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Biotic, Water-Quality, and Hydrologic Metrics Calculated for the Analysis of Temporal Trends in National Water Quality Assessment Program Data in the Western United States

Open-File Report 2012–1203

U.S. Department of the Interior
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FRONT COVER
Photograph at upper left: Sampling fish in the Santa Ana River, California. Photo by Carmen Burton, USGS.
Photograph at upper right: Sampling invertebrates in the Santa Ana River, California. Photo by Carmen Burton, USGS.
Photograph at lower: Sampling algae in West Clear Creek, Arizona. Photo by Anne Brasher, USGS.

Biotic, Water-Quality, and Hydrologic Metrics Calculated for the Analysis of Temporal Trends in National Water Quality Assessment Program Data in the Western United States

By Stephen M. Wiele, Anne M.D. Brasher, Matthew P. Miller, Jason T. May, and Kurt D. Carpenter

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U.S. Geological Survey, Reston, Virginia: 2012

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Suggested citation:
Wiele, S.M., Brasher A.M.D., Miller, M.P., May J.T., and Carpenter, K.D., 2011, Biotic, Water-Quality, and Hydrologic Metrics Calculated for the Analysis of Temporal Trends in National Water Quality Assessment Program Data in the Western United States: U.S. Geological Survey Open-File Report 2012–1203, 11 p.

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By Stephen M. Wiele, Anne M.D. Brasher, Matthew P. Miller, Jason T. May, and Kurt D. Carpenter

Abstract

The U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program was established by Congress in 1991 to collect long-term, nationally consistent information on the quality of the Nation's streams and groundwater. The NAWQA Program utilizes interdisciplinary and dynamic studies that link the chemical and physical conditions of streams (such as flow and habitat) with ecosystem health and the biologic condition of algae, aquatic invertebrates, and fish communities. This report presents metrics derived from NAWQA data and the U.S. Geological Survey streamgaging network for sampling sites in the Western United States, as well as associated chemical, habitat, and streamflow properties. The metrics characterize the conditions of algae, aquatic invertebrates, and fish. In addition, we have compiled climate records and basin characteristics related to the NAWQA sampling sites. The calculated metrics and compiled data can be used to analyze ecohydrologic trends over time.

Introduction

In 1991, the U.S. Congress established the National Water-Quality Assessment (NAWQA) Program within the U.S. Geological Survey (USGS) to collect long-term, nationally consistent information on the quality of the Nation's streams and groundwater (Gilliom and others, 1995). During the past 2 decades, the NAWQA Program has served as a primary source for nationwide information on the quality of streams and groundwater, how water quality changes over time, and how natural features and human activities affect the quality of streams and groundwater. Objective and reliable data, water-quality models, and systematic scientific studies characterize where, when, and why the Nation's water quality is degraded—and what can be done to improve and protect it for human and ecosystem needs. This information is used by national, regional, State, and local stakeholders to develop effective, science-based policies for water-quality protection and management.

The NAWQA Program utilizes interdisciplinary and dynamic studies that link the chemical and physical conditions of streams (such as flow and habitat) with ecosystem health and the biologic condition of algae, aquatic invertebrates, and fish communities. Conditions are evaluated in a hydrologic context, which is important because contaminants and their potential effects on drinking-water supplies and aquatic ecosystems vary over time and depend largely on the volume of water flowing in streams and discharging from aquifers. By incorporating interconnections among water quality, hydrology, and biologic systems, these assessments address the susceptibility of aquatic organisms to chemical and physical degradation and determine how ecosystem health and biologic responses vary among the diverse environmental settings across the Nation.

The NAWQA Program supports the collection of water-quality data, including biotic sampling, using consistent protocols that allow for comparisons of measurements over time and at different sites. Monitoring data are integrated with ancillary information on hydrologic characteristics, land use, and other landscape features. Long-term data collected as part of the NAWQA Program have been used to develop both regional and national models that can inform science-based strategies to protect and improve water quality for people and ecosystems even as population and threats to water quality continue to grow, as demand for water increases, and as the climate changes. In this report, we use algae, aquatic invertebrate, fish, water-quality, discharge, physical habitat, climate, and basin characteristic data collected in the Western and Midwestern United States for a regional analysis of temporal trends. Complete information about the program, including data and publications, is posted online at http://water.usgs.gov/nawqa/.

Purpose and Scope

This report compiles biotic, water-quality, and discharge data and presents metrics calculated from algae, aquatic invertebrate, fish, and water samples collected as part of the NAWQA Program, as well as hydrologic data collected from USGS streamgaging stations at sampling sites in the Western and selected Midwestern United States. Additionally, we report ancillary data, including physical-habitat variables, climatic data, and basin characteristics. We describe methods used to calculate metrics, and we present the metrics and related data in appendixes. These data and the calculated metrics can be used for future analyses of trends over time observed in the NAWQA datasets. Specifically, the data and metrics will be used to (1) identify sites where there has been a statistically significant temporal trend in one or more aquatic assemblages, (2) identify correlations between aquatic assemblages and assemblage metrics, (3) identify correlations between biota and physical-habitat or environmental variables at the sampling sites where trends are identified, and (4) interpret these trends and correlations within the context of land use in the watersheds.

Data Compilation and Analysis

Data on biota (algae, aquatic invertebrates, and fish), water quality, discharge, physical habitat, climate, and basin characteristics (including land use) were collected at 40 sampling sites in streams and rivers in the Western and Midwestern United States (fig. 1; table 1; app. 1). Data were not collected for all variables (that is, biota, water quality, hydrology, and so on) at all 40 sampling sites. The sampling sites from which data are available for each variable (table 1) encompass a wide range of physiographic properties, including elevation and drainage-basin area (fig. 2), as well as different ecoregions (fig. 3), climatic differences, and differences in anthropogenic influences. Many of the data used in this report are available online (table 2). The calculated metrics will form the basis for future analyses of trends in water quality and biota.

Assessment of the trends represented by the NAWQA data requires a distillation of large volumes of data into a comprehensible form. To make the analysis of trends in the NAWQA data more tractable, we have calculated metrics that represent biologic, chemical, and flow properties at the sampling sites. Water quality and discharge metrics, as well as data on physical habitat, climate, and basin characteristics, are included as variables that may correlate with trends in aquatic assemblages. In addition, trends in each of these variables can be investigated further because they may be of interest as standalone variables. Water quality and discharge

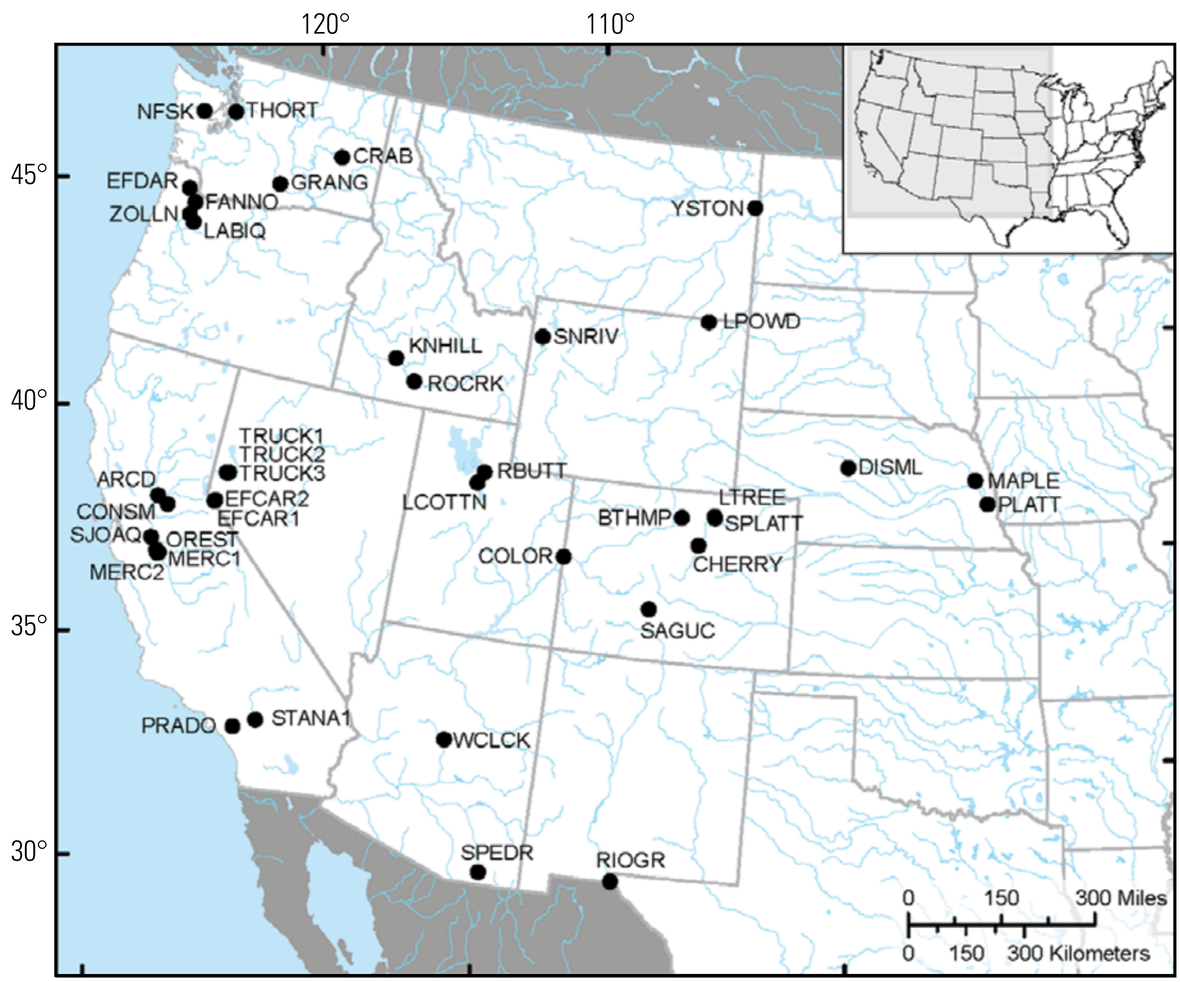

Figure 1. Locations of selected NAWQA sites and U.S. Geological Survey streamgaging stations in the study area.

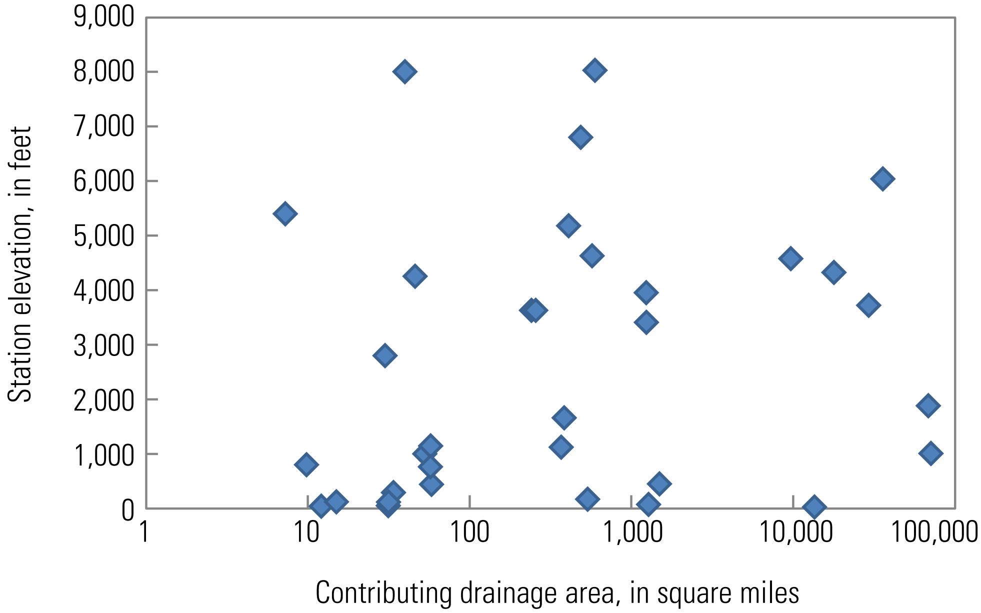

Figure 2. Contributing drainage areas and elevations of selected NAWQA sites and U.S. Geological Survey streamgaging stations in the study area.

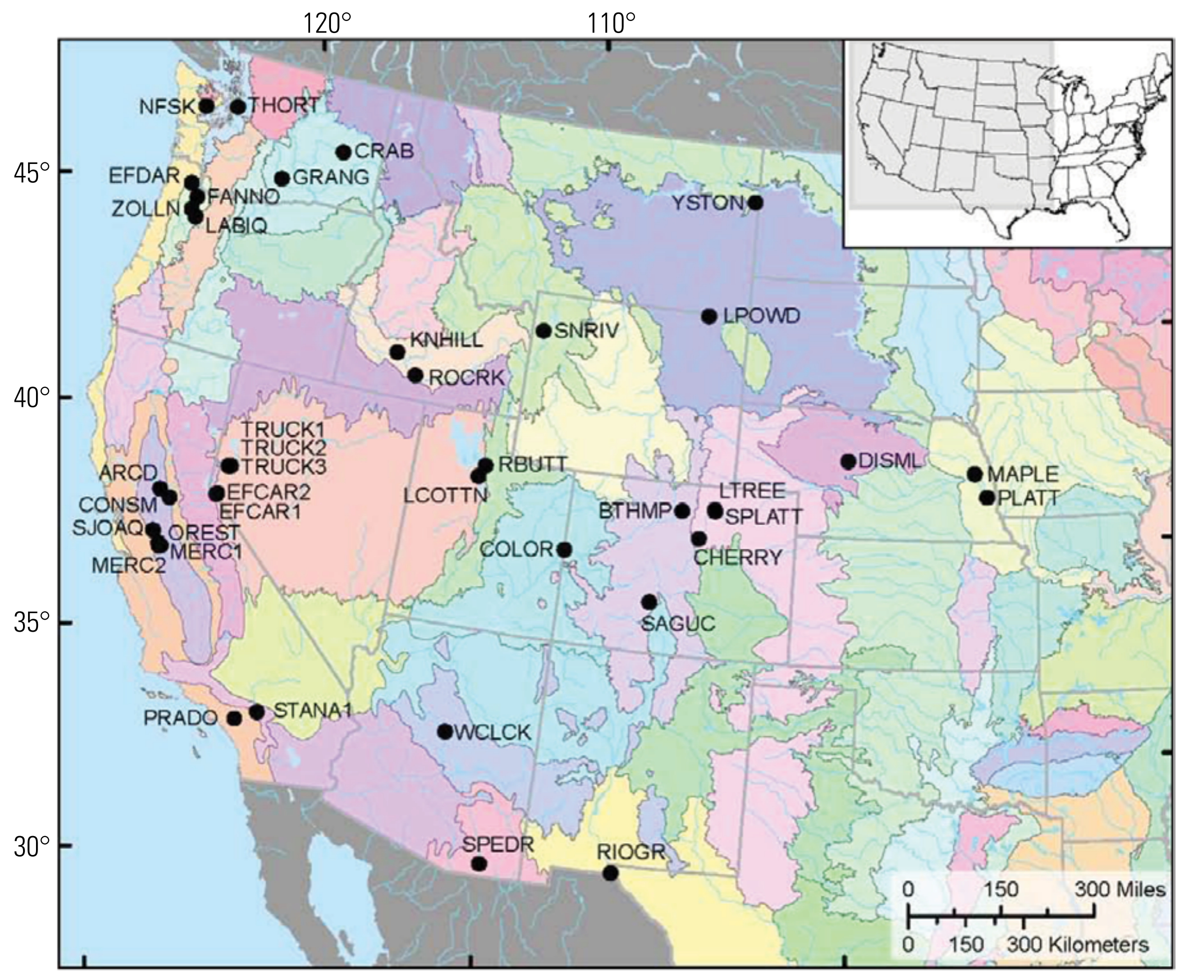

Figure 3. Ecoregions in the study area. This map is derived from a national map available at http://www.epa.gov/wed/pages/ecoregions/level_iii_iv.htm.

Table 1. Data available at study sites.

[X, data are available; ND, no data]

Site Name	Site Code	USGS STAID	Land Use	Algae	Aquatic invertebrates	Fish	Water Quality	Discharge	Physical Habitat Data	Climate (Precipitation and Temperature)	Basin Characteristics
Little Powder River Above Dry Creek, Near Weston, WY	LPOWD	06324970	Undeveloped	X	X	X	X	X	X	X	X
Yellowstone River Near Sidney, MT	YSTON	06329500	Undeveloped	X	X	ND	X	X	X	X	X
Cherry Creek at Denver, CO	CHERRY	06713500	Urban	X	X	X	X	X	X	X	X
Lonetree Creek Near Greeley, CO	LTREE	06753990	Undeveloped	X	X	ND	X	X	X	X	X
South Platte River Near Kersey, CO	SPLATT	06754000	Undeveloped	X	X	X	X	X	X	X	X
Dismal River Near Thedford, NE	DISML	06775900	Undeveloped	X	X	X	X	X	X	X	X
Maple Creek Near Nickerson, NE	MAPLE	06800000	Agriculture	X	X	X	X	X	X	X	X
Platte River at Louisville, NE	PLATTE	06805500	Undeveloped	X	ND	ND	X	X	ND	X	X
Saguache Creek Near Saguache, CO	SAGUC	08227000	Undeveloped	X	X	X	X	X	X	X	X
Rio Grande at El Paso, TX	RIOGR	08364000	Undeveloped	X	X	ND	X	X	X	X	X
Colorado River Near Colorado-Utah State Line	COLOR	09163500	Undeveloped	X	X	X	X	X	X	X	X
San Pedro River at Charleston, AZ	SPEDR	09471000	Undeveloped	X	X	X	X	X	X	X	X
West Clear Creek Near Camp Verde, AZ	WCLCK	09505800	Undeveloped	X	X	X	X	X	X	X	X
Little Cottonwood Creek at Jordan River near SLC	LCOTTN	10168000	Urban	X	X	X	X	X	X	X	X
Red Butte Creek at Fort Douglas, Near SLC, UT	RBUTT	10172200	Undeveloped	X	X	ND	X	X	X	X	X
E FK Carson River Near Gardnerville, NV	EFCAR1	10309000	Undeveloped	ND	ND	ND	ND	X	ND	ND	X
E FK Carson River Near Dresslerville, NV	EFCAR2	10309010	Undeveloped	X	X	ND	X	ND	X	X	X
Truckee River Near Tracy, NV	TRUCK1	10350340	Undeveloped	ND	ND	ND	ND	X	ND	ND	X
Truckee River below Tracy, NV	TRUCK2	10350400	Undeveloped	ND	ND	ND	ND	X	ND	ND	ND
Truckee River at Clark, NV	TRUCK3	10350500	Undeveloped	X	X	ND	ND	ND	X	X	ND
Santa Ana R BL Prado Dam CA	PRADO	11074000	Urban	X	X	X	X	X	X	X	X
Merced River Near Stevinson CA	MERC1	11272500	Undeveloped	ND	ND	ND	ND	X	ND	ND	X
Merced River Above River Road Bridge Near Newman CA	MERC2	11273500	Undeveloped	X	X	X	X	ND	X	X	X
Orestimba Creek at River RD near Crows Landing CA	OREST	11274538	Agriculture	X	X	ND	X	X	X	X	X
San Joaquin River Near Vernalis CA	SJOAQ	11303500	Undeveloped	ND	X	X	X	X	X	X	X
Cosumnes River Above Michigan Bar CA	CONSM	11335000	Undeveloped	X	X	ND	X	X	X	X	X
Arcade Creek near Del Paso Heights CA	ARCD	11447360	Urban	X	X	ND	X	X	X	X	X
NF Skokomish River Below Staircase RPDS Near Hoodsport, WA	NFSK	12056500	Undeveloped	X	X	ND	X	X	X	X	X
Thornton Creek Near Seattle, WA	THORT	12128000	Urban	X	X	X	X	X	X	X	X
Crab Creek at Rocky Ford Road Near Ritzville, WA	CRAB	12464770	Agriculture	X	X	X	X	X	X	X	X
Granger Drain at Granger, WA	GRANG	12505450	Agriculture	ND	X	ND	X	X	X	X	X
Snake River Above Jackson Lake at Flagg Ranch WY	SNRIV	13010065	Undeveloped	X	X	X	X	X	X	X	X
Rock Creek Above Hwy30/93 Xing at Twin Falls ID	ROCRK	13092747	Undeveloped	X	X	X	X	X	X	X	X
Snake River at King Hill ID	KNHILL	13154500	Undeveloped	X	X	X	X	X	X	X	X
Little Abiqua Creek Near Scotts Mills, OR	LABIQ	14200400	Undeveloped	X	X	X	X	X	X	X	X
Zollner Creek Near Mt Angel, OR	ZOLLN	14201300	Agriculture	X	X	ND	X	X	X	X	X
East Fork Dairy Creek Near Meacham Corner, OR	EFDAR	14205400	Undeveloped	X	X	X	X	X	X	X	X
Fanno Creek at Durham, OR	FANNO	14206950	Urban	X	X	X	X	X	X	X	X
Santa Ana River Above Upper PH Near Running Springs CA	STANA1	340843117032501	Undeveloped	X	X	X	ND	ND	X	X	X
Big Thompson Below Moraine Park NR Estes Park, CO	BTHMP	402114105350101	Undeveloped	X	X	X	X	X	X	X	X
Total number of sites				34	35	23	34	36	35	36	38

Table 2. Online sources of data.

Data	Source	URL
Algae	NAWQA data warehouse	http://infotrek.er.usgs.gov/apex/f?p=NAWQA:HOME:
Aquatic invertebrates	NAWQA data warehouse	http://infotrek.er.usgs.gov/apex/f?p=NAWQA:HOME:
Fish	NAWQA data warehouse	http://infotrek.er.usgs.gov/apex/f?p=NAWQA:HOME:
Water quality	National Water Information System	http://waterdata.usgs.gov/nwis
Discharge	National Water Information System	http://www.data.gov/raw/96
Physical habitat	NAWQA data warehouse	http://infotrek.er.usgs.gov/apex/f?p=NAWQA:HOME:
Climate	Oregon State PRISM Model	http://www.prism.oregonstate.edu
Basin characteristics	NAWQA Ecological Synthesis and Studies	http://water.usgs.gov/nawqa-only/ecology/data.html

time series are represented as metrics that represent conditions before, and concurrent with sampling of aquatic assemblages. Local temperature and precipitation and basin characteristics are also included as variables that may correlate with or explain variations over time or between sampling sites.

Biota

Algae, aquatic invertebrates, and fish were included in NAWQA sampling. Metrics were calculated from sampling data to be used in trend analyses.

Algae

Algae-Sampling and Laboratory-Analysis Methods

Attached benthic algae (periphyton) samples were collected from 34 NAWQA long-term-ecological-trend sites (see app. 2, table 1) during stable, low-flow conditions between July 1993 and December 2009. Periphyton samples were collected once per year for a minimum of 6 years, following standard USGS NAWQA protocols (Porter and others, 1993; Moulton and others, 2002). Algal samples were collected from five individual rocks or submerged wood substrates at five or more targeted sites (typically riffles) within each stream reach and composited into one Richest Targeted Habitat (RTH) sample. Epilithic algae from rock substrates were collected in riffles at 24 sites; at the 10 sites where riffles were absent, epidendric algae on woody debris were sampled. The same substrate was consistently sampled at each site from year to year except at the Santa Ana River near Running Springs, CA (STANA1), where artificial substrates were used in 1999 and 2000.

Subsamples for algal-species identification and enumeration were preserved in 5 percent formalin and analyzed at the Philadelphia Academy of Sciences, according to the methods of Charles and others (2002). The cell density and biovolume of diatoms and soft algae (green, blue-green, red, and golden) were determined for live cells only and verified by the presence of chloroplasts or viable protoplasm for at least 300 cells or diatom valves.

Algal biomass (chlorophyll-*a* [Chl-*a*], pheophytin-*a*, and ash-free dry mass [AFDM]) samples were collected following USGS protocols (Moulton and others, 2002). Representative subsamples of the composite sample were filtered through 0.7-µm glass-fiber filters under vacuum, shipped on dry ice to the USGS National Water-Quality Laboratory (NWQL) in Denver, CO, and analyzed fluorometrically according to U.S. Environmental Protection Agency (USEPA) Method 445.0. Annual monitoring of algal biomass did not start until 2002 or later at most sites, although some sites have data going back to 1992.

Algal-Data Compilation and Calculation of Taxonomic and Community Autecological Metrics

Algal-species data (34 species-site records from 283 RTH samples) were downloaded from the NAWQA Biological Transactional Data Base (Bio-TDB) to a Microsoft Access database on November 17, 2009. The Bio-TDB is not directly accessible by the public but is posted at the USGS NAWQA Data Warehouse (*http://water.usgs.gov/nawqa/data/*; for a description of the Bio-TDB, see http://water.usgs.gov/nawqa/sumr/04nr/dataWarehouse.pdf). Periphyton-biomass data were downloaded from the USGS National Water Information System (NWIS) NAWQA data warehouse. Algal metrics (see app. 2, table 2) characterizing the abundance, growth form, and taxonomic composition were calculated for each sample, using the USGS Algal Data Analysis System (ADAS) software (version 2.5.2; Cuffney and Brightbill, 2010). Metrics categories included low and high indicators for selected water-quality variables, including organic pollution, nutrients, dissolved oxygen, pH, salinity, total suspended sediment, and the occurrence of nuisance types of algae (Porter, 2008). Relative (percent) abundance metrics were calculated for biovolume, cell density, and richness for diatoms, soft algae, or both diatoms and soft algae (see app. 2, table 3), using the lowest possible taxonomic level.

Aquatic Invertebrates

Aquatic Sampling and Laboratory-Analysis Methods

Aquatic invertebrate samples were collected from 35 NAWQA long-term-ecologic-trends sites (see app. 3, table 1) during stable, low-flow conditions between June 1993 and December 2009. Aquatic invertebrate samples were collected once per year for a minimum of 6 years, following standard USGS NAWQA protocols (Cuffney and others, 1993; Moulton and others, 2002). At sites with riffle habitat, five replicate aquatic invertebrate samples were collected with a Slack sampler [0.5 m wide by 0.25 m high, with a 425-µm mesh (1993–97) or a 500-µm mesh (1998–2009)] in areas of similar substrate composition, current velocity, water depth, and canopy cover; sites where riffles were absent, snags (woody debris) were sampled. Snag sampling was done with the same sampling net as that used for riffle sampling at five sites within each sampling reach. The snags were visually examined, and only those that had clearly been in the stream for an extended period of time and were well colonized by aquatic biota were selected for processing.

For both sampling methods, organisms from all five sites were composited to form a single sample, placed in a 1-Liter jar, fixed with 10 percent formalin, and shipped to the NWQL for enumeration and identification. A quantitative fixed-count processing method was used to estimate the abundance of each taxon identified in the samples. Identification of organisms was done to the lowest possible taxonomic level. A complete explanation of aquatic invertebrate processing, identification, and quality-control methods was provided by Moulton and others (2000).

Compilation of Aquatic Invertebrate Data and Calculation of Taxonomic and Community Metrics

Data on aquatic invertebrate species (35 species-site records from 290 RTH samples; see app. 3, table 2) were downloaded from the NAWQA Bio-TDB to a Microsoft Access database on August 1, 2009. A broad suite of aquatic invertebrate metrics (see app. 3, table 3) based on abundance data and commonly used in water-quality assessments was calculated for each sample, using the USGS Invertebrate Data Analysis System (IDAS) software (Cuffney, 2003). Before calculating metrics, ambiguities in the taxonomic assemblage (that is, organisms not completely identifiable because of small size, incomplete development, damage, or poor preservation) were resolved by distributing the abundance of ambiguous parents among their children in accordance with the relative abundance of each child. This approach, which represents a compromise between removing redundant taxonomic information and conserving quantitative information on taxa richness and abundance (Taylor, 1997), is one of the methods suggested by Cuffney and others (2007). The types of metrics calculated reflect abundance (number of individuals) and richness (number of taxa), similarity and diversity, tolerance, and functional feeding groups, such as scrapers, shredders, gatherer-collectors, and filter-collectors (see app. 3, tables 4, 5). The functional-feeding group and regional-tolerance metrics included in the IDAS program were derived from those of Barbour and others (1999 app. B).

Fish

Fish samples were collected from 23 NAWQA long-term-ecologic-trend sites between July 1993 and 2009 during stable, low-flow periods (see app. 4, table 1), using backpack-mounted or towed-barge electrofishing units, where applicable, and supplemented with three seine hauls per site, following standardized NAWQA protocols (Meador and others, 1993a; Moulton and others, 2002). All available habitats (e.g., riffles, runs, pools, backeddies, side channels) in the stream reach (min 150 m, or 20 times the wetted width) were sampled thoroughly. In the field, captured fish were identified as to species, counted, weighed, measured (total length), examined externally for disease and anomalies, recorded, and then released back to the stream (Walsh and Meador 1998). In places where field identification was uncertain, a representative number of individuals were preserved for later identification by a certified ichthyologist.

Compilation of Fish Data and Calculation of Taxonomic and Community Metrics

Fish-species data (23 species-site records from 175 samples) were downloaded from the NAWQA Bio-TDB to a Microsoft Access database on August 1, 2009. Species composition of fish assemblages was summarized by using the relative abundance, richness, and total abundance of various taxa. Many commonly used metrics (Meador and others, 1993a, Barbour and others, 1999; Whittier and others, 2007a, b; Frimpong and Angermier, 2009), such as the number of individuals captured per reach, species tolerance, trophic status, number of taxa, and abundance of certain fish families, were calculated (see app. 4; tables 2, 3).

Analysis of Biotic Data

Trends in algae, aquatic invertebrate, and fish assemblages were examined by using multivariate statistical software (PRIMER-E, version 6; Clarke and Gorley, 2006a, b). Relative-abundance (density and biovolume for algae) data were standardized by total abundance and either square-root transformed (algae and aquatic invertebrates) or fourth-root transformed (fish) before calculating Bray-Curtis similarity matrices (Bray and Curtis, 1957) and constructing nonmetric multidimensional-scaling (MDS) species-ordination plots. This method reduces the complex multidimensionality of ecologic data (for example, multiple species across many sites) to a reduced set of axes and portrays samples according to their similarity and dissimilarity based on taxa abundance. The MDS ordination positions similar samples close to each other and dissimilar samples farther apart. For each taxa group at each sampling site, a sequential-trajectory overlay was added to the ordinations in PRIMER-E to show the pattern in species composition over time (figs. 4–6). The seriation-trajectory overlays graphically display statistically significant trends over time by representing change versus distance between points. Examples of these sequential-trajectory overlays are shown in figure 4 (algae), figure 5 (aquatic invertebrates), and figure 6 (fish). PRIMER's "relate" analysis, a nonparametric seriation procedure, was used to test for the statistical significance of the temporal changes in aquatic invertebrate assemblages at each site (Clarke and Gorley, 2006b; Clarke and others, 2006). Results of the seriation tests are presented in the respective appendixes for algae, aquatic invertebrates, and fish.

Water Quality

Water-quality samples were collected between 1990 and 2010 at 32 of the 34 sites sampled for algal-community composition, using standard USGS methods (U.S. Geological Survey, variously dated). Samples were analyzed at the NWQL, and data were downloaded from the USGS NWIS database (http://waterdata.usgs.gov/nwis/; accessed Apr. 13–20, 2010). A subset of water-quality variables that are commonly associated with algal ecology was selected (table 3) and used to generate water-quality metrics. At sites where multiple water-quality samples were collected on a single day,

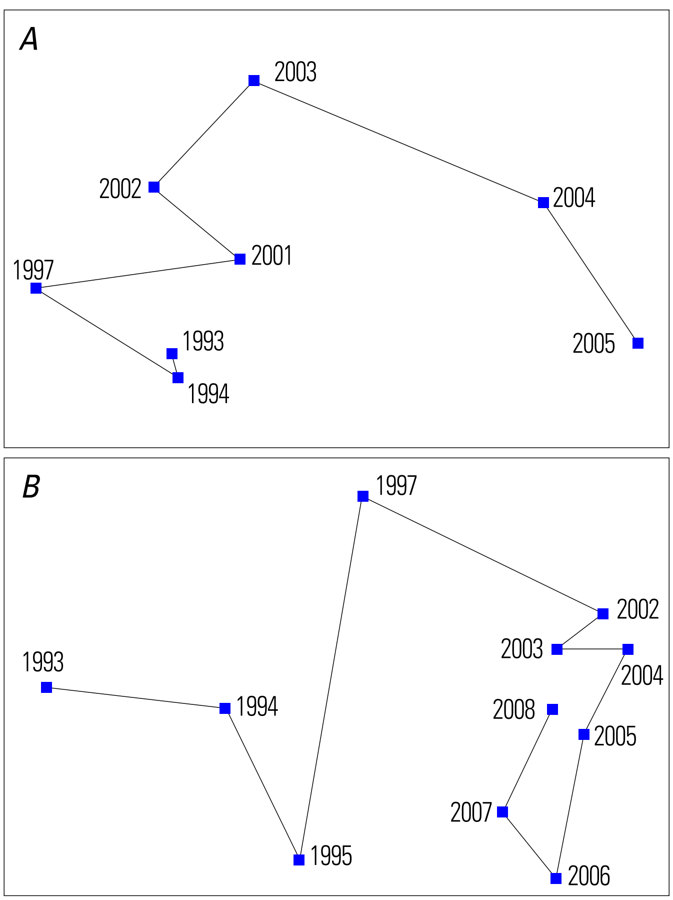

Figure 4. Examples of algal-species nonmetric multidimensional-scaling ordination and trajectory overlay for the Rio Grande at El Paso, Texas (*A*) and Rock Creek at Twin Falls, Idaho (*B*) based on relative (percent) algal biovolume. Trend for the Rio Grande is significant with P=0.001; trend for Rock Creek is significant with P=0.002.

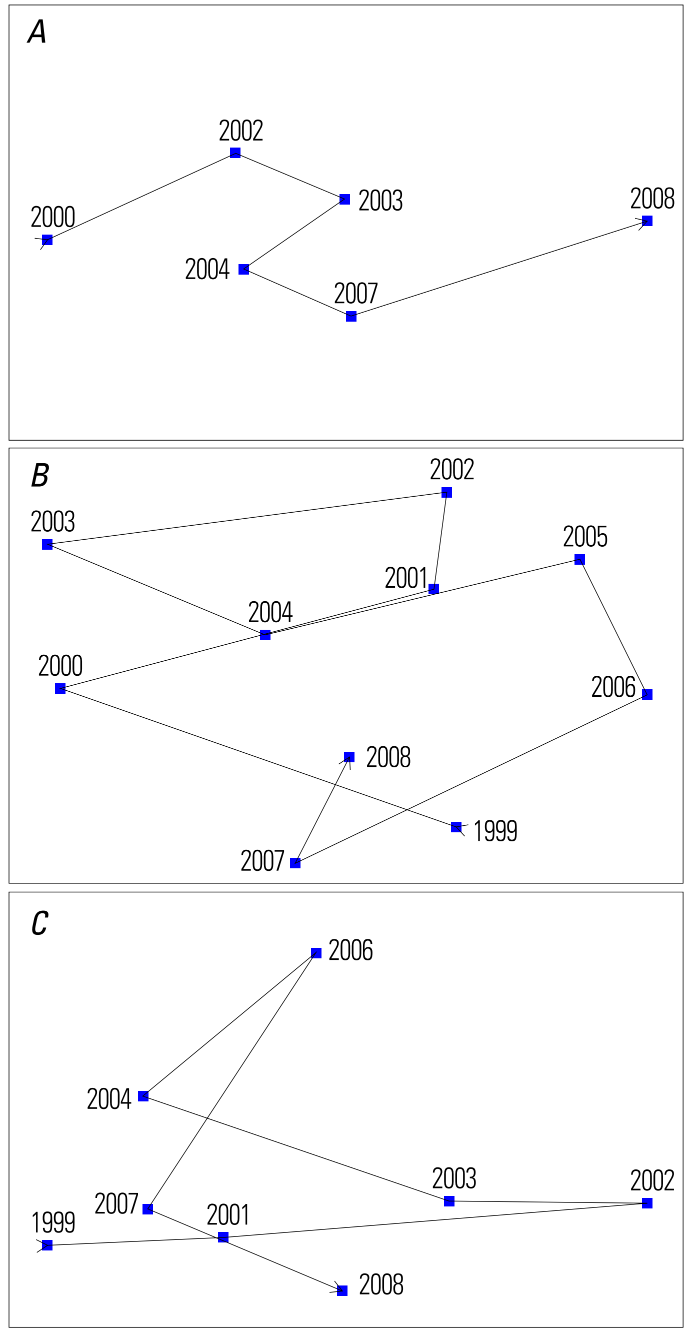

Figure 5. Examples of aquatic invertebrate nonmetric multidimensional-scaling ordination and trajectory overlay for strong significant trends in Granger Drain at Granger, Washington (*A*) a cyclical pattern in Red Butte Creek at Fort Douglas, near Salt Lake City, Utah (*B*) and a random pattern in the Little Powder River above Dry Creek, near Weston, Wyoming (*C*) based on aquatic invertebrate abundance. Trend for Granger Drain is significant with P=0.008; trend for Red Butte Creek is not significant with P=0.681; trend for Little Powder River is not significant with P = 0.694.

Table 3. Water-quality variables, USGS parameter codes (pcodes), and abbreviated variable names for which water-quality metrics were calculated.

Variable	pCode	Variable abbreviation
Water temperature (˚C)	00010	wattemp
Dissolved oxygen (mg/L)	00300	do
pH	00400	ph
Specific conductance (µS/cm @ 25˚C)	00095	sc
Calcium (mg/L)	00915	ca
Chloride (mg/L)	00940	cl
Sulfate (mg/L)	00945	so4
Suspended sediment (mg/L)	80154	ss
Total nitrogen (mg/L)	00600/062855†	tn
Ammonia (mg/L as N)	00608	dnh4n
Nitrite plus nitrate (mg/L as N)	00631	dno3no2
Ammonia plus organic nitrogen (mg/L as N)	00625	kjn
Total phosphorus (mg/L as P)	00665	tpp
Orthophosphate (mg/L)	00660	dpo4
Organic carbon (mg/L)	00681	doc

†Note: The method used for determining total nitrogen changed from parameter code 00600 to parameter code 062855 in 2003.

Table 4. Water-quality metrics calculated for five time periods before algae sampling dates.

Water-Quality Metric	Metric Abbreviation
Number of measurements	nmeas
Maximum concentration	pmax
Minimum concentration	pmin
Date of maximum concentration	datemax
Date of minimum concentration	datemin
Average concentration	pave
Standard deviation of concentration	psd
10th percentile concentration	p10
25th percentile concentration	p25
50th percentile concentration (Median)	p50
75th percentile concentration	p75
90th percentile concentration	p90

the average of each water-quality variable was calculated and used as the single daily value for subsequent metrics calculations. Metrics for a given water-quality variable were not calculated at sites where more than 15 percent of the values of the water-quality variable in question were less than the minimum reporting level (MRL).

A total of 12 water-quality metrics representing low, median, average, and high concentrations, concentration variability, and dates of maximum and minimum concentrations (table 4) were calculated for each water-quality variable to represent chemical conditions 10-, 30-, 90-, 365-, and 1,095-day periods before and concurrent with each algal-sampling date, resulting in a total of 60 metrics generated for each water-quality variable at each site (see app. 5). In each spreadsheet, the 60 metrics are listed in columns H through BO and labeled as the metric abbreviation preceded by the time step for which that metric was calculated. For example, the 25th percentile concentration for the 10 days prior to a given algal sampling date is labeled as "10p25."

Discharge

Each of the sampling sites was selected to be located near a streamflow gaging station that provided a continuous discharge record. One station, Rio Grande at El Paso, Texas (gage number 08364000), which is operated by the International Boundary and Water Commission (IBWC), U.S. Section, provided discharge records at 15-minute intervals (Delbert Humberson, written commun., January 2010). The IBWC regards 15-minute data as provisional and subject to revision. All other gages are operated by the USGS. The

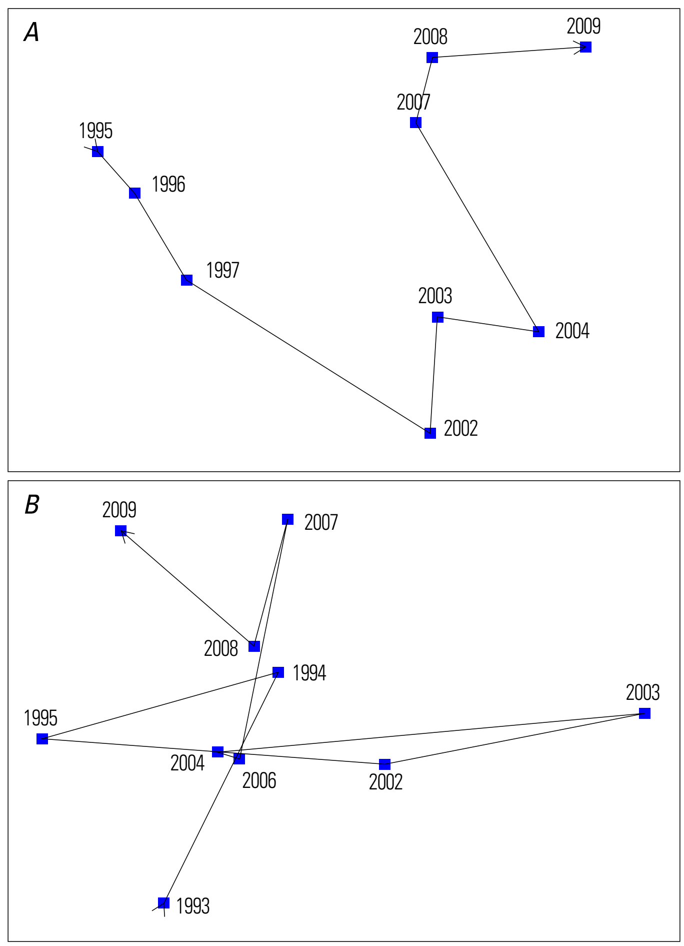

Figure 6. Examples of fish nonmetric multidimensional-scaling ordination and trajectory overlay for strong significant trends in West Clear Creek near Camp Verde, Arizona (*A*) and a cyclical pattern in Fanno Creek at Durham, Oregon (*B*) based on fish abundance. Trend for West Clear Creek is significant with P=0.001; trend for Fanno Creek is not significant with P=0.2.

Table 5. Discharge metrics calculated from daily hydrographs.

Discharge metric	Column heading in spreadsheets
Average discharge, in cubic feet per second	q_ave
Minimum discharge, in cubic feet per second	q_min
Maximum discharge, in cubic feet per second	q_max
Discharge standard deviation, in cubic feet per second	q_stdev
Discharge exceeded by 90 percent of discharges, in cubic feet per second	q90
Discharge exceeded by 50 percent of discharges, in cubic feet per second	q50
Discharge exceeded by 10 percent of discharges, in cubic feet per second	q10
Maximum daily increase in discharge, in cubic feet per second	1_day_max_rise
Maximum daily decrease in discharge, in cubic feet per second	1_day_max_fall
Total number of days discharge at or below q10	total_days_atorbelow_q10
Number of separate events discharge exceeded q90	number_events_at or above_q10
Maximum number of days discharge at or below q90 during one event	max_number_days_continuously_atorbelow_q10
Number of separate events discharge below q10	number_events_below_q90
Total number of days discharge below q10	total_days_below_q90
Total number of days discharge at or above q90	total_days_atorabove_q90
Number of separate events discharge exceeded q90	number_events_atorabove_q90
Maximum number of days discharge at or above q90 during one event	max_number_days_continuously_atorabove_q90

USGS typically reports discharge at 15-minute intervals, but daily average discharges provide sufficient resolution in this application, and were used to calculate discharge metrics. Standard methods used by the USGS to produce discharge records were described by Rantz (1982).

Metrics were selected to represent flow characteristics that could affect biologic or chemical values. The metrics selected, which are similar to those of Konrad and others (2008), represent low-, median-, and high-discharge magnitudes, changes in discharge, durations, and number of times when discharge was exceeded by 10 percent of discharges or by 90 percent of discharges for a specified time period before sampling times (table 5).

The biologic components and, possibly, the chemical components of the data may respond to antecedent flow conditions. The most significant time periods, however, are unknown before analysis and may vary among taxa. Consequently, we have calculated the metrics over a range of time periods preceding and concurrent with the sampling dates. Metrics were calculated for 10-, 30-, 90-, 365-, and 1,095-day periods before the algae, aquatic invertebrate, and fish sampling dates if the discharge record was complete over that time period. Spreadsheets containing the calculated discharge metrics are presented in appendix 6.

Physical Habitat

Physical-habitat data (table 6; see app. 7) were collected at each sampling reach as described by Meador and others (1993b) for sites sampled during 1993-97 and as modified by Fitzpatrick and others (1998) for all remaining sampling dates. Habitat was characterized at 6 (1993-97) or 11 (1998-2009) equally spaced transects along a sampling reach that was 20 times the wetted width, or a minimum of 150 m. Such channel features as wetted width, water-column velocity, elevation, substrate size, dominant substrate, geomorphic channel unit (run, riffle, pool), and riparian and canopy conditions were measured at each transect. Wetted-channel widths and lengths of geomorphic channel units were measured with a fiberglass tape or by a rangefinder. Streambank angle, height, and stability, as well as riparian width and shading, were recorded. Canopy opening, which represents the arc of open sky (0-180º) above the middle of the stream, was measured with a clinometer. Riparian shading was measured with a densiometer at the left and right streambanks. The velocity at a distance 0.6 times the depth below the water surface was measured to estimate the vertically averaged velocity, and the dominant substrate was characterized at three points along each transect. The percentages of riffles, runs, and pools were determined by dividing the combined lengths of each geomorphic unit by the total length of the stream reach.

Climate and Basin Characteristics

Estimates of monthly average precipitation (see app. 8, table 1), monthly average maximum daily temperature (see app. 8, table 2), and monthly average minimum daily temperature (see app. 8, table 3) from 1986 to 2009 for 36 sampling sites were compiled. This time frame allows for investigation of the potential for biotic, water-quality, discharge, or physical-habitat responses to lag changes in climate. Estimates were derived from climate data acquired from the Parameter elevation Regressions on Independent Slopes Model (PRISM) (Oregon State University, http://www.prism.oregonstate.edu/, accessed September 2010). A total of 29 basin characteristics that may influence biologic, chemical, and hydrologic conditions (table 7; see app. 9) were compiled for 37 sampling sites. Data were downloaded from the NAWQA Ecological Synthesis and Studies Web site at http://water.usgs.gov/nawqa-only/ecology/data.html.

Table 6. Habitat-assessment variables.

Percent pools
Percent riffles
Percent runs
Number of GCUs
Number of transects for width measurements
Minimum wetted width
Maximum wetted width
Mean wetted width
Wetted width CV
Number of depth measurements
Minimum depth
Maximum depth
Mean depth
Depth CV
Number of width/depth calculations
Minimum width/depth ratio
Maximum width/depth ratio
Mean width/depth ratio
Number of velocity measurements
Minimum velocity
Maximum velocity
Mean velocity
Velocity CV
Percent bedrock
Percent silt/clay
Percent sand <2 mm
Percent fine/medium gravel 2-16 mm
Percent coarse gravel 16-32 mm
Percent very coarse gravel 32-64 mm
Percent all sizes gravel
Percent small cobbles 64-128 mm
Percent large cobbles 128-256 mm
Percent all sizes cobble
Percent small boulder 256-512 mm
Percent large boulders
Percent silt present
Percent bank erosion
Mean percent embeddedness
Mean open canopy
Open canopy angle CV
Wetted perimeter minimum
Wetted perimeter maximum
Mean wetted perimeter
Wetted area minimum
Wetted area maximum
Mean wetted area
Mean hydraulic radius
Froude number
Average Mannings roughness

Table 7. Basin characteristics compiled for 37 sites in the western United States.

Basin drainage area, in square kilometers.
Basin classification based on highest percentage of land cover.
Population density in basin, in persons per square kilometer, from 2000 Census block data.
Population density in basin, in persons per square kilometer, from 1990 Census block data.
Basin percent urban, 2001 era.
Basin percent undeveloped, 2001 era.
Basin percent agriculture, 2001 era.
Basin percent urban, 1992 era.
Basin percent undeveloped, 1992 era.
Basin percent agriculture, 1992 era.
Basin percent mining/transitional, 1992 era.
Segment buffer percent urban.
Segment buffer percent undeveloped.
Segment buffer percent agriculture.
Segment buffer percent mining/transitional.
Estimate of nitrogen content from fertilizer and manure.
Estimate of phosphorus content from fertilizer and manure.
Level III ecoregion at sampling site.
Hydrologic landscape region at sampling site.
Nutrient ecoregion at sampling site.
Level II ecoregion at sampling site.
Dominant (highest percentage of area) Level II ecoregion within watershed.
Dominant (highest percentage of area) Level III ecoregion within watershed.
Percentage of the watershed covered by dominant Level III ecoregion.
Dominant (highest percentage of area) Nutrient ecoregion within watershed.
Percentage of the watershed covered by dominant Nutrient ecoregion.
Dominant (highest percentage of area) Hydrologic landscape region within watershed.
Percentage of watershed covered by dominant Hydrologic landscape region.
Mean basin slope, in percent.

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Produced in the Menlo Park Publishing Service Center, California
Manuscript approved for publication, September 12, 2012
Edited by George Havach
Layout and Design by Jeanne S DiLeo

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Welle and others—**Biotic, Water-Quality, and Hydrologic Metrics Calculated for the Analysis of Temporal Trends**—Open-File Report 2012–1203