Ecological Assessment of Arizona's Streams and Rivers, 2000-2004

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Cover photograph: Burro Creek, tributary to the Santa Maria River in western Arizona.
Photo credit: George Andrejko, Arizona Game and Fish Department.

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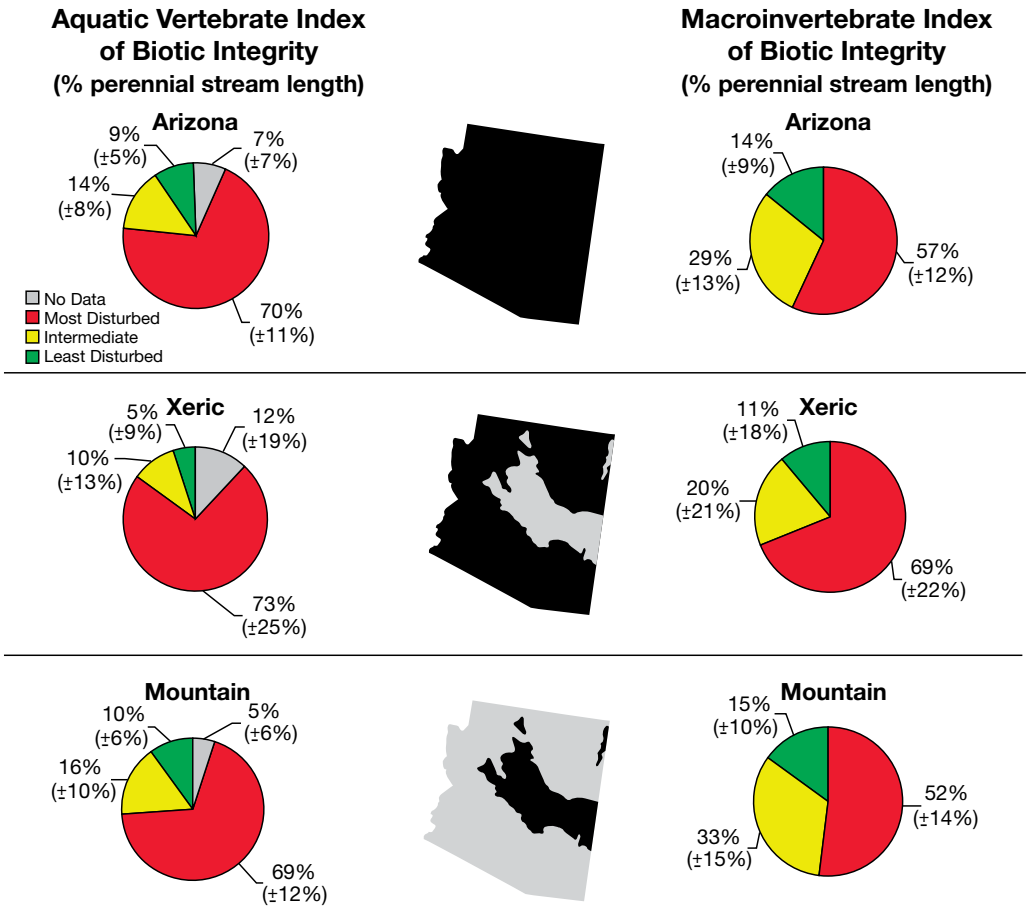
EXECUTIVE SUMMARY

The State of Arizona participated in a U.S. Environmental Protection Agency (EPA) ecological assessment of Western streams. One goal of the assessment was to report on the ecological condition of all Western perennial streams, except the 'Great Rivers' such as the lower Columbia, Snake, Missouri, and Colorado rivers. Another goal was to identify and rank the importance of chemical, physical, and biological disturbances affecting stream condition. Having achieved these goals we can provide resource managers and decision makers with the information needed to conserve and manage the ecological condition of Arizona's streams.

To help address these goals, Arizona Game and Fish Department, U.S. Geological Survey, University of Arizona, Lockheed Martin, and EPA collected biological, chemical, and physical data from 47 perennial stream locations in Arizona. A probabilistic study design was used to select study sites to ensure results would be representative of all of Arizona's perennial streams (an estimated 4,640 km of stream length, 2,973 km of which was assessed). The ecological condition of each site was categorized as most-disturbed, intermediate, or least disturbed based on aquatic vertebrate and macroinvertebrate assemblage indicators; similar categories were assigned to each site based on levels of stressors. The results provide a snapshot of the ecological condition of streams in Arizona and in two broad climatic regions, Xeric and Mountains, within the state.

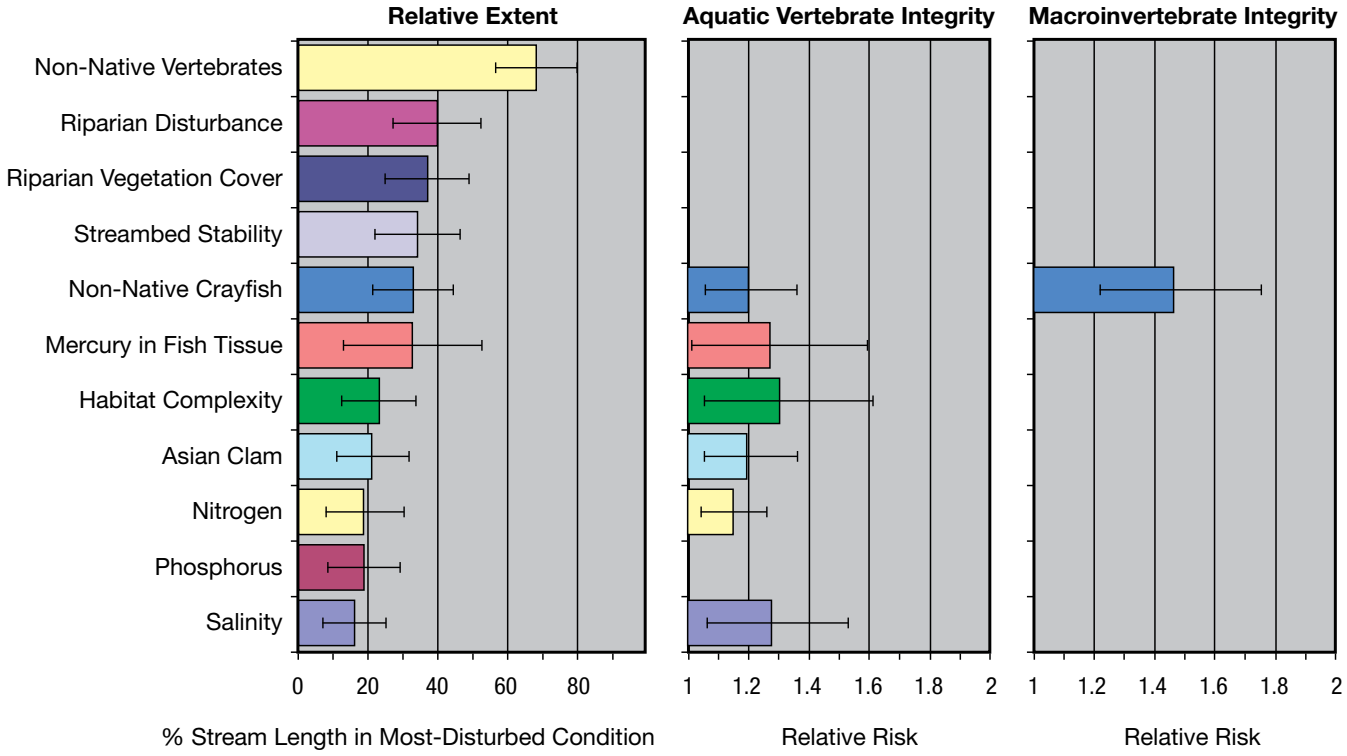
Most of Arizona's stream length was assessed to be in most-disturbed ecological condition (see figure below): 70% was in most-disturbed condition based on an aquatic vertebrate index of biotic



The majority of Arizona's stream length was in most-disturbed ecological condition.

integrity (IBI), and 57% was in most-disturbed based on a macroinvertebrate IBI. Within Arizona's two climatic regions, streams in the Mountains region tended to be in better condition than those in the Xeric climatic region.

Eleven stressors were examined which could potentially affect biotic integrity (see below). The importance of these stressors was evaluated by considering their relative extent (percentage of stream length in most-disturbed condition) and severity (the association with most-disturbed biotic integrity, as evaluated with relative risk). Statewide, non-native vertebrates had the greatest relative extent of any stressor examined, with 68% of stream length in most-disturbed condition. Salinity was the least extensive stressor, with 16% of stream length having high concentrations. A relative-risk analysis, however, indicated that high concentrations of salinity, total nitrogen and mercury in fish tissue, low levels of habitat complexity, and presence of Asian clam and crayfish were the stressors most associated with most-disturbed aquatic vertebrate condition. Of these stressors, non-native crayfish may be the best target for further study and possible management action because they were the most extensive (found in 33% of stream length) and were also associated with risk to the macroinvertebrate assemblage. It is our hope that information about the ecological condition of Arizona's streams presented in this report will be useful in developing management plans and priorities.



FORWARD

This report presents the results of an ecological assessment of perennial streams and rivers in Arizona based on data collected from 2000 to 2004 by the Arizona Game and Fish Department and the U.S. Geological Survey, as part of the U.S. Environmental Protection Agency's (EPA) Ecological Monitoring and Assessment Program (EMAP). The goals of the EMAP are to develop the necessary monitoring tools to determine the current status, extent, changes, and trends in the condition of our nation's ecological resources. The EMAP uses data-collection protocols that are consistent among states and for streams of similar sizes so that comparisons can be made on a regional and national scale. The work in Arizona was part of an EMAP effort to assess the ecological health of streams in 12 Western states by collecting data encompassing habitat, water chemistry, and fish, macroinvertebrate, and algae assemblages.

Our goal with this report is to present the assessment of Arizona's perennial streams and rivers in two ways—(1) show the ecological condition of streams and rivers based on measures of assemblages of aquatic vertebrates (e.g., fish and amphibians) and benthic macroinvertebrates (e.g., larval insects, worms, and crustaceans), and (2) assess the relative importance of potential stressors (measured chemical, biological, and physical habitat features) on these assemblages, by reporting the extent of these stressors and how much risk they pose to these assemblages in the State.

It is our intention that this report should be of use to the public as well as environmental managers, water-resource professionals, and decision makers. To put this information into the context of the ecological assessment for the Western United States, the reader is referred to the U.S. Environmental Protection Agency's "Ecological Assessment of Western Streams and Rivers" (Stoddard et al. 2005b). The data for Arizona are incorporated into that report as part of a West-wide perspective on ecological condition.

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INTRODUCTION

Safeguarding the natural environment is fundamental to the mission of the U.S. Environmental Protection Agency (EPA). The legislative mandate to undertake this part of the Agency's mission is embodied, in part, in the Clean Water Act (CWA). The CWA requires States to report the condition of their aquatic resources and list those not meeting their designated use (Section 305b and 303d, respectively). After 30 years of implementing the CWA, the public as well as water managers are asking the EPA if the quality of water resources in the United States has improved, which types of human activities are affecting streams and rivers, and which areas are affected. These were difficult questions to answer because each state had collected different types of data, at different scales, and with a variety of sampling protocols.

The Environmental Monitoring and Assessment Program (EMAP) was initiated in the late 1980's by the U.S. EPA's Office of Research and Development (ORD) as a long-term research effort with goals to: (1) develop the tools necessary to monitor and assess the status and trends of national ecological resources, (2) enable status and trend assessments of ecosystems across the U.S. with a known statistical confidence, and (3) develop the scientific understanding for translating environmental monitoring data from multiple spatial and temporal scales into assessments of ecological condition and forecasts of the future risks to the sustainability of our natural resources (U.S. Environmental Protection Agency 2006). The EMAP includes monitoring the conditions of estuaries, streams and lakes in selected geographic regions, as well as examining the surrounding landscapes in which these resources occur. This strategy forms the basis for the research needed to establish the condition of the nation's resources.

The EMAP-West measured the ecological condition of aquatic resources in 12 Western states including Arizona. Three general assessment questions were addressed by EMAP-West: (1) what proportion of stream and river miles in the western U.S. are in acceptable (or poor) biological condition?; (2) what is the relative importance of potential stressors (habitat modification, sedimentation, nutrients, temperature, grazing, timber harvest, etc.) in streams and rivers across the West?; and (3) with what stressors are streams and rivers in poor biological condition associated?

A variety of agencies cooperated with EPA to conduct the EMAP-West sampling in Arizona. In 2000-2001, Lockheed-Martin in cooperation with the U.S. Geological Survey, Arizona Water Science Center and EPA collected EMAP data. In 2002-2004, the Arizona Game and Fish Department in cooperation with the U.S. Geological Survey Arizona Water Science Center and the EPA completed the remaining EMAP data collection for Arizona. Arizona Game and Fish Department and U.S. Geological Survey Arizona Water Science Center used the data collected from 2000 to 2004 to assess the ecological condition of Arizona's streams.

The purpose of this report is to assess the ecological condition of perennial streams and rivers in Arizona based on EMAP-West sampling in the State. There are two components of the assessment: (1) assess the ecological condition of streams and rivers based on measures of the assemblages of aquatic vertebrates (e.g., fish and amphibians) and benthic macroinvertebrates (e.g., larval insects, worms, and crustaceans), and (2) assess the relative importance of potential stressors (measured chemical, biological, and physical habitat characteristics) on these assemblages. The importance of potential stressors was evaluated based both on the their extent and on a risk analysis to assess which stressors are associated with most-disturbed ecological condition in Arizona.

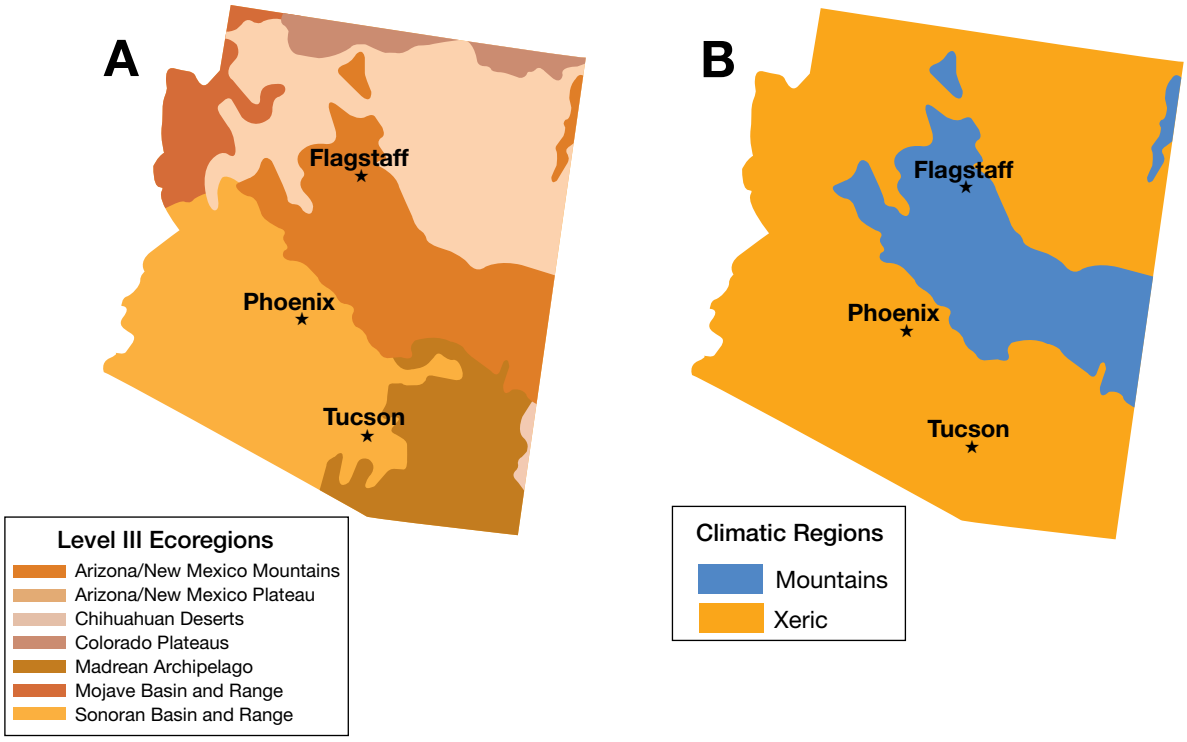

Figure 1. Omernik (1987) Level III ecoregions (A) and aggregated ecoregions (B; "Climatic Regions" Stoddard et al. 2005b) used in the Arizona assessment, showing locations of sites sampled.

Description of the Study Area

Wide variations in physiography, geology, vegetation, soils, land use, hydrology, wildlife, and climate are characteristic of Arizona. Omernik (1987) divided the United States into 104 Level III ecoregions, seven of which occur in Arizona (Figure 1a). These "ecoregions" were delineated on the basis of natural vegetation, geology, soils, and other ancillary data and represent areas of relatively homogenous ecological systems. A brief description of each of the seven ecoregions in Arizona is given in Table 1. For the EMAP-West streams assessment (Stoddard et al. 2005a and 2005b), EPA reported results at three levels of geographic resolution: a) West-wide, b) three broad ecoregions (referred to as "Climatic Regions", Xeric, Mountains, and Plains) that were aggregated from Omernik (1987) ecoregions, and c) 10 smaller ecoregions that were aggregated from Omernik (1987) ecoregions.

Most of the perennial streams in Arizona and thus, the majority of the EMAP sites in Arizona are in the Arizona/New Mexico Mountains ecoregion (Figure 1b; Table 2). Very few sites were sampled in the remaining six ecoregions. A total of 47 sites (see methods) were sampled in Arizona as part of the EMAP assessment. Because of the small sample size, we could not make accurate assessments at the level of the Omernik Level III ecoregions. Our assessment is limited to two levels: a) state-wide, and b) within the two broad climatic regions (Figure 1b). It is emphasized that these climatic regions are simply groupings of mapped Omernik (1987) Level III ecoregions, and have some overlap in geologic features and even vegetation types (e.g., Madrean Archipelago, which is included in the Xeric climatic region, has ponderosa pine forest at its higher elevations, the same vegetation type found throughout the Mountains climatic region). Characteristics of these two climatic regions are discussed in more detail below.

Ecoregion	Characteristics
Arizona/New Mexico Mountains	Low to high mountains with pinion-juniper and oak woodlands at low to mid-elevations, ponderosa pine forests at high elevations
Arizona/New Mexico Plateau	Tablelands with considerable to very high relief, plains with high mountains, semi-humid grasslands differentiate it from the Colorado Plateaus
Colorado Plateaus	Rugged tablelands, plains with high mountains, pinion-juniper woodlands, saltbrush-greasewood in low-lying areas
Sonoran Basin and Range	Desert valleys separated by low mountain ranges with desert scrubland associations, giant saguaro cactus, and palo verde-cactus scrub
Madrean Archipelago	Desert plains with abrupt high mountains forming "sky islands" containing high elevation ecosystem communities, scrubland
Mojave Basin and Range	Scattered, generally low mountains, lack of water and vegetation, predominant vegetation is creosote bush
Chihuahuan Deserts	Isolated mountains and mesas with intervening broad basins vegetated with arid grass and shrubland, except on higher mountains where oak-juniper woodlands occur

Table 1. Level III Ecoregions in Arizona (Omernik 1987).

Mountains Climatic Region

Forests of spruce, fir, and Douglas fir are found in a few high elevation parts of this climatic region (Omernik 1987). Chaparral is common on the lower elevations, pinyon-juniper and oak woodlands are found at lower and middle elevations, and the higher elevations are mostly covered with open to dense ponderosa pine forests.

The region has mountainous terrain with small, relatively shallow, intermontane basins. Land-surface elevations range from about 400 meters near the confluence of the Salt and Verde rivers to about 3,850 meters on Mt. Humphreys near Flagstaff. The mountains are predominantly volcanic, sedimentary, metamorphic, and granitic rocks that provide water locally from fractured and permeable zones but do not constitute major aquifers. The extensive consolidated sedimentary rocks (limestone, sandstone, shale, and related deposits) are more permeable and can store and transmit water. Water discharges from these sedimentary rocks to springs, streams, and basin-fill aquifers along the Mogollon Rim and in the Verde Valley (Anderson et al. 1992).

Sediments that fill the basins between mountain ranges (basin-fill deposits) may be as much as 152 meters thick. These deposits are important because they are the major water-bearing and water-yielding units in many areas.

Precipitation and air temperature are highly variable throughout the Mountains climatic region and are dependent, in large part, upon land-surface elevation. Precipitation increases and temperature decreases with increasing altitude during all seasons of the year. The large topographic relief in the Mountains climatic region contributes to the variability of temperature and precipitation. Typical variations in temperature in the Mountains region for high and low elevations are illustrated by graphs for Flagstaff and Roosevelt, respectively (Figure 2; Western Regional Climate Center 2005). Average annual precipitation varies widely over the region from as much as 36 in/yr at the highest elevations in San Francisco Mountains to as little as 16 in/yr at the low elevations along the Salt River (Spatial Climate Analysis Service 2000).

EPA's Climatic Region	Omernik Level III Ecoregion	Number of Sites Sampled
Mountains		
	Arizona/New Mexico Mountains	34
Xeric		
	Arizona/New Mexico Plateau	5
	Colorado Plateaus	1
	Sonoran Basin and Range	3
	Madrean Archipelago	3
	Mojave Basin and Range	1
	Chihuahuan Deserts	0
TOTAL		47

Table 2. Number of EMAP sites sampled in each Omernik (1987) Level III ecoregion and in the EPA's climatic regions in Arizona (Stoddard et al. 2005b).

The Mountains climatic region is the source of much of the water that sustains streams and rivers in the central and northern parts of Arizona. Most major streams and rivers in the State, with the exception of the Colorado River, have their headwaters in this climatic region. These include the Salt, Verde, Agua Fria, and Hassayampa Rivers, which are tributaries to the Gila River. The Gila River, in the central part of Arizona, has its headwaters in New Mexico within the same Omernik (1987) Level III ecoregion (Arizona/New Mexico Mountains). The upper reaches of the Salt and Gila Rivers are perennial, but they become intermittent downstream because of manmade impoundments and diversions. Streams in this climatic region can vary in length in response to changes in precipitation, increasing in wet periods and decreasing in dry periods. The streams in this climatic region tend to have short periods of high streamflow and long periods of low streamflow, which result in the "average flow" being greater than the typical base flow (Cordy et al. 1998). Annual mean streamflows for the period of record from several sites within the Mountains climatic region (Figure 3; Fisk et al. 2004) show the variability in streamflow on large (Salt River near Chrysotile) and small rivers (Verde River near Paulden) and in smaller streams (Little Colorado River above Lyman Lake).

The predominant land-uses in the Mountains climatic region are forest (57%) and rangeland (38%). Urban land use only comprises 0.3% of the area, and the largest centers of population are the cities of Flagstaff (pop. about 53,000; U.S. Census Bureau, 2004) and Prescott/Prescott Valley (pop. about 70,800; U.S. Census Bureau 2004).

Xeric Climatic Region

Vegetation in this climatic region is diverse, as it includes six Omernik (1987) Level III ecoregions. Desert vegetation types (e.g., palo verde-cactus scrub, creosote bush) predominate throughout, particularly in the lower elevations. Grass and shrubland are found in the middle elevations, and pinyon-juniper woodland in the higher elevations. A small percentage of the total area has ponderosa pine forest in the highest elevations (the 'Sky Islands' of southeastern Arizona).

The Xeric climatic region can be subdivided into two areas. One area includes the southern and western parts of this region, and is characterized by deep, northwest-trending, alluvium-filled

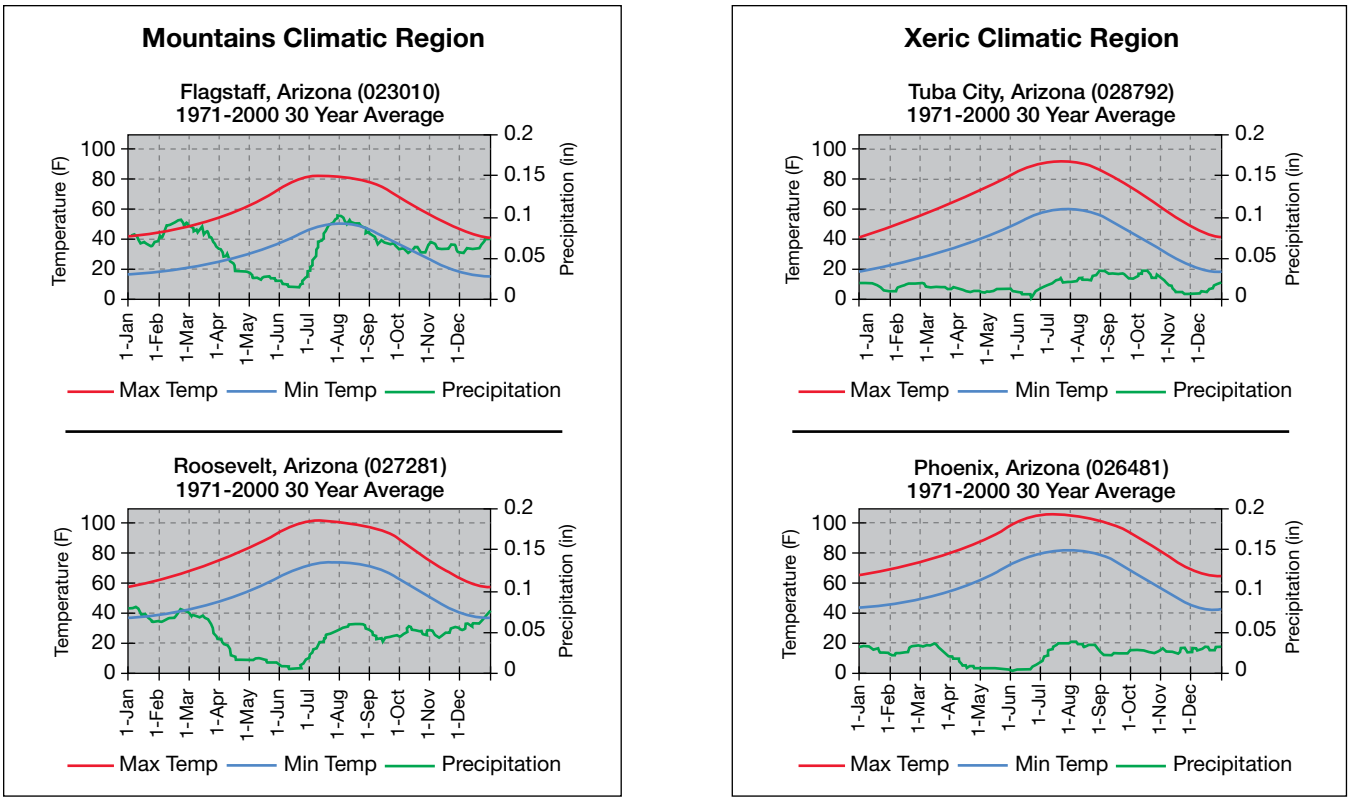

Figure 2. Average daily precipitation, and average maximum and minimum daily temperature, during 1971 through 2000 at selected sites in Arizona (from Western Regional Climate Center at www.wrcc.dri.edu/summary/climsaz.html accessed 6/12/06).

basins separated by mountain ranges, and will be referred to as "basin and range lowlands" in this report. This area contains the Chihuahuan Desert, Madrean Archipelago, Sonoran Basin and Range, and Mojave Basin and Range Level III ecoregions. Land-surface elevations range from 30 meters along the Lower Colorado River to 600 meters in the basins and more than 3,000 meters in some mountain ranges (Wilson 1962). The other area, north of the Mountains climatic region, is characterized by nearly flat-lying sedimentary rocks dissected by the Colorado River and its tributaries and contains the Colorado Plateaus and the Arizona/New Mexico Plateau Level III ecoregions and is referred to as "plateau uplands" in this report. Land-surface elevations in this part of the Xeric climatic region are above 1,500 meters in altitude with the exception of canyons and valleys. Much of the region exceeds 1,800 meters and some of the mountains are as much as 2,700 meters high (Wilson 1962).

As in the Mountains climatic region, precipitation typically increases and temperature decreases with increasing altitude in the Xeric climatic region during all seasons of the year. Less rainfall and higher temperatures are characteristic of the basin and range lowlands because of the predominance of lower land-surface elevations compared to the Mountains climatic region. Average annual precipitation over much of the basin and range lowlands is 8 to 12 in/yr (Figure 2). High temperatures are common throughout the summer months at low elevations (Figure 2; e.g., Phoenix). Despite generally higher elevations in the plateau uplands compared to the basin and range lowlands, the average annual precipitation is low--8 to 16 in/yr (Figure 2), and summer and winter temperatures

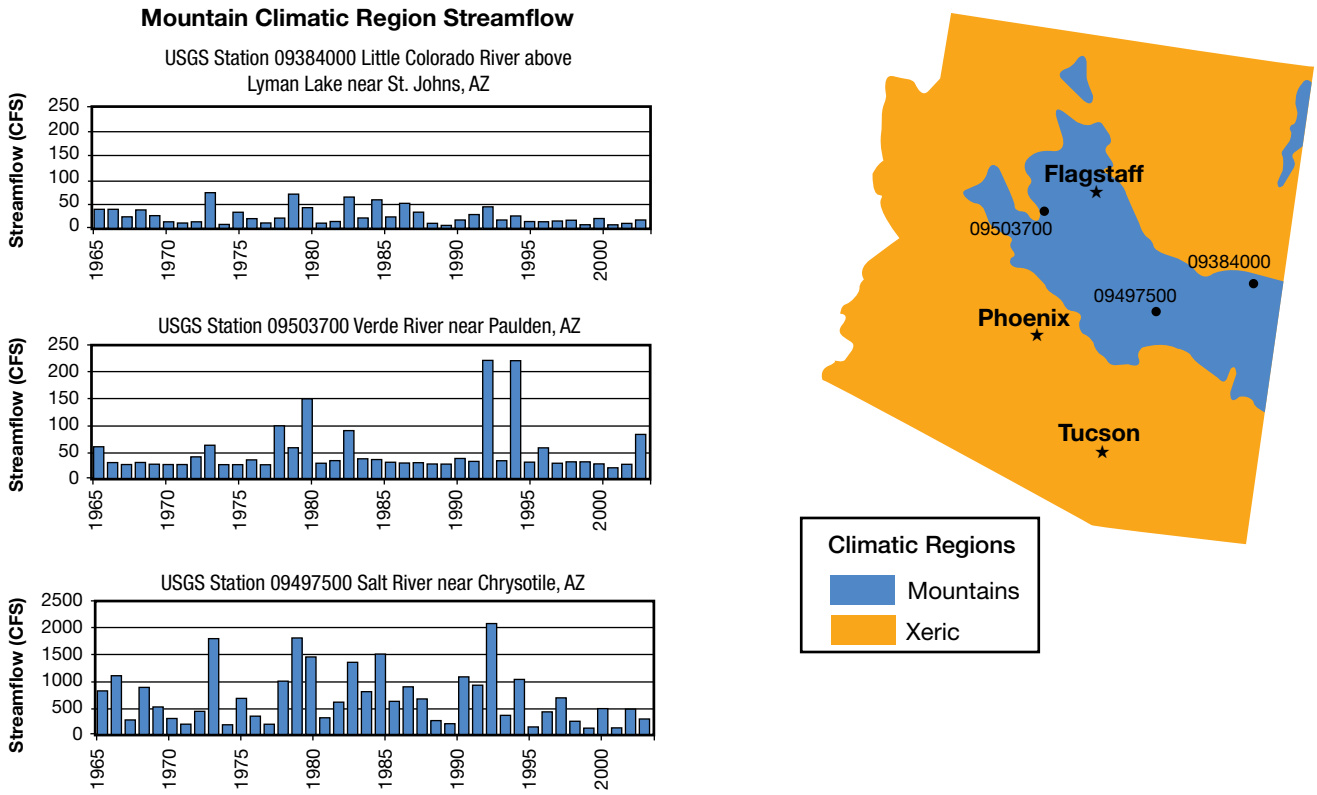

Figure 3. Annual mean stream flow at selected sites in the Mountains climatic region; gage locations are shown on map.

tend to be lower in the plateau uplands (Figure 2; e.g., Tuba City).

Perennial rivers and streams in the Xeric climatic region are relatively rare because of the aridity of the region, dams and impoundments upstream that capture streamflow, and pumping of ground water. Rivers such as the Salt and Gila in central Arizona would have perennial flow; the water rights, however are appropriated upstream for irrigation and municipal use, and dams prevent flow from reaching the lower sections of these rivers. Smaller rivers such as the Santa Cruz near Tucson were perennial in the past, but pumping of ground water caused water levels to decline as much as several hundred feet below land surface, drying up the rivers. The San Pedro River near Charleston in southeastern Arizona is one of the few remaining perennial stream reaches in the basin and range lowlands (Figure 4). For the first time in a century, however, this reach ceased flowing temporarily in 2005 (U.S. Geological Survey 2006). Some stream reaches that would otherwise be dry have perennial flow that is sustained by the discharge of treated wastewater. Intermittent, ephemeral, and effluent-dependent stream reaches were not target sites for the EMAP and were not sampled.

Many of the streams in the Xeric climatic region are intermittent or ephemeral but they can have high flow in response to intense thunderstorms. Typical streamflow hydrographs for these streams show many years with negligible annual mean streamflow and years with more than 250 days of no flow (Figure 4). Intermittent and ephemeral streams can, in some places, support aquatic life in pools that last from one storm event to the next.

Although the predominant land uses in both the basin and range lowlands and the plateau uplands

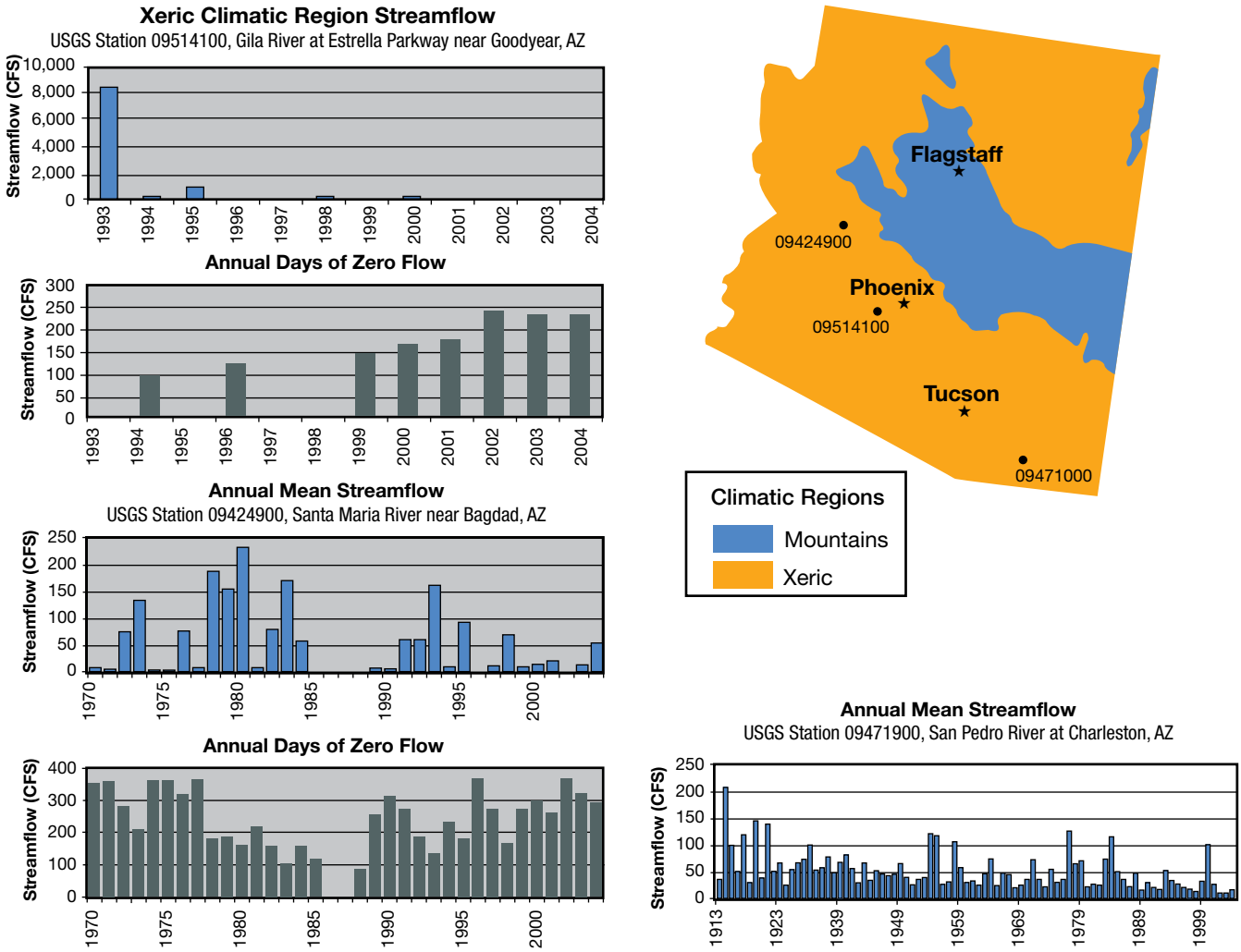

Figure 4. Annual mean streamflow and annual days of zero flow for selected sites in the Xeric climatic region in Arizona (from Fisk et al. 2005).

of the Xeric climatic region are rangeland (94%) and grassland (3 %), the two largest urban areas in Arizona are in the basin and range lowlands--Maricopa County includes Phoenix and surrounding cities (pop. 3.5 million; U.S. Census Bureau 2004) and Pima County includes Tucson and surrounding cities (pop. 907,000; U.S. Census Bureau, 2004).

Study Design

The EMAP study design consisted of collecting a wide range of biological, chemical and physical data from which indicators were developed that were sensitive to anthropogenic stress and could therefore be used to determine condition of ecological resources. Sites were sampled at a wide range of locations across diverse ecoregions. Conditions at reference sites (see below) were sampled to serve as benchmarks of condition of indicators (U.S. Environmental Protection Agency 2002). The EMAP sampling design allowed for statistical inference to produce regionally representative information. The EMAP study design is described in detail in U.S. Environmental Protection Agency (2002) Report 620/R-02/002 to which the reader is directed for more information.

Because the assessment questions addressed all perennial stream miles in 12 Western states, the EMAP used a probabilistic survey design to select

sampling sites to get an unbiased representation of aquatic resource condition across this large geographic area. The principal characteristics of probabilistic design are that: (1) the population being sampled is unambiguously described, (2) every element in the population has the opportunity to be sampled with a known probability, and (3) sample selection is carried out by a random process. This approach allows statistical confidence levels to be placed on the estimates and provides the potential to detect changes and trends in condition with repeated sampling.

The population of possible sites was all perennial streams segments identified on digitized 1:100,000 scale maps (Horn and Grayman 1993) in the 12 states. From this population, sites were selected for sampling using a stratified random design. Sample sites were selected in a systematic random fashion that distributed sampling sites throughout the study area for maximum representation over large geographic areas (U.S. Environmental Protection Agency 2002). This system was designed to select sample sites at regular intervals from a random start and use an overlying randomly-positioned grid to ensure spatial separation of sites. Within this design, site selection was stratified by state, using unequal probabilities for stream size and humid or arid areas (sites chosen are called 'probability sites'). Because of the design, several sites on the same stream, particularly higher order streams, could be selected. The EMAP had a goal of sampling 50 of these probability sites in each of the 12 Western states. A detailed description of the site selection method can be found in U.S. Environmental Protection Agency (2002) Report EPA 620/R-02/002. It should be noted that the climatic region of each site was determined from digitized maps.

The concentration of perennial streams in the Mountains climatic region in Arizona and general lack of perennial streams elsewhere in the state presented some challenges in site selection. Many of the 384 sites initially selected by the stratified random method were either non-target (i.e., not part of the target population of perennial streams), such as irrigation canals or non-existent streams (i.e., errors in the original database maps), or they were dry stream sites (e.g., non-perennial). As a result, site evaluation was required prior to sampling to ensure the sites had sufficient water for sampling and were accessible. Some sites were physically inaccessible, whereas others could not be accessed because permission was denied (e.g., most Indian nations denied access). By the end of the study, a total of 47 probability sites were sampled in Arizona during the summer months from 2000 to 2004 (Figure 1; Table 2; Appendix 1).

Reference condition, condition classes (least-disturbed, intermediate, and most-disturbed), and condition class thresholds developed by the EPA for the Western stream assessment (Stoddard et al. 2005a and 2005b) were used in the Arizona stream assessment. The EPA measured reference condition in a set of least-disturbed sites in each climatic region throughout the West. Candidate reference sites were selected from: 1) sites handpicked by EPA, State, or other monitoring programs, and 2) EMAP probability sites that passed numerous chemical and physical criteria. All of the candidate reference sites were sampled by EMAP crews using EMAP protocols. Data from sites were evaluated and those that met extensive least-disturbed criteria were considered reference sites (see Appendix 2, and Stoddard et al. 2005a for a description of the least-disturbed site classification process). In Arizona, 27 handpicked sites identified by EPA or Arizona Department of Environmental Quality (ADEQ) were sampled in the summers of 2003 and 2004 to serve as potential reference sites. Nineteen of the 27 sites were sampled in 2004, data from which has not been evaluated as to least-disturbed status, and these were therefore not available as candidate reference sites in this assessment.

For each indicator where reference condition was used to estimate thresholds, reference sites were chosen without referring to the results of the specific indicator being assessed, to avoid circularity. For example, chemical and physical habitat variables were used to classify sites as least-disturbed, and these reference sites were used to set thresholds for the biological indicators (Stoddard et al. 2005a).

For the ecological assessment of streams and rivers in Arizona, two critical components of aquatic ecosystems were evaluated: (1) the condition of the biota as described by indicators of ecological condition, and (2) the relative importance of human-caused stressors, described by aquatic indicators of stress.

Indicators of Ecological Condition

The condition of biotic communities in rivers and streams are indicators of the ecological condition of those water bodies. For the Arizona EMAP stream assessment, the biotic integrity of aquatic vertebrate and macroinvertebrate communities was assessed using indexes of biological integrity (IBI) developed by EPA during the assessment of Western streams (Stoddard et al. 2005a and 2005b). An IBI is the sum of several individual measures or metrics into a total score, which measures the capability of a community of organisms to support and maintain a balanced community with species composition, diversity, and functional organization comparable to that of least-disturbed habitat a region. Metrics summed in the IBIs include taxonomic composition, habitat use and feeding group composition, pollution tolerance, and other measures of biotic condition. Table 3 lists the IBIs and briefly describes the general metric classes used for each. Because assemblages were different in the Xeric and Mountains climatic regions, EPA developed separate IBIs for each region; i.e., specific metrics under the various metric classes were different for the Xeric and Mountains climatic regions (Appendix 3). The process used to develop the EMAP IBIs and the final metrics included in the IBIs are described in the EMAP West Statistical Summary (Stoddard et al. 2005a).

For macroinvertebrates, an additional measure of biotic health was used to assess condition. The Observed/Expected index (O/E index) is a measure of the number of kinds of macroinvertebrates that are expected at a site based on occurrence in least-disturbed sites of similar ecological settings, but not found at the site. The O/E index used is described in detail in the EMAP West Statistical Summary (Stoddard et al. 2005a).

In addition to EMAP ecological indicators, EMAP data were used to calculate a macroinvertebrate IBI developed by ADEQ, so that ecological condition based on the two macroinvertebrate IBIs could be compared at a state-level. The metrics included and the process of development of the ADEQ IBIs are described in detail in: Gerritsen and Leppo (1998), Leppo and Gerritsen (2000), and Spindler (2005).

Aquatic Indicators of Stress

The importance of human-caused stressors is a second critical component in assessing the ecological condition of streams and rivers for EMAP. Stressors can be chemical, physical, or biological components of the ecosystem that can adversely affect biotic integrity. For example, chemical stressors--those affecting water quality—include but are not limited to acid mine drainage and agricultural runoff containing contaminants such as pesticides and fertilizers. Physical stressors typically result from modification of the physical habitat of a stream or river resulting in excessive sedimentation, loss of riparian vegetation, or other physical changes to the aquatic environment. Non-native or invasive species are an example of a biological stressor in a stream or river or the associated riparian area. The same eleven stressors

Index of Biological Integrity	Metric Class
Aquatic Vertebrate IBI (value range 0-100)	• Habitat – preferred habitat for each vertebrate species (e.g., benthic, water column, vegetation) • Tolerance – each vertebrate species was classified into one of three classes, to represent their general tolerance to physical and chemical stressors (sensitive, intermediate, tolerant, super tolerant) • Trophic groups – primary diet for each vertebrate species (herbivore, invertivore, piscivore, omnivore) • Reproductive – reproductive habit for each vertebrate species • Composition – the relative abundance of different kinds of taxa • Life History – the general life history strategy for each taxon (migrating, long-lived, etc.) • Alien Species – whether each species is native or introduced in the region where it was collected
Macroinvertebrate IBI (value range 0-100)	• Composition - the relative abundance of different kinds of taxa • Diversity - evenness of the distribution of individuals across taxa • Feeding groups - primary method by which each taxa feed (e.g., scrapers, shredders, collectors, etc.) • Habit – predominant behavior (e.g., cling to substrates, burrow into substrates, etc.) • Richness - the number of different kinds of taxa • Tolerance - each taxa was classified into one of three classes, to represent their general tolerance to physical and chemical stressors (sensitive, intermediate, tolerant, super tolerant)
Macroinvertebrate O/E (value range 0 – 1+)	• Number of macroinvertebrate taxa observed (O) at a site divided by number of taxa expected (E) to occur at least-disturbed sites in similar ecological settings
ADEQ Macroinvertebrate IBI (value range 0-100)	• Taxonomic richness - number of taxa of specific groups • Taxonomic composition - percent individuals in taxa • Feeding groups – e.g., scrapers present • Pollution tolerance

Table 3. Aquatic indexes of biological integrity and metric classes. The macroinvertebrate O/E index is the ratio of Observed/Expected taxa. Metrics are given in Appendix 3.

examined by EPA in the Western stream assessment (Stoddard et al. 2005b) were examined in the Arizona stream assessment, and are described briefly in Table 4. This is but a short list of potential stressors, and is not intended to be all-inclusive.

Sample Collection Methods

Methods given below are described in more detail in Environmental Protection Agency (1998 and 2000) field manuals, and in subsequent revisions for the EMAP Western Pilot Study (Peck et al. 2005a; Peck et al. 2005b).

Initial Site Verification and Reach Determination

In the field, a global-positioning-system device was used to confirm the latitude and longitude of each site location. Sites were evaluated to determine if the stream met the EMAP criteria of a sampleable stream (flowing and accessible). For wadeable sites, a stream reach 40 times the average stream channel width was sampled, with the minimum reach length equaling 150 meters. For non-wadeable sites (sampled with a raft-mounted electroshocker) a stream reach 100 times the average stream channel width was measured. For both types of sites, eleven transects were established along the stream reach, dividing the reach into 10 sub-reaches of equal length.

Water Chemistry

At each site, a 4-liter Cubitainer® and two 60-milliliter syringes of water were collected at a point near the center of the stream reach. At the same location, the crew collected insitu or streamside measurements of dissolved oxygen and water temperature. Water samples were mailed to an analytical laboratory specified by the EPA and analyzed for major ions, nutrients, selenium, zinc, dissolved organic and inorganic carbon, conductivity, turbidity, total suspended solids, pH, and acid-neutralizing capacity.

Physical Habitat

Habitat measurements at each site included six components: (1) a thalweg profile, (2) woody debris tally, (3) channel dimensions, (4) riparian vegetation characterization, (5) assessment of channel constraint and major hydrological events, and (6) a stream-discharge measurement.

- A thalweg profile comprised measuring the maximum channel depth, classifying habitat and pool-forming features, and checking for the presence of backwaters, side channels and deposits of fine sediment at 10 - 15 equally-spaced intervals between each of 11 channel transects (100 - 150 measurements along entire reach).

- Large woody debris was counted in each sub-reach and classified into groups based on length, width, and location within or above the bankfull channel.

- Channel dimensions and riparian vegetation were measured and classified at each of the 11 transects. Channel dimensions were characterized by measurements of bank height, bank undercut, and bank angle. Channel gradient was defined by measurements of channel slope and compass bearing. At each of the 11 channel transects, the wetted stream width was measured and visual estimates were made at five points along the cross section to determine substrate size, type, and embeddedness. The area of fish cover provided by aquatic plants and physical structures was visually estimated.

- Riparian vegetation canopy cover density was measured with a densiometer at each bank and in the center of the stream, and riparian vegetation was classified by type and density structure. In addition, the proximity of anthropogenic disturbances and the presence of non-native and exotic plants were noted.

Aquatic Stressor	Stressor Type	Description
Total phosphorus (value range 0 to >0)	Chemical	Plant nutrient, common ingredient in fertilizers, contributes to excessive algae growth.
Total nitrogen (value range 0 to >0)	Chemical	Plant nutrient found in fertilizers, human and animal waste, urban runoff, and atmospheric deposition, contributes to excessive algae growth.
Salinity (value range 0 to >0)	Chemical	A measure of the dissolved minerals in water, can be reported as the ability of water to conduct electricity referred to as conductivity. Excessive salinity is common in areas of high evaporative water loss, exacerbated by reuse of water for irrigation or other uses.
Mercury in fish tissue (value range 0 to >0)	Chemical	Mercury in the environment can be converted by bacteria to methylmercury, which accumulates in algae, invertebrates, and vertebrates. Sources of mercury include mining, coal combustion, incineration of wastes, herbicides, fungicides, and pulp, paper, and textile effluents.
Streambed stability (value range <0 to >0)	Physical habitat	Measured as Relative Bed Stability (RBS), a ratio comparing particle size of observed sediments, to size of sediment each stream can move or scour during flood stage based on the size, slope, and other physical characteristics of the stream channel. Highly negative values indicate excessive sediment, and large positive values indicate armoring, both of which may negatively affect aquatic animals.
Habitat complexity (value range 0 – 7.0)	Physical habitat	Diverse aquatic communities found in complex habitat that includes large wood, boulders, undercut banks, overhanging vegetation, and tree roots. This measure sums the proportional area of in-stream habitat features, and overhanging cover that is within 1 meter of the water surface. Values close to zero indicate low levels of habitat complexity, which may be stressful to aquatic animals.
Riparian vegetation cover (value range 0 – 3.0)	Physical habitat	A complex, multilayered vegetation corridor along streams and rivers indicates capacity of stream or river to buffer against sources of stress in the watershed. This measure sums the proportional area of woody cover provided by ground vegetation, woody shrubs, and canopy trees. Values close to zero indicate low levels of riparian vegetation cover, which may be stressful to aquatic animals.
Riparian disturbance (value range 0 – 16.5)	Physical habitat	A measure of the proximity of 11 specific forms of human activity (roads, buildings, landfills, mining, etc.) along a stream or river reach weighted according to how close to the stream channel they are observed. Values close to the maximum indicate high levels of riparian disturbance, which may be stressful to aquatic animals.
Non-native vertebrate species (value range 0 - 100)	Biological	Non-native fish and amphibians can prey on, compete with and exclude natives. Measured as the percent of individuals that are non-native.
Non-native crayfish (value range 0 or 1)	Biological	Presence (value = 1) or absence (value = 0) of non-native crayfish species.
Asian clam (value range 0 or 1)	Biological	Presence (value = 1) or absence (value = 0) of non-native Asian clam.

Table 4. Indicators of anthropogenic stress to stream ecosystems examined.

- Features causing channel constraint were identified, and the percentage of constrained channel margin for the entire reach and the ratio of bankfull to valley width were estimated. Evidence of recent major floods, debris torrent scour, or significant deposition was recorded.

- Stream discharge was measured using an electronic flowmeter. Other methods were used to measure discharge (timed filling or neutral buoyant object procedure) if stream conditions were not conducive to flowmeter operation (i.e., flow too slow or shallow).

Aquatic Vertebrates

At wadeable sites, aquatic vertebrates (fish and amphibians) were collected using a backpack electrofisher, making a single pass through the entire reach; crayfish were also collected because they were vulnerable to electroshocking. The fishing effort (45 to 180 total shocking minutes) was allocated equally among all the sub-reaches. At non-wadeable sites, aquatic vertebrates were collected using an electrofishing raft, making a single pass throughout the entire reach along one bank. For both types of stream, vertebrates captured were processed at the end of each sub-reach: species were identified, counted, and checked for the presence of any external anomalies. Several voucher specimens of each species were collected and preserved in 10% buffered formalin or if they were a threatened or endangered species, photographed and returned to the stream. Voucher specimens were mailed to the Smithsonian Institute Natural History Museum to verify identifications.

Fish Tissue Contaminants

Whole fish were used for contaminant analysis. Two classes of fish tissue samples were collected. The small-fish tissue sample was comprised of small fish species, less than 100 millimeters in total length, with a combined weight of 400 grams (≈100 fish). The large-fish tissue sample consisted of three whole individuals of different species each greater than 120 millimeters in total length. The species selected for sampling were prioritized as follows: bass, trout, catfish, and suckers. This species hierarchy was used because piscivores have more potential for the bioaccumulation of contaminants than do herbivores or detritivores. Specimens were mailed to an EPA-specified analytical laboratory where they were analyzed for heavy metal and organic contaminants.

Benthic Macroinvertebrates

Benthic macroinvertebrates were collected using a modified D-frame kick net (mesh size: 500 µm; net width 30 cm). Samples were collected at a randomly selected location along each of the 11 transects and combined into a single composite sample. The sampling effort consisted of placing the D-frame kick net on the streambed with the mouth facing into the path of flowing water and delineating a 30x30 cm square area in front of the net, where the substrate was scrubbed or disturbed for approximately 30 seconds. For pool habitat and areas of dense vegetation, macroinvertebrates were netted by actively sweeping the net through a 30x30 cm area for 30 seconds. The habitat and substrate type were recorded for each sample location. Samples were mailed to an analytical laboratory specified by the EPA.

Periphyton

Periphyton samples, collected at each of the 11 transects near the location of the benthic macroinvertebrates samples were combined into a single sample. For habitats with mostly large substrates, a sample of substrate (rock or wood) was removed from the stream. A 12-cm2 area of the rock or wood surface was delineated and brushed for 30 seconds. The area brushed was thoroughly rinsed and the water added to the combined sample. For fine-sediment habitats, a 12-cm2 area of soft sediment was delineated, and the top 1 cm of sediment was vacuumed into a syringe and added to the combined sample for the site. The single combined "index" sample was divided in the field into an

identification/enumeration sample, a chlorophyll sample, and a biomass sample. These samples were mailed to the analytical laboratory specified by the EPA. Laboratory identification of periphyton taxa was not complete, hence periphyton data were not available for the Arizona assessment but will appear in a future EPA periphyton report.

Assessment Methods

The ecological indicators (aquatic vertebrate IBI, macroinvertebrate IBI, and macroinvertebrate O/E index) reported in the EMAP-West statistical summary (Stoddard et al. 2005a) were used to assess the ecological condition of Arizona's streams. In addition, we examined 11 biological, chemical, and physical habitat stressors that potentially have negative effects on ecological condition. We examined the extent of each stressor and assessed which likely had the greatest affect on the ecological indicators. A macroinvertebrate IBI developed independently by ADEQ was computed using EMAP data so that results could be compared to the EMAP macroinvertebrate IBI. Indicator data are presented in Appendix 4. Readers can access raw data by contacting the EPA Office of Research and Development in Corvallis, Oregon.

The EPA used data from least-disturbed reference sites to set thresholds of condition classes for each of the indicators (IBIs, O/E index, and stressors). Reference sites included in the Western assessment (and hence in the Arizona assessment) included: (1) hand-picked sites from state and other monitoring programs and sampled with EMAP protocols and (2) probability sites that passed numerous physical and chemical criteria (Stoddard et al. 2005a). The EPA classified sites as least-disturbed reference sites for biological indicators based on chemical and physical properties (e.g., nutrients, chloride, turbidity, excess fine sediments, riparian condition, etc.). A similar process was used for stressor indicators: least-disturbed sites were identified according to specific criteria that did not include the specific stressors themselves.

For all sites in each climatic region, IBI scores, O/E scores, and most stressor scores were divided into three condition classes based on thresholds derived from reference-site scores in that climatic region (Appendix 2): most-disturbed, intermediate, and least disturbed. For most indicators, EPA examined the distribution of reference-site indicator scores within each climatic region and used the 5th percentile of this distribution as a threshold to separate the most-disturbed sites from moderately-disturbed sites. Similarly, the 25th percentile of the reference sites was used as a threshold to distinguish moderately-disturbed sites from those in least-disturbed condition. These threshold values were then used to classify all sampled sites within the respective climatic region into the condition classes of most-disturbed, intermediate, and least-disturbed. Because this process was used for each climatic region, the resulting threshold values were different for the Mountains and Xeric climatic regions. Stressor scores were assigned to condition classes in the same fashion except for total phosphorus, total nitrogen, mercury in fish tissue, non-native vertebrates, non-native crayfish, and Asian clam (see Appendix 2).

The initial total perennial stream length in the state was estimated from digitized 1:100,000 scale USGS topographic maps (EPA's River Reach 3 File = RF3). These stream segments were evaluated based on expert consultation or on-site visits, and segments that were non-perennial streams, irrigation canals, wetlands, reservoirs, or non-existent stream channels were removed from the population of estimated total perennial stream length (target population). Then the perennial stream length that was target and could actually be sampled (sampled population) was estimated. A weighting factor, in units of kilometers of stream length, was assigned to each sampled site and was used in statistical analysis (Stoddard et al. 2005b). The weighting factor was an estimate of the length of stream that was represented by each sample site; e.g., a weight of 2.28 means that the sampled

site represents 2.28 kilometers of stream length. The weights were used to determine estimated total stream length sampled statewide and in both climatic regions, and the percentage of stream length in most-disturbed, intermediate, and least-disturbed condition for the biotic indicators and aquatic indicators of stress. To provide more information for water and land managers, the stressors were ranked based on their relative extent (proportion of stream length in most disturbed condition) and the relative risk (severity) of their effects on Arizona streams and rivers.

Relative risk describes how much more likely a stream is to have poor biotic integrity if a stressor is present (or found in high concentrations) than if it is absent (or found in low concentrations; Stoddard et al. 2005b). The relative-risk ratio represents the proportional increase in the likelihood of finding a biological indicator in the most-disturbed class when the stressor's condition in the same stream is also in the most-disturbed class (see Appendix 5 for details of relative-risk calculation). A relative-risk value of one indicates that there is no association between the stressor and the biological indicator. Values greater than one suggest a greater relative risk of finding a biological indicator in the most-disturbed class when the stressor's condition in the same stream is also in the most-disturbed class. For instance, a value of 10 indicates that you are ten times, or 1,000 percent, more likely to find a stream in most-disturbed ecological condition when a stressor is also in most-disturbed condition, than when the stressor is in least-disturbed condition. Risk estimates with the lower-bound of the 95% confidence interval less than one were considered statistically insignificant. It is emphasized that relative risk measures association, and a significant risk does not mean that a stressor causes poor biotic integrity; further research would be needed to assess cause and affect.

As indicated previously, we also wanted to know if assessments using the EMAP macroinvertebrate IBI and the ADEQ macroinvertebrate IBI resulted in similar percents of stream length in most-disturbed, moderately disturbed, and least-disturbed condition. Arizona Department of Environmental Quality's macroinvertebrate IBI is similar to the EMAP macroinvertebrate IBI in that it also divides IBI scores into three condition classes (attaining, inconclusive, and impaired; Spindler 2005). The ADEQ and EMAP condition classes are conceptually similar. The ADEQ condition class "attaining" is similar to the EMAP class "least-disturbed" in the sense that both constitute a stream in relatively good condition with respect to aquatic macroinvertebrate integrity. Conversely, the ADEQ condition class "impaired" and EMAP class "most-disturbed" describe a stream in relatively poor condition with respect to aquatic macroinvertebrate integrity. The ADEQ class "inconclusive" and EMAP class "moderately-disturbed" describe a stream in intermediate or fair condition. Like EMAP, ADEQ's condition classes incorporate reference site data to develop thresholds for the macroinvertebrate IBI scores. To make the ADEQ macroinvertebrate IBIs more comparable to the EMAP IBIs, the 5th and 25th percentiles of the ADEQ IBI reference-site distribution were used to establish thresholds for the "warm water" and "cold water" stream classifications.

Unlike EMAP, ADEQ categorizes streams on the basis of physical setting, rather than ecoregion. Streams below 5,000 feet in elevation are categorized as "warm water," and those above 5,000 feet in elevation are categorized as "cold water" (Spindler 2005). A "cold water" stream designation by ADEQ may have an EMAP Mountains climatic region designation or an EMAP Xeric climatic region designation, and similarly, a "warm water" ADEQ stream does not always have an EMAP Xeric climatic region stream designation. In addition, different metrics are included in the EMAP and ADEQ IBIs (Appendix 3). Nonetheless, we think there is enough similarity in the EMAP and ADEQ IBI process and condition assignment to

make general comparisons of statewide condition of benthic macroinvertebrates between the two methods.

RESULTS

Extent of Resource

Approximately 24,100 km of stream channel were identified as perennial within EPA's RF3 stream coverage for Arizona (Figure 5). More than three quarters (81%) of this estimated stream length was determined to be non-target (non-perennial streams, irrigation canals, wetlands, reservoirs, or map errors = non-existent stream channels). Only 4,640 km (19 %) of Arizona's estimated total stream length was determined to be perennial and therefore potential target sites for EMAP sampling. Of the target stream length, 1,420 km could not be assessed due to lack of access permission, and about 250 km was physically inaccessible due to physical barriers or unsafe conditions. This report assesses the remaining estimated 2,973 km of perennial streams in Arizona, approximately two thirds (2,037 km represented by 33 probability sites) of which were located in the Mountains climatic region, and the remainder (935 km represented by 14 probability sites) were in the Xeric climatic region. For brevity, the assessed perennial stream length is referred to as 'stream length' in the remainder of our report.

Ecological Condition of Arizona's Streams

Assessed condition of the three main ecological indicators (aquatic vertebrate IBI, macroinvertebrate IBI, and the macroinvertebrate O/E) is shown in Figure 6 for all of Arizona and for the two climatic regions in Arizona. In the state-wide portion and each of the two climatic region portions of Figure 6, and in subsequent results for chemical (Figure 8), physical (Figure 9), and biological stressors (Figure 10), condition is ranked from least disturbed on the top of each graph, to most-disturbed on the bottom. The ADEQ macroinvertebrate IBI (Figure 7) is ranked similarly (attaining ≈ least-disturbed, inconclusive ≈ intermediate, impaired ≈ most-disturbed).

Small sample sizes contributed to large confidence intervals for some population estimates. For example, only 14 sites (representing 935 km of perennial stream) were sampled in the Xeric

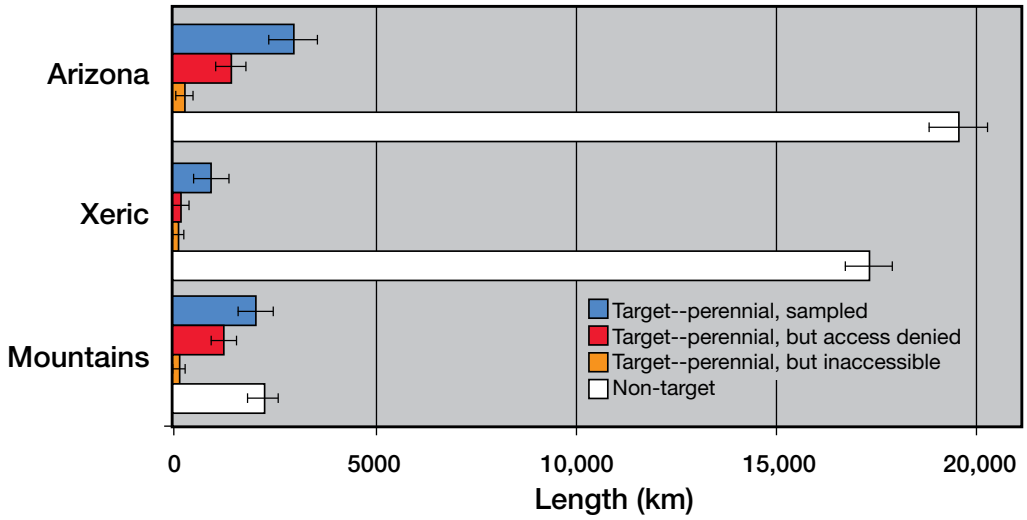

Figure 5. Length estimates (with 95% confidence intervals) for key categories of streams in the Arizona EMAP assessment, including targeted perennial streams (sampled, or not sampled because access was denied or site was inaccessible), and non-target segments (non-perennial streams, irrigation canals, wetlands, reservoirs, or non-existent stream channels).

climatic region. For aquatic vertebrate IBI population estimates, three of the 47 sites were excluded (data for two sites sampled in 2004 were not available, and a third was not fished because the crew judged the stream to be fishless) and another three (shown in Figure 6 as 'No Data') were not fished because permits were not obtained or stream size was too small. As a result, aquatic vertebrate IBI population estimates are based on 10 sites (representing 693 km) in the Xeric region and 31 sites (representing 1,885 km) in the Mountains region. For the macroinvertebrate IBI, data were not available for two sites sampled in 2004, so population estimates are based on 33 sites (1,978 km) in the Mountains region and 12 sites (862 km) in the Xeric region.

Aquatic Vertebrate Biotic Integrity

With regard to aquatic vertebrate biotic integrity, 70% of Arizona's stream length was estimated to be in most-disturbed condition, 14% was in intermediate condition, and 9% was in least-disturbed condition (Figure 6). The remaining 7% were either sampled but no aquatic vertebrates were collected (two sites) or were not sampled because permits were not obtained (one site). Percentages in each condition category for the two climatic regions were similar to those for the State as a whole, with nearly 73% of the stream length in the Xeric region in most-disturbed condition and only 5% in least-disturbed condition. In the Mountains climatic region, 69% of the stream length was in most-disturbed condition, and 10% was in least-disturbed condition.

Macroinvertebrate Biotic Integrity

For macroinvertebrate biotic integrity, 57% of Arizona's stream length was assessed as being in most-disturbed condition, 29% was in intermediate condition, and 14% was in least-disturbed condition (Figure 6). Percentages in each condition category for the two climatic regions were similar to those for Arizona as a whole.

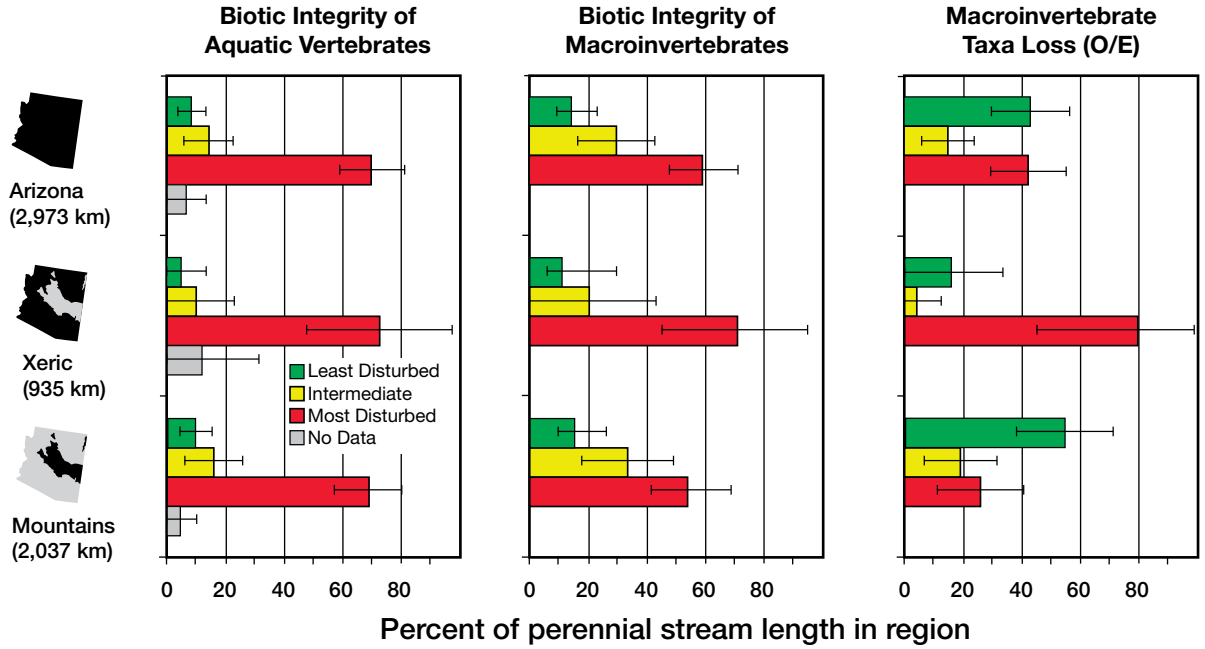

Figure 6. Summary of results for ecological condition indicators for Arizona and for two climatic regions. Bars (with 95% confidence intervals) show the percentage of perennial stream length in each region with index scores in each condition class. Numbers in parentheses are the total perennial stream length in each region. Regional results are stacked in the same order as the state-wide results, with least-disturbed condition on top and most-disturbed on bottom, except when data are not available (sites not assessed because no individuals were captured or no permit was acquired), in which case the no-data category is presented at the bottom.

For the most part, there was agreement in condition assessment between the aquatic vertebrate IBI and the macroinvertebrate IBI. There was complete agreement in condition assessment (least-disturbed, intermediate, or most-disturbed) between the aquatic vertebrate IBI and the macroinvertebrate IBI for 69% of the estimated stream length. There was complete disagreement in condition assessment based on the two IBIs (i.e., assigned a most-disturbed condition based on the macroinvertebrate IBI and a least-disturbed condition based on the aquatic vertebrate IBI, or visa-versa) for 8% of the stream length.

Macroinvertebrate Taxa Loss (Observed/Expected)

The assessment with regard to macroinvertebrate taxa loss (the O/E index) yielded a slightly different picture of stream condition than that derived from the aquatic vertebrate and macroinvertebrate IBIs (Figure 6). Nonetheless, the percentage of stream length in most-disturbed condition (those with 50% or fewer of the expected macroinvertebrate taxa) was still large (42%), with an approximately equal percentage (42%) of stream length in least disturbed condition (had more than 80% of the expected taxa). The Xeric climatic region had three times more stream length in most-disturbed condition than did the Mountains region.

There was moderate agreement in condition assignment between the aquatic vertebrate IBI and the macroinvertebrate O/E index, with complete agreement in site assessment for 44% of the estimated stream length and complete disagreement for 31% of the estimated stream length. There was less agreement in condition assignment between the macroinvertebrate IBI and the macroinvertebrate O/E index, with complete agreement in site assessment for 30% of the estimated stream length and complete disagreement for 22% of the estimated stream length.

ADEQ Macroinvertebrate Biotic Integrity

At the state level, the ADEQ macroinvertebrate IBI (Figure 7) provided a very similar picture of stream condition as that derived from the macroinvertebrate O/E index. Based on ADEQ's macroinvertebrate IBI, 41% of Arizona's stream length was estimated to be impaired (most-disturbed) and nearly 45% was in the attaining (least-disturbed) category. Warm-water and cold-water streams had a similar proportion of stream length in impaired condition (most-disturbed). Warm-water and cold-water categories do not correspond to the EMAP's Mountains and Xeric climatic

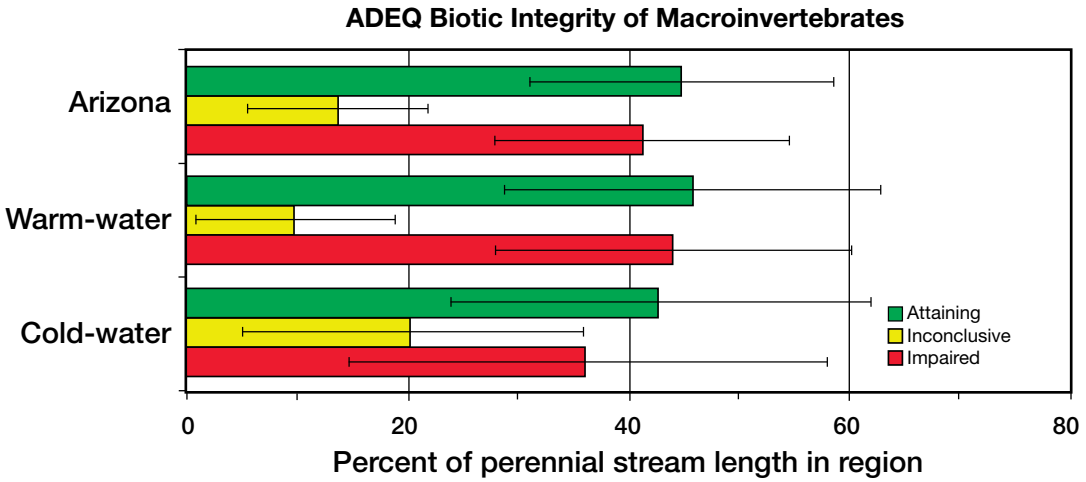

Figure 7. Summary results for Arizona Department of Environmental Quality (ADEQ) ecological condition indicator for Arizona and for cold-water (>5,000 ft elevation) and warm-water (<5,000 ft elevation) streams.

regions, so the ADEQ graphs were not included in Figure 6. Agreement in condition assessment between the ADEQ macroinvertebrate IBI and the EMAP macroinvertebrate IBI was generally low: there was complete agreement for an estimated 30% of the stream length, and complete disagreement for 36% of the stream length. The actual scores for the two IBIs were positively associated: EMAP score = 0.612*ADEQ score + 18.86; r2 = 0.478. Agreement in condition assessment between the ADEQ macroinvertebrate IBI and the O/E index was somewhat better: there was complete agreement for 39% of the stream length and complete disagreement for 38% of the stream length.

Stressor Condition

The summary results for indicators of chemical, physical, and biological stress are shown in Figures 8 through 10. These figures are arranged identically to Figure 6, so that state-wide and climatic region results can be compared across all indicators. As mentioned before, threshold values were different for the Mountains and the Xeric climatic regions for most stressors (Appendix 2).

Chemical Stressors

Phosphorus: Approximately 19% of stream length within Arizona was in most-disturbed condition for phosphorus, and 81% was classified least-disturbed (Figure 8). The Mountains climatic region (24%) and the Xeric climatic region (17%) had similar percentages of stream length in most-disturbed status (confidence intervals overlapped).

Nitrogen: Statewide nitrogen levels were in most-disturbed condition for approximately 19% of the stream length, and roughly 81% of the stream length was in least-disturbed condition (Figure 8). Xeric and Mountains climatic regions had similar percentages of stream length in most-disturbed condition (confidence intervals overlapped).

Salinity: For salinity, roughly 53% of the stream length statewide was assessed to be in the least-disturbed condition, and 16% was in the most-disturbed condition (Figure 8). A similar pattern was evident in the Mountains climatic region. The pattern in the Xeric climatic region was different, in that percentages of each of the condition classes were roughly equal. The percent of least-disturbed

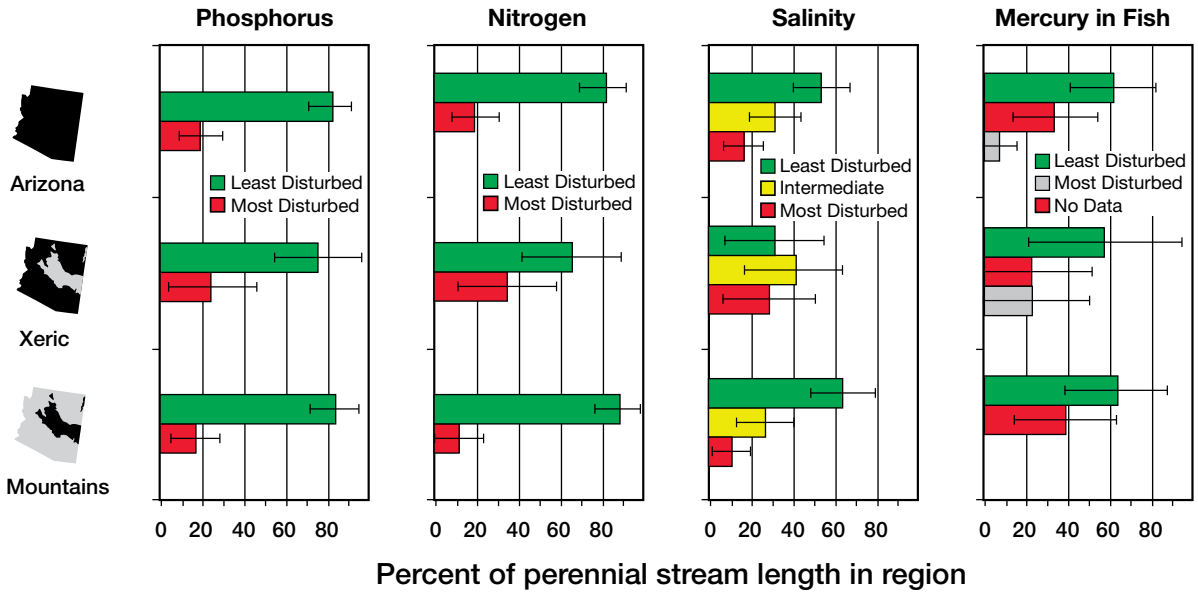

Figure 8. Summary of results for chemical indicators of stress for Arizona and the two climatic regions. Details of figure are as in Figure 6, except total phosphorus, total nitrogen, and mercury in fish tissue have only two categories of condition, least-disturbed and most-disturbed.

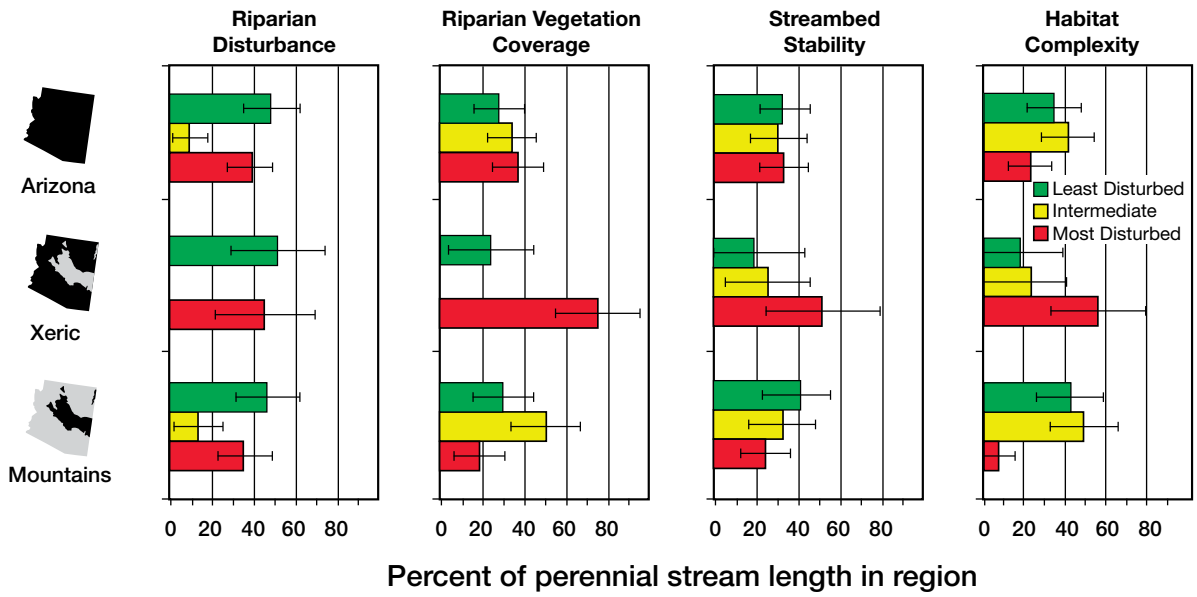

Figure 9. Summary of results for physical habitat indicators for Arizona and the two climatic regions. Details of figure are as in Figure 6.

stream length in the Mountains climatic region (63%) was double that of the Xeric climatic region (31%).

Mercury in Fish Tissue: Statewide, 33% of the stream length was estimated to be in most-disturbed condition (Figure 8) with respect to mercury in fish tissue [i.e., had one or more classes of fish (large piscivores, large non-piscivores or small forage fish) that exceeded the 0.1 micrograms of mercury per gram of fish tissue]. Approximately 60% of the stream length was assessed to be in least-disturbed condition (below the standard) and 7% was not assessed because sites did not contain fish, or insufficient samples were collected. Sample sizes for mercury in fish tissue were low (Appendix 3) because at some sites, samples were not collected because of insufficient numbers of fish, or if samples were collected, they were not yet processed in the laboratory.

Physical Habitat Stressors

Riparian Disturbance: Nearly 40% of Arizona's stream length had high levels of riparian disturbance, while about half had minimal levels of disturbance (Figure 9). A similar pattern was evident in both climatic regions. The percentage of stream length in most-disturbed condition in the Xeric climatic region in Arizona (47%) is less than the 77% reported for the Xeric climatic zone throughout the Western U.S. in the EPA Western stream assessment report (Stoddard et al. 2005b).

Riparian Vegetation Cover: Riparian vegetation cover in more than one third (37%) of Arizona's stream length was in most-disturbed condition, 34% of stream length had intermediate levels of cover, and 28% was in least-disturbed condition (Figure 9). Streams in the Xeric climatic region tended to have less riparian cover than those in the Mountains climatic region. For the Xeric climatic region, 76% of the stream length was in most-disturbed condition with respect to riparian vegetation cover compared to 19% in the Mountains climatic region.

Streambed Stability: Thirty-four percent of Arizona's stream length had excess sediments (most-disturbed), and 34% was in least-disturbed condition (Figure 9). Sedimentation appears to be a greater problem in Xeric streams than Mountain streams. Approximately half (53%) of Xeric

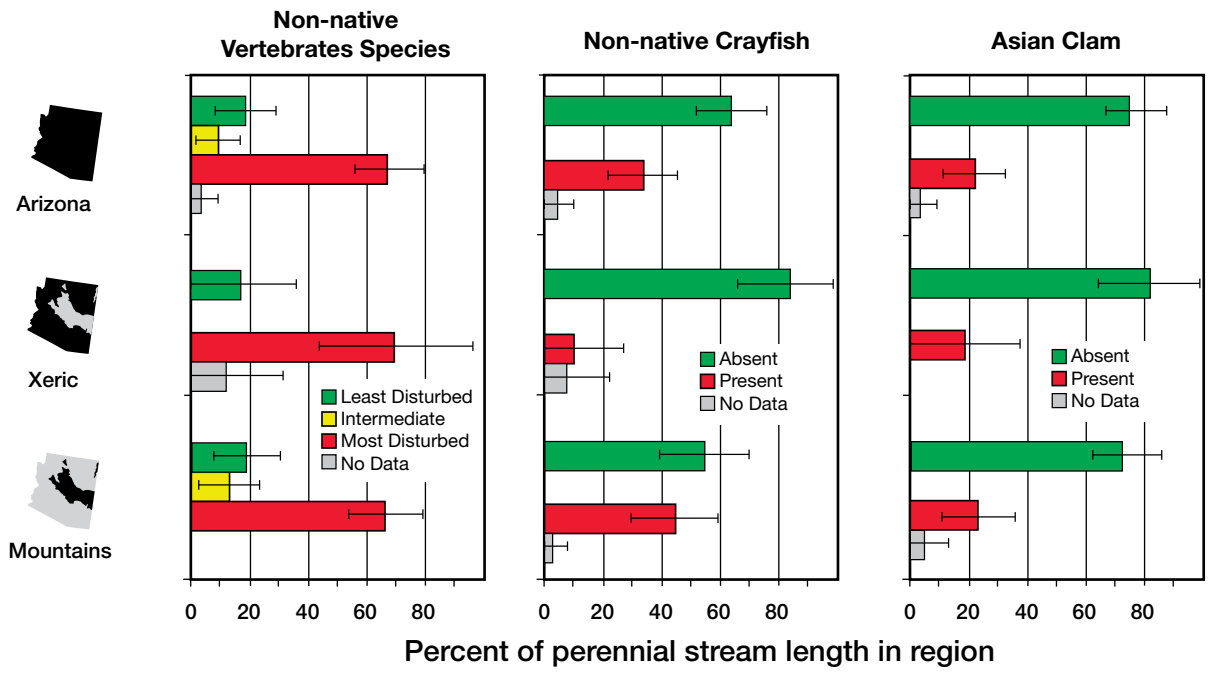

Figure 10. Summary of results for biological stressor indictors for Arizona and the two climatic regions. Details of figure are as in Figure 6.

stream length was in most-disturbed condition, whereas only 26% of Mountain stream length was in most-disturbed condition.

Habitat Complexity: Low levels (most-disturbed condition) of natural fish cover were found in nearly a quarter (23%) of Arizona's stream length (Figure 9), but most stream length was in intermediate condition (42%) or least-disturbed condition (35%). Habitat complexity was more highly disturbed in Xeric streams than in Mountain streams. Most of the Xeric stream length (57%) was highly degraded, whereas only 7% of stream length in the Mountains climatic region was in most-disturbed condition.

Biological Stressors

Non-native Vertebrate Species: Non-native aquatic vertebrate species were widespread and common in Arizona streams, with 68% of the stream length having more than 10% of individuals that were non-native (most-disturbed condition), and non-natives were absent (least-disturbed condition) in only 19% of the stream length (Figure 10). The conditions of streams in the two climatic regions were similar to those statewide: 71% of stream length was in most-disturbed condition in the Xeric climatic region compared to 67% in the Mountains climatic region.

Non-native Crayfish: Crayfish are not native to Arizona (Hobbs 1989), so the presence of crayfish indicates that a site is disturbed. Crayfish were found in 33% of Arizona's stream length (Figure 10). Crayfish were present in more of the stream length in the Mountains climatic region (44%) than in the Xeric climatic region (10%). These a re likely underestimates of crayfish occurrence because neither of the EMAP sample methods (electroshocking for fish or D-frame kick net sampling for macroinvertebrates) is specifically designed to capture crayfish.

Asian Clams: The Asian clam *(Corbicula fluminea)* is also not native to Arizona, so the presence of Asian clams indicate that a site is disturbed. Asian clams were found in 21% of Arizona's stream length, 23% of the stream length

in the Mountains climatic region, and 18% of the stream length in the Xeric climatic region (Figure 10).

Ranking of Stressors

Stressors were ranked to assess their importance, following the process that EPA used in the Western U.S. stream assessment (Stoddard et al. 2005b). Two ranking procedures were used. One involved assessing how common a stressor was relative to other stressors. The more common a stressor, in terms of the length of stream in most-disturbed condition (i.e., its relative extent), the more important it was considered. A second ranking was based on the severity of the stressors (i.e., the association of the relative extent of the stressor with most-disturbed biotic integrity); the greater the association with most-disturbed biotic integrity, the greater the importance. Relative risk, as described below, was used to assess severity.

Relative Extent

Figure 11 shows the percentage of stream length for each stressor that is in most-disturbed condition, for all of Arizona (top) and the Xeric (middle) and Mountains (bottom) climatic regions. In the statewide graph, stressors are ranked from most extensive at the top of the graph to least extensive at the bottom, and the resulting ranked order of stressors is used for the two climatic regions. When examining these graphs, we consider stressors to have statistically different extents if their confidence intervals do not overlap. For example, the statewide extent estimate for mercury in fish tissue was only statistically different from the estimate for non-native vertebrates; the confidence intervals for mercury in fish tissue overlapped with the confidence intervals of all other stressor-extent estimates except non-native vertebrates.

Statewide, non-native aquatic vertebrate species were the predominant stressor, with 68% of the perennial-stream kilometers in most-disturbed condition (Figure 11). Intermediate stressors include riparian disturbance (40%), poor riparian vegetative cover (37%), relative bed stability (34%), crayfish (33%), and mercury contamination of fish tissue (33%). The least common stressors include poor habitat complexity (23%), Asian clam presence (21%), total nitrogen (19%), total phosphorus (19%), and high salinity (16%). Except for mercury in fish tissue, the chemical stressors ranked at the bottom. The physical habitat (riparian vegetation, poor habitat complexity, streambed stability, riparian disturbance), and biological stressors (non-native vertebrates, non-native crayfish and Asian clams) rank without any clear pattern.

Non-native aquatic vertebrate species were the most common stressor in the Mountains climatic region streams (67%) and the second greatest stressor in Xeric climatic region streams (71%). The large confidence intervals make it hard to come to meaningful conclusions regarding ranking of the stressors in the Xeric climatic region. Poor stream condition within the Xeric climatic region appears to be predominately associated with stressors linked to physical habitat. The four stressors of greatest extent other than non-native aquatic vertebrate species are riparian vegetation, poor habitat complexity, streambed stability, and riparian disturbance. Non-native crayfish are the least extensive stressor, but confidence intervals for this stressor overlap with those of total phosphorus, total nitrogen, mercury-in-fish tissue, salinity, Asian clams, riparian disturbance, and streambed stability. Non-native crayfish were the second most extensive stressor in the Mountains climatic region, but confidence intervals overlapped with riparian disturbance, poor riparian vegetation cover, streambed stability, mercury contamination of fish tissue, and Asian clams. The least common stressors in the Mountains climatic region are total phosphorus, total nitrogen, salinity and habitat complexity.

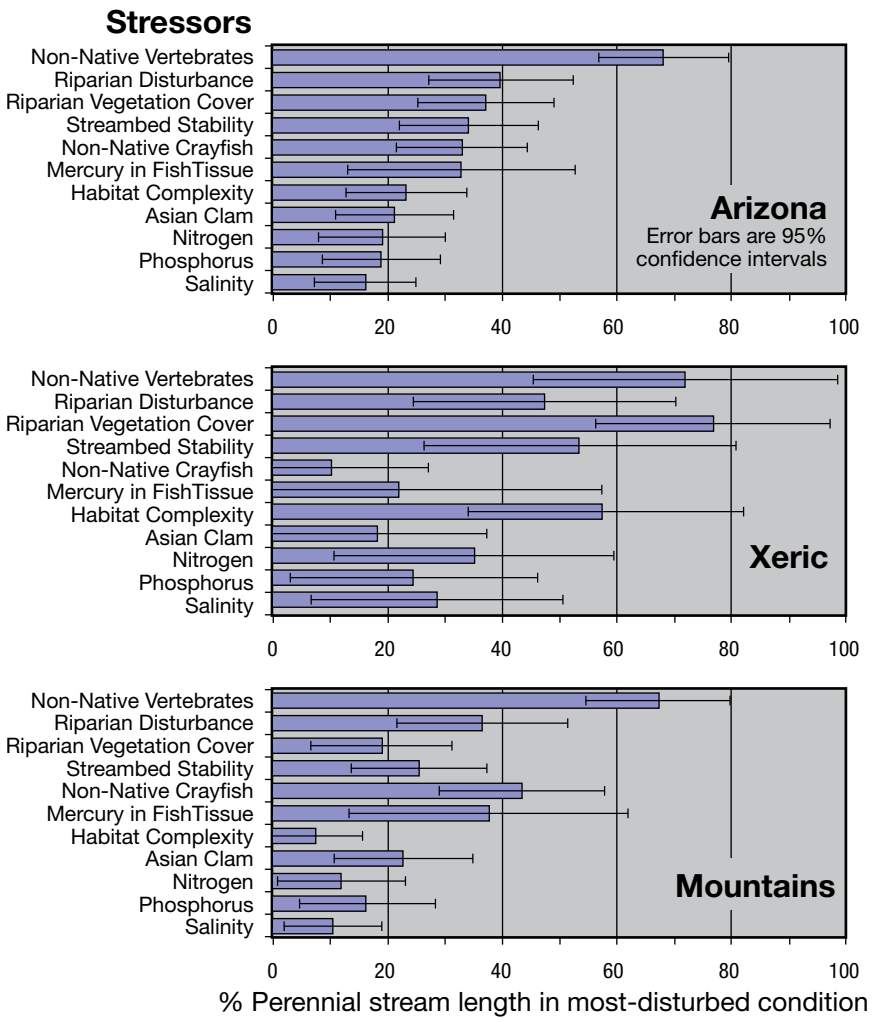

Figure 11. Relative extent of stressors (proportion of stream length with stressor in most disturbed condition) for Arizona, and the two climatic regions. The order of stressors (from highest to lowest percent in most-disturbed condition) is set by the state-wide results and is consistent in each panel.

The physical stressors habitat complexity and poor riparian vegetation coverage ranked much higher in the Xeric climatic region than in the Mountains climatic region. Non-native crayfish ranked higher in the Mountains climatic region compared to the Xeric climatic region.

Relative Risk

Statewide, the aquatic vertebrate IBI had significant risk associated with six of the examined stressors--salinity, total nitrogen, Asian clams, habitat complexity, mercury-in-fish tissue, and non-native crayfish (Figure 12); i.e., had relative risk ratio values greater than 1 with 95% confidence intervals that did not encompass 1—Appendix 1). For example, the aquatic vertebrate assemblage was approximately 1.3 times, or 30%, more likely to be in most-disturbed condition when habitat complexity, salinity, or mercury-in-fish tissue was also in most-disturbed condition compared to when these stressors were in least-disturbed condition. Similarly, the aquatic vertebrate assemblage was 1.2 times, or 20%, more likely to be in most-disturbed condition when crayfish and Asian clams were present than when they were absent, and 1.1 times more likely

to more likely to be in most-disturbed condition when nitrogen levels exceeded the threshold. In the Mountains climatic region, the aquatic vertebrate IBI had significant relative risk associated with the same set of stressors, except for mercury in fish tissue, for which risk estimates were not calculated because sample size was too small (Appendix 3). None of the stressors had statistically significant risk values in the Xeric climatic region streams (not shown in Figure 12), possibly due to the large confidence intervals, which are a result of small sample size and high variability. As with the Mountains climatic region, risk estimates associated with mercury in fish tissue were not calculated for the Xeric climatic region because sample size was too small.

Statewide, the only stressor with statistically significant risk associated with the macroinvertebrate IBI was non-native crayfish; the macroinvertebrate IBI was 1.5 times, or 50%, more likely to be in most-disturbed condition when crayfish were present than when they were absent (Figure 12). In the Mountains climatic region, the macroinvertebrate IBI had significant risk associated with poor riparian vegetation cover (relative risk = 2.9), non-native crayfish (2.1), streambed stability (1.8), poor habitat complexity (1.6), and total nitrogen (1.1). In the Xeric climatic region, the macroinvertebrate IBI did not have significant risk associated with any of the examined stressors.

The macroinvertebrate taxa loss index (O/E index) had significant risk associated with three of the examined stressors at the statewide level, poor riparian vegetation cover (relative risk = 2.7), Asian clams (1.9), and total nitrogen (1.03). None of the stressors had significant risk associated with macroinvertebrate taxa loss in the Mountains climatic region. In the Xeric climatic region (not shown in

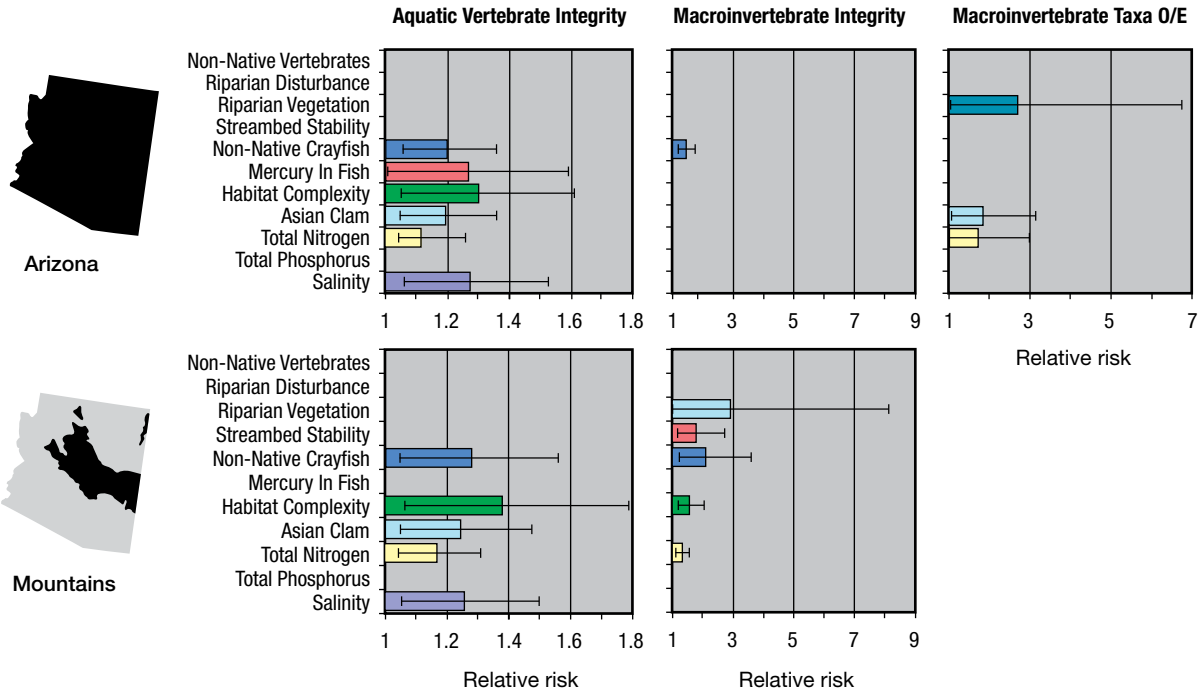

Figure 12. Relative risk of stressors to aquatic vertebrate and macroinvertebrate integrity and macroinvertebrate taxa loss in Arizona and in the Mountains climatic region. Relative risk ratios with 95% confidence intervals (error bars) that encompass 1 are not considered significant and are not shown. The Xeric climatic region is not shown because none of the risk values for aquatic vertebrate or macroinvertebrate integrity were significant. Likewise, the Mountains climatic region for the macroinvertebrate taxa loss is not shown because none of the relative risk values were statistically significant. Note that x-axis scales are different for the three biotic indicators.

Figure 12), macroinvertebrate taxa loss has significant risk from Asian clams (relative risk = 3.4 with 95% confidence interval from 1.3 to 8.6).

CONCLUSIONS

Most of Arizona's streams were assessed to be in most-disturbed ecological condition based on the EMAP's aquatic vertebrate biotic index (70%) and macroinvertebrate index (57%). A lesser, but still sizeable proportion (41-42%), was assessed to be in most-disturbed condition based on macroinvertebrate taxa loss and the ADEQ macroinvertebrate IBI. In any case, a large percentage of Arizona's stream length was assessed to be in most-disturbed condition. These results need to be tempered by the fact that relatively few sites were sampled, particularly in the Xeric climatic region, and they were sampled over a 5 year period of persistent drought. The small sample size and natural variability contributed to large confidence intervals on many of our estimates.

Streams in the two climactic regions tended to have similar ecological condition based on most indicators, but macroinvertebrate taxa loss was substantially greater in the Xeric region (79% most-disturbed) than in the Mountains region (26% most-disturbed). In addition, the percentage of stream length in most-disturbed condition with respect to the habitat stressors of low riparian vegetation coverage and low habitat complexity was greater in the Xeric climatic region than in the Mountains climatic region. However, the percentage of stream length in most-disturbed condition with regard to non-native crayfish was greater in the Mountains climatic region than in the Xeric climatic region.

Ranking the importance of the examined stressors was difficult because the confidence intervals were large and overlapped for both the extent estimates and the relative risk ratios. Stressors most likely to be responsible for poor biotic condition, and thus targets of further study and potential management action, are those that are extensive and pose high risk (Stoddard et al. 2005b). In addition, stressors that are associated with both aquatic vertebrate and macroinvertebrate assemblages may be good targets for management action because alleviating their effects would likely benefit both assemblages.

The aquatic vertebrate assemblage had significant risk associated with six of the eleven stressors examined; high concentrations of salinity, total nitrogen, and mercury in fish tissue, low habitat complexity, and presence of Asian clams and non-native crayfish. Except for mercury contamination of fish, for which there was insufficient data, the same stressors had significant risk associated with the aquatic vertebrate assemblage in the Mountains climatic region. The same six stressors were also found to pose risks (all had relative risk > 2.0) to aquatic vertebrate assemblages in the western U.S. (Stoddard et al. 2005b). However, of these six stressors, non-native crayfish and mercury contamination of fish tissue were the most extensive in Arizona. The extent estimate (33% of stream length) for non-native crayfish is likely an underestimate, because the EMAP sampling techniques were not specifically designed to sample crayfish. Crayfish were the only stressor with significant risk (relative risk = 1.5) associated with macroinvertebrate integrity at the statewide level in Arizona and had significant risk within the Mountain climatic region, although macroinvertebrate integrity within the Mountains climatic region also had risk associated with four other stressors. Non-native crayfish also posed a significant threat to both assemblages throughout the western U.S. (Stoddard et al. 2005b). Further, Arizona is the only state in the conterminous U.S. where crayfish are not native (Hobbs 1989), and nonindigenous crayfish are known to harm ecosystems and fisheries (Lodge et al. 2000), so the indication that they pose threats to macroinvertebrate and aquatic vertebrate assemblages in Arizona is not unreasonable. Hence, non-native crayfish may be the

best target for management action to improve the ecological condition of Arizona streams.

Our results indicate that Asian clams may be another good focus for future study and potential management actions to benefit aquatic vertebrate and macroinvertebrate assemblages in Arizona streams. Asian clams had relative extents of 21% statewide and 23% within the Mountains climatic region. In addition, the aquatic vertebrate IBI statewide and in the Mountains climatic region, and the macroinvertebrate O/E index statewide and in the Xeric climatic region had significant risk associated with the presence of Asian clams. Asian clams are reported to foul water intake structures (Pimentel et al. 2000) and are associated with system-level ecological changes (Phelps 1994).

Other stressors with significant relative risk ratios ranked lower in importance overall, or were associated with just one assemblage, rather both the aquatic vertebrate and macroinvertebrate assemblages. For instance, the statewide macroinvertebrate O/E index had the highest risk associated with low riparian vegetation cover, and this stressor also had the greatest relative extent (37%) of any of the stressors with significant relative risk. In addition, the macroinvertebrate IBI in the Mountains climatic had significant risk (2.9) associated with low riparian vegetation cover, although the extent of this stressor was less than 20% in the Mountains climatic region. It is not surprising that poor riparian vegetation coverage was a common stressor in Arizona streams, because it is estimated that less than 10% of Arizona's riparian acreage remains in its natural form (Krzysik 1990), and riparian vegetation is linked to the aquatic macroinvertebrate assemblage in multiple ways (Gregory et al. 1991; e.g., riparian vegetation contributes organic matter to streams, provides shade and thus decreases water temperature, and shelters a variety of terrestrial invertebrates which become prey to aquatic macroinvertebrates when they fall in the water). Efforts to improve riparian cover may benefit the macroinvertebrate assemblage.

Low habitat complexity was fairly extensive statewide (23%) and was associated with risk to the aquatic vertebrate assemblage. Restoration efforts that improve habitat complexity in Arizona will likely benefit the aquatic vertebrate assemblage, as they have been reported to benefit fish elsewhere (Burgess and Bider 1980; Roni et al. 2002). The aquatic vertebrate IBI and the macroinvertebrate IBI in the Mountains climatic region also had risk associated with low habitat complexity, but the relative extent of habitat complexity was low in the Mountains climatic region.

The aquatic vertebrate assemblage statewide had risk associated with high concentrations of mercury in fish tissue, and this stressor was fairly extensive (33%) statewide. However, mercury in fish tissue was not associated with risk to macroinvertebrates. These results are not surprising because mercury bioaccumulates, and so is found in higher concentrations in organisms in higher trophic levels. High concentrations of mercury can affect growth and reproduction of fishes (Snarski and Olsen 1982; Niimi and Kissoon 1994; Weiner and Spry 1996). Therefore, management efforts that minimize mercury in streams may benefit the fish assemblage (or terrestrial vertebrates that eat fish). However, small sample size likely affected significance of risk estimates (Appendix 3), and small sample size precluded calculation of risk estimates associated with aquatic vertebrates for the climatic regions.

Total nitrogen in high concentrations was not that extensive statewide (19%) or in the Mountains climatic region (12%) compared to other examined stressors, but the three ecological condition indicators (aquatic vertebrate IBI statewide and in the Mountains climatic regions, the macroinvertebrate IBI in the Mountains climatic region, and the macroinvertebrate taxa O/E index statewide) had

risk associated with high concentrations of total nitrogen. Arizona streams tend to be nitrogen, not phosphorus, limited (Grimm and Fisher 1986), so increased nitrogen levels will likely affect primary productivity and hence upper trophic levels. Mountains climatic region streams may have nitrogen levels associated with risk because some logging occurs, which tends to increase nutrient levels (Chamberlin et al. 1991), and nutrients tend to be in higher concentrations near stream headwaters than downstream (Grimm and Fisher 1986; Grimm et al. 1981) in the Xeric climatic region. Grazing is also known to increase nutrient levels (Scrimgeour and Kendall 2002), but it is unknown to what extent livestock grazing occurs in the two regions even though rangeland is more common in Xeric climatic region than in the Mountains climatic regions. Land use practices that minimize nitrogen transport into streams may benefit the aquatic vertebrate and macroinvertebrate communities.

Non-native aquatic vertebrates had the greatest extent of any stressor examined. This result is not surprising as non-native fish are widespread in the Southwest (Schade and Bonar 2005) and have been implicated in the decline of native fish in the region (Miller 1961; Minckley and Deacon 1991). Surprisingly, the aquatic vertebrate IBI did not have significant risk associated with non-native aquatic vertebrates in Arizona, which was the same result reported West-wide (Stoddard et al. 2005b). Although it is possible that non-native vertebrates are not associated with the condition of the aquatic vertebrate assemblage, it seems more likely, given the published evidence to the contrary (Moyle 1986; Miller 1961; Minckley and Deacon 1991), that another measure of non-native vertebrates, such as species richness, might have been a better indicator of non-native vertebrate stress. Alternatively, a different threshold level (i.e., >50% of individuals) would have resulted in a lower relative extent, and possibly a significant risk.

The condition assessment based on ADEQ's macroinvertebrate IBI differed from that based on the EMAP macroinvertebrate IBI. The difference may have largely been a result of the different individual metrics used in the EMAP and ADEQ macroinvertebrate IBIs (Appendix 3). Another likely reason for the difference is that EPA developed IBIs for each of three climatic regions for the EMAP Western assessment (Stoddard et al. 2005b), whereas ADEQ developed IBIs for each of two elevation classes (warm water sites were those less than 5000 ft, and cold water sites were those greater than 5000 ft elevation; Spindler 2005). The EPA's climatic regions were aggregations of Omernik (1987) Level III ecoregions, and the mapped location of each site determined its climatic region. As a result, streams in the Mountains climatic region could have been either cold water or warm water, and the same is true for the Xeric climatic region. The lack of correspondence may partly explain the differences in condition assessment between the ADEQ and EMAP macroinvertebrate IBIs. Greater agreement in condition assessment between the two IBIs may have been achieved if EPA had verified climatic region of each site based on an on-site evaluation of the vegetation community. This would have resulted in a reclassification of some sites from the Mountains to the Xeric climatic region, and thus would have affected overall thresholds and overall percentages of each condition category for the macroinvertebrate IBI. Such a reclassification may also have affected percentages of condition classes of all the stressors and the aquatic vertebrate IBI.

It will be beneficial to repeat this study in the future to see if the ecological condition of Arizona's streams improves or declines with increasing human population; the data from this study provide a good baseline for comparison. However, some modifications to the study are suggested. Ecological assessments at the state level in the future should sample a larger number of stream sites and a larger number of reference sites in order to

improve the accuracy of results. In addition, given that 81% of identified target stream length in the current study turned out to be non-target, a more accurate sample frame (map) of perennial streams should be created. A more accurate perennial stream map would decrease overall travel time because less time would be spent traveling to a site, only to find it dry or non-perennial and then having to travel to another site that is perennial. Also, climatic region or ecoregion designation of a site should be verified in the field to improve accuracy of designations and hence decrease the variability of IBIs and stressors within a region. Finally, our assessment only considered a few potential stressors, and there are many others that likely affect ecological condition (e.g., de-watering of streams, turbidity, bacterial or chemical contamination) and could also be examined.

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GLOSSARY

Accuracy The closeness of a measured or computed value to its true value.

Acidity A measure of the number of free hydrogen ions (H+) in a solution that can chemically react with other substances.

Algae Simple rootless plants that grow in bodies of water at rates in relative proportion to the amount of nutrients (i.e., nitrogen and phosphorus) available in the water.

Alkalinity Measure of the negative ions that are available to react and neutralize free hydrogen ions. Some of most common ions include hydroxide (OH^-), sulfate ($SO42^-$), phosphate ($PO4^-$), bicarbonate ($HCO3^-$) and carbonate ($CO3^-$).

Aquatic community An association of interacting populations of aquatic organisms in a given waterbody or habitat.

Armoring The development of a surface layer that is coarser than the bed material beneath it, extremely stable substrates that are not easily moved.

Assemblage A phylogenetic subset of a biological community (e.g., fish assemblage, macroinvertebrate assemblage).

Assessment Interpretation and evaluation of scientific results for the purpose of answering policy-relevant questions about ecological resources, including (1) determination of the fraction of the population that meets a socially defined value and (2) association among indicators of ecological condition and stressors.

Benthic Pertaining to the bottom (bed) of a water body.

Benthos Plants and animals that live in or on the bottom of an aquatic environment such as a stream.

Biological assessment An evaluation of the biological condition of a waterbody that uses biological surveys and other direct measurements of resident biota in surface waters.

Biological criteria (Biocriteria) Numeric values or narrative expressions that describe the reference biological integrity of aquatic assemblages within a water body that has been assigned a designated aquatic life use.

Biological integrity Characteristic of an aquatic system described as "A balanced, integrated, adaptive community of organisms having species composition, diversity, and functional organization comparable to that of natural habitat of the region" (Karr and Dudley, 1981)

Biological monitoring The use of a biological entity as a detector and its response as a measure to determine environmental conditions.

Carnivore An animal whose diet mainly consists of other animals.

Cobble Substrate particles 64-256 mm in diameter (also referred to as rubble).

Channel The section of the stream that contains the main flow.

Clinger Macroinvertebrate that habitually attaches itself to the bottom substrate.

Community The assemblage of populations of plants and animals that interact with each other and their environment. The community is shaped by populations and their geographic range, the types of areas they inhabit, species diversity, species interactions, and the flow of energy and nutrients through the community.

Conductivity A measure of the capacity of water to conduct electricity. Conductivity provides an indication of the concentration of dissolved minerals in the water.

Confidence interval An interval defined by two values, called confidence limits, calculated from sample data with a procedure which ensures that the unknown true value of the quantity of interest falls between such calculated values in a specified percentage of samples.

Designated uses Types of water uses specified in water quality standards for each waterbody or segment, whether or not they are being attained. For example, salmonid spawning, primary contact recreation, shellfish harvest.

Detritivore Animals whose diet mainly consists of detritus.

Detritus Fragments of organisms, primarily dead plant matter.

Dissolved oxygen Oxygen dissolved in water and available for organisms to use for respiration.

Ecological indicator Objective, well-defined, and quantifiable surrogates for environmental values.

Ecoregion A relatively homogeneous area defined by similarity of vegetation, landform, soil, geology, hydrology, and land use. Ecoregions help define designated use classifications of specific waterbodies.

Effluent-dependent stream A stream whose flow originates from waste-water facilities or agricultural runoff.

EMAP Environmental Monitoring and Assessment Program- a U.S. Environmental Protection Agency Office of Research and Development research program.

Embeddedness The degree to which boulders, rubble, or gravel in the stream bed are surrounded by fine sediment.

Ephemeral stream A stream with its channel above the water table and which only carries water during or immediately after precipitation.

Eutrophication The natural and artificial addition of nutrients to a waterbody, which may lead to depleted oxygen concentrations. Eutrophication is a natural process that can be accelerated and intensified by human activities.

Glide Slow, relatively shallow stream section with little or no surface turbulence.

Geomorphic channel types Various categories of stream channels based on similarities in channel pattern, bed material mobility, sediment transport mechanisms, position in the stream network and various combinations of slope and valley characteristics.

Gravel Substrate particles between 2 and 64 mm in diameter.

Habitat The place where a population or community (i.e., microorganisms, plants, animals) lives and its surroundings, both living and non-living.

Headwaters The origins of a stream.

Herbivore Animals whose diet consists mainly of plants.

Impairment A detrimental effect on the biological integrity of a waterbody caused by an impact- that prevents attainment of the designated use.

Impoundment A body of water contained by a barrier, such as a dam.

Index A summary of indicator scores.

Intermittent stream A stream that flows only during certain times of the year when receiving water from springs or runoff. During dry years flow may cease entirely or be reduced to a series of separate pools.

Invertebrates Animals that lack a spinal column or backbone, including mollusks (i.e., clams and oysters), insects, and worms, etc.

Land uses Activities that take place on the land, such as construction, farming, or tree clearing.

Lithophilic Aquatic animals that are associated with or spawn on stony substrates.

Metric A descriptive measure; as used in this document, a biological unit of measurement (e.g., number of taxa, number of fish species intolerant of pollution).

Macroinvertebrate Animals that lack a backbone and can be seen with the naked eye.

Non-native species A species that is not native to a particular location.

Nonpoint source pollution Pollution from sources that cannot be defined as discrete points, such as runoff from areas of timber harvest, agriculture and grazing.

Nutrients Essential chemicals (e.g., nitrogen and phosphorus) needed by plants for growth. Excessive amounts of nutrients can lead to degradation of water quality (eutrophication) by promoting excessive growth, accumulation, and subsequent decay of plants, especially algae.

Order A taxonomic unit in the scientific classification for plants and animals. An order is the unit between family and class.

Periphyton Micro-algae that grow on substrate.

Phosphorous A nutrient that is essential for plants and animals.

pH A numerical measure of the concentration of the constituents that determine water acidity (concentration of H+ to HO-). Measured on a scale of 1.0 (acidic) to 14.0 (basic); 7.0 is neutral.

Piscivore Animals whose diet mainly consists of fish.

Point-source pollution Pollution from a single point such as a pipe.

Pool Portion of a stream with low to no current velocity, often with deeper water than surrounding areas, and a smooth surface.

Population Ecological: an aggregate of interbreeding individuals of a biological species within a specified location. Statistical: the total universe addressed in a sampling effort.

Precision The closeness of repeated measurements of the same quantity.

Rheophilic Aquatic animals that prefer or depend on flowing water conditions.

Riffle An area of the stream with relatively fast currents, rough water surface, and cobble/gravel substrate.

Riparian area or zone The area of vegetation located on the bank of a natural watercourse, such as a stream, where the flows of energy, matter, and species are most closely related to water dynamics.

Scraper Macroinvertebrate that scrapes food off of the bottom substrate.

Sediment Fragments of rock, soil, and organic material transported and deposited in streams by water, wind or other natural phenomena. Can refer to any size of particles but is often used to indicate only particles smaller than 6mm.

Sensitive Species that lack the ability to live in polluted waters.

Shredder Macroinvertebrate that shreds and eats debris.

Species A group of individuals similar in certain morphological and physiological characteristics that are capable of interbreeding and are reproductively isolated from all other such groups.

Stream order A ranking of streams from headwaters to river terminus, that designates the relative position of a stream or stream segment in a drainage basin.

Stream reach Section of stream between two specific points.

Stressor Any physical, chemical, or biological entity that can cause or induce an adverse response by an organism.

Substrate The composition of the stream or river bottom ranging from rocks to mud.

Taxon (plural taxa) A level of classification within a scientific system that categorizes living organisms into similar groups based on their characteristics.

Tolerance The ability to withstand a particular condition, e.g., pollution-tolerant indicates the ability to live in polluted waters.

Tributary A body of water that drains into another, typically larger, body of water.

Turbidity Optical property of water that describes the amount of light that is refracted. Primarily related to the amount of silt and clay, turbidity is also influenced by organic particles, compounds and organisms.

Water-quality criteria Maximum concentrations of pollutants that are acceptable, if those waters are to meet water quality standards. Listed in state water quality standards.

Water-quality standards Written goals for state waters, established by each state and approved by EPA. Water quality standards have three parts: designated uses, water quality criteria and an anti-degradation policy.

Watershed A region or area bounded by ridgelines or other physical divides and draining ultimately to a particular watercourse or body of water.

APPENDIX 1: PROBABILITY SITES IN ARIZONA

Site ID	Stream Name	Date Collected	Sampling Status	County	Climatic Region	ADEQ Stream Designations	Strahler Order	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
WAZP99-0504	SALT RIVER	8/12/2004	BOATABLE	MARICOPA	MOUNTAIN	WARM	7	33.55659	-111.53547
WAZP99-0512	GILA RIVER	6/4/2000	WADEABLE	GREENLEE	XERIC	WARM	7	32.87094	-109.19751
WAZP99-0537	LITTLE COLORADO RIVER	5/29/2003	WADEABLE	NAVAJO	XERIC	WARM	8	34.98244	-110.59039
WAZP99-0539	WEST CLEAR CREEK	5/22/2000	PARTIALLY WADEABLE	YAVAPAI	MOUNTAIN	WARM	4	34.52014	-111.78366
WAZP99-0545	BLACK RIVER (NE FORK)	6/5/2000	WADEABLE	APACHE	MOUNTAIN	COLD	3	33.9124	-109.35581
WAZP99-0551	COON CREEK	5/24/2000	WADEABLE	GILA	MOUNTAIN	WARM	2	33.71258	-110.84657
WAZP99-0568	SANTA MARIA RIVER	5/20/2000	INTERRUPTED FLOW	YAVAPAI	XERIC	WARM	5	34.35257	-113.21808
WAZP99-0569	K P CREEK	6/6/2000	WADEABLE	GREENLEE	MOUNTAIN	COLD	2	33.59193	-109.32201
WAZP99-0590	BRIGHT ANGEL CANYON	9/15/2002	WADEABLE	COCONINO	XERIC	WARM	3	36.11783	-112.08298
WAZP99-0591	VERDE RIVER	5/2/2001	BOATABLE	GILA	MOUNTAIN	WARM	7	34.19901	-111.68984
WAZP99-0598	CANYON CREEK	5/23/2000	WADEABLE	GILA	MOUNTAIN	COLD	2	34.29193	-110.81325
WAZP99-0599	GILA RIVER	6/29/2004	WADEABLE	GRAHAM	XERIC	WARM	1	32.84097	-109.57963
WAZP99-0605	BLUE RIVER	6/7/2000	WADEABLE	GREENLEE	MOUNTAIN	WARM	4	33.46021	-109.1817
WAZP99-0615	CONKLIN CREEK	6/17/2000	INTERRUPTED FLOW	GREENLEE	MOUNTAIN	COLD	2	33.681	-109.44518
WAZP99-0619	VERDE RIVER	6/19/2000	WADEABLE	YAVAPAI	MOUNTAIN	WARM	5	34.67929	-111.95341
WAZP99-0632	TONTO CREEK	5/22/2001	WADEABLE	GILA	MOUNTAIN	WARM	4	34.27915	-111.07074
WAZP99-0639	CAMPBELL BLUE CREEK	5/31/2001	WADEABLE	GREENLEE	MOUNTAIN	COLD	2	33.75029	-109.21598
WAZP99-0645	NUTRIOSO CREEK	6/13/2001	WADEABLE	APACHE	MOUNTAIN	COLD	3	33.94858	-109.20244
WAZP99-0648	SILVER CREEK	6/1/2001	PARTIALLY WADEABLE	NAVAJO	MOUNTAIN	COLD	3	34.34528	-109.96471
WAZP99-0649	BURRO CREEK	5/25/2001	WADEABLE	MOHAVE	XERIC	WARM	5	34.55402	-113.53074
WAZP99-0653	NAZALINI WASH	6/28/2001	WADEABLE	APACHE	XERIC	COLD	3	35.91804	-109.3968
WAZP99-0661	VERDE RIVER	4/15/2003	BOATABLE	YAVAPAI	MOUNTAIN	WARM	7	34.47723	-111.79965
WAZP99-0669	CANYON DEL MUERTO--TSALIE CREEK	6/27/2001	WADEABLE	APACHE	MOUNTAIN	COLD	3	36.35491	-109.10664
WAZP99-0681	BLUE RIVER	6/19/2001	WADEABLE	GREENLEE	MOUNTAIN	WARM	5	33.23999	-109.19103

Appendix 1, Continued

Site ID	Stream Name	Date Collected	Sampling Status	County	Climatic Region	ADEQ Stream Designations	Strahler Order	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
WAZP99-0687	CENTERFIRE CREEK	5/30/2001	WADEABLE	APACHE	MOUNTAIN	COLD	2	33.75989	-109.43339
WAZP99-0701	BONITO CREEK	6/26/2001	WADEABLE	APACHE	MOUNTAIN	COLD	3	35.83849	-109.11306
WAZP99-0712	VIRGIN RIVER	8/1/2002	WADEABLE	MOHAVE	XERIC	WARM	1	36.80649	-114.01602
WAZP99-0716	BEAVER CREEK	6/20/2002	WADEABLE	YAVAPAI	MOUNTAIN	WARM	5	34.60769	-111.8295
WAZP99-0722	THOMPSON CREEK	7/18/2002	WADEABLE	APACHE	MOUNTAIN	COLD	2	33.89038	-109.4873
WAZP99-0728	SALT RIVER	5/7/2003	BOATABLE	GILA	MOUNTAIN	WARM	8	33.64332	-110.85701
WAZP99-0744	BUBBLING SPRINGS	8/15/2002	WADEABLE	NAVAJO	XERIC	COLD	1	36.73297	-110.56828
WAZP99-0750	EAGLE CREEK	7/30/2003	WADEABLE	GREENLEE	XERIC	WARM	5	33.13843	-109.49351
WAZP99-0768	BRIGHT ANGEL CREEK	9/15/2002	WADEABLE	COCONINO	XERIC	WARM	3	36.1214	-112.07993
WAZP99-0783	LANPHIER CANYON	7/16/2002	WADEABLE	GREENLEE	MOUNTAIN	COLD	3	33.56385	-109.11079
WAZP99-0828	NORTH FORK BLACK RIVER	8/13/2002	WADEABLE	APACHE	MOUNTAIN	COLD	3	33.86358	-109.31927
WAZP99-0833	HAIGLER CREEK	6/10/2003	WADEABLE	GILA	MOUNTAIN	WARM	3	34.19256	-111.03606
WAZP99-0839	SYCAMORE CREEK	5/6/2003	WADEABLE	YAVAPAI	MOUNTAIN	WARM	3	34.35254	-111.96975
WAZP99-0840	SAN FRANCISCO RIVER	8/14/2002	WADEABLE	APACHE	MOUNTAIN	COLD	2	33.85105	-109.15069
WAZP99-0851	TONTO CREEK	8/19/2002	WADEABLE	GILA	MOUNTAIN	WARM	5	34.11861	-111.26927
WAZP99-0861	PARIA RIVER	5/28/2003	WADEABLE	COCONINO	XERIC	WARM	5	36.86589	-111.59368
WAZP99-0863	CHERRY CREEK	5/14/2003	WADEABLE	GILA	MOUNTAIN	WARM	3	33.80028	-110.83649
WAZP99-0868	CLOVER CREEK	6/3/2003	WADEABLE	COCONINO	MOUNTAIN	COLD	3	34.55062	-111.40256
WAZP99-0876	WHEATFIELDS CREEK	6/17/2003	WADEABLE	APACHE	MOUNTAIN	COLD	4	36.20858	-109.13311
WAZP99-0888	FISH CREEK	5/20/2003	WADEABLE	GREENLEE	MOUNTAIN	COLD	3	33.68444	-109.39573
WAZP99-0893	CHERRY CREEK	5/13/2003	WADEABLE	GILA	MOUNTAIN	WARM	3	33.92252	-110.90451
WAZP99-0905	GILA RIVER	4/18/2003	BOATABLE	GRAHAM	XERIC	WARM	7	33.20788	-110.32067
WAZP99-0906	LITTLE COLORADO RIVER	6/4/2003	WADEABLE	APACHE	MOUNTAIN	COLD	5	34.28429	-109.35198

APPENDIX 2: REFERENCE CONDITION AND CONDITION CLASSES

We used reference condition and condition classes developed by the EPA. Here we provide a brief description of how reference condition and condition classes were developed. The reader is referred to the Western Assessment (Stoddard et al. 2005b) and the Western Statistical Summary (Stoddard et al. 2005a) for full detail.

As described in the main body of this report, the EPA used a subset of probability and hand-picked site data to describe least-disturbed or reference condition (i.e., as reference sites). A collection of least-disturbed sites in each climatic region was identified using regional reference-site screening criteria. The range of conditions found in these reference sites describes a distribution of values, and extremes in the distribution are used as thresholds to distinguish sites in relatively good condition from those that are clearly not. For the most part, the EPA used the 5th and 25th percentiles of the reference distribution as thresholds for the Xeric and Mountain regions.

For each indicator where reference condition was used to estimate thresholds, reference sites were chosen without referring to the results of the specific indicator being assessed, to avoid circularity. For example, chemical and physical habitat variables were used to classify sites as least-disturbed, and these reference sites were used to set thresholds for the biological indicators. The only exceptions to this process were the following:

- For macroinvertebrate taxa loss (the Observed/Expected or O/E index), the most-disturbed condition was defined as having lost more than 50% of the expected taxa. The intermediate class was defined as having lost between 20% and 50% of taxa, and the least-disturbed condition as having lost less than 20% of taxa.
- For total phosphorus, a concentration greater than 108 µg/L was considered to be in most-disturbed condition. This concentration was the average of total phosphorus standards reported in Arizona Administrative Code Water Quality Standards for surface waters http://www.azsos.gov/public_services/Title_18/18-11.htm.
- For total nitrogen, a concentration greater than 667 µg/L was considered to be in most-disturbed condition. This concentration was the average of total phosphorus standards reported in Arizona Administrative Code Water Quality Standards for surface waters http://www.azsos.gov/public_services/Title_18/18-11.htm.
- For mercury in fish tissue, a concentration greater than 0.1 µg/g of fish tissue (wet weight) was considered to be in most-disturbed condition. This concentration is reported to have adverse effects on river otter (Lontra canadensis) (Lazorchak et al. 2003).
- For non-native vertebrates, any site where more than 10% of individuals sampled were non-natives was considered most-disturbed. The intermediate class consisted of sites where non-natives were present, but were less than 10% of individuals. Sites with no non-natives were considered least-disturbed.

Mountains Climatic Region	Most-Disturbed		Least-Disturbed	
	Threshold	Percentile	Threshold	Percentile
Aquatic Vertebrate IBI (MMI_VERT)	<37	5th	≥62	25th
Macroinvertebrate IBI (MMI_BUG)	<57	5th	≥71	25th
Macroinvertebrate O/E Index (OE_BEST)	<0.5	a	0.8	a
Phosphorus (PTL)	>108 μg/L	b	≤108 μg/L	b
Nitrogen (NTL)	>667 μg/L	b	≤667 μg/L	b
Salinity (COND)	>1000 μS/cm	5th	≤500 μS/cm	25th
Mercury	>0.1 μg/g	c	≤0.1 μg/g	c
Riparian Disturbance (W1_HALL)	>0.95	95th	≤0.35	75th
Habitat Complexity (XFC_NAT)	<0.10	5th	≥0.37	25th
Streambed Stability (LRBS_BW5)	<-1.3 or >0.6	5th	≥-0.6 & ≤0.1	25th
Riparian Vegetation Coverage (XCMGW)	<0.23	5th	≥0.67	25th
Non-native Vertebrates	>10% of Individu-als	d	Absent	d
Non-native crayfish	Present	d	Absent	d
Asian clam	Present	d	Absent	d

Table A2-1. Thresholds used to separate condition classes, and the approximate percentage of the reference site distribution they represent (this table is taken directly from Stoddard et al. 2005b). Names in parentheses are variable names from the EMAP-West database.

Table A2-1, Continued

Xeric Climatic Region	Most-Disturbed		Least-Disturbed	
	Threshold	Percentile	Threshold	Percentile
Aquatic Vertebrate IBI (MMI_VERT)	<29	5th	≥40	25th
Macroinvertebrate IBI (MMI_BUG)	<47	5th	≥56	25th
Macroinvertebrate O/E Index (OE_BEST)	<0.5	a	0.8	a
Phosphorus (PTL)	>108 μg/L	b	≤108 μg/L	b
Nitrogen (NTL)	>667 μg/L	b	≤667 μg/L	b
Salinity (COND)	>1000 μS/cm	5th	≤500 μS/cm	25th
Mercury	>0.1 μg/g	c	≤0.1 μg/g	c
Riparian Disturbance (W1_HALL)	>0.9	95th	≤0.7	75th
Habitat Complexity (XFC_NAT)	<0.32	5th	≥0.6	25th
Streambed Stability (LRBS_BW5)	<-1.7 or >0.3	5th	≥-0.9 and ≤-0.1	25th
Riparian Vegetation Coverage (XCMGW)	<0.132	5th	≥0.270	35th
Non-native Vertebrates	>10% of Individu-als	d	Absent	d
Non-native crayfish	Present	d	Absent	d
Asian clam	Present	d	Absent	d
ADEQ	Attaining		Impaired	
Cold-water Macroinvertebrate IBI	≥52	25th	≤40	5th
Warm-water Macrionvertebrate IBI	≥50	25th	≤36	5th

a Thresholds for O/E Index were not based on the reference site distribution (see text).
b Thresholds for total phosphorus and total nitrogen are based on averaged state standards.
c Thresholds for mercury were based on published wildlife criterion.
d Thresholds for non-native taxa were not based on the reference site distribution (see text).

APPENDIX 3: METRICS INCLUDED IN INDICIES OF BIOLOGICAL INTEGRITY

Climatic Region	Metric Class	Metric
Mountains	Non-native species	Proportion of individuals that are non-native
	Composition	Proportion of vertebrate abundance in family Cyprinidae
	Habitat	Proportion of individuals that are sensitive and rheophilic
	Life History	Proportion of all species that are native and sensitive and long-lived
	Reproductive	Proportion of all species that are lithophilic
	Tolerance	Proportion of all species that are super tolerant
	Trophic	Proportion of individuals that are sensitive and invertivores-piscivores
Xeric	Alien species	Alien vertebrate species richness
	Composition	Proportion of vertebrate abundance in family Cyprinidae
	Habitat	Proportion of individuals that are sensitive and rheophilic
	Life History	Proportion of individuals that are native migrating
	Reproductive	Proportion of individuals that are sensitive spawners
	Tolerance	Proportion of individuals that are tolerant
	Trophic	Proportion of species that are non-tolerant invertivore-piscivores

Table A3-1. Metrics included in the EMAP aquatic vertebrate indexes of biological integrity (IBI) for Xeric and Mountains climatic regions.

Climatic Region	Metric Class	Metric
Mountain	Composition	Percent of individuals that are non-insect
	Diversity	Percent of individuals in the 5 most dominant taxa
	Feeding	Percent of taxa that are omnivores
	Habitat	Percent individuals that are burrowers
	Richness	Number of taxa of Ephemeroptera, Plecoptera, or Trichoptera
	Tolerance	Percent of taxa that are tolerant
Xeric	Composition	Percent of taxa that are non-insect
	Diversity	Shannon diversity index
	Feeding	Number of taxa that are shredders
	Habitat	Percent taxa that are clingers
	Richness	Number of taxa of Ephemeroptera, Plecoptera, or Trichoptera
	Tolerance	Percent of taxa that are non-tolerant

Table A3-2. Metrics included in the EMAP macroinvertebrate indexes of biological integrity (IBI) for Xeric and Mountains climatic regions.

Elevation Class	Metric Class	Metric
Cold-water	Richness	Total taxa richness
	Richness	Ephemeroptera taxa richness
	Richness	Trichoptera taxa richness
	Richness	Diptera taxa richness
	Feeding	Scraper taxa richness
	Feeding	Percent of individuals that are scrapers
	Composition	Percent of individuals that are in family Ephemeroptera
	Diversity	Percent of individuals in dominant taxa
	Diversity	Hilsenhoff diversity index (Hilsenhoff 1982)
Warm-water	Richness	Total taxa richness
	Richness	Diptera taxa richness
	Richness	Non-tolerant taxa richness
	Feeding	Scraper taxa richness
	Feeding	Percent of individuals that are scrapers
	Composition	Percent of individuals that are in family Plecoptera
	Diversity	Hilsenhoff diversity index (Hilsenhoff 1982)

Table A3-3. Metrics included in the ADEQ macroinvertebrate indexes of biological integrity (IBI) for cold-water (above 5,000 ft elevation) and warm-water (below 5,000 ft elevation) streams.

APPENDIX 4: INDICATOR DATA AND ANCILLARY INDICATOR INFORMATION

SITE_ID	Weight (km)	EMAP Aquatic Vertebrate IBI	EMAP Macro-invertebrate IBI	EMAP Macro-invertebrate O/E Index	ADEQ Macro-invertebrate IBI	Total Phosphorus (µg/L)	Total Nitrogen (µg/L)	Conductivity (Salinity) (µS/cm)	Mercury In Fish (µg/g)	Riparian Disturbance	Riparian Vegetation Cover	Relative Bed Stability	Habitat Complexity	Non-Native Vertebrates	Non-Native Crayfish	Asian Clam
WAZP99-0504	59.610	N/A	N/A	N/A	N/A	38.00	459.00	2048	N/A					N/A	No data	Absent
WAZP99-0512	95.377	No permit	61.27	0.48	57.09	15.00	930.00	674.7	No permit	1.95	0.15	-3.71	0.09	No permit	Absent	Absent
WAZP99-0537	59.610	18.39	25.93	0.00	15.90	19.00	310.00	4465	No sample	1.73	0.01	-1.40	0.01	0.38	Absent	Absent
WAZP99-0539	95.377	7.26	64.85	0.72	77.33	42.00	166.00	364	0.06	1.52	0.79	-0.91	0.69	0.63	Absent	No data
WAZP99-0545	39.740	9.44	19.26	0.58	26.07	92.00	324.00	112.3	0.07	1.14	0.00	-0.19	0.26	0.39	Present	Absent
WAZP99-0551	52.987	29.25	47.79	0.60	42.71	14.00	371.00	482.5	0.07	0.00	0.43	-1.06	0.61	0.00	Absent	Absent
WAZP99-0568	95.377	0.00	40.18	0.36	32.32	58.00	174.00	816.8	0.15	0.00	0.13	-1.90	0.22	0.18	Absent	Absent
WAZP99-0569	52.987	71.43	73.59	0.82	73.52	37.00	66.00	95.5	0.05	0.00	0.82	-0.55	1.08	1.00	Absent	Absent
WAZP99-0590	39.740	29.18	54.72	0.84	73.28	5.19	64.00	314.8	0.02	0.61	0.09	-1.13	0.36	0.55	Absent	Absent
WAZP99-0591	59.610	14.58	46.36	0.60	79.02	12.00	98.00	632.5	0.16	0.03	0.46	0.44	0.37	0.83	Absent	Present
WAZP99-0598	52.987	44.18	70.63	1.16	64.75	33.00	61.00	203.2	0.07	0.00	0.91	-0.62	1.16	1.00	Absent	Absent
WAZP99-0599	73.367	N/A	N/A	N/A	N/A	30.00	157.00	1426	N/A	1.66	0.18	-1.24	0.09	N/A	No data	Absent
WAZP99-0605	95.377	19.60	72.55	0.24	78.00	61.00	174.00	863.3	No sample	1.50	0.30	-0.11	0.25	0.04	Absent	Absent
WAZP99-0615	52.987	71.43	73.36	0.12	40.20	109.00	363.00	103.2	0.05	1.00	0.54	-0.07	1.36	1.00	Absent	Absent
WAZP99-0619	95.377	5.66	66.31	0.48	70.18	203.00	684.00	490.3	0.09	0.33	0.35	-1.26	0.47	0.98	Absent	Present
WAZP99-0632	95.377	42.55	41.01	0.60	62.14	45.00	265.00	280.3	0.23	0.35	0.54	-1.02	0.55	0.36	Present	Absent
WAZP99-0639	52.987	0.00	47.93	0.69	33.18	92.00	91.00	113.4	No sample	0.57	0.10	-1.83	0.21	0.00	Absent	Absent
WAZP99-0645	39.740	28.57	26.55	0.81	24.38	161.00	285.00	365.2	No sample	2.30	0.39	-3.56	0.21	0.00	Present	Absent
WAZP99-0648	39.740	14.94	11.69	0.60	21.34	62.00	155.00	159.4	0.01	2.00	0.20	1.22	0.22	0.09	Present	Absent
WAZP99-0649	95.377	12.38	28.40	0.12	37.45	17.00	410.00	529	0.07	0.27	0.20	-0.81	0.19	0.97	Absent	Present
WAZP99-0653	39.740	42.86	39.08	0.58	26.60	2.00	110.00	433	No sample	1.77	0.16	-1.24	0.23	0.00	Absent	Absent
WAZP99-0661	59.610	11.12	52.21	0.84	62.25	30.00	247.00	698.8	No sample	0.79	0.47	-0.29	0.15	0.54	Absent	Present
WAZP99-0669	39.740	36.19	64.63	0.81	53.98	72.00	210.00	269.8	0.25	1.20	0.91	-1.21	1.04	0.01	Absent	Absent

Table A4-1. Biological integrity and stressor indicator scores for each site sampled. Raw data can be accessed by contacting John Stoddard at the EPA Office of Research and Development in Corvallis, Oregon. For mercury-in-fish tissue, 'No sample' indicates that either there were insufficient numbers of fish so a sample was not collected, or samples were collected but not processed by the laboratory.

Appendix 4, Continued

SITE_ID	Weight (km)	EMAP Aquatic Vertebrate IBI	EMAP Macro-invertebrate IBI	EMAP Macro-invertebrate O/E Index	ADEQ Macro-invertebrate IBI	Total Phosphorus (µg/L)	Total Nitrogen (µg/L)	Conductivity (Salinity) (µS/cm)	Mercury In Fish (µg/g)	Riparian Disturbance	Riparian Vegetation Cover	Relative Bed Stability	Habitat Complexity	Non-Native Vertebrates	Non-Native Crayfish	Asian Clam
WAZP99-0681	95.377	36.25	58.65	0.84	76.05	40.00	133.00	426.8	0.07	0.00	0.71	-0.91	0.29	0.00	Absent	Absent
WAZP99-0687	52.987	71.43	62.93	0.92	34.34	39.00	55.00	81.2	0.04	0.66	0.26	-1.35	0.27	1.00	Absent	Absent
WAZP99-0701	39.740	No data	4.58	0.35	24.36	69.00	494.00	682.2	No data	0.39	0.28	-2.54	0.32	No data	Absent	Absent
WAZP99-0712	73.367	13.61	42.92	0.24	40.61	31.65	391.88	2918	0.06	0.61	0.77	-2.02	0.09	1.00	Absent	Present
WAZP99-0716	95.377	0.00	8.82	0.00	37.20	15.79	108.75	560.6	0.20	0.12	0.16	-0.54	0.25	1.00	Present	Present
WAZP99-0722	52.987	47.33	63.37	0.81	56.50	61.33	140.63	57.16	0.20	0.00	0.57	-1.46	1.12	0.00	Absent	Absent
WAZP99-0728	59.610	0.00	72.63	0.72	86.09	53.00	219.00	1091	No sample	0.00	0.69	-0.36	0.15	1.00	Absent	Present
WAZP99-0744	73.367	N/A	29.48	0.12	12.24	170.26	771.25	249.8	N/A	1.50	0.06	-2.11	0.00	N/A	Absent	Absent
WAZP99-0750	95.377	16.22	55.80	0.48	81.53	80.00	113.00	335.1	No sample	0.45	1.08	-0.46	0.35	0.65	Present	Absent
WAZP99-0768	39.740	32.03	55.26	0.72	70.63	5.64	74.00	321.5	0.02	0.57	0.12	-1.25	0.32	0.61	Absent	Absent
WAZP99-0783	39.740	42.86	60.25	0.35	52.55	40.16	210.00	239.7	0.21	0.06	0.81	-0.41	0.63	1.00	Absent	Absent
WAZP99-0828	39.740	41.63	59.64	0.81	46.12	46.06	409.38	134.5	No sample	0.07	0.53	-0.28	0.52	0.00	Present	Absent
WAZP99-0833	39.740	54.85	69.10	0.84	80.26	8.00	119.00	366.8	No sample	0.12	0.58	-0.11	0.44	0.34	Present	Absent
WAZP99-0839	39.740	12.71	39.16	0.96	49.02	38.00	115.00	520.5	No sample	1.63	1.10	-1.30	0.25	0.44	Present	Absent
WAZP99-0840	52.987	No data	36.94	0.69	28.43	123.34	1706.25	639.8	No data	2.50	0.00	-3.46	0.00	No data	Present	Absent
WAZP99-0851	95.377	14.97	26.77	0.24	27.15	13.24	250.00	1087	No sample	0.74	0.35	0.03	0.35	0.86	Present	Present
WAZP99-0861	95.377	28.57	42.27	0.12	27.66	221.00	1523.00	504.9	No sample	1.18	0.30	-1.89	0.01	0.00	Absent	Absent
WAZP99-0863	39.740	0.00	48.74	0.84	61.17	30.00	190.00	431.8	No sample	1.27	0.54	-1.40	0.55	1.00	Present	Absent
WAZP99-0868	39.740	35.42	67.54	0.96	41.54	49.00	81.00	391.4	No sample	0.07	0.78	-0.49	0.15	0.19	Present	Absent
WAZP99-0876	95.377	14.15	26.16	0.81	24.60	51.00	404.00	643.5	No sample	2.08	0.06	-1.00	0.10	0.34	Present	Absent
WAZP99-0888	39.740	85.71	76.78	0.92	62.88	43.00	119.00	66.66	No sample	0.08	0.85	0.21	0.52	0.00	Absent	Absent
WAZP99-0893	39.740	13.96	34.65	0.87	39.20	12.00	98.00	463.1	No sample	0.18	0.74	-0.42	0.26	0.02	Present	Absent
WAZP99-0905	59.610	0.00	42.70	0.72	23.18	335.00	1159.00	1349	No sample	0.04	0.68	-2.11	0.10	1.00	Absent	Absent
WAZP99-0906	95.377	0.50	54.29	0.60	21.86	113.00	455.00	251.5	No sample	2.38	0.25	-1.96	0.28	0.97	Present	Absent

Physical Habitat

Riparian Disturbance

Eleven categories of human-caused riparian disturbance were evaluated (Figure A4-1). At the left and right banks of each of the 11 transects the presence or absence of each of 11 categories of human caused disturbance was noted, as well as the proximity (three proximity categories) of the disturbance. A proximity-weighted index for each category was then calculated. The index values range from 0 to 1.5, with zero indicating absence of disturbance and 1.5 indicating disturbance in the immediate vicinity of the bank. Human caused disturbance was noted at 85% of the sites in Arizona. Grazing (pasture) was the most common form of disturbance (45% of the stream length), followed by trash or landfills (13%) and roads (12%).

Riparian Vegetation

Deciduous trees provided most of the canopy cover for Arizona's streams (mean = 28 % of reach), with coniferous, broadleaf evergreen, and mixed coniferous-deciduous types being far less common (all < 9% of the reach). Deciduous trees were the only type of canopy cover observed in Xeric streams, whereas in Mountain streams, canopy cover was provided by coniferous, deciduous, broadleaf evergreen, and mixed-conifer-deciduous trees.

Substrate

The types and percentages of various substrates (e.g., silt, sand, gravel, cobble, boulders) in a stream are important because they provide surfaces for algae to attach to, cover for macroinvertebrates and fish, and spawning surfaces for macroinvertebrates and fish (e.g., trout spawn in gravel). Fines can cover larger substrate sizes and make then unavailable habitat for fish and invertebrates. Fines and cobbles were the dominant substrate types in Arizona, followed by sand, large gravel, and boulders (Figure A4-2). Mountain streams

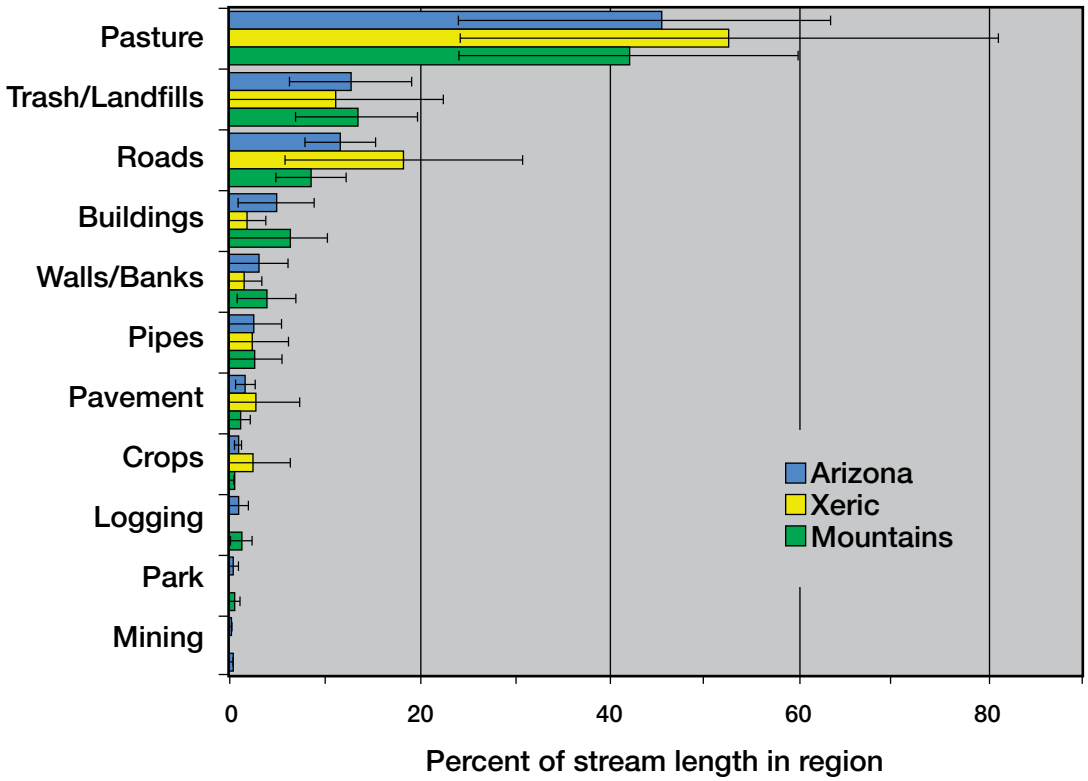

Figure A4-1. Human-caused riparian disturbance types near Arizona streams and in each climatic region; error bars are 95% confidence intervals.

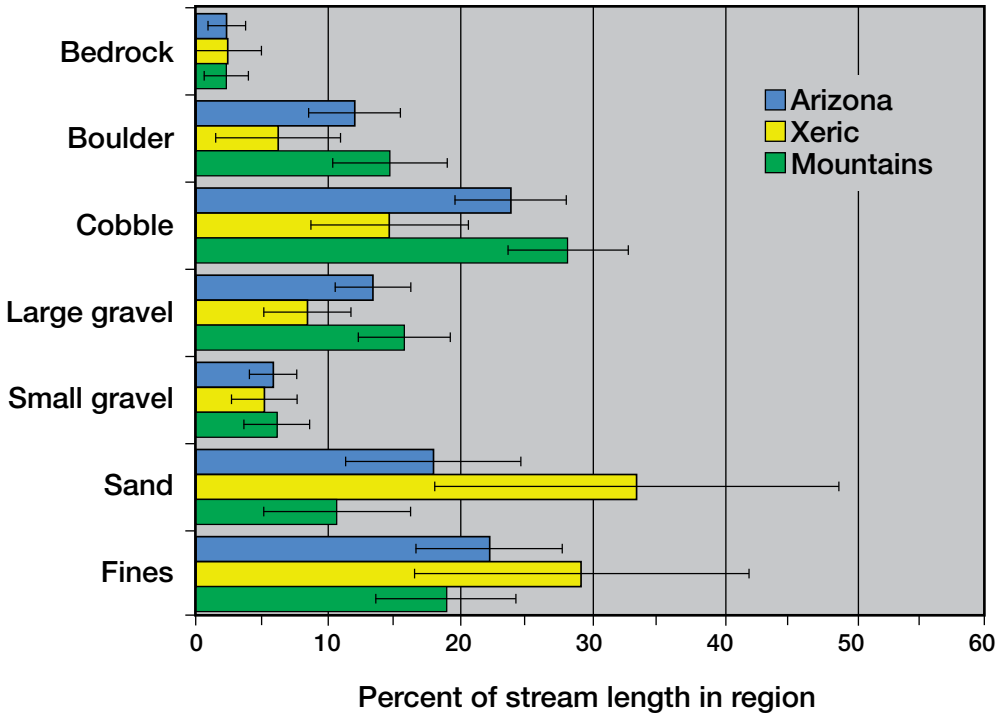

Figure A4-2. Substrate types in streams in Arizona and in the Xeric and Mountains climatic regions within the state; bars are 95% confidence intervals.

tended to have more boulders, cobble, and coarse gravels than Xeric streams, whereas Xeric streams tended to have more sand and fine substrates than Mountain streams.

Habitat complexity

Rocks were the dominant form of state-wide habitat complexity followed by aquatic plants, overhanging vegetation, woody debris and algae (Figure A4-3). Mountain streams tended to have more rock, aquatic plants, overhanging vegetation, woody debris, and undercut bank cover than Xeric streams.

Biological Assemblages

Aquatic Vertebrates

Arizona's streams and rivers that were surveyed contained 31 different species of aquatic vertebrates (Table A4-2), including 16 nonnative species (1 amphibian and 15 fish species) and 15 native species (4 amphibian and 11 fish species). Of the 47 sites sampled, data were not ready for two sites sampled in 2004, and three sites were not sampled for aquatic vertebrates because the stream was too small, and one site was not sampled because a permit was not obtained. All of the 41 sites with data available had aquatic vertebrates present; 39 of the sites (96% of stream length) had fishes but only 11 (35% of stream length) had amphibians. Nonnative fish species were more prevalent than native fish species; i.e., non-natives were found in 82% of the stream length, whereas native fishes were found in 71% of the stream length.

Longfin dace *(Agosia chrysogaster)*, speckled dace *(Rhinichthys osculus)*, desert suckers *(Catostomus clarkii),* red shiner *(Cyprinella lutrensis)*, and green sunfish *(Lepomis cyanellus)* were the most prevalent fish species and were found in 30-35% of the stream length. Common carp *(Cyrinus carpio)*, mosquito fish *(Gambusia affinis)*, fathead minnow *(Pimephales promelas)*, and Sonora sucker *(Catostomus insignis)* were found in 20-29% of the stream length. Other species were less common.

Family	Genus	Species	Native/ Non-native	Region	% Stream length
Bufonidae	*Bufo*	*punctatus*	native	M	4
		woodhousii	native	MX	6
		sp.	either	X	2
Ranidae	*Rana*	*catesbeiana*	non-native	MX	9
		pipiens	native	M	4
		yavapaiensis	native	M	2
		sp.	either	M	6
Catostomidae	*Catostomus*	*clarkii*	native	MX	31
		discobolus	native	MX	10
		insignis	native	M	21
		latipinnis	native	X	3
		sp.	native	X	2
Centrarchidae	*Lepomis*	*cyanellus*	non-native	MX	33
		macrochirus	non-native	MX	6
	Micropterus	*dolomieui*	non-native	MX	12
		salmoides	non-native	X	8
Cyprinidae	*Agosia*	*chrysogaster*	native	MX	35
	Cyprinella	*lutrensis*	non-native	MX	36
	Cyprinus	*carpio*	non-native	MX	28
	Gila	*intermedia*	native	M	2
		robusta	native	M	2
	Pimephales	*promelas*	non-native	MX	23
	Rhinichthys	*osculus*	native	MX	32
	Tiaroga	*cobitis*	native	M	4
Fundulidae	*Fundulus*	*zebrinus*	non-native	X	2
Ictaluridae	*Ameiurus*	*melas*	non-native	X	4
		natalis	non-native	MX	17
		sp.	non-native	MX	7
	Ictalurus	*punctatus*	non-native	MX	12
	Pylodictis	*olivaris*	non-native	M	5
Poeciliidae	*Gambusia*	*affinis*	non-native	MX	24
Salmonidae	*Oncorhynchus*	*apache x mykiss*	native	M	2
		gilae	native	M	4
		mykiss	non-native	MX	19
		sp.		M	2
	Salmo	*trutta*	non-native	MX	10

Table A4-2. Prevalence (% stream length) of fish and amphibian species found in Arizona's streams. Forty-three sites were sampled. M=mountains, X=xeric, sp=unidentified species.

Macroinvertebrates

Arizona's wadeable streams that were surveyed contained 192 different families of aquatic macroinvertebrates (Table A4-3). Chironomids (midges) were the most prevalent family.

Table A4-3. Prevalence (% stream length) of macroinvertebrate taxa found in Arizona's streams. Climatic regions are: M=mountains, X=xeric.

Taxa	Common name	Climatic region	% Stream length
Platyhelminthes (Phylum)	Free-Living Flatworms		
Turbellaria (Class)	Flatworms and Planarians	MX	12
Nematoda (Phylum)	Roundworms		
Nematomorpha (Class)		MX	48
Annelida (Phylum)	Worms and Leeches		
Hirudinea (Class)	Leeches		
Erpobdellidae (Family)	Freshwater Leeches	M	5
Glossiphoniidae (Family)	Leeches	M	3
Oligochaeta (Class)	Aquatic worms	MX	76
Tetrastemmatidae (Family)	Ribbon Worms	MX	9
Mollusca (Phylum)	Clams and Snails		
Gastropoda (Class)	Snails and Limpets		
Ancylidae (Family)	Pulmonate Snails or River Limpets	MX	11
Lymnaeidae (Family)	Pond Snails	M	3
Physidae (Family)	Freshwater Snails	MX	36
Planorbidae (Family)	Orb, Wheel, or Ram's Horn Trumpet Snails	MX	12
Bivalvia (Class)	Clams		
Sphraeriidae (Family)	Bivalves	M	21
Corbiculidae (Family)	Freshwater Molluscan Shells	MX	26
Arthropoda (Phylum)	Insects, Arachnids, and Crustaceans		
Chelicerata (Subphylum)			
Arachnida (Class)	Spiders and Mites		
Trombidiformes (Suborder)	Water Mites	MX	85
Arrenuridae (Family)	Water Mites	MX	10
Hydrodromidae (Family)	Water Mites	M	3
Hydryphantidae (Family)	Water Mites	M	5
Hygrobatidae (Family)	Water Mites	MX	34
Lebertiidae (Family)	Water Mites	MX	25
Limnesiidae (Family)	Water Mites	MX	16
Pionidae (Family)	Water Mites	M	7
Sperchontidae (Family)	Water Mites	MX	53
Stygothrombiidae (Family)	Water Mites	M	3
Torrenticolidae (Family)	Water Mites	M	17
Unionicolidae (Family	Water Mites	MX	12

Table A4-3, Continued

Crustacea (Subphylum)			
Decapoda (Order)	Shrimps and Crayfishes		
Cambaridae (Family)	Crayfishes	MX	32
Amphipoda (Order)	Scuds and Side-Swimmers		
Crangonyctidae (Family)	Amphipods	M	2
Gammaridae (Family)	Amphipods	M	6
Hyallidae (Family)	Amphipods	MX	13
Ostracoda (Class)	Seed Shrimp	MX	46
Atelocerata (Subphylum)			
Hexapoda (Class)			
Insecta (Subclass)			
Ephemeroptera (Order)	Mayflies		
Ameletidae (Family)	Mayflies	M	2
Baetidae (Family)	Small Minnow Mayflies	MX	93
Caenidae (Family)	Small Square-Gill Mayflies	M	19
Ephemerellidae (Family)	Spiny Crawler Mayflies	MX	9
Heptageniidae (Family)	Flathead Mayflies	MX	31
Isonychiidae (Family)	Brush-Legged Mayflies	M	8
Leptohyphidae (Family)	Mayflies	MX	60
Leptophlebiidae (Family)	Prong-Gilled Mayflies	MX	40
Siphlonuridae (Family)	Primitive Minnow Mayflies	M	3
Odonata (Order)	Damselflies and Dragonflies		
Zygoptera (Suborder)	Damselflies		
Calopterygidae (Family)	Broad-Winged Damselflies	MX	17
Coenagrionidae (Family)	Narrow-Winged or Pond Damselflies	MX	44
Anisoptera (Suborder)	Dragonflies		
Aeshnidae (Family)	Hawkers or Darner Dragonflies	M	7
Cordulegastridae (Family)	Biddies or Spike-tailed Dragonflies	M	3
Gomphidae (Family)	Club-Tail Dragonflies	MX	30
Libellulidae (Family)	Common Skimmer Dragonflies	MX	13
Plecoptera (Order)	Stoneflies		
Chloroperlidae (Family)	Sallflies or Green Stoneflies	M	8
Leuctridae (Family)	Roll-Winged Stoneflies	M	2
Nemouridae (Family)	Spring or Brown Stoneflies	M	12
Hemiptera (Order)	True Bugs		
Belostomatidae (Family)	Giant Water Bugs	M	4
Corixidae (Family)	Water Boatmen	MX	47
Naucoridae (Family)	Creeping Water Bugs	MX	30
Megaloptera (Order)	Dobsonflies, Fishflies, Alderflies		
Corydalidae (Family)	Dobsonflies, Fishflies, or Hellgrammite	MX	23

Table A4-3, Continued

Trichoptera (Order)	Caddisflies		
Apataniidae (Family)	Early smokey wing sedge or Case-Maker Caddisflies	M	2
Brachycentridae (Family)	Humpless Case-Maker Caddisflies or American Grannom	M	7
Calamoceratidae (Family)	Comb-lipped Case-Maker Caddisflies	M	3
Glossosomatidae (Family)	Saddle Case-Maker Caddisflies	MX	33
Helicopsychidae (Family)	Snail Case-Maker Caddisflies	MX	32
Hydrobiosidae (Family)	Caddisflies	M	8
Hydropsychidae (Family)	Net Spinning Caddisflies	MX	74
Hydroptilidae (Family)	Micro or Purse Case-Maker Caddisflies	MX	71
Lepidostomatidae (Family)	Little Plain Brown Sedge or Lepidostomatid Case-Maker Caddisflies	M	10
Leptoceridae (Family)	Long-Horned Case-Maker Caddisflies	MX	27
Limnephilidae (Family)	Northern Case-Maker Caddisflies	M	8
Odontoceridae (Family)	Strong Case-Maker Caddisflies or Dark Blue Wing Sedge	MX	10
Philopotamidae (Family)	Finger-Net or Silken-Tub Spinning Caddisflies	MX	9
Polycentropodidae (Family)	Trumpet-Net and Tent-Making Caddisflies	M	14
Sericostomatidae (Family)	Sericostomatid Case-Maker Caddisflies	M	3
Uenoidae (Family)	Uenoid Case-Maker Caddisflies	M	2
Lepidoptera (Order)	Butterflies and Moths		
Pyralidae (Family)	Aquatic Pyralid Moths	MX	40
Coleoptera (Order)	Beetles		
Dryopidae (Family)	Long-Toed Water Beetles	M	38
Dytiscidae (Family)	Predaceous Diving Beetles	MX	29
Elmidae (Family)	Riffle Beetles	MX	62
Haliplidae (Family)	Crawling Water Beetles	M	3
Hydraenidae (Family)	Minute Moss Beetles	X	6
Hydrophilidae (Family)	Water Scavenger Beetles	MX	6
Lutrochidae (Family)	Travertine Beetles	MX	8
Psephenidae (Family)	Water Pennies	MX	19
Diptera (Order)	True Flies		
Athericidae (Family)	Watersnipe Flies	M	1
Blephariceridae (Family)	Net-Winged midges	M	1
Ceratopogonidae (Family)	Biting Midges, No-See-Ums, or Punkies	MX	91
Chironomidae (Family)	Non-Biting Midges	MX	97
Culicidae (Family)	Mosquitos and Gnats	M	4
Dixidae (Family)	Meniscus Midges or Dixid Midges	M	17
Dolichopodidae (Family)	Long-Legged Flies	M	5
Empididae (Family)	Dance Flies	MX	53
Ephydridae (Family)	Shore Flies or Brine Flies	M	4

Table A4-3, Continued

Muscidae (Family)	House Flies or Stable Flies	M	7
Notonectidae (Family)	Backswimmers	M	2
Psychodidae (Family)	Moth Flies and Sand Flies	MX	17
Simuliidae (Family)	Black Flies or Buffalo Gnats	MX	66
Stratiomyidae (Family)	Soldier Flies	M	15
Tabanidae (Family)	Horse or Deer Flies	MX	38
Tipulidae (Family)	Crane Flies	MX	29

APPENDIX 5: ESTIMATING RELATIVE RISK

This description of relative risk was taken from EPA's Western Assessment report (Stoddard et al. 2005b). Relative risk measures the likelihood that the most-disturbed condition of a biological indicator will occur in streams that are also most-disturbed for a stressor. EPA defined relative risk (RR) as the ratio of two probabilities, or 'risks':

$$RR = \frac{\Pr(\text{most - disturbed biological condition} \mid \text{most - disturbed stressor condition})}{\Pr(\text{most - disturbed biological condition} \mid \text{most - disturbed stressor condition})}$$

where the numerator and denominator are conditional probabilities of most-disturbed biological condition, given that sites are in either most-disturbed (numerator) or least disturbed (denominator) stressor condition.

Relative risk is calculated from the estimated lengths of stream that have various combinations of biological and stressor conditions. These estimates can be arranged in a contingency table, as illustrated below for the aquatic vertebrate IBI versus the poor habitat complexity stressor.

Estimated stream length (km) sampled, Arizona		Habitat complexity condition class	
		Least	Most
Vertebrate IBI condition class	Least	145.71	0
	Most	623.92	383.34

From this table, the risk of finding a most-disturbed condition for aquatic vertebrates, in streams having most-disturbed habitat complexity, is estimated to be:

$$383.34 /(383.34 + 0) = 1.0$$

Similarly, the risk of finding a most-disturbed condition for aquatic vertebrates, in streams having least-disturbed habitat complexity, is estimated to be:

$$623.92 /623.92 + 145.71) = 0.76$$

Comparison of these two risks shows that a most-disturbed condition for aquatic vertebrates has a greater risk of occurring when habitat complexity conditions are also most disturbed (risk = 1.0) than when they are least-disturbed (risk = 0.76). Relative risk expresses this comparison as a ratio, that is:

$$RR = 1.0/0.76 = 1.3$$

In other words, we are 1.3 times, or 30%, more likely to find a most-disturbed aquatic vertebrate condition in streams with most-disturbed habitat complexity than in streams with least-disturbed habitat complexity.