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Natural Resource Stewardship and Science

Riparian Monitoring of Wadeable Streams Protocol for Park Units in the Northern Colorado Plateau Network

Version 1.05

Natural Resource Report NPS/NCPN/NRR—2018/1636

ON THE COVER

Armstrong Canyon, Natural Bridges National Monument. NPS photo.

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Prepared by
Rebecca Weissinger
Dana Witwicki
Helen Thomas
Aneth Wight
Katrina Lund
Matthew Van Grinsven

Northern Colorado Plateau Network
National Park Service
P.O. Box 848
Moab, UT 84532

Editing and Design
Alice Wondrak Biel
Northern Colorado Plateau Network
National Park Service
P.O. Box 848
Moab, UT 84532

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Acronyms

ARCH	Arches National Park
ASCII	American Standard Code for Information Interchange
BLCA	Black Canyon of the Gunnison National Park
CANY	Canyonlands National Park
CARE	Capitol Reef National Park
CPR	cardiopulmonary resuscitation
dbh	diameter at breast height
DINO	Dinosaur National Monument
EFVR	East Fork Virgin River
EPA	Environmental Protection Agency
FGDC	Federal Geographic Data Committee
GPS	global positioning system
GRTS	Generalized Random Tessellation Stratified
I&M	Inventory and monitoring
NABR	Natural Bridges National Monument
NCPN	Northern Colorado Plateau Network
NP	national park
NPS	National Park Service
NM	national monument
QA/QC	quality assurance/quality control
SOP	standard operating procedure
USGS	United States Geological Survey
WACC	Western Archeological and Conservation Center
ZION	Zion National Park

Executive Summary

Because of the scarcity of water on the Colorado Plateau and their disproportionately high use by flora and fauna, riparian areas were quickly identified as an ecosystem of concern for Northern Colorado Plateau Network (NCPN) parks during vital signs planning in 2003. Four vital signs were selected for riparian monitoring of wadeable streams: surface flow, groundwater dynamics, channel geomorphology, and riparian vegetation structure and composition.

This monitoring protocol consists of a protocol narrative and 15 standard operating procedures (SOPs) for monitoring wadeable streams in NCPN parks. The overall goal of NCPN wadeable streams monitoring is to determine long-term trends in hydrologic, geomorphic, and vegetation properties in the context of changes in other ecological drivers, stressors, and processes. Specific objectives of the riparian monitoring protocol for wadeable streams are to determine status and trends in surface and groundwater dynamics, geomorphic pro-cesses as reflected in channel and floodplain form, and vegetation dynamics.

The protocol narrative describes the sampling design for wadeable streams, which comprises the response design (data collection methods), spatial design (the population of interest and sampling locations within this population), and revisit design (timing and frequency of visits to sampling locations). It also outlines field methods for establishing a reach, and for measuring vegetation, geomorphology, and hydrology of wadeable streams. Details may be found in the SOPs, which are listed in Chapter 1 and available at irma.nps.gov. Other aspects of the protocol summarized in the narrative include procedures for data management and reporting, personnel and operating requirements, and instructions for how to revise the protocol.

Acknowledgements

Many people contributed to the development of this protocol, and several standard operating procedures were derived from established monitoring protocols. Aspects of the sampling design were inspired by the work of Faith Fitzpatrick, David Peck, and their colleagues. Vegetation sampling methods were adapted from the work of Jeff Herrick and colleagues and the U.S. Forest Service Forest Inventory and Analysis protocols. Michael Scott and Elizabeth Reynolds evaluated vegetation field methods for this protocol. Kenny Demeurichy, Joe Wheaton, Ellen Soles, Paul "Zeke" Lauck, Greg Auble, and Mike Martin provided valuable surveying expertise. Steve Garman greatly assisted in developing the survey design strategy. Gwen Gerber, David Thoma, Eric Starkey, and Dean Tucker provided insightful reviews on hydrologic aspects of the protocol. Steve Monroe provided mentoring throughout protocol development. Cynthia Dott and Marie Denn provided thorough and thoughtful reviews of this entire protocol.

Protocol Narrative

Revision History Log

Previous version #	Revision date	Author	Changes made	Reason for change	New version #
1.00	11/2011	D. Witwicki	Updated terminology for headpins/transect ends; updated methods	Previous version unclear; no longer sampling species richness	1.01
1.01	1/2013	R. Weissinger, D. Witwicki	Grammatical corrections; method clarifications; removed greenline sampling; added rationale for spatial & revisit designs	Response to peer review; greenline sampling not repeatable	1.02
1.02	7/2013	H. Thomas	Revised section 5.2 (data model)	To expand upon the management of hydrology and geomorphology data	1.03
1.03	9/2016	H. Thomas, R. Weissinger, D. Witwicki	Made minor edits to section 5.0 (Data Management); updated timing of manual flow measurements; changed gradient to channel slope; added section on modifications to the sampling design and updated related sections of reporting and analysis	To reflect current data management and hydrology practices and current sampling design strategy	1.04
1.04	4/2017	A. W. Biel	Minor editorial	Preparation for publication	1.05

1 Background

This monitoring protocol consists of this protocol narrative and the following standard operating procedures (SOPs), available at https://irma.nps.gov/DataStore/Reference/Profile/2252726:

SOP 1: Preparations for the Field Season and Equipment Needed

SOP 2: Hiring and Training Field Technicians

SOP 3: Using Global Positioning System (GPS) Units

SOP 4: Establishing the Reach and Setting up Transects

SOP 5: Repeat Photos

SOP 6: Measuring Vegetation and Surface Cover

SOP 7: Assessing Channel Substrate Particle Size Distribution Using a Pebble Count

SOP 8: Site Impact Assessment

SOP 9: Stream Channel Surveying

SOP 10: Well Installation and Hydrologic Monitoring

SOP 11: After Each Field Visit

SOP 12: After the Field Season

SOP 13: Data Management

SOP 14: Data Analysis and Reporting

SOP 15: Revising the Protocol Narrative and SOPs

The core mission of the National Park Service (NPS) is to preserve and protect natural and cultural resources for the enjoyment of future generations. The NPS Inventory and Monitoring (I&M) Division was created to provide managers with credible scientific information about park natural resources. The Northern Colorado Plateau Network (NCPN) serves 16 national park units throughout Utah, western Colorado, southwestern Wyoming, and northern Arizona.

In 2003, NCPN staff solicited input on natural resources of concern and ecosystem indicators known as "vital signs" from several hundred NPS staff and regional and national experts (O'Dell et al. 2005). Potential vital signs were evaluated for management significance and utility, ecological significance, scientific validity, feasibility and cost of implementation, and signal-to-noise ratio. Because of the scarcity of water on the Colorado Plateau and their disproportionately high use by flora and fauna, riparian areas were quickly identified as an ecosystem of concern for network parks.

Four vital signs were selected for riparian monitoring of wadeable streams:

1. surface flow,
2. groundwater dynamics,
3. channel geomorphology, and
4. riparian vegetation structure and composition.

Following the determination of network-wide vital signs, parks were asked to select their top priorities for monitoring. Four parks selected riparian monitoring of wadeable streams and chose a wadeable stream for sampling: Arches National Park (NP; Courthouse Wash), Capitol Reef NP (Fremont River), Natural Bridges National Monument (NM; Armstrong Canyon), and Zion NP (East Fork Virgin River). Related monitoring efforts at additional parks are included in separate protocols, including water quality (Thoma et al. 2009) and big rivers monitoring (in development).

1.1 Riparian areas as a focus for monitoring efforts

With some minor modifications, the text in this section is from Scott and others (2005), a report written to support the development of this protocol.

Riparian zones occupy a tiny fraction of the desert southwest landscape, yet they contribute disproportionately to regional biodiversity (Gregory et al. 1991; Naiman and Decamps 1997). A meta-analysis estimated that over 60% of species found in arid-region riparian areas are not found in adjacent upland habitats (Sabo et al. 2005). Approximately 77% of amphibian, 80% of mammal, and 90% of bird species in the southwest routinely use riparian areas for food, water, or cover (Brown et al. 1977). In addition, southwestern riparian zones are key stopovers for many North American migratory bird species (Skagen et al. 1998). Riparian vegetation contributes litter and woody debris to aquatic ecosystems, creating the foundation for in-stream food webs (Vannote et al. 1980). Other key riparian ecosystem services include improving water quality via sediment trapping (Pearce et al. 1998; Tabacchi et al. 1998), preventing erosion through bank stabilization (Beeson and Doyle 1995; Simon and Collison 2002), and reducing flood power (Birkeland 2002). The aesthetic qualities of riparian areas also make them attractive to park visitors.

By definition, riparian ecosystems are situated where upland and aquatic systems meet. As such, they are potentially sensitive indicators of landscape-level environmental change (Naiman et al. 1988). Studies on the Colorado Plateau record change in geomorphic process and riparian structure coincident with climate-related shifts in regional precipitation patterns (Hereford 1984; Hereford et al. 1996; Allred and Schmidt 1999) and land-use changes (Poff et al. 1997). Riparian ecosystems are directly influenced by a river or a stream through enhanced water supply, flooding, and erosional and depositional processes (Brinson et al. 1981).

At the same time, upland disturbance processes, across a range of scales, impose direct and indirect effects on riparian ecosystems. For example, at finer scales, debris flow and landslide disturbances impinge directly on narrow riparian zones in steep terrain. At larger scales, indirect effects of climate change and land-use practices, such as grazing and land-clearing, which degrade upland soil stability and reduce vegetation cover, alter the delivery of water and sediment to receiving streams (Trimble and Mendel 1995). This, in turn, alters the rate, magnitude, and direction of channel processes, which ultimately structure and maintain riparian ecosystems (Frissell et al. 1986). Consistent, long-term monitoring of key physical and biological elements of riparian ecosystems can provide important insights into the effects of human land and water use activities across a range of spatial scales.

A hallmark of riparian ecosystems on the Colorado Plateau is their resilience to frequent and sometimes intense physical disturbances. Rapid recovery of the structural and functional elements of riparian ecosystems following disturbance is distinct from the observed recovery of upland ecosystems in arid and semi-arid regions, where productivity is typically lower and plant recruitment is slower and more episodic (Scott et al. 2005).

High rates of recovery in riparian ecosystems result primarily from adequate moisture, which supports relatively high rates of productivity; high linear connectivity, which allows for rapid re-colonization of disturbed sites from upstream and downstream refugia; and disturbance-adapted species, whose life-history characteristics allow them to re-establish and re-colonize quickly following disturbance groups (Scott et al. 2005). These characteristics, along with the predominance of woody vegetation, contribute significantly to regional species richness (γ-diversity) by serving as habitat for plant and animal species not found in surrounding uplands (Brinson et al. 1981; Sabo et al. 2005; Hylander 2006; Sabo and Soykan 2006).

Thus, relatively healthy, naturally functioning riparian ecosystems of the Colorado Plateau are characterized by (1) surface flow variability, (2) active erosional and depositional processes, and (3) relatively shallow alluvial groundwater, which together create (4) topographically diverse alluvial surfaces representing gradients of moisture, nutrient availability, and disturbance frequency and intensity—which, in turn, structure (5) a successional patchwork of riparian plant and animal communities representing a diversity of structural and functional groups (Scott et al. 2005). Figure 1-1 presents a site-specific conceptual model of riparian ecosystems typical of the Colorado Plateau.

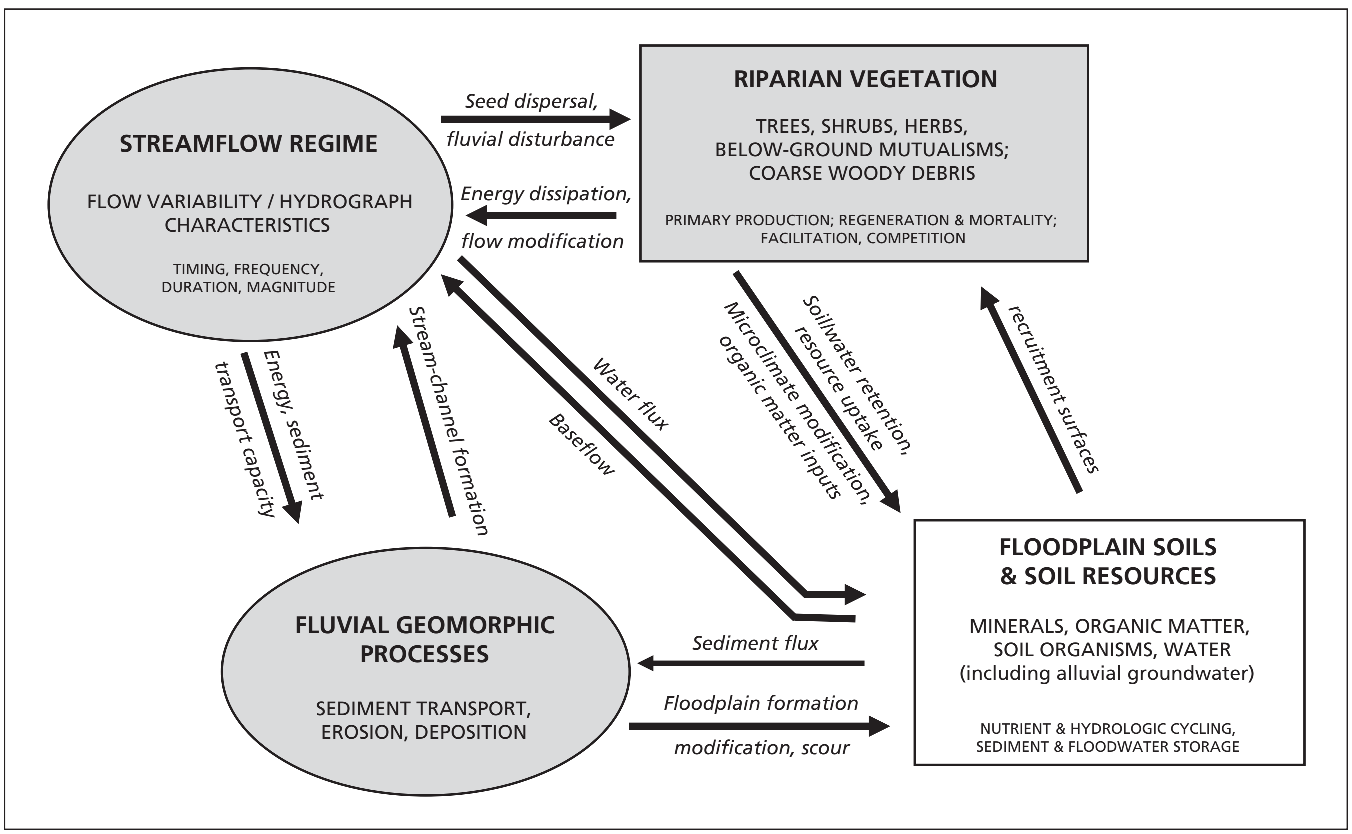

Figure 1-1. A general conceptual model of reach-scale relationships among physical and biotic components of riparian ecosystems of the Colorado Plateau. Ovals represent major drivers of ecosystem change and variability. Squares represent important structural components and processes. Arrows describe functional relationships among system components. The model is constrained by state factors, including global climate, topography, geology, time, and potential biota. From Scott and others (2005).

1.1.1 Surface flow

The natural flow regime paradigm holds that natural flow variability is primarily responsible for structuring and maintaining the physical and biotic integrity of aquatic and riparian ecosystems (Richter et al. 1996; Stanford et al. 1996; Poff et al. 1997). Ecologically relevant elements of streamflow include the magnitude, frequency, duration, timing, and change rate of flow. Although extreme flow variation can eliminate species (Zimmerman 1969), episodic floods and droughts are necessary for persistence of others (Nilsson et al. 1991; Friedman et al. 1996). In fact, the presence of species unique to riparian ecosystems may be maintained by relatively frequent hydrologic disturbance events, which act to limit the process of competitive exclusion of species in these environments (Huston 1979). Given the potential for high-intensity (monsoon) rainfall events; steep terrain; thin, patchy soils; exposures of relatively impermeable bedrock; and sparse vegetation, the hydrographs of streams originating within the Colorado Plateau are typified by relatively high-magnitude, short-duration, temporally unpredictable stormflow hydrographs with little or no baseflow (Scott et al. 2005).

1.1.2 Alluvial groundwater

Shallow alluvial groundwater is a unique and important functional feature of riparian floodplain soils, and is directly related to surface-water dynamics. Native and non-native woody phreatophytes, such as cottonwood (*Populus* spp.), willow (*Salix* spp.), and tamarisk (*Tamarix* spp.), are dependent, to varying degrees, on shallow alluvial groundwater dynamics for establishment. Spatially complex moisture gradients resulting from floodplain topographic diversity and surface and groundwater dynamics influence the diversity of herbaceous riparian plants and soil organisms (Meinzer 1927; Scott et al. 1999; Stromberg et al. 1996; Pollock et al. 1998; Horton et al. 2001; Bagstad et al. 2005; Beauchamp 2004). Water from surface flow and associated shallow alluvial aquifers is essential to the persistence of most low-elevation woody riparian species in the southwestern U.S. Thus, an integrated understanding of surface and alluvial groundwater flows, and their interactions, is fundamental to understanding establishment and survival processes of existing riparian and wetland ecosystems (Winter 1999; Woessner 2000). On coarse substrates in dry regions, early establishment and growth of cottonwood seedlings and other woody riparian pioneer species may require groundwater within 1–2 meters of the establishment surface (McBride and Strahan 1984; Mahoney and Rood 1992; Segelquist et al. 1993; Stromberg et al. 1996), but lenses of finer alluvial material may allow preferential seedling survival without making contact with groundwater for the first few growing seasons (Cooper et al. 1999). Following initial establishment, root growth allows young trees to survive gradual groundwater declines. Depth to groundwater may increase as a result of subsequent floodplain accretion or channel incision (Everitt 1968; Hereford 1986); cottonwoods have been observed at sites where depth to groundwater is 7–9 meters (Robinson 1958). However, mature riparian species, such as cottonwood, willow, and tamarisk, are typically found in riparian settings where depth to water is <4 meters (Meinzer 1927; Scott et al. 1997; Stromberg et al. 1997; Horton et al. 2001). Close proximity to groundwater also is important in the establishment and persistence of some wetland and riparian herbs (Bagstad et al. 2005). Even modest fluctuations of groundwater levels (1.5–3 m) can induce lethal moisture stress in riparian vegetation species (Scott et al. 1999; Shafroth et al. 2000).

1.1.3 Fluvial geomorphic processes

Stream channels adjust to variations in the discharge of water and the size and amount of sediment supplied to the stream from the watershed (Leopold et al. 1964). Flow governs channel dimensions, such as width, depth, and meander patterns. Channel form is mostly determined by the amount and size of bedload, even though bedload may be a small proportion of the total sediment flux (Schumm 1981). Bedload is defined here as alluvial or river-transported sediment moving on or near the bed of a channel. In streams on the Colorado Plateau, gravel is typically a small proportion of the total sediment flux, which is primarily composed of sand, silt, and clay. Because of regional watershed characteristics contributing to high, flashy peak flows and high sediment loads, unconstrained alluvial channels of Colorado Plateau streams are typically composed of low depositional bars and the active channels are often braided.

Floodplains represent one of a number of river-deposited features and are typically composed of vertically stacked fine-grained layers of sediment left by discrete floods. By definition, floodplains are level surfaces constructed by a river under prevailing climatic conditions, and are relatively frequently inundated by high flows (Leopold 1994). However, there is no regionally consistent recurrence of inundation for these features, as is found in laterally accreting floodplains along meandering rivers in other regions. Riparian vegetation establishment and succession are intimately linked to the lateral and vertical accretion of sediments that lead to floodplain formation across a range of channel forms (Schumm and Lichty 1963; Hereford 1984).

This linkage between fluvial geomorphic processes and riparian vegetation dynamics creates the topographic diversity, soil moisture and nutrient gradients, fluvial disturbance patches, and distinctive microclimates that characterize riparian ecosystems (Tabacchi et al. 1998). The spatial extent of floodplains along rivers and streams of the Colorado Plateau is highly variable and dependent on geomorphic setting. Along channels confined by bedrock, floodplain deposits may be narrow and discontinuous, or even non-existent. In contrast, channels in large, alluvial basins may have broad, spatially extensive floodplains. Vertical aggradation of floodplains and channel incision progressively disconnect riparian surfaces from surface flow in adjacent channels, creating terraces. Remnant terrace sequences from across the arid and semi-arid western U.S., including the Colorado Plateau, record several climatically driven valley cut-and-fill cycles during the Holocene period (i.e., within the last 10,000 years) coincident with wetter and drier climate periods (Emmett 1974; Elliott et al. 1999; Miller et al. 2004).

1.1.4 Riparian vegetation

Vegetation is generally recognized as the dominant functional element in riparian ecosystems (Scott et al. 2005). In addition to conducting photosynthesis, the above-ground structure of vascular plants increases roughness and thus protects floodplain soils from widespread erosion (Tabacchi et al. 1998) and enhances the deposition and retention of nutrient-rich sediments during floods (Naiman and Decamps 1997). Litter from plants reduces the erosive impacts of rainfall on soil surfaces and provides inputs to soil organic matter for nutrient cycling. Above-ground structures of riparian plants modify the physical environment by shading and depositing litter, strongly affecting spatial and temporal patterns of soil-resource availability to other organisms.

Vegetation structure contributes to the formation of microhabitats with sharp gradients of moisture and temperature, fostering biotic diversity (Gregory et al. 1991). Roots stabilize soils and stream banks (Winward 2000), are conduits for resource acquisition and redistribution, and provide organic-matter inputs to soil food webs. Vegetation also provides fuel for fire, as well as resources and habitat structure for below-ground and above-ground consumers and decomposers ranging from fungi and bacteria to birds and mammals (Brinson et al. 1981; Mitsch and Gosselink 1993). The distinctive species composition and spatial patterning of riparian vegetation is largely related to transverse or cross-valley gradients of disturbance intensity and moisture availability created primarily by variations in surface flow, depth to alluvial groundwater, topographic diversity of fluvial landforms, and valley setting (Hupp and Osterkamp 1985; Malanson 1993; Auble et al. 1994; Bendix 1994; Stromberg et al. 2006).

1.2 History of riparian research in NCPN park units

Riparian resources have been the focus of a number of studies conducted at NCPN parks (Figure 1-2). Although these park-specific studies offer valuable data, such as plant species lists, documentation of channel change,

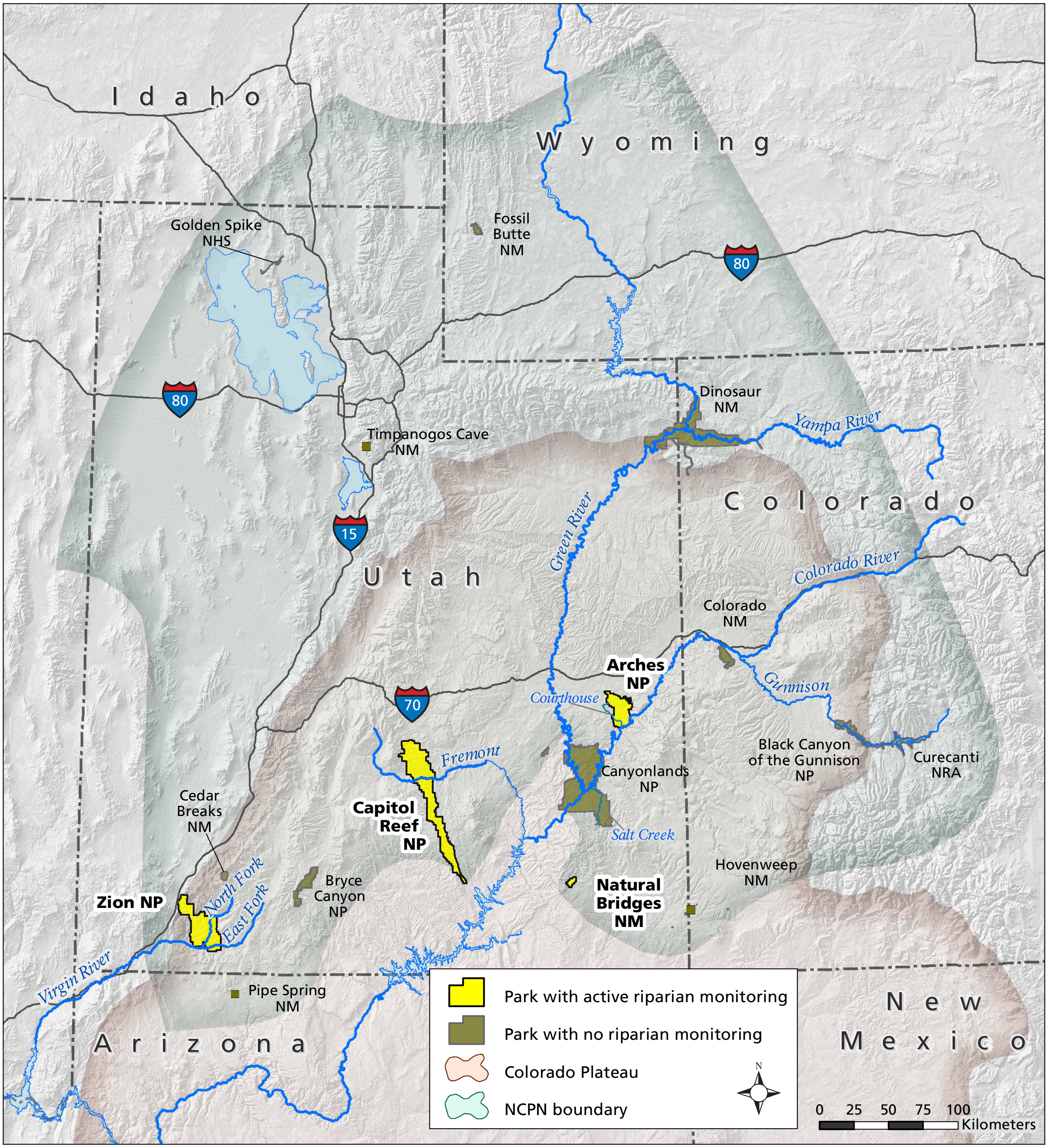

Figure 1-2. Map of park units and major drainages in the NCPN, including park units with riparian monitoring of wadeable streams.

changes in surface flow or alluvial groundwater dynamics, and information on historic conditions, few were conducted over long periods of time and even fewer have examined physical and biotic riparian resources in an integrated way.

Non-native riparian species invasions, particularly tamarisk (*Tamarix* spp.) and Russian olive (*Elaeagnus angustifolia*), have been documented, as have efforts to manage and restore riparian systems through the physical removal of these species. Birken and Cooper (2006) excavated pits through vertically accreted sediments on the lower Green River in Canyonlands National Park (NP) and aged tamarisk stems to examine patterns of tamarisk establishment and channel narrowing. On the Green River in Lodore Canyon in Dinosaur National Monument (NM), Alexander (2007) used a recently developed alluvial stratigraphic and dendrogeomorphic technique to provide a detailed history of channel change relative to flow history and the establishment and spread of tamarisk within the canyon. Ongoing surveys of channel cross-sections along the Green River in the monument (Grams and Schmidt 2002; Grams and Schmidt 2005) are incorporated in NCPN's big rivers monitoring protocol.

Simulation models were developed to predict the potential response of riparian and wetland plant species to altered flow regimes along the Gunnison River in Black Canyon of the Gunnison NP (Auble et al. 1994) and the Fremont River in Capitol Reef NP (Auble et al. 2005). Studies like these often include historical photographs that document longer-term qualitative changes in channel morphology or changes in vegetation stand structure and composition. Historical photographs with matching modern re-photographs are also documented for the North Fork Virgin River through Zion Canyon and the East Fork Virgin River through Parunuweap Canyon in Zion NP; the Green River through Stillwater Canyon in Canyonlands NP; and the Colorado River at the confluence with Courthouse Wash in Arches NP and through Meander Canyon and Cataract Canyon in Canyonlands NP (Webb et al. 2007).

Park-based monitoring efforts in the NCPN are comprised primarily of monitoring at Salt Creek in Canyonlands NP, following the 1998 closure of a road through or adjacent to the channel. A number of studies focused on Salt Creek because it is one of the most extensive riparian areas in the park, and until 1998, received heavy off-road vehicle use. Mitchell and Woodward (1993) documented the impacts of the Salt Creek road on small mammals, plants, and aquatic organisms. They compared the downstream section with a road to the upstream, roadless area, and found strong negative effects of the road on all three of these functional groups. Following road closure in 1998, Schelz (2001) monitored a variety of resources in the Salt Creek system, including vegetation composition, cover, and structure, channel morphology, aquatic macroinvertebrates, and the riparian bird community. Elmore and others (2001) found the condition of Salt Creek where the old road traverses the creek to be either non-functioning or functional-at-risk using the Bureau of Land Management's Proper Functioning Condition protocol (Prichard et al. 1998). The most recent study of Salt Creek was performed by U.S. Geological Survey (USGS) cooperators in 2009–2011, with Schelz's work forming the basis for monitoring at these locations.

2 Program Goals and Measurable Objectives

It is widely recognized that physical processes, across a range of spatial scales, control biological patterns and processes in riparian ecosystems (Frissell et al. 1986), and that biotic changes typically show a lagged response to changes in the physical system (Petts 1987). Therefore, any efforts aimed at detecting directional change in riparian ecosystems must effectively integrate measurements of the key physical variables that drive important biotic patterns and processes (Scott et al. 2005).

The overall goal of the NCPN wadeable streams monitoring program is to determine long-term trends in hydrologic, geomorphic, and vegetation properties in the context of changes in other ecological drivers, stressors, and processes. Specific objectives of the riparian monitoring protocol for wadeable streams are described below.

Determine status and trends in surface and groundwater dynamics, including:

- Depth to alluvial groundwater
- Surface flow
- Permanence of streamflow

Determine status and trends in geomorphic processes as reflected in channel and floodplain form, including:

- floodplain width and elevation
- channel width and depth
- channel planform
- channel slope
- composition of bed material

Determine status and trends in vegetation dynamics, including:

- species richness
- plant cover by life form and wetland status
- basal area and density of woody species
- canopy closure
- frequency of invasive species

Data from these objectives will be integrated to produce models, such as stage–geomorphic process relationships, and correlations, such as vegetation assemblage by geomorphic surface and depth to groundwater.

Riparian monitoring of wadeable streams additionally benefits from other vital signs monitoring and historical data. Local weather-station data can be used to interpret responses, whereas remote sensing can be used to determine change in vegetation at watershed scales caused by land use or climate change. If additional remote-sensing opportunities become available, channel sinuosity and riparian canopy connectivity will be added to the monitoring protocol. Historical flow records from gaging stations may be used to develop flood-frequency distributions for some streams. Historical photopoints will be re-located and re-photographed on a recurring basis, when possible.

3 Sampling Design

Sampling design for long-term monitoring incorporates efficient approaches to gathering data that are consistent, robust, and sufficient to achieve monitoring objectives. The sampling design for NCPN wadeable streams comprises the following components:

- Response design (data collection methods)
- Spatial design (the population of interest and sampling locations within this population)
- Revisit design (timing and frequency of visits to sampling locations).

3.1 Rationale for selected design

A common approach to riparian and aquatic monitoring is to focus efforts on a section of stream (a stream reach) and subsample the reach using cross-sectional transects (Fitzpatrick et al. 1998; Winward 2000; Heitke et al. 2010; Leary and Ebertowski 2010; Peck et al. unpublished). Geomorphology methods using channel cross-sections, channel profiles, and pebble counts are fairly standard within this framework, although the number and position of transects vary. Hydrology measures are generally recorded by using existing gage data, establishing monitoring wells, or conducting velocity measures during site visits. Vegetation methods vary considerably and must be adapted to fit regional vegetation community characteristics of patch size and heterogeneity, stand structure, and species assemblages. The integration of geomorphology, hydrology, and vegetation data follows methods developed by Stromberg and others (1996) and Lite and Stromberg (2005) that co-locate sampling of monitoring wells, geomorphic cross-sections, and vegetation measures and enable statistical correlations between subsets of data.

A USGS pilot study tested a response design for NCPN riparian vegetation monitoring that included sampling cross-sectional transects using nested frequency and cover plots, shrub line-intercept, tree-density belt transects, and a reach census for large-diameter riparian tree species (Scott and Reynolds 2007). Based on this effort, NCPN ecologists determined that nested plots were unable to capture sufficient data to monitor uncommon riparian species and were inefficient and imprecise for sampling dominant riparian species due to set-up time requirements and observer bias in foliar cover estimates. Rare species (found in only one vegetation plot) accounted for 35–47% of species totals across the four pilot-study sites, and species accumulation curves failed to approach a maximum at species-rich sites. In addition, few species (0–13.5% of total species) reached the 30–70% frequency target for monitoring (Elzinga et al. 1998) in any nested plot size. Quadrats often straddled several geomorphic surfaces (10–15% of 1-m^2 plots and 25–30% of 10-m^2 plots), making data integration difficult. In addition, narrow geomorphic surfaces, such as those often found adjacent to the channel in Colorado Plateau riparian systems, were often missed entirely.

Line-intercept captured shrub cover in much less time than nested plots. Belt transects and nested plots performed similarly in capturing tree species cover, but belt transects were sampled in less than one-third of the time needed to sample nested plots. Belt transects adequately captured stand demographics, but undersampled large trees, which were subsequently captured in a reach census.

As an alternative to plot sampling, the NCPN adopted point-intercept methods along permanent cross-sections to track changes in dominant riparian species cover (Elzinga et al. 1998; Herrick et al. 2005) and added greenline transects along perennial streambanks to increase sampling in the narrow near-channel riparian zone (Winward 2000; Leary and Ebertowski 2010). After collecting two years of data using both shrub line-intercept and point-intercept methods, shrub cover estimates were evaluated and found to differ by less than 5% (unpublished data). Thus, shrub line-intercept was dropped from the protocol because it was redundant with our point-sampling efforts. After four years of greenline sampling, a repeatable method could not be established, and this sampling was also removed from the protocol. All methods will need to be tested for their ability to detect trends once sufficient data are available.

The spatial and revisit designs used by the NCPN for wadeable streams monitoring are modeled after survey designs developed by the Environmental Protection Agency's Environmental Mapping and Assessment Program for streams (Peck et al. unpublished). Survey designs have fewer assumptions and provide more reliable and legally defensible parameter estimates than other approaches (Edwards 1998; Nusser et al. 1998). We attempt to apply these techniques at a smaller scale to efficiently monitor change in selected areas of streams in specific park units. Sampling frames are developed to make the selected areas of each stream spatially explicit, and then the Generalized Random Tessellation Stratified (GRTS) method of reach selection is used to create spatially-balanced random samples within the sampling frame. These methods produce a sample that represents the length of the stream of interest, incorporates probabilistic sampling to meet statistical assumptions, and allows flexibility to modify the sample size in the future.

3.2 Response design

The sampling unit for riparian monitoring of wadeable streams is a stream reach. Measurements of vegetation and physical drivers are co-located at each reach. A reach is 180–360 meters in length, with seven equally spaced transects that run perpendicular to the channel (Figure 3-1). The reach, as defined here, is intended to be a representative portion of a stream segment. Stream segments are typically thousands of meters in length and represent relatively uniform sets of physical, chemical, and biological conditions within a stream (Fitzpatrick et al. 1998). Stream segments are analogous to valley segments as defined in the process-oriented, hierarchical geomorphic classification of Montgomery and Buffington (1993; 1998).

Vegetation measurements occur on permanent cross-section transects (Figure 3-2) and at the reach scale (Figure 3-1). Total-station surveys of the stream channel are performed along each of the cross-section transects and following the channel thalweg throughout the reach. Surface and groundwater dynamics are measured using three wells located along one of the transects. Wells may not be installed at all reaches, and full implementation of hydrologic monitoring will be determined by management questions and funding availability.

The response design, which is essentially the

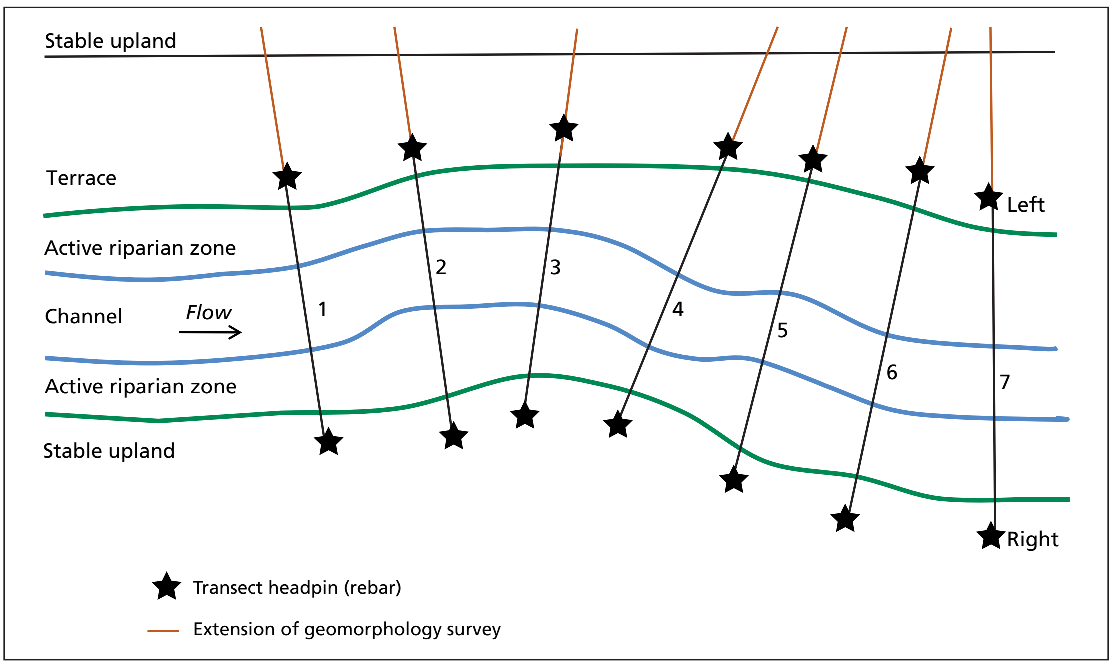

Figure 3-1. Example of a riparian monitoring reach with seven equidistant cross-section transects. "4" is the centroid, star symbols indicate locations of headpins, and the green line represents the upland–riparian zone boundary. Vegetation transects sample the active riparian zone while geomorphology transects extend to a stable upland surface.

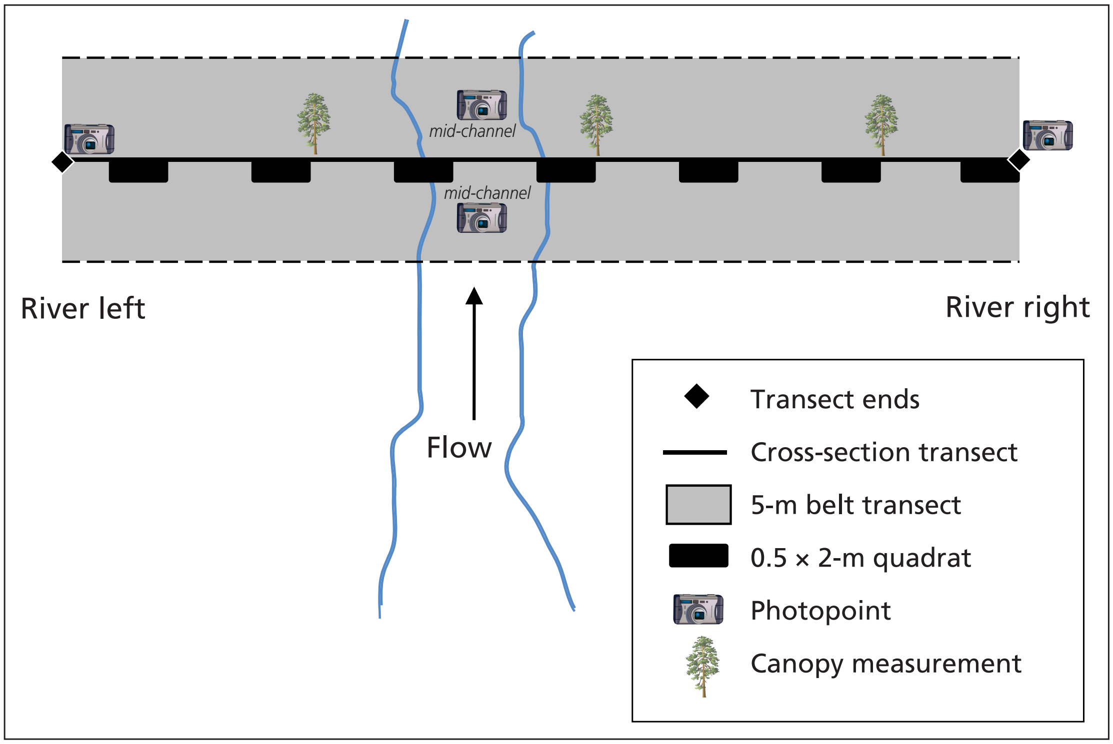

Figure 3-2. Locations of vegetation sampling along each permanent cross-section transect. Understory vegetation is sampled using a point-intercept method at 0.5-meter intervals along the cross-section. Canopy closure is sampled at 10-meter intervals on the cross-section. Seedling, sapling, and overstory tree density is recorded in a 5-meter belt transect. Exotic plant frequency is sampled in 0.5 × 2-meter quadrats. A census of large-diameter trees occurs at the reach scale.

same as the field methods, is described in detail in Chapter 4. All measures recorded along transects are subsamples scaled to the reach level. Reach-level measures are the primary values used in summaries and statistical analyses, although some measures may be integrated at the transect or geomorphic-surface level before being scaled to the reach.

3.3 Spatial design

3.3.1 Sampling frame

The focus of this protocol is wadeable streams with perennial, intermittent, or ephemeral flow regimes. *Perennial* streams have flow year-round, and retain a base flow even during dry weather periods. In contrast, *intermittent* streams have surface flow for only certain times of the year but have a shallow water table in at least portions of the stream. *Ephemeral* streams have surface flow for relatively short periods of time in direct response to precipitation. Individual streams are selected for monitoring by the park units based on management priorities (Table 3-1 and Figure 1-2).

Once a stream is selected, it is assessed for accessibility. Pourovers, large boulders, and

Table 3-1. Wadeable streams selected for monitoring.

Park	Stream name	Stream type	Length of sampling frame (km)	% of stream excluded	Reason for exclusion
Arches NP	Courthouse Wash	Intermittent	15.2	19	Above major tributary
Capitol Reef NP	Fremont River	Perennial	14.9	34	Highly managed area; constricted canyon
Natural Bridges NM	Armstrong Canyon	Ephemeral	7.4	0	N/A
Zion NP	East Fork Virgin River	Perennial	8.8	28	Inaccessible, constricted bedrock and colluvium

other obstacles that restrict access in narrow canyons are excluded from the sampling frame. In most NCPN park units, the length of streams is short enough that the entire accessible length of a stream can be included in the sampling frame. Depending on monitoring goals for a specific stream, the stream can be stratified using features that are not expected to change over the period of long-term monitoring, such as geology or watershed area.

Obvious non-target areas can be filtered out of the sampling frame (see Table 3-1). This may include bedrock or colluvial-constrained areas, and areas above or below major tributaries that do not relate to the management question of interest.

The source GIS data layer used to create the sampling frame is the 1:24,000 National Hydrography Dataset, developed by the USGS and Environmental Protection Agency (EPA). Digital coverage includes flowline geodatasets that designate the centerlines of streams. In general, streams are not stratified due to the relatively short length of streams within each park unit. This allows for inference to the entire length of the stream within the sampling frame. On the Fremont River in Capitol Reef NP, segments are stratified due to differences in geology and geomorphology that largely affect streamflow, sinuosity, and channel incision. This design allows for inference to the entire length of the stream within the sampling frame, and for each segment to be analyzed separately and compared with other segments of the stream in the sampling frame. Specific details of sampling designs are documented in a separate report for each stream. This information is also summarized in Appendix A (https://irma.nps.gov/DataStore/Reference/Profile/2252442).

Panel	Year 1	2	3	4	5	6	7	8	9	10
1	1	1	–	–	–	–	–	1	1	–
2	–	1	1	–	–	–	–	–	1	1
3	–	–	1	1	–	–	–	–	–	1
4	–	–	–	1	1	–	–	–	–	–
5	–	–	–	–	1	1	–	–	–	–
6	–	–	–	–	–	1	1	–	–	–
7	1	–	–	–	–	–	1	1	–	–

Figure 3-3. Number of reaches sampled each year based on a seven-year rotating panel revisit design. This revisit design is used to sample Courthouse Wash in Arches National Park and the East Fork of the Virgin River in Zion National Park.

3.3.2 Spatial balance

After the sampling frame has been finalized, a spatially balanced random sample of monitoring reaches is selected using a GRTS method (Stevens and Olsen 2004). For most streams, no stratification is employed; sites are selected using equal probabilities. In cases where stream segments are stratified (e.g., the Fremont River), the number of samples selected for each segment is weighted according to the total length of each segment. Reaches are evaluated sequentially in the field before final selection. Reaches with major tributary inputs (>10% of the watershed), major spring inputs, >25% bedrock constriction (Capitol Reef and Zion NPs) or bedrock channel (Arches NP, Natural Bridges NM), changes in stream type (e.g., valley setting or flow permanence), or the presence of significant archeological or historic resources are rejected for sampling.

3.4 Revisit design

At each stream, the number of reaches is limited by affordable effort and the length of the sampling frame rather than by variability of vegetation. Revisit designs are stream-specific and attempt to balance the need for observing inter-annual variability with maximizing replication (Woodward 2004).

Vegetation and geomorphology monitoring occur at all reaches. A rotating panel design is used to increase the overall sample size (see Figure 3-3 for an example). Reaches are sampled 1–2 years in a row and then rested for 3–5 years so a total of 5–7 reaches are monitored on each stream (Table 3-2). On some reaches of each stream, vegetation is sampled for two consecutive years to tease out interannual differences due to factors such as temperature, precipitation, and flow, and to better estimate trends. Geomorphology surveying occurs between the two growing seasons when vegetation is sampled so

Table 3-2. Outline of revisit design for each stream sampled by the Northern Colorado Plateau Network.

Park	Stream name	Total number of reaches	Reaches sampled per year	Years until all reaches are sampled
Arches NP	Courthouse Wash	7	2	7
Capitol Reef NP	Fremont River	6	2–3	5
Natural Bridges NM	Armstrong Canyon	5	2	5
Zion NP	East Fork Virgin River	7	2	7

it can be linked to both years of data when no major flood events occur. Sampling some part of a stream each year allows us to detect the effects of major flood events within one year after they occur.

Shallow groundwater and surface-water wells are continuously monitored with pressure transducer dataloggers. Information from the dataloggers, as well as manual surface flow and groundwater measurements, are collected at least once every eight weeks from March to November. Transects with wells are surveyed every year.

3.5 Modifications to the revisit schedule and survey design strategy

After 4–6 years of sampling and an initial analysis of data from the East Fork Virgin River (EFVR) in Zion National Park (Witwicki and Weissinger 2015), the sampling strategy was modified.

To enhance our ability to analyze significant hydrologic events, specifically large floods, deviations from the monitoring schedule may be made to permit measurements at all reaches on a river in the same year, so that results are more comparable and measurements can be directly attributed to flows during the previous year (versus several previous years). If this happens, the remainder of the monitoring scheduled on the affected stream, at other wadeable streams, or on other protocols may need to be altered to balance the workload.

As of 2016, 3–5 reaches per stream were established, with a maximum of 5–7 reaches per stream at full implementation. Deviations from the revisit schedule, along with a low total number of reaches sampled per stream, make it difficult to achieve one of our original goals: inference to the entire length of a stream in the sampling frame. Preliminary analyses at Zion NP confirmed this, and in the associated report (Witwicki and Weissinger 2015), we analyzed changes at each reach separately. In this type of analysis, each reach acts as an indicator site. On the EFVR, we found that the reaches responded differently to flooding in a number of ways (Witwicki and Weissinger 2015).

In the future, we plan to test a revisit schedule in which reaches with hydrologic equipment are visited annually and we rotate through visits to the remaining reaches. We will also focus on repeat visits of existing reaches after major floods as we continue to evaluate the overall sampling strategy of this protocol.

4 Field Methods

The response design for this protocol uses a stream reach with seven permanently marked transects as the sampling unit (see Figure 3-1). Reaches are 180–360 meters long, and <100-meter transects are equally spaced throughout the reach. Most measurements are taken along these transects. Details of measurement methods, with example datasheets, are documented in the individual SOPs. The field-crew leader ensures completeness of all datasheets and clarifies any ambiguities before the end of each field trip.

It is important to maximize efficiency when collecting field data. Key considerations include determining the number of crew members needed to perform each protocol, and the order in which the various measurements are performed. Setting up the tagline (see Section 4.2.1) typically requires all crew members. Most other duties can be divided among crew members. Vegetation sampling requires two crew members (an observer and a recorder) for most procedures. Pairings are rotated to ensure consistency among crew members with species identification and monitoring techniques. Within a pair, the tasks of observer and recorder are alternated to minimize observer fatigue. The recorder is responsible for ensuring that all data listed on the datasheets are collected, including plot metadata. The observer is responsible for data accuracy (e.g., species identification, tree measurements).

4.1 Field-season preparations

Sampling dates are scheduled and logistics organized prior to the start of the field season. This includes applying for and renewing research permits, hiring the field crew, arranging camping or park housing, updating emergency contact information, and acquiring backcountry permits (see SOP #1). All of the equipment and supplies are organized, tested, and ordered to ensure availability by the beginning of the field season. Copies of the datasheets are printed. Directions, revisit datasheets, and species lists are generated for each reach.

It is necessary to allow ample time to process background checks and other paperwork for newly hired crew members. Before collecting data, field-crew members must be trained in NCPN's field safety protocol, monitoring procedures, and plant identification (SOP #2), and must review the entire protocol, especially the SOPs. The field-crew leader must ensure that crew members understand all procedures and evaluate their understanding during training.

4.2 Sampling procedures

4.2.1 Establishing the reach

After navigating to the reach centroid, the field crew evaluates the site (SOP #4) to determine if it meets criteria for establishing a permanent reach. The reach length and distance between the transects are determined by the width of the active riparian zone. Transects are established perpendicular to the channel and marked with rebar (i.e., headpins), usually at the endpoints. Waypoints, reference photos, and written instructions are taken to help relocate them. Kevlar taglines marked at one-meter intervals are strung between the headpins and used to guide the transect tapes. Reaches must be established in the order provided to maintain spatial balance of the sampling design.

4.2.2 Vegetation measurements

A point-intercept method is used to record percent cover of understory and ground-cover attributes at 0.5-meter intervals along each cross-section transect (see Figure 3-2). Density and diameter at breast height (dbh) of trees are recorded by species in a five-meter belt centered on each transect. Canopy closure is recorded along each transect at 10-meter intervals using a concave spherical densiometer. Frequency of exotic species is recorded in 1-m^2 quadrats placed every five meters along the cross-section transects. All trees ≥25 cm dbh within the reach are tagged and dbh is measured. SOP #6 details methods for collecting vegetation data.

During the vegetation monitoring visit, in-stream and riparian disturbances are described and the presence of exotic species is recorded during a timed reach walk (see SOP #8). When revisiting any existing reach, a revisit datasheet is used to record general observations during the visit (SOP #4). This form provides the field crew with an opportunity to note qualitative information about site conditions which is not otherwise recorded in the site impact assessment.

4.2.3 Geomorphic measurements

Geomorphology is measured primarily through pebble counts and stream-channel surveys. Pebble counts are conducted at each cross-section transect to monitor particle size distribution within the channel (see SOP #7). Pebble counts require crew members to reach to the bottom of the stream, pick up a pebble, and take measurements. Pebble counts are performed each time vegetation is monitored because air and water temperatures are typically too cold to perform this measurement during surveys.

Stream-channel surveys are performed at each reach using a total station (SOP #9), and survey control points are established. For each cross-section transect, data are recorded at one-meter intervals along the tagline and at any significant slope-break points to provide a reasonably accurate depiction of topography. The thalweg is surveyed throughout the reach at one-meter intervals to capture important channel features. Locations of headpins and hydrologic monitoring equipment are also recorded in the survey.

4.2.4 Hydrologic measurements

Stream stage and groundwater elevations are measured in one instream well and one or two riparian wells installed along one of the cross-section transects (SOP #10). Each well contains a pressure transducer that records data at 15- or 30-minute intervals. Data from hydrologic monitoring equipment are downloaded, and manual water-level and flow measurements are recorded at least once every eight weeks from March to November.

4.3 End-of-season procedures

While all crew members are still available, the project manager should complete a protocol review, which entails asking crew members specific questions about the clarity and efficiency of all monitoring and safety procedures and acquiring general feedback.

The equipment list is updated with the number of equipment items that are functional and available for the next field season. This updated list is compared to perceived needs of the next season, and supplies are replenished as necessary.

5 Data Management

Effective data management to ensure data quality, interpretability, security, longevity, and availability is critical to the success of the riparian monitoring program. The NCPN data management plan (Beer et al. 2005) describes these procedures in general terms. This section outlines the application of those procedures to riparian monitoring. SOP #13 provides explicit instructions.

5.1 Data organization

This long-term monitoring project generates large quantities of data and numerous products, and a well-organized digital file structure is essential to avoid confusion and potential data corruption. Each NCPN project uses a similar folder structure replicated on both the active (X:\) and archive (R:\) network drives. Data for the current field season are stored on the X:\ drive. At the end of each field season, final data and data products, along with other seasonal files, are transferred to the permanent project folder on the R:\ drive, where they are stored in read-only format.

5.2 Data model

Three main types of riparian monitoring data are collected and managed: vegetation, hydrology, and geomorphology data. Vegetation data are entered into a Microsoft Access database developed by the NCPN that is designed to accommodate all data on the various field forms. The database conforms to Natural Resource Database Template standards established by the Inventory and Monitoring Division. The design includes standardized core tables for elements, such as Locations and Events, that are common to most monitoring datasets, as well as field data tables that can be customized to meet project data requirements. NCPN field data tables are organized largely by SOP and are linked in time and space to enable integrated data analysis. Species, contacts, and attribute look-up tables provide standardized values for many data fields, and metadata tables track database revisions.

Hydrology data are uploaded to the Aquarius system hosted by the NPS Water Resources Division. Aquarius is commercial software for managing timeseries data. Most processing and analysis of the hydrology data is done within Aquarius. Copies of raw digital data files and derived datasets generated in Aquarius are stored on the NCPN server.

Geomorphology data are exported from the data collector and stored on the NCPN server. The raw data files, post-processed data files, and metadata describing all post-processing are stored on the server.

5.3 Data entry

Data are acquired as specified in the protocol SOPs using two different methods: (1) digitally recorded by a total station (geomorphology), GPS (spatial data), or datalogger (hydrology) and (2) manually recorded on paper datasheets (vegetation and pebble counts).

Digital data must be uploaded from the data recorder using specialized software and then converted into a format that is compatible with the NCPN database. Using digital data recording minimizes transcription errors and increases the efficiency of data collection.

Data recorded on paper datasheets are entered into the NCPN database as soon as possible after a field visit. Keeping current with data entry facilitates finding and correcting errors while information is still fresh in the minds of the field crew. Where appropriate, pick lists and domain limits restrict values entered into a field to ensure that only valid names or measures are entered. Field-crew members should follow guidelines in the Riparian Database User's Guide when entering data.

5.4 Data verification and validation

Data verification occurs after data entry, when all records in the database are compared to the original paper datasheets and errors are corrected. Data validation is the process of reviewing data for range and logic errors. Although some validation features, such as range limits, are built into the database via data-entry forms and queries, the project leader is also responsible for reviewing the data for content or context errors. After all data verification and validation has been completed, the dataset is added to the master project database and can be used for data analysis and reporting.

5.5 Metadata procedures

All database tables and fields are defined and documented in a data dictionary and/or in Section 5 of a Federal Geographic Data Committee (FGDC)-compliant metadata file. FGDC-compliant metadata are created for all spatial data. Information on data manipulations and the status of data verification and validation is recorded by project staff in a data management log.

5.6 Data archiving

Digital data are archived in their native database format at the end of each field season after all data have been entered, verified, and validated. A complete copy of the database in its native database format is also archived whenever the database version changes. These version archives are supplemented by a platform-independent copy of the database tables in ASCII format. All archived files are designated as read-only. All files, both active and archival, are stored on a secure server with regular backup routines that include an off-site storage rotation.

Field forms and photographic prints or slides are irreplaceable resources that must be managed so that their quality and integrity are maintained long-term. Copies of these materials are used for project binders that are regularly used or referenced, while originals are accessioned into the NCPN archives for permanent storage and care.

The NCPN archives are located at the Western Archeological and Conservation Center (WACC) in Tucson, Arizona. All riparian monitoring final data and data products, both digital and hard-copy formats, are archived at WACC after each field season.

6 Reporting and Analysis

6.1 Data summary reports

Data summary reports describe the field effort and briefly summarize data collected in a park for the period reported. These reports also highlight observed resources of management concern and general ecological observations of interest that were noted by the crew. Each report includes an overview of any necessary changes to protocol procedures and proposed future monitoring efforts. Information from data summary reports and other analyses is further summarized in 1–2 page briefs that provide resource managers with a concise summary of issues of concern.

6.2 Status and trend reports

Once reaches on a stream have been visited multiple times, the monitoring design will be evaluated, and a status and trend assessment will be performed. The purposes of this analysis are to:

1. Describe the current conditions (status) of riparian indicators (see Table 6-1) using standard univariate and multivariate descriptive statistics and graphical techniques, and interpret these conditions in the context of management objectives,
2. Describe any trends or abrupt changes after significant hydrological events in riparian indicators using mixed-effects models and multivariate analytical techniques,
3. Use modeling and other data-exploration techniques to evaluate potential explanatory variables and co-variates over broad thematic and spatial scales,
4. Synthesize this wide range of information to explore patterns and better understand riparian processes and dynamics, and
5. Evaluate the effectiveness of the sampling design to address monitoring goals.

Status and trend reports are generated periodically (ideally, every 5–7 years for each park unit with riparian monitoring).

Table 6-1. Indicators of riparian health for each vital sign.

Vital sign	Indicators
Riparian vegetation	Native and total plant richness and cover Mesic : xeric plant cover by surface elevation Basal area and density of woody species Mean canopy closure Species assemblages by inundation duration and frequency Species assemblages by geomorphic surface elevation
Geomorphology	Mean active channel width and depth (m) Reach-scale channel slope (m/km) Channel bed particle size distribution Mean floodplain width and elevation (m) Inundation duration of floodplain (% of growing season) Inundation frequency of floodplain (return frequency in years)
Surface flow (Hydrology)	Mean and range of annual and/or growing season stream stage (m) Mean and range of annual and/or growing season stream discharge (m^3/sec) Mean and range of annual flood stage (m) Flow permanence (% of growing season)
Groundwater dynamics (Hydrology)	Mean annual and/or growing season depth to groundwater (m) Range (min-max) of inter- and intra-annual fluctuations of groundwater (m)

7 Personnel Requirements and Training

7.1 Roles and responsibilities

The NCPN vegetation ecologist organizes and oversees the riparian monitoring program with assistance from the NCPN hydrologist. The vegetation ecologist acts as the project manager and is responsible for training the permanent biological or physical science technician that acts as the field-crew leader. The crew leader oversees 2–3 seasonal staff, leads the vegetation and geomorphology field-data collection, and directs data entry and verification. A permanent hydrologic technician leads hydrologic data collection. The project manager is responsible for data validation, as well as data summary, analysis, and reporting. The crew leader and the permanent hydrologic technician assist with data summaries and annual reports. The NCPN data manager coordinates data archiving, security, dissemination, and database design. The data manager, in collaboration with the project manager, also develops data entry forms and other database features for quality assurance and data summary. The data manager is ultimately responsible for ensuring that adequate QA/QC procedures are built into the database and that appropriate data handling procedures are followed.

7.2 Qualifications

Lead biological or physical science technician. The field-crew leader should have excellent botanical skills and previous experience identifying riparian plant species. In addition, the crew leader should have experience running a total station and directing others in collecting geomorphic survey data. Because these two skill sets are often not found together, the NCPN should be prepared to spend considerable time training the crew leader if one skill is lacking.

Seasonal biological science technicians (or interns or volunteers). Field technicians must have good botanical skills and, preferably, experience identifying riparian species of the Colorado Plateau. Additional qualifications include an ability to work well with others, good attention to detail, experience taking vegetation monitoring measurements, good physical fitness, and basic computer skills. Crew members should also have good organizational skills, memory retention, and the ability to work methodically and consistently under difficult conditions.

Hydrologic technician. The technician should have previous experience installing and maintaining instream and shallow groundwater wells and the related instrumentation.

7.3 Training

Prior to data collection, crews should become intimately familiar with all SOPs and park-specific materials, such as plant species lists and access information. Each person should be trained in all protocol-specific data-collection methods within their assigned tasks (vegetation, geomorphology, or hydrology), such that s/he can independently perform any necessary task. For crew members involved in vegetation monitoring, the vegetation ecologist and/or field-crew leader will provide training on appropriate plant species. Herbarium specimens and comparative notes on difficult or uncommon species will be provided for field observers. Observers should be tested frequently on their ability to identify plant species, with the test tailored to more problematic species.

The field-crew leader is responsible for ensuring that all crew members read and understand the NCPN field safety SOP prior to the field season. The field-crew leader and hydrologic technician are trained as Wilderness First Responders if they do not already have this or a more rigorous wilderness medical certification. CPR and first aid training is provided for all other crew members at the beginning of the season. Each crew member must be proficient in the use of safety equipment, such as satellite phones, and is responsible for safeguarding him/herself at all times.

8 Operational Requirements

The annual workload for this protocol consists of field-data collection in spring, summer, and fall; data verification and validation in fall and winter; and data summary, analysis, and reporting throughout the year.

Vegetation data are collected during the growing season, between late May and early October. Sampling visits should be scheduled to optimize phenology for the group of NCPN park units included in riparian monitoring. Park units should be visited at approximately the same time each year to maximize repeatability. Pebble counts and site impact assessments are performed during the vegetation sampling visit. Field work is typically conducted in eight-day hitches that include a travel day on each end. Vegetation data are ideally collected by a crew of four, and a reach can be completed in approximately 2–3 days (100 person hours per reach). The time commitment for a crew of four is approximately four pay periods per year (1,280 person hours). Data entry requires an estimated 160 person hours.

Stream channels are surveyed when riparian vegetation is leafless, generally late fall or early spring. Surveys are most efficient with one person running the total station and two technicians running rod. The time commitment for a crew of three is approximately three pay periods per year (720 person hours). Data processing requires an additional 160 person hours.

Well installation can occur at any time the ground is not frozen, but will likely occur in spring or fall to avoid weather extremes. Routine visits to wells for hydrologic monitoring and data downloading occur at least once every eight weeks from March to November. Visits timed to capture the greatest variation in stage and streamflow will enable computation of a robust stage-discharge relationship over time. Once installed, hydrologic data can be collected by one person in less than a day per stream, or approximately two pay periods (160 person hours) over the course of the year. Well installation requires 2–3 technicians and takes up to a day per well, or three days per transect (90 person hours per transect).

9 Revising the Protocol

This sampling protocol consists of a protocol narrative and 15 separate SOPs. The protocol narrative provides the history and justification for the program and an overview of sampling methods. Over time, methodological improvements, changes in available resources and expertise, and reassessments of the sampling design will result in revisions to this monitoring protocol. The protocol narrative will be revised only if major changes are made to the protocol. The SOPs, in contrast, are step-by-step instructions for performing each task. They are expected to be revised more frequently than the protocol narrative. Steps for changing the protocol narrative and SOPs are outlined in SOP #15.

Careful documentation of such revisions, including an archive of previous versions, is essential for maintaining consistency in data collection, analyses, and reporting. To summarize changes, the monitoring database for each component contains a field to identify the protocol version used to gather and analyze data. The narrative and each SOP contain a Revision History Log that needs to be completed each time the narrative or an SOP is revised. The purpose of this log is to explain why changes were made and to track document version numbers.

The NCPN uses a Master Version Table, maintained in SOP #15, to track which versions of the narrative and SOPs are used in each version of the monitoring protocol. The information contained in the Master Version Table is essential if project information is to be properly analyzed and interpreted.

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Natural Resource Stewardship and Science
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Fort Collins, Colorado 80525

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