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Natural Resource Stewardship and Science

Big Rivers Monitoring within Dinosaur National Monument

A summary of monitoring results to detect change in channel condition

Natural Resource Report NPS/NCPN/NRR—2018/1635

ON THE COVER
Monitoring crew floating the Yampa River, Dinosaur National Monument.
NPS/L. Gommermann.

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Prepared by
Michael L. Scott
Department Watershed Sciences
Utah State University
5210 Old Main Hill
NR 210
Logan, UT 84322-5210

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

David M. Merritt
Julian A. Scott
U.S. Forest Service
2150 Centre Avenue, Building A
Fort Collins, CO 80526

David J. Cooper
Department of Forest and Rangeland Stewardship
123 Forestry Building
Colorado State University
Fort Collins, CO 80523

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

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Acronyms

AC	active channel
AF	active floodplain
cfs	cubic feet per second
cms	cubic meters per second
CO	Colorado
DEM	digital elevation model
IF	inactive floodplain
m	meters
mm	millimeters
NCPN	Northern Colorado Plateau Network
NID	National Inventory of Dams
NM	national monument
NP	national park
NPS	National Park Service
PCO	principal ordinates ordination
RTK	real-time kinematic
U	upland
USGS	U.S. Geological Survey
UT	Utah
UTM	Universal Transverse Mercator
VMAD	virgin mean annual discharge

Species List

Common name	Scientific name
bluegrass	*Poa*
Canadian horseweed	*Conyza canadensis*
cheatgrass	*Bromus tectorum*
cocklebur	*Xanthium strumarium*
common reed	*Phragmites australis*
cottonwood	*Populus fremontii*
field horsetail species	*Equisetum* spp.
greasewood	*Sarcobatus vermiculatus*
Indian hemp	*Apocynum cannabinum*
prairie cordgrass	*Spartina pectinata*
ribseed sandmat	*Chamaesyce glyptosperma*
saltgrass	*Distichlis spicata*
sandbar willow	*Salix exigua*
scouring horsetail	*Equisetum hyemale*
silverweed cinquefoil	*Argentina anserina*
skunkbush sumac	*Rhus trilobata*
smooth horsetail	*Equisetum laevigatum*
spike rush	*Eleocharus palustrus*
tamarisk	*Tamarix ramosissma*
toad rush	*Juncus bufonius*
water knotweed	*Polygonum amphibium*
western goldentop	*Euthamia occidentalis*
western wheatgrass	*Pascopyrum smithii*
wild licorice	*Glycyrrhiza lepidota*

Executive Summary

The Northern Colorado Plateau Network (NCPN) big rivers monitoring program is designed to detect long-term, directional change in riverine and riparian ecosystems resulting from human activities and/or broad-scale and persistent climate shifts. Early detection of such changes can help land and water managers to better anticipate, manage, and perhaps mitigate the effects of future changes in water supplies.

In this report, we use relevant new research, along with hydrologic and vegetation analyses and geospatial mapping, to refine the NCPN big rivers monitoring program and detect channel narrowing or widening along the Green and Yampa rivers in Dinosaur National Monument. Channel narrowing is a widely documented response of rivers to natural or human-caused changes in the flow regime.

Using flow data from the seven largest rivers in the Upper Colorado River Basin, we show how dam construction and flow management have reduced flow variability on all of these large rivers except the Yampa and White rivers, making these rivers relatively unique natural resources on the Colorado Plateau. Based on previous geomorphic research, we stratify our monitoring sites by channel type. Monitoring at sentinel sites involves integrated measurements of total and species-specific plant cover; quantitative assessments of erosion and deposition based on digital elevation models; mapping and textural analysis of distinct alluvial deposits (facies); and repeat photography. Using a large network of vegetation quadrats, we identify a concise list of plant species that serve as indicators of ecological conditions across the range of fluvial geomorphic conditions in the monument. Finally, we present a conceptual model showing how largely unvegetated active-channel features along a relatively unregulated river like the Yampa are converted to vegetated floodplain during channel narrowing. This model is the basis of our monitoring design, which involves intensive monitoring at sentinel sites and rapid monitoring assessments, or rapidos, across a broad spatial range of geomorphic features with known sensitivities to narrowing.

Results from two sentinel sites over the first few years of monitoring demonstrated measurable, site-specific responses to annual variation in streamflow. Erosion and deposition occurred across the two sentinel sites we examined, with large net erosion occurring on the unregulated Yampa River between 2011 and 2014, compared with small net deposition on the partially-regulated Green River over the same period. Vegetation showed similar patterns of cover variation across active floodplain surfaces at both sentinel sites. In contrast, there was site-specific cover variation on active-channel surfaces between sites. Additional years of measurement will be needed to establish cause-and-effect relationships at sentinel sites.

Rapid-assessment techniques detected clear differences between geomorphic features on the Green and Yampa rivers. However, refinements need to be made in order to detect year-to-year differences at the same sites. The establishment of a baseline of measurements over a number of years will provide the basis against which to evaluate any future trends in channel form.

Acknowledgements

We thank Gregor Auble and Polly Gibson (U.S. Geological Survey, Fort Collins Science Center) for assistance with estimating inundation characteristics of vegetation quadrats at sentinel sites from pressure-transducer data. Wally McFarlane and Joe Wheaton (Utah State University); Mark Wondzell, Tamara Naumann, Brandon Gottung, Alex Randolph-Lowe, Wade Plafcan, Katrina Lund, Luke Gommermann, Michael Bozek, Chris Dach, Tanner Perkins, Adam Mahood, Dale Koulmetz, Josh Doucette, Emily Spencer, Sophia Kast, Trista Crook, and Peter Williams (National Park Service); and Chris Holmquist-Johnson, Emily Palmquist, and Eric Wahlig (U.S. Geological Survey) all contributed good thoughts and companionship during meetings and field work. Bonnie Campbell and Helen Thomas were instrumental in leading the data-management efforts, while Aneth Wight generated new maps at every request and provided GPS support. Mark Wondzell and Rebecca Weissinger both provided thoughtful reviews that improved this report.

1 Background, Purpose, and Need

1.1 Introduction

Across dryland regions of the western U.S., large rivers have cut dramatic canyons through complex topography, creating a diversity of world-renowned riverine and riparian landscapes. The U.S. Government has protected many of these features for public use and enjoyment in the National Park System. However, increasing demands to develop water sources for agriculture and expanding regional human populations threaten the functional integrity of these ecosystems. Continued population growth and projected future warming and drying of the climate will intensify the challenges faced by the National Park Service (NPS) and other land-management agencies charged with protecting river-based resources.

The Northern Colorado Plateau Network (NCPN) big rivers monitoring program is a structured process designed to detect long-term, directional change in riverine and riparian ecosystems resulting from streamflows that have been altered by human activities and/or broad-scale and persistent climate shifts. Early detection of such changes can help land and water management agencies to better anticipate, manage, and perhaps mitigate the effects of future changes in water supplies.

The network's multi-scalar, hypothesis-driven monitoring protocol was developed to detect channel narrowing along big rivers. The protocol is specifically focused on detecting channel narrowing and the hypothesized changes to geomorphic features and vegetation that accompany it. Channel narrowing is a predictable response to decreases in streamflow resulting from human activities, climate shifts, or both. Channel narrowing involves the establishment and persistence of vegetation on formerly active-channel surfaces and the related conversion of channel bed and bar forms to floodplain surfaces by lateral and vertical accretion of sediment. Conversely, channel widening can occur when high flows are able to mobilize the shoreline and remove vegetation. Accordingly, our approach involves detecting bi-directional changes in the cover and composition of vegetation, net deposition of alluvial sediment, and decreases in sediment particle size in depositional environments shown to be sensitive to channel narrowing. We use a combination of spatially extensive rapid assessments and intensive, repeat measurements at a small number of sentinel monitoring locations.

Initial efforts occurred on the Yampa and Green rivers in Dinosaur National Monument (NM). The background, logic, design, and proposed implementation of a big rivers monitoring protocol for the monument was described in detail in Scott and others (2012) and Perkins and others (in review). Since the Scott and others (2012) report, we have collected, analyzed, and created additional background data and supporting datasets, and other researchers have published results of studies in Dinosaur NM that are directly relevant to our monitoring approach. Finally, we have refined the protocol and collected 1–5 years' of monitoring data at a number of sites on both rivers within the monument.

This report incorporates new, supporting data and research to inform our final protocol, describes our working methodologies, and summarizes the results of monitoring data collected from 2010 to 2014 at two sentinel sites within Dinosaur National Monument. The Deerlodge Park sentinel site is located on the largely unregulated Yampa River, in a broad, alluvial valley representing a restricted-meander channel type (Grams and Schmidt 1999; Larson 2004). The Seacliff sentinel site is located in a debris fan-dominated channel type (Grams and Schmidt 1999) of the partially regulated Green River, below the confluence with the Yampa River. The different hydrologic and geomorphic settings of these sentinel sites allow us to compare the methods and results of the big rivers monitoring protocol.

We begin by presenting a general conceptual model illustrating key differences in channel and vegetation conditions along regulated and unregulated rivers. Channel narrowing is a widely documented response of rivers to natural or human-caused changes in the flow regime. Monitoring for narrowing or widening can provide important information on the long-term effects of flow-management decisions on riverine and riparian resources.

Chapter 2 of this report examines flow variability along the seven major river systems in the larger Upper Colorado River basin, as well as the methods and results that refine understanding of important physical processes and their geospatial context along the Yampa River in Dinosaur NM.

Based on previous geomorphic research, we stratify monitoring sites by channel type. In different channel types, river-level geology creates distinctive hydrologic and geomorphic controls over channel processes, including the pattern and extent of active-channel and floodplain features. We also demonstrate that vegetation differs significantly across channel types and geomorphic features, and identify a concise set of plant species that serve as indicators of specific ecological conditions across the range of fluvial geomorphic conditions at Dinosaur NM.

Understanding this context is critical to designing a more effective monitoring program. Supporting information collected by us and others has strengthened our overall monitoring design and helped establish our data-collection methods. Decision points about what constitutes progressive and widespread channel narrowing require characterization of baseline conditions and examination of long-term trends in several key metrics.

To that end, we present a second conceptual model of how monitored changes in vegetation cover and composition can signal channel narrowing. This model is the basis for our monitoring design, which involves intensive monitoring at sentinel sites and rapid monitoring assessments, or rapidos, across a broad spatial range of geomorphic features with known sensitivities to narrowing.

Chapter 3 describes the methods and results of the first five years of the long-term monitoring program at the Deerlodge Park and Seacliff sentinel sites. Some portions of the protocol, such as geomorphic mapping, vegetation plots, transducers, and photos, have shown great promise in detecting changes at our sentinel sites. Other methods, such as facies mapping, rapidos, and quickplots, need further refinement and testing to determine their utility.

1.2 Channel narrowing on regulated and unregulated big rivers

A conceptual model (Figure 1-1) helps illustrate the differences in channel and vegetation conditions along a relatively unregulated river versus a regulated river. Because of their relatively high flow variability, largely unvegetated, active-channel bedforms are prominent bottomland features along large, unregulated regional rivers. These surfaces are sensitive to temporary accumulation of fine sediments and colonization by vegetation during temporary reductions in flow, such as might result from short-term drought. A return to more typical flow variability would be expected to erode fine sediments, scour vegetation, and restore the pattern and extent of active-channel features. Persistent reductions in flow, such as those that would result from long-term drought conditions and/or human-caused flow depletions, would lead to progressive channel narrowing as active-channel features converted to vegetated floodplain (Figure 1-1A).

Along regulated rivers, formerly active-channel features are transformed to some extent by narrowing, depending upon the degree of flow regulation. In such cases, changes in channel condition are likely to involve temporary widening from removal of sediments and vegetation during rare, large floods. With a return to regulated conditions, post-flood narrowing would occur: the channel could widen or narrow incrementally with sustained increases or decreases in flow variability away from baseline flow conditions (Figure 1-1B).

On the active or unvegetated channel surface, narrowing includes deposition of sediments and accompanying vegetation encroachment. Positive feedback loops between vegetation and deposition can contribute to a state transition in which active channel is converted to vegetated floodplain. As veg-

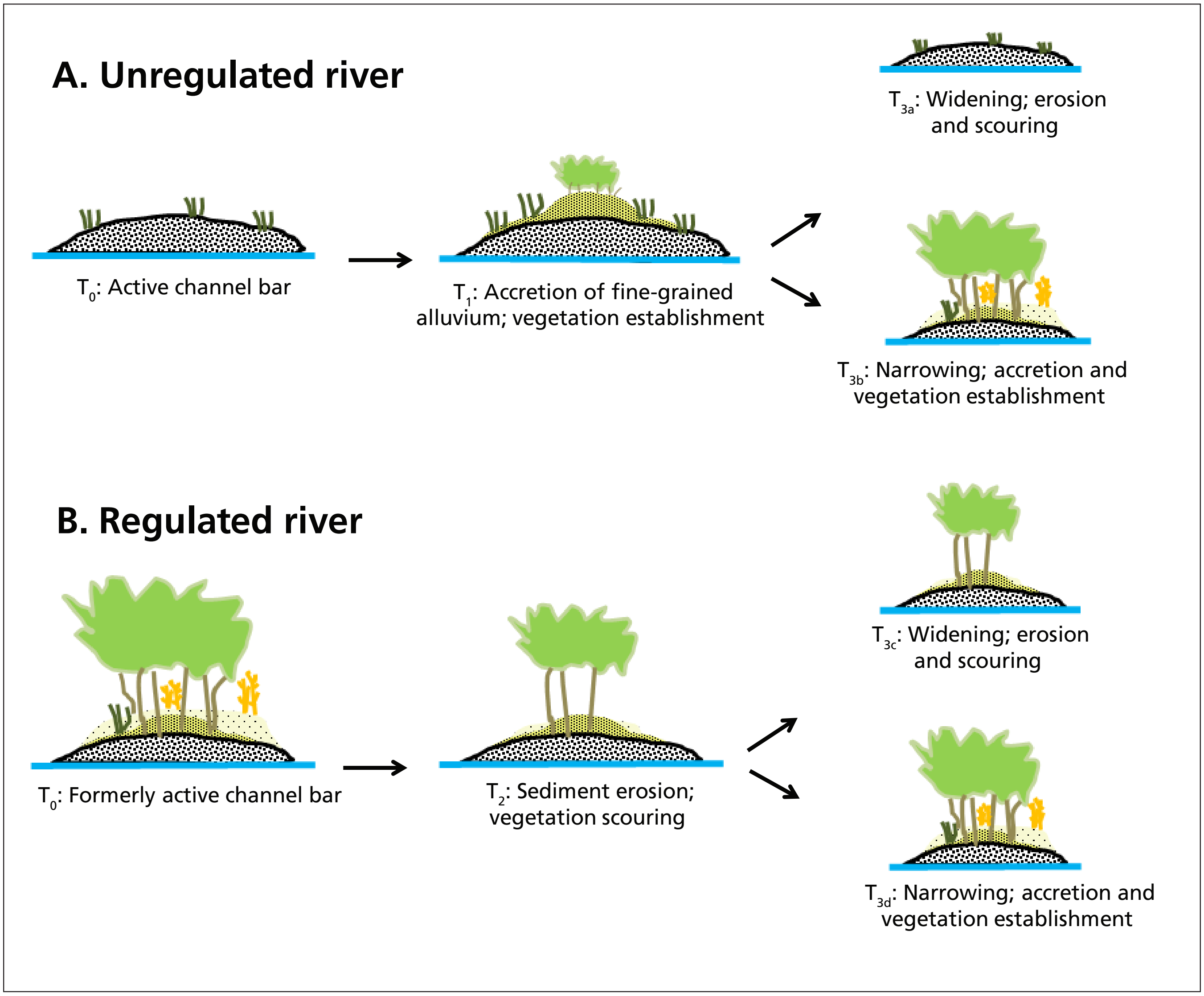


Figure 1-1. A conceptual model illustrating differences in channel and vegetation conditions along an (A) unregulated and (B) regulated river. Because of high flow variability, relatively unregulated rivers, like the Yampa, feature extensive, active bar forms with little or no perennial vegetation at any given time (A, T_0). Following temporary flow reductions, such features may accumulate fine sediments that can become colonized by vegetation (A, T_1). Return to normal flow variability restores active-channel features by eroding sediments and scouring/inundating vegetation (A, T_{3a}). Persistent flow reductions lead to narrowing with continued sediment accretion and vegetation establishment (A, T_{3b}). Formerly active bar forms along regulated rivers exhibit some degree of narrowing in the form of fine sediment accretion and encroachment by perennial vegetation (B, T_0). Following unusually large or long-duration floods, temporary channel widening may occur as sediments and vegetation are removed (B, T_2). Sustained increases in the magnitude, frequency, and duration of high flows would result in permanent widening (B, T_{3c}), whereas return to regulated conditions would lead to narrowing (B, T_{3d}).

etation persists, it increases in cover and becomes more stable. This vegetation then serves to slow the river down as it reduces scour and shear stresses, resulting in lateral and vertical accretion of fine-grained alluvium that requires higher floods to mobilize the accumulated sediment. Flow variability (including large floods) over time may return the feature to initial conditions. However, lack of flow variability may lead to a permanent state transition with a new surface that is disconnected from the river except for during extremely high flows (Figure 1-1).

1.3 The need for long-term monitoring of channel condition along big rivers

Channel narrowing is an important focus of the NCPN big rivers monitoring protocol, in part because the Yampa River in Dinosaur NM is one of the few unregulated big rivers remaining in the southwestern U.S. As such, its largely wild hydrology makes it a unique natural resource. However, a number of recent regional water-development proposals have identified the Yampa as a source of developable water. Thus, establishing baseline conditions is critical to detecting future changes along the Yampa that might result from changing weather patterns or water development.

Along flow-regulated rivers where narrowing has already occurred (Grams and Schmidt 1999; Allred and Schmidt 1999; Graf 2006), monitoring for narrowing or widening can provide important information on the long-term effects of dam operations and flow-management decisions on riverine and riparian resources. Thus, variations of this big rivers monitoring protocol are now being implemented on the Yampa and Green rivers in Dinosaur NM, the Green and Colorado rivers in Canyonlands National Park (NP), the Gunnison River in Black Canyon of the Gunnison NP, the Colorado River in Grand Canyon NP, and the Rio Grande in Big Bend NP.

The rivers of Dinosaur NM also offer a unique opportunity to compare a regulated and unregulated river, as well as a partially regulated river (below the confluence of the Yampa and Green rivers). The Yampa and the Green have approximately the same watershed and mean annual flow. They are both driven by snowmelt-based peak flows with lower summer and winter base flows. By monitoring both rivers, we can hypothesize about the effects of potential water development proposals on the Yampa.

2 Understanding the Monitoring Context and Setting at Dinosaur National Monument

2.1 Comparing hydrology and flow modification of the Green and Yampa rivers

Our working hypothesis for this project was that river regulation reduces flow variability, which in turn structures and maintains dynamic riparian and aquatic ecosystems (see Figure 1-1). To begin, we examined the degree to which water development and flow modification have occurred within the Yampa and Green river catchments compared to other large rivers within the entire Colorado River basin. This information provides valuable context to forward-looking change-detection monitoring along these rivers.

To assess human impacts on flow and channel continuity of large river systems, Dynesius and Nilsson (1994) quantified “degree of flow regulation” as the ratio of reservoir storage capacity to virgin mean annual discharge (VMAD, the river discharge before any significant human manipulations). We used this metric to contrast the Yampa River system to the six other major river systems in the larger Upper Colorado River basin: the San Juan, Upper Green, Gunnison, Upper Colorado, Dolores, and White rivers. We calculated reservoir capacity for each river system using the National Inventory of Dams (NID) geospatial coverage (https://catalog.data.gov/dataset/national-inventory-of-dams). The NID data include both coordinate data and reservoir capacity for each dam in the U.S. The capacity of each reservoir was summed to yield total reservoir storage for the entire basin.

The U.S. Bureau of Reclamation’s Colorado River Basin Natural Flow and Salt Data provide natural flow estimates for use in modeling in the Colorado River Simulation System (USBR 2014). These data include average annual discharge in acre-feet over the years 1906–2010, computed using gage records for all major watersheds of the greater Colorado River Basin and accounting for consumptive uses and reservoir regulation. We used these data as our VMAD for each river basin. The U.S. Geological Survey (USGS) gages selected for comparing our seven basins were Green River near Greendale, UT; San Juan River near Bluff, UT; Dolores River at Gateway, CO; Gunnison River near Grand Junction, CO; Colorado River near Cameo, CO; Yampa River at Deerlodge Park, CO; and White River near Watson, UT (gage numbers 09234500, 09379500, 09179500, 09152500, 09095500, 09260050, 09306500, respectively). These gages are located at or near the terminus of their respective basins.

As per Dynesius and Nilsson (1994), we calculated the degree of flow regulation for each basin as described above. We also compared annual variability in flow magnitude across the seven river systems using the annual ratio of the flow that exceeded 95% of flows to that which exceeded 5% of the flows. For this analysis, we used the same seven USGS gages listed above. Of the seven major river basins in the larger upper Colorado watershed, the Yampa has the third-largest basin area and fourth-largest VMAD. In contrast, it is has the second-smallest percentage of flow regulation, with a basin-wide aggregate storage capacity that is 13% of VMAD. In comparison, the aggregate storage capacity of each of the Upper Green, San Juan, Dolores, Gunnison, and Upper Colorado basins is more than 40% of VMAD. Of the seven basins, the White River basin is the only one with less flow regulation than the Yampa—but the Yampa basin is twice as large in area, with three times the VMAD.

The Yampa basin emerged from the twentieth century without a single major dam. The three largest reservoirs in the Yampa basin (Elkhead Creek, Willow Creek, and Stagecoach) have a combined storage capacity that is less than 3% of the capacity of the Flaming Gorge Reservoir on the Green River. Of the 103 dams in the Yampa basin, only two are located on the main stem—and they are located near the headwaters, therefore having less of an effect of flow variability throughout the river.

In the absence of major dams, the Yampa

River has maintained a relatively high level of flow variability. Of the seven basins compared in this study, the Yampa had the most variable annual range of flows (Figure 2-1). On average, since 2000, the ratio of high to low flow has been 82:1 on the Yampa. Of the other six basins, only the Dolores had a ratio greater than 10:1. In conclusion, our analyses of seven large rivers from the Upper Colorado River Basin support the assumption that river regulation reduces flow variability, as is seen on all large rivers in the basin except for the Yampa. The Yampa is a unique example of a large river on the Colorado Plateau with a relatively wild hydrology featuring a high degree of flow variability (Figure 2-1).

2.2 Mapping channel types and geomorphic processes

2.2.1 Yampa River

Large-scale channel planform, including channel-bed and bank morphology and floodplain forms and processes, is controlled in part by bedrock geology (Grams and Schmidt 1999 and 2002; Brierley and Fryirs 2005). To better characterize and quantify river-channel form and geomorphic processes operating in Dinosaur NM, we developed a geomorphic map of fluvial surfaces in a GIS database for the Yampa River within Dinosaur NM. We used the channel classification and geomorphic mapping system developed for the Green River in Dinosaur NM by Grams and Schmidt (1999; 2002) as a guide for this work.

We obtained georeferenced geologic maps for the study reach from the USGS's MapView program (http://ngmdb.usgs.gov/maps/mapview/) to help us identify and map broad-scale geomorphic features. These features included river-level bedrock exposures, talus, debris fans, and colluvial deposits that impinge on the river channel, including Quaternary terrace deposits and large, contemporary alluvial deposits. We classified and mapped finer-scale fluvial features in a GIS platform (ArcMap 10.0) using high-resolution (16-cm) true-color imagery and LiDAR data taken on September 21, 2011. At the time, discharge at the Deerlodge Park USGS stream gage (#09620050) was measured at approximately 24 cubic meters per second (cms), or 848 cubic feet per second

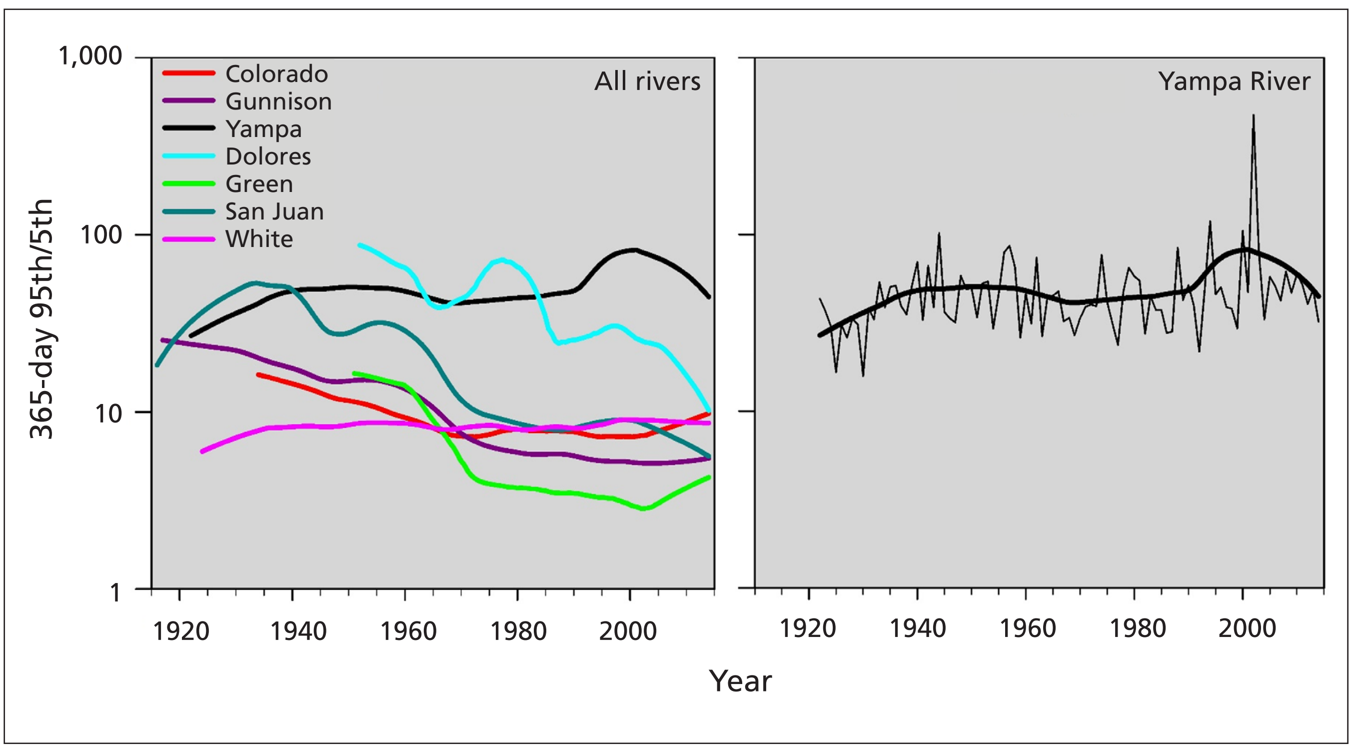


Figure 2-1. A comparison of historical flow variability for seven rivers within the Colorado River basin, including the Green and Yampa rivers. Flow variability is represented as the ratio of the annual 95th percent exceedance flow (low) divided by the 5th percent exceedance flow (high). Flow variability has declined over time on all rivers except for the White and Yampa rivers (left panel). The annual hydrograph is over-plotted on the flow variability curve for the Yampa River (right panel).

(cfs). The imagery, which was taken following the second-largest flood on record (and largest annual flow volume) for the Yampa River at Deerlodge Park, serves as a benchmark against which future channel and vegetation changes can be evaluated. Within the study area, we mapped each fluvial feature as a polygon and assigned it the following attributes: (1) channel type, (2) geomorphic feature, (3) dominant grain size, and (4) geomorphic surface of the feature above the water at a discharge of 24 cms (848 cfs). These attributes are defined below.

We described three *channel types* based on previous work by FLO Engineering (1998), Grams and Schmidt (1999), and Larson (2004): restricted meanders in the alluvial valley of Deerlodge Park, along with debris fan-affected and entrenched-meander channel types in the canyon-bound portions of Yampa Canyon (Figure 2-2). The depositional environment differed within each distinct channel type and included a variety of *geomorphic features* (i.e., point bars, mid-channel bars, and expansion bars). We chiefly used the descriptions of Brierley and Fryirs (2005) to identify geomorphic features. Grain size of unvegetated geomorphic features was observable on the imagery and ranged from large, angular talus debris, to boulders and cobbles, to sands. Vegetated floodplain surfaces examined in the field were universally fine-grained, consisting primarily of sand-sized but sometimes containing some minor fraction of silt-sized material. Thus, floodplain surfaces completely obscured by vegetation were assigned the finest textural class (sand) without visual confirmation. The elevation and extent of mapped geomorphic surface features along the Yampa River reflected localized erosional and depositional processes that differed from bedrock to alluvial reaches (Grams and Schmidt 1999) and included a range of different bed and bank morphologies as well as floodplain forms and processes (Brierley and Fryirs 2005).

Identified *geomorphic surfaces* included active channel (AC); active floodplain (AF); inactive floodplain (IF); and upland (U). The active channel was defined as that portion of the channel where frequent high flows have largely precluded the establishment of perennial vegetation (O'Connor et al. 2003; Gendaszek et al. 2012). Floodplain surfaces had

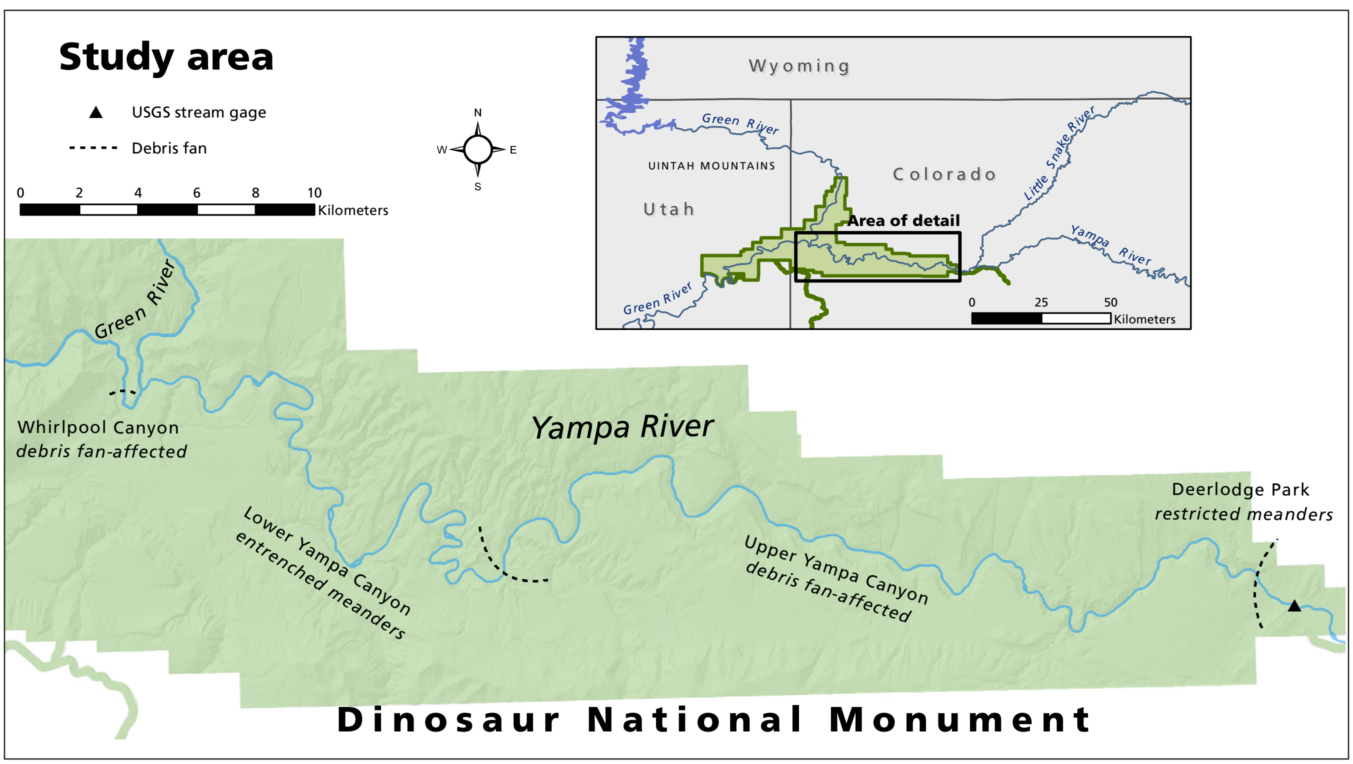


Figure 2-2. The Yampa River study area within Dinosaur National Monument. Three distinct channel types occur within the study area, including restricted meanders in Deerlodge Park, debris fan-affected in the upper Yampa Canyon, and entrenched meanders in lower Yampa Canyon. The occurrence of the three channel types is controlled by bedrock geology at river level (see text).

relatively high, persistent cover of perennial vegetation. Depending on location, the active floodplain surface begins to be inundated by discharges between 340 and 396 cms (~13,000 to ~14,000 cfs; 1.5–2.2 year recurrence-interval flood), as measured at the Deerlodge Park USGS stream gage (Manners et al. 2013). The transition from active to inactive floodplain represents a continuum but for purposes of this study, the inactive floodplain was defined as those floodplain surfaces inundated by a flow of 708 cms (~25,000 cfs), which has an average return interval of 34 years. This corresponds with a height of approximately 3.5 meters above the 24 cms (~850 cfs) stage at the Deerlodge Park gage. We used the LiDAR imagery to assist in defining the active floodplain/inactive floodplain boundary during mapping. Inactive-floodplain surfaces often support large, mature cottonwood trees in Deerlodge Park and mature box-elder trees in Yampa Canyon, which also aided in their identification.

The three identified channel types exhibited notable differences in the total areal extent of alluvium per river kilometer as well as the relative distribution, number, and extent of depositional environments. Area of alluvium was calculated from the geospatial mapping of *geomorphic features* within each channel type. These depositional settings influence the pattern and extent of geomorphic surfaces from active channel to inactive floodplain (Table 2-1). The short, alluvial, restricted-meander channel type had an order of magnitude more alluvium per river kilometer than did either the entrenched-meander or debris fan-affected channel types. Of this total, 23% represented active-channel deposits distributed among lateral-bar, point-bar, and mid-channel-bar geomorphic features. The majority of alluvium in the restricted-meander channel type was inactive floodplain (67%), reflecting relatively long-term storage of sediments in this low-gradient channel type. In the canyon-bound reaches, the debris fan-af-

Table 2-1. Number and area of geomorphic features and geomorphic surfaces within those features by channel type, Yampa River study area, Dinosaur National Monument.

			Area (% of study area)			
Channel type	Geomorphic feature	Number	Geomorphic feature	Active channel	Active floodplain	Inactive floodplain
Restricted meander	debris fan	0	0.00	0.00	0.00	0.00
	eddy	0	0.00	0.00	0.00	0.00
	expansion bar	0	0.00	0.00	0.00	0.00
	lateral bench	6	28.10	0.00	3.35	24.75
	lateral bar	2	4.08	4.08	0.00	0.00
	mid-channel bar	5	1.96	1.96	0.00	0.00
	point bar	4	2.60	2.51	0.09	0.00
Debris fan-affected	debris fan	109	1.06	0.12	0.05	0.00
	eddy	75	0.18	0.09	0.07	0.02
	expansion bar	10	0.09	0.08	0.01	0.00
	lateral bench	111	0.38	0.00	0.20	0.17
	lateral bar	167	0.41	0.39	0.02	0.00
	mid-channel bar	7	0.04	0.04	0.00	0.00
	point bar	42	0.24	0.18	0.06	0.00
Entrenched meander	debris fan	14	0.69	0.05	0.03	0.02
	eddy	12	0.07	0.02	0.02	0.03
	expansion bar	3	0.04	0.04	0.00	0.00
	lateral bench	88	1.56	0.00	0.53	1.03
	lateral bar	54	0.45	0.45	0.00	0.00
	mid-channel bar	76	1.06	0.65	0.37	0.04
	point bar	45	0.86	0.48	0.22	0.16

fected channel type had the smallest amount of stored alluvium, with 60% represented by active-channel geomorphic surfaces.

Lateral bars and point bars composed the majority of finer-grained active-channel surfaces. The remaining active-channel deposits, such as eddy bars, upper pool deposits, and expansion bars, were primarily associated with fan–eddy complexes (Schmidt 1990), which are the dominant geomorphic control in this channel type. Floodplains were limited and composed primarily of active- and inactive-floodplain surfaces in the form of narrow, lateral benches. In contrast, the entrenched-meander channel type had more than twice the area of alluvium per river kilometer than did the debris fan-affected channel type but less area of active channel (41%). Like the other canyon-bound channel type, most of the active- and inactive-floodplain area was composed of lateral benches. Mid-channel and point bars were also important source areas of active floodplain (see Table 2-1). In summary, as has been described elsewhere, river-level geology along the Yampa River (as well as the Green River in Dinosaur NM) has strong influence on channel planform, fluvial geomorphic processes, and the resulting pattern, extent, and types of fluvial landforms.

2.2.2 Green River

Grams and Schmidt (1999; 2002) conducted similar work along the Green River in Dinosaur NM. Grams and Schmidt (1999) also found that meandering reaches (aka restricted meanders) had an order of magnitude more alluvium than canyon reaches (entrenched meanders and debris fan-affected), and that most alluvium was stored in mid-channel bars and expansive floodplains. However, in the canyon reaches, about 70% of all fine- and coarse-grained alluvium above the low-water stage was stored in fan-eddy complexes (aka debris fan-affected reaches). For comparative purposes, Tables 2-2 and 2-3 provide some data from their findings.

Table 2-2. Area (1,000 m²/km) of geomorphic surfaces by reach and depositional environment, Green River, Dinosaur National Monument.

Depositional environment	Level	Lodore Canyon	Echo Park	Whirlpool Canyon	Island Park	Split Mountain Canyon
Channel-margin bars	Active	1	51	1	0	0
	Post-dam floodplain	2	2	1	0	0
	Intermediate bench	2	15	1	0	0
	Terrace	9	105	3	0	1
Mid-channel bars	Active	0	0	0	20	0
	Post-dam floodplain	0	0	0	25	0
	Intermediate bench	0	0	0	40	0
	Terrace	0	0	178	178	0
Point bars	Active	0	55	1	2	2
	Post-dam floodplain	1	1	1	0	0
	Intermediate bench	1	2	1	0	1
	Terrace	2	6	0	0	0
Expansion bars	Active	1	0	6	0	4
	Post-dam floodplain	2	0	1	0	2
	Intermediate bench	3	0	0	0	5
	Terrace	2	0	0	0	13
Eddy bars	Active	1	2	4	0	2
	Post-dam floodplain	2	0	1	0	0
	Intermediate bench	3	1	3	0	1
	Terrace	3	1	3	0	1

Source: Grams and Schmidt (1999; 2002)

Table 2-3. Distribution of surficial deposits, rapids, and fan–eddy complexes in five subreaches, measured from surficial geological maps, Green River, Dinosaur National Monument.

Geomorphic characteristic	Measure	Subreach					Channel type		Study area
		Lodore Canyon	Echo Park	Whirlpool Canyon	Island Park	Split Mountain	Canyons	Meanders	
Reach	Reach length (km)*	28.5	3.2	14.2	11.6	8.0	50.6	14.8	65.4
	Area of alluvium (m^2/km)	34,962	323,366	30,008	769,943	33,164	33,319	675,688	175,947
Rapids	Count	53	0	26	2	12	91	2	93
	Frequency (count/km)	1.9	0.0	1.8	0.2	1.0	1.8	0.1	1.4
Debris fans	Count	81	1	53	5	35	169	6	175
	Frequency (count/km)	2.8	0.3	3.7	0.4	2.9	3.3	0.4	2.7
	Total area (m^2)	739,543	5,598	259,407	13,250	281,211	1,280,161	19,118	1,299,279
	Average area (m^2)	9,130	5,598	4,894	2,704	8,035	7,575	3,186	7,424
Deposits by area	Gravel (%)	6	23	32	32	32	16	31	29
	Fine-grained (%)	62	65	55	67	27	55	67	66
	Mixed (%)	32	12	13	1	41	29	2	5
Deposits in fan–eddy complex**	Gravel (%)	80	0	85	0	100	89	0	7
	Fine-grained (%)	51	2	89	0	100	64	0	8
	Mixed (%)	72	0	68	0	100	78	0	58
	All alluvium (%)	60	1	85	0	100	72	0	10
Deposits in eddy bars	Fine-grained (%)	34	1	63	0	100	42	0	5

*Length of mapped reach (8 km of 11.9 km-long Split Mountain Canyon were mapped)

**Percentage of all deposits within each reach of indicated type that are within eddy complexes

Source: Grams and Schmidt (1999; 2002)

2.3 Conducting vegetation analyses

We hypothesize that differences in channel processes and the pattern and extent of different fluvial landforms should have strong direct and indirect effects on the structure, extent, and composition of riparian vegetation. Thus, we examined broad and fine-scale patterns of riparian vegetation along the Yampa River in Dinosaur NM. At the broad scale, we examined composition and cover across three distinct channel types in canyon-bound and alluvial reaches of the Yampa River. At a finer scale, we quantified patterns in the extent and composition of riparian vegetation across a range of active and inactive fluvial surfaces (active channel to inactive floodplain) for each of the different channel types.

We used vegetation data from our pilot protocol efforts and collected by others (prior to initiation of this big rivers monitoring program; D. Merritt, D. Cooper, pers. comm.) to examine vegetation patterns and develop indicator species for the geomorphic surfaces relevant to this project. We used multivariate analytical methods to quantify differences in vegetation patterns across channel types and geomorphic surfaces. We also identified indicator species with high fidelity to a geomorphic surface or surfaces within each channel type to aid in the early identification of state transitions from one surface type to another.

2.3.1 Broad and fine-scale vegetation patterns on the Yampa River

Between 1993 and 2002, riparian vegetation was sampled throughout the Yampa River study reach using thirty-seven 10 × 10-meter quadrats (D. Merritt, pers. comm.) and 208 dimensionless relevés (D. Cooper, pers. comm.). Vegetation was sampled from the edge of the water at low flow to (and into) the adjacent upland along transects oriented perpendicular to the river. Transect locations were subjectively chosen to represent the range of hydrogeomorphic settings (Grams and Schmidt 1999; Brierley and Fryirs 2005). Vegetation was sampled in bands of relatively uniform elevation along each transect. Within each band, a large quadrat or relevé was established and an estimate of cover for all woody and herbaceous vascular plants, by species, was recorded. The relevé locations were referenced to metal rods driven into the ground at transect endpoints. The 10 × 10-meter quadrats were surveyed with a rod and auto-level, relative to a known USGS benchmark.

Development and pilot testing for this big rivers protocol occurred from 2009 to 2012. During this time, eight hundred eighty-seven 1 × 1-meter quadrats (Scott et al. 2012) were located systematically along transects at sentinel sites throughout the Yampa River bottomland within Dinosaur NM. In 2010 and 2013, one hundred ninety-six and two hundred forty-eight 1 × 1-meter quadrats were located randomly across the bottomland (Scott et al. in prep.). Finally, in 2014, Scott and Merritt sampled 15 randomly located 1 × 1-meter quadrats (Scott et al. in prep.). We combined field observations and aerial imagery to map four geomorphic surfaces: active channel (AC); active floodplain (AF); inactive floodplain (IF); and upland (U) (O'Connor and Grant 2003; Gendaszek et al. 2012; Scott et al. in prep.), and used the map to assign a geomorphic surface to 1,470 of the 1,591 quadrats and relevés. We applied principal coordinates ordination (PCO) in PRIMER (Clarke and Gorley 2015) to these 1,470 samples to explore patterns of species variability among quadrats and species.

From a total of 1,591 quadrats and relevés sampled along the Yampa River from all three of these efforts (Cooper, Merritt, and Scott), only 1,462 were determined to have accurate geomorphic surface information. We used principal coordinates ordination (PCO) in PRIMER (Clarke and Gorley 2015) to visually explore broad patterns of species variability among quadrats.

For this analysis, we retained quadrats that were empty of species ("bare" quadrats) by assigning them a pseudospecies designation. Ordination can reveal structure in large, complex datasets by identifying similarity between species and samples, projecting results in two dimensions such that the most similar species and samples will appear close together in ordination space and those most dissimilar will appear far apart. One hallmark of an unregulated river, such as the Yampa, is extensive, largely bare geomorphic features.

This hallmark was reflected in the ordination (see large number of active-channel and active-floodplain plots with low to no cover, Figure 2-3). The ordination showed clear gradients structuring plant species composition on four geomorphic surfaces: active channel, active floodplain, inactive floodplain, and upland. The cover gradient along the first axis was likely a combination of frequency and intensity of fluvial disturbance for active-channel and active-floodplain plots and moisture limitations for inactive-floodplain and upland plots.

Results of the first PCO analysis demonstrated clear gradients, separating vegetated quadrats on the left side of the ordination from largely bare quadrats on the right. The second axis represents a moisture gradient, where largely active-floodplain quadrats dominated by sandbar willow (*Salix exigua*), in the lower left, give way to species characteristic of drier floodplains, such as western wheatgrass (*Pascopyrum smithii*), on the right. The broad overlap of active-floodplain plots with both active-channel plots and inactive-floodplain and upland plots reflects a broad continuum of change in vegetation across these surfaces, maintained by the variable and wide-ranging flows of the Yampa. Such broad vegetation transitions are typically not seen along regulated rivers, where differences between predominantly wetland and upland vegetation occur relatively abruptly over short distances (Merritt and Cooper 2000).

Next, bare quadrats were dropped from a permutational multivariate analysis of variance (PerMANOVA) and PCO analyses in PRIMER (Clarke and Gorley 2015) to reveal vegetation patterns relative to geomorphic

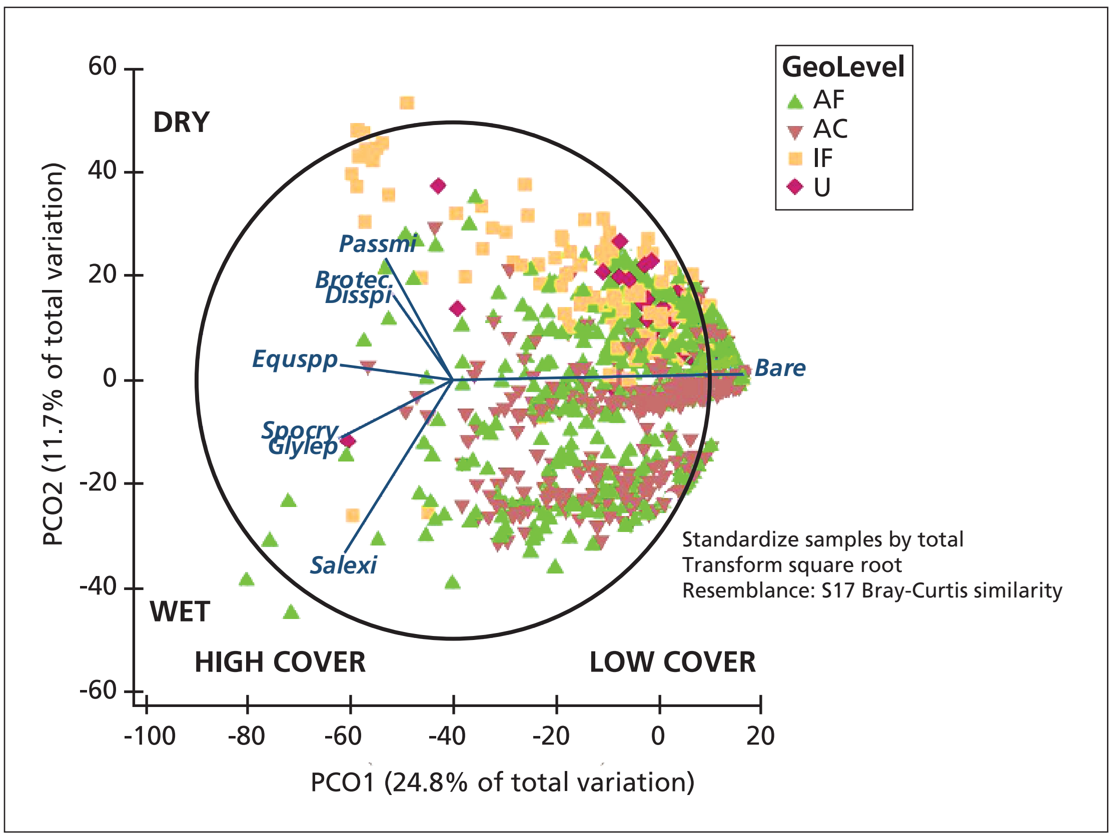


Figure 2-3. Principal coordinates ordination (PCO) of species and samples from 1,462 quadrats and relevés sampled along the Yampa River in Dinosaur National Monument. A total of 798 quadrats were bare of vegetation but were included in the ordination as a pseudospecies. The ordination showed clear gradients structuring plant-species composition on four geomorphic surfaces: active channel (AC), active floodplain (AF), inactive floodplain (IF), and upland (U). The cover gradient along the first axis was likely a combination of frequency and intensity of fluvial disturbance for active-channel and active-floodplain plots and moisture limitations for inactive-floodplain and upland plots. Species codes: *Bare=Bare pseudospecies; Brotec=Bromus tectorum; Disspi=Distichlis spicata; Equspp=Equisetum* species*; Glylep=Glycyrrhiza lepidota; Passmi= Pascopyrum smithii; Salexi=Salix exigua; Spocry= Sporobolus cryptandrus.*

surfaces. Other criteria for inclusion in these analyses were:

- species must occur in at least three quadrats;
- quadrats must contain at least three species; or
- quadrats with less than three species must have a total vegetation cover value of ≥30%.

This resulted in elimination of 798 quadrats and inclusion of 664 vegetated quadrats (42% of the total quadrats sampled). Percent cover data were square-root transformed. Bray-Curtis dissimilarity matrices were constructed for use in PerMANOVA and PCO analysis. Due to unequal sample sizes (unbalanced design) between the factors in the design, Type III sums of squares were used to partition the sums of squares in the model. With the edited vegetation dataset, we examined broad-scale differences in vegetation across the three channel types as well as the contribution of geomorphic surfaces across and within channel types.

PerMANOVA analyses of vegetated quadrats indicated significant, broad-scale differences in plant-species composition across the three channel types (debris fan-affected, entrenched meander, and restricted meander; Pseudo-F = 6.90, p = 0.001), geomorphic surfaces (active channel, active floodplain, inactive floodplain, and upland; Pseudo-F = 9.77, p = 0.001), and the interaction between these terms (Pseudo-F = 4.69, p=0.001). Differences between geomorphic surfaces within each channel type were varied. All geomorphic surfaces were significantly different floristically in entrenched-meander channels. All geomorphic surfaces in debris fan-affected channels were significantly different except for upland and inactive floodplains. In the restricted-meander channel type, where few active-channel quadrats contained any vegetation, there was no significant difference between active-channel and active-floodplain plots. All other surfaces in this channel type were significantly different. Table 2-4 summarizes the PerMANOVA t-test results of pairwise surface comparisons within each channel type.

PCO results by channel type, for vegetated quadrats only, provided additional insights into vegetative differences across geomorphic surfaces and within channel types (Figures 2-4 to 2-6). Vegetation patterns by channel type are distinctive. For example, the restricted-meander, active-channel quadrats were largely devoid of vegetation or contained very low cover of a few, largely annual species, such as cocklebur (*Xanthium strumarium*) and toad rush (*Juncus bufonius*). Thus, few active-channel quadrats appeared in the ordination of the restricted-meander channel type (Figure 2-4). Instead, the ordination consisted of broadly overlapping active- and inactive-floodplain quadrats dominated by woody, early successional cottonwood (*Populus fremontii*) and sandbar willow on one side of the first axis of the ordination and perennial, rhizomatous herbs, such as western wheatgrass and field horsetail

Table 2-4. Results of perMANOVA pairwise t-test comparisons of floristic differences between geomorphic surface types within three different channel types along the Yampa River in Dinosaur National Monument.

Geomorphic surfaces	Debris fan-affected		Entrenched meander		Restricted meander	
	t-statistic	*P*	t-statistic	*P*	t-statistic	*P*
AC, AF	1.67	0.003*	4.21	0.001*	1.14	0.201
AC, IF	2.59	0.001*	5.84	0.001*	1.39	0.068
AC, U	2.51	0.001*	3.72	0.001*	3.41	0.002*
AF, IF	2.12	0.001*	4.13	0.001*	2.43	0.001*
AF, U	2.30	0.001*	3.01	0.001*	4.81	0.001*
IF, U	1.10	0.27	1.88	0.001*	4.68	0.001*

*Highly significant results, p<0.01.

AC=active channel; AF=active floodplain; IF=inactive floodplain; U=upland.

Figure 2-4. Principal coordinates ordination (PCO) of vegetation quadrats showing relationships of geomorphic surfaces and vectors of important species within the restricted-meander channel type. Geomorphic surface abbreviations: AC=active channel; AF=active floodplain; IF=inactive floodplain; and U=upland. Species codes: *Brotec=Bromus tectorum; Dessop= Descurainia sophia; Equspp=Equisetum* species; *Passmi= Pascopyrum smithii; Popdel=Populus deltoides; Salexi=Salix exigua; Sarver=Sarcobatus vermiculatus.*

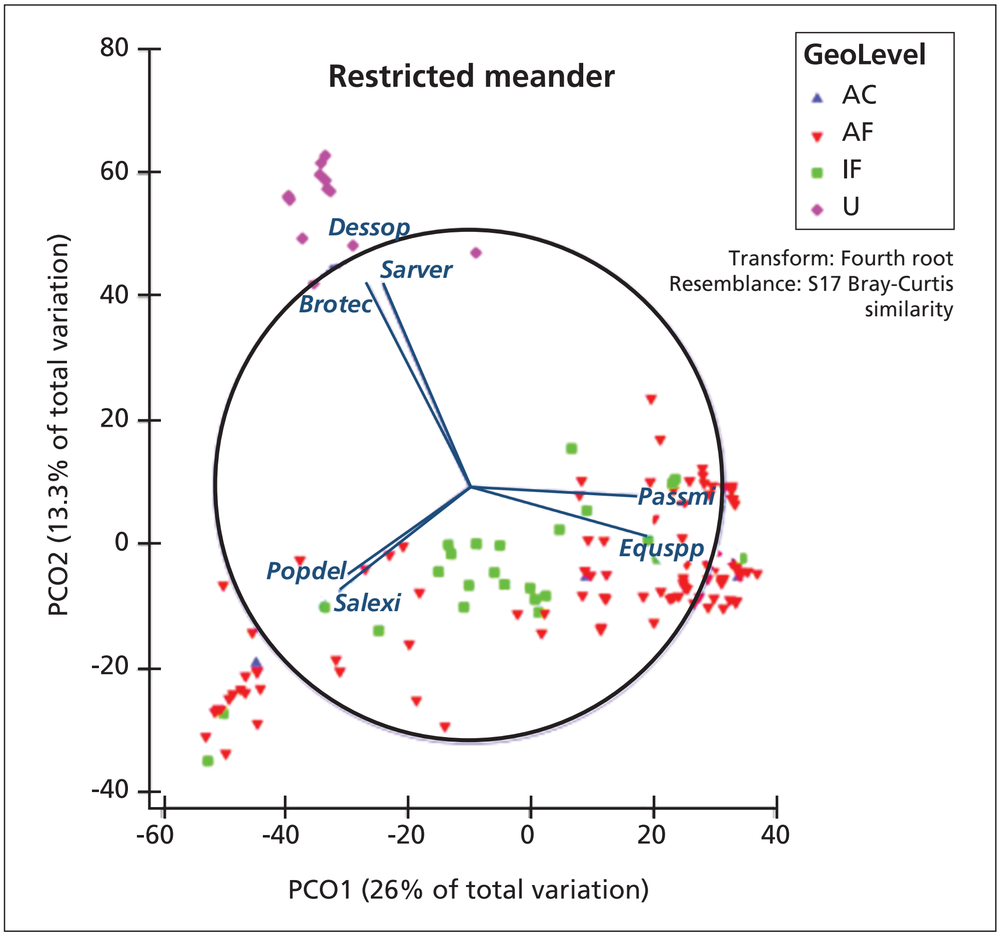
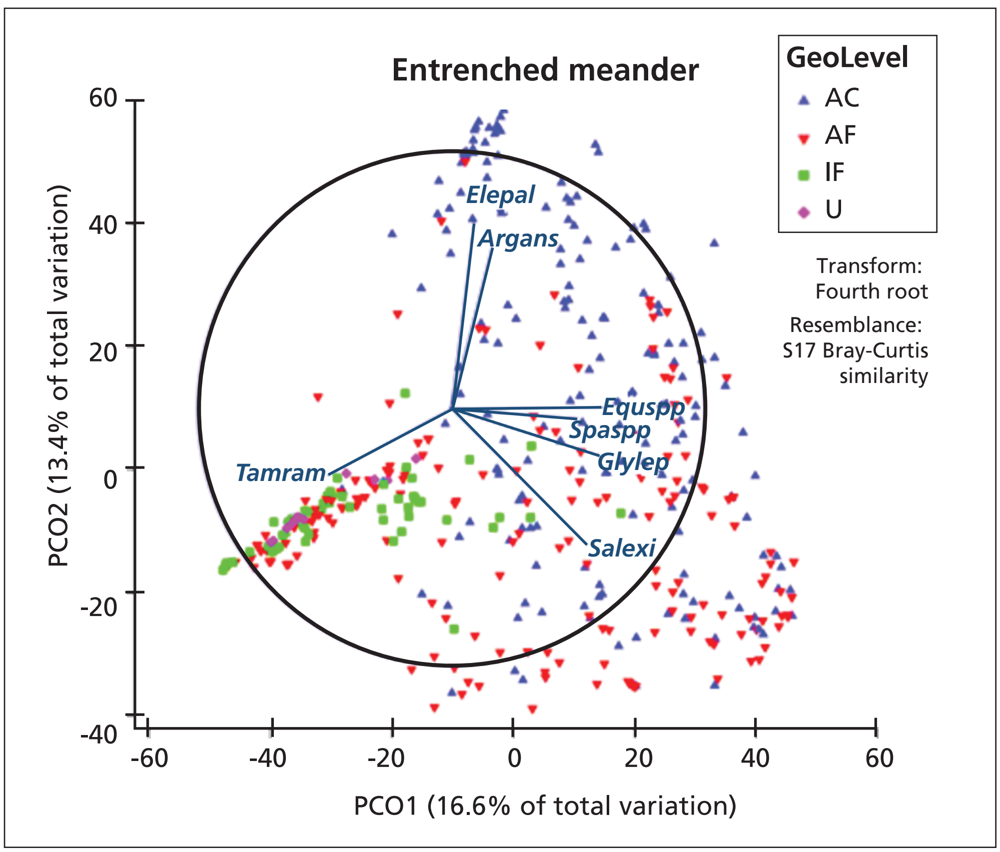


Figure 2-5. Principal coordinates ordination (PCO) of vegetation quadrats showing relationships of geomorphic surfaces and vectors of important species within the entrenched-meander channel type. Geomorphic surface abbreviations: AC=active channel; AF=active floodplain; IF=inactive floodplain; and U=upland. Species codes: *Argans= Argentina anserina; Elepal= Eleocharis palustris; Equspp=Equisetum* species; *Glylep=Glycyrrhiza lepidota; Salexi=Salix exigua; Spaspp=Spartina* species; *Tamram=Tamarix ramosissma*.



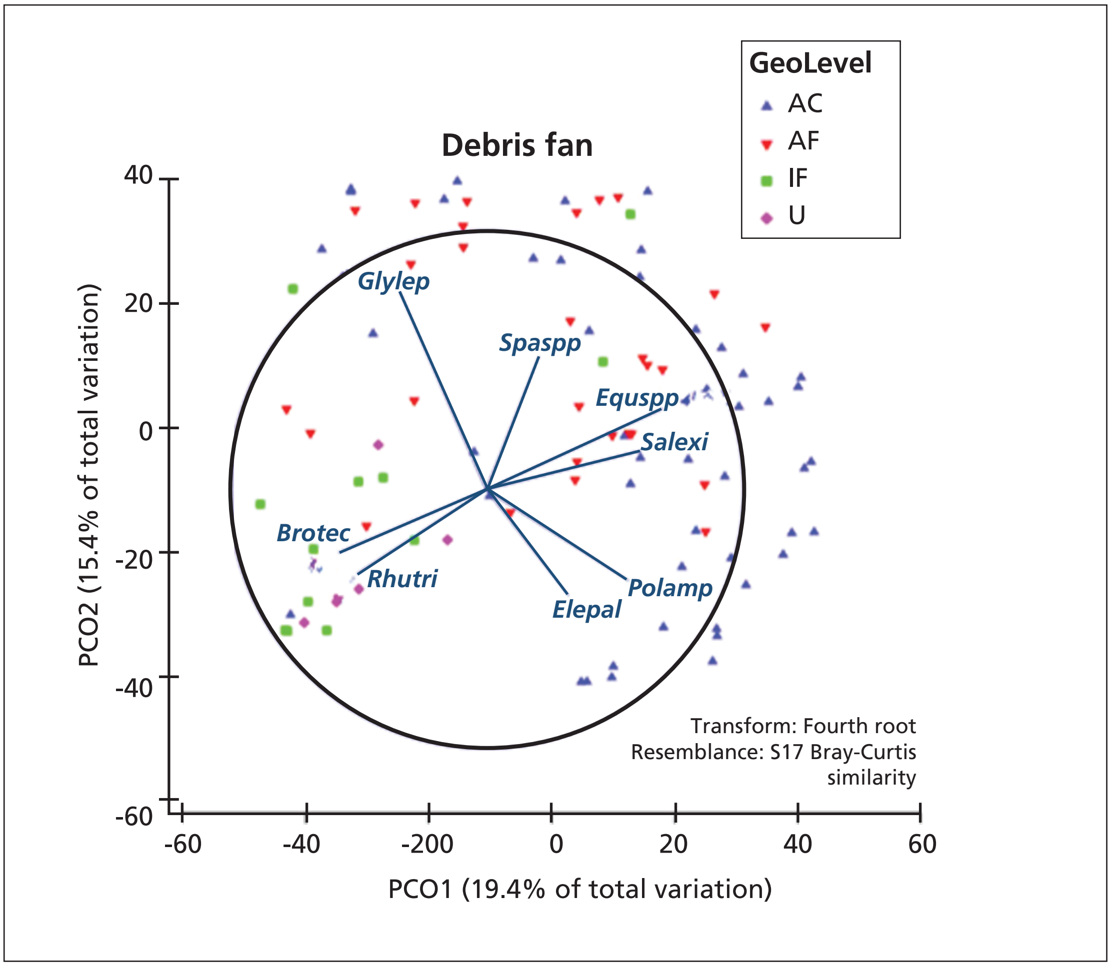


Figure 2-6. Principal coordinates ordination (PCO) of vegetation quadrats showing relationships of geomorphic surfaces and vectors of important species within the debris fan-affected channel type. Geomorphic surface abbreviations: AC=active channel; AF=active floodplain; IF=inactive floodplain; and U=upland. Species codes: *Brotec=Bromus tectorum; Elepal= Eleocharis palustris; Equspp=Equisetum* species; *Glylep=Glycyrrhiza lepidota; Polamp= Polygonum amphibium; Rhutri= Rhus trilobata; Salexi=Salix exigua; Spaspp=Spartina* species.

species (*Equisetum* spp.), on the other. This likely represented a disturbance and/or inundation gradient. In the restricted-meander channel type, willow and young cottonwood occurred primarily along the edge of the active channel, whereas western wheatgrass, field horsetail, and other herbs dominated the expansive floodplains. Here also, upland vegetation, dominated by the woody shrub, greasewood (*Sarcobatus vermiculatus*), contrasted sharply along the second ordination axis with the bottomland vegetation, perhaps representing a moisture gradient.

The entrenched-meander channel-type ordination (see Figure 2-5) displayed a more distinct separation of geomorphic surfaces along both axes. A tight grouping of upland, inactive-floodplain and some active-floodplain quadrats on the left side of the first ordination axis transitioned to a mix of active-floodplain and active-channel plots on the right. This represented a rather clear moisture gradient. The species vector for tamarisk was strongly correlated with the grouping of active- and inactive-floodplain quadrats, which may reflect its role in floodplain construction in this channel setting, as reported by Manners and others (2014). Vectors for sandbar willow, horsetails, wild licorice (*Glycyrrhiza lepidota*), and prairie cordgrass (*Spartina pectinata*) were associated with active-channel and active-floodplain surfaces. Whether these largely rhizomatous perennial species play an active role in floodplain construction is unclear, but in entrenched-meander settings, they are typically found in association with fine-textured deposits. These deposits likely represent settings with lower shear stresses (Larson 2004) that may be sensitive to floodplain construction and channel narrowing in response to reduced flow variability. In contrast, the clustering of active-channel plots at the top of the second ordination axis likely reflect higher-energy/more frequently inundated environments. Such sites were associated with spike rush (*Eleocharus palustrus*) and silverweed cinquefoil (*Argentina anserina*), which are common on gravel and cobble bars.

Ordination results for the debris fan-affected channel type were similar to those from the entrenched-meander channel type. The first ordination axis predominantly represented a moisture gradient and the second axis represented a disturbance/inundation duration gradient (see Figure 2-6). In this ordination, most of the upland and inactive floodplain quadrats clustered on the lower left side of the ordination and aligned with species vectors for cheatgrass (*Bromus tectorum*) and skunkbush sumac (*Rhus trilobata*). The upper right side of ordination space was largely a mix of active-floodplain and active-channel quadrats, with quadrats dominated by wild licorice, prairie cordgrass, horsetail species, and sandbar willow. As in the entrenched-meander channel type, this group of species was associated with finer-textured deposits in the active channel and on active-floodplain surfaces. Finally, in the lower right quadrat of the ordination space, spike rush, along with water knotweed (*Polygonum amphibium*), was primarily associated with frequently inundated active-channel deposits.

Although the elimination of a large number of bare quadrats and rare species facilitated some of the multivariate analyses described above, the distribution and abundance of bare (or nearly bare) quadrats can be considered one of the best indicators of active-channel conditions—and they are a critical component of the big rivers monitoring protocol. Multivariate vegetation analyses supported our hypothesis that underlying differences in fluvial geomorphic features and processes, across different channel types, are correlated with significant differences in the cover and composition of riparian vegetation. Ordination results presented here suggest these vegetation differences are driven in part by gradients of disturbance and moisture, which have been shown to be important in other riparian settings (Auble et al. 1994, 2005; Friedman et al. 1998). These results have important implications for channel-change monitoring and suggest that species with high fidelity to specific geomorphic surfaces and channel types could be used as indicators of changing physical environmental conditions.

2.3.2 Plant indicator species analyses

Indicator species are a small set of species that reflect the physical or biotic conditions of specific environments and provide evidence for the effects of environmental change. They are especially useful in long-term environmental monitoring (De Cáceres et al. 2012). Using the vegetated quadrat data described above, we performed an indicator-species analysis, Indval package in R, employing the functions *multipatt* and *pruneindicators* (Dufrene and Legendre 1997) to identify a select group of species or species combinations with high positive predictive value and sensitivity for specific geomorphic surfaces within each channel type. As the result of our analysis, Table 2-5 presents a succinct list of species or species combinations that can be used as leading indicators of state changes in geomorphic surfaces—specifically, the conversion of active-channel surfaces to floodplain as part of a progressive channel-narrowing process. Two values were used to assess the indicator species or species combinations: (A) positive predictive value and (B) sensitivity or fidelity. In our case, A was the conditional probability that a sampled location belonged to a specific geomorphic surface within a channel type, given the presence of the indicator species. B represented the probability of finding the indicator species on that type of geomorphic surface within the channel type (De Cáceres et al. 2012).

We identified important indicator species or species combinations for each geomorphic surface within channel types. To obtain indicator species for each surface, we had to adjust significance levels for the A and B statistics, typically between 0.2 and 0.5. Indi-

Table 2-5. Results of indicator species analyses listing the channel type, geomorphic surface(s), and indicator species (or combinations), and their conditional probabilities, *A* and *B*.

Channel type	Geomorphic surface	Indicator species and species combinations	*A*	*B*
Debris fan-affected	active channel	*Equisetum* spp.	0.726	0.632
		Polygonum amphibium	0.969	0.387
		Salix exigua	0.701	0.489
	active floodplain	*Glycyrrhiza lepidota*	0.534	0.607
		Equisetum spp. + *Glycyrrhiza lepidota*	0.695	0.428
		Apocynum cannabinum + *Glycyrrhiza lepidota*	0.801	0.230
	inactive floodplain	*Bromus tectorum*	0.450	0.538
		Rhus trilobata	0.593	0.384
		Tamarix ramosissma	0.710	0.307
	upland	*Heterotheca villosa*	0.969	0.571
		Alyssum desertorum + *Bromus tectorum*	0.750	0.428
		Ericameria nauseosa	1.000	0.285
Entrenched meander	active channel	*Eleocharis palustris*	0.715	0.424
		Argentina anserina	0.831	0.337
		Equisetum arvense	0.924	0.279
	active floodplain	*Salix exigua*	0.702	0.405
		Tamarix ramosissma	0.648	0.272
		Glycyrrhiza lepidota	0.561	0.288
	inactive floodplain	*Bromus tectorum*	0.902	0.688
		Bromus tectorum + *Pascopyrum smithii*	0.966	0.311
		Pascopyrum smithii	0.885	0.311
	upland	*Alyssum desertorum* + *Bromus tectorum* + *Sporobolus cryptandrus*	0.636	0.583
		Alyssum desertorum + *Sporobolus cryptandrus*	0.533	0.666
		Alyssum desertorum + *Bromus tectorum*	0.583	0.583
Restricted meander	active channel	*Chamaesyce glyptosperma* + *Echinochloa crus-galli* + *Juncus bufonius* + *Plantago major*	0.333	0.577
		Chamaesyce glyptosperma + *Echinochloa crus-galli* + *Juncus bufonius* + *Plantago major* + *Polygonum lapathifolium*	0.333	0.577
		Chamaesyce glyptosperma + *Echinochloa crus-galli* + *Juncus bufonius* + *Plantago major* + *Populus fremontii*	0.333	0.577
	active floodplain	*Equisetum* spp.	0.827	0.707
		Equisetum spp. + *Pascopyrum smithii*	0.685	0.555
		Distichlis spicata + *Equisetum* spp.	0.868	0.292
	inactive floodplain	*Poa* spp. *(pretense and compressa)*	0.793	0.653
		Poa spp. + *Populus fremontii*	0.951	0.500
		Pascopyrum smithii + *Poa* spp.	0.812	0.576
	upland	*Bromus tectorum*	0.949	1.000
		Bromus tectorum + *Descurainia sophia*	1.000	0.857
		Bromus tectorum + *Sarcobatus vermiculatus*	1.000	0.857

The *A* statistic is the positive predictive value of the indicator for the geomorphic surface within a channel type. The *B* statistic is the sensitivity or fidelity of the indicator to the specific surface (see text). Channel-type abbreviations: DFA=debris fan affected; ENM=entrenched meanders; REM=restricted meanders. Geomorphic surface abbreviations: AC=active channel; AF=active floodplain; IF=inactive floodplain.

cator-species results were consistent with the ordination results and provided us with a list of species that generally showed high affinity and relatively frequent occurrence on one or a combination of geomorphic surfaces. These species broadly differed between the alluvial, restricted-meander channel type and the two canyon-bound channel types. A notable exception included scouring horsetail (*E. hyemale*) and smooth horsetail (*E. laevigatum*), which were consistently found growing in active-channel to active-floodplain surfaces in debris fan-affected channels and on active floodplains in restricted-meander channels (see Table 2-5).

Active-channel indicators were found on active-channel deposits, typically occurring with relatively low cover and frequency. For example, the weedy annuals, ribseed sandmat (*Chamaesyce glyptosperma*) and cocklebur, were found sparingly on sandy, active-channel bars in the alluvial, restricted-meander channel type. Spike rush and silverweed cinquefoil, perennial wetland species, were active-channel indicators in the entrenched-meander channel type, where vegetation cover on coarser-textured bars was typically higher than in the alluvial reach. Water knotweed (*Polygonum amphibium*) was an active-channel indicator in the debris fan-affected channel type. This species begins growth as an aquatic plant during high, springtime river stages and concludes growth as a terrestrial plant following stage declines. Sandbar willow and field horsetails were also active-channel indicators in the debris fan-affected channel type. Active-channel indicators have high affinity to active-channel surfaces. If the channel feature on which they were growing began converting to floodplain, their densities would be expected to decrease.

Similarly, the appearance of active-floodplain indicators on the active-channel portion of features is hypothesized to be strong evidence of floodplain construction and a directional channel-narrowing process, at least locally. Thus, active- and inactive-floodplain indicators are important monitoring tools. Common and easily identifiable floodplain indicators in the restricted-meander channel type included field horsetails, western wheatgrass, and saltgrass (*Distichlis spicata*). Important and easily identifiable floodplain indicators in the debris fan-affected channel type included wild licorice, along with the species combinations of wild licorice and Indian hemp (*Apocynum cannabinum*), and wild licorice and field horsetails. In restricted-meander channels, sandbar willow, tamarisk (*Tamarix ramosissma*), and wild licorice were notable active-floodplain indicators (see Table 2-5).

We found some species, including field horsetails, tamarisk, and sandbar willow, to be significant indicators of two geomorphic surfaces, such as active channel and active floodplain or active and inactive floodplains. Work by Manners and others (2014) in two entrenched-meander channel reaches of the Yampa documented the active participation of tamarisk and sandbar willow in the channel narrowing that has taken place in these settings over the past 50 years. They documented four distinct "styles" of narrowing involving these species to various degrees. The involvement of these species in vertical accretion of floodplain surfaces is suggested by their identified fidelity to multiple surfaces. Tamarisk is also frequently encountered on active-channel surfaces in debris fan-affected and entrenched-meander channel types (M. Scott, personal observation) but did not appear as significant in the indicator analyses. Although tamarisk and sandbar willow may be the main participants in floodplain construction, the other rhizomatous perennials associated with multiple surfaces may play a role in the channel-narrowing process—or would at least be expected to appear and persist through different stages of that process. The degree of active involvement of these other species in the narrowing process deserves further study.

Indicator species are used in this monitoring protocol to assist in early identification of persistent environmental changes resulting from changes in streamflow variability; specifically, the transition from active channel to vegetated floodplain. The following section presents a conceptual model of how changes in vegetation cover and composition, including indicator species, can be used in monitoring to signal channel narrowing.

2.3.3 Detecting state changes using indicator species: A conceptual model

The detection of channel narrowing using indicator species is hypothesized to proceed as described and illustrated in Figure 2-7: at T_0, a channel feature exists with reach-specific, active-channel indicator species (e.g., water knotweed, spike rush), low overall plant cover, and lots of bare ground. At T_1, the feature has tamarisk/sandbar willow, which can be considered leading indicators of narrowing. Lateral and vertical accretion of fine-grained alluvium may be associated with these species. At the same time, there may be an increase in cover of reach-specific active-channel and active-channel + active-floodplain indicator species (e.g., wild licorice, sandbar willow, field horsetails). Flow variability (including large floods) could flood the surface and, over time, return the feature to initial conditions (T_0). However, lack of flow variability may lead to a new state, as indicated by T_2. 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 active-floodplain + inactive-floodplain species; for example, skunkbush sumac, bluegrass (*Poa* spp.), cheatgrass. As vegetation persists, it increases in cover and becomes more stable. This vegetation then serves to reduce scour and shear stress, resulting in lateral and vertical accretion of fine-grained alluvium and necessitating higher floods to mobilize the accumulated sediment. Persistence of these changes would be strong evidence of site-specific narrowing, which could be verified on a broad scale using remotely sensed imagery. The combination of these changes can result in a state transition to a new surface that then becomes disconnected from the river and might only be mobilized by very large floods.

2.4 Summary of supporting data and analyses

Our analyses provide clear evidence that the Yampa River is the last remaining large river in the Colorado River basin that retains a relatively wild hydrograph featuring high inter- and intra-annual variability. Geomorphic mapping provided quantitative information on the spatial configuration and areal extent of depositional environments and geomorphic surfaces (e.g., active channel, active floodplain), which differed significantly across three distinct channel types occurring along the Yampa River within Dinosaur NM.

Differences in geomorphic processes among channel types resulted in significant differ-

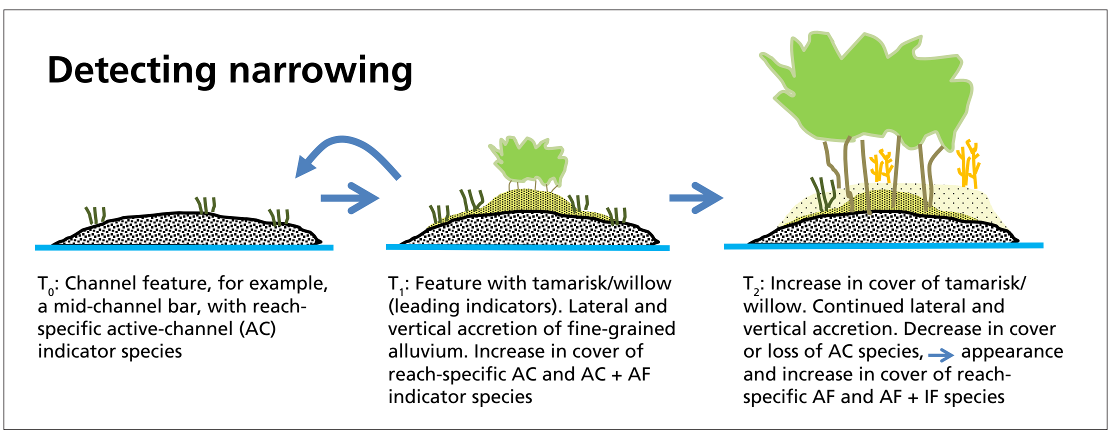


Figure 2-7. A conceptual model of how narrowing on an active-channel feature along a largely unregulated river could be detected using reach- and geomorphic surface-specific indicator species. T_0 represents initial conditions on a channel-bar feature with reach-specific, active-channel indicator species. 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).

ences in species composition and cover of riparian vegetation among channel types and across geomorphic surfaces within channel types. This work showed that by using indicator species specific to channel type and geomorphic surface, we should be able to detect geomorphic surface state changes quickly and accurately and, thus, track changes in channel condition and channel narrowing (see Figure 2-7).

Finally, unpublished work by Larson (2004) and recently published work by Manners and others (2014) support the idea that geomorphic features in specific geomorphic settings, such as eddy bars in the debris fan-affected channel type and mid-channel bars in the entrenched-meander channel type, are sensitive to floodplain construction and, thus, channel narrowing. Further, by trapping sediments during higher flows, species such as tamarisk and sandbar willow actively participate in the channel-narrowing process in certain hydrogeomorphic settings.

3 Pilot Monitoring: Methods, Results, and Evaluation

Given our findings that river-level geology controls channel form and process, resulting in significant differences in composition and abundance of riparian vegetation, our final monitoring design includes sentinel and rapido monitoring sites that reflect differences in channel form and process. Sentinel monitoring sites (Perkins et al. in review) are located within a number of different channel types along the Green and Yampa rivers within Dinosaur NM. Channel types fall into two broad categories: alluvial and canyon-bound. Freely or restricted meandering alluvial channels are found in Deerlodge Park on the Yampa and Browns Park and Island Park on the Green. Canyon-bound channel types include debris fan-dominated channels in Lodore and Whirlpool canyons on the Green, debris fan-affected channels on the Yampa, and entrenched-meander channels on both rivers (Figure 3-1). Rapido monitoring sites (Perkins et al. in review) are designed to quickly sample active-channel and floodplain surfaces across a broad spatial range of channel types within Dinosaur NM.

3.1 Sentinel sites

3.1.1 Methods

Sentinel sites are designed to be monitored every 1–3 years, with relatively high-intensity data collected at each site. Monitoring at these sites includes repeat measurements of hydrology, geomorphology, sedimentary structure of the geomorphic feature being monitored (facies mapping), vegetation, and repeat photos (Figure 3-2). In this report, we

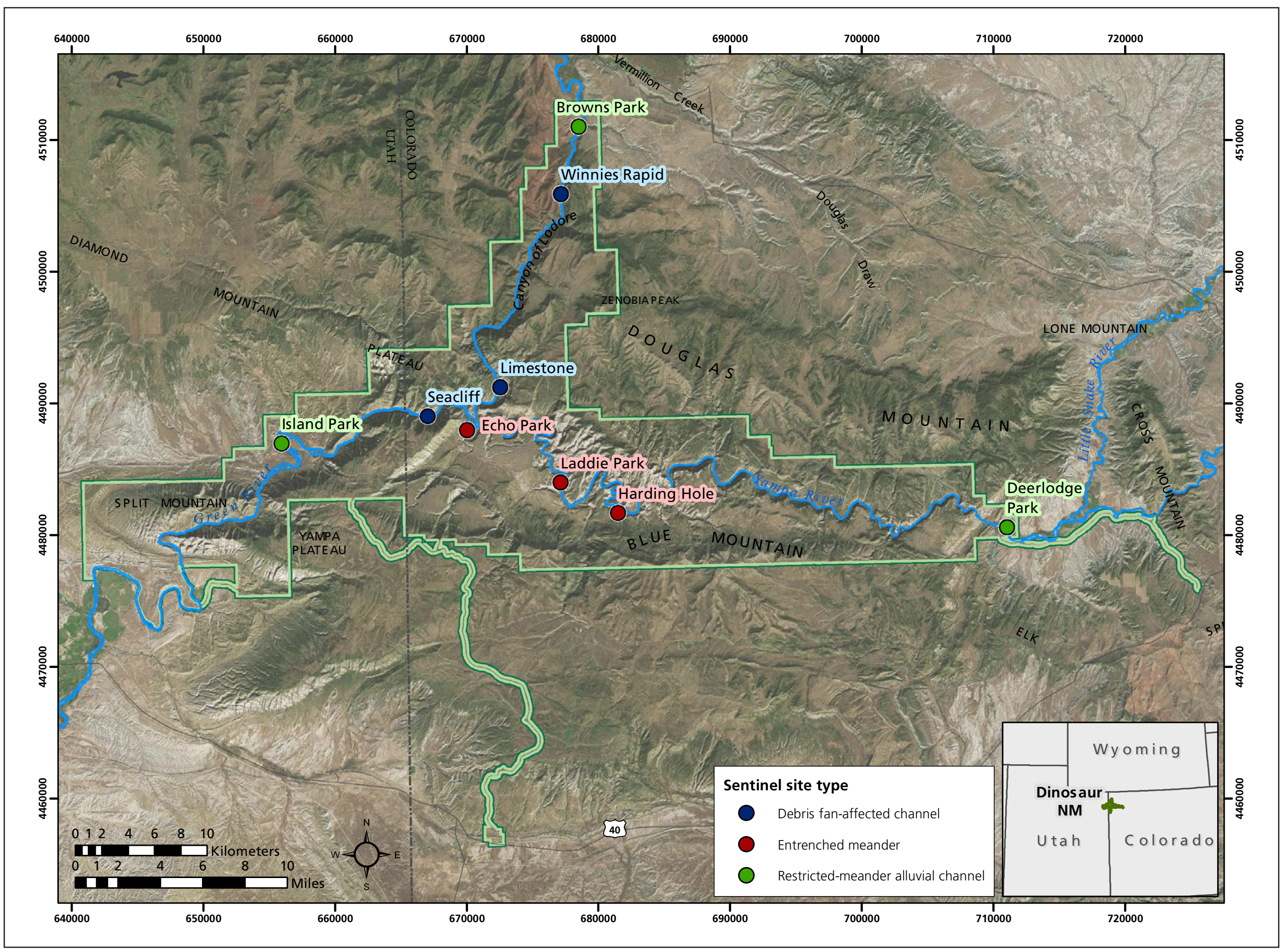


Figure 3-1. The location of nine sentinel monitoring sites within Dinosaur National Monument. These sites represent all of the channel forms found along the Yampa and Green rivers within Dinosaur National Monument.

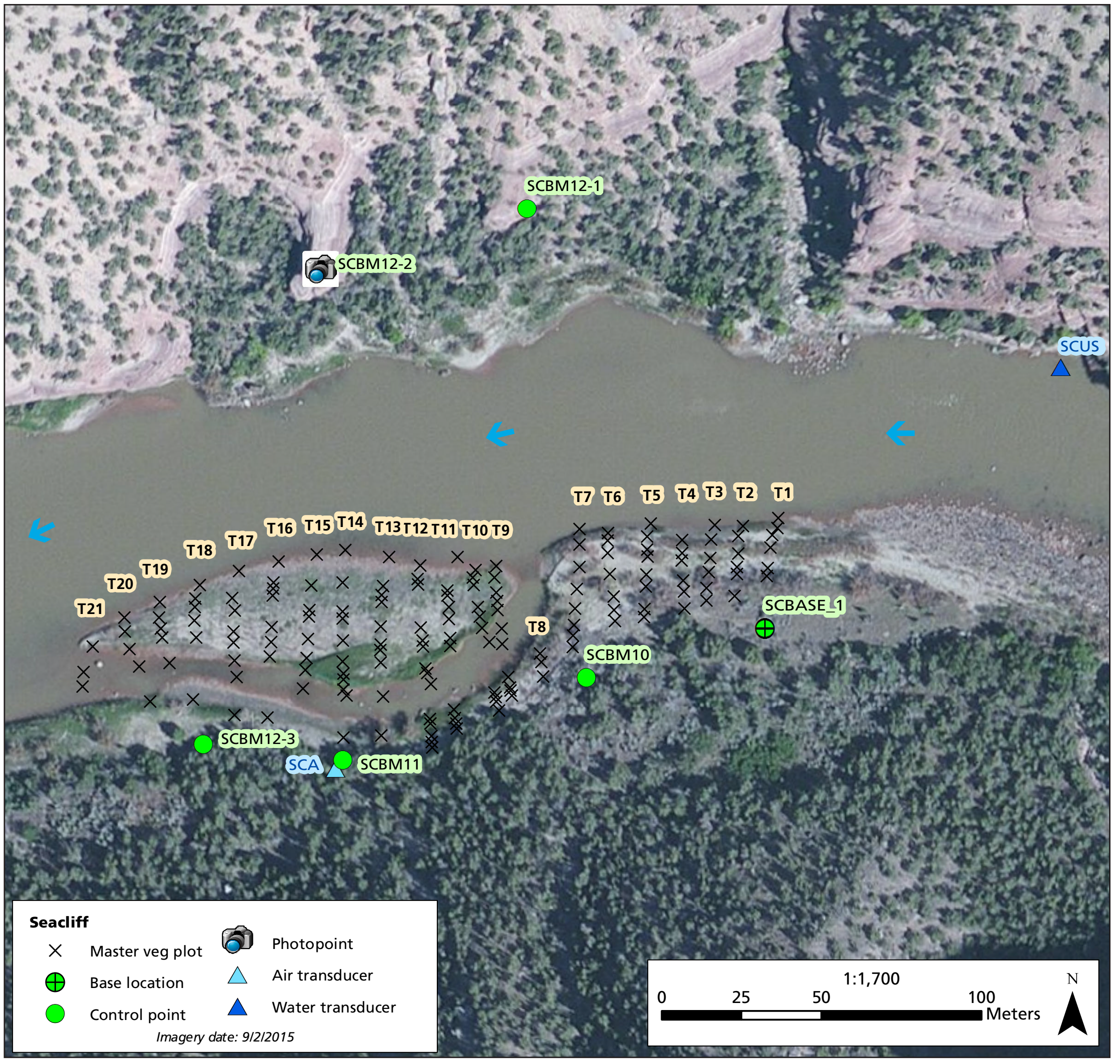


Figure 3-2. Seacliff sentinel site showing plot locations, benchmarks for surveying, air and water transducers, and overview photo locations. The downstream water transducer is not shown, as it is located 200 meters downstream. Depicting its location would have altered the scale of the graphic.

present the results from data collected from 2010 to 2014 at two sentinel sites: Deerlodge Park, in the restricted-meander alluvial channel type of the Yampa River; and Seacliff, in the debris fan-dominated channel type of Whirlpool Canyon on the Green River (see Figure 3-2).

As described above, high-resolution imagery from 2011 was used as a baseline for vegetation cover and to create geomorphic maps of active-channel surfaces, with active-channel and active-floodplain surfaces delineated at approximately 24 cms (~850 cfs) along the Yampa River (Figure 3-3). For the Green River, we used similar mapping done by Grams and Schmidt (1999). A total of nine sentinel sites were selected in Dinosaur NM to reflect a range of channel types (see Figure 3-2) and hydrologic conditions, as well as geomorphic features hypothesized to be sensitive to future channel-narrowing processes. Data collection began in 2010 for a few of the sites, with later start-times for sites added in subsequent years. Because of staff, funding, and logistical limitations, future monitoring will follow a rotating panel across sites.

3.1.1.1 Hydrology

Site hydrology was measured as stream-stage elevation across the feature being monitored. Solinst water-level dataloggers (water transducers) were installed in April and July 2013 at Seacliff and Deerlodge Park, respectively. These dataloggers were installed at or below the water level in stable locations upstream and downstream of the sentinel site. An upland (air transducer) datalogger recorded

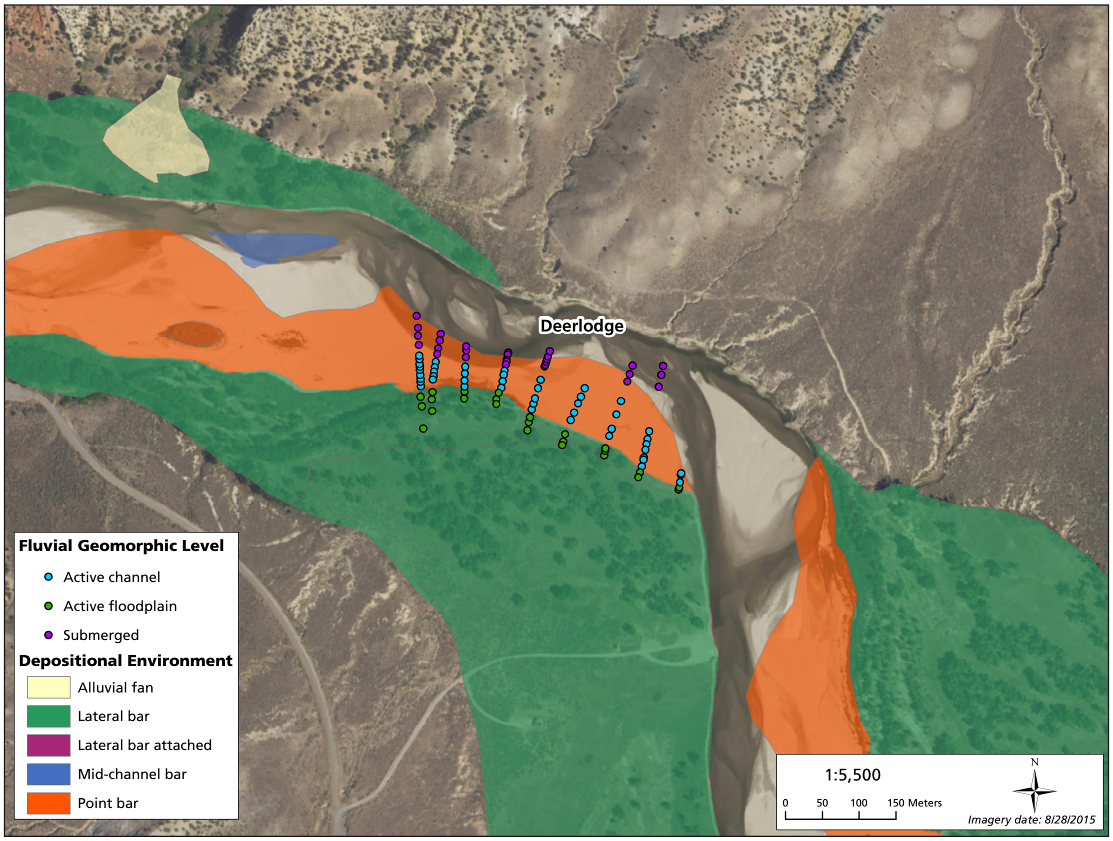


Figure 3-3. Sentinel monitoring at Deerlodge Park, showing depositional environments as identified in the geomorphic mapping of the Yampa River. The distribution of vegetation-sampling quadrats, placed as transects across active-channel and active-floodplain surfaces at the site, is also shown.

changes in atmospheric pressure (https://www.solinst.com/products/). The elevation of each transducer was surveyed for real-world location and elevation using RTK surveying. We interpolated river stage between transducers by creating a flat surface from the upstream transducer to the downstream transducer. We also estimated proportional distance of the quadrat along the theoretical river reach (for Deerlodge Park, this theoretical river reach is composed of four linear segments to account for a large bend in the river). For example, a point located halfway between the upstream and downstream transducers would have a "position of 0.5." This value was always the same for a given plot.

In conjunction with the known elevation of each surveyed vegetation quadrat, we calculated 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). Days with a tie (i.e., 12 hours underwater, 12 hours above water) were counted as underwater for the day. We limited the period of record to complete days (i.e., data for all 24 time points). Due to mounting installation issues at Seacliff, we only had data for both sites from 2014. For Deerlodge Park and Seacliff, the periods of record for 2014 were 170 and 94 days, respectively. Finally, we calculated the proportion or percent of days within the period of record when the quadrat was underwater as follows: [percent inundated] = [number of days inundated] / [days in the period of record]. Ideally, the days in the period of record would cover the entire growing season. However, because the transducers were initially not positioned low enough to capture the entire growing season at Seacliff, the period of record there was limited to 94 days. The transducers have been repositioned. Future reports will have complete records.

3.1.1.2 Geomorphology

Geomorphic measurements at the sentinel sites included bar and floodplain topography as well as near-channel bathymetry. All topographic features were surveyed using Nikon Nivo 3.M total station and Trimble RTK GPS surveying equipment. After establishing a survey control network at each sentinel site, we surveyed all vegetation quadrat elevations and transducers. Each year, topographic features (e.g., tops of banks, toes of banks, edge of water, chutes, sandcaps) were surveyed to create a topographic map of each sentinel site. Digital elevation models (DEMs; 10-cm resolution) were created from the topographic surveys. Using Geomorphic Change Detection software in ArcGIS, two years of DEMs were overlaid to show areas of erosion and deposition with a 10-cm threshold and report volumetric values of change.

3.1.1.3 Facies mapping

Facies, used here in the context of fluvial processes, are bodies of sediment that are recognizably distinct from surrounding sediments and reflect different depositional environments. Facies mapping of alluvial deposits took place on each sentinel site. The largest facies were mapped first, proceeding to the smallest. At each facies, the primary attribute was recorded by the dominant size class: boulder (>256 mm); cobble (64–256 mm); pebble (16–64 mm); gravel (2–16 mm); sand (1–2 mm); fines (<1 mm). If the facies was bimodal, then a modifier was added (e.g., bouldery, cobbley), with the first modifier being most dominant. The amount of vegetation was recorded for each facies: bare to sparse (<5%), sparse (5–25%), becoming vegetated (26–50%), vegetated (>50%).

Presence or absence of wake deposits, shadow deposits, or ridges downstream of sparse individual plants or stands was noted. Wake and shadow deposits are deposits of sand or finer sediment downstream of some form of debris or vegetation. These deposits could eventually become their own facies. Ridges are on wake or shadow deposits and are recorded if they are larger than 30 centimeters high. Large, woody debris and associated wake or shadow deposits downstream of the debris were also recorded, as was presence of small woody debris. A 360° image, created by stitching photographs together using Photosynth, was taken from a location on the facies from which the facies could best be observed.

After facies were mapped, we measured grain-size distributions with sieves and scales at two locations in each facies. No grain-size distribution measurements were conducted on boulder bars. At each site, we recorded surface and subsurface grain-size distribution. For the surface grain-size distribution measurement, we took 2–5 shovelsful from the surface and placed them into a five-gallon bucket. The material was then shaken vigorously to ensure that aggregations of smaller sediment particles made it to the next sieve. We then recoded the weight with a scale of the following four size classes: >64 mm, 16–64 mm, 2–16 mm, and <2 mm.

3.1.1.4 Vegetation

Vegetation measurements occurred near the end of the growing season. These included the random placement of 1 × 1-meter quadrats in a pre-determined number of transects systematically located across the geomorphic feature being monitored at each sentinel site, including all active-channel and active-floodplain surfaces (see Figures 3-2 and 3-3). Sampling adequacy was assessed using bootstrapping techniques and standard error of the mean estimates. The same number of transects and approximate numbers of quadrats were used in subsequent monitoring efforts. Although quadrats were not initially relocated in the same locations across sampling years, the use of RTK surveying now allows accurate relocation of sample plots at each sentinel site. Vegetation within each quadrat was assessed as percent cover to the nearest 1% for each species encountered. Total quadrat cover was also determined, as was the modal particle size, ranging from fines through boulders, according to Wentworth (1922), modified by Perkins and others (in review).

3.1.1.5 Repeat photography

Repeat photo locations that provided good overview perspectives of each sentinel site were chosen. The real-world coordinates of these photopoint locations were established by RTK surveying and a photo taken of the photopoint location, noting the date and time of day.

3.1.2 Results

3.1.2.1 Hydrology

Measurements of stream-stage hydrology at sentinel sites allowed us to classify vegetation and the geomorphic surfaces (i.e., active channel, active floodplain) on which it grew in terms of two hydrologic variables: (1) days inundated and (2) percentage of the measured time period inundated. This type of classification makes it unnecessary to rely on visual identification of surfaces, which can be subjective and could bias determination of when a surface transitions from one 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 for identifying geomorphic surfaces and detecting transitions from one surface type to another.

Transducers were in place only for the 2014 field season. We used the stream-stage hydrology data from the Deerlodge Park and Seacliff sentinel sites to illustrate how the field classification of vegetation quadrats by geomorphic surface type was reclassified to reflect the inundation characteristics of these quadrats. First, the mean and standard deviation of the percentage of days inundated during the measurement period were calculated for all field-classified active-channel, active-floodplain, and transitional (active-channel/active-floodplain) quadrats. Because the active channel in Deerlodge Park was largely devoid of vegetation, field classifications of quadrats at that site were either active-channel or active-floodplain. In contrast, at the Seacliff sentinel site, as at other sites in canyon-bound settings, there was a gradient of vegetation cover from the active channel to active floodplain. Therefore, field classification included quadrats identified as transitional (AC/AF) based on position and amount of vegetation cover.

At both sentinel sites, averages for percentage of the study period inundated differed notably between quadrats classified as active-channel versus active-floodplain. In general, active-channel quadrats at both sites had average inundation percentages of 45% or more, whereas active-floodplain quadrats averaged less than 10%. A few quadrats in each of these categories were clearly misclassified in the field. For example, a quadrat classified in the field as active-floodplain was inundated for more than 80% of the study period and therefore reclassified as active-channel. Also, a number of plots classified as transitional at Seacliff averaged around 15% inundation, with a few averaging near 50% and others less than 10%. Accordingly, quadrats were sorted into three groups: active-channel (≥45% inundation); transitional (≥10% and <45% inundation); and active-floodplain (<10% inundation) at each sentinel site, based on how well quadrat percent inundation matched the average inundation of the initial classification.

Vegetation data were also used to support reclassifications. For example, when reclassifying a quadrat from active-channel to active-floodplain, the presence of floodplain indicator species in the quadrat provided supporting evidence for the reclassification. Following reclassification of quadrats, means and standard deviation of inundation percentages for each geomorphic surface were calculated for the two sentinel sites. The results are summarized in Table 3-1, and show

Table 3-1. Summary of the mean percentage of the 2014 study period inundated for three different geomorphic surface types at the Deerlodge Park and Seacliff sentinel sites.

Geosurface	Mean percentage of study period inundated (± std. dev.)	
	Deerlodge Park	Seacliff
Active channel	46 (±8)	57 (±23)
Transitional (active channel/active floodplain)	19 (±10)	22 (±2)
Active floodplain	5 (±6)	5 (±6)

Reclassification of field-identified quadrats was based on inundation characteristics and supported by the presence or absence of indicator species for active-channel and active-floodplain surfaces (see Table 2-5).

relatively close agreement for each surface between the sites. With more information on inundation across years, we expect to develop a statistically robust way of reclassifying quadrats based on hydrologic characteristics.

3.1.2.2 Geomorphology

The Geomorphic Change Detection software allowed us to provide a spatially explicit quantification of volumetric change in the alluvial material composing our sentinel sites. The location, volume of alluvial material eroded and deposited, and the net change in the lateral bar that represents the Deerlodge Park sentinel site are summarized in Figures 3-4 to 3-8. Results show that although both erosion and deposition were occurring across the site, relatively large net erosion occurred in the low-flow years of 2012 and 2013, and there was overall net erosion between 2011 and 2014. This could be due in part to net deposition in the flood year of 2011 (see Figures 3-4, 3-8), but we do not have data for that year. Peak flow in 2012 was only in the 7th percentile, yet still resulted in some net erosion from 2011 (Figures 3-5, 3-8). Net deposition occurred in 2014, in association with a somewhat larger-than-average peak flow (Figures 3-6, 3-8). However, over the three years examined (2012–2014), there was net erosion of nearly 8,000 cubic meters on the sentinel site bar and adjacent floodplain (Figures 3-7, 3-8).

Interpretation of changes in channel geometry at the feature and channel-type scales will require an understanding of baseline variability under the current streamflow and sediment regimes. Metrics such as channel width, amount of erosion and deposition, and elevation change associated with changes in indicator plant species will all help us to establish this baseline and evaluate the level of future changes. At Deerlodge Park, near the confluence with the Little Snake River, the Yampa River supplies the majority of the streamflow, while the Little Snake River provides the majority of sediment (~70%) (Andrews 1978; 1986). Because of this, any depletion of flow on the Yampa upstream of Dinosaur NM, with continued inputs of sediment from the Little Snake, would result in sediment surplus in Deerlodge Park and, likely, notable channel narrowing (Grams and Schmidt 2005; Schmidt and Wilcock 2008). The recent installation of sediment gages on the Yampa, Little Snake, and Green rivers upstream and downstream of the monument will be critical to anticipating, monitoring, and interpreting long-term channel change.

The location, volume of alluvial material eroded and deposited, and the net change in the lateral bar that represents the Seacliff sentinel site are summarized in Figures 3-9 to 3-13. Results show a more stable site than Deerlodge Park, due in part to larger sediment sizes in a debris fan-affected channel type (versus sand in the alluvial, restricted-meander channel type at Deerlodge Park). Over a four-year period, portions of the adjacent floodplain and the sandcap along the backchannel edge of the bar grew in size and height (Figure 3-13). Most other areas only had small changes in erosion and deposition between years and over the period examined here. Overall, there was net deposition of about 100 m^3 on the site from 2011 to 2014 (versus nearly 8,000 m^3 net erosion at Deerlodge Park) (Figures 3-9, 3-13).

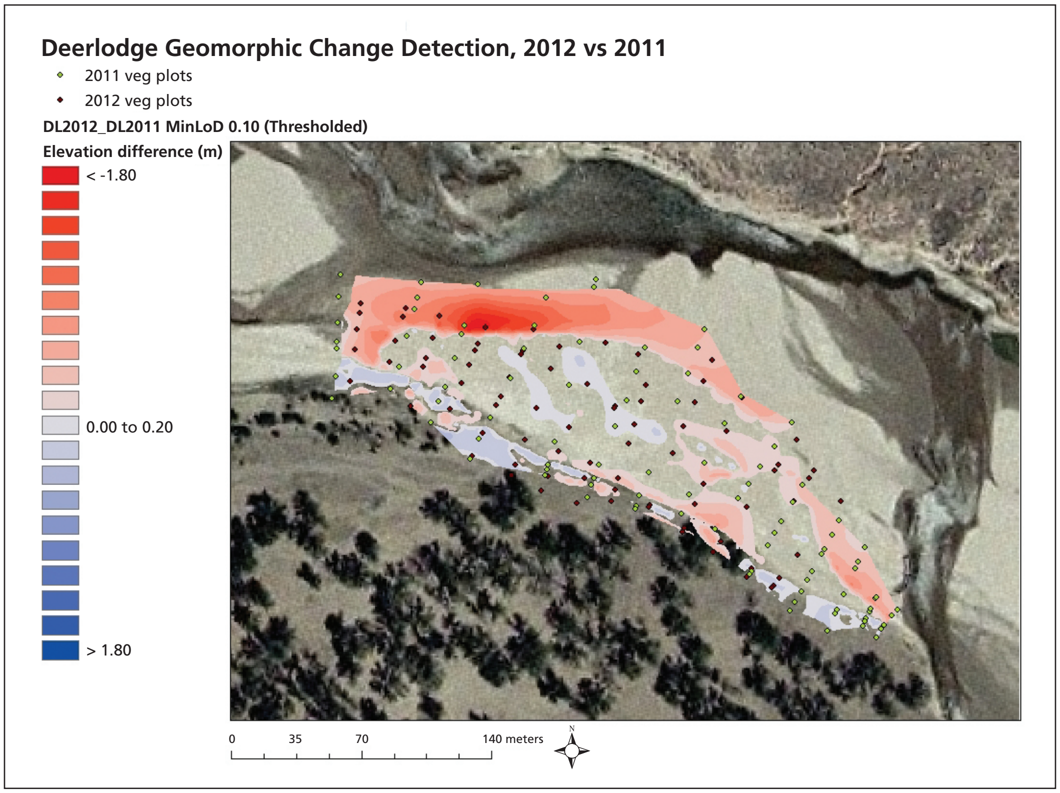


Figure 3-4. Planview of the Deerlodge Park sentinel site, depicting spatial areas of erosion (red shading) and deposition (blue shading) between 2011 and 2012. The figure was thresholded to only show differences greater than 10 centimeters. Figure shows erosion at the downstream end of the site. Flow is from right to left in the image.

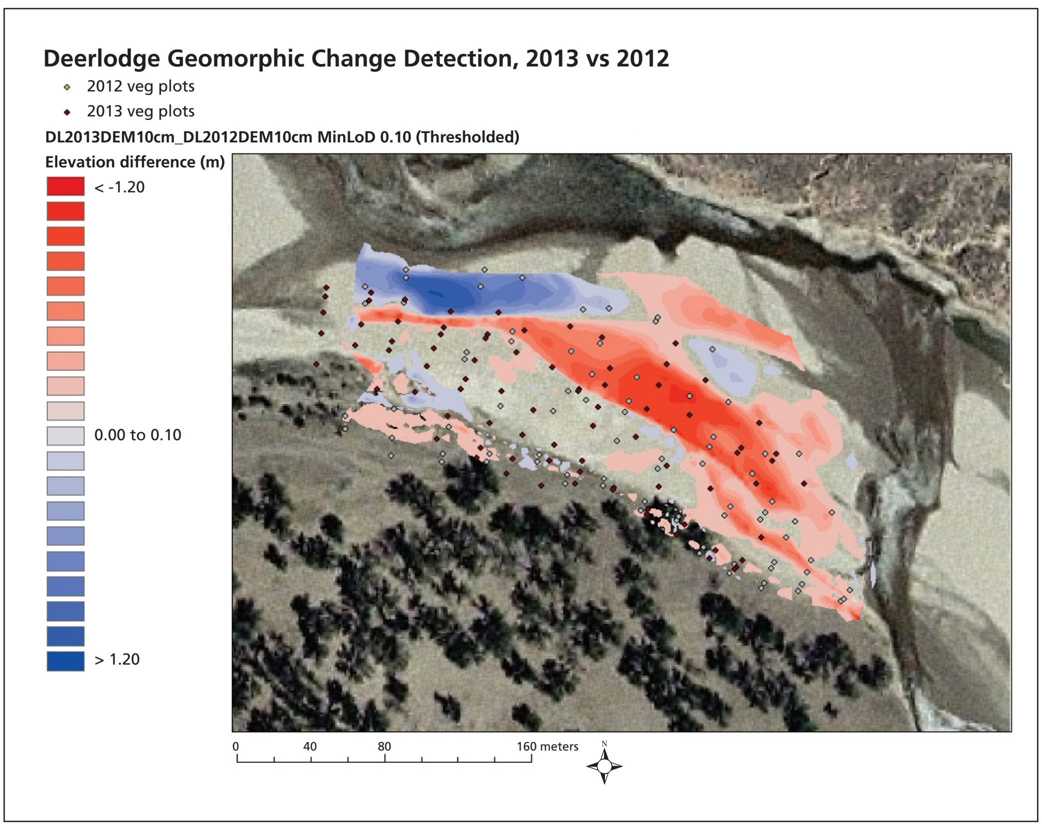


Figure 3-5. Planview of the Deerlodge Park sentinel site, depicting spatial areas of erosion (red shading) and deposition (blue shading) between 2012 and 2013. The figure was thresholded to only show differences greater than 10 centimeters. Figure shows erosion at the center and right side (upstream) and deposition at the downstream end of the site. Flow is from right to left in the image.

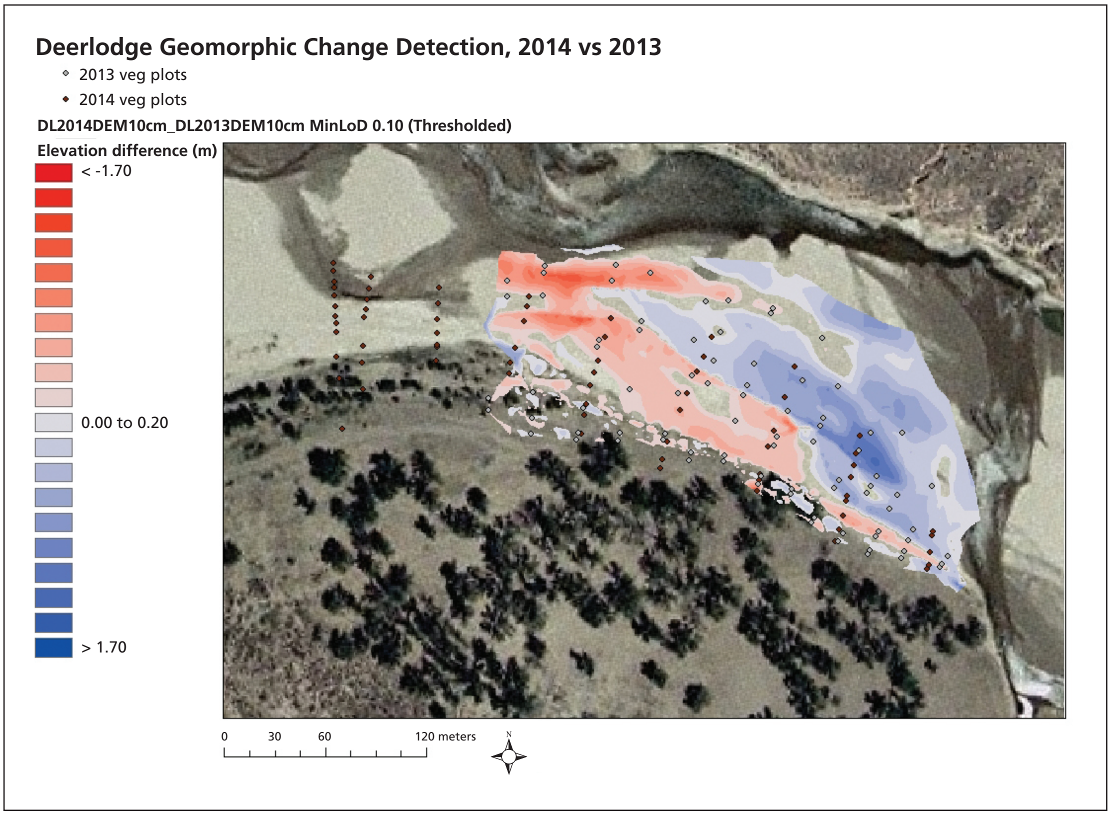


Figure 3-6. Planview of the Deerlodge Park sentinel site, depicting spatial areas of erosion (red shading) and deposition (blue shading) between 2013 and 2014. The figure was thresholded to only show differences that are greater than 10 centimeters. Figure shows deposition at the center and right side (upstream) and erosion at the downstream end and left side of the site. Flow is from right to left in the image.

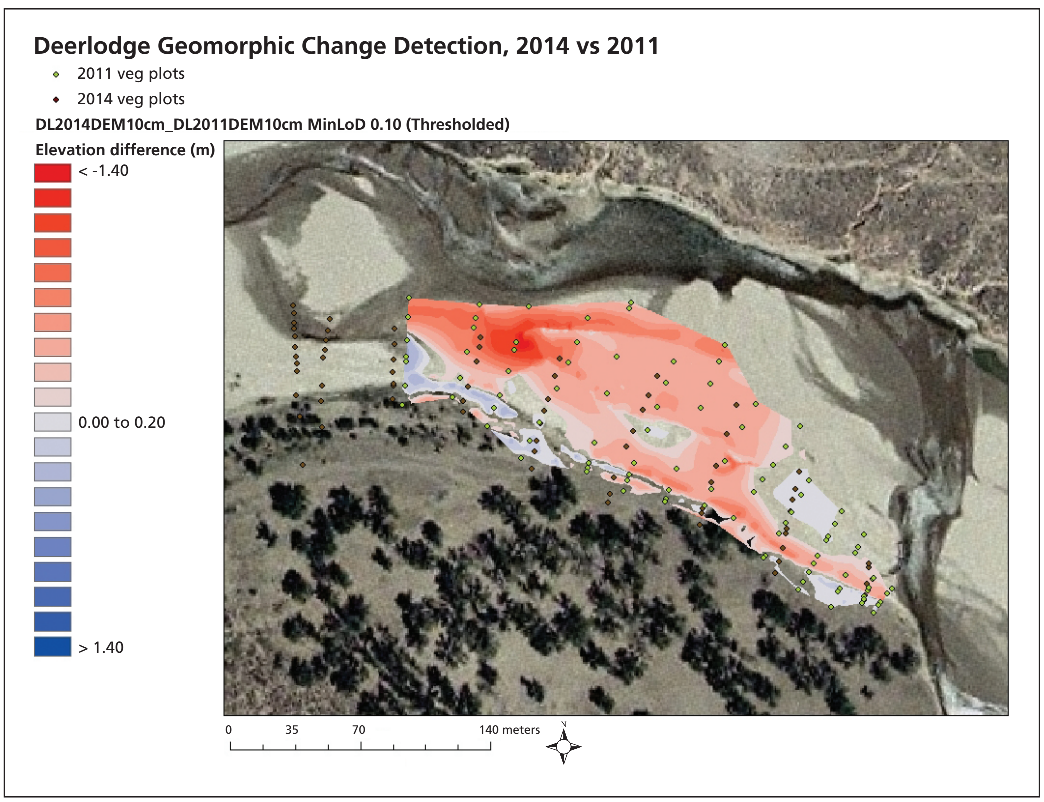


Figure 3-7. Planview of the Deerlodge Park sentinel site, depicting spatial areas of erosion (red shading) and deposition (blue shading) between 2011 and 2014. The figure was thresholded to only show differences greater than 10 centimeters. Figure shows general erosion of the site. Flow is from right to left in the image.

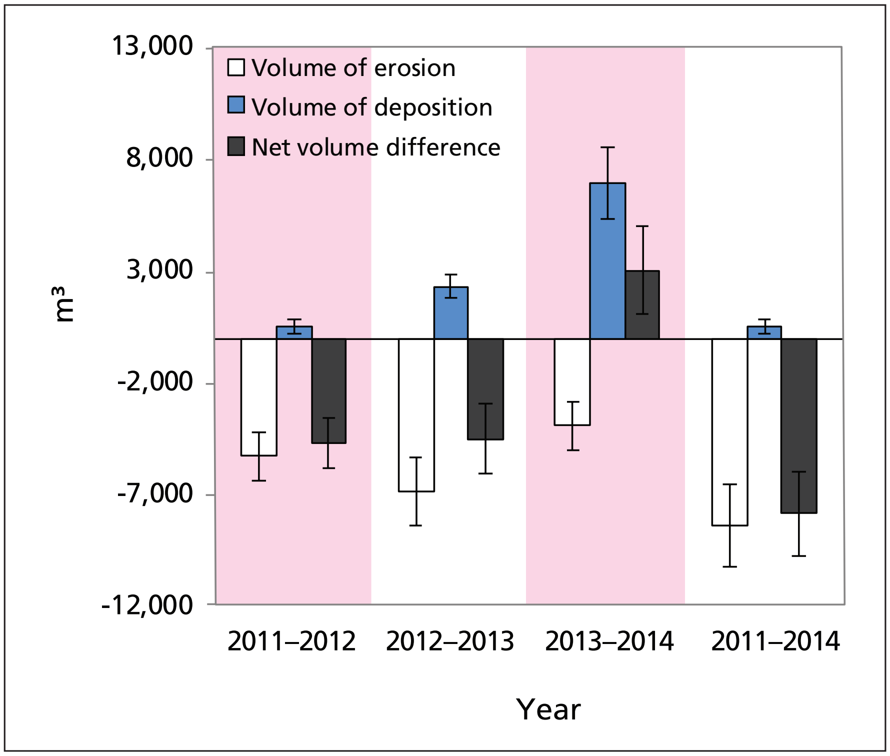


Figure 3-8. Total volume of erosion, deposition, and net volume difference at the Deerlodge Park sentinel site, 2011–2014.

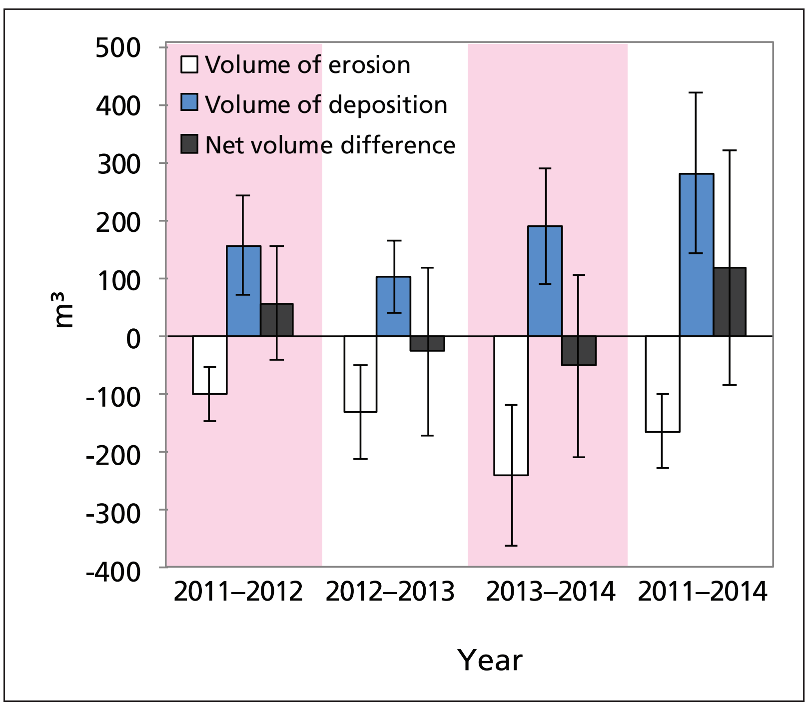


Figure 3-9. Total volume of erosion, deposition, and net volume difference at the Seacliff sentinel site, 2011–2014.

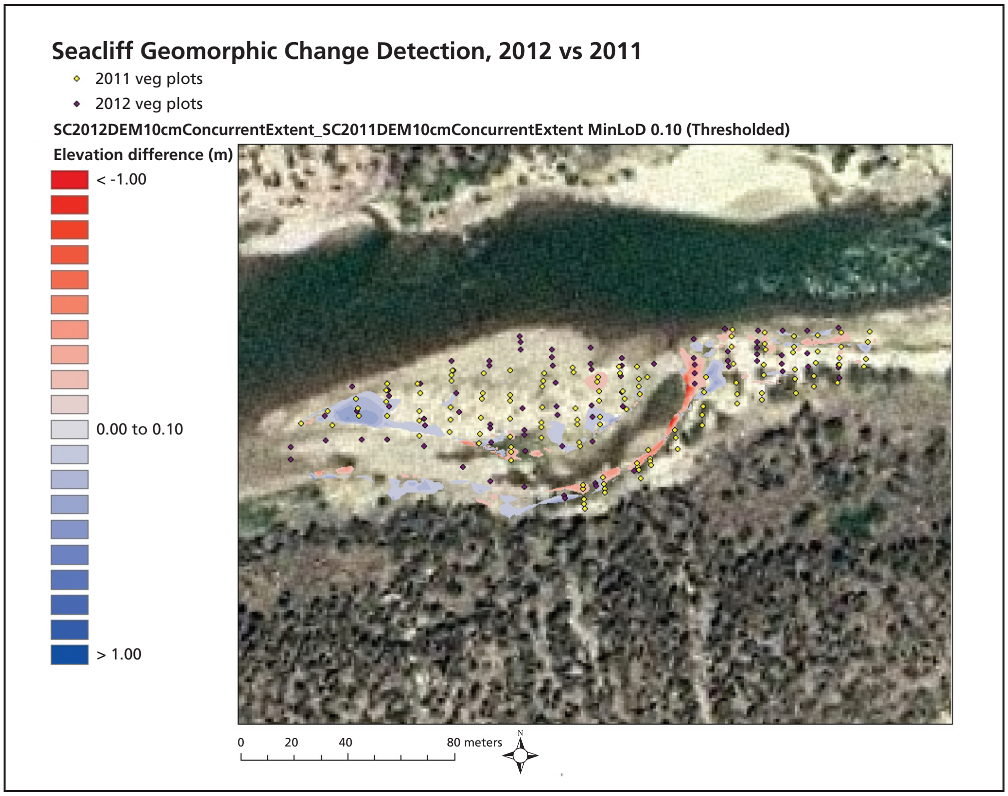


Figure 3-10. Planview of the Seacliff sentinel site, depicting spatial areas of erosion (red shading) and deposition (blue shading) between 2011 and 2012. The figure was thresholded to only show differences greater than 10 centimeters. Figure shows little change other than some deposition at the downstream end of the site. Flow is from right to left in the image.

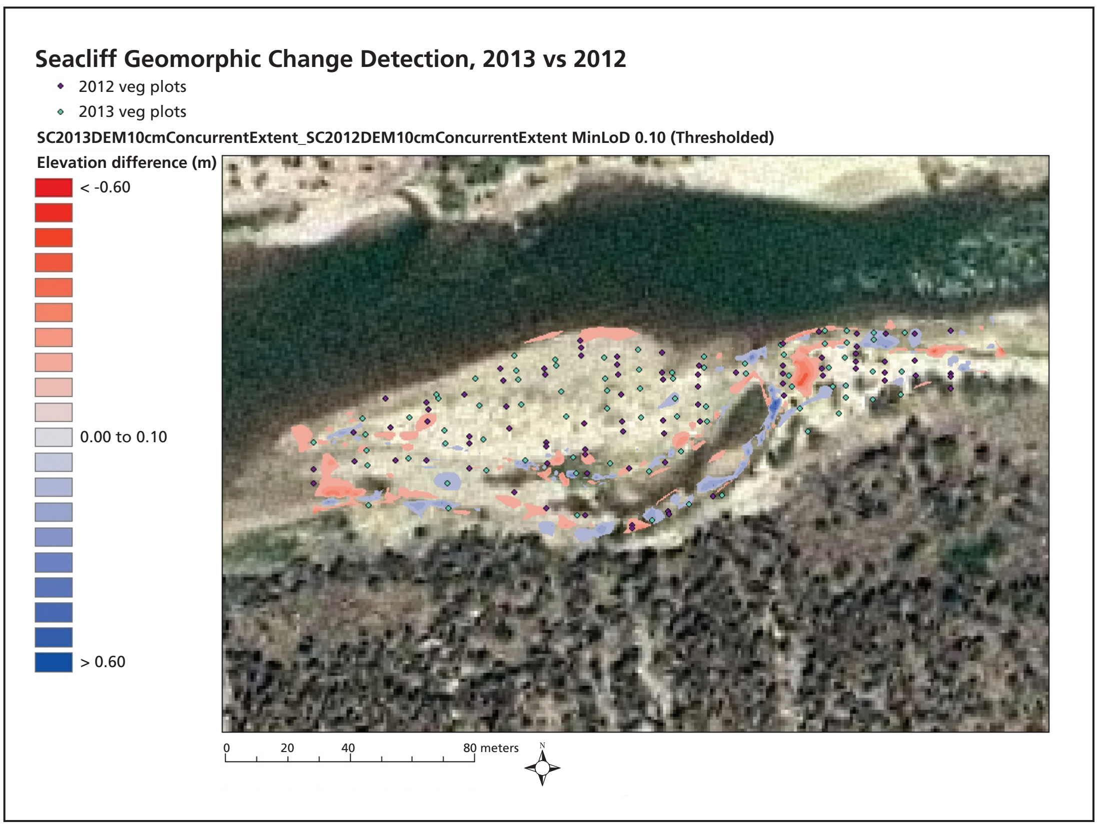


Figure 3-11. Planview of the Seacliff sentinel site, depicting spatial areas of erosion (red shading) and deposition (blue shading) between 2012 and 2013. The figure was thresholded to only show differences greater than 10 centimeters. Figure shows little change between the two sample periods. Flow is from right to left in the image.

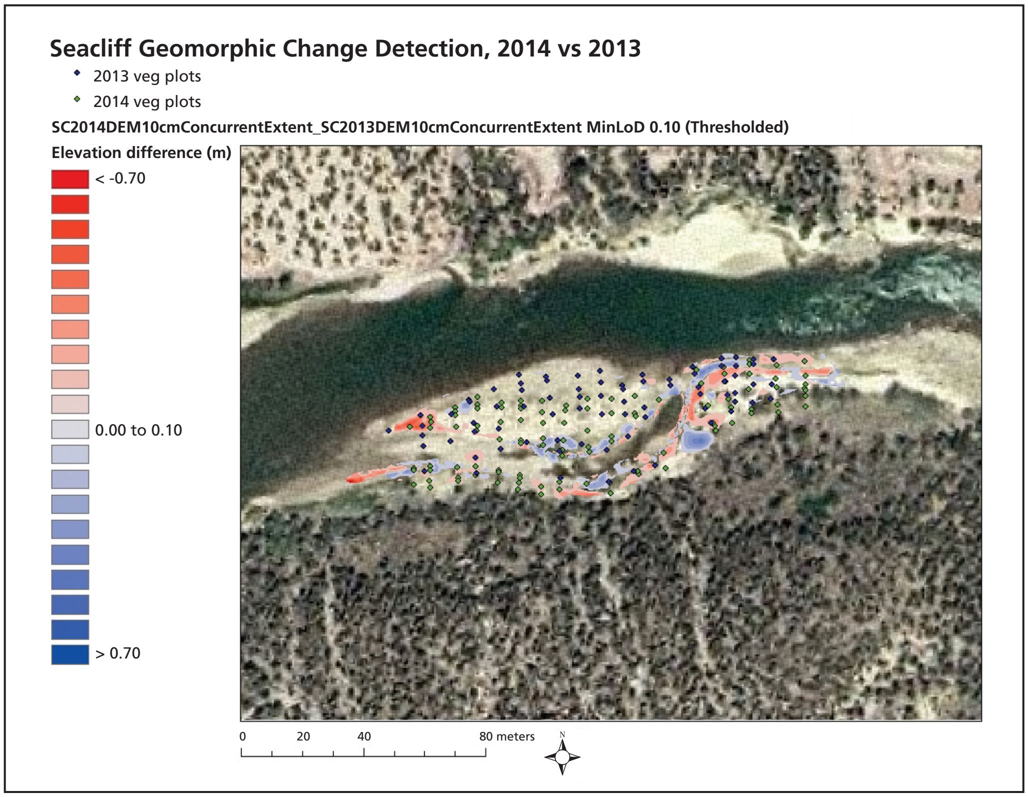


Figure 3-12. Planview of the Seacliff sentinel site, depicting spatial areas of erosion (red shading) and deposition (blue shading) between 2013 and 2014. The figure was thresholded to only show differences greater than 10 centimeters. Figure shows some erosion at the downstream end of the site with erosion and deposition at the upstream end. Flow is from right to left in the image.

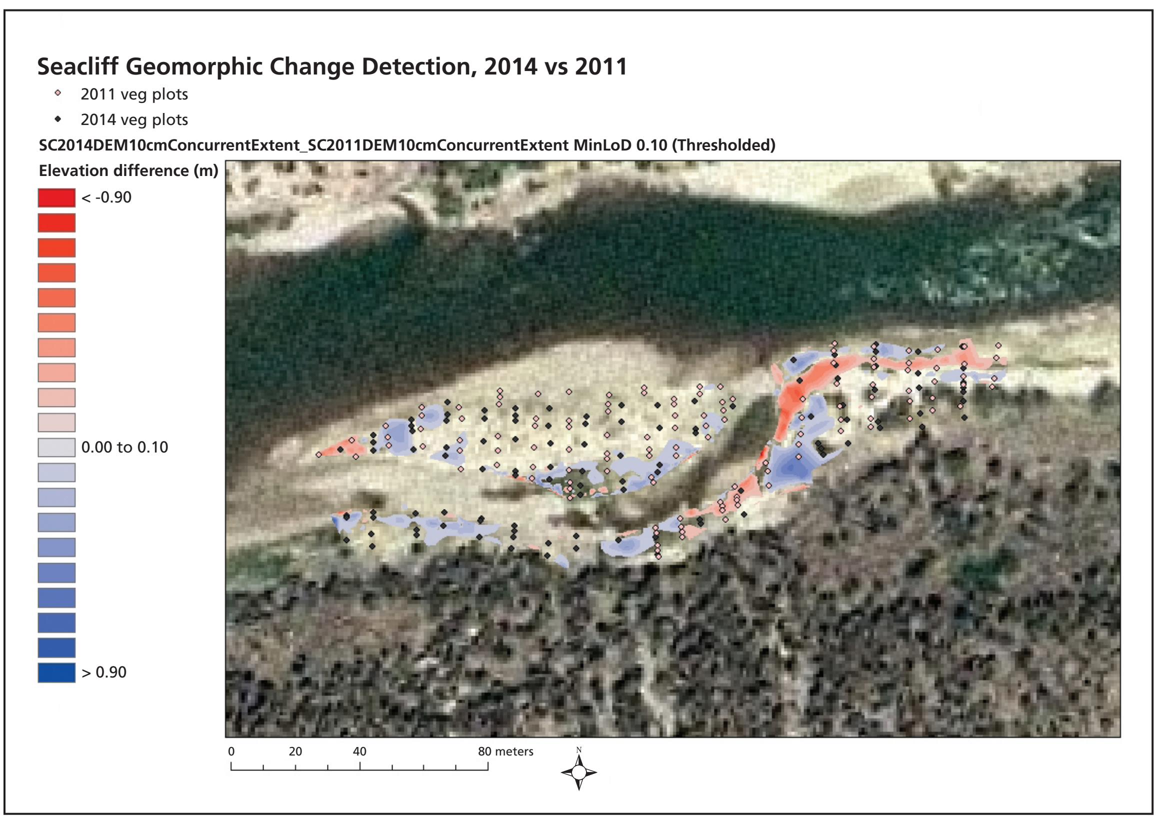


Figure 3-13. Planview of the Seacliff sentinel site, depicting spatial areas of erosion (red shading) and deposition (blue shading) between 2011 and 2014. The figure was thresholded to only show differences greater than 10 centimeters. Figure shows some deposition on the sandcaps in the center of the site and mixed deposition and erosion at the downstream and upstream ends. Flow is from right to left in the image.

3.1.2.3 Facies mapping

Facies mapping is designed to detect changes in size and composition of substrate at a sentinel site. In some instances, it may indicate a type of channel-narrowing state change. For example, if, in the process of narrowing, a cobble bar became progressively covered by a deposit of sand, this would be noted in facies maps. In other instances, facies mapping may demonstrate the effects of different flows on the sentinel site.

At Deerlodge Park, there is one large sand facies (Figure 3-14) that was mapped consistently between 2013 and 2014. Grain-size distributions were very similar in this facies between 2013 and 2014 (Figure 3-15). In 2013, the observer noted a pebbly-gravel facies on the river right side of the sand facies, while in 2014 the observer detected a much smaller sandy-cobble facies in the same general area (Figure 3-14). The decrease in size of this facies may have been due to deposition in this area between 2013 and 2014 (see Figure 3-6).

The Seacliff facies were stable between 2013 and 2014. Grain-size distributions were also similar between years (Figures 3-16 and 3-17). The 2013 sandy cobble facies at the upstream end of the island was called pebbly sand in 2014 (Figure 3-16), yet the grain-size distribution for surface and subsurface remained similar (Figure 3-17). Small size changes in individual facies can be the result of different observers.

3.1.2.3 Vegetation

Summary results of vegetation monitoring at the Deerlodge Park and Seacliff sentinel sites are presented in Tables 3-2 and 3-3. Vegetation data for these sites include 2010, one year prior to the defined baseline year of 2011.

On the Yampa River, 2011 featured the largest average daily flow (i.e., largest annual flow), the second-largest flood on record, and highest average daily flow for July (Table 3-4, Figure 3-18). Flow patterns along the Green River at Seacliff (as judged by the gage at Jensen, UT) were similar to the Yampa for 2010–2014, yet were somewhat less variable (Figure 3-19). This reduced variation was likely because the regulated Green River contributes approximately half of the flow at Seacliff (Table 3-5, Figure 3-19). Annual average daily flow during the monitoring period ranged from the 6th to 84th percentiles on the Green River and the 1st to 93rd percentiles on the Yampa (Tables 3-4 and 3-5).

Results from both sites showed similar levels and trends in vegetation cover on active-floodplain surfaces, with distinct decreases in cover following the high flow of 2011 (Figure 3-20). In 2011, extensive areas of the floodplain were covered by alluvial sand deposits at Seacliff after the flood. Vegetation cover remained low in the two subsequent, low-flow years. In 2014, there was a high peak and high base flow, as well as an increase in vegetation to near-2010 cover values of approximately 27% mean total cover across both sites.

Plant cover and trends in plant cover were distinctly different on active-channel surfaces. In part, this reflects differences in channel setting, geomorphic processes, and flow modification between the two sentinel sites (Figure 3-20). For example, active-channel bars in the alluvial setting of Deerlodge Park were sand-dominated and reworked by spring flows. The lateral bar that forms the Deerlodge Park sentinel site is likely reworked and re-deposited during most peak flows. Thus, it was largely devoid of vegetation, except for those plants that establish each year following recession of flow (see Figures 3-4 to 3-7 for planviews; see Figure 3-21 for photos of these types of changes). Also, because of relatively large stream-stage fluctuations on the Yampa, the sandy, higher, and less-frequently inundated portions of the bar can become dry during the growing season and they are not easily colonized by perennial vegetation. Thus, cover remained very low in the active channel at the Deerlodge Park sentinel site, with values consistently at or below 1% mean total cover.

The increase in cover in the active channel observed in 2014 was due in part to high cover values in two plots. Active-channel plot AC 29 had adult willow (*Salix exigua*) cover and, based on hydrology, was considered a transitional active-channel/active-floodplain quadrat. Active-floodplain plot AF 7 contained relatively high cover of three floodplain-indicator species. AF 7 plot was reclassified to an active-channel quadrat because of high estimated inundation values. None-

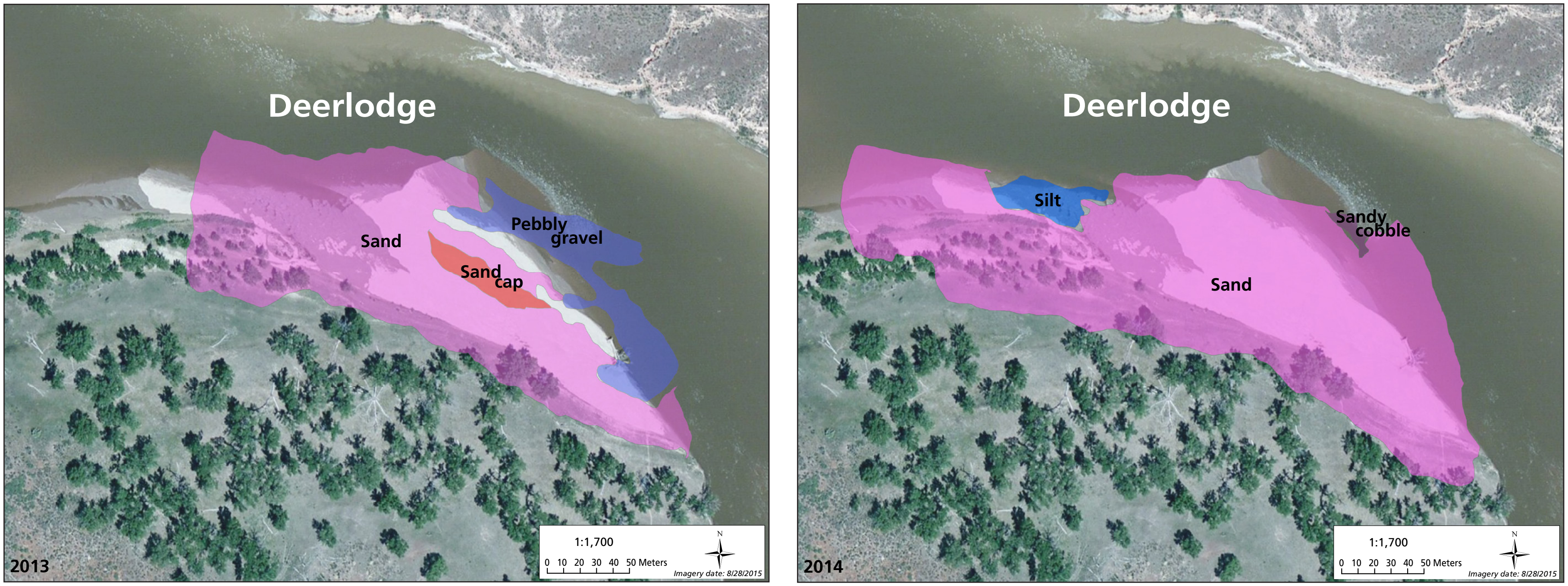


Figure 3-14. Facies mapping from the Deerlodge Park sentinel site, 2013 and 2014. Figure shows a large, stable sand facies with changing facies on the river-right side of the sand facies, dependent on flows. Facies mapping is designed to detect state changes. Small size changes in individual facies can be the result of different observers. Flow is from right to left in the image; river-right is toward the top of the image.

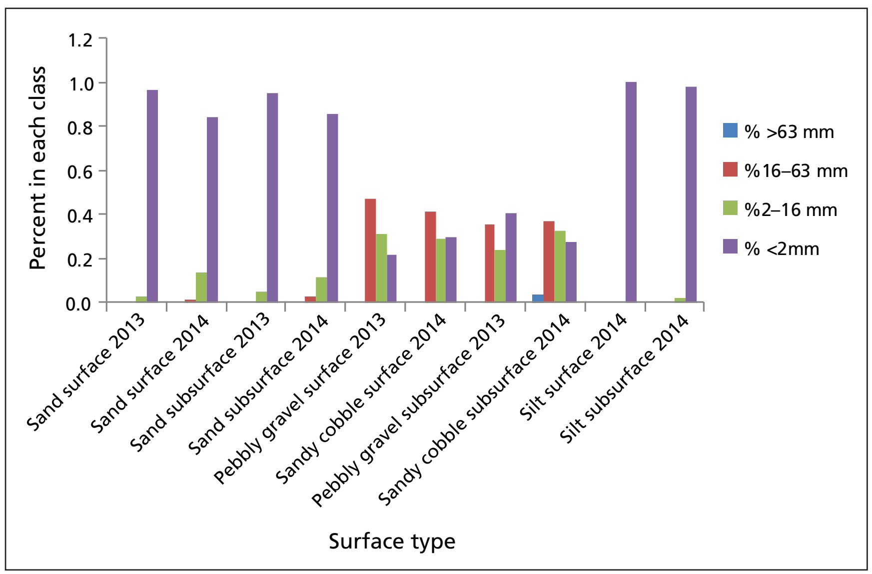


Figure 3-15. Surface and subsurface grain-size distributions from the facies at the Deerlodge Park sentinel site in 2013 and 2014.

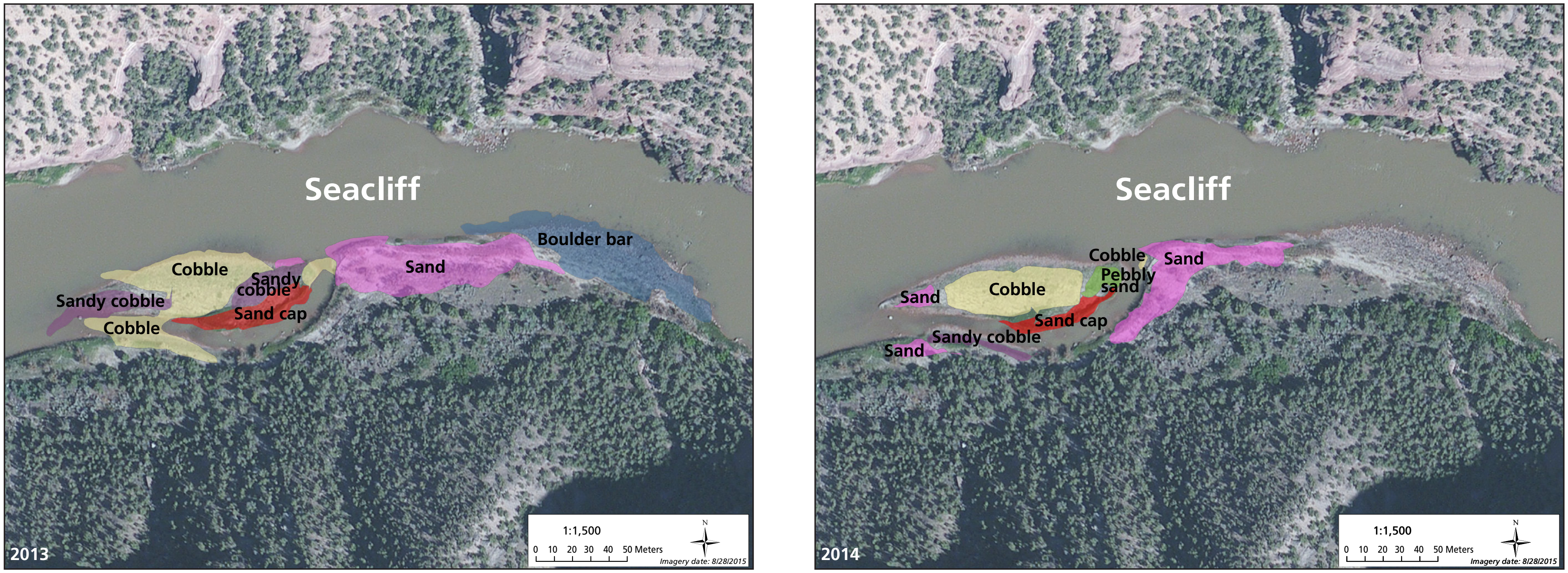


Figure 3-16. Facies mapping from the Seacliff sentinel site. Figure shows a largely stable site from 2013 to 2014. Facies mapping is designed to detect state changes. Small size changes in individual facies can be the result of different observers. Flow is from right to left in the image.

Figure 3-17. Surface and subsurface grain-size distributions from the facies at Seacliff sentinel site in 2013 and 2014.

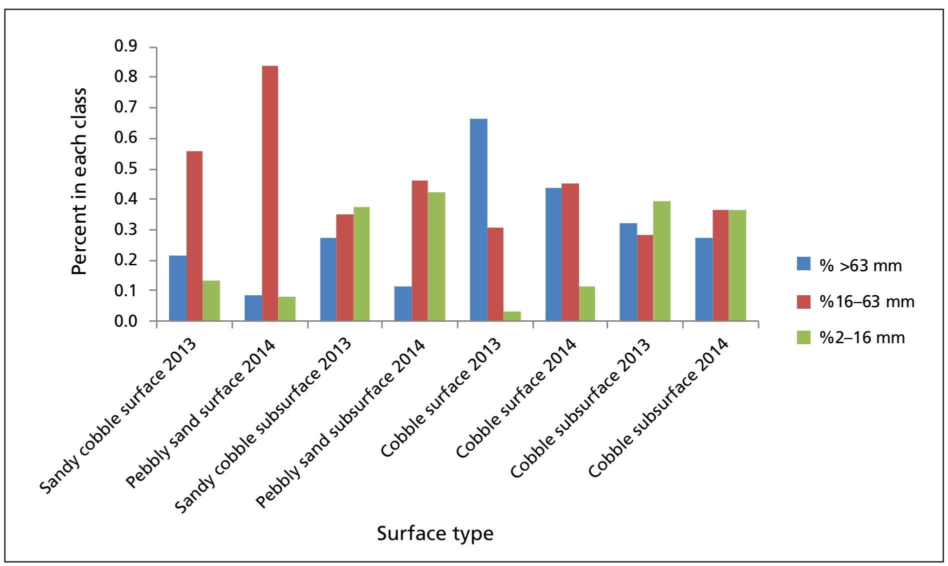


Table 3-2. Summary of vegetation cover and dominant substrate type from the Deerlodge Park sentinel site for active-channel (AC) and active-floodplain (AF) surfaces.

	Vegetation (AC)		Substrate (AC)			Vegetation (AF)		Substrate (AF)		
Year	Mean total cover (%) (SE)	% quadrats occupied	Dominant substrate	% quadrats occupied	n	Mean total cover (%) (SE)	% quadrats occupied	Dominant substrate	% quadrats occupied	n
2010	0.04 (0.02)	7	Sand	89	54	29.2 (4.8)	100	Sand	100	21
2011	0.2 (0.08)	8	Sand	97	62	12.3 (1.7)	100	Fines	63	32
2012	0.3 (0.2)	7	Sand	94	54	15.5 (2.3)	100	Sand	100	25
2013	#0.46 (0.24)	24	Sand	67	55	11.0 (1.2)	100	Sand	100	28
2014	#1.3 (1.1)	15	Fines	50	46	22.0 (3.6)	89	Fines	68	28

Sampling dates in all years were late summer, post-snowmelt flood.
S=sand; C=cobble; #=Includes transitional active floodplain quadrats (AC/AF)
#includes transitional active floodplain quadrats

Table 3-3. Summary of vegetation cover and dominant substrate type from the Seacliff sentinel site for active-channel and active-floodplain surfaces.

	Vegetation (AC)		Substrate (AC)			Vegetation (AF)		Substrate (AF)		
Year	Mean total cover (%) (SE)	% quadrats occupied	Dominant substrate	% quadrats occupied	n	Mean total cover (%) (SE)	% quadrats occupied	Dominant substrate	% quadrats occupied	n
2010	10.7 (1.3)	100	Cobble	68	25	25.8 (3.6)	100	Sand	92	25
2011	16.9 (1.7)	100	Cobble	44	73	15.2 (2.6)	85	Sand	96	46
2012	#4.3 (0.5)	96	Sand	56	55	13.3 (3.4)	97	Sand	100	28
2013	#5.2 (0.8)	95	Sand	58	57	13.1 (3.7)	100	Sand	100	20
2014	#19.4 (2.5)	99	Sand	50	74	18.8 (3.2)	100	Sand	91	32

#includes transitional active floodplain quadrats

Table 3-4. Average daily flow (ADF) and peak flow and percentile for the Yampa River, Deerlodge Park (#09260050) stream gage, 2010–2014.

Year	Annual (ADF)		July (ADF)		August (ADF)		Peak flow	
	cfs	Percentile	cfs	Percentile	cfs	Percentile	cfs	Percentile
2010	2,131	43	1,305	43	418	43	17,400	19
2011	4,431	1	8,703	1	1,097	10	27,400	2
2012	973	93	136	97	98	90	5,980	94
2013	1,112	83	312	87	157	73	10,100	61
2014	2,331	33	1,264	47	719	20	16,900	26

Flows are in cubic feet per second (cfs). Percentiles based on flows from 1983 to 2014.

Figure 3-18. Hydrograph of Yampa River discharge at Deerlodge Park featuring peak flows from 2010 to 2014. The average two-year recurrence flow calculated for the period 1923–2011 (Manners et al. 2014) is indicated. This is the discharge considered necessary to inundate the active floodplain. We present discharge in cubic feet per second here to be consistent with reported gage information.

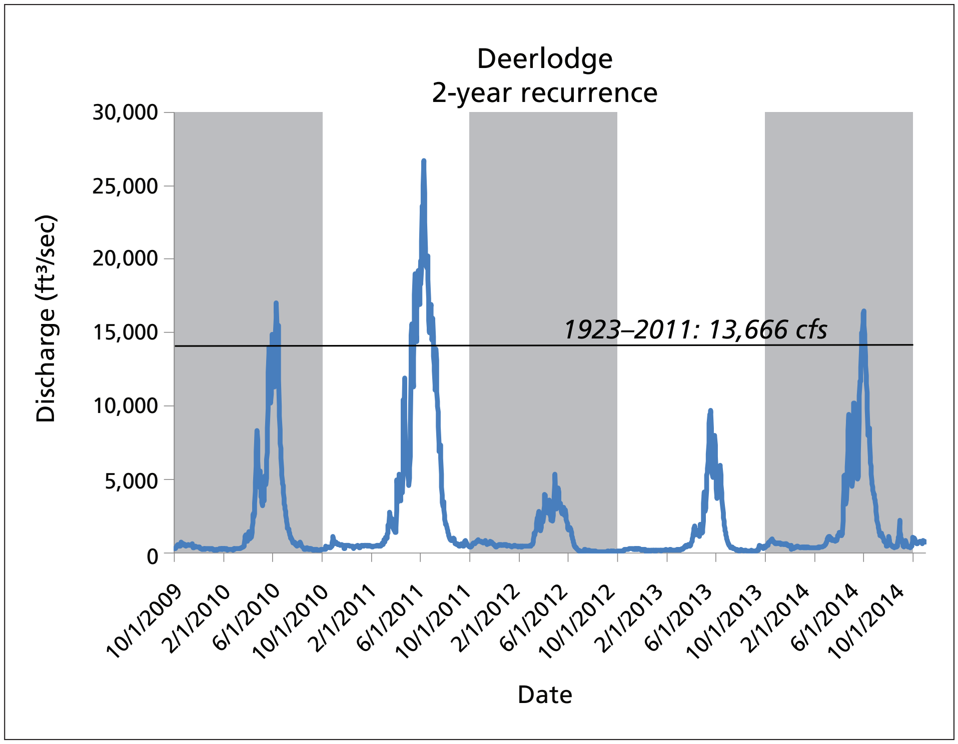


Figure 3-19. Hydrograph of Green River discharge at Jensen, UT, featuring peak flows from 2010 to 2014. The average two-year recurrence flow calculated for the pre- and post-dam periods (Grams and Schmidt 2002) is indicated. This is the discharge considered necessary to inundate the active floodplain. We present discharge in cubic feet per second here to be consistent with reported gage information.

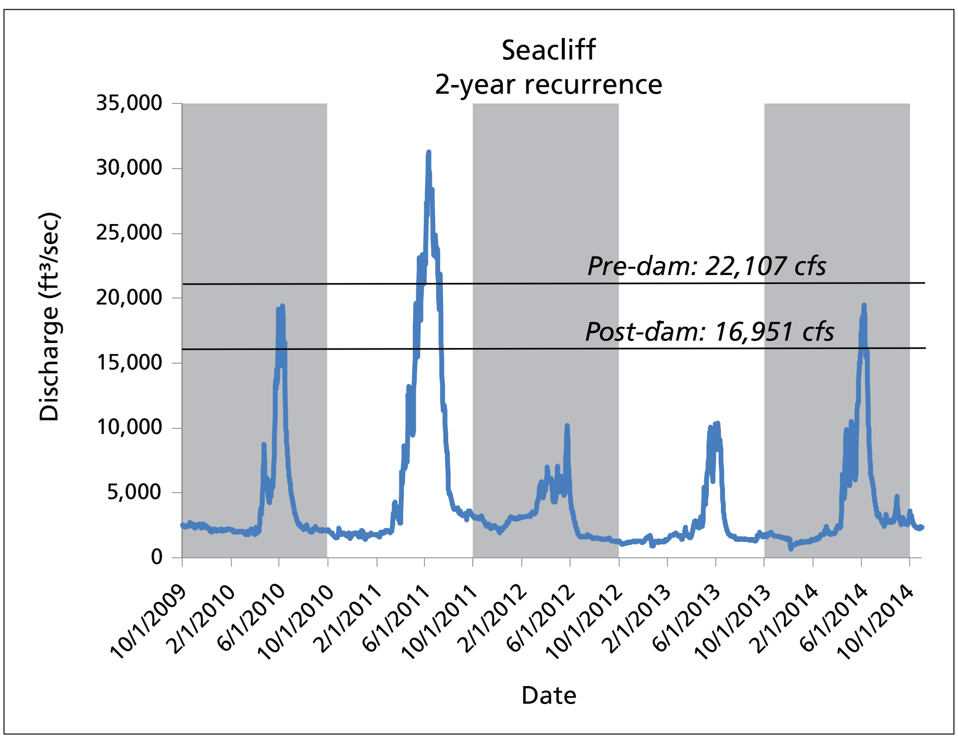


Table 3-5. Average daily flow (ADF) and peak flow and percentile, Green River near Jensen, UT (#09261000) stream gage, 2010–2014.

Year	Annual (ADF)		July (ADF)		August (ADF)		Peak flow	
	cfs	Percentile	cfs	Percentile	cfs	Percentile	cfs	Percentile
2010	3,818	50	3,168	50	2,199	34	20,500	28
2011	7,230	6	14,730	6	4,007	9	32,200	3
2012	3,138	66	1,611	84	1,469	69	10,600	84
2013	2,409	84	1,615	81	1,417	75	11,000	78
2014	3,866	41	3,390	44	3,096	16	20,100	34

Flows are in cubic feet per second (cfs). Percentiles based on flows from 1983 to 2014.

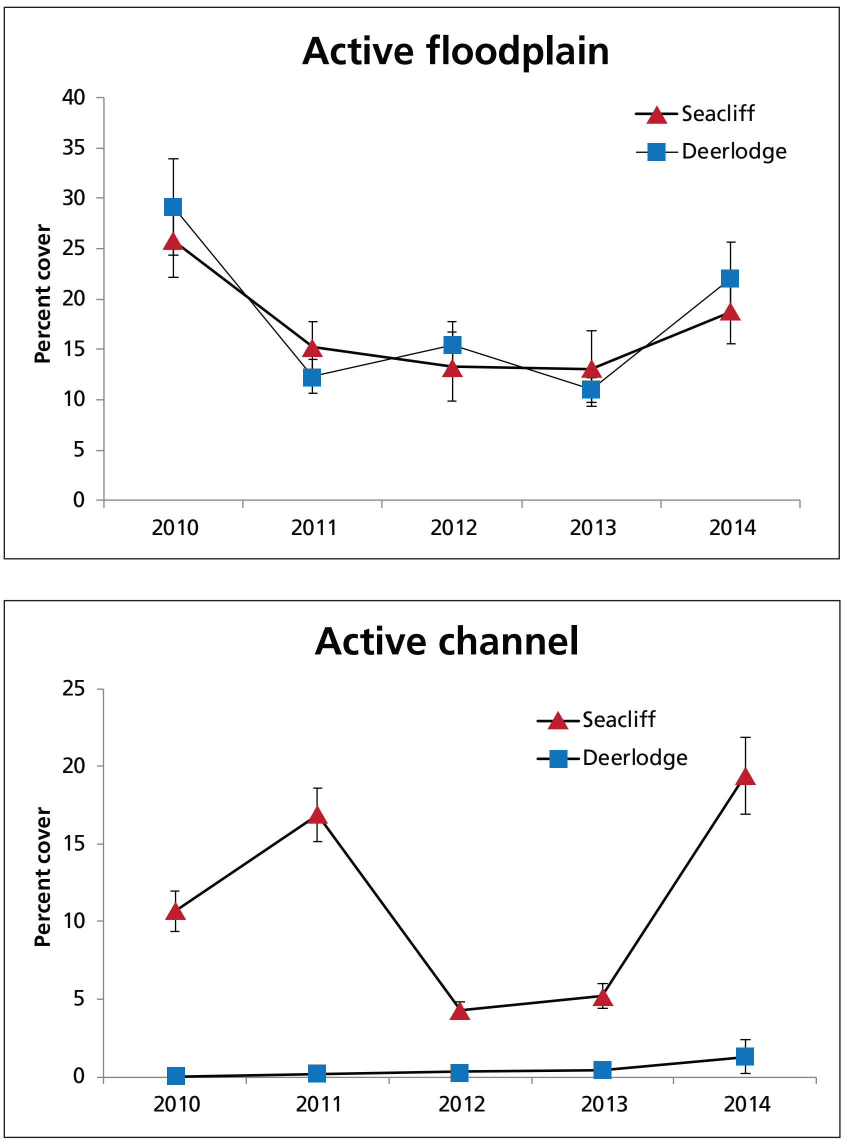


Figure 3-20. Percent cover of vegetation on active-channel and active-floodplain surfaces for the Seacliff and Deerlodge Park sentinel sites, as measured in the field in 2010–2014. Sampling dates in all years are late summer, July–September, post-snowmelt flood.

theless, vegetation cover for active-channel surfaces in Deerlodge Park remained well below values for active-channel deposits in canyon-bound channel settings, such as in Yampa and Whirlpool canyons.

The active-channel bar at the Seacliff sentinel site is an expansion gravel bar formed below a debris fan in the debris fan-dominated channel type of Whirlpool Canyon (Grams and Schmidt 1999). Here, as on other gravel bars in canyon settings on both the Yampa and Green rivers, a number of perennial plant species are typical of active-channel settings (see Table 2-5), and there is a transitional gradient in cover and species between active-channel and active-floodplain surfaces that corresponds with the hydrologic inundation gradient. With the addition of transitional (AC/AF) quadrats, vegetation cover values on active-channel bars in canyon settings can approach those of active-floodplain surfaces, especially along flow-controlled portions of the Green River. At the Seacliff sentinel site, vegetation on active-channel surfaces increased following the 2011 flood and declined noticeably in the two below-average peak-flow years of 2012 and 2013. Values increased again to a mean total cover value of approximately 20% in the above-average peak-flow year of 2014 (see Figure 3-20).

Processes underlying the observed year-to-year response of vegetation cover relative to flow at Seacliff may relate in part to changes in flow, including the two-year recurrence flow, which decreased by ~23% following completion of Flaming Gorge dam in 1964 (Allred and Schmidt 1999, see Figure 3-19). Decreases in the magnitude of the average two-year recurrence flow, which is generally considered to be the discharge that inundates the active floodplain, would result in expansion of active-floodplain surfaces onto the active channel, resulting in channel narrowing, which has been documented for the Green River in Dinosaur NM—and Whirlpool Canyon, specifically (Grams and Schmidt 2002; Manners et al. 2013). In years when peak flows exceeded the two-year recurrence flow, the total average cover values of vegetation on active-channel surfaces at the Seacliff sentinel site approached those observed on active-floodplain surfaces at both sentinel sites. However, cover declined to single-digit percentages in low-flow years (see Figure 3-20). One interpretation of this pattern is that following flow regulation, active-channel surfaces between the old and new two-year-recurrence flow stages began to transition to floodplain. Indeed, some patches of floodplain existed as vegetated sandcaps on this expansion bar and a number of quadrats on lower surfaces, identified as transitional (AC/AF), contained one or more active- and inactive-floodplain indicator species.

Growth of floodplain and other plant species on this coarse-textured expansion bar may be responding directly to stream stage during the growing season. For example, in years when flows equaled or exceeded the post-dam two-year-recurrence flow (2010, 2011, and 2014), floodplain and transitional surfaces were inundated or sub-irrigated and vegetation growth was enhanced. In years when flows remained below the two-year-recurrence stage (2012, 2013), floodplain and transitional surfaces were comparatively dry and growth of existing vegetation was limited by water availability. The increase in cover values in 2011 may have, in part, been due to sampling issues. A large portion of the site that was available for sampling in 2012–2014 was underwater and not sampled in 2011. Most of the plots that were underwater likely had very low cover.

By establishing baseline conditions at sentinel sites over a number of years, we can begin to understand and interpret the specific ways in which these sites respond to prevailing conditions. This understanding, in turn, will allow us to better predict and detect changes in channel condition resulting from natural or human-related changes in streamflow.

3.1.2.4 Repeat photography

One or more photopoints have been established for each of the sentinel sites. The purpose of these photos is to document long-term, broad-scale changes in the geomorphic condition of the sentinel site. Such photos have been very effective at interpreting long-term changes in vegetation and channel condition in the Grand Canyon (Webb 1996; Webb et al. 2011). Figures 3-21 and 3-22 are examples of the reference photos established for the Deerlodge Park and Seacliff sentinel sites.

Figure 3-21. Reference photos of Deerlodge Park from river-right to river-left: (A) July 15, 2014, at 1,290 cfs, (B) July 21, 2015, at 809 cfs, and (C) July 13, 2016, at 896 cfs. Reference photos were not established until 2014. These photos show the large amount of deposition that occurs in restricted-meander channel types. Note the deposition of sand on the downstream edge from 2014 to 2015 and again from 2015 to 2016. Also note the change in orientation of the large cottonwood tree from 2015 to 2016. Flow is from left to right in the images.

Figure 3-22. Reference photos of Seacliff: (A) September 29, 2014, at 3,010 cfs, (B) August 2, 2015, at 2,300 cfs, and (C) July 31, 2016, at 2,170 cfs. To be effective, photo matches must be relocated and reframed with high precision to the founding photo and be of similar quality and ideally taken with the same camera, lens, and focal length.

3.1.3 Evaluation

We evaluated the effectiveness and utility of our sentinel-site monitoring design and implementation by responding to the following questions:

- ***Can our current methods detect widening or narrowing of the channel along relatively unregulated rivers and along regulated rivers where the channel has already narrowed to some degree?*** In short, yes. Preliminary results indicated that site hydrology measurements closely tracked measured stage changes at the nearest gages. The geomorphic change-detection approach showed patterns of erosion and deposition at the two sentinel sites examined. Vegetation quadrats on active-channel features showed annual variation in cover that exceed expected sampling errors (see Figure 3-20) and likely resulted from interannual variation in site environmental conditions.
- ***Do our results to date support our expectations?*** Yes. We expect a natural variation in our metrics, especially along the unregulated Yampa River. This variation would represent a longer-term baseline condition, providing reasonable stationarity or consistent variation in flow over a number of years. Detecting directional trends in our metrics will require establishing a baseline of perhaps five or more years.
- ***Were there surprises or unexpected results?*** Perhaps the only surprising result was the increase in vegetation cover in active-channel quadrats at the Seacliff sentinel site following the 2011 flood (see Figure 3-20). Whereas a large flood might have been expected to eliminate vegetation (by scouring or prolonged inundation), this did not occur. Similarly, vegetation cover decreased significantly in the two subsequent years, which featured below-average peak flow, and increased again following an above-average peak flow. We provide a possible explanation consistent with this observed pattern (see Section 3.1.2.3). However, we will need additional years of measurement to better identify cause-and-effect relationships at our sentinel sites.

3.2 Rapidos and quickplots

Sentinel sites were not chosen randomly, but rather because past research and expert opinion identified them as likely candidates for narrowing. Rapidos are randomly chosen and serve as a safeguard if changes occurring at the sentinel sites are not representative of the river corridor. Quickplots are an additional component of rapidos that are more quantitative and provide another line of analysis to examine channel narrowing.

Rapidos (rapid-assessment sites) complement our sentinel sites. They represent a range of hydrogeomorphic settings with hypothesized sensitivities to future channel narrowing. Geomorphic surfaces were classified as sensitive (essentially bare, active channel surfaces considered sensitive to future vegetation encroachment and floodplain construction), insensitive (surfaces that are vegetated, stable, and considered insensitive to future narrowing), and very sensitive (partially vegetated and therefore hypothetically very sensitive to transitioning from active to inactive surfaces; Manners et al. 2010). Finally, we identified insensitive reaches, typically in narrow, bedrock-confined settings, with no potential rapido sites. Rapidos include all areas that could potentially narrow within a river reach. Monitoring sites are chosen randomly from these sites.

Quickplots are two-meter-radius circular plots established on sand caps, which are often an early sign of channel narrowing. Observers note the presence of indicator species, total vegetation cover, and percent cover of sand, silt, and clay.

3.2.1 Methods

Geomorphic features, including point bars, mid-channel bars, and expansion bars, were identified through image analysis of the entire park as sites that could potentially narrow. These sites were chosen for sampling using the rapido and quickplot approaches. These sites reflect a range of depositional environments throughout the study area. Maps of each feature, using 2011 imagery for the

Green River and 2005 imagery for the Yampa River, were stored on an iPad for field use.

An observer walked the active-channel portion of the feature using the delineation on an iPad. After walking the feature and examining the imagery, the observer subjectively determined whether there was more, less, or the same amount of vegetation in the active-channel area relative to the image. If the choice between "more" or "less" was unclear, then the observer was instructed to choose the "same" amount of vegetation. While walking the boundary of the active channel, observers noted the presence or absence of active-floodplain and inactive-floodplain indicator species (Table 3-6).

Observers also noted key (fluvial) geomorphic characteristics on the active-channel portion of the feature. The dominant substrate (boulders, sand, cobbles) and the number of chutes (notably lower areas where water pooled up before flowing downstream) were noted. On the shore opposite the feature, the observer noted whether the dominant and (if necessary) secondary opposite margins were adjusting, adjustable, or fixed, because is it useful to know if the other side could be adjusted by flows (e.g., sandbar) or will be fixed over time (e.g., cliff wall). The observer also noted whether the bar edge had been recently trimmed (i.e., if there was recent erosion of the edge of the feature). Lastly, the presence of sandcaps was noted. Sandcaps form downstream of vegetation and large debris. They can be key indicators of future narrowing because the shear stress is reduced in these areas, allowing vegetation to grow.

If sandcaps could be identified from imagery prior to going in the field, then 2–4 one-meter (3.14 m^2 sample area) quickplots were located and marked on the imagery and in a GPS unit (Figure 3-23). Observers also established new quickplots if a sandcap was detected at a feature. After navigating to the quickplot location, observers rotated a meter stick in place to trace out a circle two meters in diameter. Within the circle, the observer noted the presence of indicator species (see Table 2-5); the total vegetation cover to the nearest 5%; and percent cover of sand, silt, and clay.

3.2.2 Results

We completed 118 and 55 rapidos on the Yampa and Green rivers, respectively, from July to September 2013 and 2014. When a rapido was completed in both 2013 and 2014, we only used data from 2014 in this analysis. Species richness, and the active- and inactive-floodplain indicators,tamarisk seedlings, saplings, and adults; Canadian horseweed, (*Conyza canadensis*); western goldentop (*Euthamia occidentalis*); and common reed (*Phragmites australis*), all had higher percent frequencies of occurrence on the Green River in both park and canyon settings than on the Yampa River. Horsetail spp. and saltgrass were higher on the Green River in canyon settings (Table 3-7) than on the Yampa River. This is consistent with the floodplain construction and channel narrowing that has occurred or is occurring on most or many

Table 3-6. A subset of floodplain indicator species to be evaluated for presence using both the rapido and quickplot-based rapid assessments.

Scientific name	Common name
Conyza canadensis	Canadian horseweed
Distichlis spicata	saltgrass
Equisetum hyemale and *E. laevigatum*	scouringrush horsetail and smooth horsetail
Euthamia occidentalis	western goldentop
Pascopyrum smithii	western wheatgrass
Phragmites australis	common reed
Salix exigua seedlings	narrowleaf willow seedlings
Salix exigua saplings/adults	narrowleaf willow saplings/adults
Tamarix ramosissima seedlings	tamarisk seedlings
Tamarix ramosissima saplings/adults	tamarisk saplings/adults

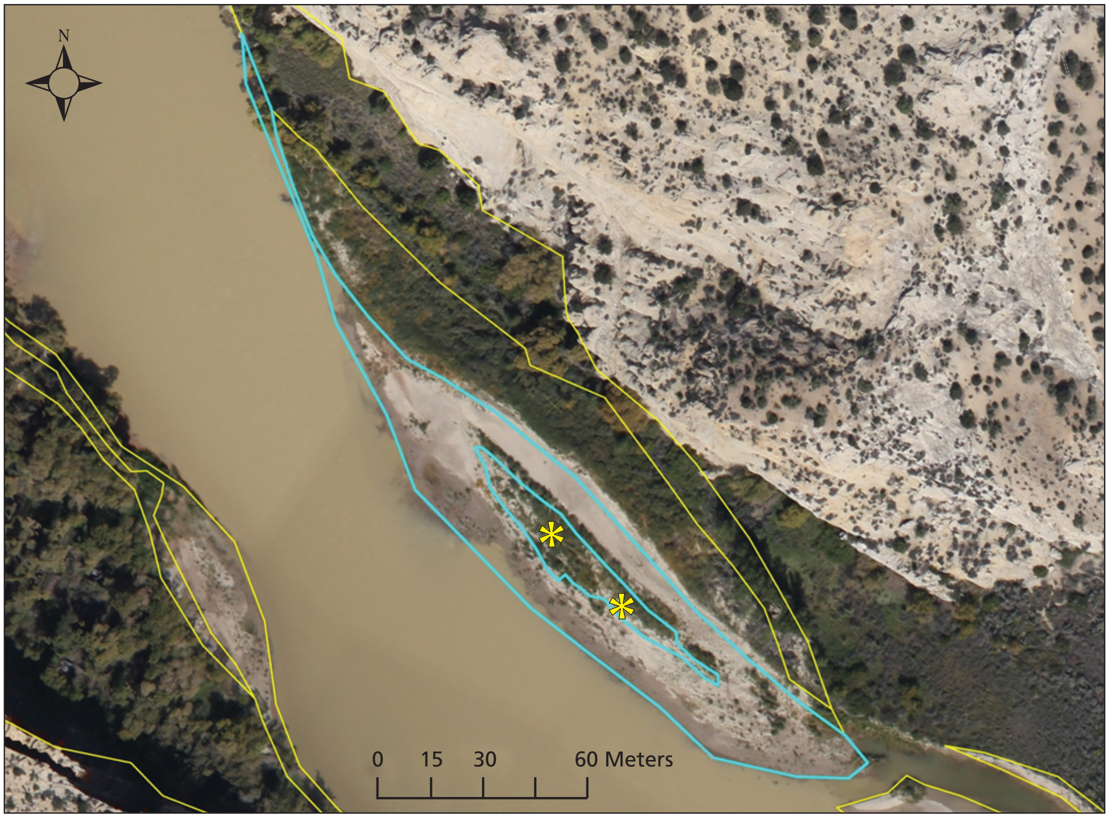


Figure 3-23. A lateral bar located just downstream of the Deerlodge Park USGS gage. The blue polygon delineates the active-channel surface. Yellow polygons are other geomorphic surfaces (active floodplain, inactive floodplain, or uplands) not included in the rapido assessment. At the center of the bar is a vegetated sandcap, which corresponds in elevation and total vegetation cover with an active-floodplain surface. The yellow asterisks mark locations of the quickplots sampled on the sandcap.

Table 3-7. Number of channel-bar forms sampled and percent frequency of presence for indicator plant species on these features using rapid-assessment sampling.

			Percent frequency of selected indicator species										
River	**Channel setting**	**n**	**SALEXI seedlings**	**SALEXI saplings/adults**	**TAMRAM seedlings**	**TAMRAM saplings/adults**	**CONCAN**	**EQUSPP**	**DISSPI**	**PASSMI**	**EUTOCC**	**PHRAUS**	**Species richness**
Yampa	Canyon	108	82	55	44	44	9	46	17	16	6	1	3.4
Green (above confluence)	Canyon	14	50	7	100	64	29	93	57	43	100	71	7.1
Green (below confluence)	Canyon	28	86	29	96	75	32	86	43	14	61	25	6.1
Yampa	Park	10	100	70	40	20	0	40	0	0	10	0	3.2
Green (above confluence)	Park	13	75	50	92	83	17	42	0	0	58	8	4.3
Yampa (2013)	All	26	100	81	73	46	12	35	15	12	6	0	3.8
Yampa (2014)	All	26	100	73	50	46	4	58	23	23	69	0	4.1

See Table 2-5 for full list of indicator species.

The Yampa River, Green River above the Yampa confluence, and Green River below the confluence were sampled in both canyon-bound and alluvial park channel settings. In 2013 and 2014, twenty-six features were sampled along the Yampa River as an estimate of natural and sampling variability.

SALEXI=*Salix exigua*, TAMRAM=*Tamarix ramosissima*, CONCAN=*Conyza canadensis*, EQUSPP=*Equisetum hyemale* and *E. laevigatum*, DISSPI=*Distichlis spicata*, PASSMI=*Pascopyrum smithii*, EUTOCC=*Euthamia occidentalis*, PHRAUS=*Phragmites australis* geomorphic features as a result of flow regulation by Flaming Gorge dam (Grams and Schmidt 1999). In contrast, such narrowing is more limited and is occurring in specific hydrogeomorphic settings on the unregulated Yampa River (Manners et al. 2014).

The Yampa River had a higher percentage of features with sandcaps than the Green River and, when compared to historic imagery, also had more features with increasing vegetation than the Green River (Table 3-8). However, the features on the Yampa River were compared to 2005 imagery, while the features on the Green River were compared to 2011 imagery.

A subset of 26 rapidos was completed on the same features in 2013 and 2014. These rapidos showed very little change between 2013 and 2014 (see Table 3-8), indicating that interannual observer variability may be low. Additional tests done during the same year with two different observers should be completed to further test this hypothesis.

Although this rapid-assessment approach is promising, our preliminary results suggest direct comparisons among bar forms in different stages of the narrowing process will need to be carefully and consistently defined and further refined. For example, most bar forms on the Green River have been largely stabilized by vegetation following the initiation of flow regulation in 1964. Thus, future narrowing on these features will be limited to only those portions of the features that remain as active-channel. In contrast, on the largely unregulated Yampa River, entire bar forms are active-channel features, which may show a different narrowing response than portions of largely stabilized bars. Further conversion of partially stabilized channel-bar forms may not involve the formation of sandcaps.

We completed 124 and 48 quickplots on the Yampa and Green rivers, respectively, from July to September 2013 and 2014. When a quickplot was completed in both 2013 and 2014, we only used data from 2014 in this analysis. Tamarisk seedlings and saplings/adults had a higher percent frequency of occurrence on the Green River than the Yampa River in canyon settings and overall, sandbar willow seedlings and saplings/adults were present more frequently on the Yampa River than the Green River in canyon settings. A subset of 25 quickplots was monitored in both 2013 and 2014. These quickplots showed very little change between years (Table 3-9).

It is encouraging that the rapidos and quickplots followed the same general pattern of increased species richness on the Green River when compared to the Yampa River. We think these methods may be useful for a periodic assessment of river condition. However, observers generally felt uncomfortable with their repeatability for a long-term monitoring program. They were concerned that when the imagery was poor or the GPS was unreliable, two different observers might have different opinions on the location of the active-channel boundary—particularly on the Yampa River, where this boundary is not well defined. Repeating a survey of the same spatial area is crucial to a long-term monitoring program. For rapidos, the baseline year was 2005 for the Green River and 2011 for the Yampa. However, observers often felt influenced by conditions on the ground, and might tend to follow the current boundary of the active channel even if narrowing had occurred. The area where active channel converts to active floodplain is crucial to detecting narrowing. Particularly when GPS reception was poor, this boundary was determined by the observer, making it virtually im-

Table 3-8. Number of features sampled and percent frequency of the status of sandcaps and vegetation on geomorphic surfaces in Dinosaur National Monument using rapid-assessement sampling July–September 2013 and 2014.

River	n	Sandcaps				Vegetation		
		No	Maybe	Forming	Yes	More	Less	Same
Yampa	124	51%	12%	2%	35%	65%	0	35%
Green	48	69%	8%	0	23%	28%	3%	69%

Table 3-9. Number of channel-bar forms sampled and percent frequency of occurrence of indicator plant species in quickplots.

River	Channel setting	n	Percent frequency of selected indicator species										Species richness
			SALEXI seedlings	SALEXI saplings/adults	TAMRAM seedlings	TAMRAM saplings/adults	CONCAN	EQUSPP	DISSPI	PASSMI	EUTOCC	PHRAUS	
Yampa	Canyon	109	45	35	19	30	10	19	9	17	9	0	1.8
Green	Canyon	9	11	11	78	67	0	11	0	0	11	0	1.9
Yampa	All	122	47	34	16	25	9	16	7	14	7	0	1.8
Green	All	13	31	31	69	54	15	8	0	0	15	0	2.2
Yampa (2013)	All	25	28	36	8	32	4	20	4	4	0	0	1.4
Yampa (2014)	All	25	36	28	12	20	12	8	4	12	0	0	1.3

See Table 2-5 for full list of indicator species. The Yampa River, Green River above the Yampa confluence, and Green River below the confluence were sampled in both canyon-bound and alluvial park channel settings. In 2013 and 2014, twenty-six features were sampled along the Yampa River as an estimate of natural and sampling variability.

SALEXI=*Salix exigua*, TAMRAM=*Tamarix ramosissima*, CONCAN=*Conyza canadensis*, EQUSPP=*Equisetum hyemale* and *E. laevigatum*, DISSPI=*Distichlis spicata*, PASSMI=*Pascopyrum smithii*, EUTOCC=*Euthamia occidentalis*, PHRAUS=*Phragmites australis*

possible to survey the same area as in a prior year if narrowing had occurred. Even if the GPS worked well (with an accuracy of 5–10 m), many of the indicator species would be present, making it hard to determine whether they should be counted as present or absent if they were in the active-channel boundary of 2005 and 2011.

3.2.3 Evaluation

We evaluate the effectiveness and utility of our rapido monitoring design and implementation by responding to the following questions:

- ***Can our current methods detect categorical change in channel condition (e.g., narrowing, widening, no change) at sites covering a broad spatial extent?*** Unclear. Results of rapido monitoring over two years detected clear qualitative differences between geomorphic features on the Green and Yampa rivers, consistent with past narrowing on the Green. However, it is unclear if these methods could be used to track more subtle changes over time on each respective river, due to difficulties in re-measuring the same spatial locations.
- ***Do our results to date support our expectations?*** Yes, but refinements need to be made. For example, bounding the active channel versus the active floodplain so that we can detect changes at the same sites from year to year is a concern, given current technology. Also, existing narrowing on the Green versus the Yampa needs to more explicitly recognized in this monitoring approach. Establishing baseline measurements over a number of years will allow us to evaluate any future trends in channel form, such as narrowing or widening.
- ***Were there surprises or unexpected results?*** Perhaps the biggest surprise was the higher increase in vegetation cover from 2005 to 2013–2014 on active features along the Yampa relative to comparisons between 2011 and 2013–2014 on the Green. However, the timeframe of comparison on the Yampa was longer, making it difficult to assess if this greater increase in cover was biologically relevant. Higher-resolution imagery for the same years will improve accuracy of comparisons along and between the Yampa and Green rivers in Dinosaur National Monument.

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Natural Resource Stewardship and Science
1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

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