

U.S. Department of the Interior
National Park Service
Inventory and Monitoring Program
Big River Monitoring Protocol for the Park Units in the
Northern Colorado Plateau Network

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Version 1.00 (December 2016)

Version 1.00 (December 2016)

Revision History Log:

Prev. Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #

Important Note: This sampling protocol consists of this protocol narrative and the following standard operating procedures (SOPs) and appendices:

- SOP 1: Prior to the Field Season and Equipment Lists
- SOP 2: Training Observers
- SOP 3: GPS Methods
- SOP 4: Sentinel Site Set Up
- SOP 5: Photos
- SOP 6: Measuring Vegetation
- SOP 7: Hydrologic Measurements
- SOP 8: Surveying
- SOP 9: After Each Field Visit
- SOP 10: After Each Field Season
- SOP 11: Data Management
- SOP 12: Data Analysis and Reporting
- SOP 13: Revising the Protocol
- SOP 14: Facies Mapping and Grain Size Distribution
- SOP 15: Curecanti National Recreation Area Methods
- SOP 16: RTK Surveying Set Up and Operation
- SOP 17: RTK2 Surveying Office Processing
- SOP 18: Remote sensing of vegetated and non-vegetated areas

I. Introduction

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

In 2003, NCPN staff solicited input on natural resources of concern and ecosystem indicators known as “vital signs” from several hundred NPS staff and regional and national experts (O’Dell et al. 2005). Potential vital signs were evaluated for management significance and utility, ecological significance, scientific validity, feasibility and cost of implementation, and signal to noise ratio. Because of the scarcity of water on the Colorado Plateau, the importance of large rivers and the disproportionately high use by flora and fauna (Hubbard 1977, DeBano and Schmidt 2004), riparian areas were quickly identified as an ecosystem of concern for the NCPN. Following the determination of network-wide vital signs, parks were asked to select their top priorities for monitoring. Four NCPN park units were selected for Big River Monitoring: Black Canyon of the Gunnison National Park (BLCA), Canyonlands National Park (CANY), Curecanti National Recreation Area (CURE), and Dinosaur National Monument (DINO). Related monitoring efforts at additional parks are included in separate protocols for wadeable streams (Weissinger et al. 2013), water quality (Thoma et al. 2007), land surface phenology (Thoma et al. 2013), landscape dynamics (Thoma 2016), and invasive plants (Perkins et al. 2016).

In these four NCPN units, big rivers and riparian zones provide stark contrast to the surrounding desert environment. These river ecosystems provide habitat for federally-listed terrestrial and aquatic species, are intimately intertwined with unique geologic features cited in enabling legislation, and are major recreational destinations. However, as demands for water from the Colorado River basin increase, water development projects have altered streamflow in virtually all of the Colorado River basin. In most cases, stream flows—and peak flows—have been reduced, leading to channel simplification. Channel simplification can result in a number of negative impacts, including channel narrowing, reduced diversity and scale of geomorphic surfaces and associated habitats, disconnection of the river from its floodplain, increases in invasive plants, and changes to riparian vegetation and biodiversity.

We hypothesize that under anticipated climate change and increasing human demands for water, streamflow regimes will shift in response to (1) more droughts and bigger floods in some places, and (2) more droughts and fewer, smaller floods in others because of water resource development. These shifts may lead to channel simplification through vegetation encroachment, stabilization of formerly active channel deposits, and the creation of new floodplain surfaces due to lateral and vertical deposition of alluvial sediments.

We selected three vital signs for big river monitoring:

- 1) channel geomorphology,
- 2) riparian vegetation structure and composition, and
- 3) stream flow

This protocol structures monitoring based on how large rivers of the region are predicted to respond to future natural and human-induced changes in stream flow, resulting in direct, measurable changes in channel form and function, as well as related changes in the abundance, composition, and distribution of riparian vegetation. The NCPN has approximately \$1.1 million annually to implement eleven protocols in 16 national park units. Given the limited time and financial resources NPS has available to devote to monitoring extensive reaches of big rivers in remote locations, we have developed a multi-scalar approach to monitoring big rivers with three integrated elements. These elements combine remotely sensed and ground-based data and include: A) field-based, detailed, and quantitative assessments of geomorphic and vegetation change at sentinel sites that are predicted to be sensitive to channel narrowing; B) a broad-scale, remotely sensed assessment of geomorphic and vegetation change, particularly in relation to channel narrowing; and C) the integration of sentinel sites with historical monitoring and research data at sites (legacy sites) that provide context and insight into dynamics of channel change and the factors that drive this change.

We seek to opportunistically integrate our monitoring efforts with legacy research and monitoring sites, which were established prior to NCPN monitoring. We define legacy sites to be those which have been the focus of past monitoring and/or research efforts (e.g., Deerlodge Park, Echo Park, Laddie Park in DINO, Warner Point in BLCA, endangered fish sites at CANY). Each park has at least one to three legacy sites. The research and monitoring may be ongoing, inactive, or intermittent at these sites, but can be more intensive and spatially extensive than the sentinel sites. As such, we placed some sentinel sites specifically at legacy sites to tie into existing control networks and monitoring efforts. This will allow NCPN to leverage the longer term record of data, and the data from this protocol can be integrated with the legacy data, which are funded with other resources. Further, past research results at legacy sites can provide detailed ecological context to co-located monitoring efforts. For example, Manners et al. (2010, 2014) work in Laddie Park, provides a detailed historical reconstruction of the process by which tamarisk was involved in transforming portions of a mid-channel gravel bar into a stable, inactive flood plain. This partnership approach has also led to the implementation of variations of this big river monitoring protocol on the Colorado River in Grand Canyon National Park and the Rio Grande River at Big Bend National Park. This will allow comparisons to be made across the major river parks in the Intermountain Region.

The four parks where NCPN does big river monitoring contain two of the major confluences and portions of four of the major rivers in the Upper Colorado River Basin. The Yampa River remains as the longest relatively free-flowing reach of river in the Colorado River basin and partially “naturalizes” the flow-regulated Green River below the confluence. DINO provides a unique paired comparison between the regulated Green River, the unregulated Yampa River of

comparable annual discharge, and the partially flow-restored Green River below the confluence. CANY provides the summation of the Green and Colorado River drainages as they converge in the park before disappearing below the surface of Lake Powell. At BLCA, big river monitoring data will be tightly tied to evaluating the success of the NPS water right to the Gunnison River.

A. Channel Narrowing and Simplification

Despite the physical, biological, and aesthetic importance of these large rivers, human demands on the Colorado River basin's water and hydropower continue to grow. Increasing human population fuels increased demands for Colorado River water in Utah, Colorado, Arizona, Nevada, California, Wyoming and New Mexico. This demand includes existing within-basin uses and newly proposed trans-basin diversions from upper basin sources, including Flaming Gorge Reservoir and the Gunnison and Yampa Rivers. Streamflow in virtually all of the rivers within the Colorado River drainage specifically, and across the southwestern US in general, have been altered by water development projects. In most cases, peak flows have been reduced, resulting in channel narrowing, geomorphic simplification and loss of riparian structure and related biological diversity (Williams and Wolman 1984, Grams and Schmidt 2002). In many cases base flows have also increased which can result in vegetation expansion (Sankey et al. 2015).

Channel narrowing or simplification and related vegetation changes have been noted on large rivers throughout the region since the mid-twentieth century. These changes have occurred following reductions in streamflow related to climate change and water development (Hereford 1984, Allred and Schmidt 1999, Grams and Schmidt 2005, Dean and Schmidt 2011, Manners et al. 2014). However, there has been some short-term widening documented at DINO by Lyons et al. (1992) caused by large floods that occurred in the mid-1980s and some slowing of the narrowing process at CANY (Perkins et al. in prep). Channel narrowing involves reductions in the size and geomorphic complexity of stream channels, along with related changes in the width, structure and composition of riparian vegetation (Graf 2006). Grams and Schmidt (2002) found that narrowing occurred due to the deposition of fine grained sediments in DINO, and within debris-fan dominated canyons narrowing was the greatest where there was the greatest reduction in stream power. This resulted in a post-dam floodplain that is disconnected from the river.

In many cases, this narrowing has been accompanied and in some settings enhanced by the establishment and spread of the non-native riparian shrub tamarisk (*Tamarix ramosissima* and hybrids) (Everitt 1993, Birken and Cooper 2006, Manners et al. 2010, Dean et al. 2011). In addition to contraction of the width of the riparian zone (Auble et al. 2005), the narrowing process simplifies channel form and spatial complexity, and thus reduces important in-channel habitat for native aquatic species, including endangered fish (Schmidt and Brim-Box 2004, Van Steeter and Ptilick 1998). A continuing process of channel narrowing can be expected along large rivers of the southwestern US as increasing demands for water by growing regional

populations (Sabo et al. 2010) collide with potentially reduced supplies resulting from predicted intensification of regional drought conditions (Seager et al. 2007).

Channel narrowing proceeds as portions of the active channel convert to stable, vegetated floodplain surfaces. Floodplains represent one of a number of river-deposited features and are typically composed of vertically stacked fine-grained layers of sediment left by discrete floods. By definition, floodplains are level surfaces constructed by a river under prevailing climatic conditions, and are relatively frequently inundated by high flows (Leopold 1994); however, there is no regionally consistent recurrence of inundation of these features, as is found in laterally accreting floodplains along meandering rivers in other regions. Along channels confined by colluvium or bed rock, floodplain deposits may be narrow and discontinuous (Grams and Schmidt 2002), or even non-existent. In contrast, channels in large alluvial basins may have large, spatially extensive floodplains. Vertically aggraded floodplains progressively become disconnected from surface flows in adjacent channels (Manners et al. 2010), and may be abandoned if the regional climate becomes drier.

Riparian vegetation establishment and succession is 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, Bradley and Smith 1986, Boggs and Weaver 1994, Allred and Schmidt 1999, Dean et al. 2011). This tight linkage between fluvial geomorphic processes and riparian vegetation dynamics allows the encroachment of persistent vegetation onto formerly active channel deposits to serve as a proxy measure of channel narrowing. Early detection and quantification of the channel narrowing process would identify reaches sensitive to narrowing so that management actions could be implemented in a more efficient and cost effective way, help inform dialogue between NPS and water users, and perhaps influence future water management decisions.

The channel simplification question is slightly different at CURE. At this park there is only 6 km of free flowing river that encompasses an area of approximately 193 hectares before it enters Blue Mesa Reservoir. The Gunnison River is made up of the dammed Taylor River, and undammed East River and Tomichi Creek. In addition to peak flows, ice flows occur in this area and can result in scouring and vegetation damage. CURE staff is primarily interested in narrow-leaf cottonwood recruitment (*Populus angustifolia*) and channel migration that can lead to cottonwood recruitment events. *Populus* establishment along meandering streams has been largely eliminated due in part to reduced rates of meandering (Bradley and Smith, 1986, Rood and Mahoney, 1990, Johnson, 1992). Flood flows are needed to produce *Populus* germination sites (Stromberg et al. 1991, Scott et al. 1997). The flow recessions that follow a peak allow for root elongation at the exposed germination sites (Mahoney and Rood 1991, 1992, Segelquist et al. 1993), and subsequent base flows are needed to supply soil moisture for seedlings. Shafroth et al. (1998) found that the conditions that allow *Populus* to establish are also conducive to other woody vegetation establishment. Scott et al. (1997) found that only infrequent large floods could establish site conditions for *Populus* due to limited channel movement. CURE staff is concerned

that due to flow regulation and constructed berms that constrain the river to defined channels, the flows that are necessary for cottonwood recruitment have been diminished.

B. Methods for Monitoring Big Rivers

There are a number of direct and indirect metrics that might be used to assess a long-term channel narrowing process. Measuring streamflow over time would be the most direct way of assessing change in streamflow that might lead to channel narrowing, but it is difficult to relate flow changes to channel response without also measuring changes in channel geometry. Changes in channel geometry through the conversion of active channel surfaces to less active and more stable surfaces is a hallmark of channel narrowing (Graf 2006) that is often intimately related to the establishment of riparian vegetation. We chose to focus our monitoring efforts on hydrologic, geomorphic and vegetation changes because these represent the most immediate and observable manifestations of the channel narrowing process.

Direct measures of channel narrowing often involve repeated topographic surveys at permanently located full channel cross-sections over time. Such direct measures can provide detailed and temporally rich information on localized channel change, but often are spatially limited, making it difficult to infer change at larger spatial scales (Moody and Pizzuto 1999, Allred and Schmidt 2002). A time sequence of air photos provides an indirect but spatially integrated quantification of channel change over larger areas, but generally is too coarse to provide a more detailed interpretation of floodplain formation and related channel narrowing (Graf 1978, Merritt 1997). Some combination of fine- and coarse-scale analyses of channel narrowing can provide a more robust interpretation (Manners et al. 2010, Dean and Schmidt 2011). Full cross-sections with bathymetry, like the studies above, are probably the optimal method for measuring geomorphic changes along a river. However, the costs in labor or equipment are cost prohibitive for NCPN. We do conduct our geomorphology work at low flow where we survey 75-90% of the channel, only avoiding the deepest sections due to safety. While under optimal conditions we would have full cross sections, the changes in the deep sections that we do not see (river incision, disconnecting from floodplain) will eventually show up on the banks where we do sample. Water penetrating LiDAR is also effective at getting bathymetry, but does not work in sediment laden rivers as found on the Colorado Plateau.

Another widely used method for monitoring riparian areas is like those developed by the EPA for the Environmental Monitoring and Assessment Program (EMAP). The EMAP protocol incorporates seven complete stream cross-sections for geomorphology and riparian vegetation, and ground water wells to understand alluvial groundwater hydrology. This is similar to riparian and aquatic monitoring approaches that focus efforts on a section of stream (a stream reach) and subsample that reach using cross-sectional transects (Fitzpatrick et al. 1998, Winward 2000, Heitke et al. 2010, Leary and Ebertowski 2010). The NCPN has developed a wadeable streams protocol for small and ephemeral streams in the network (Weissinger et al. 2013) based loosely on the EMAP methods. Extensive sampling to evaluate the efficiency and effectiveness for

various ecological measures and measurement techniques took place to develop the NCPN wadeable streams protocol (Scott and Reynolds 2007). While this approach works well for wadeable streams on a small scale and provides a framework of components to be followed for big river monitoring, it is not achievable at the scale of NCPN big rivers.

Other arid land riparian methods were reviewed and evaluated and determined to not be of sufficient rigor, repeatable (Stacey et al. 2005, Herrick et al. 2005 [Riparian channel and gully profile]), or alternatively too expensive for NCPN resources (Lord et al. 2009, Grams 1997, Grams and Schmidt, 2002, 2005, Melis 2011). Due to the extensive lengths of rivers in remote settings within NCPN parks and the limited resources available for monitoring, we sought to focus most of our effort on: (1) detailed annual monitoring at a select number of sites (sentinel sites) that we hypothesize are sensitive to potential changes in streamflow; and (2) remote sensing across a broad spatial scale to capture any changes that might be occurring outside of the sentinel sites.

C. Geomorphic Indicators of Channel Simplification and Narrowing

Geomorphic indicators of the channel narrowing process involve construction 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). Large dams can result in 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). Graf et al. (1991) and Hereford et al. (1996) showed that the process that disconnects floodplains began when the frequency of large floods decreased, and these floodplains were constructed by moderate magnitude summer and fall floods transporting large suspended-sediment loads.

On the regulated Green River in DINO Grams and Schmidt (2002) found the channel adjustment occurred by formation of new floodplains inset within a formerly larger pre-dam channel. Vertically accreting floodplains do not necessarily reflect a correspondence between bankfull and effective discharge because the vertically aggrading floodplain has a constantly changing elevation. Allred and Schmidt (2002) measured rates of aggradation and inundation frequencies of vertically accreting floodplains on the Green River near Green River, UT. Island aggradation (which is in essence a unique form of vertical floodplain accretion) is limited to the water surface level corresponding to river stage at peak flow and the competence of these flows to mobilize coarse bed material (Pitlick and Van Steeter, 1998; Osterkamp, 1998; Allred and Schmidt, 1999). Merritt and Cooper (2000) found that the area occupied by islands and fluvial marshes was likely to continue to increase throughout Browns Park on the Green River, just above DINO, as long as there is a supply of sediment available for island development. Gravel bars often provide important spawning habitat for endangered fish. If these bars aggrade and disconnect from the

main channel, they become less mobile and tend to accumulate fine sediment which in turn allows for vegetation establishment, and ultimately further disconnect the surface from the active channel making them unavailable to these fish species. Additional and less direct consequences of channel narrowing may involve changes in aquatic invertebrates related to changes in streamflow, water temperature and habitat changes (Vinson 2001).

River channels adjust to variations in the discharge of water and the size and amount of sediment supplied to the stream from the watershed (Leopold et al. 1964). Flow governs channel dimensions like 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. Decreased flows can result in sediment mass balance surplus, which leads to the development of floodplains, regardless of whether or not invasive riparian vegetation is present (Everitt, 1993; Allred and Schmidt, 1999).

Vegetation that establishes in the active channel may contribute to narrowing by facilitating accretion and reduced channel capacity by increasing hydraulic roughness and increasing sediment deposition rates. Graf (1978) and Allred and Schmidt (1999) suggest that the establishment of exotic species, such as *Tamarix*, has accelerated the process of channel narrowing on the lower Green River. They found that the primary causes of both widening and narrowing of the active channel, was the erosion of channel margins, steepening of banks and subsequent bank failure, as well as the elimination of point bar deposits and transitional surfaces on the insides of meanders. Similarly, using stratigraphic and dendrogeomorphic historical reconstructions of channel change in combination with a time sequence of aerial photographs, Manners et al. (2010) documented localized channel narrowing along the Yampa River in Harding Hole and Laddie Park since 1939, the earliest available aerial photography. They documented a progressive narrowing process, which involved establishment of tamarisk during a series of low-flow years, followed by lateral and vertical accretion of fine-grained sediment deposited in subsequent flood years. Active and inactive floodplain surfaces were variously constructed on mid-channel gravel bars, eddy bars and lateral bars. Thus, a persistent increase in the area of relatively stable vertically and laterally accreting, fine-grained sediments in the active channel is a direct geomorphic indicator of channel narrowing. In some cases, the creation of these geomorphic features is facilitated by riparian vegetation.

D. Vegetation Indicators of Channel Simplification and Narrowing

Riparian vegetation establishment and succession is intimately linked to the lateral and vertical accretion of sediments that leads to floodplain formation across a range of channel forms (Schumm and Lichty 1963, Hereford 1984). This linkage between fluvial geomorphic processes and riparian vegetation dynamics creates the topographic diversity, soil moisture and nutrient gradients, fluvial disturbance patches, and distinctive microclimates that characterize riparian ecosystems (Tabacchi et al. 1998). The spatial extent of floodplains along rivers and streams of

the Colorado Plateau is highly variable and dependent on geomorphic setting. Along channels confined by bedrock, floodplain deposits may be narrow and discontinuous, or even non-existent. In contrast, channels in large alluvial basins may have broad, spatially extensive floodplains. Vertical aggradation of floodplains and channel incision progressively disconnect riparian surfaces from surface flow in adjacent channels, creating terraces. Remnant terrace sequences from across the arid and semi-arid western U.S., including the Colorado Plateau, record several climatically driven valley cut-and-fill cycles during the Holocene period (i.e. within the last 10,000 years) coincident with wetter and drier climate periods (Emmett 1974, Elliott et al. 1999, Miller et al. 2004).

Vegetative indicators of channel narrowing involve increases in the extent and cover of vegetation in formerly active channel locations. This increase in vegetation is typically linked with the progressive formation of both active and inactive 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.

Work by Manners et al. (2014) in two restricted meander reaches of the Yampa, documented the active participation of tamarisk and sandbar willow in the channel narrowing that has taken place in these settings over the past 50 years. Although tamarisk and sandbar willow may be the main participants in floodplain construction, the other rhizomatous perennials that exist on multiple surfaces of different elevations (and therefore different stream flow rates where they are inundated) may play a role in the channel narrowing process, or would at least be expected to appear and persist through different stages of the narrowing process. In addition riparian bird diversity is related to the structural complexity of riparian vegetation (Scott et al. 2003) and loss of such complexity through channel narrowing with invasions of non-native monocultures (i.e. tamarisk and Russian olive) and loss of back channels and associated vegetation can have important indirect effects on riparian bird communities.

The detection of channel narrowing is hypothesized to proceed as described and illustrated below. Reach-specific interpretations of narrowing could be hypothesized to proceed as follows (Figure 1): at T^0 a channel feature exists with reach-specific active channel indicator species. At T^1 the feature now has, for example, Tamarisk/sandbar willow which can be considered leading indicators of narrowing. Lateral and vertical accretion of fine-grained alluvium may be associated with these species. At the same time there may be an increase in cover of reach-specific active channel and active floodplain indicator species. At T^2 an increase in cover of Tamarisk/willow is expected. There is continued lateral and vertical accretion of fine-grained alluvium. A decrease in cover or loss of active channel species would be predicted along with the appearance and increase in cover of reach-specific active floodplain and inactive floodplain 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.

Detecting narrowing

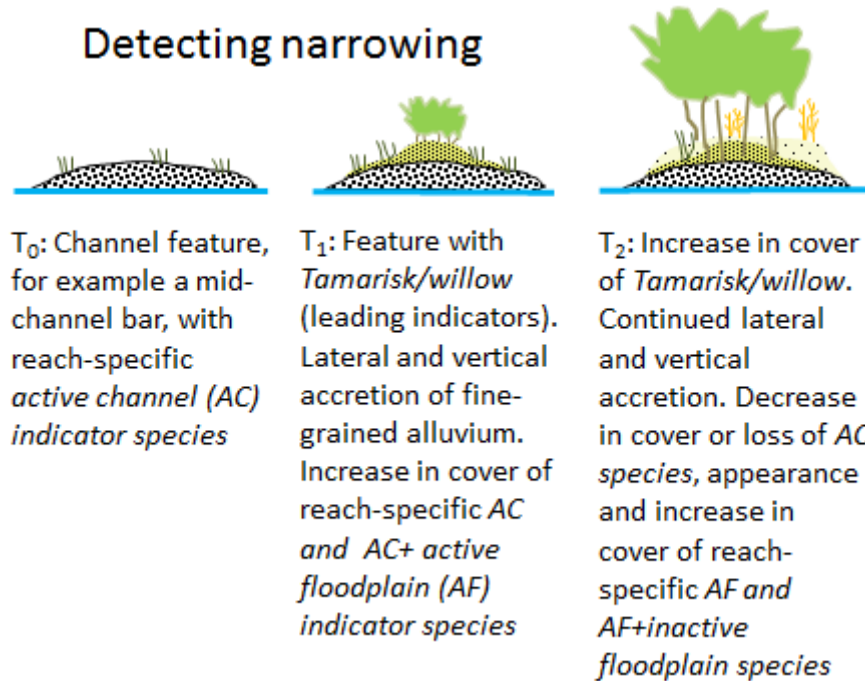


Figure 1. A conceptual model of how narrowing on an active channel feature would be detected using reach and geomorphic level specific indicator plant species.

Several studies have found distinctive assemblages of plant species or indicator species associated with different flows and geomorphic surfaces. Control on the distribution, abundance and composition of vegetation by streamflow and flow-controlled geomorphic processes has been reported along the Green and Yampa rivers in DINO (Merritt and Cooper 2000). The physical factors of rivers prevent most plants from establishing in the active channel, but Fischer et al. (1983) noted a group of plants, growing in what they call the floodzone (referred to as active channel elsewhere in this report), that were resistant to scouring and tolerant of inundation, including *Equisetum hyemale*, *E. laevigatum*, *Carex aquatilis* [sic] (likely *emoryi*), *Eleocharis* sp. (likely *palustris*), *Glycyrrhiza lepidota*, *Apocynum cannabinum*, *Asclepias* sp. (likely *speciosa*), *Polygonum amphibium*, *Iva axillaris* and *Franseria discolor* [sic] (now *Ambrosia tomentosa*). This group or guild of species (sensu Merritt et al. 2010) is composed of dominantly perennials, capable of vegetative reproduction, with annual above ground tissues that arise from perennial belowground roots or rhizomes. Identification of guilds or non-phylogenetic groupings of plants, with similar evolved adaptations to specific attributes of the flow regime, has been proposed as a way of predicting how vegetation flow-response guilds would change in response to projected changes in streamflow (Merritt et al. 2010). Auble et al. (2009) developed simulation models with examining the effects of varying flows on vegetation at BLCA and on the Fremont River at Capitol Reef National Park (Auble et al. 2005). Sankey et al. (2015) examined the spatiotemporal variability in riparian vegetation in the Grand Canyon relative to flow regulation and determined points of inundation for different zones of vegetation.

We have conducted our own analyses from legacy sites and NCPN monitoring to modify this list with park specific indicators at BLCA, CANY, and DINO (Scott et al. 2012, Scott and Perkins in prep).

Vegetation is generally recognized as the dominant functional element in riparian ecosystems (Scott et al. 2005). In addition to conducting photosynthesis, the aboveground structure of vascular plants increases roughness and thus protects floodplain soils from widespread erosion (Tabacchi et al. 1998) and enhances the deposition and retention of nutrient-rich sediments during floods (Naiman and Decamps 1997). Litter from plants reduces the erosive impacts of rainfall on soil surfaces and provides inputs to soil organic matter for nutrient cycling. Aboveground structures of riparian plants modify the physical environment by shading and depositing litter, strongly affecting spatial and temporal patterns of soil-resource availability to other organisms. Vegetation structure contributes to the formation of microhabitats with sharp gradients of moisture and temperature fostering biotic diversity (Gregory et al. 1991). Roots stabilize soils and stream banks (Winward 2000), are conduits for resource acquisition and redistribution, and provide organic-matter inputs to soil food webs. Vegetation also provides fuel for fire, as well as resources and habitat structure for belowground and aboveground consumers and decomposers ranging from fungi and bacteria to birds and mammals (Brinson et al. 1981, Mitsch and Gosselink 1993). The distinctive species composition and spatial patterning of riparian vegetation is largely related to transverse or cross-valley gradients of disturbance intensity and moisture availability created primarily by variations in surface flow, depth to alluvial groundwater, topographic diversity of fluvial landforms, and valley setting (Hupp and Osterkamp 1985, Malanson 1993, Auble et al. 1994, Bendix 1994, Stromberg et al. 2006).

Because some species occur naturally but with limited frequency in the active channel and others are associated with more than one geomorphic surface, using plant species as indicators of narrowing requires some interpretation. Indicator species have significant, though not necessarily exclusive fidelity to specific surface types; thus, their presence alone is strongly suggestive of the prevailing physical conditions where they are found. The specific logic flow underlying the use of plants as indicators of channel narrowing is this: 1) because of reduced streamflows the combination of inundation and shear-stresses that kept the active channel largely free of perennial vegetation are diminished; thus, 2) portions of the formerly active channel become colonized by perennial vegetation and the effective area of active channel is reduced; 3) plants colonizing topographically low channel features trap flood-deposited sediments and thus actively build floodplain surfaces, whereas; 4) plants that colonize and stabilize topographically high channel deposits play a more passive role in converting channel to floodplain (Manners et al. 2010). Occasional large floods may reset or widen the active channel (Dean and Schmidt 2011) but a progressive, long-term loss of active channel area by vegetation encroachment and floodplain construction or conversion characterizes channel narrowing (Schumm and Lichty 1963, Grams and Schmidt 2002, Friedman et al. 1996, 1998). Certain hydrogeomorphic settings are more sensitive to narrowing, and certain plants, like tamarisk, are more effective at trapping

sediment and converting active channel to floodplain (Graf 1978, Larson 2004, Birken and Cooper 2006, Manners et al. 2010).

Specific, plant-based indicators of channel narrowing thus 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 guild of 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.

E. Hydrological Indicators of Channel Simplification and Narrowing

It is widely recognized that physical processes, across a range of spatial scales, control biological patterns and processes in riparian ecosystems (Frissell et al. 1986), and that biotic changes typically show a lagged response to changes in the physical system (Petts 1987). Therefore, any efforts aimed at detecting directional change in riparian ecosystems must effectively integrate measurements of key variables, such as hydrology, vegetation, and geomorphology that drive important biotic patterns and processes (Scott et al. 2005). Geomorphic and vegetative indicators of channel narrowing are tightly tied to hydrology. Days of inundation, flow rate, shape of the hydrograph and depth of flow all relate to scour, accretion, and the encroachment and removal of vegetation. A 2- or 3-dimensional hydraulic model would be one way to integrate hydrology, however due to the extensive work and expensive equipment to conduct river bathymetry, we determine that it is beyond the fiscal resources of this protocol. Instead we are using pressure transducers to record river stage (above and below) each sentinel site from which we can determine the minimum inundating discharge and/or inundation duration at each plot or point of interest. Thus, our approach involves relating flow to detected directional changes in the cover and composition of vegetation, net deposition of alluvial sediment and changes in sediment particle size in depositional environments that have been shown to be sensitive to channel narrowing. These data will provide valuable information in evaluating different flows in regulated river sections as well as showing the effects of natural and semi-natural hydrographs on unregulated rivers on the important components of the river.

F. Problem of Sampling over Large and Long Rivers

Sampling vegetation and geomorphology in big, canyon-bound rivers in NCPN units presents a variety of challenges. Some of these challenges are similar to any sampling in vegetated riparian settings and active fluvial environments. The primary irony being that one of the things we care about (i.e., riparian vegetation) is the very thing that makes accurately measuring one of the other main things we care about (i.e., topography) so difficult. Most topographic sampling relies either on a line of site to the ground or the ability to physically occupy the ground (e.g., with a survey rod and prism), vegetation simply limits this. Other challenges relate to sampling topography in big water, where large portions are un-wadeable and some portions are un-boatable and not easily overcome with remote sensing technologies due in part to steep canyon walls. The specific

challenges associated with sampling big, canyon-bound rivers are their remote nature, generally poor access, minimum-tool restrictions in wilderness areas, and the limitations and hazards that canyon geometry and cliff heights present to remote sensing data acquisitions from aerial platforms. These factors logistically constrain what can and cannot be done, as well as define some minimum costs as many sites are only accessible by boat via a multi-day research expedition. However, the biggest problem is simply a function of the scope of sampling relative to limited resources. Despite there being only four Big River parks, there are several important differences between them necessitating similar, yet slightly different monitoring approaches at each park.

The rivers are long (upwards of 100's of km) and the scale at which channel narrowing might be explained mechanistically ranges from the sediment sizes present scale up through reach-scales. The problem has historically been that we cannot sample everywhere at adequate resolution. To a certain extent, remote sensing and new survey technologies are changing this predicament – in that we can now sample 100's of kms of river for reasonable cost. However, remote sensing does not and will likely never be a substitute for some on-the ground sampling nor does it provide opportunities for user judgment and interpretation during ground-based sampling efforts.

G. History of Big River Research and Monitoring in NCPN Parks

Riparian resources have been the focus of a number of studies conducted at river parks within the NCPN. Although these park-specific studies offer valuable data such as plant species lists, documentation of channel change, changes in surface flow or alluvial groundwater dynamics, or information on historic conditions, few were conducted over long periods of time and even fewer have examined physical, hydrological, and biotic riparian resources in an integrated way.

A range of investigators have studied the geomorphic setting, condition and behavior of the Yampa and Green Rivers as it is related to channel narrowing within Dinosaur National Monument. These studies typify some of the settings found in other big, canyon-bound rivers in NCPN park units. Andrews (1986) reported a 13% (23 m) decrease in channel width on the Green River in Browns Park from 1966 to 1977, and Lyons et al. (1992) reported a decrease in channel width of 3–12% between 1964 and 1974, while Merritt and Cooper (2000) found an 11% decrease in channel width between 1954 and 1977. Grams (1997) and Grams and Schmidt (1999, 2002) showed that channels narrowed by approximately 20 to 25 percent throughout Browns Park and Lodore Canyon due to decreased sediment supply, and tamarisk encroachment along the upper Green River downstream from Flaming Gorge Dam. In Lodore Canyon, channel narrowing largely occurred by vegetation stabilization and vertical accretion of fine sediment on gravel bars, and vegetation encroachment on eddy sandbars—especially those no longer inundated by post-dam flows (Grams and Schmidt, 2002). As a result, a stable intermediate bench formed on the pre-dam floodplain below a now inactive high-elevation terrace, but above the modern, post-dam floodplain (Figure 4) (Grams and Schmidt, 2002). In most reaches of Lodore Canyon, only the highest post-dam discharges inundate this intermediate surface,

whereas typical annual flood peaks inundate the inset post-dam floodplain (Grams and Schmidt, 2002). Alexander (2007) showed that most of the sediment on the intermediate bench was deposited by two discrete events, the pre-dam 1962 flood and the 1983 controlled flood released from the dam. These surfaces are likely to continue to accrete during high flows, which may further isolate these surfaces from typical dam release flows (Mueller et al. 2014). These surveys of channel cross-sections along the Green River in DINO (Grams and Schmidt 2002, Grams and Schmidt 2005) are considered legacy sites in this protocol.

There are certain hydrogeomorphic environments that are more prone to floodplain building and channel narrowing than others. Such settings along the Yampa River in DINO include: eddy bars above and below debris fans in steeper, narrow canyon settings (above River Mile (RM) 21), and mid-channel, alternate and eddy bars in reaches where the channel is wider, the gradient flatter and storage of fine-grained sediments more extensive (below RM 21) (Manners et al. 2010). Air photo analyses (Manners et al. 2010), indicate there has been progressive channel narrowing at Laddie Park and Harding Hole along the Yampa River since 1938 (earliest air photos) but it has not been uniform. A 2 km reach in Laddie Park narrowed 8.3% from 1961 to 2010. In contrast, average channel widths in the Harding Hole reach decreased by 3% over the same period. The establishment and spread of tamarisk was intimately related to narrowing in these locations. Using stratigraphic and dendrogeomorphic analyses to reconstruct the history of channel change in Laddie Park, Manners et al. (2010) found that tamarisk established on the downstream end of a large, mid-channel bar during a period (1949-1951) when peak flows did not exceed the 2 year average return flood. By 1952, a year with a significant flood peak, the established tamarisk survived the inundation and shear forces associated with this flood and burial by vertically accreted fine sediment. Over the next five decades, tamarisk recruitment, primarily during drought periods, was related to lateral and vertical accretion of sediments during subsequent, large floods. The 1984 flood of record deposited a large package of sediment on the Laddie Park Island, creating an inactive floodplain surface. Drought conditions between 1989 and 1992 produced another cohort of tamarisk and initiated another phase of narrowing. Establishment of this drought cohort was followed by significant inset bar formation and channel narrowing following a series of floods in the mid-1990s.

Historical photographs with matching modern re-photographs are also documented for the Colorado and Green Rivers in CANY (Webb et al. 2007) and the Green river in DINO (Grams and Schmidt 2002) that visually depict channel narrowing. Other studies focus specifically on channel narrowing elsewhere in the Upper Colorado and are of direct relevance (Allred and Schmidt 1999, Gaeuman et al. 2005). Further downstream on the Green River, Allred and Schmidt (1999) recorded a 14% reduction in channel width between 1959 and 1996.

Mueller et al. (2014) examined the effects of the 2011 flood in Lodore Canyon, which was the third largest since the closure of Flaming Gorge Dam. Scour of the bed occurred in deep pools downstream of channel constrictions. Eddy sandbars in flow recirculation zones increased in size and height, with the biggest gains in the fluctuating flow zone (area that fluctuates daily

during dam operations). Sand accretion was also common on gravel bars and along channel margins. Even though there was sandbar growth, there was likely a net export of sand from the study reaches due to bed degradation in the main channel. The 2011 flood resulted in small bank erosion of floodplains, but large bed motion necessary to clear surfaces of tamarisk did not happen (Mueller et al. 2014).

Merriitt and Cooper (2000) noted the differences in vegetation patterns due differences to in moisture conditions across the floodplain on the Green River in Browns Park and Deerlodge Park on the Yampa River. At Browns Park, marshes with anaerobic soils supported wetland species (*Salix exigua*, *Eleocharis palustris*, *Schoenoplectus pungens*, and *Juncus nodosus*) while terraces had xeric soil conditions and supported communities more typical of deserts (*Seriphidium tridentatum*, *Sarcobatus termiculatus*, and *Sporobolus airoides*). The Yampa River had species spread across a gradual environmental moisture gradient from the active channel (*Xanthium strumarium*, *Salix exigua*, *Populus deltoides* subsp. *wislizenii*, and *Tamarix ramossissima*) to high floodplain surfaces characterized by *Populus* forests and meadow communities. They found that the channel at Browns Park had undergone a complex series of morphologic changes since regulation began, in contrast to Deerlodge Park, which has remained in a state of relative quasi-equilibrium.

There have been a variety of studies on debris fan formation at DINO (Hammack and Wohl 1996, Larsen et al. 2004), as well as upslope studies that have looked at the occurrence of landslides, which lead to the formation and evolution of these debris fans (Larsen et al. 2006). The debris fans are critical to understanding the occurrence of the majority of the eddy-bars (part of larger fan-eddy complex) in the canyon bound sections of these rivers. Whether these channels are in a state of net aggradation, equilibrium, or net degradation is ultimately tied to the sediment budget of a river, an important component of which is storage. Changes in sediment storage can be used to understand the dynamics and occurrence of channel narrowing and/or widening (Grams and Schmidt 2002, Grams and Schmidt 2005, Grams et al. 2007). These studies have utilized a variety of field techniques, ranging from geomorphic mapping, cross sections, full topographic surveys, stream gaging and analytical techniques ranging from repeat aerial photography analysis, hydraulic modeling, and change detection at cross sections or with repeat topography. These studies help define the physical template and geomorphic history, which then helps explain the vegetative response and distributions.

In the 1990's and early 2000's there was an increase in studies in BLCA related to the park's application for, and eventually obtaining a water right. Auble et al. (1994) conducted vegetation sampling at the Warner Point reach in BLCA and developed both a community classification and relations between hydrology and community distribution. Friedman and Auble (1999) developed a model that related annual mortality of box elder to streamflow (shear stress and extended inundation) at Warner Point. Several investigators have examined sediment transport at BLCA. Elliott and Hammack (1999, 2000) studied entrainment of riparian gravel and cobbles in the Warner Point reach and estimated the flows required to mobilize geomorphic features. Chase

(1992) estimated streamflow thresholds for gravel and cobble motion. Liquori (1995) described the delivery mechanisms and transport of talus and debris-flow deposits in the BLCA bottom land. Dubinski (2005) and Dubinski and Wohl (2007) estimated a historical sediment budget for the Gunnison River in BLCA and developed a model relating streamflow to channel mobilization for different sediment particle sizes throughout BLCA. A simulation model was developed to predict the potential response of riparian and wetland plant species to altered flow regimes in BLCA (Auble et al. 1994, 2009).

There were several studies on non-native brown (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) at two sites in the Gunnison Gorge downstream of BLCA (Nehring and Miller 1987, Nehring 1988, and Nehring and Anderson 1993). This work included quantification of physical habitat simulation models (PHABSIM, Bovee and Milhous, 1978; Bovee, 1982) that combined hydraulic simulation and empirical suitability curves to estimate weighted usable area of suitable habitat for different species and life stages. These data along with fish census data suggest that fry habitat is most limiting for trout in this part of the Gunnison River. Concern about endangered fish species that live in the Gunnison downstream of BLCA (McAda, 2003) has motivated a number of studies and analyses of downstream sections of the Gunnison River and is a consideration in water-management decisions in the Aspinall Unit upstream from BLCA that influence Gunnison River streamflow through BLCA (Bureau of Reclamation, 2009).

Non-native riparian species invasions, in particular tamarisk (*Tamarix sp.*) and Russian olive (*Elaeagnus angustifolia*), and attempts at restoration have had large effects on these rivers. Birken and Cooper (2006) excavated pits through vertically accreted sediments on the lower Green River in CANY and aged tamarisk stems to examine patterns of tamarisk establishment and channel narrowing. Cooper et al. (2003) found widespread tamarisk invasion on the post-dam floodplain in Lodore Canyon in 1962 and 1963 (Cooper et al. 2003). Perkins et al. (2015) found that invasive plants were 2-3 times more prevalent on the highly regulated Green River than on the unregulated Yampa River. Perkins and Wight (2016) mapped invasive plants along the Gunnison River at BLCA and found that common burdock (*Artium minus*), Canada thistle (*Breca arvensis*), reed canarygrass (*Phalaroides arundinacea*), and common mullein (*Verbascum thapsis*) all declined from earlier sample periods (2003-04 and 2010-12) when compared to the most recent sampling period (2014-15), and speculated that environmental flows may be contributing to the decrease. On the Green River in Lodore Canyon in Dinosaur National Monument (DINO), Alexander (2007) used a recently developed alluvial stratigraphic and dendrogeomorphic technique to provide a detailed history of channel change relative to flow history and the establishment and spread of tamarisk within the canyon.

II. Protocol Objectives

The overall goal of the NCPN big river monitoring program is to determine long-term trends in hydrologic, channel and floodplain geomorphic, and vegetation variables in the context of changes in stream flows which can act as large disturbances or re-setting events, and other ecological

drivers, stressors, and processes. Specific objectives of the big river monitoring protocol are described below.

- Determine the effects of different flows on vegetation and geomorphic indicators of channel simplification
- Determine the environmental flows necessary to maintain active channel, active floodplain, and inactive floodplain components of the riparian community
- Determine status and trends in geomorphic processes as reflected in channel and floodplain form
- Determine status and trends in vegetation patterns
- Determine rates of narrowing and changes in narrowing in response to regulated and unregulated flows using remote imagery

Objectives for CURE.

- Determine changes in the river channel (encroachment, channel migration, riparian vegetation) over time
- Determine regeneration rates for cottonwoods and if cottonwood recruitment is sufficient to maintain cottonwood gallery forests
- Determine the environmental flows necessary to maintain cottonwood gallery forest

Data from these objectives will be integrated to produce models such as stage-geomorphic process relationships and correlations such as vegetation assemblage by geomorphic surface. Monitoring of big rivers additionally benefits from other vital signs monitoring and historical data. Local weather station data can be used to interpret responses, whereas remote sensing can be used to determine change in vegetation at watershed scales caused by land use or climate change. Historical flow records from gaging stations may be used to develop flood frequency distributions for some streams. Historical photo points will be re-located and re-photographed on a recurring basis, when possible.

III. Sampling Design

A. Response Design

The sampling unit for riparian monitoring of big rivers is a sentinel site. Measurements of vegetation, hydrologic and physical drivers will be co-located at each sentinel site and will be monitored concurrently. The size of the sentinel site is dependent on the river. At BLCA, features range from 15-60 m in length within two sites that are 700 and 500 m in length, at DINO sentinel sites range from 200 to 500 m in length, and at CANY in the broad alluvial portions of the river above the confluence the sites range from 200 to 1,000 m in length. At CURE where

the methodologies are different and there is only 6 km of free-flowing river we have focused on the entire river as a single site.

Vegetation measurements occur in permanent 1m² plots (1x1m or 2x0.5m). 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. River stage is measured using transducers that are located above and below the sentinel sites.

Given that river level geology controls channel form and process and that this results in significant differences in composition and abundance of riparian vegetation, our final monitoring design includes sentinel sites located within a number of different channel types. Channel types fall into two broad categories; alluvial and canyon-bound. Freely or restricted meandering alluvial channels are found in Deerlodge Park on the Yampa and Brown's and Island parks on the Green at DINO, all of CURE, and all of the sentinel sites at CANY. Canyon-bound reaches include debris fan dominated channels in Lodore Canyon, debris fan affected channel on the Yampa and entrenched meander channels found on the Green and Yampa rivers and all of the sites at BLCA.

B. Spatial Design

The sentinel sites were not chosen at random. They were chosen based on logistics, safety, presence of legacy data, significant park resources, and sensitive to fluvial geomorphic change and subsequent channel narrowing. At BLCA we are sampling the only two sentinel sites that are safely accessible by foot when carrying large packs necessary for transporting sampling equipment. Within these sites we chose areas where change could occur and did not sample sections with steep canyon walls. At DINO we also did not choose any sites that were in the steep walled canyons that are insensitive to change. On the wild Yampa river where low summer flows can prevent summer boating, we chose all three sites that are accessible by foot. Three of the six sites on the Green River at DINO are also available by foot. All nine of the sites at DINO were chosen based on being sensitive to change as determined by experts who have more than two decades of experience at the park as well as the importance to endangered fish (three sites). We have sentinel sites on each of the three river sections – Yampa River and the Green River above and below the confluence. Each river section had one park and two canyon sentinel sites. At CANY where there was not as much previous research we developed a dynamism index to determine which sites were most sensitive to channel narrowing. This dynamism index used remote sensing imagery from 1976 - 2014 to develop scores for amount of change, relative change, evidence of narrowing and expansion, standard deviation of change from 1976-2009, and recent change (2002-2014). Sites (three of selected sites) that were important to endangered fish also affected the selection process. Logistics and being able to use one base station for surveying also contributed. At CURE we have 10 transects placed randomly through all 6 km of river with the park.

In part, due to the non-random selection of sentinel sites, at CANY and DINO we also conduct remote sensing of all park settings to examine channel narrowing by mapping vegetated (>50% vegetation) and unvegetated (<50% vegetated) polygons.

C. Revisit Design

At each river, the number of sentinel sites is limited by affordable effort. Revisit designs are river-specific and attempt to balance the need for observing inter-annual variability with maximizing replication (Woodward 2004).

Vegetation and geomorphology monitoring occurs on all rivers, but a rotating panel design is used to increase the overall sample size. Some sentinel sites are sampled annually, while others are sampled every 2-3 years. The CURE reach is only sampled every 5 years or after a large peak flow (Table 2). Sampling some part of a river each year allows us to detect the effects of major flood events within one year after they occur. The revisit design below is dependent upon a crew of 8 for 4 hitches (8 days each) with an additional crew of 4 for a single hitch the year when CURE sampling takes place.

Sampling of vegetation and geomorphology takes place during summer baseflow and after vegetation has reached its peak growth (July-September). Surface water is continuously monitored with transducers at all sites except CURE. Information from the transducers is collected once a year.

Park	River	Site	Target Date	Sampling Frequency
BLCA	Gunnison	East Portal	August	Annually
BLCA	Gunnison	Red Rocks	August	Annually
BLCA	Gunnison	Warner Point	August	5-10 years
CANY	Green	Millard	September	Annually
CANY	Green	Queen Anne	September	Annually
CANY	Green	Bonita Bend	September	Annually
CANY	Green	Holeman Canyon	September	Annually
CANY	Green	Sphinx	September	Annually
CANY	Green	Upper Tuxedo	September	Annually
CANY	Colorado	Musselman Canyon	September	Annually
CANY	Colorado	Sangria	September	Annually
CURE	Gunnison	Cooper/Neversink	July/August	Every 5 years or major peak flow
DINO	Green	Brown's Park	July	Two out of three years
DINO	Green	Winnie's	July	Two out of three years
DINO	Green	Limestone	July	Two out of three years
DINO	Green	Echo Park	July	Annually
DINO	Green	Seacliff	July	Annually
DINO	Green	Island Park	July	Two out of three years
DINO	Yampa	Deerlodge	July	Annually
DINO	Yampa	Harding Hole	July	Annually

DINO	Yampa	Laddie Park	July	Annually
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IV. Field Methods

Details of taking measurements, with example data sheets, are documented in the individual SOPs. It is important to maximize efficiency when collecting field data. Key considerations include determining the number of crew members to perform each protocol, and the order in which the various measurements are performed. It is essential that some crew members are able to do multiple tasks among the vegetation, geomorphology, hydrologic and photo data that is collected at each site. The crew leader needs to maintain a dynamic environment where a task that is lagging behind can have more personnel put towards it. It is essential for crew efficiency that tasks get completed at close to the same time as the crew all leaves a site together due to river logistics and safety.

A. Field Season Preparations

Sampling dates are scheduled and logistics organized prior to the start of the field season. This includes applying for and renewing research and river permits, hiring the field crew, arranging camping, coordinating with the park as almost all river trips utilize park staff and resources, updating emergency contact information, and acquiring backcountry permits (see SOP #1). All of the equipment and supplies are organized, tested, and ordered to ensure availability by the beginning of the field season. Directions, revisit data sheets, and species lists are generated for each sentinel site.

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

Just prior to the trip the crew leader should coordinate with all personnel coming on the trip to ensure that all people have their safety gear and permit-required items (groover, fire pan, kitchen), and the meal plan and shuttles are finalized. Trip reports from previous years should also be reviewed prior to the trip. The crew shall finalize and send a back-country safety plan to Glen Canyon Dispatch on the day of departure.

B. Sampling Procedures

1. Establishing and revisiting the site

Black Canyon of the Gunnison National Park – At BLCA 3-4 stub transects are established at each feature (Figure 2). There are 10 features at East Portal and 7 features at Red Rocks. A stub

transect is one where the transect ends in the water and does not span the entire river, referred to as “transect” from now on. Each transect has a permanent head pin and an orientation pin. There must be at least three survey control points that are permanent and elevationally stable that will be visible from multiple instrument locations.

Using the headpin and orientation pin a tagline is stretched from the headpin to a temporary pin (rebar) that is placed a safe distance into the water. The 0 meter mark on the tagline should be directly over the headpin. While setting up the tagline, observers should minimize trampling of vegetation. The tagline and/or transect tape should be as straight as possible, both vertically and horizontally and threaded through vegetation as necessary.

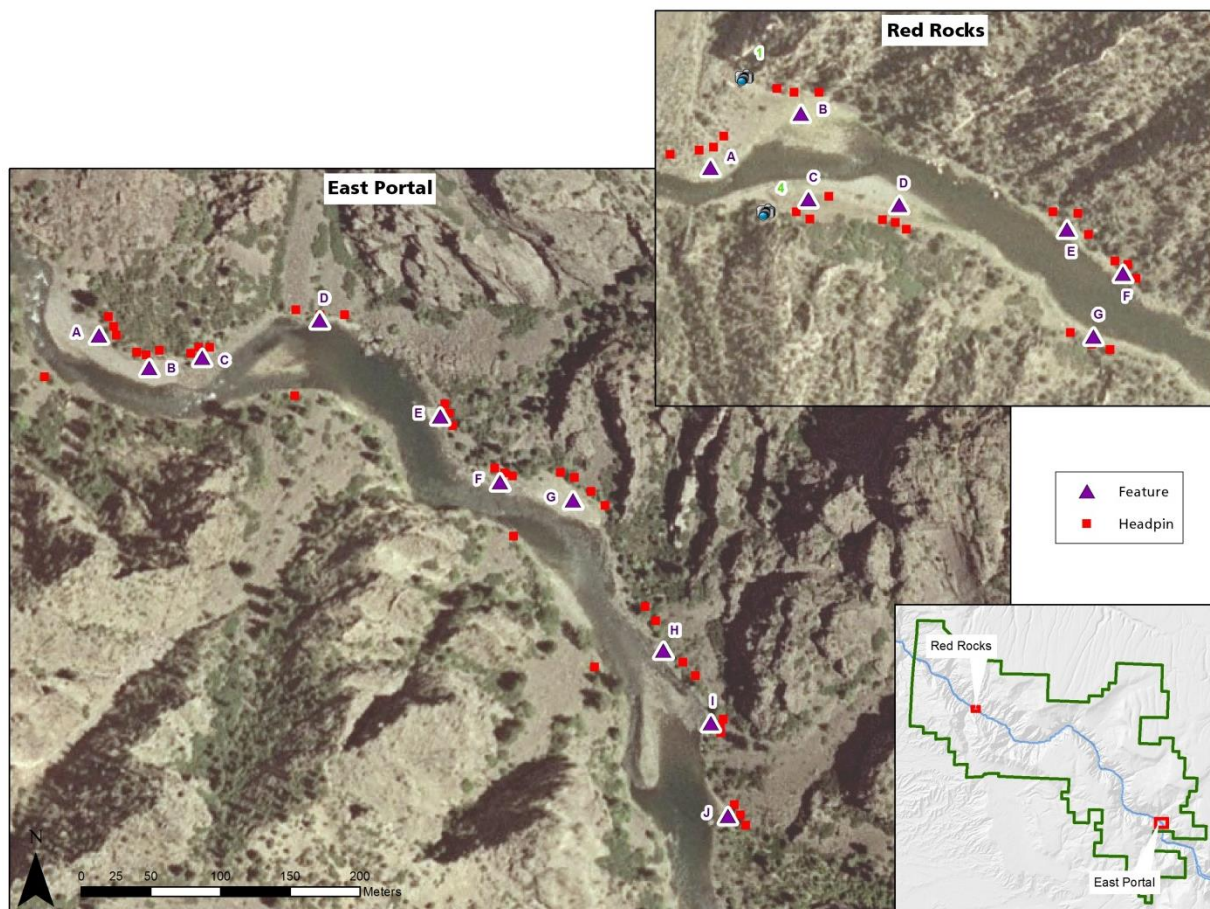


Figure 2. Sites and features selected for monitoring at Black Canyon of the Gunnison National Park.

Canyonlands National Park - Three to twelve transects are placed on each sentinel site for monitoring purposes. Transects are permanent, but do not have any permanent rebar, headpins, or markers. Transects will be relocated using real-time kinetic (RTK) surveying based on established control points. Transects are perpendicular to the valley floor and may not be perpendicular to flow as the channel changes. Transects are spaced equidistant throughout the feature. The number of transects may change from year to year, based on erosion or deposition

of the sentinel site. Transects may be added or eliminated in future years. Transect length may change from year to year, depending on the movement of the active floodplain, water level, and safety while wading. There are permanent control plots at all sites and at least three control points must be established that are permanent and elevationally stable.

Plots are permanent and are placed every 3 m along each transect. The surveyor will establish the plots to be recorded. The surveyor will extend plots to a safe wading distance (waist deep in slow water, less deep in faster water) and will extend the plots to at least 2 plots in the active flood plain. Upon locating a plot, the center of the plot will be marked with a temporary pin flag and plot number. For plots that are completely submerged, the surveyor will tell the assistant that the plot is completely submerged and will note the modal particle size (see SOP 6 for details). Based on geomorphic and vegetative characteristics, the surveyor will also note whether the geomorphic surface of the plot (active channel [AC], active floodplain [AF], inactive floodplain [IF], uplands [UP]) has changed from the previous designation. The surveyor can also note a transitional plot, for example AC/AF. If there is no one qualified to make this designation on a trip, it is acceptable to skip this step.

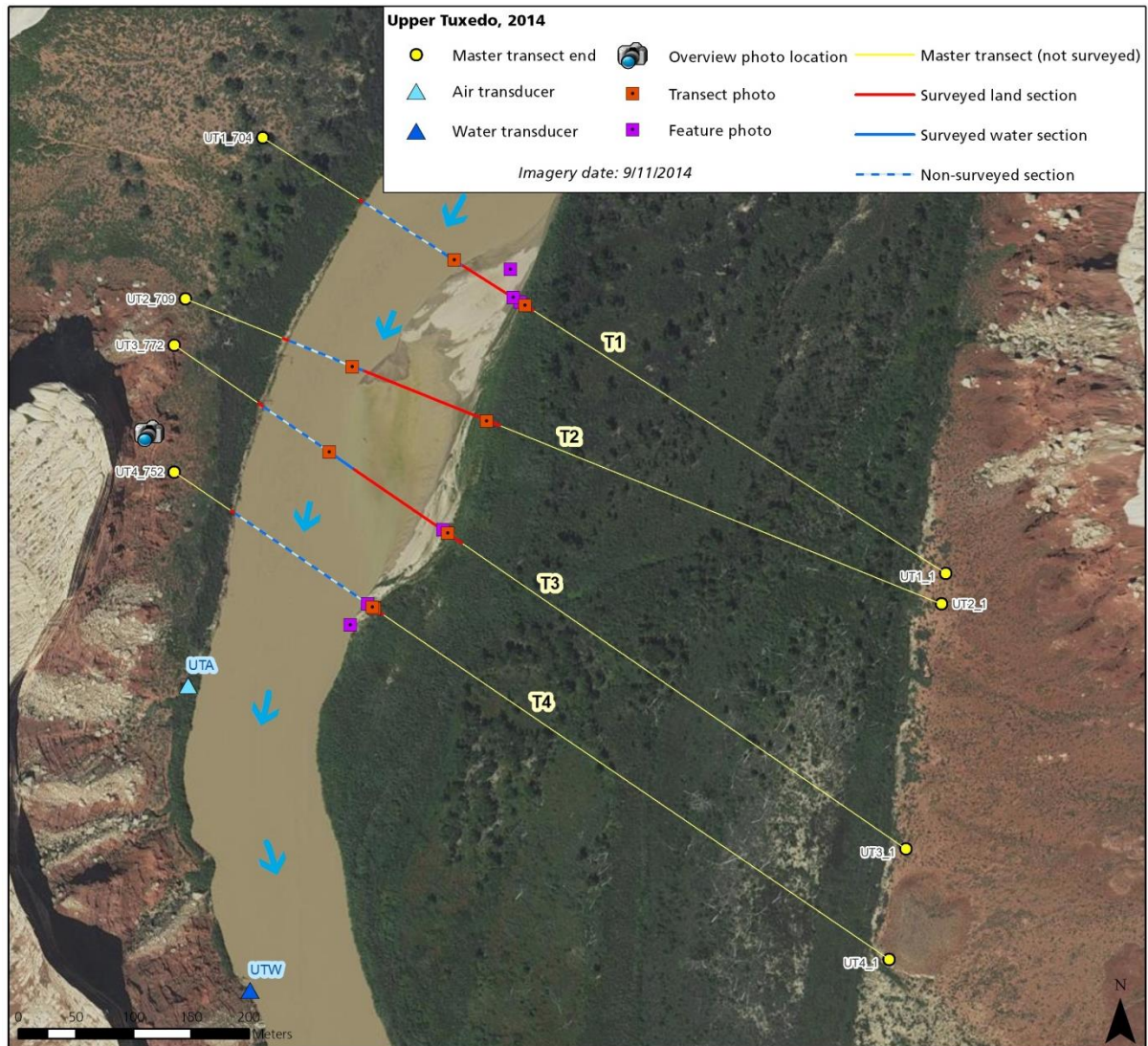


Figure 3. Transect layout at Upper Tuxedo site. Flow is from the top of the page to the bottom.

Dinosaur NM – On each of the 3 river reaches (the Yampa and the Green above and below the confluence with the Yampa) we have 3 sites. Each site has 7-10 permanent transects and 50-120 permanent plots. Initially, these transects and plots were not permanent. Due to the acquisition of RTK survey equipment and the increased statistical power of repeated plots. These plots were established in 2015 on the Green River and 2016 on the Yampa River. These plots consist of the 2011 transects and plots plus the “extension” of plots that was possible in 2012 due to lower water levels. The extension using the 2012 plots was done by looking at the spatial extent that was completed in 2012, but placing the extent in line with the 2011 transects. If a site was not done in 2011, 2012 was used as the master set of plots.

The master set of plots will be pre-loaded on to the RTK survey gear for each site. A surveyor and an assistant will use the RTK equipment to re-locate each plot. Upon locating a plot, the

center of the plot will be marked with a temporary pin flag and plot number. For plots that are completely submerged, the surveyor will tell the assistant that the plot is completely submerged and will note the modal particle size (see SOP 6 for details). Based on geomorphic and vegetative characteristics, the surveyor will also note whether the geomorphic surface of the plot (active channel [AC], active floodplain [AF], inactive floodplain [IF], uplands [UP]) has changed from the previous designation. The surveyor can also note a transitional plot, for example AC/AF. If there is no one qualified to make this designation on a trip, it is acceptable to skip this step. There are permanent control plots at all sites and at least three control points must be established that are permanent and elevationally stable.

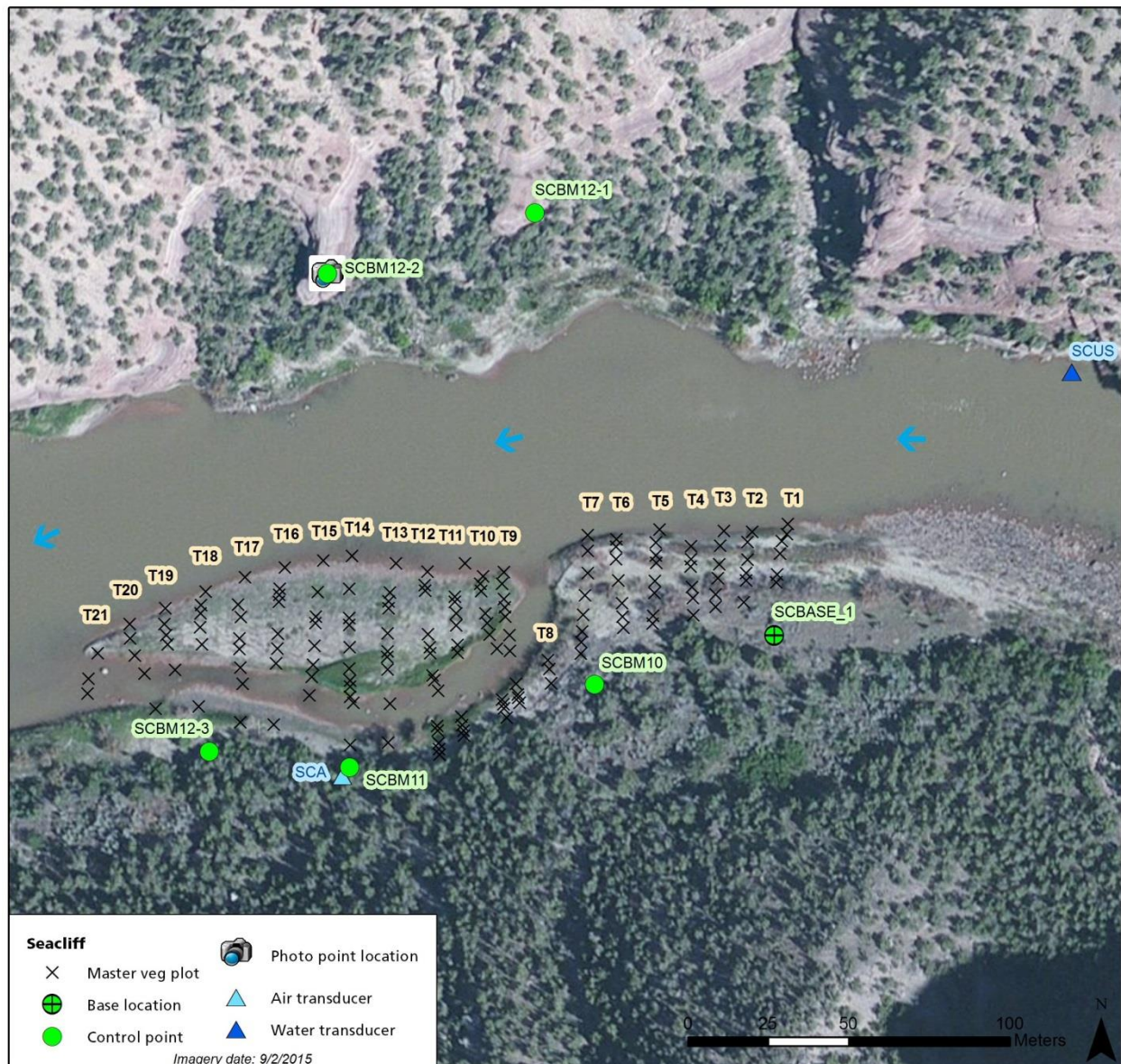


Figure 4. The Sea Cliff sentinel site feature with bench marks and plot locations (actual sentinel site would have more plots).

Curecanti National Recreation Area

Ten transects were randomly placed at CURE (Figure 5). All measurements are done using a GPS unit so headpins are not needed even though transects are permanent. Transects are perpendicular to the valley floor (although they may not be perpendicular to flow as the channel changes), and extend from the uplands to uplands or the park boundary whichever comes first.

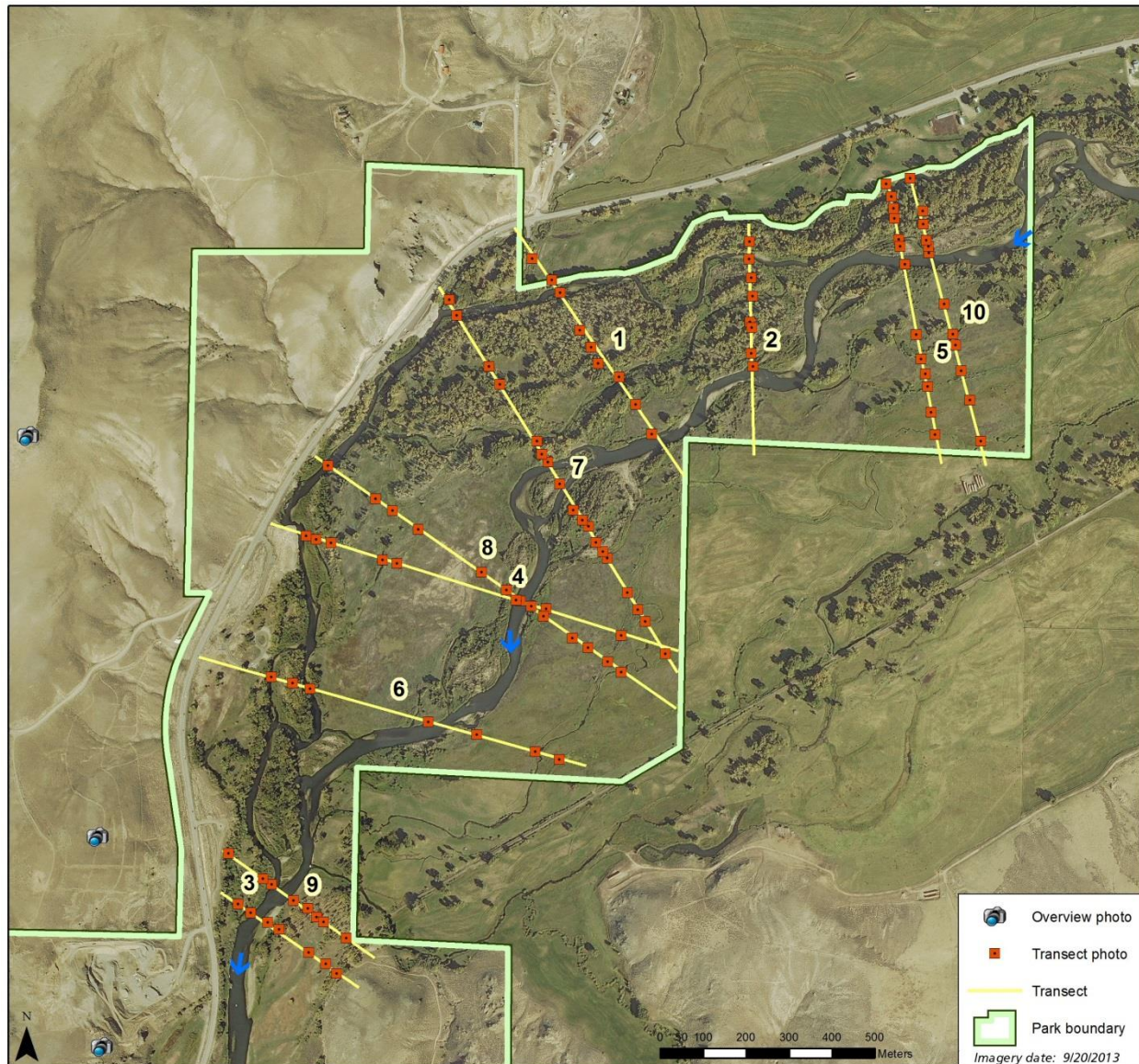


Figure 5. Transects established at Curecanti NRA.

2. Vegetation Measurements

Vegetation Plots - We use 1 m² (1X1 m at DINO and CANY, 0.5 by 2m at BLCA) plots to characterize vegetation composition, percent cover and frequency of occurrence on the active channel and floodplain surfaces at each site. Plots were initially located randomly across

systematic transects at DINO, every 3 m on transects at CANY, and every 0.5 to 2 m at BLCA depending on the slope. The steeper the slope, the more frequent the plots are. Without a variable plot density, flatter areas, which represent a narrow range of flow rates, would be sampled more heavily than steeper areas, which experience a wider range of flow rates per linear distance. Plots are loaded into the RTK units and are laid out by the surveyors at CANY and DINO. Botanists lay out their own plots along the tag line at BLCA.

Vegetation measurements occur near the peak of the growing season. Sampling adequacy was assessed using bootstrapping techniques and standard error of the mean estimates. Vegetation within each plot was assessed as percent cover to the nearest 1% for each species encountered and total plot cover was determined for CANY and DINO. At BLCA the total plant cover is determined and the presence or absence of indicator species is observed. Visual estimation is based on a plan view projection of outline polygon of plant subtracting the open spaces within the polygon. If the sun were directly overhead, the percentage that is shaded is the percent cover. Woody canopy cover above 1.5 m by species in each plot is recorded at all three parks. The modal particle size of the plot, ranging from fines through boulders, according to the modified Wentworth scale (Wentworth 1922) is also determined. At least once per day, botanists cross calibrate on cover and particle size estimates including some recorded replicate measurements.

Plant Walk – At each sentinel site a plant walk is conducted. All plant species observed at a sentinel site are recorded, noting date and approximate time spent looking. The objective of the plant walk is to record as many species as possible. This can be 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. If time is running short, this step may be skipped in some years.

Curecanti National Recreation Area – All vegetation measurements at CURE are taken with a GPS. Vegetation measurements pertain to areas that are occupied by different size classes (seedlings, saplings, poles, and mature trees) of cottonwoods. Plant species are also used as indicators to delineate geomorphic surfaces.

3. Geomorphic Measurements

Survey of Sentinel Site – 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, all vegetation plots and transducers are surveyed. For sites using a total station, back sights are also established. Additional measurements are made along the transects at CANY (every 3m, break points and edge of water), BLCA (every m, edge of water and break points), and at the DINO Island Park sentinel site (break points and edge of water). At DINO, a digital elevation map of the site is made. Topographic features (i.e., tops of banks, toes of banks, chutes, sand caps, etc.) were also surveyed to create a topographic map of each sentinel site. Using Geomorphic Change Detection software in ArcGIS, two years of

DEMs are overlaid to show areas of erosion and deposition with a 10cm threshold and report volumetric values of change. When high water rack lines are available they are surveyed at all sites.

The differences in the methodology are due to scale and technology available. At BLCA, the range of flows are small when compared to DINO and CANY and when compared to the historic high flows prior to the construction of the Aspinall Units on the Gunnison River. Therefore the size of change expected is small (often <30 cm) and it is essential that we repeat transects in order to observe these small changes. In addition, the canyon walls are too steep for RTK to make consistent measurements across the features.

At DINO the sentinel sites are intermediate in size and a complete digital elevation model (DEM) can be made in about the same time as it would take to set up and survey transects. Areas of deposition and scour are usually not more than a meter of annual change. The complete DEM allows us to make estimates of scour and deposition across the entire site.

At CANY and at the Island Park site at DINO, the sites are up to 1 km in length. To make a DEM at this site would consume most of our annual survey efforts just to do one site. Due to the broad alluvial valleys and the volume of sand, the changes at these sites are large (meters of sand) and are more likely to be picked up on transects.

Facies mapping – These measurements are only taken at DINO and are used to evaluate state changes (i.e. a cobble bar becomes covered with fines or sand in the process of channel narrowing). If sites are established below the confluence at CANY, then this method will be implemented there. These methods are not used at BLCA or CANY sites because the changes in facies are much more subtle and harder to detect.

Facies mapping is generally done towards the end of the sentinel site visit and creates a digital sketch of the sentinel site. After completing the vegetation work, a person should have a good idea of how the sentinel site is laid out. Facies mapping involves the delineation of depositional units of uniform particle size across the active channel feature at each of the sentinel sites. Begin by mapping the most dominant facie and proceed to the less dominant facies. The mapping is done either on an iPad or on a hard copy map of the sentinel site. All data is recorded in the description field for the mapped facie on the iPad. Each facie is recorded by the primary attribute, i.e. boulder, cobble, pebble. At each facie the observer records the level of vegetation and woody debris at coarse scales and whether there are wake or shadow deposits (sand deposits behind woody debris or vegetation) present (Figure 6).

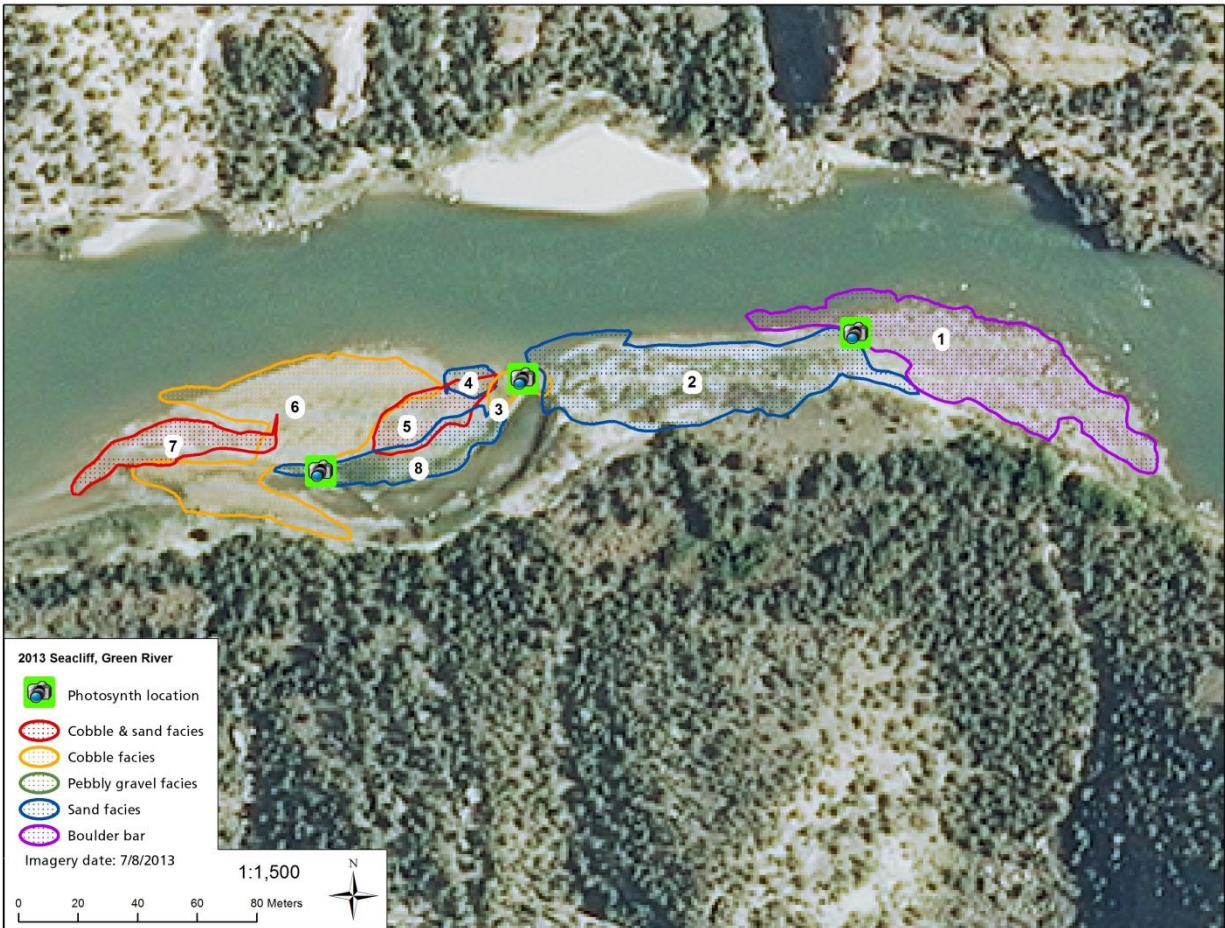


Figure 6. Example of facies mapped at Seacliff in 2013.

Grain Size Distributions – These measurements will support the facies mapping if a state change occurs. These measurements are only taken at DINO. If sites are established below the confluence at CANY, then this method will be implemented there.

Grain size distributions do not need to be taken every year, but should be done a minimum of once every 5 years or if a state change is observed. In other years, it can be done time permitting. For each facie at a sentinel site, record grain size distributions at two sites with sieves and scales for finer textured surfaces. No grain size distributions are done at boulder bars. At each site record a surface and sub-surface grain size distribution.

Curecanti National Recreation Area – Using a hand held GPS the boundaries of the active channel, active floodplain, inactive floodplain, and uplands are marked along the transects. In addition, abandoned meanders, dry active channels and the water's edge are marked along the transects. All wetted channels are delineated throughout the entire reach.

4. Hydrologic Measurements

Site hydrology is measured as stream stage elevation across the feature being monitored at BLCA, CANY, and DINO. Water transducers are installed at or below the water level in stable locations upstream and downstream of the sentinel site in such a way that the slope of the water for any given discharge can be drawn across the sentinel sites. An air transducer is installed on land in the vicinity of the water transducers. 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 60 minutes.

Prior to departing for the field, air tests are run to ensure that the transducers are reading similarly and not drifting apart. In addition, air tests should be run on transducers that are already deployed at least once per year. In both cases, each air 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 (two water and one air). Let the transducers run for at least a 24 hour period. When conducting air 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 air 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 air 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. Spots 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 compensated using Solinst or Hoboware software to subtract the air pressure from the water pressure measurements. This information then gives a depth of water at the transducer locations which translates to water depth across the sentinel site and which can be used to determine the number of days that each plot was inundated with water.

5.Photos

Black Canyon of the Gunnison National Park – Transect, feature, reference, and overview photos are taken at BLCA. Transect photos are taken from each end of each stub transect while the tagline is stretched out along the transect with a portrait orientation. An upstream and downstream feature photo is taken at each feature to monitor the overall geomorphic feature and is taken in a landscape orientation. Pin flags are used to center both transect and feature photos and locations where the photographer is located to ensure that the same picture is taken as

previous years. Overview photos are taken from above the feature and relocated using a hand held GPS and reference photos. Previous year's overview photos are used to frame the new photo. Reference photos 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. Transect, feature, and overview photos are taken every year. Reference photos only need to be taken if something in the photo has changed (tree has fallen that is a significant marker) or if a new control point is established.

Canyonlands National Park – Transect, feature, reference, and overview photos are taken at CANY. Transect photos are taken from each end of stub transects while plot flags are in-place to show the extent of transect. Transect photos are taken with a portrait orientation. If the transect is obscured by extensive vegetation, additional transect photos are taken along the same transect. At a minimum, an upstream and downstream feature photo is taken at each end of the upstream and downstream most transect to monitor the overall geomorphic feature. Feature photos are taken in a landscape orientation. If the feature has a lot of transects (>5), additional feature photos are taken in from the center transect(s) facing upstream and downstream. If these feature photos do not capture the entire feature, additional feature photos are added. Previous feature photos are used to center both transect and feature photos, and locations where the photographer is located are the same to ensure that the same picture is taken as previous years. Overview photos are taken from above the feature and relocated using a hand held GPS or RTK unit and reference photos. Previous year's overview photos are used to frame the new photo. Reference photos are taken to document locations of all survey control, transducers, or other specific features or items that need to be located in the future. Feature and overview photos are taken every year. Transect photos are only taken on transects where there has been a significant change, such as large deposition or erosion of sediment or encroaching or widening of the vegetation. If no significant changes have occurred, then transect photos should be repeated every 5 years. Reference photos only need to be taken if something in the photo has changed (tree has fallen that is a significant marker) or if a new control point is established.

Dinosaur National Monument – Photosynths (three dimensional photos), reference, and overview photos are taken at DINO. Photosynths are taken from 2-4 locations on each sentinel site using an iPad. These are 360 degree panoramas of the sentinel site. The iPad is used to relocate these Photosynth locations. Overview photos are taken from above the feature and relocated using a hand held GPS and reference photos. Previous year's overview photos are used to frame the new photo. Reference photos are taken to document locations of all survey control, transducers, or other specific features or items that need to be located in the future. Include the cliff line, surrounding perennial vegetation, and/or other recognizable landmarks in the background to help the returning field crew relocate these points. Photosynths and overview photos are taken every year. Reference photos only need to be taken if something in the photo has changed (tree has fallen that is a significant marker) or if a new control point is established.

Curecanti National Recreation Area – Overview and transect photos are taken at CURE. Overview photos are taken from above the feature and relocated using a hand held GPS and reference photos. Previous year’s overview photos are used to frame the new photo. Transect photos are taken along the transects at any river channels, abandoned meanders, secondary channels, or anywhere else we found had a high density of seedlings/saplings. At each point, 4 photos are taken. The photo directions are based on the transect line. Upstream (US)/downstream (DS) is perpendicular from the transect line and river right (RR)/river left (RL) is in line with the transect.

6. Remote Imagery

The sentinel sites selected as part of this monitoring program were chosen because they are sensitive to change. Since they were not selected randomly they may not be representative of the entire river reaches at each park. Therefore, we evaluate vegetated and unvegetated areas using freely acquired aerial imagery. If an area is >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 7).

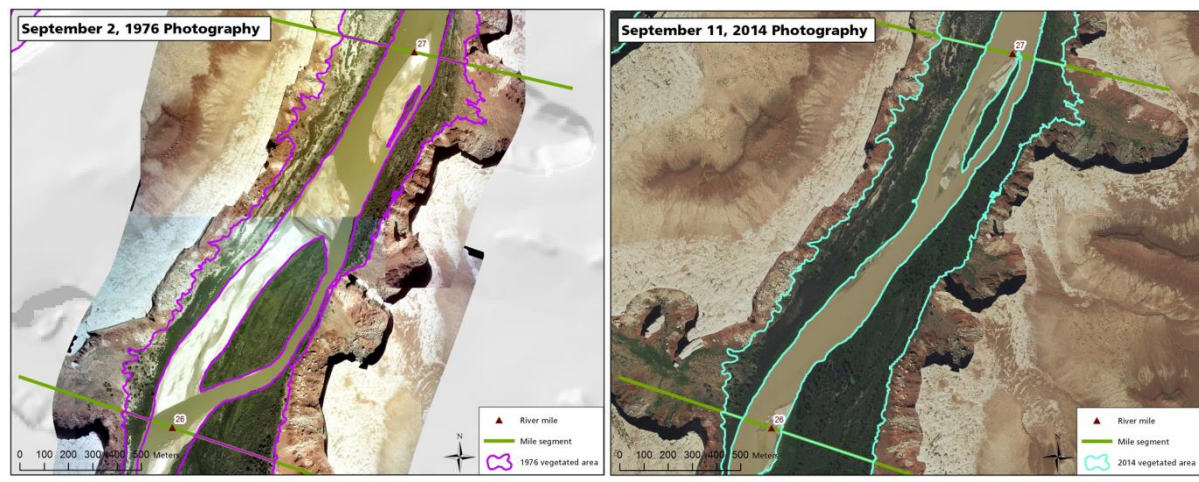


Figure 7. Examples of remote sensing vegetated and unvegetated polygons from 1976 and 2014 on the Green River in Canyonlands National Park.

C. End of Season procedures

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

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

V. Data Management

Effective data management to ensure data quality, interpretability, security, longevity, and availability is critical to the success of the big river monitoring program. The NCPN has developed a data management plan (Beer et al. 2005) that describes these procedures in general terms. The following outlines the application of those procedures to big river monitoring, and SOP #11 provides explicit instructions.

A. Data Organization

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

B. Database Design

There are three main types of river monitoring data that are collected and managed: vegetation, hydrology, and geomorphology data. Vegetation data are entered into a Microsoft Access database developed by the NCPN. This database is designed to accommodate all data on the various field forms. The database design is inspired by 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 and space to enable integrated data analysis. Species, contacts, and attribute look-up tables provide standardized values for many data fields, and metadata tables track database revisions 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 NCPN server. Geomorphology data will be stored on the NCPN server. Some of the geomorphology data will be imported into the big rivers database.

C. Data Entry, Verification, and Validation

Data are acquired as specified in the protocol SOPs using two different methods: 1) digitally recorded by a total station or RTK (geomorphology), camera (photo), 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 are entered into the big rivers 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 restrict values entered into a field to ensure that only valid names or measures are entered.

Data verification occurs after data entry, when 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.

D. Data Documentation and Certification

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.

E. Data Archival Procedures

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 accessioned into the NCPN archives for permanent storage and care.

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

VI. Reporting and Analysis

After raw data from the field season are quality checked and certified, they are then summarized to the feature or sentinel site level. Additional QA/QC is 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 big river analyses is the feature or site, and sub-samples recorded on plots must be scaled to this level. Vegetation and geomorphology data may be integrated at the transect level, flow level (flow at which the plot is inundated), or geomorphic surface (active channel, active floodplain, etc.). Summary queries were created in Access to expedite this process.

Data from the 1-m² plots are used to calculate percent frequencies of species or groups of indicator species, species richness, proportion of native:introduced, and the number of unique species encountered. Percent cover is calculated for total plant cover, each species, and groups of indicator species.

After survey post processing, relevant geomorphic surfaces are delineated by areas (volumes) of erosion or deposition or differences in transect topography over time. The data can then be integrated with vegetation and hydrologic measurements. Modal particle sizes at BLCA, CANY, and DINO, and facies mapping and substrate samples at DINO can be used to evaluate state changes. For example, mid-channel gravel and/or cobble bars along the Yampa River, 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, 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.

A. Integrated Analyses

Vegetation data are integrated with the geomorphology survey DEMs and transects to derive guilds 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.

The river stage can be interpolated between transducers by estimating the proportional distance of the plot along the theoretical river reach. For example, a point located halfway between the upstream and downstream transducers would have a “position of 0.5”. This value is always the same for a given plot. In conjunction with the known elevation of each surveyed vegetation plot, we will 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 ≥ 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': $\text{[pct.inundated]} = \text{[days.inundated]} / 365 \text{ days}$). 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. We can also calculate the potential widths and area of active channel, active floodplain, and inactive floodplain at each site.

Measurements of stream stage hydrology at sentinel sites allow us to classify the vegetation and the geomorphic surfaces or levels (i.e., active channel, active flood plain) on which they grow in terms of two hydrologic variables: days inundated and the percentage of the measured period a plot was inundated. This eliminates relying on visual identification of a surface, which can be subjective and could bias determination of when a surface makes a state transition from one surface type to another (e.g., active channel converting to active flood plain). It has been demonstrated that the occurrence of riparian plant species is strongly related to the inundation duration of the surfaces on which they grow (Auble et al. 1994, Auble et al. 2005). This reinforces the validity of using indicator species or guilds (Merritt et al. 2010) for identifying geomorphic surfaces as well as detecting transitions from one surface type to another, related to the channel narrowing process. Pilot data from DINO indicates that in general, active channel plots had average inundation percentages of 45% or more whereas active floodplain plots averaged less than 10%.

These data can be used to develop classification trees to determine which areas of the site are active channel, active floodplain and inactive floodplain. Vegetation data can also be used to support reclassifications. For example, when reclassifying a plot from active channel to active flood plain, the presence of floodplain indicator species in the plot provided supporting evidence for the reclassification. With more information in inundation across years, we expect to develop a statistically robust way of reclassifying plots based on hydrologic characteristics.

B. Reporting

Comprehensive analyses and reports are completed periodically on the long term data set and should be structured like typical scientific manuscripts (introduction, methods, results, discussion, and literature cited sections) and 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.

VII. Personnel Requirements and Training

A. Roles and Responsibilities

An ecologist will serve as the project manager for big river monitoring. Data management is the shared responsibility of the project manager and the data manager. Typically, the project manager oversees data collection, data entry, data verification and validation, as well as data summary, analysis, and reporting. The data manager designs the database and oversees data security, archiving, and dissemination. The data manager, in collaboration with the project

manager, also develops data entry forms and other database features to assure data quality and to automate report generation. The data manager and project manager are responsible for building adequate QA/QC procedures into the database management system and for following appropriate data handling procedures. The crew leader oversees 3-5 seasonal staff, leads the vegetation, photo, hydrologic and geomorphology field data collection, and directs data entry and verification. The crew leader assists with data summaries and annual reports. The NCPN data manager coordinates data archiving, security, dissemination, and database design.

B. Qualifications

Project Manager – The project manager must have a strong background in ecology and geomorphology. Since the project manager is also a project manager for other monitoring programs, they may not initially have all skills required, but must be willing to quickly learn in areas that they are not experienced. Project manager must also have excellent leadership, organization, and communication skills as the program relies extensively on partnerships with parks and other entities.

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

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

C. Training

Training is essential for developing competent observers. Observers will review plant identification using herbarium specimens, keys, and photographs. The crew leader will provide a refresher on plant identification, GPS navigation, and cover estimation. Observers will be tested frequently on their ability to identify plant species.

Training for total station or RTK surveying must be done prior to the field season. Most of this training must be obtained from outside NCPN. Past training has been done through the NPS Water Resources Division and the USGS Fort Collins Science Center.

Big river monitoring has an extra risk due to the river environment. Swiftwater rescue training is offered regularly and it is the goal to have the Project Manager and the Lead Technician to be certified in Swift Water Rescue. NCPN will also try to certify as many seasonal biotechnicians as possible each year.

VIII. Operational Requirements

A. Field Season Preparations and Equipment Set-up

Sampling trips shall be scheduled and organized prior to the start of each field season. Prior to working in the field, observers must review the network safety plan and the entire protocol. All equipment and supplies, especially survey gear and GPS units, should be organized and prepared for the field season.

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

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

B. Sequence of Events During Field Season

Prior to visiting the field sites, the park will be contacted according to park procedure. All equipment required for sampling is assembled and checked (SOP 1). Each day the project manager or crew leader provides a briefing regarding safety, plant identification, and park navigation. The crew leader assigns crew members for the tasks for the day. For plant work, prior to beginning work in the field, observers collectively estimate plant cover over in a plot and compare observations in order to calibrate cover class estimates. The annual workload for this protocol consists of field data collection in summer and early fall, data verification and validation in fall and winter, and data summary, analysis, and reporting in winter through summer.

Vegetation data are collected after the peak of the growing season, between July and September. Sampling visits should be scheduled to optimize phenology for the group of NCPN park units included in riparian monitoring. Park units should be visited at approximately the same time each year to maximize repeatability. DINO has traditionally been completed in July, BLCA in August, CURE in July/August, and CANY in September. Field work is typically conducted in eight-day hitches including a travel day on each end. River trips are best done with at least a crew of six, but often up to 12. The time commitment for a crew is approximately 5 pay periods per year.

Transducer installation must occur during low base flow in either summer or winter. Data downloads are done during the annual visit. Geomorphic measurements are done during low summer base flow, generally July to October.

C. Post-Collection Processing

Research specimens may be collected to confirm identification of plant species, especially those that are likely to be identified incorrectly (SOP 6). In some cases, small or partial samples may be quickly collected and stored in a field notebook. Location, description, and habitat information are recorded using an unknown specimen data sheet. Research specimens are only for confirmation of taxonomy and will not be stored in a collection. Alternatively, photographs may also be used to document unknown specimens.

IX. Revising the Protocol

This sampling protocol consists of a protocol narrative and 18 separate SOPs. The protocol narrative provides the history and justification for the program and an overview of sampling methods. Over time, methodological improvements, changes in available resources and expertise, and reassessments of the sampling design will result in revisions to this monitoring protocol. The protocol narrative will be revised only if major changes are made to the protocol. The SOPs, in contrast, are step-by-step instructions for performing each task. They are expected to be revised more frequently than the protocol narrative. Steps for changing the protocol narrative and SOPs are outlined in SOP #18.

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

The NCPN uses a Master Version Table and Version Key Number to track which versions of the narrative and SOPs are used in each version of the monitoring protocol. The Version Key # is essential if project information is to be properly analyzed and interpreted. The protocol narrative, SOPs, and data should never be distributed independently of the Master Version Table.

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