



# Riparian Monitoring Protocol Implementation Plan for Park Units in the Southern Colorado Plateau Network

Natural Resource Report NPS/SCPN/NRR—2018/1766



#### ON THE COVER

Riparian habitat on the Escalante River in Glen Canyon National Recreation Area.  
Photography by: Southern Colorado Plateau Network, NPS.

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# Riparian Monitoring Protocol Implementation Plan for Park Units in the Southern Colorado Plateau Network

Natural Resource Report NPS/SCPN/NRR—2018/176

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# 1 Introduction and Summary

In arid and semiarid regions like the Colorado Plateau, riparian zones typically provide a striking visual contrast to surrounding upland environments. Riparian corridors include a notably diverse set of landforms, plant and animal communities, physical processes, and environments within the larger landscape (Naiman et al. 1993). Because of the unique contribution and importance of riparian areas to regional biodiversity (Sabo et al. 2005), and the disproportionately high use of these systems by plant and animal species (Hubbard 1977, DeBano and Schmidt 2004), riparian zones were identified as ecosystems of concern for the Southern Colorado Plateau Network (SCPN). These ecosystems often provide habitat for federally-listed endangered and threatened terrestrial and aquatic species, and are intimately associated with unique geologic features cited in the enabling legislation for a number of national parks and monuments. They are also the primary focus for an array of recreational activities on public lands.

Riparian ecosystems, especially in arid and semiarid regions, are universally recognized for their many natural resource values. Yet, they remain vulnerable to a number of persistent and emerging threats. For example, because of features like relatively high rates of flood disturbance, linear connectivity, and high edge-to-area ratios, riparian ecosystems are prone to invasion by non-native species (Planty-Tabacchi et al. 1996, Richardson et al. 2007, Perkins et al. 2015, Scott et al. 2018). Additionally, riparian systems are, and will continue to be threatened by aridification, or a period of transition to an increasingly water-scarce environment (Colorado River Research Group 2018). This is occurring as a direct result of climate-related increases in temperatures, due in part to continued emissions of greenhouse gasses into the atmosphere. Temperature-related losses to the Colorado River will result in flows that are projected to be 20% lower than current flows by mid-century. Any possible increases in precipitation would provide little offset to

these declines (Udall and Overpeck 2017). Similarly, increases in primary productivity with rising CO<sub>2</sub> levels are not likely to overcome the negative effects of increased aridity; and drought-tolerant, non-native riparian species are likely to outcompete native riparian species like cottonwood (*Populus* sp.) and willow (*Salix* sp.) (Perry et al. 2012).

SCPN has targeted a broad range of riparian area for monitoring, from ephemeral washes to large, regional rivers, such as the Escalante and Mancos Rivers (Table 1). Final decisions as to which riparian areas will be monitored by SCPN will be made with the affected parks in the fall of 2018. The rationale to be used in selecting sites for monitoring is explained in Appendix A. This Protocol Implementation Plan (PIP) covers all of the targeted riparian areas using two approaches: 1) for larger streams, SCPN will utilize the Northern Colorado Plateau's (NCPN) published wadeable streams monitoring protocol (Weissinger et al 2018) which incorporates vegetation, hydrology (groundwater or surface water), and geomorphology; and 2) for several smaller, ephemeral washes, SCPN will utilize Weissinger et al. (2017) to monitor baseline vegetation conditions with a resampling frequency every 5 years, or after major disturbance events combined with more frequent measurements of groundwater wells and geomorphology. For those systems where geomorphology or groundwater is the primary interest, we will conduct measurements of groundwater and/or geomorphology with minimal to no vegetation sampling.

In studying such riparian systems, we are interested in understanding how riparian vegetation, hydrology, and geomorphology change spatially and compositionally in response to disturbance events (drought or large flood events), or to longer term changes in precipitation, temperature, surface flows and ground water. NCPN's wadeable streams monitoring protocol seeks to address these issues through integrated measurements of geomorphic cross-sections,

Table 1. Rivers, streams, and washes that may be included in SCPN's riparian monitoring program with proposed protocol to be used. Click [here](#) for 508 accessible version of this table in Appendix C.

| Park                                                                                    | Stream/River                                                 | Sections of Weissinger et al. (2017) to be Implemented | Stream Type             | Why Monitor?                                                                                                            | Comment                                                                                                                                   |
|-----------------------------------------------------------------------------------------|--------------------------------------------------------------|--------------------------------------------------------|-------------------------|-------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| <b>High Priority Riparian</b>                                                           |                                                              |                                                        |                         |                                                                                                                         |                                                                                                                                           |
| AZRU                                                                                    | Animas                                                       | Groundwater                                            | Perennial               | Groundwater concerns                                                                                                    | Only option                                                                                                                               |
| CACH                                                                                    | Tsaile Creek                                                 | Wadeable Streams                                       | Perennial/ Intermittent | Plantings, control of invasive species, livestock?                                                                      | Will need to only one. Final decision in October. Evaluate with springs.                                                                  |
|                                                                                         | Chinle Wash                                                  | Wadeable Streams                                       | Intermittent            |                                                                                                                         |                                                                                                                                           |
| CHCU                                                                                    | Chaco Wash                                                   | Washes/ Wadeable Streams                               | Ephemeral               | Track long-term groundwater and channel change, historical decline in riparian vegetation                               | More important than springs (D. Hawkins 8.6.18).                                                                                          |
| ELMO                                                                                    | Historic Pool                                                | Hydrology only                                         | Surface pool            | Pool level                                                                                                              |                                                                                                                                           |
| HUTR                                                                                    | Pueblo Colorado Wash                                         | Wadeable Streams                                       | Intermittent            |                                                                                                                         | Only option.                                                                                                                              |
| MEVE                                                                                    | Mancos River                                                 | Continue hydrology only                                | Perennial               | no gauge on the Mancos River                                                                                            | Top riparian priority for park, but this is lower priority than springs.                                                                  |
| NAVA                                                                                    | Betatakin Canyon                                             | Washes/Wadeable Streams                                | Intermittent/ ephemeral | Cultural                                                                                                                | Keet Seel is higher park priority than Betatakin. Choose only one. Evaluate with springs. Final decision in October.                      |
|                                                                                         | Keet Seel Canyon                                             | Washes/Wadeable Streams                                | Intermittent/ ephemeral | Cultural                                                                                                                |                                                                                                                                           |
| PETR                                                                                    | North Boca Negra, Mairehaven, Ladeara and Rin-conanda Arroyo | Washes                                                 | Ephemeral               |                                                                                                                         | Will need to choose one during October 2018 site visit. Geomorphology most important                                                      |
| SAPU                                                                                    | Cañon Sapato                                                 | Wadeable Streams                                       | Perennial               | Cultural. Run-off flows and channel morphology including headcutting. Complete riparian picture                         | Cañon Sapato is higher priority than Abo. (M. LeFrancois 7/25/2018). Interested in all components of riparian.                            |
| <b>Medium Priority Riparian – To be implemented after High Priority Riparian</b>        |                                                              |                                                        |                         |                                                                                                                         |                                                                                                                                           |
| GLCA                                                                                    | Escalante                                                    | Wadeable                                               | Perennial               | Evaluate channel and vegetation change following Russian olive removal; invasive species – or is it coming back native? | Top riparian priority for park. Springs are higher priority than riparian.                                                                |
| PEFO                                                                                    | Puerco River                                                 | Wadeable Streams                                       | Intermittent            |                                                                                                                         | Groundwater and vegetation components most important, morphology not as important. Puerco higher priority than springs. 20 miles of wash. |
| <b>Low Priority Riparian – To be implemented after High and Medium Priority Springs</b> |                                                              |                                                        |                         |                                                                                                                         |                                                                                                                                           |
| BAND                                                                                    | Capulin Creek                                                | Wadeable Streams                                       | Perennial               | Post fire changes in veg and channel                                                                                    | Will need to choose only one.                                                                                                             |
|                                                                                         | Rito de los Frijoles                                         | Wadeable Streams                                       | Perennial/ Intermittent |                                                                                                                         |                                                                                                                                           |
| GRCA                                                                                    | Robbers Roost                                                | Wadeable Streams                                       | Perennial               |                                                                                                                         | Will need to choose only one.                                                                                                             |
|                                                                                         | Bright Angel                                                 |                                                        |                         |                                                                                                                         |                                                                                                                                           |
|                                                                                         | Hermit                                                       |                                                        |                         |                                                                                                                         |                                                                                                                                           |

percent cover of vegetation, major species composition, and groundwater dynamics.

Management interests for some of the smaller streams and washes may only extend to one or two physical components such as groundwater or geomorphology. This PIP allows park units to select a subset of wadeable stream metrics or the entire wadeable streams protocol, depending on the riparian area of interest and the particular management questions and concerns.

## 1.1 Stream type descriptions

### 1.1.1 *Wadeable Streams*

A hallmark of smaller 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).

The high rates of recovery for vegetation in riparian ecosystems are primarily due to adequate moisture in the disturbed regions. Moisture supports: (1) relatively high rates of productivity; (2) high linear connectivity, which allows for rapid re-colonization of disturbed sites from upstream and downstream refugia; and (3) disturbance-adapted species, whose life-history characteristics allow them to reestablish and re-colonize quickly following disturbances (Scott et al. 2005). The high rate of recovery after disturbance and predominance of woody vegetation in these systems contribute significantly to regional species richness ( $\gamma$ -diversity) by providing 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 deposi-

tional 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 (and pathway) of riparian plant and animal communities representing a diversity of structural and functional groups (Scott et al. 2005).

Shallow alluvial groundwater is a unique and important functional feature of southwestern US riparian flood plain soils, and is closely related to surface water dynamics. Native and non-native woody phreatophytes, like cottonwood, willow and tamarisk, are dependent, to varying degrees, on shallow alluvial groundwater sources. Spatially complex moisture gradients resulting from flood-plain topographic diversity and surface and ground-water dynamics influence the diversity of herbaceous riparian plants and soil organisms (Meinzer 1927, Scott et al. 1997, Stromberg et al. 1997, Pollock et al. 1998, Horton et al. 2001, Beauchamp 2004, Bagstad et al. 2005). Where ground water is absent or too deep, these washes have little to no riparian vegetation but are still affected by periodic floods. Some of these washes are also found in bedrock canyons with little to no capacity for geomorphic change. Narrower bedrock channels typically have little to no persistent vegetation, only annuals that can grow on channel deposits following flood recession.

### 1.1.2 *Ephemeral and intermittent washes*

Compared with perennial streams, ephemeral and intermittent washes have flashier (large and quick changes in flow) flow regimes which often results in a less discernable or distinctive active channel, floodplain and upland zones. Because there is little or no surface flow for much of the year, riparian vegetation is highly dependent on alluvial groundwater. While erratic and episodic flooding can cause widespread geomorphic change and plant mortality, channel changes that allow some individuals to be

away from the disturbances of additional floods (Schumm and Lichty 1963) can favor the establishment of relatively long-lived riparian species. Large magnitude floods widen channels, create new channel alignments, redistribute sediment, and thus create topographic diversity. Channel narrowing and riparian vegetation establishment occurs between large flood events (Friedman and Lee 2002).

Ephemeral stream networks lie along a hydrogeomorphic gradient which is scaled to the watershed area, and, in turn, influences the structure and composition of riparian plant communities. Ephemeral channels typically drain small watershed areas and are associated with higher fluvial disturbance, higher groundwater variability and largely xeric, upland streamside vegetation assemblages. As watershed area increases, flow shear stresses are reduced, alluvial groundwater becomes less variable, flood plains become more distinct and extensive, and vegetation is dominated by obligate riparian and wetland trees and shrubs (Shaw and Cooper 2008).

Depth to groundwater is key to the survival of riparian vegetation in ephemeral and intermittent systems. Regional drought depletes alluvial aquifers which can induce plant stress and reduce plant productivity. Under more severe drought conditions, trees die from water stress or are weakened, making them more susceptible to mortality from insects, pathogens, and diseases.

## **1.2 Previous studies of riparian resources in SCPN park units**

Riparian resources have been the focus of a number of studies conducted at SCPN parks. Although these park-specific studies provide valuable data, such as plant species lists, documentation of channel change, and information on historical conditions, few studies have been conducted over long periods of time, and even fewer have examined physical and biotic riparian resources in an integrated way.

### ***1.2.1 Hydrology studies***

Few studies of surface or groundwater hydrology have been conducted in SCPN parks. In 1998 two observation wells were installed on the Pueblo Colorado Wash flood plain as part of a stream restoration project in Hubbell Trading Post National Historic Site (HUTR) (Zeedyk 2004). Also in 1998 a network of wells was installed in the Chaco Wash flood plain of Chaco Culture National Historical Park (CHCU) to monitor shallow ground water availability to riparian plants (Whitefield 1998). Other available hydrologic data is limited to streamflow gages in and near the parks. These gages are operated and maintained by state and federal agencies and by the Navajo Nation. The availability of hydrologic data is subject to funding and varies by site.

### ***1.2.2 Fluvial geomorphology and channel change studies***

The study of the effects of physical environmental variables has been another focus of riparian research. Studies examining fluvial geomorphology and channel change have been conducted across many SCPN parks. In most cases, these studies have focused on channel narrowing and channel incision (or arroyo cutting), and, in some cases, channel aggradation processes. For example, several studies have been conducted examining long-term channel cut (aggradation) and fill (degradation) cycles at Chaco Wash in CHCU (DeAngelis 1972, Love 1980, Simon, Li and Associates, Inc. 1982 a&b, Gellis 2002, Friedman et al. 2015). Similar studies of fluvial geomorphology and channel change have been conducted at Canyon de Chelly National Monument (CACH) (Dolan 1993, Rydout 1983, 1985), Glen Canyon National Recreation Area (GLCA) (Boison and Patton 1985, Birkeland 1999, Scott et al. 2018), HUTR (Zydeek 2004), and Petroglyph National Monument (PETR) (Gellis 1993, 1996).

The link between physical variables and riparian plant communities is a major focus of research at SCPN parks. For example, Irvine and West (1976) correlated riparian

vegetation along the lower Escalante River, including GLCA, with a number of physical characteristics, including stratigraphy, soil texture and moisture, river bank aspect, flow velocity, and angle, height and width of river terraces. In addition, Birkeland (1999) examined the relationship between flood power and woody riparian vegetation along perennial streams in five canyons of the Escalante River basin. Recently, Scott et al. (2018) examined channel narrowing and the invasion of Russian olive along the Escalante River in Grand Staircase Escalante National Monument and GLCA.

### 1.2.3 Vegetation-focused riparian studies

Many early studies of riparian ecosystems in SCPN parks focused on vegetation—general species lists, vegetation surveys, and descriptions of vegetation and plant community types. These types of data exist for Bandelier National Monument (BAND) (Jacobs 1989), CACH (Cook 1994, Harlan and Dennis 1976), GLCA (Clover and Jotter 1944, Spence 1992), HUTR (Gandhi and Hatch 1987), Mesa Verde National Park (MEVE) (Quaintance 1935), Navajo National Monument (NAVA) (Johansen 1977) and Walnut Canyon National Monument (WACA) (Schelz et.al. 2013).

More specifically,

- Shaw and Cooper (2008) studied the spatial distribution of riparian vegetation in an ephemeral stream network at Petrified Forest National Park (PEFO).
- Rink (2004) completed a plant inventory for CACH and compared contemporary and historical photographs of many riparian sites to document vegetation change over time. His work also included general location information for rare species.
- Foliage-height and density of perennial vascular plants, and percent cover of annual plants were recorded annually for four years (Baker 2004) along Pueblo Colorado Wash at HUTR.
- Other studies looked at the effects of

invasive species and/or removal of such species in riparian ecosystems, such as these studies of CACH by several Colorado State University researchers:

- Cadol (2007) used a time series of rectified aerial photographs to examine the possible role that tamarisk and Russian olive played in channel narrowing and incision observed throughout the main canyons of the monument.
- Jaeger (2009) examined the role of invasive plant species in relation to local and regional channel change.
- Reynolds (2009) focused further on the role of invasive species in the riparian ecosystem at CACH, and the effects of several removal strategies.

These projects also looked at the effects of invasive species removal:

- Grand Canyon National Park (GRCA) initiated a project designed to remove tamarisk from tributaries of the Colorado River in 2002. The park completed tamarisk removal and control work in 130 side canyons during the period 2002-2007. The project included photo point monitoring and vegetation monitoring at established transects with a revisit interval of approximately five years (Grand Canyon National Park 2011).
- MEVE implemented a tamarisk removal program on the Mancos River in 1999, treating the entire length of the river within the park. Resprouts of tamarisk were cut and treated with chemicals in 2002 (Colyer 2005).

Finally, data on the effects of anthropogenic disturbances, such as grazing, on riparian systems exist for some SCPN parks, including BAND (Allen 1991), CACH (Roberts and Gardiner c2003), GLCA (Haberle 1996, Boobar 1999), and PEFO (DePoy c1990, Knight 1990, 1992, Bowman 1991). In addition, the effects of landscape-scale wildfire on riparian ecosystems has been studied in BAND (Veenhuis 2002) and MEVE (Joyal 2008).

## 2 Conceptual Framework for Monitoring

Surface flow, alluvial groundwater, fluvial geomorphology, and riparian vegetation are the four key components of SCPN's riparian monitoring program (Table 2). In larger rivers and streams with perennial flow, surface water drives the vegetation community. As you move along the hydrologic gradient towards more intermittent and ephemeral washes, alluvial groundwater becomes more important. In all systems it is important to understand linkages between surface stream flow, geomorphology, riparian vegetation and alluvial groundwater.

### 2.1 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 during an event. Although extreme flow variation can eliminate species (Zimmerman 1969), episodic floods and droughts are necessary for the 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 on the Colorado Plateau are typified by relatively high-magnitude, short-duration, temporally unpredictable stormflow hydrographs with little or no baseflow (Scott et al. 2005).

A two- or three-dimensional hydraulic model would be one way to integrate hydrologic components, such as days of inundation, flow rate, shape of the hydrograph, depth of flow, and sediment supply, which all influ-

ence scour, accretion, and the encroachment and removal of vegetation. However because river bathymetry requires expensive equipment and extensive work in deeper channels, we determined that it is beyond the fiscal resources of this protocol. Instead we will use pressure transducers to record stage (above and below monitoring sites), from which we can determine the minimum inundating discharge and/or inundation duration at each plot or point of interest. This is more relevant in the larger, perennial streams. It becomes less important as you move along the gradient towards ephemeral washes, where ground water becomes more important and the entire channel can be waded, and river bathymetry can be completed. The transducer data will provide information valuable for evaluating different flows as well as showing the effects of natural and semi-natural hydrographs on unregulated rivers.

### 2.2 Alluvial Groundwater

Shallow alluvial groundwater is a unique and important functional feature of riparian floodplain soils, and is directly connected to surface-water dynamics. 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). Thus, an 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).

Following initial establishment, root growth allows young trees to survive gradual groundwater declines (Mahoney and Rood 1992; Segelquist et al. 1993). Depth to groundwater may increase as a result of subsequent floodplain accretion or channel incision (Everitt 1968; Hereford 1986), and cottonwoods have been observed at sites

Table 2. Monitoring components of the riparian protocol with management issues and potential measures.

| Component             | Management issues informed by monitoring                                                                                                                                                                                                                                                                                                                     | Potential Measures                                                                                                                                                                                                                                                                                                                                                                                            |
|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Surface flow          | Changes (timing, rate of change, amount) in hydrographs due to regulation or depletions on regulated rivers, and due to climate change on unregulated rivers. These changes have a direct effect on geomorphology and riparian vegetation.                                                                                                                   | <ul style="list-style-type: none"> <li>• days of inundation</li> <li>• mean annual discharge</li> <li>• annual peak flow</li> <li>• duration and timing of flow</li> <li>• number of peak flow events</li> </ul>                                                                                                                                                                                              |
| Alluvial groundwater  | Decreases due to aquifer depletion and/or climate change that can affect flora and fauna and cultural aspects                                                                                                                                                                                                                                                | <ul style="list-style-type: none"> <li>• mean annual depth to water</li> <li>• growing season depth to water</li> <li>• inter- and intra-annual fluctuations</li> </ul>                                                                                                                                                                                                                                       |
| Fluvial geomorphology | Changes in geomorphology can show channel narrowing, creation of new channels and channel aggradation. Changes in channel affect cultural resources at several parks. Geomorphic responses are key in monitoring disturbances such as large floods, fire, and loss of vegetation cover through mortality.                                                    | <ul style="list-style-type: none"> <li>• Mean active channel width and depth (m); width: depth ratio</li> <li>• Reach-scale channel slope (m/km)</li> <li>• Channel bed particle size distribution</li> <li>• Mean floodplain width and elevation (m)</li> <li>• Inundation duration of floodplain (% of growing season)</li> <li>• Inundation frequency of floodplain (return frequency in years)</li> </ul> |
| Riparian vegetation   | Species composition – decreases or changes due to increased recreation use, exotic species, grazing, aquifer depletion, and climate change. Indicator species can be indicators of and active participants in channel narrowing and simplification. Vegetation responses are key to understanding responses to disturbances like fires and forest pathogens. | <ul style="list-style-type: none"> <li>• Native and total plant richness and cover</li> <li>• Mesic : xeric plant cover by surface elevation</li> <li>• Basal area and density of woody species</li> <li>• Mean canopy closure</li> <li>• Species assemblages by inundation duration and frequency</li> <li>• Species assemblages by geomorphic surface elevation</li> </ul>                                  |

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 is also 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).

Depth to alluvial groundwater, determined from measurements taken at a groundwater well or piezometer, will contribute to metrics like mean annual and growing season depth to water, and inter- and intra-annual fluctuations. These metrics are key to the survival and production of the riparian plant community.

### 2.3 Fluvial Geomorphic Processes

Fluvial geomorphic processes refer to the transport of sediment by moving water. Stream channel dimensions and form are affected by 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 regional watershed characteristics contribute 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 are one of a number of riparian features formed through fluvial geomorphic processes. They 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 that are relatively frequently inundated by high flows (Leopold 1994). However, since these high flows do not recur in a consistent manner compared to laterally accreting floodplains along rivers in other regions, they promote less organized vegetation.

The spatial extent of floodplains along rivers and streams on 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 following large floods and/or channel incision can 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 and Hammack 1999; Miller et al. 2004).

For rivers, geomorphic responses to the channel narrowing process include the formation of stable and persistent floodplain surfaces by lateral and vertical accretion of fine-grained sediments on formerly active channel deposits (Schumm and Lichty 1963, Allred and Schmidt 1999). Channel narrowing can occur in many ways. One way is through the construction of large dams. In addition to channel narrowing or widening, large dams can cause sediment deficit, changes in average grain size, channel incision and bed-sediment evacuation (Permberton 1976, Williams and Wolman 1984, Grams et al. 2007). These changes can lead to disconnected floodplains as vegetation encroaches and stabilizes sand and gravel bars that are less frequently, or no longer inundated by post-dam flows (Grams et al. 2007, Grams and Schmidt 2002). Hereford et al. (1996) and Graf et al. (1991) worked on the Little Colorado and Paria Rivers, respectively, and showed that when the frequency of large floods decreased, flood plains became disconnected. Hereford et al. (1996) showed that accretion had ceased on the Little Colorado because the flood plain had likely reached a critical height above the channel that was unreachable to the current flow regime. Similarly flood plain accretion had not occurred on the Paria since 1980 (Graf et al. 1991). In other rivers, the loss of the long duration winter snowmelt floods, caused by upstream water capture by dams and irrigation networks, resulted in a surplus of sediment in downstream reaches. The loss of these long duration spring floods, without a reduction in sediment-bearing summer/fall floods has resulted in sediment accumulation and related channel narrowing (Dean and Schmidt 2011, Walker 2017).

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).

## 2.4 Riparian Vegetation

Vegetation is generally recognized as the dominant functional element in riparian ecosystems (Scott et al. 2005). In addition to conducting photosynthesis, vegetation, by shading and depositing litter, affects spatial and temporal patterns of soil-resource availability to other organisms. Vegetation structure also fosters biodiversity by modifying the physical environment and contributing to the formation of microhabitats with sharp gradients of moisture and temperature (Gregory et al. 1991). The above-ground structure of vascular plants increases roughness, and thus protects floodplain soils from widespread erosion (Tabacchi et al. 1998) which 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. 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. These gradients are 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). Vegetative indicators of channel narrowing involve increases in the extent and cover of vegetation into formerly active channel locations. This increase in vegetation is typically linked with the progressive formation of both active (regularly flooded every 3-10 years) and inactive (flooded more than 10 years) floodplain surfaces. There are a number of species that are significantly and uniquely associated with specific flow-related geomorphic surfaces such as the active channel as well as active and inactive floodplains.

Reach-specific interpretations of narrowing is hypothesized as follows using a mid-channel bar feature (Figure 1): at  $T_0$ , a mid-channel bar has reach-specific active channel indicator species, such as *Equisetum* sp., *Apocynum cannabinum*, and *Glycyrrhiza lepidota* present. Over time ( $T_1$ ) the feature is colonized with additional plant species, such as tamarisk or sandbar willow, which can be considered leading vegetative indicators of channel narrowing processes. Both lateral and vertical accretion of fine-grained alluvium are often associated with the colonization and persistence of these species. At the same time, there may be an increase in areal cover of reach-specific active channel and active floodplain indicator species (*Salix* sp., *Equisetum* sp.). There is continued lateral and vertical accretion of fine-grained alluvium at  $T_2$ . Concurrent with those increases is the decrease in cover or loss of active channel species. Persistence of these changes would be strong evidence of site-specific narrowing, which could be verified on a broad-scale using remotely sensed imagery.

Specific, plant-based indicators of channel narrowing include: 1) the progressive loss of active channel indicator species; 2) the persistent presence of active and inactive floodplain indicator species in active channel locations; 3) increases in the frequency and cover of the active channel indicator species in the active channel above baseline values; and 4) increases in the frequency and cover of sandbar willow and tamarisk, in the active channel, above baseline values.

## Detecting narrowing

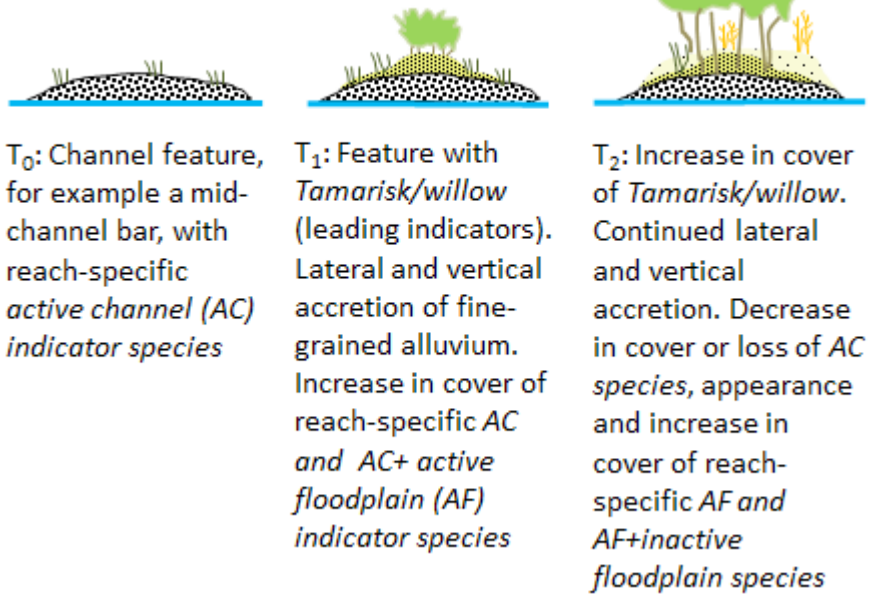


Figure 1. A conceptual model of how narrowing on an active channel feature would be detected using reach and geomorphic level specific indicator plant species.

## 3 Measurable Objectives

The overall goal of the SCPN riparian monitoring program is to determine long-term trends in hydrologic, geomorphic, and vegetation variables in the context of changes in stream flows, which can act as large disturbances or ecological re-setting events, alluvial groundwater, and other ecological drivers, stressors, and processes. Specific objectives for wadeable streams and intermittent/ephemeral washes are described below.

### 3.1 Wadeable Streams

- Determine status and trends in groundwater dynamics, including:
  - Depth to alluvial groundwater
- 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 species
  - basal area and density of woody species
  - canopy closure
  - frequency of occurrence of invasive species
  - inventory of rare species

### 3.2 Intermittent/Ephemeral Washes

- Determine status and trends in depth to alluvial groundwater
- 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

- Determine status and trends in vegetation dynamics, including:
  - species richness
  - plant cover by species
  - basal area and density of woody species
  - frequency of occurrence of invasive species
  - inventory of rare species

## 4 What's Being Measured and How?

We selected three vital signs for riparian monitoring:

1. Fluvial geomorphology
  - channel form (size and shape)
  - sediment size
2. Riparian vegetation structure and composition
3. Hydrology
  - stream flow
  - depth to groundwater

While the principles are the same, the methods will change depending on whether it is a river, stream, or wash; and whether it is in a narrow canyon where a total station must be used or in a more open area where real-time kinematic (RTK) survey reception is better.

### 4.1 Establishing and Revisiting the Site (SOP #2)

For most wadeable streams and washes, we identified accessible portions of each stream or wash and then selected reaches for monitoring. Reaches are stretches of rivers or washes that have a similar geomorphic setting (i.e. alluvial reaches, bedrock constrained reaches). The reach length and distance between transects for wadeable streams and washes are determined by the width of the active riparian zone (multiples of the width). For larger streams, such as the Escalante, we will select a priori, sites composed of distinct geomorphic features (sentinel sites that have different depositional environments, i.e. point bar, lateral bar, eddy deposit) that are based on access, legacy data, and that are not constrained to bed rock channels so the channel has the ability to narrow or widen. At each feature or reach, transects are established perpendicular to the channel (Figure 2). Waypoints are identified, reference photos are taken, and written instructions are prepared to help relocate sites on subsequent re-visits.

Transects are established to mark locations where vegetation and geomorphic variables

will be measured. When total stations are being used, each transect is marked with a permanent head pin and an associated orientation pin. An orientation pin is used at larger transects and is placed in line with the transect to help with placement of transects. In places where it is possible to use RTK, orientation pins are not needed and the head pins do not need to be physically monumented because the site can be relocated with the RTK. At least three survey control points that are permanent and physically stable should be visible from multiple instrument locations. Transects are placed perpendicular to the valley floor and may (or may not) be perpendicular to flow as the channel changes.

#### 4.1.1 Canyon-bound settings: Total Station surveying (SOP #6)

To measure vegetation and geomorphic variables, transects are established at each reach or feature. Using the headpin and orientation pin, a tagline is stretched along the transect from headpin to headpin. While setting up the tagline, observers should take care to minimize trampling of vegetation. The tagline should be as straight as possible, both vertically and horizontally and threaded through vegetation as necessary. For wadeable streams and washes, kevlar taglines marked at one-meter intervals are strung between the headpins and used to mark vegetation locations.

#### 4.1.2 Open settings: RTK surveying

In open settings where RTK surveying is possible, transects are laid out at each reach or sentinel site. They are permanent, but do not have any permanent rebar, headpins, or other markers. Transects are relocated with RTK surveying using established control points. The number and length of transects is constant (7) for wadeable streams and washes. At the Escalante, the length of each transect that is sampled may change from year to year, depending on the movement of the active floodplain, water level, and whether it is safe to wade in the stream, but

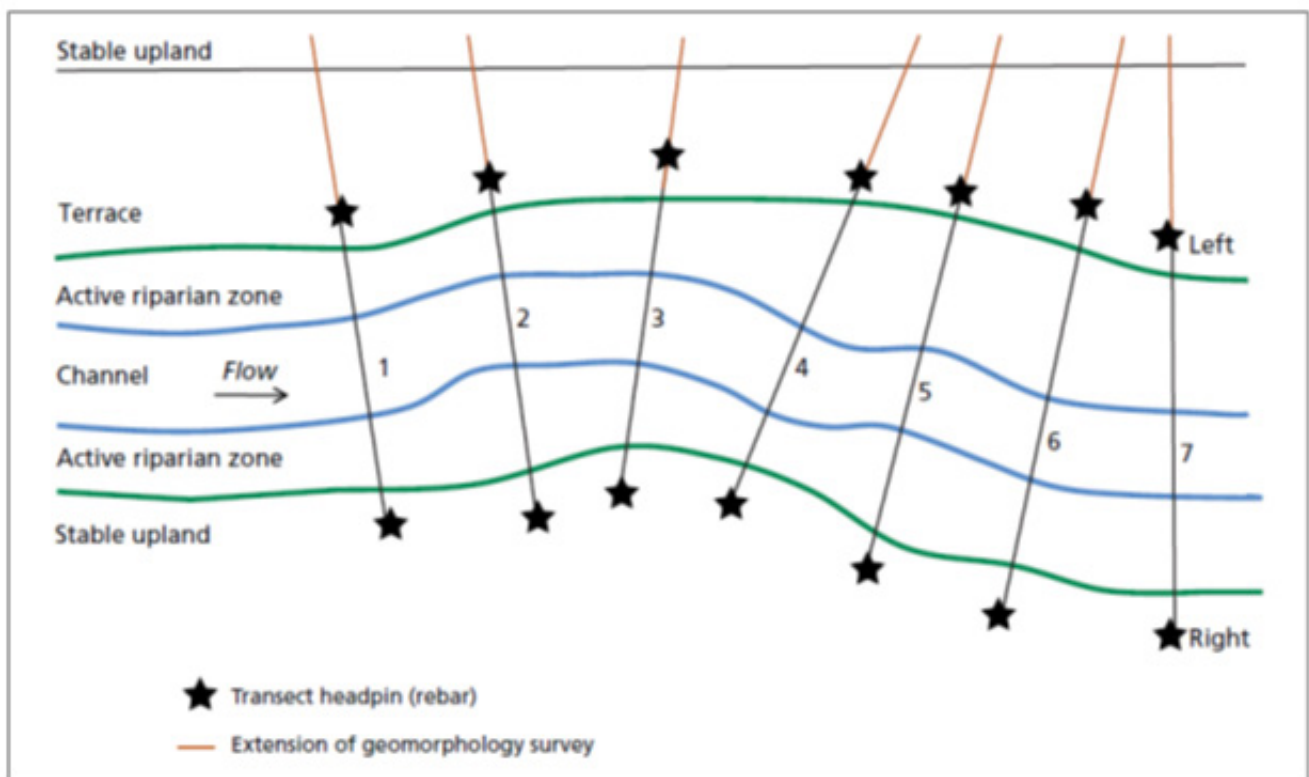


Figure 2. Example of a riparian monitoring reach for Southern Colorado Plateau Network parks, with seven equidistant cross-section transects. The centroid transect is labeled “4”, star symbols indicate locations of headpins, and the green line represents the upland–riparian zone boundary. For larger rivers, such as the Escalante, the transects are centered on a geomorphic feature of interest (eddy deposit, lateral bar, point bar), which could result in 3-11 transects at the feature.

the overall endpoints of each transect will not change. At least three control points that are permanent and elevationally stable must be established at each reach. Points to be used for vegetation point intercept are flagged along the transect by the surveyor.

## 4.2 Vegetation Measurements (SOP #4)

A point-intercept method is used to record percent cover of understory and ground-cover attributes at 0.5 m intervals along each cross-section transect (Figure 3). 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 m intervals using a concave spherical densiometer. Frequency of exotic species is recorded in 1 m<sup>2</sup> quadrats placed every five meters along the cross-section transects. All trees ≥25 cm dbh within the reach are tagged and dbh is

measured.

During the vegetation monitoring visit, instream and riparian disturbances are described and the presence of exotic species is recorded during a timed reach walk. Large trees (>25 cm dbh) and smaller trees (2-25 cm DBH) are detected in a 5 m belt transect. When revisiting any existing reach, a revisit datasheet is used to record general observations during the visit. 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.

At each sampling reach a comprehensive plant walk is conducted covering the entire reach. Names of all plant species observed are recorded during the walk, noting date and approximate time spent looking. The objective of the plant walk is to record as many species as possible. The walk can be

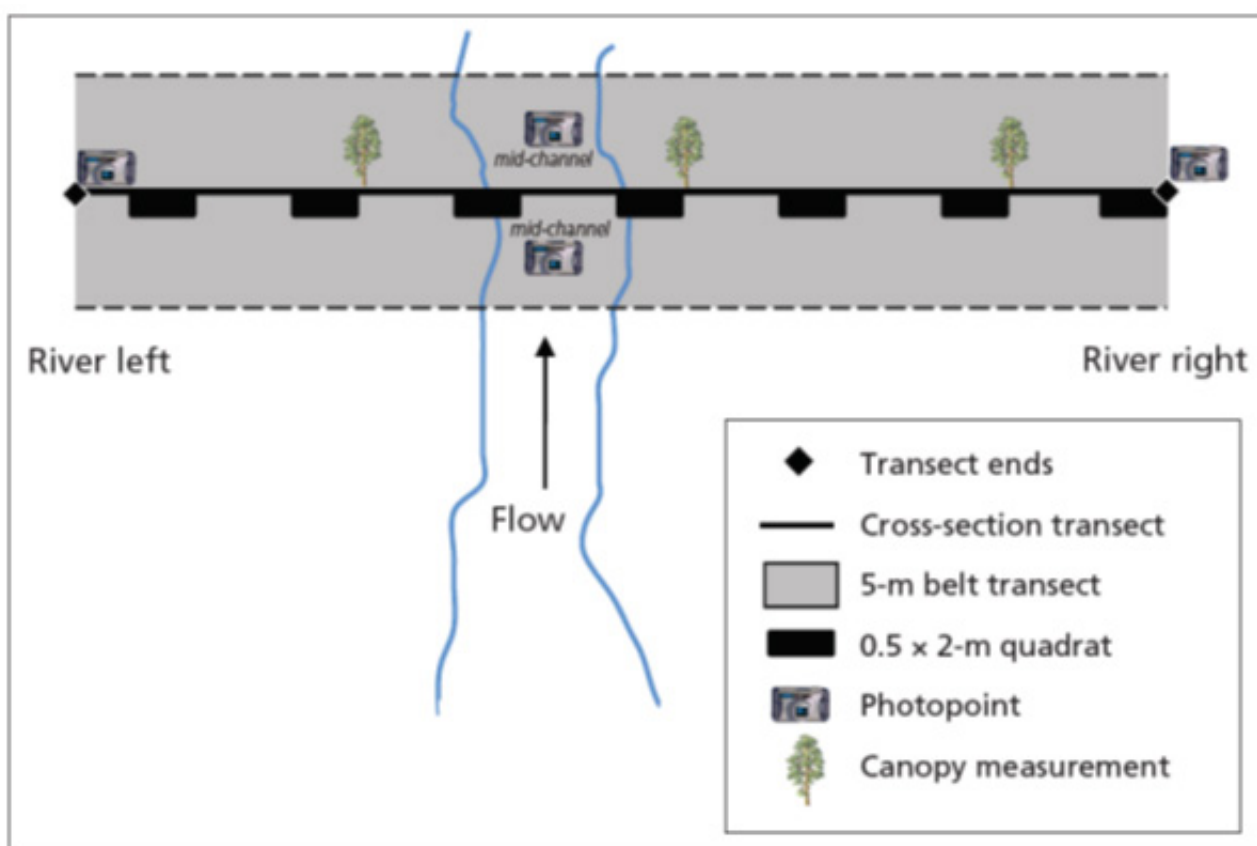


Figure 3. Response design for integrated riparian monitoring of Southern Colorado Plateau Network parks. Locations of vegetation sampling for wadeable streams and washes are indicated along each permanent cross-section transect. Understory vegetation is sampled using a point-intercept method at 0.5-meter intervals along the cross-section. Canopy closure is sampled at 10 m intervals on the cross-section. Seedling, sapling, and overstory tree density is recorded in a 5 m belt transect. Exotic plant frequency is sampled in  $0.5 \times 2$  m quadrats. A census of large-diameter trees (greater than or equal to 25 cm DBH) occurs at the reach scale.

done in increments as the work schedule allows. When scheduling allows, consider conducting the plant walk before beginning plot monitoring as a good way of vegetation team calibration.

### 4.3 Geomorphic Measurements (SOP #6)

Geomorphic measurements are surveyed using Nikon Nivo 3.M total station and Trimble Real-Time Kinematics (RTK) GPS surveying equipment. After establishing a survey control network at each sentinel site and back sights (control points used to verify location) at sites using a total station, all transducers and ground wells are surveyed. Transects are measured at every meter, along break points, and edge of water. When high water rack lines are available they are sur-

veyed at all sites. The thalweg is also surveyed throughout the reach at 1 m intervals to capture important channel features.

### 4.4 Hydrologic Measurements (SOP #5)

#### 4.4.1 Sites where surface water is primary

Site hydrology is measured as stream stage elevation across the reach or sentinel site being monitored. Water transducers are installed at or below the water level in stable locations upstream and downstream of the monitoring location in such a way that the slope of the water for any given discharge can be drawn across the sentinel sites or reaches. A transducer is installed on land in the vicinity of the water transducers for

atmospheric pressure corrections. The elevation of each transducer is surveyed for real world location and elevation using RTK survey or total station. The logging interval is set for once every 15-60 minutes depending on flow characteristics (flashiness).

Prior to departing for the field, personnel should run atmospheric pressure tests to ensure that the transducers are reading similarly and not drifting apart. Atmospheric pressure tests should be run on transducers that are already deployed at least once per year. In both cases, each atmospheric pressure test should include as many transducers as possible to support as many “should be the same” comparisons as possible. The minimum number of transducers should be a set of three transducers that will be used at one site (one placed in the water upstream and downstream of the site and one atmospheric pressure). Personnel should let the transducers run for at least a 24-hour period. When conducting atmospheric pressure tests during annual monitoring it might only be possible to have a 12-hour test. However if this 12-hour test can be done with at least one transducer that has previously been atmospheric pressure tested prior to the trip for a longer period, then if all transducers match, this provides greater assurance in a 12 hour test that the transducers are working properly. These atmospheric pressure test data will help identify potential fixed offsets among transducers, which will then be used in analysis, or may show a transducer is no longer operational and needs to be replaced before leaving the site.

Water transducers are ideally placed during low water in PVC casing that allows the transducer to be submerged after installation. Locations should be selected that are out of the way of scour and potential ice damage, but also have the same general slope of the water as the sentinel site. The ideal transducer location also has a view of the sky so that an RTK rover can be placed on top of the casing. Reference marks are made above the transducer and a set of measurements are made on each visit to determine

if the transducer has shifted and to provide a reference check on the actual transducer recordings.

Transducer data are then temperature and barometric-pressure compensated using Solinst or Hoboware software. This information then gives a depth of water at the transducer locations. By having a transducer above and below the site, we can calculate slope and a pool of water that goes up and down with changes in flow. We can then use this slope of water to estimate water depth across the sentinel site at each plot or any location. This can be used to determine the number of days that each plot was inundated with water.

#### ***4.4.2 Sites where groundwater is primary***

Groundwater elevations are measured in in-stream and riparian wells installed along one of the cross-section transects. Each well contains a pressure transducer that records data at 60-minute intervals. Data from hydrologic monitoring equipment are downloaded, and manual water-level measurements are recorded 3-4 times per year from March to November.

### **4.5 Photographs**

Reference and overview photographs are taken at each site (SOP #3). Overview photographs are taken from above the feature and relocated using a hand held GPS and reference photographs. Previous year's overview photographs are used to frame the new photograph. Reference photographs are taken to document locations of all survey control, headpins, orientation pins, or other specific features or items that need to be located in the future. Overview photographs are taken every year. Reference photographs only need to be taken if something in the photograph has changed (tree has fallen that is a significant marker) or if a new control point is established.

### **4.6 Aerial Imagery**

At larger sites we evaluate vegetated and unvegetated areas using freely acquired

aerial imagery (SOP #10). If the vegetation has an aerial coverage of >50% vegetated, it is considered vegetated. We select a base year and then keep the upland boundary the

same for all vegetated polygons which allows us to observe vegetation encroachment and channel narrowing over time (Figure 4).



Figure 4. Examples of remote sensing vegetated and unvegetated polygons from 1976 and 2014 on the Green River in Canyonlands National Park.

## 5 Sampling Design and Monitoring Schedule

### 5.1 Response Design

The sampling unit for riparian monitoring is a reach. Measurements of vegetation, hydrologic and physical drivers will be co-located at each reach. A reach is 180–360 meters in length, with seven equally spaced transects that run perpendicular to the channel. 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 (see Figure 3). Total-station or RTK 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 wells located at the reach or sentinel site. Wells may or may not be installed at all reaches, and full implementation of hydrologic monitoring will be determined by specific management questions and funding availability.

The response design, which is essentially the same as the field methods, is described in Section 4. All measures recorded along transects are subsamples scaled to the reach or sentinel site level. Reach-level and sentinel site-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.

### 5.2 Spatial Design

The focus of this protocol is rivers, streams, and washes 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 1, p.2).

Once a stream is selected, it is assessed for accessibility. Areas with pourovers (large bedrock that makes upstream passage difficult, dangerous, and or/impassable), large boulders, and other obstacles that restrict access in narrow canyons are excluded from the sampling frame. In many SCPN 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 the 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. 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 smaller parks 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.

After the sampling frame has been finalized, final monitoring sites are hand selected. Reaches with major tributary inputs (>10% of the watershed), major spring inputs, >25% bedrock constriction or bedrock

channel, changes in stream type (e.g., valley setting or flow permanence), or the presence of significant archeological or historic resources are rejected for sampling.

### 5.3 Revisit Design

At each river, stream or wash, the number of monitoring sites is limited by our crew size of 6 on one 8 day research trip per river, stream, or wash. Revisit designs are river/wash-specific and attempt to balance the need for observing inter-annual variability with maximizing replication (Woodward 2004).

Vegetation, surface water hydrology and geomorphic monitoring may all occur at some sites, but a rotating panel design will be used to increase the overall sample size at sites with long stretches of rivers and streams. Some sites will be sampled annually, while others will be sampled every 2-3 years.

Reaches will be sampled 1–2 years in a row and then rested for 3–5 years so that a total of 3–5 reaches are monitored on each stream or wash (Table 3). 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. Geomorphology surveying occurs between the two growing seasons when vegetation is sampled so 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.

For vegetation in washes, baseline vegetation measurements are taken in year 1, and then are only re-sampled every 5 years, or after a major disturbance event. Shallow groundwater and surface-water wells will be continuously monitored with pressure transducer located at hydraulic control points in the stream reaches. Information from the data loggers, as well as manual surface flow and groundwater measurements, will be collected at least once every twelve weeks along wadeable streams and washes from March to November. Vegetation and geomorphic sampling will take place during summer baseflow and after vegetation has reached its peak growth (June-September).

Table 3. Revisit design for Integrated Riparian Monitoring in Southern Colorado Plateau parks. Number of reaches sampled each year (indicated by "X") are based on a seven-year rotating panel revisit design.

| Reach | Year |   |   |   |   |   |   |   |   |    |
|-------|------|---|---|---|---|---|---|---|---|----|
|       | 1    | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1     | X    | X | – | – | – | X | X | – | – | –  |
| 2     | –    | X | X | – | – | – | X | X | – | –  |
| 3     | –    | – | X | X | – | – | – | X | X | –  |
| 4     | –    | – | – | X | X | – | – | – | X | X  |
| 5     | –    | – | – | – | X | X | – | – | – | X  |

## 6 Data Management, Analysis, and Reporting

Effective data management ensures data quality, interpretability, security, longevity, and availability, and is critical to the success of the riparian monitoring program. In this section we describe how these principles are applied to riparian monitoring on the Colorado Plateau. NCPN and SCPN are sharing methods and databases which will enable us to allow for combine analyses across parks on the Colorado Plateau.

### 6.1 Database Design

For the riparian monitoring program at SCPN, we will collect and manage four main types of data: vegetation, surface water, alluvial groundwater, and geomorphic data. Vegetation data are entered into Microsoft Access databases developed by the NCPN. These databases are designed to accommodate all data on the various field forms. The database design follows the I&M program's Natural Resource Database Template, but with modifications which bring it in line with the 2015 I&M database standards (Frakes et al. 2015). The database tables are organized largely by SOP and are linked in time (by transect) and space (sampling event) 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 and data edits.

Hydrology data are uploaded to the Aquarius system hosted by the NPS Water Resources Division. Aquarius is commercial software for managing time series 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 SCPN server. Geomorphic data will also be stored on the SCPN server.

### 6.2 Data Entry, Verification, and Validation (SOP #8)

Data are acquired according to the Standard Operating Procedures for this protocol using two different methods: 1) digitally

recorded using a total station or RTK (geomorphology), camera (photograph), GPS (spatial), or data logger (hydrology) and, 2) manually recorded on paper data sheets (vegetation, facies mapping, and grain size). Data recorded on paper data sheets should be entered into the database as soon as possible after a field visit. Data entry should be completed by someone who participated in data collection or is familiar with the project and data. Where appropriate, pick lists and domain limits in the database are used to restrict values entered into a field and ensure that only valid names or measures are entered.

Data verification occurs after data entry, and is the process whereby all records in the database are compared to the original paper data sheets and errors are corrected. The completion of data verification and other QA/QC processes will be tracked in the database. 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.

### 6.3 Data Documentation and Certification (SOP #8)

After the dataset is validated, the accompanying metadata is completed. Metadata is defined as structured information about the content, quality, condition, and other characteristics of a dataset. Additionally, metadata provide the means to catalog and search among datasets, thus making them available to a broad range of potential data users. Any records that did not meet the documented quality standards in the validation process must be clearly identified in the metadata.

### 6.4 Archiving data

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. Frequent backups are critical for preventing data loss. Full backup copies of the monitoring project will be stored at an off-site location.

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 digitized and accessioned into the SCPN archives for permanent storage and care.

## 6.5 Analysis and Reporting (SOP #9)

After raw data from the field season are quality checked and certified, they are then summarized to the feature or sentinel site level. Additional quality assurance/quality control measures are performed, comparing these data to previously collected data to catch misidentified species and values that represent unlikely amounts of change between years. Once data quality issues are resolved, analyses can be conducted.

The sampling unit for all riparian analyses is the feature or reach, and sub-samples recorded on plots or transects must be scaled to this level. Vegetation and geomorphic data may be integrated at the transect level, flow level (flow at which the plot is inundated, height above a base flow discharge), or geomorphic surface (active channel, active floodplain, etc.). Summary queries were created in Access to expedite this process.

Vegetation data from point intercept are used to calculate percent frequencies of species or groups of indicator species, species richness, proportion of native to introduced species, and the number of unique species encountered. Percent cover is calculated for total plant cover, each species, and groups of indicator species.

Modal particle sizes (sediments, pebble, gravel, boulder etc.) and point-intercept data can be used to evaluate state changes. For example, mid-channel gravel and/or cobble bars along many streams and rivers on the Colorado Plateau, typically have a cap of sand on their downstream end. The lateral and vertical expansion of a sand cap on the downstream end of the large, mid-channel island in Laddie Park in Dinosaur National Monument, was shown to coincide with the establishment and spread of tamarisk, along with progressive channel narrowing, beginning in the late-1940s and early-1950s (Manners et al. 2014). Thus, tracking the size of a fine-grained deposit like a sand cap over time, through topographic surveying and facies mapping, would provide early and important evidence of a channel narrowing process.

Vegetation data are integrated with the geomorphic transects to derive ecological and physiological guilds (mesic shrubs, xeric trees, hydric herbs, etc.) and indicators of active channel, active floodplain, and inactive floodplain plant cover by surface elevation and species richness and percent cover by geomorphic surface and flow elevation. These data are further integrated with the hydrological data.

In conjunction with the known elevation of each surveyed vegetation plot, we can calculate the number of days within the period of record when the plot was underwater for a majority of the day; (i.e., underwater for  $\geq 12$  time points during the day). We can then calculate the proportion of days within the period of record when the plot was underwater (using the daily 'average':  $[\% \text{ inundated}] = [\text{days inundated}] / 365 \text{ days}$ ). Inundation frequency of the floodplain (return frequency in years) requires multiple years of hydrologic data in addition to a survey of the flood plain. Logistic regression can be used to relate plant species occurrence in plots to inundation duration. Depth to groundwater measurements can be analyzed by the mean annual and mean growing season depth, the minimum and maximum depths as well as inter- and intra-annual variation.

These depths can be compared to the critical depths needed to sustain riparian vegetation.

Comprehensive analyses and reports will be completed periodically on the long term data set, and should be structured like typical scientific manuscripts (introduction, methods, results, discussion, and literature cited sections). They may include any of the analyses described in this section. Status and trend analyses are performed after at least 5 years of monitoring data are collected. When significant trends are detected, reasons for these trends should be evaluated by literature reviews, comparison with similar data sets, and additional assessments using ancillary information. When unidirectional trends are not detected, correlations may help us understand system drivers. Responses and trends corresponding to large flow events or abnormally dry periods may be more informative for river monitoring than long-term trends.

## 7 Budget

Estimated costs for conducting field-based integrated riparian monitoring in SCPN parks are provided in Table 4.

Table 4. SCPN integrated riparian annual monitoring budget

| Budget item                                         | Annual cost (\$) |
|-----------------------------------------------------|------------------|
| NAU water resources staff: Geomorphology/Vegetation | 25,500 – 27,000  |
| NAU water resources staff: Hydrology                | 27,500 – 30,000  |
| Equipment and supplies                              | 2,000 – 3,000    |
| Travel                                              | 800 – 1600       |
| Total                                               | 55,800 – 61,600  |

## 8 Safety

SCPN is committed to providing safe working conditions for its employees and cooperators. The network does this by:

- providing thorough training so that employees have the knowledge, skills and abilities to perform their jobs safely
- providing training for employees and supervisors to recognize unsafe and unhealthful work practices and conditions
- ensuring that employees know and follow safety work rules and procedures
- ensuring that all vehicles and equipment are in good working condition
- providing a safety committee to review any incidents that may occur and make recommendations to prevent their recurrence.

The network has prepared a Field Safety Plan that specifically addresses conditions that may be encountered in the course of fieldwork conducted by its water resources, integrated upland, and bird monitoring crews (Southern Colorado Plateau Network 2013, revised 2018). All field crew members should thoroughly review the safety procedures in this plan at the beginning of every field season. In addition, the field crew should familiarize themselves with the back-country guidelines, job hazard analyses, and emergency protocols for the parks in which they work as applicable. It is the responsibility of network staff and cooperating employees to be aware of project-specific safety concerns and to take the necessary safety precautions.

## 9 Standard Operating Procedures

The following standard operating procedures (SOPs) (Table 5) for riparian monitoring in SCPN parks can be found in the NPS Integrated Resource Management Application project for the Integrated Riparian

Monitoring protocol, and are based on the NCPN Big River Monitoring Protocol (Perkins et al. 2018) and the NCPN Wadeable Streams Monitoring Protocol (Weissinger et al. 2018).

Table 5. Standard Operating Procedures (SOPs) required for the Riparian Monitoring Protocol Implementation Plan for Southern Colorado Plateau Network parks. SOPs are listed by task category and are grouped together in the NPS Integrated Resource Management Application (IRMA) project for the Riparian Monitoring Protocol at <https://irma.nps.gov/DataStore/Reference/Profile/2254859>.

| SOP Number and Title                           | Citation                                                                                                                                                                                                                                                                                                                                | Notes                                                                                      |
|------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| 1. Prior to the Field Season and Equipment     | Weissinger et al. 2018. Standard Operating Procedure (SOP) # 4 Preparations for the field season and equipment needed and Perkins et al. 2018. Standard Operating Procedure (SOP) #1 Prior to the Field Season and Equipment Lists                                                                                                      | –                                                                                          |
| 2. Site Establishment Wadeable/Washes          | Weissinger et al. 2018. Standard Operating Procedure (SOP) # 4 Establishing the Reach and Setting up Transects and Perkins et al. 2018. Standard Operating Procedure (SOP) # 1 Prior to the Field Season and Equipment Lists                                                                                                            | –                                                                                          |
| 3. Photos                                      | Perkins et al. 2018. Standard Operating Procedure (SOP) #5 Photos                                                                                                                                                                                                                                                                       | –                                                                                          |
| 4. Vegetation                                  | Weissinger et al. 2018. Standard Operating Procedure (SOP) #6 Measuring Vegetation and Surface Cover                                                                                                                                                                                                                                    | –                                                                                          |
| 5. Well Installation and Hydrologic Monitoring | Weissinger et al. 2018. Standard Operating Procedure (SOP) # 10 Well Installation and Hydrologic Monitoring                                                                                                                                                                                                                             | NCPN Wadeable streams protocol to be used where groundwater monitoring is primary concern. |
| 6. Surveying                                   | Perkins et al. 2018. Standard Operating Procedure (SOP) #8 Surveying, #16 Trimble RTK Basic Operating Procedures Instructions in the Field, #17 Trimble Business Center (TBC) Basic Office Operations and Field QAQC Operating Instructions and Weissinger et al. 2018. Standard Operating Procedure (SOP) # 9 Stream Channel Surveying | –                                                                                          |
| 7. After each field visit                      | Weissinger et al. 2018. Standard Operating Procedure (SOP) #11 After each field visit                                                                                                                                                                                                                                                   | –                                                                                          |
| 8. Data Management                             | Weissinger et al. 2018. Standard Operating Procedure (SOP) # 13 Data Management.                                                                                                                                                                                                                                                        | –                                                                                          |
| 9. Data summary, analysis and reporting        | Weissinger et al. 2018. Standard Operating Procedure (SOP) # 14 Data analysis and reporting.                                                                                                                                                                                                                                            | –                                                                                          |
| 10. Aerial imagery                             | Perkins et al. 2018. Standard Operating Procedure (SOP) #18 Remote sensing of vegetated and non-vegetated areas                                                                                                                                                                                                                         | –                                                                                          |
| 11. Revising the Protocol                      | Weissinger et al. 2018. Standard Operating Procedure (SOP) # 11 Revising the Protocol Narrative and SOPs                                                                                                                                                                                                                                | –                                                                                          |

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## Appendix A

### Current and Proposed Long-Term Monitoring in Southern Colorado Network Parks

Below is a list of monitoring protocols implemented in SCPN parks (indicated with an “X”), and where riparian and springs will be implemented in 2019. Riparian and Springs monitoring in parks are rated as high priority (H), medium priority (M) and low priority (L). In selecting the parks where we will implement riparian and springs protocols, we considered where monitoring was already taking place. In parks where we are not currently monitoring, we will implement riparian and/or springs protocols where applicable. In parks where we are conducting multiple monitoring projects, monitoring riparian and springs ecosystems would be a lower priority. See Appendix B for park acronym definitions.

| Monitoring Protocol                                                                                                                                                                                       | Parks          |      |                         |      |      |      |      |      |      |                  |                |      |      |      |      |                |      |                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|------|-------------------------|------|------|------|------|------|------|------------------|----------------|------|------|------|------|----------------|------|-----------------|
|                                                                                                                                                                                                           | AZRU           | BAND | CACH                    | CHCU | ELMA | ELMO | GLCA | GRCA | HUTR | MEVE             | NAVA           | PEFO | PETR | SAPU | WACA | WUPA           | YUHO | # of Parks      |
| Aquatic Macroinvertebrates                                                                                                                                                                                | –              | X    | X                       | –    | –    | –    | –    | X    | –    | X                | –              | –    | –    | –    | –    | –              | –    | 4               |
| Habitat-based Bird Communities                                                                                                                                                                            | –              | X    | X                       | –    | –    | –    | –    | X    | –    | X                | –              | X    | –    | –    | –    | X              | –    | 6               |
| Integrated Upland Vegetation and Soils                                                                                                                                                                    | X              | X    | –                       | X    | X    | –    | X    | X    | –    | X                | –              | X    | X    | –    | X    | X              | –    | 11              |
| Water Quality                                                                                                                                                                                             | –              | X    | X                       | –    | –    | –    | X    | X    | –    | X                | –              | –    | –    | –    | –    | –              | –    | 5               |
| Vegetation Condition and Phenology, and Snow Cover Extent                                                                                                                                                 | X              | X    | X                       | X    | X    | X    | X    | X    | X    | X                | X              | X    | X    | X    | X    | X              | X    | 19 <sup>1</sup> |
| # of protocols implemented (not including Riparian and Springs)                                                                                                                                           | 2              | 5    | 4                       | 2    | 2    | 1    | 3    | 5    | 1    | 5                | 1              | 3    | 2    | 1    | 2    | 3              | 2    | 44              |
| Riparian                                                                                                                                                                                                  | H <sup>2</sup> | L    | 1 of 2 M/L <sup>3</sup> | H    | –    | H    | M    | L    | H    | H/L <sup>4</sup> | H <sup>5</sup> | M    | H    | H    | H    | –              | –    | 14              |
| Springs                                                                                                                                                                                                   | –              | –    | 1 of 2 M/L <sup>3</sup> | M    | –    | –    | H    | L    | –    | L                | –              | L    | –    | –    | –    | H <sup>6</sup> | H    | 8               |
| # of Protocols proposed to be implemented with Riparian and Springs Included                                                                                                                              | 3              | 6    | 6                       | 4    | 2    | 2    | 5    | 7    | 2    | 7                | 2              | 5    | 2    | 2    | 3    | 4              | 2    | 64              |
| # of Protocols to be implemented in 2019- with only high priority riparian and springs included.                                                                                                          | 3              | 5    | 4                       | 3    | 1    | 2    | 4    | 5    | 2    | 6                | 1              | 3    | 2    | 1    | 3    | 4              | 2    | 51              |
| <sup>1</sup> This total includes Rainbow Bridge National Monument and Sunset Crater National Monument, which are not included in this table. This is the only monitoring to be conducted for these parks. |                |      |                         |      |      |      |      |      |      |                  |                |      |      |      |      |                |      |                 |
| <sup>2</sup> AZRU riparian will be groundwater wells only for high priority in 2019, other components will be low priority.                                                                               |                |      |                         |      |      |      |      |      |      |                  |                |      |      |      |      |                |      |                 |
| <sup>3</sup> CACH will choose riparian or springs as medium priority and the other one will be low priority. Choice to be made in October 2019.                                                           |                |      |                         |      |      |      |      |      |      |                  |                |      |      |      |      |                |      |                 |
| <sup>4</sup> MEVE will be surface water only for high priority in 2019, the other components will be low priority.                                                                                        |                |      |                         |      |      |      |      |      |      |                  |                |      |      |      |      |                |      |                 |
| <sup>5</sup> NAVA will choose riparian or springs for monitoring in October 2019.                                                                                                                         |                |      |                         |      |      |      |      |      |      |                  |                |      |      |      |      |                |      |                 |
| <sup>6</sup> WUPA groundwater wells will be maintained by the park, SCPN will do data management.                                                                                                         |                |      |                         |      |      |      |      |      |      |                  |                |      |      |      |      |                |      |                 |

## Appendix B

### Park Acronyms

| Park                                        | Abbreviation |
|---------------------------------------------|--------------|
| Aztec Ruins National Monument               | AZRU         |
| Bandelier National Monument                 | BAND         |
| Canyon De Chelly National Monument          | CACH         |
| Chaco Culture National Historical Park      | CHCU         |
| El Malpais National Monument                | ELMA         |
| El Morro National Monument                  | ELMO         |
| Glen Canyon National Recreation Area        | GLCA         |
| Grand Canyon National Park                  | GRCA         |
| Hubbell Trading Post National Historic Site | HUTR         |
| Mesa Verde National Park                    | MEVE         |
| Navajo National Monument                    | NAVA         |
| Petrified Forest National Park              | PEFO         |
| Petroglyph National Monument                | PETR         |
| Rainbow Bridge National Monument            | RABR         |
| Salinas Pueblo Missions National Monument   | SAPU         |
| Sunset Crater Volcano National Monument     | SUCR         |
| Walnut Canyon National Monument             | WACA         |
| Wupatki National Monument                   | WUPA         |
| Yucca House National Monument               | YUHO         |

## Appendix C

### 508 Accessible Table 1

Table 1. Rivers, streams, and washes that may be included in SCPN's riparian monitoring program with proposed protocol to be used for monitoring.

| Category                                                                                                                             | Park | Stream/River                                                 | Sections of Weissinger et al. (2017) to be Implemented | Stream Type             | Why Monitor?                                                                                    | Comment                                                                                                                   |
|--------------------------------------------------------------------------------------------------------------------------------------|------|--------------------------------------------------------------|--------------------------------------------------------|-------------------------|-------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|
| High Priority Riparian Area                                                                                                          | AZRU | Animas                                                       | Groundwater                                            | Perennial               | Groundwater concerns                                                                            | Only option                                                                                                               |
| High Priority Riparian Area                                                                                                          | CACH | Tsaile Creek                                                 | Wadeable Streams                                       | Perennial/ Intermittent | Plantings, control of invasive species, livestock?                                              | Will need to only one. Final decision in October. Evaluate with springs.                                                  |
| High Priority Riparian Area                                                                                                          | CACH | Chinle Wash                                                  | Wadeable Streams                                       | Intermittent            | Plantings, control of invasive species, livestock?                                              | Will need to only one. Final decision in October. Evaluate with springs.                                                  |
| High Priority Riparian Area                                                                                                          | CHCU | Chaco Wash                                                   | Washes/ Wadeable Streams                               | Ephemeral               | Track long-term ground-water and channel change, historical decline in riparian vegetation      | More important than springs (D. Hawkins 8.6.18)                                                                           |
| High Priority Riparian Area                                                                                                          | ELMO | Historic Pool                                                | Hydrology only                                         | Surface pool            | Pool level                                                                                      | –                                                                                                                         |
| High Priority Riparian Area                                                                                                          | HUTR | Pueblo Colorado Wash                                         | Wadeable Streams                                       | Intermittent            | Geomorphology/vegetation/ hydrology                                                             | Only option                                                                                                               |
| High Priority Riparian Area                                                                                                          | MEVE | Mancos River                                                 | Continue hydrology only                                | Perennial               | No gauge on the Mancos River                                                                    | Top riparian priority for park, but this is lower priority than springs.                                                  |
| High Priority Riparian Area                                                                                                          | NAVA | Betatakin Canyon                                             | Washes/Wadeable Streams                                | Intermittent/ ephemeral | Cultural                                                                                        | Keet Seel is higher park priority than Betatakin. Choose only one. Evaluate with springs. Final decision in October 2018. |
| High Priority Riparian Area                                                                                                          | NAVA | Keet Seel Canyon                                             | Washes/Wadeable Streams                                | Intermittent/ ephemeral | Cultural                                                                                        |                                                                                                                           |
| High Priority Riparian Area                                                                                                          | PETR | North Boca Negra, Mairehaven, Ladeara and Rin-conanda Arroyo | Washes                                                 | Ephemeral               | Geomorphology/erosion                                                                           | Will need to choose one during October 2018 site visit. Geomorphology most important                                      |
| High Priority Riparian Area                                                                                                          | SAPU | Cañon Sapato                                                 | Wadeable Streams                                       | Perennial               | Cultural. Run-off flows and channel morphology including headcutting. Complete riparian picture | Cañon Sapato is higher priority than Abo. (M. LeFrancois 7/25/2018). Interested in all components of riparian.            |
| <sup>1</sup> To be implemented after High Priority Riparian<br><sup>2</sup> To be implemented after High and Medium Priority Springs |      |                                                              |                                                        |                         |                                                                                                 |                                                                                                                           |

Table 1 (continued). Rivers, streams, and washes that may be included in SCPN's riparian monitoring program with proposed protocol to be used for monitoring.

[illegible]

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