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Riverscape Interpretation in Great Basin National Park

A Geomorphic Assessment of Streams and Riparian Areas

Diversity of stream types found in Great Basin National Park.
NPS / SCOTT SHAHVERDIAN

Riverscape interpretation in Great Basin National Park: A geomorphic assessment of streams and riparian areas

Science Report NPS/SR—2025/237

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Abstract

Streams can be challenging systems to manage due to their dynamic nature and complex feedbacks between hydrologic, geomorphic, and biological processes that operate over a range of timescales. Stream-riparian ecosystems, also known as riverscapes or river corridors, are affected by events ranging from single storms to large-scale landscape disturbances such as wildfires and landslides. Understanding riverscape dynamics is necessary for identifying potential causes of their degradation, appropriate management actions, and potential restoration strategies. Developing appropriate expectations requires a conceptual understanding of how riverscape conditions and processes vary across the watershed. However, effective interpretation of riverscapes often requires specific expertise related to landscape processes and fluvial geomorphology.

This report presents core fluvial geomorphic concepts and develops a reach type classification for riverscapes across Great Basin National Park (GRBA). We begin by identifying landscape factors and basic fluvial geomorphic principles needed to interpret stream forms and processes in GRBA, differentiating the physical characteristics of stream reaches and the processes that maintain them. The report then describes the forms and dynamics of seven different reach types in GRBA. We relied on a combination of remotely sensed data and field observations to categorize GRBA streams. We identify and describe attributes and dominant processes shaping each reach type.

Many GRBA streams are found in steep valleys with coarse substrates. These streams have low sensitivity to disturbances, meaning that they are resistant to change. GRBA also supports a limited number of lower-gradient reaches with finer substrates that are more sensitive to disturbances. GRBA streams have variable degrees of confinement, affecting their capacity for lateral adjustment through channel migration or activation of alternative parallel channels. Large wood is important in creating habitat features and influencing stream dynamics throughout GRBA, although the specific processes and habitats influenced by wood vary across reach types. Glacial history and modern hillslope processes are also important features of current stream processes in GRBA, causing the stream reaches in broader valleys to have unusually low sensitivity to disturbance and allowing them to resist disruption to core fluvial processes.

This document provides more of an introductory framework and conceptual foundation, rather than serving as a complete how-to manual for managing park streams. Any specific management questions encountered in the future are likely to require more focused investigation. Our goal is that this document will further build a foundation that leads to wise interpretations, expectations, and decisions regarding river management in GRBA.

Introduction

Managing streams and riparian areas (i.e., riverscapes) presents several challenges for land managers. Riverscapes are dynamic systems that adjust to changes in flow, sediment, and wood over timescales ranging from single storm events to annual cycles to rare debris flows. Riverscapes are also the sites of complex feedback loops between biological processes, such as riparian vegetation growth and beaver activity, and the geomorphic processes of erosion and deposition. Riverscapes vary in their sensitivity to disturbances depending on their setting and history; thus, similar disturbance events can cause different types and magnitudes of response across settings.

Appropriate management of riverscapes depends on accurate assessment and interpretation of their forms and functions, which itself requires an understanding of how streamflow, sediment, and wood interact with watershed position, valley setting, and natural and anthropogenic landscape histories. Historically, river management has focused on highly specific instream habitats, often geared at benefiting conservation and recreation opportunities related to fisheries. There has also been an emphasis on channel stability, although this is at odds with the natural dynamism associated with healthy riverscapes. In this report we focus on the large-scale factors and processes that create and maintain healthy conditions. Based on factors such as watershed position, valley setting, wood dynamics, and flow regime, we categorize streams into reach types. Reach types are defined by a characteristic set of morphological attributes, which are shaped by local factors. Different reach types have different capacities for lateral adjustment, which is a stream's ability for its channel to move positions within its valley bottom, and by sensitivity, which is a stream's capacity to withstand disturbance without upsetting its dynamic equilibrium. We highlight lateral adjustment capacity and sensitivity specifically because they are helpful for land managers to understand when making decisions that may affect riverscapes.

Great Basin National Park (GRBA), located near the town of Baker in eastern Nevada, has recently undertaken restoration efforts at Strawberry Creek after a large wildfire led to debris flows, increased sediment delivery, and significant erosion and deposition that impacted habitat for Bonneville Cutthroat Trout (BCT). These events highlight how GRBA would benefit from a parkwide geomorphic-based assessment of its riverscapes to help guide future management.

How this Report Builds on Previous Assessments

Resource assessments previously completed for GRBA include the Geologic Resources Inventory Report (Graham, 2014) and Natural Resource Condition Assessment (NRCA) (Comer et al., 2016). However, riverscapes are highly specific and dynamic portions of the landscape with complex physical and biological feedbacks. They are often described by their riparian attributes or instream biology, especially using fish and macroinvertebrate species (e.g., NRCA report). In certain circumstances, those metrics serve as excellent surrogates for riverscape health; however, they do little to describe the dynamic behavior of riverscapes that support biological communities. This report provides a more detailed description of the physical processes that drive riverscape form and function in GRBA. It does not provide a parkwide mapping of reach types; however, it does provide a coarser mapping of stream geomorphic sensitivity, which can help park staff predict what reaches are more likely to respond to stream restoration. This report can be used in conjunction with previously completed reports to better understand how riverscape processes create the conditions for specific instream and riparian ecological communities to survive and thrive.

The NRCA report on GRBA provides excellent descriptions of the hydrologic regime, identifies risks posed by alterations to the regime, provides empirical data, and identifies how flow conditions vary with elevation and locations ranging from headwaters to piedmont (Comer et al., 2016). As such, those questions are not addressed in this report. Instead, this report addresses questions related to fluvial geomorphology, including:

1. What stream morphologies are found across GRBA?
2. What historic geologic and geomorphic events influence contemporary stream forms and functions?
3. How do hillslope processes and fluvial processes interact across different stream reaches in GRBA?
4. How does the hydrologic regime interact with the geomorphic setting to produce characteristic stream morphologies?
5. What is the role of large wood in creating and maintaining fluvial processes and stream features throughout GRBA?
6. What historic land use practices may have influenced stream forms and functions, and how so?
7. What is the role of ecosystem engineers, such as beaver, on stream forms and functions?

This report focuses on describing the processes that characterize riverscapes across GRBA. It is intended to provide GRBA staff with a qualitative and spatially partitioned understanding of the riverscape conditions found throughout GRBA and explain the processes leading to those conditions. More precise, quantitative assessments may be appropriate prior to undertaking specific management actions in specific stream reaches, but they are beyond the scope of this parkwide assessment.

Contents of This Report

This report is divided into three parts. Part I, "Conceptual Foundation for Riverscape Interpretation," provides background information on general fluvial geomorphic topics necessary for assessing and interpreting riverscapes, including disturbance regimes (i.e., process domains), valley setting, flow regime, sediment regime, and wood regime. It also addresses dynamism, explores spatial and temporal variability, identifies common geomorphic responses to disturbance, and introduces channel evolution models. This section is intended to provide a conceptual foundation, with relevant examples from GRBA provided. Readers with a strong foundation in fluvial geomorphology can skip to Part II.

Part II, "Riverscape Assessment for Great Basin National Park", applies the concepts outlined in Part I to identify characteristic reach types for riverscapes in GRBA (Figure 1). These include grouping stream segments by similar valley setting, channel characteristics, disturbance regimes, and flow, sediment, and wood dynamics. Differentiating reach types provides a baseline understanding needed for interpreting riverscape conditions and for developing management strategies that recognize fundamental differences between settings. We describe characteristics of different reach types, as well as identify how their valley setting, disturbance regime, flow, sediment, and wood interact to create those attributes. This section describes the form and function of the different reach types throughout GRBA, building a place-based foundation for future management actions.

Figure 1. Example photos of different riverscape settings in GRBA, reflecting their differences in valley setting, watershed position, landscape history, disturbance regime and flow, sediment, and wood dynamics. NPS / SCOTT SHAHVERDIAN

Part III, "Management Implications for Great Basin National Park", uses the reach types outlined in Part II as the basis for a management-focused delineation of riverscapes throughout GRBA. Its goal is to provide a spatially explicit delineation of reach types that are likely to respond differently to management actions. It is based on the understanding developed in Parts I and II and is meant to be referenced when land managers are more concerned with application than detailed differences among reach types.

This report is not intended to provide a foundation for specific management activities or serve as baseline data for those activities. Management actions concerning riverscapes are likely to require more detailed investigations and characterizations of the project area in question, and they should be tailored to specific management objectives. Nothing in this report should replace those more detailed studies. Rather, this report provides a conceptual background for the range of conditions that may be present or attainable, and it identifies the different fluvial processes required to create and maintain healthy stream and riparian ecosystems. Finally, this report limits its focus to perennial streams that drain the eastern side of GRBA. There are several perennial streams that drain the western side; however, they are relatively remote, very limited in extent (1–2 km) and were not assessed as part of this effort.

Part I. Conceptual Foundation for Riverscape Interpretation

Riverscapes are dynamic parts of the landscape that are influenced by their watersheds, valleys, and their flow, sediment, wood, and disturbance regimes. These factors combine to produce characteristic channel dimensions and forms (e.g., number of channels, width, depth, substrate, and geomorphic units). This section summarizes how different characteristics and forces influence stream form and function. It also describes how these factors intersect to create streams and habitat features that vary systematically throughout the watershed. The following subsections highlight the influences of watershed position, valley setting, disturbance regime, geomorphic sensitivity, flow regime, sediment regime, wood regime, and how these driving factors relate to channel morphology, change through time, and riverscape diversity.

Watershed Position

Within its watershed, a stream generally progresses from high elevation, high-gradient, low-discharge headwaters, to low elevation, low-gradient conditions. Along this continuum, riverscapes experience changes in climate, valley setting, disturbance regime, flow, and wood dynamics that influence the forms and characteristics we observe. These aspects include gradient, substrate, vegetation community, number of active channels, channel width and depth, water temperature, and instream habitat units. An understanding of landscape position and upstream watershed characteristics is critical for riverscape interpretation.

Valley Setting and Capacity for Lateral Adjustment

Valley setting relates to channel confinement and a channel's connectivity to adjacent landforms (Figure 2). These landforms—whether hillslopes, alluvial fans, or terraces—are the valley bottom's confining margins. Connectivity refers to the transfer of materials from one landform (e.g., hillslope) to another (e.g., stream channel). Riverscapes can be described in terms of multiple dimensions of connectivity, most commonly lateral (i.e., hillslope and floodplain to channel), longitudinal (i.e., downstream), and vertical (i.e., channel to subsurface). In a confined valley setting, floodplains are absent or limited, and the stream channel is adjacent to its confining margin. In GRBA, common confining features include bedrock outcrops, forested hillslopes, talus, and glacial terraces. These confined areas are more likely to have high longitudinal connectivity (i.e., water, wood, and sediment move easily downstream), and limited lateral connectivity due to the absence of a significant floodplain. Because of the limited floodplain area, these areas tend not to support extensive riparian communities, and the vegetation communities are less influenced by fluvial processes of erosion, deposition, and overbank flow than by hillslope processes and forest dynamics. These areas can be influenced by dramatic hillslope processes, such as landslides, which in a confined setting are capable of exerting major influence on streams.

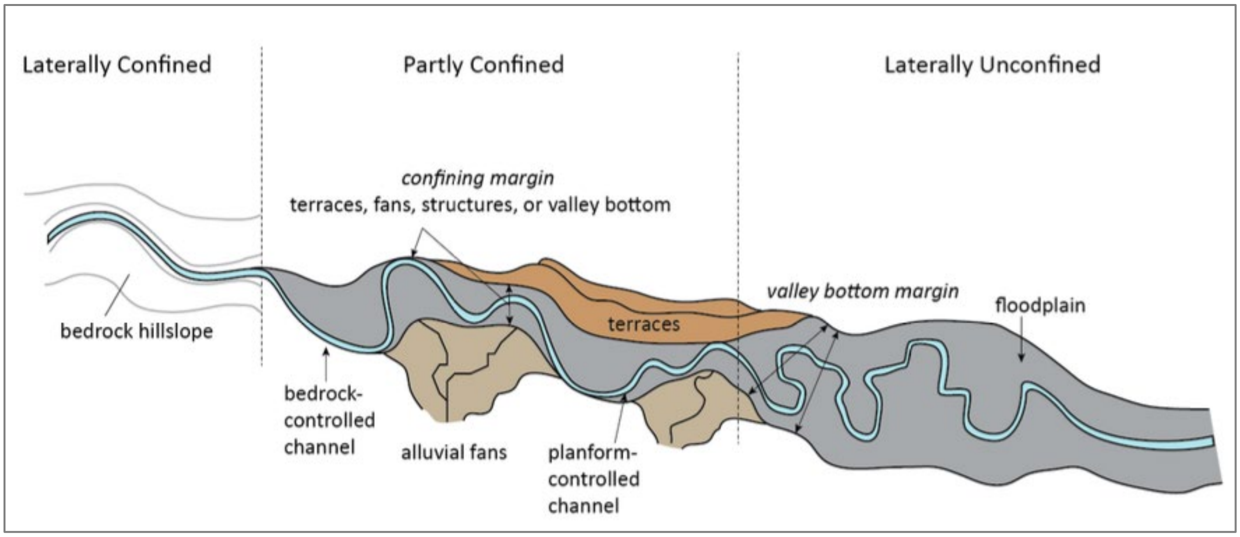

Figure 2. Types of valley settings, ranging from laterally confined (left, upstream) to partly confined (middle), to laterally unconfined (right, downstream). Confined settings tend to be more common in higher portions of the watershed, while laterally unconfined conditions are found in larger valleys. In GRBA most streams are confined or partly confined. OPEN-SOURCE FIGURE REPRODUCED FROM O'BRIEN, ET AL. (2015)

Nearly all streams in GRBA are confined or partly confined, meaning that lateral migration is restricted by or controlled by adjacent upland landforms. Partly confined reaches tend to be found at lower elevations (e.g., Lehman Creek near Lower Lehman Creek Campground), though there are examples of partly confined settings at high elevations (e.g., Lehman Creek near Wheeler Peak Campground). Different valley settings influence the ways in which sediment and wood are transported, and they will produce different instream habitat conditions.

Across landscapes, streams with larger valley bottoms (i.e., lower confinement) have a greater capacity for lateral adjustment. Lateral adjustment capacity describes the ability of a stream to move across the valley bottom by the progressive erosion of streambanks and deposition on the inside of meander bends, or by channel avulsion, which is the process where a new channel is created when an older channel is abandoned. As a result of lateral adjustments, the stream channel occupies different locations across the valley bottom through time. Movement of a channel across its valley bottom highlights the dynamism of riverscapes, in which the general forms (e.g., sinuosity, channel width, pools) remain similar, but their locations on the valley bottom change. This dynamism is a critical component of riverscape health. In the case of a stream that moves across its valley bottom, the processes of erosion and deposition are continuously creating new habitat niches for riparian species that allow for continuously changing riparian vegetation dynamics with diverse age classes. Lateral adjustment via bank erosion or channel avulsion is also an important mechanism for the recruitment of wood to the stream channel. The capacity for lateral adjustment does not imply the rate of adjustment. For example, a laterally unconfined, meandering river may slowly move across its valley bottom via bank erosion and point bar deposition on an annual timescale. By contrast, many streams in GRBA have wide valley bottoms but annual movement across the valley bottom appears sporadic. Instead, infrequent and episodic delivery of sediment and wood forcing channel avulsions or reoccupation of historic channels is the process by which the active channel moves location within its valley bottom.

Disturbance Regime

The disturbance regime (i.e., process-domains sensu (Montgomery, 1999)) describes how different reaches within a watershed are impacted by types of disturbance events, such as avalanches, landslides, beaver dams, annual floods, or high intensity storms. Disturbance regimes also describe the different magnitudes and frequency of events that impact riverscapes. Some events, like annual peak flow, are relatively low-magnitude and high-frequency. Within the riverscapes of GRBA, these events may be responsible for limited erosion and deposition that create instream complexity for aquatic species. Other disturbances, such as landslides, are infrequent, high-magnitude events that can cause immediate and significant changes. For example, summer convective storms led to a post-fire landslide in the Strawberry Creek watershed and delivered sediment that covered the valley bottom in coarse angular boulders (Figure 3). When assessed with a focus on instream habitat quality for Bonneville Cutthroat Trout (BCT), the post-landslide conditions found in Strawberry Creek within the impacted reach are poor; however, these conditions are part of the natural range of conditions that result from the disturbance regime. Furthermore, habitat conditions should be assessed at the spatial and temporal extents related to the use of BCT, which are often greater than the reach scale. A more detailed discussion of the importance of considering different spatial and temporal extents is discussed later within Part I.

Over long timescales, riverscapes can be dramatically shaped by infrequent, high-intensity events. In Idaho, up to 33–66% of the sediment stored in alluvial fans was determined to have been delivered post-fire (Riley et al., 2015). While it is tempting to characterize post-fire landscapes as impaired, especially in areas where human influence has altered the fire regime, many fires and their geomorphic consequences are often part of the natural cycle of disturbance.

Figure 3. Strawberry Creek in August 2021, after a large debris flow landslide. Across much of GRBA, streams and floodplains are heavily influenced by hillslope processes and events such as landslides. While the immediate impact of such events appears dramatic, they are a natural component of riverscapes, especially in confined settings where hillslopes are highly connected to the valley bottom. NPS / SCOTT SHAHVERDIAN

Geomorphic Sensitivity

According to Chambers, et al. (2021), "sensitivity describes the capacity of the geomorphic system to absorb change and remain in a state of dynamic equilibrium." This means that in response to a disturbance, sensitive streams will change a lot while low-sensitivity streams will remain largely unchanged. In riverscapes, the "changes" that are being absorbed are fluctuations related to streamflow, sediment, and wood. For the remainder of this document, when referring to *sensitivity*, we are referring to the ability for a riverscape to absorb changes to the flow, sediment, and wood regime and retain its essential characteristics. In general, streams with coarse bed and bank material are less sensitive than streams with finer bed and bank material. Bed and bank material composition are influenced by valley setting as well as stream power (a function of discharge and slope). If discharge is similar in upstream and downstream reaches due to an absence of significant tributaries, then lower slope reaches will have a lower stream power than reaches higher in the watershed and will have a higher sensitivity than higher-elevation reaches.

Flow Regime

The natural flow regime describes the flow conditions of a given stream by their magnitude, frequency, duration, timing, and flashiness (Poff et al., 1997). These five components are linked to specific physical and biological processes that influence ecological health and geomorphic form. Flow magnitude, specifically during peak flows, is responsible for much of the erosion and deposition of sediment that shape stream channels and determine channel characteristics such as width, depth and substrate. Frequency describes how often flows of a given magnitude occur. For example, do peak flows occur once a year from snowmelt runoff, or multiple times per year as the result of both snowmelt runoff and precipitation events? Duration describes the length of time of any given flow condition, whether high flow or baseflow. Timing describes the time of year during which different flow conditions occur. The timing of specific flow conditions is intimately linked to the life histories of aquatic and riparian species. Sexually reproducing cottonwoods, for example, require specific flow conditions and timing that overlap with the release of seeds. Fish spawn during certain flow conditions that facilitate their movement to reach appropriate spawning sites. Finally, the degree of flashiness, which is the rate at which flow changes, varies widely and influences species' ability to adjust to changes in flow rate.

The flow regimes of streams throughout GRBA are characterized by both peak flows from spring snowmelt runoff and high-intensity summer precipitation events. The timing of snowmelt runoff coincides with spawning for BCT, and higher flows facilitate upstream-downstream fish movement that may be more difficult as flows recede. Peak flows are also important for the regeneration of sexually reproducing cottonwoods found at lower elevations.

Sediment Regime

Similar to the flow regime, the sediment regime describes the magnitude, frequency, duration, and timing of sediment moving throughout a watershed (Wohl et al., 2015). Measuring these attributes is notoriously challenging for several reasons, including the episodic nature of sediment transport, as well as the technical challenges of measuring sediment transport, especially during high flow conditions when most sediment is transported. Nonetheless, a conceptual understanding of the sources of sediment, size, distribution, and the processes that deliver it to the channel is important to understanding riverscape dynamics. For example, headwater streams located high in a watershed are more likely to be sediment supply limited and are capable of transporting accessible sediment to downstream reaches, while low gradient reaches lower in a basin are more likely to be sediment transport limited causing them to store sediment in bars and floodplains. The dominant source locations and processes of delivery also change throughout a basin. In more confined headwater settings, the primary source of sediment is likely to be hillslopes and heavily influenced by hillslope processes such as mass wasting, rilling, and gullying. By contrast, lower in a basin, sediment sources are likely to include the floodplain and alluvial fans that are eroded into by the channel itself.

While quantification of the sediment regime is challenging, and unlikely to be assessed in many scenarios, understanding how changes to the sediment regime are likely to impact riverscapes in a qualitative or directional manner can provide land managers with important insights into stream behavior and response to specific management actions. For example, increased sediment supply by grazing or fire is likely to create areas of increased deposition. However, decreases to sediment supply from alterations such as dams or gravel mining and sediment extraction may lead to channel armoring and incision. In GRBA, dewatering in Snake Creek limits sediment transport to downstream reaches. While a focused study would be required to quantitatively evaluate sediment transport rates and whether, and to what extent, dewatering has resulted in geomorphic changes in downstream reaches, the classification presented in this report suggests that lower Snake Creek is likely to respond to decreased sediment supply by incising. By contrast, decreases in sediment supply to other reaches, for example confined sections of Baker Creek, would be unlikely to lead to incision.

Wood Regime

Wood is a critical component of many riverscapes, including those in GRBA. Wood influences hydraulics to create resting and feeding zones for fish, it influences patterns of erosion and deposition to maintain complex instream habitat, and it promotes channel-floodplain connectivity by increasing instream roughness (Figure 4). Wood is often a key element in promoting processes that maintain healthy riverscapes. For example, by forcing overbank flows and altering patterns of erosion and deposition, wood creates the conditions for riparian recruitment and maturation, which is the source of woody material to the channel in partly confined riverscapes. From headwaters to the GRBA boundary, wood is a major factor influencing channel characteristics and behavior, although the specific ways in which wood influences instream habitat vary. In high elevation, confined, steep headwaters, wood can force the development of step-pool channels, while in low elevation, lower-gradient channels, wood jams can force the development of scour pools and bars. In post-fire Strawberry Creek, large wood jams are associated with extensive lateral and vertical deposition that produces channel infilling and avulsion.

Figure 4. Example of wood forming a step. In this case, no pool is formed above or below the step. NPS / SCOTT SHAHVERDIAN

The wood regime describes the recruitment, transport, and storage of wood in fluvial networks (Wohl et al., 2019). Patterns of recruitment, transport, and storage vary throughout a watershed based on tree growth, valley setting, watershed position, and flow characteristics. In confined headwaters with limited floodplains, wood is recruited from adjacent hillslopes by hillslope processes and natural tree mortality. By contrast, in partly confined settings wood may be recruited by natural tree mortality and fluvial processes such as bank erosion that undermines trees adjacent to the channel. In areas with appropriate streamflow, gradient, and vegetation, beaver can be an important mechanism of wood recruitment, bringing wood from the floodplain and adjacent hillslope into the channel to beaver dams.

Once recruited, wood is transported and stored in the channel or on the floodplain. The ability of a channel to transport and store wood depends on the size of the channel, length of wood, channel complexity and roughness characteristics, and streamflow. All streams across GRBA are characterized by wood storage, though the specific type and impact of wood varies. Impacts of wood across GRBA riverscapes include forcing multi-threaded channels, creating step-pool morphology in high-gradient streams, forcing scour pools and bar deposition in streams with more mobile substrate, and historically forming beaver dams and ponds. Although not found in all park stream reaches, beaver have been important locally in several lower and middle elevation streams, where evidence of their past occupancy can be found in chewed stumps as well as the stepped valley-bottom profile associated with dams that span the valley bottom (e.g., Strawberry Creek).

Channel Morphology and Geomorphic Units

Valley setting, flow, sediment, and wood regimes are important factors partly because they combine to create specific channel forms and geomorphic units (e.g., pools, bars, cutbanks, riffles) that provide habitat for aquatic and terrestrial species. It is these attributes that are commonly used to assess channel condition, and they can be used to set management goals. While precise quantification of stream processes, such as streamflow, sediment and wood delivery, and recruitment, transport, and storage, is often difficult and may require long time frames to accurately assess, it is possible to evaluate channel morphology and geomorphic units during a single field visit. These channel forms are commonly relied on for condition assessments and management targets.

The myriad of riverscape attributes that can be assessed can be broadly characterized as being geomorphic (e.g., number of channels, bank height and angle, substrate, presence of specific geomorphic units), hydrologic, chemical, or biological. Which attributes are focused on often depends on management objectives. Where instream habitat for aquatic species is a motivating factor, then discrete habitat features such as pools and riffles are likely to be of interest, as well as water quality factors such as temperature. The fluvial geomorphic perspective is specifically concerned with instream geomorphic units like pools, riffles, bars, and cutbanks as well as floodplain features such as high flow channels, overbank deposits, and levees. Geomorphic units can be described by their topographic shape, orientation, or location within a channel. Shape may be classified as concave (e.g., pools), convex (e.g., bars), or planar (e.g., cascades, runs, glides). In general, the simplification of riverscapes, for example channel straightening and armoring and the removal of wood can reduce instream complexity, often manifest as a reduction in concave and concave geomorphic units, and a corresponding increase in planar geomorphic units. However, some reach types naturally support more planar features such as cascades, rather than pools and bars. The value of reach typing, therefore, is to attempt to establish what geomorphic units can and should be supported in different settings. In general, more physically complex and resilient streams are characterized by concave, convex, and planar geomorphic features, while simplified streams tend to be dominated by planar features.

The type, frequency, and size of geomorphic units tends to vary systematically downstream based on the valley settings and related driving processes. For example, in steep headwaters, channels are likely to be composed of cascades or step-pool geomorphic units (Montgomery and Buffington, 1997). Pools in these settings will assume different characteristics than in lower-gradient reaches. For example, in areas dominated by cascades, pools are unlikely to be channel-spanning, while pools in step-pool reaches are more likely to be channel-spanning. By contrast, in lower-gradient, partly confined settings, geomorphic units are more likely to include riffles, bars, and scour pools that are less common in confined, high-gradient reaches.

In addition to instream geomorphic units, channel geometry features like planform shape, width, and depth vary throughout any given watershed. In confined settings with a narrow valley bottom, a stream is more likely to be dominated by a single-thread, straight channel while in lower-gradient, partly confined or unconfined settings, a multi-threaded channel, and/or highly sinuous channel is more likely to be present.

A strong conceptual foundation is built by linking valley setting and driving processes with the geomorphic units and channel morphology at a given stream reach. Additionally, synthesizing these factors can be used to build expectations concerning how quickly and/or frequently those forms are apt to change in response to natural or human disturbances. Part II describes specific channel characteristics in different reach types across GRBA.

Change Through Time—Channel Evolution Models

In addition to the spatial diversity riverscapes exhibit, individual reaches change through time in response to disturbance events or land use changes that alter the delivery of water and sediment to the channel. Castro and Thorne (2019) proposed a stream evolution triangle to incorporate how physical processes such as sediment delivery and streamflow interact with biological attributes, ultimately producing riverscape form and function (Figure 5).

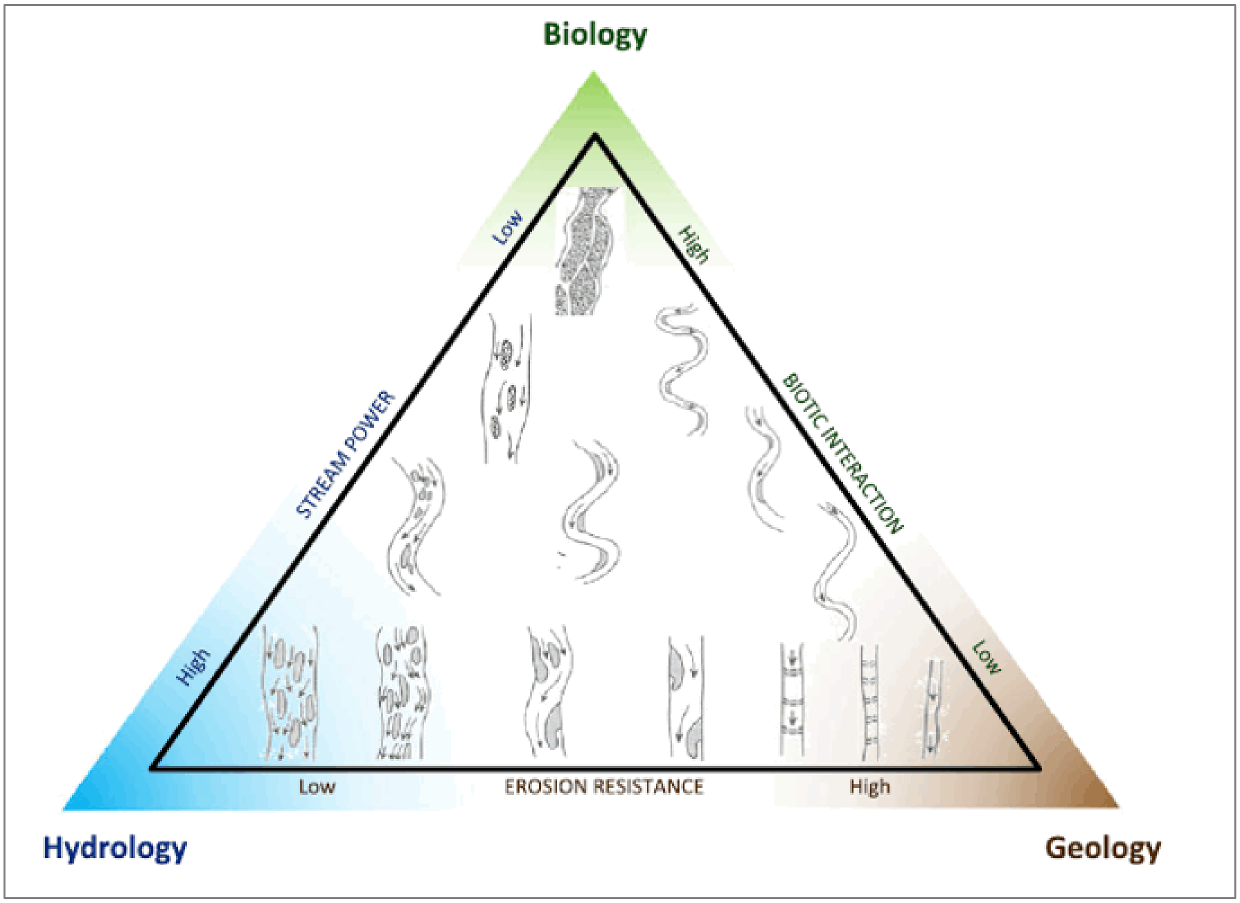

Figure 5. Stream evolution triangle that illustrates how hydrology, geology, and biology interact to produce rivers with different planform characteristics. OPEN-SOURCE FIGURE REPRODUCED FROM CASTRO AND THORNE (2019)

Channel evolution models (CEMs) are conceptual frameworks that describe how a certain reach may progress through several different stages in response to disturbance. Those stages may include periods of incision (downcutting), widening, and aggradation, before returning to a state of dynamic equilibrium. CEMs provide insight into possible changes resulting from a disturbance or change in upland conditions, but they are not deterministic. Nonetheless, they provide a useful lens through which expectations for riverscape behavior can be established. Different reach types are likely to respond to disturbance events in different ways, and some reach types are more sensitive to disturbance events than others. Generally, reaches characterized by high confinement, steep gradients, and coarse substrate are insensitive (i.e., less likely to change) in response to changes in water and sediment delivery and disturbance events. In contrast, unconfined and partly confined, lower-gradient reaches with finer substrate are more apt to be affected by changes to streamflow, sediment delivery, or other disturbances.

The CEM proposed by Cluer and Thorne (2014) (Figure 6) illustrates how a riverscape may respond to disturbance by experiencing incision (Stage 2), widening (Stage 4–5), and aggradation (Stage 5–8). While this model strongly resembles previous CEMs (e.g., Schumm (1984) it diverges in several important ways. First, it suggests that many rivers are not naturally single-thread channels, and that in certain cases a single-thread channel is itself a response to previous disturbance or manipulation. Second, it proposes that the response to disturbance does not always progress in a linear pathway from incision, to widening, and aggradation, but instead may effectively short-cut this pathway by experiencing aggradation immediately following incision. Other studies have shown that restoration can shorten the time associated with recovery by promoting several mechanisms including increasing the rate of widening, of aggradation, and/or effectively skipping the widening phase altogether (Pollock et al., 2014). Lastly, it suggests that it is possible for streams to become “arrested” in a degraded state, and not progress through the full recovery pathway (Stage 3s) without intervention (i.e., active restoration).

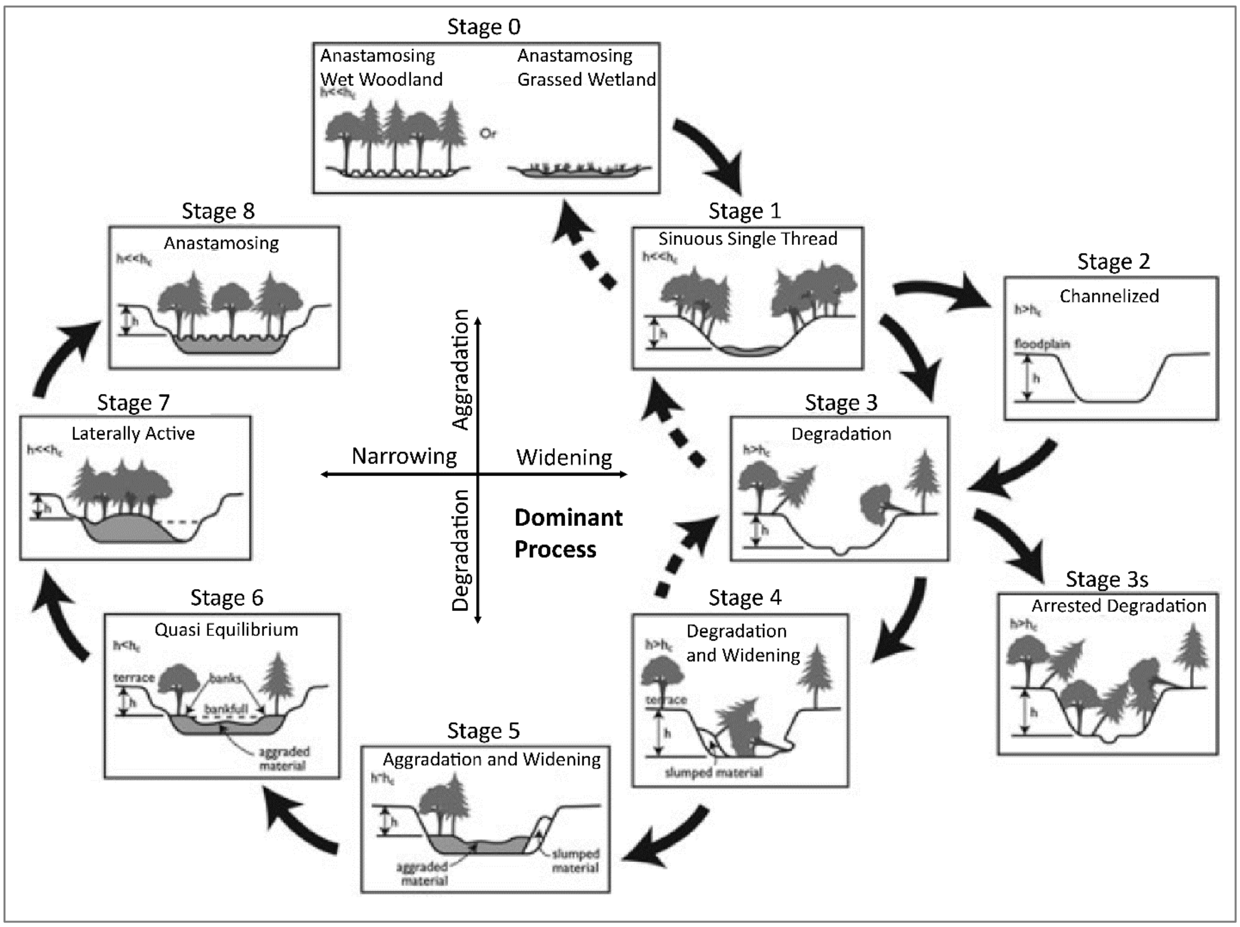

Figure 6. A channel evolution model showing how a stream can change through time. It suggests that multi-threaded streams were more common historically, that recovery from disturbance can proceed in both a clockwise or counterclockwise trajectory, and that it is possible for streams to be “arrested” in a degraded state that will not recover without intervention. FIGURE REPRODUCED WITH PERMISSION FROM CLUER AND THORNE (2014)

Riverscape Diversity

Riverscapes naturally adjust their form over multiple spatial extents and timescales based on the characteristics and processes outlined above. The result is a dynamically evolving system where different portions of the riverscape may support different instream and floodplain habitat conditions at different times. Diversity of physical conditions is important to the long-term resilience of riverscapes and landscapes, and this evolving diversity in turn supports species and ecosystems. This complex and intertwined understanding of riverscapes is a step forward from the historical management of rivers that has often focused on the reach scale and habitat conditions for particular species, often fish (Fausch, 2002). The historical viewpoint has sometimes led to overly precise targets for conservation, identified by Hiers et al. (2016) as “the problem of precisionism”. Instead, the interconnected and changing web of riverscape forms and processes summarized throughout Part I reveals that effective management of these dynamic environments comes from consideration of the interacting fluvial processes over multiple spatial and temporal scales. In Part II, we will identify different natural conditions found throughout GRBA and describe the processes that are important to their form and function.

Part II. Riverscape Assessment for Great Basin National Park

Overview of GRBA Riverscapes

Part II uses the concepts outlined in Part I to classify GRBA perennial streams into seven distinct reach types. Each reach type represents segments of GRBA streams that are characterized by similar forms and behavior. This portion of the report includes: an overview of the general physiographic setting, consideration of stream classification systems and applications, a description of the current approach to classification undertaken, and finally a description of the seven reach types identified for GRBA streams.

Site Description

GRBA is located in eastern Nevada, encompassing 77,180 acres (312 km^2) of the Southern Snake Range in the Great Basin region. The Park has a relief of ~2100 m from the high point of Wheeler Peak (3,982 m) down to the lowest park boundary at ~1890 m. The north-south orientation of the Snake Range, a characteristic of many mountain ranges in the Great Basin, and the significant relief result in a steep east-west topographic profile that produces many high-gradient streams across the Park. There are 130 km (81 mi) of perennial streams in GRBA (Baker, 2007).

Vegetation patterns in GRBA are strongly influenced by elevation and associated changes in temperature and precipitation. General ecological community types range from mid-elevation desert (1,524–1,981 m) up through alpine tundra (3,353–3,962 m). Annual precipitation ranges from as little as 15 cm in the valleys near the eastern Park boundary to >76 cm at high elevations (Comer et al., 2016). Parkwide annual precipitation averages 33 cm (Comer et al., 2016).

Past glaciation has imprinted on GRBA valley bottoms to shape the valleys that the park's contemporary streams flow through. Glacial advancement and retreat left a range of erosional and depositional features on the landscape. The most highly visible features, such as horns, aretes, and cirques can be seen at Wheeler Peak. Less obvious features, such as terminal and lateral moraines, are visible from the Wheeler Peak and Mather overlooks (Graham, 2014). Glaciers advanced down to 2,300–2,500 m above sea level in several valleys, including in the Baker Creek and Lehman Creek drainages, where they reached approximately the Baker Creek and Upper Lehman Creek Campground trailheads. An important impact of glaciation is that many of the very large rocks the glaciers deposited are too big to be transported by the streams today.

Approach to Classifying Streams in GRBA

A primary objective of geomorphic stream assessments is classifying streams based on similar characteristics and behavior. Classifying streams into *reach types* can aid in identifying similarities in their form and behavior both within and across watersheds. Because different reach types are more or less sensitive to disturbance, their identification can help managers interpret riverscape conditions and prioritize management efforts. Identifying differences in the natural settings and characteristic forms of riverscapes is necessary for developing appropriate management and/or restoration strategies. For example, a confined, steep headwater reach has different characteristics and is expected to respond differently to disturbance compared to a partly confined low gradient reach.

Similarly, restoration approaches that rely on the construction of instream structures are likely to force different responses depending on the reach type where they are built. In confined, steep, coarse settings, they may lead to the formation of step-pool morphology and have a limited influence on adjacent hillslope vegetation, while in partly confined, moderate-gradient sections they may force scour pools, bank erosion, channel avulsion and have the potential to benefit riparian areas by increasing overbank flows and raising the water table.

Multiple stream classification systems already exist, but streams in GRBA do not fit easily into previously described classifications such as those provided by Rosgen (1994) or Montgomery and Buffington (1997). Therefore, it was determined that a customized classification for GRBA would be most valuable for park managers. Our approach to classification for GRBA draws most heavily on the River Styles approach (Brierley and Fryirs, 2013) which is an open-ended classification system that allows the user to identify unique reach types based on their particular location. Our approach relies on the characteristics and concepts outlined in Part I, namely watershed position, valley setting, disturbance regime, and capacity to adjust based on its flow, sediment, and wood regime.

We relied on a combination of remote data and field observations to develop a coarse yet spatially explicit suite of reach types in GRBA. We describe how the drivers of river form and function (e.g., watershed position, valley setting, disturbance regime, flow, sediment, and wood regimes) differ among reach types. Remote data sets included recent aerial imagery, high-resolution topography, hydrography data from the National Hydrography Dataset (NHD), and vegetation mapping (LANDFIRE). These datasets were used to identify landforms such as the valley bottom and to produce longitudinal profiles for perennial streams that drain the eastern portion of GRBA.

Field observations were used to assess characteristics not easily observed by remote data sets, including channel planform and geometry, substrate, wood recruitment and storage, historic beaver dam activity and evidence of channel behavior. We used these observations as evidence of the dominant processes shaping different stream reaches. We did not collect quantitative data during field visits. While such data can be useful in stream classification, it was beyond the scope of this assessment. We relied on the following variables to classify GRBA streams: (1) Valley gradient (i.e., slope), (2) Valley width, (3) Channel bed sediment substrate size, (4) Process domains and disturbance regime (i.e., what is the balance between hillslope and fluvial processes?), (5) Glacial influence on contemporary processes, and (6) Vegetation community (e.g., meadows vs. forest, deciduous vs. coniferous).

In addition to the variables listed above, we used observations of wood storage, as well as the relationship between wood characteristics (e.g., tree height and diameter) and channel characteristics to develop an understanding of the wood dynamics within each reach. Because wood dynamics drive and are driven by fluvial processes, we use it as an input into our classification.

We directly visited an accessible and representative sample of GRBA streams. Over the course of four days, we hiked portions of North Fork Big Wash, South Fork Big Wash, Snake Creek, Pole Canyon Creek, Timber Creek, South Fork Baker Creek, Baker Creek, and Lehman Creek. These field visits complemented our existing familiarity with Snake Creek and Strawberry Creek. We did not visit any streams on the west side of the Park, but the designated reach types are designed to apply to them as well.

General Description of GRBA Riverscapes and Stream Reaches

All perennial streams in GRBA have high channel gradients, with the lowest gradients at 3% and many streams with gradients of 8–12%. Within other classification schemes (e.g., Rosgen, 1994; Montgomery and Buffington, 1997) all streams within GRBA would likely fall within one or two categories (e.g., "A" channels in Rosgen; "cascade" or "step-pool" in Montgomery and Buffington); however, it is important to recognize that there is significant variability within GRBA streams with respect to valley setting and confinement, channel geometry, channel planform, and wood dynamics. Many existing conceptual models of streams, and indeed many actual streams, show a high correlation between valley setting and valley gradient, in which confined streams are characterized by high slopes and coarse substrate. Many high-gradient streams in GRBA, however, are just partly confined and have adjacent floodplain pockets, or discontinuous floodplains. These stream reaches tend to support significant woody riparian vegetation and upland species like conifers. While there is ample evidence of adjustment, it appears these channels do not adjust during annual peak flows but require higher flow events. Field observations following high annual runoff did not record evidence of recent channel migration via bank erosion and bar deposition or channel avulsions, suggesting that such adjustments require higher magnitude flows than occur annually.

Wood is common across nearly all reach types in GRBA (Figure 7). In many lower-elevation and partly confined settings, large wood jams force the creation and/or activation of channels by forcing sediment deposition and causing flow separation. Wood transport is low in the higher-elevation settings dominated by conifers, as evidenced by significant downed wood but minimal wood jams. Wood appears to be critical in creating complex instream habitat. Where wood is absent, stream channels are dominated by planar sections that lack geomorphic and habitat complexity. In many cases the valley bottom is characterized by multiple channels, but rarely are the channels simultaneously active.

Figure 7. Wood is an important and common feature across nearly all stream reaches in GRBA. The function wood plays varies among reach types. In confined reaches, it may force step pools (top left); in partly confined areas it splits flow in both high-gradient (top right) and low-gradient (bottom left) settings. In low gradient sections with finer bed and bank material it can also force undercut banks, scour pools and bars (bottom right). NPS / SCOTT SHAHVERDIAN

There is limited evidence of beaver activity, and most is found in lower elevations with lower gradients and narrower valley bottoms that support aspen, cottonwood, and willow. Perhaps counterintuitively, beaver activity appears to have been supported only in more confined settings where dams were able to be built across the entire valley bottom (e.g., in Strawberry Creek below the trailhead), whereas in riverscapes with very wide valleys (e.g., lower Baker Creek) which maintain relatively high (i.e., 5%) gradients, we did not observe evidence of historic beaver activity.

Valley topography in GRBA is highly complex. Many of GRBA's lower-elevation areas with wide valleys are characterized by significant topographic variability and diverse substrates ranging from fine-grained sediment to boulders. Multiple channels are often present, although commonly inactive (i.e., without flowing water). Despite a wide valley setting and multiple channels, it seems unlikely that these channels experience frequent lateral migration and movement across their valley bottom. Instead, the coarse sediments present across these valleys highlight the impact of hillslope contributions of sediment and/or sediment delivered during glacial periods, which are unlikely to be transported under the contemporary flow regime. In this sense, some reaches within the Park are imposed on an inherited landscape that they do little to influence or change in modern times.

Trees and shrubs are present throughout all riverscapes in GRBA, and species composition is heavily dependent on elevation. Higher elevations are dominated by coniferous species on both hillslopes and valley bottoms, while at lower elevations, cottonwood, aspen, birch, and willow become more common. In some lower-elevation locations, ponderosa pine are present adjacent to the channel (e.g., lower Lehman Creek) (Figure 8).

Figure 8. At lower elevations in GRBA, such as Lehman Creek pictured here, ponderosa pine and rabbitbrush can be found growing adjacent to the channel. This stream represents a partly confined, inherited valley topography reach (Reach Type V, as described in next section). NPS / SCOTT SHAHVERDIAN

The Seven Reach Types in GRBA

We classify all GRBA's perennial stream segments as falling into one of seven reach types. In this section we describe the characteristic attributes and dynamics of each reach type as well as identify where they are found (Figure 9). Key characteristics are summarized at the end of the section.

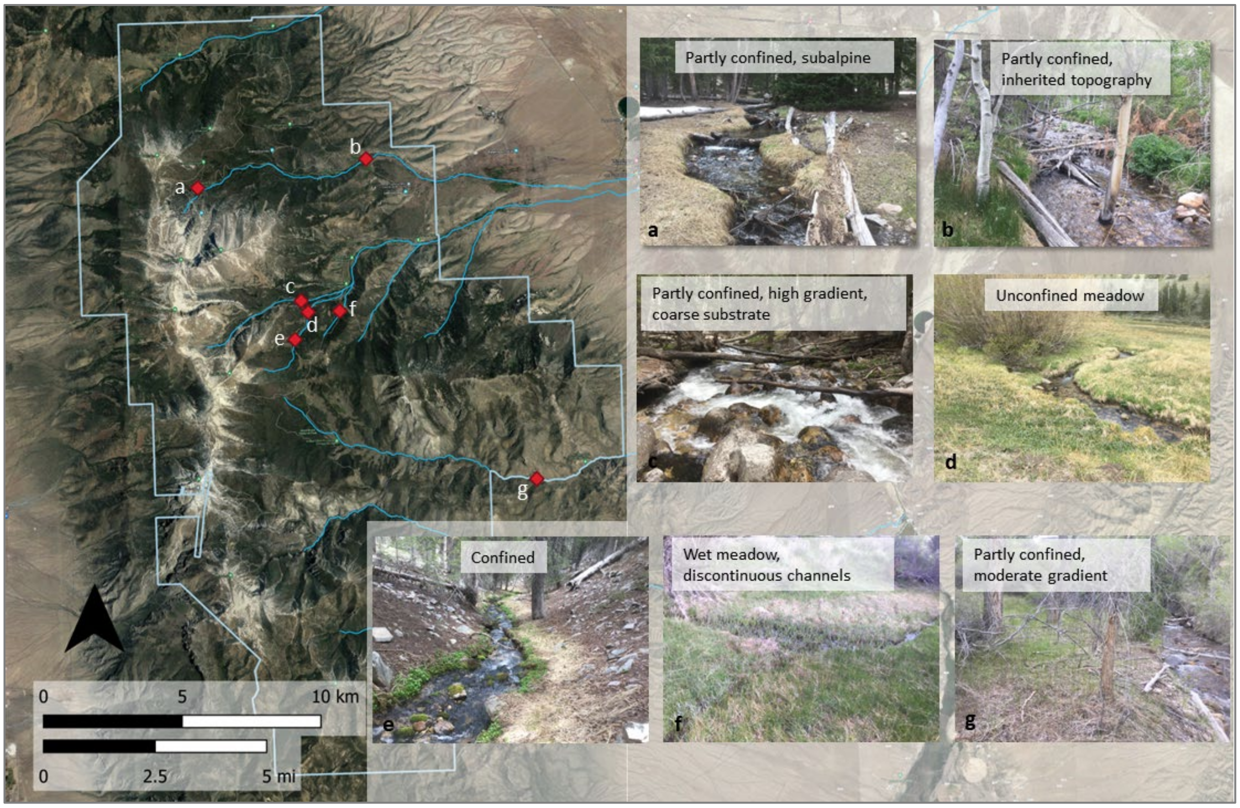

Figure 9. Representative photos showing the seven reach types identified for GRBA streams. Matching lower-case letters identify where photos were taken within the park. NPS / SCOTT SHAHVERDIAN

Reach Type (I): Confined

Confined reaches are characterized by a narrow valley bottom and a high degree of connectivity to adjacent hillslopes (Figures 10 and 11). These areas tend to support a single channel, with limited areas of discontinuous floodplain potentially present. This reach type is common throughout the Park, has variable slopes, ranging from 5 to 20%, and is notably not highly correlated with elevation. As a result, specific channel characteristics, such as channel substrate and geomorphic units, are variable. In the absence of large woody debris, these reaches tend to be dominated by planar geomorphic units such as rapids or runs. Where wood is present, it forces the formation of step-pools and bars. These areas have limited to no lateral adjustment capacity and low geomorphic sensitivity.

Figure 10. A confined stream reach (Type I) as illustrated by South Fork Baker Creek. The channel is confined by adjacent hillslopes on both sides. Channel substrate is a mix of sand to boulders. NPS / SCOTT SHAHVERDIAN

Figure 11. A confined stream reach (Type I) as illustrated by South Fork Big Wash. The channel is highly connected to its adjacent hillslope. In this small section of stream, the lack of wood has resulted in a channel dominated by a rapid that represents just a single planar geomorphic unit. NPS / SCOTT SHAHVERDIAN

Reach Type (II): Partly Confined, Subalpine

We visited only one example of the partly confined, subalpine reach type during this assessment, located at the headwaters of Lehman Creek, near the Wheeler Peak Campground (Figure 12). This reach type is also present at the upper portion of Snake Creek and Baker Creek (pers. comm., Park staff). This is likely an uncommon reach type across GRBA, and located only at high-elevation, wide-valley, low-gradient sites, which are glacially influenced and uncommon. This reach type exhibits channel geometry similar to the unconfined meadow reach type (Type VII), but it is dominated by large conifer rather than herbaceous riparian species or willow. It can support multiple channels. Instream geomorphic units are predominantly planar except where large wood is present and forcing the creation of bars and pools. Channel substrate ranges from gravel to cobble and is semi-angular, indicating short transport distances, which is consistent with its position high in the watershed. It has both a moderate capacity for lateral adjustment and moderate geomorphic sensitivity.

Figure 12. A partly confined, subalpine stream reach (Type II) as illustrated by Upper Lehman Creek near Wheeler Peak Campground. NPS / SCOTT SHAHVERDIAN

Reach Type (III): Partly Confined, High-gradient, Coarse Substrate

This reach type is usually located at higher elevations in heavily forested areas dominated by mixed conifer and aspen. The substrate is dominated by large, rounded boulders that are unlikely to be transported under the modern climate except for during extreme flow events (Figures 13 and 14). Despite confined conditions being the norm for very high gradients, this GRBA reach type is characterized by a partly confined valley setting which allows for the formation of multiple channels. Slopes are variable, ranging from 8 to 15%. These channels are most commonly activated in response to instream wood, whether a single tree, or wood jam that forces upstream deposition of sediment and shunts flows out of the main channel. Channel avulsions are more likely to occur than lateral channel migration through progressive bank erosion. These reaches may support several channels, though there are also sections where only one active channel is currently present. Infrequent pools may be present, although they are generally small and forced by flows that plunge over boulders. The high roughness provided by boulders, as well as long pieces of wood relative to the narrow channel, effectively trap wood instead of transport it. This reach type is characterized by a moderate lateral adjustment capacity and low sensitivity. These reaches are often located in areas that were glaciated, such as along the upper portions of Baker Creek and Lehman Creek.

Figure 13. A partly confined, high-gradient, coarse substrate reach (Type III) as illustrated by Baker Creek upstream of South Fork Baker Creek confluence. NPS / SCOTT SHAHVERDIAN

Figure 14. A partly confined, high-gradient, coarse substrate reach (Type III) with a lower gradient than seen in Figure 9, illustrated here by Lehman Creek approximately 1.5 miles upstream from the Lehman Creek Trailhead. NPS / SCOTT SHAHVERDIAN

Reach Type (IV): Partly Confined, Moderate-gradient

Partly confined, moderate-gradient reaches are located at lower elevations in GRBA. These areas are differentiated from the partly confined, high-gradient reach types by the mixed substrate, which ranges from sand to cobble, and only occasionally includes boulders. Slopes range from 3 to 6%. The geomorphic units in these reaches are composed of planar features such as rapids and runs, but rarely include the cascades present in the high-gradient areas. As opposed to higher-elevation areas where the woody vegetation is largely composed of mixed conifer and aspen, at lower elevations cottonwoods, willow, and birch become the primary source of woody vegetation near the channel (Figure 15). Importantly, these species are more dependent on fluvial dynamics for their establishment and health compared to high-elevation vegetation communities. Pinyon pine and juniper may also be present, either on adjacent hillslopes or in areas of the valley bottom with limited water. Within this reach type, large wood is important and is more likely to create instream features such as pools, undercut banks, and bars. Wood is also more likely to force bank erosion and lateral migration, rather than channel avulsions, which are more common in the partly confined high-gradient reach type (Type III). The best example of this reach type can be found in the lower portions of Snake Creek. This reach type has just moderate capacities for lateral adjustment and geomorphic sensitivity, although these characteristics are still the highest among GRBA reach types.

Figure 15. A partly confined, moderate-gradient stream reach (Type IV) as illustrated by the lower portion of Snake Creek. These low-elevation areas have woody vegetation dominated by riparian species such as cottonwood, willow, and birch, which all rely more directly on fluvial processes than the conifers found at higher elevations. NPS / SCOTT SHAHVERDIAN

Reach Type (V): Partly Confined, Inherited Valley Topography

Partly confined riverscapes are often characterized by a wide floodplain across which streams move through time, creating a spatially and temporally diverse mosaic of aquatic and riparian habitats (Figures 8 and 16). For streams to rework valley bottom topography, however, they must have the stream power to move channel and valley bottom sediments. Along lower-elevation portions of several creeks in GRBA, wide valley bottoms are characterized by highly complex topography that includes multiple, often inactive, channels and long linear ridges that run up and down valley. Valley bottom sediments range from fine sediment to large angular boulders, which the current streams do not transport during annual peak flows. As a result, these streams behave more like confined streams over short time scales despite their wide valley bottom. Complex valley topography is likely influenced by a combination of hillslope processes (e.g., landslides) as well as previous climatic conditions and sediment delivery (e.g., elevated sediment delivery during glaciation). Regardless of the specific cause, these streams occupy a limited portion of their valley bottom at any time. The activation and deactivation of channels within these settings appears to result from large sediment deposits often forced by large wood. Like most other streams across GRBA, in the absence of the instream roughness of large wood, this reach type's geomorphic units are predominantly planar. Despite having a high capacity for lateral adjustment, these reaches have low sensitivity and generally have a limited capacity to change their form.

Figure 16. Partly confined, inherited valley topography reach (Type V) as illustrated by Lehman Creek downstream of Lower Lehman Creek Campground. The complex valley bottom topography appears to have been created by previous climatic conditions associated with glaciation and hillslope processes. NPS / SCOTT SHAHVERDIAN

Reach Type (VI): Wet Meadow, Discontinuous Channels

In areas with relatively low drainage areas and subsequently low streamflow and high groundwater inputs, wet meadows with discontinuous channels are present. Where channels do exist, they are narrow and shallow and show little evidence of either erosion or deposition. This reach type is dominated by herbaceous riparian vegetation that may even be growing within the channel itself (Figure 17). In some instances, the presence of a channel may itself be a sign of degraded conditions, though making this determination is challenging. These areas have a low lateral adjustment capacity and high geomorphic sensitivity, being particularly vulnerable to impacts such as grazing and invasive species.

Figure 17. A wet meadow, discontinuous channel reach (Type VI) as illustrated here at Timber Creek. Sedges and rushes growing in the channel indicate a lack of geomorphic activity. NPS / SCOTT SHAHVERDIAN

Reach Type (VII): Unconfined Meadow

Unconfined meadows appear as short reaches of low energy and unique habitat in several locations within GRBA (Figure 18). These reaches are characterized by lower gradients and a wide valley bottom. Vegetation in these reaches is dominated by herbaceous riparian, rather than woody riparian species. These areas can support multiple channels, and streambanks are generally low lying and stabilized by dense roots associated with herbaceous riparian vegetation. Channel substrate ranges from cobble to sand. Due to their finer bed and bank material and lower valley confinement, they are characterized by a moderate lateral adjustment capacity and moderate sensitivity. They are found at variable elevations, but they are always characterized by low stream power, a result of low slopes and limited drainage areas leading to streamflow.

Figure 18. An unconfined meadow reach (Type VII) illustrated by South Fork Baker Creek. This reach type is present in several isolated locations throughout GRBA, but it is less common than other reach types. NPS / SCOTT SHAHVERDIAN

Reach Type Summary

The seven stream reach types that characterize GRBA riverscapes are summarized in Table 1 and depicted in Figure 9.

Table 1. The seven stream reach types that characterize GRBA riverscapes. Each reach type is briefly described according to some of its most relevant physical characteristics, geomorphic processes, and management implications.

Reach Type	Watershed position	Valley bottom width (m)	Gradient (%)	Substrate	Wood regime	Geomorphic characteristics	Representative location	Lateral adjustment capacity	Relative sensitivity	Management implications
(I) Confined	Upper-mid basin	5–15	5–20	Sand - boulder	Recruited by natural tree mortality and hillslope processes; limited transport; stored as single pieces	Single thread channel; variable geomorphic unit assemblages depending on gradient; may include step-pool and planar units	South Fork Baker Creek at 2800 m.a.s.l.	Low	Low	Form is driven entirely by hillslope processes, very limited adjustment capacity, and low sensitivity means they are a low priority for direct intervention.
(II) Partly confined, subalpine	Upper basin	20–40	4–8	Gravel, sand, cobble	Recruited by natural tree mortality and bank erosion; limited transport; likely stored as large single pieces	Multi-threaded and moderate gradient; geomorphic units include step-pools and scour pools forced by wood, undercut banks, bars.	Upper portion of Lehman Creek near Wheeler Peak Campground	Moderate	High	Uncommon reach type in GRBA found near Wheeler Peak Campground. Higher priority for conservation and potential instream restoration.
(III) Partly confined, high-gradient, coarse substrate	Upper basin	10–40	8–15	Cobble, boulder	Recruited by channel avulsion and natural tree mortality; limited transport; stored in jams and single pieces	Single or multi-threaded, highly resistant bed and banks, dominated by high-gradient planar features such as cascades and rapids	Baker Creek upstream of the South Fork Baker confluence	Moderate	Low	Instream restoration can impact local habitat conditions and formation of specific habitats (e.g., pools), but unlikely to see widespread changes to the channel.
(IV) Partly confined, moderate gradient	Lower basin	10–50	3–6	Gravel, sand, cobble	Riparian forests provide source; recruited by fluvial processes; stored in jams.; historical beaver presence possible.	Single or multi-threaded; geomorphic units include scour pools, cutbanks, undercut banks, runs, and bars.	Lower Snake Creek	Moderate	Moderate	Able to be influenced by stream management/ restoration that includes direct intervention as well as addressing upslope conditions

Table 1 (continued). The seven stream reach types that characterize GRBA riverscapes. Each reach type is briefly described according to some of its most relevant physical characteristics, geomorphic processes, and management implications.

Reach Type	**Watershed position**	**Valley bottom width (m)**	**Gradient (%)**	**Substrate**	**Wood regime**	**Geomorphic characteristics**	**Representative location**	**Lateral adjustment capacity**	**Relative sensitivity**	**Management implications**
(V) Partly confined, inherited valley topography	Upper-mid basin	40–80	6–10	Cobble, boulder, gravel	Recruited by natural mortality of valley bottom trees, bank erosion, and channel avulsion; stored in jams.	Single or multi-threaded; often with several inactive channels; generally moderate gradients; geomorphic units include bars, runs, and rapids; wood can force significant deposition, channel reactivation, scour pool formation	Lehman Creek downstream of Lehman Creek campground	Moderate	Low	Despite a wide valley bottom these streams behave more like confined reaches due to coarse bank substrates. Addition of wood more likely to force local geomorphic change than engagement with the full valley bottom.
(VI) Wet meadow, discontinuous channel	Upper basin	5–20	7–11	Sand, silt, gravel	Low wood influence; herbaceous vegetation dominates; wood may be input by non-fluvial processes	Shallow, narrow and discontinuous channel	Upper Timber Creek	Low	High	Area is highly sensitive to direct impacts of grazing and or changes in the delivery of water and sediment. Responsive to restoration.
(VII) Unconfined meadow	Mid basin	50–100 m	≤ 4	Gravel, sand, cobble	Limited riparian woody plants and low wood recruitment; stored as small jams or single pieces	Narrow channel that may support steep banks due to high cohesion from herbaceous plants	South Fork Baker Creek 1.5 km upstream of Baker Creek confluence	High	High	Uncommon reach type in GRBA that provides unique habitat. High sensitivity means that these reaches are more likely to respond to changes in water, sediment or wood inputs and will respond to restoration.

Part III. Management Implications for Great Basin National Park

In Part III, we describe management implications of the concepts and classification presented in Parts I and II. An inherent challenge in identifying management implications based on a classification of stream type is that this type of assessment, in and of itself, does not have specific management implications, since it is fundamentally a description of existing conditions. At its best, a riverscape classification provides land managers with the foundation needed to support management decisions. Management decisions, however, take into account multiple factors, including stakeholder perspectives, specific resource concerns, financial considerations, and often are responses to discrete or urgent events. Any attempt to identify the management implications of an assessment can therefore easily slip into "what-if" scenarios. While many scenarios may be plausible, attempting to outline them in their multitude and specificity is beyond the scope of this report. Instead, we present suggestions for how the information presented in this report can be used to support management in GRBA. We do so by illustrating one example of how this report can provide a foundation for decision-making in the hypothetical case of a future wildfire. We also summarize the reach types presented in Part II by their sensitivity and adjustment capacity, which are important attributes to understand when evaluating management actions concerning riverscapes. Finally, we suggest that any future monitoring efforts, or resource specific assessments (e.g., BCT) need to be based on an understanding of the different reach types found in GRBA.

The concepts and classification provided in Parts I and II form the basis for making management decisions by allowing land managers to answer questions such as: "Along what reaches are stream forms and functions most likely to be influenced by riverscape management actions, such as stream restoration?"; "What reaches are geomorphically sensitive and have a high capacity for adjustment?"; "What types of natural disturbances affect different reach types?"; "What is the natural range of variability in stream forms associated with different reach types?"; "Are riverscape conditions more influenced by fluvial processes or by processes largely independent of fluvial processes?" Examples of processes that are largely independent of fluvial processes are upland and hillslope processes such as the establishment, growth, mortality, and falling of conifers. While the wood contributions of these trees are a critical component of riverscape health, fluvial processes themselves are less important to the creation and maintenance of the conditions for continued wood establishment, recruitment to the channel, and habitat maintenance.

Management decisions related to riverscapes across GRBA may include identification of areas that may benefit from stream restoration versus areas whose long-term health is more dependent on upland restoration; selection of a particular method, or type of restoration (e.g., low tech vs highly engineered approaches); or establishing target conditions for restoration that are based on a site's natural potential. A less direct but equally important consideration is that a better understanding of riverscape form and function gives Park staff the understanding needed to develop realistic expectations for how specific management actions are likely to impact a riverscape and other resource management objectives. For example, if improving instream habitat for BCT or expanding riparian areas is a management priority, working in partly confined, moderate-gradient reaches (Type IV) is more likely to achieve management objectives than working in confined reaches (Type I). Below, we provide an example of how a better understanding of riverscapes can help Park staff make decisions following a specific disturbance event, wildfire.

Following wildfire, streams are often the site of significant geomorphic change and are prioritized for restoration. In GRBA, if a future wildfire burns across a range of reach types, ranging from partly confined, moderate gradient (Type IV) to unconfined meadow (VII), to confined (I), the information provided in this report can help Park staff choose the most appropriate management strategies by understanding the natural setting and dynamics of different reach types. Confined reaches (I), with low adjustment capacity, low sensitivity, and sediment supply limited are most likely to benefit from treatments that prioritize the revegetation of adjacent uplands, rather than direct intervention in the stream. Unconfined meadows (VII), with high sensitivity are a unique and particularly vulnerable reach type that could benefit a great deal from direct interventions post-fire. Similarly, partly confined, moderate-gradient reaches (IV), with moderate sensitivity would benefit from direct interventions due to their vulnerability to dramatic geomorphic changes and their ability to support robust riparian communities. The specific treatments and expectations for their capacity to influence riverscapes, such as the ability of restoration to change instream habitat or force channel-floodplain connectivity, should be grounded in the natural setting and processes that characterize each reach type (i.e., the forms and functions described in Part II).

Lateral Adjustment Capacity and Sensitivity—Implications for Management

We classified streams according to their lateral adjustment capacity and sensitivity, which we qualitatively classify as low, medium, or high (Figures 19 and 20). Except for the rare short segments of unconfined meadow reaches (Type VII), all GRBA stream reaches had low or moderate adjustment capacity. This is because all streams in GRBA occur in a high relief, mountainous setting. Streams with a high lateral adjustment capacity are more likely to be found in the low relief, lower-elevation basin settings found beyond the park boundary. Similarly, most stream length in GRBA is characterized by low or medium sensitivity. Notable exceptions to this are found in the unconfined meadow (VII) and partly confined, subalpine (II), and wet meadow, discontinuous (VI) reach types, which have high sensitivity.

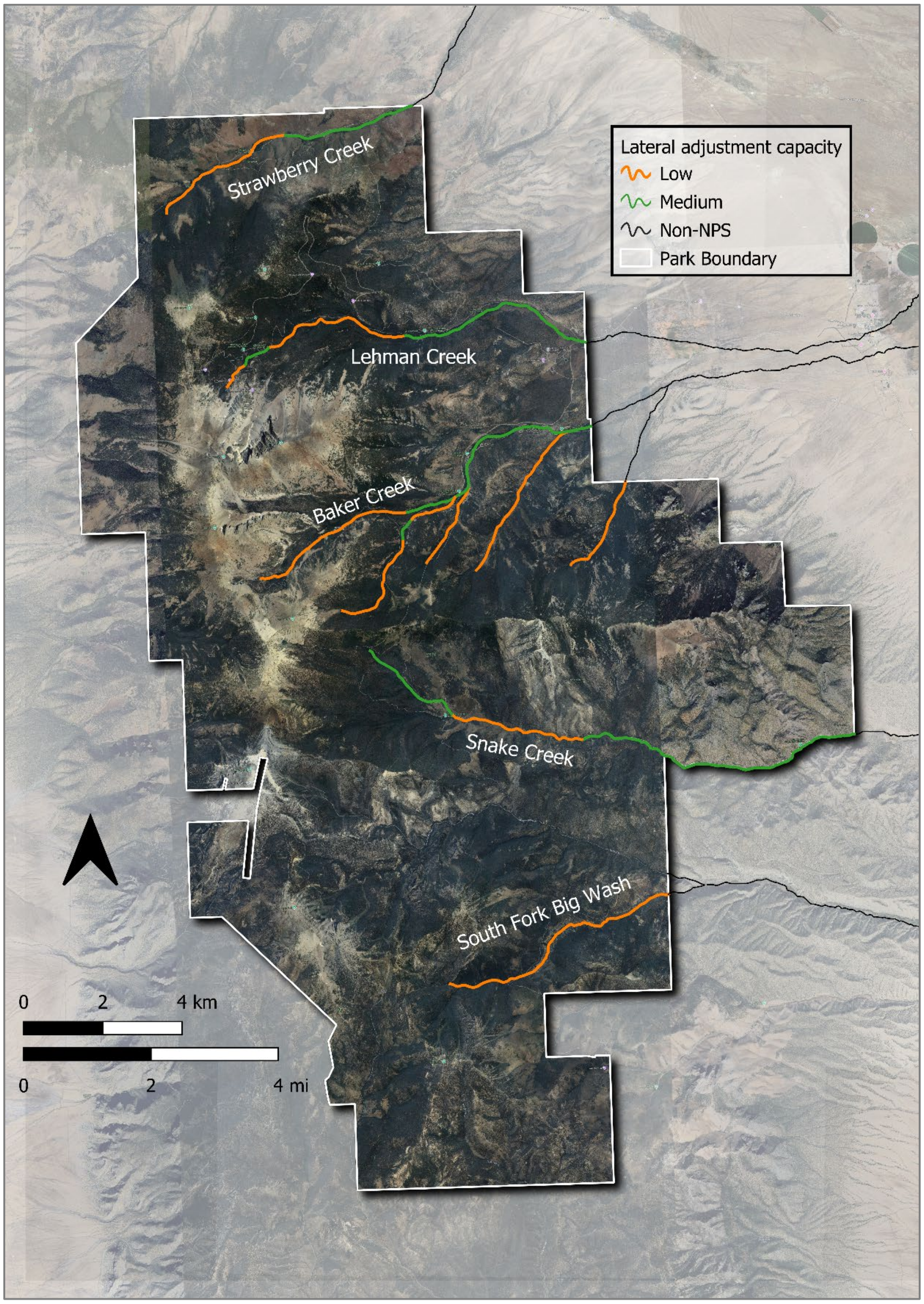

Figure 19. Map illustrating lateral adjustment capacity of stream segments across GRBA. Note that reaches with "high" lateral adjustment capacity (Reach Type VII only) were too rare and short to be displayed at this scale. NPS / SCOTT SHAHVERDIAN

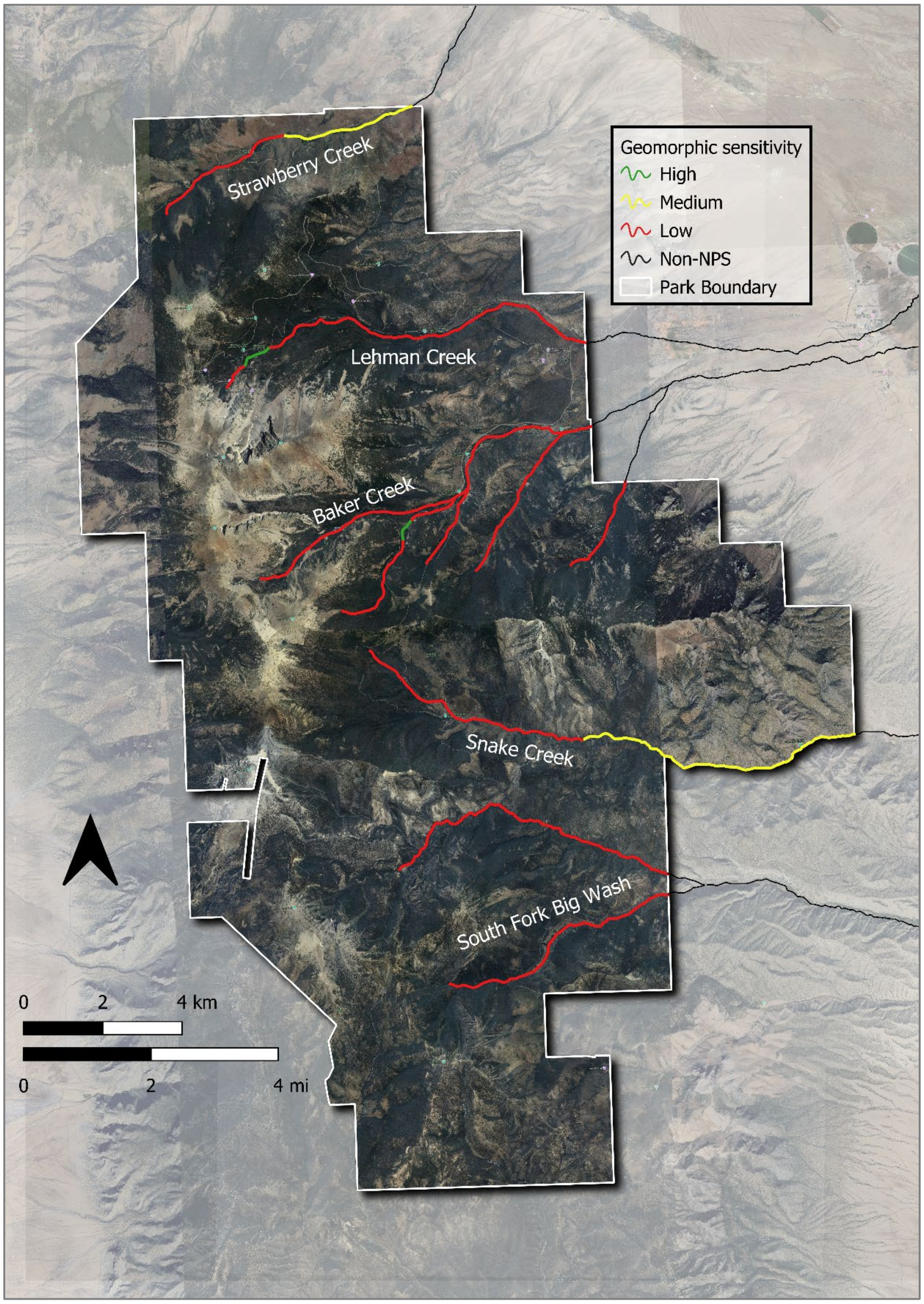

Figure 20. Map illustrating the degree of geomorphic sensitivity for stream reaches across GRBA. Most reaches have a low geomorphic sensitivity due to the combination of narrow valley bottom, high gradients, and coarse substrate. NPS / SCOTT SHAHVERDIAN

Interpreting GRBA streams is challenging because the park has many streams that have wide valley bottoms *and* high gradients with coarse substrate, attributes which are not commonly found together. These streams, therefore, have a moderate capacity for lateral adjustment but are characterized by low sensitivity. Most stream reaches in GRBA have low sensitivity due to a combination of their degree of confinement, coarse substrate, and inherited valley bottom topography. However, there are several reach types, specifically the unconfined meadow (VII); partly confined, subalpine (II); and wet meadow, discontinuous (VI) reach types that have high sensitivity. Between these reach types and the low sensitivity reach types, is the partly confined, moderate-gradient (IV) type which has a moderate sensitivity. The juxtaposition of a high capacity for lateral adjustment (i.e., wide valley bottom) and low sensitivity is showcased by lower Lehman Creek. Despite a wide valley bottom, this area is characterized by high slopes and a coarse substrate, which make it relatively insensitive to changes in flow, sediment, or wood inputs. This reach does have the capacity to adjust laterally (i.e., change its location within the valley bottom) but is only likely to do so in response to large changes to streamflow, sediment, or wood delivery.

Generally, streams that have a lower lateral adjustment capacity and lower sensitivity are less likely to be impacted by natural or anthropogenic disturbance or by restoration activities, especially if those activities are process-based, as opposed to more intensive (e.g., channel realignment). In GRBA, this may mean that the best course of action may often *not* require direct intervention because in many reach types it is unlikely to exert significant influence. Restoration, or other management actions affecting riverscapes are most likely to be impactful in reach types with moderate to high lateral adjustment capacity and medium to high sensitivity.

Monitoring Riverscapes in GRBA

Finally, we suggest that future monitoring and evaluation of riverscapes across GRBA could include all reach types. Each reach type is influenced by a slightly different set of factors, so monitoring all reach types ensures that Park staff are able to evaluate the full suite of variables that influence GRBA riverscapes. Monitoring confined (I) reach types can provide information regarding forest stand health by assessing how trees are being recruited to the channel. Monitoring partly confined moderate-gradient (IV) reaches will reflect the interplay of natural riparian vegetation dynamics and stream changes due to changes in streamflow and sediment supply. Monitoring unconfined meadows (VII) can provide insight into changes in streamflow and sediment supply and the impacts of herbivory on vegetation and channel forms. Table 2 proposes some general riverscape attributes that could be good targets for park monitoring activities.

Table 2. Select attributes of riverscapes and their significance. There are numerous methods and levels of precision that can be used to assess and monitor each of the attributes.

Attribute	Significance
Planform	Number of channels and sinuosity are elements of complexity in partly confined settings
Channel geometry	Proxy for channel-floodplain connectivity (i.e., incision)
Instream geomorphic units	Features such as pools, bars, and undercut banks are critical for evaluating instream habitat quality for BCT
Wood	Significant across a wide range of reach types due to its ability to create complex instream habitat, force channel migration in partly confined settings, promote sediment retention, and force channel-floodplain connectivity
Beaver dams	Important feature in partly confined moderate-gradient settings, capable of influencing instream habitat, channel-floodplain connectivity, and riparian dynamics
Riparian vegetation	Indicator of available water resources, often related to channel-floodplain connectivity, and a critical source of wood to the channel in partly confined settings
Hillslope vegetation	The principal source of wood to channels in confined settings, and a contributor in partly confined settings

Similarly, existing monitoring programs, such as those dedicated to BCT, should also account for the reach type when interpreting data and developing conclusions. Accounting for the natural differences in setting, form, and function of different reach types can provide insights into whether or not different reach types have different capacities to support specific natural resources, and whether or not different reach types are particularly vulnerable to different stressors. For example, changes to snowpack and the magnitude and timing of streamflow due to climate change may have different impacts on different reach types, and appropriate management actions should be based on each site's natural potential and a sound understanding of how its potential responses to specific management actions. As climate change alters precipitation patterns, temperature, and consequent biological communities, a site's historic potential may differ from its future potential. While the specific impacts of climate change on GRBA riverscapes are beyond the scope of this report, the classification and descriptions provided partly lay the foundation for a reach-scale assessment of how different climate scenarios and impacts are likely to impact different portions of the park.

Challenges and Future Directions

This assessment was undertaken to help provide staff at GRBA with foundational concepts necessary to understand and interpret the park's various streams. It purposefully focuses on the processes and dynamics that influence river forms and functions. A natural limitation of such an effort is that *observation* of processes unfolding requires time. An inherent challenge in geomorphic assessments is making inferences of process, based on single snapshots in time. Brierley, et al. (2021) refer to this as "the dark art of interpretation in geomorphology." The lower portion of Lehman Creek exemplifies the challenges of interpreting riverscapes based on a single point in time. Lower Lehman Creek is partly confined and has multiple inactive channels. While such channels clearly indicate the historic presence of water, what remains uncertain is the timescales over which these channels are activated, and whether or not several channels may flow simultaneously. GRBA staff have important data collection efforts ongoing that can inform how streams throughout GRBA change through time.

Recently, stream restoration work was undertaken on GRBA's Strawberry Creek, a stream that continues to experience significant changes following the Strawberry Fire in 2016. Restoration was undertaken to improve instream conditions for riparian communities as well as for Bonneville Cutthroat Trout by forcing hydraulic and geomorphic changes. Park staff continue to monitor this work and perform maintenance as needed. This work is being performed in a medium sensitivity area with moderate capacity for lateral adjustment, which are sound geomorphic attributes to target for strong bang-for-the-buck management efforts. Continued monitoring of this work can provide insight into how other similar reach types may respond to restoration throughout GRBA.

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