National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Streams Monitoring at Montezuma Castle and Tuzigoot National Monuments

Status Report for Water Years 2009–2011

Natural Resource Technical Report NPS/SODN/NRTR—2014/871







ON THE COVER

Clockwise from top left: Beaver Creek, Montezuma Castle National Monument (Castle unit); Verde River, Tuzigoot National Monument; Wet Beaver Creek, Montezuma Castle National Monument (Well unit). NPS photos.

Streams Monitoring at Montezuma Castle and Tuzigoot National Monuments

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Natural Resource Technical Report NPS/SODN/NRTR—2014/871

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May 2014

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Gwilliam, E. L., K. Raymond, S. Buckley, A. Hubbard, C. McIntyre, and T. Nauman. 2013. Streams monitoring at Montezuma Castle and Tuzigoot national monuments: status report for water years 2009–2011. Natural Resource Technical Report NPS/SODN/NRTR—2014/871. National Park Service, Fort Collins, Colorado.

NPS 309/124571, 378/124571, May 2014

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Acronyms

µg/L	micrograms per liter
µS/cm	micro-Siemens per centimeter
ADEQ	Arizona Department of Environmental Quality
$CaCO_3$	calcium carbonate
cfs	cubic feet per second
DO	dissolved oxygen
DWR	Department of Water Resources
EMAP	Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, and Trichoptera
ft	feet
GCU	geomorphic classifcation units
GIS	Geographic Information Systems
GPRA	Government Performance and Results Act
HBI	Hilsenhoff Biotic Index
IBI	Index of Biotic Integrity
L	liters
m	meters
mg/L	milligrams per liter
ml	milliliters
MMI	multi-metric indices
MOCA	Montezuma Castle National Monument
MOCA-TUZI	Montezuma Castle and Tuzigoot national monuments
MOCC	Montezuma Castle National Monument–Castle unit
MOWE	Montezuma Castle National Monument–Well unit
MPN	most probable number
NAQWA	National Water Quality Assessment program
NC	not collected
ND	not detected
NELAP	National Environmental Laboratory Accreditation Program
NHP	National Historical Park
NM	National Monument
NPS	National Park Service
NTU	nephelometric turbidity unit
ppb	parts per billion
PPE	personal protective equipment
QA/QC	Quality Assurance/Quality Control
SE	standard error
SODN	Sonoran Desert Network
SWQB	Surface Water Quality Bureau
TDS	total dissolved solids
TSS	total suspended solids
TUZI	Tuzigoot National Monument
USGS	U.S. Geological Survey
WRD	Water Resource Division
WY	water year

Executive Summary

The goal of Sonoran Desert Network (SODN) streams monitoring is to detect broad-scale changes in aquatic and riparian ecological condition and to communicate this information to park managers. To support a comprehensive understanding of stream condition, SODN employs a holistic approach that integrates geomorphological, hydrological, and biological indicators of six vital signs: surface water quality, surface water quantity, stream channel morphology, riparian vegetation, benthic macroinvertebrates and periphyton, and fish and crayfish.

This document reports and interprets results from the first several years of protocol development and the first two years (2009–2011) of protocol implementation at Montezuma Castle and Tuzigoot national monuments (NMs), where the network monitors stream segments in Beaver Creek (Montezuma Castle NM, Castle unit), Wet Beaver Creek (Montezuma Castle NM, Well unit), and the Verde River (Tuzigoot NM). We found the overall status of those stream segments in Water Year (WY) 2011 to be satisfactory and typical for observed measurements in similar stream segments in the middle Verde River watershed. The focus of this report is on current status of the selected parameters. Trend evaluations will be included in a later synthesis report.

Of the 762 individual measurements or analyses conducted in WY 2011, 312 were associated with a regulatory standard. Of those 312 samples, 99.7% were compliant with state standards. This achieves the National Park Service's Government Performance and Results Act (GPRA) goal of meeting 99.3% of state and federal standards. There were two exceedances of Arizona state surface water quality standards during WY 2011, both for arsenic. One exceedance each was recorded for Beaver Creek and Wet Beaver Creek.

Mean annual flow was lower than usual during WY 2011 (60–72% of typical flow amounts), but flood events occurred that were sufficient to maintain ecological function of the streams. Stream channels surveyed in Beaver Creek were found (1) to be less steep and more sinuous than the typical metrics of other streams in the Verde River Basin, (2) to have a larger proportion of fine-size particles in the stream sediment, and (3) to have larger, deeper pools.

No new species were added to the species list at any of the units via riparian vegetation monitoring. The permeation of the parks by non-native species was high, with non-natives found at from one-third to over half of sample plots in all three stream segments and with more than 10% cover in all structural layers. It is suggested that SODN staff meet with park staff to discuss the implications of this analysis.

Analysis of data for benthic macroinvertebrates indicated systems that are moderately disturbed but generally attaining state and federal standards. Park managers and SODN staff should meet to discuss the possible causes of these results, and the implications for stream ecology.

Continued, long-term monitoring of streams components at Montezuma Castle and Tuzigoot national monuments will allow us to alert park managers of potential concerns and track the progress of potential management actions.

1 Introduction

1.1 Background

Perennial streams are among the most critical and impacted natural resources of the Sonoran Desert. The presence and extent of surface water has traditionally provided a focus for human habitation in the region, resulting in prehistoric and historic development coincident with reliable and abundant rivers, streams, wetlands, and springs. Further, more than 90% of all species in the ecoregion utilize aquatic ecosystems for some portion of their lifecycles (Phillips and Comus 2000), yet natural surface waters have decreased by an estimated 99% since the mid-19th century due to human demands for water (Tellman et al. 1997).

Eight of the 11 Sonoran Desert Network (SODN) parks contain regionally important surface waters (Sprouse et al. 2004). Perennial rivers and streams (hereafter "streams") are an important subset of surface waters in SODN parks, with portions of three major river systems (or their tributaries) found in Gila Cliff Dwellings, Montezuma Castle, and Tuzigoot national monuments, and in Tumacácori National Historical Park (Figure 1-1). As human development in the American Southwest accelerates, these critical waters and the abiotic and biotic resources they support will grow in significance, as will the threats to their persistence. Therefore, effective protection of streams and their aquatic ecosystems is of paramount importance to managers of SODN parks (NPS 2005).

To support a comprehensive understanding of stream condition, SODN employs a holistic approach to monitoring that integrates geomorphological, hydrological, and biological indicators of six vital signs: surface water quality (core water quality parameters, alkalinity, primary nutrients, biological condition, pollutant metals, carcinogens and toxins, *E. coli*.), surface water quantity, stream channel morphology, riparian vegetation, benthic macroinvertebrates and periphyton, and fish and crayfish (Appendix A). When investigated in combination, these vital signs will provide a useful index of stream condition and function.

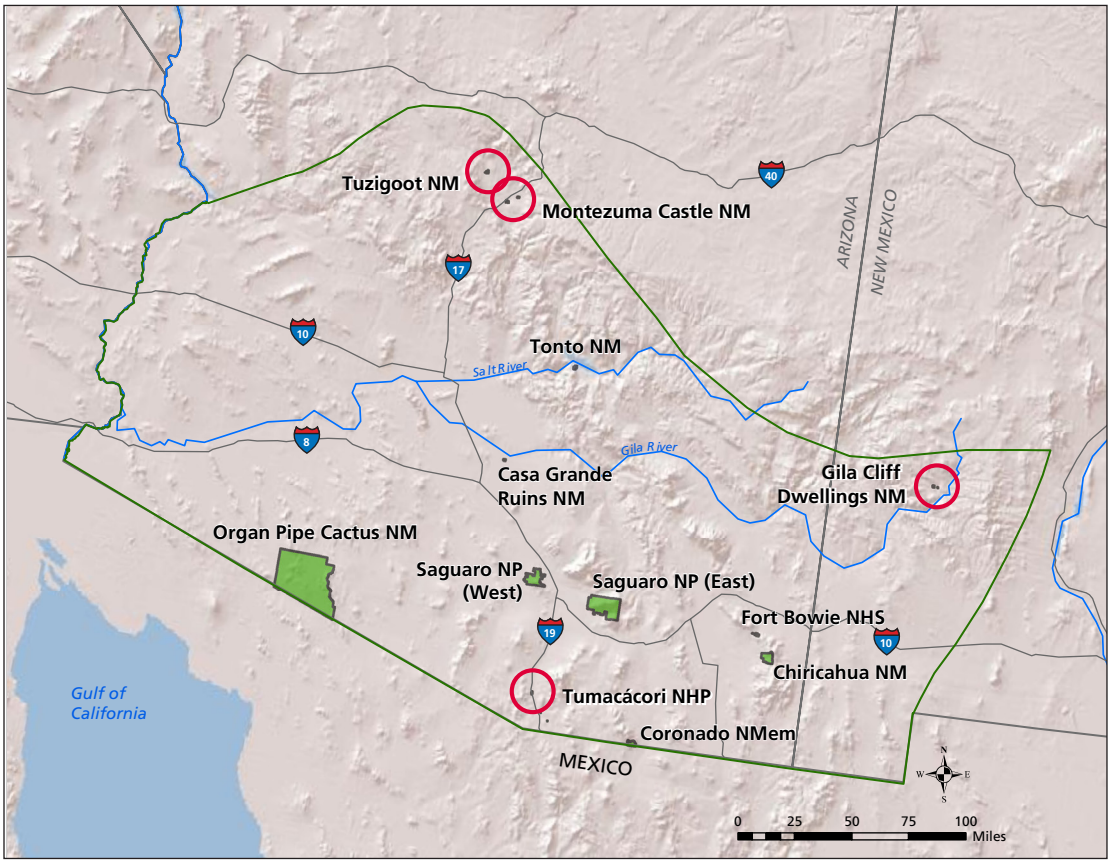


Figure 1-1. Map of Sonoran Desert Network parks. Portions of three major river systems (or their tributaries) are found in the highlighted parks.

1.2 Goal and objectives

The goal of Sonoran Desert Network streams monitoring is to detect broad-scale changes in aquatic and riparian ecological condition by observing selected ecological drivers, stressors, and processes, and to communicate this information to park managers. This integrated approach explores patterns and identifies candidate explanations to support effective management and protection of park natural resources in a cumulative fashion, such that the results of each successive round of monitoring build upon the knowledge gained from previous efforts and related research and monitoring activities.

Objectives of SODN streams monitoring are:

1. Water quality: Determine status as well as seasonal and annual trends in core water quality parameters; selected inorganic, nutrient, and metals parameters; and microbiological elements, toxins, and suspended solids.
2. Water quantity: Determine status and measure trend in annual, seasonal, and monthly stream discharge means and totals; and flood/low flow magnitude and frequency.
3. Channel morphology: Determine the status of stream-channel habitat and measure trends in channel cross-section area, channel slope, sinuosity, and stream flow continuity.
4. Riparian vegetation: Measure trend in common riparian vegetation abundance (including non-native species), community structure and recruitment.
5. Macroinvertebrates: Determine status of biological indices and trends in macroinvertebrate taxa abundance, richness, and derived metrics.
6. Fish: Determine status and measure trends in native and non-native fish abundance and frequency.

1.3 Scope of this report

This document reports and interprets results from the first several years of protocol development and the first two years (2009–2011) of protocol implementation at Montezuma Castle and Tuzigoot national monuments. Data collected as far back as 2007 are sometimes included for analysis and context. The focus of this report is on current status of the selected parameters; trend evaluations will be conducted in a later synthesis report. This report interprets data from protocol development and monitoring in the context of management objectives and ecological considerations. The scope of this report is limited to the perennial aquatic and riparian areas of the parks. Ephemeral and intermittent systems and associated xeroriparian areas will be addressed in the SODN Washes protocol.

2 Methods

2.1 Sample design

The SODN streams monitoring protocol employs a modular design, permitting protocol adaptation as resources and priorities change over time. The current assemblage of modules (quarterly sampling, stream discharge, channel morphology, riparian vegetation, and benthic macroinvertebrates) is considered to be the most basic level of implementation that will allow an understanding of ecosystem processes in aquatic and riparian areas of SODN parks (Table 2-1).

The modules are composed of carefully selected standard techniques and methods developed by the U.S. Geological Survey (USGS), Environmental Protection Agency (EPA), and other agencies and organizations and adapted for use at each park unit. Using standard methods allows for a more rapid implementation of monitoring, and the ability to compare results across the watershed and region. Each module is implemented at a different spatial and temporal scale to capture meaningful data that are appropriate for each parameter.

2.1.1 Sample units

Each module of the streams monitoring protocol is implemented at one of three spatial scales, or sample units, at one of several temporal scales. The three types of spatial sample units are stream segment, index reach, and index site, each decreasing in spatial inference, respectively (Table 2-2; Figure 2-1). Under the current protocol design (Figures 2-2 to 2-4), the scope of statistically valid inference is the sample unit (i.e., not the entire stream or park) .

2.1.1.1 Stream segment

The stream segment is the section of perennial stream at a SODN park unit bounded by inflow from a perennial stream, administrative boundary, or other geographic feature. The network monitors channel morphology and riparian vegetation at the stream-segment sample unit. Because there is currently only one stream segment in each SODN park unit, statistics for those parameters (e.g., mean abundance of a riparian plant species) are valid across the entire stream segment, encompassing the riparian area of the park unit.

The length of administered stream segments in network parks ranges from 0.4 km to 4.8 km (Table 2-3). The streams monitoring protocol design allows for the addition of sample units (e.g., new stream segments) as park boundaries are expanded or if the protocol is used in park units with more than one stream segment.

Table 2-1. Sonoran Desert Network vital signs associated with stream protocol modules.

Stream monitoring protocol module	Vital signs
Quarterly sampling (Includes sampling water quality, including *in situ* continuous monitoring of core water quality parameters and samples collected to be analyzed in a contracted lab)	Core water quality parameters (discrete and continuous), nutrients, metals, microorganisms, carcinogens and toxins, suspended sediments
Water quantity (continuous) (Includes conducting discharge measurements and downloading data sets from USGS stream gages and from NPS gages)	Water quantity
Channel morphology	Channel morphology
Riparian vegetation	Riparian vegetation life form abundance, riparian vegetation community structure, recruitment of dominant plant species, riparian non-native plants
Benthic macroinvertebrates	Aquatic macroinvertebrates & periphyton
Fish*	Fish community dynamics

*Not currently implemented at Montezuma and Tuzigoot national monuments.

Table 2-2. Temporal and spatial scale of stream monitoring modules.

Stream monitoring protocol module	Sample unit	Temporal scale
Quarterly sampling	Index site	Every three months
Water quantity (continuous)	Index site	Continuous, annually
Channel morphology	Across segment	Five years*
Riparian vegetation	Across segment	Five years*
Benthic macroinvertebrates	Index reach	Annually
Fish**	Regional	Annually

*with the contingency of resampling after a ≥100-year flood event
**not currently implemented at Montezuma and Tuzigoot national monuments.

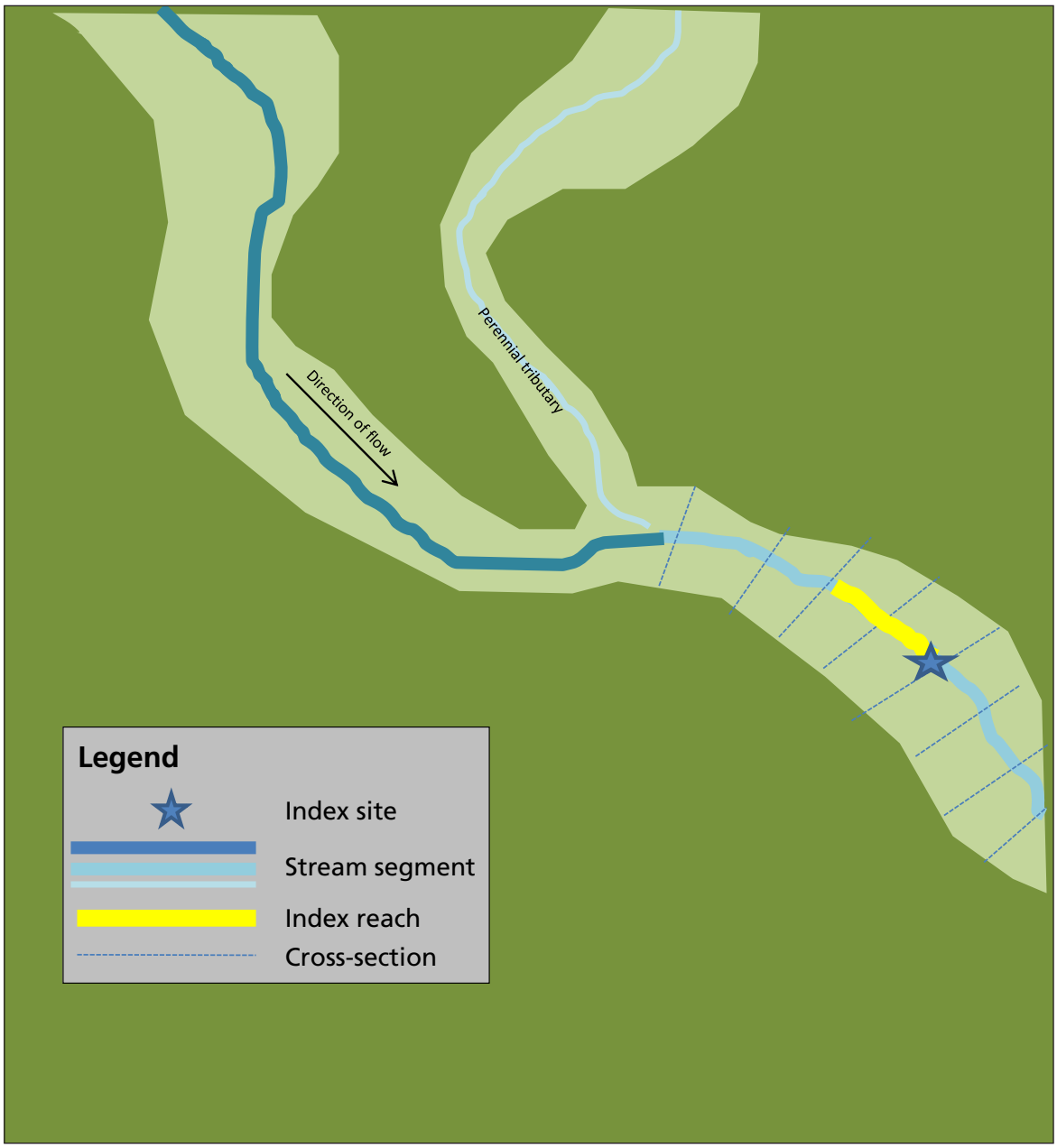


Figure 2-1. Stream protocol sample design.

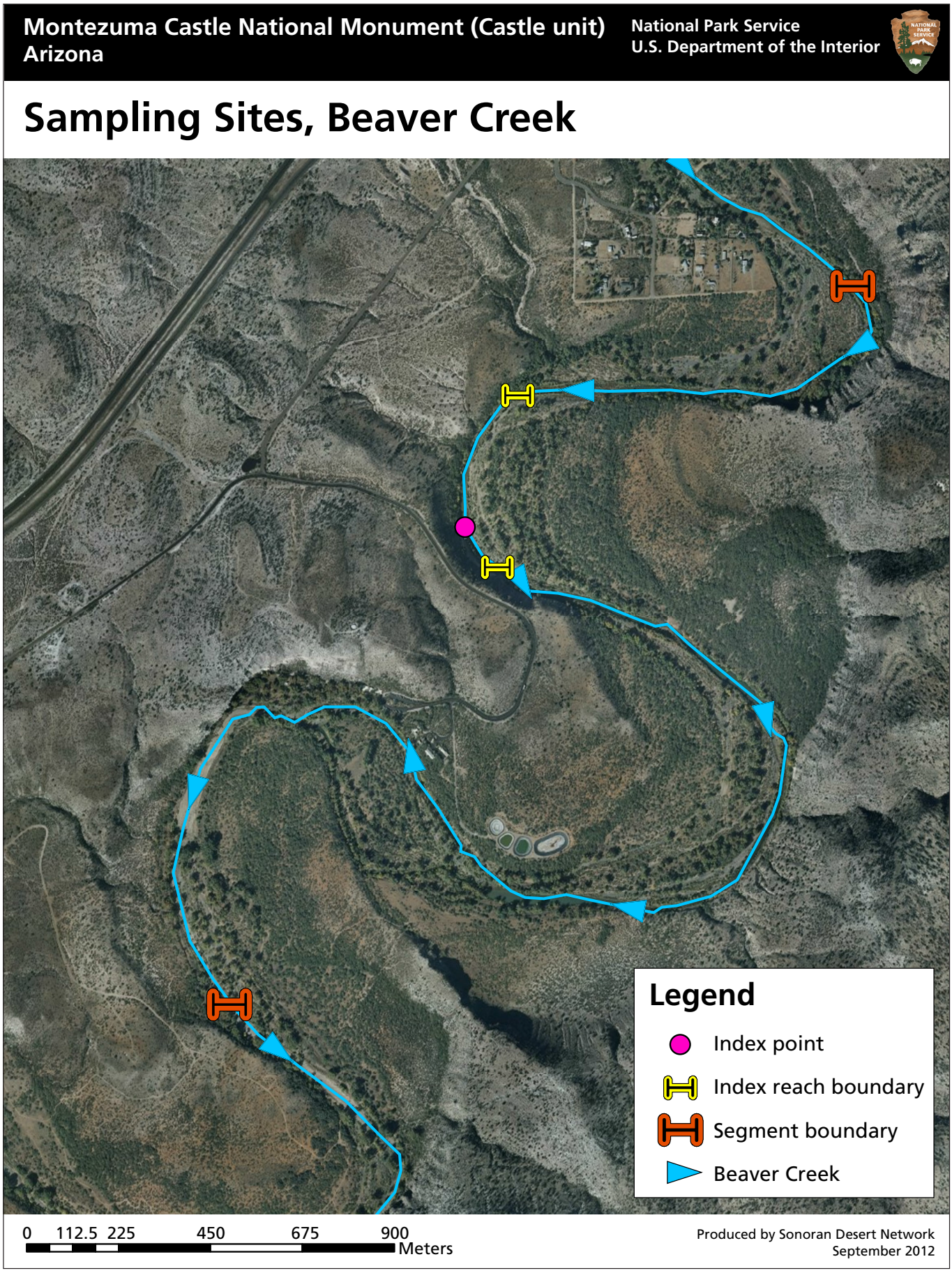


Figure 2-2. Sample units on Beaver Creek, Montezuma Castle National Monument (Castle unit).

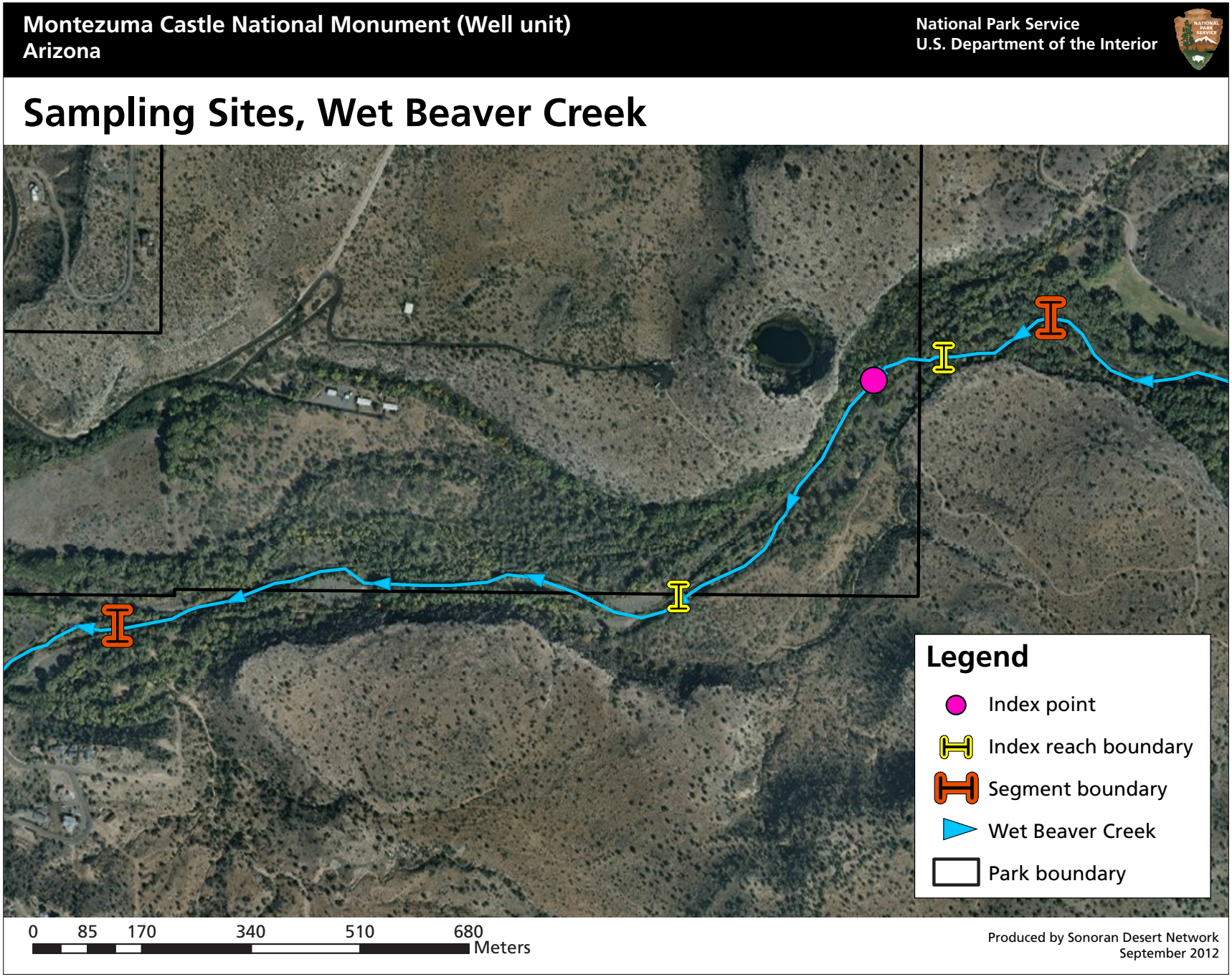


Figure 2-3. Sample units on Wet Beaver Creek, Montezuma Castle National Monument (Well unit).

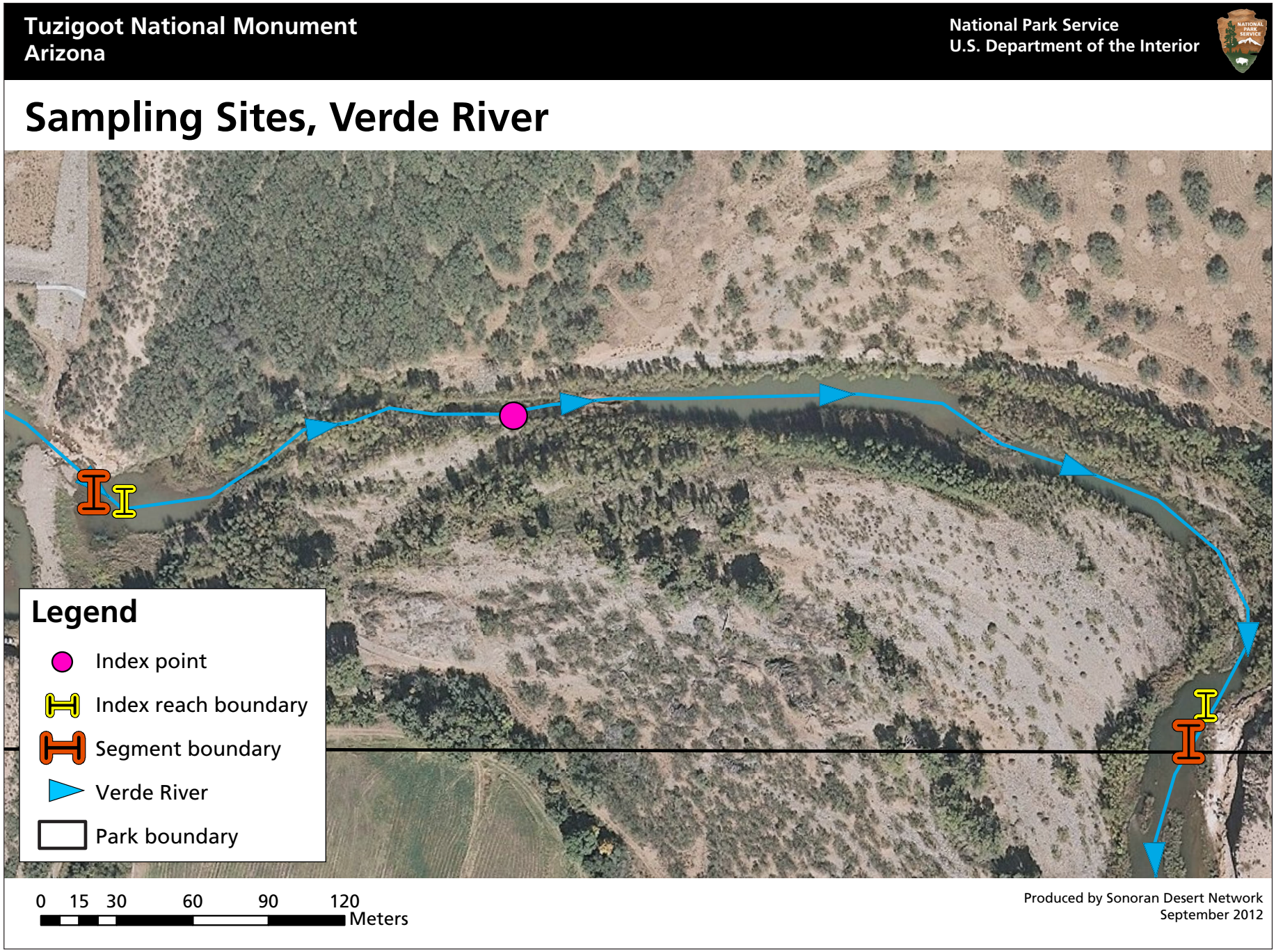


Figure 2-4. Sample units on Verde River, Tuzigoot National Monument.

Table 2-3. Length of administered stream segments in Sonoran Desert Network parks.

Park unit	Stream	Administered stream length
Gila Cliff Dwellings NM	West Fork Gila River	2.1 km
Montezuma Castle NM (Castle unit)	Beaver Creek	4.8 km
Montezuma Castle NM (Well unit)	Wet Beaver Creek	2.1 km
Tumacácori NHP	Santa Cruz River	2.3 km
Tuzigoot NM	Verde River	0.4 km

2.1.1.2 Index reach

Within each stream segment is at least one index reach, generally a 100–300-m stretch of river. Because there is only one stream segment in each SODN park unit, there is also only one index reach (and one index site; see Section 2.1.1.3). The index reach corresponds to monitoring reaches used by the EPA Environmental Monitoring and Assessment Program (EMAP), USGS National Water Quality Assessment program (NAQWA), and Arizona Department of Environmental Quality (ADEQ). This allows for valid comparison of data collected at this sample unit with that collected by other agencies. Benthic macroinvertebrates and index-reach habitat data are collected at this sample unit.

2.1.1.3 Index site

Within each index reach is an index site where continuous stream discharge data are collected, either at a USGS stream gage (Beaver Creek), or an NPS monitoring installation (Wet Beaver Creek and the Verde River). Water-quality samples are collected at the index site. It must be noted that stream-discharge and water-quality data collected at the index site provide statistical inference for that site only, not across the index reach or the entire stream segment.

2.2 Assessment points

To achieve the NPS's core mission of resource protection, resource management and monitoring must be explicitly linked (Bingham et al. 2007). SODN advocates the use of management assessment points as a bridge between science and management. Management assessment points, which are ". . . pre-selected points along a continuum of resource-indicator values where scientists and managers have agreed to stop and assess the status or trend of a resource relative to program goals, natural variation, or potential concerns" (Bennetts et al. 2007), aid interpretation of ecological information within a management context. They do not define strict management or ecological thresholds, inevitably result in management actions, or reflect any legal or regulatory standard; they are only intended to serve as a potential early warning system allowing scientists and managers to pause, review the available information in detail, and consider options. Bennetts and others (2007) have provided a detailed explanation of this concept and its application to monitoring and management of protected areas.

Assessment points are established for each vital sign in this report. SODN has used a combination of state standards (e.g., water quality), literature, and professional judgment to determine these benchmarks. In most cases, where descriptive statistics can be derived from the data, SODN has endeavored to use either confidence intervals around the parameter means or measurements within x standard deviations—whichever is ecologically significant or has management implications.

We intend for these assessment points to (1) initiate a discussion of potential indicators and assessment points—a conversation that will expand as a natural resource condition assessment is completed for the park and additional park planning commences; and (2) provide a useful framework for evaluating streams data in a broader ecological and managerial context. In all cases, SODN will work with park resource managers to identify the most meaningful and effective assessment points for future reports.

2.3 Water quality

SODN water quality monitoring measures a set of core parameters (temperature, specific

conductivity, pH, dissolved oxygen, turbidity, and discharge), metals and metalloids (aluminum, arsenic, barium, boron, calcium, copper, iron, lead, manganese, magnesium, molybdenum, uranium, and zinc), nutrients (phosphorus, total organic carbon, and nitrogen), microbiological organisms (total coliforms and *E. coli*), and inroganics (alkalinity, fluoride, sulfate, total dissolved solids, and total suspended solids).

2.3.1 Target population

The target population for SODN water quality monitoring is a subset of potential daytime water quality measurements in perennial streams selected through a judgmental or targeted process. Because of the generally small size of each stream segment, coupled with the high costs of analysis and assessment of existing data (NPS 1995; NPS 1999; Sprouse et al. 2002), network staff determined that a single index site located in each stream segment was adequate to achieve program goals. Index sites are co-located with existing USGS or NPS stream gage stations (Beaver and Wet Beaver creeks, respectively) or established following USGS suggestions for establishing gage sites (Rantz et al. 1982).

Samples are collected annually to ascertain the variability of water quality across the segment. Following USGS methods (Wagner et al. 2006), results indicated that stream water is well mixed (excluding the large pools on the Verde River and Beaver Creek) and generally uniform across each stream segment (Gwilliam and Raymond in progress).

2.3.2 Field and laboratory methods

Field and laboratory methods generally follow methods recommended by the USGS field manual (USGS variously dated) and the NPS Water Resources Division (Irwin 2008). Field methods for the collection of water quality data include the use of a handheld multiparameter water quality instrument, and a 4L Nalgene sampling container. The water quality instrument is used to collect data on core water quality parameters (temperature, specific conductivity, pH, dissolved oxygen, turbidity, and discharge). The Nalgene container is used to collect a grab sample for analysis either at the contracted lab (TestAmerica) or with other SODN analytical gear (e.g., in the case of turbidity). All samples are kept cool and transported to the contracted lab in Phoenix, Arizona, or analyzed as soon as possible to meet all state-mandated hold times. Details on methods can be found in the SODN Stream Monitoring Protocol Quarterly Sampling SOPs.

The NPS Water Resources Division requires that any water quality analysis be conducted by a laboratory certified by the NELAP (National Environmental Laboratory Accreditation Program), using EPA and USGS standard methods (Irwin 2008). SODN analyses are currently conducted at TestAmerica, (www.testamericainc.com), which is NELAP-certified. Appendix B lists analytes and methods.

2.3.3 Analysis

The sampling methodology used in the SODN water quality monitoring program has implications for data interpretation in a management context. Quarterly grab samples represent conditions at the index site at the time of sampling; they do not represent the condition of the entire stream segment, spatially or temporally. Samples are routinely collected several times per year in order to build a database that represents the range of conditions that occur, with a focus on baseflow conditions. Thus, rare and short-term events are often not captured.

2.3.3.1 Water quality standards and terminology

This report contains terminology that may not be readily understood by non-specialists. For clarification purposes, various terms and concepts that may cause confusion will be defined here. A water quality standard refers to an individual parameter and its associated beneficial use designation, in conjunction with a criterion, which is the numeric component against which a result is compared. Each state is mandated by the EPA to create beneficial use designations and numeric components for water quality parameters. Arizona standards are published in the Arizona Administrative Code, Title 18, Chapter 11. A selection of standards is found in Appendix B.

One site visit yields approximately 60 water quality parameter measurements, or results (see Appendix B). Each result is evaluated

against any existing water quality standard (Appendix B); this is referred to as a use evaluation in this report. Each beneficial use designation may contain distinct criteria for one parameter, and each site may contain up to seven distinct beneficial use designations. Therefore, one parameter measurement from one site visit may result in multiple use evaluations (e.g., for full-body contact and aquatic and wildlife warm-water chronic standards).

2.3.3.2 Chronic and acute standards

For a single parameter, numeric criteria for water quality standards address potential effects of both chronic exposure over an extended period of time (months) and acute exposure over a short period of time (hours or days). Permitted levels are much lower for chronic exposure than for acute exposure. Criteria for chronic exposure are not directly comparable to the results obtained from a one-time monthly grab sample. From a compliance standpoint, the acute instantaneous criteria afford the only direct comparison for such data. However, from a resource-conservation standpoint, instantaneous grab-sample data, when compared against more stringent chronic criteria, can provide a means of early warning and an indication of a problem that may require more attention.

For these reasons, parameter results were compared against the chronic standards to create the graphical and tabular data included in this report. Each exceedance was then re-evaluated against the less-stringent acute criteria. If a chronic exceedance also exceeded the acute standard, then documentation was provided in the results section for that individual site.

2.3.4 Assessment points

2.3.4.1 Parameters with regulatory standards

For parameters with regulatory standards for aquatic and wildlife warm-water and human health through contact, we will use the Arizona aquatic and wildlife warm-water chronic standard and the full-body contact standard as the assessment points. For example, the aquatic and wildlife warm-water acute state standard for dissolved arsenic under is 0.34 mg/L, and the chronic standard is 0.15 mg/L. The SODN assessment point would be set at 0.15 mg/L. Appendix B provides a list of selected Arizona state water quality standards used for assessing these parameters.

2.3.4.2 Parameters without regulatory standards

There are parameters without state standards that may be ecologically important without directly impacting the health and welfare of wildlife or humans. In these cases, we propose assessment points based on the ecological literature and professional knowledge of these ecosystems and park management goals. Proposed assessment points are summarized in Table 2-4.

Table 2-4. Management assessment points proposed for water quality parameters without state standards, Montezuma Castle and Tuzigoot national monuments.

Parameter	Assessment point (Is value outside this range?)
Alkalinity as $CaCO_3$	20–400 mg/L
Calcium	>1 mg/L*
Chloride	<100mg/L**
Dissolved Aluminum	>0.01 mg/L
Dissolved Calcium	>1 mg/L
Dissolved Iron	<0.3 mg/L
Dissolved Magnesium	>1 mg/L
Dissolved Manganese	<.2 mg/L
Dissolved Potassium	>1 mg/L*
Dissolved Silica	>1 mg/L*
Dissolved Sodium	>1 mg/L
Hardness (as $CaCO_3$)	>1 mg/L
Magnesium	<100 mg/L
Potassium	>1 mg/L*
Silica	>1 mg/L
Sodium	>1 mg/L
Sulfate	<80 mg/L
Total Hardness	>1 mg/L

*Major non-toxic ecologically important chemical parameter typically should be found in concentrations >1mg/L.

** Value should be less than 100 mg/L or ≤ concurrently collected sulfate or bicarbonate concentration.

2.4 Water quantity

The amount of water flowing through a stream is the primary ecosystem driver in perennial and ephemeral riparian areas (Sponseller and Fisher 2006). Where, when, and how much the river flows influence nearly all the physical and biological processes in a riparian area, including riverbed particle size,

water quality, and which animals and plants are found living in and around the stream. Understanding the status and trends of stream baseflow, as well as the intensity, duration, and frequency of floods and drought, forms the basis for understanding and interpreting the ecology of riparian and aquatic systems (Gwilliam et al. in progress).

Streamflow data for this report are taken from USGS and NPS gages on Beaver Creek, Wet Beaver Creek, and the Verde River. Data are gathered from USGS online resources for the USGS gages on Wet Beaver and the Verde River, from logging pressure transducers, and from discharge measurements collected by NPS staff. Analysis of regional hydrology and streamflow is drawn from recent reports by the USGS and The Nature Conservancy (Blasch et al. 2006; Haney et al. 2008). Gage site descriptions are from the USGS (2011a, b, c).

2.4.1 Target population

The target population for water quantity monitoring is the mean annual and seasonal daily discharge values and flood frequency and intensity calculated from data collected at USGS and NPS stream gages on Beaver Creek, Wet Beaver Creek, and the Verde River.

2.4.2 Field methods

Data are collected from stream gages located at and/or near each park unit's index site. Long-term data to determine annual medians and return intervals are calculated from the nearest USGS stream gage with sufficient data records. Discharge measurements are made by SODN staff with a Flow Tracker acoustic Doppler velocity meter following USGS methods. Measurements made by Montezuma Castle NM staff are made with a Price AA "pygmy" type velocity meter following USGS methods (Rantz et al. 1982).

2.4.3 Analysis

In this report, we summarize mean daily discharge, mean monthly discharge, and peak flow for the range of reporting years, comparing data collected in Water Year (WY) 2011 to historical gage records and flow statistics at other locations, or at similar systems in the watershed, to put results into context (Table 2-5).

Table 2-5. Water years used for analysis.

Location	Water years used for analysis
Beaver Creek	2004–2009, 2011–2013
Wet Beaver Creek	1961–1982, 1985–1986, 1988–2012
Verde River	1965–2012

2.4.3.1 Mean daily discharge

We calculated the annual mean daily discharge from each gage (Beaver Creek, Wet Beaver Creek, and the Verde River) for WY11, including annual sum of acre feet of water discharged. Hydrographs for WY2011 and the entire gage record were also calculated. A hydrograph, or graphical representation of streamflow over time, is a useful way to display the occurrence, length, and intensity of streamflow over a water year. The hydrographs presented in this report cover both the water year, to communicate annual flow, intensity, and timing, and the entire record of the gage, to communicate the patterns of flow between years.

2.4.3.2 Proportion of seasonal flow

We calculated the proportion of total flow at each gage by hydrologic season. We used the hydrologic season defined by the NPS baseline water quality data inventories and analyses for Montezuma Castle and Tuzigoot national monuments (NPS 1995; NPS 1999).

2.4.3.3 Mean monthly discharge

This analysis calculated the mean daily discharge by month for WY2011, and compared it to the value calculated from the entire respective record for the gage.

2.4.3.4 Peak flow and return interval estimate

The peak flows from WY2011 were compared to the calculated return intervals generated from the USGS PKFlow software (USGS 2007). The frequency of flooding events of a certain magnitude is referred to as a return interval, or the percent chance a flood of a particular magnitude will occur in any given year. For example, a flood considered a "25-year flood" has a 4% chance of occurring in any given year. An important flood threshold is a "channel maintenance," or "bankfull" event,

occurring every 1.5–2 years. These events are ecologically important for scouring channels of fine materials, forming bars, and other processes (Rosgen 1996).

2.4.4 Assessment points

The assessment points established for water quantity (Table 2-6) are designed to stimulate and facilitate conversation between SODN staff and park staff about the condition of the system and the impact of flow on the ecology of the aquatic and riparian areas of the park units. These assessment points are a starting point and are expected to undergo extensive refinement over time as we work with parks to identify assessment points that will assist with meeting park management goals. SODN suggests the assessment points shown in Table 2-6 be used for water quantity at Montezuma Castle and Tuzigoot NMs (MOCA-TUZI).

2.5 Channel morphology

The primary ecological functions of stream channels are to dissipate the energy associated with overland flow and to transport sediment, water, and nutrients within and from the watershed (Dunne and Leopold 1978). As a result, stream channels are constantly adjusting to watershed conditions. Rare, stochastic flow events are of particular importance at MOCA-TUZI, and channel morphometrics will respond to the frequency, magnitude, and duration of these events. Geomorphic characteristics of stream channels, such as channel shape, interact with biological components, most notably vegetation, to determine the type, extent, and configuration of riparian ecosystems. Monitoring channel morphology for streams at MOCA-TUZI provides an important indicator of watershed condition and integrates ecological and geomorphological processes, including soil erosion, nutrient cycling, discharge characteristics, and the occurrence and magnitude of disturbance events, as well as surface and groundwater quantity and quality.

2.5.1 Target population

The target population is the cross-section of the stream channel, elevation of the stream channel, and particle size in the channel of the stream segment in each park unit. Channel morphology is conducted according to a five-year panel design, with contingency sampling for events of greater magnitude than a 100-year flood return interval.

2.5.2 Field methods

Cross-sections are assigned a random start point, then systematically allocated in GIS and surveyed using a Nikon Total Station DTM-330 survey instrument. For Beaver Creek (the only segment surveyed in the time period covered by this report) in 2010, the first cross-section was allocated randomly within 50 m of the upstream boundary of the park. Subsequent cross-sections were placed approximately 480 m downstream (along the stream channel). The orientation and length of the cross-sections was determined using the current (2009) channel morphology as determined by aerial imagery. Cross-sections should be large enough to capture natural variation in morphology.

The survey crew navigated to and along the cross-sections using handheld GPS units. All

Table 2-6. Management assessment points proposed for water quantity, Montezuma Castle and Tuzigoot national monuments.

Issue	Assessment point metric
Were there any no-flow events at the gage or measurement station?	>0
Were there any 50-year or greater flow events?	Max flow >50-year return interval discharge
Was there a "low-flow" season?	Sum of seasonal daily average discharge measurements <1st quartile rank
Was there a "high-flow" season?	Sum of seasonal daily average discharge measurements > 3rd quartile rank
Were there more than two "bankfull" flow events during the past year?	# bankfull events >2

slope inflection showing elevation changes of greater than approximately 10 centimeters were recorded.

In spring 2009, SODN estimated substrate composition at 11 cross-sections. The field crews conducted ocular estimates, to the nearest 5%, of sediment cover by sediment type (bedrock, boulder, cobble, gravel, sand, silt/clay). The estimates were made along the wetted area of the cross-section and within a rectangular area 5 m upstream and downstream of the cross-section. Following data entry and standard QA/QC procedures, the data were exported to Microsoft Excel (Gwilliam and Raymond in progress). Within Excel, the dominant sediment size per transect was determined. The average sediment class, and standard deviation and standard error, were calculated for the entire stream reach. Microsoft Excel was used to generate charts showing the sediment composition of each cross-section and the reach.

2.5.3 Analysis

To estimate slope, cross-section A (farthest upstream) was assigned as the starting location and the distance along the stream was calculated for each cross-section. Sinuosity was calculated in GIS by dividing the distance along the stream channel from cross-sections 1 to 11 (stream length) by the straight line distance between cross-sections 1 and 11 (valley length). Because a thalweg survey was not conducted, the slope and sinuosity of the stream channel were estimated using data from the 11 cross-sections and existing GIS data. The maximum elevation (m) of the water at each cross-section was also determined.

Survey data points were converted to a single ArcGIS shapefile (NAD83 UTM Zone 12) and a Microsoft Excel file for each cross-section. In Excel, the Pythagorean Theorem was used to determine the distance along the transect for each survey point (from the rebar at on left side of the river). The distance along the transect and the survey-point elevation were used to generate cross-section charts and calculate total cross-sectional area.

2.5.4 Assessment points

Table 2-7 shows the management assessment points proposed for channel morphology. These assessment points are recommended as a starting point for understanding status and trends in channel-morphology metrics.

These assessment points were selected to alert managers to changes in the morphology of a stream of a magnitude that could impact future ecological function. Assessment points are still being developed and current assessment points are being tested.

2.6 Riparian and aquatic vegetation

The riparian zone extends from the active river channel out to an indeterminate point where the transition to uplands is complete. Sometimes this transition is obvious, delineated by a clear geologic feature, such as a bedrock cliff face (Figure 2-5). Typically, however, the transition is gradual. Many species found in riparian zones are facultative phreatophytes, or plants that do not need ready access to groundwater but are instead able to use both the near-surface groundwater found near streams and the water in the soil to survive (e.g., velvet mesquite).

Proximity to the river influences plants and vegetation community structure in several ways, including through physical impact to plants by floods (e.g., washed away by flood), fluvial modification of the substrate (e.g., fine substrate deposition), and the availability of water (depth to groundwater). The SODN streams protocol has divided the riparian area of each stream segment into three sample frames: aquatic, greenline, and riparian-zone.

Table 2-7. Management assessment points proposed for channel morphology, Montezuma Castle and Tuzigoot national monuments.

Issue	Assessment point
Sinuosity	>10% change
Cross-sectional area	>10% change in any one cross-section, or of the total cross-sectional area
Dominant particle size	Change from one type to another
Particle size assessment	Fine-size particle increase >10%



Figure 2-5. Example of clear delineation between riparian and upland. Note the cliff face with upland vegetation on top of cliff and riparian community below.

2.6.1 Target population

The target population is common perennial vascular plants in the riparian and aquatic areas of the stream segment and channel cross-sections, with a particular (but not limited) focus on non-native and obligate wetland taxa. Three groups were examined during the riparian vegetation monitoring covered in this report:

- Aquatic: benthic, submerged, and emergent vascular plants found growing in the flowing stream or wetted areas.
- Greenline: samples from the vegetation found in the first line of perennial vegetation from the stream wetted edge, usually within 10 m.
- Riparian-zone: samples from the vegetation found 10 m from the edge of the stream to ~300 m away from the stream wetted edge to the riparian boundary.

Results from each sample frame are presented separately. Analysis will continue to determine the optimal design (e.g., dividing each sample frame into separate strata, dividing the current frames into more or fewer strata). This work will continue into WY13.

2.6.2 Field methods

Data on vegetation abundance and frequency were collected using point-intercept on transects and presence/absence in plots (respectively). In the point-intercept method, each riparian vegetation transect is 20 m long, perpendicular to the cross-section (see channel geomorphology section), and centered on the cross-section so the cross-section intercepts the transect at the 10-m mark. At each meter along the transect, crew members stood a "bayonet" (i.e., a fiberglass rod approximately 1.5 m × 8 mm in diameter) equipped with a bubble level on the ground, then identified each vascular plant taxon touching the bayonet in several structural layers: ground (<1 cm), herbaceous (1 cm–0.5 m), subcanopy (0.5–2 m) and canopy (>2 m). A periscope (an instrument enabling the worker to determine overhead intersection with the bayonet) was used to determine canopy species.

For presence and absence, the crew visually inspected one meter out from each side of the transect to identify any other taxa not discovered via the point-intercept method. This method was also used in the aquatic sample, in which the crew searched 5 m upstream and downstream of the cross-section in the wetted area of the stream on both banks (as terrain allowed). Unknown plants were collected in the field and returned to the lab, where they were identified using the pertinent key and compared to vouchers in the University of Arizona herbarium. Unknown entries in the database were then rectified with revised taxa identification.

2.6.3 Analysis

Frequency of taxa was calculated by dividing the total number of sample plots in the stream segment (aquatic, greenline or zone) by the number of plots in which a particular taxon was detected. This yields the % of plots, or frequency with which a particular taxon occurred.

Abundance was calculated by summing the number of point-intercept "hits" for a particular taxon by structural layer (on each riparian-zone or greenline transect), then dividing the number of hits by the number of total possible hits (20, in the case of the riparian vegetation transects).

This yielded a percent cover, or abundance

for each taxon for each transect, by structural layer. The mean of the abundance by taxon and structural layer for the stream segment was calculated by summing the abundance value and dividing by the number of sample plots.

The following data were calculated for each park unit:

- Frequency of aquatic taxa—list of vascular plant taxa by percent of sample plots in which they were detected. Only taxa encountered at more than 10% of sample plots were reported.
- Frequency of greenline taxa—a list of vascular plant taxa by percent of sample plots in which they were detected. Only taxa encountered at more than 10% of sample plots were reported.
- Frequency of riparian-zone taxa—a list of vascular plant taxa by percent of sample plots in which they were detected. Only taxa encountered at more than 10% of sample plots were reported.
- Abundance of vegetation by structural layer—mean abundance of plants by structural type (Judd et al. 2007).

2.6.4 Assessment points

The management assessment points identified and recommended as a starting point for understanding status and trends in riparian vegetation are shown in Table 2-8. They focus on the distribution of non-native species and changes in obligate wetland species. These assessment points were selected to alert managers to distributions and frequency of plant taxa of management concern. Assessment points are still being developed and current assessment points are being tested.

2.7 Benthic macroinvertebrates

Benthic macroinvertebrates (hereafter, macroinvertebrates) are an important biological component in streams. They contribute to nutrient cycling and organic decomposition and are an important prey for fish and other aquatic vertebrates. Living on the bottom substrates or the sediment in streams, macroinvertebrate communities respond differently to a variety of stressors. Thus, the type of stress on a stream can be determined by analyzing species distribution for the macroinvertebrate community (Peck et al. 2003). Macroinvertebrates can provide a powerful biological indicator of water quality and local conditions (Karr et al. 1986; Rosenberg and Resh 1993). They have been used extensively to assess stream condition because they are sensitive to pollutants and have high species richness. They also live in contact with sediment where pollutants tend to concentrate, and taxa and lifeform response to pollutants are relatively well established (Karr et al. 1986; Reice and Wohlenberg 1993). Because they are relatively long-lived, macroinvertebrates integrate exposure to water condition over substantial time scales.

2.7.1 Target population

The target population is macroinvertebrates located in (1) only riffle habitat in the index reach of each stream segment and (2) each habitat type (e.g., glide) in the index reach of each stream segment.

2.7.2 Field methods

SODN macroinvertebrate sample collection periods are scheduled to coincide with ADEQ sample collection periods to ensure compatibility of monitoring samples (Brasher et al. in review). In Arizona, the sampling window for warm-water streams is from April to May (Lawson 2005).

Table 2-8. Management assessment points proposed for riparian and aquatic vegetation, Montezuma Castle and Tuzigoot national monuments.

Issue	Assessment point
Non-native plant dispersal	Non-native plants found in >50% of sample sites
Non-native plant invasion	% total plant cover is >10% non-native in each structural layer
Loss of obligate wetland taxa (richness and distribution)	Outside baseline 95% confidence interval for wetland obligate taxa richness and distribution

Each site consists of a ≥150-m reach, composed of 11 equally spaced transects (Figures 2-6 to 2-8). Two types of samples were collected in each site:

- Replicate quantitative samples were collected from five targeted riffle habitats to provide estimates of abundances of organisms. Using a kicknet with a 0.25-m opening, we collected a timed sample from a 0.25-m^2 area at each targeted riffle.
- A qualitative sample was collected to develop a comprehensive list of species present in the reach. Using nets, samples were actively collected from all habitat types within each sampling reach and compiled into one composite sample.

In addition, for each of the quantitative targeted riffle microhabitats, we measured depth, velocity, particle size, and particle embeddedness. For each of the 11 transects, we measured wetted and active channel widths, water depth, velocity, and canopy closure at 16 points along each transect. For the entire reach, we identified and measured the length of geomorphic classification units (GCUs; Bisson et al. 1982), and identified the dominant vegetation and land cover. Reach characterization data represent the proportion of the reach characterized by that particular GCU.

We collected physical habitat data at three spatial scales: microhabitat, transect, and reach. A detailed description of sampling methods can be found in Brasher and others (in review).

2.7.3 Lab methods

Aquatic macroinvertebrate samples were sent to the National Aquatic Monitoring Center's BugLab, a Bureau of Land Management laboratory at Utah State University in Logan, Utah, where a taxonomist, certified by the North American Benthological Society, identified all aquatic macroinvertebrates to the family or genus level.

2.7.4 Analysis

Genera were classified into functional feeding-guilds using the classifications presented in Barbour and others (1999). If functional-class information was not available for a particular genus, we applied a more generalized, family-level classification. We selected aquatic macroinvertebrate metrics that are generally considered to be sensitive, reliable indicators of water quality and/or stream health (see Appendix C for a table of metrics and their definitions).

Most of these metrics have been used to detect changes in water quality and habitat conditions in other streams in the southern Rocky Mountains ecoregion (Griffith et al. 2005). Also, they enable a comprehensive assessment of multiple aspects of community structure because they represent a range of ecological characteristics. SODN will periodically evaluate the interpretive value of the listed metrics and may drop or add additional metrics based upon these evaluations. In this report, we summarize aquatic macroinvertebrate data in terms of community structure and function.

2.7.4.1 ADEQ Index of Biotic Integrity

The ADEQ Index of Biotic Integrity (IBI) for warm water is calculated from nine metrics that have a predictable response to disturbance in terms of water quality and habitat disturbance. The IBI results in a score of 0–100 for each sample, which is then characterized as either attaining biotic integrity of the aquatic ecosystem, impaired, or inconclusive.

2.7.4.2 EMAP multi-metric indices

In 2005, in an assessment of western streams, the EPA developed multi-metric indices (MMI) to evaluate the benthic macroinvertebrate communities in different ecoregions (Stoddard et al. 2005). The EMAP Mountains MMI covers a large latitude range, extending from the Mogollon Rim to the U.S. border with Canada, and pertains to an area that includes the Omernik ecoregion Arizona/New Mexico Mountains, which encompasses Montezuma Castle and Tuzigoot NMs (Omernik 1987). The EMAP MMI includes six metrics and results in a score of 0–100. Numeric scores are assigned a narrative value of least disturbed, moderately disturbed, or most disturbed.

2.7.4.3 Individual metrics

Metric indices, such as the ADEQ IBI and

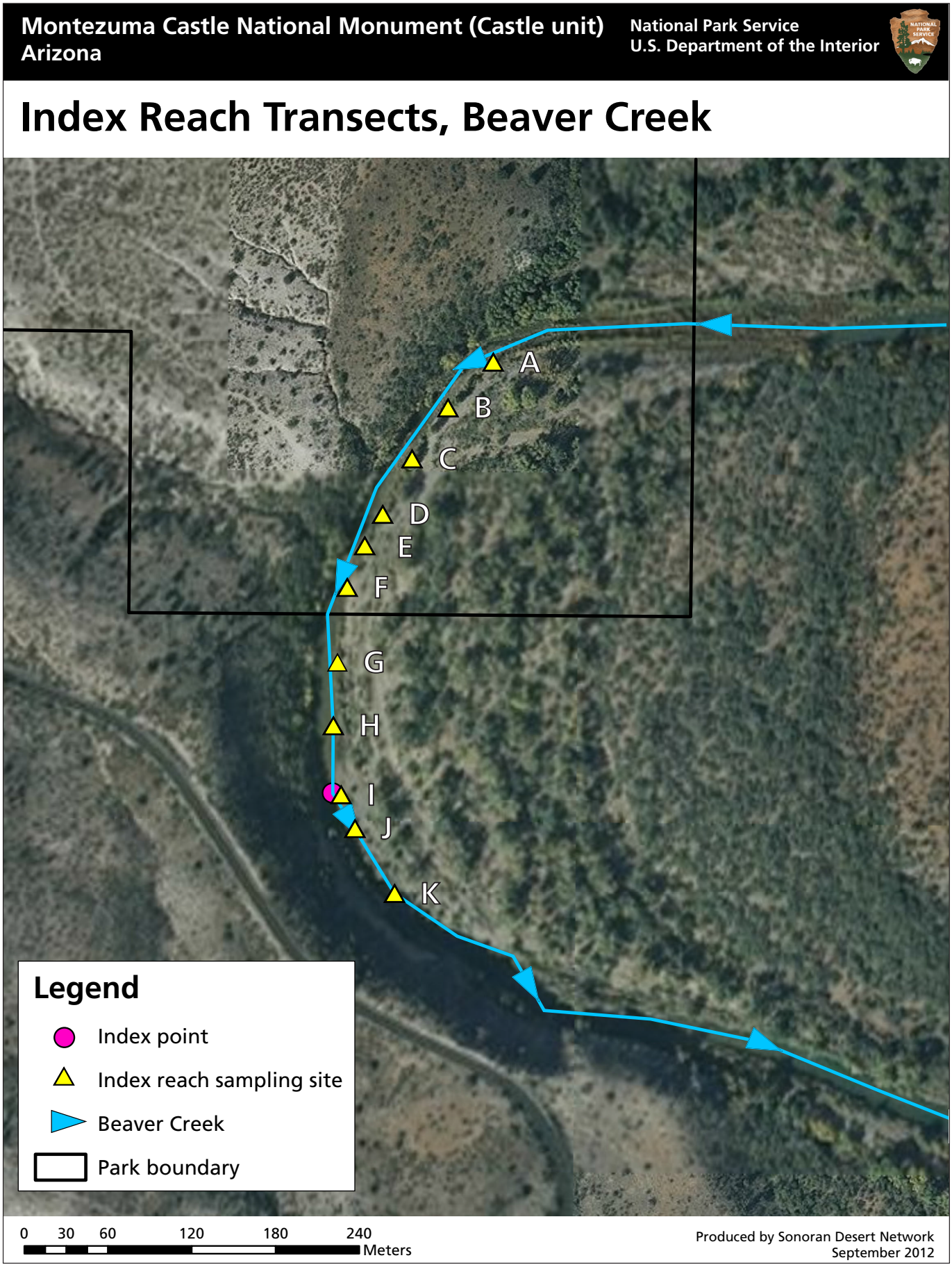


Figure 2-6. Index-reach transects, Beaver Creek, Montezuma Castle National Monument (Castle unit).

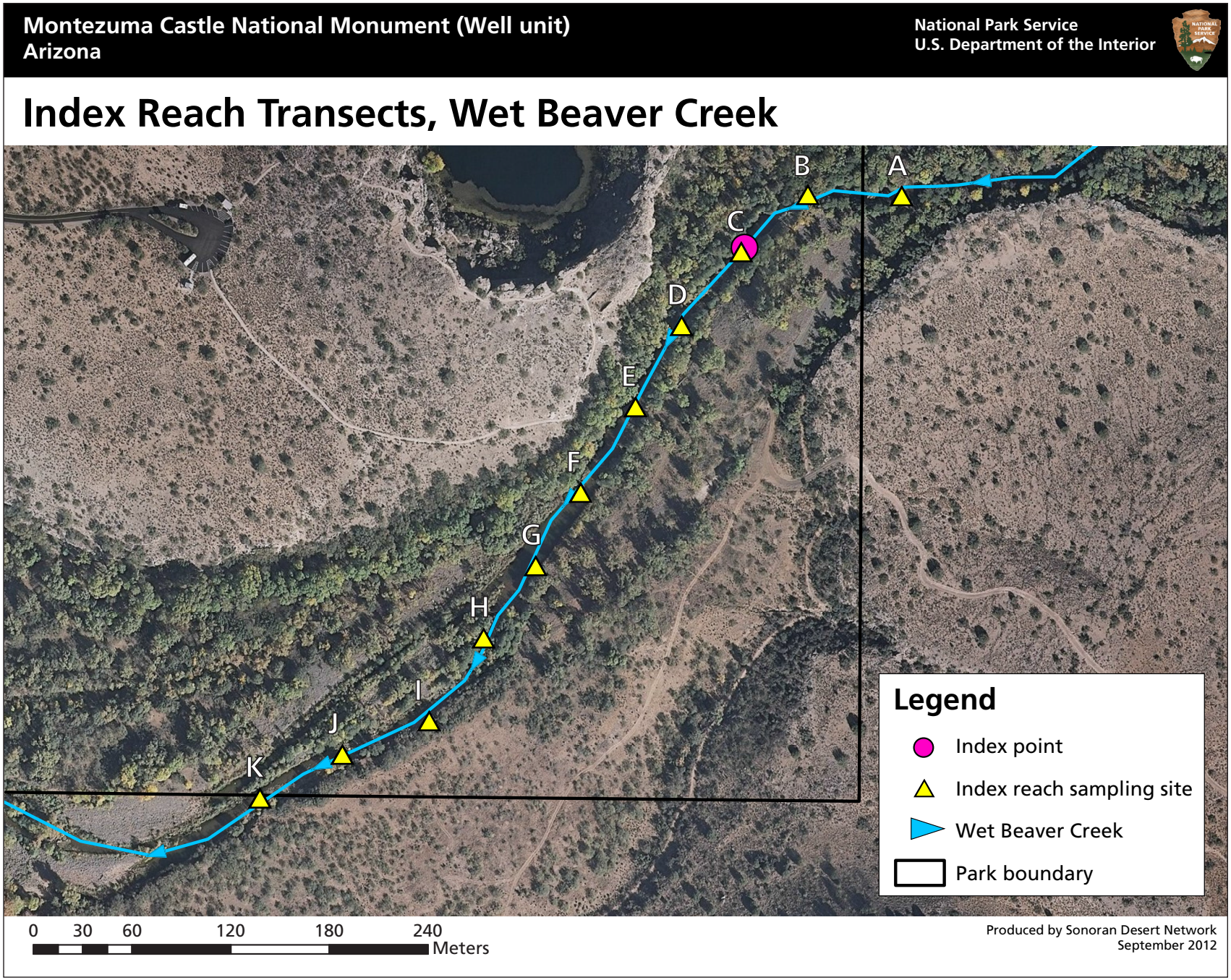


Figure 2-7. Index-reach transects, Wet Beaver Creek, Montezuma Castle National Monument (Well unit).

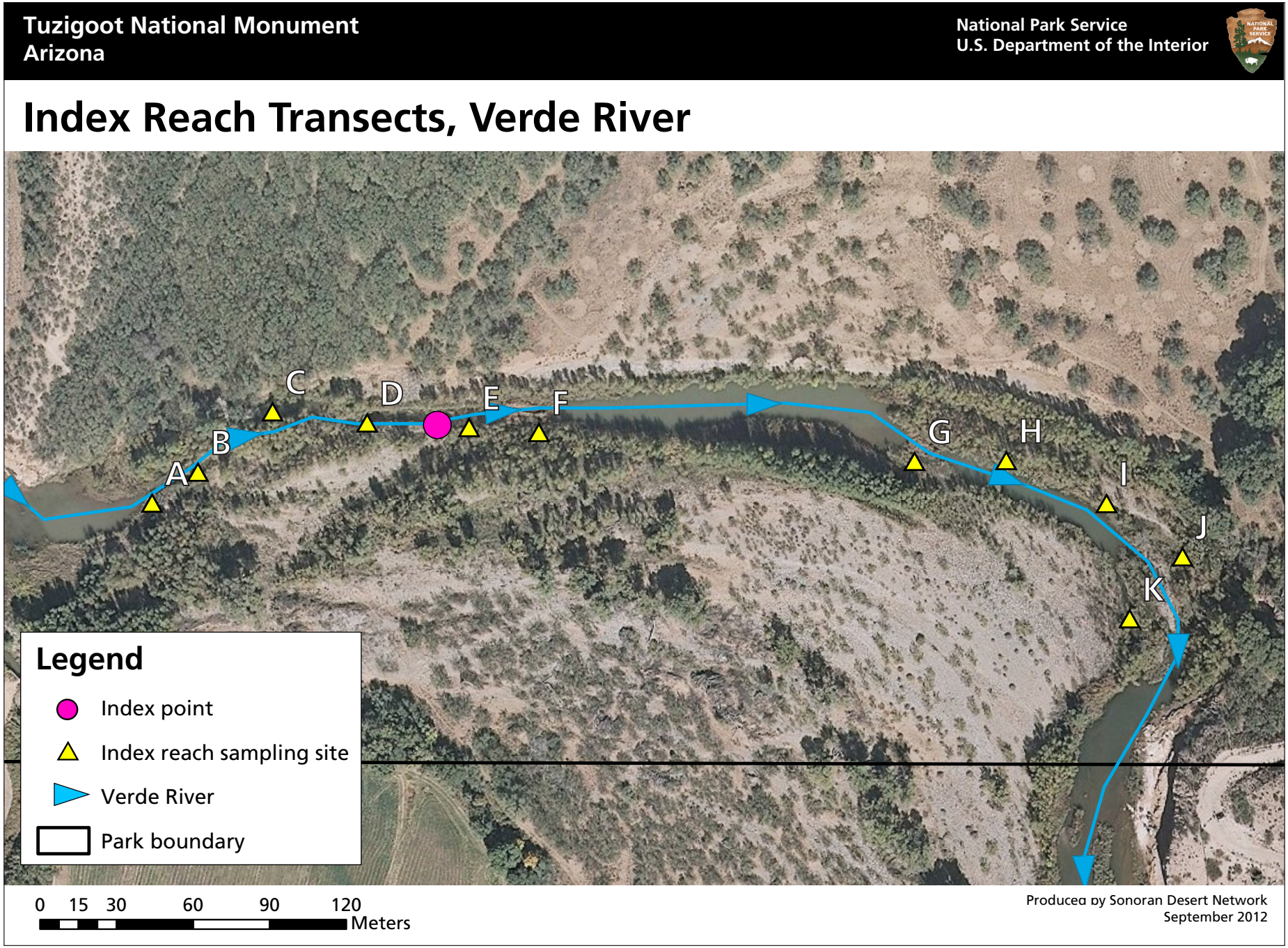


Figure 2-8. Index-reach transects, Verde River, Tuzigoot National Monument.

the EMAP IBI, summarize aquatic habitat quality and water quality in a single score and associated rating. However, looking at individual metrics can also provide insight about ecosystem status. Some metrics have a negative relationship with disturbance; as disturbance increases, the metric decreases. Other metrics have a positive relationship with disturbance.

Four richness metrics that have a negative relationship with disturbance are taxa richness (Barbour et al. 1992; Karr and Chu 1999), EPT (Ephemeroptera, Plecoptera, and Trichoptera) richness (Karr and Chu 1999; Richards et al. 1997), intolerant taxa richness (Fore et al. 1996), and predators (Karr and Chu 1999; Kerans and Karr 1994). Metrics that have a positive relationship with disturbance include percent Chironomidae (Fore et al. 1996), percent dominant (Barbour et al. 1996), and the Hilsenhoff Biotic Index (Hilsenhoff 1987).

Taxa richness—. The number of distinct taxa is an estimate of the benthic community structure, and representative of overall stream health.

EPT richness—. The insect orders Ephemeroptera, Plecoptera, and Tricoptera are a subset of aquatic macroinvertebrates that are commonly considered to be sensitive to pollution and habitat disturbance.

Intolerant taxa richness—. Intolerant taxa are considered particularly sensitive to disturbance.

Predators—. Predators are higher on the trophic chain; therefore, examining predator richness can be an indication of balance in the overall aquatic community.

Chironomidae—. Chironomidae is the most diverse and abundant family of aquatic insects in freshwater systems (Coffman and Ferrington 1984). Due to its diversity, the family as a whole is generally tolerant of disturbance. A diverse group of chironomids can survive in stagnant, deep, sediment pools.

Dominant taxa—. The degree to which one taxon dominates the benthic community is highly correlated to the degree of stress in the aquatic ecosystem.

Hilsenhoff Biotic Index—. The Hilsenhoff Biotic Index is a measure of tolerance to organic pollution, such as nutrient enrichment. Taxa sensitive to organic pollution have a low index value, while tolerant taxa have a high index value. The mean of the tolerance values of all the individuals in the sample is the Hilsenhoff biotic index score, 0–10. This index has been used to detect nutrient enrichment, high sediment loads, low dissolved oxygen, and thermal impacts.

2.7.5 Assessment points

SODN uses biological indices established at both state and national levels as assessment points (Table 2-9). A meeting with park managers should be considered if index values fall into the categories shown in the "Assessment point" column of Table 2-9.

The network is currently collecting baseline data on individual metrics, as well as data from similar sites in the Verde River basin. Obtaining these data will allow us to select meaningful benchmarks for evaluation of future data.

Table 2-9. Management assessment points proposed for macroinvertebrates, Montezuma Castle and Tuzigoot national monuments.

Issue	Assessment point
Overall macroinvertebrate community health	Rates as inconclusive or impaired in the ADEQ Index of Biotic Integrity
	Rates as moderately or most disturbed in the EMAP multi-metric indices

ADEQ = Arizona Department of Environmental Quality

EMAP = U.S. Environmental Protection Agency Emvironmental Monitoring and Assessment Program

3 Results and Discussion

This chapter communicates salient data from each park unit and puts those data into context. Supporting datasets are included in the appendices.

3.1 Water quality

Water quality samples were collected at the index site on each stream (see Figures 2-2, 2-3, 2-4). Each index site was visited quarterly during WY2011, for a total of four visits to each park unit during this time period (Table 3-1). A total of 762 individual measurements (e.g., pH field measurement) or analyses (e.g., lab analysis for dissolved arsenic) were conducted—254 at each of the three sites.

3.1.1 Compliance with Arizona state surface water quality standards

During WY2011, of the 762 individual measurements or analysis, 312 were associated with an Arizona surface water quality standard (see Appendix B). For measurements and analysis conducted in situ or on water samples, 99.7% were compliant with state standards. The NPS GPRA (Government Performance and Results Act) goal of meeting 99.3% of state and federal standards was met at each unit (Table 3-2).

There were two exceedances of Arizona state surface water quality standards during WY2011, both for arsenic. Arsenic from the sample collected on Wet Beaver Creek at Montezuma Well (MOWE) in October 2010 was measured at 0.032 mg/L, just exceeding the standard for full-body contact (e.g., swimming). Arsenic from the sample collected on Beaver Creek at Montezuma Castle in May 2011 was measured at 0.03 mg/L, which is the state standard for full-body contact (Table 3-3).

3.1.2 Water quality constituents

SODN collects data on more than 60 individual water quality parameters selected to provide information about ecological processes and human health (see Appendix B). Parameters that were detected during WY2011 are

Table 3-1. Water quality sampling dates, Montezuma Castle and Tuzigoot national monuments, WY2011.

Water body	Park unit	Park code	Fall	Winter	Spring	Summer
Beaver Creek	Montezuma Castle NM (Castle unit)	MOCC	10/19/2010	2/8/2011	5/26/2011	8/25/2011
Wet Beaver Creek	Montezuma Castle NM (Well unit)	MOWE	10/19/2010	2/8/2011	5/25/2011	8/25/2011
Verde River	Tuzigoot NM	TUZI	10/18/2010	2/7/2011	5/26/2011	8/24/2011

Table 3-2. Compliance with Arizona state surface water standards, Montezuma Castle and Tuzigoot national monuments, WY2011.

Water body	% compliance
Beaver Creek (MOCC)	99.6%
Wet Beaver Creek (MOWE)	99.6%
Verde River (TUZI)	100%

Table 3-3. Exceedances of state water quality standards, Montezuma Castle National Monument, WY2011.

Water body	Date	Parameter	Concentration (mg/L)	State standard concentration	Use code
Beaver Creek (MOCC)	10/19/10	Arsenic	0.032	0.03 mg/L	FBC
Wet Beaver Creek (MOWE)	05/25/11	Arsenic	0.03	0.03 mg/L	FBC

FBC = full-body contact (e.g., swimming)

reported below by parameter group.

Many of the individual parameters were not detected during analysis. This indicates that the parameter either was not present or was present at a concentration below the reporting limit (i.e., the value at which a reliable concentration can be identified) or detection limit (i.e., the value at which the parameter can be detected) of the analytical equipment. Analytical limits are detailed in Appendix B.

3.1.2.1 Core water quality parameters

In WY2011, SODN collected data on core water quality parameters, a group of ecologically important metrics that provide the most basic level of information about water quality (Irwin 2008). These were discrete measurements made in the field and represent conditions at the index site during water quality sampling only. All measured values were within historical bounds and able to sustain wildlife and human health (Table 3-4).

Temperature—. Water temperature was measured during all visits to sample sites. The highest temperature, 28.6°C (84°F) was recorded on the Verde River on August 24, 2011. The lowest temperature, 7.4°C (45.3°F), was recorded on Wet Beaver Creek on February 8, 2011. Temperatures may be higher or lower than these measurements at other discrete locations at MOCA-TUZI (e.g., shallow pools in summer), but temperatures were generally observed within the expected range.

Specific conductivity—. Specific conductivity values, on the whole, were within the expected range and the national average of 50–500. Specific conductivity was higher at the Verde River sampling site than at the others, and higher at the Beaver Creek site than at the Wet Beaver Creek site. This result was expected, because as watersheds get progressively larger, there is more opportunity for more dissolved material to become entrained in the water column.

pH—. The stream water of MOCA-TUZI was slightly basic, with a median pH value for all three sample sites of 8.29. These values were within the acceptable regulatory range and the expected range for ecosystem function. The slightly basic quality of MOCA-TUZI waters is likely a result of the limestone bedrock in the stream watersheds contributing carbonates (i.e., calcium and

Table 3-4. Values for core water quality parameters, Montezuma Castle and Tuzigoot national monuments, WY2011.

Date	Temperature (°C)	Specific conductivity (µS/cm)	pH	DO (mg/L)	Turbidity (NTU)	Discharge (cfs)
Beaver Creek (MOCC)						
10/19/2010	17.7	514	8.04	8.18	26.97	6.80
02/08/2011	9.3	439.3	8.06	8.96	5.61	11.39
05/26/2011	20.1	417.7	8.34	7.36	4.36	4.34
08/25/2011	26.2	467.4	8.00	*	12.1	0.42
Wet Beaver Creek (MOWE)						
10/19/2010	19.1	446.4	8.09	8.46	20.47	7.47
02/08/2011	7.4	350.5	7.91	9.39	5.61	12.79
05/25/2011	23	377.1	8.56	7.15	2.99	8.25
08/25/2011	21.7	405	8.23	8.43	3.66	5.89
Verde River (TUZI)						
10/18/2010	20.1	518	8.4	8.4	11.59	29.8
02/07/2011	11.3	467.7	8.75	9.55	2.09	32.84
05/26/2011	18.9	494.2	8.49	7.02	7.50	1.95
08/24/2011	28.6	446.5	8.36	8.87	28.1	3.0

*Due to equipment failure, the Beaver Creek sample from 8/25/11 was not collected as oxygen concentration (mg/L), but as percent dissolved oxygen, with a value of 81.5%. See page ix for abbreviations.

magnesium) to the stream water column, increasing the pH to observed levels. This basic pH, and the accompanying alkalinity values (see Table 3-8) enable the water to buffer (i.e., absorb without significantly changing) drivers of pH (e.g., acid rain or mine leachates) and to cause any deleterious concentrations of metals to form generally less toxic or non-toxic precipitates and/or other insoluble compounds.

Dissolved oxygen—. Dissolved oxygen (DO) values for MOCA-TUZI were all in the acceptable range, falling below 8 mg/L during the May sample, when the temperature was very high and flow was low.

Turbidity—. In WY2011, all turbidity values were within the expected and acceptable range. Turbidity on all three streams was generally below 15 NTU (nephelometric turbidity unit), with a median value of 7.5 NTU. This value is consistent with other concurrent measurements, such as total dissolved solids (TDS) and total suspended solids (TSS) and specific conductivity (see Table 3-8)—all measurements of material dissolved or suspended in stream water.

Discharge—. There is a loss of water between the sampling sites at Beaver Creek and Wet Beaver Creek. Discharge measurements taken during the warmer months show that the system between the two sites loses flow through a combination of losing reaches and evapotranspiration.[1] Direct evaporation of water, and transpiration of water by vegetation, directly from the stream and from the saturated soil zone adjacent to the river, may also contribute to an overall loss of flow.

This decrease in surface flow can impact the water quality of the river, concentrating analytes through the evaporation process and reduced dilution. The discharge measurements collected at Beaver Creek were, for the most part, less than those collected at the Verde River, indicating that the storage capacity of the underlying fluvial material of Beaver Creek is greater, and that the factors mentioned above that lead to losing reaches may have greater impact there.

3.1.2.2 Metals and metalloids

SODN conducts analyses on water samples for metals (and metalloids) that have ecological and/or human health importance. SODN does not discuss results in comparison to drinking water standards or agricultural standards because Montezuma Castle and Tuzigoot NMs do not get drinking water from their streams, nor do they use the water for any agricultural purpose (e.g., watering livestock or irrigating fields).

Metal concentrations that were greater than the reporting and/or detection limits are reported in Table 3-5. All measurements fell within the range of established standards for human health (through swimming and wading) and for aquatic and wildlife use except for two exceedances for arsenic, as described in Section 3.1.1 and below.

Aluminum—. Total aluminum was detected at all sample sites during all but one sample period (Wet Beaver Creek, 2/8/2011). Because elevated concentrations of dissolved aluminum (especially when they exceed the concentration of calcium and magnesium) can indicate the presence of acidic drainage from mine tailings, which would be unlikely but possible at Tuzigoot NM, SODN suggests that a Tuzigoot-specific management assessment point be established (> detection limit) for dissolved aluminum, to alert MOCA-TUZI managers to possible acidic mine leachate.

Arsenic—. Beaver Creek and Wet Beaver Creek both had exceedances of the state standard for total arsenic in WY2011. The concentration of arsenic in streams at Montezuma Castle and Tuzigoot NMs hovers around the state standard of 0.03 mg/L, with WY2011 mean concentrations at the Beaver Creek and Wet Beaver Creek sample stations being 0.024 and 0.028 mg/L, respectively. These WY2011 concentrations are typical for the region. Arsenic concentrations have occasionally exceeded state standards in the past (e.g., total arsenic 0.11 mg/L on August 18, 2010). Historically, arsenic has been regularly detected in samples from all three streams in and around the administered

[1] A losing reach is a stretch of river in which a portion of the water flowing through the reach is lost to groundwater recharge and other processes such that there is less water flowing downstream of the reach than upstream.

Table 3-5a. Concentrations (mg/L) of metals and metalloid parameters (A–I), Montezuma Castle and Tuzigoot national monuments, WY2011.

Date	Aluminum	Arsenic	Arsenic (Dissolved)	Barium	Barium (Dissolved)	Boron	Boron (Dissolved)	Calcium	Calcium (Dissolved)	Copper	Iron	Iron (Dissolved)
Beaver Creek (MOCC)												
10/19/2010	1.2	**0.032**	0.031	NC	NC	0.31	0.32	52	51	ND	0.88	ND
02/08/2011	0.26	0.023	0.019	NC	NC	0.25	0.24	58	57	ND	0.21	ND
05/26/2011	0.14	0.028	0.026	NC	NC	0.25	0.26	46	46	ND	0.2	ND
08/25/2011	0.14	0.029	0.027	0.19	0.19	0.32	0.31	50	50	ND	0.26	0.047
Wet Beaver Creek (MOWE)												
10/19/2010	0.32	0.022	0.025	NC	NC	0.17	0.18	49	51	ND	0.33	ND
02/08/2011	ND	0.017	0.015	NC	NC	0.12	0.13	46	48	ND	0.08	ND
05/25/2011	0.11	**0.03**	0.025	NC	NC	0.15	0.16	47	46	ND	0.13	ND
08/25/2011	0.1	0.029	0.028	0.28	0.28	0.19	0.19	51	53	ND	0.15	ND
Verde River (TUZI)												
10/18/2010	0.41	0.014	0.014	NC	NC	0.17	0.17	53	53	ND	0.3	0.08
02/07/2011	0.093	0.014	0.014	NC	NC	0.17	0.18	59	59	ND	0.073	ND
05/26/2011	0.18	0.022	0.024	NC	NC	0.17	0.18	56	55	ND	0.18	ND
08/24/2011	0.53	0.018	0.018	0.19	0.18	0.16	0.16	49	47	0.0035	0.39	ND

All concentrations are reported in mg/L and indicate the total value (i.e., total or total recoverable fraction) unless otherwise indicated (e.g., dissolved). ND = parameter not detected. NC = parameter not collected during that sample period.
Red bolded values represent exceedances.

stream segments at MOCA-TUZI (NPS 1995).

A background concentration of arsenic is considered to be the result of natural weathering processes in the Verde River watershed, primarily from oxidized sulfides of the Verde Formation and Tertiary volcanic deposits (Blasch et al. 2006). These elevated levels of arsenic have the potential to decrease the resilience of plant and animal populations to other stresses and make then more susceptible to disruptions in ecological function (e.g., low flow).

It is recommended that the park limit staff contact with stream water without proper personal protective equipment (PPE) (i.e., waders), especially during low-flow periods, when concentrations of arsenic are typically higher.

***Barium*—.** Barium was detected at all three index stations in WY0211. Barium values from MOCA-TUZI are higher than the national average, indicating a source in the watershed.

***Boron*—.** Beaver Creek and Wet Beaver Creek generally have higher concentrations of boron than other tributaries of the Middle Verde Watershed, and contribute to the increase in boron concentrations observed in the Verde River at Cottonwood, Arizona (Blasch et al. 2006). There appears to be a seasonal influence—likely a response to low flow rates—on concentrations of boron during the summer and early fall, especially at Beaver Creek. None of the boron concentrations measured exceeded any standard.

***Calcium*—.** The ubiquitous limestone bedrock of the Middle Verde Watershed is likely the main source of calcium in the streams at MOCA-TUZI. The calcium detected at MOCA-TUZI was primarily the cation (i.e., dissolved calcium), which, with magnesium ions, creates the slightly basic pH of the stream waters at MOCA-TUZI.

Table 3-5b. Concentrations (mg/L) of metals and metalloid parameters (L–Z), Montezuma Castle and Tuzigoot national monuments, WY2011.

Date	Lead	Manganese	Manganese (Dissolved)	Magnesium	Magnesium (Dissolved)	Molybdenum	Molybdenum (Dissolved)	Potassium	Silica	Silica (Dissolved)	Sodium	Sodium (Dissolved)	Uranium	Uranium (Dissolved)	Zinc (Dissolved)
Beaver Creek (MOCC)															
10/19/2010	ND	0.041	0.022	27	27	ND	ND	3.6	27	21	26	26	NC	NC	ND
02/08/2011	ND	0.021	ND	27	24	ND	ND	2.9	19	18	21	21	NC	NC	ND
05/26/2011	ND	0.032	0.024	27	28	ND	ND	2.9	19	19	22	22	NC	NC	0.025
08/25/2011	ND	0.041	0.019	28	29	0.002	ND	3.2	26	25	27	26	ND	ND	ND
Wet Beaver Creek (MOWE)															
10/19/2010	ND	0.042	0.032	24	24	ND	ND	2.6	24	23	17	17	NC	NC	ND
02/08/2011	ND	ND	ND	22	22	ND	ND	2.2	18	18	13	14	NC	NC	ND
05/25/2011	ND	ND	ND	21	23	ND	ND	2.2	19	20	16	16	NC	NC	ND
08/25/2011	ND	0.024	0.014	23	23	ND	ND	2.5	24	23	18	19	ND	ND	ND
Verde River (TUZI)															
10/18/2010	ND	0.042	0.033	26	27	ND	ND	2.7	21	20	23	24	NC	NC	ND
02/07/2011	ND	ND	ND	29	27	ND	ND	2.3	18	18	25	26	NC	NC	ND
05/26/2011	ND	0.058	0.05	33	36	ND	ND	2.5	20	20	25	26	NC	NC	ND
08/24/2011	0.0016	0.037	0.014	27	27	ND	0.002	2.4	22	20	23	23	0.001	0.0013	ND

All concentrations are reported in mg/L and indicate the total value (i.e. total or total recoverable fraction) unless otherwise indicated (e.g., dissolved). ND = parameter not detected. NC = parameter not collected during that sample period.
Red bolded values represent exceedances.

Copper—. Copper was detected in only one sample in WY2011, at the Verde River on August 24, 2011, at 3.5 µg/L (parts per billion), a very small concentration. It has been detected in the past at higher concentrations, at the Verde River sampling stations (mean 0.018 mg/L), but generally within the expected range of values (national mean 0.010 mg/L).

Iron—. Total iron was detected at all the MOCA-TUZI sampling sites during WY2011, with a median value of 0.21 mg/L for all three sites. Dissolved iron was detected only twice, on August 25, 2011, at Beaver Creek (0.047 mg/L) and October 18, 2010, at the Verde River (0.08 mg/L). In aquatic systems with sufficient dissolved oxygen and the pH ranges found at MOCA-TUZI sites, iron will form iron oxyhydroxides that precipitate to form a brown coating on rocks and sediment on the stream bottom, or a colloidal suspension of gels and flocculants (Figure 3-1).



Figure 3-1. Wet Beaver Creek iron oxyhydroxide precipitate.

***Lead*—.** Total lead was detected at the Verde River sample site on August 24, 2011 (0.0016 mg/L, or 1.6 ppb). This concentration is within the expected concentrations for total lead (Weiner 2008).

***Manganese*—.** The median value of manganese concentration for all MOCA-TUZI samples was 0.014 mg/L. As was the case at MOCA-TUZI, manganese is typically found in concentrations of less than 0.02 mg/L (Wiener 2008).

***Magnesium*—.** At all MOCA-TUZI sample sites, the median value of magnesium concentration during WY2011 was 27 mg/L. The ample amount of limestone in the watershed likely provides much of the magnesium to the stream as magnesium carbonates. Magnesium should be present at levels from 1 to 100 mg/L. The SODN assessment point reflects this expected range, but the network plans to refine this assessment point in the future to enable detection of trends in magnesium concentrations.

***Molybdenum*—.** Molybdenum was detected only at the Verde River sample site, at 0.002 mg/L (2 ppb), which is below the concentrations considered typical for unpolluted waters (Weiner 2008).

Table 3-6. Values for nutrient parameters, Montezuma Castle and Tuzigoot national monuments, WY2011.

Date	Nitrate-N	Total organic carbon	Total phosphorus
Beaver Creek (MOCC)			
10/19/2010	ND	NC	0.049
02/08/2011	ND	NC	ND
05/26/2011	ND	NC	ND
08/25/2011	ND	3	ND
Wet Beaver Creek (MOWE)			
10/19/2010	ND	NC	ND
02/08/2011	ND	NC	ND
05/25/2011	ND	NC	ND
08/25/2011	0.59	1.7	ND
Verde River (TUZI)			
10/18/2010	ND	NC	0.049
02/07/2011	ND	NC	ND
05/26/2011	ND	NC	ND
08/24/2011	ND	2.5	ND

ND = parameter not detected.
NC = parameter not collected during that sample period.

***Uranium*—.** Uranium was detected at the Verde River sampling site on August 24, 2010, at 0.0013 mg/L (13 ppb)—well below the EPA standard. The low concentration of uranium detected indicates that the amount detected is a background concentration and typical for the region.

***Zinc*—.** Only dissolved zinc was detected at the Beaver Creek sample site on May 26, 2011; the analytical capacity of the laboratory to detect smaller concentrations of dissolved zinc was greater than for total zinc during this sampling period. The concentration detected was 0.025 mg/L, within the range expected for natural waters (Weiner 2008).

3.1.2.3 Nutrients

SODN collected water samples for analysis of nutrients, including total nitrogen and the parameters that compose total nitrogen and total phosphorus. Concentrations that were greater than the reporting and detection limits are reported in Table 3-6. All measurements fell within the range of established standards.

***Phosphorous*—.** Total phosphorus measurement exceeded the EPA's suggested ecological benchmark of 0.01 mg/L on October 18–19, 2010, at Beaver Creek and the Verde River (both 0.049 mg/L). Sustained levels of phosphorus commensurate with those measured at MOCA-TUZI in October 2010 can lead to nuisance plant growth and eutrophication in streams (USGS 2000).

***Total organic carbon*—.** Total organic carbon does not have federal or state surface water standards. The concentrations detected at the MOCA-TUZI sites fell within the expected range for perennial surface waters (Westerhoff and Anning 2000).

***Nitrogen*—.** None of the associated nitrogen analytes (nitrate, nitrite, and total nitrogen) exceeded any state or federal standard. Nitrate was detected only once, at Wet Beaver Creek, at a concentration (0.59 mg/L)—just below the national mean background concentration of 0.6 mg/L. A concentration of nitrate higher than 0.06 mg/L is indicative of possible human impact on water quality (USGS 1999). The sample that closely approached that level was collected at Wet Beaver Creek in late August (8/25/2011), and

may have been a result of low summer flow concentrating nutrients, as opposed to human impact upstream of the MOWE index sampling station.

3.1.2.4 Microbiological

SODN sampled for two microbiological parameters, *E. coli* and total coliform, during WY2011 (Table 3-7). On several occasions, the value exceeded the detection limit of the analysis conducted (see Table 3-7). All measurements fell within the range of established standards, however.

Total coliforms—. The results of total coliform collected at MOCA-TUZI during WY2011 represented typical concentrations of these bacterial taxa.

E. coli—. The highest *E. coli* result (212 MPN/100 ml) of WY2011 was measured at Beaver Creek on October 18, 2010. Although that value did not exceed state standards, it was higher than typically observed results, and was associated with a small, localized rain event.[2] Although discharge data did not indicate a meaningfully higher flow (6.80 cfs), other data collected at the time—turbidity (26.37 NTU), specific conductance (514 µS/cm), and total suspended solids (16 mg/L)—indicated that the local precipitation event increased the amount of material in the stream.

3.1.2.5 Inorganics

SODN collected water samples during WY2011 for analysis of inorganic parameters. Concentrations of inorganic group parameters that were greater than the reporting and detection limits are reported in Table 3-8. All measurements fell within the range of established standards.

Alkalinity—. The median alkalinity value for all MOCA-TUZI sample sites was 240 mg/L, which is typical for the Middle Verde Watershed (Blasch et al. 2006).

Fluoride—. Fluoride was detected at all three MOCA-TUZI sample sites on October 18–19, 2010, with a median value of 0.54 mg/L. This concentration is within the expected natural range (<1 mg/L) but is the highest value SODN has detected since 2007. The value was also unusual because of the simultaneously abundant amounts of calcium cations; fluoride will usually combine with the calcium cation to form fluorite. The relatively high value could indicate a regional source of fluoride, which may be abundant in some volcanic rocks in the watershed, combined with a flow event.

Sulfate—. Sulfate concentrations should be between 10 and 80 mg/L. In WY2011, sulfate concentrations were in this range at the Verde River sampling site, but below 10 mg/L at the Beaver Creek and Wet Beaver Creek sampling sites. However, samples collected in and around the MOCA/MOWE sites indicate that those concentrations are typical for those sites (NPS 1995; Blasch et al. 2006).

Table 3-7. Values for microbiological parameters, Montezuma Castle and Tuzigoot national monuments, WY2011.

Sample date	*E. coli.* (MPN/100 ml)	Total coliform MPN/100 ml
Beaver Creek (MOCC)		
10/18/2010	212.12	>2,419.6*
02/07/2011	3.07	140.03
05/25/2011	31.3	1,556.37
08/25/2011	5.57	>2,419.6*
Wet Beaver Creek (MOWE)		
10/18/2010	38.63	>2,419.6*
02/07/2011	15.7	5.61
05/25/2011	18.7	2,190.7
08/23/2011	75.2	>2,419.6*
Verde River (TUZI)		
10/18/2010	30.27	1,901.83
02/07/2011	ND	61.3
05/25/2011	11.17	1,028.97
08/23/2011	12.23	>2,419.6*

ND indicates the parameter was not detected.
MPN = most probable number
*exceeded detection limit of analysis conducted

[2] *E. coli.* has exceeded the Arizona partial-body contact standard of 701.86 MPN/100L (but not the standard used by SODN, which evaluates against the more stringent standard for full-body contact) in the recent past (on 2/23/2010). This measurement was taken during a period of higher flow (estimated to be ~200 cfs). Increased amounts of *E. coli* may be typical during high flow events, especially during precipitation events. There was a small precipitation event associated with this flow, indicating that the recorded measurement may be the result of an increase in surface flow that entrained fecal material and other sources of *E. coli* bacteria.

Table 3-8. Values for inorganic parameters, Montezuma Castle and Tuzigoot national monuments, WY2011.

Sample date	Alkalinity as $CaCO_3$	Fluoride	Sulfate	Total dissolved solids	Total suspended solids
Beaver Creek (MOCC)					
10/19/2010	260	0.54	3.8	300	16
02/08/2011	280	ND	5.1	290	ND
05/26/2011	240	ND	4.2	270	11
08/25/2011	260	ND	6.4	280	ND
Wet Beaver Creek (MOWE)					
10/19/2010	230	0.51	2.7	280	ND
02/08/2011	230	ND	3.4	230	ND
05/25/2011	220	ND	3.2	250	ND
08/25/2011	230	ND	3.5	240	ND
Verde River (TUZI)					
10/18/2010	250	0.56	25	330	25
02/07/2011	280	ND	27	320	ND
05/26/2011	250	ND	49	340	ND
08/24/2011	240	ND	29	280	16

All results are in mg/L; ND indicates the parameter was not detected during that sample date.

Total dissolved solids and total suspended solids—. TDS results from all three sample sites were similar, with a median value of 280 mg/L. TSS were only detected at the Beaver Creek and Verde River sample sites, at values much lower than those for TDS (median value 16 mg/L). This indicates that the majority of the suspended solids in MOCA-TUZI stream water are smaller than 45µ—likely, minerals and salts, such as calcium carbonate, magnesium carbonate, sulfates, and silica compounds.

3.1.3 Discussion

Water quality at Montezuma Castle and Tuzigoot NMs is determined primarily by natural processes, such as percolation of groundwater through basal material, weathering of bedrock, and biological activity in soils (USGS 2000), and is characterized by hard, mineral-rich waters. Stream waters at these parks have significant concentrations of calcium and magnesium compounds, primarily carbonates and sulfates.

The ambient water quality of Beaver Creek, Wet Beaver Creek, and the Verde River is typical for streams in the region that are similar in size and subject to impacts from adjacent land use (e.g., West Clear Creek; USGS 2000); however, several constituents of the water quality are of concern, such as *E. coli* and arsenic.

Due to the documented presence of lead, arsenic, and *E. coli.*, it is suggested that NPS employees take care when working in or near these three streams, and be properly trained to use and wear PPE that limits skin contact with the water (e.g., waders). The PPE should be cleaned and rinsed after each use. It is recommended that visitors not have contact with the stream water. Every attempt should be made to prevent the unintentional ingestion of water (e.g., through splashing and playing). Under no circumstances should anyone intentionally ingest untreated stream water.

3.1.4 Assessment points

3.1.4.1 Parameters with regulatory standards

It is recommended that SODN staff meet with park resource staff to review the exceedance of the assessment point (i.e., human health full-body contact) for arsenic, as noted in Section 3.1.1. No other parameters with regulatory standards were exceeded during WY2011.

3.1.4.2 Parameters without regulatory standards

Assessment points for parameters without Arizona state standards were not exceeded during WY2011 at either park unit (Table 3-9).

Table 3-9. Water quality assessment points for parameters without regulatory standards, Montezuma Castle and Tuzigoot national monuments, WY2011.

Parameter	Assessment point (Is value outside range below?)	Beaver Creek (MOCC)		Wet Beaver Creek (MOWE)		Verde River (TUZI)	
		Point met?	Recommendation	Point met?	Recommendation	Point met?	Recommendation
Alkalinity as $CaCO_3$	20–400 mg/L	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring
Calcium	>1 mg/L*	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring
Chloride	<100mg/L**	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring
Dissolved Aluminum	>0.01 mg/L	ND	Continue monitoring	ND	Continue monitoring	ND	Continue monitoring
Dissolved Calcium	>1 mg/L	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring
Dissolved Iron	<0.3 mg/L	No	Continue monitoring	ND	Continue monitoring	No	Continue monitoring
Dissolved Magnesium	>1 mg/L	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring
Dissolved Manganese	<.2 mg/L	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring
Dissolved Potassium	>1 mg/L*	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring
Dissolved Silica	>1 mg/L*	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring
Dissolved Sodium	>1 mg/L	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring
Hardness (as $CaCO_3$)	>1 mg/L	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring
Magnesium	<100 mg/L	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring
Potassium	>1 mg/L*	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring
Silica	>1 mg/L	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring
Sodium	>1 mg/L	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring
Sulfate	<80 mg/L	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring
Total Hardness	>1 mg/L	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring

*Major non-toxic ecologically important chemical parameter typically should be found in concentrations of >1mg/L.
** Value should be less than 100 mg/L or ≤ than concurrently collected sulfate or bicarbonate concentration.
ND = not detected

3.2 Water quantity

Water quantity data presented for WY2011 include mean daily discharge (annual mean daily flow in cfs, annual discharge in acre feet, and hydrographs of mean daily discharge) for both WY2011 and the USGS gage record. Data are reported on the proportion of seasonal flow and mean monthly discharge for the gage record and from WY2011. Peak flow during WY2011 is reported and estimates of return intervals are calculated for each stream.

3.2.1 Beaver Creek

Data on streamflow at Beaver Creek have been collected since 2004. Due to the brevity of the record, caution must be exercised with interpretation of these data, including the return estimates, seasonally proportional flows, and comparison to mean flow rates.

At time of writing, the USGS had not issued a rating curve (a mathematical model that estimates the rate of streamflow in cfs as measured by the stream gage) for the Beaver Creek gage (09504000) for WY2011. To report WY2011 discharge, an approximation of discharge was calculated from WY2009 discharge data using the USGS rating curve for that year. An equation for the "best fit" curve was calculated from the WY2009 USGS discharge measurements and applied to WY2011 stream stage data to estimate discharge (Figure 3-2).

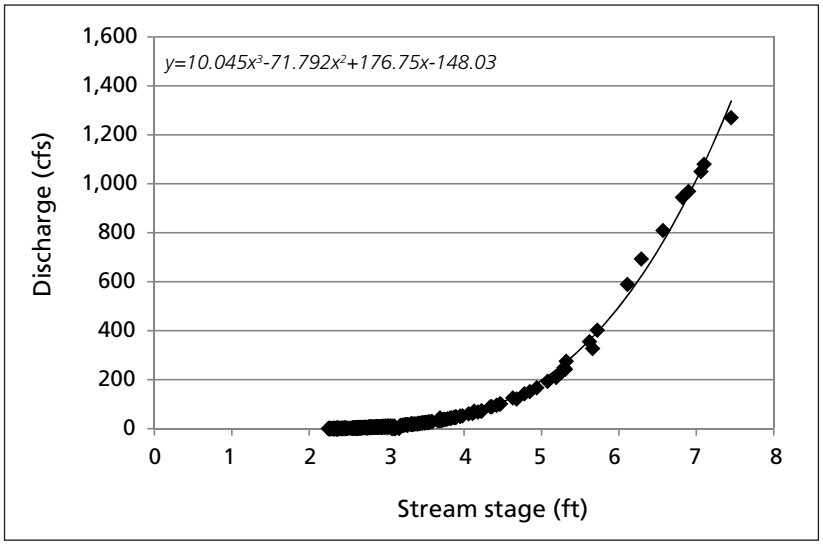


Figure 3-2. Plot of stream stage vs. USGS discharge measurements, Beaver Creek, WY2009. The polynomial equation represents the "best fit" curve that models the 2009 discharge data.

3.2.1.1 Mean daily discharge

During WY2011, the annual mean daily flow from the Beaver Creek gage was 48.04 cfs (Figure 3-3). The annual sum acre feet of stream discharge in WY2011 was 33,449 acre ft/yr.

Discharge on Beaver Creek during WY2011 was generally lower than the gage record mean values (i.e., values calculated by all the data available from that gage) (Figure 3-4). The mean daily discharge (Figure 3-5) was only 64% of the gage record (48.04 cfs vs. 74.56 cfs; Table 3-10), with much of the difference occurring during late winter, in January and February. The winter-season discharge was 10% less than the mean (62% vs. 74%) for that season, and those two months were only ~30% of the gage record mean (Figure 3-6). This lack of winter flow created a deficit from which the system never recovered (see Section 3.2.1.2).

3.2.1.2 Proportion of seasonal flow

For this analysis, we summed the daily mean discharge values by hydrologic season as defined in NPS (1995). In WY2011, the winter season contributed 74% of annual discharge and the spring season contributed 22% of annual discharge (Figure 3-6).

In both 2010 and 2011, spring seasonal streamflow at Beaver Creek fell off steeply and the late spring final pulse of runoff from precipitation higher in the watershed was absent (indicated by arrow in Figure 3-7—note remarkably sharp drop-off in WY2010). This decrease in flow, coupled with the lack of precipitation in April–June (less than 25% of the 30-year average amount; Figure 3-8) and increase in evapotranspiration as riparian vegetation began to leaf out, created the conditions under which the pool shown in Figure 1-2 ran dry (Figure 3-9). Understanding patterns in flow and climate will help us to anticipate the implications for the flora and fauna of Beaver Creek.

3.2.1.3 Mean monthly discharge

In WY2011, data from the Beaver Creek gage showed that a majority of the flow took place in the winter and spring (see Figure 3-6). Most of the flow, and most of the high-flow events, occurred during February and April, corresponding to snowmelt and rain-on-snow events higher in the watershed (Figure 3-10).

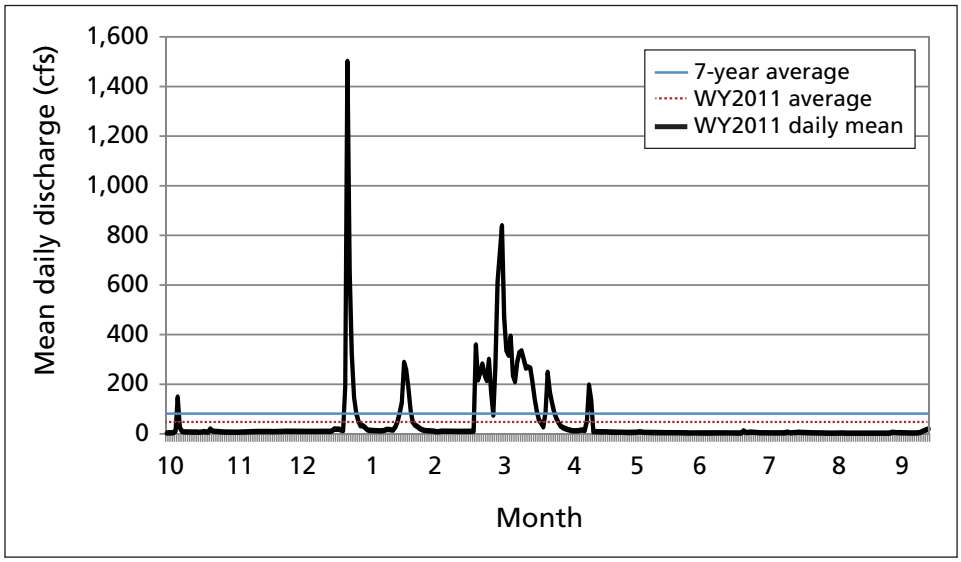


Figure 3-3. Mean daily discharge (cfs), Beaver Creek, WY2011.

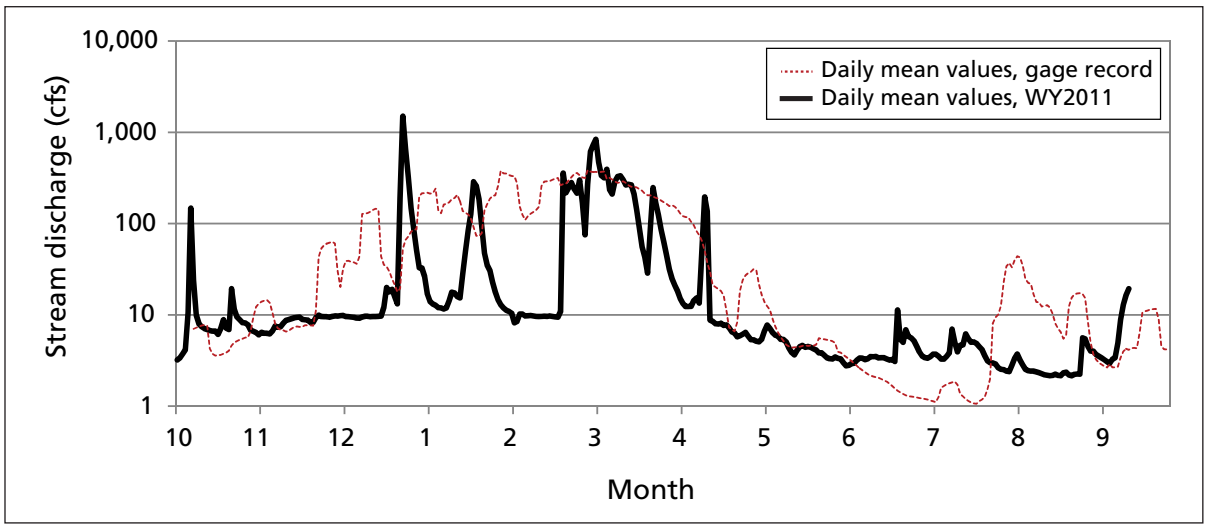


Figure 3-4. Hydrograph of WY2011 Beaver Creek gage daily mean values (black line), compared with gage record daily mean (red dotted line—7 day average applied to smooth curve). Note the departure from the gage record mean in the months of December to February. Although the flow approached the gage record mean in March and April, the winter deficit was never made up, due to the average summer flow and the weak monsoon ending the year.

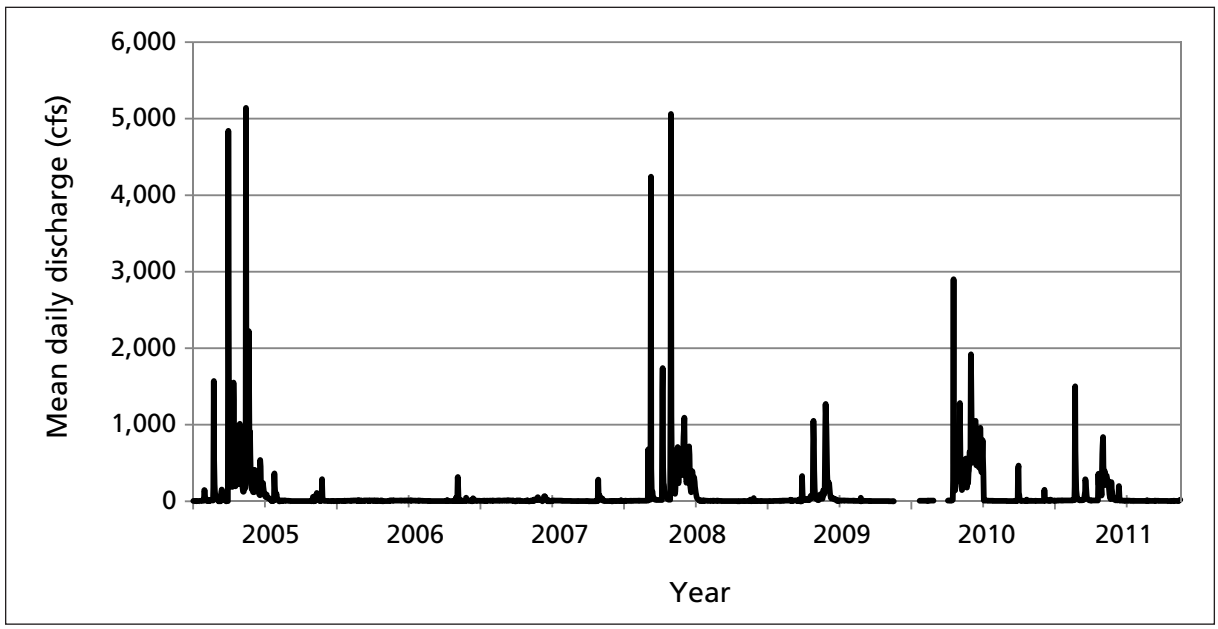


Figure 3-5. Mean daily discharge (cfs), Beaver Creek, WY2005–2011.

Table 3-10. Annual mean daily flow, Beaver Creek, WY2005–2011, with standard error (SE).

Water year	Annual mean daily flow (cfs)	SE
2005	148.13	23.63
2006	6.89	1.08
2007	7.78	0.94
2008	123.95	21.36
2009	44.28	8.59
2010	166.47	19.99
2011	48.04	7.04
7-year average	**74.56**	**5.62**

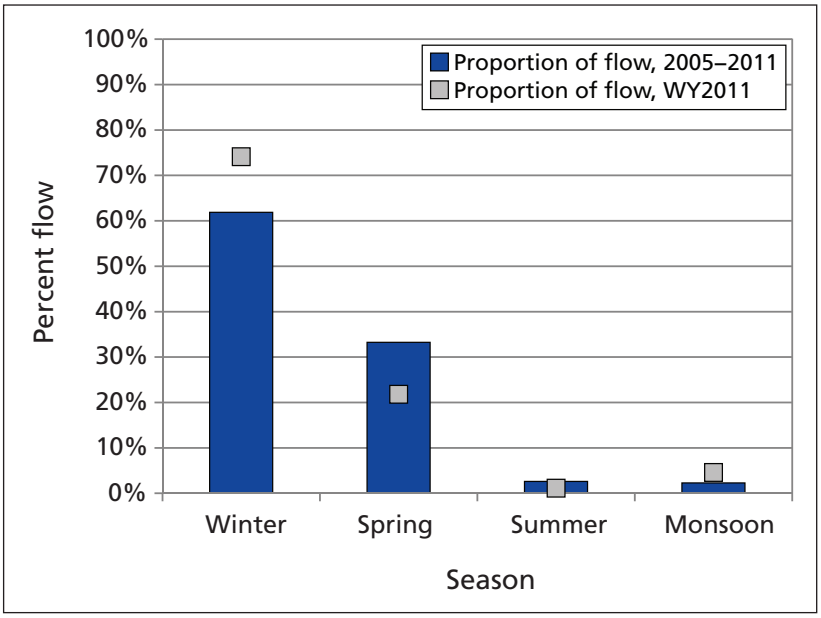


Figure 3-6. Proportion of seasonal streamflow, Beaver Creek, WY2005–2011. The sum of daily mean flow amounts was calculated by season. Percentage is proportion of the total flow for each year in each season (Winter: November–March, Spring: March–April, Summer: May–July, Monsoon: July–November). Seasons were taken from NPS (1995). Grey markers indicate proportion from WY2011.

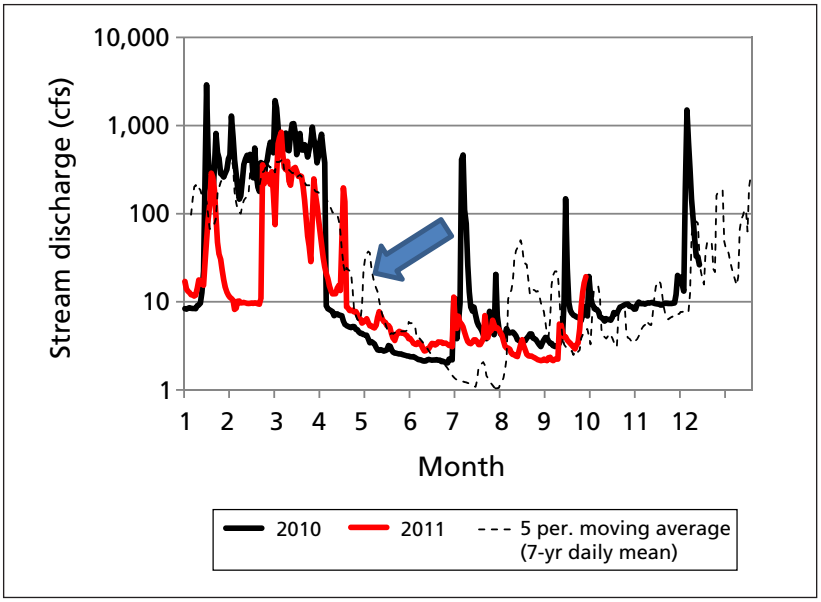


Figure 3-7. Comparison of mean daily discharge hydrographs, Beaver Creek, WY2010 and 2011. Arrow indicates where spring seasonal streamflow fell off steeply and the late spring final pulse of runoff from precipitation higher in the watershed was absent.

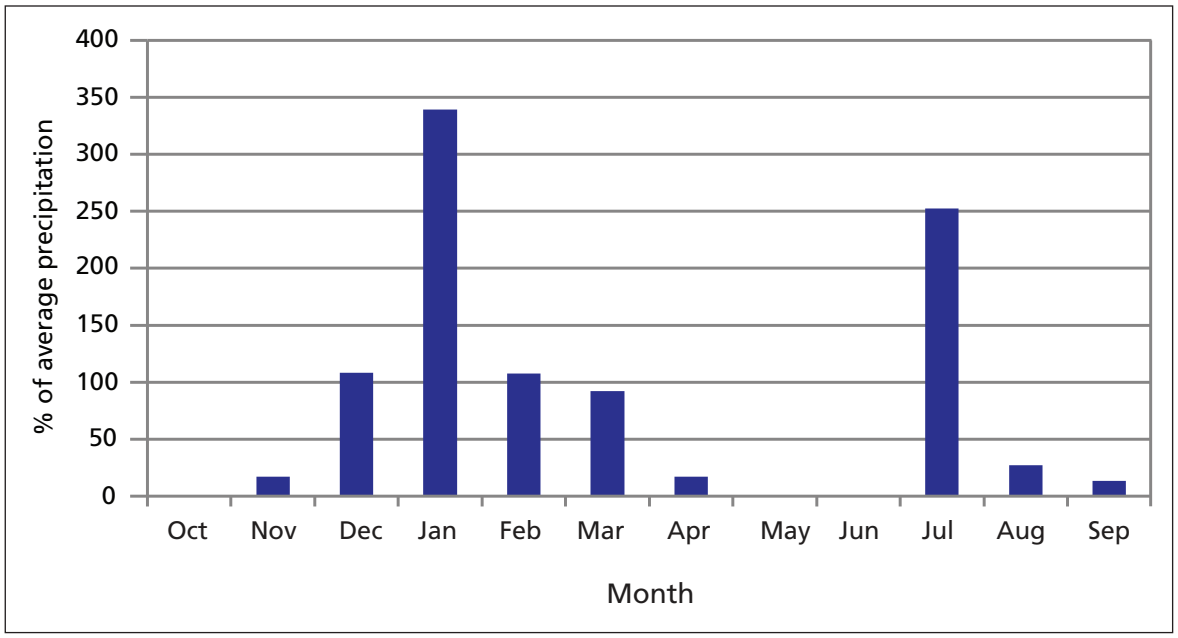


Figure 3-8. Water Year 2010 departure from averages, Beaver Creek, 1981–2010.



Figure 3-9. Montezuma Castle NM on June 4, 2010 (upper photo) and June 22, 2010 (lower photo) (Google Earth). In the upper photo, a small amount of water can be observed in the upper left of the sandy area, hugging the left edge of the stream channel below the cliff. In the lower photo, all the water is gone.

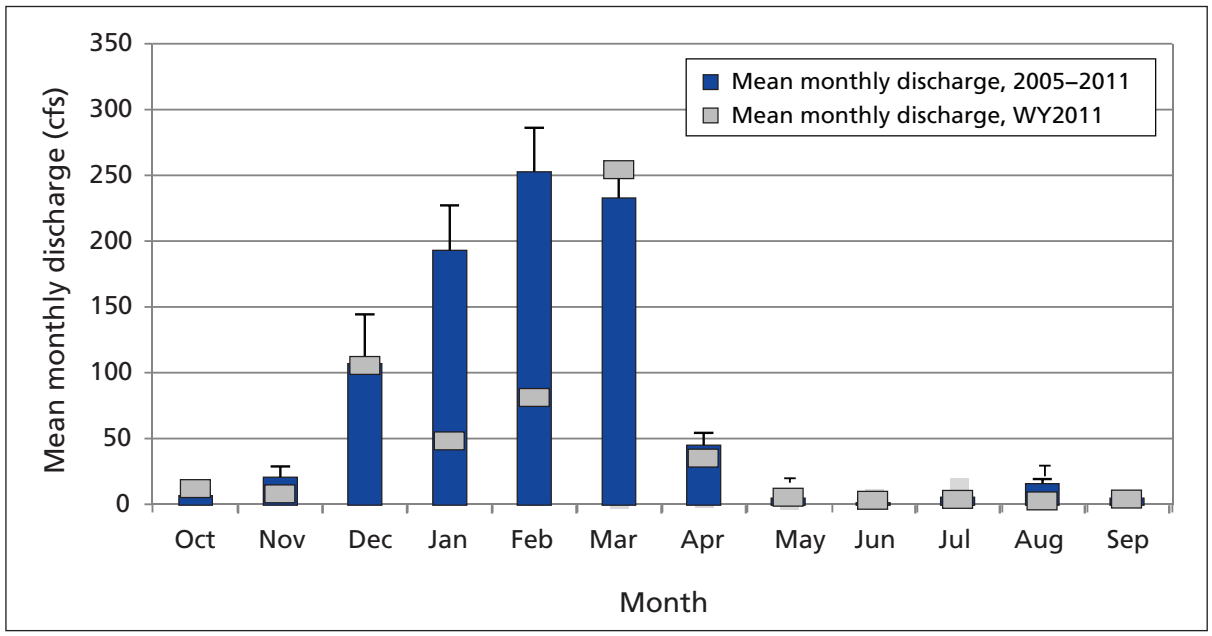


Figure 3-10. Mean monthly discharge, Beaver Creek, WY2005–2011, USGS gage 09505400. Bars indicate six-year monthly discharge means. Error bars are SE of mean for 6-year monthly average. Grey marker indicates mean monthly discharge during 2011.

3.2.1.4 Peak flow and return interval estimate

The peak flow recorded at the Beaver Creek gage during WY2011 was 1,433 cfs, occurring on March 3, 2011 (Figures 3-11, 3-12). This event could be considered a bankfull, or channel-maintenance event. Such events maintain the shape of the stream and transport bed material and organic material in and out of the stream segment (Rosgen 1996). Most peak flow events typically occur in winter and spring at Beaver Creek, with occasional peaks resulting from monsoon events.

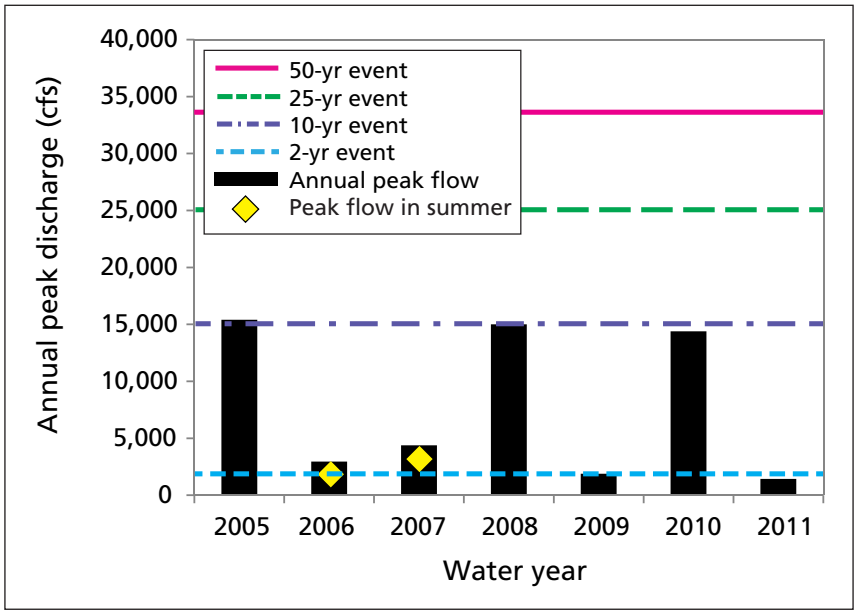


Figure 3-11. Peak flow and return intervals, Beaver Creek, WY2005–2011. Lines indicate return intervals using USGS PKFlow software (USGS 2007). Return intervals based on five years of data should be considered provisional. Grey diamonds indicate that peak flow occurred in the summer season. All other peak flows occurred in winter.



Figure 3-12. High flow on Beaver Creek at Montezuma Castle NM in early March 2010.

3.2.2 Wet Beaver Creek

Data for Wet Beaver Creek come from the USGS gage located approximately seven miles upstream from the Wet Beaver Creek stream index point. Data collected by the NPS at the index point will be used in future analysis.

3.2.2.1 Mean daily discharge

The annual mean daily flow for Wet Beaver Creek during WY2011 was 22.32 cfs, below the 43-year average of 31.17 cfs (Figures 3-13 and 3-14). The annual sum of discharge in acre feet for the Wet Beaver Creek USGS gage was 16,157 acre ft/yr.

The discharge on Wet Beaver Creek during WY2011 was generally lower than the gage record mean values. The daily mean discharge was 72% of the gage record (22.32 cfs vs. 31.17 cfs), with much of the difference occurring during winter, with January, February, and April being well below average (see Figure 3-13).

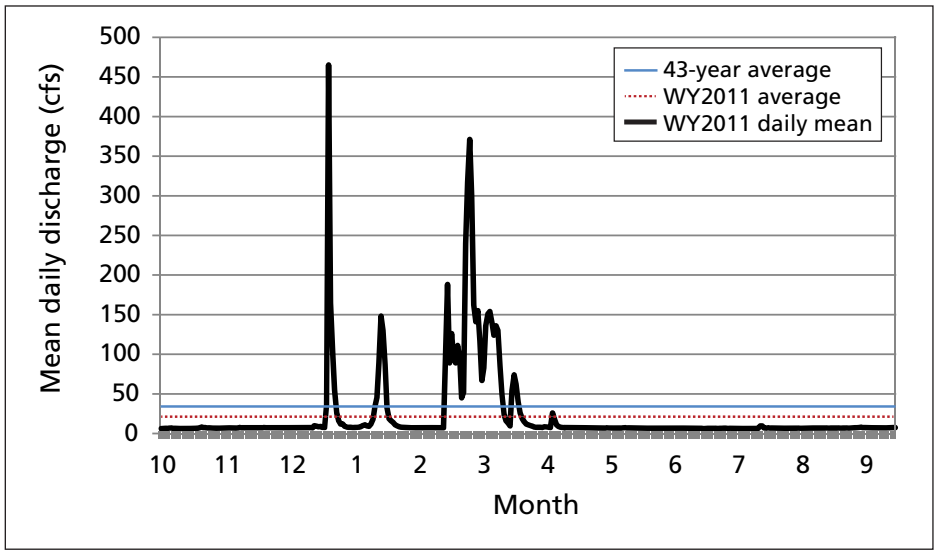


Figure 3-13. Mean daily discharge (cfs), Wet Beaver Creek, WY2011.

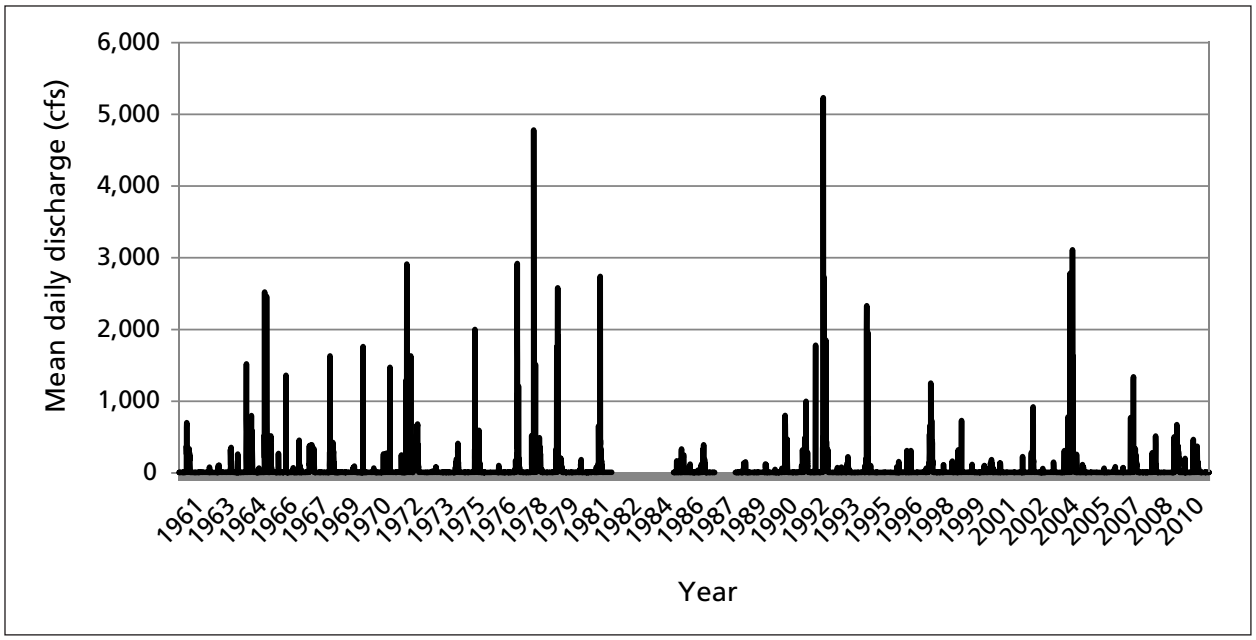


Figure 3-14. Mean daily discharge (cfs), Wet Beaver Creek, 1961–2011. These numbers are from USGS station 09505200 and do not include 1983, 1984, or 1988. The station was non-operational during part or all of those years.

3.2.2.2 Proportion of seasonal flow

For this analysis, we summed the daily mean discharge values by hydrologic season as defined in NPS (1995). Historically, nearly half of the annual flow occurred in the winter season (49%), and one-third in the spring (34%) (Figure 3-15). In WY2011, however, spring-season discharge was 9% less than the mean (25% vs. 34%) for that season, and although March was average, April was measured at only 15% of the gage average for that month. This lack of flow is an example of what can be expected as the pulse of runoff from snow on the Mogollon Rim comes earlier and earlier each year. The flow pattern in April was similar to that of May and the other summer months (see Figure 3-13). This earlier occurrence of the winter–spring melt pulse can have an impact on animals and plants that depend on a particular pattern of flow and drying, combined with length of daylight, water and air temperature.

3.2.2.3 Mean monthly discharge

A majority of the flow occurred in winter and spring during WY2011 (Figure 3-16). The maximum discharge of 110 cfs in March reflected snowmelt off the Mogollon Rim. Spring and summer months were at baseflow conditions, approximately 7 cfs.

3.2.2.4 Peak flow and return interval estimate

The peak flow recorded at the Wet Beaver Creek gage during WY2011 was 876 cfs, occurring on December 23, 2010 (Figure 3-17).

The results from the return interval model (Figure 3-17) indicate that a flow event of ~2,000 cfs (see 2-yr interval line in Figure 3-17) is considered capable of sustaining ecosystem function (i.e., maintaining channel structure, moving bed material and organic material). A flow event of this magnitude occurs approximately every two years. On Wet Beaver Creek, a flow of this magnitude has occurred in 15 of the last 30 years but did not occur in WY2011.

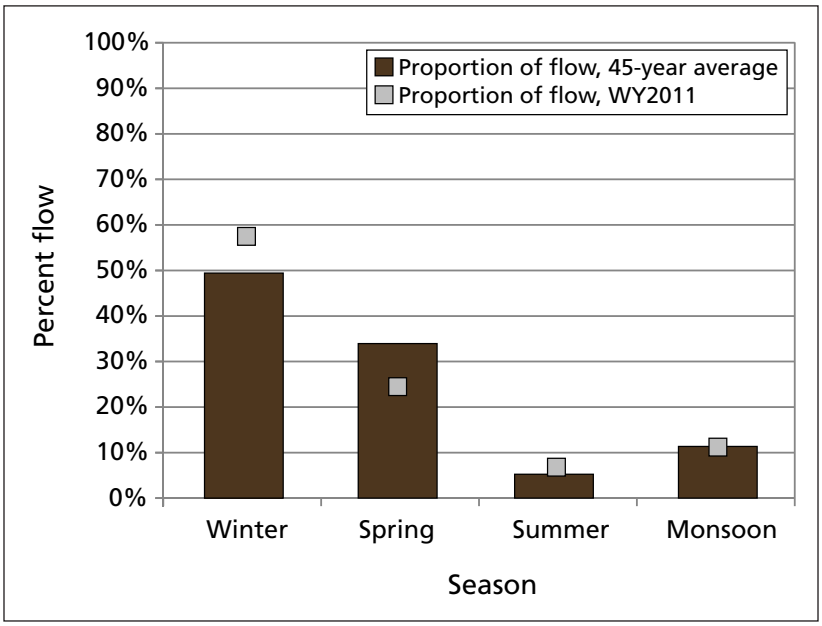


Figure 3-15. Proportion of seasonal streamflow, Wet Beaver Creek, WY2011. The sum of daily mean flow amounts were calculated by season (Winter: November–March, Spring: March–April, Summer: May–July, Monsoon: July–November. Seasons were taken from NPS (1995). Error bars indicate standard error. Grey markers indicate proportion from WY2011.

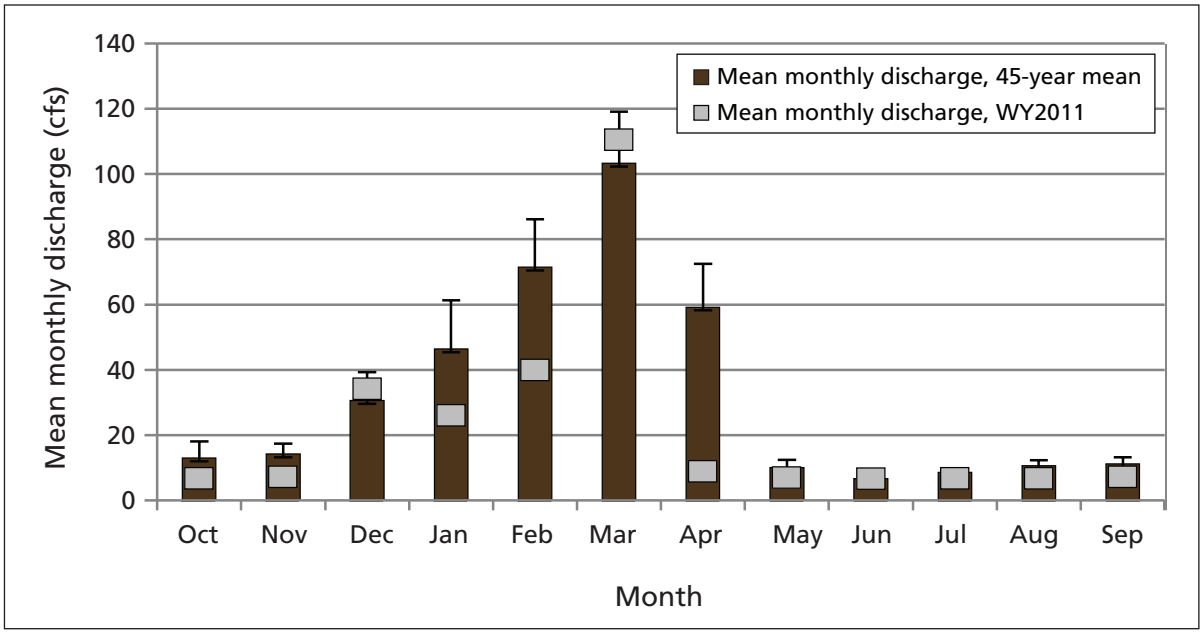


Figure 3-16. Mean monthly discharge, Wet Beaver Creek, 1961–2011. Error bars indicate standard error. Grey squares indicate monthly mean for WY2011.

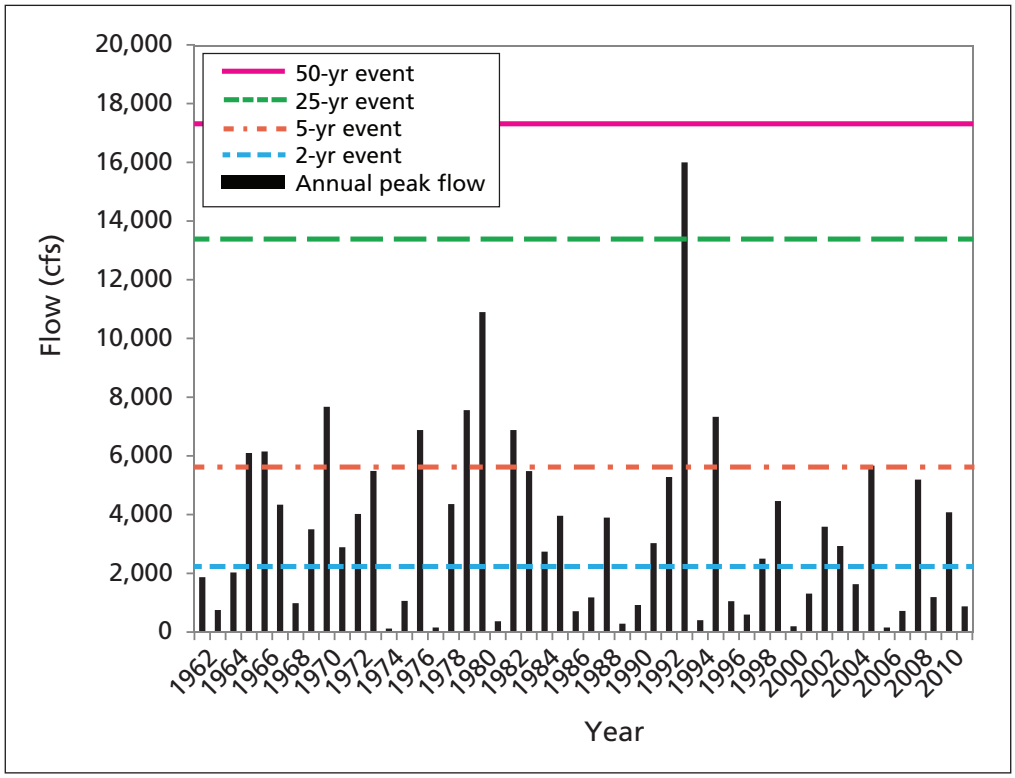


Figure 3-17. Peak flow and return intervals, Wet Beaver Creek, WY1962–2011. Dotted lines indicate estimates of discharge values corresponding to return interval, or the likelihood of a flood of that intensity to occur.

3.2.3 Verde River

The data for the Verde River section of this report were taken from the Clarkdale USGS gage, upstream from the Tuzigoot NM river index site. The presence of an agricultural diversion dam between the gage and the stream segment makes these data directly applicable only to the river upstream from the diversion. However, the seasonal and monthly discharge data, especially for large events that overtop the dam, are vitally important to the ecology of the Tuzigoot NM stream segment, as this flow allows river-based hydrologic and morphologic processes to drive ecological function in the segment.

3.2.3.1 Mean daily discharge

The annual mean daily flow of the Verde River in WY2011 was 99.91 (SE 7.13) cfs, which was below the 47-year record mean of 167.21 (SE 5.12) cfs (Figures 3-18 and 3-19). The annual stream discharge in acre feet at the Clarkdale USGS gage was 72,336 acre feet/year.

3.2.3.2 Proportion of seasonal flow

The Verde River illustrates the importance of snowmelt and winter and spring storms on the annual flow of the river; the 47-year record shows that three-quarters of annual flow typically occurs during winter and spring (see black bars, Figure 3-20). In WY2011, however, 59% of flow occurred in winter and spring. These seasons were below the gage average, while the summer and monsoon seasons were above average.

3.2.3.3 Mean monthly discharge

The monthly discharge in WY2011 was generally average, but was far below average in late winter (February–March) (Figure 3-21).

The mean monthly discharge of the Verde River in WY2011 was generally below the 45-year gage mean, and far below the gage monthly means in February and March, when flow is usually high. This was the result of low snowfall on the Mogollon Rim during winter 2010–2011.

This signal is also seen in the record from the Wet Beaver Creek gage monthly data (see Figure 3-16), but moreso in the Verde, likely because the Verde River record receives water from many tributaries and is reflecting an "average" of the response to precipitation in the contributing area above the gage. Other diversions and groundwater pumping from the near-surface alluvium may also have an impact, but how much is unknown (Blasch 2006).

3.2.3.4 Peak flow and return interval estimate

The peak flow recorded at the Verde River gage during WY2011 was 3,830 cfs, occurring on October 6, 2010 (Figure 3-22).

3.2.4 Discussion

The quantity of water flowing through the three streams at MOCA-TUZI is highly dependent on precipitation (both rain and snow), base flow (e.g., input from groundwater and springs), evapotranspiration, and diversion of flow (e.g., agricultural diversions).

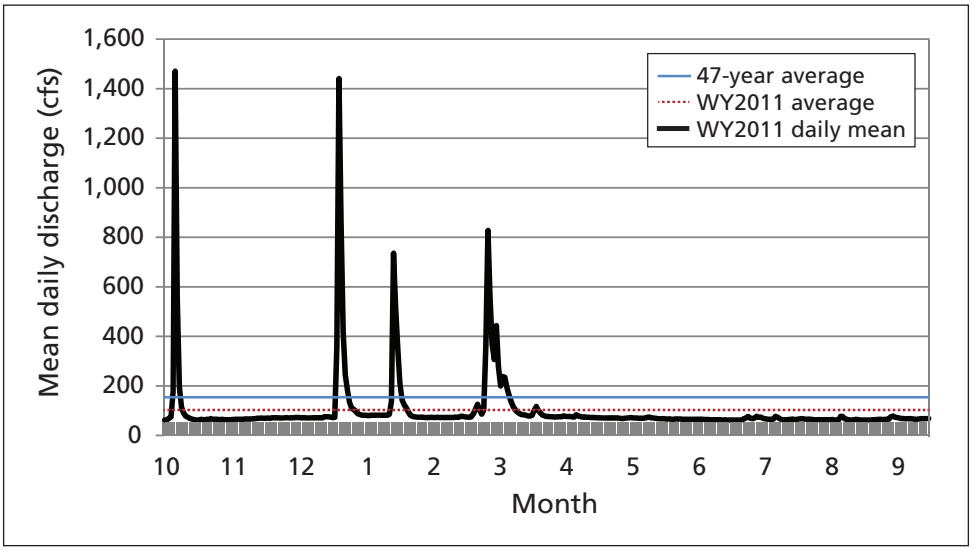


Figure 3-18. Mean daily discharge (cfs), Verde River, WY2011.

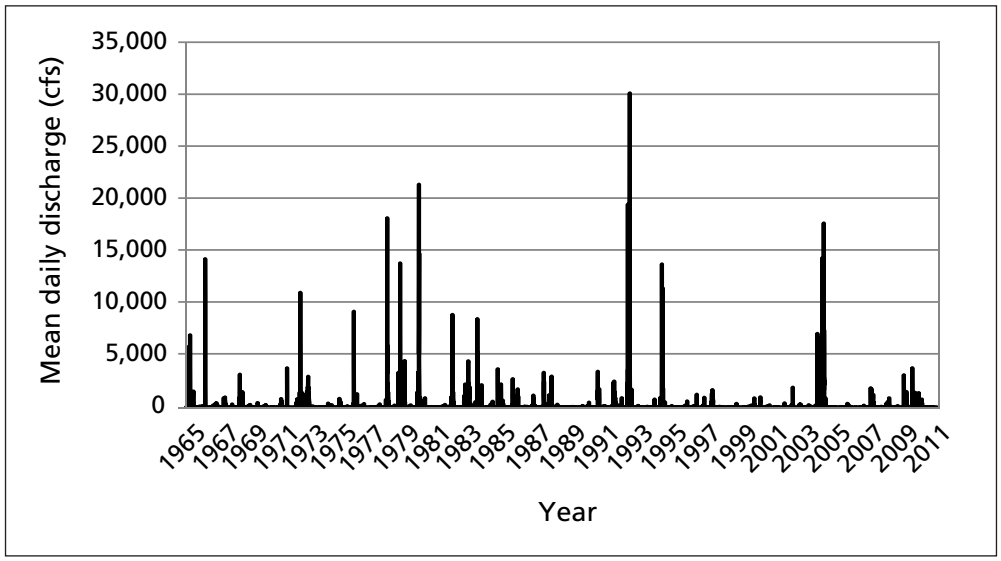


Figure 3-19. Mean daily discharge (cfs), Verde River, WY1965–2011.

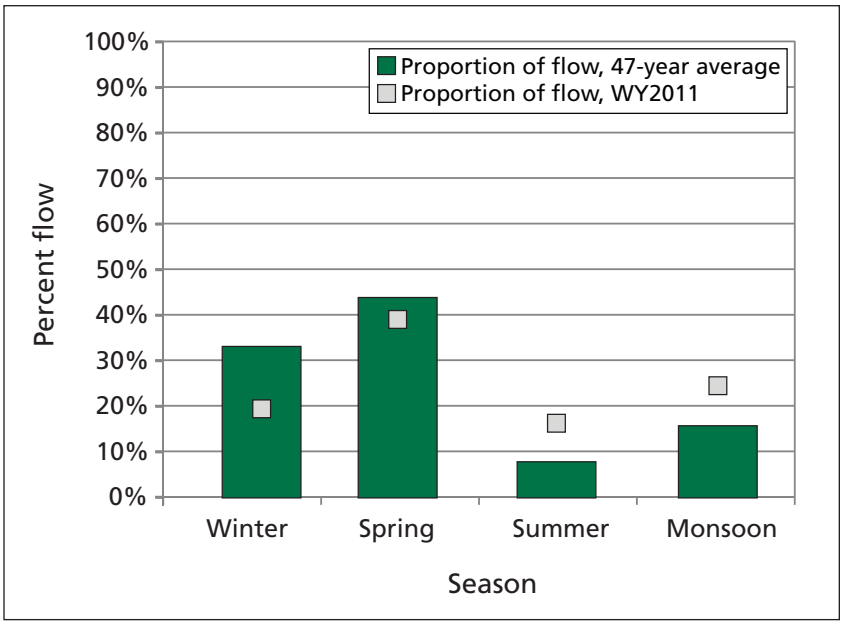


Figure 3-20. Proportion of seasonal streamflow, Verde River, WY1965–2011. The sum of daily mean flow amounts were calculated by season (Winter: November–March, Spring: March–April, Summer: May–July, Monsoon: July–November. Seasons were taken from NPS (1999). Grey markers indicate proportion from WY2011.

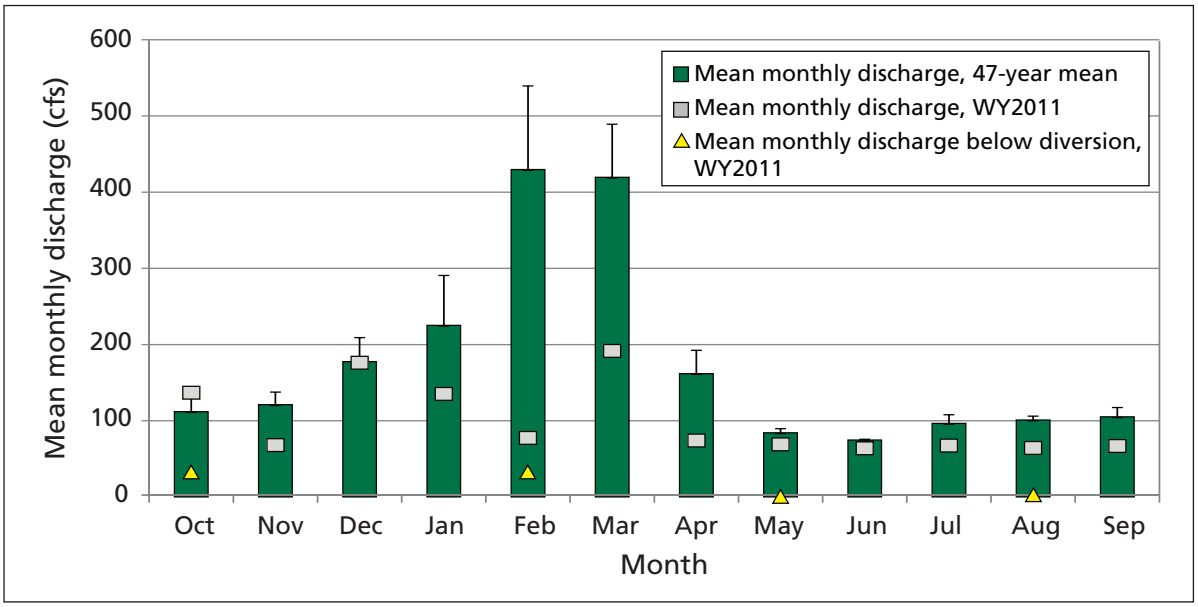


Figure 3-21. Mean monthly discharge, Verde River, 1965–2011. Bars indicate mean monthly discharge (error bars are standard error) for 47 year record at the Clarkdale USGS gage on the Verde River. Squares indicate mean monthly discharge values for WY2011. Triangles indicate discharge measurements made during WY2011 in the Tuzigoot NM stream segment below the diversion (see Section 3.2.4).

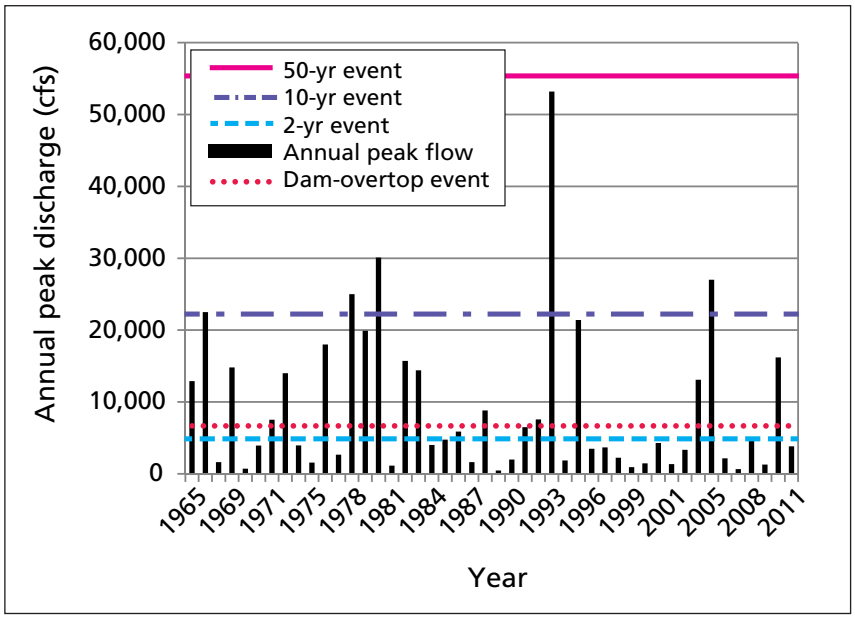


Figure 3-22. Peak flow and return intervals, Verde River, 1965–2011.

The quantity of water helps determine the effectiveness of ecological flows (i.e., flows where the timing, intensity, and duration are sufficient to provide the aquatic and riparian ecosystems the resources needed to remain ecologically functional) (Haney et al. 2008). It is important to understand if annual flow was sufficient for ecological flow during the past water year, and what patterns are evident that may help us to predict the impact of flow on the biology and physical nature of Beaver Creek, Wet Beaver Creek, and the Verde River.

Table 3-11. Ranking of annual and seasonal summed mean daily flow, Wet Beaver Creek, WY2009–2011.

Year	Year rank (of 46)*	Seasonal rank (of 46)*			
	Annual	Winter	Spring	Summer	Monsoon
2009	29	18	42	36	42
2010	8	9	6	26	12
2011	27	20	27	23	34

Table includes years 1962–2011, except for 1983–1985 and 1987–1988, when data did not meet quality standards.
Light grey indicates lowest 25% quartile of ranked years (i.e., driest). Dark grey indicates top 25% quartile of ranked years (i.e., wettest).

3.2.4.1 Historical context

Streamflow during 2009–2011 on Wet Beaver Creek exhibited inter-annual variability of flows, with 2009 and 2011 being drier (29th and 27th of 49 years) and 2010 wetter (8th of 49 years) (Table 3-11). In 2009, low flow caused reaches of Beaver Creek to dry completely, including some of the deep pools on Beaver Creek (see Figure 1-2). The drying of these pools and reaches of the creek resulted from an exceptionally dry spring, summer, and monsoon season, all in the bottom quartile of flow seasons (Table 3-11). Anticipating similar drying of sections of Beaver Creek in years with similar flow patterns will allow for management opportunities, such as removing invasive crayfish and making observations of diurnal patterns in water quality.

For Wet Beaver Creek (and Beaver Creek by proxy[3]), using summed daily mean discharge, WY2011 was an average year—twenty-seventh wettest of the 46-year record (see Table 3-11). This is an imperfect metric (it masks the importance of high-flow events); however, it allows for easy comparison between water years (Appendix D), generally summarizing annual and seasonal conditions in the stream. Due to the short period of record at the Beaver Creek gage, the USGS Wet Beaver Creek gage should be considered representative of Beaver Creek discharge for WY2009–2011.

Most of the annual flow, and most large floods in the three streams, occur in the winter and spring hydrologic seasons. The largest flows are usually associated with rain-on-snow events in the higher elevations of the contributing area (surface area that drains into the stream) of each stream (Blasch et al. 2006).

3.2.4.2 January 2010 flood events

Beaver Creek—.The peak flow for WY10 on Beaver Creek occurred on January 21, 2010—a flood event (maximum discharge of 14,393 cfs) that was sufficient to overtop the gabion (retaining wall) protecting interpretive trails and displays below the cliff dwell-

[3]SODN currently uses data from the USGS stream gage located approximately 7 miles upstream from the NPS-administered Wet Beaver Creek stream segment. It has a long record (49 years) that can be used to effectively and meaningfully compare data between years and to multi-year means. Data has also been collected at the index site on Wet Beaver Creek within the boundary of the Well Unit of Montezuma Castle NM. Initial analyses indicate that there is a strong relationship between the two gages, especially at lower flow rates. To ascertain if the data from the USGS Wet Beaver Creek gage is representative of the water level (and by proxy, discharge), at the Montezuma Well site, a correlation analysis (using the Kendall correlation coefficient) was performed on Wet Beaver Creek stage data from the USGS gage and the NPS pressure transducer on Wet Beaver Creek at the Montezuma Well unit. Mean daily stage data from September, October, and November 2010 were used (n=56). A meaningful and significant correlation (r^2=0.635; p<0.0001) was noted, indicating a strong correlation between discharge at the USGS gage and the Montezuma Well site. Therefore, we believe it is valid to use the USGS gage to understand general signals (flow and flooding intensity and duration) in flow and flood events at Montezuma Well. It is acknowledged that the comparison is not exact—there are intermittent and ephemeral streams that discharge into Wet Beaver Creek between the two gages that impact flow, particularly during flood events—but the analysis conducted during typical flow strongly indicates that the USGS gage is an excellent indicator of flow.

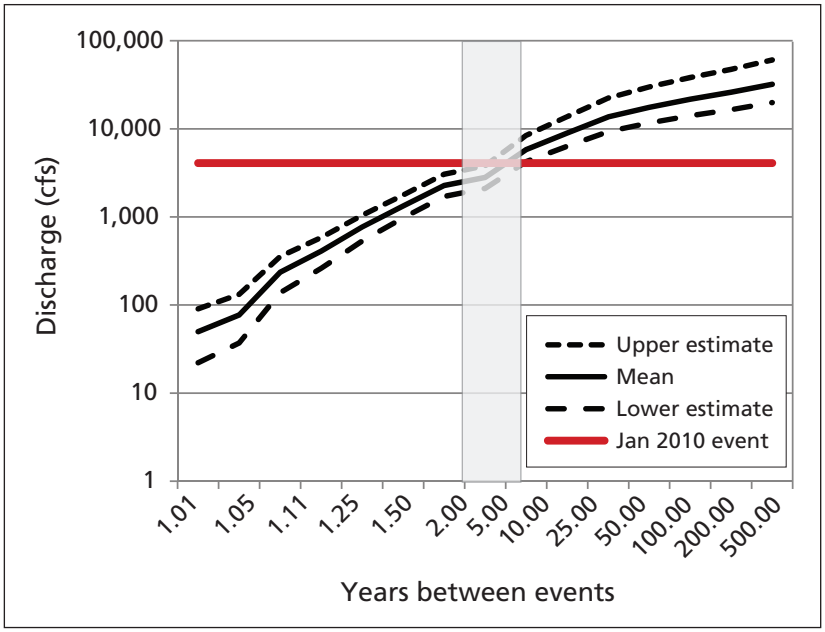


Figure 3-23. Flood return interval estimates for Wet Beaver Creek. The horizontal axis indicates the estimate of how many years will pass between flow events of a given magnitude. The vertical axis is a measurement of stream discharge (cfs) on a log scale. The dotted lines are the top and bottom of the 95% confidence interval of the estimate, the solid line the mean value of the estimate. The red line indicates the recorded flow of the January 2010 flood event. The grey box covers the possible flow range estimated. In the case of Wet Beaver Creek (2–8 years).



Figure 3-24. Flow overtopping the diversion dike at Tuzigoot NM, January 2010.

ings at the Castle unit of Montezuma Castle NM. Events of similar magnitude (~14,000 cfs) occurred on Beaver Creek in 2005, 2008, and 2010, and the same January 2010 event on Wet Beaver Creek (data from USGS gages 09505200 and 09505350, respectively) is estimated to be a relatively frequent event, on the scale of a 2-to-8-year frequency (Figure 3-23). A flood that is able to overtop the gabion should be considered a five-year event, meaning in any given year, there is a 20% chance a flood of this magnitude will occur. Park managers should be aware of the relative frequency of events capable of impacting park infrastructure.

The engineering plan for the gabion should be revisited to evaluate whether the protection provided by the current gabion system will be sufficient to protect park infrastructure in light of likely future changes in flood patterns on the Beaver Creek system. Climate change models (Christensen and Lettenmaier 2007), and recent observations (Stewart et al. 2005; Regonda et al. 2005) indicate that the pulse of streamflow from snowmelt is occurring 1–4 weeks earlier than in the past. These current and predicted changes, combined with the implications of continued drought in the American Southwest (Woodhouse et al. 2010), will have an impact on the effort required to protect park infrastructure and park natural and cultural resources.

***Verde River*—.** On January 22, 2010, a flow event of 6,700 cfs occurred, which was sufficient to overtop the diversion structure at the upstream end of the Verde River stream segment (Figure 3-24). This event corresponds to an event that would occur every 2.5 years, or what is considered the upper end of the predicted frequency of a bankfull, or channel-maintenance flow (i.e., a flow event that maintains and develops channel location in the floodplain, sinuosity, slope, and sediment particle-size distribution).

Relative to stream discharge, the most important value at Tuzigoot NM is the amount of discharge that provokes over-topping of the diversion dam. The return interval estimate for the Verde River at Clarkdale (see Figure 3-22) indicates that the elevation of the diversion structure is sufficient to stop most channel-maintenance events, calculated to be approximately 3,000–6,000 cfs. Maintenance of

the diversion structure is key to its ability to resist flow events.

The maintenance of this dam, and the subsequent amount of river water leaking through the diversion dam, are likely the major control on the amount of river flow into the monument—a factor mostly beyond the control of park managers. Discharge measurements from the Verde River above (from the USGS gage near Clarkdale) and below the diversion (in the Tuzigoot NM stream segment, from measurements by SODN staff), indicate that the flow through the monument is approximately 14% (SE 4.25%) of concurrent Verde River flow. There was no correlation between the two discharge measurements (Kendall correlation coefficient [tau] R^2=-0.144, p=0.675), meaning that the factors controlling the amount of flow in the monument are likely poorly related to the flow magnitude above the diversion.

3.2.5 Assessment points

SODN is proposing and reviewing the usefulness of water quantity assessment points, which are used to initiate conversation between managers and SODN staff about ecologically meaningful events that occurred during the previous water year, and the ecological and other important implications of these events. These assessment points are expected to be adjusted as their effectiveness is evaluated (Table 3-12). In WY2011, none of the assessment points was reached.

3.3 Channel morphology

During spring 2010, eleven cross-sections were surveyed on Beaver Creek. A thalweg survey of Beaver Creek was also an objective, but was postponed due to high water flows. The Verde River and Wet Beaver Creek stream segments were not visited during this sample period. The cross-sections at Beaver Creek will be revisited in 2015 and the cross-sections at Wet Beaver Creek and the Verde River will be initially sampled in 2015.

3.3.1 Beaver Creek

The results of channel-morphology monitoring at Beaver Creek are summarized in Figure 3-25 and in the following sections. A more detailed presentation of the data by cross-section can be found in Appendix E.

3.3.1.1 Sinuosity

Beaver Creek is relatively straight between the pairs of cross-sections (e.g., segments D–E). The overall stream-channel distance from cross-section A to K was more than twice the straight-line distance between the two cross-sections. Overall sinuosity was 2.1.

3.3.1.2 Slope

Water elevation at the start of the segment was 978.8 m, dropping to 958.7 m at the end of the segment, a change of 20.1 m over ~5,200 m. The overall slope between cross-sections A and K on Beaver Creek was 0.4%, with the slope between successive cross-sections ranging from 0.1% to 0.9%. The stream in the segment generally followed a riffle-pool pattern typical of southwestern streams.

3.3.1.3 Particle size assessment

Cobble was the median substrate size in Beaver Creek, which is consistent with the other tributaries to the Verde River (Sprindler 2004). A wide range of particle sizes was encountered, from silt to large limestone bedrock outcroppings.

3.3.1.4 Cross-sectional area

Total cross-sectional area ranged from 1,066 m^2 (cross-section J) to 10,516 m^2 (cross-section A).

3.3.2 Discussion

Beaver Creek, as it flows through the castle unit of Montezuma Castle NM, is a highly sinuous, low-gradient stream, which makes it substantially different from other tributaries of the Verde River. The mean slope of the Verde River tributaries is 0.9% (Spindler 2004), which is more than two times greater than the slope of Beaver Creek at Montezuma Castle NM (0.4%). The mean sinuosity of tributaries to the Verde River is 1.2, indicating that streams in the Verde River basin are, on average, less sinuous than the Beaver Creek segment (regional tributaries 1.2 vs. Beaver Creek segment 2.1). The high sinuosity may explain the low slope of the segment; by curving, Beaver Creek covers a greater distance to lose the same elevation as a stream flowing in a straight channel would.

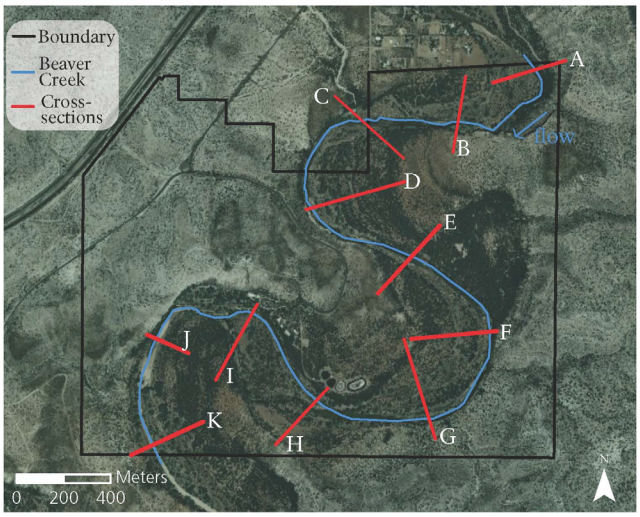
Table 3-12. Water quantity assessment points, Beaver Creek, Wet Beaver Creek, and Verde River, WY2011.

Issue	Assessment point	Beaver Creek		Wet Beaver Creek		Verde River	
		Point met?	Recommendation	Point met?	Recommendation	Point met?	Recommendation
Were there any no-flow events at the gage or measurement station?	>0	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring
Were there any 50-year or greater flow events?	Maximum flow >50-year return interval discharge	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring
Was it a "low-flow" season?	Sum of seasonal daily average discharge measurements <1st quartile rank	NC	Continue monitoring	No	Continue monitoring	NC	Continue monitoring
Was it a "high-flow" season?	Sum of seasonal daily average discharge measurements >3rd quartile rank	NC	Continue monitoring	No	Continue monitoring	NC	Continue monitoring
Were there more than two "bankfull" flow events during the past year?	# bankfull events >2	No	Continue monitoring	No	Continue monitoring	No	Continue monitoring

NC = value was not calculated because of data quality issues or the data were not directly applicable to the stream segment.

Montezuma Castle Channel Morphology

Cross-Section Layout (2010)



Cross-Section Characteristics

Cross-Section	2010 Total Cross-sectional Area (m²)	2010 Water Elevation (m)	2009 Dominant Substrate Type
A	10,516	979.8	Gravel
B	1,761	977.2	Cobble
C	4,154	976.6	Cobble
D	1,823	974.2	Cobble
E	5,255	972.4	Cobble
F	2,328	970.2	Cobble & gravel
G	3,033	969.2	Cobble
H	4,557	967.6	Boulder
I	1,301	963.5	Cobble
J	1,066	962.0	Sand
K	1,495	958.7	Bedrock

Stream Channel Characteristics

*Sinuosity (2010) = 2.1

*Channel slope (2010) = 0.4

#Dominant Sediment Type (2009) = Cobble

*Beaver Creek was flowing too swiftly at the time of the 2010 survey to allow for a thalweg survey. Therefore, sinuosity and slope were estimated using the cross-sectional data and aerial imagery in GIS.

#Sediment composition estimates from 2009 are based on occular estimates of substrate cover by sediment type within 5m up and downstream of cross-section.

Sediment Composition (2009)

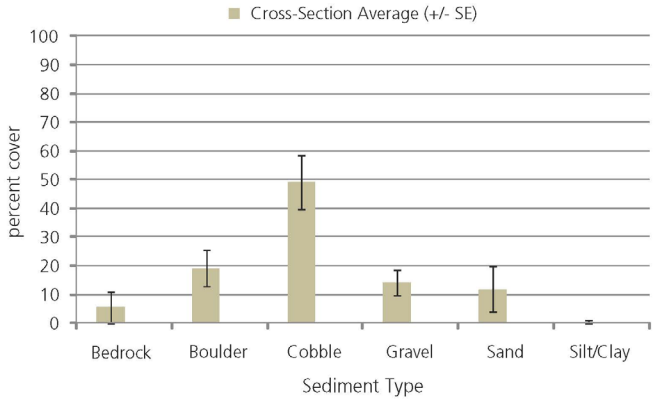


Figure 3-25. Stream-channel morphology characteristics of 11 cross-sections, Beaver Creek, 2009–2010.

The distribution of substrate over the size classes was similar between Beaver Creek and other tributaries to the Verde River, with one notable exception: Beaver Creek had nearly twice the percent of fines (13%). This is likely because Beaver Creek has a slightly lower gradient, resulting in a greater accumulation of fines, and perhaps has greater local inputs from erosion (Nauman 2010). SODN has identified this fine sediment as an assessment point for consideration by managers due to the negative impact that fine sediments can have on the algae and benthic macroinvertebrates that act as primary producers in the aquatic ecosystem.

Although the Beaver Creek stream segment follows a riffle-pool stream structure, the pools are typically large, deep, and, depending on location, semi-permanent features. The bed material in these pools is mostly large cobble or bedrock, overlain by a variable amount of finer sediments. These pools make the Beaver Creek segment unique in SODN streams monitoring. The pools are important refugia for aquatic plants and animals during both dry periods and flood events, collect fine particulate matter that can lead to an increase in nutrients and other materials, and may experience hypoxic events and chemical changes during summer low-flows.

Davis Hole Pool, adjacent to the water treatment pools at the Castle unit, is upstream from a large cobble dam that may have led to bifurcation of the streamflow, creating microhabitats along each reach. It is suspected that a complex surface/groundwater interaction occurs between the cobble dam and the

limestone bedrock outcropping at the downstream boundary of the monument. Water flowing in the alluvium underneath the river interacts with these geologic features to accelerate or decelerate the rate of drying in this pool, depending on base flow in the river, amount of contribution from groundwater, and evapotranspiration rates. This scenario is played out at various scales along the entire Beaver Creek stream segment. As the amount of data on the system increases, SODN and cooperators will be able to connect the signals with the impact on the ground, and in the water at the MOCA-TUZI stream systems.

3.3.3 Assessment points

In the future, channel-morphology assessment points (see Table 2-7) will be based on changes from the initial results described in Section 3.3. There are no results to report at this time.

3.4 Riparian and aquatic vegetation

During May 2009 and June and July 2010, a total of 212 riparian and aquatic vegetation plots were sampled on Beaver Creek, Wet Beaver Creek, and the Verde River (Table 3-13).

The sampling resulted in 161 plant taxa detected in the three sample frames at Beaver Creek (Appendix F). At Wet Beaver Creek and the Verde River, 91 and 95 taxa, respectively, were detected in two sample frames: greenline and riparian-zone. A total of 226 distinct taxa were detected.

3.4.1 Beaver Creek

3.4.1.1 Frequency of aquatic taxa

The most frequently encountered macrophytes (aquatic plants) were the emergent graminoids, such as *Eleocharis* sp. (Table 3-14).

3.4.1.2 Frequency of greenline taxa

The most frequently detected taxa in the greenline was the annual, rough cocklebur (*Xanthium strumarium)*, a native plant but also a tenacious invasive found in over half of the greenline plots (Table 3-15). The next three most-frequently detected plants were non-natives, including Johnsongrass (*Sorghum halepense*).

Abundance of greenline vegetation types by structural layer—. All major lifeforms were encountered in the greenline at Beaver Creek, with the greatest cover in the herbaceous layer (<0.5 m) (Table 3-16, Figure 3-26).

3.4.1.3 Frequency of riparian-zone taxa

The most frequent riparian-zone taxon was broom snakeweed (*Gutierrezia sarothrae*), found on 30% of the transects (Table 3-17). Most of the frequent (>10%) encountered taxa are forb/herb or shrubs that are widely distributed throughout the riparian zone.

Abundance of riparian-zone vegetation types by structural layer—. All major lifeforms were encountered in the riparian zone at Beaver Creek, with the greatest cover in the herbaceous layer stratum (<0.5 m; Table 3-18, Figure 3-27).

Table 3-13. Number of sample plots visited during sampling, WY2009–2010.

Stream segment	Sampling dates	Sample frame		
		Aquatic	Greenline	Riparian zone
Beaver Creek (MOCC)	May 2009	11	22	85
Wet Beaver Creek (MOWE)	June 2010	NC	15	37
Verde River (TUZI)	June–July 2010	NC	12	30

NC = not collected

Table 3-14. Frequency of aquatic taxa by functional group, Beaver Creek, WY2009–2010.

Scientific name	Common name	Growth habit	Frequency*	Indicator status
Annual graminoid		Graminoid	40%	
Eleocharis parishii	Parish's spikerush	Graminoid	40%	FACW
Perennial graminoid		Graminoid	30%	
Eleocharis rostellata	beaked spikerush	Graminoid	30%	OBL
Schoenoplectus tabernaemontani	softstem bulrush	Graminoid	30%	OBL
Paspalum distichum	knotgrass	Graminoid	20%	FACW
Annual forb		Forb/Herb	10%	
Carex aquatilis	water sedge	Graminoid	10%	OBL
Croton texensis	Texas croton	Forb/Herb	10%	NA
Equisetum	horsetail	Forb/Herb	10%	FACW
Hydrocotyle verticillata	whorled marshpennywort	Forb/Herb	10%	OBL
Mentha spicata	**spearmint**	**Forb/Herb**	**10%**	OBL
Paspalum dilatatum	dallisgrass	Graminoid	10%	FAC
Typha latifolia	broadleaf cattail	Forb/Herb	10%	OBL
Zannichellia palustris	horned pondweed	Forb/Herb	10%	OBL

*Frequency = percentage of transects on which taxon was found.
Bold indicates non-native species.
OBL=obligate; FACW=facultative wetland; FAC=facultative; NA=not assessed

Table 3-15. Frequency of greenline taxa, Beaver Creek, WY2009–2010.

Scientific name	Common name	Duration	Growth habit	Frequency*
Xanthium strumarium	rough cocklebur	Annual	Forb/Herb	54.55%
Melilotus officinalis	**yellow sweetclover**	**Annual, Perennial**	**Forb/Herb**	**36.36%**
Mentha spicata	**spearmint**	**Perennial**	**Forb/Herb**	**36.36%**
Sorghum halepense	**Johnsongrass**	**Perennial**	**Graminoid**	**36.36%**
Lotus corniculatus	bird's-foot trefoil	Perennial	Forb/Herb	31.82%
Amorpha fruticosa	desert false indigo	Perennial	Shrub	22.73%
Celtis laevigata	sugarberry	Perennial	Tree	22.73%
Equisetum hyemale	scouringrush horsetail	Perennial	Forb/Herb	18.18%
Fraxinus velutina	velvet ash	Perennial	Tree	18.18%
Eleocharis parishii	Parish's spikerush	Perennial	Graminoid	13.64%
Elymus trachycaulus	slender wheatgrass	Perennial	Graminoid	13.64%
Schoenoplectus tabernaemontani	softstem bulrush	Perennial	Graminoid	13.64%
Gutierrezia sarothrae	broom snakeweed	Perennial	Subshrub	13.64%
Platanus wrightii	Arizona sycamore	Perennial	Tree	13.64%

*Frequency = percentage of transects on which taxon was found.
Bold indicates non-native species.

Table 3-16. Percent cover (SE) of greenline vegetation types by structural layer, Beaver Creek, WY2009–2010.

Lifeform	Layer		
	Canopy	Subcanopy	Herbaceous
Vine	--	0.68	--
Standing dead	--	1.14	2.27
Tree	27.95 (1.84)	14.55 (0.43)	6.36 (0.15)
Shrub	0.23	8.18 (0.76)	2.50 (0.46)
Subshrub	--	0.91 (0.20)	0.45 (0.00)
Annual forb	--	5.68 (1.12)	12.05 (0.97)
Perennial forb	--	1.36 (0.17)	10.23 (0.40)
Annual grass	--	0.45 (0.00)	5.23 (0.32)
Perennial grass	--	6.59 (0.63)	15.00 (0.43)
Other/multiple classes	4.77 (0.00)	5.91 (0.62)	8.64 (0.46)
Total abundance	**32.95 (5.42)**	**45.45 (1.44)**	**62.73 (1.62)**

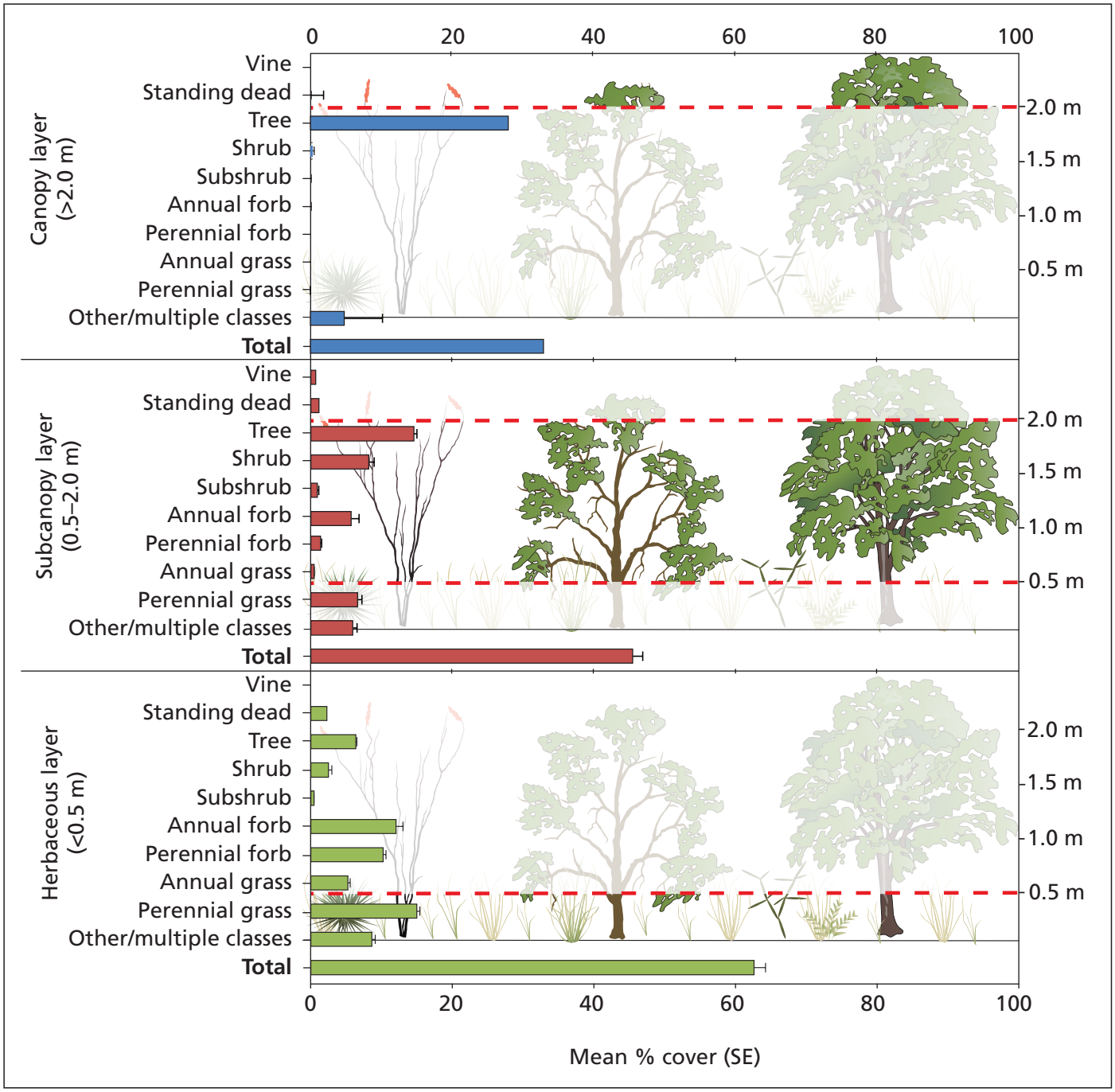


Figure 3-26. Percent cover (SE) of greenline vegetation types by structural layer, Beaver Creek, WY2009–2010.

Table 3-17. Frequency of riparian-zone taxa, Beaver Creek, WY2009–2010.

Scientific name	Common name	Duration	Growth habit	Frequency*
Gutierrezia sarothrae	broom snakeweed	Perennial	Subshrub	31%
Melilotus officinalis	**yellow sweetclover**	**Annual**	**Forb/Herb**	**20%**
Mahonia haematocarpa	red barberry	Perennial	Shrub	19%
Salsola kali	**Russian thistle**	**Annual**	**Forb/Herb**	**17%**
Sporobolus cryptandrus	sand dropseed	Perennial	Graminoid	17%
Astragalus	milkvetch	Various	Forb/Herb	16%
Solanum elaeagnifolium	silverleaf nightshade	Perennial	Subshrub	15%
Erodium cicutarium	redstem stork's bill	Annual	Forb/Herb/Shrub	14%
Ambrosia	ragweed	Various	Shrub	14%
Acacia greggii	catclaw acacia	Perennial	Tree	11%

*Frequency = percentage of transects on which taxon was found.
Bold indicates non-native species.

Table 3-18. Percent cover (SE) of riparian-zone vegetation types by structural layer, Beaver Creek, WY2009–2010.

Lifeform	Layer		
	Canopy	Subcanopy	Herbaceous
Vine	--	--	--
Standing dead	--	0.18	0.12
Tree	34.29 (1.08)	21.00 (0.46)	3.65 (0.09)
Shrub	0.82 (0.12)	4.71 (0.10)	2.82 (0.11)
Subshrub	--	0.12 (0.02)	2.35 (0.09)
Annual forb	--	0.47 (0.06)	7.71 (0.61)
Perennial forb	0.06 (0.03)	0.12 (0.02)	2.24 (0.04)
Annual grass	--	0.06	18.94 (0.91)
Perennial grass	--	0.71 (0.07)	9.53 (0.24)
Other/multiple classes	--	--	0.53 (0.04)
Total	**35.18 (4.88)**	**27.35 (2.30)**	**47.88 (1.86)**

Entries with no SE had only one record for that type.

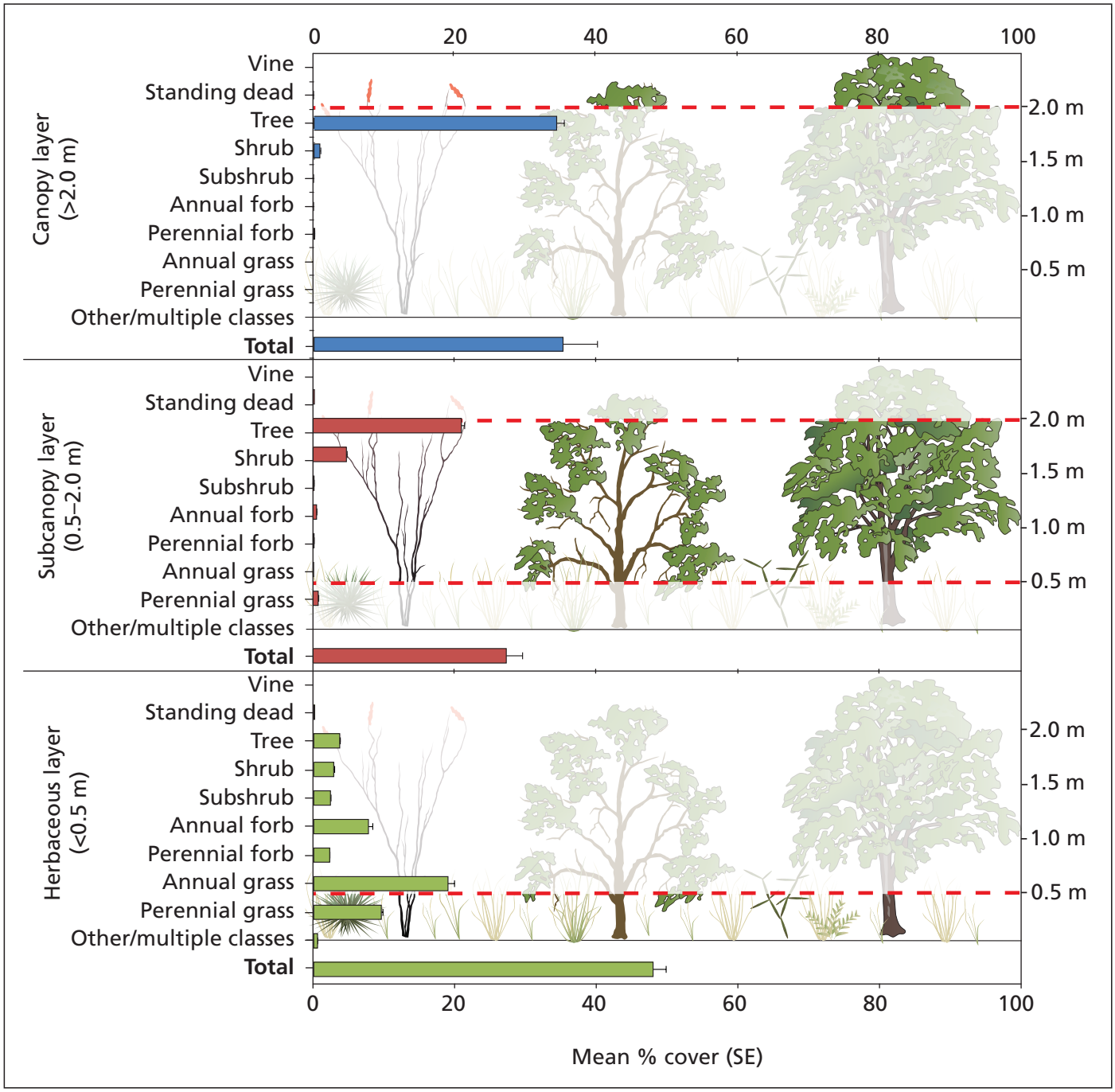


Figure 3-27. Percent cover (SE) of riparian-zone vegetation types by structural layer, Beaver Creek, WY2009–2010.

3.4.2 Wet Beaver Creek

3.4.2.1 Frequency of aquatic taxa

Data on the frequency of aquatic taxa were not collected during this sample period.

3.4.2.2 Frequency of greenline taxa

The most frequently detected taxa in the greenline sample frame at Wet Beaver Creek was the invasive Johnsongrass, found on 50% of the plots. Four of the top five most-frequently detected plants were non-native (Table 3-19).

Abundance of greenline vegetation types by structural layer—. The canopy layer was the most abundant at Wet Beaver Creek (59% cover), with trees driving the abundance (54%) (Table 3-20, Figure 3-28). The herbaceous layer was a close second (57.3%), driven by annual forbs (16%) and perennial grasses (20%).

3.4.2.3 Frequency of riparian-zone vegetation

The subshrubs broom snakeweed (*Gutierrezia sarothrae*) and Chihuahuan brickellbush (*Brickellia floribunda*) were most frequently encountered in the riparian plots at Wet Beaver Creek, both located in 32% of the sites (Table 3-21). Two non-native species, yellow sweetclover (*Melilotus officinalis*) and soft brome (*Bromus hordeaceus*), rounded out the top five, along with velvet mesquite (*Prosopis velutina*).

Abundance of riparian-zone vegetation types by structural layer—. The canopy and herbaceous layers were of nearly identical abundance (47% and 46%, respectively), with trees and grasses (annual and perennial) driving each structural layer, respectively (Table 3-22, Figure 3-29).

Table 3-19. Frequency of greenline taxa, Wet Beaver Creek, WY2009–2010.

Scientific name	Common name	Duration	Growth habit	Frequency*
Sorghum halepense	**Johnsongrass**	**Perennial**	**Graminoid**	**50%**
Juncus torreyi	Torrey's rush	Perennial	Graminoid	43%
Melilotus officinalis	**yellow sweetclover**	**Annual**	**Forb/Herb**	**36%**
Verbascum thapsus	**common mullein**	**Biennial**	**Forb/Herb**	**29%**
Schedonorus phoenix	**tall fescue**	**Perennial**	**Graminoid**	**29%**
Populus fremontii	Fremont cottonwood	Perennial	Tree	29%
Xanthium strumarium	rough cocklebur	Annual	Forb/Herb	21%
Polygonum persicaria	**spotted ladysthumb**	**Annual**	**Forb/Herb**	**21%**
Mentha spicata	**spearmint**	**Perennial**	**Forb/Herb**	**21%**
Enneapogon desvauxii	nineawn pappusgrass	Perennial	Graminoid	21%
Juncus saximontanus	Rocky Mountain rush	Perennial	Graminoid	21%
Fraxinus velutina	velvet ash	Perennial	Tree	21%
Typha latifolia	broadleaf cattail	Perennial	Forb/Herb	14%
Polypogon monspeliensis	**annual rabbitsfoot grass**	**Annual**	**Graminoid**	**14%**
Brickellia floribunda	Chihuahuan brickellbush	Perennial	Subshrub	14%
Platanus wrightii	Arizona sycamore	Perennial	Tree	14%
Alnus oblongifolia	Arizona alder	Perennial	Tree	14%

*Frequency = percentage of transects on which taxon was found.
Bold indicates non-native species.

Table 3-20. Percent cover (SE) of greenline vegetation types by structural layer, Wet Beaver Creek, WY2009–2010.

Lifeform	Layer		
	Canopy	Subcanopy	Herbaceous
Vine	--	--	0.33 (0.17)
Standing dead	0.33	2.33	6.67
Tree	54.00 (3.44)	23.67 (1.02)	6.00 (0.29)
Shrub	--	0.33 (0.08)	0.00 (0.00)
Subshrub	--	0.33 (0.11)	0.00 (0.00)
Annual forb	--	6.33 (1.10)	16.33 (1.69)
Perennial forb	--	--	1.67 (0.14)
Annual grass	--	--	0.33 (0.04)
Perennial grass	--	7.00 (1.00)	20.33 (0.77)
Other/multiple classes	4.67 (1.56)	3.33 (0.38)	5.67 (0.25)
Total	**59.00 (10.59)**	**43.33 (2.31)**	**57.33 (2.28)**

Entries with no SE had only one record for that type.

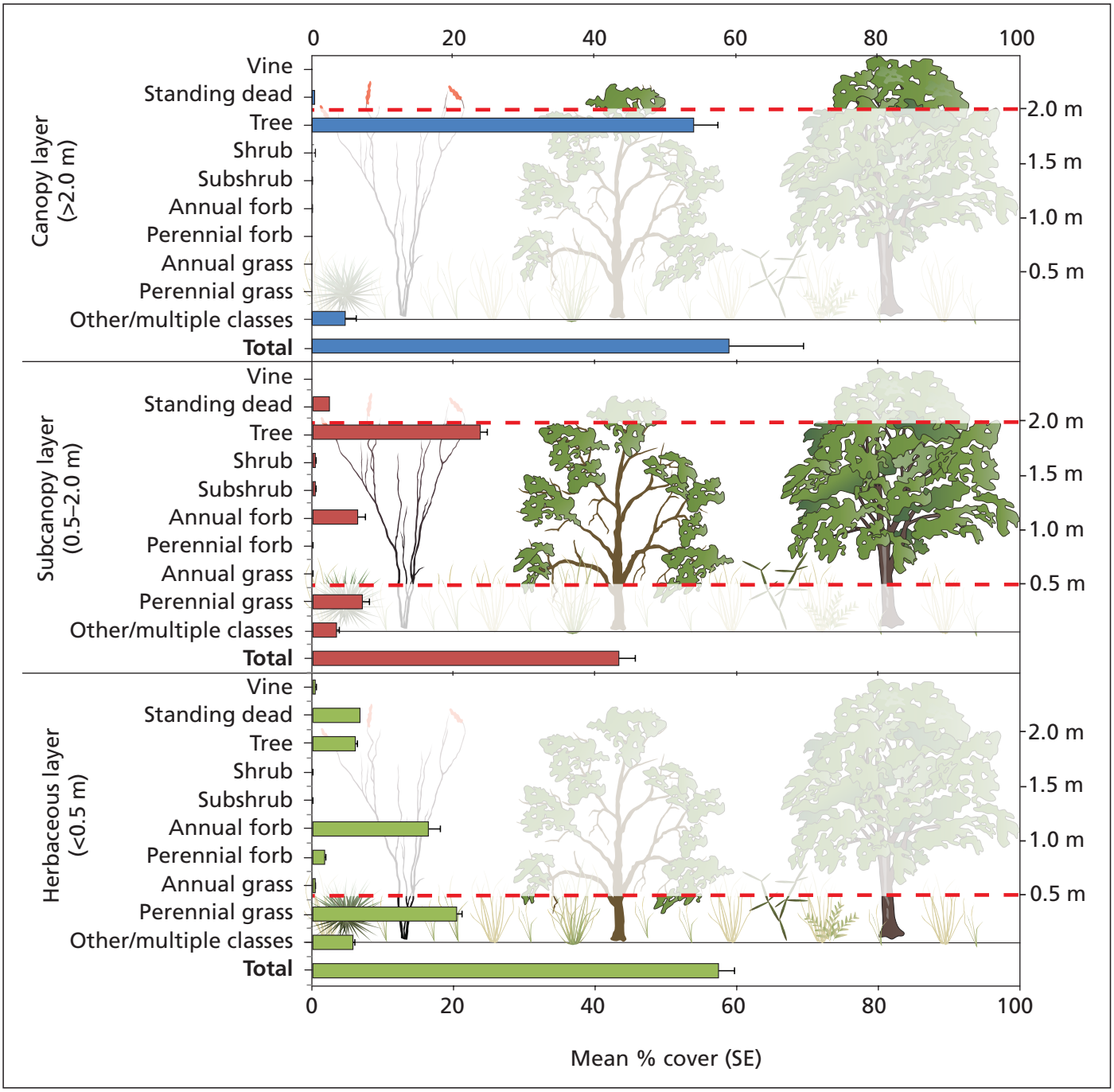


Figure 3-28. Percent cover (SE) of greenline vegetation types by structural layer, Wet Beaver Creek, WY2009–2010.

Table 3-21. Frequency of riparian-zone taxa, Wet Beaver Creek, WY2009–2010.

Scientific name	Common name	Duration	Growth habit	Frequency*
Gutierrezia sarothrae	broom snakeweed	Perennial	Subshrub	32%
Brickellia floribunda	Chihuahuan brickellbush	Perennial	Subshrub	32%
Melilotus officinalis	**yellow sweetclover**	**Annual**	**Forb/Herb**	**18%**
Bromus hordeaceus	**soft brome**	**Annual**	**Graminoid**	**18%**
Prosopis velutina	velvet mesquite	Perennial	Tree	18%
Mahonia haematocarpa	red barberry	Perennial	Shrub	16%
Juniperus monosperma	oneseed juniper	Perennial	Tree	16%
Mimosa aculeaticarpa	catclaw mimosa	Perennial	Tree	16%
Phaseolus angustissimus	slimleaf bean	Perennial	Vine	16%
Artemisia ludoviciana	white sagebrush	Perennial	Subshrub	13%
Vitis arizonica	canyon grape	Perennial	Vine	13%
Bromus rubens	**red brome**	**Annual**	**Graminoid**	**11%**
Acacia greggii	catclaw acacia	Perennial	Tree	11%
Chilopsis linearis	desert willow	Perennial	Tree	11%

*Frequency = percentage of transects on which taxon was found.
Bold indicates non-native species.

Table 3-22. Percent cover (SE) of riparian-zone vegetation types by structural layer, Wet Beaver Creek, WY2009–2010.

Lifeform	Layer		
	Canopy	Subcanopy	Herbaceous
Vine	0.95	0.68	--
Standing dead	0.14	0.41	4.59
Tree	45.00 (1.08)	17.43 (0.42)	3.11 (0.06)
Shrub	0.41 (0.05)	0.54 (0.05)	1.49 (0.09)
Subshrub	0.14	0.68 (0.12)	2.70 (0.12)
Annual forb	0.54	0.14 (0.03)	3.38 (0.34)
Perennial forb	0.00 (0.00)	0.00 (0.00)	0.95 (0.05)
Annual grass	--	0.00	15.81 (1.40)
Perennial grass	--	0.27 (0.03)	14.05 (0.25)
Other/multiple classes	--		0.27 (0.03)
Total	**47.16 (6.38)**	**20.14 (1.90)**	**46.35 (1.78)**

Entries with no SE had only one record for that type.

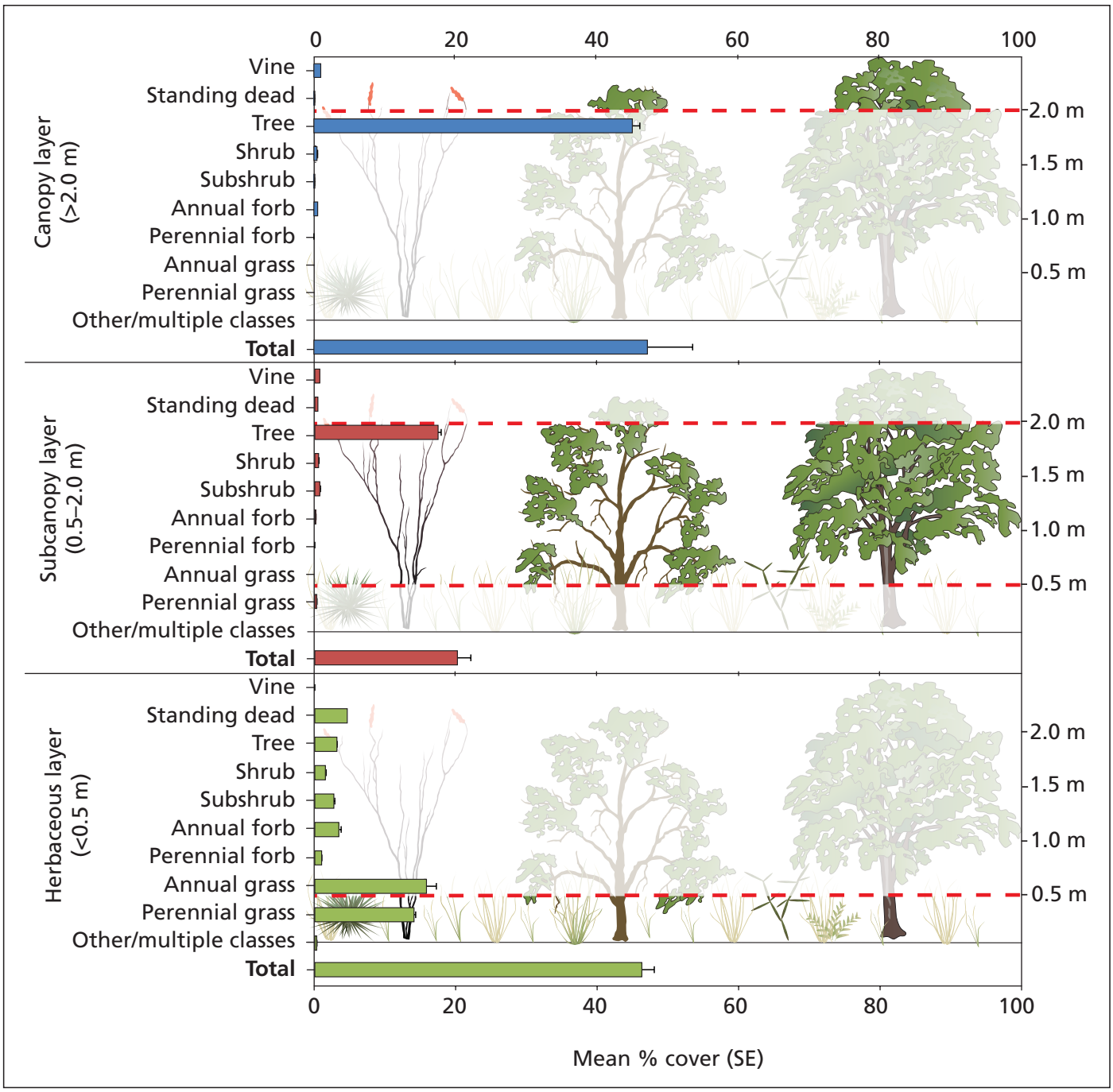


Figure 3-29. Percent cover (SE) of riparian-zone vegetation types by structural layer, Wet Beaver Creek, WY2009–2010.

3.4.3 Verde River

3.4.3.1 Frequency of aquatic taxa

Data on the frequency of aquatic taxa were not collected during this sample period.

3.4.3.2 Frequency of greenline taxa

The most frequently occurring plant taxon in the Verde River greenline zone was the invasive rough cocklebur (*Xanthium strumarium*), with the top five including only one native, Fremont cottonwood (Table 3-23). Salt cedar (*Tamarix ramosissima*) was found on one-third of all sample transects.

Abundance of greenline vegetation types by structural layer—. The most abundant structural layer was the subcanopy, driven by tree species (Table 3-24, Figure 3-30).

3.4.3.3 Frequency of riparian-zone taxa

The most frequently encountered taxa in the riparian zone at the Verde River site were the two grasses, red brome (a ubiquitous nonnative) and the native bunchgrass, sand dropseed (*Sporobolus cryptandrus*) (Table 3-25).

Abundance of riparian-zone vegetation types by structural layer—. The most abundant structural layer was the herbaceous layer, driven by forbs and grasses (Table 3-26, Figure 3-31).

Table 3-23. Frequency of greenline taxa, Verde River, WY2009–2010.

Scientific name	Common name	Duration	Growth habit	Frequency*
Xanthium strumarium	**rough cocklebur**	**Annual**	**Forb/Herb**	**50%**
Melilotus officinalis	**yellow sweetclover**	**Annual**	**Forb/Herb**	**42%**
Populus fremontii	Fremont cottonwood	Perennial	Tree	33%
Tamarix ramosissima	**saltcedar**	**Perennial**	**Tree**	**33%**
Plantago lanceolata	**narrowleaf plantain**	**Annual**	**Forb/Herb**	**25%**
Polypogon monspeliensis	**annual rabbitsfoot grass**	**Annual**	**Graminoid**	**25%**
Muhlenbergia asperifolia	scratchgrass	Perennial	Graminoid	25%
Baccharis salicifolia	mule-fat	Perennial	Shrub	25%
Brickellia floribunda	Chihuahuan brickellbush	Perennial	Subshrub	25%
Sonchus asper	**spiny sowthistle**	**Annual**	**Forb/Herb**	**17%**
Hydrocotyle verticillata	whorled marshpennywort	Perennial	Forb/Herb	17%
Lotus corniculatus	bird's-foot trefoil	Perennial	Forb/Herb	17%
Cynodon dactylon	**Bermudagrass**	**Perennial**	**Graminoid**	**17%**

*Frequency = percentage of transects on which taxon was found.
Bold indicates non-native species.

Table 3-24. Percent cover (SE) of greenline vegetation types by structural layer, Verde River, WY2009–2010.

Lifeform	Layer		
	Canopy	Subcanopy	Herbaceous
Vine	--	0.00	2.08 (1.04)
Standing dead	0.00	2.08	3.33
Tree	22.92 (1.20)	17.92 (0.77)	2.92 (0.15)
Shrub	0.00	0.00 (0.00)	0.83 (0.28)
Subshrub	--	0.00 (0.00)	0.00 (0.00)
Annual forb	--	5.00 (1.12)	12.50 (1.34)
Perennial forb	4.17	11.67 (2.13)	14.58 (0.80)
Annual grass	--	0.00 (0.00)	2.92 (0.20)
Perennial grass	--	7.08 (0.65)	25.00 (0.65)
Other/multiple classes	12.50 (4.17)	10.42 (0.78)	11.67 (0.62)
Total	**39.58 (4.39)**	**54.17 (1.98)**	**75.83 (2.56)**

Entries with no SE had only one record for that type.

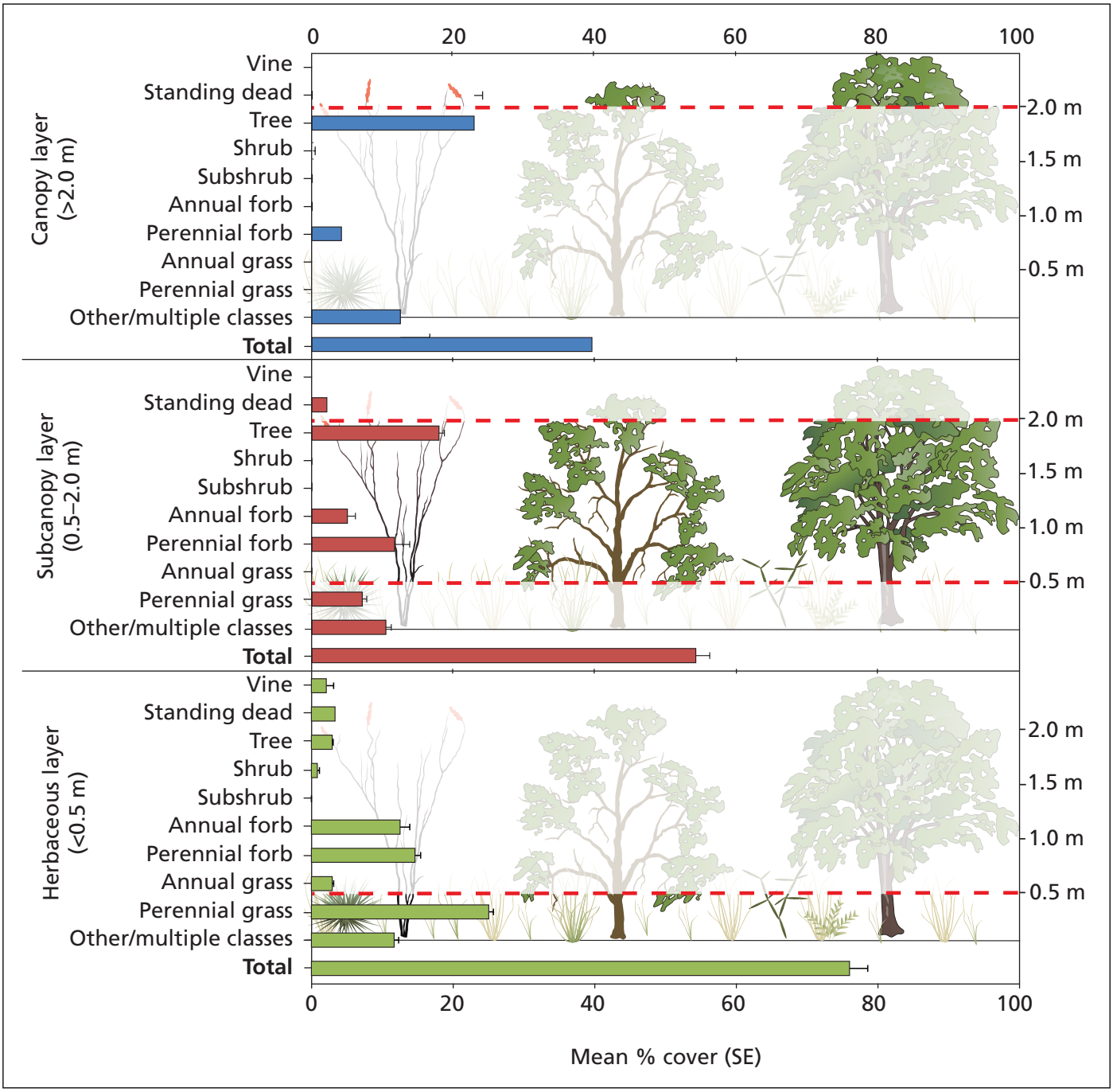


Figure 3-30. Percent cover (SE) of greenline vegetation types by structural layer, Verde River, WY2009–2010.

Table 3-25. Frequency of riparian-zone taxa, Verde River, WY2009–2010.

Scientific name	Common name	Duration	Growth habit	Frequency*
Bromus rubens	**red brome**	**Annual**	**Graminoid**	**31%**
Sporobolus cryptandrus	sand dropseed	Perennial	Graminoid	31%
Xanthium strumarium	**rough cocklebur**	**Annual**	**Forb/Herb**	**28%**
Melilotus officinalis	**yellow sweetclover**	**Annual**	**Forb/Herb**	**24%**
Brickellia floribunda	Chihuahuan brickellbush	Perennial	Subshrub	21%
Polypogon monspeliensis	**annual rabbitsfoot grass**	**Annual**	**Graminoid**	**14%**
Aristida purpurea	purple threeawn	Annual	Graminoid	14%
Chilopsis linearis	desert willow	Perennial	Tree	10%
Populus fremontii	Fremont cottonwood	Perennial	Tree	10%
Tamarix ramosissima	**saltcedar**	**Perennial**	**Tree**	**10%**

*Frequency = percentage of transects on which taxon was found.
Bold indicates non-native species.

Table 3-26. Percent cover (SE) of riparian-zone vegetation types by structural layer, Verde River, WY2009–2010.

Lifeform	Layer		
	Canopy	Subcanopy	Herbaceous
Vine	0.00	0.00	0.83 (0.11)
Standing dead	0.00	1.50	5.17
Tree	27.17 (0.90)	13.50 (0.26)	5.00 (0.18)
Shrub	3.50 (0.66)	0.33 (0.04)	0.50 (0.04)
Subshrub	0.00	1.17 (0.39)	1.83 (0.14)
Annual forb	0.00	1.17 (0.24)	4.33 (0.25)
Perennial forb	0.17 (0.08)	0.50 (0.17)	12.67 (0.37)
Annual grass	--	0.00	2.33 (0.22)
Perennial grass	--	0.00 (0.00)	4.33 (0.07)
Other/multiple classes	--	--	1.00 (0.11)
Total	**30.83 (3.83)**	**18.17 (1.45)**	**38.00 (1.14)**

Entries with no SE had only one record for that type.

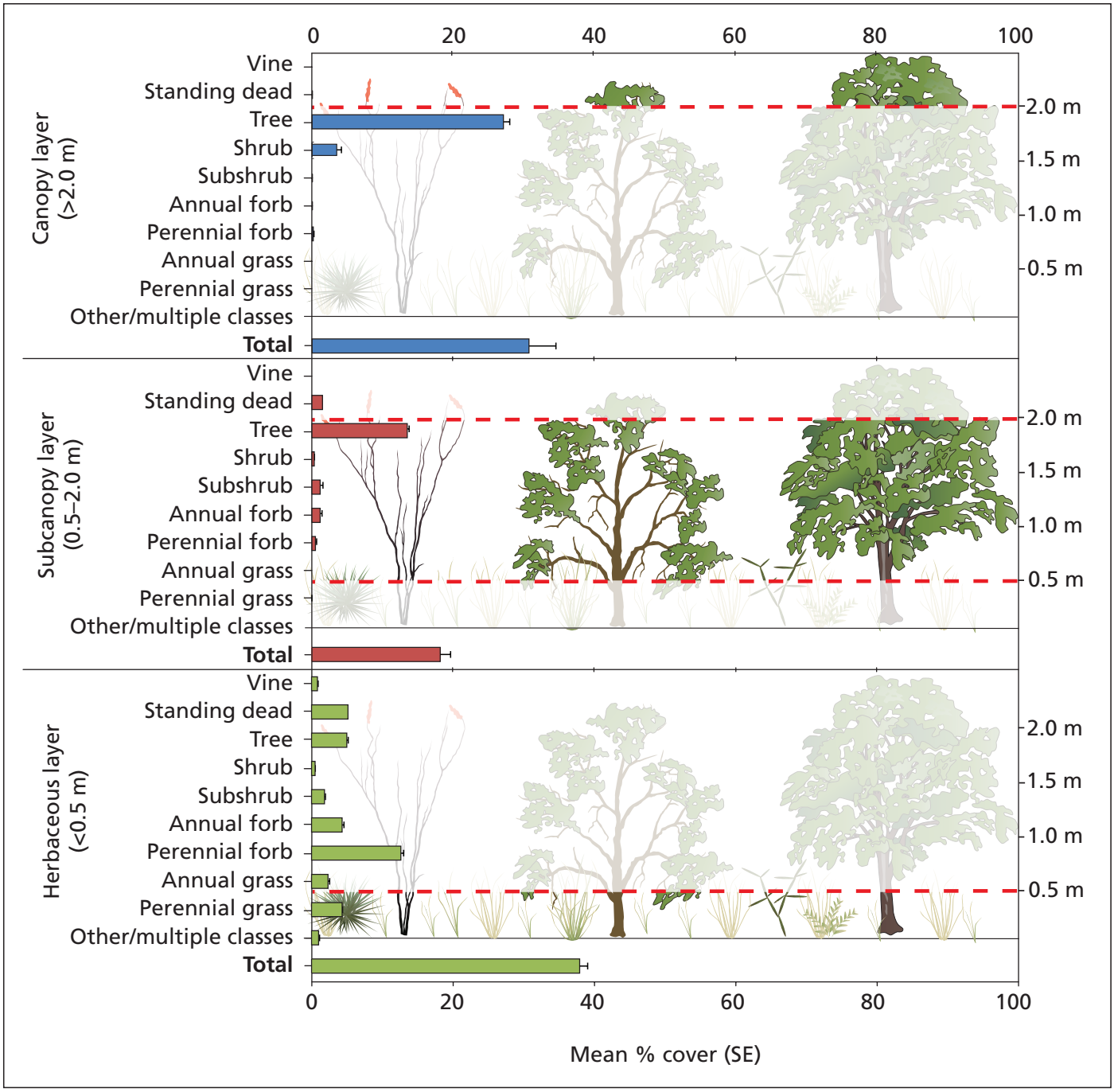


Figure 3-31. Percent cover (SE) of riparian-zone vegetation types by structural layer, Verde River, WY2009–2010.

3.4.4 Discussion

Riparian systems are one of the most diverse ecosystems found in the Southwest, due mainly to the presence and accessibility of water and the disturbance regime (Haney et al. 2008). The availability of water in riparian areas (commonly the main limiting factor in upland vegetation ecology) and the complex microhabitats created by fluvial activity offer the opportunity for many plant taxa to be present.

3.4.4.1 Disturbance history

The geomorphically diverse and dynamic riparian environment at Montezuma Castle and Tuzigoot NMs has led to the dominance of vegetation adapted to this regime (e.g., Fremont cottonwood), creating plant communities that depend on the flood disturbance, transport of nutrients, and availability of water.

Changes in the flooding regime, through anthropogenic (e.g., agricultural diversions) or natural causes (e.g., drought caused by oceanic oscillations) can lead to decline or modification of riparian plant communities. Such changes to riparian systems are often exploited by non-native plant species. The riparian areas at all three sample units are permeated by non-native species that have taken advantage of both the natural disturbance cycle and direct modifications to the riparian area, such as the agricultural diversion at Tuzigoot. Data from 2009 and 2010 indicate that non-native species are ubiquitous (found at from one- third to over one-half of sample plots in all three stream segments) and also comprise a sizeable abundance (>10% cover) in some structural layers—mostly the herbaceous layer, where they are typically encountered.

Several of these non-native species, such as Johnsongrass (*Sorghum halepense*) and salt cedar (*Tamarix ramosissima*), have the proven ability to change both the vegetation community (by outcompeting native riparian taxa) and even the ecological function of the system. Park managers are aware of these populations and are actively managing several non-native species.

The composition of plants at all three sample sites—in particular, the high frequency of Johnsongrass, yellow sweetclover (*Melilotus officinalis*), spearmint (*Mentha spicata*), and tall fescue (*Schedonorus phoenix* [=*Lolium arundinaceum*])—also indicates a history of disturbance. All of these species are escaped cultivars and most all were brought to the Verde Valley as (or with) forage species. Except for spearmint and tall fescue (the former obligate and the latter facultative), none of these species are obligate wetland species, indicating that the riparian zones are vulnerable to invasion by non-native and upland vegetation.

3.4.4.2 Vegetation composition of greenline and riparian zones

Across the park units, obligate wetland species comprised only 3–12% of all species (Table 3-27).

The importance of separating the greenline and riparian zone sample frames for monitoring purposes was illustrated in several ways—first, by the divergence in occurrence of obligate wetland plant taxa between the two (Table 3-28). The number of obligate riparian taxa dropped off precipitously 10 m from the active channel. Many of the obligate taxa were grasses, sedges, and rushes or forbs of diverse sizes. SODN is currently assessing methods for monitoring these obligate species.

Table 3-27. Percent of total taxa composed of obligate wetland species by stream segment.

Stream	% obligate wetland taxa
Beaver Creek (MOCC)	7%
Wet Beaver Creek (MOWE)	3%
Verde River (TUZI)	12%

Source: USDA PLANTS, http://plants.usda.gov/

Table 3-28. Percent of plots containing obligate wetland species in greenline and riparian zones, Montezuma Castle and Tuzigoot national monuments, WY2009–2010.

Stream segment	# taxa	% plots with obligate wetland species by zone		
		Greenline	Riparian	Total
Beaver Creek (MOCC)	161	50%	2%	**52%**
Wet Beaver Creek (MOWE)	91	33%	0%	**33%**
Verde River (TUZI)	95	58%	13%	**71%**

The influence of distance from the active channel on vegetation composition was clear at Wet Beaver Creek, where the most frequently encountered riparian-zone tree taxa included velvet mesquite, oneseed juniper (*Juniperus monosperma*), catclaw mimosa (*Mimosa aculeaticarpa*), acacia (*Acacia greggii*), and desert willow (*Chilopsis linearis*) (see Table 3-21). All of these can be considered either facultative phreatophytes (e.g., velvet mesquite), or typically upland species (acacia). The greenline zone was most frequently populated with Fremont cottonwood, velvet ash (*Fraxinus velutina*), Arizona sycamore (*Platanus wrightii*), and Arizona alder (*Alnus oblongifolia*), all obligate or facultative phreatophytes (Haney et al. 2008). These tree species are the most obvious members of the riparian community upon observation (Figure 3-32). A similar pattern was found at the Beaver Creek stream segment.

In addition to the differences in species composition and types between the sampling frames, each zone also had a distinct structure and assemblage of lifeforms associated with it. At Beaver Creek and Wet Beaver Creek, the amount of cover of forbs and grasses (annual and perennial) differed substantially between the greenline and riparian zones. The greenline zone had a large amount of cover in the herbaceous layer (<0.5 m) from both forbs (~15–30%) and grasses, while the riparian zone had few to no forbs (<10%). The forb, rough cocklebur (*Xanthium strumarium*), was found in at least 50% of greenline sample plots at the Beaver Creek and Verde River segments, and the graminoid, Johnsongrass, was found in at least 50% of greenline sample plots at the Wet Beaver Creek segment.

Most of the top 10 most frequently encountered taxa in the greenline zones at all stream segments were graminoids or forbs. The substrate is less dynamic in the riparian zone, decreasing opportunities for microhabitats and disturbance that annual grasses and forbs can rapidly exploit.

3.4.4.3 Clues to system ecology

The different species found at the sample segments provide information about the ecology of the system. Obligate taxa, such as horsetail or rushes, need to have their "feet wet" (i.e., be growing in water or saturated soil), or at least be frequently inundated by stream water. Vegetation data collected for this report indicated that the wetted extent was not consistent across the entirety of either MOCA or MOWE, evidenced particularly by the deficit of sedges (*Carex*) and rushes (*Typha*) species at both units. The Verde River stream segment had a higher frequency of swamp sedge (*Carex senta*) across all greenline zone plots, indicating a more consistent water flow in the Verde River segment than in the Beaver Creek and Wet Beaver Creek segments. The presence of *Typha* indicated that there were areas of standing water sufficient to support that species.



Figure 3-32. The character of the greenline zone is obvious in this photo of the fall foliage at Beaver Creek. Not only is the color of the vegetation different (in this case, the deciduous foliage of the cottonwood trees), but the texture of the vegetation also differs from the surrounding landscape, composed of mesquite and other trees and shrubs.

There was a complex of species present at Tuzigoot NM, including flatsedge (*Cyperus* spp.), American bulrush (*Schoenoplectus americanus*), sedges, and rushes, that supports the conclusion that the Verde River segment is a consistently wetted system and, as a consequence, supports a richer riparian flora than the Beaver Creek and Wet Beaver Creek segments (see Table 3-28). A comparison of greenline zone data indicated a riparian system that is continually wetted.

3.4.4.4 Implications for monitoring operations

The design for SODN riparian vegetation monitoring took into consideration the number of trained personnel and time that could be reasonably allocated to this project by largely adapting the methods used by the SODN uplands monitoring crew to the requirements of this project. Familiarity with the methods, along with talent and experience in botany and plant identification, help to reduce worker bias and increase accuracy.

At time of writing, the riparian vegetation module of the SODN streams protocol had been implemented at Montezuma Castle NM (both units), Tuzigoot NM, and Pecos National Historical Park. These parks encompass a range of stream-segment sizes and a number of cross-sections and sample transects. Completing all the fieldwork and data management on a large stream segment, such as Beaver Creek, takes a four-person crew approximately two eight-day tours. Completing one large segment or several smaller segments in one water year is sustainable with current SODN staffing and budget.

3.4.4.5 Is the riparian vegetation at Montezuma Castle and Tuzigoot NMs within the range of natural variability?

Within the context of the network's vital signs for species composition and community structure, we conclude that riparian vegetation at the Beaver Creek and Wet Beaver Creek stream segments are within the range of natural variability. There was a surprising lack of Fremont cottonwood at Beaver Creek; we suspect that the lack of this riparian species is due to the morphology of the Beaver Creek system and the timing and size of flood events needed for cottonwood recruitment (Haney et al. 2008).

The riparian vegetation at the Verde River segment has been extensively modified by (1) the diversion of most stream base flow and (2) channel maintenance, or "bankfull" flow events. The diversion has led to a complex morphologic and vegetative response to the restricted low-end flow (<~7000 cfs), and the influence of flood events of sufficient size to overtop and/or destroy the diversion dam (greater than ~10-year event). This combination of influences has led to the formation of deep, marsh-like pools and a broadening of the lateral distribution of typical wetland species across the riparian area. It has also allowed for the greater abundance of non-native plant taxa, especially salt cedar (*Tamarix* spp.).

3.4.5 Assessment points

Non-native plants are a concern for land managers, and serve as an indication of disturbance to the ecosystem. The permeation of the parks by non-native species was high, with non-natives found in more than 50% of the sites and more than 10% cover in all structural layers. It is suggested that SODN staff meet with park staff to discuss the implications of this analysis (Table 3-29).

Table 3-29. Riparian and aquatic vegetation assessment points, Montezuma Castle and Tuzigoot national monuments, WY2009–2010.

Issue	Assessment point	Beaver Creek (MOCA)		Wet Beaver Creek (MOWE)		Verde River (TUZI)	
		Point met?	Recommendation	Point met?	Recommendation	Point met?	Recommendation
Non-native plant dispersal	Non-native plants found in >50% of sample sites	Yes	Meet and discuss	Yes	Meet and discuss	Yes	Meet and discuss
Non-native plant invasion	% total plant cover is >10% non-native in each structural layer	Yes	Meet and discuss	Yes	Meet and discuss	Yes	Meet and discuss
Loss of obligate wetland taxa (richness and distribution)	Outside baseline 95% confidence interval for wetland obligate taxa richness and distribution	NA	Continue monitoring	NA	Continue monitoring	NA	Continue monitoring

NA = not assessed

3.5 Benthic macroinvertebrates

In spring 2007–2009, aquatic macroinvertebrate samples and physical habitat data were collected at index reaches on Beaver Creek, Wet Beaver Creek, and the Verde River (Table 3-30) while testing two macroinvertebrate collection protocols: targeted riffle and reachwide (multi-habitat). The targeted riffle samples were a composite of 8–12 kicknet samples collected in riffle habitats (Lawson 2005; Peck et al. 2006). The reachwide samples were a composite of 11 kicknet samples taken at 11 preset transects throughout the stream reach (Peck et al. 2006). A total of 13 macroinvertebrate samples were collected from the three streams. The current set of data is not sufficient to provide long-term trends but does provide a baseline for analysis with future macroinvertebrate datasets as well as an informative narrative on the state of the aquatic ecosystem during the sampling period.

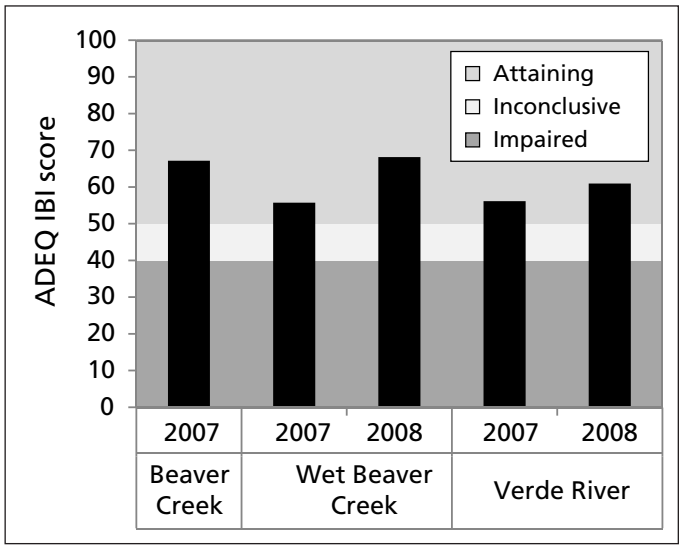


Figure 3-33. Arizona Department of Environmental Quality Index of Biotic Integrity scores for Montezuma Castle and Tuzigoot national monuments, WY2007–2008.

3.5.1 ADEQ Index of Biotic Integrity

In spring 2007, macroinvertebrate samples were collected from Beaver Creek, Wet Beaver Creek, and the Verde River. In spring 2008, samples were collected from only Wet Beaver Creek and the Verde River, following the ADEQ biocriteria program protocol, which targets riffle habitat only (Lawson et al. 2005). The samples were then processed by EcoAnalysts (in 2007) and the National Aquatics Monitoring Center (in 2008). The Arizona IBI for warm-water aquatic communities was calculated for each sample. All five samples were found to be attaining biotic integrity and meeting the state standard (Figure 3-33). The average score across the five samples was 61.6.

***Discussion*—.**The ADEQ IBI for warm-water streams takes into consideration regional climate, flow regimes, and geology. Within this context, all five samples were found to be attaining state standards for their designated uses. These samples will act as a baseline for assessing change in future years. In the spring of 2008, ADEQ monitored several sites in the Verde River basin (ADEQ 2008), for which the mean IBI score of warm-water sites was 52.8—lower than the average SODN score. This difference may be the result of sampling at different times within the same season or may represent an actual difference in the biotic communities; the protected status of the reaches at MOCA-TUZI, which are not subject to competing land uses directly adjacent to the stream, can result in better aquatic habitat.

3.5.2 EMAP multi-metric indices

In Spring 2007, 2008, and 2009, SODN col-

Table 3-30. Dates of macroinvertebrate sample collection, Montezuma Castle and Tuzigoot national monuments, WY2007–2009.

Collection protocol	Water year	Beaver Creek (MOCA)	Wet Beaver Creek (MOWE)	Verde River (TUZI)
Targeted riffle (ADEQ)	2007	4/16/2007	4/19/2007	5/8/2007
	2008	NC	6/4/2008	6/4/2008
	2009	NC	NC	NC
Reach-wide (multi-habitat) (ADEQ and MMI)	2007	4/16/2007	4/19/2007	5/8/2007
	2008	6/3/2008	6/4/2008	6/5/2008
	2009	5/6/2009	5/6/2009	NC

NC = data were not collected.

lected a total of 13 macroinvertebrate samples that were analyzed using the EMAP MMI: five targeted riffle samples and eight reachwide samples. One sample rated as most disturbed, 11 as moderately disturbed and one as least disturbed (Figure 3-34).

3.5.2.1 Discussion

The results from the EMAP MMI scores were more variable and inconsistent than the ADEQ IBI scores, with samples rating as least, moderately, and most disturbed. Two factors may be causing these inconclusive results: the range of design for the EMAP MMI, and a bias in sampling methods.

The EMAP MMI–Mountain Region methodology was designed for western streams across a 12-state area that includes ecoregions as dissimilar as the Arizona mountains and Pacific Northwest. Persistent droughts in the American Southwest have changed typical flow and flood regimes, resulting in drying of many streams. This drought-induced lack of flow, combined with the stochastic nature of monsoon rains and other region-specific environmental differences, likely has effects on MOCA-TUZI aquatic macroinvertebrate communities that cause them to routinely score lower than the other least-disturbed communities throughout the intermountain region. The MMI also does not distinguish between warm-water streams and the cold-water streams that are common in other parts of the western mountains. Biotic communities in warm-water streams generally rate lower in biotic indices than cold-water streams, given otherwise equivalent environments.

The EMAP MMI sampling protocol states that samples can be collected in two ways: a targeted riffle sample or a multi-habitat, reachwide sample. Based on this limited data set, riffle samples rated higher than the reachwide samples. Of the five riffle samples, four rated as moderately disturbed and one as least disturbed, which was consistent with the ADEQ IBI scores. However, of the eight reachwide samples, only three rated as moderately disturbed, while five rated as most disturbed: Beaver Creek 2007, 2008, 2009; Wet Beaver Creek 2009; and Verde River 2007. These low ratings further demonstrate the climatic variability of the region.

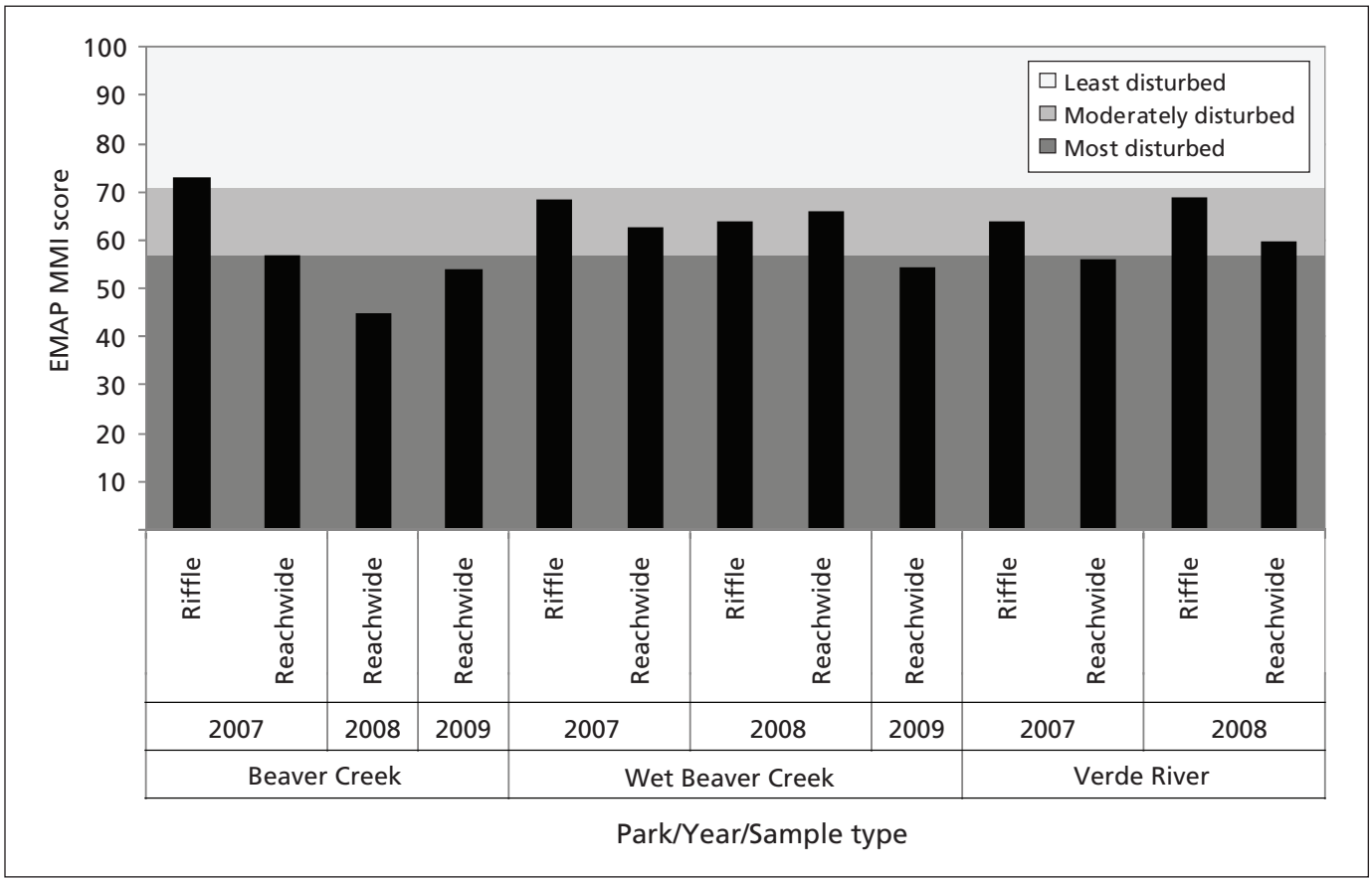


Figure 3-34. EMAP MMI scores for Beaver Creek, Wet Beaver Creek, and the Verde River, WY2007–2009.

The lowest-rated sample was taken on Beaver Creek in spring 2008. At the time of sampling, Beaver Creek was not continuously flowing through the index reach; some sections of the reach were non-flowing deep pools. No riffle sample was collected because no riffle habitat was available. The reachwide sample was collected, but only at seven of the 11 cross-sections. The reduced flow and increased pool habitat affected the aquatic community's overall diversity and weighted it toward more tolerant taxa, resulting in a rating of "most disturbed."

3.5.3 Individual metrics

3.5.3.1 Species richness

In 2007, species richness was relatively high at all three parks, ranging from 36 to 64 distinct taxa (Figure 3-35). In the 2008 and 2009 samples, species richness decreased dramatically, ranging from 12 to 30. The decrease in species richness from 2007 to 2008–2009 was likely because the spring of 2008 was drier than normal. At the time the samples were collected, Beaver Creek, Wet Beaver Creek, and the Verde River were below baseflow (1.77 cfs, 7.49 cfs, and 1.33 cfs, respectively). Roughly one-third of the stream index reach at Beaver Creek was dry, meaning that the index reach was a series of deep pools, rather than a contiguous, flowing stream. Low flow levels, warmer water temperatures, and discontinuous flows directly affect the diversity of organisms that a stream can support (Barbour et al. 1992). The year 2009 was also dry, but at the time of sampling, water levels were closer to baseflow. Taxa richness in riffle samples at Wet Beaver Creek in both 2007 and 2008 (36, 27) were higher than the 2008 taxa richness at ADEQ sites on the same stream upstream and downstream from MOWE (22, 15) (ADEQ 2008).

3.5.3.2 EPT

The mean EPT richness scores across all samples were 8 (Beaver Creek), 14 (Wet Beaver Creek), and 14 (Verde River). EPT taxa richness was lowest at Beaver Creek, where the reach consists of heavily sedimented pools and a few small riffles (Figure 3-35). Beaver Creek has minimal canopy cover, which affects both water temperature and dissolved oxygen levels. The segment also experiences more frequent periods of flooding and drying than the other two segments. These environmental factors favor taxa that are more tolerant of disturbance. The reaches at Wet Beaver Creek and the Verde River also feature large pools, but they have greater canopy cover and a more stable flow regime.

3.5.3.3 Intolerant taxa

Taxa intolerant of disturbance were found in every sample collected in the Verde River. Intolerant taxa were absent at Beaver Creek in 3 out of 4 samples, and absent at Wet Beaver Creek in 2 of 5 samples. (Figure 3-35) The Verde River at TUZI is highly modified (see Section 3.2.3), resulting in lower mean flow and more infrequent disturbance events. Of the three stream reaches, Beaver Creek experiences the most frequent disturbance events—primarily, intermittent flow during the spring and flooding during the spring and monsoon seasons, resulting in fewer intolerant taxa.

3.5.3.4 Predators

Predator richness was proportional to overall species richness, even during periods of disturbance (Figure 3-35). Predator richness was proportional to overall taxa richness, ranging from 16% to 33% across all samples. The decrease in predator taxa in 2008 and 2009 demonstrated that a reduction in the aquatic macroinvertebrate community occurred relatively equally across trophic levels.

3.5.3.5 Percent Chironomidae

Beaver Creek had the highest percentage of Chironomidae, at 65% in spring 2008 (Figure 3-36). The stream was intermittently flowing during this period, and separated into isolated pools. Although percent Chironomidae varied in the samples, no other relationship was observed. Percent Chironomidae was generally higher in reachwide samples than in targeted riffle samples.

Because many Chironomidae taxa are burrowers that thrive in low-oxygen, sedimented environments, reachwide samples that consist primarily of pools are expected to have a higher percent of this family. Percent Chironomidae was especially high in the reachwide sample for Beaver Creek in 2008. During this sampling period, the reach was reduced to a series of pools in which many non-chironomid taxa could not have survived.

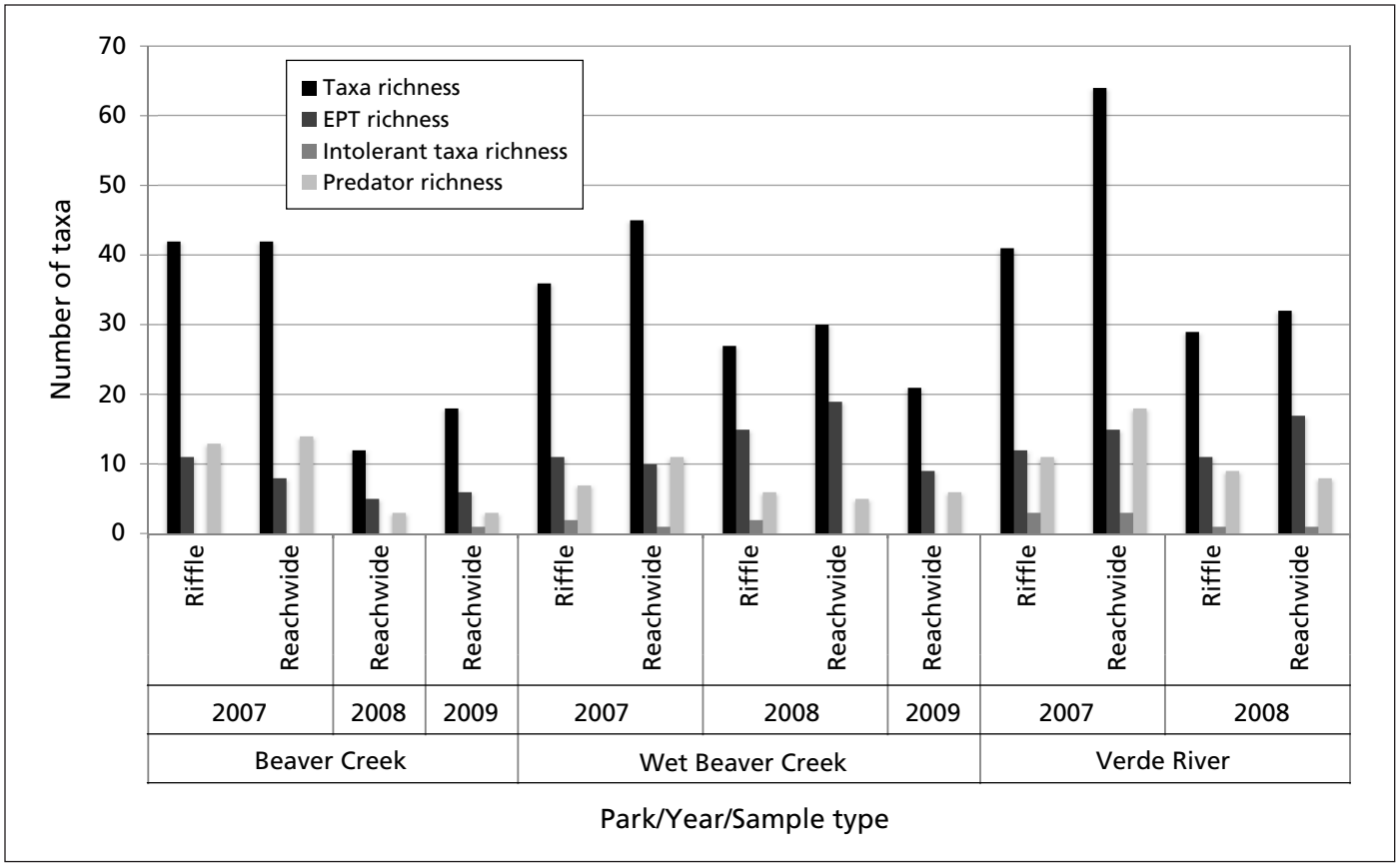


Figure 3-35. Metrics with a negative relationship to disturbance for macroinvertebrate samples collected at Montezuma Castle and Tuzigoot national monuments, WY2007–2009.

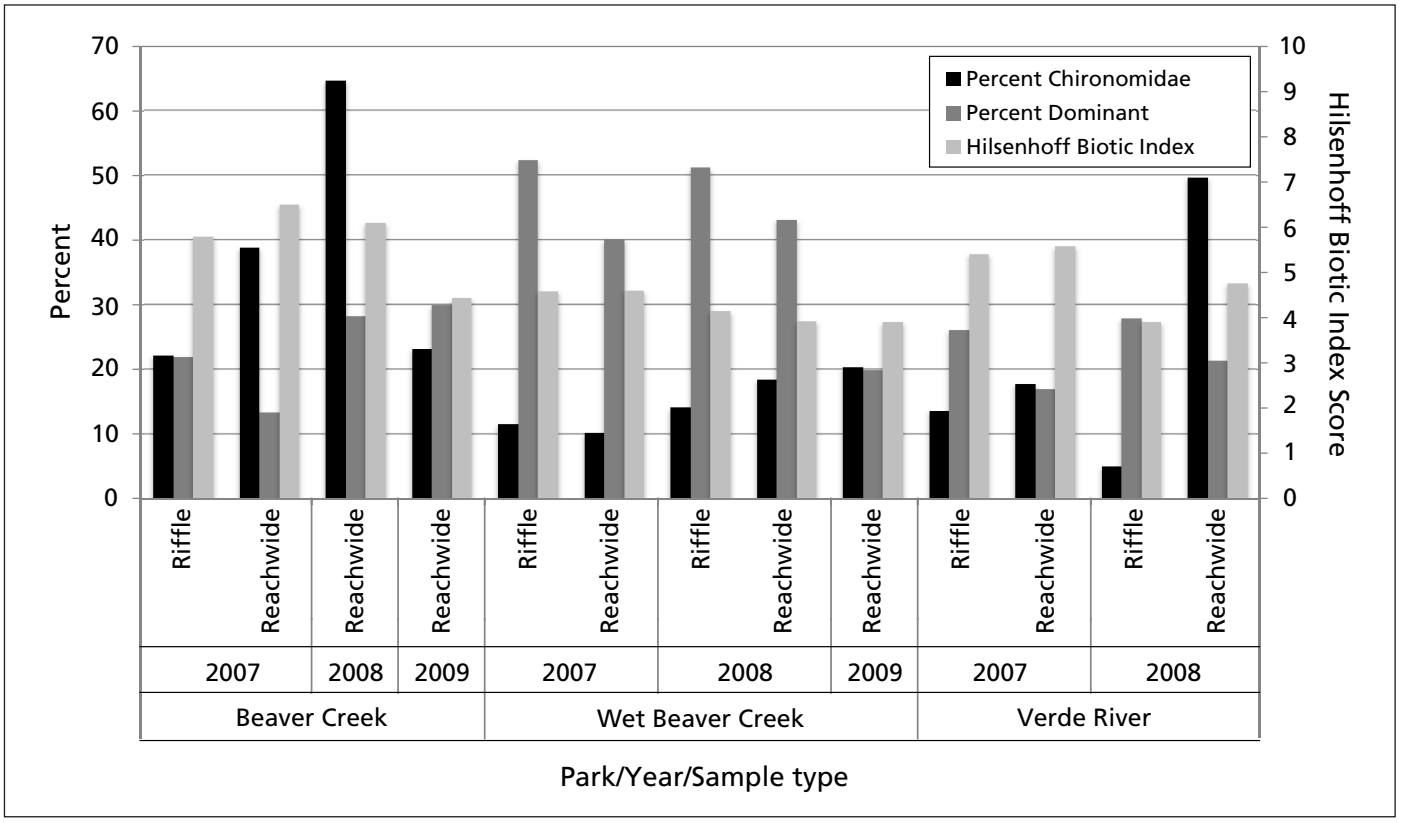


Figure 3-36. Metrics with a positive relationship to disturbance for macroinvertebrate samples collected at Montezuma Castle and Tuzigoot national monuments, WY2007–2009.

3.5.3.6 Dominant taxa

Wet Beaver Creek had the highest mean for percent dominance (41%), while Beaver Creek and the Verde River both had 23%. The high percent of dominant taxa at Wet Beaver Creek in 2007 and 2008 may indicate that habitat conditions limited the number of taxa. The dominant taxa in 4 out of 5 samples on Wet Beaver Creek were *Baetis* sp.—short-lived mayflies that live in rocky-bottomed lotic habitat. *Baetis* sp., a widespread genera of Ephemeroptera with larval and pupal aquatic stages that live in both erosional and depositional habitats, are abundantly found in the Verde River basin (Spindler 2004). While sensitive to pollution, they have variable tolerance for habitat disturbance. Their high abundance may be a result of sampling coinciding with their peak larval development or it may signify that water quality was marginal during some sampling periods, favoring taxa with short larval and pupal aquatic stages. Percent dominant taxa at Beaver Creek and the Verde River was in acceptable range.

3.5.4 Hilsenhoff Biotic Index

The mean scores on the Hilsenhoff Biotic Index (HBI) were 5.7 (Beaver Creek), 4.2 (Wet Beaver Creek), and 4.9 (Verde River), indicating that all three streams may be nutrient-enriched.

3.5.4.1 Discussion

The mean HBI scores for MOCA-TUZI indicate that Beaver Creek may have a higher level of nutrient enrichment than Wet Beaver Creek and the Verde River. Although this finding was not supported by water quality data collected from 2007 to 2009, those data only represent the state of the ambient water quality at the time of sample collection, whereas macroinvertebrates integrate water quality over a period of time. Continued monitoring should help determine whether nutrient concentrations in Beaver Creek generally differ from those in Wet Beaver Creek or the Verde River.

The riffle HBI scores collected by SODN staff at Wet Beaver Creek in both 2007 and 2008 (4.58, 4.14) were lower than the 2008 HBI scores at ADEQ sites on Wet Beaver Creek upstream and downstream from MOWE (5.69, 5.59) (ADEQ 2008). All four scores were categorized as enriched, but the lower scores at MOWE may indicate that its protected status contributes to better habitat quality.

3.5.5 Assessment points

None of the applicable samples collected in WY2007–2009 triggered the AZ ADEQ IBI assessment point. However, all of the applicable samples except one (from Beaver Creek in 2007) triggered the EMAP-MMI assessment point (Table 3-31).

The assessment points are useful to stimulate communication between park and SODN staff. In this case, there is a chance that most of the sites triggered the MMI assessment point because the metrics used may not be appropriate, and the season in which the samples were collected may not have perfectly corresponded with the metrics used to calculate the index.

SODN is refining the macroinvertebrate sampling schedule to reduce as much sampling bias as possible in order to improve the usefulness of these assessment points.

Table 3-31. Macroinvertebrates assessment points, Montezuma Castle and Tuzigoot national monuments, WY2007–2009.

Issue	Assessment point	Point met?									Recommendations
		Beaver Creek			Wet Beaver Creek			Verde River			
		2007	2008	2009	2007	2008	2009	2007	2008	2009	
Overall macroinvertebrate community health	Rates as inconclusive or impaired in the AZDEQ Index of Biotic Integrity	No	No	No	No	No	No	No	No	No	Continue monitoring
	Rates as moderately or most disturbed in the EMAP multi-metric indices	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Meet and discuss

4 Literature Cited

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Appendix A. Descriptions of Vital Signs and Associated Parameters

Core water quality parameters. Core water quality parameters reflect the function of the physical and biological environment with which water interacts. SODN core parameters—temperature, specific conductance (the ability of a solution to conduct an electrical current, i.e., the lower the conductivity, the "purer" the water), turbidity, pH, dissolved oxygen, and discharge rate—are easily measured and constitute a means of characterizing potential stressors to the health of aquatic systems. Monitoring for these parameters dovetails with the goals of the NPS servicewide Water Quality Monitoring Program, which requires each network to collect all of these parameters (except for turbidity) with any water quality monitoring effort.

Alkalinity. Alkalinity characterizes the ability of a water body to buffer changes in pH. Naturally occurring ions, such as carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), and hydroxide (OH^-) buffer streams from sudden changes in pH due to the addition of acid. Alkalinity of a stream is influenced by surrounding geology and soils and by effluent. Alkalinity benefits wildlife in two ways. First, it protects fish and other organisms against sudden changes in pH. Second, under the right conditions, carbonate and bicarbonate ions facilitate the precipitation of metals from solution, reducing the exposure of aquatic biota to high dissolved-metal concentrations.

Primary nutrients. Nutrient levels in a stream result from a hierarchy of biotic and abiotic processes occurring in the watershed, riparian zone, hyporheic zone, parafluvial zone, and the stream itself. Nitrogen and phosphorus are essential macronutrients for plant and animal life but in excess, they can interact with the biological and physical environment to reduce availability of high-quality aquatic habitat, altering the composition and species diversity of aquatic communities. Measures of total nitrogen and total phosphorus indicate the potential for biological effects resulting from nutrient loading.

Biological condition. Measurements of biological condition, along with visual and olfactory qualitative assessments of water condition, complement the other water quality vital signs and provide insight to the overall biological condition of water. Biological oxygen demand (BOD) is a measure of how much oxygen is consumed by biological organisms to decompose organic matter in a body of water. Chemical oxidation of organic matter also influences BOD. Dissolved oxygen levels below 6 mg/L stress fish and other organisms that depend on oxygen for respiration.

Pollutant metals. In high concentrations, pollutant metals cause major disruption of aquatic ecosystems by lowering reproductive success, interfering with normal growth and development, and, in extreme cases, causing death. The relationship of metal toxicity to aquatic species is complex but well established. Surface waters in SODN parks are exposed to pollutant metals through both point and nonpoint sources, including mine drainage, roadways, aerosolized particles dispersed through industrial processes, and by the release of metals naturally occurring in near-surface rock strata and sediments. Most of these contaminants bioaccumulate in aquatic food webs and may pose long-term threats to all trophic levels of the aquatic environment.

Carcinogens and toxins. Measurements documenting the existence and concentrations of any known toxic or carcinogenic substances that can impact the health and well-being of park visitors or staff, or impact the health of wildlife and other biota, are of interest to park managers. SODN collects samples for analysis for cyanide and many herbicides, pesticides, and pharmaceuticals that have been identified by the U.S. Environmental Protection Agency as having a known or possible negative impact on the health of humans or animals.

***Escherichia coli (E. coli*).** As one of the main species of bacteria living in the lower intestines of mammals, the presence of *E. coli.* in water is an indication of fecal contamination. Extreme conditions for these parameters are good proxies for stream pollution and they act as an early warning for potential pathogen risks for aquatic and terrestrial biota.

Surface water quantity. Characteristics of surface-water discharge define perennial stream systems. The probability distribution of flows over a range of magnitudes shapes the landscape and the biological systems that develop in a watershed. Discharge is one of the core water quality parameters and is also a separate vital sign because of the importance of surface water in the Sonoran Desert. The amount and timing of flow is controlled by watershed events, conditions, and channel morphological characteristics. In turn, flow rates influence water quality and biological parameters.

Stream channel morphology. The primary ecological functions of stream channels are to dissipate the energy associated with overland flow and to transport sediment, water, and nutrients within and from the watershed. As a result, stream channels are constantly adjusting to watershed conditions. Rare, stochastic flow events are of particular importance in the SODN parks of interest, and channel morphometrics will respond to the frequency, magnitude, and duration of these events. Geomorphic characteristics of stream channels, such as channel shape, interact with biological components, most notably vegetation, to determine the type, extent, and configuration of riparian ecosystems. Monitoring channel morphology for streams in SODN parks provides an important indicator of watershed condition and integrates ecological and geomorphological processes, including soil erosion, nutrient cycling, discharge characteristics, and the occurrence and magnitude of disturbance events, as well as surface and groundwater quantity and quality.

Longitudinal profile. A longitudinal profile of the sampling reach measures the elevation of the thalweg (deepest point in the channel) at transitions between habitat types and other channel features. It is used to determine the channel slope of the stream segment. In addition, the longitudinal profile survey provides a detailed plan-form view of the stream.

Stream habitat. Stream habitat heterogeneity is important for maintaining a diverse and healthy aquatic community. Riffles are associated with high-gradient areas, resulting in fast-moving water, turbulence, shallow depths, and a cobble/gravel substrate. Runs are similar to riffles; they have a swift current but a smooth surface and tend to be deeper than riffles. Glides are slower and deeper than runs, but surface flow is apparent. Pools are deep, extremely slow-moving, and often have a heavily sedimented substrate.

Sediment composition. Streambed substrate is composed of material present in the watershed that is eroded, transported, sorted, and deposited by the current. Sediment size is classified on the Wentworth scale, ranging from boulders to cobble, gravel, sand, and silt. Particle size is larger in higher-gradient streams and smaller in lower-gradient streams. SODN monitors sediment composition to identify and track change in stream habitat and across the stream segment in response to flooding and land-use change.

Riparian vegetation. Riparian vegetation, which grows in areas where land and waterways meet, is a vital functional component of riparian ecosystems. Riparian vegetation represents a small percentage of the land cover in the Southwest but provides important services, functions, and benefits. Riparian vegetation filters contaminants from water before infiltrating into groundwater drinking supplies, slows flood waters, reduces erosion potential along stream banks, increases groundwater recharge, and provides habitat for resident and migratory wildlife species. Riparian vegetation communities vary depending on geomorphology and are sensitive to hydrologic change. Some riparian trees, such as cottonwoods and willows, primarily rely on groundwater and are sensitive to change. Abrupt and permanent drops in groundwater of one meter have killed mature cottonwoods and willows (Haney et al 2008).

Benthic macroinvertebrates. Benthic macroinvertebrates (aquatic invertebrates, generally greater than 1/2 millimeter in size, hereafter, macroinvertebrates) are an important biological component in streams. They contribute to nutrient cycling and organic decomposition and are important prey for fish and other aquatic vertebrates. Living on the bottom substrates or the sediment in streams, macroinvertebrate communities respond differently to a variety of stressors. Thus, the type of stress on a stream can be determined by analyzing species distribution for the macroinvertebrate community (Peck et al. 2003). Macroinvertebrates can provide a powerful biological indicator of water quality and local conditions (Karr et al. 1986, Rosenberg and Resh 1993). They have been used extensively to assess stream condition because they are sensitive to pollutants and have high species richness. They also live in contact with sediment where pollutants tend to concentrate, and taxa and lifeform response to pollutants are relatively well established (Karr et al. 1986; Reice and Wohlenberg 1993). Because they are relatively long lived, macroinvertebrates integrate exposure to water condition over substantial time scales.

Fish and crayfish. Fish are the highest-level organisms in the stream monitoring program. Fish assemblages can serve as effective indicators of ecological conditions because they are long-lived and mobile, forage at different trophic levels, integrate ecosystem conditions at higher and lower trophic levels, and are reasonably easy to identify in the field. Fish also respond to higher-order processes that are captured in the other elements, particularly stream channel morphology, riparian vegetation, and water quantity (for physical habitat); water quality (for health), and macroinvertebrates (for food). Non-native (exotic) aquatic wildlife species pose a significant risk to the aquatic wildlife in SODN streams. Crayfish are an important non-native predator of fish and are one of the most serious threats to native aquatic biota because they effectively compete with aquatic herbivores, prey on aquatic invertebrates and vertebrates, disrupt normal nutrient cycling, and decrease aquatic macroinvertebrate diversity (Creed 1994). In addition, their extensive burrowing leads to bank erosion, increased turbidity, and siltation. Other non-native aquatic wildlife species of concern include American bullfrogs, non-native fish, and quagga mussels. Nearly all of the fish species found in SODN parks are either of special concern (e.g., Gila topminnow), or non-native and invasive (e.g., green sunfish). The presence of rare or invasive fish species is of interest to park managers, and may result in specific management actions. In addition to being important focal resources for park management, monitoring fish populations in conjunction with other key attributes of aquatic ecosystems can provide a powerful assessment of the ecological integrity of surface waters (Barbour et al. 1999; Moulton et al. 2002).

Appendix B. Selected Arizona State Water Quality Standards

Table B1. Selected Arizona state water quality standards.

Analyte	Unit	Fish Consumption	Full Body Contact	Partial Body Contact	Aquatic and Wildlife Warm Water General	Aquatic and Wildlife Warm Water Acute	Aquatic and Wildlife Warm Water Chronic	Aquatic and Wildlife Effluent Dependent Water	Aquatic and Wildlife Effluent Dependent Water Acute	Aquatic and Wildlife Effluent Dependent Water Chronic	Agricultural irrigation	Agricultural Livestock Watering	Specific for Verde River (MOCA, MOWE, TUZI)
pH (minimum)	pH units		6.50	6.50	6.50			6.50			4.50	6.50	
pH (maximum)	pH units		9.00	9.00	9.00			9.00			9.00	9.00	
Dissolved oxygen (Minimum, AZ-3.0mg/l from3 hours after sunrise to sunset, 1.0mg/l sunset to three hours after sunrise)	mg/L				6.00			3.00					
E. Coli (geometric mean)	cfu/100ml		126.00	126.00									
E. Coli (single sample)	cfu/100ml		235.00	575.00									
Ammonia-N	mg/L					*25	*26		*25	*26			
Antimony	mg/L	0.64	0.75	0.75									
Arsenic	mg/L	0.08	0.03	0.28							2.00	0.20	
Barium	mg/L		98.00	98.00									
Beryllium	mg/L	0.08	1.87	1.87									
Boron	mg/L		186.67	186.67							1.00		
Cadmium	mg/L	0.08	0.70	0.70							0.05	0.05	
Chlorine residual	mg/L		4.00	4.00		0.02	0.01		0.02	0.01			
Chromium	mg/L										1.00	1.00	
Chromium VI	mg/L	0.15	2.80	2.80									
Copper	mg/L		1.30	1.30							5.00	0.50	
Cyanide, Free	mg/L	16.00	18.67	18.67		0.04	0.01		0.04	0.01		0.20	
Dissolved Antimony	mg/L					0.09	0.03		1.00	0.60			
Dissolved Arsenic	mg/L					0.34	0.15		0.34	0.15			
Dissolved Cadmium	mg/L					*4	*5		*4	*5			
Dissolved Chromium III	mg/L					*7	*8		*7	*8			
Dissolved Chromium VI	mg/L					0.02	0.01		0.02	0.01			

Table B1. Selected Arizona state water quality standards, cont.

Analyte	Unit	Fish Consumption	Full Body Contact	Partial Body Contact	Aquatic and Wildlife Warm Water General	Aquatic and Wildlife Warm Water Acute	Aquatic and Wildlife Warm Water Chronic	Aquatic and Wildlife Effluent Dependent Water	Aquatic and Wildlife Effluent Dependent Water Acute	Aquatic and Wildlife Effluent Dependent Water Chronic	Agricultural irrigation	Agricultural Livestock Watering	Specific for Verde River (MOCA, MOWE, TUZI)
Dissolved Copper	mg/L					*10	*11		*10	*11			
Dissolved Iron	mg/L						1.00			1.00			
Dissolved Lead	mg/L					*13	*14		*13	*14			
Dissolved Mercury	mg/L					0.00	0.00		0.00	0.00			
Dissolved Nickel	mg/L					*16	*17		*16	*17			
Dissolved Silver	mg/L					*19			*19				
Dissolved Zinc	mg/L					*20	*20		*20	*20			
Fluorene	mg/L	1.07	37.33	37.33									
Fluoride	mg/L		140.00	140.00									
Lead	mg/L		0.02	0.02							10.00	0.10	
Manganese	mg/L		130.67	130.67							10.00		
Mercury	mg/L		0.28	0.28								0.01	
Nitrate-N	mg/L		3733.33	3733.33									
Nitrite-N	mg/L		233.33	233.33									
Selenium	mg/L	0.67	4.67	4.67		0.00				0.00	0.02	0.05	
Silver	mg/L	8.00	4.67	4.67									
Thallium	mg/L	0.00	0.08	0.08		0.70	0.15		0.70	0.15			
Total Nitrogen (mean)	mg/L												3.00
Total Phosphorus (mean)	mg/L												0.10
Total Phosphorus (single sample)	mg/L												1.00
Total suspended solids					80.00								
Uranium			2.80	2.80									
Zinc		5.11	280.00	280.00							10.00	25.00	

*Number refers to appropriate table in Arizona Administrative Code, Title 18: Environmental Quality, Chapter 11: Department of Environmental Quality, Article 1: Water Quality Standards; http://www.azsos.gov/public_services/Title_18/18-11.htm. 4 = AZ Table 4; 5 = AZ Table 5; 7 = AZ Table 7; 8 = AZ Table 8; 10 = AZ Table 10; 11 = AZ Table 11; 13 = AZ Table 13; 14 = AZ Table; 16 = AZ Table 16; 17 = AZ Table 17; 19 = Table 19; 20 = AZ Table 20

Table B2. Parameters and associated EPA analytical methods.

Analyte	EPA method	Detection limit (mg/L)	Reporting limit (mg/L)
Acidity	SM2310B	2	2
Alkalinity as $CaCO_3$	SM2320B	2	2
Aluminum	EPA 200.8	0.0085	0.01
Ammonia-N	SM 4500NH3-D	0.38	0.5
Antimony	EPA 200.8	0.0003	0.002
Arsenic	EPA 200.8	0.0009	0.001
Barium	EPA 200.8	0.0003	0.001
Beryllium	EPA 200.8	0.0001	0.0005
Bicarbonate Alkalinity as $CaCO_3$	SM2320B	2	2
Biological Oxygen Demand	SM 5210B	5	5
Boron	EPA 200.7	0.02	0.05
Cadmium	EPA 200.8	0.0001	0.001
Calcium	EPA 200.7	0.05	0.1
Carbonate Alkalinity as $CaCO_3$	SM2320B	2	2
Cation/Anion Balance	Calc	0	0
Chloride	EPA 300.0	0.3	0.5
Chromium	EPA 200.8	0.0009	0.002
Copper	EPA 200.8	0.0005	0.002
Dis Aluminum	EPA 200.8-Diss	0.0085	0.01
Dis Antimony	EPA 200.8-Diss	0.0003	0.002
Dis Arsenic	EPA 200.8-Diss	0.0009	0.001
Dis Barium	EPA 200.8-Diss	0.0003	0.001
Dis Beryllium	EPA 200.8-Diss	0.0001	0.0005
Dis Boron	EPA 200.7-Diss	0.02	0.05
Dis Cadmium	EPA 200.8-Diss	0.0001	0.001
Dis Calcium	EPA 200.7-Diss	0.05	0.1
Dis Chromium	EPA 200.8-Diss	0.0009	0.002
Dis Copper	EPA 200.8-Diss	0.0005	0.002
Dis Iron	EPA 200.7-Diss	0.015	0.04
Dis Lead	EPA 200.8-Diss	0.0002	0.001
Dis Magnesium	EPA 200.7-Diss	0.012	0.02
Dis Manganese	EPA 200.8-Diss	0.0007	0.001
Dis Mercury	EPA 245.1-Diss	0.0001	0.0002
Dis Molybdenum	EPA 200.8-Diss	0.0002	0.002
Dis Nickel	EPA 200.8-Diss	0.5	0.002
Dis Phosphorus	EPA 200.7-Diss	0.02	0.04
Dis Potassium	EPA 200.7-Diss	0.37	0.5
Dis Selenium	EPA 200.8-Diss	0.0005	0.002
Dis Silica	EPA 200.7-Diss	0.028	0.11
Dis Silver	EPA 200.8-Diss	0.0001	0.001
Dis Sodium	EPA 200.7-Diss	0.19	0.5
Dis Thallium	EPA 200.8-Diss	0.0002	0.001
Dis Uranium	EPA 200.8-Diss	0.0002	0.001

Table B2. Parameters and associated EPA methods, cont.

Analyte	EPA method	Detection limit (mg/L)	Reporting limit (mg/L)
Dis Zinc	EPA 200.8-Diss	0.004	0.02
Fluoride	EPA 300.0	0.15	0.5
Hydroxide Alkalinity as $CaCO_3$	SM2320B	2	2
Iron	EPA 200.7	0.015	0.04
Lead	EPA 200.8	0.0002	0.001
Magnesium	EPA 200.7	0.012	0.02
Manganese	EPA 200.8	0.0007	0.001
Mercury	EPA 245.1	0.0001	0.0002
Molybdenum	EPA 200.8	0.0002	0.002
Nickel	EPA 200.8	0.0005	0.002
Nitrate-N	EPA 300.0	0.015	0.2
Nitrite-N	EPA 300.0	0.038	0.2
Nitrogen, Total	Calc	1.6	1.7
pH	SM 4500H+	0	1.68
Potassium	EPA 200.7	0.37	0.5
Selenium	EPA 200.8	0.0005	0.002
Silica	EPA 200.7	0.028	0.11
Silver	EPA 200.8	0.0001	0.001
Sodium	EPA 200.7	0.19	0.5
Specific Conductance	SM2510B	1	1
Sulfate	EPA 300.0	0.3	0.5
Temperature °C	SM 4500H+	0	0
Thallium	EPA 200.8	0.0002	0.001
Total Cyanide	SM4500CN-E	0.0022	0.005
Total Dissolved Solids	SM2540C	1	10
Total Hardness	SM2340B	0.17	0.33
Total Kjeldahl Nitrogen	SM4500-NH3 D	0.34	1
Total Organic Carbon	SM5310B	0.5	1
Total Phosphorus	EPA 200.7	0.02	0.04
Total Suspended Solids	SM 2540D	1	10
Uranium	EPA 200.8	0.2	0.001
Zinc	EPA 200.8	0.004	0.02

Table B3. Water quality results, Montezuma Castle and Tuzigoot national monuments, WY2011.

Parameter	Montezuma Castle (Beaver Creek)				Montezuma Well (Wet Beaver Creek)				Tuzigoot (Verde River)			
	10/19/10	02/08/11	05/26/11	08/25/11	10/19/10	02/08/11	05/26/11	08/25/11	10/18/10	02/07/11	05/25/11	08/24/11
Core Water Quality Parameters												
Temperature (°C)	17.70	17.70	17.70	17.70	19.10	7.40	23.00	21.70	20.10	11.30	18.90	28.60
pH	8.04	8.06	8.34	8	8.09	7.91	8.56	8.23	8.40	8.75	8.49	8.36
Dissolved Oxygen (mg/L)	8.18	8.96	7.36	6.59	8.46	9.39	7.15	8.43	8.40	9.55	7.02	8.87
Specific Conductance (µS/cm)	514.00	439.30	417.70	467.40	446.40	350.50	377.10	405.00	518.00	467.70	494.20	446.50
E.Coli (cfu/100ml)	212.12	3.07	31.30	31.30	38.63	15.70	15.70	75.20	30.27	-3333	11.17	12.23
Turbidity (NTU)	26.97	5.61	4.36	12.10	20.47	5.61	2.99	3.66	11.59	2.09	7.50	28.10
Water Quantity												
Discharge (cfs)	6.81	11.40	4.34	0.42	7.47	12.80	8.25	5.89	29.80	32.84	1.96	3.08
Water Quality Parameters (from Lab)												
Acidity (mg/L)	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333
Alkalinity as CaCO3 (mg/L)	260	280	240	260	230	230	220	230	250	280	250	240
Aluminum (mg/L)	1.2	0.26	0.14	0.14	0.32	-3333	0.11	0.1	0.41	0.093	0.18	0.53
Ammonia-N (mg/L)	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333
Antimony (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	-3333
Arsenic (mg/L)	0.032	0.023	0.028	0.029	0.022	0.017	0.03	0.029	0.014	0.014	0.022	0.018
Barium (mg/L)	-	-	-	0.19	-	-	-	0.28	-	-	-	0.19
Beryllium (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	-3333
Bicarbonate Alkalinity as CaCO3 (mg/L)	260	280	240	260	230	230	220	230	250	270	250	240
Biological Oxygen Demand (mg/L)	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333
Boron (mg/L)	0.31	0.25	0.25	0.32	0.17	0.12	0.15	0.19	0.17	0.17	0.17	0.16
Cadmium (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	-3333
Calcium (mg/L)	52	58	46	50	49	46	47	51	53	59	56	49
Carbonate Alkalinity as CaCO3 (mg/L)	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	8.2	-3333	-3333
Cation/Anion Balance (mg/L)	3.69	3.12	4.68	2.44	3.42	1.63	2.91	3.34	1.37	0.67	4	1.51
Chloride (mg/L)	18	16	15	19	9.9	8.1	9.4	11	13	15	14	13
Chromium (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	-3333

Table B3. Water quality results, Montezuma Castle and Tuzigoot national monuments, WY2011, cont.

Parameter	Montezuma Castle (Beaver Creek)				Montezuma Well (Wet Beaver Creek)				Tuzigoot (Verde River)			
	10/19/10	02/08/11	05/26/11	08/25/11	10/19/10	02/08/11	05/26/11	08/25/11	10/18/10	02/07/11	05/25/11	08/24/11
Copper (mg/L)	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	0.0035
Dis Aluminum (mg/L)	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333
Dis Antimony (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	-3333
Dis Arsenic (mg/L)	0.031	0.019	0.026	0.027	0.025	0.015	0.025	0.028	0.014	0.014	0.024	0.018
Dis Barium (mg/L)	-	-	-	0.19	-	-	-	0.28	-	-	-	0.18
Dis Beryllium (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	-3333
Dis Boron (mg/L)	0.32	0.24	0.26	0.31	0.18	0.13	0.16	0.19	0.17	0.18	0.18	0.16
Dis Cadmium (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	-3333
Dis Calcium (mg/L)	51	57	46	50	51	48	46	53	53	59	55	47
Dis Chromium (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	-3333
Dis Copper (mg/L)	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333
Dis Iron (mg/L)	-3333	-3333	-3333	0.047	-3333	-3333	-3333	-3333	0.08	-3333	-3333	-3333
Dis Lead (mg/L)	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333
Dis Magnesium (mg/L)	27	24	28	29	24	22	23	23	27	27	36	27
Dis Manganese (mg/L)	0.022	-3333	0.024	0.019	0.032	-3333	-3333	0.014	0.033	-3333	0.05	0.014
Dis Mercury (mg/L)	-3333	-	-	-3333	-3333	-	-	-3333	-3333	-	-	-3333
Dis Molybdenum (mg/L)	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	0.002
Dis Nickel (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	-3333
Dis Phosphorus (mg/L)	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333
Dis Potassium (mg/L)	3.3	2.7	2.7	3.2	2.4	2.2	2.2	2.9	2.4	2.4	2.3	2.3
Dis Selenium (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	-3333
Dis Silica (mg/L)	21	18	19	25	23	18	20	23	20	18	20	20
Dis Silver (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	-3333
Dis Sodium (mg/L)	26	21	22	26	17	14	16	19	24	26	26	23
Dis Thallium (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	-3333
Dis Uranium (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	0.0013
Dis Zinc (mg/L)	-3333	-3333	0.025	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333
Fluoride (mg/L)	0.54	-3333	-3333	-3333	0.51	-3333	-3333	-3333	0.56	-3333	-3333	-3333
Hydroxide Alkalinity as CaCO3 (mg/L)	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333
Iron (mg/L)	0.88	0.21	0.2	0.26	0.33	0.08	0.13	0.15	0.3	0.073	0.18	0.39
Lead (mg/L)	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	0.0016

Table B3. Water quality results, Montezuma Castle and Tuzigoot national monuments, WY2011, cont.

Parameter	Montezuma Castle (Beaver Creek)				Montezuma Well (Wet Beaver Creek)				Tuzigoot (Verde River)			
	10/19/10	02/08/11	05/26/11	08/25/11	10/19/10	02/08/11	05/26/11	08/25/11	10/18/10	02/07/11	05/25/11	08/24/11
Magnesium (mg/L)	27	27	27	28	24	22	21	23	26	29	33	27
Manganese (mg/L)	0.041	0.021	0.032	0.041	0.042	-3333	-3333	0.024	0.042	-3333	0.058	0.037
Mercury (mg/L)	-3333	-	-	-3333	-3333	-	-	-3333	-3333	-	-	-3333
Molybdenum (mg/L)	-3333	-3333	-3333	0.002	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333
Nickel (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	-3333
Nitrate-N (mg/L)	-3333	-3333	-3333	-3333	-3333	-3333	-3333	0.59	-3333	-3333	-3333	-3333
Nitrite-N (mg/L)	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333
Nitrogen, Total (mg/L)	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333
Potassium (mg/L)	3.6	2.9	2.9	3.2	2.6	2.2	2.2	2.5	2.7	2.3	2.5	2.4
Selenium (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	-3333
Silica (mg/L)	27	19	19	26	24	18	19	24	21	18	20	22
Silver (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	-3333
Sodium (mg/L)	26	21	22	27	17	13	16	18	23	25	25	23
Sulfate (mg/L)	3.8	5.1	4.2	6.4	2.7	3.4	3.2	3.5	25	27	49	29
Thallium (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	-3333
Total Cyanide (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	-3333
Total Dissolved Solids (mg/L)	300	290	270	280	280	230	250	240	330	320	340	280
Total Hardness (mg/L)	240	250	230	240	220	200	210	220	240	270	280	230
Total Kjeldahl Nitrogen (mg/L)	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333
Total Organic Carbon (mg/L)	-	-	-	3	-	-	-	1.7	-	-	-	2.5
Total Phosphorus (mg/L)	0.049	-3333	-3333	-3333	-3333	-3333	-3333	-3333	0.049	-3333	-3333	-3333
Total Suspended Solids (mg/L)	16	-3333	11	-3333	-3333	-3333	-3333	-3333	25	-3333	-3333	16
Uranium (mg/L)	-	-	-	-3333	-	-	-	-3333	-	-	-	1
Zinc (mg/L)	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333	-3333

Appendix C. Macroinvertebrate Indices

Table C-1. Metrics used in Arizona's Index of Biotic Integrity for warm-water aquatic communities.

Metric	Definition	Expected response to disturbance
Taxa richness	Number distinct macroinvertebrate taxa	Decrease
# Ephemeroptera taxa	Number of mayfly taxa	Decrease
# Trichoptera taxa	Number of caddisfly taxa	Decrease
# Diptera taxa	Number of true fly larvae taxa	Decrease
# Scraper taxa	Number of distinct taxa utilizing periphyon, particularly algae and diatoms	Decrease
Hilsenhoff Biotic Index	Abundance-weighted average of pollution tolerance of assemblage	Increase
% Scraper	Percent abundance of scraper functional feeding group, compared with total abundance of the sample	Decrease
% Ephemeroptera	Percent abundance of mayflies, compared with total abundance of the sample	Decrease
% Dominant Taxon	Percent abundance of the single most abundant taxon, compared with total abundance of the sample	Increase

Table C-2. Metrics used in the Environmental Monitoring and Assessment Program's multi-metric indices (Mountain Region).

Metric	Definition	Expected response to disturbance
# EPT taxa	Number of mayfly, caddisfly and stonefly taxa	Decrease
% Non-insect	Percent abundance of non-insect taxa, compared with total abundance of the sample	Increase
% Dominant 5 taxa	Percent abundance the five most abundant taxa, compared with total abundance of the sample	Increase
% Omnivore taxa	Percent of omnivore taxa, compared to total taxa richness	Increase
% Burrowers	Percent abundance of taxa that live in soft, fine sediment, compared with total abundance of the sample	Increase
% Tolerant taxa	Percent of taxa with an Hilsenhoff Biotic Index score >=8 (considered tolerant to disturbance), compared to total taxa richness	Increase

Appendix D. Wet Beaver Creek Annual Seasonal Discharge Ranking

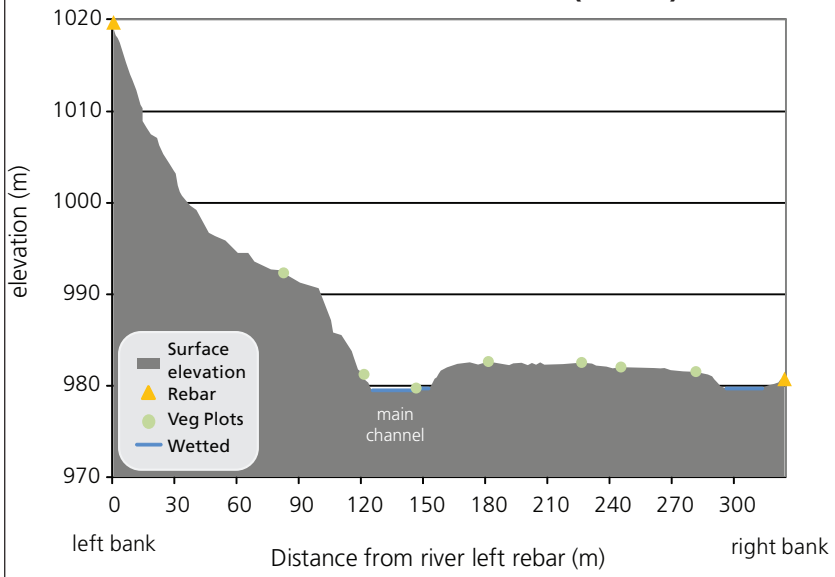
#	Year	Monsoon	#	Year	Spring	#	Year	Summer	#	Year	Winter	#	Year	Sum
1	1972	8,361.2	1	1973	17,434	1	1973	37,11.9	1	1993	27,088.1	1	1993	32,585.7
2	1970	3,093.8	2	1998	16,497	2	1998	8,51.4	2	1978	23,426.4	2	1978	32,239.6
3	1992	2,991.6	3	1965	11,325	3	1976	767.2	3	2005	18,591.6	3	1965	30,610.5
4	1999	2,692.1	4	1982	8,963.4	4	1972	742.9	4	1980	18,179.7	4	1973	26,602.8
5	1971	2,138.5	5	1979	8,874	5	1980	731.9	5	1965	17,672	5	1980	24,871.5
6	1967	1,741.7	**6**	**2010**	**8,542.7**	6	1979	653.3	6	1995	11,863	6	2005	23,365.9
7	2004	1,690.7	7	1991	7,683.6	7	1975	611.3	7	2008	11,020.5	7	1998	21,900.8
8	1964	1,485.9	8	1978	7,417.9	8	1982	606.3	8	1968	9,384.3	**8**	**2010**	**19,025.2**
9	2005	1,397.4	9	1975	6,203	9	1965	592.7	**9**	**2010**	**8,763.8**	9	1979	17,709.4
10	2001	1,289.5	10	1962	5,742.6	10	1966	568.1	10	1992	7,462.2	10	1992	15,876
11	1996	1,280.4	11	1969	5,669.7	11	2003	561.6	11	1979	7,359.1	11	2008	15,269.6
12	**2010**	**1,219**	12	1980	5,154	12	1974	553.7	12	2004	6,912.7	12	1968	15,150.7
13	2000	1,216.8	13	2003	5,014.5	13	1978	552	13	1969	6,408.4	13	1995	14,831.1
14	1963	1,214.7	14	1992	4,897.5	14	1970	546.2	14	1962	5,690	14	1991	14,331.1
15	2002	1,159.2	15	1966	4,544.1	15	1964	542.8	15	1976	5,457.6	15	1972	14,309.9
16	1966	1,157.2	16	1968	4,489.9	16	1969	535.2	16	1991	5,356.8	16	1969	13,486
17	1986	1,051.6	17	1987	4,264.6	17	2008	531.9	17	1972	4,786.3	17	1982	13,437.9
18	1965	1,020.8	18	1976	4,227.1	18	1981	526.7	**18**	**2009**	**4,719.9**	18	1962	12,740.5
19	2007	999	19	1993	4,184.4	19	1992	524.7	19	1973	4,585.1	19	1976	11,216.7
20	2003	989.4	20	1964	4,153.9	20	2004	521.7	**20**	**2011**	**4,270.9**	20	1966	10,440.9
21	1993	888.2	21	1997	3,504.3	21	1971	514.1	21	1971	4,246.3	21	2004	10,166.1
22	1997	880.7	22	2008	2,881.5	22	2000	513.1	22	1966	4,171.5	22	1975	9,177.5
23	1998	877.5	23	2005	2,880	**23**	**2011**	**505.2**	23	1997	3,702.9	23	2003	9,126.4
24	1969	872.7	24	1986	2,421.5	24	2002	502.3	24	1998	3,674.9	24	1997	8,564.2
25	1973	871.8	25	2001	2,039.5	25	1968	500.1	25	1982	3,245.2	25	1987	8,340.8
26	1981	864.7	26	1981	1,833.3	**26**	**2010**	**499.7**	26	1987	3,196	26	1971	7,605
27	1975	859.6	**27**	**2011**	**1,820.5**	27	1977	497.6	27	2003	2,560.9	**27**	**2011**	**7,430.5**
28	1974	851.9	28	1995	1,734.2	28	2005	496.9	28	2001	2,367.9	28	1964	7,120.4
29	1977	846	29	1994	1,385.3	29	1999	493.2	29	1986	2,273.4	**29**	**2009**	**6,405.4**
30	1978	843.3	30	1970	1,334.1	30	1967	492.5	30	2007	2,118.3	30	1986	6,207.9
31	1990	842	31	1999	1,333.5	31	2001	487.6	31	1989	1,862.8	31	2001	6,184.5
32	1962	840.5	32	1990	1,331.7	32	1991	483.6	32	1994	1,824.5	32	1970	6,057.6
33	2008	835.7	33	1974	1,056.1	33	1990	482.3	33	1975	1,503.6	33	1999	5,490.2
34	**2011**	**833.9**	34	2004	1,041	34	1963	480.1	34	1970	1,083.5	34	1994	4,318.4
35	1979	823	35	1989	818.8	35	1997	476.3	35	2000	1,044.7	35	2007	4,186
36	2006	822.5	36	2000	780.8	**36**	**2009**	**474.7**	36	1974	985	36	1981	4,137.6
37	1991	807.1	37	1971	706.1	37	1962	467.4	37	1999	971.4	37	1989	3,865.1
38	1980	805.9	38	2007	625.5	38	1995	465.2	38	1963	951	38	1967	3,743.6
39	1968	776.4	39	1963	623.8	39	1986	461.4	39	1964	937.8	39	2000	3,555.4
40	1995	768.7	40	1967	588.6	40	1989	445.1	40	1967	920.8	40	1990	3,526.3
41	1976	764.8	41	1977	534.7	41	2007	443.2	41	1996	920	41	1974	3,446.7
42	**2009**	**760.4**	**42**	**2009**	**450.4**	42	2006	441.9	42	1981	912.9	42	1963	3,269.6
43	1989	738.4	43	1972	419.5	43	1996	430.1	43	2002	912.5	43	1996	2,993.1
44	1994	691.3	44	2002	387.1	44	1993	425	44	1977	889.2	44	2002	2,961.1
45	1982	623	45	2006	371.3	45	1994	417.3	45	1990	870.3	45	1977	2,767.5
46	1987	470.9	46	1996	362.6	46	1987	409.3	46	2006	868.8	46	2006	2,504.5

Highlighted, bolded entries represent the years covered in this report. Dividing lines indicate the top and bottom 25% of values.

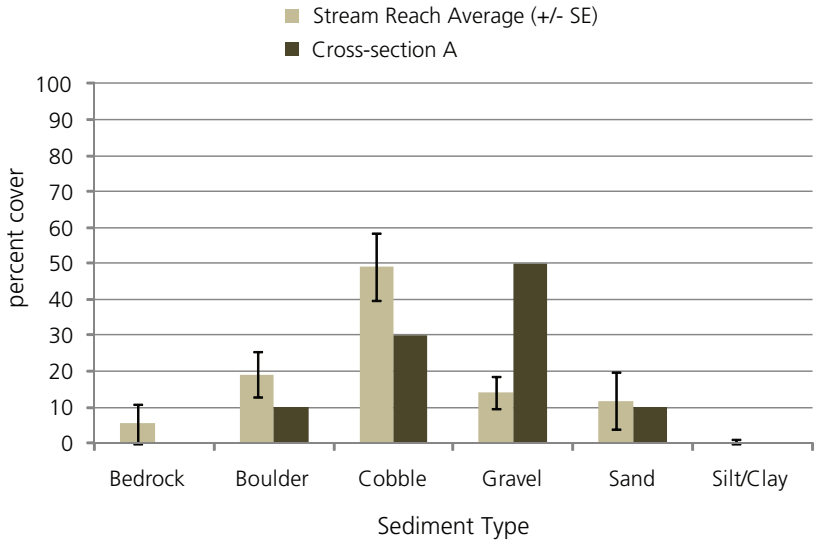
Appendix E. Channel Morphology Cross-Sections

Montezuma Castle Cross-Section A

Cross-Sectional View (2010)



Sediment Composition (2009)



Plan / Aerial View (2010)



Channel Characteristics

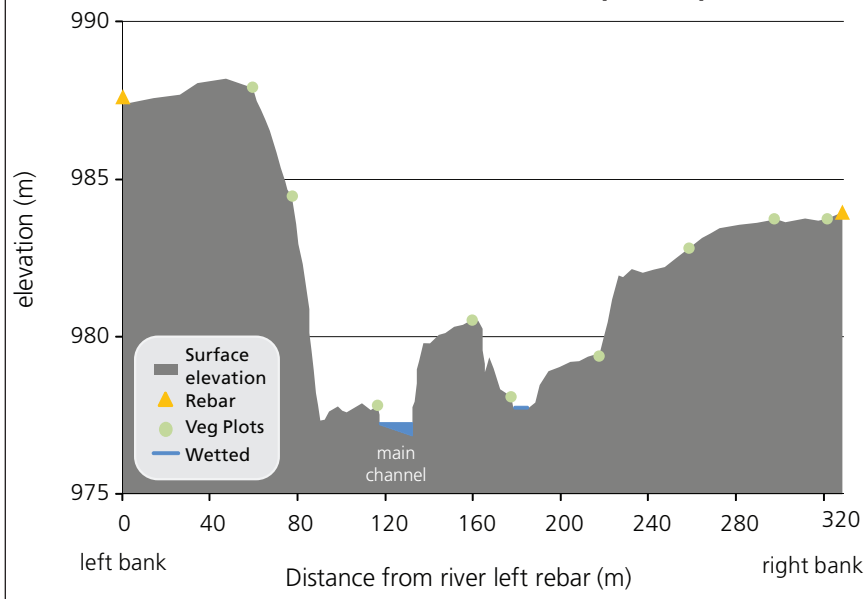
*Total Cross-Section Area (2010) = 10,516 m²
*Water Surface Elevation (main channel; 2010) = 980 m
*Main Channel Wetted Width (2010) = 14.4 m
*Main Channel Average Wetted Depth = unknown
*Main Channel Wetted Width-Depth Ratio = unknwon
#Dominant Sediment Type (2009) = Gravel

*Beaver Creek was flowing too swiftly at the time of the 2010 survey to allow for safe measurements within the wetted area. Therefore, total cross-sectional area numbers are conservative estimates and average wetted depth and derived measures cannot be calculated. In the plots on the left, the wetted areas are based on measurements taken from the bank and do not fully represent the morphology within the wetted area.

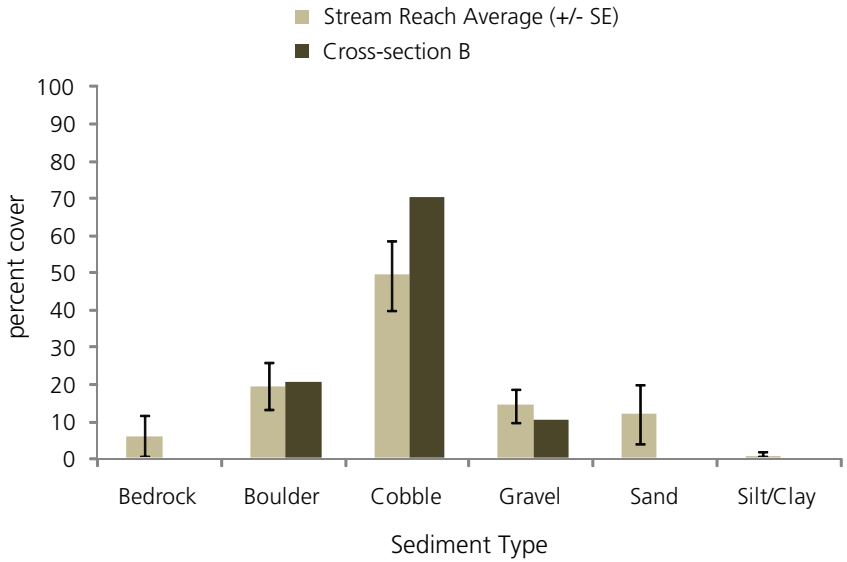
#Sediment composition estimates from 2009 are based on occular estimates of substrate cover by sediment type within 5m up and downstream of cross-section.

Montezuma Castle Cross-Section B

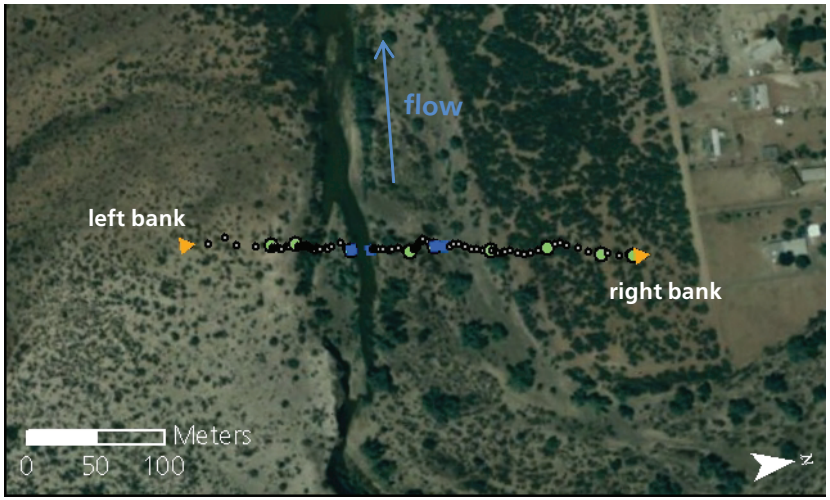
Cross-Sectional View (2010)



Sediment Composition (2009)



Plan / Aerial View (2010)



Channel Characteristics

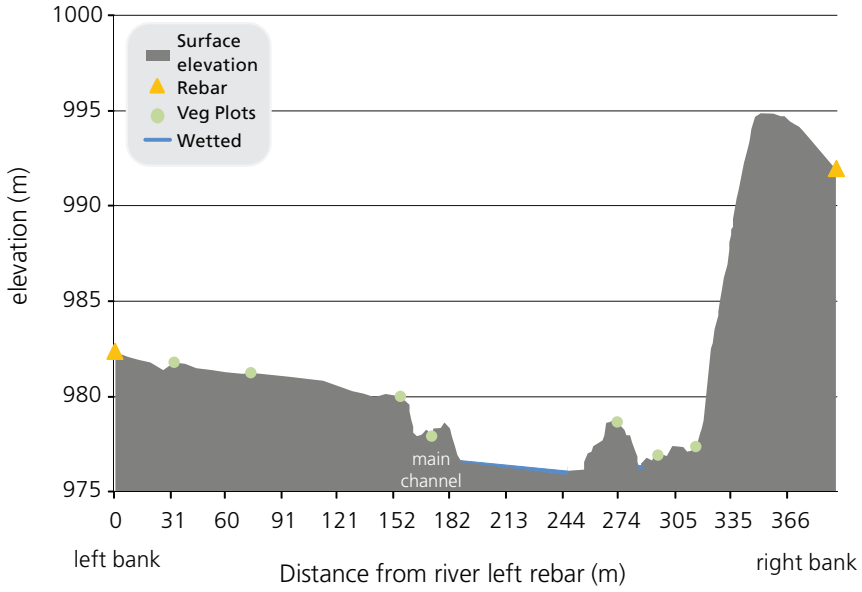
*Total Cross-Section Area (2010) = 1,761 m²
*Water Surface Elevation (main channel; 2010) = 977 m
*Main Channel Wetted Width (2010) = 14.4 m
*Main Channel Average Wetted Depth = unknown
*Main Channel Wetted Width-Depth Ratio = unknwon
#Dominant Sediment Type (2009) = Cobble

*Beaver Creek was flowing too swiftly at the time of the 2010 survey to allow for safe measurements within the wetted area. Therefore, total cross-sectional area numbers are conservative estimates and average wetted depth and derived measures cannot be calculated. In the plots on the left, the wetted areas are based on measurements taken from the bank and do not fully represent the morphology within the wetted area.

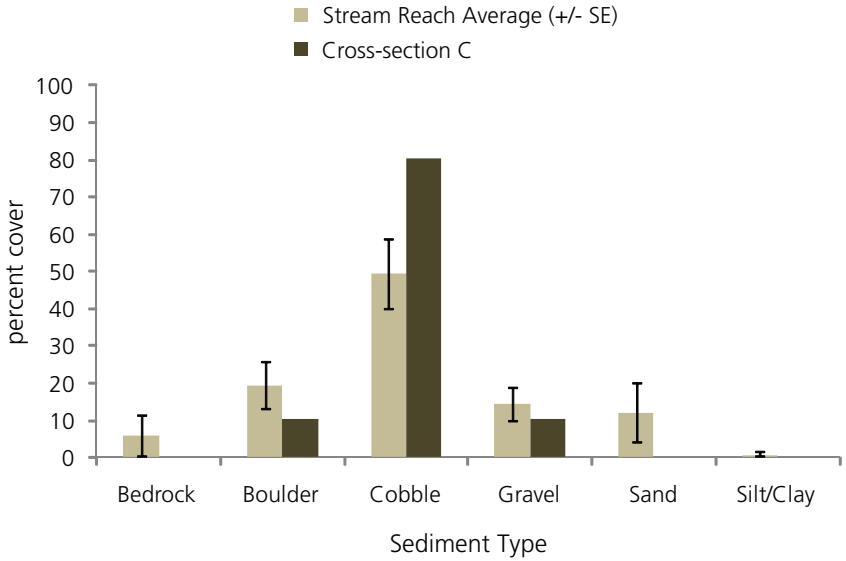
#Sediment composition estimates from 2009 are based on occular estimates of substrate cover by sediment type within 5m up and downstream of cross-section.

Montezuma Castle Cross-Section C

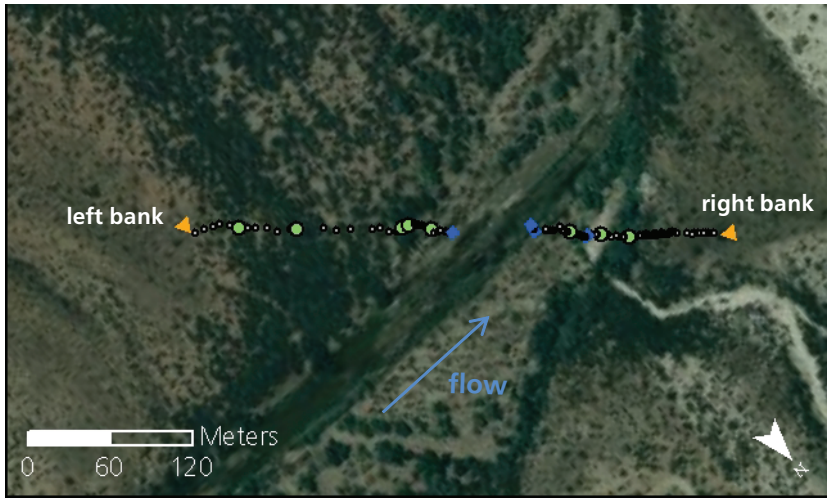
Cross-Sectional View (2010)



Sediment Composition (2009)



Plan / Aerial View (2010)



Channel Characteristics

*Total Cross-Section Area (2010) = 4,877 m^2

*Water Surface Elevation (main channel; 2010) = 977 m

*Main Channel Wetted Width (2010) = 57.7 m

*Main Channel Average Wetted Depth = unknown

*Main Channel Wetted Width-Depth Ratio = unknwon

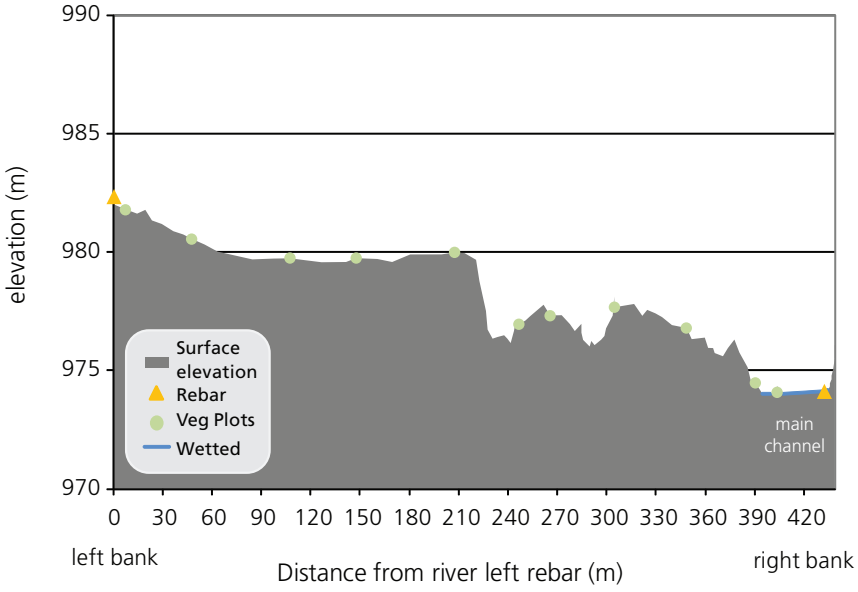
#Dominant Sediment Type (2009) = Cobble

*Beaver Creek was flowing too swiftly at the time of the 2010 survey to allow for safe measurements within the wetted area. Therefore, total cross-sectional area numbers are conservative estimates and average wetted depth and derived measures cannot be calculated. In the plots on the left, the wetted areas are based on measurements taken from the bank and do not fully represent the morphology within the wetted area.

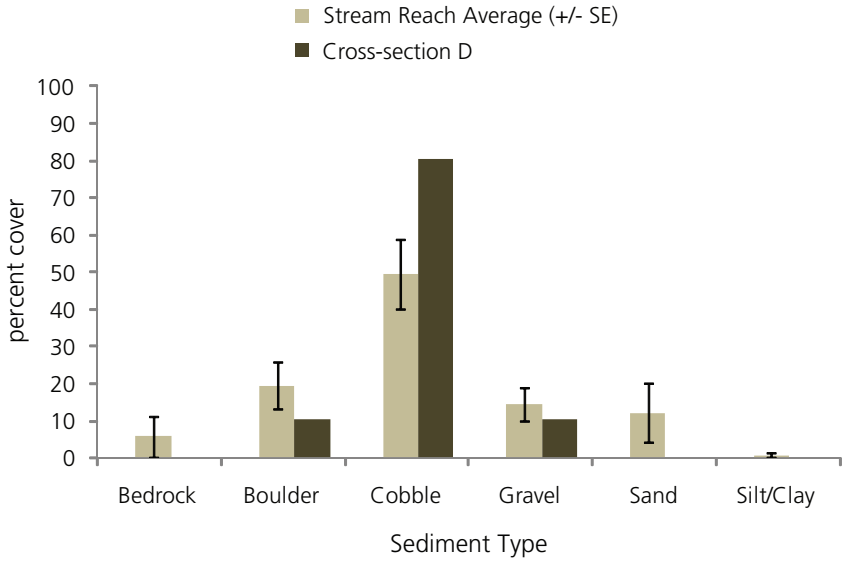
#Sediment composition estimates from 2009 are based on occular estimates of substrate cover by sediment type within 5m up and downstream of cross-section.

Montezuma Castle Cross-Section D

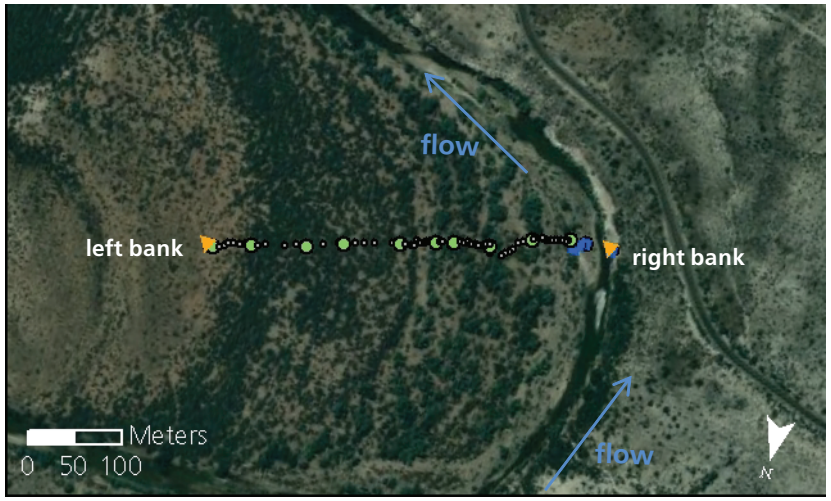
Cross-Sectional View (2010)



Sediment Composition (2009)



Plan / Aerial View (2010)



Channel Characteristics

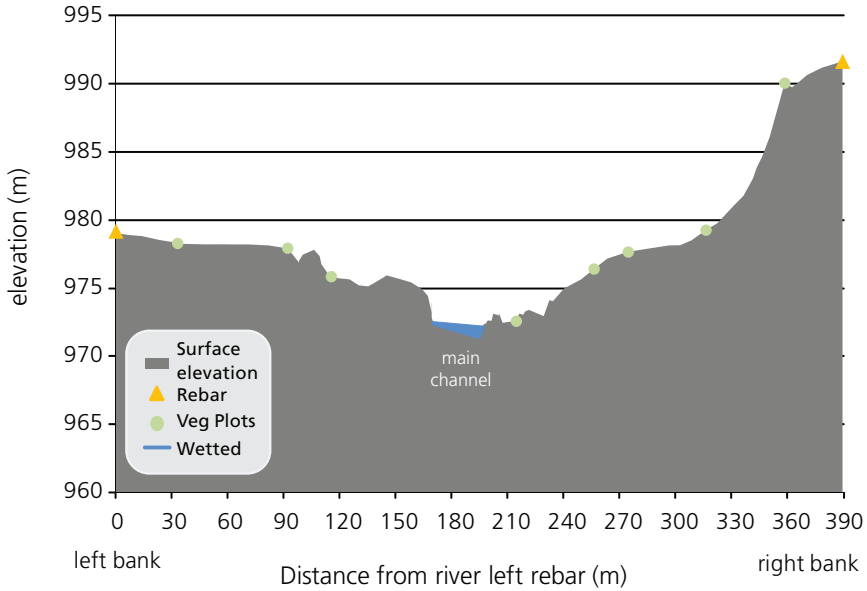
*Total Cross-Section Area (2010) = 1,823 m²
*Water Surface Elevation (main channel; 2010) = 974 m
*Main Channel Wetted Width (2010) = 32.8 m
*Main Channel Average Wetted Depth = unknown
*Main Channel Wetted Width-Depth Ratio = unknwon
#Dominant Sediment Type (2009) = Cobble

*Beaver Creek was flowing too swiftly at the time of the 2010 survey to allow for safe measurements within the wetted area. Therefore, total cross-sectional area numbers are conservative estimates and average wetted depth and derived measures cannot be calculated. In the plots on the left, the wetted areas are based on measurements taken from the bank and do not fully represent the morphology within the wetted area.

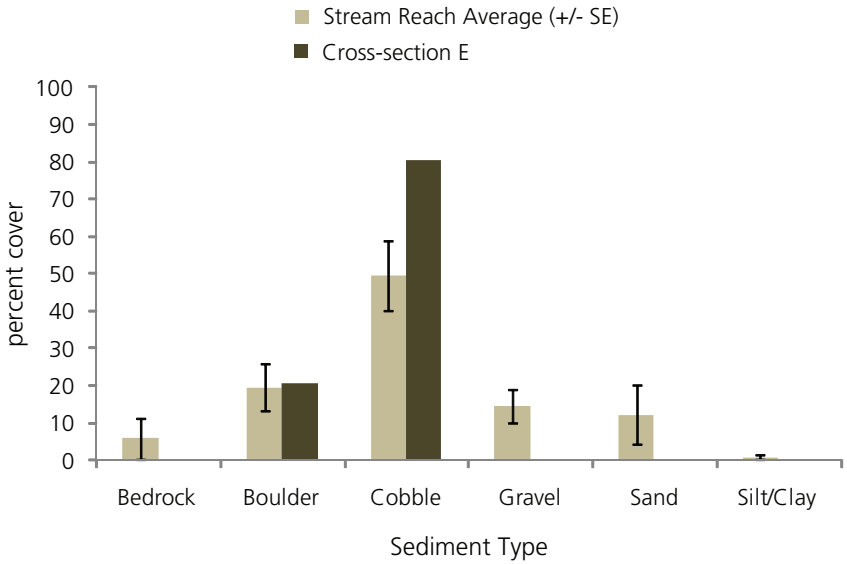
#Sediment composition estimates from 2009 are based on occular estimates of substrate cover by sediment type within 5m up and downstream of cross-section.

Montezuma Castle Cross-Section E

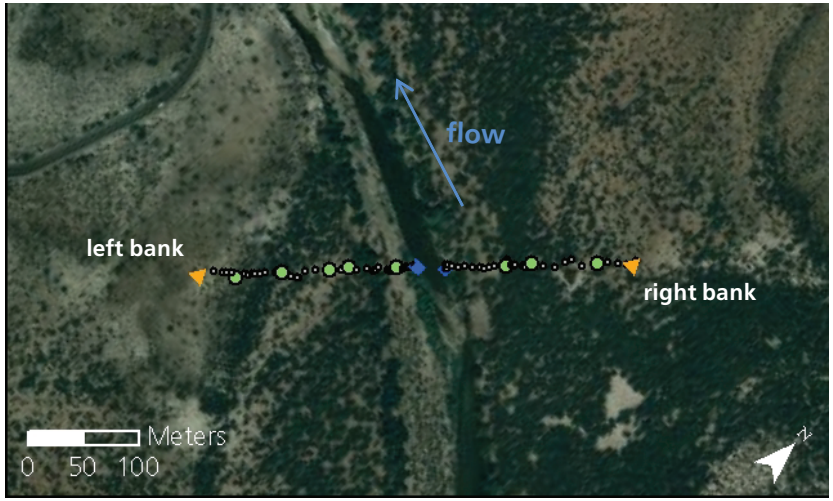
Cross-Sectional View (2010)



Sediment Composition (2009)



Plan / Aerial View (2010)



Channel Characteristics

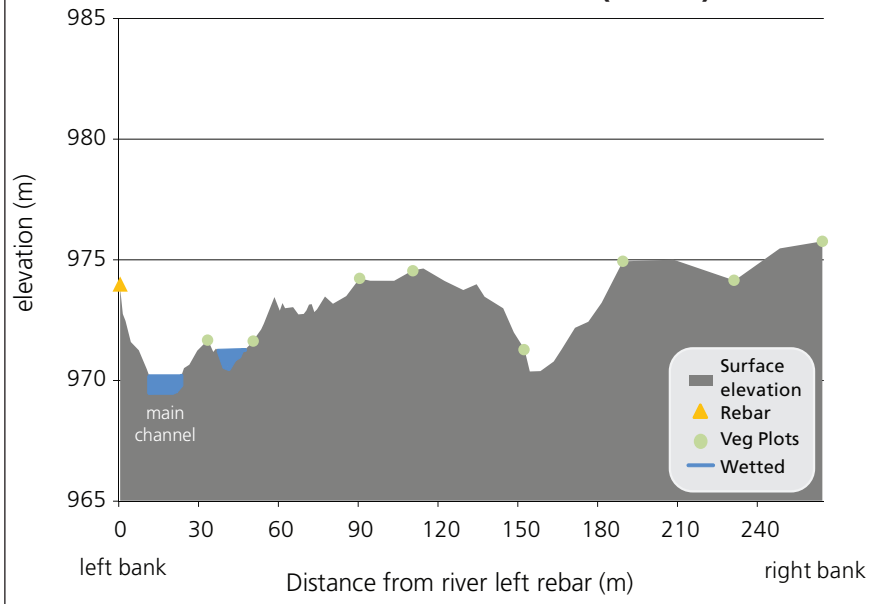
*Total Cross-Section Area (2010) = 5,255 m^2
*Water Surface Elevation (main channel; 2010) = 972 m
*Main Channel Wetted Width (2010) = 26.5 m
*Main Channel Average Wetted Depth = unknown
*Main Channel Wetted Width-Depth Ratio = unknwon
#Dominant Sediment Type (2009) = Cobble

*Beaver Creek was flowing too swiftly at the time of the 2010 survey to allow for safe measurements within the wetted area. Therefore, total cross-sectional area numbers are conservative estimates and average wetted depth and derived measures cannot be calculated. In the plots on the left, the wetted areas are based on measurements taken from the bank and do not fully represent the morphology within the wetted area.

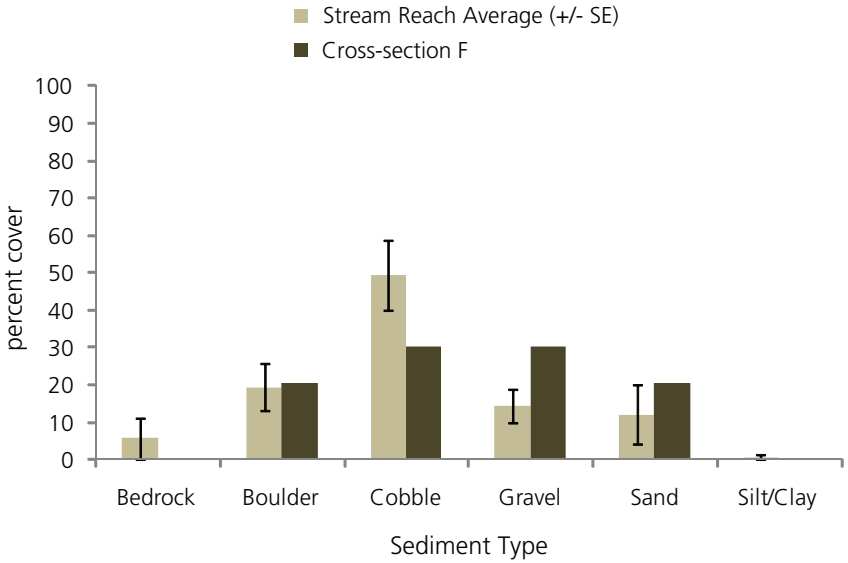
#Sediment composition estimates from 2009 are based on occular estimates of substrate cover by sediment type within 5m up and downstream of cross-section.

Montezuma Castle Cross-Section F

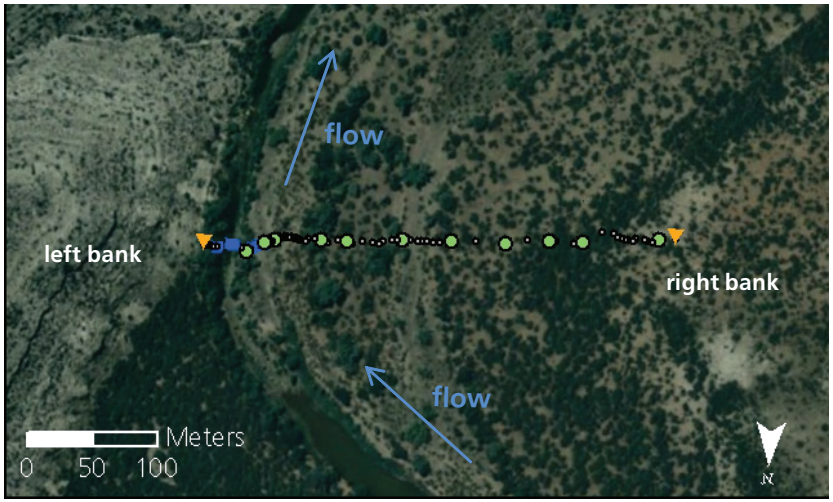
Cross-Sectional View (2010)



Sediment Composition (2009)



Plan / Aerial View (2010)



Channel Characteristics

*Total Cross-Section Area (2010) = 2328 m^2

*Water Surface Elevation (main channel; 2010) = 970 m

*Main Channel Wetted Width (2010) = 12.5 m

*Main Channel Average Wetted Depth = unknown

*Main Channel Wetted Width-Depth Ratio = unknwon

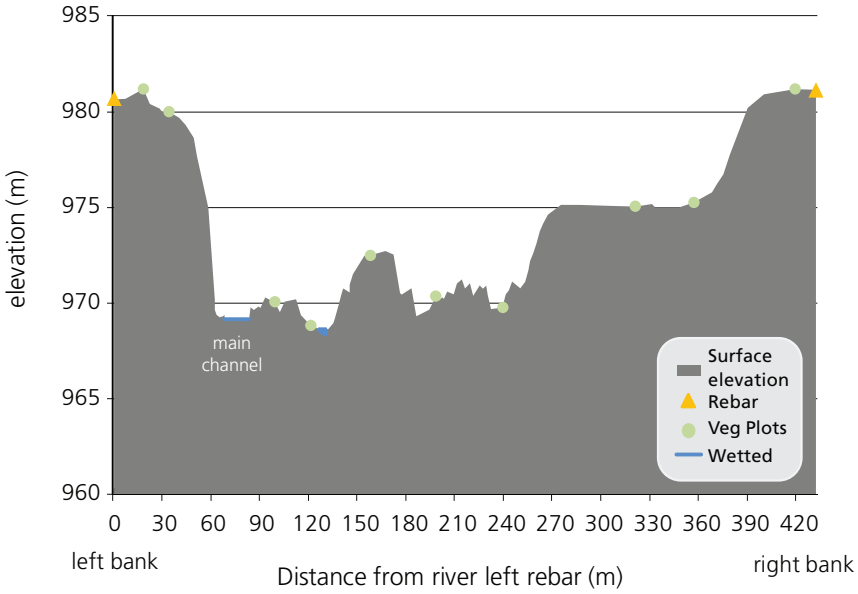
#Dominant Sediment Type (2009) = Cobble & gravel

*Beaver Creek was flowing too swiftly at the time of the 2010 survey to allow for safe measurements within the wetted area. Therefore, total cross-sectional area numbers are conservative estimates and average wetted depth and derived measures cannot be calculated. In the plots on the left, the wetted areas are based on measurements taken from the bank and do not fully represent the morphology within the wetted area.

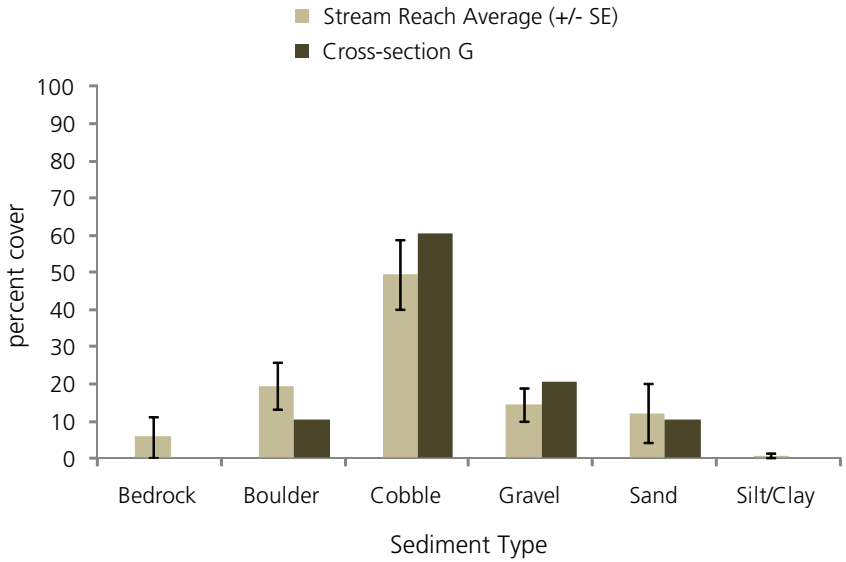
#Sediment composition estimates from 2009 are based on occular estimates of substrate cover by sediment type within 5m up and downstream of cross-section.

Montezuma Castle Cross-Section G

Cross-Sectional View (2010)



Sediment Composition (2009)



Plan / Aerial View (2010)



Channel Characteristics

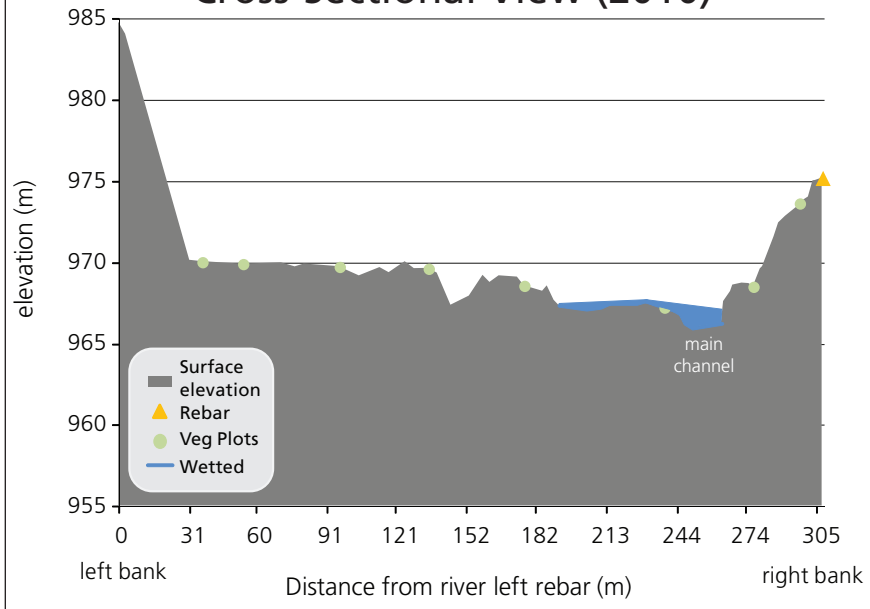
*Total Cross-Section Area (2010) = 3,033 m²
*Water Surface Elevation (main channel; 2010) = 969 m
*Main Channel Wetted Width (2010) = 15.1 m
*Main Channel Average Wetted Depth = unknown
*Main Channel Wetted Width-Depth Ratio = unknwon
#Dominant Sediment Type (2009) = Cobble

*Beaver Creek was flowing too swiftly at the time of the 2010 survey to allow for safe measurements within the wetted area. Therefore, total cross-sectional area numbers are conservative estimates and average wetted depth and derived measures cannot be calculated. In the plots on the left, the wetted areas are based on measurements taken from the bank and do not fully represent the morphology within the wetted area.

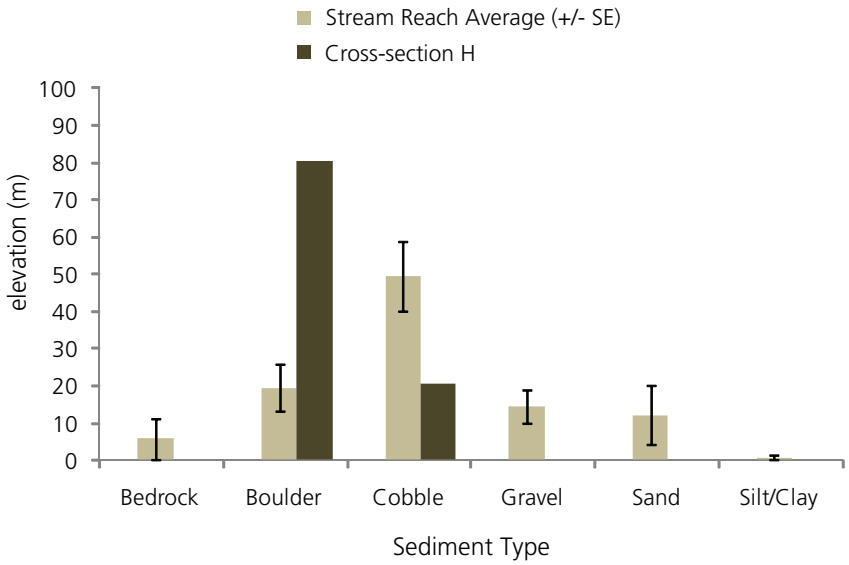
#Sediment composition estimates from 2009 are based on occular estimates of substrate cover by sediment type within 5m up and downstream of cross-section.

Montezuma Castle Cross-Section H

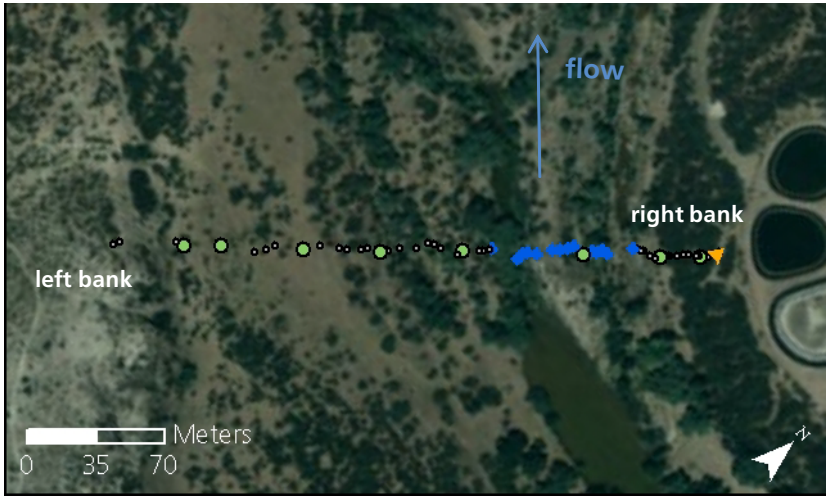
Cross-Sectional View (2010)



Sediment Composition (2009)



Plan / Aerial View (2010)



Channel Characteristics

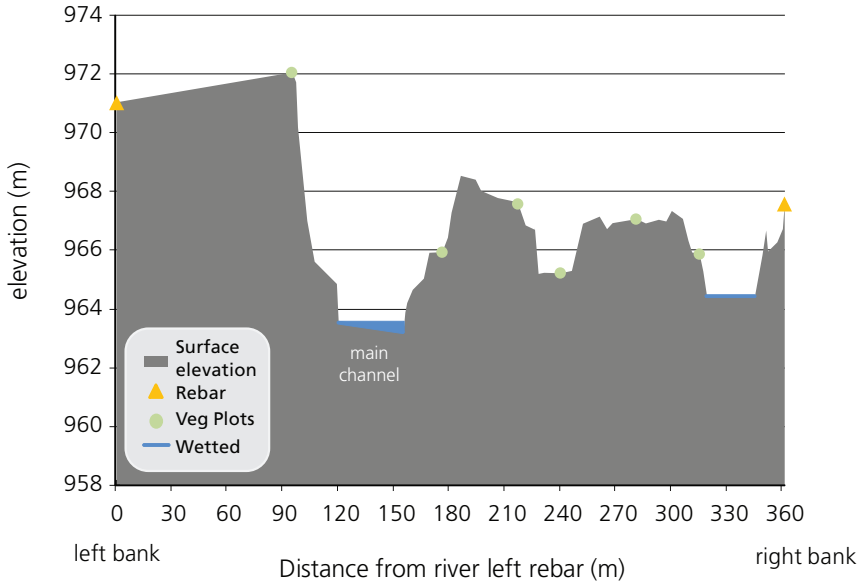
*Total Cross-Section Area (2010) = 4,557 m^2
*Water Surface Elevation (main channel; 2010) = 968 m
*Main Channel Wetted Width (2010) = 72 m
*Main Channel Average Wetted Depth = unknown
*Main Channel Wetted Width-Depth Ratio = unknwon
#Dominant Sediment Type (2009) = Cobble

*Beaver Creek was flowing too swiftly at the time of the 2010 survey to allow for safe measurements within the wetted area. Therefore, total cross-sectional area numbers are conservative estimates and average wetted depth and derived measures cannot be calculated. In the plots on the left, the wetted areas are based on measurements taken from the bank and do not fully represent the morphology within the wetted area. There is no rebar on the left bank.

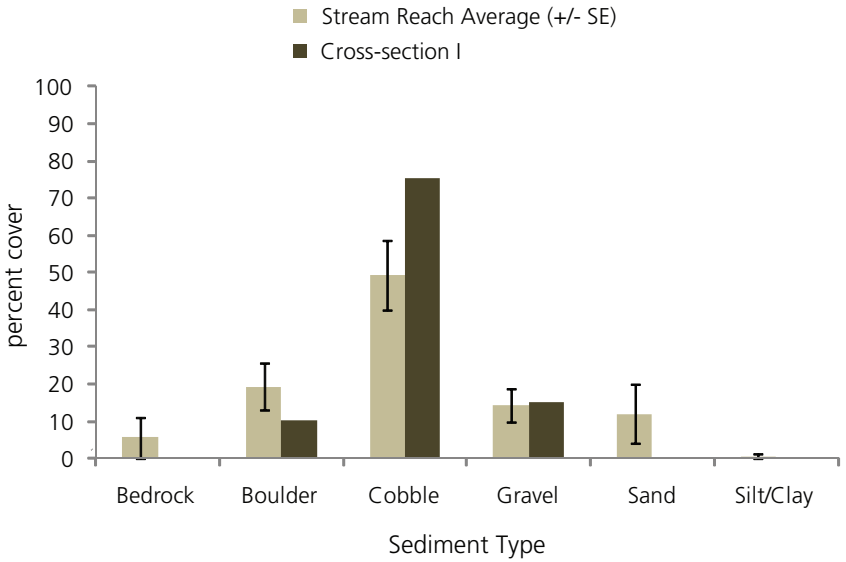
#Sediment composition estimates from 2009 are based on occular estimates of substrate cover by sediment type within 5m up and downstream of cross-section.

Montezuma Castle Cross-Section I

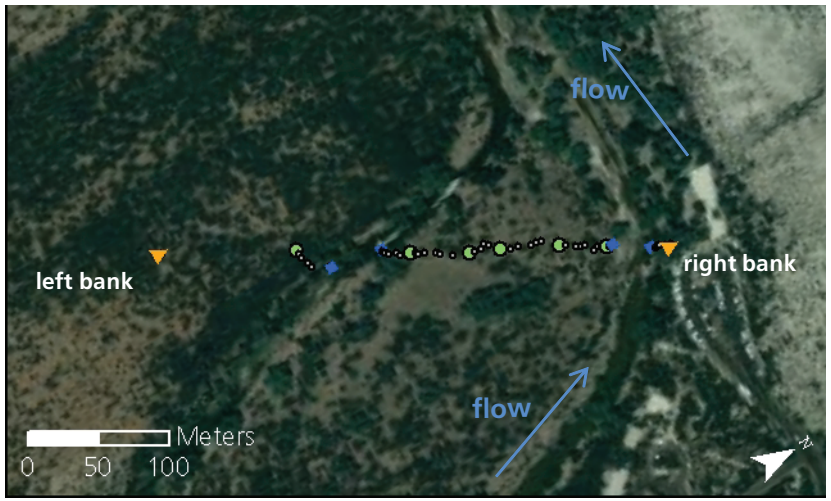
Cross-Sectional View (2010)



Sediment Composition (2009)



Plan / Aerial View (2010)



Channel Characteristics

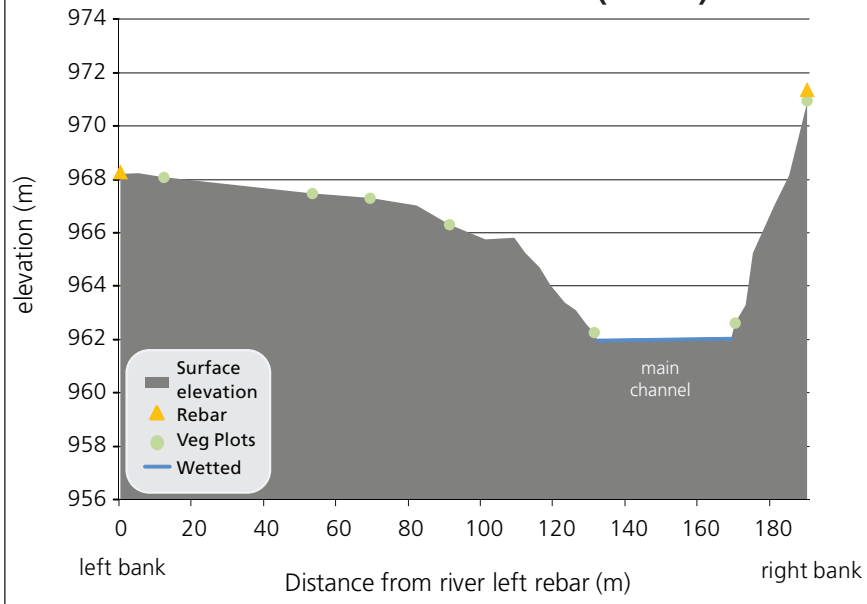
*Total Cross-Section Area (2010) = 1,301 m²
*Water Surface Elevation (main channel; 2010) = 964 m
*Main Channel Wetted Width (2010) = 35.1 m
*Main Channel Average Wetted Depth = unknown
*Main Channel Wetted Width-Depth Ratio = unknwon
#Dominant Sediment Type (2009) = Cobble

*Beaver Creek was flowing too swiftly at the time of the 2010 survey to allow for safe measurements within the wetted area. Therefore, total cross-sectional area numbers are conservative estimates and average wetted depth and derived measures cannot be calculated. In the plots on the left, the wetted areas are based on measurements taken from the bank and do not fully represent the morphology within the wetted area.

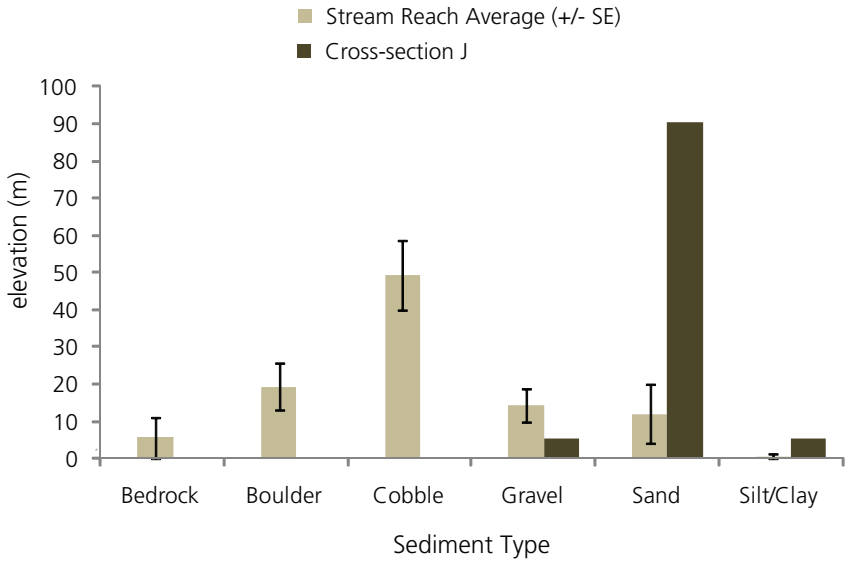
#Sediment composition estimates from 2009 are based on occular estimates of substrate cover by sediment type within 5m up and downstream of cross-section.

Montezuma Castle Cross-Section J

Cross-Sectional View (2010)



Sediment Composition (2009)



Plan / Aerial View (2010)



Channel Characteristics

*Total Cross-Section Area (2010) = 1,066 m^2

*Water Surface Elevation (main channel; 2010) = 962 m

*Main Channel Wetted Width (2010) = 37.5 m

*Main Channel Average Wetted Depth = unknown

*Main Channel Wetted Width-Depth Ratio = unknwon

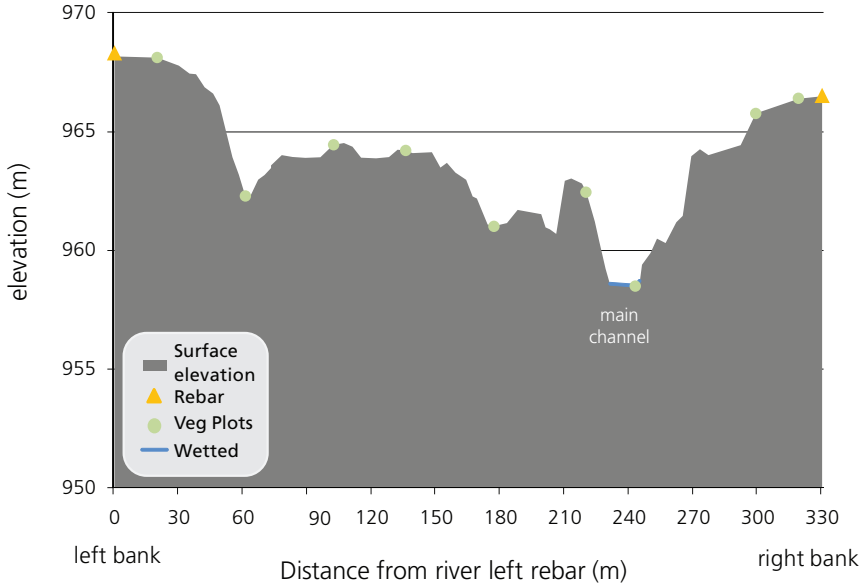
#Dominant Sediment Type (2009) = Sand

*Beaver Creek was flowing too swiftly at the time of the 2010 survey to allow for safe measurements within the wetted area. Therefore, total cross-sectional area numbers are conservative estimates and average wetted depth and derived measures cannot be calculated. In the plots on the left, the wetted areas are based on measurements taken from the bank and do not fully represent the morphology within the wetted area.

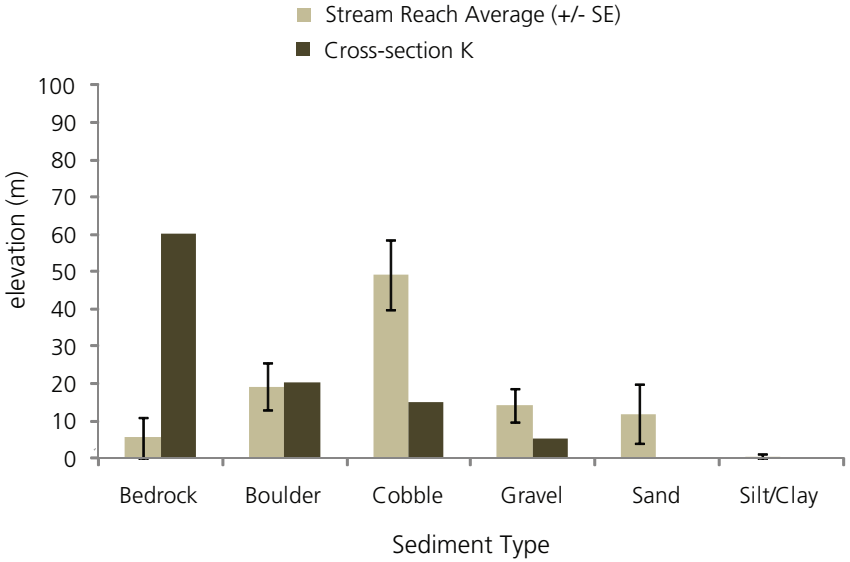
#Sediment composition estimates from 2009 are based on occular estimates of substrate cover by sediment type within 5m up and downstream of cross-section.

Montezuma Castle Cross-Section K

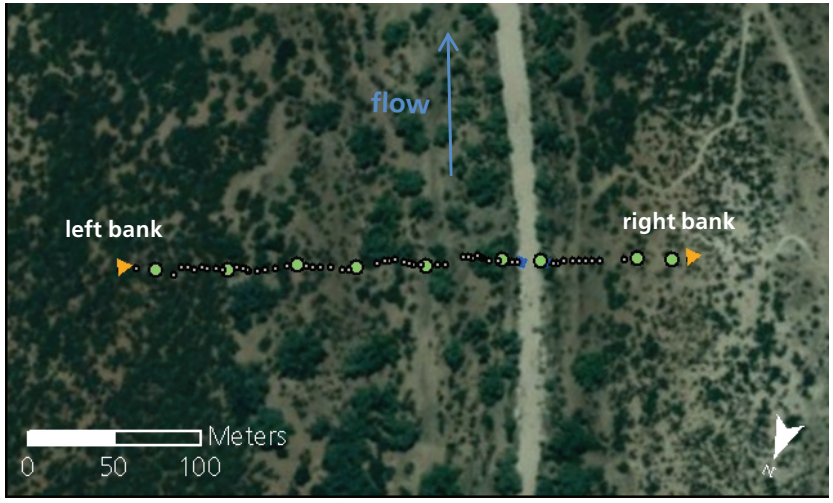
Cross-Sectional View (2010)



Sediment Composition (2009)



Plan / Aerial View (2010)



Channel Characteristics

*Total Cross-Section Area (2010) = 1495 m^2

*Water Surface Elevation (main channel; 2010) = 959 m

*Main Channel Wetted Width (2010) = 13.7 m

*Main Channel Average Wetted Depth = unknown

*Main Channel Wetted Width-Depth Ratio = unknwon

#Dominant Sediment Type (2009) = Bedrock

*Beaver Creek was flowing too swiftly at the time of the 2010 survey to allow for safe measurements within the wetted area. Therefore, total cross-sectional area numbers are conservative estimates and average wetted depth and derived measures cannot be calculated. In the plots on the left, the wetted areas are based on measurements taken from the bank and do not fully represent the morphology within the wetted area.

#Sediment composition estimates from 2009 are based on occular estimates of substrate cover by sediment type within 5m up and downstream of cross-section.

Appendix F. Riparian Vegetation Species Lists

Table F1. Riparian species, Beaver Creek, Montezuma Castle National Monument.

Scientific name	Common name
Abutilon P. Mill.	Indian mallow
Acacia constricta Benth.	whitethorn acacia
Acacia greggii Gray	catclaw acacia
Acourtia wrightii (Gray) Reveal & King	brownfoot
Agrimonia striata Michx.	roadside agrimony
Agrostis stolonifera L.	creeping bentgrass
Alga, green sp.	green algae
Allionia incarnata L.	trailing windmills
Alnus oblongifolia Torr.	Arizona alder
Alnus P. Mill	alder
Ambrosia L.	ragweed
Ambrosia psilostachya DC.	Cuman ragweed
Amorpha fruticosa L.	desert false indigo
Aristida L.	threeawn
Aristida purpurea Nutt.	purple threeawn
Aristida ternipes Cav.	spidergrass
Artemisia campestris	field sagewort
Artemisia dracunculus L.	tarragon
Artemisia L.	sagebrush
Artemisia ludoviciana Nutt.	white sagebrush
Astragalus allochrous Gray	halfmoon milkvetch
Astragalus L.	milkvetch
Atriplex canescens (Pursh) Nutt.	fourwing saltbush
Avena fatua L.	wild oat
Baccharis emoryi Gray	Emory's baccharis
Baccharis L.	baccharis species
Baccharis salicifolia (Ruiz & Pavón) Pers.	mule's fat
Baccharis sarothroides Gray	desertbroom
Baileya multiradiata Harvey & Gray *ex* Gray	desert marigold
Berberis haematocarpa Wooton	red barberry
Bidens laevis (L.) B.S.P.	smooth beggartick
Boerhavia L.	boerhavia
Bouteloua curtipendula (Michx.) Torr.	sideoats grama
Bouteloua eriopoda (Torr.) Torr.	black grama
Brassica L.	mustard
Brickellia californica (Torr. & Gray) Gray	California brickellbush
Brickellia ElL.	brickellbush
Brickellia floribunda Gray	Chihuahuan brickellbush
Bromus diandrus Roth	ripgut brome
Bromus hordeaceus L.	soft brome
Bromus rubens L.	red brome
Bromus tectorum L.	cheatgrass

Table F1. Riparian species, Beaver Creek, Montezuma Castle National Monument, cont.

Scientific name	Common name
Calliandra Benth.	fairy duster
Calliandra humilis Benth.	dwarf stickpea
Calochortus Pursh	mariposa lily
Carex aquatilis Wahlenb.	water sedge
Celtis laevigata Willd. var. *reticulata* (Torr.) L.D. Benson	netleaf hackberry
Centaurea melitensis L.	Maltese star-thistle
Chaetopappa ericoides (Torr.) Nesom	rose heath
Chilopsis linearis (Cav.) Sweet	desert willow
Croton texensis (Klotzsch) MuelL.-Arg.	Texas croton
Cuscuta indecora Choisy	bigseed alfalfa dodder
Cyclospermum leptophyllum (Pers.) Sprague *ex* Britt. & Wilson	marsh parsley
Cylindropuntia (Engelm.) Kreuzinger	cholla
Cynodon dactylon (L.) Pers.	Bermudagrass
Dasyochloa pulchella (Kunth) Willd. *ex* Rydb.	low woollygrass
Datura L.	jimsonweed
Datura wrightii Regel	sacred thorn-apple
Echinocereus fendleri (Engelm.) F. Seitz	pinkflower hedgehog cactus
Echinopepon wrightii (Gray) S. Wats.	wild balsam apple
Eleocharis parishii Britt.	Parish's spikerush
Eleocharis R. Br.	spikerush
Eleocharis rostellata (Torr.) Torr.	beaked spikerush
Elymus	wild rye
Elymus elymoides (Raf.) Swezey	squirreltail
Elymus trachycaulus (Link) Gould *ex* Shinners	slender wheatgrass
Enneapogon desvauxii Desv. *ex* Beauv.	nineawn pappusgrass
Ephedra trifurca Torr. *ex* S. Wats.	longleaf jointfir
Equisetum hyemale L.	scouringrush horsetail
Equisetum L.	horsetail
Erigeron divergens Torr. & Gray	spreading fleabane
Erigeron L.	fleabane
Eriogonum davidsonii Greene	Davidson's buckwheat
Eriogonum trichopes Torr.	little deserttrumpet
Eriogonum wrightii Torr. *ex* Benth.	bastardsage
Erodium cicutarium (L.) L'Hér. *ex* Ait.	redstem stork's bill
Erodium L'Hér. *ex* Ait.	stork's bill
Fraxinus velutina Torr.	velvet ash
Galium L.	bedstraw
Galium stellatum Kellogg	starry bedstraw
Galium wrightii Gray	Wright's bedstraw
Gaura hexandra Ortega	harlequinbush
Glandularia bipinnatifida (Nutt.) Nutt.	Dakota mock vervain
Gutierrezia sarothrae (Pursh) Britt. & Rusby	broom snakeweed
Hedeoma nana (Torr.) Briq.	dwarf false pennyroyal

Table F1. Riparian species, Beaver Creek, Montezuma Castle National Monument, cont.

Scientific name	Common name
Heterotheca villosa (Pursh) Shinners	hairy false goldenaster
Hordeum L.	barley
Hydrocotyle verticillata Thunb.	whorled marshpennywort
Ipomopsis longiflora (Torr.) V. Grant	flaxflowered ipomopsis
Juniperus L.	juniper
Juniperus monosperma (Engelm.) Sarg.	oneseed juniper
Juniperus osteosperma (Torr.) Little	Utah juniper
Krameria erecta Willd. *ex* J.A. Schultes	littleleaf ratany
Krameria L.	ratany
Larrea tridentata (Sessé & Moc. *ex* DC.) Coville	creosote bush
Linaria dalmatica (L.) P. Mill.	Dalmatian toadflax
Lolium L.	ryegrass
Lotus corniculatus L.	birdfoot deervetch
Lupinus concinnus J.G. Agardh	scarlet lupine
Lycium pallidum Miers	pale desert-thorn
Marrubium vulgare L.	horehound
Melilotus officinalis (L.) Lam.	yellow sweetclover
Mentha spicata L.	spearmint
Mentzelia L.	blazingstar
Mimosa aculeaticarpa Ortega	catclaw mimosa
Mimulus	monkey flower
Mimulus rubellus Gray	little redstem monkeyflower
Mirabilis L.	four o'clock
Mirabilis multiflora (Torr.) Gray	Colorado four o'clock
Muhlenbergia porteri Scribn. *ex* Beal	bush muhly
Nuttallanthus texanus (Scheele) D.A. Sutton	Texas toadflax
Oenothera caespitosa Nutt.	tufted evening-primrose
Oenothera L.	evening-primrose
Opuntia engelmannii Salm-Dyck	cactus apple
Parthenium incanum Kunth	mariola
Paspalum dilatatum Poir.	dallisgrass
Paspalum distichum L.	knotgrass
Pennisetum setaceum (Forsk.) Chiov.	crimson fountaingrass
Phaseolus angustissimus Gray	slimleaf bean
Phoradendron Nutt.	mistletoe
Plantago L.	plantain
Platanus wrightii S. Wats.	Arizona sycamore
Pleuraphis mutica Buckley	tobossa grass
Polanisia dodecandra (L.) DC.	redwhisker clammyweed
Polypogon monspeliensis (L.) Desf.	annual rabbitsfoot grass
Prosopis velutina Woot.	velvet mesquite
Rumex crispus L.	curly dock
Salix L.	willow

Table F1. Riparian species, Beaver Creek, Montezuma Castle National Monument, cont.

Scientific name	Common name
Salsola kali L.	Russian thistle
Schedonorus phoenix (Scop.) Holub	tall fescue
Schoenoplectus (Rchb.) Palla	bulrush
Schoenoplectus tabernaemontani (K.C. Gmel.) Palla	softstem bulrush
Setaria leucopila (Scribn. & Merr.) K. Schum.	streambed bristlegrass
Solanum elaeagnifolium Cav.	silverleaf nightshade
Solidago L.	goldenrod
Sonchus asper (L.) Hill	spiny sowthistle
Sonchus L.	sowthistle
Sorghum halepense (L.) Pers.	Johnsongrass
Sphaeralcea St.-Hil.	globemallow
Sporobolus contractus A.S. Hitchc.	spike dropseed
Sporobolus cryptandrus (Torr.) Gray	sand dropseed
Stephanomeria Nutt.	wirelettuce
Streptanthus Nutt.	twistflower
Symphyotrichum Nees	aster
Tamarix ramosissima Ledeb.	saltcedar
Tiquilia canescens (DC.) A. Richards.	woody crinklemat
Typha latifolia L.	broadleaf cattail
Urochloa arizonica (Scribn. & Merr.) O. Morrone & F. Zuloaga	Arizona signalgrass
Verbascum thapsus L.	common mullein
Verbesina encelioides (Cav.) Benth. & Hook. f. *ex* Gray	golden crownbeard
Xanthium strumarium L.	rough cockleburr
Yucca elata (Engelm.) Engelm.	soaptree yucca
Zannichellia palustris L.	horned pondweed
Zinnia grandiflora Nutt.	Rocky Mountain zinnia
Ziziphus obtusifolia (Hook. *ex* Torr. & Gray) Gray	lotebush

Table F2. Riparian species, Wet Beaver Creek, Montezuma Castle National Monument.

Scientific name	Common name
Abutilon parvulum Gray	dwarf Indian mallow
Acacia greggii Gray	catclaw acacia
Agave palmeri Engelm.	Palmer's century plant
Alnus oblongifolia Torr.	Arizona alder
Ambrosia L.	ragweed
Aristida ternipes Cav.	spidergrass
Artemisia L.	sagebrush
Artemisia ludoviciana Nutt.	white sagebrush
Astragalus L.	milkvetch
Atriplex canescens (Pursh) Nutt.	fourwing saltbush
Baccharis salicifolia (Ruiz & Pavón) Pers.	mule's fat
Berberis haematocarpa Wooton	red barberry
Bothriochloa barbinodis (Lag.) Herter	cane bluestem
Bouteloua curtipendula (Michx.) Torr.	sideoats grama
Bouteloua gracilis (Willd. *ex* Kunth) Lag. *ex* Griffiths	blue grama
Brickellia Ell.	brickellbush
Brickellia floribunda Gray	Chihuahuan brickellbush
Bromus hordeaceus L.	soft brome
Bromus L.	brome
Bromus rubens L.	red brome
Carex L.	sedge
Celtis ehrenbergiana (Klotzsch) Liebm.	spiny hackberry
Celtis L.	hackberry
Celtis laevigata Willd. var. *reticulata* (Torr.) L.D. Benson	netleaf hackberry
Chilopsis linearis (Cav.) Sweet	desert willow
Cirsium P. Mill.	thistle
Condalia Cav.	snakewood
Cyperus L.	flatsedge
Elymus trachycaulus (Link) Gould *ex* Shinners	slender wheatgrass
Enneapogon desvauxii Desv. *ex* Beauv.	nineawn pappusgrass
Equisetum L.	horsetail
Eragrostis intermedia A.S. Hitchc.	plains lovegrass
Erigeron L.	fleabane
Frangula betulifolia (Greene) V. Grub.	beechleaf frangula
Fraxinus velutina Torr.	velvet ash
Gutierrezia sarothrae (Pursh) Britt. & Rusby	broom snakeweed
Hedeoma nana (Torr.) Briq.	dwarf false pennyroyal
Hordeum L.	barley
Hydrocotyle verticillata Thunb.	whorled marshpennywort
Hymenoclea monogyra Torr. & Gray *ex* Gray	singlewhorl burrobrush
Juncus L.	rush
Juncus saximontanus A. Nels.	Rocky Mountain rush
Juncus torreyi Coville	Torrey's rush

Table F2. Riparian species, Wet Beaver Creek, Montezuma Castle National Monument, cont.

Scientific name	Common name
Juniperus monosperma (Engelm.) Sarg.	oneseed juniper
Machaeranthera asteroides (Torr.) Greene var. *asteroides* (Torr.) Greene	fall tansyaster
Marrubium vulgare L.	horehound
Melilotus officinalis (L.) Lam.	yellow sweetclover
Mentha spicata L.	spearmint
Mimosa aculeaticarpa Ortega	catclaw mimosa
Mimulus	monkey flower
Mirabilis L.	four o'clock
Pascopyrum smithii (Rydb.) A. Löve	western wheatgrass
Paspalum dilatatum Poir.	dallisgrass
Paspalum distichum L.	knotgrass
Penstemon parryi (Gray) Gray	Parry's beardtongue
Penstemon Schmidel	beardtongue
Phaseolus angustissimus Gray	slimleaf bean
Phaseolus L.	tepary bean
Plantago L.	plantain
Platanus wrightii S. Wats.	Arizona sycamore
Pleuraphis mutica Buckley	tobossa grass
Polanisia dodecandra (L.) DC.	redwhisker clammyweed
Polygonum persicaria L.	spotted ladysthumb
Polypogon monspeliensis (L.) Desf.	annual rabbitsfoot grass
Populus fremontii S. Wats.	Fremont cottonwood
Prosopis velutina Woot.	velvet mesquite
Rhus trilobata Nutt.	skunkbush sumac
Rhus virens Lindheimer *ex* Gray	evergreen sumac
Salix exigua Nutt.	narrowleaf willow
Salix L.	willow
Salsola kali L.	Russian thistle
Schedonorus phoenix (Scop.) Holub	tall fescue
Solidago L.	goldenrod
Sonchus L.	sowthistle
Sorghum halepense (L.) Pers.	Johnsongrass
Sphaeralcea rusbyi Gray	Rusby's globemallow
Sphaeralcea St.-Hil.	globemallow
Tamarix ramosissima Ledeb.	saltcedar
Typha domingensis Pers.	southern cattail
Typha L.	cattail
Verbascum thapsus L.	common mullein
Viola L.	violet
Vitis arizonica Engelm.	canyon grape
Xanthium strumarium L.	rough cockleburr
Yucca elata (Engelm.) Engelm.	soaptree yucca

Table F3. Riparian species, Verde River, Tuzigoot National Monument.

Scientific name	Common name
Agrostis	bent grass
Agrostis exarata Trin.	spike bentgrass
Ailanthus altissima (P. Mill.) Swingle	tree of heaven
Allionia incarnata L.	trailing windmills
Alnus oblongifolia Torr.	Arizona alder
Ambrosia L.	ragweed
Ambrosia psilostachya DC.	Cuman ragweed
Aristida purpurea Nutt.	purple threeawn
Aristida ternipes Cav.	spidergrass
Artemisia campestris	field sagewort
Artemisia dracunculus L.	tarragon
Artemisia L.	sagebrush
Arundo donax L.	giant reed
Baccharis salicifolia (Ruiz & Pavón) Pers.	mule's fat
Baccharis sarothroides Gray	desertbroom
Berberis haematocarpa Wooton	red barberry
Bidens L.	beggartick
Brickellia californica (Torr. & Gray) Gray	California brickellbush
Brickellia floribunda Gray	Chihuahuan brickellbush
Bromus arizonicus (Shear) Stebbins	Arizona brome
Bromus diandrus Roth	ripgut brome
Bromus L.	brome
Bromus rubens L.	red brome
Bromus tectorum L.	cheatgrass
Carex L.	sedge
Carex senta Boott	swamp carex
Celtis laevigata Willd. var. *reticulata* (Torr.) L.D. Benson	netleaf hackberry
Chilopsis linearis (Cav.) Sweet	desert willow
Cuscuta L.	dodder
Cuscuta umbellata Kunth	flatglobe dodder
Cynodon dactylon (L.) Pers.	Bermudagrass
Datura wrightii Regel	sacred thorn-apple
Distichlis spicata (L.) Greene	inland saltgrass
Echinochloa colona (L.) Link	jungle rice
Eleocharis R. Br.	spikerush
Equisetum arvense L.	field horsetail
Equisetum L.	horsetail
Equisetum laevigatum A. Braun	smooth horsetail
Eragrostis lehmanniana Nees	Lehmann lovegrass
Eriogonum Michx.	buckwheat
Eriogonum palmerianum Reveal	Palmer's buckwheat
Fraxinus velutina Torr.	velvet ash
Gaura coccinea Nutt. *ex* Pursh	scarlet beeblossom

Table F3. Riparian species, Verde River, Tuzigoot National Monument, cont.

Scientific name	Common name
Gnaphalium palustre Nutt.	western marsh cudweed
Grindelia Willd.	gumweed
Gutierrezia sarothrae (Pursh) Britt. & Rusby	broom snakeweed
Helianthus annuus L.	common sunflower
Hordeum jubatum L.	foxtail barley
Hydrocotyle verticillata Thunb.	whorled marshpennywort
Juncus torreyi Coville	Torrey's rush
Lactuca serriola L.	prickly lettuce
Lotus corniculatus L.	birdfoot deervetch
Machaeranthera asteroides (Torr.) Greene var. *asteroides* (Torr.) Greene	fall tansyaster
Marrubium vulgare L.	horehound
Melilotus officinalis (L.) Lam.	yellow sweetclover
Mentha spicata L.	spearmint
Mentzelia multiflora (Nutt.) Gray	Adonis blazingstar
Mimulus guttatus DC.	seep monkeyflower
Mirabilis L.	four o'clock
Morus microphylla Buckl.	Texas mulberry
Muhlenbergia asperifolia (Nees & Meyen *ex* Trin.) Parodi	scratchgrass
Oenothera L.	evening-primrose
Opuntia engelmannii Salm-Dyck	cactus apple
Paspalum distichum L.	knotgrass
Plantago lanceolata L.	narrowleaf plantain
Plantago virginica L.	Virginia plantain
Polygonum persicaria L.	spotted ladysthumb
Polypogon Desf.	polypogon
Polypogon monspeliensis (L.) Desf.	annual rabbitsfoot grass
Populus fremontii S. Wats.	Fremont cottonwood
Prosopis velutina Woot.	velvet mesquite
Ranunculus L.	buttercup
Rumex crispus L.	curly dock
Salix exigua Nutt.	narrowleaf willow
Salix gooddingii Ball	Goodding's willow
Salix L.	willow
Salsola kali L.	Russian thistle
Sarcostemma cynanchoides Dcne.	fringed twinevine
Schoenoplectus acutus (MuhL. *ex* Bigelow) A.& D. Löve	hardstem bulrush
Schoenoplectus americanus (Pers.) Volk. *ex* Schinz & R. Keller	chairmaker's bulrush
Setaria Beauv.	bristlegrass
Sonchus asper (L.) Hill	spiny sowthistle
Sonchus L.	sowthistle
Sporobolus cryptandrus (Torr.) Gray	sand dropseed
Symphyotrichum divaricatum (Nutt.) Nesom	southern annual saltmarsh aster
Tamarix ramosissima Ledeb.	saltcedar

Table F3. Riparian species, Verde River, Tuzigoot National Monument, cont.

Scientific name	Common name
Typha domingensis Pers.	southern cattail
Typha L.	cattail
Verbascum thapsus L.	common mullein
Vitis arizonica Engelm.	canyon grape
Xanthium strumarium L.	rough cockleburr

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NPS 309/124571, 378/124571, May 2014

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U.S. Department of the Interior

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