% or more. An additional 29% of stream length in this region lost 20–50% of taxa; 13% lost 10–20% of taxa; and only 28% of stream length lost fewer than 10% of taxa. Eleven percent of stream length in the Plains and Lowlands region experienced a taxa loss of 50% or more, 25% of stream length lost 20–50% of

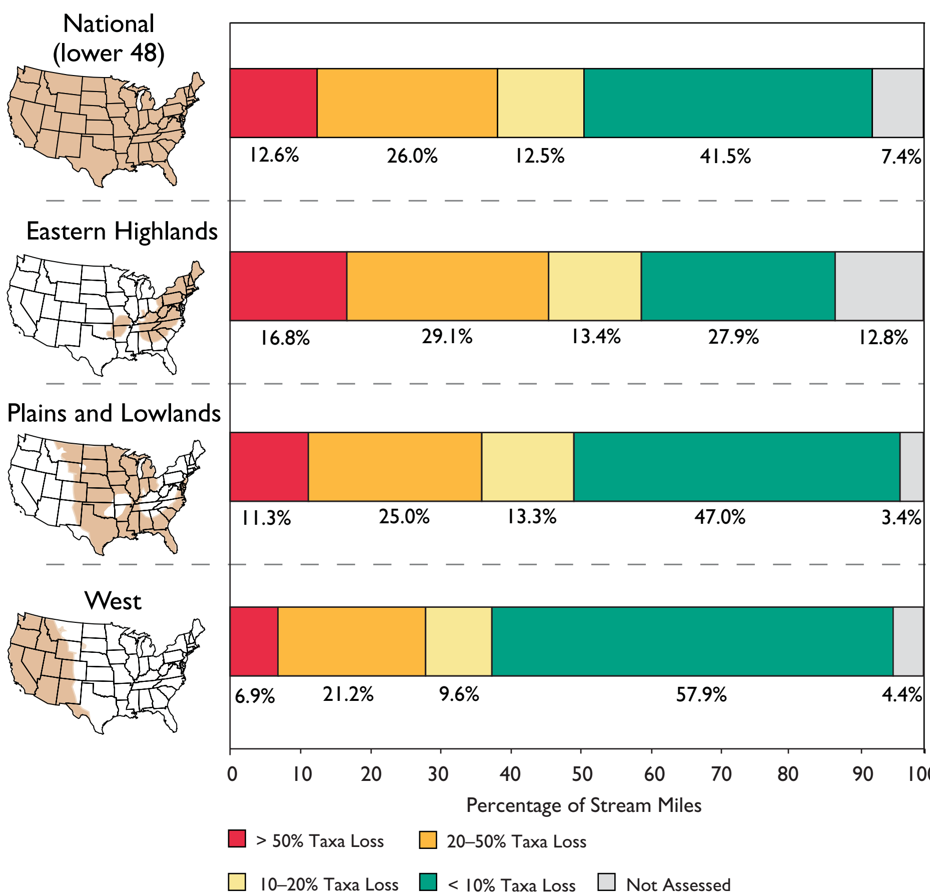

Figure 14. Macroinvertebrate taxa loss as measured by the O/E Ratio of Taxa Loss (U.S. EPA/WSA). The O/E Taxa Loss indicator displays the loss of taxa from a site compared to reference for that region. Scores 0.1 lower than reference represent a 10% loss in taxa.

taxa; 13% lost 10–20% of taxa; and 47% lost fewer than 10% of taxa. In the West, 7% of stream length experienced a taxa loss of 50% or more, 21% of stream length lost 20–50% of taxa; 10% lost 10–20% of taxa; and 58% of stream length lost less than 10% of taxa.

Aquatic Indicators of Stress

As people use the landscape, their actions can produce effects that are stressful to aquatic ecosystems. These aquatic stresses can be chemical, physical, or in some cases, biological. The WSA has selected a short list of stressors from each of these categories as indicators for assessment. This list is not intended to be all-inclusive, and in fact, some important stressors are not included because there is currently no way to assess them at the site scale (e.g., water withdrawals for irrigation). Future assessments of U.S. stream and river condition will include a more comprehensive list of stressors from each of these categories.

WSA indicators are based on direct measures of stress in the stream or adjacent riparian areas, not on land use or land cover alterations, such as row crops, mining, or grazing. Many human activities and land uses can be sources of one or more stressors to streams; however, the WSA only assesses stressors to determine the general condition of the resource and which stressors are most significant and does not track the source of these stressors. Source tracking, an expensive and time-consuming process, is a logical future step for the WSA and similar national assessments.

A summary of the national and regional results for indicators of chemical and physical habitat are shown in Figures 15 through 22. WSA results for these indicators for each of the nine WSA ecoregions are presented in Chapter 3 of this report.

Chemical Stressors

Four chemical stressors were assessed as indicators in the WSA: total phosphorus, total nitrogen, salinity, and acidification. These stressors were selected because of national or regional concerns about the extent to which each might be impacting the quality of stream biota. The thresholds for interpreting data were developed from a set of least-disturbed reference sites for each of the nine WSA ecoregions, as described in Chapter 1, *Setting Expectations*. The results for each ecoregion were tallied to report on conditions for the three major regions and the entire nation.

Total Phosphorus Concentrations

Phosphorus is usually considered the most likely nutrient limiting algal growth in U.S. freshwater waterbodies. Because of the naturally low concentrations of phosphorus in stream systems, even small increases in phosphorus concentrations can impact a stream's water quality. Some waters—such as streams originating from groundwater in volcanic areas of eastern Oregon and Idaho—have naturally higher concentrations of phosphorus. This natural variability is reflected in the regional thresholds for high, medium, and low, which are based on the least-disturbed reference sites for each of the nine WSA ecoregions.

Highlight

Nutrients and Eutrophication in Streams

Eutrophication is a condition characterized by excessive plant growth that results from high levels of nutrients in a waterbody. Although eutrophication is a natural process, human activities can accelerate this condition by increasing the rate at which nutrients and organic substances enter waters from their surrounding watersheds. Agricultural runoff, urban runoff, leaking septic systems, sewage discharges, eroded streambanks, and similar sources can increase the flow of nutrients and organic substances into streams, and subsequently, into downstream lakes and estuaries. These substances can overstimulate the growth of algae and aquatic plants, creating eutrophic conditions that interfere with recreation and the health and diversity of insects, fish, and other aquatic organisms.

Nutrient enrichment due to human activities has long been recognized as one of the leading problems facing our nation's lakes, reservoirs, and estuaries. It has also been more recently recognized as a contributing factor to stream degradation. In broadest terms, nutrient over-enrichment of streams is a problem because of the negative impacts on aquatic life (the focus of the WSA); adverse health effects on humans and domestic animals; aesthetic and recreational use impairment; and excessive nutrient input into downstream waterbodies, such as lakes.

Excess nutrients in streams can lead to excessive growth of phytoplankton (free-floating algae) in slow-moving rivers, periphyton (algae attached to the substrate) in shallow streams, and macrophytes (aquatic plants large enough to be visible to the naked eye) in all waters. Unsightly filamentous algae can impair the aesthetic enjoyment of streams. In more extreme situations, excessive growth of aquatic plants can slow water flow in flat streams and canals, interfere with swimming, snag fishing lures, and clog the screens on water intakes of water treatment plants and industries.

Nutrient enrichment in streams has also been demonstrated to affect animal communities in these waterbodies (see the References section at the end of this report for examples of published studies). For example, declines in invertebrate community structure have been correlated directly with increases in phosphorus concentration. High concentrations of nitrogen in the form of ammonia (NH_3) are known to be toxic to aquatic animals. Excessive levels of algae have also been shown to be damaging to invertebrates. Finally, fish and invertebrates will experience growth problems and can even die if either oxygen is depleted or pH increases are severe; both of these conditions are symptomatic of eutrophication.

As a system becomes more enriched by nutrients, different species of algae may spread and species composition can shift; however, unless such species shifts cause clearly demonstrable symptoms of poor water-quality—such as fish kills, toxic algae, or very long streamers of filamentous algae—the general public is unlikely to be aware of a potential ecological concern.

Phosphorus influx leads to increased algal growth, which reduces dissolved oxygen levels and water clarity within the stream. (See *Highlight: Nutrients and Eutrophication in Streams* for more information about the impacts of excess phosphorus and nitrogen.) Phosphorus is a common component of fertilizers, and high phosphorus concentrations in streams may be associated with poor agricultural practices, urban runoff, or point-source discharges (e.g., effluents from sewage treatment plants).

Findings for Total Phosphorus

Approximately 31% of the nation's stream length (207,355 miles) has high concentrations of phosphorus, 16% (108,039 miles) has medium concentrations, and 49% (327,473 miles) has low concentrations (Figure 15). Of the three major regions, the Eastern Highlands has the greatest proportion of stream length with high concentrations of phosphorus (43%, or 117,730 miles), followed by the Plains and Lowlands (25%, or 60,324 miles) and the West (19%, or 28,174 miles) regions.

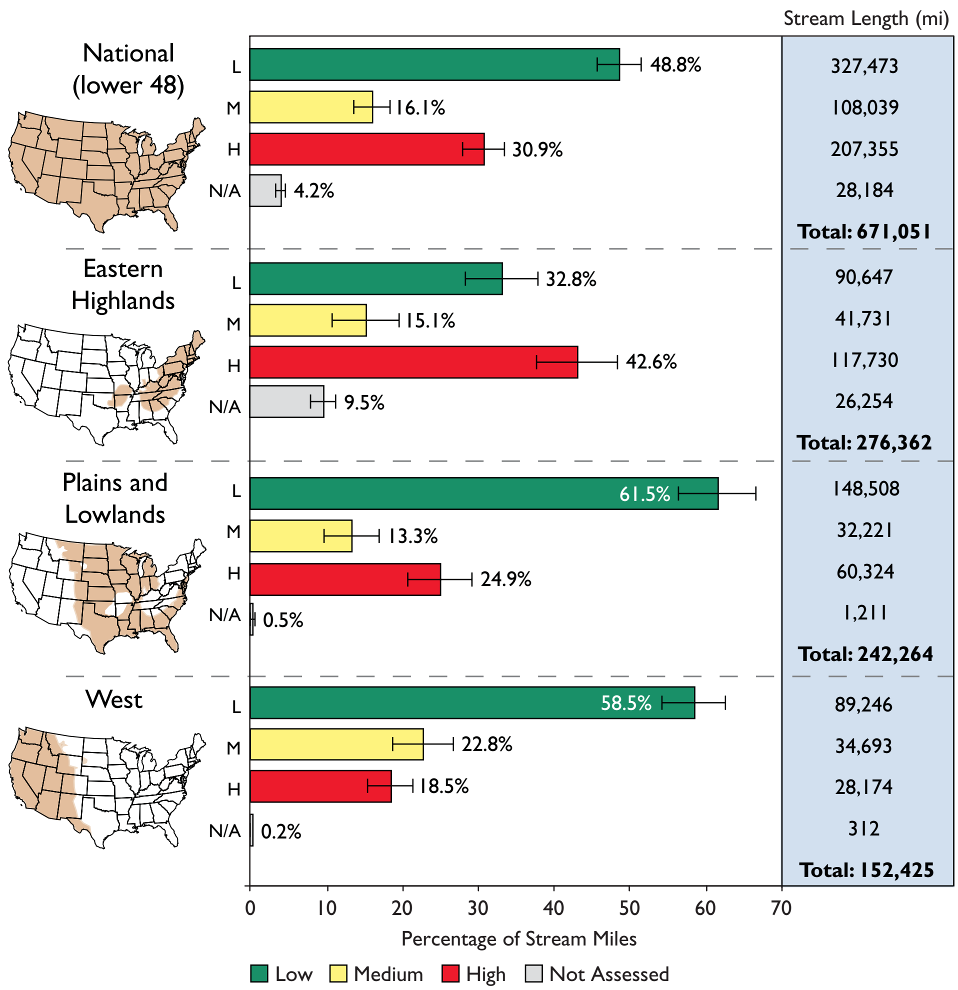

Figure 15. Total phosphorus concentrations in U.S. streams (U.S. EPA/WSA). Percent of stream length with low, medium, and high concentrations of phosphorus based on regionally relevant thresholds derived from the least-disturbed regional reference sites. Low concentrations are most similar to reference condition; medium concentrations are greater than the 75th percentile of reference condition; and high concentrations are greater than the 95th percentile of reference condition.

Total Nitrogen Concentrations

Nitrogen, another nutrient, is particularly important as a contributor to coastal and estuarine algal blooms. Nitrogen is the primary nutrient limiting algal growth in some regions of the United States, particularly in granitic or basaltic geology found in parts of the Northeast and the Pacific Northwest. Increased nitrogen inputs to a stream can stimulate growth of excess algae, such as periphyton, which results in low dissolved oxygen levels, a depletion of sunlight available to the streambed, and degraded habitat conditions for benthic macroinvertebrates and other aquatic life (see *Highlight: Nutrients and Eutrophication in Streams*). Common sources of excess nitrogen include fertilizers, wastewater, animal wastes, and atmospheric deposition.

Findings for Total Nitrogen

A significant portion of the nation's stream length (32%, or 213,394 miles) has high concentrations of nitrogen compared to least-disturbed reference conditions, 21% (138,908 miles) has medium concentrations, and 43% (290,565 miles) has relatively low concentrations (Figure 16). As with phosphorus, the Eastern

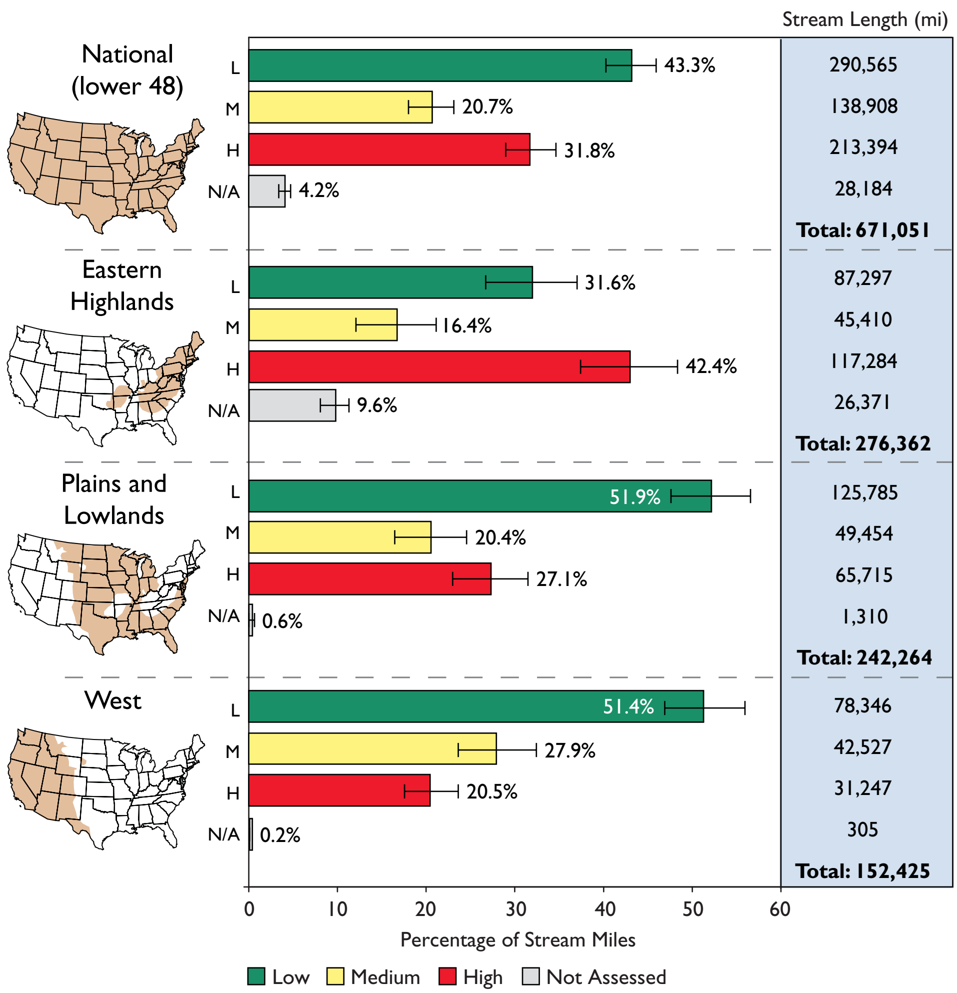

Figure 16. Total nitrogen concentrations in U.S. streams (U.S. EPA/WSA). Percent of stream length with low, medium, and high concentrations of nitrogen based on regionally relevant thresholds derived from the least-disturbed regional reference sites. Low concentrations are most similar to reference condition; medium concentrations are greater than the 75th percentile of reference condition; and high concentrations are greater than the 95th percentile of reference condition.

Highlands region has the greatest proportion of stream length with high concentrations of nitrogen (42%, or 117,284 miles), followed by the Plains and Lowlands (27%, or 65,715 miles) and the West (21%, or 31,247 miles).

Salinity

Excessive salinity occurs in areas with high evaporative losses of water and can be exacerbated by repeated use of water for irrigation or by water withdrawals. Both electrical conductivity and total dissolved solids (TDS) can be used as measures of salinity; however, conductivity was used for the WSA.

Findings for Salinity

Roughly 3% of the nation's stream length (19,889 miles) has high levels of salinity, 10% (69,585 miles) has medium levels, and 83% (553,530 miles) has low levels compared to levels found in least-disturbed reference sites for the nine WSA ecoregions (Figure 17). The Plains and Lowlands region has the greatest proportion of stream length with high levels of salinity (5%, or 12,113 miles), followed by the West (3%, or 4,009 miles) and Eastern Highlands (1%, or 3,593 miles).

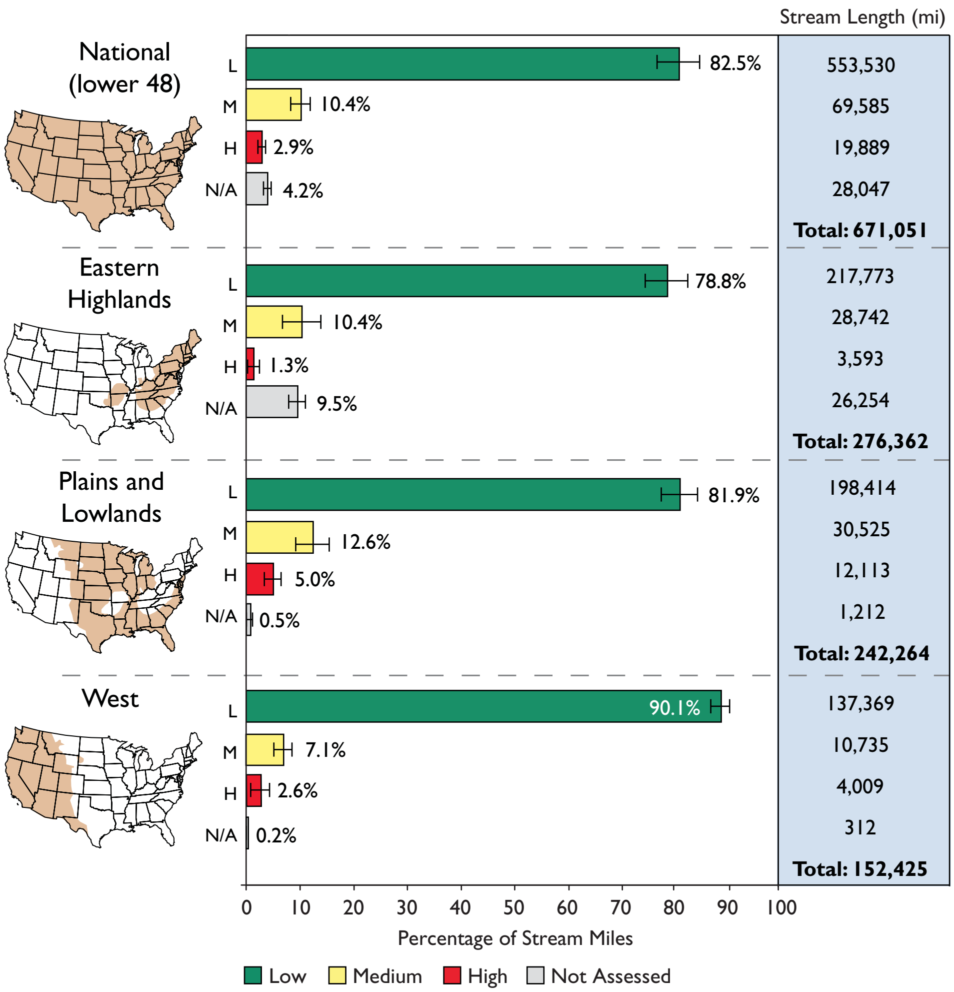

Figure 17. Salinity conditions in U.S. streams (U.S. EPA/WSA). This indicator is based on electrical conductivity measured in water samples. Thresholds are based on conditions at least-disturbed regional reference sites.