National Park Service
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Natural Resource Stewardship and Science

Big Rivers Monitoring Protocol for Park Units in the Northern Colorado Plateau Network

Version 1.01

Natural Resource Report NPS/NCPN/NRR—2018/1707



ON THE COVER

Deerlodge Park, Yampa River, Dinosaur National Monument. NPS photo.

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Natural Resource Report NPS/NCPN/NRR—2018/1707

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Contents

Figures v
Tables v
Executive Summary vii
Acknowledgements ix

Protocol Narrative 1

1 Introduction 1
- 1.1 Channel narrowing and simplification 3
- 1.2 Geomorphic indicators of channel narrowing and simplification 4
- 1.3 Vegetation indicators of channel simplification and narrowing 6
- 1.4 Hydrological indicators of channel simplification and narrowing 9
- 1.5 Problems of sampling over large and long rivers 9
- 1.6 History of big rivers research and monitoring in NCPN parks 10
- 1.7 Protocol objectives 13

2 Sampling Design 15
- 2.1 Methods for monitoring big rivers 15
- 2.2 Response design 16
- 2.3 Spatial design 16
- 2.4 Revisit design 17

3 Field Methods 19
- 3.1 Field-season preparation 19
- 3.2 Sampling procedures 19
- 3.3 End of season procedures 28

4 Data Management 29
- 4.1 Data organization 29
- 4.2 Database design 29
- 4.3 Data entry, verification, and validation 29
- 4.4 Data documentation and certification 29
- 4.5 Data archival procedures 30

5 Analysis and Reporting 31
- 5.1 Integrated analyses 31
- 5.2 Reporting 32

6 Personnel Requirements and Training 33
- 6.1 Roles and responsibilities 33
- 6.2 Qualifications 33
- 6.3 Training 33

7 Operational Requirements 35
- 7.1 Field season preparations and equipment set-up 35
- 7.2 Sequence of events during field season 35
- 7.3 Post-collection processing 35

8 Revising the Protocol 37

9 Literature Cited 39

Figures

Figure 1-1. A conceptual model of how narrowing on an active-channel feature along a largely unregulated river could be detected using reach- and geomorphic surface-specific indicator species 7

Figure 3-1. Sites and features selected for monitoring at Black Canyon of the Gunnison National Park. 20

Figure 3-2. Transect layout at Upper Tuxedo site, Green River, Canyonlands National Park..... 21

Figure 3-3. The Seacliff sentinel site feature, with benchmarks and plot locations, Green River, Dinosaur National Monument. 22

Figure 3-4. Transects established at Curecanti National Recreation Area. 23

Figure 3-5. Example of facies mapped at Seacliff in 2013. 25

Figure 3-6. Satellite imagery of the Green River from 1976 and 2014 shows narrowing and simplification of the channel over time, as well as vegetation encroachment. 28

Tables

Table 2-1. Sampling frequency in NCPN parks with big rivers monitoring. 18

Executive Summary

Because of the scarcity of water on the Colorado Plateau, the importance of large rivers, and their disproportionately high use by flora and fauna, riparian areas are an ecosystem of concern for the Northern Colorado Plateau Network (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 rivers monitoring: Black Canyon of the Gunnison National Park (NP), Canyonlands NP, Curecanti National Recreation Area (NRA), and Dinosaur National Monument (NM).

This monitoring protocol consists of a protocol narrative and 18 standard operating procedures (SOPs) for monitoring big rivers in NCPN parks. The overall goal of NCPN big rivers monitoring is to determine long-term trends in hydrologic, geomorphic (channel and floodplain), and vegetation variables in the context of changes in stream flows that can act as large disturbances or re-setting events, and other ecological drivers, stressors, and processes. Specific objectives of the big rivers monitoring protocol are to determine the effects of different flows on vegetation and geomorphic indicators of channel simplification; the environmental flows necessary to maintain active-channel, active-floodplain, and inactive-floodplain components of the riparian community; status and trends in geomorphic processes as reflected in channel and floodplain form; status and trends in vegetation patterns, and rates of narrowing and changes in narrowing in response to regulated and unregulated flows using remote imagery. Objectives for Curecanti NRA are somewhat different. There, we aim to determine changes in the river channel (encroachment, channel migration, riparian vegetation) over time; regeneration rates for cottonwoods and if cottonwood recruitment is sufficient to maintain cottonwood gallery forests, and 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.

The protocol narrative describes the justification, sampling design, and field methods for NCPN big rivers monitoring. Details may be found in the SOPs, which are listed in Chapter 1 and available at irma.nps.gov. Other aspects of the protocol summarized in the narrative include procedures for data management, analysis, and reporting; personnel and operating requirements; and instructions for how to revise the protocol.

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Protocol Narrative

Revision History Log

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1.00	2/2018	D. Perkins	Editorial	Peer review comments	1.01

1 Introduction

This sampling protocol consists of this protocol narrative and the following standard operating procedures (SOPs) and appendices, available at https://irma.nps.gov/DataStore/Reference/Profile/2254835:

- SOP 1: Preparations for the Field Season and Equipment Needed
- SOP 2: Hiring and Training Observers
- SOP 3: Using Global Positioning System (GPS) Units
- SOP 4: Sentinel Site Set-Up (BLCA/CANY/DINO)
- SOP 5: Photographs (BLCA/CANY/DINO)
- SOP 6: Measuring Vegetation (BLCA/CANY/DINO)
- SOP 7: Transducers and Hydrologic Monitoring (BLCA/CANY/DINO)
- SOP 8: Surveying
- SOP 9: After Each Field Visit
- SOP 10: After the Field Season
- SOP 11: Data Management
- SOP 12: Data Analysis and Reporting
- SOP 13: Revising the Protocol Narrative and SOPs
- SOP 14: Facies Mapping and Grain-Size Distribution (DINO)
- SOP 15: Non-Survey Field Methods (CURE)
- SOP 16: Trimble RTK Basic Operating Instructions in the Field
- SOP 17: Trimble Business Center Office and Field QA/QC Operating Instructions
- SOP 18: Vegetated vs. Non-vegetated Mapping in the Northern Colorado Plateau Network

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) Division of the NPS was created to provide managers with credible scientific information about park natural resources. The Northern Colorado Plateau Network (NCPN) serves 16 national park units throughout Utah, western Colorado, southwestern Wyoming, and northern Arizona.

In 2003, NCPN staff solicited input on natural resources of concern and ecosystem indicators known as "vital signs" from several hundred NPS staff and regional and national experts (O'Dell et al. 2005). Potential vital signs were evaluated for management significance and utility, ecological significance, scientific validity, feasibility and cost of implementation, and signal-to-noise ratio. Because of the scarcity of water on the Colorado Plateau, the importance of large rivers, and their 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 rivers monitoring: Black Canyon of the Gun-

nison National Park (NP), Canyonlands NP, Curecanti National Recreation Area (NRA), and Dinosaur National Monument (NM).*

In these four NPS 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 (Christensen and Lettenmaier 2007, Hoerling and Eischeid 2007, Seager et al. 2007, Woodhouse et al. 2016). 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 rivers monitoring:

1. channel form (size and shape) and sediment size,
2. riparian vegetation structure and composition, and
3. streamflow.

This protocol structures monitoring based on how large rivers of the northern Colorado Plateau are predicted to respond to future natural and human-induced changes in streamflow, resulting in direct, measurable changes in channel form and function, as well as related changes in the abundance, composition, and distribution of riparian vegetation. Given the limited time and financial resources the NPS has available to monitor extensive reaches of big rivers in remote locations, we have developed a multi-scalar approach with three integrated elements that combine remotely sensed and ground-based data:

1. field-based, detailed, and quantitative assessments of geomorphic and vegetation change at sentinel sites predicted to be sensitive to channel narrowing;
2. a broad-scale, remotely sensed assessment of geomorphic and vegetation change, particularly in relation to channel narrowing; and
3. the integration of sentinel sites with historical monitoring and research data at legacy sites that provide context and insight into dynamics of channel change and the factors that drive this change.

We seek to integrate our monitoring efforts with legacy research and monitoring sites established prior to NCPN monitoring. We define legacy sites as those which have been the focus of past monitoring and/or research efforts (e.g., Deerlodge Park, Echo Park, Laddie Park in Dinosaur NM, Warner Point in Black Canyon of the Gunnison NP, endangered fish sites at Canyonlands NP). Each park has 1–3 legacy sites. The research and monitoring may be ongoing, inactive, or intermittent at these sites, but can be more intensive and spatially extensive than at 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 data record and integrate the data from this protocol with the legacy data, which are funded with other resources.

*Related monitoring efforts at additional parks are included in separate protocols for wadeable streams (Weissinger et al. 2018), water quality (Thoma et al. 2007), land surface phenology (Thoma et al. 2017), landscape dynamics (Thoma 2016), and invasive plants (Perkins et al. 2016).

Past research results at legacy sites can also provide detailed ecological context to co-located monitoring efforts. For example, work by Manners and others (2011, 2014) 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 floodplain. This partnership approach has also led to the implementation of variations of this big rivers monitoring protocol on the Colorado River in Grand Canyon National Park and the Rio Grande River at Big Bend National Park. This will allow these vegetation, hydrologic, and geomorphic data to be compared across Intermountain Region national parks with large rivers.

The four parks where NCPN does big rivers 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 the longest relatively free-flowing reach of river in the Colorado River basin and partially "naturalizes" the flow-regulated Green River below the confluence. Dinosaur NM 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. Canyonlands NP sees the summation of the Green and Colorado rivers as they converge in the park before disappearing below the surface of Lake Powell. At Black Canyon on the Gunnison NP, big rivers monitoring data will be tightly tied to evaluating the success of the NPS water right to the Gunnison River.

1.1 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, and across the southwestern U.S. in general, has been altered by water development projects. In most cases, peak flows have been reduced, resulting in channel narrowing (Williams and Wolman 1984, Grams and Schmidt 1999). In many cases, base flows have also increased, which can result in vegetation expansion (Sankey et al. 2015). Channel narrowing can consist of a decrease in channel width, simplification of geomorphic complexity, aggradation of floodplains/bars, and related changes in the width, structure, biodiversity, and composition of riparian vegetation (Graf 2006, Williams and Wolman 1984, Grams and Schmidt 1999).

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. They are typically composed of vertically stacked, fine-grained layers of sediment left by discrete floods. By definition, floodplains are level surfaces constructed by a river under prevailing climatic conditions, 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 bedrock, floodplain deposits may be narrow and discontinuous (Grams and Schmidt 1999), or even non-existent. In contrast, channels in large alluvial basins may have large, spatially extensive floodplains. Vertically aggraded floodplains may progressively become disconnected from surface flows in adjacent channels (Manners et al. 2011), and may be abandoned if the regional climate becomes drier. At Dinosaur NM, Grams and Schmidt (1999) found that narrowing occurred due to the deposition of fine-grained sediments. Within debris-fan dominated canyons, narrowing was greatest where there was the greatest reduction in stream power. This resulted in a post-dam floodplain that is disconnected from the river.

Riparian vegetation establishment and succession are intimately linked to the lateral and vertical accretion of sediments that lead to floodplain formation across a range of channel forms (Schumm and Lichty 1963, Hereford 1984, 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 measure of channel narrowing. In many cases, narrowing has been accompanied and enhanced by the establishment and spread of the nonnative riparian shrub, tamarisk (*Tamarix ramosissima* and hybrids) (Everitt 1993, Birken and Cooper 2006, Manners et al. 2011, Dean et al. 2011).

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).* A continuing process of channel narrowing can be expected along large rivers of the southwestern U.S. 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).

Among other impacts, simplification of channel form and spatial complexity reduces important in-channel habitat for native aquatic species, including endangered fish (Schmidt and Brim-Box 2004, Van Steeter and Pitlick 1998). 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 the NPS and water users, and perhaps influence future water management decisions.

At Curecanti NRA, resource concerns are slightly different. Here, park staff is primarily interested in narrowleaf cottonwood recruitment (*Populus angustifolia*) and channel migration that can lead to cottonwood recruitment events. They are 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.

At this park, only six kilometers of free-flowing river encompass an area of approximately 193 hectares before entering 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.

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, Mahoney and Rood 1992, Segelquist et al. 1993). Subsequent base flows are needed to supply soil moisture for seedlings. Shafroth and others (1998) found that the conditions that allow *Populus* to establish are also conducive to other woody vegetation establishment. Scott and others (1997) found that only infrequent large floods could establish site conditions for *Populus* due to limited channel movement.

1.2 Geomorphic indicators of channel narrowing and simplification

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). Channel narrowing can oc-

*It should be noted that Lyons and others (1992) documented some short-term widening at Dinosaur NM, caused by large floods that occurred in the mid-1980s, as well as some slowing of the narrowing process at Canyonlands NP (Perkins et al. in prep).

cur in many ways. Large dams can result in sediment deficit, changes in average grain size, channel incision, channel narrowing or widening, 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 1999). Graf and others (1991) and Hereford (1984), working on the Paria and Little Colorado rivers, respectively, showed that their floodplains were constructed by moderate-magnitude summer and fall floods transporting large suspended-sediment loads. The process that disconnects floodplains began when the frequency of large floods decreased. Hereford and others (1996) showed that accretion had ceased because the floodplain had likely reached a critical height above the channel that the current flow regime could no longer reach. No floodplain accretion had occurred on the Paria since 1980 (Graf et al. 1991).

In many other rivers, upstream water catchment by dams and irrigation networks caused the loss of long-duration winter snowmelt. The loss of these long-duration floods, without a reduction in the summer/fall floods, has resulted in sediment accumulation (Dean and Schmidt 2011, Walker 2017). In Dinosaur NM, dam releases for power-plant capacity have contributed to aggradation of floodplains along the Green River (Alexander 2007). While channel narrowing has occurred due to lateral accretion along the Green River at Dinosaur NM and the Green and Colorado rivers at Canyonlands NP, it is not clear if the floodplain has reached the critical height at which accretion has ceased.

On the regulated Green River in Dinosaur NM, Grams and Schmidt (1999) found that channel adjustment occurred through the 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 (1999) measured rates of aggradation and inundation frequencies of vertically accreting floodplains on the Green River near Green River, Utah. Island aggradation (which is, in essence, vertical floodplain accretion) is limited to the water-surface level corresponding to river stage at peak flow, and the ability 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 Dinosaur NM, as long as there was a supply of sediment available (e.g., via bank collapse and tributary inputs) 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. This, in turn, allows for vegetation establishment and, ultimately, further disconnection of the surface from the active channel, making the gravel bars unavailable to fish. 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 water discharge and the size and amount of sediment supplied to the stream from the watershed (Leopold et al. 1964). Flow governs channel dimensions, such as width, depth, and meander patterns. Channel form is mostly determined by the amount and size of bedload, even though bedload may be a small proportion of the total sediment flux (Schumm 1981). Bedload is defined here as alluvial or river-transported sediment moving on or near the bed of a channel. Decreased flows can result in sediment mass-balance surplus, which leads to the development of floodplains regardless of whether invasive riparian vegetation is present (Everitt 1993, Allred and Schmidt 1999).

Vegetation that establishes in the active channel may contribute to narrowing by increasing hydraulic roughness and sediment deposition rates, thereby facilitating accretion and reduced channel capacity. Graf (1978) and Allred and Schmidt (1999) suggest that the establishment of exotic species, such as tam-

arisk, 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 were the erosion of channel margins, steepening of banks and subsequent bank failure, and the elimination of point-bar deposits and transitional surfaces on the insides of meanders. Using stratigraphic and dendrogeomorphic historical reconstructions of channel change in combination with a time sequence of aerial photographs, Manners and others (2011) documented localized channel narrowing along the Yampa River in Harding Hole and Laddie Park since 1938 (the earliest available aerial photography). They documented a progressive narrowing process that 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, channel narrowing is manifested in the vertical and lateral accretion of fine-grained sediments within and adjacent to the active channel. In some cases, the creation of these geomorphic features is facilitated and/or exacerbated by riparian vegetation (Dean and Schmidt 2011, Tal and Paola 2010, Tal et al. 2004, Manners et al. 2014).

1.3 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 surfaces that are rarely inundated. 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. A number of species 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 and others (2014) in two restricted-meander reaches of the Yampa River 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 streamflow rates where they are inundate) 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, Merritt and Bateman 2012). Loss of such complexity through channel narrowing and associated invasions of non-native monocultures (i.e., tamarisk and Russian olive [*Elaeagnus angustifolia*]) can have important indirect effects on riparian bird communities—as can loss of back channels and associated vegetation.

Channel narrowing, as it affects the active channel and active floodplain surfaces, is hypothesized to proceed as described and illustrated below. The active channel surfaces are generally flooded every 1–2 years and are sparsely vegetated. The active floodplain is flooded every 3–15 years and is sparsely vegetated at the active channel edge. The active floodplain becomes more vegetated with species that are tolerant of peak flows as one moves away from the channel. Fine sediment and vegetation cover over 40%, often by tamarisk and willow (*Salix* spp.), can mark the end of the active floodplain and the beginning of the inactive floodplain. The inactive floodplain is generally only flooded every 15–25 years.

Reach-specific interpretations of narrowing could be hypothesized to proceed as follows (Figure 1-1):

- At T_0, a channel feature exists with reach-specific, active-channel indicator species.
- At T_1, the feature has, for example, tamarisk/sandbar willow (*Salix exigua*), 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.

Several studies have found distinctive assemblages of plant species or indicator species associated with different flows and geomorphic surfaces. Control of the distribution, abundance, and composition of vegetation by streamflow and flow-controlled geomorphic processes has been reported along the Green and Yampa rivers in Dinosaur NM (Merritt and Cooper 2000). Although the physical factors of rivers prevent most plants from establishing in the active channel, Fischer and others (1983) noted a group of plants growing in what they call the floodzone (referred to as the active channel in this report) that were resistant to scouring and tolerant of inundation. They included scouring horsetail

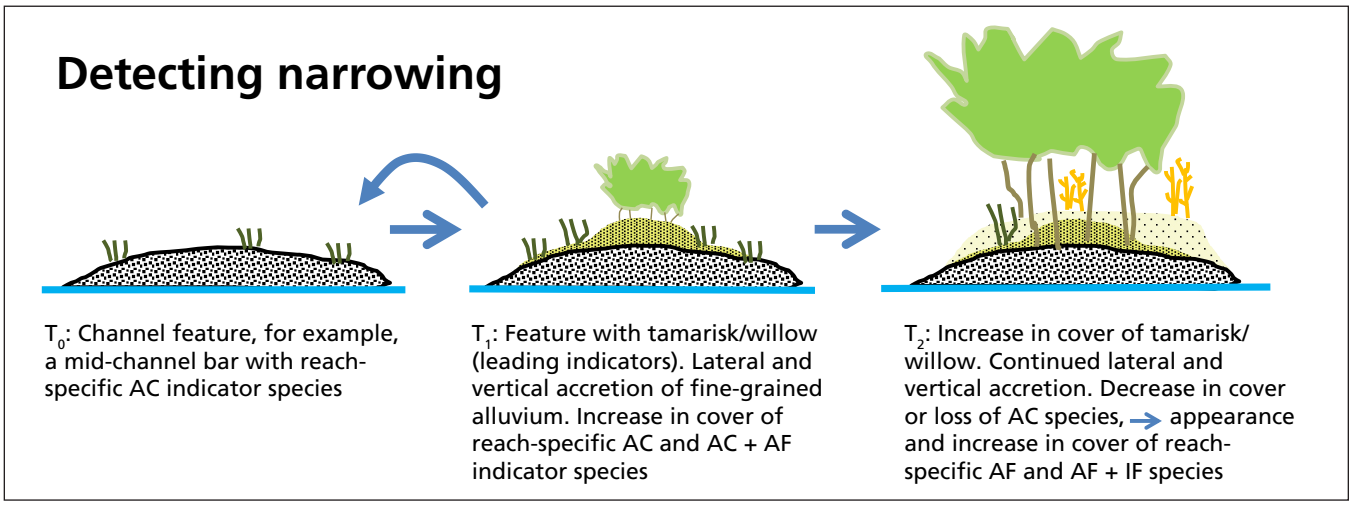


Figure 1-1. A conceptual model of how narrowing on an active-channel feature along a largely unregulated river could be detected using reach- and geomorphic surface-specific indicator species. T_0 represents initial conditions on a channel-bar feature with reach-specific, active-channel indicator species. At T_1, floodplain construction and channel-narrowing are indicated by accretion of sediments and increases in the cover of active-channel species as well as the appearance of new active-channel and/or active-floodplain species. Flow variability over time may return the channel feature to initial conditions, or persistent reductions in flow variability may lead to progressive narrowing, as indicated by continued sediment accretion, increased vegetation cover, loss of typical active-channel species, and the appearance of new active and inactive floodplain species (T_2). AC = active channel, AF = active floodplain, IF = inactive floodplain.

(*Equisetum hyemale*), smooth horsetail (*E. laveigatum*), water sedge (*Carex aquatilis* [*sic*; likely *emoryi*]), common spikerush (*Eleocharis* sp., likely *palustris*), American licorice (*Glycyrrhiza lepidota*), common dogbane (*Apocynum cannabinum*), milkweed (*Asclepias* sp., likely *speciosa*), water knotweed (*Polygonum amphibium*), povertyweed (*Iva axillaris*), and skeletonleaf bursage (*Franseria discolor* [*sic*; now *Ambrosia tomentosa*]). This group or guild of species (sensu Merritt et al. 2010) is composed of dominant perennials capable of vegetative reproduction, with annual aboveground tissues that arise from underground 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 and others (2009) developed simulation models examining the effects of varying flows on vegetation at Black Canyon of the Gunnison NP and on the Fremont River at Capitol Reef NP (Auble et al. 2005). Sankey and others (2015) examined the spatiotemporal variability in riparian vegetation in the Grand Canyon relative to flow regulation and determined points of inundation for different vegetation zones. We have conducted our own analyses from legacy sites and NCPN monitoring to modify this list with park-specific indicators at Black Canyon of the Gunnison NP, Canyonlands NP, and Dinosaur NM (Scott and Perkins 2018).

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, protecting 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). Plant litter 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 biodiversity (Gregory et al. 1991). Roots stabilize soils and streambanks (Winward 2000, Polvi et al. 2014), 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 in the active channel naturally but with limited frequency, 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 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.
2. Thus, 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 flood-

plain surfaces.

4. Plants that colonize and stabilize topographically high channel deposits play a more passive role in converting channel to floodplain (Manners et al. 2011).

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 1999, Friedman et al. 1996, 1998). Certain hydrogeomorphic settings are more sensitive to narrowing, and certain plants, such as tamarisk, are more effective at trapping sediment and converting active channel to floodplain (Graf 1978, Larson 2004, Birken and Cooper 2006, Manners et al. 2011).

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.

1.4 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). Days of inundation, flow rate, shape of the hydrograph, depth of flow, and sediment supply all relate to scour, accretion, and the encroachment and removal of vegetation. A two- or three-dimensional hydraulic model would be one way to integrate hydrology. However, due to the extensive work and expensive equipment required to conduct river bathymetry, such a model is beyond the fiscal resources of this protocol.

Instead, we are using pressure transducers to record river stage above and below each sentinel site. This will allow us to determine the minimum inundating discharge and/or inundation duration at each plot or point of interest. This approach relates 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 and show the effects of natural and semi-natural hydrographs on important components of unregulated rivers.

1.5 Problems of sampling over large and long rivers

Sampling vegetation and geomorphology in big, canyon-bound rivers in NCPN parks presents a variety of challenges. Some of these challenges are similar to any sampling in vegetated riparian settings and active fluvial environments: one of the elements being measured (riparian vegetation) is the very thing that makes it difficult to accurately measure one of the other elements (topography). Most topographic sampling relies on either a line of sight to the ground or the ability to physically occupy the ground (e.g., with a survey rod and prism). Vegetation limits both of these activities.

It is also challenging to sample topography in big water, where large portions cannot be waded, other portions cannot be boated, and steep canyon walls can stymie remote-sensing technologies. 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 haz-

ards that canyon geometry and cliff heights present to remote-sensing data acquisition from aerial platforms. These factors logistically constrain what can and cannot be done. They also 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. There are several important differences between the four NCPN parks where big rivers are monitored. Those differences necessitate similar, yet slightly different monitoring approaches at each park.

The scale at which channel narrowing might be explained mechanistically ranges from sediment size to reach. 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; we can now sample hundreds of kilometers of river for reasonable cost. However, remote sensing does not and will likely never be a substitute for some on-the-ground sampling.

1.6 History of big rivers research and monitoring in NCPN parks

A number of studies at NCPN parks have focused on riparian resources. These park-specific studies offer valuable data, such as plant species lists, documentation of channel change, changes in surface flow or alluvial groundwater dynamics, and information on historic conditions. However, few were conducted over long periods of time. Even fewer 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 relative to channel narrowing in Dinosaur NM. These studies typify some of the settings found in other big, canyon-bound rivers in NCPN parks. Andrews (1986) reported a 13% (23-m) decrease in channel width on the Green River in Browns Park from 1966 to 1977. Lyons and others (1992) reported a decrease in channel width of 3–12% between 1964 and 1974. Merritt and Cooper (2000) found an 11% decrease in channel width between 1954 and 1977. Grams (1997) and Grams and Schmidt (1999) showed that channels narrowed by approximately 20%–25% 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 resulted from 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 1999). 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 (Grams and Schmidt 1999). 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 1999). 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 Dinosaur NM (Grams and Schmidt 1999, Grams and Schmidt 2005) are considered legacy sites in this protocol.

Certain hydrogeomorphic environments are more prone to floodplain building and channel narrowing than others. Such settings along the Yampa River in Dinosaur NM include eddy bars above and below debris fans in steeper, narrow canyon settings (above River Mile 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 River Mile 21) (Manners et al. 2011). The same work by Manners and others (2011) documents progressive, but non-uniform channel narrowing at Laddie Park and Harding Hole along the Yampa River since 1938. A two-kilometer 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. Manners and others (2011) 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 two-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, as well as 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 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 also visually depict channel narrowing for the Colorado and Green rivers in Canyonlands NP (Webb et al. 2007) and the Green River in Dinosaur NM (Grams and Schmidt 1999). Other relevant studies focused specifically on channel narrowing elsewhere in the upper Colorado River watershed (Allred and Schmidt 1999, Gaeuman et al. 2005). On the Green River near Green River, Utah, Allred and Schmidt (1999) recorded a 14% reduction in channel width between 1959 and 1996.

Mueller and others (2014) examined the effects of the 2011 flood in Lodore Canyon, which was the third largest since the completion 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. Although 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 the large bed motion necessary to clear surfaces of tamarisk did not happen (Mueller et al. 2014).

Merritt and Cooper (2000) noted the differences in vegetation patterns due to differences 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 (sandbar willow, common spikerush [*Eleocharis palustris*], common threesquare [*Schoenoplectus pungens*], and knotted rush [*Juncus nodosus*]), while terraces had xeric soil conditions and supported communities more typical of arid environments (basin big sagebrush [*Seriphidium tridentatum*], greasewood [*Sarcobatus termiculatus*], and alkali sacaton [*Sporobolus airoides*]). On the Yampa River, species were spread across a gradual environmental moisture gradient from the active channel (rough cocklebur [*Xanthium struminarium*], sandbar willow, Rio Grande cottonwood [*Populus deltoides* subsp. *wislizenii*], and tamarisk) to high floodplain surfaces characterized by cottonwood 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 Dinosaur NM (Hammack and Wohl 1996, Larsen et al. 2004), as well as upslope studies examining 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 1999, Grams and Schmidt 2005, Grams et al. 2007). These studies utilized a variety of field techniques, including geomorphic mapping, cross-sections, full topographic surveys, and stream gaging, and analytical techniques including 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 help explain the vegetative response and distributions.

In the 1990s and early 2000s, there was an increase in studies in Black Canyon of the Gunnison NP related to the park's application for, and eventually obtaining, a water right. After conducting vegetation sampling at the Warner Point reach, Auble and others (1994) developed a community classification and identified relations between hydrology and community distribution. Friedman and Auble (1999) developed a model that related annual mortality of box elder (*Acer negundo*) to streamflow (shear stress and extended inundation) at Warner Point. Several investigators have examined sediment transport at the park. 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 park bottomland. Dubinski (2005) and Dubinski and Wohl (2007) estimated a historical sediment budget for the Gunnison River in the park and developed a model relating streamflow to channel mobilization for different sediment particle sizes throughout the park. A simulation model was developed to predict the potential response of riparian and wetland plant species to altered flow regimes in Black Canyon of the Gunnison NP (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 Black Canyon of the Gunnison NP (Nehring and Miller 1987, Nehring 1988, 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 River downstream of the park (McAda 2003) has motivated a number of studies and analyses of downstream sections of the river and is a consideration in water-management decisions in the Aspinall unit, upstream from the park, that influence Gunnison River streamflow through Black Canyon of the Gunnison NP (BOR 2009).

Non-native riparian-species invasions (in particular, tamarisk and Russian olive) and restoration attempts have had large effects on these rivers. Birken and Cooper (2006) excavated pits through vertically accreted sediments on the lower Green River in Canyonlands NP and aged tamarisk stems to examine patterns of tamarisk establishment and channel narrowing. Cooper and others (2003) found widespread tamarisk invasion on the post-dam floodplain in Lodore Canyon in 1962 and 1963 (Cooper et al. 2003). Perkins and others (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 Black Canyon of the Gunnison NP and found that common burdock (*Artium minus*), Canada thistle (*Breea arvensis*), reed canarygrass (*Phalaroides arundinacea*), and common mullein (*Verbascum thapsus*) all declined from earlier sampling periods (2003–2004 and 2010–2012) when compared to the most recent sampling period (2014–2015). They speculated that environmental flows may be contributing to the decrease. On the Green River in Lodore Canyon, in Dinosaur National Monument, 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.

We have developed a long-term monitoring program for the large river resources at four National Park Service units. Using the literature, we have selected indicators to detect channel narrowing and simplification at sentinel sites in these parks.

1.7 Protocol objectives

The overall goal of the NCPN big rivers monitoring program is to determine long-term trends in hydrologic, geomorphic (channel and floodplain), and vegetation variables in the context of changes in stream flows that can act as large disturbances or re-setting events, and other ecological drivers, stressors, and processes. Specific objectives of the big rivers monitoring protocol are to:

- 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, and
- Determine rates of narrowing and changes in narrowing in response to regulated and unregulated flows using remote imagery.

Objectives for Curecanti NRA are somewhat different. There, we aim to:

- 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, and
- 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. Big rivers monitoring additionally benefits from other vital signs monitoring and historical data. Local weather station data can be used to interpret responses. 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 photograph points will be re-located and re-photographed on a recurring basis, when possible.

2 Sampling Design

2.1 Methods for monitoring big rivers

A number of direct and indirect metrics may be used to assess a long-term channel-narrowing process. Measuring streamflow over time would be the most direct way of assessing change 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, more stable surfaces—is a hallmark of channel narrowing (Graf 2006), often intimately related to the establishment of riparian vegetation. The NCPN will focus its monitoring efforts on hydrologic, geomorphic, and vegetation changes because these provide strong, robust, measurable indications of the channel-narrowing process.

Direct measures of channel narrowing often involve repeated topographic surveys at permanently located channel and floodplain 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 et al. 1999, Allred and Schmidt 1999). A time sequence of aerial photographs can provide an indirect but spatially integrated quantification of channel change over larger areas, but aerial photography is generally collected with low temporal resolution 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. 2011, Dean and Schmidt 2011).

Complete channel and floodplain cross-sections with bathymetry are probably the optimal method for measuring geomorphic changes along a river. However, the costs in labor or equipment are cost-prohibitive for NCPN. The network conducts geomorphic work at low flow. This allows us to survey 75–90% of the channel, only avoiding the deepest sections due to safety. While under optimal conditions we would survey complete cross-sections of the channel and floodplain, we anticipate that changes in the deeper parts of the channel due to river incision (or the progressive disconnection from the floodplain) will eventually show up on the banks, where we do sample. Water-penetrating LiDAR is also effective at obtaining bathymetry, but does not work in sediment-laden rivers, such as those found on the Colorado Plateau.

The U.S. Environmental Protection Agency (EPA)'s Environmental Monitoring and Assessment Program (EMAP) has developed a widely used method for monitoring riparian areas. The EMAP protocol incorporates seven complete stream cross-sections for monitoring geomorphology and riparian vegetation, and groundwater wells for monitoring alluvial groundwater hydrology. Other, similar approaches to riparian and aquatic monitoring focus on subsampling a section of stream (a stream reach), and subsampling that reach using cross-sectional transects (Fitzpatrick et al. 1998, Winward 2000, Heitke et al. 2010, Leary and Ebertowski 2010). The U.S. Forest Service's National Riparian Core Protocol (Merritt et al. 2017) characterizes channel geometry, species composition, and habitat characteristics.

The NCPN has developed a wadeable steams protocol for small and ephemeral streams in the network (Weissinger et al. 2018), based loosely on the EMAP methods. As that protocol was developed, extensive sampling was done to evaluate the efficiency and effectiveness of various ecological measures and measurement techniques (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 rivers monitoring, it is not achievable at the scale of NCPN big rivers.

Other aridland riparian methods were reviewed, evaluated, and determined to not be of sufficient rigor or repeatable (Stacey et al. 2005, Herrick et al. 2005). Others were too expensive for NCPN settings (Lord et al. 2009, Grams 1997, Grams and Schmidt 2002, Grams and Schmidt 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 the sentinel sites.

2.2 Response design

The sampling unit for riparian monitoring of big rivers is a sentinel site. Measurements of vegetation, hydrologic, and physical drivers are co-located at each sentinel site and monitored concurrently. The size of a sentinel site is dependent on geomorphic features driven by the river's peak and annual flow, and the constraints (canyons) that allow or restrict the river channel's movement. At Black Canyon of the Gunnison NP, sentinel sites range from 15 to 60 meters in length within two sites that are 700 and 500 meters in length. At Dinosaur NM, sentinel sites range from 200 to 500 meters in length. At Canyonlands NP, in the broad alluvial portions of the river above the confluence, the sites range from 200 to 1,000 meters in length. At Curecanti NRA, where the methodologies are different and there are only six kilometers of free-flowing river, we have focused on the entire river as a single site.

Vegetation measurements occur in permanent plots of one square meter (1 × 1 m or 2 × 0.5 m). Stream-channel surveys, using either a total station or real-time kinematic (RTK) technology, are performed along each of the cross-section transects and following the channel thalweg throughout the reach. River stage is measured using transducers located upstream and downstream from 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. At Dinosaur NM, freely or restricted meandering alluvial channels are found in Deerlodge Park on the Yampa River, and at Browns and Island parks on the Green River. These channel types are also found in all of Curecanti NRA, and all of the sentinel sites at Canyonlands NP. Canyon-bound reaches include debris fan-dominated channels in Lodore Canyon on the Green River, debris fan-affected channels on the Yampa, and entrenched-meander channels found on the Green and Yampa rivers in Dinosaur NM, and all of the sites at Black Canyon of the Gunnison NP.

2.3 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 sensitivity to fluvial geomorphic change and subsequent channel narrowing. At Black Canyon of the Gunnison NP, we are sampling the only two sentinel sites that are safely accessible on foot while carrying large packs necessary for transporting sampling equipment. Within these sites, we chose areas where change could occur and are at sampling sections with steep canyon walls.

At Dinosaur NM, we also did not choose any sites that were in the steep-walled canyons that are insensitive to change, or where the channel margins are so narrow that change would be hard to detect. On the wild Yampa River, where low summer flows can prevent summer boating, we chose three sites that are accessible on foot. Three of the six sites on the Green River at Dinosaur NM are also accessible on foot. All nine sites at Dinosaur NM were chosen based on their sensitivity to change as determined by experts who have more than two decades of experience at the park, as well as their importance to endangered fish (three sites). These sites generally have a low gradient where there are wider areas of active channel, active floodplain, and inactive floodplain, so that widening and narrowing can be observed. There are sentinel sites on each of the three river sections—on the Yampa and Green above the confluence, and on the Green below the confluence. Each river section has one alluvial-park and two canyon-bound sentinel sites. The broad parks are restricted meanders with large amounts of alluvium that allow the channel to migrate within the bedrock restrictions at Browns Park, Deerlodge Park, and Island

Park. The canyon-bound sentinel sites are either entrenched meanders or debris fan-affected reaches where the river has less room to work due to bedrock constrictions.

At Canyonlands NP, where there was not as much previous research, we developed a dynamism index to determine which sites were most sensitive to channel narrowing. To do this, we mapped vegetated and unvegetated polygons along the river (see SOP 18). This dynamism index used the polygons from 1976 to 2014 to develop scores for each river mile based on the following factors:

- total amount of change (raw hectares converted from unvegetated to vegetated),
- relative change (raw hectares converted from unvegetated to vegetated/the total change possible),
- evidence of narrowing and expansion,
- standard deviation of change (1976–2009), and
- recent change (2002–2014).

The total amount of change and relative change allowed us to evaluate wide sites compared to sites heavily restricted by canyon walls. Sites important to endangered fish (three of the selected sites) also affected the selection process. Logistics were also considered, along with the ability to use one base station for surveying.

At Curecanti NRA, 10 transects are placed randomly through all six kilometers of river in the park.

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

2.4 Revisit design

At each river, the number of sentinel sites is limited by affordable effort: one 8-day research trip per river reach (Green River, Dinosaur NM; Yampa River, Dinosaur NM; Gunnison River, Black Canyon of the Gunnison NP; Green River, Canyonlands NP). 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 occur on all rivers. A rotating panel design is used to increase the overall sample size. Some sentinel sites are sampled annually, while most others are sampled every 2–3 years (Table 2-1). The Curecanti NRA reach is only sampled every five years, or after a large peak flow. 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 is dependent upon a crew of eight for four field trips (aka hitches of 8 days each), with an additional crew of four for a single hitch in the year when sampling takes place at Curecanti NRA.

Sampling of vegetation and geomorphology occurs during summer baseflow, after vegetation has reached peak growth (July–September). Surface water is continuously monitored with transducers at all sites except Curecanti NRA. Information from the transducers is collected once each year.

Table 2-1. Sampling frequency in NCPN parks with big rivers monitoring.

Park	River	Site	Target date	Sampling frequency
Black Canyon of the Gunnison NP	Gunnison	East Portal	August	Annually
	Gunnison	Red Rocks	August	Annually
	Gunnison	Warner Point	August	5–10 years
Canyonlands NP	Green	Millard	September	Annually
	Green	Queen Anne	September	Annually
	Green	Bonita Bend	September	Annually
	Green	Holman Canyon	September	Annually
	Green	Sphinx	September	Annually
	Green	Upper Tuxedo	September	Annually
	Colorado	Musselman Canyon	September	Annually
	Colorado	Sangria	September	Annually
Curecanti NRA	Gunnison	Cooper/Neversink	July/August	Every 5 years or major peak flow
Dinosaur NM	Green	Browns Park	July	Two out of three years
	Green	Winnies	July	Two out of three years
	Green	Limestone	July	Two out of three years
	Green	Echo Park	July	Annually
	Green	Seacliff	July	Annually
	Green	Island Park	July	Two out of three years
	Yampa	Deerlodge	July	Annually
	Yampa	Harding Hole	July	Annually
	Yampa	Laddie Park	July	Annually

3 Field Methods

Methods and techniques for taking measurements, with example data sheets, can be found in the individual SOPs. It is important to maximize efficiency when collecting field data. Key considerations include determining the number of crew members needed to perform each protocol, and the order in which the various measurements are performed. With vegetation, geomorphology, hydrology, and photographic data are collected at each site, it is essential for some crew members to perform multiple tasks. For efficiency, logistics, and safety, tasks must be completed at close to the same time so the crew can all leave a site together.

3.1 Field-season preparation

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 for use of staff and resources, updating emergency contact information, and acquiring backcountry permits (see SOP #1). All 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, 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 ensure that all personnel coming on the trip have the proper safety gear and permit-required items (portable toilet, fire pan, kitchen), and that 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 backcountry safety plan to Glen Canyon NRA Dispatch on the day of departure, as outlined in the NCPN Field Safety Standard Operating Procedure.

3.2 Sampling procedures

3.2.1 Establishing and revisiting the site

3.2.1.1 Black Canyon of the Gunnison National Park

At Black Canyon of the Gunnison NP, only two sites are accessible for crews and heavy equipment. Within these two sites, we selected geomorphic features (sentinel sites with different depositional environments) to monitor. There are 10 features at East Portal and 7 features at Red Rocks. At each feature, 3–4 stub transects are established (Figure 3-1). A stub transect (referred to as "transect" from now on) is one that ends in the water and does not span the entire river. Each transect has a permanent headpin and an orientation pin. There must be at least three permanent, physically stable survey control points visible from multiple instrument locations.

Using the headpin and orientation pin, a tagline is stretched from the headpin to a temporary pin (rebar) 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.

3.2.1.2 Canyonlands National Park

There are 3–12 transects placed on each sentinel site for monitoring purposes. Transects are permanent but do not have any permanent rebar, headpins, or markers. Transects are relocated using 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. The length of transect that is sampled may change from year to year, depending on movement of the active floodplain, water level, and safety while wading, but the overall endpoints of the transect do not change. There are

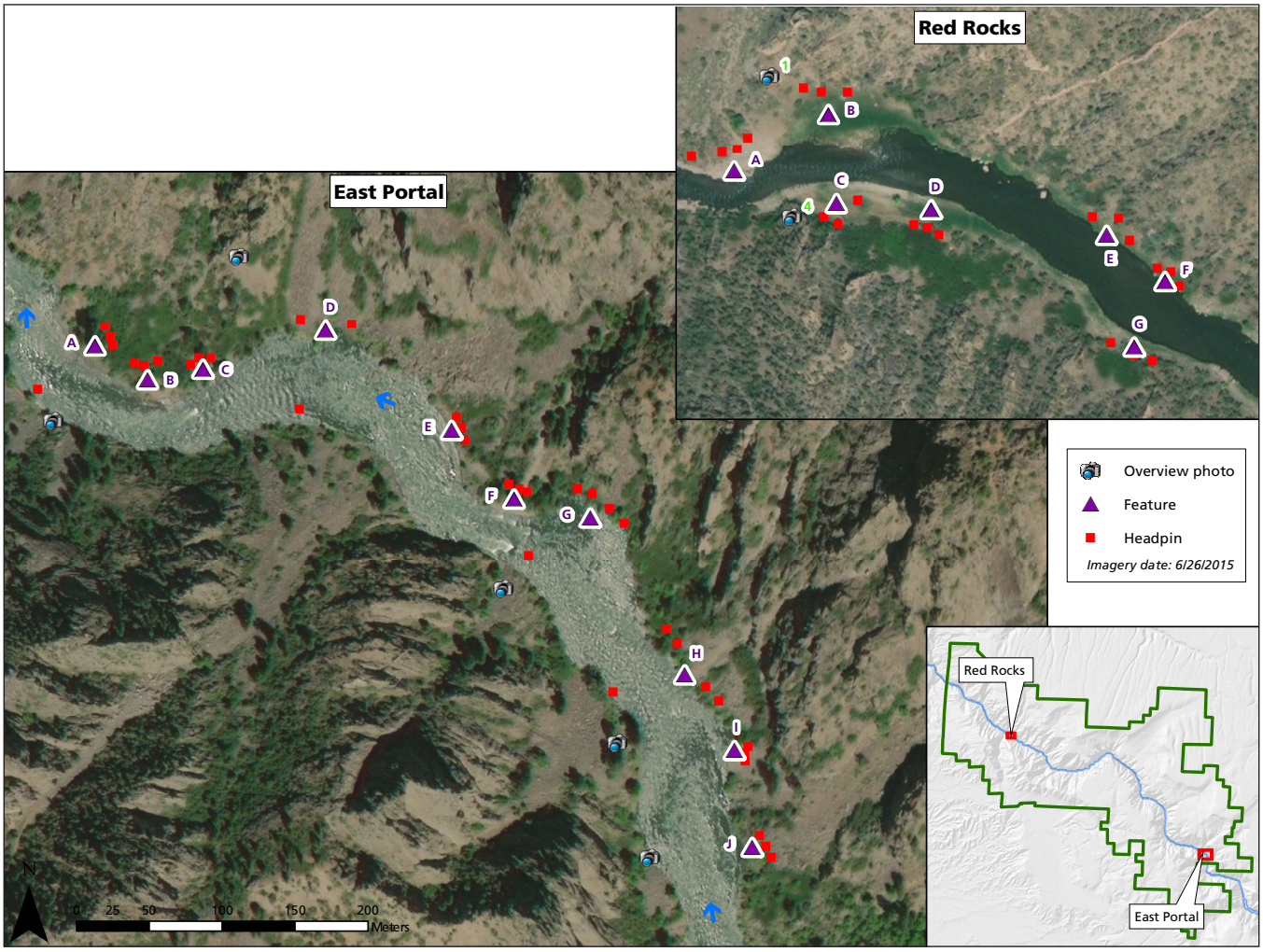


Figure 3-1. Sites and features selected for monitoring at Black Canyon of the Gunnison National Park.

permanent control plots at all sites. At least three permanent, elevationally stable control points must be established (Figure 3-2).

Plots are permanent and placed every three meters along each transect. The surveyor establishes the plots to be recorded. The surveyor extends plots to a safe wading distance (waist-deep in slow water, less deep in faster water). After the surveyor reaches the active floodplain, s/he places at least two plots into the active floodplain. Upon locating a plot, the center of the plot is marked with a temporary pinflag and plot number. For plots that are completely submerged, the surveyor tells the assistant that the plot is completely submerged and notes the modal particle size (see SOP #6 for details). Based on geomorphic and vegetative characteristics, the surveyor also notes 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.

3.2.1.3 Dinosaur National Monument

There are three sentinel sites on each of the three river reaches at Dinosaur National Monument (the Yampa River and the Green above and below the confluence with the Yampa) (Figure 3-3). Each site has 7–10 permanent transects and 50–120 permanent plots. Initially, these transects and plots were not permanent. Following the acquisition of RTK survey equipment and the increased statistical power of repeated plots, permanent plots were established on the Green River in 2015, and on the Yampa River in 2016. These plots consist of the 2011 transects and plots

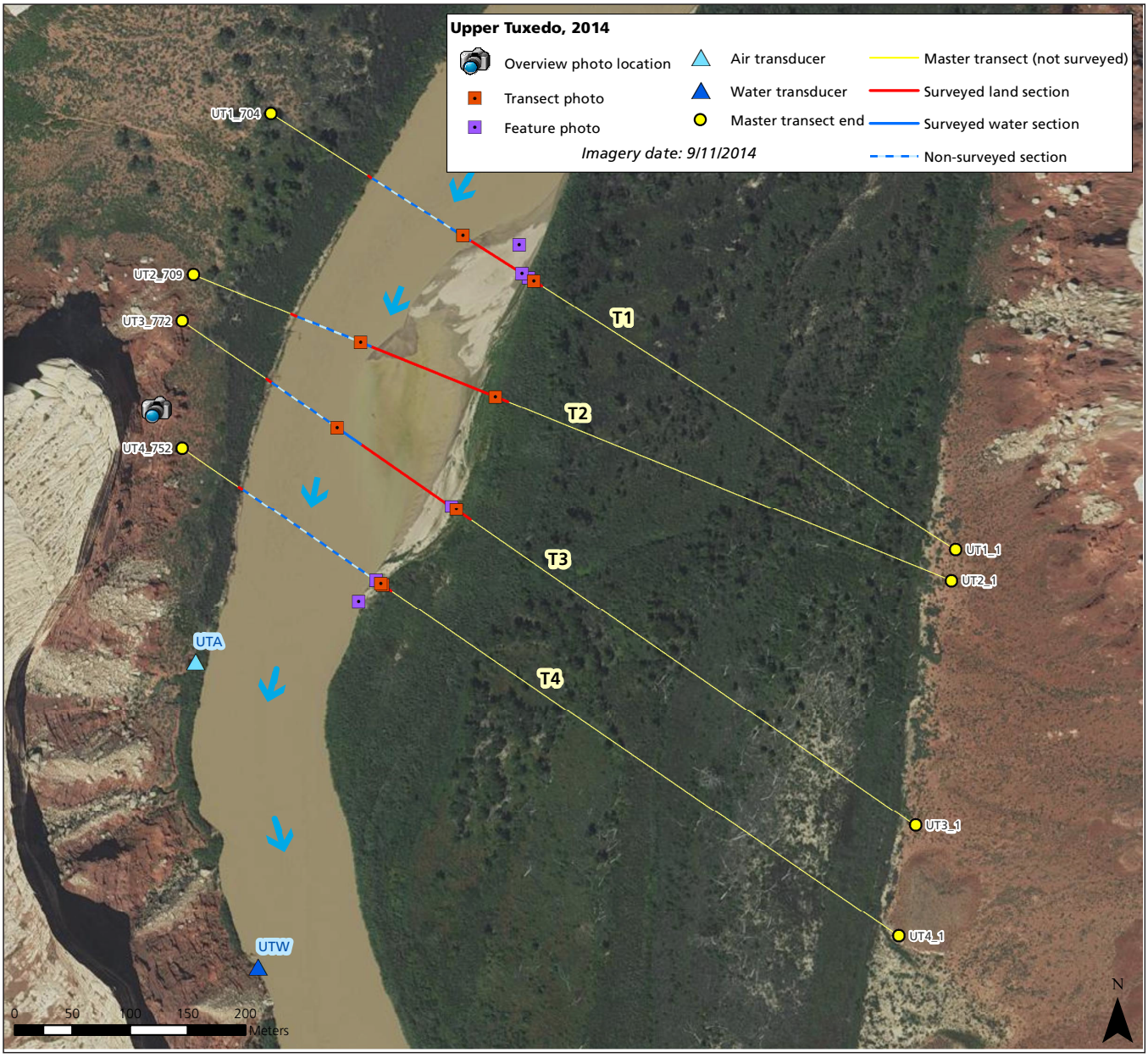


Figure 3-2. Transect layout at Upper Tuxedo site, Green River, Canyonlands National Park. Flow is from the top of the page to the bottom.

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 completed in 2012, but placing the extent in line with the 2011 transects. If a site was not done in 2011, then 2012 was used as the master set of plots.

The master set of plots is pre-loaded onto the RTK survey gear for each site. A surveyor and an assistant use the RTK equipment to relocate each plot. Upon locating a plot, the center of the plot is marked with a temporary pin flag and plot number. For plots that are completely submerged, the surveyor tells the assistant that the plot is completely submerged and notes the modal particle size (see SOP #6 for details). Based on geomorphic and vegetative characteristics, the surveyor also notes whether the geomorphic surface of the plot (AC, AF, IF, 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. At least three permanent and elevationally stable control points must be established.

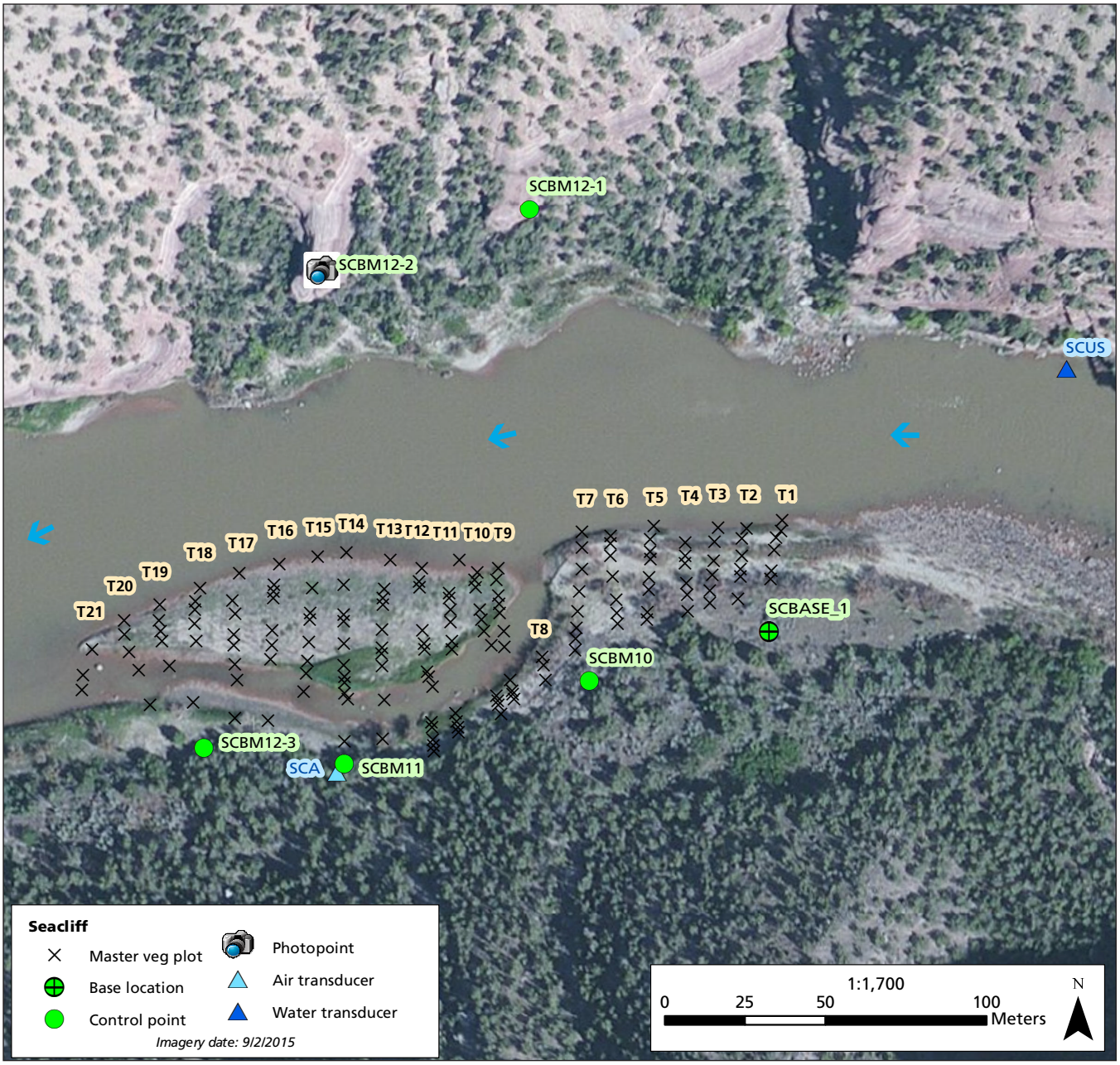


Figure 3-3. The Seacliff sentinel site feature, with benchmarks and plot locations, Green River, Dinosaur National Monument.

3.2.1.4 Curecanti NRA

Ten transects were randomly placed at Curecanti NRA (Figure 3-4). 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 on one side of the river to the uplands on the other side, or the park boundary, whichever comes first.

3.2.2 Vegetation measurements

3.2.2.1 Vegetation plots

We use 1-m^2 plots (1 × 1 m at Dinosaur NM and Canyonlands NP, 0.5 × 2 m at Black Canyon of the Gunnison NP) 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 Dinosaur NM, every

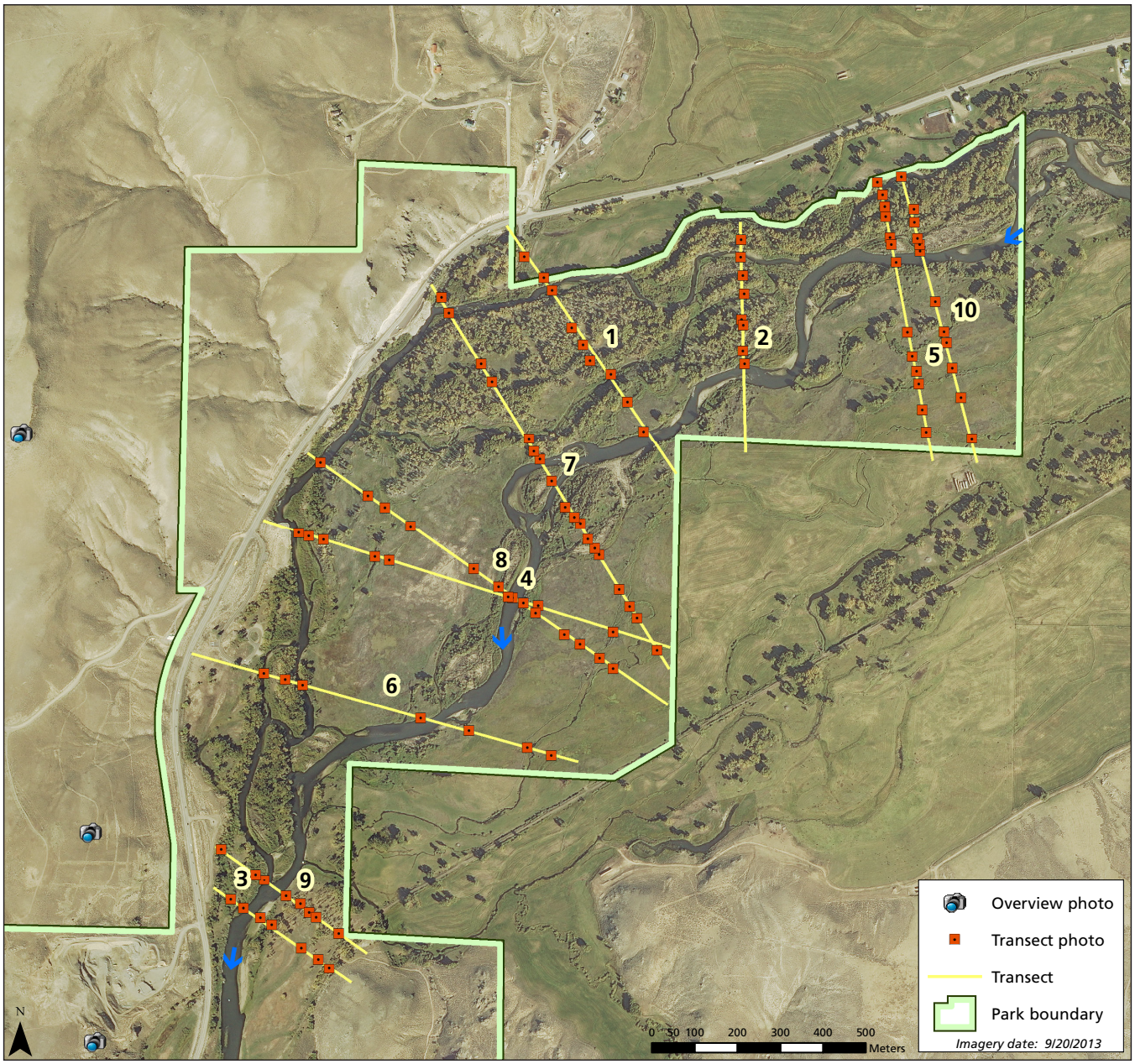


Figure 3-4. Transects established at Curecanti National Recreation Area.

three meters on transects at Canyonlands NP, and every 0.5–2 meters at Black Canyon of the Gunnison NP, 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 laid out by the surveyors at Canyonlands NP and Dinosaur NM. At Black Canyon of the Gunnison NP, plots are laid out by botanists, as the sampling plots are not always the same as the survey locations.

Sampling adequacy was assessed using bootstrapping techniques and standard error of the mean estimates. For vegetation cover, sampling adequacy was assessed using bootstrap resampling. Briefly, percent total cover data from randomly selected plots at each sentinel site were used in a bootstrap procedure in R (boot package). Using one thousand resamples, we estimated the 95% confidence interval of cover based on the number of

plots sampled (5–100). A plot of the 95% confidence interval of cover by number of plots was used to determine the minimum number of plots needed at each site to include, with 95% confidence, all the cover data contained within the 90th and 10th quartiles.

Vegetation measurements are done near the peak of the growing season. Vegetation within each plot is assessed as percent cover to the nearest 1% for each species encountered. Total plot cover is determined for Canyonlands NP and Dinosaur NM. At Black Canyon of the Gunnison NP, total plant cover is determined and the presence or absence of indicator species is observed. Visual estimation is based on a planview projection of outline polygon of plant, subtracting the open spaces within the polygon. If the sun is directly overhead, the percentage that is shaded is the percent cover. Woody canopy cover above 1.5 meters is recorded by species in each plot at all three parks.

The modal particle size of the plot (the size class e.g., sand, pebble, cobble, ranging from fines through boulders, that takes up the most percentage of the plot) is also determined according to the modified Wentworth scale (Wentworth 1922). At least once per day, botanists cross-calibrate cover and particle-size estimates, including some recorded replicate measurements.

3.2.2.2 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 possible, conducting the plant walk before plot monitoring begins can be a good way to calibrate the vegetation team.

3.2.2.3 Curecanti NRA

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

3.2.3 Geomorphic measurements

3.2.3.1 Survey of sentinel site

Geomorphic measurements are surveyed using Nikon Nivo 3.M total station and Trimble 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 transects at Canyonlands NP (every 3 m, break points, and edge of water), Black Canyon of the Gunnison NP (every m, break points, and edge of water), and at the Island Park sentinel site in Dinosaur NM (break points and edge of water). At Dinosaur NM, a digital elevation map of the site is made. Topographic features (e.g., tops of banks, toes of banks, chutes, sand caps) are surveyed to create a topographic map of each sentinel site. Using Geomorphic Change Detection software in ArcGIS, two years of digital elevation models (DEMs) are overlaid to show areas of erosion and deposition with a 10-centimeter threshold and report volumetric values of change. When high water rack lines are available, they are surveyed at all sites.

The methodological differences are due to scale and available technology. At Black Canyon of the Gunnison NP, the range of flows is small compared to that of Dinosaur NM and Canyonlands NP, and when compared to the historic high flows prior to the construction of the Aspinall unit 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 Dinosaur NM, the sentinel sites are intermediate in size and a complete 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 Canyonlands NP and the Island Park site at Dinosaur NM, the sites are up to one kilo-

meter long. Here, to make a DEM at one site would consume most of our annual survey efforts. Due to the broad alluvial valleys and the volume of sand, the changes at these sites are large (meters of sand) and more likely to be picked up on transects.

3.2.3.2 Facies mapping

Facies mapping involves the delineation of depositional/erosional units of uniform particle size across the active channel feature at each sentinel site. Facies mapping is generally done toward the end of the sentinel-site visit and consists of a hand-drawn map or digital sketch of the sentinel site. The most-dominant facies is mapped first, followed by the less-dominant facies. All data are recorded in the description field for mapped facies on the iPad. Each facies is recorded by primary attribute (e.g., boulder, cobble, pebble). At each facies, 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. After completing the vegetation work, the crew should have a good idea of the physical organization of the sentinel site.

Facies mapping of emergent topography is done at Dinosaur NM (Figure 3-5) and used to evaluate state changes (e.g., a cobble bar becomes covered with fines or sand in the process of channel narrowing). If sites are established below the confluence at Canyonlands NP, then this method will be implemented there. These methods are not used at sites in Black Canyon of the Gunnison or Canyonlands NP because the changes in facies are much more subtle and hard to detect.

3.2.3.3 Grain-size distributions

These measurements will support the facies mapping if a state change occurs. For each fa-

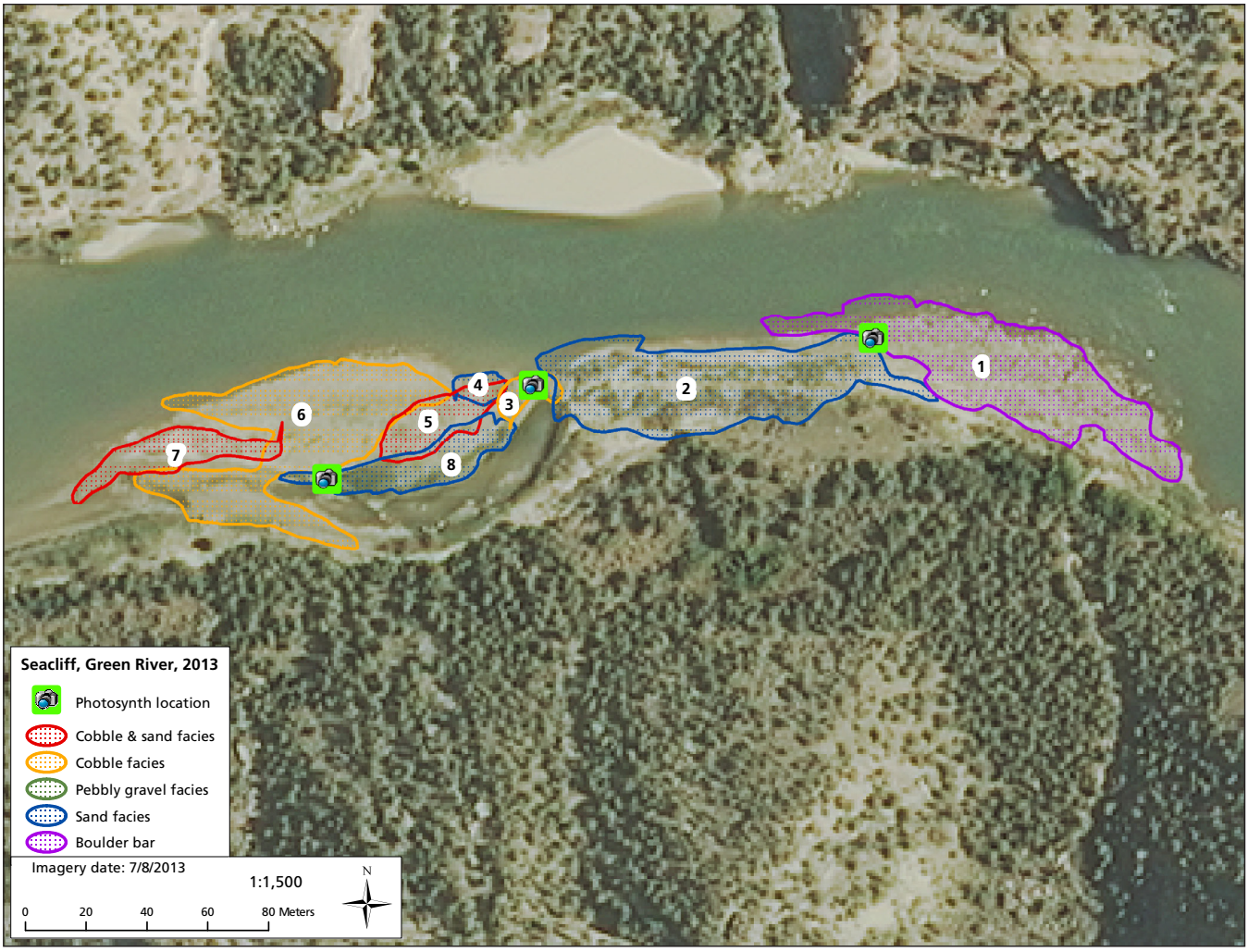


Figure 3-5. Example of facies mapped at Seacliff in 2013.

cies at a sentinel site, grain-size distributions are recorded at two sites (surface and subsurface), with sieves and scales for finer-textured surfaces. No grain-size distributions are done at boulder bars. Grain-size distributions do not need to be taken every year, but should be done a minimum of once every five years or if a state change is observed. In other years, they can be done if time permits.

These measurements are only taken at Dinosaur NM. If sites are established below the confluence at Canyonlands NP, then this method will be implemented there.

3.2.3.4 Curecanti NRA

Using a handheld 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.

3.2.4 Hydrologic measurements

Site hydrology is measured as stream-stage elevation across the feature being monitored at Black Canyon of the Gunnison NP, Canyonlands NP, and Dinosaur NM. 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. A transducer is installed on land in the vicinity of the water transducers for atmospheric pressure corrections. The elevation of each transducer is surveyed for real-world location and elevation using RTK survey or total station equipment. The logging interval is set for once every 60 minutes.

Before departing for the field, atmospheric-pressure tests are run to ensure that the transducers are reading similarly and not drifting apart. At least once per year, atmospheric-pressure tests should also be run on transducers that are already deployed. In both cases, each test should include as many transducers as possible to support as many "should be the same" comparisons as possible. At least three transducers should be used at each site (one placed in the water upstream and downstream of the site and one for atmospheric pressure). The transducers should run for at least a 24-hour period. When conducting atmospheric-pressure tests during annual monitoring, it might only be possible to have a 12-hour test. However, if this 12-hour test can be done with at least one transducer that has previously been tested for a longer period prior to the trip, and if all transducers match, this provides greater assurance that the transducers are working properly. Data from the atmospheric-pressure tests will help identify potential fixed offsets among transducers that can then be used in analysis—or may show that 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 them to be submerged. Locations out of the way of scour and potential ice damage should be selected, but they should have the same general slope of the water as the sentinel site. The ideal transducer location also has a view of the sky so 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 provide a reference check on the actual transducer recordings.

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

3.2.5 Photographs

3.2.5.1 Black Canyon of the Gunnison National Park

Transect, feature, reference, and overview photographs are taken at Black Canyon of the Gunnison NP. Transect photographs are taken with a portrait orientation. These pho-

tographs are taken from each end of each stub transect while the tagline is stretched out along the transect.

At each feature, an upstream and downstream feature photograph is taken in landscape orientation to monitor the overall geomorphic feature. To ensure the same picture is taken as in previous years, pin flags are used to center both transect and feature photographs and locations where the photographer stood.

Reference photographs are taken to document locations of all survey control points, headpins, orientation pins, or other specific features or items that need to be located in the future.

Overview photographs are taken from above the feature and relocated using a handheld GPS and reference photographs. Previous overview photographs are used to frame the new photograph. Transect, feature, and overview photographs are taken every year. Reference photographs only need to be taken if something in the photograph has changed (e.g., a tree that is a significant marker has fallen) or a new control point is established.

3.2.5.2 Canyonlands National Park

Transect, feature, reference, and overview photographs are taken at Canyonlands NP. Transect photographs are taken with a portrait orientation. With plot flags in place, photographs are taken from each end of the stub transects to show their extent. If the transect is obscured by extensive vegetation, then additional photographs are taken along the same transect.

Feature photographs are taken in a landscape orientation. At a minimum, one feature photograph is taken looking upstream and downstream from each end of the upstream- and downstream-most transect to monitor the overall geomorphic feature. If the feature has many transects (>5), then additional feature photographs are taken from the center transect(s) facing upstream and downstream. If these feature photographs do not capture the entire feature, then additional feature photographs are taken. Previous feature photographs are used to center both transect and feature photographs. Photographs are taken from the same location each time to ensure that the same picture is taken as in previous years.

Reference photographs are taken to document locations of all survey control, transducers, or other specific features or items that need to be located in the future. Overview photographs are taken from above the feature and relocated using a handheld GPS or RTK unit and reference photographs. Overview photographs from previous years are used to frame the new photograph.

Feature and overview photographs are taken every year. Transect photographs 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 photographs should be repeated every five years. Reference photographs only need to be taken if something in the photograph has changed (e.g., a tree that is a significant marker has fallen) or if a new control point is established.

3.2.5.3 Dinosaur National Monument

Photosynths (three-dimensional photographs), reference, and overview photographs are taken at Dinosaur NM. Photosynths are 360° panoramas of the sentinel site. They are taken from 2–4 locations on each sentinel site using a tablet with GPS capabilities. The tablet is used to relocate photosynth locations with a combination of the GPS location and pictures from previous visits.

Reference photographs are taken to document locations of all survey control, transducers, or other specific features or items that need to be located in the future. Reference photos may include the cliff line, surrounding perennial vegetation, and/or other recognizable landmarks in the background to help the returning field crew relocate these points.

Overview photographs are taken from above the feature and relocated using a handheld GPS and reference photographs. Previous year's overview photographs are used to frame the new photograph. Photosynths and overview photographs are taken every year. Reference photographs only need

to be taken if something in the photograph has changed (e.g., a tree that is a significant marker has fallen) or if a new control point is established.

3.2.5.4 Curecanti NRA

Overview and transect photographs are taken at Curecanti NRA. Overview photographs are taken from above the feature and relocated using a handheld GPS and reference photographs. Previous year's overview photographs are used to frame the new photograph.

Transect photographs are taken along the transects at any river channels, abandoned meanders, secondary channels, or anywhere else found to have a high density of seedlings/saplings. At each point, four photographs are taken. The photographs are taken in directions based on the transect line. Upstream/downstream photos are taken perpendicular from the transect line. River right/river left photos are taken in line with the transect.

3.2.6 Remote imagery

The sentinel sites selected as part of this monitoring program were chosen because they are sensitive to change. Because they were not randomly selected, 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. This allows us to observe vegetation encroachment and channel narrowing over time (Figure 3-6).

3.3 End of season procedures

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

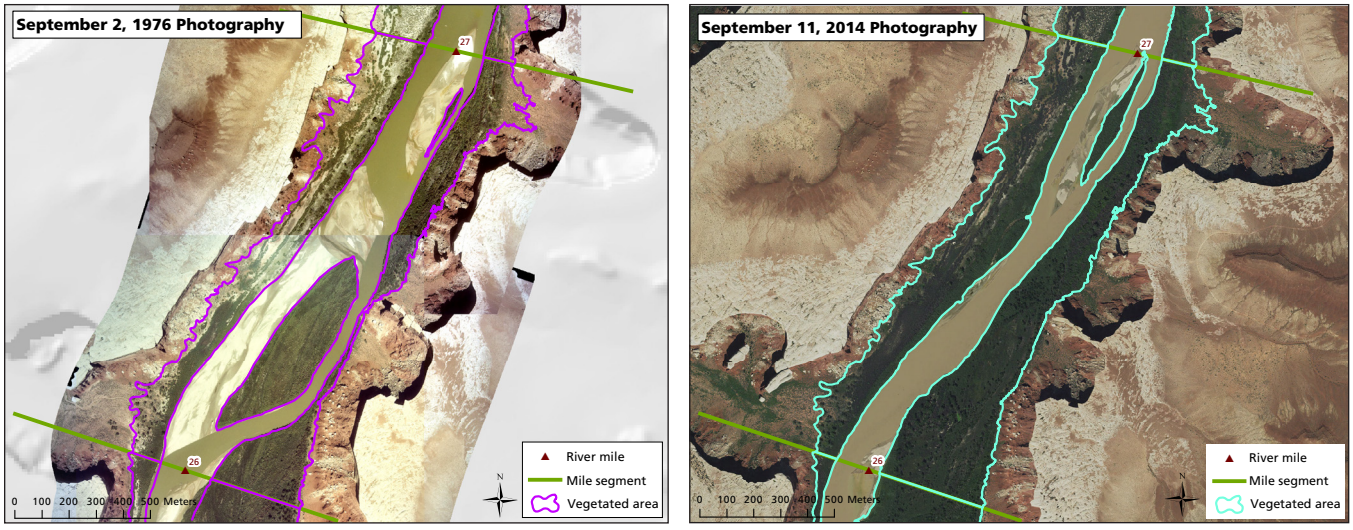


Figure 3-6. Satellite imagery of the Green River from 1976 (left) and 2014 (right) shows narrowing and simplification of the channel over time, as well as vegetation encroachment. Note that the side channel seen in 1976 was completely filled in by 2011.

4 Data Management

Effective data management to ensure data quality, interpretability, security, longevity, and availability is critical to the success of the big rivers 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 rivers monitoring. SOP #16 provides explicit instructions.

4.1 Data organization

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

4.2 Database design

Three main types of river monitoring data 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 that 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.

4.3 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 (photograph), GPS (spatial), or data logger (hydrology), and (2) manually recorded on paper data sheets (vegetation, facies mapping, and grain size). Data recorded on paper data sheets 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 (quality assurance/quality control) 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.

4.4 Data documentation and certification

After the dataset is validated, the accompanying metadata are completed. Metadata are 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.

4.5 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 digitized and 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.

5 Analysis and Reporting

After raw data from the field season are quality-checked and certified, they are 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. After data-quality issues are resolved, analyses can be conducted.

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

Vegetation data from the 1-m^2 plots are used to calculate percent frequencies of species or groups of indicator species, species richness, proportion of native:introduced plants, 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, deposition, or differences in transect topography over time. The data can then be integrated with vegetation and hydrologic measurements. Modal particle sizes at Black Canyon of the Gunnison NP, Canyonlands NP, and Dinosaur NM, and facies mapping and substrate samples at Dinosaur NM, 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 (such as a sand cap) over time, through topographic surveying and facies mapping, would provide early and important evidence of a channel-narrowing process.

5.1 Integrated analyses

Vegetation data are integrated with DEMs from the geomorphology survey and transects to derive guilds and indicators of (1) active-channel, active-floodplain, and inactive-floodplain plant cover by surface elevation and (2) 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 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:

pct.inundated = days.inundated / 365 days

Inundation frequency of the floodplain (return frequency in years) requires multiple years of hydrologic data and a survey of the floodplain. 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 vegetation and the geomorphic surfaces or levels (e.g., active channel, active floodplain) on which it grows in terms of two hydrologic variables: (1) days inundated and (2) the percentage of the measured period for which 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 floodplain). 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 and detecting transitions from one surface type to another. Pilot data from Dinosaur NM indicates that in general, active-channel plots had average inundation percentages of 45% or more, whereas active-floodplain plots averaged less than 10%.

This inundation, combined with shear stress, can also be used to evaluate geomorphic changes. Changes in erosion or accretion in cross-sections at Black Canyon of the Gunnison NP and Canyonlands NP, and changes in total and net erosion and accretion at Dinosaur NM, can be calculated and related to flows and inundation rates. Changes in the proportion of plots (or of the site) that have different sediment sizes can also be related to flow rates and days inundated. Changes in heights are often associated with a change in vegetation present.

Together, 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. Indicator species analysis could be used to determine the probability of being on a particular surface if a species (or group of species) is/are encountered, and the likelihood of encountering the species if on a surface. For example, when reclassifying a plot from active channel to active floodplain, the presence of floodplain-indicator species in the plot provides supporting evidence for the reclassification. With more information on inundation across years, we expect to develop a statistically robust way of reclassifying plots based on hydrologic characteristics.

5.2 Reporting

Comprehensive analyses and reports on the long-term dataset are completed periodically. They should be structured like typical scientific manuscripts (i.e., 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 five years of monitoring data are collected. When significant trends are detected, reasons for these trends should be evaluated by literature reviews, comparison with similar datasets, 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.

6 Personnel Requirements and Training

6.1 Roles and responsibilities

An ecologist will serve as the project manager for big rivers monitoring. Data management is the shared responsibility of the project manager and the data manager. Typically, the project manager oversees data collection, entry, 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, photograph, 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.

6.2 Qualifications

6.2.1 Project manager

The project manager should have a strong background in plant ecology and geomorphology. Because the project manager may also manage other monitoring programs, s/he may not initially have all skills required, but must be willing to quickly learn about areas in which s/he is inexperienced. The project manager must also have excellent leadership, organization, and communication skills, as the program relies extensively on partnerships with parks and other entities.

6.2.2 Lead biological or physical science technician

The 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 GPS, 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.

6.2.3 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.

6.3 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 U.S. Geological Survey Fort Collins Science Center.

Big rivers 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 certified in swiftwater rescue. NCPN will also try to certify as many seasonal biotechnicians as possible each year.

7 Operational Requirements

7.1 Field season preparations and equipment set-up

Sampling trips will 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 documents outlining access to site locations. 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 crew leader will provide training on appropriate plant species. Herbarium specimens and comparative notes on difficult or uncommon species will be provided for field observers. Observers should be tested frequently on their ability to identify plant species, with the test tailored to more problematic species.

The field-crew leader is responsible for ensuring that all crew members read and understand the NCPN Field Safety SOP prior to the field season. The 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/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.

7.2 Sequence of events during field season

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 big rivers monitoring. Park units should be visited at approximately the same time each year to maximize repeatability. Dinosaur NM has traditionally been completed in July, Black Canyon of the Gunnison NP in August, Curecanti NRA in July/August, and Canyonlands NP 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 five 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.

Prior to visiting the field sites, the crew leader contacts the park according to park procedure. The project manager or crew leader assembles and checks all equipment required for sampling (see SOP #1). On each day of a hitch, the project manager or crew leader provides a briefing regarding safety, plant identification, and park navigation. The crew leader assigns crew members 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.

7.3 Post-collection processing

Research specimens may be collected to confirm identification of plant species, especially those that are likely to be identified incorrectly (see 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.

8 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 #13.

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.

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