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Characterization of Water Quality and Biological Communities, Fish Creek, Teton County, Wyoming, 2007–2011

Scientific Investigations Report 2013–5117

U.S. Department of the Interior
U.S. Geological Survey

Front cover. Fish Creek at site A–RB, October 2011.

Back cover. *Left coloumn, top to bottom:*

Collecting an algal sample using the cylindrical delimiter and brush, March 2007.
Photograph by Jerrod D. Wheeler.

Making a discharge measurement at site A–R6D, April 2011.
Photograph by Cheryl A. Eddy-Miller.

Evaluating aquatic plants using rapid periphyton survey bucket at site A–R7, August 2009.
Photograph by Jerrod D. Wheeler.

Right column, top to bottom:

Collecting a water-quality sample at site A–R6D, August 2007.
Photograph by Jerrod D. Wheeler.

Collecting macroinvertebrate samples at site A–R6D, May 2007.
Photograph by Jerrod D. Wheeler.

Making a pebble count measurement at site A–R6D, October 2008.
Photograph by Cheryl A. Eddy-Miller.

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U.S. Department of the Interior
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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square centimeter (cm^2)	0.001076	square foot (ft^2)
square centimeter (cm^2)	0.1550	square inch (in^2)
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.386	square mile (mi^2)
	Volume	
liter (L)	33.82	ounce, fluid (fl. oz)
cubic micrometer (μm^3)	0.000000000000061	cubic inch (in^3)
cubic centimeter (cm^3)	0.06102	cubic inch (in^3)
cubic centimeter (cm^3)	1,000,000,000,000	cubic micrometer (μm^3)
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
	Mass	
milligram (mg)	0.00003527	ounce, avoirdupois (oz)
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Altitude, as used in this report, refers to distance above the vertical datum.

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C) or millisiemens per centimeter at 25 degrees Celsius (mS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Stable isotope values of nitrogen and oxygen are referenced to a standard and are given in parts per thousand or per mil.

Water year is the 12-month period, October 1 through September 30, and is designated by the calendar year in which it ends. Thus, the water year ending September 30, 2011, is called the “2011” water year.

Abbreviations

<	less than
>	greater than
$\geq$	greater than or equal to
δ	delta notation
$\delta^{15}N$	isotope ratio of ^{15}N to ^{14}N compared to a reference standard
$\delta^{18}O$	isotope ratio of ^{18}O to ^{16}O compared to a reference standard
ρ	correlation coefficient
AFDM	ash-free dry mass
AIR	atmospheric nitrogen
ANOVA	analysis of variance
EPT	Ephemeroptera, Trichoptera, and Plecoptera
N	nitrogen
N:P	ratio of nitrogen to phosphorus concentrations on a molar basis
NAIP	near-infrared aerial photography
NO_3	nitrate
O	oxygen
P	phosphorus
p	probability
P_{max}	maximum rate of productivity
ssp.	subspecies
SWE	snow-water equivalent
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VSMOW	Vienna Standard Mean Ocean Water

Characterization of Water Quality and Biological Communities, Fish Creek, Teton County, Wyoming, 2007–2011

By Cheryl A. Eddy-Miller,[1] David A. Peterson,[1] Jerrod D. Wheeler,[1] C. Scott Edmiston,[1] Michelle L. Taylor,[1] and Daniel J. Leemon[2]

Abstract

Fish Creek, an approximately 25-kilometer-long tributary to Snake River, is located in Teton County in western Wyoming near the town of Wilson. Fish Creek is an important water body because it is used for irrigation, fishing, and recreation and adds scenic value to the Jackson Hole properties it runs through. Public concern about nuisance growths of aquatic plants in Fish Creek has been increasing since the early 2000s. To address these concerns, the U.S. Geological Survey conducted a study in cooperation with the Teton Conservation District to characterize the hydrology, water quality, and biologic communities of Fish Creek during 2007–11.

The hydrology of Fish Creek is strongly affected by groundwater contributions from the area known as the Snake River west bank, which lies east of Fish Creek and west of Snake River. Because of this continuous groundwater discharge to the creek, land-use activities in the west bank area can affect the groundwater quality. Evaluation of nitrate isotopes and dissolved-nitrate concentrations in groundwater during the study indicated that nitrate was entering Fish Creek from groundwater, and that the source of nitrate was commonly a septic/sewage effluent or manure source, or multiple sources, potentially including artificial nitrogen fertilizers, natural soil organic matter, and mixtures of sources.

Concentrations of dissolved nitrate and orthophosphate, which are key nutrients for growth of aquatic plants, generally were low in Fish Creek and occasionally were less than reporting levels (not detected). One potential reason for the low nutrient concentrations is that nutrients were being consumed by aquatic plant life that increases during the summer growing season, as a result of the seasonal increase in temperature and larger number of daylight hours.

Several aspects of Fish Creek's hydrology contribute to higher productivity and biovolume of aquatic plants in Fish Creek than typically observed in streams of its size in Wyoming. Especially in the winter, the proportionately large, continuous gain of groundwater into Fish Creek in the perennial section keeps most of the creek free of ice. Because sunlight can still reach the streambed in Fish Creek and the water is still flowing, aquatic plants continue to photosynthesize in the winter, albeit at a lower level of productivity. Additionally, the cobble and large gravel substrate in Fish Creek provides excellent attachment points for aquatic plants, and when combined with Fish Creek's channel stability allows rapid growth of aquatic plants once conditions allow during the spring.

The aquatic plant community of Fish Creek was different than most streams in Wyoming in that it contains many different macrophytes—including macroalgae such as long streamers of *Cladophora*, aquatic vascular plants, and moss; most other streams in the state contain predominantly algae. From the banks of Fish Creek, the bottom of the stream sometimes appeared to be a solid green carpet. A shift was observed from higher amounts of microalgae in April/May to higher amounts macrophytes in August and October, and differences in the relative abundance of microalgae and macrophytes were statistically significant between seasons.

Differences in dissolved-nitrate concentrations and in the nitrogen-to-phosphorus ratio were significantly different between seasons, as concentrations of dissolved nitrate decreased from April/May to August and October. It is likely that dissolved-nitrate concentrations in Fish Creek were lower in August and October because macrophytes were quickly utilizing the nutrient, and a negative correlation between macrophytes and nitrate was found.

Macroinvertebrates also were sampled because of their role as indicators of water quality and their documented responses to perturbation such as degradation of water quality and habitat. Statistically significant seasonal differences were noted in the macroinvertebrate community. Taxa richness and relative abundance of Ephemeroptera, Plecoptera, and Trichoptera, which tend to be intolerant of water-quality degradation, decreased from April/May to August; the same time

[1]U.S. Geological Survey.

[2]Teton Conservation District.

period saw a corresponding increase in Diptera and noninsects, particularly Oligochaeta (worms) that are more tolerant.

Seasonal changes in macroinvertebrate functional feeding groups were significantly different. The relative abundance of gatherer-collector and scraper feeding groups decreased from April/May to August, accompanied by an increase in filterer-collector and shredders feeding groups. Seasonal changes in feeding groups might be due to the seasonal shift in aquatic plant communities, as indicated by comparison with other streams in the area that had fewer aquatic macrophytes than Fish Creek. Statistical tests of macroinvertebrate metrics indicated few differences between years or biological sampling sites on Fish Creek, although the site farthest upstream sometimes was different not only in terms of macroinvertebrates but also in streamflow, water quality, and aquatic plants.

Potential effects of contributions of additional nutrients to the Fish Creek ecosystem beyond the conditions sampled during the study period are not known. However, because virtually all of the detectable dissolved nitrate commonly was consumed by aquatic plants in August (leaving dissolved nitrate less than the reporting level in water samples), it is possible that increased nutrient contributions could cause increased growth of aquatic plants. Additional long-term monitoring of the stream, with concurrent data analysis and interpretation would be needed to determine the effects of additional nutrients on the aquatic plant community and on higher levels of the food chain.

Introduction

Fish Creek, an approximately 25-kilometer (km)-long tributary to Snake River, is located in Teton County in western Wyoming near the town of Wilson (fig. 1). Fish Creek is an important water body because it is used for irrigation, fishing, and recreation and adds scenic value to the Jackson Hole properties it runs through. The clear, cold water in Fish Creek makes it an important spawning tributary for the Snake River cutthroat trout (*Oncorhynchus clarkii* ssp.; Baxter and Stone, 1995). The Fish Creek drainage is located along the southwestern margin of Jackson Hole. Fish Creek's drainage area includes part of the southern extent of the Teton Range and the southwestern part of Jackson Hole and is 183 square kilometers (km^2) at the U.S. Geological Survey (USGS) streamgage Fish Creek at Wilson, Wyoming (13016450, fig. 2) (Eddy-Miller and others, 2009). Groundwater and groundwater/surface-water interaction studies near Fish Creek have shown that streamflow in Fish Creek is very responsive to changes in groundwater levels, and flow in the creek is a combination of groundwater discharge to the stream and surface-water inflows from tributaries and irrigation diversions that terminate in Fish Creek (Nelson Engineering, 1992; Hinckley Consulting and Jorgensen Engineering, 1994; Wheeler and Eddy-Miller, 2005; Wyoming State Engineer's Office, 2005; Eddy-Miller and others, 2009).

Public concern about nuisance growths of aquatic plants in Fish Creek has been increasing since the early 2000s (Brian Remlinger, Teton Conservation District, oral commun., 2004). Aquatic plants, such as algae and vascular aquatic plants, are integral parts of a healthy stream ecosystem because they are primary producers in the aquatic food chain, providing food and habitat for invertebrates and other organisms. Excessive growths of aquatic plants, however, can be esthetically displeasing and a nuisance for anglers, irrigators, and other water users (Peterson and others, 2001) and can alter stream ecology. During daylight hours, aquatic plants produce oxygen that is essential for aquatic life, sometimes resulting in supersaturated concentrations of oxygen. At night, dissolved oxygen concentrations can decrease to levels lethal to fish, particularly trout, as a result of the decomposition of plant cells and other organic matter in the water and the related microbial respiration and consumption of oxygen. Respiration and decomposition of organic matter consume oxygen throughout the day and night but are offset by photosynthesis during daylight hours (Kaenel and others, 2000).

To address concerns about nuisance algal growths in Fish Creek, the USGS conducted a study in cooperation with the Teton Conservation District to characterize the water quality and biological communities of Fish Creek. This report describes and includes the 2007–08 samples initially evaluated in Eddy-Miller and others (2010) and samples collected for this study between March 2009 and October 2011. The total dataset evaluated includes water-quality samples collected for analyses of physical properties and water chemistry between March 2007 and October 2011 from six surface-water sites and three wells. During this same period, aquatic plant and macroinvertebrate samples were collected and habitat characteristics were measured at the surface-water sites.

The purpose of this report is to describe the characteristics of the hydrologic system, the water quality, and the biological communities of Fish Creek in western Wyoming using data collected during 2007–11. Specifically, this report describes (1) the evaluation of nitrogen and phosphorus concentrations and potential sources of nutrients by using isotopes of nitrate; (2) characteristics of the algal, vascular aquatic plant, and macroinvertebrate communities and habitat of Fish Creek; and (3) evaluation of relations between ecosystem components using nonparametric and multivariate statistics.

Description of Study Area

Teton County in Wyoming is experiencing rapid growth and development in the west bank area of Snake River (figs. 2, 3). Nelson Engineering (1992) estimated that 1,670 homes were in the west bank area in 1992. Between 1992 and 2007, an additional 640 homes were constructed in the west bank area (Jennifer Bodine, Teton County Planning and Development, written commun., 2008). Since 2007, development has continued with the addition of a golf course and homes near

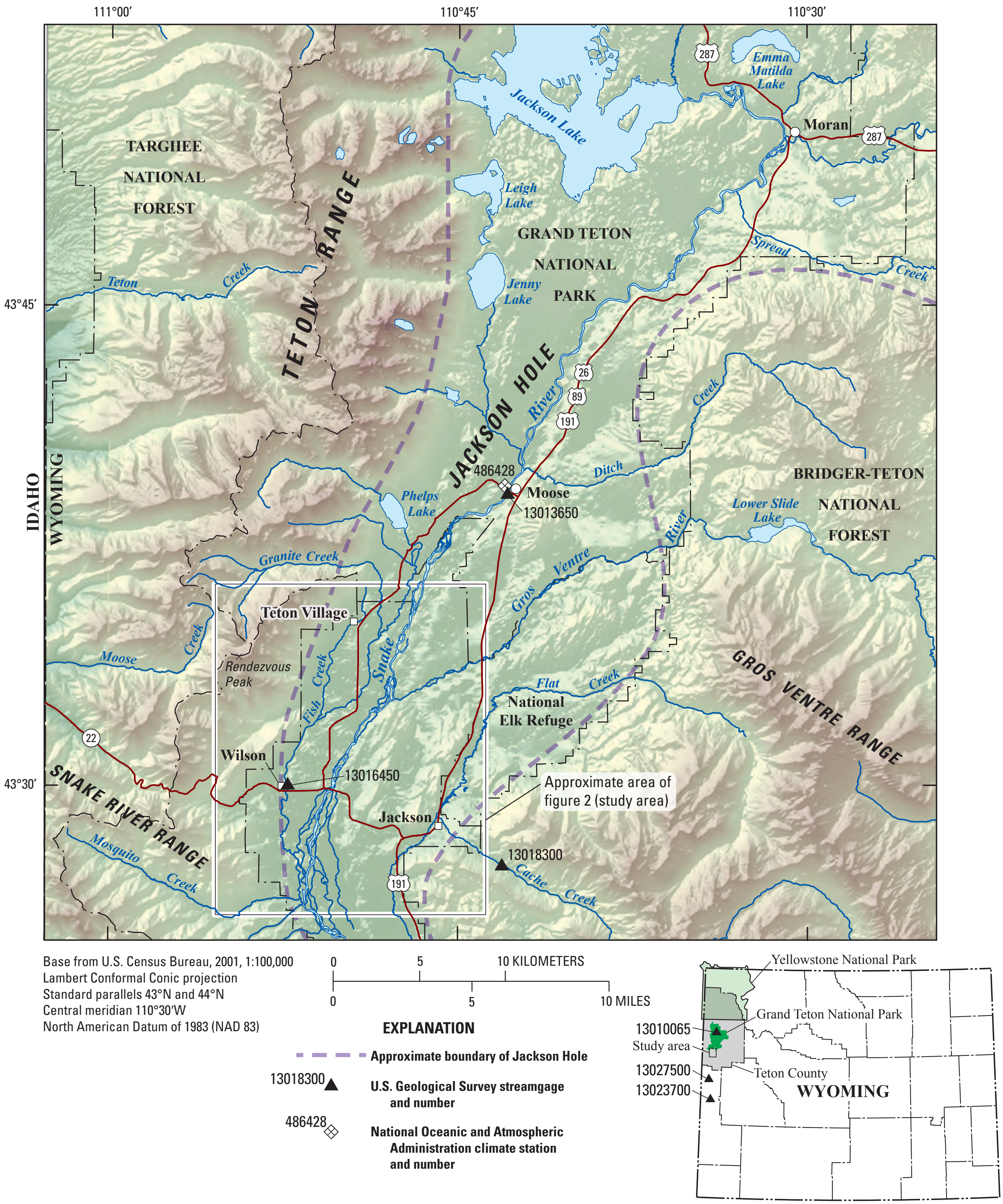


Figure 1. Location of Fish Creek study area in relation to larger Jackson Hole area, Teton County, Wyoming.

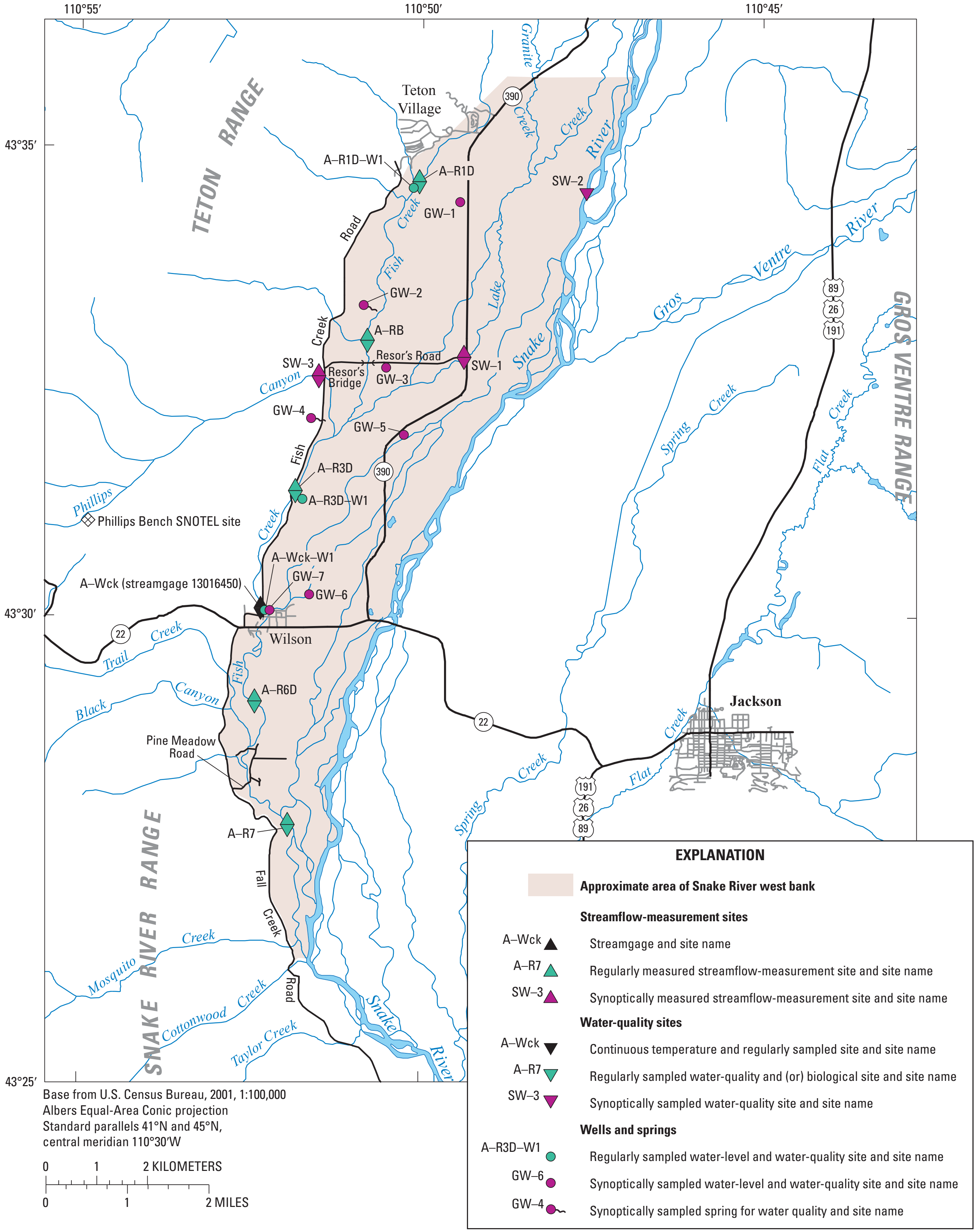


Figure 2. Study area showing locations of surface-water and groundwater sampling sites on and near Fish Creek, Teton County, Wyoming.

Teton Village and residential building in the rest of the west bank area. Water is supplied to area residents from the alluvial aquifer, either through a water supply system or individual wells. Effluent from most of these residences and businesses is discharged into the alluvial aquifer through septic systems or injection wells at sewage treatment plants. The exception is effluent from the town of Wilson, which is piped to Jackson's waste disposal system. The Fish Creek drainage area has multiple human activities that have the potential to affect water quantity and quality, such as a ski area, golf courses, cattle grazing lands, horse stables, and land irrigated for agricultural and esthetic uses. Altitudes in the study area range from approximately 1,875 meters (m) at Fish Creek at the Wilson streamgage to about 3,300 m at the summit of Rendezvous Peak.

Hydrologic Setting

The Fish Creek streambed is incised into glacial outwash and fluvial sediments and primarily composed of small gravel to medium cobble substrate. The main stem of Fish Creek parallels the mountain front and is a relatively linear channel along most of its upper reach. As described in previous reports (Eddy-Miller and others, 2009, 2010), Fish Creek has a unique flow regime compared to other mountain front streams because Fish Creek gains flow from Snake River, to which Fish Creek is a tributary. Some inflows to Fish Creek are from surface-water diversions from Snake River, and because of the tilt of the valley toward the west, some water infiltrated into the alluvial aquifer from Snake River then discharges as groundwater to Fish Creek. Additionally, the peak streamflows result from infiltrated snowmelt runoff through groundwater rather than from surface-water inflow derived from upstream snowmelt (Wheeler and Eddy-Miller, 2005; Eddy-Miller and others, 2009). Fish Creek's small drainage area and a levee system on Snake River prevent major flooding. Flow characteristics are affected by a combination of local climate, snowpack runoff timing and magnitude, local groundwater contribution, irrigation application and return flow, and Snake River. Channel and streambed characteristics are affected by a relatively low streambed gradient, coarse bed material, and the flow regime.

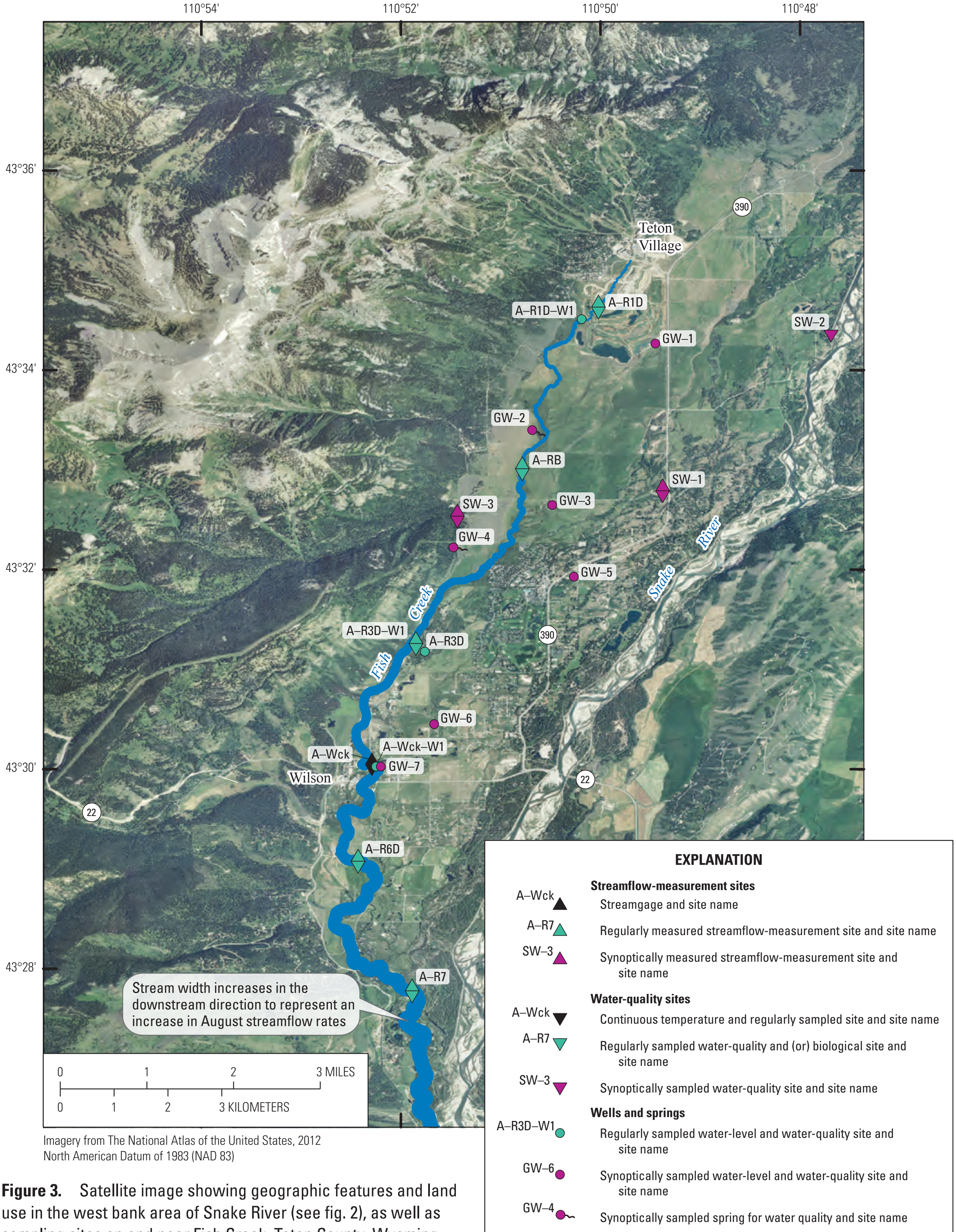
On the west side of Snake River is an alluvial aquifer known locally as the west bank aquifer that underlies the west bank area of Snake River shown in figure 2. The alluvial aquifer and the valley drainage of Fish Creek are bounded on the north by Granite Creek and on the east by Snake River. The west boundary is the Teton Range, a north-south-trending, upthrown fault block that generally parallels Fish Creek (Eddy-Miller and others, 2010). The southern extent of the alluvial aquifer pinches off where Fish Creek merges with Snake River. The water table in the alluvial aquifer can rise because of natural recharge from precipitation on the valley floor, recharge from local flood irrigation, and injection of tertiary-treated sewage. The water table also rises from infiltration (recharge) of water from tributaries and Snake River, which is topographically higher in altitude than Fish Creek at a given latitude (Wyoming State Engineer's Office, 2005).

Fish Creek surface-water inflows include springs, irrigation diversions from area rivers and streams, irrigation return flows, and tributary streams. Groundwater discharge contributes a substantial percentage of the flow to Fish Creek (Eddy-Miller and others, 2009), although the volume of water contributed from groundwater varies along the length of the creek. This variety of inflows to Fish Creek creates an annual hydrograph at the Wilson streamgage different from hydrographs of the predominantly snowmelt-driven systems elsewhere in the Jackson Hole valley (Eddy-Miller and others, 2010, fig. 6). Additionally, the large amount of relatively warmer groundwater inflow to the creek, especially in the winter, leads to minimal ice formation along the length of the perennial part of Fish Creek. Figure 4 summarizes published information (Nelson Engineering, 1992; Wheeler and Eddy-Miller, 2005; Wyoming State Engineer's Office, 2005; Eddy-Miller and others, 2009, 2010) and data collected for this study to graphically depict generalized flow paths of groundwater and surface water during April/May, August, and October.

Flow in Fish Creek in the area near Teton Village, the creek headwaters, is strongly affected by two factors: (1) runoff from snowmelt directly upstream in the drainage basin and (2) the large fluctuations in the water table from applied irrigation water and an increased stage in Snake River (Eddy-Miller and others, 2009). From Teton Village to near Resor's Bridge (fig. 2), the creek is seasonal, typically flowing from about late April through October. Near Resor's Bridge, the creek becomes perennial and flow is affected by increased groundwater discharge from a rising water table due to infiltration of valley snowmelt, a snowmelt pulse from the west-side mountains, infiltration of irrigation water application, and increased recharge from the higher stage of Snake River to the alluvial aquifer (Eddy-Miller and others, 2009). About 2 km downstream from Resor's Bridge, Lake Creek, which has flow augmented by a diversion from Snake River (Nelson Engineering, 1992), contributes the largest volume of flow of any tributary to Fish Creek. Flows in Fish Creek at Wilson streamgage are affected in the summer by tributary inflows and a small, constant input of groundwater. Flows at Wilson streamgage in the winter have similar groundwater inputs, but the tributary inputs are minimal (Eddy-Miller and others, 2009).

Climate

Average monthly temperatures at National Oceanic and Atmospheric Administration climate station 486428 in Moose, Wyo., (fig. 1) ranged from 10.3 degrees Celsius (°C) in January to 16.0°C in July during the period 1958–2007 (National Climatic Data Center, 2012). Average temperatures decrease with increasing altitude. Total average precipitation near the study area, in the form of rain and snow, ranges annually from



Imagery from The National Atlas of the United States, 2012
North American Datum of 1983 (NAD 83)

Figure 3. Satellite image showing geographic features and land use in the west bank area of Snake River (see fig. 2), as well as sampling sites on and near Fish Creek, Teton County, Wyoming.

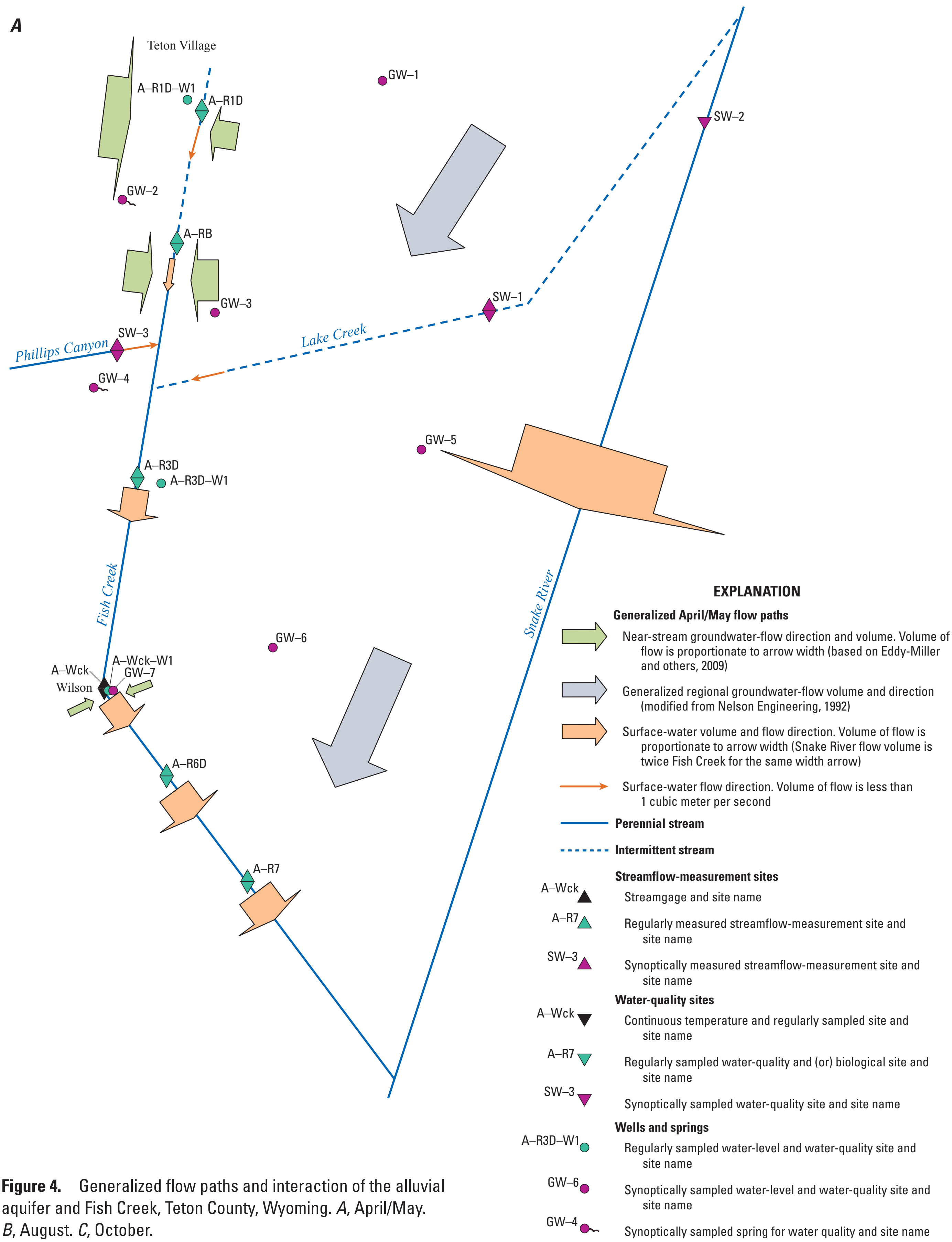


Figure 4. Generalized flow paths and interaction of the alluvial aquifer and Fish Creek, Teton County, Wyoming. *A*, April/May. *B*, August. *C*, October.

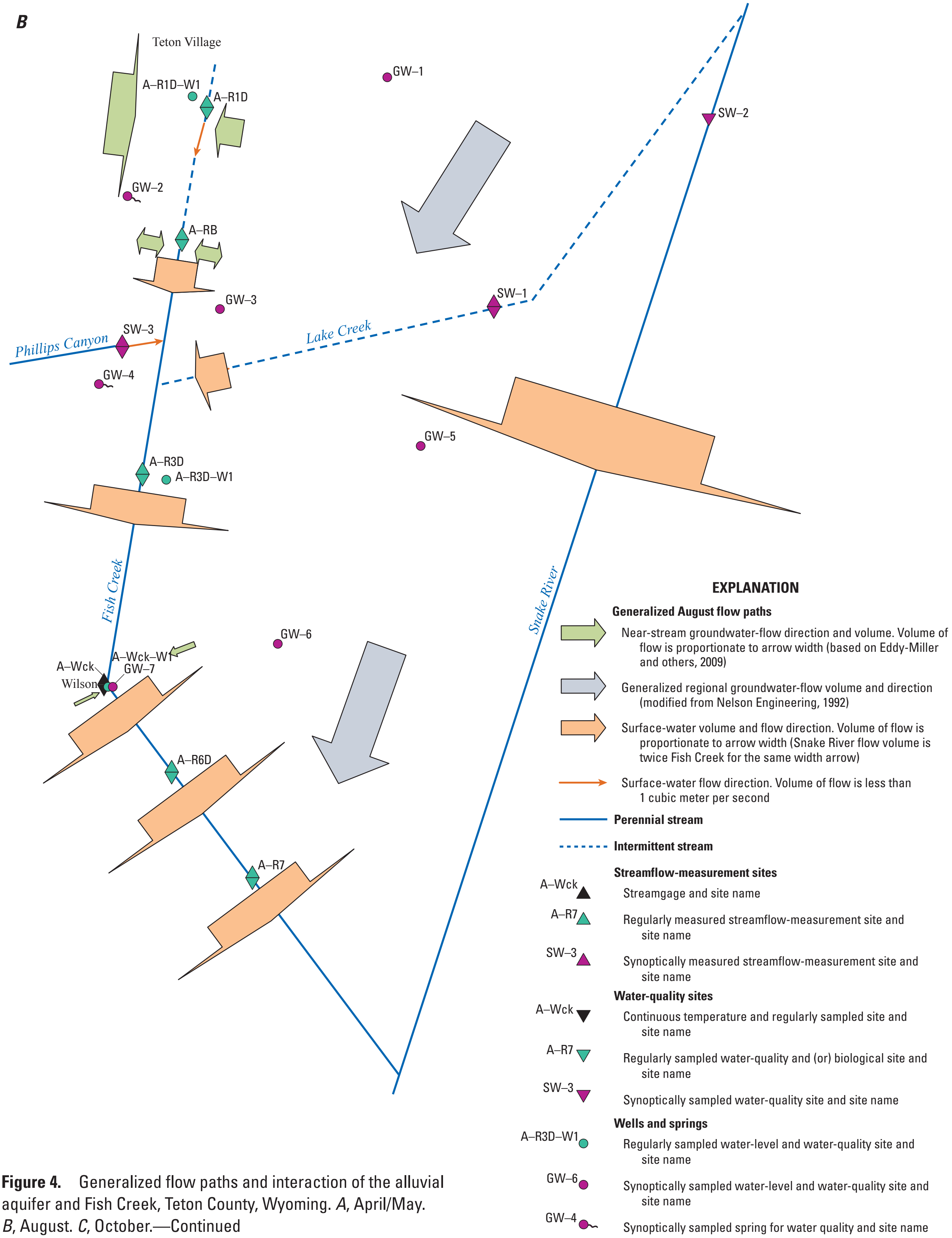


Figure 4. Generalized flow paths and interaction of the alluvial aquifer and Fish Creek, Teton County, Wyoming. *A*, April/May. *B*, August. *C*, October.—Continued

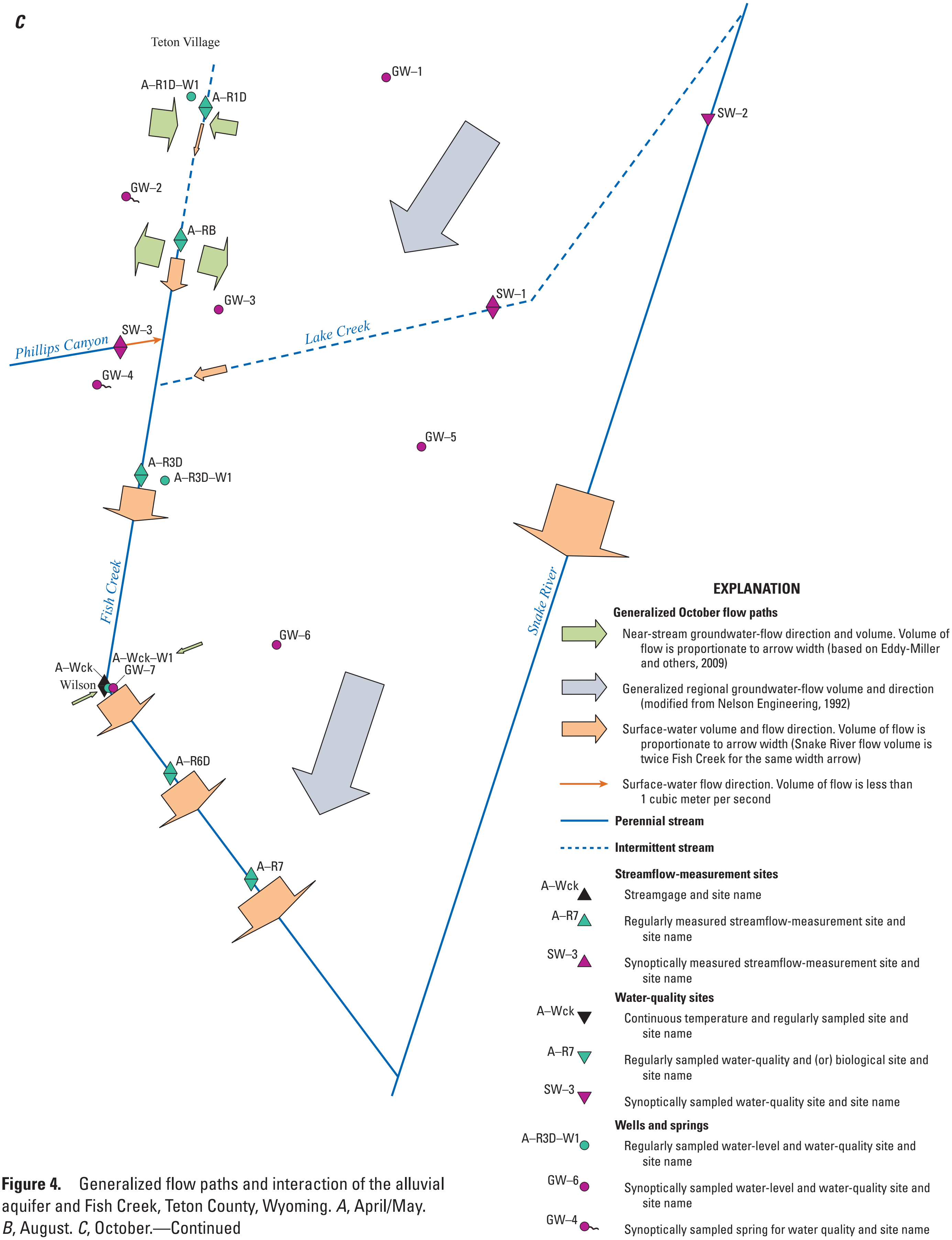


Figure 4. Generalized flow paths and interaction of the alluvial aquifer and Fish Creek, Teton County, Wyoming. *A*, April/May. *B*, August. *C*, October.—Continued

54 centimeters (cm) at an altitude of 1,960 m near Moose, Wyo., (National Climatic Data Center, 2012) to more than 178 cm in the Teton Range at altitudes above 3,000 m (Oregon Climate Service, 2010). At the Phillips Bench SNOTEL station (altitude of 2,500 m) located about 4 km west-northwest of the Wilson streamgage (fig. 2), the mean annual precipitation for the period 1971–2000 was 112 cm (Natural Resources Conservation Service, 2012).

Methods of Study Design and Sample Collection

Surface-water and groundwater sites were selected for regular sampling on the basis of their locations along the reach of Fish Creek from near the headwaters at Teton Village to a location about 3 km south of Wilson (Eddy-Miller and others, 2010). Additional surface-water sites and groundwater sites were sampled synoptically to evaluate nitrate and stable isotope concentrations from water upstream or upgradient from Fish Creek (table 1).

Study Design

Surface-water and groundwater sites were selected along the length of Fish Creek to characterize the streamflow, water-quality, and biological characteristics of the stream. Six surface-water sites, A–R1U (fig. 2 in Eddy-Miller and others, 2010), A–R1D, A–RB, A–R3D, A–Wck, and A–R6D (fig. 2), and three newly installed monitoring wells, A–R1D –W1, A–R3D–W1, and A–Wck–W1 (fig. 2), were sampled during 2007. These initial sites were selected, in part, to relate water-quality and biological sampling results to a seepage investigation (Wheeler and Eddy-Miller, 2005) and a groundwater/surface-water interaction study (Eddy-Miller and others, 2009) of Fish Creek. During the 2008–11 sampling efforts, surface-water sites A–R1U and A–R1D were discontinued as sampling sites for the full set of analyses (water-quality and biological sampling), but A–R1D remained a regularly sampled water-quality sampling site. Site A–R7 (fig. 2) was added as a sampling site for the full set of analyses (table 1). The six regularly sampled surface-water sites where water-quality samples were collected (sites A–R1D , A–RB, A–R3D, A–Wck, A–R6D, and A–R7) are described as regularly sampled sites. The five regularly sampled sites with perennial flow, where biological samples were collected (sites A–RB, A–R3D, A–Wck, A–R6D, and A–R7) are referred to in this report as the regularly sampled biological sites. The three regularly sampled groundwater sites where water-quality samples were collected (sites A–R1D –W1, A–R3D–W1, and A–Wck–W1) are described as regularly sampled sites.

After the 2007 sampling, sampling periods were chosen to coincide with late-season base flow in April/May (sampling between April 25 and May 9), the summer post peak-flow period in August (sampling between August 10 and 26), and fall base flow in October (sampling between October 17 and 25) (table 2). Details of the types of sampling that occurred at each site during 2007–08 and details of site setup and well completion information can be found in Eddy-Miller and others (2010).

Three surface-water sites and seven groundwater sites were sampled synoptically to augment water-quality data collected at regularly sampled sites (table 1). The synoptic samples were collected in April and October 2011 and are shown in table 2.

Sample Collection and Analysis

Eddy-Miller and others (2010) described in detail the data collection methods used during the first two years of the study (2007–08); the methods remained the same throughout the course of the study (2007-11). Physical properties were determined in the field for all surface-water and groundwater sites during each visit. Streamflow was measured at surface-water sites, and water-level data were collected at groundwater sites. Physical properties of dissolved oxygen, pH, specific conductance, and water temperature were measured at all surface-water and groundwater sites during each visit. Water-quality samples from Fish Creek and nearby groundwater sites were collected for analyses of nutrients and nitrate isotopes, depending on the sampling schedule (table 2). Biologic samples (aquatic plants and macroinvertebrates) were collected and habitat characteristics of streambed substrate (pebble count) and riparian canopy were measured at selected surface-water sites (table 2). At selected surface-water sites, aquatic plant communities were surveyed using the rapid periphyton survey and biologic samples were analyzed for algal taxonomy, chlorophyll-*a*, and macroinvertebrate taxonomy. All samples were collected and analyzed as described in Eddy-Miller and others (2010).

Accurate altitude and location data were needed for each surface-water/groundwater pair (A–R1D and A–R1D –W1, A–R3D and A–R3D–W1, and A–Wck and A–Wck–W1). In October 2011, the stream stage reference points and tops of casing for each monitoring well were surveyed using differential leveling to an accuracy of 0.001 m.

The isotopic signature of nitrate was used to help determine sources of nitrate in water. A nitrate molecule is composed of one nitrogen (N) atom and three oxygen (O) atoms. Isotopes of a particular element have the same number of protons in the atomic nucleus but different numbers of neutrons, resulting in different atomic masses (heavy or light isotopes). The relative abundance of the nitrogen and oxygen isotopes in nitrate can be precisely measured using mass spectrometry. Many chemical and physical processes can produce large variations in the relative abundance of nitrogen and oxygen isotopes in nitrate. This isotopic variability can be useful for distinguishing sources of nitrate (Böhlke and McMahon, 2009). In general terms, the oxygen isotopic composition

Table 1. Sampling sites on and near Fish Creek, Teton County, Wyoming, 2007–11.

[S, seasonal; P, perennial; m^3/s, cubic meters per second; m, meters; na, not applicable; E, estimated]

Site name	Station number	Station name	Reach type	Well depth (m)	Average instantaneous streamflow or spring discharge during water-quality sampling (2007–11) (m^3/s)	Average water level during water-quality sampling (2007–11) (m below land surface)	Number of instantaneous flow or water-level measurements
		Regularly sampled surface-water sites					
A–R1D	433438110495901	Fish Creek about 1 mile south of Teton Village, Wyo.	S	na	0.57	na	12
A–RB	433302110504701	Fish Creek 1/2 mile above Resor's Bridge, Wyo.	P	na	1.86	na	17
A–R3D	433117110515101	Fish Creek about 1.5 miles north of Wilson, Wyo.	P	na	5.23	na	17
A–Wck	13016450	Fish Creek at Wilson, Wyo.	P	na	5.49	na	17
A–R6D	432906110522601	Fish Creek about 1 mile south of Wilson, Wyo.	P	na	6.18	na	17
A–R7	432748110515301	Fish Creek at Crescent H Ranch, near Wilson, Wyo.	P	na	6.98	na	12
		Synoptically sampled surface-water sites					
SW–1	433247110491701	Lake Creek at State Highway 390, near Wilson, Wyo.	S	na	0.3	na	2
SW–2	433421110474101	Snake River at Rocking H Ranch near Teton Village, Wyo.	P	na	E106[1]	na	2
SW–3	433234110512601	Phillips Canyon at Fish Creek Road, near Wilson, Wyo.	P	na	0.15	na	2
		Regularly sampled groundwater sites					
A–R1D–W1	433431110501101	42-117-25bcd01	na	2.59	na	0.74	13
A–R3D–W1	433122110514201	41-117-15aaa01	na	2.68	na	0.80	14
A–Wck–W1	433005110521801	41-117-22dbb07	na	2.47	na	0.75	15
		Synoptically sampled groundwater sites					
GW–1	433417110492701	42-117-25dad01	na	E18[2]	na	E5	1
GW–2	433225110504101	42-117-35ddb01	na	spring	E0.02[3]	na	2
GW–3	433240110504601	41-117-02dab01	na	E18[2]	na	0.50	1
GW–4	433214110512801	41-117-11bba01	na	spring	E0.03[3]	na	2
GW–5	433157110501601	41-117-12bca01	na	E18[2]	na	2.34	1
GW–6	433028110514001	41-117-23bbb01	na	E18[2]	na	1.77	2
GW–7	433005110521701	41-117-22dbb08	na	E18[2]	na	0.76	1

[1]Streamflow estimated using measured streamflow values from Snake River streamgage at Moose, Wyo. (13013650).

[2]Estimate based on communication with drillers and landowners.

[3]Spring discharge estimated using volumetric measurements and calculations.

Table 2. Schedule for analyses of physical properties, water chemistry, aquatic plants, macroinvertebrates, and habitat at regularly sampled and synoptically sampled sites on and near Fish Creek, Teton County, Wyoming, 2009–11.

[Q, streamflow; WL, water level; IQW, instantaneous water quality; CQW, continuous water quality; N, nutrients; --, no sample scheduled or attempted; NI, nitrate isotopes; Ch, chlorophyll-*a*; AT, algal taxonomy; RPS, rapid periphyton survey; M, macroinvertebrate taxonomy; RC, riparian canopy; PC, pebble count; EF, equipment failure; SI, stable isotopes of water]

Regularly sampled sites									
Sampling types	Surface-water sites						Ground-water sites		
	A–R1D	A–RB	A–R3D	A–Wck	A–R6D	A–R7	A–R1D–W1	A–R3D–W1	A–Wck–W1
April/May 2009									
Physical properties	Q	Q	Q	Q	Q	Q	WL	WL	WL
	IQW	CQW	CQW	CQW	CQW	CQW	IQW	IQW	IQW
Water chemistry	N	N	N	N	N	N	N	N	N
	--	--	--	--	--	--	NI	--	--
Aquatic plants	--	Ch	Ch	Ch	Ch	Ch	--	--	--
	--	AT	AT	AT	AT	AT	--	--	--
	--	RPS	RPS	RPS	RPS	RPS	--	--	--
Macroinvertebrates	--	M	M	M	M	M	--	--	--
Habitat	--	RC	RC	RC	RC	RC	--	--	--
August 2009									
Physical properties	Q	Q	Q	Q	Q	Q	WL	WL	WL
	IQW	CQW	CQW	CQW	CQW	CQW	IQW	IQW	IQW
Water chemistry	N	N	N	N	N	N	N	N	N
Aquatic plants	--	Ch	Ch	Ch	Ch	Ch	--	--	--
	--	AT	AT	AT	AT	AT	--	--	--
	--	RPS	RPS	RPS	RPS	RPS	--	--	--
Macroinvertebrates	--	M	M	M	M	M	--	--	--
Habitat	--	RC	RC	RC	RC	RC	--	--	--
October 2009									
Physical properties	Q	Q	Q	Q	Q	Q	WL	WL	WL
	IQW	CQW	CQW	CQW	CQW	CQW	IQW	IQW	IQW
Water chemistry	N	N	N	N	N	N	N	N	N
Aquatic plants	--	Ch	Ch	Ch	Ch	Ch	--	--	--
	--	AT	AT	AT	AT	AT	--	--	--
	--	RPS	RPS	RPS	RPS	RPS	--	--	--
Habitat	--	PC	PC	PC	PC	PC	--	--	--
	--	RC	RC	RC	RC	RC	--	--	--
April/May 2010									
Physical properties	--	Q	Q	Q	Q	Q	WL	WL	WL
	--	CQW	CQW	CQW	CQW	CQW	IQW	IQW	IQW
Water chemistry	--	N	N	N	N	N	N	N	N
Aquatic plants	--	Ch	Ch	Ch	Ch	Ch	--	--	--
	--	AT	AT	AT	AT	AT	--	--	--
	--	RPS	RPS	RPS	RPS	RPS	--	--	--
Macroinvertebrates	--	M	M	M	M	M	--	--	--
Habitat	--	PC	PC	PC	PC	PC	--	--	--
August 2010									
Physical properties	Q	Q	Q	Q	Q	Q	WL	--	WL
	IQW	CQW	EF	CQW	CQW	CQW	IQW	--	IQW
Water chemistry	N	N	N	N	N	N	N	N	N
Aquatic plants	--	Ch	Ch	Ch	Ch	Ch	--	--	--
	--	AT	AT	AT	AT	AT	--	--	--
	--	RPS	RPS	RPS	RPS	RPS	--	--	--
Macroinvertebrates	--	M	M	M	M	M	--	--	--
Habitat	--	RC	RC	RC	RC	RC	--	--	--
October 2010									
Physical properties	Q	Q	Q	Q	Q	Q	WL	WL	WL
	IQW	CQW	CQW	CQW	CQW	CQW	IQW	IQW	IQW
Water chemistry	N	N	N	N	N	N	N	N	N

Table 2. Schedule for analyses of physical properties, water chemistry, aquatic plants, macroinvertebrates, and habitat at regularly sampled and synoptically sampled sites on and near Fish Creek, Teton County, Wyoming, 2009–11.—Continued

[Q, streamflow; WL, water level; IQW, instantaneous water quality; CQW, continuous water quality; N, nutrients; --, no sample scheduled or attempted; NI, nitrate isotopes; Ch, chlorophyll-*a*; AT, algal taxonomy; RPS, rapid periphyton survey; M, macroinvertebrate taxonomy; RC, riparian canopy; PC, pebble count; EF, equipment failure; SI, stable isotopes of water]

Regularly sampled sites									
Sampling types	Surface-water sites						Ground-water sites		
	A–R1D	A–RB	A–R3D	A–Wck	A–R6D	A–R7	A–R1D–W1	A–R3D–W1	A–Wck–W1
Aquatic plants	--	Ch	Ch	Ch	Ch	Ch	--	--	--
	--	AT	AT	AT	AT	AT	--	--	--
	--	RPS	RPS	RPS	RPS	RPS	--	--	--
Habitat	--	PC	PC	PC	PC	PC	--	--	--
April/May 2011									
Physical properties	Q	Q	Q	Q	Q	Q	WL	WL	WL
	IQW	CQW	CQW	CQW	CQW	CQW	IQW	IQW	IQW
Water chemistry	N	N	N	N	N	N	N	N	N
	NI	NI	NI	NI	NI	NI	NI	NI	NI
	SI	SI	SI	SI	SI	SI	SI	SI	SI
Aquatic plants	--	Ch	Ch	Ch	Ch	Ch	--	--	--
	--	AT	AT	AT	AT	AT	--	--	--
	--	RPS	RPS	RPS	RPS	RPS	--	--	--
Macroinvertebrates	--	M	M	M	M	M	--	--	--
Habitat	--	RC	RC	RC	RC	RC	--	--	--
August 2011									
Physical properties	Q	Q	Q	Q	Q	Q	WL	WL	WL
	--	CQW	CQW	CQW	CQW	CQW	IQW	IQW	IQW
Water chemistry	N	N	N	N	N	N	N	N	N
	NI	NI	NI	--	NI	--	NI	NI	NI
	SI	SI	SI	SI	SI	--	SI	SI	SI
Aquatic plants	--	Ch	Ch	Ch	Ch	Ch	--	--	--
	--	AT	AT	AT	AT	AT	--	--	--
	--	RPS	RPS	RPS	RPS	RPS	--	--	--
Macroinvertebrates	--	M	M	M	M	M	--	--	--
Habitat	--	--	--	--	--	--	--	--	--
October 2011									
Physical properties	Q	Q	Q	Q	Q	Q	WL	WL	WL
	IQW	CQW	CQW	CQW	CQW	CQW	IQW	IQW	IQW
Water chemistry	N	N	N	N	N	N	N	N	N
	NI	NI	NI	--	--	--	NI	NI	NI
	SI	SI	SI	--	--	--	SI	SI	SI
Aquatic plants	--	Ch	Ch	Ch	Ch	Ch	--	--	--
	--	AT	AT	AT	AT	AT	--	--	--
	--	RPS	RPS	RPS	RPS	RPS	--	--	--
Habitat	--	PC	PC	PC	PC	PC	--	--	--

Synoptically sampled sites										
Sampling types	Surface-water sites			Groundwater sites						
	SW–1	SW–2	SW–3	GW–1	GW–2	GW–3	GW–4	GW–5	GW–6	GW–7
April 2011										
Physical properties	Q	Q	Q	WL	NA	WL	NA	WL	WL	WL
	IQW	IQW	IQW	IQW	IQW	IQW	IQW	IQW	IQW	IQW
Water chemistry	N	N	N	N	N	N	N	N	N	N
	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI
	SI	SI	SI	SI	SI	SI	SI	--	SI	SI
October 2011										
Physical properties	Q	Q	Q	--	NA	--	NA	--	WL	--
	IQW	IQW	IQW	--	IQW	--	IQW	--	IQW	--
Water chemistry	N	N	N	--	N	--	N	--	N	--
	--	--	NI	--	NI	--	NI	--	NI	--
	SI	SI	SI	--	SI	--	SI	--	SI	--

(^{18}O and ^{16}O) of nitrate indicates how the nitrate was formed, whereas the nitrogen isotopic composition (^{15}N and ^{14}N) can help discern the sources of the nitrate (Clark and Fritz, 1997; Kendall and McDonnell, 1998).

Stable isotopes typically are reported using delta (δ) notation, which compares the ratio between heavy and light isotopes of a sample to that of a reference standard. Delta values are expressed as a difference in parts per thousand, or per mil, from values of a reference standard. In this report, $\delta^{15}N$ ($^{15}N/^{14}N$) values are reported in per mil relative to atmospheric nitrogen (AIR), and $\delta^{18}O$ ($^{18}O/^{16}O$) values are reported in per mil relative to Vienna Standard Mean Ocean Water (VSMOW). The value for δ is calculated using the following equation (Clark and Fritz, 1997):

$$\delta \text{ (in per mil)} = [(Rx/Rs) - 1] \times 1{,}000 \quad (1)$$

where

Rx is the ratio of the heavy-to-light isotope of the sample, and

Rs is the ratio of the heavy-to-light isotope of the applicable reference standard (AIR or VSMOW).

In order to help understand the source of nitrate to the Fish Creek drainage basin, 53 samples were collected from Fish Creek and nearby groundwater for analyses of nitrogen and oxygen isotopes of nitrate (NO_3). One pair of replicate samples also was collected and analyzed; the differences were 0.02 per mil for $\delta^{15}N$ [NO_3] and 1.13 per mil for $\delta^{18}O$ [NO_3].

Methods of Data Analysis

Eddy-Miller and others (2010) described data collected during the first two years of the study (2007–08), but three additional years of data (2009–11) created a more robust dataset and enabled the use of statistical analysis to better describe the data and ecosystem relations. Statistical comparisons of water quality, aquatic plant communities, and algal and macroinvertebrate metrics were performed using S+ (TIBCO Software Inc., 2008) with a significance level (p) for all tests of 0.05. Following procedures described by Helsel and Hirsch (1992), Kruskal-Wallis rank sum tests were used to test for significant differences in characteristics and metrics between sites, years, and seasons. Relations among and between characteristics and metrics deemed to be significant (that is, $p < 0.05$) were further tested with analysis of variance (ANOVA) using Tukey's method for multiple comparisons on rank-transformed data (Helsel and Hirsch, 1992). Water-quality and algal and macroinvertebrate abundance data were rank-transformed before a Spearman's correlation coefficient (rho) and associated significance level (ρ) were determined (Helsel and Hirsch, 1992). Values of ρ generally can range from 0.00 (no correlation) to 1.00 (complete correlation) and were considered significant at $\rho < 0.05$.

Cumulative flow curves showing the total volume of runoff at the Wilson streamgage from the beginning of the water year to a particular day were created by summarizing the computed daily flows (U.S. Geological Survey, 2012a) from each day beyond the first day of the water year to that particular day. The cumulative flow curves for the lowest and highest runoff years used daily data from each day of the lowest and highest runoff years, respectively. The cumulative flow curves for the average year used the average daily flow for each of the 365 days of the year, and therefore does not represent an actual year.

Methods for Determining Stream Channel Changes through Time

Photogrammetric analysis of Fish Creek was used to quantify historical changes in the stream channel using techniques similar to those employed on Salt Creek in Utah (Anne Brasher, U.S. Geological Survey, oral commun., 2012). Imagery from 1945, 1983, and 2009 were used. Images from 1945 and 1983 were the highest quality from the historical time period and spanned the years of available images. All images had a maximum 1-m spatial resolution in order to have the most accurate evaluation of changes over time. All images were obtained from the Teton Conservation District (2011). The 1945 imagery is black and white aerial photography with 0.6-m spatial resolution, acquired in the summer of 1945 and orthorectified by Aero-Graphics, Inc., in 2010. The 1983 scene is near-infrared aerial photography (NAIP) with 1-m spatial resolution produced by the U.S. Department of Agriculture (USDA). The 2009 imagery is also USDA NAIP (*http://www.fsa.usda.gov/FSA/apfoapp?area=home&subject=prog&topic=nai*) with 1-m spatial resolution obtained from the NAIP ArcGIS Image Server.

Five sections were selected for stream channel evaluations to correspond with the five regularly sampled biological sites (A–RB, A–R3D, A–Wck, A–R6D, and A–R7). For each site, the stream channel approximately 500 m upstream and approximately 500 m downstream from each site was delineated using polygons in a geographic information system, ArcMap 9.3 (Esri, Redlands, California; *http://www.esri.com/*), at a scale less than 1:1,000. Because each scene was acquired in the summer, it is assumed that the streamflow was at or near the maximum annual stream width, so the water surface was used as the key component for delineating the active stream channel. Contrast was increased in the imagery to make the water appear darker and therefore easier to distinguish from the bank, resulting in a more discernible stream channel boundary.

Methods for Determining Bedload Transport

Bedload transport at two sites on Fish Creek, A–R3D and A–R6D, was calculated to better understand streambed stability. For each site, the potential for the median sediment-particle size to become mobilized (entrainment potential) was calculated using methods and equations described in Elliott and others (2011). Median sediment-particle size from pebble counts, and area and wetted perimeter from streamflow measurements were used for the calculations. Streambed slopes were calculated for each reach length using a USGS 1:24,000-scale topographic map.

Hydrologic Characteristics

Streamflow in Fish Creek is unique because of several geologic and hydrologic factors. Channel morphology and bedload transport potential were analyzed and used to describe the stream channel stability. Streamflow in Fish Creek was analyzed using data from the Wilson streamgage and climatic data from two stations near Fish Creek. Data collected for this study and results from Eddy-Miller and others (2009) were used to describe the interaction of surface water and groundwater in the area near Fish Creek.

Stream Characteristics

The main stem of Fish Creek parallels the mountain front and is a relatively linear channel along most of its upper reach. In its lower reach, at and downstream from Wilson, some gradual sinuosity occurs and there is evidence of historical meanders; however, analyses performed for this study demonstrates that relative morphologic stability has existed for at least 65 years along at least three sections in this area. Channel and bed characteristics are influenced by a relatively low streambed gradient, coarse bed material, and the flow regime.

Channel Morphology

Photogrammetric analysis of Fish Creek was used to quantify historical changes in the stream channel and is shown on figure 5. A summary of the total area of each reach length is shown in table 3. Of note is the relative similarity between the total area calculations for 1945 and 2009 at site A–Wck (co-located with the Wilson streamgage). The lack of change to overall width and the continuity of the meander in the center of the reach demonstrate the general morphologic stability of the channel at this location, as well as land uses, primarily residential, that do not markedly accelerate erosion and widening of the channel.

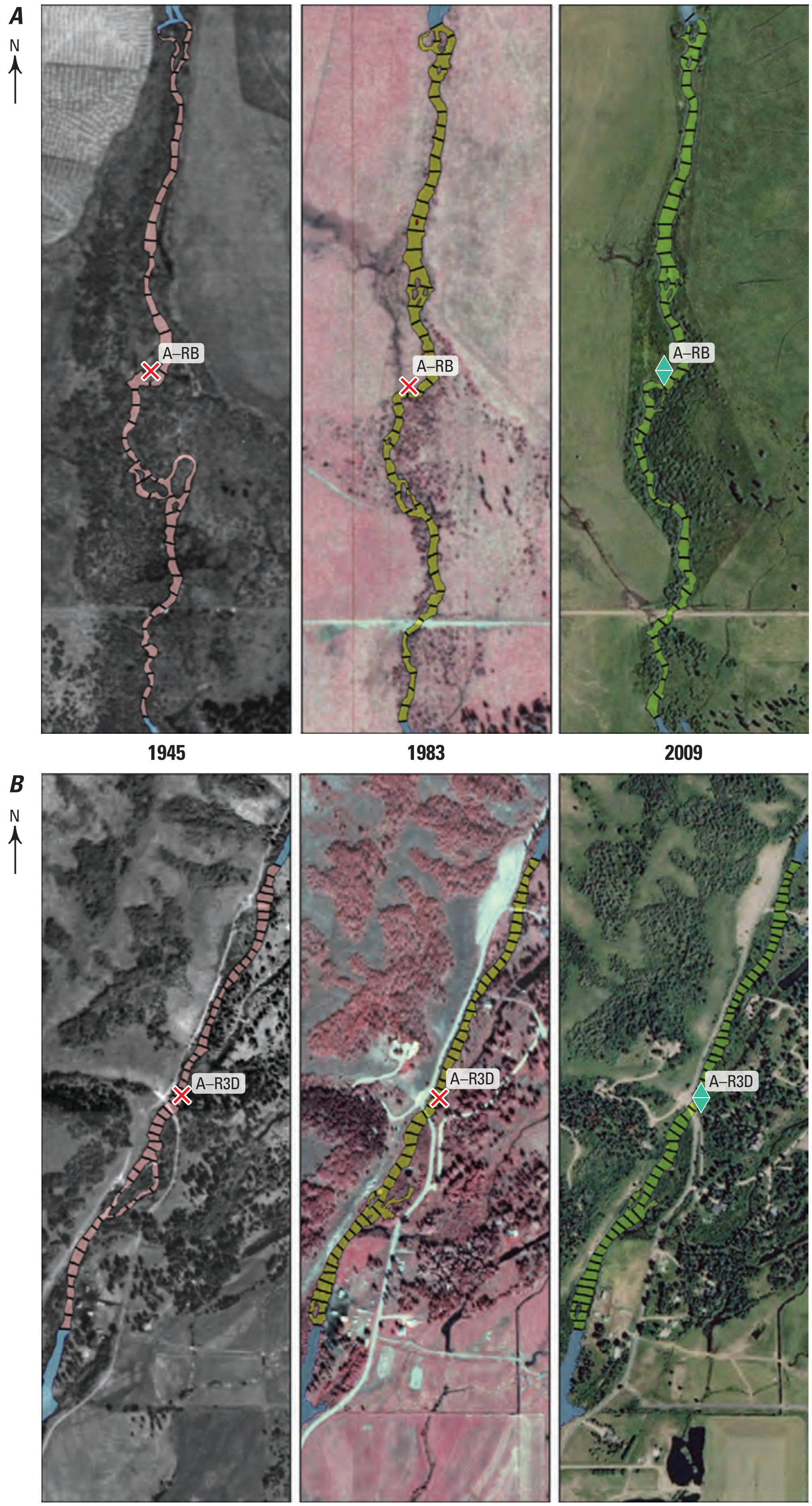
Bedload Transport and Channel Stability

Fish Creek typically carries minimal amounts of sediment, either suspended or as bedload. Suspended sediment is material moved and maintained in suspension by the upward component of turbulent currents, whereas bedload is sediment that is moved by rolling or skipping on or near the stream bed (Edwards and Glysson, 1999). Field observations between 2004 and 2011 only noted suspended sediment during one sampling period, August 2009. Exceptions to the suspended load observations can include sediment pulses derived from landslides affecting tributaries along the nearby mountain front, overland runoff during periods of rapid snowmelt, or localized human activities. These events typically are both infrequent and short in duration.

During the study period, it was observed that coarse streambed material in Fish Creek is relatively immobile. A small amount of streambed material movement along riffles and higher velocity sections exists, but large-scale movement and bed material replenishment appear to be limited in the system. This observation is supported by the lack of point bar development or aggradation of sediment over several years of flows large enough to incur large channel geometry changes in expected locations. In addition, the continuity in the distribution of streambed particle size among each of the five study years also lends support to this observation. Sediments typically are large gravel to medium cobble and have relatively consistent particle-size distribution at each site (fig. 6). Sediment size distribution obtained with pebble counts also was consistent for a given site from year to year during the course of the five-year study, even as the stream encountered a wide variety of peak flows. Fine silt, sand, and gravel accumulations were observed in the creek, typically on the inside of channel bends and in lower velocity pools. Areas of mid-channel deposition of fines also were present occasionally but appeared to be held in traction by biota.

Entrainment, or the mobilization of sediment by flowing water, is one mechanism by which channels undergo change. The ability of a channel to transport sediment depends on the slope of the streambed and related stream velocity and on the size of sediment particles. This process includes the transport of coarse bed sediment for channel geometry maintenance and the flushing of fine sediments and gravel from around cobbles (Elliott and others, 2011).

The potential for bed movement in Fish Creek was estimated for two sampled reaches with perennial flow. Sites A–R3D and A–R6D were selected because of their location downstream from the Lake Creek confluence, which would potentially lead to larger streamflow and therefore the best chance for movement, and because of their representative position in upper and lower reaches of Fish Creek. At both sites, it was determined that the amount of flow needed to continually mobilize the bed material (median sediment-particle size) and therefore result in streambed change would exist only at stream stages above the top of at least one streambank. For site A–R3D, widespread bed movement would occur only when stream depths approached 1.5 m to 2.0 m. For site A–R6D, this movement would require stream depths of approximately 1.5 m. Both of these depth approximations exceed the current site channel configurations and are above the top of the streambank, so that amount of flow likely would result in overbank flooding rather than channel movement. In the upper reach of Fish Creek, the bed stability likely would be greater



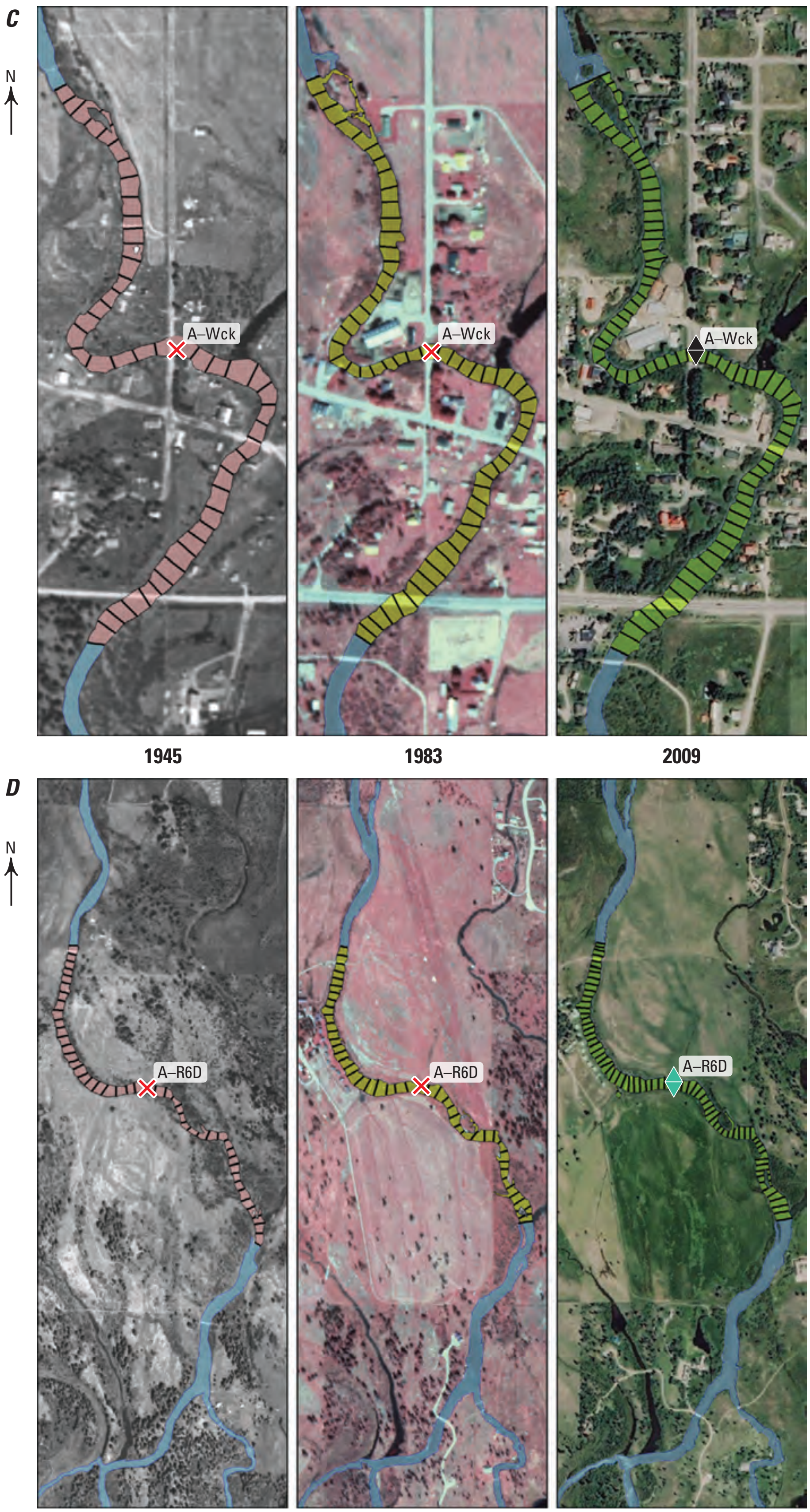
EXPLANATION

Colored polygons represent area of stream channel used in geographic information system analysis

A–RB Regularly measured streamflow-measurement, and water-quality and (or) biological site and site name

Location of site sampled 2007–11

Figure 5. Stream channel delineations in 1945, 1983, and 2009 for the five regularly sampled biological sites, Fish Creek, Teton County, Wyoming. The scales of the photos vary, but the length of the colored portion of the reach is 1 kilometer in each photo. *A*, A–RB. *B*, A–R3D. *C*, A–Wck. *D*, A–R6D. *E*, A–R7.



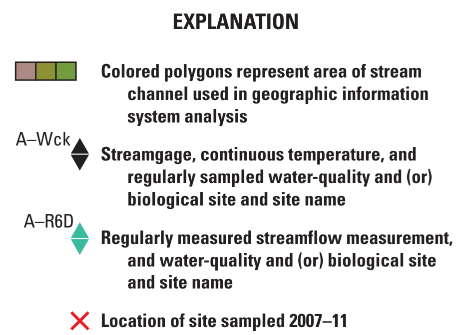


Figure 5. Stream channel delineations in 1945, 1983, and 2009 for the five regularly sampled biological sites, Fish Creek, Teton County, Wyoming. The scales of the photos vary, but the length of the colored portion of the reach is 1 kilometer in each photo. *A*, A–RB. *B*, A–R3D. *C*, A–Wck. *D*, A–R6D. *E*, A–R7.—Continued

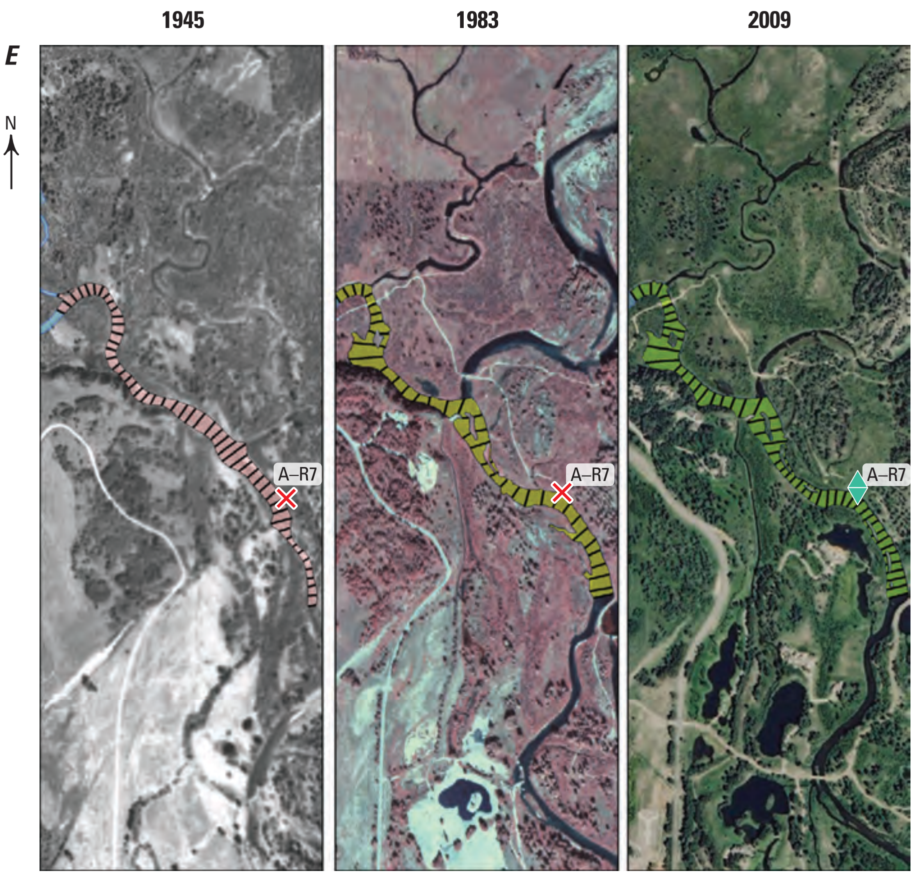


Figure 5. Stream channel delineations in 1945, 1983, and 2009 for the five regularly sampled biological sites, Fish Creek, Teton County, Wyoming. The scales of the photos vary, but the length of the colored portion of the reach is 1 kilometer in each photo. *A*, A–RB. *B*, A–R3D. *C*, A–Wck. *D*, A–R6D. *E*, A–R7.—Continued

Table 3. Area of a 1-kilometer length of stream channel in 1945, 1983, and 2009 at sites A–RB, A–R3D, A–Wck, A–R6D, and A–R7, Fish Creek, Teton County, Wyoming.

[m^2, square meters]

Site	Area of each reach by year (m^2)		
	1945	1983	2009
A–RB	10,000	12,000	12,000
A–R3D	18,000	21,000	22,000
A–Wck	22,000	21,000	22,000
A–R6D	21,000	24,000	27,000
A–R7	26,000	32,000	34,000

than or equal to the lower reach because the bed slope and the streamflow decreased comparatively at sites upstream from Lake Creek.

Channel morphology and bedload transport can be used in tandem to describe streambed characteristics. Channel morphology showed some changes occurring at different sites between some of the time periods analyzed (table 3). Of note, however, is that between 1945 and 2009 the stream channel upstream and downstream from site A–Wck, a high-angle meander (fig. 5*C*), showed little change. The lack of channel change at this site supports the theory that Fish Creek does not create enough shear stress to change the channel by flow alone. Changes in the channel morphology at other sites, as shown in table 3 and figure 5, are more likely caused by human changes to either land use or hydrology.

Climate Characterization during Study

Temperature and precipitation, snowpack in particular, were evaluated for the study period to determine relations between climatic variables and streamflow in Fish Creek and to assess the variation that occurred during the study years. Mean monthly temperatures at an altitude of 1,960 m at the Moose, Wyo., climate station ranged from -13.5°C during January to 21.0°C during July for the 2007–2011 study period (National Climatic Data Center, 2012). Average daily temperatures range from around -20°C during the winter to around 20°C during the summer (fig. 7). During the study period, annual mean temperatures ranged from -0.8°C in 2011 to 4.6°C in 2007. Precipitation varies during the year, with a general pattern of snowfall in the late fall, winter, and early spring and intermittent thunderstorm rain events and

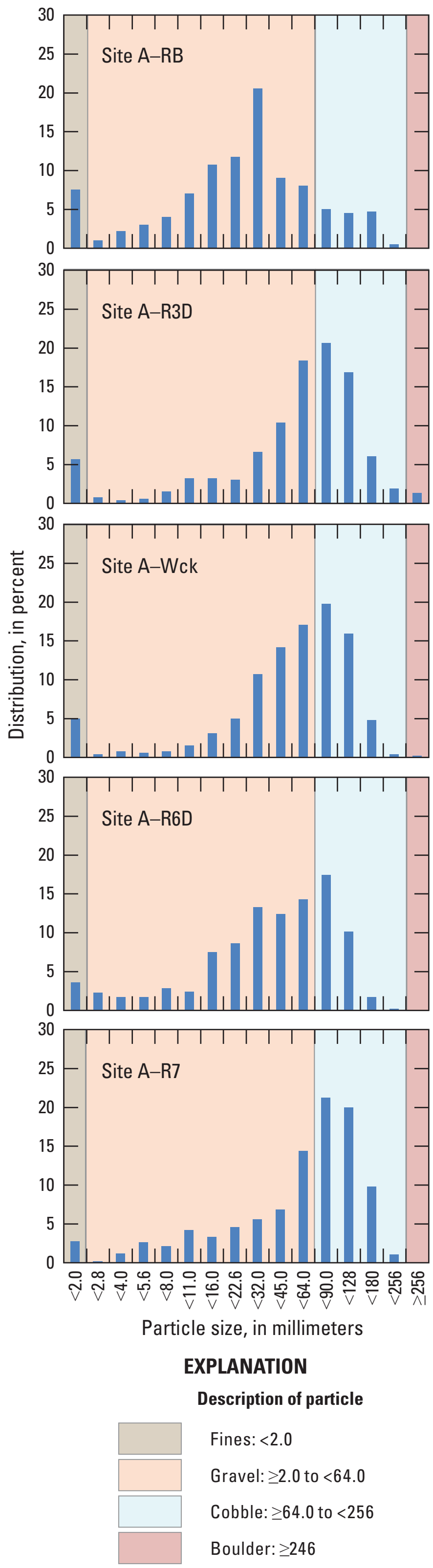


Figure 6. Average streambed substrate size distribution at the five regularly sampled biological sites on Fish Creek, Teton County, Wyoming, 2008–11. (<, less than; ≥, greater than or equal to)

regional rain events in the summer. Annual total precipitation data collected at the Moose, Wyo., climate station during the study period ranged from 41.9 cm in 2007 to 70.1 cm in 2010. Total snowfall on the valley floor at the Moose site ranged from 290 cm in 2007 to 510 cm in 2008. During 2011, when mountain snowpack was well above average, total snowfall at Moose was 460 cm (National Climatic Data Center, 2012).

Snowpack and precipitation data from the Phillips Bench SNOTEL site (2,500 m), approximately 5 km west-southwest of Resor's Bridge, was evaluated in relation to streamflows recorded at the Wilson streamgage for the five-year study period. For each year, daily snow-water equivalent (SWE) and precipitation values were compared to the 30-year median SWE and 30-year average precipitation values (1981–2010) for the Phillips Bench SNOTEL site (Natural Resources Conservation Service, 2012). This comparison, coupled with daily snow depth data, was used to help determine the variability of the snowpack conditions prior to melt that were encountered during the study. Also included in the comparison are SWE and precipitation values for 1997 when the instantaneous peak streamflow of record occurred at the Wilson streamgage. As expected, peak streamflow timing and magnitude are largely affected by the amount of snowpack and how quickly complete melting occurs (table 4). In addition to affecting instantaneous peak streamflows, the snowpack and local climatic conditions also affect the overall duration of the high-flow. Peak streamflows in Fish Creek during the study period ranged from nearly the highest measured at Fish Creek (rank of 2 out of 18 years) in 2011 to the nearly the lowest (rank of 14 out of 18 years) in 2007 (table 4).

In general, 2007 was the warmest of the study years, 2010 was the driest, and 2011 was the coolest and had the highest precipitation values at higher altitudes. The yearly measurements of snow depth and SWE values on April 15 generally support this comparison, with snowpack below normal for 2006–07 (water year 2007) and 2009–10 (water year 2010), near and just above normal for 2007–08 and 2008–09 (water years 2008 and 2009, respectively), and substantially above normal for 2010–11 (water year 2011); a water year is the 12-month period, October 1 through September 30, and is designated by the calendar year in which it ends. Snow depth variability between the study years showed a wide range, with nearly twice the amount of snow left in the mountains on April 15 in 2011 than in 2007. Snow depth data were not available for 1997, but SWE and precipitation values between 1997 and 2011 were similar. The estimated complete snowmelt date was two weeks earlier in 1997 than in 2011. Study years 2008 and 2009 had similar climate and snowpack conditions and similar complete snowmelt dates. The range of streamflow and climatic variation that occurred during the study period (table 4), shows that 2007–11 were not solely drought years or wet years. These analyses also show the effect of snowmelt on Fish Creek's dynamic flow regime.

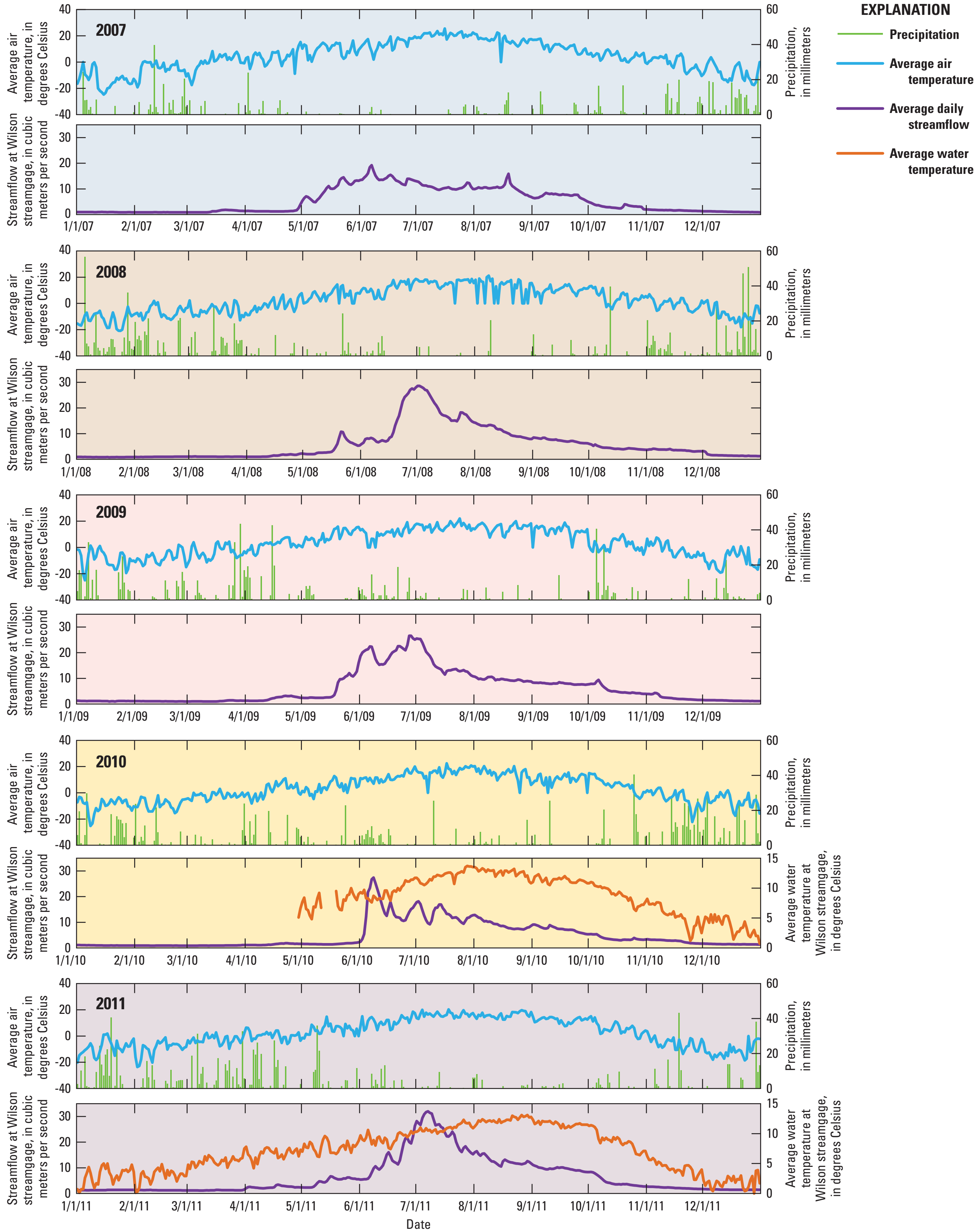


Figure 7. Mean daily temperature and daily precipitation measured at the National Oceanic and Atmospheric Administration climate station 486428 in Moose, Wyoming, and mean daily streamflow and temperature measured at Wilson streamgage (station 13016450), by year, Fish Creek, Teton County, Wyoming, 2007–11. (Date given in month/day/year format)

Table 4. Climatic data for Moose and Phillips Bench, Wyoming, stations and streamflow data at the Wilson streamgage, Fish Creek, Teton County, Wyoming, 2007–11.

[Long-term average for peak streamflows is based on 18 years (1994–2011) of streamflow data; long-term median for SWE and long-term average for accumulated precipitation at SNOTEL site is based on 30 years (1981–2011) of data. Date given in month/day/year format; NOAA, National Oceanic and Atmospheric Administration; m3/s, cubic meters per second; SWE, snow-water equivalent; cm, centimeters; --, not applicable or not calculated]

Year	Climatic data at NOAA climate station in Moose, Wyo.			Streamflow at Fish Creek at Wilson streamgage[2]			Climatic data at Phillips Bench SNOTEL site[3]			
	Average high temperature[1] (degrees Celsius)	Average low temperature[1] (degrees Celsius)	Average precipitation[1] (centimeters)	Peak streamflow (m^3/s)	Date of peak streamflow	Rank of peak streamflow	April 15 SWE (cm)	April 15 snow depth (cm)	April 15 accumulated precipitation (cm)	Complete snow-melt date
2007	13.10	-3.94	41.9	20.5	6/6/2007	14	47.0	117.0	60.2	5/19/2007
2008	11.11	-5.74	54.9	29.4	7/1/2008	6	90.4	226.0	94.5	6/25/2008
2009	11.56	-5.42	55.1	27.6	6/28/2009	10	76.5	218.0	82.3	6/13/2008
2010	11.57	-5.53	70.1	28.6	6/8/2010	8	48.5	152.0	52.6	6/11/2008
2011	10.99	-6.29	66.5	32.8	7/7/2011	2	94.7	257.0	94.5	7/5/2008
Long-term average	--	--	--	26.4	--	--	66.0	--	72.6	--

[1]Data from National Climatic Data Center (2012) for National Oceanic and Atmospheric Administration climate station 486428 in Moose, Wyoming.

[2]Data from U.S. Geological Survey (2013b) for station 13016450.

[3]Data from Natural Resources Conservation Service (2012) Phillips Bench SNOTEL site.

Streamflow

Instantaneous streamflow and stream-stage measurements made during the collection of water-quality and biologic samples at surface-water sites during 2007–11 are included in *table 5* (Microsoft® Excel format). Instantaneous streamflow at the five regularly sampled biological sites ranged from an estimated 0.01 cubic meters per second (m^3/s) at site A–RB to 13 m^3/s at sites A–R6D and A–R7, indicating that water-quality samples were collected during a wide variety of hydrologic conditions.

Streamflow in Fish Creek is affected by groundwater inflow, snowmelt runoff, tributary inflow, irrigation diversions, and irrigation return flows. Streamflow at the Wilson streamgage has been continuously measured since March 1994 (U.S. Geological Survey, 2012a). Streamflow at the Wilson streamgage is about 1.1 m^3/s, during base-flow conditions, and typically is greater than 14 m^3/s during mid-May to mid-July (Wheeler and Eddy-Miller, 2005). Peak streamflow generally occurs between mid-May and early July with a prolonged recession to base flow conditions from mid-July into mid- to late November (fig. 7). The period of recession consists of two general components: (1) an initial, steep drop in flows as the snowpack diminishes that typically lasts into late July and early August and (2) a more gradual attenuation of flows from August to November affected by several factors including groundwater input flows, flow in Snake River, and irrigation practices that largely translate through the primary tributary, Lake Creek. Streamflow data for Lake Creek (U.S. Geological Survey, 2012a) collected seasonally from April to September in 2009 and 2010 indicate that this tributary contributes approximately 40 percent of the flow in Fish Creek. This flow includes both natural runoff during the early part of the season and irrigation flow during other time periods.

During this study, flow conditions were variable and ranged widely in timing, magnitude, and duration as related to sampling events (U.S. Geological Survey, 2013a). The median peak streamflow at the Wilson streamgage is 28.6 m^3/s (U.S. Geological Survey, 2013b). Peak streamflow values collected during the study ranged from 20.5 m^3/s in 2007 to 32.9 m^3/s in 2011. The highest peak streamflow for the period of gaged record (1994-2011) was 40.5 m^3/s in 1997.

During water years 2007 and 2010, a below average snowpack and warm temperatures produced an early streamflow peak that receded to typical summer flows fairly rapidly. A larger instantaneous peak occurred in 2010 due to the rapid rise in streamflow associated with warm temperatures and rapid snowmelt (fig. 7) and receded over a relatively short period of time.

During 2008 and 2009, the snowpack was above average and peak streamflows were near the median. Snowpack was slightly greater in 2008 than in 2009, but the rate at which melt occurred was slightly faster in 2009. This combination produced peak streamflows that were similar in magnitude and timing for both years. Recessional flows were higher in 2008 than in 2009 through mid-August, likely due to the larger snowpack and slightly cooler temperatures of 2008. However, by the end of August, the computed daily flows for 2008 had dropped below those for 2009 for the remainder of the water year.

In contrast, a heavy snowpack and cooler temperatures occurred during water year 2011, which produced not only the highest peak of the study period but also the longest duration of higher flows (fig. 7). Maximum SWE values at the Phillips Bench SNOTEL station for 2011 were similar to 1997 (highest streamflow peak) and the second highest peak streamflow of record occurred during 2011. The rate of runoff for 2011 lagged behind 1997 because of a lingering snowpack.

Cumulative streamflow curves for water years 2007–2011 were plotted with selected statistics based on data for water years 1995–2011 and show the differences in volume of runoff that passed by the Wilson streamgage during each year of the study (fig. 8). The shape of the curve along the corresponding timeline shows flow conditions present during sampling and overall flow conditions for a particular water year. Cumulative streamflow for 2007 began and ended the year near the average, even though runoff began and finished early. Higher flows in August boosted cumulative streamflow values back to near the average (fig. 8). Cumulative streamflow for 2008 and 2009 were both above average, as expected; however, September 2008 flows were lower than those for September 2009. During 2009, an initial peak occurred around the first of June at more than one-half of the annual peak, which increased the cumulative streamflow during this part of the record. The two years with the most noticeable difference are 2010 and 2011. The flow-duration curve for 2010 shows the brief and rapid snowmelt peak that receded quickly; it also shows that the July streamflow for that year was the same as the July streamflow for the lowest year of the record period. Flows in the creek derived from irrigation during August and September 2010 sustained the flow above the lowest cumulative flow on record. In contrast, sustained flows during the high-water period in 2011 produced record cumulative flow values for the period recorded at the Wilson streamgage.

Groundwater and Groundwater/Surface-Water Interactions

Groundwater-level measurements made during the collection of water-quality samples at monitoring wells are shown in *table 6* (Microsoft® Excel format). Measurements indicate the groundwater levels are less dynamic (fluctuate less) in the lower reaches of Fish Creek (wells A–R3D–W1 and A–Wck–W1) than in the area near Teton village (well A–R1D–W1) (table 6 and U.S. Geological Survey, 2013c). The difference in maximum and minimum water levels at wells A–R3D–W1 and A–Wck–W1 was about 0.4 m and 0.5 m, respectively. The difference in well A–R1D–W1 was more than the depth of the well, 2.3 m, because the water level near well A–R1D–W1 was lower than the bottom of the well during the winter. These results are similar to those found in

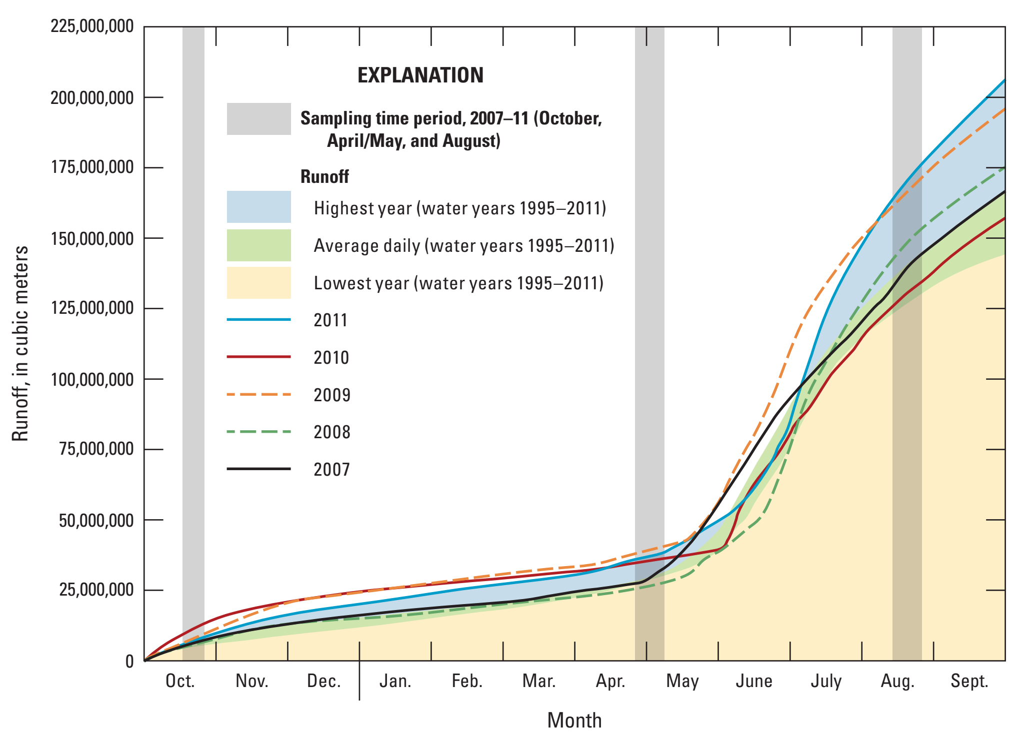


Figure 8. Cumulative flow duration curves for water years 2007–11 as measured at the Wilson streamgage (station 13016450), Fish Creek, Teton County, Wyoming.

Eddy-Miller and others (2009), Nolan and Miller (1995), and Nelson Engineering (1992).

The altitude of groundwater levels (hydraulic head) in the three monitoring wells were calculated using the surveyed altitude of the top of each well casing. The altitude of the groundwater level then was compared to the altitude (stage) of Fish Creek at the paired surface-water site, and these data, in combination with the distance between the paired sites, were used to determine a groundwater-surface slope (fig. 9). The groundwater-surface slope can be assumed to be the hydraulic gradient for these localized areas of the alluvial aquifer.

The groundwater-surface slope calculated for each site shows not only that the altitude of the groundwater levels fluctuate more at well A–R1D–W1 compared to the two other wells, but also that the groundwater-surface slope is more dynamic throughout the year in the upper reach of Fish Creek near Teton Village (fig. 9). The other two paired sites showed less change throughout the year with regard to the groundwater-surface slope. Figure 9 shows that, at each site, the groundwater-surface slope may have been different between seasons but was consistent during the same season each year. These findings, in particular the relative change in groundwater-surface slope over the span of a year, agree with flux values modeled for 2005–06 data collected at the sites near pair A–R1D and A–R1D–W1 (modeled site Teton Village cross section) and pair A–Wck and A–Wck–W1 (modeled site Wilson) (Eddy-Miller and others, 2009).

Water-Quality Characterizations

Water-quality properties and water-chemistry analyses were used to characterize the water quality of Fish Creek from the upper part of the stream near the headwaters to the most downstream site near its confluence with Snake River. Properties were measured at and samples collected from the six regularly sampled surface-water sites (site A–R1D in addition to the five regularly sampled biological sites) and three regularly sampled groundwater sites, as well as the synoptically sampled surface-water and groundwater sites. The sampling schedule during spring (April/May), summer (August), and fall (October) helped to characterize seasonal characteristics of the stream.

Water-Quality Properties

Field measurements of water-quality properties (dissolved oxygen, pH, specific conductance, and water temperature) were used to characterize the physical nature of Fish Creek. Streamflow and stream stage, or groundwater-levels and water-quality properties were measured each time a site was visited (tables 5, 6). In addition, water-quality properties were continuously monitored at selected surface-water sites (table 2); properties are shown in figures 23–31 in the

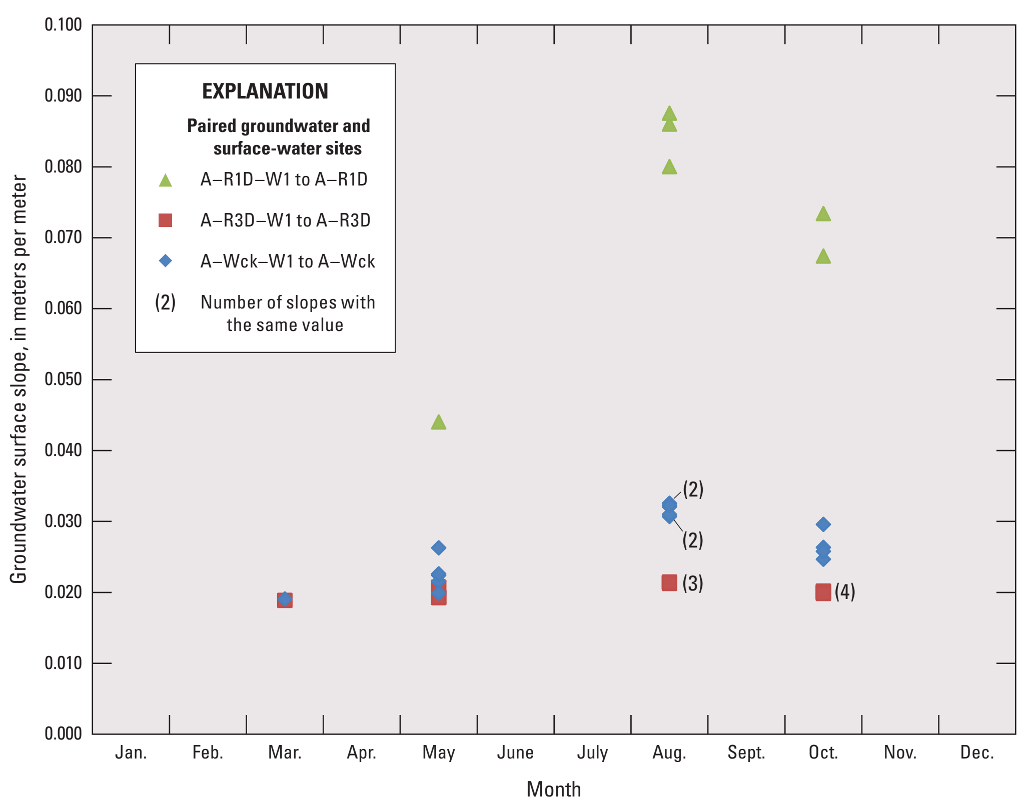


Figure 9. Slope of groundwater surface between paired monitoring well sites and stream sites on Fish Creek, Teton County, Wyoming, 2007–11.

"Supplemental Data" section for 2009–11 data and in Eddy-Miller and others (2010) for 2007–08 data.

Median values of continuous water-quality properties were determined at all five regularly sampled biological sites for each 48-hour period coinciding with the three water-quality sampling periods for each year of the study (*table 7*; Microsoft® Excel format). Table 8 summarizes the analysis of variance (ANOVA using Tukey's method) of each water-quality property between sites, years, and seasons. Statistically significant differences ($p < 0.05$) for pH and specific conductance were found between site A–RB and the other regularly sampled biological sites; site A–RB had lower pH values than all other sites and lower specific conductance values than sites A–R3D and A–R7. Statistically significant differences in pH and specific conductance also were found between sites A–Wck and A–R7. No significant differences ($p > 0.05$) were found for any water-quality property between any of the five study years, but significant differences were found between seasons. All water-quality properties had a significant difference between April/May and August, dissolved oxygen and specific conductance had a significant difference between April/May and October samples, and specific conductance and temperature had a significant difference between August and October (table 8).

Nutrients

Samples from regularly and synoptically sampled surface-water and groundwater sites were analyzed for nutrients (nitrogen and phosphorus species) (tables 5 and 6), where dissolved concentrations of nutrients are determined from filtered samples. Nitrate was the dominant species of dissolved nitrogen present in all samples, accounting for at least 80 percent of the nitrogen in all but 4 surface-water samples and 1 groundwater sample (tables 5, 6). Percentages of total nitrate were calculated using the filtered, analytically determined total nitrogen, because Rus and others (2012) determined unfiltered, analytically determined total nitrogen could have a low bias. Orthophosphate accounted for almost all of the dissolved phosphate in both surface-water and groundwater samples; phosphorus was rarely present in an undissolved form (based on difference in phosphorus concentrations between filtered and unfiltered analyses in tables 5, 6), likely because of the lack of sediment transported in Fish Creek.

Nitrate

The median concentration of dissolved nitrate in surface water was largest for samples collected from site A–R1D near Teton Village (0.24 milligrams per liter [mg/L] as N) (table 9, fig. 10*A*) and concentrations decreased downstream as far as site A–Wck (0.018 mg/L as N). Median dissolved nitrate concentrations were similar at sites A–Wck, A–R6D, and A–R7 (0.018, 0.020, and 0.010 mg/L as N, respectively) and also were similar to median concentrations of samples collected from the synoptically sampled streams and rivers in the Fish Creek area (table 9). Sites A–R3D, A–Wck, A–R6D, and A–R7 occasionally had no detectable concentrations of nitrate in the sample (table 9). Site A–R1D had a higher median than surface-water samples collected from other regularly and synoptically sampled streams and rivers in the Fish Creek area.

Table 8. Analysis of variance in median values for water-quality property data collected continuously over 48 hours (except where noted in table 7), Fish Creek, Teton County, Wyoming, 2007–11.

[Significance tested by Tukey method at probability level less than 0.05 ($p < 0.05$). mg/L, milligram per liter; µS/cm, microsiemen per centimeter at 25 degrees Celsius; Apr., April; Aug., August; Oct., October]

Water-quality property	Significant differences between sites	Significant differences between years	Significant differences between seasons
Dissolved oxygen (mg/L)	None	None	Apr./May and Aug., Apr./May and Oct.
pH (standard units)	A–RB and A–R3D, A–RB and A–Wck, A–RB and A–R6D, A–RB and A–R7, A–Wck and A–R7	None	Apr./May and Aug.
Specific conductance (µS/cm)	A–RB and A–R3D, A–RB and A–R7, A–Wck and A–R7	None	Apr./May and Aug., Apr./May and Oct., Aug. and Oct.
Temperature (°C)	None	None	Apr./May and Aug., Aug. and Oct.

Table 9. Summary of nutrient concentration in samples from surface water and nearby groundwater, Fish Creek, Teton County, Wyoming, 2007–11.

[mg/L, milligram per liter; <, less than]

Site name	Number of samples	Statistic	Dissolved nitrate (mg/L)	Dissolved orthophosphate (mg/L)	Molar nitrogen to molar phosphorus ratio
Regularly sampled surface-water sites					
A–R1D	11	Minimum	0.11	0.035	5.5
		Median	0.24	0.045	11.5
		Maximum	1.86	0.088	46.7
A–RB	14	Minimum	0.017	0.004	3.1
		Median	0.074	0.012	16.5
		Maximum	0.57	0.025	104.9
A–R3D	14	Minimum	<0.016	0.003	2.2
		Median	0.033	0.007	11.8
		Maximum	0.24	0.010	76.8
A–Wck	15	Minimum	<0.01	<0.008	2.1
		Median	0.018	0.006	5.1
		Maximum	0.15	0.010	54.2
A–R6D	15	Minimum	<0.01	<0.004	2.5
		Median	0.020	0.006	7.4
		Maximum	0.21	0.01	78.5
A–R7	12	Minimum	<0.008	<0.004	2.2
		Median	0.010	0.006	5.2
		Maximum	0.22	0.010	79.2
Synoptically sampled surface-water sites					
SW–1	3	Minimum	<0.02	<0.004	2.2
		Median	0.02	0.008	5.3
		Maximum	0.02	0.010	22.1
SW–2	2	Minimum	<0.04	0.011	4.0
		Median	0.03	0.014	4.6
		Maximum	0.04	0.017	5.2
SW–3	2	Minimum	0.08	0.017	9.1
		Median	0.08	0.018	9.7
		Maximum	0.08	0.019	10.4
Regularly sampled groundwater sites					
A–R1D–W1	14	Minimum	0.21	0.015	10.2
		Median	0.32	0.043	15.3
		Maximum	4.30	0.057	170.2
A–R3D–W1	15	Minimum	0.08	0.011	7.8
		Median	0.13	0.017	20.3
		Maximum	0.42	0.041	76.5
A–Wck–W1	15	Minimum	0.13	0.036	5.3
		Median	0.33	0.052	13.7
		Maximum	1.42	0.064	60.4

Table 9. Summary of nutrient concentration in samples from surface water and nearby groundwater, Fish Creek, Teton County, Wyoming, 2007–11.—Continued

[mg/L, milligram per liter; <, less than]

Site name	Number of samples	Statistic	Dissolved nitrate (mg/L)	Dissolved orthophosphate (mg/L)	Molar nitrogen to molar phosphorus ratio
Synoptically sampled groundwater sites					
GW–6[1]	2	Minimum	0.33	0.071	10.3
		Median	0.38	0.078	16.2
		Maximum	0.43	0.085	22.1
Springs (GW–2 and GW–4)	4	Minimum	0.10	0.010	23.0
		Median	0.19	0.014	29.4
		Maximum	0.34	0.015	53.7
Other wells (GW–1, GW–3, GW–5, GW–7)	4	Minimum	0.12	0.011	11.2
		Median	0.16	0.015	23.1
		Maximum	0.23	0.016	36.3

[1]Well GW–6 was analyzed seperately from other synoptically sampled wells because most of the nutrient values were substantially different from the other wells.

Changes in dissolved nitrate concentrations in surface water between sites, years, and seasons were statistically examined. Dissolved nitrate concentrations at site A–R1D were statistically different from concentrations at the other Fish Creek sites (table 10). Differences between years of the study were not statistically different. Dissolved nitrate concentrations were significantly different between the April/May and August samples (table 10); concentrations in April/May tended to be higher than concentrations in August (fig. 10*A*).

Of the three regularly sampled groundwater sites, the median concentration of dissolved nitrate in groundwater was highest at sites A–R1D–W1 and A–Wck–W1 (0.32 and 0.33 mg/L as N, respectively) and lowest at site A–R3D–W1 (0.13 mg/L as N) (table 9, fig. 10*B*). Median concentrations of dissolved nitrate in samples from synoptically sampled wells and springs in the alluvial aquifer were similar to the median concentration for well A–R3D–W1 (table 9), with the exception of well GW–6, which had a median concentration that was similar to the median concentrations for wells A–R1D–W1 and A–Wck–W1. However, dissolved nitrate concentrations were not statistically different between the samples collected from the three regularly sampled monitoring wells near Fish Creek and the samples collected from wells and springs in other parts of the alluvial aquifer (table 10).

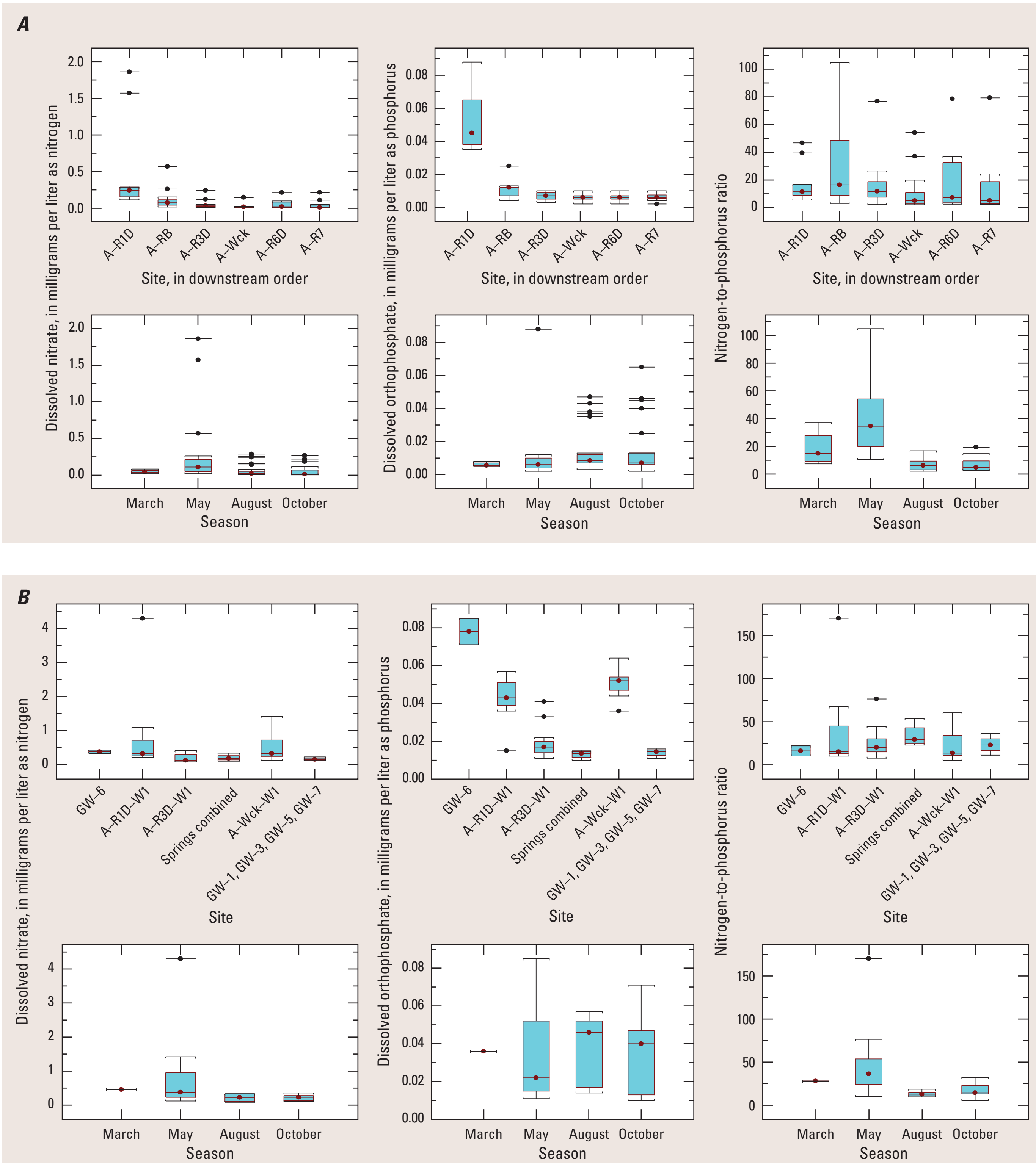
Changes in dissolved nitrate concentrations in groundwater also were evaluated by year and season for regularly sampled sites. Synoptically sampled sites were visited only in 2011 (table 2), so data from those sites were not included in the analysis of changes between years and season. Dissolved nitrate concentrations from regularly sampled sites were not significantly different between years but were significantly different between seasons (table 10). Seasonal differences in concentrations were significant between samples collected April/May and August and between samples collected April/May and October (table 10); concentrations in the April/May samples tended to be higher than concentrations in both August and October (fig. 10*B*).

Orthophosphate

The median concentration of dissolved orthophosphate in surface water was highest at site A–R1D near Teton Village (0.045 mg/L as P) (table 9, fig. 10*A*), decreased downstream at site A–RB (0.012 mg/L as P), and then decreased to similarly lower median values at the rest of the sites (0.007, 0.006, 0.006, and 0.006 mg/L as P at sites A–R3D, A–Wck, A–R6D, and A–R7, respectively). Sites A–Wck, A–R6D, and A–R7 each had one sample with no detectable concentrations of dissolved orthophosphate in the sample (table 9). Median dissolved orthophosphate concentrations were similar among all regularly and synoptically sampled sites, except site A–R1D (table 9).

The concentrations of dissolved orthophosphate at site A–R1D were shown to be statistically different from the concentrations of dissolved orthophosphate at the other regularly sampled Fish Creek sites (table 10). Concentrations of dissolved orthophosphate were not statistically different between study years or seasons.

The median concentration of dissolved orthophosphate in groundwater from regularly sampled sites was highest at wells A–R1D –W1 and A–Wck–W1 (0.043 and 0.052 mg/L as P, respectively) and lowest at site A–R3D–W1 (0.017 mg/L as P) (table 9, fig. 10*B*). Median dissolved orthophosphate concentrations in synoptically sampled wells and springs in the alluvial aquifer area tended to be similar to concentrations



EXPLANATION

- Individual observation greater than 1.5 times the interquartile range
- Largest value within 1.5 times interquartile range above 75th percentile
- 75th percentile
- 50th percentile (median)
- 25th percentile
- Interquartile range
- Smallest value within 1.5 times interquartile range below 25th percentile
- Individual observation less than 1.5 times the interquartile range

Figure 10. Concentrations of dissolved nitrate, dissolved orthophosphate, and molar nitrogen-to-phosphorus ratio by site and by season in samples collected from surface water and nearby groundwater, Fish Creek, Teton County, Wyoming, 2007–11. *A*, Regularly sampled surface-water sites. *B*, Regularly and synoptically sampled groundwater sites. (N, nitrogen; P, phosphorus)

in well A–R3D–W1 (table 9), with the exception of site well GW–6, which had a median orthophosphate concentration higher than the median concentration at wells A–R1D–W1 and A–Wck–W1.

The concentrations of dissolved orthophosphate at wells A–R1D–W1 and A–Wck–W1 were statistically different from the concentrations at well A–R3D–W1 (table 10) and other synoptically sampled alluvial aquifer sites, except site GW–6. Dissolved orthophosphate concentrations were statistically different between well GW–6 and all other groundwater sites sampled for the study (table 10), with concentrations higher at well GW–6 than at the other groundwater sites in the study. Changes in dissolved orthophosphate concentrations in groundwater also were statistically analyzed by year and season at regularly sampled sites, but no statistically significant difference was found between years or seasons (table 10).

Nitrogen-Phosphorus Ratio

Ratios of molar total nitrogen to molar total phosphorus, known as the N:P ratio, can be used as an indicator of the limiting nutrient because algal cells utilize those nutrients in

Table 10. Analysis of variance in nutrient concentrations of surface water and nearby groundwater, Fish Creek, Teton County, Wyoming, 2007–11.

[Significance tested by Tukey method at probability level less than 0.05 ($p < 0.05$). mg/L, milligrams per liter; Apr., April; Aug., August; Oct., October; N:P ratio, molar nitrogen to molar phosphorus ratio]

Nutrient	Significant differences between sites	Significant differences between years	Significant differences between seasons
Regularly sampled surface-water sites			
Dissolved nitrate (mg/L)	A–R1D and A–RB, A–R1D and A–R3D, A–R1D and A–Wck, A–R1D and A–R6D, A–R1D and A–R7	None	Apr./May and Aug.
Dissolved orthophosphate (mg/L)	A–R1D and A–RB, A–R1D and A–R3D, A–R1D and A–Wck, A–R1D and A–R6D, A–R1D and A–R7	None	None.
N:P ratio	None	None	March and Apr./May, Apr./May and Aug., Apr./May and Oct.
Regularly sampled groundwater sites			
Dissolved nitrate (mg/L)	None	None	Apr./May and Aug., Apr./May and Oct.
Dissolved orthophosphate (mg/L)	A–R1D–W1 and A–R3D–W1, A–R3D–W1 and A–Wck–W1	None	None.
N:P ratio	None	None	Apr./May and Aug., Apr./May and Oct.
Regularly and synoptically sampled groundwater sites			
Dissolved nitrate (mg/L)	None	Not analyzed	Not analyzed.
Dissolved orthophosphate (mg/L)	GW–6 and A–R1D–W1, GW–6 and A–R3D–W1, GW–6 and A–Wck–W1, GW–6 and springs, GW–6 and wells, A–R1D–W1 and A–R3D–W1, A–R1D–W1 and springs, A–R1D–W1 and wells, A–R3D–W1 and A–Wck–W1, A–Wck–W1 and springs, A–Wck–W1 and wells	Not analyzed	Not analyzed.
N:P ratio	None	Not analyzed	Not analyzed.

specific ratios. For example, Borchardt (1996) indicates that ambient N:P ratios greater than 20:1 are considered phosphorus limited and ratios less than 10:1 are nitrogen limited, but the distinction is unclear for ratios between 10:1 and 20:1.

The median N:P ratios in surface water were highest in samples collected from site A–RB (table 9, fig. 10*A*) and ratios at this site had a large range (from 3.1 to more than 104.9, table 9). The minimum and median N:P ratios found in synoptically sampled surface water near Fish Creek (sites SW–1, SW–2, and SW–3) were similar to ratios found in samples collected from Fish Creek; the maximum N:P ratios, however, were much lower at sites SW–1, SW–2, and SW–3 than at sites on Fish Creek (table 9).

Changes in N:P ratios in samples collected from regularly sampled surface-water sites were examined for significant differences between sites, years, and seasons, and the only factor that had a statistically significant difference was season. The N:P ratios at regularly sampled surface-water sites were significantly different between April/May and all the other seasons (March, August, and October) (table 10). The N:P ratios in April/May tended to be higher than the N:P ratios in August (figs. 11 and 12). The general shift was from a primarily P-limited or neither P- nor N-limited stream in April/May to a generally N-limited stream in August and October. Additionally, the N:P ratios in Fish Creek in August and October were within the range used by Lohman and Priscu (1992) as an indicator of nitrogen limitation at stream sites in western Montana.

The median N:P ratios in groundwater had a large range, similar to the range found in surface-water sites (table 9, fig. 10*B*). Median values from wells, including well GW–6, and springs in the alluvial aquifer area tended to be similar to ratios for the three regularly sampled monitoring wells near Fish Creek. Differences in ratios were not significant between the samples collected from the regularly sampled monitoring wells near Fish Creek and the samples collected from the synoptically sampled wells and springs in the alluvial aquifer.

Changes in N:P ratios in groundwater between years and seasons also were evaluated at the regularly sampled sites. Differences in N:P ratios from the regularly sampled groundwater sites were not significant between years, but were significant between seasons (table 10). Figure 12 shows the N:P ratios for the paired groundwater and surface-water sites. Similar to the regularly sampled biological sites, the seasonal difference was significant between ratios from groundwater

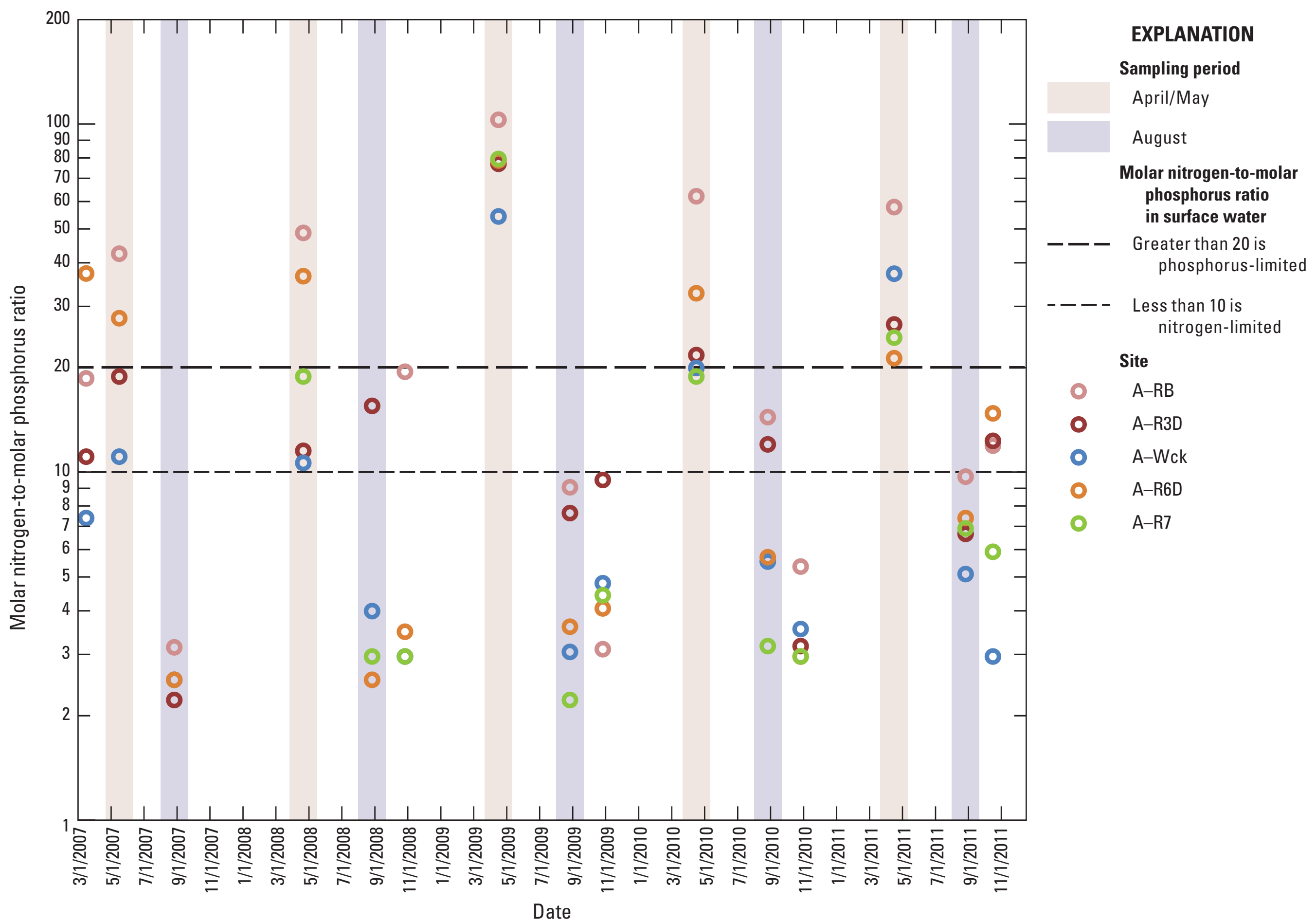


Figure 11. Ratio of molar nitrogen to molar phosphorus at five regularly sampled biological sites, Fish Creek, Teton County, Wyoming, 2007–11. (Date in month/day/year format)

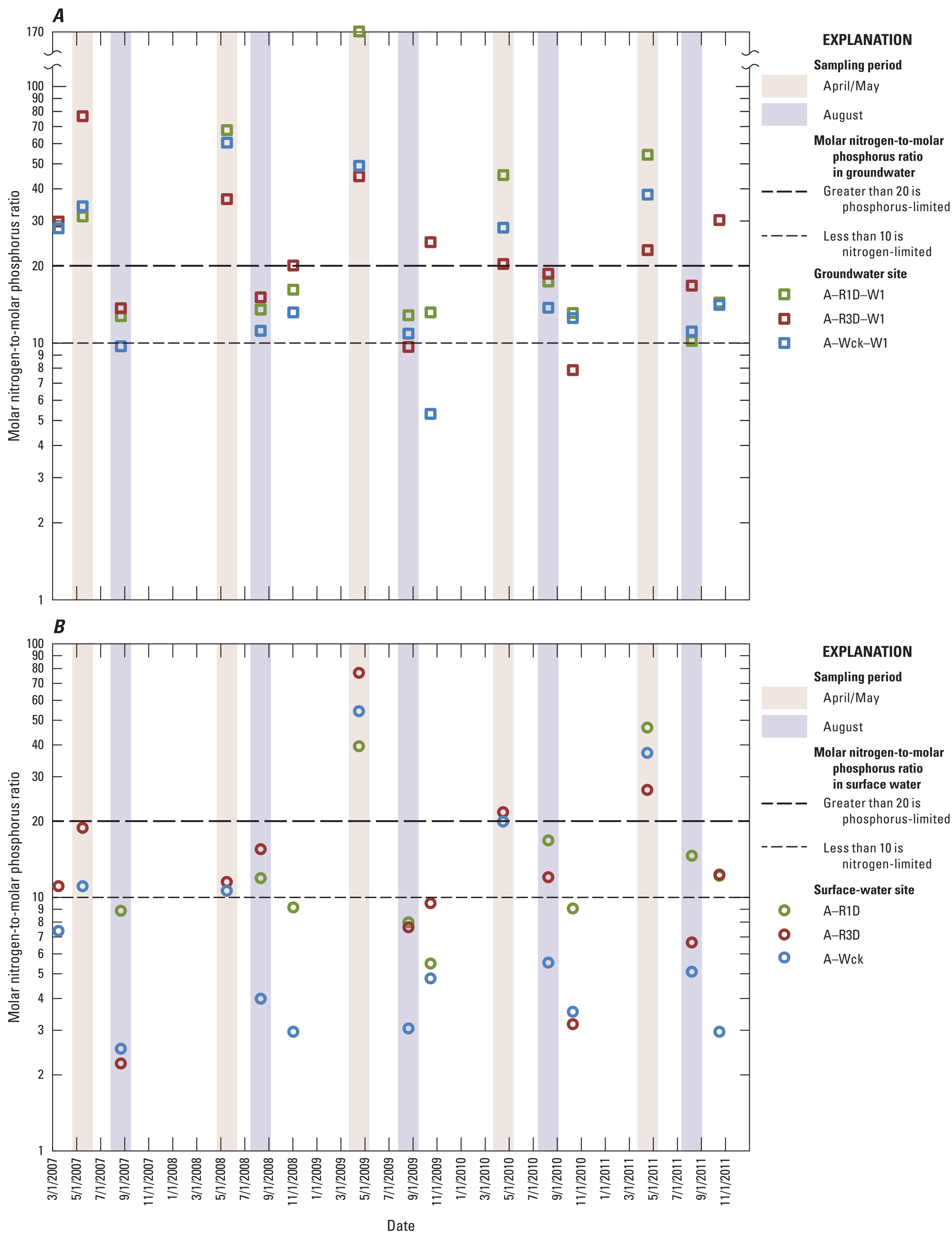


Figure 12. Ratio of molar nitrogen to molar phosphorus at paired *A*, groundwater and *B*, surface-water sites in the Fish Creek area, Teton County, Wyoming, 2007–11. (Date in month/day/year format)

samples collected in April/May and samples collected in both August and October (table 10); the N:P ratio in April/May tended to be higher than the values in either of the other seasons (fig. 12*A*). Groundwater in general had higher N:P ratios than surface water for most of the pairs, which likely indicates that processes in the stream are more quickly affecting the nutrients in surface water.

Isotopes of Nitrate

Nitrate was detected in samples collected from surface water in and near Fish Creek and in samples from groundwater near Fish Creek. Samples collected from groundwater typically were higher in $\delta^{15}N$ [NO_3] and lower in $\delta^{18}O$ [NO_3] than surface-water samples (fig. 13). The $\delta^{18}O$ [NO_3] values in samples collected from Fish Creek and nearby groundwater (fig. 13) ranged from -0.51 to 11.23 per mil, and the $\delta^{15}N$ [NO_3] values ranged from 2.48 to 16.20 per mil.

The $\delta^{15}N$ [NO_3] and $\delta^{18}O$ [NO_3] values of a sample can be compared to published values to help determine sources of nitrate in the water. However, because of variations in published values, mixing of nitrate sources along a flow path, and biological processes, the comparison of a sample's nitrate isotope values to published values is not absolute and can only estimate the source of nitrate, especially in the range from -5 to 8 $\delta^{15}N$ [NO_3]. For example, published $\delta^{15}N$ [NO_3] values between 0 and 5 per mil, similar to values from many Fish Creek samples, commonly are associated with nitrate that could have multiple potential sources, including artificial nitrogen fertilizers and natural soil organic matter, as well as a mixture of sources (Clark and Fritz, 1997; Kendall and McDonnell, 1998; Böhlke, 2003; Böhlke and McMahon, 2009). Therefore, additional samples from within the Fish Creek drainage but not from Fish Creek itself (also called end members) were collected in April and August 2011 to help interpret the data when used with published values.

End member samples from the Fish Creek watershed were collected from Snake River and Lake Creek on the east side and from Phillips Canyon on the west side (SW–1, SW–2, and SW–3); groundwater end member samples were collected from two springs and five wells throughout the alluvial aquifer, which were deeper than the regularly sampled monitoring wells (GW–1, GW–2, GW–3, GW–4, GW–5, GW–6, and GW–7). All values of $\delta^{18}O$ [NO_3] in Fish Creek samples fall into the category of nitrate from a biogenic source (Böhlke and McMahon, 2009). The two samples from well GW–6 have the highest $\delta^{15}N$ [NO_3] values (table 6 and fig. 13*A*) . When compared to published data, these values (16.20 and 11.83 per mil) are consistent with nitrate originating from manure or septic/sewage effluent (Aravena and others, 1993; Clark and Fritz, 1997; Kendall and McDonnell, 1998; Böhlke, 2003; Hinkle and others, 2008). Two sites, GW–4 and SW–3, are on the far west end of the valley floor and have minimal potential effects from human activity in the Fish Creek drainage. The two $\delta^{15}N$ [NO_3] values from spring GW–4 (2.82 and 2.93 per mil; table 6) and the two values from site SW–3 (5.09 and 3.08 per mil; table 5), indicate that nitrate present in the samples likely is from either atmospheric deposition of nitrogen in the Teton Range, possibly including components of nitrogen from agricultural activities upwind in Idaho (Elser and others, 2009), or local soil organic matter. Site SW–2, on Snake River on the east side of the valley, also had a $\delta^{15}N$ [NO_3] value lower than most Fish Creek drainage samples at 3.9 per mil (fig. 13).

Using all of the end member samples (SW–1, SW–2, SW–3, GW–1, GW–2, GW–3, GW–4, GW–5, GW–6, and GW–7), it is possible to evaluate the samples collected from the surface-water sites on Fish Creek and the nearby groundwater sites shown grouped in the upper reach near Teton Village (fig. 13*B*), the middle reaches near sites A–RB and A–R3D (fig. 13*C*), and the lower reach near and downstream from Wilson (fig. 13*D*). End member samples are shown on all figure 13 plots for purposes of comparison.

Most samples in the upper reach have $\delta^{15}N$ [NO_3] values that range from 6 to 10 per mil (fig. 13*B*) . Nitrate concentrations tended to be higher in samples collected in April/May, when the water table is rising in the area, than in the rest of the year. The tendency of the site A–R1D and well A–R1D–W1 data to plot near the samples from site GW–6 and nitrate concentrations greater than 1.5 mg/L indicate that a large contributor of nitrate likely is manure and septic/sewage effluent.

Most samples in the middle reaches have $\delta^{15}N$ [NO_3] values that range from 3 to 8 per mil with one sample near 10 per mil (fig. 13*C*), which is a visually noticeable shift to smaller $\delta^{15}N$ [NO_3] values from the samples collected in the upper reach. The middle reach samples also tended to have smaller concentrations of nitrate than the upper and lower reach samples (fig. 13*C*). Values for most of these samples tended to plot near sites SW–2, SW–3, and well GW–3, likely indicating a mixture of sources. The one exception was a sample collected from well A–R3D–W1, which had a $\delta^{15}N$ [NO_3] value of 10.03 per mil (table 6). This $\delta^{15}N$ [NO_3] value likely is indicative of septic effluent as the source of nitrate for three reasons: (1) the value 10.03 per mil compared to published values and the other Fish Creek samples, (2) the presence of wastewater chemicals detected in the sample (Eddy-Miller and others, 2010), and (3) the presence of a disinfectant in the sample sent to the Reston Stable Isotopes Laboratory (USGS) for analysis of $\delta^{15}N$ [NO_3] that was affecting the bacteria used as the denitrifier for analysis, a situation that has been observed in the past from samples collected from wastewater (Haiping Qi, U.S. Geological Survey, written commun., 2007).

Most samples in the lower reaches had $\delta^{15}N$ [NO_3] values ranging from 6 to 11 per mil (fig. 13*D*), which is a visually noticeable shift to larger $\delta^{15}N$ [NO_3] values from samples collected in the middle reach and a range similar to that of samples collected in the upper reach. The combination of the shift from the middle reach, the similarity to the upper reach, and the general increase in the $\delta^{15}N$ [NO_3] values indicates that the nitrate in the lower reaches is from a mixture of sources, but with a higher proportion of nitrate from manure or septic/sewage effluent.

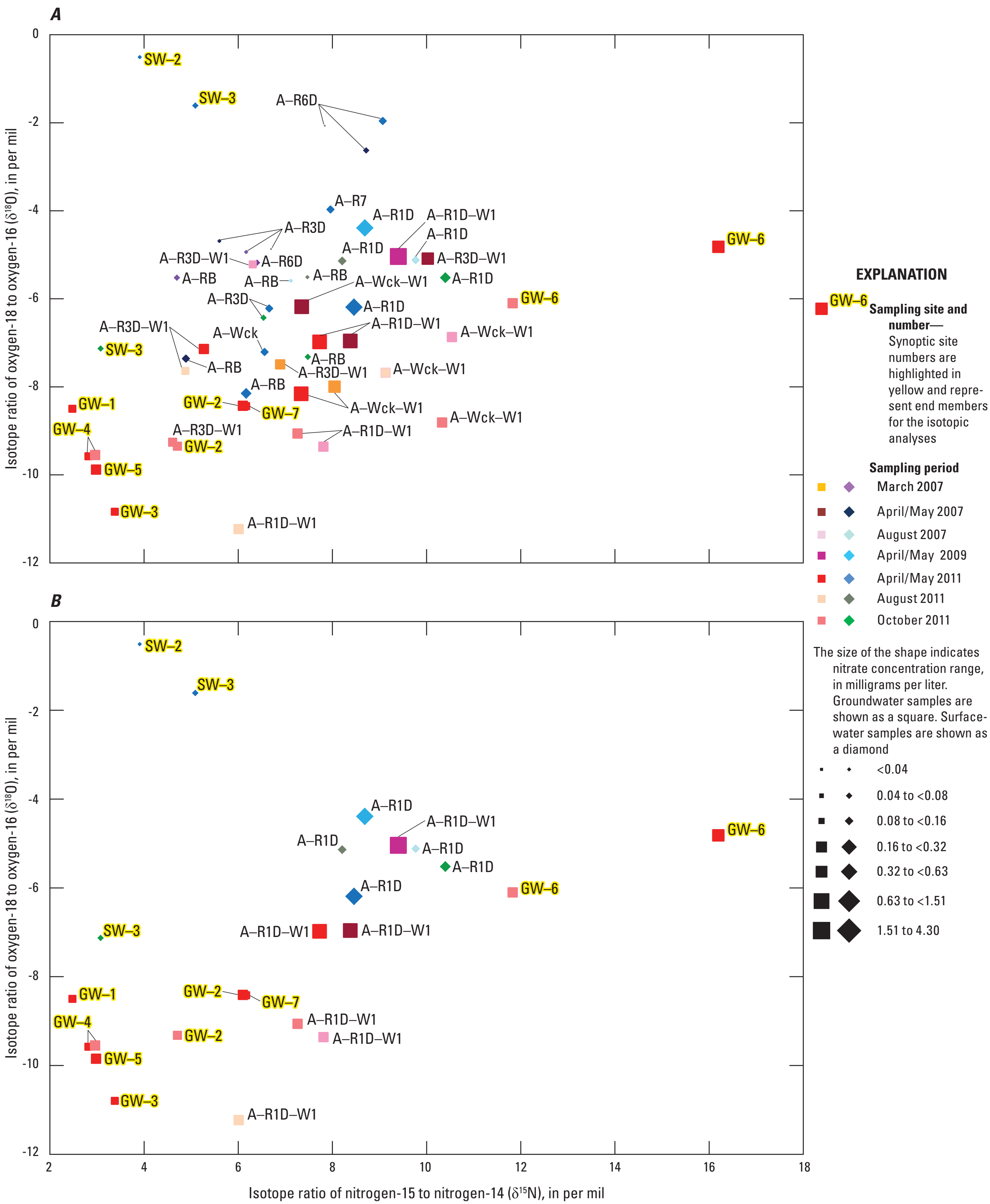


Figure 13. Isotopic composition of nitrate in samples collected from surface water and nearby groundwater, Fish Creek, Wyoming, 2007–11. *A*, All samples. *B*, Sites in and near the upper reach of Fish Creek. *C*, Sites in and near the mid-section reach of Fish Creek. *D*, Sites in and near the lower reach of Fish Creek.

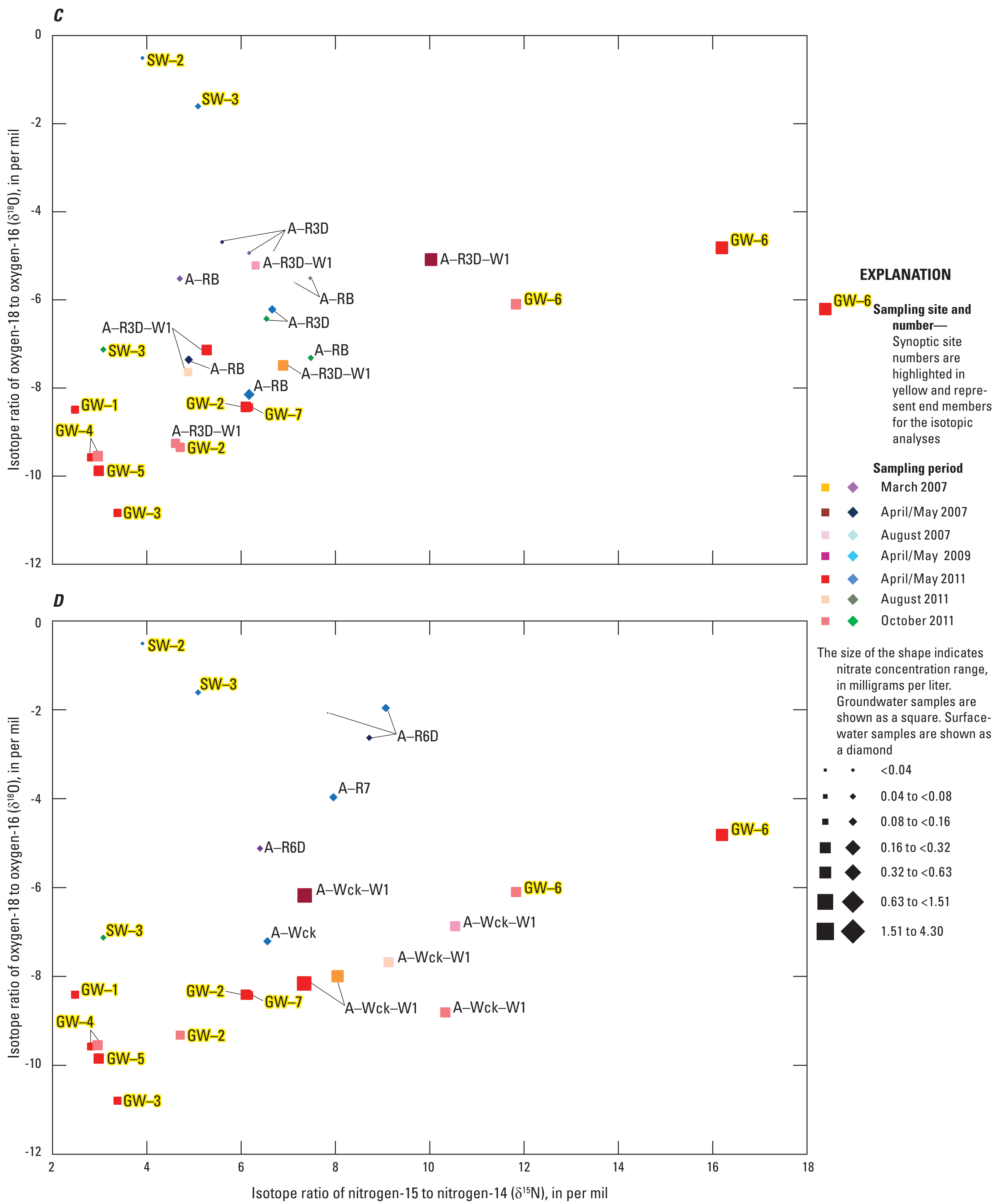


Figure 13. Isotopic composition of nitrate in samples collected from surface water and nearby groundwater, Fish Creek, Wyoming, 2007–11. *A*, All samples. *B*, Sites in and near the upper reach of Fish Creek. *C*, Sites in and near the mid-section reach of Fish Creek. *D*, Sites in and near the lower reach of Fish Creek.—Continued

Biological Community and Habitat Characteristics

Biological samples (aquatic plants and macroinvertebrates) were collected and habitat characteristics were measured at surface-water sites to characterize the biologic communities of Fish Creek as described in Eddy-Miller and others (2010). For aquatic communities, composition, productivity, and algal communities were characterized. For macroinvertebrate communities, composition and traits were characterized. For habitat characterizations, riparian canopy and streambed substrate (pebble counts) were measured. Algal and macroinvertebrate taxonomy data are presented in terms of community composition and traits because algal and macroinvertebrate communities act as integrators of environmental variables such as water quality over a longer time period than a water-quality sample or measurement collected at one point in time. An analysis of variance in the biological communities was performed to statistically determine differences in the communities between sites, years, and seasons.

Aquatic Plant Communities

When viewed from the shore or a bridge, Fish Creek commonly appeared to be bright green because of a green mat of aquatic plants on the bottom of the creek. The mat typically was composed of a mixture of vascular aquatic plants, macroalgae (such as long streamers of *Cladophora*), microalgae, and moss (fig. 14). Sandy areas in Fish Creek are considered unsuitable substrate for most algal species to grow based on the field observations that showed a lack of attachment points for algae due to the tendency of the small, sandy particles to roll in the turbulent water. Once vascular aquatic plants became established, sand and particles smaller than sand were trapped, which then promoted growth of vascular aquatic plants at some sites (A–Wck and A–R6D). Average aquatic plant life in Fish Creek at sites A–RB, A–R3D, A–Wck, A–R6D, and A–R7 for years 2007–11 is shown on figure 15. Because of the difference in biovolume and growth potential of microalgae compared to other aquatic plants, an additional category of macrophytes was created for analysis. The macrophyte category included vascular aquatic plants, macroalgae (including *Cladophora*), and moss. In general, although the percentage of the total for each group differed, all aquatic plant groups seen in Fish Creek were found at all sites.

Aquatic Plant Community Composition

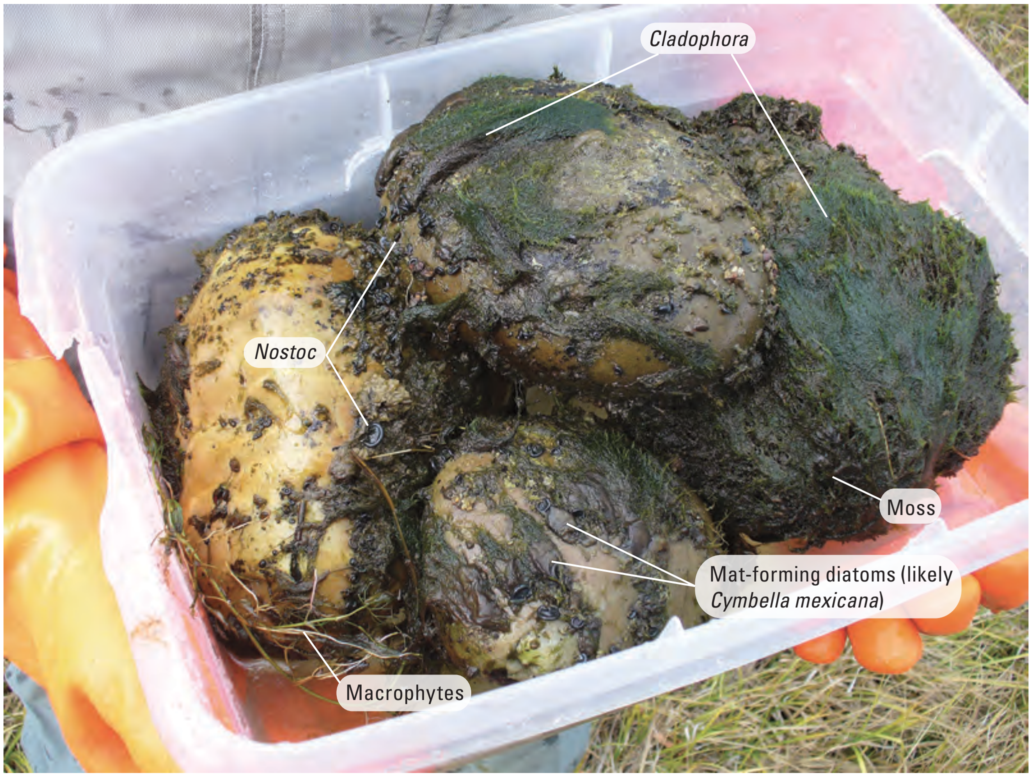
The most common components of the aquatic plant community in Fish Creek were submergent vascular aquatic plants (large, rooted plants), macroalgae classified as either *Cladophora* or other macroalgae, and microalgae (fig. 15). The average percentage of macrophytes was greater than 50 percent at all sites except site A–RB, which averaged 32 percent macrophytes. Samples of the visually dominant vascular aquatic plants were collected during a few sampling events for taxonomic identification during 2007; they were described in Eddy-Miller and others (2010) as a grass-like vascular aquatic plant (*Stuckenia filiformis* ssp. *Filiformis, formerly known as Potamogeton filiformis*), water milfoil (probably *Myriophyllum sibiricum*), and a member of the buttercup family (*Ranunculus aquatilis*). The filamentous green algae of *Cladophora* are macroalgae but is represented as a separate category because of its abundance and habit of growing in long branched filaments (commonly 20–30 cm long) and because it was easily identified in the field. The category of other macroalgae includes species of the genus *Nostoc*, a blue-green algae that grow in ball- or ear-shaped colonies (fig. 14*A*), and macroalgae not taxonomically identified in the field.

Aquatic Plant Community Changes

The percentages of aquatic plant and sandy, bare streambed (described as unsuitable substrate on fig. 15) observed along the transect at each site are shown on figure 15. The average composition of the aquatic plant community in Fish Creek appeared to shift in the downstream direction (fig. 15), and all of the sites had an average macrophyte cover of greater than 40 percent in October, which is considered high macrophyte growth by the USGS Water-Quality Assessment Program (Maret and others, 2010). In general, site A–RB had a higher average percentage of unsuitable substrate than the other Fish Creek sites; the percentage of unsuitable substrate was significantly different ($p < 0.05$) between site A–RB and the other sites (table 11). The average percentage of microalgae also was largest at site A–RB, but was statistically different only between sites A–RB and A–Wck. Site A–RB had the lowest average percentages of macrophytes (fig. 15) which was significantly different from all other sites (table 11). The average percentage of *Cladophora* was largest at site A–Wck (fig. 15) and site A–Wck was statistically different from the other sites (table 11). The percentage of vascular aquatic plants was highest at site A–R6D, but site A–R6D was statistically different from only site A–RB. Site A–R7 had a the largest average percentage of moss, which was statistically different from the percentages at all other sites (table 11, fig. 15). Among the five regularly sampled biological sites, A–R3D and A–Wck had the most similar aquatic plant communities (fig. 15).

Most aquatic plants showed little change in the percentage of each category between 2007 and 2011. The percentages of other macroalgae category were significantly different between years (table 11). However, the other macroalgae category is a combination of algae that makes up a relatively small part of the total aquatic plant community (fig. 15) and changes in just a few organisms could result in the statistically significant differences.

A



B

C

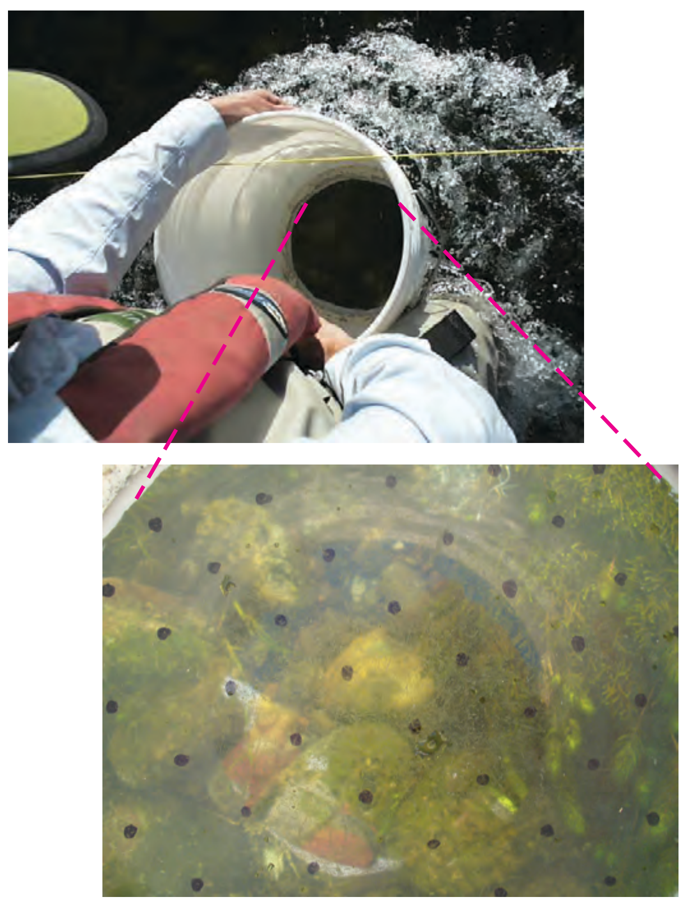
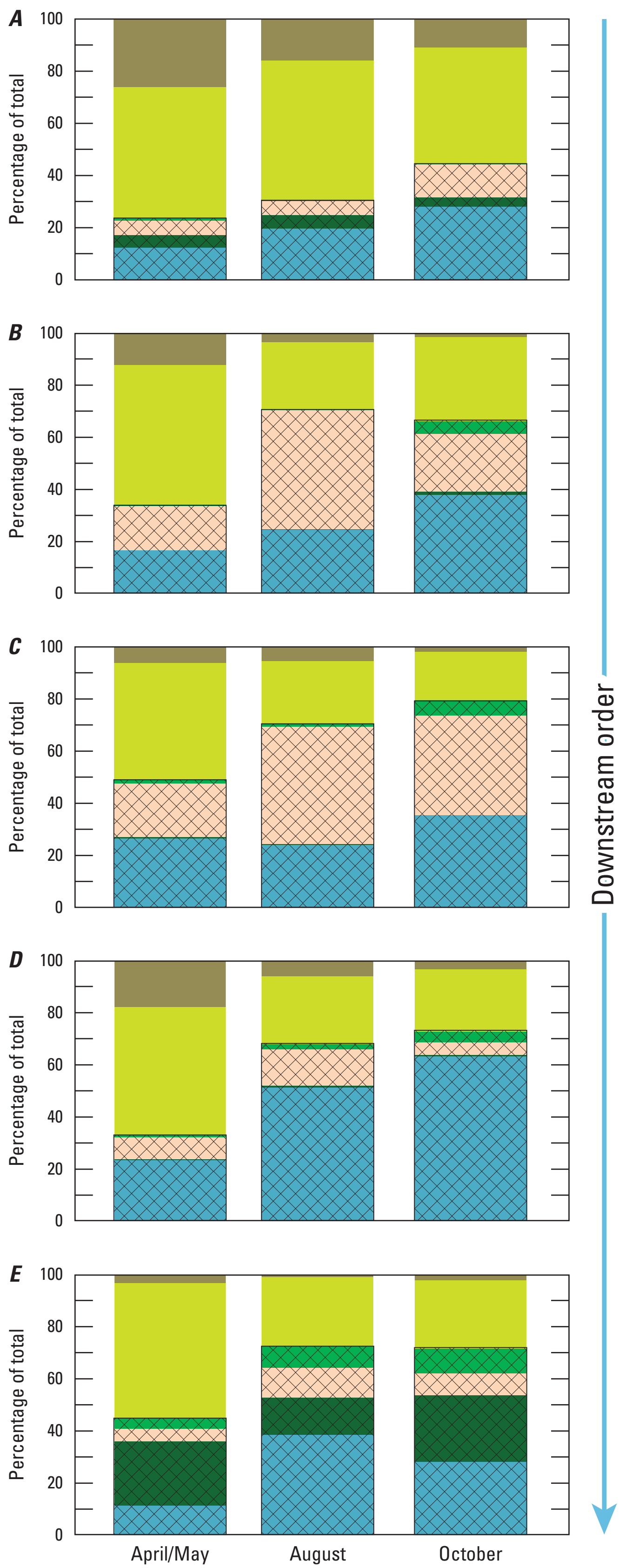
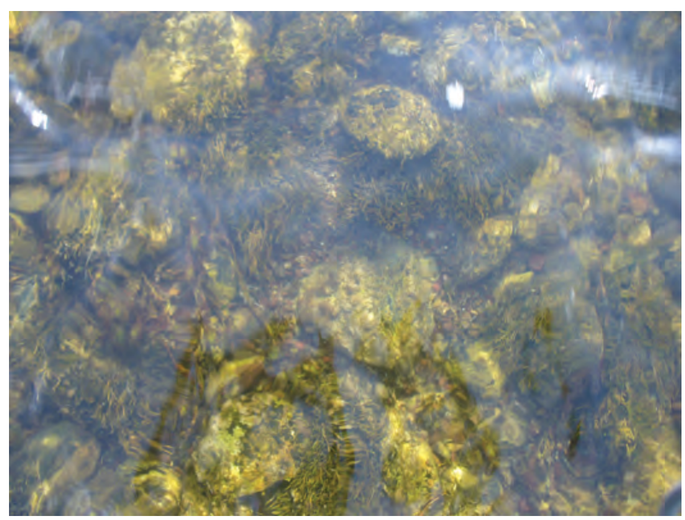


Figure 14. Evaluation of aquatic plant communities at sites on Fish Creek, Teton County, Wyoming, 2007–11. *A*, Rocks collected for algal taxonomic analysis (site A–RB, October 2007). *B*, *Cladophora* on cobble (site A–R3D, October 2011). *C*, Rapid periphyton survey (site A–R7, August 2009).



Cladophora at site A–R3D, August 2008.

Vascular aquatic plants at site A–R6D, October 2008.



Moss at site A–R7, May 2008.

Figure 15. Average aquatic plant community determined with rapid periphyton survey at five regularly sampled biological sites, Fish Creek, Teton County, Wyoming. *A*, Site A–RB, 2007–11. *B*, Site A–R3D, 2007–11. *C*, Site A–Wck, 2007–11. *D*, Site A–R6D, 2007–11. *E*, Site A–R7, 2008–11.

Table 11. Analysis of variance in aquatic plant communities, Fish Creek, Teton County, Wyoming, 2007–11.

[Significance tested by Tukey method at probability level less than 0.05 ($p < 0.05$). Apr., April; Aug., August; Oct., October]

Metric	Significant differences between sites	Significant differences between years	Significant differences between seasons
Percent unsuitable substrate	A–RB and A–R3D, A–RB and A–Wck, A–RB and A–R6D, A–RB and A–R7, A–R6D and A–R7	None	Apr./May and Aug., Apr./May and Oct.
Percent microalgae	A–RB and A–Wck	None	Apr./May and Aug., Apr./May and Oct.
Percent other macroalgae	None	2007 and 2011, 2008 and 2011, 2009 and 2011, 2010 and 2011	None.
Percent *Cladophora*	A–RB and A–R3D, A–RB and A–Wck, A–R3D and A–R6D, A–R3D and A–R7, A–Wck and A–R6D, A–Wck and A–R7	None	None.
Percent moss	A–RB and A–R3D, A–RB and A–Wck, A–R3D and A–R6D, A–RB and A–R7, A–R3D and A–R7, A–Wck and A–R7, A–R6D and A–R7	None	None.
Percent vascular aquatic plants	A–RB and A–R6D	None	Apr./May and Aug., Apr./May and Oct.
Percent macrophytes (other macroalgae, *Cladophora*, moss, vascular aquatic plants)	A–RB and A–R3D, A–RB and A–Wck, A–RB and A–R6D, A–RB and A–R7	None	Apr./May and Aug., Apr./May and Oct.
Ash-free dry mass	A–RB and A–R3D, A–RB and A–Wck, A–RB and A–R7	2008 and 2010	None.
Chlorophyll-*a*	None	2008 and 2010, 2009 and 2010	Apr./May and Oct., Aug. and Oct.
Maximum rate of productivity (P_{max})	None	None	Apr./May and Oct.

Although the overall composition of the aquatic plant community was similar throughout the year at each site, a few general seasonal changes can be seen (fig. 15). During April/May, all sites had microalgae as the dominant aquatic plant group. The plant community changed over the course of the summer and into the fall as macrophytes became dominant at all sites, except site A–RB, during August and October. It is likely that these larger plants lose some of their mass during the winter, resulting in a larger percent abundance of microalgae in April/May. The analysis of variance for the aquatic plant communities shows a significant difference between seasons in the percentage unsuitable substrate, microalgae, vascular aquatic plants, and macrophytes categories (table 11) confirming the general field observations.

Aquatic Plant Community Production

Concentrations of dissolved oxygen in water were measured continuously on a diel basis for this study (see the section "Water-Quality Properties,") and were used as an indicator of primary productivity of the aquatic plant community (Sorenson and others, 1999). Concentrations of dissolved oxygen and values of pH increased during the daylight hours (2007–08 data in Eddy-Miller and others, 2010; 2009–11 data in figs. 23–31 in "Supplemental Data") as a result of photosynthesis by algae, vascular aquatic plants, and moss present in the stream. The linear part of the dissolved-oxygen curve (Eddy-Miller and others, 2010, fig. 15) was used to compute P_{max}, the maximum rate of productivity, using the technique of Sorenson and others (1999). The difference between the maximum and minimum dissolved oxygen concentrations over the linear part of the curve was divided by the number of hours in the linear part of the curve to obtain an average value of P_{max} for each day, and the average P_{max} values for each day were averaged for each sampling period (table 12). The value of P_{max} is a relative measure of stream metabolism because the technique of Sorenson and others (1999) does not account for the effect of reaeration arising from differences in oxygen saturation between the stream and the atmosphere (Odum, 1956). Dissolved-oxygen concentrations are affected by respiration of the aquatic plant community and decomposition of organic matter, which take place 24 hours per day (Bott, 2006).

Respiration can be measured using various techniques, such as calculating the rate of decrease in dissolved-oxygen concentrations during the predawn hours (Peterson and others, 2001). Respiration rates were not calculated for Fish Creek because the predawn concentrations of dissolved oxygen in Fish Creek generally increased instead of decreasing as expected (that is, a dissolved oxygen sag), perhaps due to reaeration of the water across riffles.

Values of P_{max} in Fish Creek during 2007–11 ranged from 0.39 milligram per liter per hour (mg/L/hr) at site A–RB in April/May 2007 to 1.43 mg/L/hr at site A–R3D in April/May 2007 (table 12). The values of P_{max} listed by site and season in table 12 were calculated by averaging P_{max} from each of the two or three diel cycles available from each site in each sampling period. For comparison, values of P_{max} in Yellowstone River in Montana and Wyoming generally were less than 0.40 mg/L/hr, with the exception of one site associated with nuisance algal conditions where P_{max} reached 0.61 mg/L/hr (Peterson and others, 2001).

Although variability in P_{max} was noted among the sites and, on average, site A–R3D had the highest average of 0.86 mg/L/hr, values of P_{max} were not statistically different (p greater than or equal to 0.05) between sites (table 11). The P_{max} value varied from year to year, but was not statistically different between years. The average values of P_{max} by season (table 12, bottom row) increased from April/May to August and from August to October in all five years of sampling. The seasonal increases in P_{max} values were significantly different between April/May and October (table 11).

Algal Communities

Concentration data for chlorophyll-*a*, one of the primary photosynthetic pigments in algal cells (Graham and Wilcox, 2000), and ash-free dry mass (AFDM), a measure of organic matter including algae, bacteria, fungi, and other organisms, in algae samples collected during 2007–11 are shown in table 5. Algal taxonomic identification data were used to characterize algal community traits and are available on the Web (U.S. Geological Survey, 2012b).

Algal Standing Crop

Concentrations of chlorophyll-*a* and AFDM, cell density, and cell biovolume are indicators of algal standing crop. Chlorophyll-*a* concentrations at the regularly sampled biological sites typically ranged from around 100 to around 300 milligrams per square meter (mg/m^2) (table 5). The range and values of minimum and maximum concentrations differed between sites, but the difference was not statistically significant, even when considering an extremely high concentration (3,540 mg/m^2) at site A–Wck in October 2008 (tables 5, 11). Chlorophyll-*a* concentrations were statistically different between both April/May and October and between August and October; chlorophyll-*a* concentrations tended to be largest in October. Chlorophyll-*a* concentrations also were significantly different between 2010 and both 2008 and 2009; 2010 concentrations tended to be lower than the other two years.

Concentrations of chlorophyll-*a* in Fish Creek also were considerably higher than historical data from other streams in the area (U.S. Geological Survey, 2012a). The average chlorophyll-*a* concentration of two samples from streamgage 13010065, Snake River near Flagg Ranch, Wyo. (fig. 1) in 2002–04 was 16 mg/m^2; the average chlorophyll-*a* concentration of two samples collected from streamgage 13013650, Snake River at Moose, Wyo. (fig. 1) in 1996–97 was 1.7 mg/m^2. A sample collected from streamgage 13027500, Salt River near Etna, Wyo. (fig. 1) in 1993 had a chlorophyll-*a* concentration of 1.1 mg/m^2.

The AFDM concentrations in the algal samples from the regularly sampled biological sites tended to range from a low value of less than 25 grams per square meter (g/m^2) at site A–RB to a maximum value of 661.7 at site A–Wck (table 5). The AFDM concentrations generally were lowest at site A–RB, and were found to be statistically different from concentrations at sites A–R3D, A–Wck, and A–R7 (table 11). The AFDM concentrations were significantly different between only one set of years—2010 was lower than 2008—and were not significantly different between seasons. Chlorophyll-*a* concentrations from Fish Creek were correlated with AFDM concentrations ($\rho = 0.82$). Correlations between other measures of standing crop were small ($\rho < 0.50$).

Cell density describes the number of algal cells per square centimeter ($cells/cm^2$). Cell densities for samples collected generally ranged from about 1 or 2 million $cells/cm^2$ to around 10 million $cells/cm^2$ (*table 13*; Microsoft® Excel format). A few high densities (outliers) were measured at most sites, but the most noticeable was the sample from site A–Wck that had a cell density of more than 48 million $cells/cm^2$ in October 2008. This sample had cell densities of about 10 million $cells/cm^2$ each for two blue-green algae, *Homoeothrix janthina* and *Phormidium* (U.S. Geological Survey, 2012b). Statistical analysis determined the cell density (taxa relative

Table 12. Maximum rate of dissolved oxygen production, P_{max}, in milligrams per liter per hour, Fish Creek, Teton County, Wyoming, 2007–11.

[NA, not available or not applicable]

Site name	2007			2008			2009			2010			2011			Average by site
	April/ May	August	October	April/ May	August	October	April/ May	August	October	April/ May	August	October	April/ May	August	October	
A–RB	0.39	0.77	1.10	NA	0.42	0.60	0.49	0.57	0.58	0.76	0.46	0.78	0.56	0.46	0.41	0.56
A–R3D	1.43	0.76	1.17	0.50	0.69	0.73	1.09	0.83	1.12	0.71	NA	1.14	0.57	0.54	0.80	0.86
A–Wck	NA	0.94	0.75	0.76	0.68	0.76	0.48	0.98	1.16	0.62	0.96	1.19	0.52	0.49	1.32	0.83
A–R6D	0.53	0.80	0.74	0.63	0.72	0.99	0.60	0.87	1.06	0.64	0.92	1.22	0.51	0.70	1.03	0.80
A–R7	NA	NA	NA	0.50	0.83	0.66	0.60	0.64	1.01	0.77	NA	1.08	0.67	0.64	0.95	0.76
Average by season	0.78	0.82	0.89	0.60	0.67	0.75	0.65	0.78	0.98	0.70	0.78	1.08	0.57	0.57	0.90	

USGS hydrologist programming Sonde to record stream temperature, specific conductance, pH, and dissolved oxygen at site A–RB, March 2007.

Water-quality Sonde in stream at site A–RB, March 2007.

abundance based on cell density) for all algal species was not significantly different between the five sites (table 14). Cell densities for all algal species from samples collected in 2007 tended to be lower than other years, and differences were statistically different between 2007 and both 2008 and 2009 (table 14). The cell density for all algal species from Fish Creek samples were not significantly different between seasons.

The biovolume of a sample describes the mass of the sample collected in cubic micrometers per square centimeter ($\mu m^3/cm^2$). The measure of biovolume is different from cell density; for example, the presence of large algal cells such as *Cladophora* is better represented by biovolume than by cell density (Porter, 2008). The biovolume from Fish Creek samples had a large range of values, from the lowest value of 300 million $\mu m^3/cm^2$ at site A–RB in May 2007 to the highest value of nearly 2 trillion $\mu m^3/cm^2$ at site A–R6D in August 2008. Statistical analysis found that taxa relative abundance based on biovolume for all algal species was significantly different between site A–RB and both sites A–R3D and A–Wck (table 14); Site A–RB tended to have lower biovolume than other sites (table 13).

Algal Community Composition

Samples for identification of algal taxonomy were collected in April/May, August, and October 2007–11 from regularly sampled biological sites (table 2, and table 2 in Eddy-Miller and others, 2010). Metrics summarizing those samples were generated in terms of taxa richness, cell density and relative abundance, and total and relative biovolume. Metrics related to biovolume have been recommended for eutrophication assessment of streams with large growths of filamentous algae (Porter, 2008).

A total of 335 distinct algal taxa were identified in the 72 algal taxonomy samples collected during the five-year study. Samples contained total taxa ranging from 40 to 85, of which most were diatoms (table 13). An average of 58 algal taxa per sample was identified, with diatoms averaging 50 taxa per sample. Green algae averaged 3 taxa per sample, and blue-green algae averaged 5 taxa per sample. Yellow algae, euglenoid algae, and algae of unknown taxonomy also were identified, but they made up a very small percentage of the algal taxa when present and were not present in the majority of the samples.

Although diatoms predominated in terms of taxa richness, blue-green algae predominated in terms of cell density and green algae predominated in terms of biovolume (table 13). Blue-green algae made up an average of 69 percent of the cell density per sample, with diatoms constituting 27 percent, and the remainder was made up by green and other algae. Green algae made up an average of 76 percent of the biovolume per sample, with diatoms constituting an average of 13 percent, and blue-green and other algae made up the remainder. The dominance of green algae in terms of biovolume is due in part to the occurrence of *Cladophora,* which has relatively large cells.

Predominant algal taxa based on cell density were blue-green algae, particularly *Homoeothrix,* and *Phormidium.* The diatom *Achnanthidium* and the green algae *Cladophora* were common in some of the samples.

Cladophora was the dominant algal taxa based on biovolume at sites A–R3D, A–Wck, A–R6D, and A–R7 in about 85 percent of the samples; *Cladophora* was in about 50 percent of the samples at site A–RBA–RB. Other taxa that were common in terms of biovolume in some samples included the diatoms *Didymosphenia geminata, Cymbella mexicana,*[1] and *Cocconeis* (often an epiphyte on *Cladophora),* undetermined blue-green algae, and the green algae *Spirogyra*. The species *Didymosphenia geminata* is of particular interest because *Didymosphenia* is known for sometimes creating nuisance conditions in the United States and other areas of the world (U.S. Environmental Protection Agency, 2013). Unlike some streams that note nuisance conditions due to *Didymosphenia*, the sites on Fish Creek where *Didymosphenia geminata and Cymbella mexicana* occurred as the dominant taxa by biovolume did not see *Didymosphenia geminata* and *Cymbella mexicana* as the dominant taxa the following sampling time.

Taxonomic analysis of algal samples collected beyond the study area at sites on Cache Creek (streamgage 13018300, fig. 1, August 2011) and Salt River above Reservoir near Etna, Wyo. (streamgage 13027500, fig 1, August 1995) (U.S. Geological Survey, 2012c) indicated some differences from samples from Fish Creek. Algal community taxa richness was lower in Cache Creek and Salt River (averages of 29 taxa per sample) than in Fish Creek (average 58 taxa per sample). Averages in Cache Creek and Salt River for cell density (162,000 $cells/cm^2$) and biovolume (954 million $\mu m^3/cm^2$) were one to two orders of magnitude lower than in averages in Fish Creek (average cell density of 7 million $cells/cm^2$ and average biovolume of 74 billion $\mu m^3/cm^2$). The taxa richness, cell density, and cell biovolume data indicate a much richer and more abundant algal community at sites on Fish Creek than at the other two sites. Although Fish Creek had algal community differences among sites, similarities were common among sites, including the predominance of diatoms with respect to taxa richness, the predominance of blue-green algae with respect to cell density, and the predominance of green algae with respect to cell biovolume. Some of the similarities appeared in dominant taxa as well; in particular, *Homoethrix, dominant* in Cache Creek, and *Cladophora*, dominant in Salt River, were often dominant taxa in Fish Creek samples.

[1]The diatom *Cymbella mexicana* can form mats that superficially resemble the woolly, brown-gray mats formed by *Didymosphenia* (M. Potapova, Academy of Natural Sciences–Philadelphia, written commun., July 23, 2007).

Table 14. Analysis of variance in algal communities in Fish Creek, Teton County, Wyoming, 2007–11.

[Significance tested by Tukey method at probability level less than 0.05 ($p < 0.05$). Apr., April; Aug., August; Oct., October]

Metric	Significant differences between sites	Significant differences between years	Significant differences between seasons
Taxa richness			
All algal species	A–RB and A–R6D, A–RB and A–R7	2007 and 2010, 2007 and 2011, 2008 and 2010, 2008 and 2011, 2009 and 2010, 2009 and 2011	None.
Diatoms	A–RB and A–R6D, A–RB and A–R7	2007 and 2011, 2008 and 2010, 2008 and 2011, 2009 and 2010, 2009 and 2011	None.
Green algae	None	2007 and 2010	None.
Blue-green algae	None	None	None.
Taxa relative abundance based on cell density			
All algal species	None	2007 and 2008, 2007 and 2009	None.
Diatoms	None	2007 and 2010, 2007 and 2011, 2008 and 2010, 2008 and 2011, 2009 and 2010, 2009 and 2011	None.
Green algae	None	2008 and 2010, 2009 and 2010	Apr./May and Aug.
Blue-green algae	None	2007 and 2010, 2007 and 2011, 2008 and 2010, 2008 and 2011, 2009 and 2011	None.
Taxa relative abundance based on biovolume			
All algal species	A–RB and A–R3D, A–RB and A–Wck	None	None.
Diatoms	None	2008 and 2010, 2009 and 2010	Aug. and Oct.
Green algae	A–RB and A–R3D, A–RB and A–Wck, A–RB and A–R6D, A–RB and A–R7	None	None.
Blue-green algae	A–RB and A–R3D, A–RB and A–Wck, A–RB and A–R6D	2007 and 2009	None.
Algal trait relative abundance based on cell density (all algae)			
Nitrogen fixers	A–RB and A–Wck, A–RB and A–R6D, A–RB and A–R7, A–R3D and A–R6D, A–R3D and A–R7	2007 and 2008, 2007 and 2009	None.

Table 14. Analysis of variance in algal communities in Fish Creek, Teton County, Wyoming, 2007–11.—Continued

[Significance tested by Tukey method at probability level less than 0.05; Apr., April; Aug., August; Oct., October]

Metric	Significant differences between sites	Significant differences between years	Significant differences between seasons
Algal trait relative abundance based on cell density (all algae)—Continued			
Motile algae	A–RB and A–R3D, A–RB and A–Wck, A–R3D and A–R7, A–Wck and A–R7	2007 and 2009	None.
Water-quality group relative abundance based on cell density (diatoms)			
Organic-nitrogen autotrophs high	None	2007 and 2009	None.
Always high oxygen tolerance	None	2007 and 2008, 2007 and 2009, 2007 and 2010, 2007 and 2011	Apr./May and Aug., Apr./May and Oct., Aug. and Oct.
Alkalibiontic	A–RB and A–R3D, A–RB and A–Wck, A–RB and A–R6D, A–RB and A–R7	2007 and 2009	None.
Fresh-brackish	None	2007 and 2009, 2009 and 2010, 2009 and 2011	Apr./May and Oct., Aug. and Oct.
Bahls pollution class: sensitive	None	None	Apr./May and Aug., Aug. and Oct.
Algal trait relative abundance based on biovolume (all algae)			
Nitrogen fixers	A–RB and A–Wck, A–RB and A–R6D, A–RB and A–R7, A–R3D and A–R6D, A–R3D and A–R7, A–Wck and A–R7	None	None.
Motile algae	A–RB and A–R3D, A–RB and A–Wck, A–RB and A–R6D	None	None.
Water-quality group relative abundance based on biovolume (diatoms)			
Organic-nitrogen autotrophs high	None	2007 and 2009	Apr./May and Oct.
Always high oxygen tolerance	A–RB and A–Wck	None	Apr./May and Aug., Apr./May and Oct., Aug. and Oct.
Alkalibiontic	A–RB and A–R3D, A–RB and A–Wck, A–RB and A–R6D, A–RB and A–R7	None	None.
Fresh-brackish	A–RB and A–Wck	None	Apr./May and Oct., Aug. and Oct.
Bahls pollution class: sensitive	None	None	Apr./May and Aug., Apr./May and Oct.

Algal Community Changes

The algal community was analyzed statistically using analysis of variance (ANOVA) to determine if changes in the community or community traits changed by site, year, or season. Changes in taxa were tested using taxa richness, relative abundance, and relative biovolume (table 13); only diatoms, green algae, and blue-green algae were tested. About one half the statistical analyses of taxa showed significant differences among sites (table 14). Changes in algal traits such as motility or water-quality tendencies also were statistically analyzed in terms of relative density and relative biovolume. Most categories of traits and tendencies (about 75 percent) had no significant differences between sites, years, or seasons.

Algal Taxa Changes between Sites

Algal taxa richness based on all algal species generally increased in the downstream direction (fig. 16*A*). Results from ANOVA testing indicated values of algal taxa richness and diatom taxa richness were significantly different between site A–RB, where values of richness was lowest, and both sites A–R6D or A–R7 (table 14). Taxa richness of green algae and blue-green algae were not significantly different between sites.

Relative proportions of algal taxa abundance indicated statistically significant differences in biovolume between sites but not in cell density (table 14). Relative abundance based on biovolume varied between sites, but only green algae and blue-green algae were statistically different between sites, and only when compared by biovolume (table 14). Blue-green algae made up a larger percentage of the taxa by biovolume at site A–RB compared to the other sites (fig. 16*B*), and differences in relative abundance of blue-green algae by biovolume at site A–RB were statistically different from those at sites A–R3D, A–Wck, and A–R6D. Conversely, relative abundance of green algae by biovolume, which was predominantly *Cladophora*, tended to be lowest at site A–RB and was significantly different from abundances at the other four sites. The relative abundance of all algal species by biovolume at site A–RB also was significantly different from (lower than) some of the other sites.

Algal Taxa Changes between Years

Algal community taxa richness for all species varied significantly between years (table 14) and tended to be lower in 2007–09 than in 2010–11 (fig. 16*C*). Diatom taxa richness showed the same general patterns as algal community taxa richness (tables 14 and 13). Differences in taxa richness for green algae were significantly different only between 2007 and 2010 and no differences in taxa richness for blue-green algae were significant between years.

The relative abundance of algal taxa based on cell density showed more differences between years than abundance based on biovolume (table 14). Differences between years based on cell density were seen in all algal species, diatoms, green algae, and blue-green algae. In general, the relative abundance of diatoms based on cell density decreased over the study period, and 2010 and 2011 were significantly different from the other three study years (table 14, fig. 16*D*). Blue-green algae showed an opposite change. It had an increase in relative abundance based on cell density over the study period (table 13), and 2007 and 2008 were each significantly different from both 2010 and 2011, and 2009 was different from 2011. Green algae typically made up a smaller relative abundance of the samples and did not show the same overall change as the diatoms or the blue-green algae, but it did have a significant difference between 2010 and both 2008 and 2009.

The relative abundance of algal taxa based on biovolume showed a pattern similar to relative abundance based on density over the course of the study in that the diatoms generally decreased, the blue-green algae generally increased, and the green algae had small amounts of change (table 13). Statistically significant differences in relative abundance based on biovolume were determined for diatoms between 2010 and both 2008 and 2009 (table 14); in each case, 2010 had a smaller diatom biovolume (table 13).

Green algae had no statistical differences in relative abundance based on biovolume between years. A significant difference in the biovolume of blue-green algae was indicated between 2007 and 2009.

Algal Taxa Changes between Seasons

Relatively few differences between seasons were significant for taxa richness, and relative abundances based on density and biovolume (table 14). Green algae was the only algal taxon that was significantly different between seasons based on cell density: the relative abundance for April/May tended to be lower than the values for August (table 13). The relative abundance of green algae based on cell density was typically low (0–10 percent), and small changes in percent abundance have a large effect on the analysis. Similarly, the relative abundance of diatoms was relatively low based on biovolume, and diatoms was the only taxon to show a significant difference (table 14): the relative abundance of diatoms tended to be lower in August than in October (table 13).

Algal Trait Changes between Sites

Algal traits were examined as measures of autecology, or environmental preferences and water-quality optima. Some traits, such as nitrogen fixation and motility, were examined at the community level and included all algal species. Other traits, such as the Bahls pollution class (Bahls, 1993) and pH preference, were examined for the diatom community because traits are better known for diatoms (Porter, 2008) and because diatoms make up the largest part of the algal community richness in Fish Creek (table 13).

Nitrogen fixers include some species of diatoms and blue-green algae that are able to fix atmospheric nitrogen as a nutrient source (Peterson and Grimm, 1992; Borchardt, 1996). Nitrogen fixers made up an average of seven percent by relative abundance in the algal community of Fish Creek and were significantly different between sites (table 14, fig. 17*A*). Nitrogen fixers made up only one percent of biovolume on average. Significant differences in relative abundance of nitrogen fixers based on biovolume were noted between sites (table 14), but the colonial nature of blue-green algae might have influenced those results by causing occasional high counts.

Motility refers to the ability of the algae to move and avoid sedimentation. Average values for motile taxa in Fish Creek were 31 percent relative abundance and 6 percent relative biovolume. Differences for both relative abundance of motile algae were significant between sites for both cell density and biovolume (table 14). Site A–RB tended to have a higher relative abundance of motile algae than other sites except A–R7 (fig. 17*B*) and also had higher biovolume of motile algae than other sites (table 13), which may indicate the algal communities at site A–RB, and to a lesser extent at site A–R7, are responding to levels of sedimentation that are greater than at other sites.

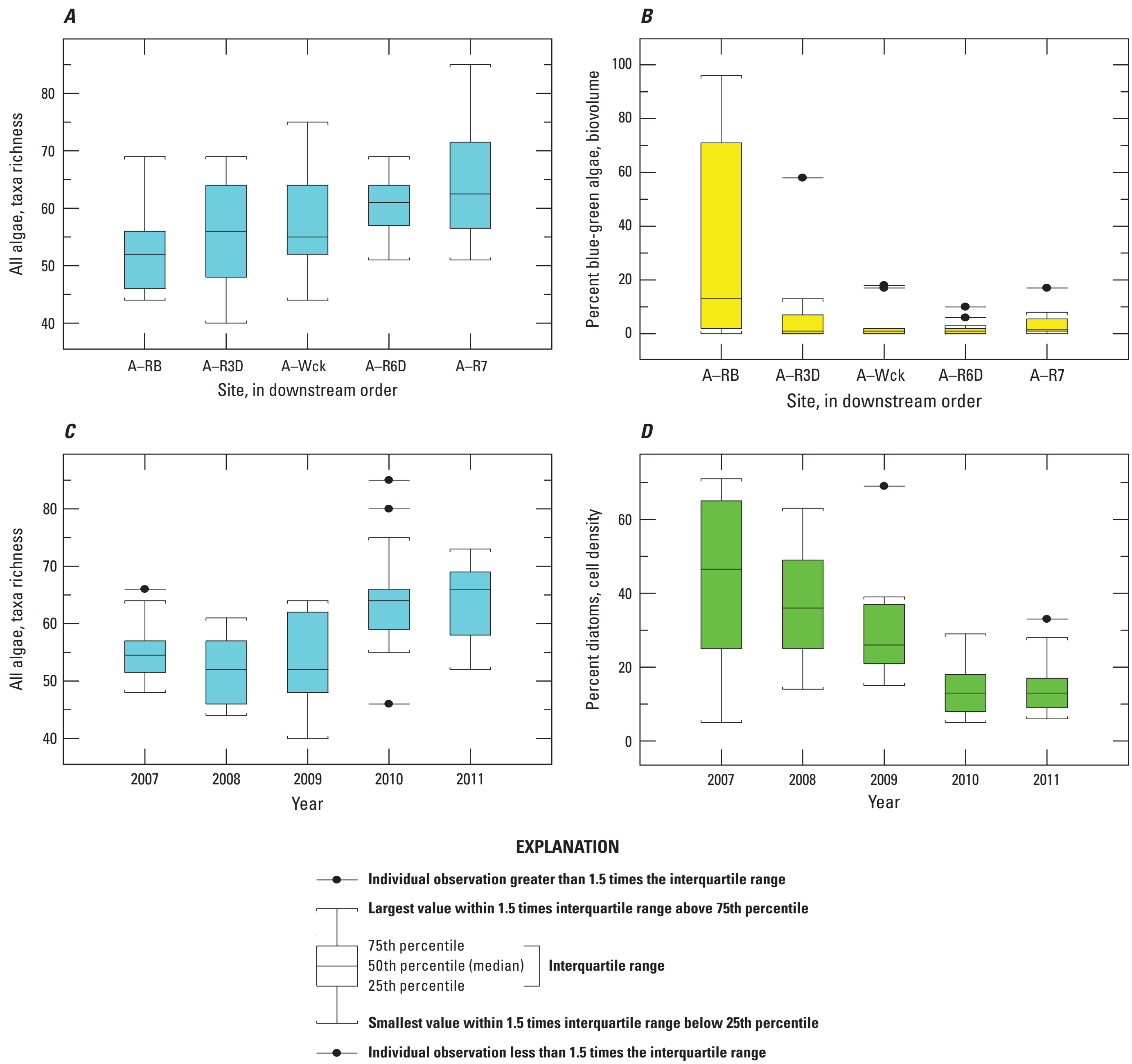
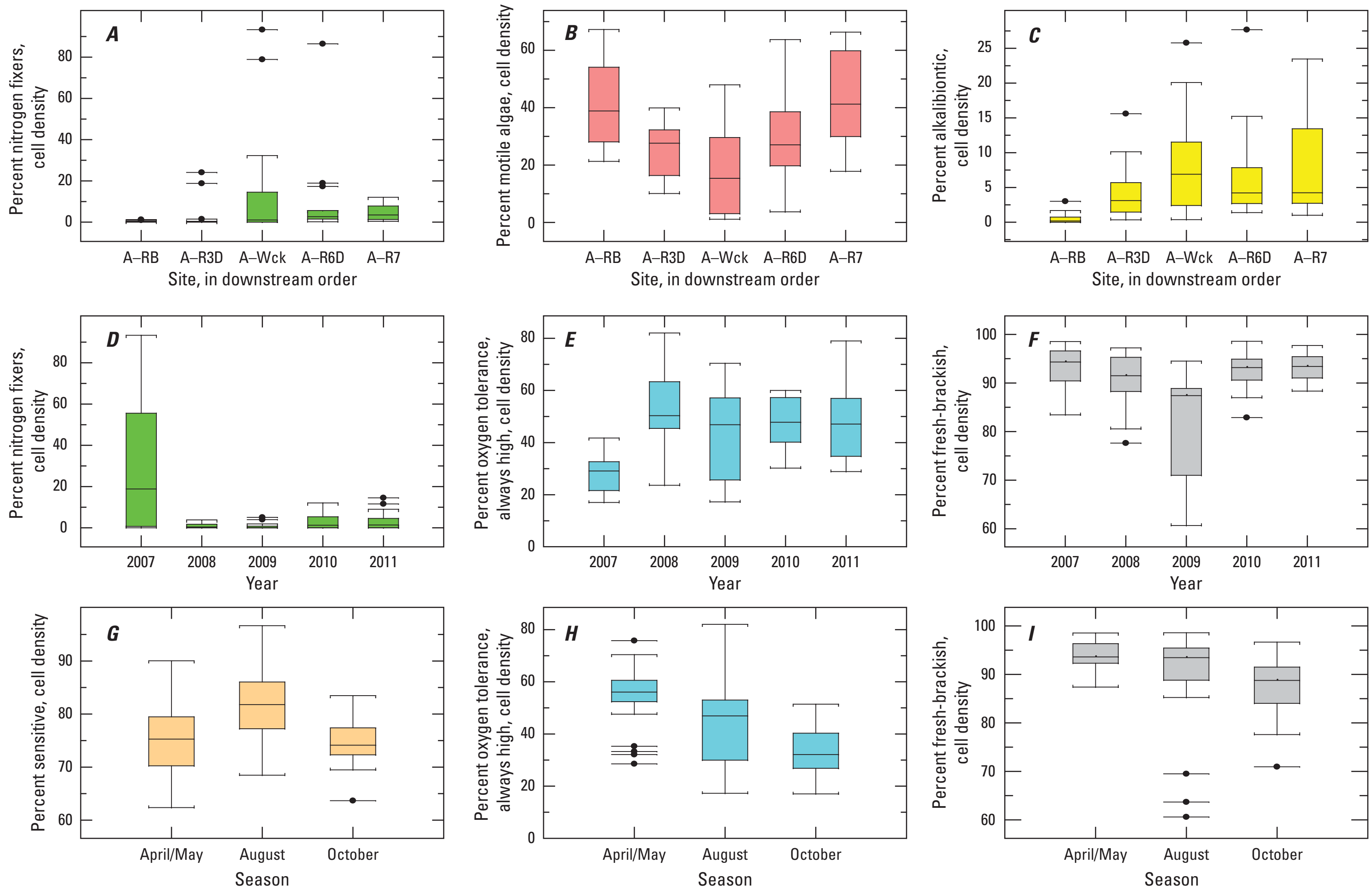


Figure 16. Selected algal community characteristics at regularly sampled biological sites, Fish Creek, Teton County, Wyoming, 2007–11. *A*, Taxa richness for all algae by site. *B*, Biovolume of blue-green algae by site. *C*, Taxa richness for all algae by year. *D*, Cell density of diatoms by year.



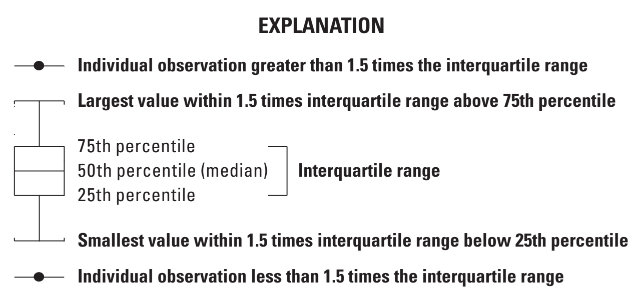


Figure 17. Selected algal traits based on percent cell density at regularly sampled biological sites, by site, year, and season, Fish Creek, Teton County, Wyoming, 2007–11. *A*, Nitrogen fixers (all algae) by site. *B*, Motile taxa (all algae) by site. *C*, Alkalibiontic diatoms by site. *D*, Nitrogen fixers (all algae) by year. *E*, Always high oxygen tolerance diatoms by year. *F*, Fresh-brackish diatoms by year. *G*, Bahls sensitive diatoms by season. *H*, Always high oxygen tolerance diatoms by season. *I*, Fresh-brackish diatoms by season.

Pollution classes defined by Bahls (1993) for streams in Montana were used to evaluate the overall sensitivity to pollution in the diatom communities in Fish Creek. Of the three classes assigned by Bahls (most tolerant, less tolerant, and sensitive), most diatoms in Fish Creek were in the sensitive class (table 13). The sensitive class made up an average of 77 percent based on relative abundance and 87 percent based on biovolume. The relative abundances of the sensitive class were not significantly different between sites based on either density or biovolume (table 14).

Oxygen tolerance of diatoms refers to the relative oxygenation of a stream with relatively high amounts of organic enrichment (for example, sewage) and high biochemical oxygen demand compared to a well-oxygenated stream with little organic enrichment (Van Dam and others, 1994; Porter, 2008). Diatoms associated with high dissolved oxygen concentrations (greater than 75 percent saturation; oxygen tolerance fairly high, table 13) generally predominated in Fish Creek, with smaller proportions of diatoms associated with moderate or low dissolved oxygen concentrations. The relative abundance of the taxa cell density with oxygen tolerance in the always high metric (nearly 100 percent dissolved oxygen saturation) was not significantly different between sites, but the biovolume of such taxa at site A–RB was significantly different from (higher than) the biovolume at site A–Wck (table 14).

The preference or tolerance of the diatom community for organically-bound nitrogen can help describe water quality of a stream. Metrics for organic nitrogen indicated diatom communities were primarily nitrogen autotrophs that do not require high concentrations of organic nitrogen (Van Dam and others, 1994; Porter, 2008). No statistically significant differences in the relative abundance of organic nitrogen autotrophs, based on either cell density or biovolume, were indicated between sites (table 14).

Algal communities in Fish Creek tended to have increasing pH optima in the downstream direction. The dominant pH classification was alkaliphilic, with an optimum pH generally greater than 7, and averaged a relative abundance of 63 percent by cell density and 73 percent by biovolume. Alkalibiontic diatoms, with an optimum pH always greater than 7, made up a smaller portion of the diatom community and indicated increasing relative abundance based on cell density (fig. 17*C*) and biovolume in the downstream direction. The relative abundance of alkalibiontic diatoms at site A–RB were statistically different from the relative abundance at all other sites (table 14).

Diatoms in Fish Creek were predominantly in the fresh-brackish class (Van Dam and others, 1994) (table 13), which are diatoms preferring moderately saline water. The fresh-brackish class made up an average of 90 percent based on cell density and 69 percent based on biovolume. The relative abundance of diatoms in the fresh-brackish class were significantly different between sites A–RB and A–Wck based on biovolume (table 14), and site A–RB tended to have the highest relative abundance of this group (table 13).

Algal Trait Changes between Years

Statistical analysis of the relative abundance of nitrogen fixers in the algal community indicated a significant difference between 2007 and both 2008 and 2009 based on cell density (table 14); 2007 tended to have a higher relative abundance (fig. 17*D*). Relative abundance of nitrogen fixers based on biovolume was not significantly different between years.

Analysis of relative abundance of motile algae indicated one significant difference between years based on cell density (between 2007 and 2009) and no significant differences based on biovolume (table 14). Relative abundance of motile algae in the algal community in 2007 was significantly different from (lower than) abundance in 2009.

Most of the diatom trait metrics indicated few differences between years. For example, the relative abundance of taxa in the sensitive Bahls sensitive pollution class was not statistically difference between years based on either cell density or biovolume (table 14). Organic nitrogen autotroph metrics indicated the only statistically significant differences were that relative abundance based on cell density was higher and based on biovolume was lower in 2007 than in 2009. Relative abundance of alkalibiontic diatoms (pH always greater than 7) in 2007 was significantly different from (higher than) abundance in 2009 based on cell density, but no differences were significant between the years based on biovolume (table 14). The relative abundance of diatoms with high oxygen tolerance in 2007 was significantly different from (lower than) abundance in 2008–11 based on cell density (table 14, fig. 17*E*). Relative biovolume of diatoms with high oxygen tolerance was not significantly different between years. Relative abundance of diatoms with fresh-brackish (moderate) salinity tolerance tended to be lower in 2009 than other years based on cell density (fig. 17*F*), and were significantly different between 2009 and most other years (table 14). The lower relative abundance of diatoms with fresh-brackish salinity tolerance in 2009 was accompanied by a higher relative abundance of diatoms with a higher salinity preference (brackish-fresh water of Van Dam and others, 1994) (table 13). Relative abundance of diatoms with fresh-brackish salinity tolerance was not significantly different between years based on biovolume.

Algal Trait Changes between Seasons

No significant differences based on either cell density or biovolume were noted between seasons for nitrogen fixers, motile algae, or pH preference (table 14). In contrast, both the cell density and the biovolume of the Bahls sensitive pollution class were significantly different between seasons. Proportions of the sensitive class for both cell density (fig. 17*G*) and biovolume tended to be high during August and low during April/May and October (table 13). In general, fewer sensitive species and more tolerant species were found in August than in April/May.

Oxygen tolerance metrics also indicated that seasonal differences were significant (table 14) but not in the same pattern as for the Bahls pollution class. The relative abundance of diatoms with high oxygen tolerance based on cell density (fig. 17*H*) and biovolume tended to be highest in April/May and lowest in October.

Relative abundance of the cell density of organic nitrogen autotrophs between seasons was not significantly different but was significantly different based on biovolume (table 14). Relative abundance of organic nitrogen autotrophs was lower in April/May than in October (table 13).

Seasonal differences were significant for both relative abundance and biovolume of diatoms with fresh-brackish salinity tolerance (table 14). The proportions of diatoms with fresh-brackish salinity tolerance tended to be highest in April/May and lowest in October for both cell density and biovolume(fig. 17*I*).

Macroinvertebrate Communities

Samples for identification of macroinvertebrate taxonomy were collected in April/May and August of 2007–11 from regularly sampled biological sites. Macroinvertebrate taxonomy data are available on the Web (U.S. Geological Survey, 2012b). For this report, raw data were analyzed using Invertebrate Data Analysis System as described in Eddy-Miller (2010), which resolves ambiguous taxa by distributing parents among children.

Macroinvertebrate Community Composition

The macroinvertebrate taxa richness was calculated for all regularly sampled biological sites using the 48 samples collected [*table 15* (Microsoft® Excel format), fig. 2]. Average of total taxa richness ranged from 38 taxa per sample at site A–RB to 46 taxa per sample at sites A–R6D and A–R7. Diptera (true flies) composed about one-half of the macroinvertebrates identified in Fish Creek, based on both taxa richness and relative abundance (table 15). Within the Diptera order, the family Chironomidae (midges) predominated and averaged about 14 taxa per sample and 39 percent relative abundance. Orthocladiinae, a subfamily of Chironomidae, averaged 7 taxa per sample and 26 percent of the relative abundance of macroinvertebrates. Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), collectively known as EPT, had smaller proportions of the overall community taxa richness and relative abundance than Diptera but averaged about 14 taxa per sample and 42 percent relative abundance over the course of the study. Traditionally, EPT taxa are considered indicators of favorable water quality, in contrast to some Diptera species and many noninsects that are tolerant of poor water quality (Barbour and others, 1999). Noninsects composed an average of 10 taxa per sample in Fish Creek and comprised mostly various taxa of Oligochaeta (worms) but also Acari (primarily mites), Amphipoda (such as scuds), Mollusca (snails and fingernail clams), Nematoda (nematodes), and Turbellaria (flatworms) (U.S. Geological Survey, 2012b). A few taxa of Coleoptera (beetles) and Hemiptera (true bugs) were identified in the samples and are referred to throughout the report as “other insects.” Odonata (dragonflies and damselflies) were not identified in any of the samples. Figure 18 shows the average taxa richness from all sites during each sampling period. In general, taxa richness in the August sample tended to be lower than taxa richness in the preceding April/May sample.

The taxa richness of macroinvertebrate samples from site A–RB were primarily attributed to Diptera alone or in combination with EPT, depending on the sampling time (table 15, fig. 19). Diptera commonly was nearly 50 percent of the relative abundance of samples at site A–RB and accounted from more than 80 percent of the relative abundance of two samples (August of 2007 and 2008; fig. 19; table 15). Although the relative abundance of EPT in samples from site A–RB varied from 4 to 85 percent of the sample, the taxa richness was never less than 8; combined, they were the dominant taxa in almost half of the samples.

Macroinvertebrate samples from sites A–R3D and A–Wck were primarily composed of Diptera alone or in combination with EPT, depending on season, similar to site A–RB; however, the average total number of taxa was higher at sites A–R3D and A–Wck than at site A–RB by an average 8 or 9 taxa, respectively (table 15). The greater variety of taxa at sites A–R3D and A–Wck compared to site A–RB was not consistently due to one particular order but tended to include more Trichoptera, Diptera, and Coleoptera taxa. The combined EPT orders made up more than 50 percent of the relative abundance of macroinvertebrates in all of the April/May samples at sites A–R3D and A–Wck and one August sample from A–Wck; whereas, Diptera made up the majority of the relative abundance in all of the other August samples.

Macroinvertebrate samples from sites A–R6D and A–R7 had the highest average total taxa richness with 46 (table 15). Similar to the sites upstream, Diptera commonly was the most dominant taxa at sites A–R6D and A–R7, but the grouped orders of EPT did not make up the dominant taxa as often as at the upstream sites. At site A–R6D, EPT typically had the highest relative abundance of macroinvertebrates in the April/May sample, and Diptera had the highest relative abundance in the August sample (fig. 19). Site A–R7, however, reversed the typical pattern observed upstream; Diptera had the highest relative abundance in April/May and EPT were highest in August (fig. 19).

Macroinvertebrate community taxa richness was compared to data collected at three sites on two nearby creeks: Cache Creek near Jackson, Wyo. (streamgage 13018300), Salt River above Smoot, Wyo. [site 13023700 (fig. 1)] and Salt River above Reservoir near Etna, Wyo. [streamgage 13027500 (fig. 1)] (U.S. Geological Survey, 2012c). Macroinvertebrate communities in Fish Creek during the August sampling period were generally similar to samples collected during August from sites on Cache Creek and Salt River. However, the taxa richness of Ephemeroptera and Plecoptera was notably lower and noninsect taxa richness notably higher in Fish Creek than in Cache Creek and Salt River. Additionally, the relative abundances of EPT were lower and relative abundances of Diptera and noninsects higher in Fish Creek than in Cache Creek and Salt River. The relative abundance of most functional feeding groups, such as gatherer-collectors, was similar between the two datasets, although relative abundance of the scraper feeding group was notably lower in Fish Creek than Cache Creek or Salt River. The August samples from Fish Creek had lower proportions of intolerant (to pollution as described by Bahls, 1993) macroinvertebrates and higher proportions of tolerant macroinvertebrates than samples from Cache Creek and Salt River.

Macroinvertebrate Community Changes

The macroinvertebrate community was evaluated statistically to determine if changes in the community or parts of the community changed in relation to site, year, or season. Changes in taxa were tested using both taxa richness and relative abundance (table 16). Changes in density and diversity, functional feeding groups, and tolerance group metrics also were statistically evaluated.

Macroinvertebrate Taxa Changes between Sites

Analysis of macroinvertebrate taxa based on both richness and relative abundance showed some variation between sites but only a few statistically significant differences ($p < 0.05$) (table 16) . The taxa richness of all macroinvertebrates was significantly different between site A–RB and both sites A–Wck and A–R6D; richness was lower at site A–RB than at sites A–Wck and A–R6D (fig. 20*A*). The taxa richness of all individual groups (metrics), with the exception of the noninsect group, was not significantly different between sites. The number of noninsects was significantly different between site A–RB and both sites A–R6D and A–Wck–R7, as is seen in particular in the much smaller number of Oligochaeta species at site A–RB (U.S. Geological Survey, 2012b). The differences in macroinvertebrate taxa between sites based on relative abundance were similar to the results based on richness; most metrics did not have a statistical difference between sites. Noninsects were again significantly different between sites A–RB and A–R7 based on relative abundance. Results of the relative abundance analysis were different from those for richness in that Coleoptera was significantly different at many of the sites, whereas there was no significant difference in taxa richness between the sites (table 16). Coleoptera was significantly different between site A–R7 and all other sites and was higher at site A–R7 than at the other sites (table 15). Coleoptera taxa at site A–R7 were of the Elmidae family (riffle beetles), primarily *Optioservus* and *Cleptelmis ornata*, which are aquatic in both larval and adult forms.

Macroinvertebrate Taxa Changes between Years

Macroinvertebrate taxa at all sites were grouped and tested to determine if changes in populations occurred between years. Most metrics showed no statistically significant differences between years based on both richness and relative abundance, but metrics associated with Diptera, Chironomidae, and Orthocladiinae did have significant differences between

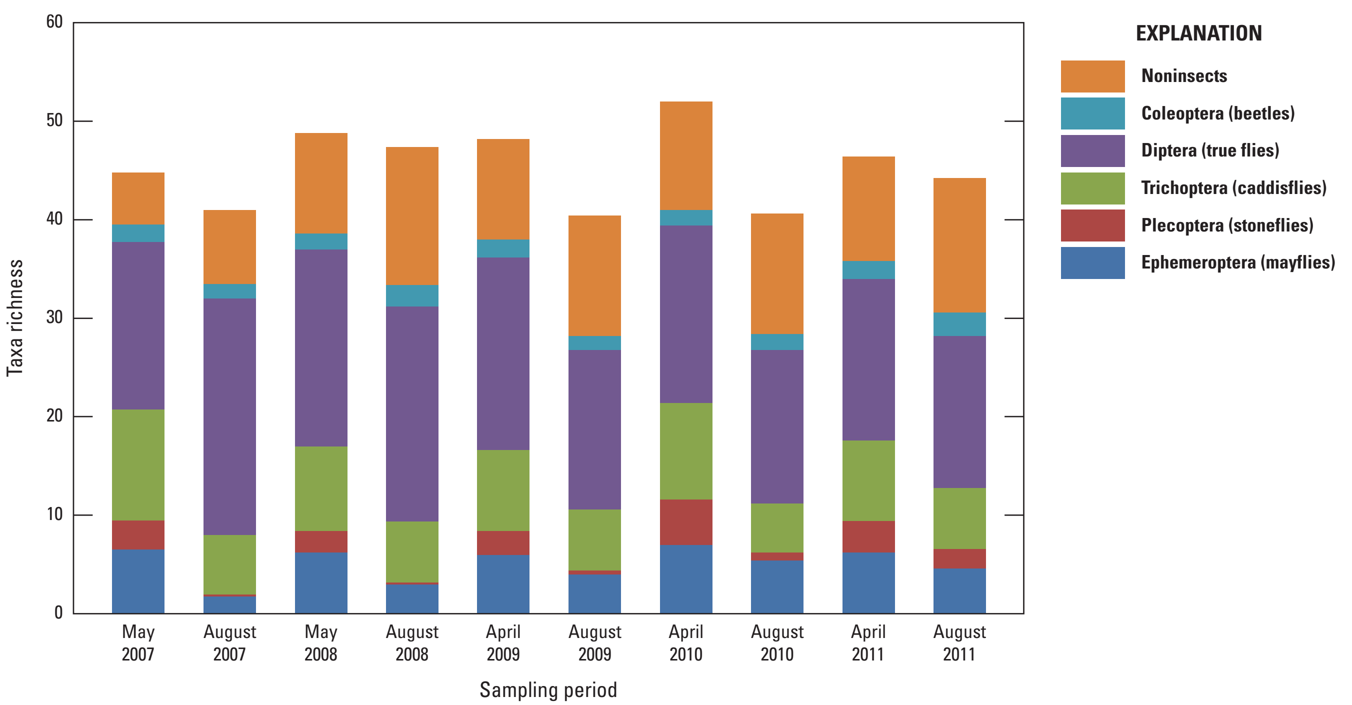


Figure 18. Average taxa richness of macroinvertebrate communities for five regularly sampled biological sites (A–RB, A–R3D, A–Wck, A–R6D, A–R7) by sampling period, Fish Creek, Teton County, Wyoming, 2007–11.

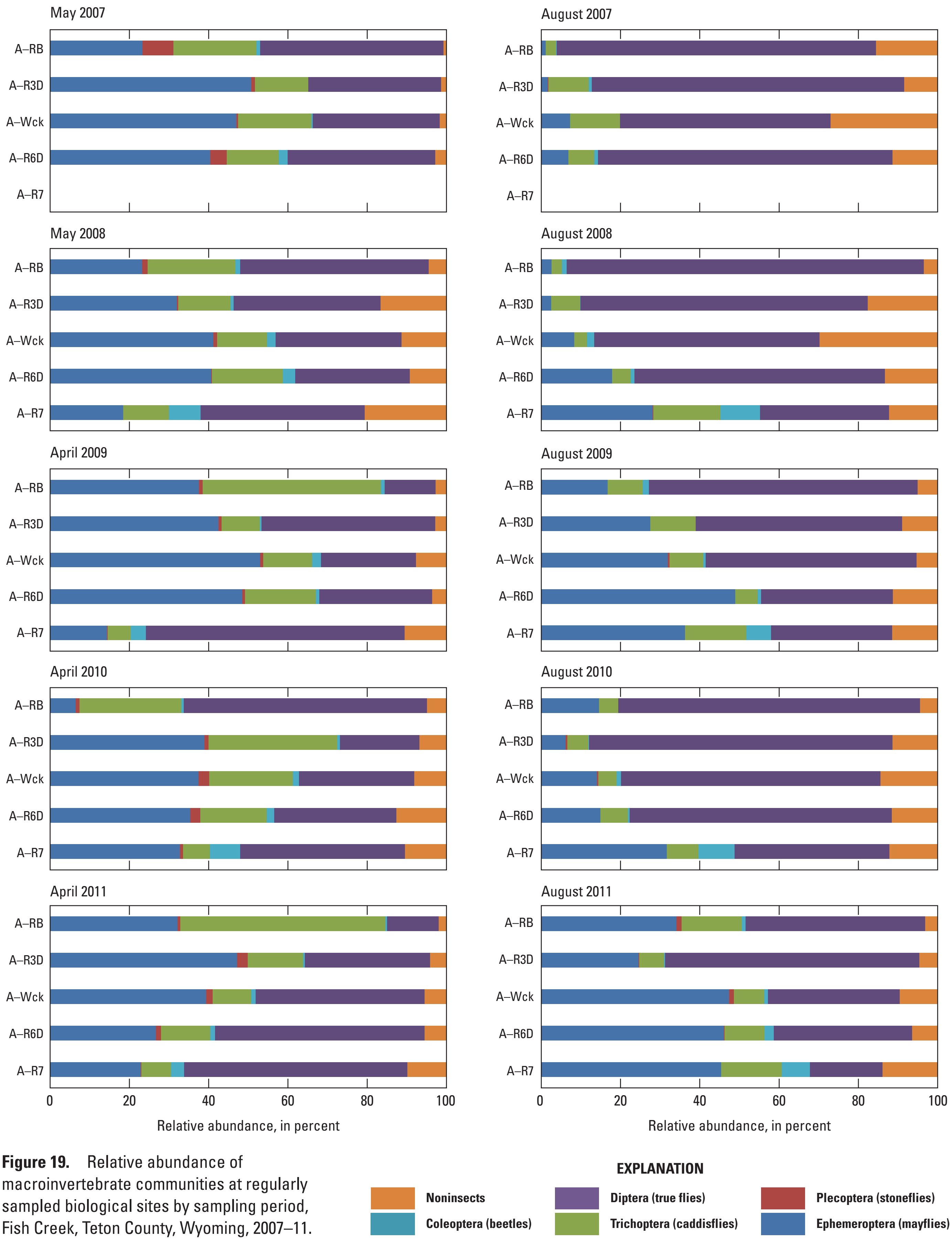


Figure 19. Relative abundance of macroinvertebrate communities at regularly sampled biological sites by sampling period, Fish Creek, Teton County, Wyoming, 2007–11.

Table 16. Analysis of variance in macroinvertebrate community, Fish Creek, Teton County, Wyoming, 2007–11.

[Significance tested by Tukey method at probability level less than 0.05 ($p < 0.05$). Apr., April; Aug., August]

Metric	Significant differences between sites	Significant differences between years	Significant differences between seasons
Taxa richness			
All macroinvertebrates	A–RB and A–Wck, A–RB and A–R6D	None	Apr./May and Aug.
Ephemeroptera	None	None	Apr./May and Aug.
Plecoptera	None	None	Apr./May and Aug.
Trichoptera	None	None	Apr./May and Aug.
Diptera	None	2007 and 2011, 2008 and 2010, 2008 and 2011	None.
[1]Chironomidae	None	2007 and 2010, 2007 and 2011, 2008 and 2010, 2008 and 2011	None.
[2]Orthocladiinae	None	None	Apr./May and Aug.
Coleoptera	None	None	None.
Noninsect	A–RB and A–R6D, A–RB and A–R7	2007 and 2008, 2007 and 2009, 2007 and 2010, 2007 and 2011	Apr./May and Aug.
Taxa relative abundance			
Ephemeroptera	None	None	Apr./May and Aug.
Plecoptera	None	None	Apr./May and Aug.
Trichoptera	None	None	Apr./May and Aug.
Diptera	None	None	Apr./May and Aug.
[1]Chironomidae	None	None	None.
[2]Orthocladiinae	None	2007 and 2011	Apr./May and Aug.
Ratio of Orthocladiinae to Chironomidae	None	2007 and 2011	Apr./May and Aug.
Coleoptera	A–RB and A–R7, A–R3D and A–Wck, A–R3D and A–R6D, A–R3D and A–R7, A–Wck and A–R7, A–R6D and A–R7	None	None.
Noninsect	A–RB and A–R7	None	Apr./May and Aug.

Table 16. Analysis of variance in macroinvertebrate community, Fish Creek, Teton County, Wyoming, 2007–11.—Continued

[Significance tested by Tukey method at probability level less than 0.05 ($p < 0.05$). Apr., April; Aug., August]

Metric	Significant differences between sites	Significant differences between years	Significant differences between seasons
Density and diversity			
Density	None	2007 and 2009	Apr./May and Aug.
Percent of one most dominant taxon	None	2007 and 2009, 2007 and 2011, 2008 and 2009, 2008 and 2011	None.
Percent of five most dominant taxa	None	2007 and 2011, 2008 and 2009, 2008 and 2011	None.
Shannon diversity index	None	2007 and 2011, 2008 and 2009, 2008 and 2011, 2010 and 2011	None.
Functional feeding group relative abundance			
Predator	None	None	None.
Gatherer-collector	None	None	Apr./May and Aug.
Filter-collector	A–RB and A–R3D	None	Apr./May and Aug.
Scraper	A–R3D and A–R7, A–Wck and A–R7, A–R6D and A–R7	None	Apr./May and Aug.
Shredder	None	2007 and 2010, 2007 and 2011, 2008 and 2010, 2008 and 2011	Apr./May and Aug.
Tolerance score[3] metrics			
Total tolerant species	None	None	Apr./May and Aug.
Tolerance[3] group relative abundance			
Intolerant	None	None	Apr./May and Aug.
Moderately tolerant	None	None	Apr./May and Aug.
Tolerant	None	2008 and 2009, 2008 and 2010, 2008 and 2011	None.

[1]Chironomidae is a family in the order Diptera.

[2]Orthocladiinea is a sub-family in the Chironomidae family.

[3]Based on classification of Hilsenhoff (1987) and Cuffney (2003).

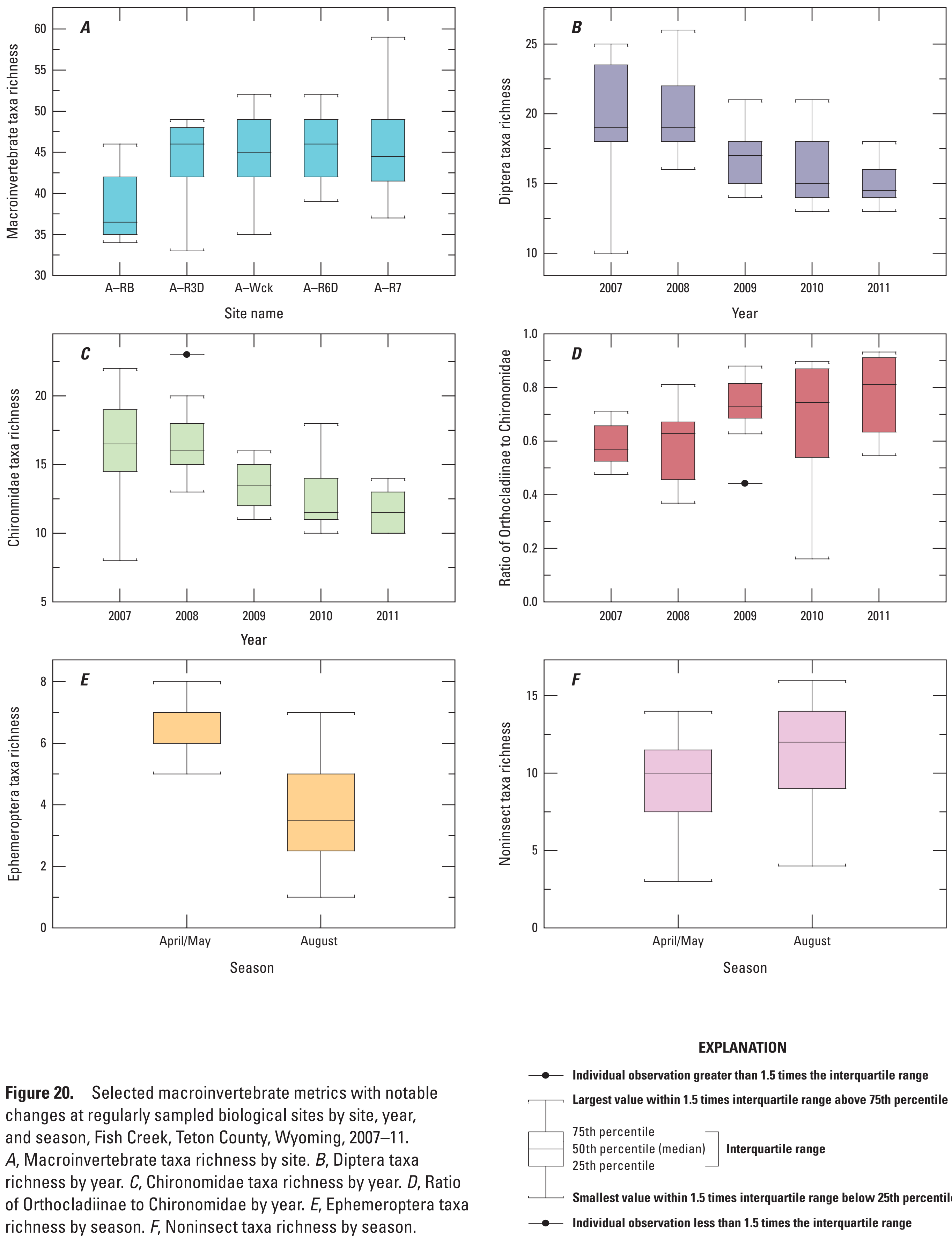


Figure 20. Selected macroinvertebrate metrics with notable changes at regularly sampled biological sites by site, year, and season, Fish Creek, Teton County, Wyoming, 2007–11. *A*, Macroinvertebrate taxa richness by site. *B*, Diptera taxa richness by year. *C*, Chironomidae taxa richness by year. *D*, Ratio of Orthocladiinae to Chironomidae by year. *E*, Ephemeroptera taxa richness by season. *F*, Noninsect taxa richness by season.

some years (table 16). The taxa richness of Diptera and Chironomidae in 2007 and 2008 was significantly different from 2010 and 2011, as the number of taxa at most sites declined from the beginning to the end of the study (table 15, fig. 20*B* and *C*). The relative abundance of Diptera, Chironomidae, and Orthocladiinae was not significantly different between years, but the ratio of Orthocladiinae to Chironomidae in 2007 was significantly different (lower in 2007) from that in 2011 (table 16, fig. 20*D*).

Macroinvertebrate Taxa Changes between Seasons

Taxa richness and relative abundance of Ephemeroptera (fig. 20*E*), Plecoptera, and Trichoptera decreased between April/May and August and were significantly different between seasons ($p < 0.05$) (table 16). Other taxonomic groups, such as Diptera, Chironomidae, and Coleoptera, had no significant differences in taxa richness between seasons. Orthocladiinae were significantly different between seasons based on both taxa richness and relative abundance (table 16) and showed a decline, similar to EPT. The ratio of Orthocladiinae to Chironomidae was significantly different between seasons ($p < 0.05$) and declined from an average of 0.72 in April/May to an average of 0.64 in August (from 72 to 64 percent) (table 16). Taxa richness and relative abundance of noninsects in August were significantly different from (higher than) that in April/May (fig. 20*F*).

The combination of a significant difference in EPT between seasons and the lack of significant difference in EPT between years likely indicates a recurring seasonal pattern. A continual shift or trend in the Fish Creek macroinvertebrate community was not found over the course of the study period. Life cycle processes (such as maturing from the aquatic form to a terrestrial adult form) could create differences between the April/May and August sampling. However, because EPT presence is greater at other sites (such as Cache Creek and Salt River) than at Fish Creek sites at the same time of the year, the seasonal shift in macroinvertebrate communities of Fish Creek is likely not entirely attributable to life cycle processes.

Macroinvertebrate Density and Diversity Changes between Sites, Years, and Seasons

No statistical differences in the density of macroinvertebrates were found between sites, but density in 2007 was different from (lower than) density in 2009, and density in April/May was different from (higher than) density in August (tables 15, 16). The percentages of the one most dominant species and the five most dominant species, in conjunction with the Shannon diversity index (Hughes, 1978), were evaluated as measures of macroinvertebrate community diversity. A sample that has a large percentage of the one and the five most dominant species, or a lower Shannon index score, tends to have a less diverse community because non-dominant taxa are overshadowed by the large number of dominant taxa. The dominance metrics and Shannon diversity index scores were not significantly different between sites or seasons, but some significant differences were noted between years (table 16). Percentages for the one and five most dominant species tended to be higher in 2009 and 2011 compared to both 2007 and 2008 (table 15). As expected, the Shannon values tended to be lower in 2009 and 2011, with statistically significant differences in 2011 samples, in particular (table 16).

Macroinvertebrate Trait Changes between Sites

Functional feeding groups and tolerance of the macroinvertebrate communities were examined as traits or indicators of community dynamics. Functional feeding groups indicate feeding preferences and classify macroinvertebrates into five groups: gatherer-collectors, filterer-collectors, scrapers, shredders, and predators (Barbour and others, 1999). Tolerance represents relative sensitivity to perturbation from various stressors such as organic pollution and sedimentation (Barbour and others, 1999). Differences in feeding groups and tolerance between sites, years, and seasons were analyzed to determine any statistically significant differences (table 16, fig. 21).

The gatherer-collector functional feeding group composed an average relative abundance of 69 percent of the macroinvertebrates but was not significantly different between sites (table 16). Statistically significant differences in functional feeding groups between sites were indicated for the filterer-collector and scraper groups. Site A–RB tended to have a lower relative abundance of the filterer-collector group compared to other sites (table 15, fig. 21*A*), but a statistically significant difference was found only between sites A–RB and A–R3D (table 16). Site A–R7 tended to have a larger number of scrapers in its macroinvertebrate population (fig. 21*B*), and statistically significant differences were indicated for relative abundance of scrapers between site A–R7 and sites A–R3D, A–Wck, and A–R6D (table 16, fig 21*B*). The relatively high abundance of scrapers was largely due to the presence of *Optioservus* (riffle beetles), which made up an average of 5.7 percent of the macroinvertebrates at site A–R7 (U.S. Geological Survey, 2012b). *Optioservus* also was present in many of the samples from other sites but at lower proportions.

The macroinvertebrate tolerance scores were not significantly different between sites (table 16). Tolerance scores were based on a range of 0 to 10, from least to most perturbation or organic enrichment (Hilsenhoff, 1987; Cuffney, 2003). No differences between sites were significant in relative abundance of intolerant (score range of 0 to <4), moderately tolerant (score range of 4 to <7), or tolerant (score range of 7 to 10) macroinvertebrates (table 16).

Macroinvertebrate Trait Changes between Years

The relative abundance of most functional feeding groups were not significantly different between years (table 16). The exception was the shredder feeding group, which had a higher relative abundance in 2007 and 2008 than in later years of the study (table 15) and had significant differences between years (table 16). The decrease in relative abundance of scrapers from 2007–08 to later years is primarily due to a decrease in the

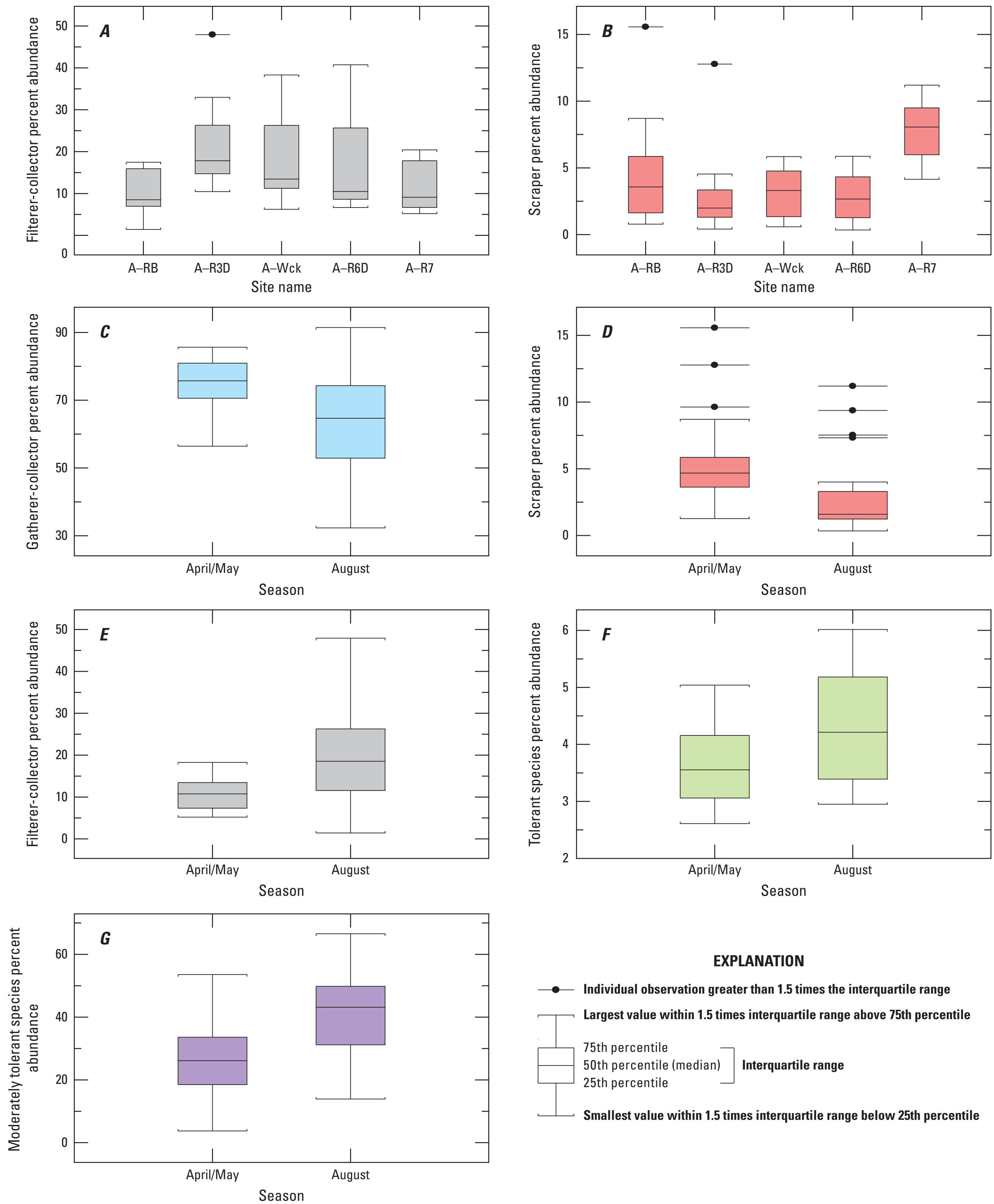


Figure 21. Selected macroinvertebrate traits with notable changes at regularly sampled biological sites, by site and by season, Fish Creek, Teton County, Wyoming, 2007–11. *A*, Percent filterer-collectors by site. *B*, Percent scrapers by site. *C*, Percent gatherer-collector by season. *D*, Percent scrapers by season. *E*, Percent filterer-collectors by season. *F*, Percent tolerant species by season. *G*, Percent moderately tolerant species by season.

caddisfly (Trichoptera) *Lepidostoma* (U.S. Geological Survey, 2012b), for unknown reasons.

Tolerance group statistics indicated the relative abundance of tolerant macroinvertebrates in 2008 was statistically different from 2009, 2010, and 2011 (table 16) with a higher percentage of tolerant species in 2008 than other years (table 15). The tolerance score and relative abundance of intolerant and moderately tolerant macroinvertebrates were not significantly different between years.

Macroinvertebrate Trait Changes between Seasons

The relative abundance of most functional feeding groups and tolerance groups were significantly different between seasons (table 16). Differences by season were significant for all functional feeding groups except predators. Relative abundance of the gatherer-collector and scraper functional feeding groups decreased between April/May and August (table 15, fig. 21*C* and *D*), whereas the filterer-collector (fig. 21*E*) and shredder functional feeding groups increased between April/May and August. Decreases in gatherer-collectors between April/May and August were due to decreases in relative abundance of taxa such as *Ephemerella* (Ephemeroptera), *Amiocentrus aspilus* (Trichoptera), and *Diamesa* (Diptera:Chironomidae:Diamesinae) (U.S. Geological Survey, 2012b). Increases in filter/collectors were due to increases in taxa such as *Arctopsyche grandis* (Trichoptera) and *Simulium* (Diptera). The relative abundance of some taxa, such as *Baetis tricaudatus* (Ephemeroptera, gatherer-collector), did not change much between seasons. *Baetis tricaudatus* was a fairly common species, with an average relative abundance of 19 percent in April/May and 20 percent in August (U.S. Geological Survey, 2012b). All tolerance group metrics, except relative abundance of tolerant species (fig. 21*F*), had statistically significant differences between seasons (table 16). The tolerance score and relative abundance of moderately tolerant species (fig. 21*G*) increased from April/May to August, whereas the relative abundance of intolerant macroinvertebrates decreased during this time from April/May to August (table 15). This seasonal pattern in tolerance likely reflects the seasonal decrease in EPT taxa, which tend to be intolerant, and the increase in noninsects and other macroinvertebrates that are more tolerant.

Habitat Characteristics

Habitat characteristics of streambed substrate (pebble count) and riparian canopy were measured at the regularly sampled biological sites at various times throughout the study (table 2 and Eddy-Miller and others, 2010). Streambed substrate data were collected six times, and riparian canopy data were collected six times in October 2008; April/May, August, and October, 2009; August 2010; and April/May 2011.

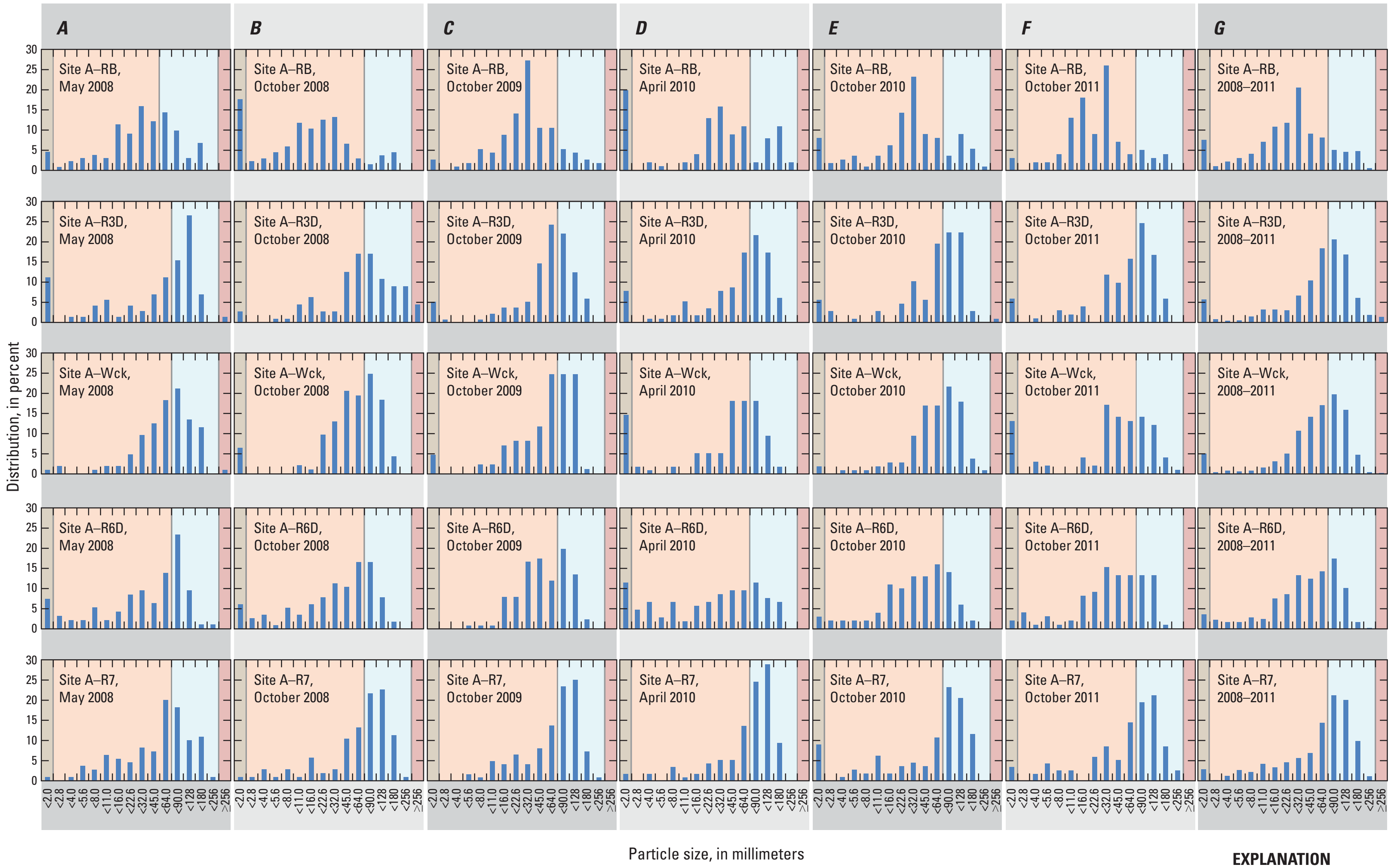
Streambed Substrate

The streambed substrate for the entire width of the reach near each site was measured six times during the study in between each of the annual peak flows (fig. 22). The median particle size of the streambed substrate was calculated for all sites using data collected all six times (table 17). The streambed substrate, as mentioned in the section “Hydrologic Characteristics,” is primarily very coarse gravel to cobble in size (table 17). Additionally, when algal samples were recorded, percent of embedded substrate (embeddedness) also was recorded and the median value was computed (table 17). Embeddedness of the substrate (that is, sediment filled in around larger particles) varied between 0 and near 40 percent embedded, but median values of embeddedness were all less than 15 percent (table 17). Comparison of substrate between peak flows showed no detectable relation between substrate size distribution or embeddedness and the magnitude of the flows each year.

The streambed substrate at site A–RB, the most upstream regularly sampled biological site on Fish Creek, had slightly smaller substrate than the downstream sites (table 17, fig. 6) with a median particle size of 23.8 millimeters (mm), classified as coarse gravel. Sites A–R3D, A–Wck, and A–R6D had slightly larger streambed substrate with median particle sizes of 60.4 mm, 54.0 mm, and 38.4 mm, respectively (each classified as very coarse gravel). Site A–R6D tended to have more medium and coarse gravel than sites A–R3D and A–Wck, which leads to a lower median particle size. Site A–R7 had the largest median particle size of 66.6 mm, classified as cobble. Even at sites with the highest percentage of particles less than 2 mm (fine particles), the average percentage of fines was no more than about 8 percent, again indicating the streambed was primarily gravel and cobble substrate and was minimally embedded.

Riparian Canopy

Shading of Fish Creek was minimal at most sites, with grassy banks and few trees. Densiometer readings were recorded twice each season at sites A–RB, A–R3D, A–Wck, A–R6D, and A–R7 (table 2 and Eddy-Miller, 2010) as an indicator of riparian canopy cover and shading that might limit light availability for photosynthesis by the aquatic plant communities. The median riparian canopy cover was 0 percent at sites A–RB, A–R6D, and A–R7, 4 percent at site A–R3D, and 11 percent at site A–Wck (table 17). Although two of the sites did have a measurable riparian canopy, the small median value, the large width of the channel, and the relatively short height of the riparian vegetation allow most of the stream channel to receive full sunlight; differences between sites were negligible.



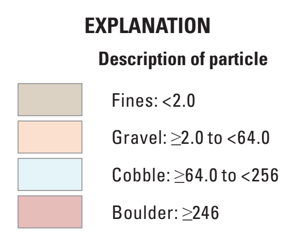


Figure 22. Streambed substrate size distribution at regularly sampled biological sites, Fish Creek, Teton County, Wyoming, 2008–11. *A*, May 2008. *B*, October 2008. *C*, October 2009. *D*, April 2010. E, October 2010. *F*, October 2011. *G*, Average for 2008–2011. (<, less than; ≥, greater than or equal to)

Table 17. Median particle size, median embeddedness, and median riparian canopy at regularly sampled biological sites, Fish Creek, Teton County, Wyoming, 2007–11.

[D_{50}, median particle diameter using log-normal distribution; mm, millimeters]

Site name	Median particle size (D_{50}) (mm)	Median particle size type classification	Median substrate embeddedness (percent)	Median riparian canopy (in percent)
A–RB	23.8	Coarse gravel	4	0
A–R3D	60.4	Very coarse gravel	14	4
A–Wck	54.0	Very coarse gravel	9	11
A–R6D	38.4	Very coarse gravel	6	0
A–R7	66.6	Cobble	12	0

Relations between Hydrology and Ecology

Understanding relations among the organisms and their environment (ecology) is critical to understanding the dynamics of Fish Creek and planning for any potential measures to control the growth of aquatic plants in Fish Creek. Streamflow and water quality affect aquatic plants and vice versa. Aquatic plants, as the base of the food chain, affect the macroinvertebrate communities and in turn the fish communities. This study was not designed to collect every possible ecosystem component that can affect another, such as major ions or micronutrients required by aquatic plants in water, fish samples, or additional samples at other times of the year. However, the ecosystem components sampled for in this study—biological and water-quality samples over a five-year sampling period at the five regularly sampled biological sites on Fish Creek—did provide an opportunity to determine some of the ecosystem connections.

In the broadest analysis, a few patterns related to site, year, and season were observed regardless of the ecologic component analyzed. First, site A–RB, the most upstream of the regularly sampled biological sites, commonly was different from all the other sites, whether looking at streamflow (lower flows), water quality (lower specific conductance), aquatic plants (smaller amount of macrophyte growth), algae (higher percentage of microalgae), or macroinvertebrates (lower taxa richness). Second, the study period included years when climatic variables were near the peak of record and years when values were near the low record, both in temperature and snowfall. This did lead to a difference in the streamflow at the Wilson streamgage, but few other ecologic components showed a consistent change between years.

Seasonal changes were seen in most ecosystem components. The fact that seasonal changes were so regularly detected is an indication that the sampling methods are able to detect changes in the ecosystem. This implies that a change between years should be detectable, but few trends between years were seen over the study period. It should be noted that five years of data is a short period of time to statistically determine trends, and long-term data collection would be needed to determine if trends in the various ecosystem components are present over time.

Relations between Hydrology and Water Chemistry

The hydrology of Fish Creek is unique compared to most mountain streams in that groundwater contributes substantial flow to the creek over the entire year rather than just during base-flow time periods in the fall and winter. Because of this continuous groundwater discharge to the creek, land-use activities in the west bank area can affect the surface water. Septic systems, sewage injection, and lawn fertilization can contribute nutrients to the creek. Nutrients were detected in the surface water and nutrient concentrations tended to decline downstream from Teton Village. The interpretation of isotope data and the continued higher concentrations of dissolved nitrate in groundwater in all of the paired groundwater wells (A–R1D –W1, A–R3D–W1, and A–Wck–W1) than in surface water indicates that nutrient loading continues in varying degrees along the length of Fish Creek. Nitrate concentrations were higher in groundwater than in the surface water in and near Fish Creek. Evidence of groundwater transporting nitrate and of land use contributing nitrate into Fish Creek was observed in shifts of isotopic values of nitrate: from values indicating a larger contribution of septic/sewage sources in the upper reaches, to a mixture of sources in the middle reaches, back to a septic/sewage signature in the lower reaches.

The volume of surface-water inflow from Snake River discharging to Fish Creek between the upper section and mid-section of Fish Creek was not quantified, but numerous diversions exist to bring surface water into the Fish Creek drainage. This water from Snake River has low nutrient concentrations and likely dilutes the higher concentrations of nutrients in groundwater that discharge into Fish Creek.

Relations between Hydrology and Aquatic Plants

Several aspects of Fish Creek's hydrology help create an excellent habitat for the growth of aquatic plants. Especially in the winter, the proportionately large, continuous gain of groundwater into Fish Creek in the perennial reaches keeps the majority of the creek free of ice. This ice-free condition is not typical in Jackson Hole, and many creeks, such as Flat Creek, typically have an ice-covered channel for 3–4 months of the year. Because sunlight can still reach the streambed in Fish Creek and the water is still flowing, aquatic plants continue photosynthesizing in the winter, albeit at a lower level of productivity.

Additionally, the cobble and large gravel substrate in Fish Creek provides excellent attachment points for aquatic plants. In particular, the large gravel and cobbles provide growing locations (attachment sites) for microalgae and macroalgae. Additionally, Fish Creek's channel stability and lack of flood flows keep the majority of the bedload from moving, thereby creating stable attachment sites for algae and moss and allowing rapid growth of aquatic plants once conditions allow during the spring. The fact that new colonies do not have to reestablish each year enables the algae to quickly begin growing when conditions are conducive.

The hydrology of Fish Creek likely plays a part in why site A–RB tends to be different from sites downstream. Site A–RB is near the location where the creek changes from intermittent to perennial and where the creek stage tends to drop in relation to the streambed in the winter. The lower water altitude (stage) typically exposes some rock tops during this time, which likely favors the growth of diatoms rather than the larger plant-like *Cladophora*, moss, or vascular aquatic plants.

Relations between Water Chemistry and Aquatic Plants

Fish Creek is different from most streams in Wyoming because its aquatic plant community is composed of many different members (fig. 15) while the authors have observed most other streams in the State are predominantly algae. Algae are important to evaluate, as the community acts as an integrator over time and can change in response to water-quality changes. Because the aquatic plant community had at times only a small percentage of algae, all aquatic plants also were compared to water quality.

Macrophyte Effect on Water Quality

The composition of the various macrophytes (macroalgae, including *Cladophora*; moss; and vascular aquatic plants) in Fish Creek varied between sites (fig. 15), but combined acted as a "crop" that consumed nutrients from the water for photosynthesis. A statistically significant shift from higher amounts of microalgae in April/May to higher amounts of macrophytes in August and October was observed (table 11, fig. 15). Another indicator, maximum rate of aquatic plant productivity (P_{max}), also showed a substantial change in the activity of the photosynthesizing organisms in the creek between months that are dominated by microalgae (lower P_{max}) compared to months dominated by macrophytes (higher P_{max}); the difference between April/May and October was statistically significant (table 16).

The amount of dissolved nitrate and the N:P ratio were significantly different between seasons (table 10), as concentrations of nitrate were higher in April/May than in August (tables 5, 6, figs. 11, 12). It is likely that nitrate concentrations in Fish Creek were lower in August and October because macrophytes were quickly utilizing the nutrient; a negative correlation between macrophytes and nitrate ($\rho = -0.7$) was found. The decrease in the N:P ratio each year between April/May and August and October to a level where P is no longer the limiting nutrient also shows how increased growth of macrophytes affects the water quality. A negative correlation also was found between the N:P ratio and percent macrophytes ($\rho = -0.7$).

Macrophyte effects on water quality also were likely seen in differences in pH between sites and differences in dissolved oxygen between seasons. The larger amount of photosynthesis that occurs as the result of a larger crop of macrophytes tended to create higher values of pH in sites downstream from site A–RB and larger amplitude changes in the dissolved-oxygen diel cycles in August and October. Warmer water temperatures in August and October likely contribute to overall lower concentrations of dissolved oxygen. Because aquatic plants in Fish Creek do not massively die off in the late fall and winter but rather decrease slowly, a shift to an oxygen-depleted condition was never observed during the April–October sampling season.

Water Quality Effects on Diatoms

The predominance of sensitive diatoms in Fish Creek classifies its water overall as good (Bahls, 1993). Evaluation of biological life in Fish Creek helps reflect long-term conditions in the creek, whereas water samples, from surface water in particular, represent the conditions for a shorter period of time.

Fish Creek did have some site and seasonal changes in water chemistry, namely dissolved oxygen and pH, as described in "Water-Quality Characterizations." The statistically different pH concentrations between site A–RB and the other regularly sampled biological sites (with site A–RB having lower pH than the other sites) is reflected in the statistically significant difference in both the cell density and biovolume of alkalibiontic diatoms (those preferring pH levels greater than 7). The seasonal pattern of dissolved oxygen, higher in April/May than in August and October, corresponded with a higher cell density and biovolume of lithobiotic diatoms in April/May than in August and October.

Relations between Macroinvertebrates and Water Quality/Aquatic Plants

Macroinvertebrates commonly are used as integrators of water quality in a stream because of their susceptibility to long-term conditions of water quality and documented tolerance or intolerance of poor water quality (Barbour and others, 1999). Stream water in Fish Creek is relatively cold throughout the year and has few toxic chemicals (Eddy-Miller and others, 2010), little suspended sediment, stable gravel- and cobble-sized substrate, low dissolved solids, and favorable pH. Some taxa, such as *Baetis tricaudatus* (Ephemeroptera, gatherer-collector feeding group, intolerant species as defined by Barbour and others, 1999), did not change much between seasons. *Baetis tricaudatus* was a fairly common species, with an average relative abundance of 19 percent in April/May and 20 percent in August. Overall, a seasonal difference in intolerant species (as exemplified in a decrease in EPT taxa) was significant between April/May and August, with an increase in more tolerant noninsects and other macroinvertebrates during the same time period.

Seasonal differences also were noted for the relative abundance of functional feeding groups. The relative abundance of gatherer-collectors and scrapers decreased from April to August, accompanied by an increase in the relative abundance of filter/collectors and shredders. Seasonal differences in feeding groups might be due to the seasonal shift in aquatic plant communities. For example, Merritt and Cummins (1996) describe scrapers as grazing on mineral and organic surfaces. The mineral surfaces in Fish Creek are the rock surfaces characterized as containing microalgae during the aquatic plant community surveys. The decrease in microalgae surfaces from April/May to August is one potential reason for the decrease of macroinvertebrate scrapers. The increase in filter/collectors and shredders from April/May to August likely reflects favorable conditions for macroinvertebrates that can gather their food in spite of, or because of, greater amounts of aquatic plant matter (macrophytes). Additionally, comparison of the Fish Creek macroinvertebrate community to the Cache Creek and Salt River communities indicates the seasonal shift is not entirely attributable to a seasonal emergence of nymphs to adults, as all three of the other sites had a greater presence of EPT taxa than Fish Creek in August. Instead, differences in the proportions of the functional feeding groups may be the result of the prevalence of macrophytes as the dominant aquatic plant life in Fish Creek but not the other sites.

Relations among Ecosystem Components

As described previously, a large part of Fish Creek's inflow is from groundwater. Overall, Fish Creek tends to have good water quality. Isotopic evaluation of nitrate isotopes and nutrient concentrations in groundwater indicate that nutrients are coming into the creek from groundwater, especially in the upper and lower reaches, and that the source of nitrate commonly is from a septic/sewage or manure source, or a mixed source. Dissolved nitrate concentrations in Fish Creek from samples collected at the five regularly sampled biological sites were always less than 1 mg/L, and were occasionally not detectable in some samples. One potential reason for the low dissolved nitrate concentrations is that nitrate is being consumed by aquatic plant life as the "crop" grows each year as a result of the seasonal increase in temperature and longer number of daylight hours. Additionally, aquatic plants, and macrophytes in particular, have an ideal habitat in Fish Creek with its stable channel and clear water. The biovolume of macrophytes (in particular vascular aquatic plants and moss) in Fish Creek was higher than what is typically observed in streams of its size around the State.

Invertebrate taxa richness in Fish Creek was similar to other creeks in the area. However, the decrease of EPT taxa in Fish Creek in August is likely due to a change in food source, as the taxa population in Cache Creek and Salt River does not show a decrease in EPT taxa. Overall macroinvertebrate richness for Fish Creek in August indicates that while there are still bugs for the fish to eat in the creek, fewer EPT taxa are present.

It is unknown how additional nutrients in the system beyond the conditions sampled during the study period would affect the macrophyte crop in Fish Creek. However, because nitrate concentrations were low in August (no detections in the water sample), it is possible that increased nitrate could result in increased growth of macrophytes. How this additional growth would affect macroinvertebrates is unknown. In order to determine if growth in the human population in the area would affect Fish Creek, additional long-term and consistent monitoring of the stream, and data analysis and interpretations, would be needed.

Summary

Fish Creek, an approximately 25-kilometer-long tributary to Snake River, is located in Teton County in western Wyoming near the town of Wilson. Fish Creek is an important water body because it is used for irrigation, fishing, and recreation and adds scenic value to the Jackson Hole properties it runs through. Public concern about nuisance growths of aquatic plants in Fish Creek has been increasing since the early 2000s. Aquatic plants, such as algae and vascular aquatic plants, are integral parts of a healthy stream ecosystem because they are primary producers in the aquatic food chain, providing food and habitat for invertebrates and other organisms. Excessive growths of aquatic plants, however, can be esthetically displeasing and a nuisance for anglers, irrigators, and other water users.

To address concerns about nuisance algal growths in Fish Creek, the U.S. Geological Survey conducted a study in cooperation with the Teton Conservation District to characterize the water quality and biological communities of Fish Creek. This report describes and includes previously evaluated samples (2007–08) and samples collected between April/May 2009 and October 2011. The purpose of this report is to describe the characteristics of the hydrologic system, the water quality, and the biological communities of Fish Creek in western Wyoming using data collected during 2007–11. This report also uses statistical techniques to describe relations among ecosystem components.

On the west side of Snake River is an alluvial aquifer that discharges into Fish Creek. Surface-water inflows to Fish Creek can include springs, irrigation diversions from area rivers and streams, irrigation return flows, and tributary streams. Groundwater discharge contributes a substantial portion of the flow to Fish Creek, although the volume of water contributed from groundwater varies along the length of the creek.

Observations showed Fish Creek typically carried minimal amounts of sediment, either suspended or as bedload. The potential for bed movement in Fish Creek was estimated for two sampled reaches with perennial flow. At both sites, it was determined that the amount of flow needed to continually mobilize the bed material and therefore result in streambed change would only exist at stages above the top of the streambed.

In general, 2007 was the warmest of the study years, 2010 was the driest, and 2011 was the coolest and had the highest precipitation values at higher altitudes. Peak streamflow timing and magnitude were compared to the amount of snowpack and how quickly complete melting occurs; as expected snowpack volume and the timing of snowpack melting had a large effect on streamflows at the Fish Creek at Wilson, Wyoming streamgage. In addition to instantaneous peak streamflows, the overall duration of the high-flow period on Fish Creek is affected by snowpack and local climatic conditions.

Peak streamflow generally occurs between mid-May and early July with a prolonged recession to base flow occurring from mid-July into late November. Groundwater input, flow in Snake River, and irrigation practices that largely translate through the primary tributary, Lake Creek, are primary factors in the late summer and early fall flow in Fish Creek.

Groundwater-level measurements were made during the collection of water-quality samples at wells. Measured water levels indicate the groundwater level is less dynamic in the lower reaches of Fish Creek than in upper reach near Teton.

Median values of continuous water-quality properties were determined at all five regularly sampled biological sites, and the analysis of variance of each water-quality property between sites, years, and seasons was calculated. Differences in pH and specific conductance were significant between some sites. Differences between seasons were significant; all water-quality properties had a significant difference between April/May and August.

Samples analyzed for nutrients indicated that dissolved nitrate was the dominant species of dissolved nitrogen present in all samples, accounting for at least 80 percent of the nitrogen in all but 4 surface-water samples and 1 groundwater sample. Dissolved orthophosphate accounted for almost all of the dissolved phosphate in both surface-water and groundwater samples, and phosphorus was rarely present in an undissolved form, likely because of the lack of sediment transported in Fish Creek.

The median concentrations of dissolved nitrate and orthophosphate in surface water was highest in samples collected from the most upstream site near Teton Village and decreased downstream. Concentrations of dissolved nitrate were significantly different between the most upstream site and the other Fish Creek sites. Dissolved nitrate concentrations were not significantly different between years of the study, but were significantly different between seasons. Surface-water and groundwater samples were collected for analyses of nitrogen and oxygen isotopes of nitrate. Evaluation of nitrate isotopes and dissolved nitrate concentrations in groundwater indicate that nitrate was entering Fish Creek from groundwater, and that the source of nitrate commonly was from a septic/sewage effluent, manure, or mixed source.

When viewed from the shore or a bridge, Fish Creek commonly appeared to be bright green because of a green mat of aquatic plants on the bottom of the creek. The mat typically was composed of a mixture of vascular aquatic plants, macroalgae, microalgae, and moss. Barren, sandy areas are considered unsuitable substrate for most algal species to grow, but high abundances of vascular aquatic plants were found at sites with sandy areas. Because of the difference in biovolume and growth potential of microalgae compared to all other aquatic plants, an additional category of macrophytes was created for analysis. The macrophyte category included vascular aquatic plants, macroalgae (including *Cladophora*), and moss. The average percent of macrophytes was greater than 50 percent at all but one site where macrophytes averaged 32 percent.

The average composition of the aquatic plant community in Fish Creek appeared to shift in the downstream direction. Differences in the composition of the aquatic plant community in Fish Creek were statistically significant between some sites.

Concentrations of dissolved oxygen in water were measured continuously on a diel basis and were used as an indicator of primary productivity of the aquatic plant community. The linear part of the dissolved-oxygen curve was used to compute P_{max}, the maximum rate of productivity. Although variability in P_{max} was noted among the sites, differences between the sites were not statistically different. The P_{max} value had variability from year to year, but no year was statistically different from the others. The average values of P_{max} by date increased from April/May to August and from August to October in all five years of sampling. The seasonal increases in P_{max} values were significantly different between April/May and October.

Concentrations of chlorophyll-*a* and ash-free dry mass (AFDM), cell density, and cell biovolume are indicators of algal standing crop. Chlorophyll-*a* concentrations were not statistically different between sites or years but were statistically different between seasons. October was different from both April/May and August; the largest chlorophyll-*a* concentrations typically were in October. Concentrations of chlorophyll-*a* in Fish Creek also were considerably higher than historical data from other streams in the area. Concentrations of AFDM were statistically different between sites. Concentrations of AFDM were statistically different between 2008 and 2010—2010 was lower than 2008—but were not statistically different between seasons.

Statistical analysis determined the algal cell density was not significantly different between the five sites. Cell densities from samples collected in 2007 tended to be lower than other years, and differences between 2007 and both 2008 and 2009 were statistically significant. The cell density from Fish Creek samples was not statistically different between seasons. Statistical analysis determined that algal biovolume was significantly different between some sites.

A total of 335 distinct algal taxa were identified in the 72 algal taxonomy samples collected during the five-year study. An average of 58 algal taxa per sample were identified, with diatoms averaging 50 taxa per sample. Green algae averaged 3 taxa per sample, and blue-green algae averaged 5 taxa per sample. Yellow algae, euglenoid algae, and algae of unknown taxonomy also were identified, but they made up a very small percentage of the algal taxa when present and were not present in the majority of the samples. Although diatoms predominated in terms of taxa richness, blue-green algae predominated in terms of cell density and green algae predominated in terms of biovolume. The taxa richness, cell density, and cell biovolume data indicate a much more abundant and diverse algal community at sites on Fish Creek than at nearby sites on Cache Creek and Salt River.

The algal community was evaluated statistically to determine if changes in the community or community traits changed by site, year, or season. Algal taxa richness generally increased in the downstream direction, and algal taxa richness and diatom taxa richness were significantly different between some sites. Algal community taxa richness was significantly different between years and tended to be lower in 2007–09 than in 2010–11. The relative abundance of algal taxa based on cell density showed more differences between years than abundance based on biovolume. Relatively few differences between seasons were noted for taxa richness, total density, taxa relative abundance, total biovolume, or taxa relative to biovolume.

Algal traits were examined as measures of autecology, or environmental preferences and water-quality optima, and were statistically evaluated. Most diatoms in Fish Creek were in the sensitive Bahls pollution class and were associated with high dissolved oxygen concentrations. Few statistical differences in algal traits were significant between sites or years. Statistically significant seasonal differences were noted for the sensitive Bahls pollution class and for high oxygen tolerance, as fewer sensitive species and more tolerant species were present in August than in April/May.

The macroinvertebrate taxa richness was calculated for all regularly sampled biological sites; average total taxa richness ranged from 38 to 46 taxa per sample.

The macroinvertebrate community was evaluated statistically to determine if changes in the community or parts of the community changed in relation to site, year, or season. Changes in taxa were tested using both taxa richness and relative abundance. Analysis of macroinvertebrate taxa based on both richness and relative abundance showed some variation between sites but only a few statistically significant differences. Analysis of changes between years also showed few statistical differences. Seasonal changes in taxa richness and relative abundance of Ephemeroptera, Plecoptera, and Trichoptera (EPT) were significantly different, marked by a decrease from April/May to August.

Changes in density and diversity, functional feeding groups, and tolerance group metrics also were evaluated statistically. Differences in functional feeding groups between sites were significant between the filterer-collector and scraper groups. The macroinvertebrate tolerance scores indicated no significant differences between sites. Changes in most functional feeding groups were not significantly different between years, but tolerant species were significantly different between 2008 and other years. Most functional feeding groups and tolerance groups showed changes between seasons. Relative abundance of the gatherer-collector and scraper functional feeding groups and of intolerant species decreased between April/May and August, whereas relative abundance of the filterer-collector and shredder functional feeding groups increased between the two seasons.

Habitat characteristics of streambed substrate (pebble count) and riparian canopy were measured at the regularly sampled biological sites. Median particle size of Fish Creek substrate ranged from 23.8 to 66.6 millimeters. On average, fine particles (less than 2 millimeters) made up no more than 8 percent of the substrate. Shading of Fish Creek was minimal at most sites, with grassy banks and few trees, and most of the stream channel was able to receive full sunlight; differences between sites were negligible.

Understanding relations among the organisms and their environment (ecology) is critical to understanding the dynamics of Fish Creek and planning for any potential measures to control the growth of aquatic plants in Fish Creek. Streamflow and water quality affect aquatic plants and vice versa. Aquatic plants, as the base of the food chain, affect the macroinvertebrate communities and in turn the fish communities. This study was not designed to collect every possible ecosystem component that can affect another, such as major ions or micronutrients required by aquatic plants in water, fish samples, or additional samples at other times of the year. However, the ecosystem components that were sampled for this study over the five-year sampling period at the five main-stem sites on Fish Creek with biological and water-quality sampling, did provide an opportunity to determine some of the ecosystem connections that can be seen with data collected during the study period.

In the broadest analysis, a few patterns related to site, year, and season were observed regardless of the ecologic component analyzed. First, the most upstream of the five regularly sampled biological sites was more often different from all the other sites, whether looking at streamflow, water quality, aquatic plants, algae, or macroinvertebrates. Second, the study period contained years when climatic variables were near the peak of record and years when values near the low record were recorded, both in temperature and snowfall. This did lead to a difference in the streamflow at the Wilson streamgage, but few other ecologic components showed a consistent change between years. Seasonal changes were observed in most ecosystem inputs and components.

The hydrology of Fish Creek is unique compared to most mountain streams in that groundwater contributes substantial flow to the creek over the entire year rather than just during base-flow time periods in the fall and winter. Because of this continuous groundwater discharge to Fish Creek, land-use activities in the west bank area can affect the surface water. Septic systems, sewage injection, and lawn fertilization can contribute nutrients to the creek.

Several aspects of Fish Creek's hydrology help create an excellent habitat for the growth of aquatic plants. Especially in the winter, the proportionately large, continuous gain of groundwater into Fish Creek in the perennial section keeps the majority of the creek free of ice. Because sunlight can still reach the streambed in Fish Creek and the water is still flowing, aquatic plants continue photosynthesizing in the winter, albeit at a lower level of productivity. Additionally, the cobble and large gravel substrate in Fish Creek provides excellent, stable attachment points for aquatic plants, including algae and moss, and Fish Creek's channel stability allows rapid growth of aquatic plants once spring conditions allow.

Fish Creek is different from most streams in Wyoming because its aquatic plant community is composed of many different members rather than predominantly microalgae. Because the aquatic plant community had at times only a small percentage of algae, all aquatic plants also were compared to water quality. The composition of the various macrophytes (macroalgae, including *Cladophora*; moss; and vascular aquatic plants) in Fish Creek varied between sites, but combined they act as a "crop" that consumes nutrients from the water for photosynthesis. A shift was observed from higher amounts of microalgae in April/May to higher amounts of macrophytes in August and October, and statistical differences in the relative abundance of microalgae and macrophytes were significantly different between seasons.

Dissolved nitrate concentrations and the nitrogen-phosphorus ratios were significantly different between seasons, as concentrations of dissolved nitrate are higher in April/May compared to August and October. It is possible that dissolved nitrate concentrations in Fish Creek were lower in August and October because macrophytes quickly utilized the nutrient; a negative correlation between macrophytes and nitrate was found. The decrease in the nitrogen to phosphorus ratio each year from April/May to August and October to a level where phosphorus was no longer the limiting nutrient also shows how increased growth of macrophytes has the potential to affect the water quality. A negative correlation also was found between nitrogen to phosphorus ratio and percent macrophytes.

Because aquatic plants in Fish Creek do not massively die off in the late fall and winter but rather decrease slowly, a shift to an oxygen-depleted condition was never observed during the April–October sampling season.

Macroinvertebrates commonly are used as integrators of water quality in a stream because of their susceptibility to long-term conditions of water quality and documented tolerance or intolerance of poor water quality. The relative abundance of some taxa, such as *Baetis tricaudatus* (Ephemeroptera, intolerant species, gatherer-collector feeding group), did not change much between seasons. *Baetis tricaudatus* was a fairly common species, with an average relative abundance of 19 percent in April/May and 20 percent in August. Overall, a seasonal decrease in intolerant species (as exemplified in a decrease in EPT taxa) was significant between April/May and August, with an increase in more tolerant noninsects and other macroinvertebrates during the same time period.

Seasonal changes also were noted in functional feeding groups. The relative abundance of gatherer-collectors and scrapers decreased from April/May to August, accompanied by an increase in filterer-collectors and shredders. Seasonal change in feeding groups might be due to the seasonal shift in aquatic plant communities. Comparison of the Fish Creek macroinvertebrate community to the Cache Creek and Salt River communities indicates the seasonal shift was not entirely attributable to a seasonal emergence of nymphs to adults, as all three of the other sites had a greater presence of EPT taxa than Fish Creek. Instead, differences in the proportions of the functional feeding groups may be the result of the prevalence of macrophytes as the dominant aquatic plant life in Fish Creek but not the other sites.

Invertebrate taxa richness was similar to other creeks in the area. However, Fish Creek had a decrease in EPT, which were primarily the gatherer-collectors and scrapers from April/May to August. This change is likely due to a change in food source, as the taxa population in Cache Creek and Salt River does not appear to show a decrease in EPT taxa. Overall macroinvertebrate richness indicates that while there were still bugs for the fish to eat in the creek, fewer EPT taxa were seen in August. It is unknown how additional nutrients in the system beyond the conditions sampled during the study period would affect the macrophyte crop in Fish Creek. However, because all of the nitrate commonly was consumed by aquatic plants in August (no detections in the water sample), it is possible that increased nitrate could result in increased growth of macrophytes. How this additional growth would affect macroinvertebrates is unknown. In order to determine if growth in the human population in the area would affect Fish Creek, additional long-term and consistent monitoring of the stream would be needed.

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Site A-R1D, August 2009. Photograph by David A. Stonestrom.

Site A-Wck, August 2009. Photograph by David A. Stonestrom.

Site A-RB, May 2007. Photograph by Cheryl A. Eddy-Miller.

Site A-R6D, November 2004. Photograph by Jerrod D. Wheeler.

Site A-R3D, April 2011. Photograph by Cheryl A. Eddy-Miller.

Site A-R7, August 2009. Photograph by Cheryl A. Eddy-Miller.

Supplemental Data

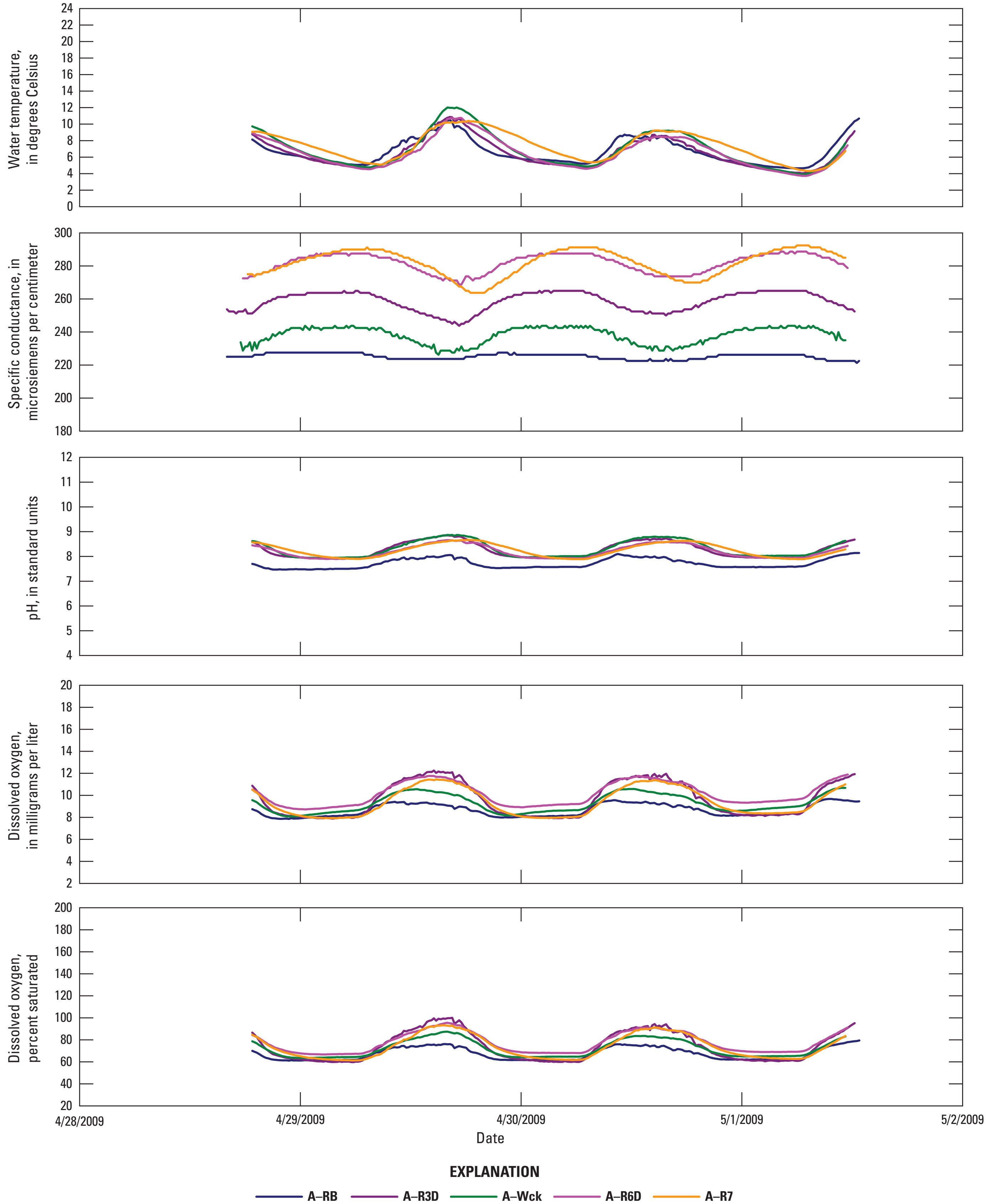

Figure 23. Continuously collected measurements of water-quality properties from regularly sampled biological sites on Fish Creek, Teton County, Wyoming, April/May 2009.

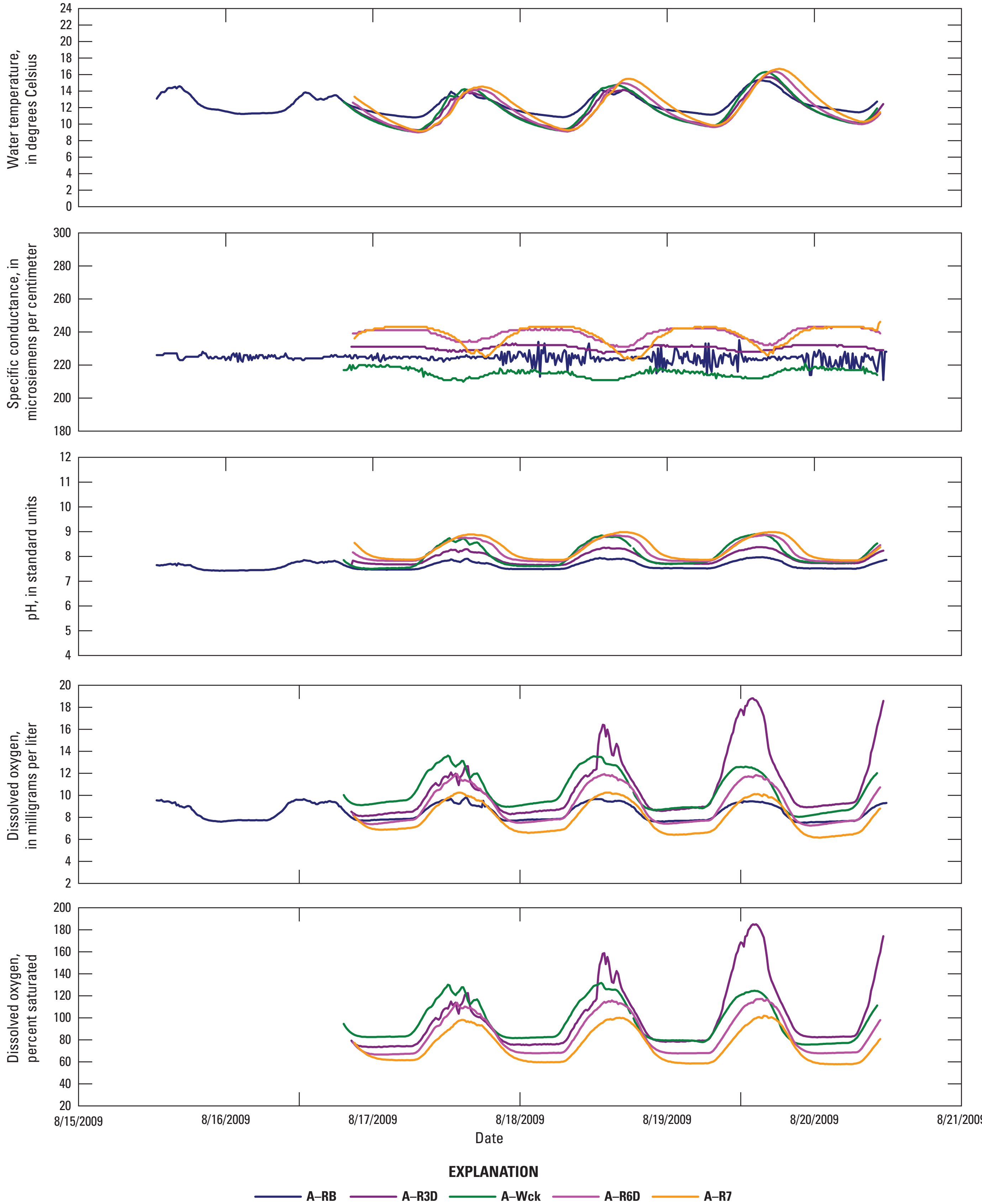

Figure 24. Continuously collected measurements of water-quality properties from regularly sampled biological sites on Fish Creek, Teton County, Wyoming, August 2009.

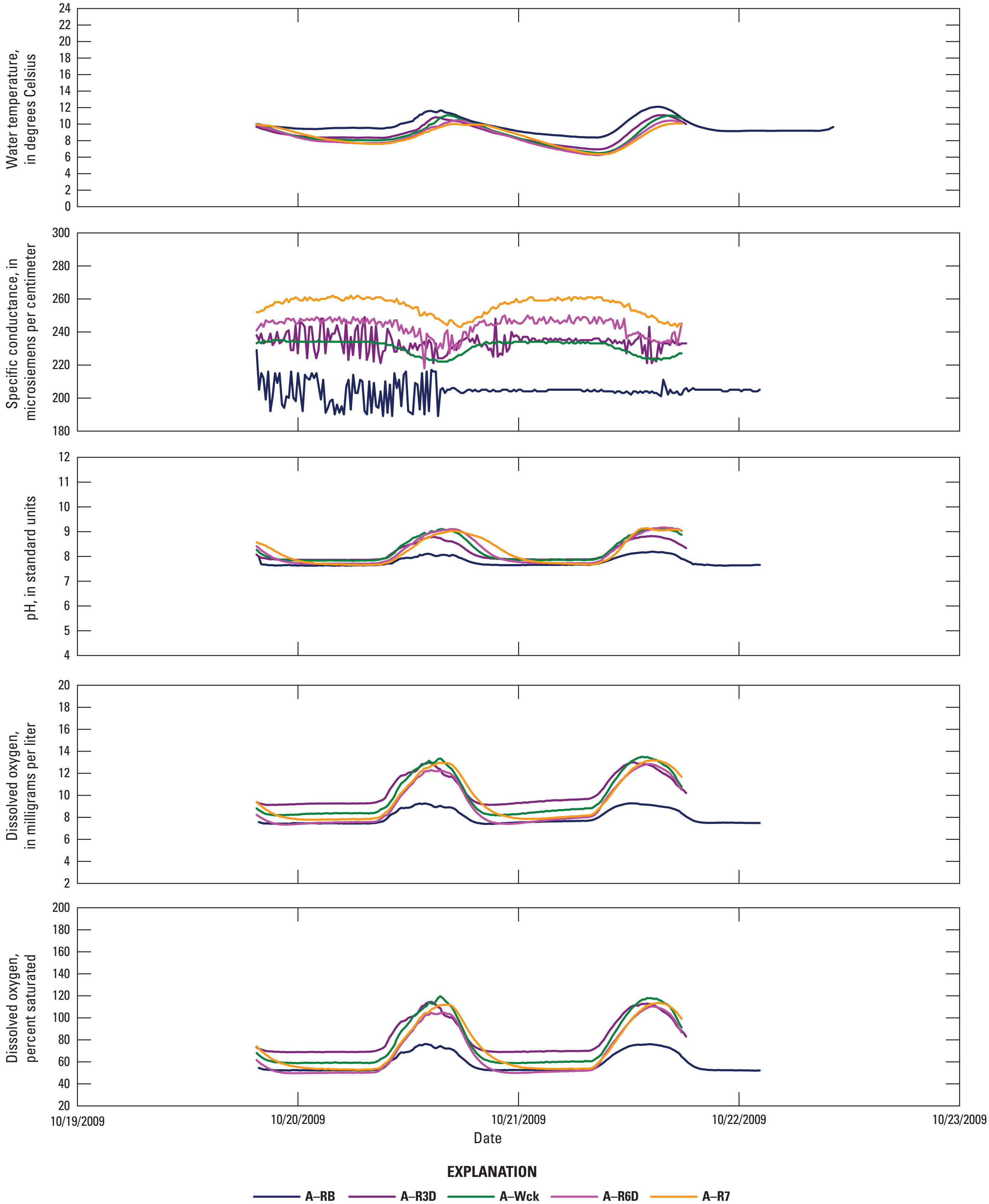

Figure 25. Continuously collected measurements of water-quality properties from regularly sampled biological sites on Fish Creek, Teton County, Wyoming, October 2009.

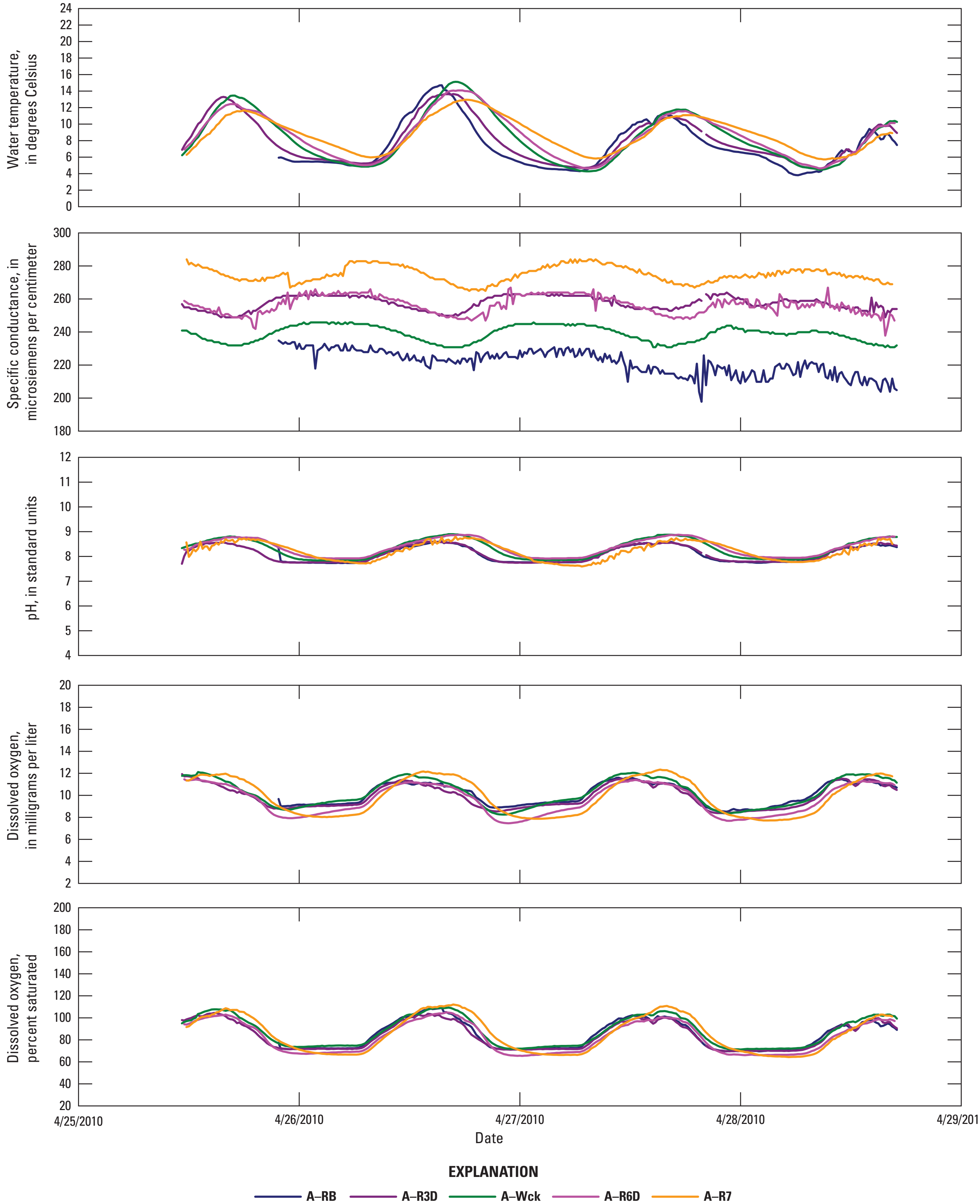

Figure 26. Continuously collected measurements of water-quality properties from regularly sampled biological sites on Fish Creek, Teton County, Wyoming, April/May 2010.

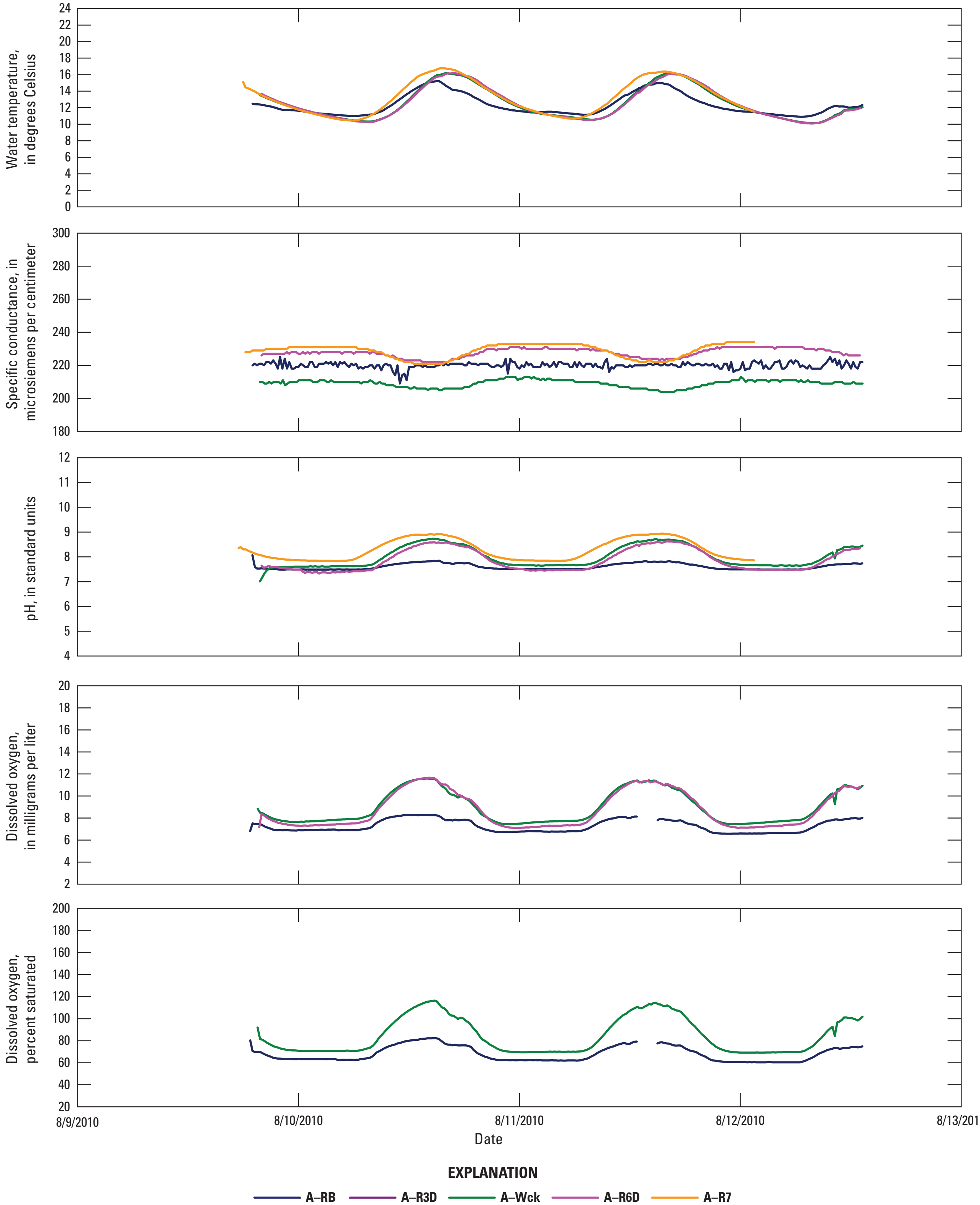

Figure 27. Continuously collected measurements of water-quality properties from regularly sampled biological sites on Fish Creek, Teton County, Wyoming, August 2010.

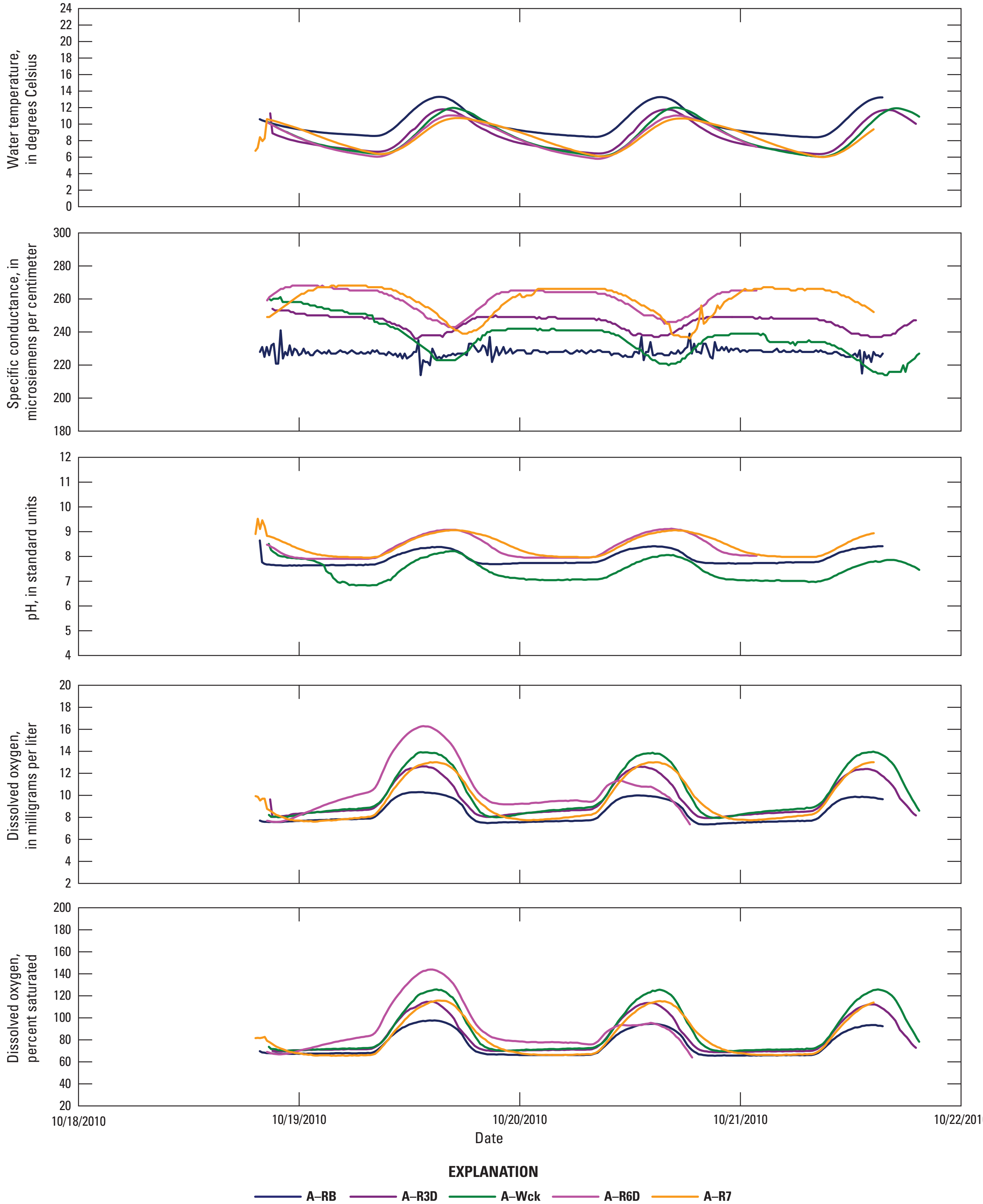

Figure 28. Continuously collected measurements of water-quality properties from regularly sampled biological sites on Fish Creek, Teton County, Wyoming, October 2010.

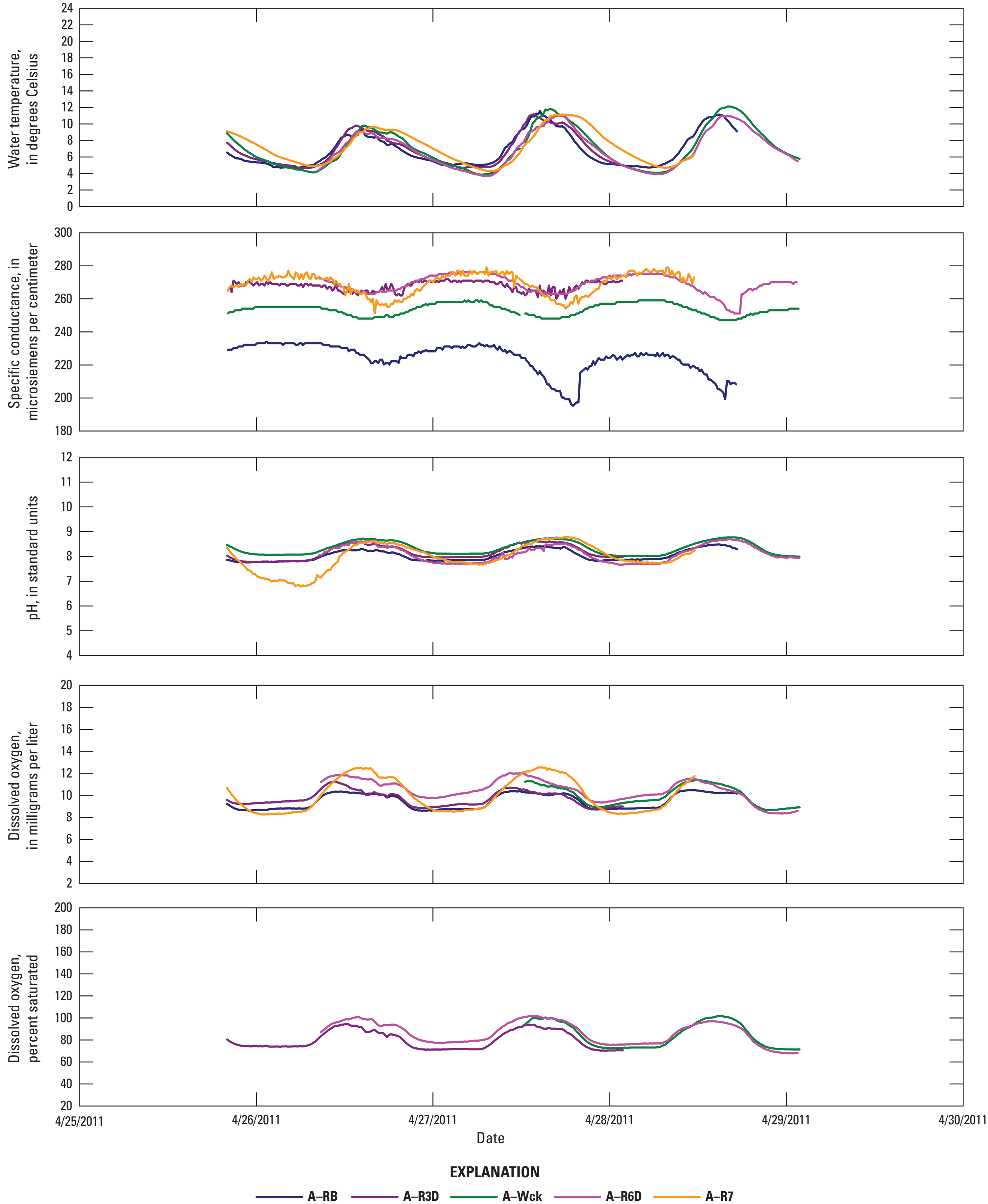

Figure 29. Continuously collected measurements of water-quality properties from regularly sampled biological sites on Fish Creek, Teton County, Wyoming, April/May 2011.

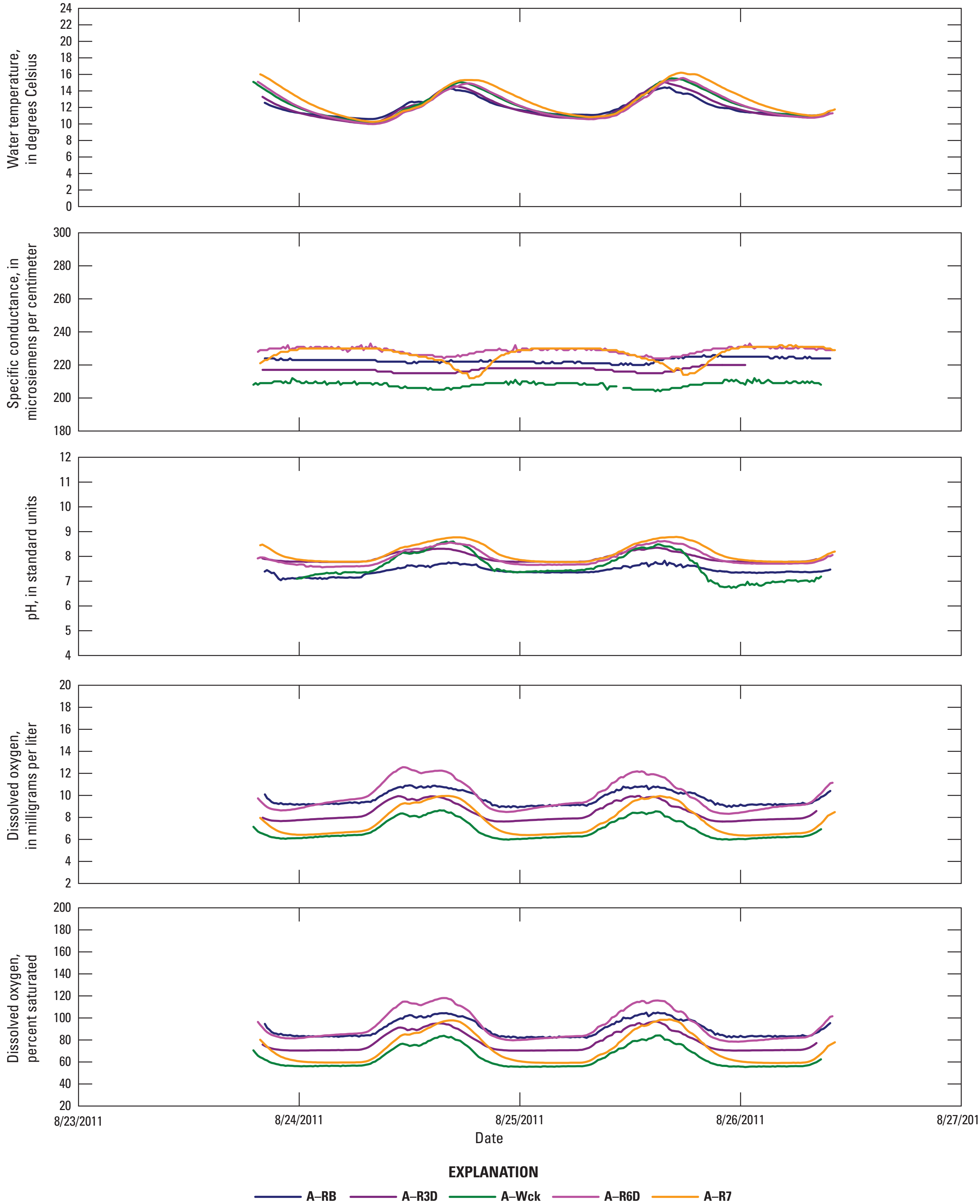

Figure 30. Continuously collected measurements of water-quality properties from regularly sampled biological sites on Fish Creek, Teton County, Wyoming, August 2011.

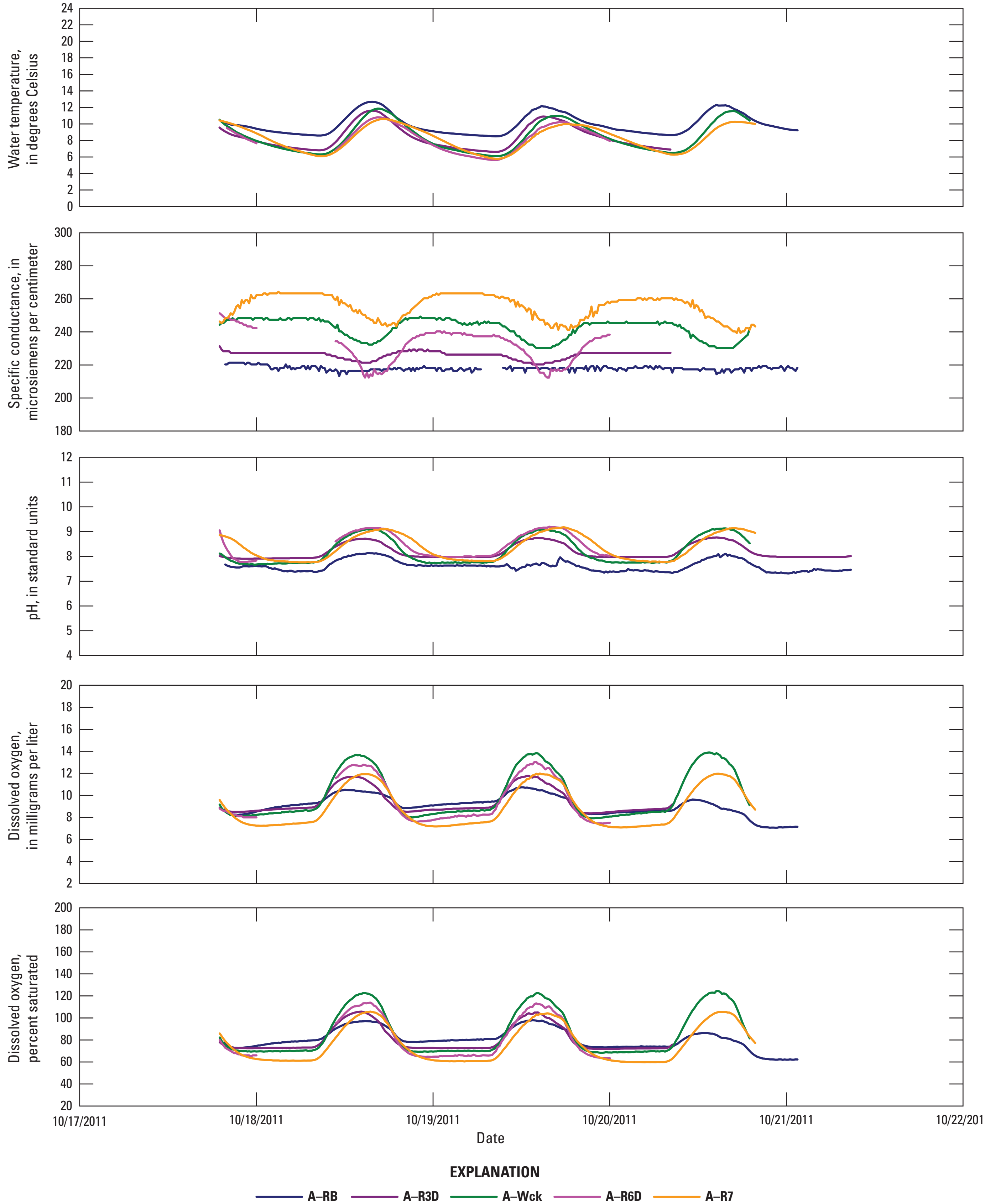

Figure 31. Continuously collected measurements of water-quality properties from regularly sampled biological sites on Fish Creek, Teton County, Wyoming, October 2011.

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