Grand Valley River Corridor Initiative

Fluvial Hazard Zone Mapping Addendum for the Colorado River and Gunnison River in the Grand Valley, Mesa County, Colorado

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PUBLICATION AND CONTACT INFORMATION

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The mapping was completed by following the “Colorado Fluvial Hazard Zone Delineation Protocol Version 1.0” (Blazewicz et al., 2020). Additional guidance documents and supporting educational material is available on the Colorado Water Conservation Board’s website at: www.ColoradoFHZ.com

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Disclaimer

Fluvial Hazard Zone (FHZ) maps are intended to delineate the area a stream has occupied in recent history, may occupy, or may physically influence as it stores and transports water, sediment, and debris. FHZ maps do not predict the magnitude, frequency, or rate of fluvial geomorphic hazards. The intended use of these FHZ maps is to supplement other on-going and completed studies that are examining land use planning, floodplain management, and stream corridor conservation efforts. The information presented in FHZ maps should always be used in conjunction with other studies and analysis.

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It is the responsibility of the FHZ map sponsor agency, not the authors of this study, to evaluate the FHZ and revise the FHZ maps as conditions in the watershed change based on the best data and technical guidance available.

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Executive Summary

Fluvial geomorphic processes are natural phenomena within stream corridors and include commonly observed occurrences such as erosion, the transport and deposition of sediment, the recruitment and jamming of wood, and the structural influences of plants and animals. Fluvial geomorphic processes become hazardous when they encounter infrastructure, houses, businesses, and other investments within and adjacent to the stream corridor.

To recognize and assess the hazards associated with erosion, sediment deposition, and other dynamic river processes, the Colorado Water Conservation Board (CWCB) has developed a technical protocol to identify and map the areas where fluvial hazards may exist to help communities better understand their existing risk.

The State of Colorado's Fluvial Hazard Zone (FHZ) Mapping Program represents a significant and necessary step forward in adaptively managing stream corridors, preparing for, and mitigating flood impacts, and making informed land use decisions based on an awareness of fluvial processes. In Colorado, flood hazard identification and mitigation must recognize that streams are naturally dynamic, prone to move within a corridor, and apt to modify their margins as they transport and deposit water, sediment, and debris inputs from their watersheds. Flood insurance claims and property loss data demonstrate that in Colorado, reliance on traditional flood inundation maps alone does not provide a comprehensive characterization of the hazards imposed by fluvial processes. Fluvial Hazard Zone Mapping process considers these dynamic stream processes and represents an important step forward in identifying and communicating these hazards.

The Fluvial Hazard Zone (FHZ) is the area a stream has occupied in recent history, may occupy, or may physically influence as it stores and transports water, sediment, and debris.

Fluvial Hazard Zone Maps are created by fluvial geomorphologists—scientists who study how flowing water shapes and modifies the Earth's surface through erosional and depositional processes. Mapping is completed through the interpretation and synthesis of geomorphic, geologic, hydrologic, and biotic information (i.e., data that describes the physical location, form, flooding intensity, active sediment and debris transport, and ecological conditions of a riverine system).

Fluvial Hazard Zone maps provide communities, individual property owners, and emergency response teams with information on flood- and stream-related hazards beyond those identified by traditional floodplain mapping. Fluvial Hazard Zone maps may be adopted and used for land use regulation at the local level, however, they are not and will not be regulated nor mandated by the State of Colorado. As stream corridors are environmentally and economically important areas, Fluvial Hazard Zone maps can also aid in prioritizing lands for conservation or maintenance of fluvial hazard compatible land uses. As Colorado's Fluvial Hazard Zone Mapping Program progresses, it is also demonstrating value for post-wildfire flood planning and response.

In addition to providing information related to community safety, Fluvial Hazard Zone maps provide a delineated area where many of the complex physical, chemical, and biological interactions of stream systems could be expected to occur. Recognizing that stream corridors (i.e., streams and their associated riparian, subsurface and in-channel areas, as well as geomorphic floodplains) move and store sediment, debris, and water and employing management practices that avoid conflict with these processes are important; this recognition is important not only for our safety and financial investments, but also because these natural river processes are foundational for preserving the ecosystem services found in riparian corridors.

The Fluvial Hazard Zone has been mapped for the Colorado and Gunnison Rivers within Mesa County. This map and associated deliverables detailed below can be used to:

1. Identify river corridor hazards in addition to inundation hazards identified by FEMA floodplain maps and communicate these hazards to the community.

2. Plan and manage infrastructure and development within a dynamic and active river corridor in which down valley channel migration is active.

3. Identify opportunities and areas to allow migration, resulting in ongoing creation and maintenance of habitat for Endangered Species Act (ESA) listed species.

4. Support river compatible development within the river corridor.

1.0 Fluvial Hazard Mapping Background

1.1 Fluvial Processes

Stream corridors are naturally dynamic environments. Fluvial geomorphic processes associated with streams include the erosion, transport, and deposition of sediment, debris, and wood within stream corridors. These physical processes, which may occur gradually over time or abruptly during a flood, become hazards when they interact with human investments within stream corridors.

Streams naturally change their shape and location as a result of the interactions between hydrology, geology, and biology. Stream change may also be influenced by human interventions directly through the placement of armoring or levees and indirectly through actions such as flow regulation and urbanization in the contributing watershed. Stream change is ever-present and even “stable” stream channels will shift from year to year as a result of the influence of annual or sub-annual runoff.

Change in a stream corridor becomes a hazard when an adjusting stream threatens infrastructure, houses, businesses, property, and vital transportation corridors or crossings. Fluvial geomorphic hazards are particularly acute when they not only threaten property and infrastructure but also human lives. Because change in stream corridors is episodic, and in some cases infrequent, development and investment in stream corridors may not incorporate information regarding the hazards from this change. Characterizing and mapping these hazards can aid in identifying where property and infrastructure may be at risk and inform future development decisions in and adjacent to stream corridors.

1.2 Fluvial Geomorphic Hazards

To better identify these fluvial geomorphic hazards, Fluvial Hazard Zone (FHZ) maps can be developed. The Fluvial Hazard Zone is defined as the area a stream has occupied in recent history, may occupy, or may physically influence as the stream stores and transports water, sediment, and debris. These fluvial geomorphic processes may occur gradually over years or suddenly during a flood event. The primary objective of Fluvial Hazard Zone mapping in Colorado is to identify areas where fluvial geomorphic change is expected, characterize and identify these processes, and ultimately reduce risk to life and property through increased awareness, avoidance, and mitigation.

Traditionally local governments have regulated stream corridors by relying on Federal Emergency Management Agency (FEMA) Guidance and Standards to create Flood Insurance Rate Maps (FIRMs), which are used to establish insurance premiums through the National Flood Insurance Program (NFIP). These maps delineate only flood inundation hazards— as a result, properties located well above base flood elevations or outside FIRM floodplain boundaries are often affected by floods yet they are unaware of and unprepared for the potential damage stemming from stream movement, the erosion of streambanks or hillslopes, or the impacts of sediment and debris deposition.

WHY NOT "EROSION HAZARD MAPPING" OR "SETBACKS"?

Erosion is just one of the geomorphic hazards associated with streams. Simply measuring, modeling, or calculating erosion or bank retreat is insufficient in capturing all fluvial geomorphic hazards in a stream corridor. Other fluvial geomorphic hazards include deposition of sediment and large wood which can aggrade channels and cause significant hazard even if the channel itself does not technically erode. Similarly, channel avulsions, fan processes, channel braiding, and cutoffs have the potential to relocate channels abandoning bends where erosion hazards were mapped. Similarly, setbacks defined from an existing static channel location can quickly be made obsolete during a flood as whole channel relocations are common. FHZ maps identify areas susceptible to erosion but also include areas where these other fluvial geomorphic hazards exist.

Floods have resulted in 11 federal disaster declarations for Colorado, with one or more major flood occurring every decade in the state. Average annualized flood-related property damage in Colorado from 1911 to 2013 is estimated to be $99 million dollars (inflation-adjusted for 2021) (Blazewicz et al., 2020)). Since 1978, approximately 49% of all NFIP claims in Colorado have come from policies written outside the high-risk area depicted on the FEMA FIRMs, demonstrating their inadequacy for mapping flood risk.

While the process of identifying fluvial geomorphic hazards on a map may be a new endeavor in many places, the act of mapping does not introduce a new hazard to a community or landowner. The hazard has always existed; the map explicitly characterizes and delineates it. Just as with inundation hazards, by identifying, mitigating, and planning for fluvial geomorphic hazards, our communities can reduce their vulnerability to flood damage in the stream corridor and become better equipped to adapt to future conditions.

Fluvial Hazard Zone mapping delineates where stream channels within a river corridor may widen or migrate (Active Stream Corridor), where they may find new courses across a floodplain (Avulsion Hazard Zone), and where they might result in erosion and mass wasting of the hillslopes adjacent to the floodplain (Fluvial Hazard Buffer). An FHZ map does not attempt to define the likelihood of damage from fluvial processes nor the rate of change of geomorphic forms within the stream corridor. The mapped boundary defines a zone within which fluvial processes have occurred in the past and may occur in the future, as well as areas that are likely to be indirectly impacted by erosion or failure (i.e., mass wasting) of the valley margin.

These components of a Fluvial Hazard Zone map are described in more detail in Section 2. Methods for delineating them are provided in Colorado Fluvial Hazard Zone Delineation Protocol, Version 1.0 available for download at www.ColoradoFHZ.com.

1.3 Colorado's Fluvial Hazard Zone Mapping Program

The State of Colorado hosts a diversity of stream types and associated fluvial geomorphic hazards, and therefore requires a Fluvial Hazard Zone mapping protocol that can be tailored to the dominant processes of stream and floodplain change within a particular geographic and geologic setting while also leaving flexibility for adaptation to specific regional attributes, as well as for more detailed refinement. The Colorado Water Conservation Board, along with their partner agencies, set out to develop a Fluvial Hazard Zone Mapping Program that would employ a scientifically defensible set of mapping standards that could be applied to any stream system in the state. The Protocol was designed to delineate an accurate Fluvial Hazard Zone with a moderate level of effort primarily through the synthesis of geologic and geomorphic information (data that describes the physical forms and processes of a stream system). The FHZ Protocol relies primarily on spatial data such as aerial photography, LiDAR-based digital elevation models (DEMs), and geologic maps, as well as field observations to interpret geomorphic features. Hydraulic and biotic information may also be utilized.

The process for mapping Fluvial Hazard Zones in Colorado builds on a body of work developed in other regions of the United States, including the states of Washington and Vermont. The Protocol was piloted on approximately 450 miles of stream corridors throughout the state, peer reviewed, and released for public comment in January 2020. The Colorado Fluvial Hazard Zone Delineation Protocol Version 1.0 was finalized and released for general use in the Summer of 2020. The Fluvial Hazard Zone delineations associated with this Addendum was developed using the recommendations and framework provided in the Colorado Fluvial Hazard Zone Delineation Protocol, Version 1.0.

Guidance was also developed to support communities that may want to incorporate FHZ mapping into their community planning and is available at www.ColoradoFHZ.com.

1.4 Fluvial Hazard Zone Mapping Applications

Fluvial Hazard Zone maps may provide a wide range of benefits to individuals and communities. First and foremost, they are a tool to help stakeholders visualize and understand the inherent risk that exists on lands that have been—and will someday again—be shaped by water moving through a landscape. They also help to identify areas subject to hazards after wildfires and areas where floodplain rehabilitation and flood management projects are likely to have a considerable impact.

This section outlines some of the ways Fluvial Hazard Zone maps can be used and applied depending on the priorities and goals of the community and planning effort.

AVOIDING FLOOD DAMAGES THROUGH PLANNING AND INFORMED DEVELOPMENT

Ultimately, the most cost-effective tool to mitigate the impact of fluvial hazards is to reduce exposure to the hazard though forward-looking land use planning and/or regulations and standards for development within mapped Fluvial Hazard Zones. The FHZ delineation process and the resulting maps are intended to provide local land use, floodplain, and emergency response managers insight into the likely long-term behavior of their streams and serve as additional hazard information. It also communicates these hazards to the public so that they are better informed in making emergency preparations as well as personal and business decisions. Fluvial Hazard Zone maps can be integrated into:

DEVELOPMENT REVIEW

Guidelines and best practices for development within the FHZ can be updated to account for processes within the stream corridor. These may be similar to practices for development within a FEMA Floodplain, but there also may be differences. For example, a common practice for development within a floodplain is elevating the ground surface to allow for building to be built above the floodplain. This practice may not be compatible within an active stream corridor as channel migration into such development could occur. Examples of using the FHZ for development review include incorporating buffers from the active stream channel for building and other infrastructure footprints and setting utilities back to beyond the fluvial hazard buffer where feasible.

COMPREHENSIVE PLANNING

Long-term planning that directs land development and infrastructure away from areas subject to fluvial hazards will result in avoided damages during future floods. As identified in the Protocol, managing or limiting development within the Fluvial Hazard Zone may:

- Reduce the costs of repairing or replacing infrastructure and major civil works;
- Provide for temporary flood water storage and allow for a reduction of peak flood flows in adjacent and downstream communities (Habersack et al., 2015; Sholtes and Doyle, 2010);
- Reduce reliance on channelization, levees, and bank armoring, which are often detrimental to stream health, are expensive to maintain, and have proven to be prone to failure. Structural river controls, unless or until they fail, often increase erosion and deposition processes in adjacent and downstream communities (Brierley and Fryirs, 2005; Brookes, 1988; Huggett, 2003; Nagle, 2007);
- Reduce public expenditures for disaster response and recovery;
- Reduce costs of future flood recovery efforts.

Fluvial Hazard Zone mapping can be used for a multitude of purposes but any decisions regarding land use or other regulation are made at a local, not State or Federal, level. Fluvial Hazard Zone maps also do not impact flood insurance rates or premiums.

Since the late 1990s, there has been a growing movement to allow space for river corridors in community planning in the form of “Room for the River” or “Freedom Space” programs (Biron et al., 2014; Rijke et al., 2012). Fluvial Hazard Zone mapping is a science-based tool that communities can use to define the priority areas in which to incorporate a room for the river management strategy into their long-term planning.

REGULATION

Fluvial Hazard Zone maps are not regulated or mandated by the State. However, as allowed under Colorado statute, county and municipal governments may choose to incorporate Fluvial Hazard Zone maps into their local land use and development permitting process. A Fluvial Hazard Overlay District model ordinance was developed for the CWCB FHZ Program with the intent of assisting communities that wish to utilize zoning to be able to integrate fluvial hazard zone maps into their existing regulatory mechanisms. Additional regulatory tools include establishing disaster recovery ordinances and the possibility of credit for communities who incorporate Fluvial Hazard Zone regulation within the NFIP’s Community Rating System.

IDENTIFICATION OF CONSERVATION, OPEN SPACE, AND RECREATIONAL OPPORTUNITIES

Riparian areas provide diverse, dynamic, and complex habitats that are among the most important in Colorado (Rondeau et al., 2011). Fluvial geomorphic processes create shifting mosaics of highly productive habitat for riparian, aquatic and terrestrial species (Cluer and Thorne, 2014); and provide opportunities to protect (and improve) water quality (Piegay et al., 2005; Rupprecht et al., 2009). Fluvial processes occur on a variety of spatial and temporal scales, from local bank erosion to avulsions that create long swaths of new channel. They may even rework floodplains entirely, creating a patchwork mosaic of habitat types and successional stages. This diversity of habitat creates recreational opportunities for wildlife viewing, fishing, foraging, and hunting, as well as trail and path networks for recreation and alternative transportation. Protection of these dynamic areas for ecological conservation, open space, and recreation will reduce the need to place constraints on the streams over time and instead allow them to adjust and stabilize based on their prevailing flow and sediment regimes. Using Fluvial Hazard Zone maps, conservation and recreation planners may identify lands where the environmental benefits of unconstrained rivers are enhanced by the societal benefit of limiting human exposure to fluvial geomorphic hazards.

IDENTIFICATION OF FLOODPLAIN RESTORATION AND REHABILITATION PROJECTS

Fluvial Hazard Zone maps may provide guidance for river and floodplain rehabilitation project identification, scoping, and goals. Generally, the FHZ boundary should be considered when identifying the project extent of any restoration, rehabilitation, or flood mitigation project. The Fluvial Hazard Zone boundaries and supporting documentation can also provide information on geomorphic and hydrologic processes relevant to site-specific restoration. For instance, they may identify areas where restored side channels or floodplain features will be connected, or distinguish active and erosive reaches from depositional reaches. Additionally, identification of disconnected floodplains through FHZ mapping provides an inventory of areas with potential for reconnection. Data products used in the delineation of the FHZ are similar to those used for design and analysis of stream corridor restoration processes (Powers et al., 2018).

CONSERVATION OF AGRICULTURAL LANDS AND PRACTICES

Many lands adjacent to streams are currently being used for agriculture and grazing. Generally speaking, these land uses are considered compatible for areas within the Fluvial Hazard Zone. Mapping the FHZ and incorporating the boundaries into community plans can help to prioritize the maintenance of existing agricultural land uses and practices in stream corridors.

WILDFIRE PLANNING AND RESPONSE

FHZ maps are a valuable tool for communicating hazards associated with rainfall after wildfires. After a wildfire, FHZ maps can be quickly and cost-effectively created to delineate areas vulnerable to sediment and debris impacts spurred by rainfall over the burn scar. Mapping these post-fire hazards may allow downstream residents to prepare by preemptively moving vehicles, storage units, and other items to safer locations and to develop evacuation plans. This can also provide communities with an assessment of vulnerable populations for emergency response planning.

Before a wildfire, FHZ maps can be used to identify and prioritize the conservation or restoration of natural depositional areas which can trap debris and sediment that erodes from burned hillslopes upstream of populated areas. The conservation of these areas is important for two reasons: 1) it prevents development and investment in high-risk locations; and 2) these areas can act as a sediment sink and energy sponge, absorbing material and energy from debris flows and mitigating impacts to downstream residents and communities. Furthermore, conserved and natural stream corridors, especially those where beaver (*Castor canadensis*) have been reintroduced and wet meadows and ponds are present, are thought to provide natural fire breaks, potentially aiding a community's firefighting effort during a wildfire.

EMERGENCY PLANNING

The mapping of Fluvial Hazard Zones can illuminate which critical emergency response infrastructure (e.g., fire and rescue stations, hospitals, schools, and shelters) may be vulnerable to previously unaccounted for flood hazards. This can aid a community in planning where to station resources, shelter people, and/or invest in redundant systems so that if one critical component goes offline the whole emergency response system is not paralyzed. Fluvial Hazard Zone maps may also help communities consider which evacuation routes may be unreliable during a flood due to road and bridge washouts from fluvial processes. Disaster response planning without fluvial hazard zone maps is likely to provide an incomplete assessment of a community's true vulnerabilities.

1.5 Flood Insurance Rate Maps vs. Fluvial Hazard Zone Maps

The boundaries of the FHZ and FEMA floodplain generally will not coincide and should be considered independent of, but complementary to, one another. (Figure 1-1). Using both types of maps is critical to understanding the suite of hazards that exist in stream corridors and, when taken collectively, could be used to delineate a stream corridor within which special floodplain land use regulations may exist.

Flood Insurance Rate Maps (FIRMs), generally referred to as "floodplain maps," are based on fixed-bed hydraulics and statistical interpretations of historic river flows. FIRMs provide a single snapshot of the estimated maximum extent of flood inundation that has a 1-percent chance of occurring in any given year, colloquially referred to as the "100-year flood." FIRMs have traditionally provided the basis for local communities to regulate and manage floodplains as well as guide programs for emergency planning, safety, preservation, preparation, and mitigation. Floodplain maps are reviewed and approved by FEMA to assist in setting federal flood insurance rates through the National Flood Insurance Program (NFIP).

Despite long shelf-lives, many floodplain and floodway boundaries depicted on FIRMs are reliable for only short periods after their production, as river channels and stream corridors are in a continual state of change and the underlying topography upon which the hydraulics are based becomes out-of-date. But more importantly, **FIRMs do not inform users of an area's susceptibility to fluvial processes either within or outside of the areas prone to inundation by flood waters**. As a result, areas located well above the FIRM's base flood elevations or outside FIRM floodplain boundaries are often affected by floods, yet communities in these areas are unaware of and unprepared for the potential impacts.

FHZ mapping captures hazards stemming from stream movement, the erosion of streambanks or hillslopes, and the impacts of sediment and debris deposition. FHZ mapping assumes that the ground beneath or adjacent to floodwaters is going to change either incrementally or dramatically as the area is exposed to energy, water, sediment, and debris during a flood. FHZ mapping is not directly tied to hydrologic statistics, specific storms, or runoff events and is not associated with a probability of occurrence. FHZ maps may not identify areas susceptible to standing water or very low energy flowing or pooling water, or groundwater upwelling or seepage. Features of Flood Insurance Rate Maps (FIRMs) and FHZ maps are shown below (from Blazewicz et al., 2020).

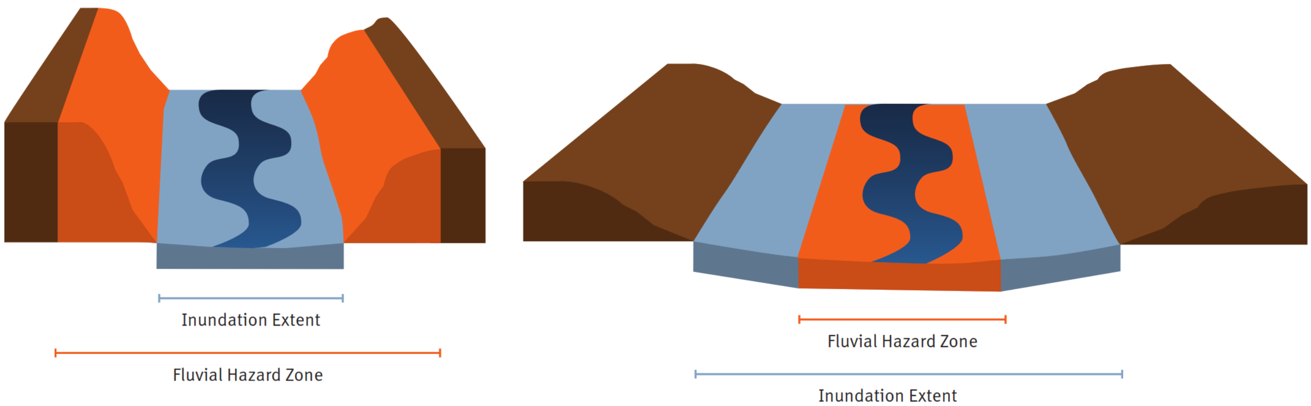


Figure 1-1: Comparison of the inundation extent (e.g., FEMA-defined floodplain) and Fluvial Hazard Zone for two different types of stream systems. On the left, the FHZ extends some distance into the erodible valley margins and therefore encompasses more than a FIRM would. On the right, the extent of floodplain inundation (or the regulatory floodplain) is wider than the area where fluvial hazards are expected. Figure adapted from Blazewicz et al. 2020.

FLOOD INSURANCE RATE MAPS (FIRM)

- Map areas of flood water inundation.
- Correspond to only one estimated peak flow.
- Use a variety of data and methods to map flood surface elevations and extent. This may include historical flood data, rainfall data, topographic data (i.e., LiDAR and field surveys), along with computer models that calculate results for hydraulic equations.
- Rules for map development are set by the federal government via FEMA.
- Assumes a static stream system with no changes to a stream's shape throughout the duration of a flood.
- Developed with methods that typically do not account for the transport of sediment and debris.
- Are typically made by engineers with experience in hydrologic (rainfall and watershed) and hydraulic (stream channel and floodplain) computer modeling.
- Created as part of the National Flood Insurance Program (NFIP) and used to determine where flood insurance is required and what rates apply.
- Federal and State-regulated product (for community participation in the NFIP).

FLUVIAL HAZARD ZONE MAPS (FHZ)

- Identify where a stream may move or may cause damage during a flood (e.g., erode a high bank and undermine a structure or deposit sediment and debris).
- Show susceptibility to flood hazards rather than probability.
- Use a variety of data and methods including high resolution topographic data (i.e., LiDAR), geologic and soils maps, and field verification.
- Assume that stream dimensions change during a flood and that flows are transporting sediment and debris.
- Rely on fluvial geomorphic (stream form and process) expertise to interpret landforms within the floodplain and along a stream.
- Do not affect flood insurance rates, though those with structures within the FHZ are encouraged to purchase flood insurance.
- Regulation, if any, is determined by local communities.
- Non-federally regulated product.

1.6 Interpreting Fluvial Hazard Zone Maps and Understanding Their Limitations

Fluvial Hazard Zone maps are presented as a planning tool to be used in identifying conservation and restoration opportunities and for reducing future flood damage; however, the FHZ does not represent an all-inclusive characterization of stream corridor hazard and should be utilized with other tools such as FEMA Special Flood Hazard Area delineations, debris flow hazard maps, and landslide hazard maps.

The FHZ boundary delineates the extent of the area likely to be influenced by fluvial processes. While fluvial processes are unlikely to occur outside of the FHZ boundary, events such as debris flows, debris jams, landslides, earthquakes, dam failures, and diversion channel captures may trigger geomorphic responses not mapped within the FHZ. In addition to the aforementioned, the following is a list of acknowledged limitations of the FHZ mapping methodology. FHZ Mapping:

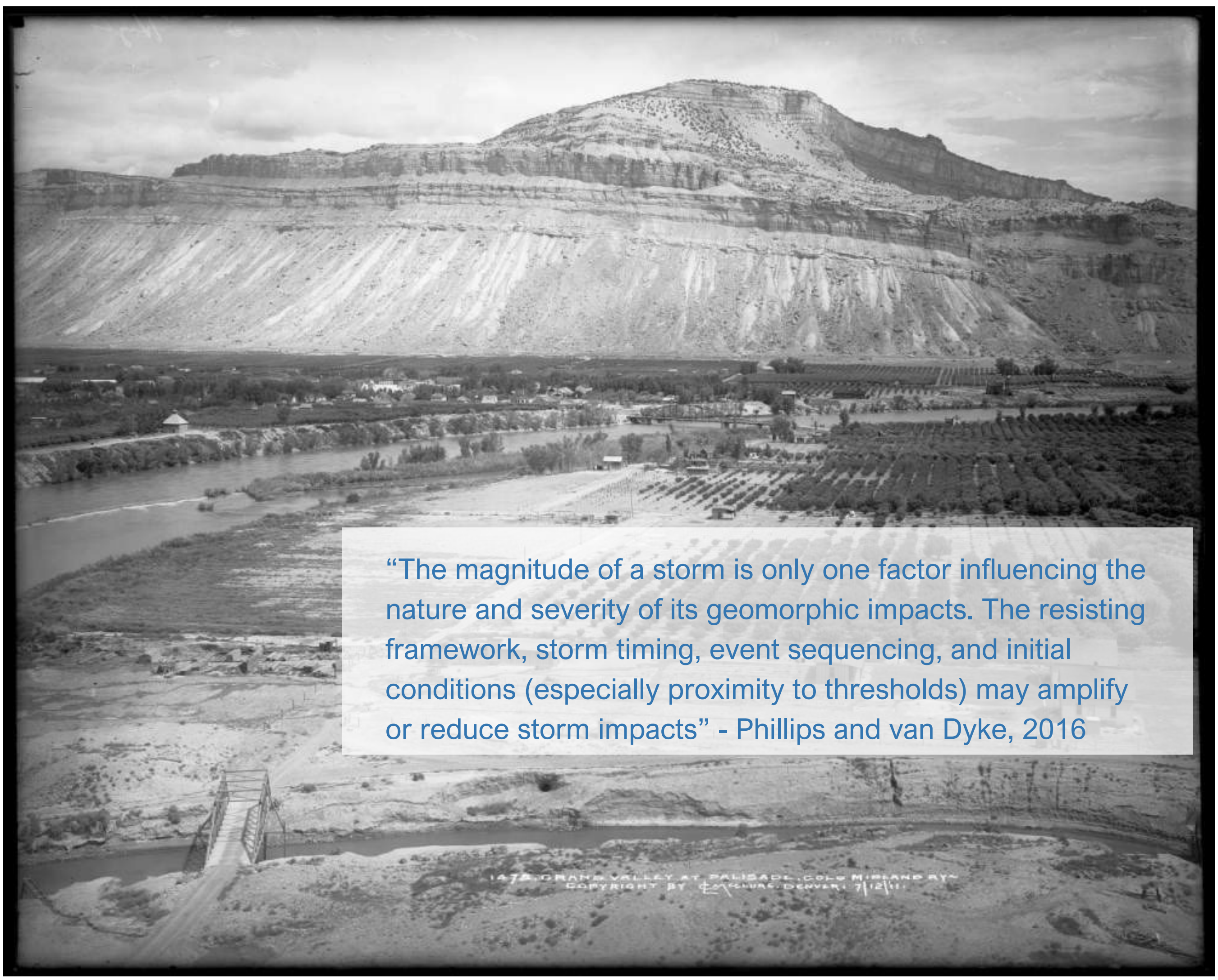
- Is a planning level analysis meant to be interpreted and applied at larger scale (e.g., multiple parcels) rather than fine scales (site planning within a parcel).
- May not provide a detailed account of fluvial hazards in very small drainages where runoff is transitioning from overland flow to channelized flow.
- May not capture the full extent of geomorphic hazards resulting from catastrophic events such as a dam failure.
- Is dependent on the availability of high-resolution LiDAR. In the absence of this data, the FHZ boundaries are likely to be less accurate and/or require an extended field assessment.
- May not account for all bedrock that may be controlling vertical or lateral channel movements.
- Identifies fluvial geomorphic hazards within and adjacent to the stream corridor that has been mapped (i.e., the study reaches). Adjacent hazards related to tributary streams, gullies, and fans may not be mapped or identified unless explicitly stated.

1.7 Risk and Probability in Fluvial Hazard Zones

People have become accustomed to thinking about flood hazards through the lens of recurrence intervals (e.g., 10-year flood) and annual exceedance probability (e.g., 10% AEP) as this is how FEMA and the NFIP communicate flood probabilities. Geomorphic hazards, however, do not lend themselves to this same type of statistical analysis given the strongly non-linear and complex relationship between flood magnitude and geomorphic response. Geomorphic changes in stream systems are the result of positive and negative feedbacks between interacting units of variable scale in the climatic, hydrologic, geologic, biotic, and anthropomorphic realms. Accurate quantitative assignments of probability for these multi-faceted, variable, and even unknown relationships (such as underlying geology, soil saturation, water and sediment connectivity, stressors, and explicit estimations of the changes in river conveyance properties over time) are currently not available (Sofia and Nikolopoulous, 2020; Naylor et al., 2016; Phillips and van Dyke, 2016). Furthermore, the effects of on-going climate change and the anomalies of wildfires disrupt statistical assessments of probabilities of disturbance in stream systems (Naylor et al., 2016; Walsh et al., 2014).

In trying to quantify the probability of the occurrence of fluvial hazards within mapped Fluvial Hazard Zones, the following variables would need to be evaluated:

- Precipitation quantity, location, and duration;
- Sediment and debris supply from upstream reaches;
- Debris flow and landslide locations and sizes;
- Erodibility of materials within the Active Stream Corridor and valley margins;
- Location of channel blockages;
- Wildfires impacts on all of the above;
- Timing and corresponding stream response to all the above, in absolute and in relative terms.



"The magnitude of a storm is only one factor influencing the nature and severity of its geomorphic impacts. The resisting framework, storm timing, event sequencing, and initial conditions (especially proximity to thresholds) may amplify or reduce storm impacts" - Phillips and van Dyke, 2016

2.0 Fundamental Components of Fluvial Hazard Zone Maps

2.1 Fundamental Components of the Fluvial Hazard Zone

The Fluvial Hazard Zone consists of two primary components, and these will be present on every Fluvial Hazard Zone map:

Active Stream Corridor (ASC) The Active Stream Corridor encompasses the lands shaped by fluvial erosion and deposition under the prevailing flow and sediment regimes (i.e., the modern geomorphic floodplain) (Figures 2-1 and 2-1). Dominant processes within this boundary are lateral channel migration, scour of the floodplain, and deposition of alluvium.

Fluvial Hazard Buffer (FHB) The Fluvial Hazard Buffer accounts for erosion-prone land located beyond the Active Stream Corridor, such as hillslopes and terraces, that may be susceptible to slope failure as a result of toe erosion caused by fluvial scour. It is a buffer applied to the outer boundary of the Active Stream Corridor (Figures 2-1 and 2-2).

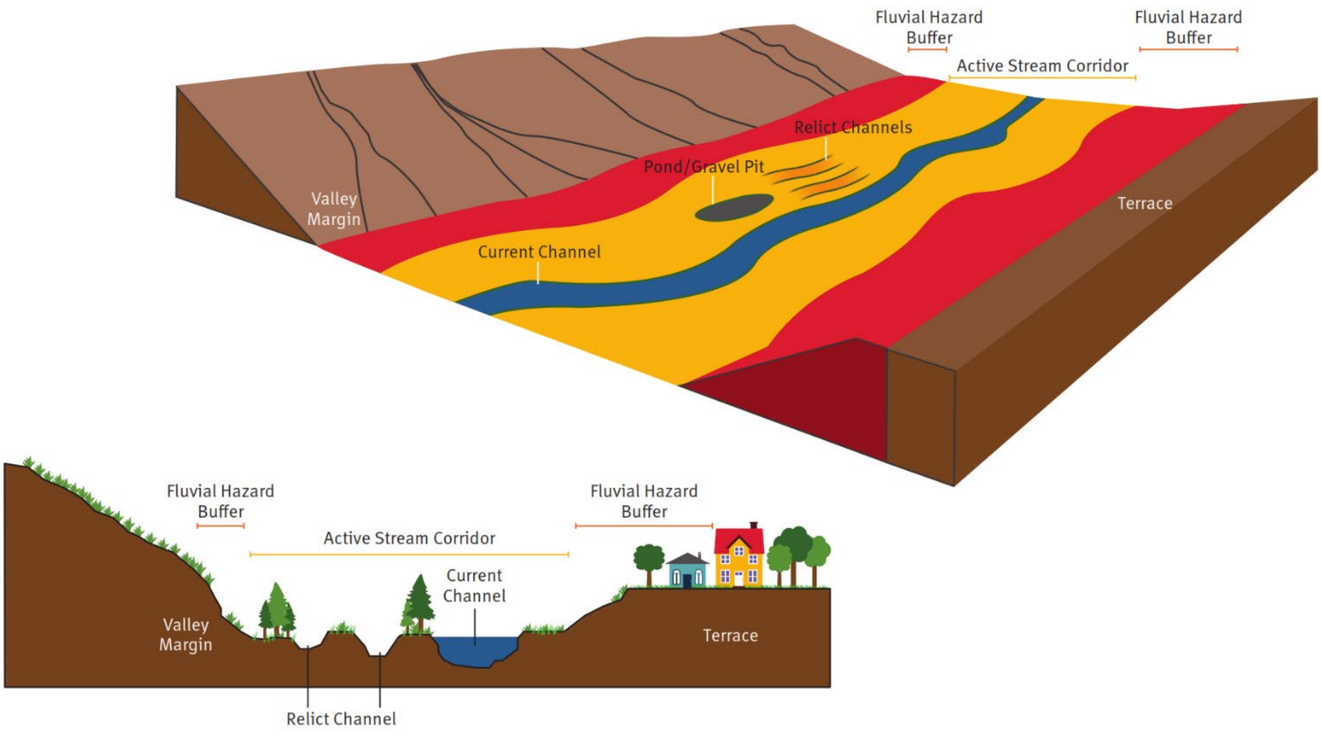


Figure 2-1: The Active Stream Corridor and Fluvial Hazard Buffer are primary components of a Fluvial Hazard Zone map. Figure from Blazewicz et al. 2020.

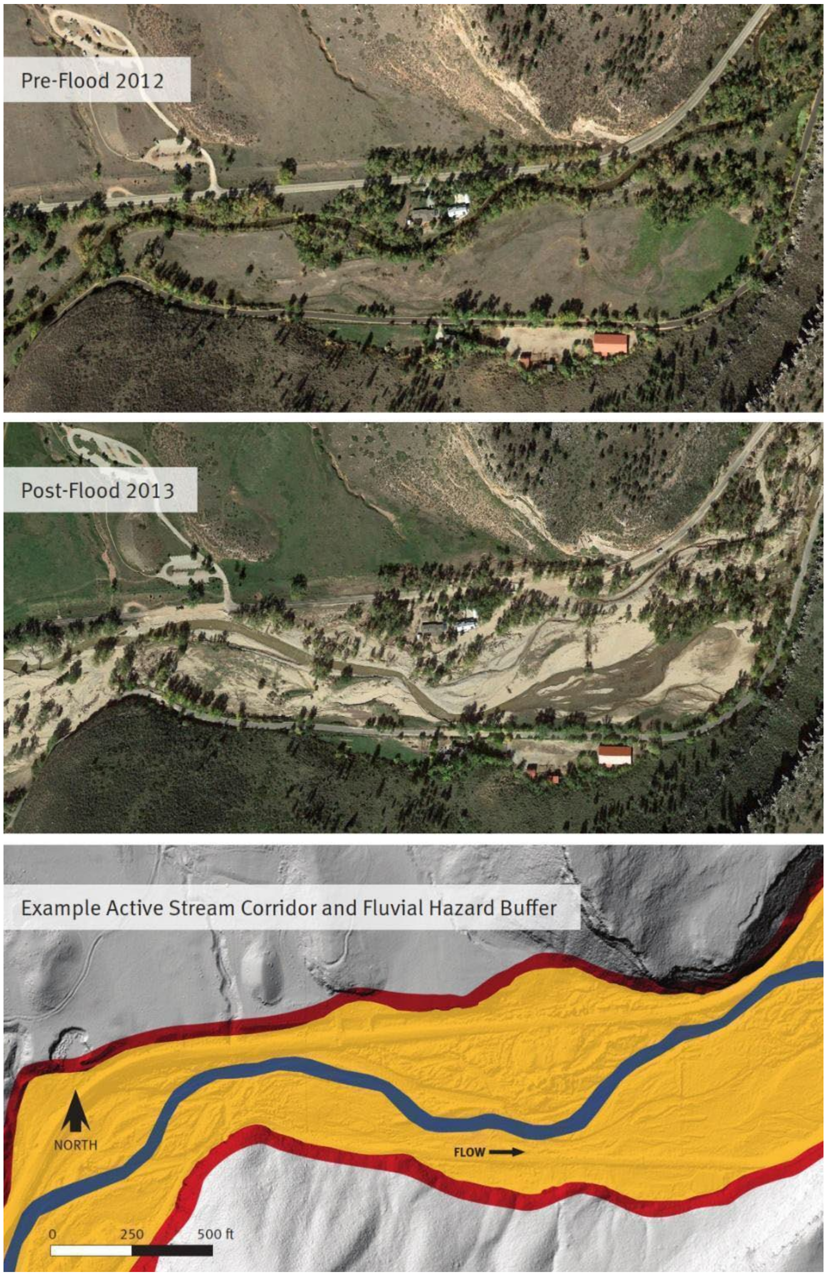


Figure 2-2: Example of Active Stream Corridor as demonstrated before and after the 2013 Front Range Flood (South St. Vrain Creek, Boulder County). Figure from Blazewicz et al. 2020

2.2 Auxiliary Map Components

Auxiliary Fluvial Hazard Zone components demarcate locations where other types of fluvial hazards or fluvial hazards that are not captured by the Active Stream Corridor or Fluvial Hazard Buffer, are likely to occur. The designation of areas where human interventions have reduced the natural extent of the Active Stream Corridor are also considered. Auxiliary Fluvial Hazard Zone components are the: Avulsion Hazard Zone (AHZ), Fans (F), Geo-technical Flags (GF) and Disconnected Active Stream Corridors (D-ASC). Not all streams will have these Auxiliary Fluvial Hazard Zone components, but all mapping efforts must assess if these components are present and map them if they are (Figure 2-3).

Disconnected Active Stream Corridor (D-ASC) identifies lands that would normally be mapped as part of the Active Stream Corridor but may not be currently subject to fluvial processes due to human-engineered structures (e.g., certified levees). While these areas may still be subject to inundation during flooding, fluvial geomorphic hazards are not expected.

Avulsion Hazard Zone (AHZ) identifies pathways outside of the Active Stream Corridor that a channel might (re)occupy. Only avulsion pathways that exist outside the Active Stream Corridor are identified as Avulsion Hazard Zones.

Fan (F) Alluvial and debris fans are typically triangular-shaped landforms created by deposition of material at the intersection of a tributary valley with a larger valley. They may also form in the mainstem of a study stream where a steep confined reach rapidly loses confinement and gradient.

In the FHZ Protocol, tributary fans are identified with a point or flag at the topographic apex of the feature. Fans created by the mainstem of the stream should be included within the Active Stream Corridor.

Geotechnical Flag (GF) identifies areas where hillslope failures initiated by toe erosion may extend past the Fluvial Hazard Zone delineation due to hillslope steepness, height, and/or material. These should always be examined further through geotechnical analysis before development decisions are made.

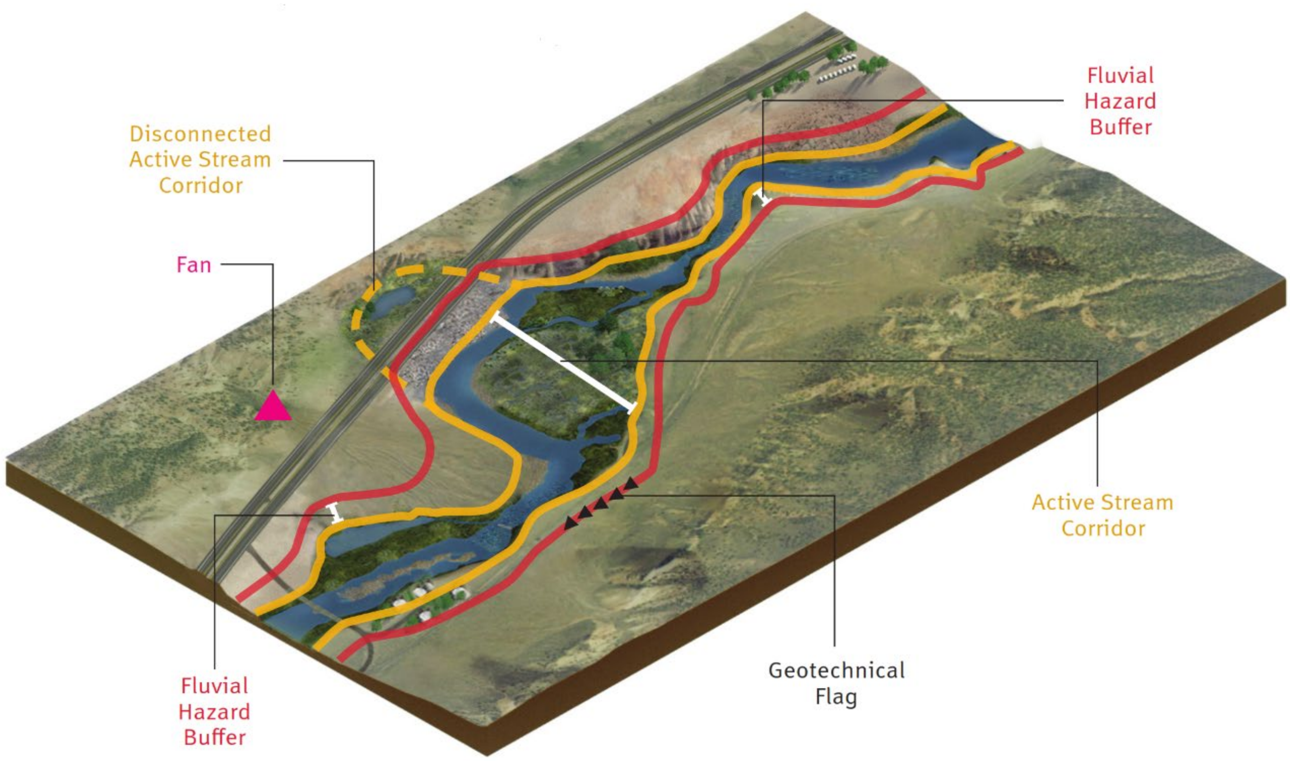


Figure 2-3: Example Fluvial Hazard Zone map containing primary (ASC, FHB) and auxiliary (D-ASC, Fan, and GF) components. Figure adapted from Blazewicz et al. 2020.

3.0 Fluvial Hazard Zone Mapping Process

3.1 Fluvial Hazard Zone Mapping Process Overview

The Draft FHZ maps and data associated with this Addendum were established following the Colorado Fluvial Hazard Zone Delineation Protocol, Version 1.0. These maps, and the supporting documentation, are intended *for planning purposes only*. Finalization of map products for incorporation into community regulatory programs are strongly advised to go through a process led by the community, as well as a public outreach, education, and review process, and are intended for planning purposes. This FHZ mapping process followed the process described below:

1. **DETERMINE AREA OF INTEREST**

   The objective of this study was to complete the Fluvial Hazard Zone mapping for select reaches of the Colorado and Gunnison Rivers within Mesa County, as identified by the project sponsor.

2. **CONDUCT RESEARCH**

   Research into the physiographic, geologic, hydrologic, and geomorphic setting and context was compiled in 2022. This research is summarized in Section 4 of this report.

3. **MAP THE FLUVIAL HAZARD ZONE**

   FHZ boundaries were drafted in late 2022 and refined in early 2023 after third party review.

4. **INTERNAL AND EXTERNAL REVIEW**

   Internal review consisting of field verification, documentation of the mapping process, data sources, and contextualization and the dominant hydro-geomorphic processes influencing the Fluvial Hazard Zone. An external review from a third-party was completed for quality control and technical feedback. In addition, technical and qualitative feedback has been received from the municipal and agency stakeholder group.

5. **DELIVERY OF DRAFT MAP PRODUCTS AND SUMMARY REPORT**

   Draft FHZ delineations are provided as a part of an online web map and as a geodatabase. Supplemental material includes this Addendum, reach information sheets and the metadata for the Fluvial Hazard Zone shapefiles. This Addendum serves as the documentation of the mapping process, provides transparency for that process and allows for reproducibility. Products are recommended to be utilized for community planning needs and public information on stream and river corridor processes and hazards.

3.2 Map Distribution, Maintenance, and Updates

Map distribution will be determined on a community basis. Online, web-based maps are strongly recommended. When displaying maps online it is not recommended to display map boundaries at a scale finer than 1:1,000 for Fluvial Hazard Zone delineations.

In Colorado, it is recommended that full map revision occur:

- Every 30 years, or
- Following a flood with significant stream corridor change from fluvial processes, or
- When human actions have influenced the stream's location and/or function, or
- When significant land use or watershed changes (e.g., wildfires) occur.

Map updates, if necessary, are recommended to fall into the categories of "minor updates" or "major updates." Major updates involve a remapping of the stream using the FHZ methodology. This may involve collection of field data and updated spatial data, and re-analysis to re-map FHZ boundaries. Major updates should be considered when significant alterations to hydrology or sediment supply occur (e.g., dam construction, urbanization, wildfire, and landslides), after major flood events that create significant geomorphic change, or when large scale infrastructure projects are constructed that include Disconnecting Structures (as defined in the Protocol) or other infrastructure that are anticipated to alter reach scale fluvial geomorphic processes. Minor updates include the correction of mapping errors and adjustments along portions of the mapped area due to new information (e.g., unmapped bedrock outcrop). Documentation of each map update or edit should be retained as part of the public record.

3.3 Outreach and Communication

Public involvement, education, and outreach is an ongoing process that is likely to evolve. Developing open communication between the mapping organization and the community not only builds trust within the public, but it also yields critical information for mapping teams. It is important to acknowledge that while many elements of Fluvial Hazard Zone mapping are focused on deliverables, an open conversation about the process and objectives of the local FHZ program is important to maintain. A communication strategy that focuses on simplicity, consistency, and building trust is imperative to community engagement and buy-in.

FHZ mapping products should be distributed in a manner that educates and empowers local agencies and the public. What may resonate most with the public is the narrative of their watershed and the role they have in shaping its future--and it theirs. Regardless of the medium through which it is told, the story should include flood history, climate, geology, land and water use changes, and riparian health summaries and will be enhanced by photos and explanatory graphics. This is generally the same information the FHZ mapping team must compile and synthesize and is largely outlined in this Addendum.

4.0 Colorado River and Gunnison River Fluvial Hazard Mapping

4.1 Study Area

The study area for this FHZ mapping project includes 46.4 miles of the Colorado River divided into 10 geomorphically distinct reaches from within De Beque Canyon to the entrance of Ruby-Horsethief Canyon downstream of Fruita. It also includes 15.2 miles of the Gunnison River (three geomorphic reaches) spanning just upstream of Whitewater, CO to the confluence with the Colorado River (Figure 4-1). These reaches serve as basic units of analysis within the FHZ mapping process. Similar valley settings, surficial geology, geomorphic processes, and surrounding land use all inform where reaches begin and end along the river corridor.

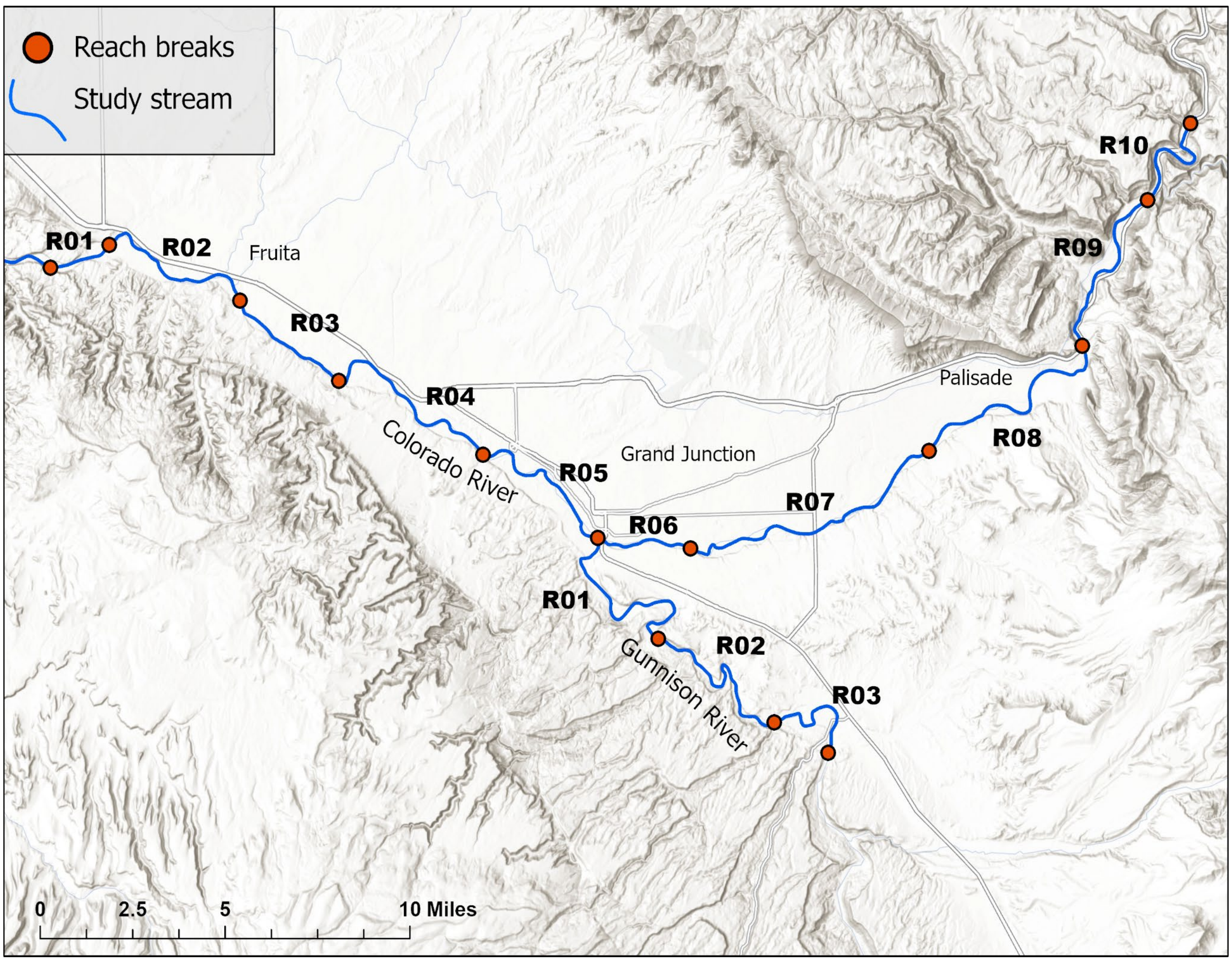


Figure 4-1: Colorado and Gunnison Rivers FHZ study area. Reach IDs are in bold.

4.2 Physio-Geographic, Geologic, and Ecologic Setting

Physio-geographic regions are a useful categorization of areas based on geologic, topographic, and climatic conditions. Each physio-geographic region has relatively homogenous geologic and climatic histories, as well as driving physical processes and ecology. The Colorado and Gunnison Rivers in these study reaches lie in the Colorado Plateau physio-geographic region, which is bounded by the Unita and Wasatch mountain ranges to the west in Utah and the Rocky Mountains in Colorado to the east. The Colorado Plateau is a semiarid to arid region with a vast array of deep bedrock canyons composed of sedimentary rocks, as well as substantial faulting and folding of features. The resultant landforms have created a unique and complex landscape that is home to multiple national parks and monuments (Canyonlands, Grand Canyon, etc.).

The Grand Valley, a part of the Uncompahgre Plateau, has a complex geologic history. The Grand Valley was part of the initial tectonic uplift and mountain formation of the ancestral Rockies over 260 million years (MA) ago but was eroded and buried by sediments (White et al., 2015). The ancient mountain range was then deformed and compressed during the most recent mountain building period (Laramide orogeny, 80 - 40 MA), forming what is now the Uncompahgre Plateau and the substantial number of faults and folds that characterizes the region (White et al., 2015).

Although portions of both the Colorado and Gunnison watersheds, as well as the Grand Mesa, were at least in part glaciated during the Pleistocene, the Grand Valley and our study area were not. However, the upstream glacial activity influenced the reaches in our study area via greater influxes of discharge and sediment. The rivers had to work through this influx of sediment, ultimately incising into it and forming inset floodplains and the outwash terraces found in the valley today (Sinnock, 1981). Gravel deposits on the Gunnison indicate that the river transitioned to a high-energy, braided river as it worked across these glacial sediments and deposited them (White et al., 2014). Braided systems tend to be highly dynamic, with shifting channels and a mosaic of floodplain surfaces. The complex relationships between water and sediment supply, vegetation, and beaver likely resulted in the formation of the alluvial valleys that settlers ultimately settled in and manipulated for agricultural and developmental interests. The surficial geology of the Grand Valley as mapped by the USGS demonstrates the complexity of this geologic history. A sample of the surficial geology within the Grand Valley is presented in Figure 4-2.

The study areas is located within the Colorado Plateau ecoregion. In the Colorado Plateau, riparian areas are host to native willow (Salix exigua) and cottonwood (Populus deltoides) cohorts. Grasses, reeds, and bulrush plants are also common (Rocchio et al., 2002). However, nonnative plants such as the tamarisk (Tamarisk chinensis) and Russian olive (Elaeagnus angustifolia) have overtaken many regions (VanSteeter & Pitlick, 1998). The river corridor is also host to a variety of endangered or threatened fish and bird species, including the Colorado pikeminnow (Ptychocheilus lucius), razorback sucker (Xyrauchen texanus), and the yellow-billed cuckoo (Coccyzus americana) (Rocchio et al., 2002; U.S. Fish & Wildlife Service 1994, 2021). Hydrologic and geomorphic studies focused on federally listed, native fish have found that more physically complex corridors that are at least occasionally inundated are incredibly important for their life cycles (Irving & Burdick, 1995; Pitlick & Cress, 2000; Valdez & Nelson, 2006).

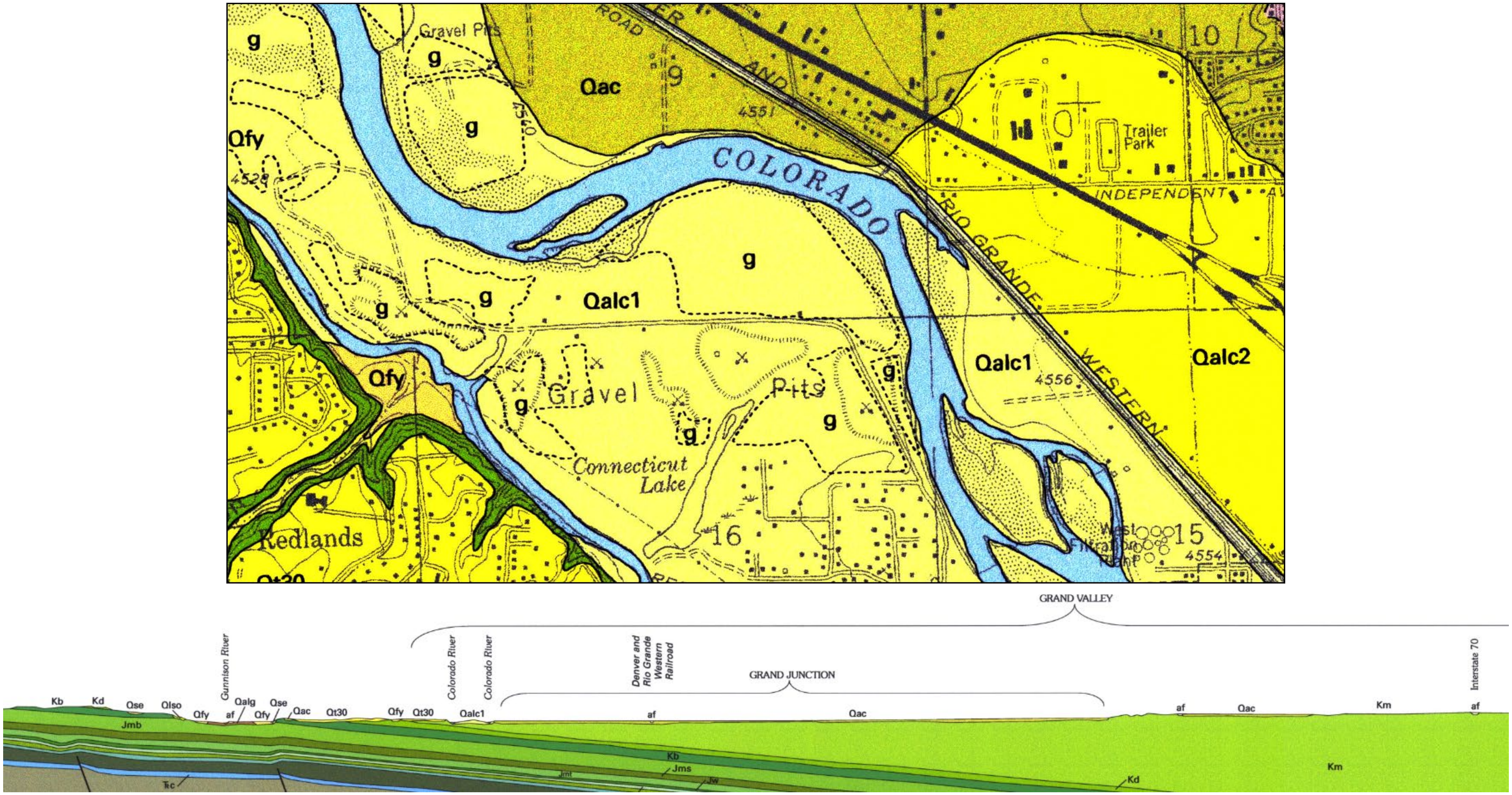


Figure 4-2: (Top) Geologic map of the Colorado River corridor near Grand Junction, CO, 1;24,000 scale (from Scott et al., 2002). This modern mapping identifies the relative ages of the alluvial deposits (Qalc1, Qalc2), fan deposits (Qfy), and Pleistocene alluvial-colluvial terraces (Qac). The green areas on the south valley margin are mapped as Mancos Shale (Km). Gravel ponds (g) are also noted. (Bottom) Geologic cross section of the Grand Valley running roughly south (left) to north (right) and crossing the Gunnison and Colorado Rivers upstream of their confluence (from Scott et al., 2002)

4.3 Hydrologic Context

The Colorado River basin that drains to the Grand Valley, which includes the Gunnison River is important as both a water and energy source to the semiarid Southwest United States and northern Mexico. More than 40 million people rely on the Colorado River basin for drinking water (Wheeler et al., 2022), which is supplied by the numerous dams, reservoirs, and diversions built on the river (Figures 4-3 and 4-4). As of 1989, there were at least 24 “major” dams present on the Colorado River upstream of the Colorado-Utah border (Pitlick & Cress, 2000). Some 14 transbasin diversion tunnels and ditches remove 500,000 acre feet of water (approximately 11% of average runoff volume) from the Colorado and Gunnison River Basins upstream of Grand Junction (Figure 4-4, CWCB, 2022). Though none of these reservoirs were designed for this purpose, cumulatively, they serve to reduce flood flows and alter the hydrology of the Colorado and Gunnison rivers in the Grand Valley (Amec Foster Wheeler, 2017).

Figure 4-3: Early 20th century (~1912) image of diversion system along the Colorado River near Palisade, CO (Denver Public Library).

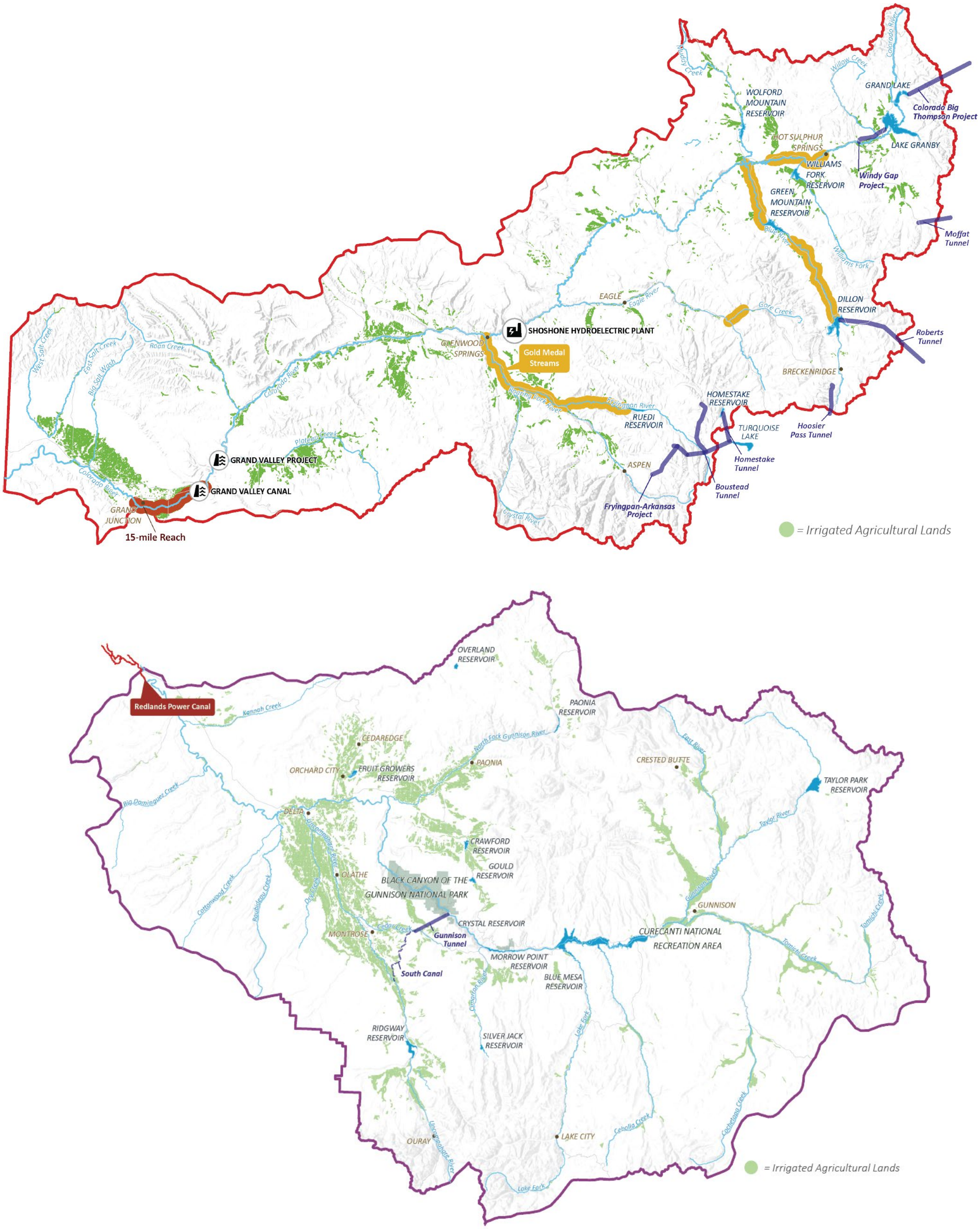


Figure 4-4. Colorado and Gunnison River Basins showing major reservoirs and water diversions (From CWCB 2022).

The Colorado River in the Grand Valley has a drainage area at Fruita of approximately 17,000 mi^2. It receives most of its flow from the snowmelt season of the Rocky Mountains and follows a spring snowmelt hydrograph (Figure 4-5). However, a multi-decadal drought, combined with increasing aridity, and earlier and smaller snowmelt runoff events due to a changing climate, have impacted and will likely continue to reduce flows in the Colorado, threatening water and power usage across the Southwest and Mexico (Wheeler et al., 2022). This change can be seen by comparing the median hydrographs for all years and for the 2000-2021 period shown in Figure 4-5. The Gunnison River is the largest tributaries to the Colorado River study reach with a drainage area of approximately 8,000 mi^2. It is also heavily regulated from the Aspinall and Uncompahgre Projects. Other tributaries that provide additional flow to the study reach are Plateau Creek, which enters in De Beque Canyon, and Salt and Leech Creeks, which enter in the Grand Valley.

Despite the heavy regulation, various notable floods have been recorded along the Colorado River in the Grand Valley in recent history, with the largest flood occurring in 1884. Although no gages existed at that time to record the true discharge, high water marks near Fruita suggested discharges of 125,000 ft^3 (Amec Foster Wheeler, 2017). Estimated to have a recurrence interval of nearly 500 years (a 0.2% annual chance), this event was due an exceptional snowmelt year. Other heavy snowmelts in 1921, 1983, 1984, and 2011 resulted in substantial flooding and river movement, several of which occurred after the major upstream reservoirs and trans basin diversions were constructed (Amec Foster Wheeler, 2017). In the upper areas of the Colorado River Basin, the largest of floods, and likely the greatest resulting geomorphic change, are influenced by the combined forces of snowmelt and rainfall.

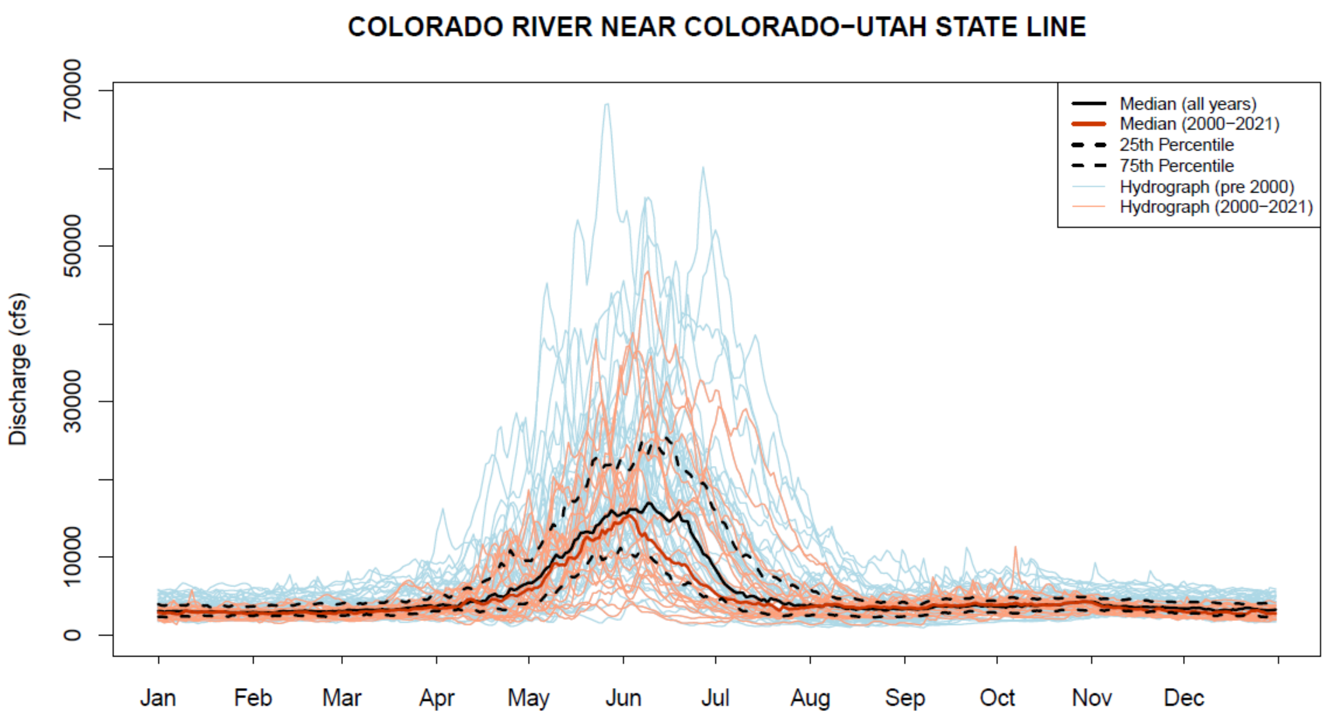


Figure 4-5: Annual hydrographs and median (all years and post 2000) with quartile hydrographs (all years) for flows passing through the USGS gage at the Colorado-Utah State line (Station ID: 09163500).

Though peak discharges have been relatively lower over the past 20 years (Figure 4-6), notable peaks in 2011, 2014, and 2019 occurred. Channel migration, new island formation, and bank erosion along the Grand Valley accompanied the large peak flows and are a clear indication of the important connection between hydrology and geomorphic change. Although less common, larger flows and the increased sediment loads they carry and mobilize are ultimately a major influence on river corridor morphology. In comparison, a reduction in large flows may, over time, result in less dynamism, reduced connection with riparian and floodplain areas, and thus the potential encroachment by humans and developments, who may be unaware of the river corridor's historic and potential extent and level of dynamism. Additionally, native and exotic vegetation establish during extended periods of low runoff years, serving to narrow and simplify the geomorphology of the study rivers (Van Steeter and Pitlick, 1998).

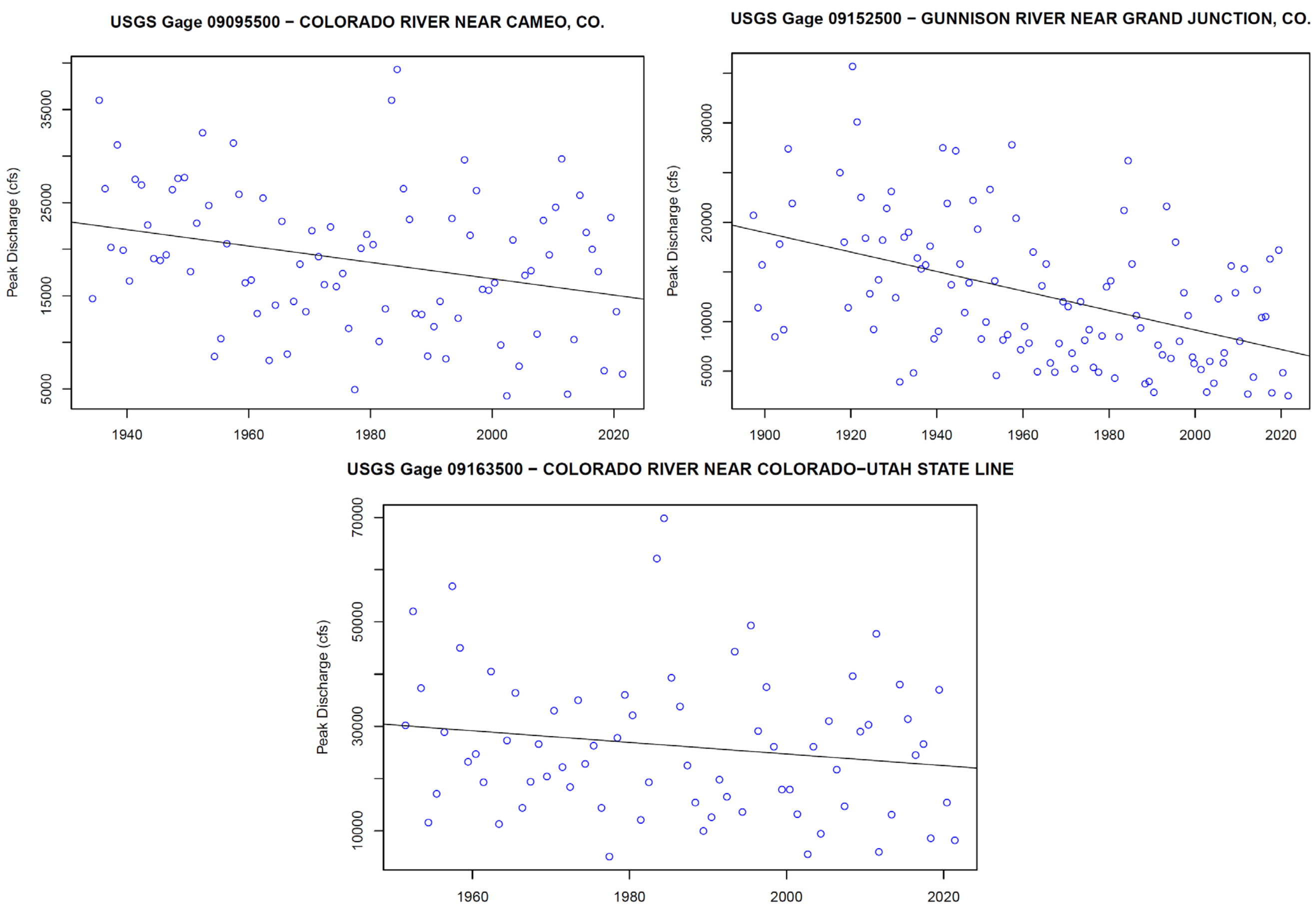


Figure 4-6: Peak streamflow over time for the Colorado (at Cameo in De Beque Canyon and the CO-UT Stateline) and Gunnison Rivers as recorded at USGS stream gages. All three gages show decreasing linear trends of peak discharge over time; however, only the trends at the gages on the Colorado River at Cameo and on the Gunnison River (top two) are statistically significant.

4.4 Geomorphic Setting, Context, Trajectory, and Sensitivity

4.4.1 General Setting and Context

Within the most upstream and downstream reaches of the Colorado River study area (Colorado R01, R09, and R10), the river travels through steep, confined canyons of sedimentary rocks it has eroded into over millions of years (Figure 4-1). Various tributaries (perennial and ephemeral or washes) enter the river here, supplying sediment. Some alluvial fans are present at these confluences, particularly in the upstream canyon reaches within De Beque Canyon. Generally, sediment may be supplied by the tributaries and washes during storm or high flow events, but ultimately transported through (not deposited in) these reaches. At present, these canyon reaches are geomorphically uniform, with a large main channel and few islands and side channels. Though these reaches are likely naturally less complex than the reaches within the Grand Valley due to their confinement and greater slope, the frequency of side channels, islands, and system complexity is likely lower now than prior to urbanization, gravel mining, and the installation of diversion structures in the basin. However, some opportunity for complexity through larger flows reconnecting floodplains may exist.

As the Colorado River travels through the Grand Valley, the river becomes less confined (Figure 4-7). Valley margins along the northern side consist of terraces of colluvium and alluvium of glacial origin as well as more contemporary alluvium. To the south, the river cuts into bluffs of Mancos Shale, where debris flows and hillslope failures are common.

The Colorado River is more geomorphically complex in the Grand Valley than the canyon reaches, hosting various islands, side channels, connected floodplains, and moderate to dense riparian vegetation. Much of the Colorado River throughout the Grand Valley has been highlighted as critical habitat for endangered, native fish species, such as the Colorado Pikeminnow chub (Rocchio et al., 2002; U.S. Fish and Wildlife Service, 1994) which benefits from the varied and variably-inundated floodplain topography. The dynamism seen in many of these reaches reflects the transition from a canyon to a partially-confined or unconfined valley with a wider channel and floodplain, where stream power has been reduced (lower slope, greater unconfinement). The reaches throughout the Grand Valley are thus more depositional in nature, though the extent of this varies by reach. Sediment is gained from the slow migration of the channel across the floodplain as it erodes and deposits alluvium (sand, gravel, and cobble). This gradual channel migration has historically created side channels formed when the Colorado River abandons its former channel.

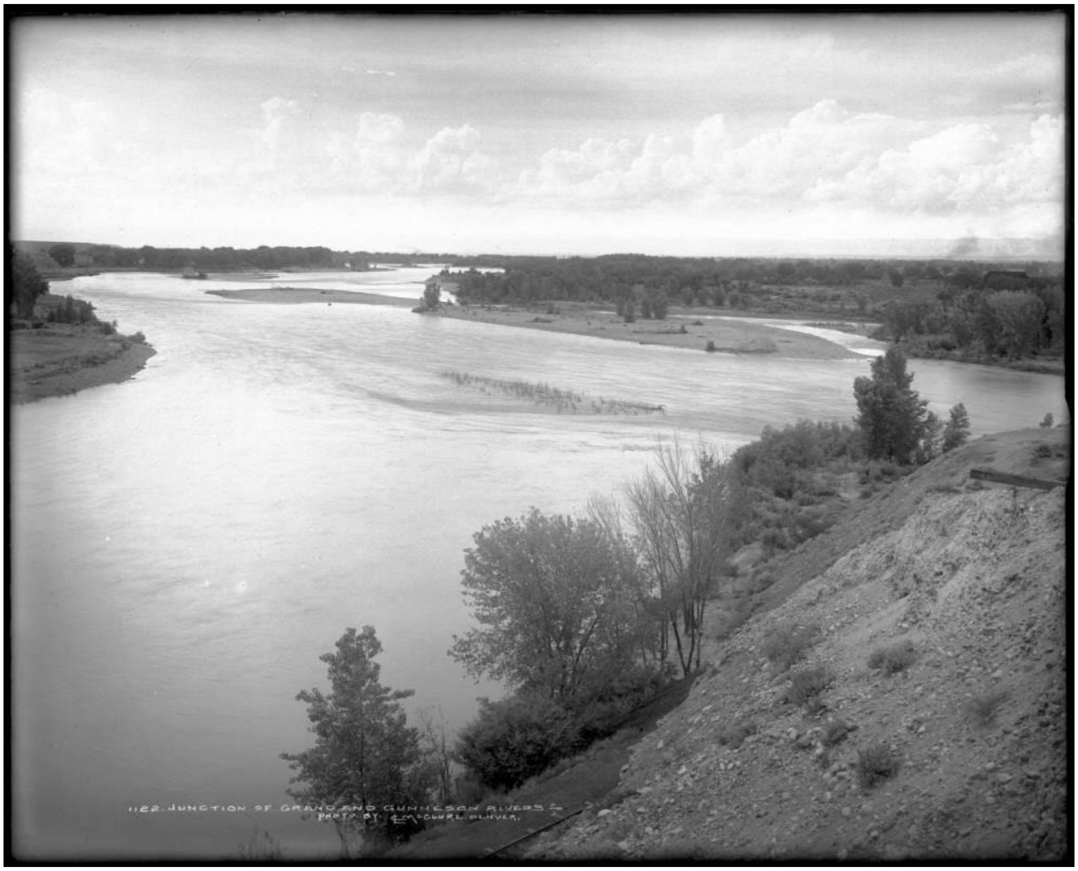


Figure 4-7: Early 20th century (~1907) image of the confluence between the Colorado and Gunnison Rivers looking downstream from the right bank of the Gunnison and the left bank of the Colorado (Denver Public Library).

Despite the dynamism in some reaches along the Grand Valley, the influence of urbanization is visible in many reaches, particularly near the communities of Grand Junction, Fruita, and Palisade. Many developments exist on the Pleistocene-age terraces, but also on artificial fill that has encroached into the river corridor. Substantial armoring, as well as a US Army Corps of Engineers-certified levee, are present along the northern banks, influencing channel morphology, which tends to be more single-threaded in these locations. Many reaches here are affected by gravel mining and gravel ponds as well as urban developments. For more information on the effects of urbanization on river corridors and fluvial hazards, please review Section 4.5 of this Addendum.

The Gunnison study area begins at a relatively unconfined meander bend around Whitewater, CO, where it travels through an alluvial floodplain here. It quickly re-enters a canyon and encounters several small tributaries, many of which have created alluvial fans which provide sediment to the river. The canyon here consists of sedimentary rock with landslide deposits, colluvium, and alluvial fans present on valley margins. Pleistocene terraces from prior glaciation are also present along the corridor throughout.

The Gunnison River study reaches are more similar in nature to the Colorado Canyon reaches (Colorado R01, R09, and R10) than the reaches in the Grand Valley: there is some geomorphic complexity, with a few side channels, overbank chutes, and islands, but the complexity is controlled significantly by the confinement of the canyon and a steeper slope (greater stream power and erosive capacity). The Gunnison River has also been substantially impacted by human influence, particularly by the number of diversions within and upstream of the reaches, likely helping to reduce the lateral extent and dynamism of the current river corridor. The most upstream reach (Gunnison R03) is heavily urbanized and modified, with aggressive channelization and armoring occuring around the community of Whitewater, as well as gravel ponds and railroad infrastructure. However, the downstream reaches are much less influenced directly by development.

4.4.2 Sediment Supply and Corridor Complexity

Water and sediment are supplied by different regions of the Colorado and Gunnison river basins. The Rocky Mountains and upper part of the drainage supply much of the flow coursing through the Grand Valley. As the Colorado River traverses through the Colorado Plateau, it picks up sediment from more erosive valley margins as well as tributary streams and washes draining the sedimentary geology of this region (Council et al., 1991; Pitlick & Cress, 2000). The confluence of the Colorado and Gunnison Rivers is a point of geomorphic importance for the study (Figure 4-4), with the Gunnison providing a significant source of sediment that influences downstream but not upstream reaches..

The bed material of the Colorado and Gunnison rivers ranges in size from sand to cobble with a median surface grain size in the gravel to small cobble range (40-60 mm) and a sub-armor median grain size in the gravel range (20 – 40 mm) (Pitlick & Van Steeter 1998). However, some 98% of the sediment passing through the Grand Valley in these rivers is much finer—in the clay to sand range—and is transported as suspended sediment load (Butler, 1986; VanSteeter & Pitlick, 1998). Though small in a relative sense, the remaining approximately 2% of sediment transport that occurs as bed material load within the study area is much more noticeable. Much of the channel migration, creation of side channels and islands that leads to multi-threaded reaches is heavily influenced by the erosion and deposition of coarse bed materials (sand, gravel, and cobble). When this coarse material is eroded from river banks, it rolls and jumps along the bed, and is then deposited downstream in bars and islands leading to the complexity of the Colorado River in the Grand Valley.

Dramatic incision over the past several centuries on Colorado River tributaries within the Colorado Plateau has been observed and linked to historical changes in climate and land use activities (Livaccari & Hodge, 2009). These tributaries would normally act as wash systems, but irrigation-induced perennial flows may be inducing the substantial incision, which has likely introduced finer sediment to the Colorado River corridor within the study area. Though an increase in fine sediment into a river system has the potential to make it more dynamic, as finer sediment is more readily eroded and deposited, this influence may be attenuated by vegetation encroachment within the river corridor.

With the introduction of numerous dams and diversions along the Upper Colorado River Basin, as well as a changing climate and multidecadal drought, a trend of decreasing peak flows, and more recently mean annual flows along with suspended sediment loads has been observed (Council et al., 1991; Pitlick & Cress, 2000). The decrease in sediment load carried by the Colorado and Gunnison Rivers (as well as bankfull flows capable of inundating floodplains) is important in that it may be associated with the concurrent decrease in river corridor complexity. Between 1937 and 1993, overall decreases in side-channel and island areas, as well as main channel width, occurred throughout the Colorado River

Basin (Pitlick & Cress, 2000; VanSteeter & Pitlick, 1998), which can result in floodplain disconnection and a reduction in fish habitat. It has been found that the majority of sediment carried by the river and critical for habitat and complexity creation and maintenance is carried by bankfull or greater flows, but the heavily regulated nature of the Upper Colorado River Basin likely reduces the frequency of such flows (Pitlick & Van Steeter, 1998). Though an overall trend of channel narrowing, and side channel wetted area has been found in the study area, large snowmelt runoff years do still bring about channel widening, migration, and creation of new side channels (1983, 1984, 2011, 2019). As such, the Colorado River continues to be a dynamic system.

4.4.3 Channel Migration and Change on the Colorado River

In addition to the primary components of the Fluvial Hazard Zone Mapping Protocol, we consider the general fluvial processes and trends of geomorphic change within our study area reaches of the Colorado River as shown by the delineations of bank margins over an 85-year period. We utilized six sets of aerial imagery (1937, 1956, 1986, 1994, 2012, 2020) and manually delineated the bank lines of the channel. The edge of vegetation or center of tree crowns was used as a proxy for the bank line in many cases where a defined bankline did not exist. Side channels that were likely to be inundated during bankfull flows were included in the delineation.

Although understanding the migration of river channels is limited by the short period of available data, this analysis provides information as to how the Colorado River has moved over the last 85 years, which is a longer documented record than most rivers have. More importantly, the record provides insight to how the river behaved prior to the major dams installed after the 1930s.

The temporal trajectory of delineated bank lines reinforce research that suggests the Colorado River in this region has experienced significant changes in corridor complexity over the past 85 years. Between 1937 and 1993, the total area of islands and side channels decreased by approximately 25% (Van Steeter & Pitlick, 1998). As backwaters and side channels were filled by sediment, the main channel of the river also narrowed considerably, and riparian vegetation established in these areas. As discussed in previous sections, the geomorphic complexity that is seen in the Colorado River may be sustained by larger flows capable of transporting sediment. As the volume and peak of runoff decreases in some parts of the study area, the frequency of channel migration, island formation, and channel avulsion events decreases.

Despite this trajectory of diminished channel dynamism, large flows can and do still occur on the Colorado River resulting in many sections of the river still sustaining complexity and dynamism (Figures 4-8 and 4-9). The historic channel locations within Reach R05, which extends from the Colorado-Gunnison confluence to the Redlands Parkway crossing, exemplify how a river can naturally change its path over time. The Colorado River is not static and should be considered a dynamic system that adjusts and changes.

The Redlands Parkway examples illustrate the geomorphic complexity created by large floods (Figure 4-8). The early half of the 1980's saw multiple high snowpacks, resulting in large floods, especially in 1983 and 1984. In the Redlands Parkway region, the river responded to this flooding by channel widening, erosion into meander bend cutbanks, and the development of islands and side channels.

Channel migration is predicted to occur for flows on the Colorado River that meet or exceed the "bankfull discharge", which fills the main channels before spilling out into the floodplain. The bankfull discharges on the Colorado River have an annual chances of being equaled or exceeded of 33% to 20% (3- to 5- year recurrence interval or 22,000 cfs) on the 15-mile reach and 67% to 50% (1.5- to 2-year recurrence interval or 35,000 cfs) downstream of the confluence with the Gunnison (Pitlick and Van Steeter 1998).

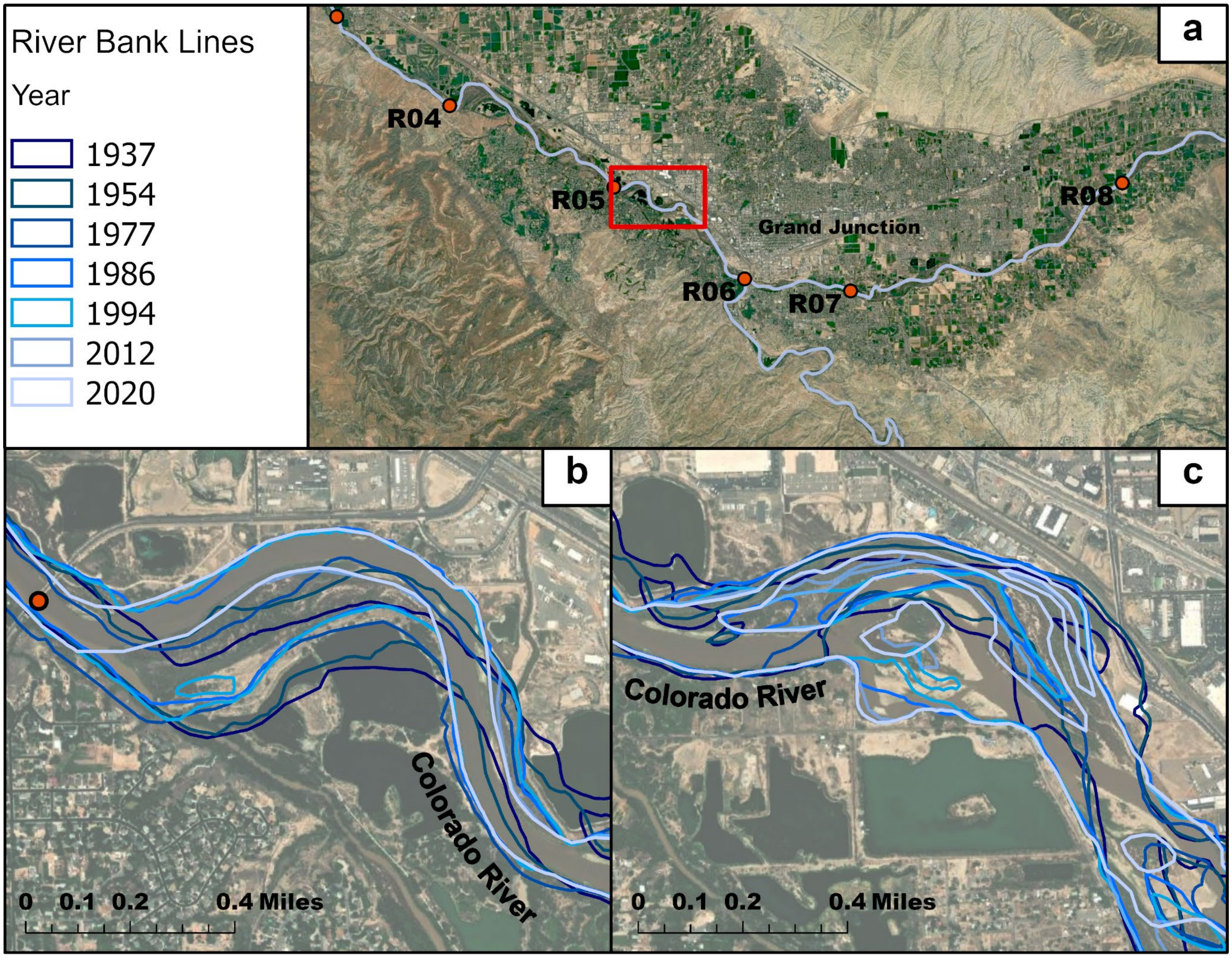


Figure 4-8: Examples of channel migration near Redlands Parkway (Colorado Reach R05): a) study extent, b) all delineated banklines near Redlands Parkway, c) all delineated banklines just upstream of Redlands Parkway.

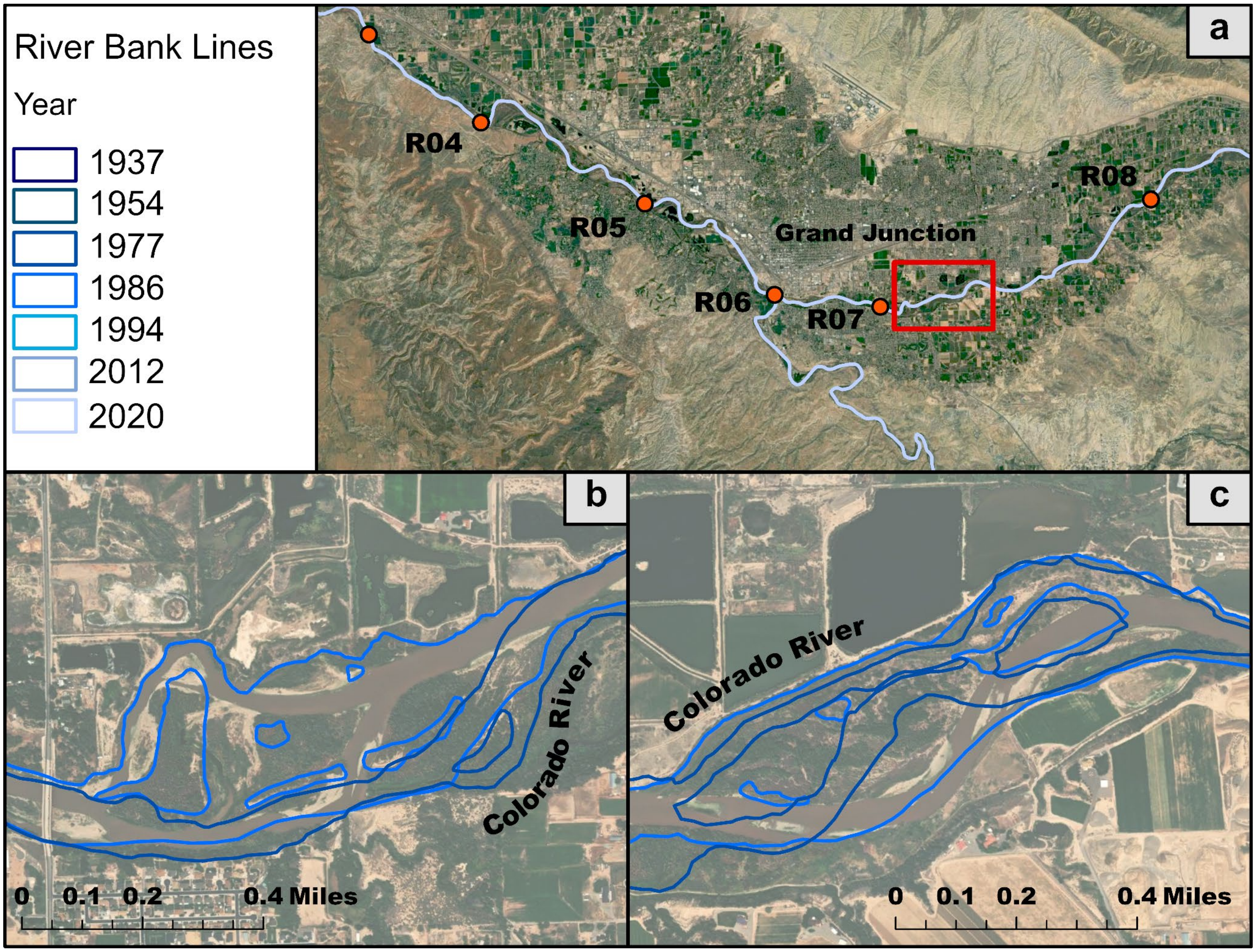


Figure 4-9: Examples of channel changes after flood events, just upstream of 29 Road (Colorado Reach R07): a) study extent, b) delineated banklines (1977, 1986) near 29 Road with examples of island and side channel creation, c) delineated banklines (1977, 1986) upstream of 29 Road with examples of meander erosion and channel widening.

4.4.4 Trajectory and Sensitivity

As noted previously, the level of geomorphic dynamism within the study reaches has been diminishing over the 20th and now 21st centuries with reduced flood peaks and durations. This has resulted in a geomorphic trajectory of channel narrowing, less frequent channel migration events, and overall simplification of the river corridors. Geomorphic simplification refers to the historically multi-threaded (many channels) river form of many reaches within the study area, which contains islands and side channels, converting to a more single-thread form. During spring snowmelt runoff events at meet or exceed bank full discharge, it is likely that sediment will be transported through the system, including coarse gravel and cobbles. These floods are potentially less likely due to the heavy regulation of the rivers, but still can and do occur after heavy snowmelt and rainfall and flows greater than bankfull are important in establishing the complexity seen on the river. Although the washes and tributaries are sensitive to disturbance (erodible), the Colorado and Gunnison Rivers themselves are not sensitive to disturbances because of the high flows required to carry the sediment loads responsible for notable planform adjustment. Based on sediment characterization within terrace and gravel pit deposits, there is evidence that the Colorado has carried and accommodated coarse sediment loads in recent history (Pitlick et al., 1999; Pitlick & Cress, 2000), suggesting that shifting planform complexity in response to high flows is a typical long-term response within the system. However, some regions within the study area, such as the confluence between the two rivers, may be more sensitive.

The long-term trajectories of the Colorado and Gunnison Rivers are likely that of continued and potentially increased flow and sediment starvation. Barring any changes from upstream water management, this may result in further reduction in corridor complexity, fish and critical wildlife habitat, a change in planform width and depth, and a reduction in corridor width and influence. However, floods can and do still occur, particularly as the changing climate may transition the snowmelt system to a rainfall-dominated system. These floods can support some of the complexity created by previous events. This also means that the river is still capable of moving its location and sustaining dynamism (i.e., migration) in the river corridor. Development and gravel mining within the Grand Valley may also pose continued and future reduction in and encroachment on wetlands and connected floodplain areas. These activities occurring adjacent to the river and within the active river corridor are exposed to fluvial hazards as the river migrates.

4.5 Fluvial Process Modifiers and Stressors

Within the Grand Valley, the Colorado River and Gunnison River are both subject to natural and human stressors that influence the dominant physical and biological processes occurring within the river corridor, and this can ultimately affect the overlying geomorphic trajectory of a reach. Below we provide examples of such modifiers and stressors.

4.5.1 Bridges, Crossings, and Diversion Structures

The introduction of infrastructure such as bridges or culverts can magnify or diminish fluvial processes within the river corridor. These structures, especially when they are under-sized for the river corridor, are located near tight bends, or are located where notable slope changes occur, can influence where flow, sediment, and wood travel. During floods, these crossings may result in a disruption, trapping sediment and debris upstream of the structure. This disruption in transport of material downstream, and the subsequent deposition upstream of the structure can influence overbank flows and channel migration or avulsions, even in regions not expected to be directly influenced by flood events. Downstream, the corridor is starved of sediment supply, often resulting in greater erosive energies and exacerbating riverbank erosion and riverbed scour. This erosion and scour may then pose a risk to the integrity of the structure or downstream infrastructure. The change in transport, and regions of deposition or erosion may also influence the ability for organisms to access upstream and downstream reaches. Examples of this within the study area include multiple channel-spanning diversion structures, roadway embankments, and bridges. Within the Grand Valley, several bridges and approaching roadways create hard points within the Active Stream Corridor, arresting down valley channel migration, increasing the potential for dangerous flow conditions, and starving downstream reaches of sediment that can create and sustain dynamism and geomorphic complexity.

4.5.2 Roads and Railway Beds

Roads and railways can influence and impede the processes occurring within the Active Stream Corridor, including channel migration, sediment transport, and flood conveyance. When roads and railways are oriented parallel to the corridor and to flow, they can act as levees, while those oriented perpendicular act more similarly to dams, with similar hazards as seen with under-sized crossings. This infrastructure is vulnerable to erosion and deposition leading to potential damage.

Within our study region, the confined canyon reaches upstream of Palisade (Colorado R09 and R10) are influenced by Interstate 70 as well as a railroad line running largely parallel to (and sometimes crossing) the corridor throughout the canyon. Although these canyon reaches have more naturally constricted Active Stream Corridors, this infrastructure further reduces the area with which the river can engage. The railroad also follows along the toe of multiple alluvial fans, a potentially risky location during storm events when tributaries may introduce coarse sediment to the main channel.

Further downstream on the Colorado River, various encroachments of roads and the railway, as well as channel crossings, exist, constricting the Active Stream Corridor and posing potential hazard during disturbances. Most notably is the corridor cutoff enacted by I-70 just upstream of the City of Fruita near 16 Rd (Figure 4-10). The highway separates the historically active corridor (as seen in 1937 imagery) from where the current river travels, and even travels over a slowly diminishing active side channel within the area. Driving the Colorado River into largely one channel, as well as reducing and disconnecting floodplain and riparian areas, has likely resulted in greater sediment loads being transported downstream rather than depositing and driving geomorphic complexity. Riparian habitat has also decreased, and flood conveyance and erosive energy has increased, leading to greater potential downstream risks.

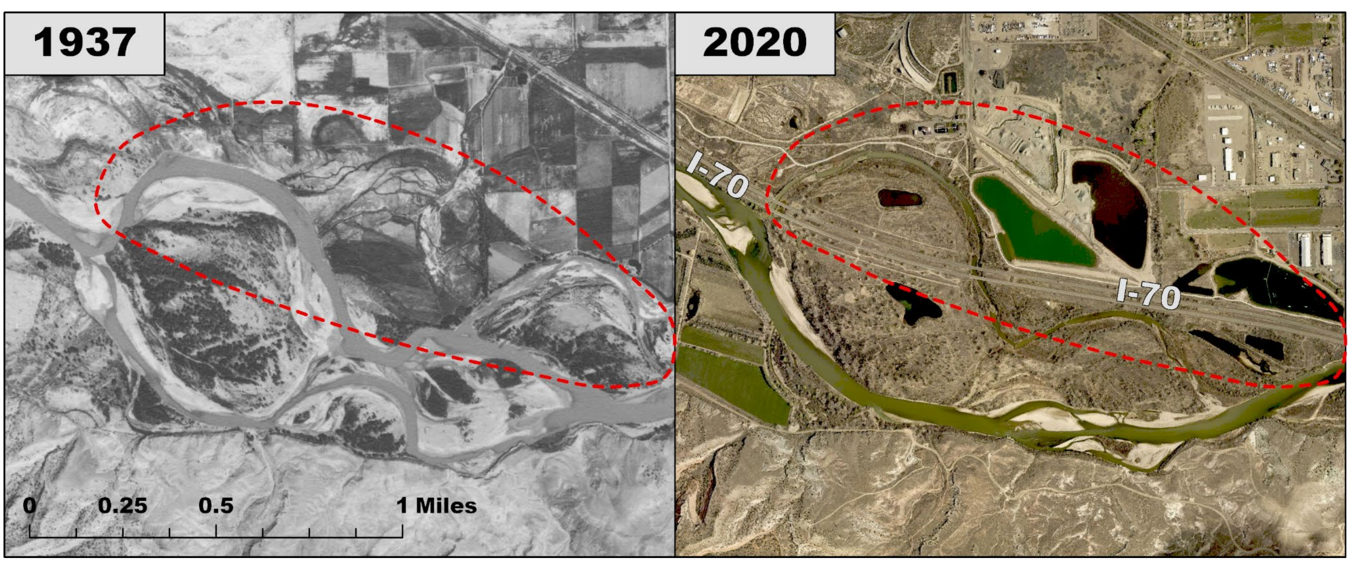


Figure 4-10: Before (1937) and after (2020) imagery documenting the effect I-70 played on corridor disconnection.

4.5.3 Channelization, Armoring, and Disconnection of Floodplains

A common result of development near rivers is channelization where the channel is straightened or forced into a single-thread planform, meanders are relocated or eliminated, and vegetation and large wood or beaver are removed. Associated with this is bank armoring to prevent channel migration or widening. These acts can significantly alter the trajectory of a river corridor, with often negative impacts on floodplain connectivity, as well as local and downstream erosive energy.

Various sections of the Grand Valley are armored, particularly through the middle, more urbanized reaches passing along and downstream of Grand Junction. Bank armoring or revetment, either from engineered or non-engineered riprap is often subject to failure from a variety of mechanisms. The armor is typically installed along discrete lengths, where erosive energy typically then increases. The channel may scour into the armoring, which can result in failure (mobilization of the armor material) if not properly sized or graded. Where channel migration flanks bank armoring, the large armor material can be left stranded in the channel. Finally, though bank armor may arrest bank erosion locally, erosive energy of high flows to downstream locations or banks, potentially exacerbating erosion there.

4.5.4 Fill and Development

Fill and development along rivers is a common occurrence, often resulting in a loss of corridor width, connection, and complexity. This can significantly impact the fluvial and ecological processes occuring in the river corridor, while also imposing a false sense of security to landowners as fluvial signatures and historic corridor extents are buried or erased. Much of the Active Stream Corridor within the Grand Valley has experienced moderate to high levels of development and, in some cases, floodplain fill. Some of this development also lies within the Fluvial Hazard Buffer. Where development occurs within the Active Stream Corridor, a decision is implicitly or explicitly made to actively manage the ongoing or episodic fluvial processes, including bank erosion and deposition. The cost to maintain developments within such areas can be very significant, and often leads to conflict between community development goals and river conservation and restoration. The components of the Fluvial Hazard Zone are not typically influenced by such development (as per the Fluvial Hazard Zone Protocol) unless they are federally certified levees or federal highways and interstates.

4.5.5 Debris Flows and Alluvial Fans

Debris flows can be an influential and devastating disturbance within a river corridor. Debris flows may initiate on hillslopes and valley margins when hillslopes are unstable, often as a result of intense precipitation, and can deliver substantial amounts of sediment and debris to a river corridor. Debris flows can deposit sediment and material across the river corridor and influence not only downstream but also upstream fluvial processes. Depending on the system, debris fans can also span whole valleys, forcing the river to avulse and work through the deposited material. Such occurrences are mostly likely in the canyon reaches of the study area, resulting in fluvial hazards extending outside of the delineated components of the FHZ.

Alluvial fans within the study area influence the morphology of the channel and both the Active Stream Corridor and Fluvial Hazard Buffer. Many of these are persistent features on the landscape but are also more erodible than some native material such as the Mancos Shale that dominates the left (south) bank of the Colorado River.

4.5.6 Wildfires and Forest Disease

In many Colorado watersheds, wildfire and forest disease are factors that may influence valley margin and river corridor processes. These stressors can influence both the hydrologic and sediment regimes of a river, which can shift fluvial hazards in and downstream of a reach. Although the Grand Valley has a semiarid upland ecology and few recent fires have specifically impacted the study region, these factors may still influence the Grand Valley and should be considered carefully. A primary concern of wildlife on the Fluvial Hazard Zone is where fire can lead to debris flows within more confined reaches or in tributaries that can deliver substantial amounts of debris to the main channels.

Fires in tributary watersheds to the Colorado and Gunnison Rivers within the canyon reaches may increase the likelihood of debris flows entering these reaches. Fires have occurred within the Grand Valley river corridor and impacted floodplain forests. Such fires may be ecologically impactful. However, their impact to fluvial geomorphic processes is most likely limited to augmenting channel migration rates where bank vegetation has been reduced or removed. It is also important to note that although the Fluvial Hazard Zone mapping components will probably encompass some areas that would be affected by wildfire, it is unlikely that all areas will be included. Geotechnical studies are required to better understand and delineate where potential hillslope hazards may exist post-fire.

4.5.7 Gravel and Aggregate Mining

During floods, gravel ponds can play an influential role in transferring or shifting hazards. The capture of reservoirs, ponds, and gravel pits of a migrating river can result in erosion and deposition in areas that do not typically experience fluvial processes. For this reason, such areas are typically included in the Active Stream Corridor delineation. Within our study region, there is a large presence of gravel mining and gravel ponds. Because of the potential hazard associated with pit capture during disturbances, the Active Stream Corridor has been extended to include these gravel ponds (Figure 4-11).

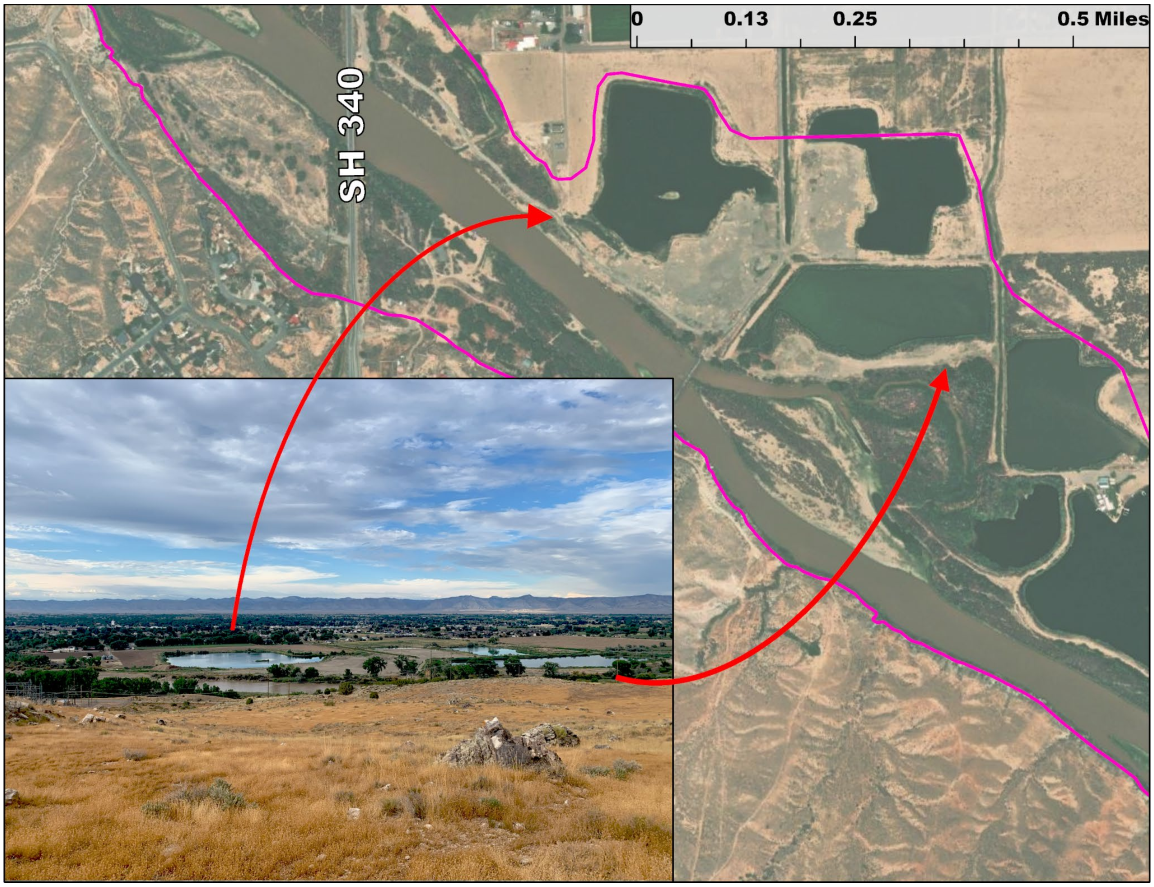


Figure 4-11: Examples of the numerous gravel ponds that exist within the Active Stream Corridor (pink lines). This example is near Fruita and 16 Rd just upstream of CO State Highway 340.

5.0 Mapping Notes

The study reaches were mapped according to the methods outlined in the Colorado Fluvial Hazard Zone Delineation Protocol, Version 1.0. Table 5-1 is a quick reference for outlining the method and presence/absence of auxiliary features by reach. Sections 5.1, 5.2, and 5.3 provide a brief summary of the mapping method. Appendix A provides detailed notes for each reach.

Table 5-1: Quick reference for delineation methods and presence of FHZ auxiliary components in the study reaches.

Reach (listed geographically from ups downstream to upstream)	Active Stream Corridor (ASC) Method	Fluvial Hazard Buffer (FHB) Width	Avulsion Hazard Zone (AHZ) Presence	Fan (F) Presence and Persistence	Geotechnical Failure Flag (GF) Presence	Disconnected Active Stream Corridor (D-ASC) Presence
Colorado R01	Fluvial Signature	Type III: Large Snowmelt Streams	No	Yes, erodible	No	No
Colorado R02	Fluvial Signature	Type III: Large Snowmelt Streams	No	Yes, persistent	No	Yes
Colorado R03	Fluvial Signature	Type III: Large Snowmelt Streams	No	No	No	No
Colorado R04	Fluvial Signature	Type III: Large Snowmelt Streams	No	Yes, erodible	No	Yes
Colorado R05	Fluvial Signature	Type III: Large Snowmelt Streams	No	Yes, persistent	No	No
Colorado R06	Fluvial Signature	Type III: Large Snowmelt Streams	No	No	No	No
Colorado R07	Fluvial Signature	Type III: Large Snowmelt Streams	No	Yes, erodible	No	No
Colorado R08	Fluvial Signature	Type III: Large Snowmelt Streams	No	Yes, erodible	No	No
Colorado R09	Fluvial Signature	Type III: Large Snowmelt Streams	No	Yes, erodible	No	No
Colorado R10	Fluvial Signature	Type III: Large Snowmelt Streams	No	Yes, persistent	No	No
Gunnison R01	Fluvial Signature	Type III: Large Snowmelt Streams	No	Yes, persistent	Yes	No
Gunnison R02	Fluvial Signature	Type III: Large Snowmelt Streams	No	Yes, erodible	No	No
Gunnison R03	Fluvial Signature	Type III: Large Snowmelt Streams	No	Yes, ephemeral	No	No

5.1 Active Stream Corridor

We used the Fluvial Signature method as documented in the CWCB FHZ Protocol to map the Active Stream Corridor in the Grand Valley. The Fluvial Signature method is primarily used for moderate to large sized streams (2nd and 3rd order and above) that have moderately steep gradients, more confined valley bottoms, and a floodplain with identifiable fluvial signatures. The Fluvial Signature method can also be utilized for valleys with relatively unconfined valley bottoms, such as the Colorado River. This method requires the identification of fluvial signatures on the geomorphic floodplain, which can be done via field observations and assessment of remote sensing products (LiDAR, Relative Elevation Model, geologic maps). Various guidelines exist within the FHZ Protocol for where the geomorphic floodplain has been altered. For example, it is important to consider where agriculture or urbanization has removed the evidence of fluvial activity, particularly in relation to the current geomorphic regime and trajectory. In addition, features such as gravel ponds, a notable characteristic of the Grand Valley, can impact natural conditions and influence how the Active Stream Corridor is delineated.

5.2 Fluvial Hazard Buffer

We utilized the Type III guidance found in Section 5 of the FHZ Protocol to delineate Fluvial Hazard Buffers (FHBs) across all reaches within the study area. The Type III guidance is recommended for larger watersheds that are influenced primarily by snowmelt runoff, such as the Colorado and Gunnison Rivers. As recommended by Appendix G, the width of the Fluvial Hazard Buffer ranged between 0.25 and 1.0 average channel widths of each reach. Specific FHB widths were tailored to each reach based on valley margin erodibility (margin material) and river corridor erosivity (hydrologic settings, slope, distance between channel and valley margin). In general, more confined reaches, such as Colorado R09 and Colorado R10, or reaches with erodible banks, such as those migrating into alluvium, had wider Fluvial Hazard Buffers, than those that are more unconfined or further away from erodible valley margins. Where the active channel was adjacent to an erodible valley margin, the Fluvial Hazard Buffer is typically one (1) channel width beyond the margin of the Active Stream Corridor. Where the valley margin consists of more resistant material, such as shale and mudstone, or the more distal from the active channel, the Fluvial Hazard buffer is reduced to 0.5 channel width. Finally, 0.25 channel width was used for cases where exposed sandstone or the Interstate bordered the Active Stream Corridor. For more detailed information regarding FHB widths of the study reaches, see the associated reach sheets.

5.3 Auxiliary Hazards

Auxiliary Fluvial Hazard Zones, as detailed in Section 2.2, identify areas where fluvial hazards may exist but are not captured by other Fluvial Hazard Zone components, such as the Active Stream Corridor or Fluvial Hazard Buffer.

Various fans were identified in the study area. Many fans were found along steep canyon faces, particularly in relation to the Mancos Shale formation that is present along the southern edge of the Colorado River, for example. However, some fans may not have been identified and there are no comprehensive geohazard assessments for the region, which is highly recommended for future work.

Geotechnical Flags identify locations where hillslope failures impacting the valley margin may extend beyond the Fluvial Hazard Buffer. Similar to fans, geotechnical flags do not identify the extent of this influence beyond the FHZ components but serve as an opportunity to consider site-scale geotechnical assessments of hillslope stability. These are typically identified where valley margins consisting of steep, erodible and/or unconsolidated material exist. Though this hazard may exist within the study area, especially along the Mancos Shale bluffs bordering the southern margin of the Colorado River, we did not identify any geotechnical flags. This is because the majority of the formations comprising steep valley margins were consolidated to partially consolidated material (shale, mudstone, sandstone).

Disconnected Active Stream Corridors are areas in a valley that would historically be in the Active Stream Corridor but are not currently experiencing fluvial processes due to disconnecting infrastructure such as levees or major highways. Within the Grand Valley, as highlighted previously, two Disconnected Active Stream Corridor were identified: (1) in and around Las Colonias and (2) near Fruita, where I-70 cuts off the historic Active Stream Corridor (Figure 4-7).

6.0 Applications and Recommendations

In this final section of the Grand Valley FHZ addendum, we present applications, recommendations, and best practices for managing the dynamics Colorado and Gunnison River corridors. This information ranges from general to site specific. It is not comprehensive but includes recommendations and observations for the majority of the study area. The feasibility of these high level and conceptual recommendations have not been explored in depth. A detailed river corridor master plan and/or capital improvement plan would provide comprehensive analysis of site-scale river conditions, areas of concerns, and potential river corridor projects.

6.1 Best Practices for Urban River Corridor Management

The Colorado and Gunnison rivers tend to naturally migrate in the down- and across valley directions within their floodplains. This natural migration can pose hazards to development and infrastructure that may be located within this migration zone (the active stream corridor, or ASC). It can also result in ongoing maintenance and repair challenges and costs related to “picking a battle” with this migration. In some cases, half measures or patchwork interventions can exacerbate the perceived problem locally or downstream. Additionally, natural channel migration creates and maintains the complex floodplain habitat (side channels, oxbows, backwater and alcove environments) that support various life stages of our native fish and ultimately Colorado’s compliance with the Endangered Species Act.

Here we present high level recommendations and best practices for managing human development and infrastructure within a dynamic corridor are presented in this section as guidelines to consider for planning, siting, and design. Detailed and site-specific recommendations would result from a river corridor master planning process. Figure 6-1 presents examples of river-compatible infrastructure design that may be applied to the Grand Valley River Corridor.

6.1.1 River Corridor Master Planning

A river corridor master plan can provide a detailed evaluation of existing land use zoning, building/site development policies or standards, parks and recreation, multi-model transportation, floodplain hazards, environmental and habitat considerations, and other community values within the river corridor. By distilling this information, a special or overlay district with its own policies and best practices can be developed to support and account for these values and hazards. Such a plan can inform where to site new and rehabilitated infrastructure and how to develop and connect the community with the river corridor in a more compatible and less costly and hazardous manner. A river corridor master plan can create consensus-driven approaches to river corridor design that provide the developer flexibility, room for channel migration and flood hazards, and foster community-identified values and aesthetics.

6.1.2 Freedom Space for River Migration

Where is it tolerable for a river to migrate and where is it not? Intervening to arrest or slow down valley and lateral migration everywhere is not an economical or practical solution to managing a dynamic river in an urban corridor. By armoring banks or building river training infrastructure, the erosive energy of a river may be transferred to some location downstream. Natural channel migration supports native ecosystems. Areas in which natural channel migration is allowed to occur are typically in the regulatory floodway or floodplain and can also serve as open space areas for passive recreation. Planning for migration and identifying areas where channel migration is tolerable, that is, river freedom space, is an important tool in river corridor management. We have identified areas where migration is active and where development or infrastructure are currently limited (Figures 6-2 to 6-5). These are areas where collaboration with landowners may result in some level of tolerable channel migration.

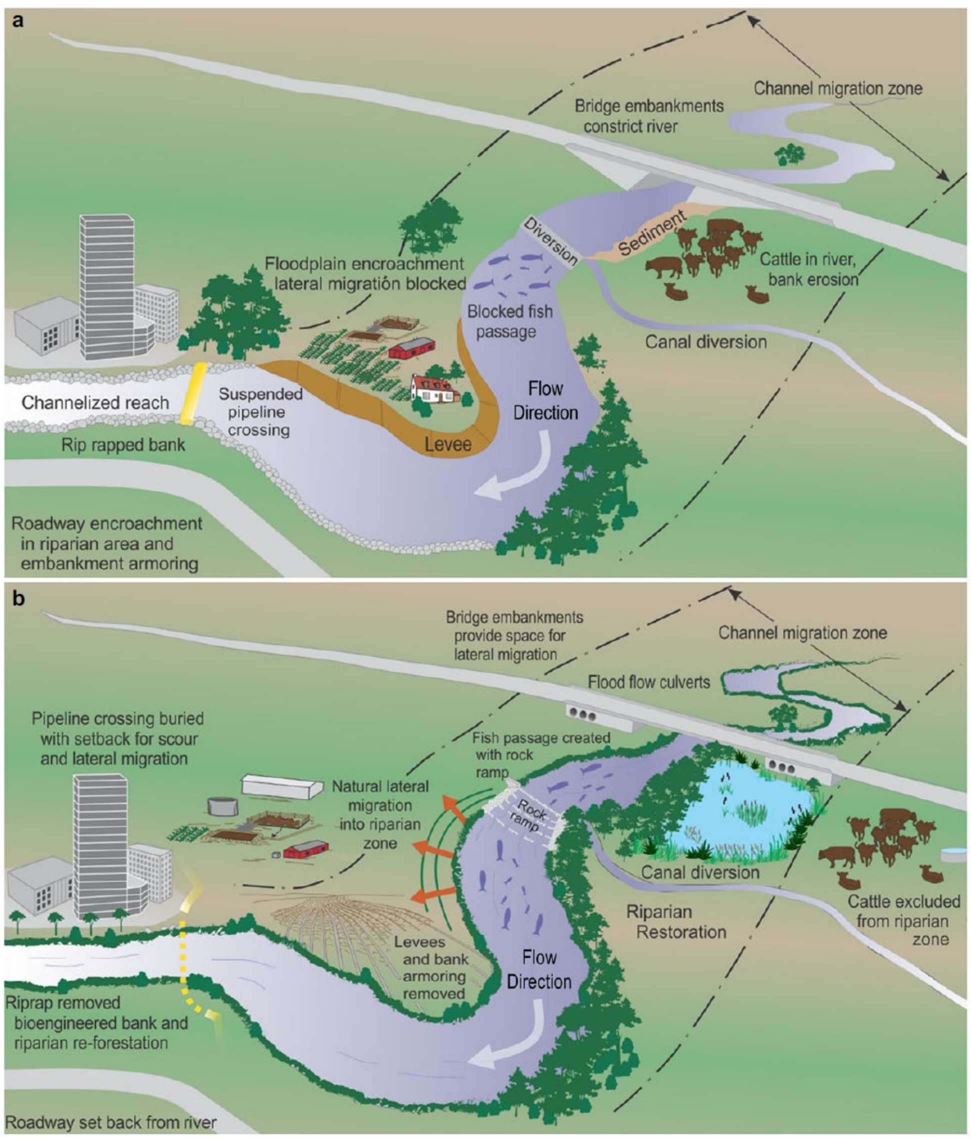


Figure 6-1. Examples of less (a) and more (b) river compatible infrastructure design. From Sholtes et al. (2018).

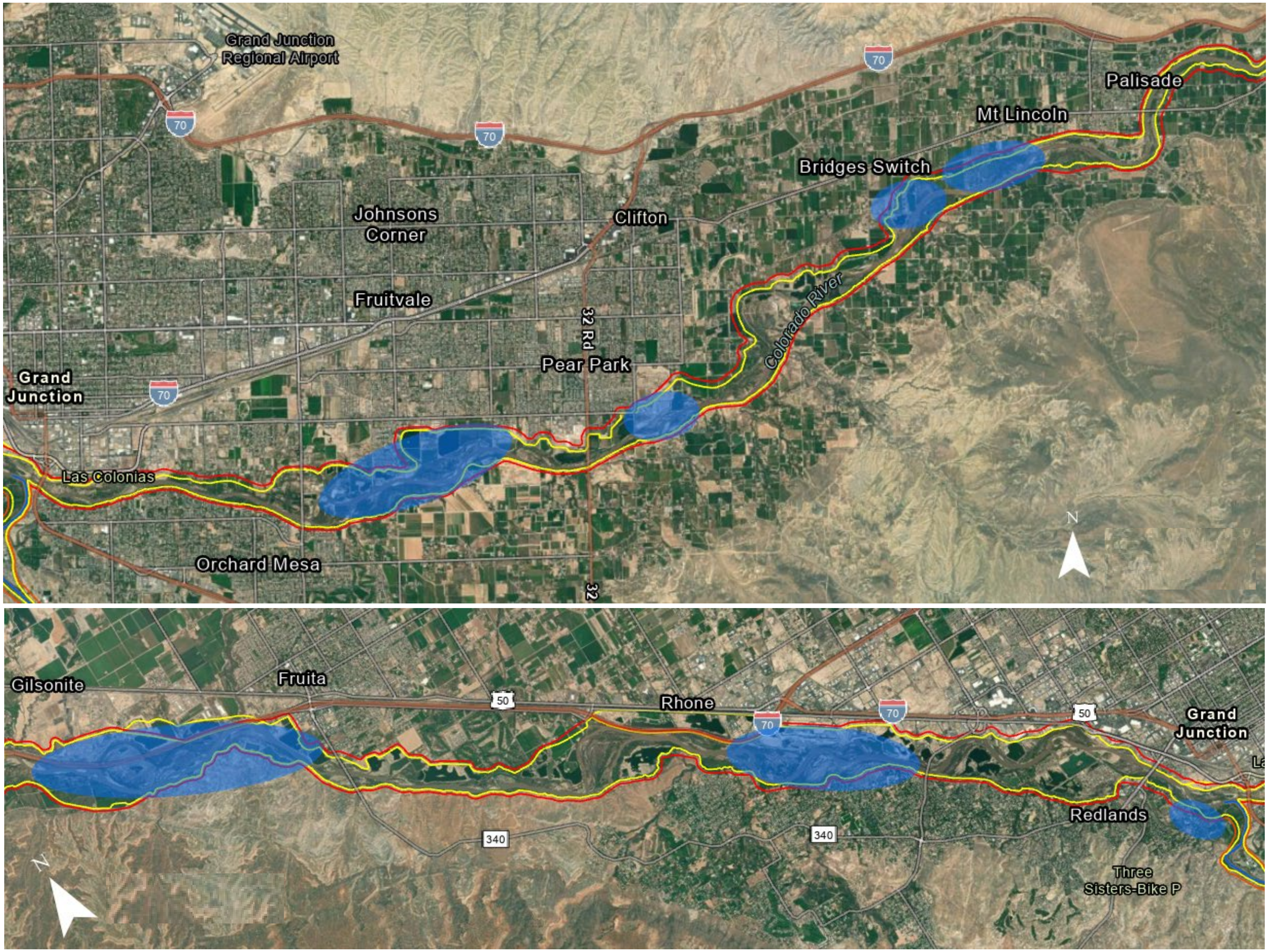


Figure 6-2. Areas (blue) where channel migration may be supported within the Grand Valley.

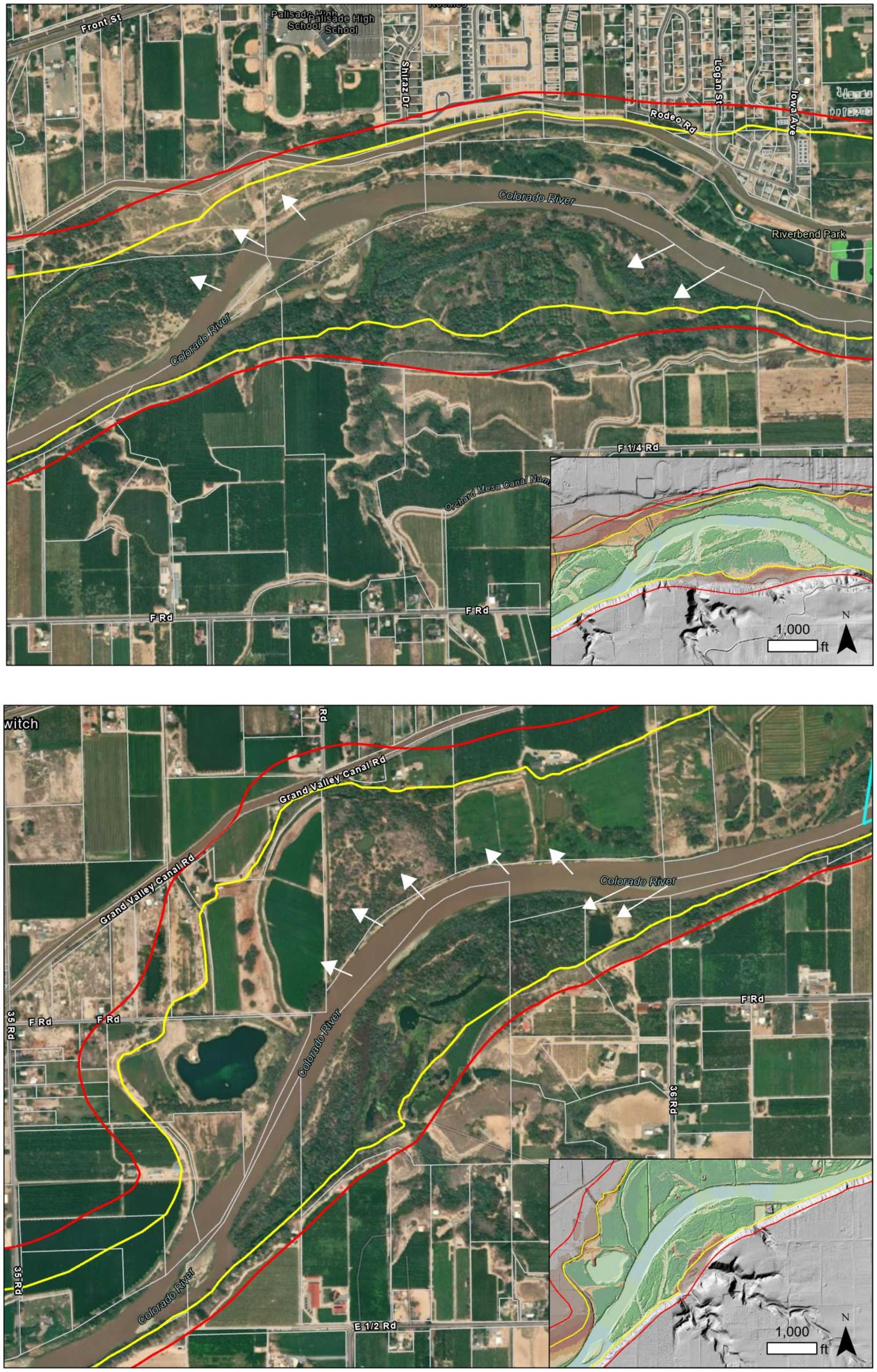


Figure 6-3. Potential channel migration zones within the Grand Valley's Active Stream Corridor. White arrows indicate likely direction of channel migration. (Top) Just downstream of Riverbend Park in Palisade. (Bottom) Unincorporated Mesa County at 35 ½ Road.

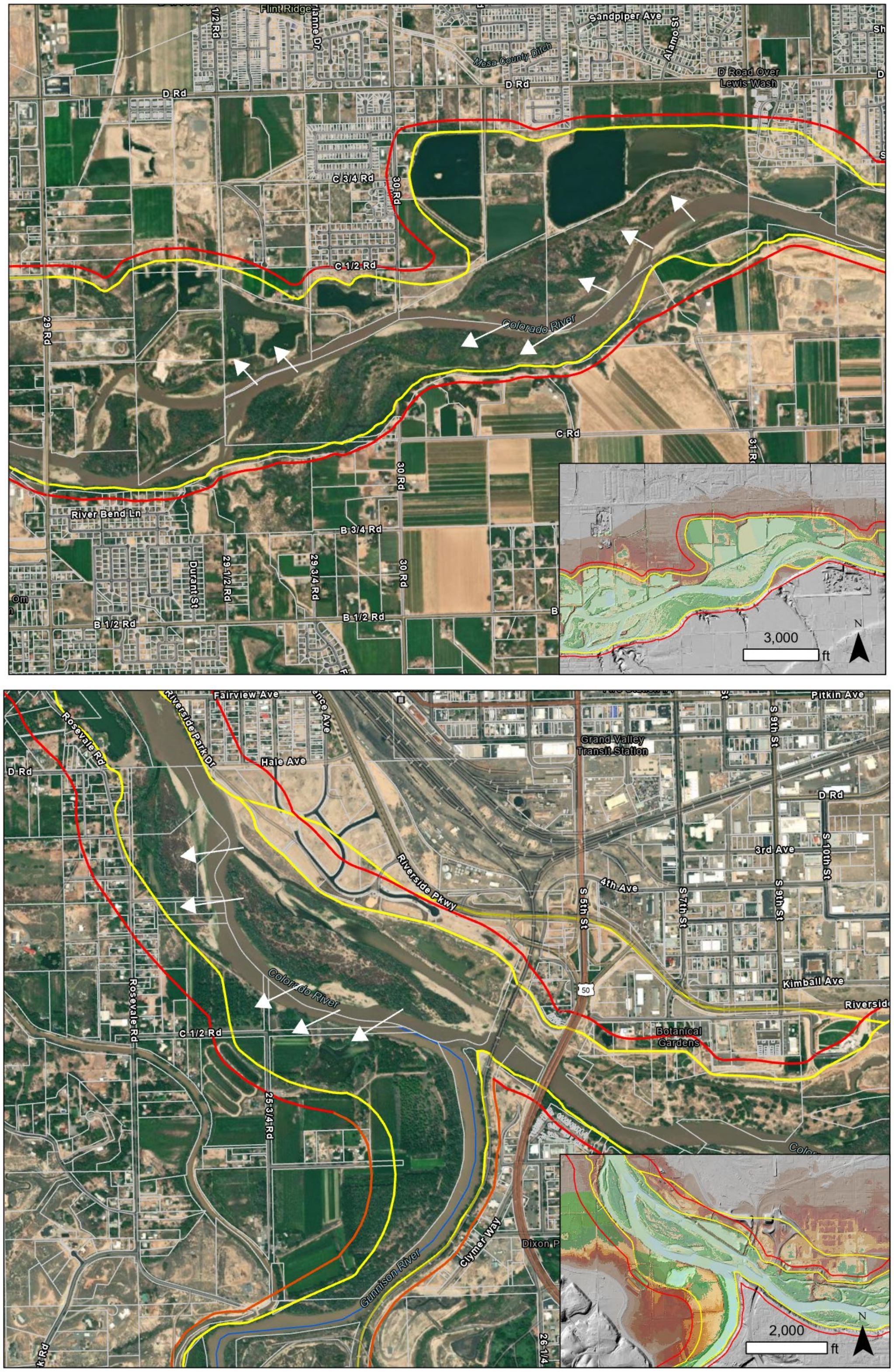


Figure 6-4. Potential channel migration zones within the Grand Valley's Active Stream Corridor. White arrows indicate likely direction of channel migration. (Top) Unincorporated Mesa County at 31 Road to 29 ½ Road. (Bottom) Just downstream of confluence with the Gunnison along left bank.

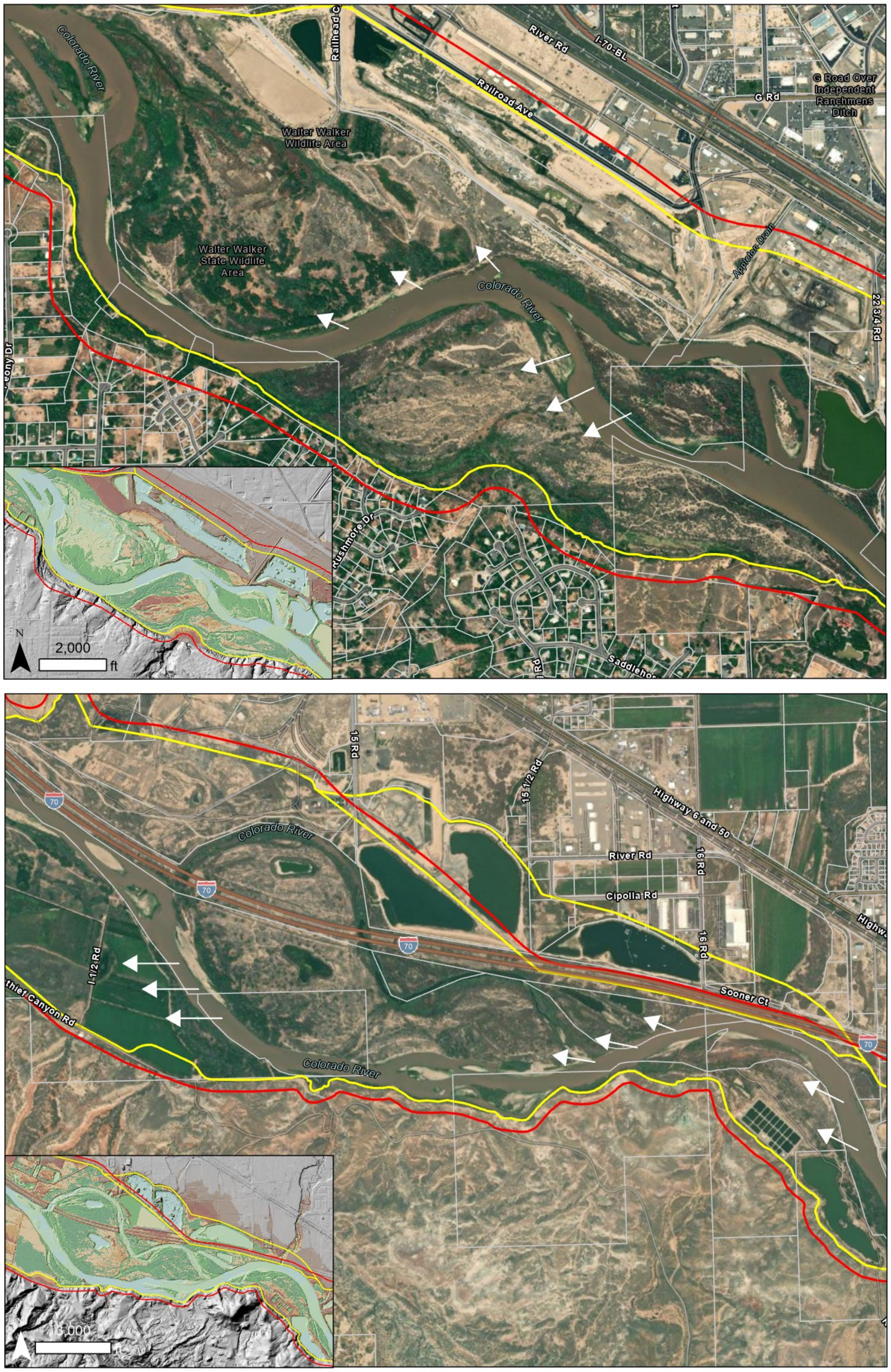


Figure 6-5. Potential channel migration zones within the Grand Valley's Active Stream Corridor. White arrows indicate likely direction of channel migration. (Top) At Walter Walker State Wildlife Area. (Bottom) Unincorporated Mesa County in the vicinity of 15 Road to 16 Road.

6.1.3 Planning for Migration

In many areas within the Grand Valley, down valley channel migration is approaching or has approached certain hard points where infrastructure and development already exist. Where rivers encounter artificial hard points, they tend to migrate up to and potentially around them. An example of this exists at Redlands Parkway where the Colorado River has been continuously migrating down valley towards the parkway's elevated embankment and bridge across the floodplain as well as approaching the 29 Road (Figure 6-6). Another area where this has already occurred and is causing problems from a geomorphic and safety standpoint is where the river bifurcates near Connected Lakes at the high-tension powerline crossing.

In locations where channel migration is approaching or adjacent to infrastructure there are typically two options: (1) move or modify the infrastructure and (2) mitigate the migration. Moving or modifying infrastructure within the ASC may involve widening abutments or embankments for bridges, burying pipelines with a wide enough setback to avoid channel migration, or simply removing infrastructure (Figure 6-1). Mitigating the migration may include bank armoring and/or river training structures. Such interventions should be designed to address local and downstream migration. They should also consider local and downstream impacts of arresting migration. Specific examples of where options (1) or (2) may be more or less feasible are explored in the subsequent sections below.

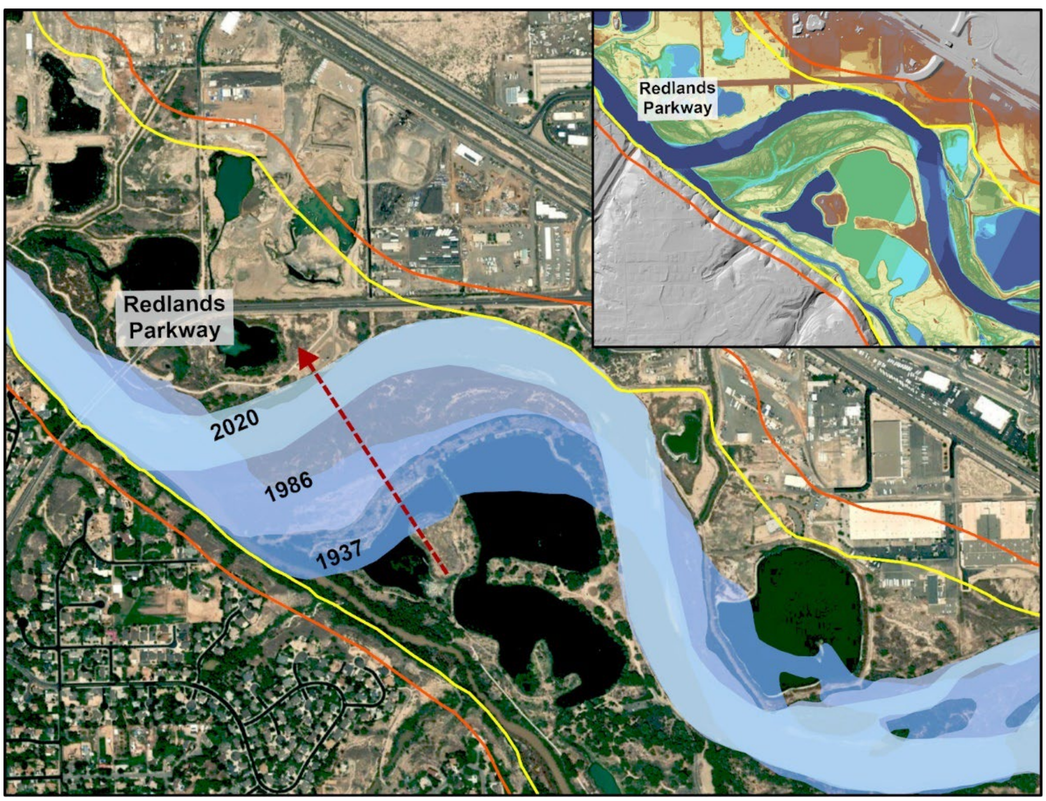


Figure 6-6. Progressive channel migration towards Redlands Parkway.

6.1.4 Bank Armoring

Riprap and other bank armoring techniques are a common tool used to prevent or slow down bank erosion and channel migration. The challenge with any bank armoring project relates to the limited extent to which bank armoring is typically installed and the river’s tendency to move around or flank these treatments. When a river erodes a bank as it migrates laterally and down valley, it is expending energy. When erosive flow encounters riprap, that erosive energy may be transferred downstream resulting in more erosive energy (and potentially erosion) than would have otherwise existed.

There are many examples of failed or failing riprap located along the Colorado River in the Grand Valley, as well as riprap that the channel has migrated beyond leaving the material in the middle of the channel. Most bank armoring projects have a limited lifespan and require regular maintenance to ensure they continue to meet project needs. As such, designing and installing riprap or other bank armoring becomes a long-term financial and maintenance commitment to “holding the line” with a particular streambank. Figures 6-7 and 6-8 show examples of bank armoring in the Grand Valley.

Figure 6-7. Bank armoring structures flanked by a migrating Colorado River. Located at approximately 30 ½ Road.

Figure 6-8. (Left) Bank armoring that transitions to a side channel where flood energy is naturally dissipated. (Right) Abrupt end of bank armoring with bank erosion occurring downstream along unarmored bank. Yellow lines indicate hypothetical flow paths.

Because armoring miles of streambank is not feasible nor desirable, a bank armoring project is often limited in extent. Considerations for bank erosion at the upstream and downstream extents of the bank armoring should be made in the design as well as in siting these extents. For example, a downstream extent for a bank armoring project may tie in with other infrastructure such as a bridge, extend downstream beyond an outer bank where migration is most active, or transition to grading and vegetation designed to mitigate this erosive energy (Figure 6-8).

6.1.5 Siting Infrastructure and Utilities

Active stream corridors typically share footprints with utilities, transportation infrastructure, as well as stormwater conveyance and treatment infrastructure. As a community installs, replaces, or rehabilitates this infrastructure, they have an opportunity to (re)design it in a way that is more compatible with channel dynamism within the ASC. Surface and subsurface infrastructure and utilities that travel along a stream corridor should avoid the ASC and FHB where feasible. Where not feasible, areas within the ASC that are more likely to encounter channel dynamism, such as the outside of meander bends should be avoided. The discussion above in the “Planning for Migration” section is also pertinent to this. Channel crossing infrastructure can be buried below the channel bed over the length of the ASC/FHB or include longer spans to provide more room for channel dynamism (Figure 6-1).

The Grand Valley enjoys a paved multi-model trail across most of the Colorado River corridor. In some locations, this path is immediately adjacent to the river. Because of this, it has been impacted by bank erosion and has required maintenance and armoring. Future segments of this or other concrete paths should identify areas less prone to erosion or channel migration. Using the relative elevation model generated from this study, floodplain and floodway boundaries, and the ASC and FHB boundaries can help identify surfaces and areas less subject to erosion and flooding.

6.1.6 Gravel Ponds

Sand and gravel mining is very common along both the Colorado and Gunnison Rivers in the Grand Valley. These open water pits extract the alluvial (river deposited) sediment that makes up the subsurface of the floodplain. After mining is completed, an open water gravel pond is left behind, often immediately adjacent to the river. Due to the nature of the material being extracted, gravel ponds are often located within the river corridor. The border between these ponds and the river or ASC is typically a non-engineered berm or dike, unless improved for other purposes such as creating a park with a fishing pond. Additionally, these gravel ponds typically harbor non-native and invasive fish.

Gravel ponds can deter channel migration where bank armoring and berming have gone in around them. During flood events, these berms may be breached, thus being captured by the river. Where several gravel ponds exist in line along a river corridor, river channel avulsion may occur in which the channel finds an alternative path through the ponds. Examples of gravel pond capture and avulsion by rivers exist upstream on the Colorado River at Rifle (Figure 6-9) and in the Grand Valley (Figure 6-10).

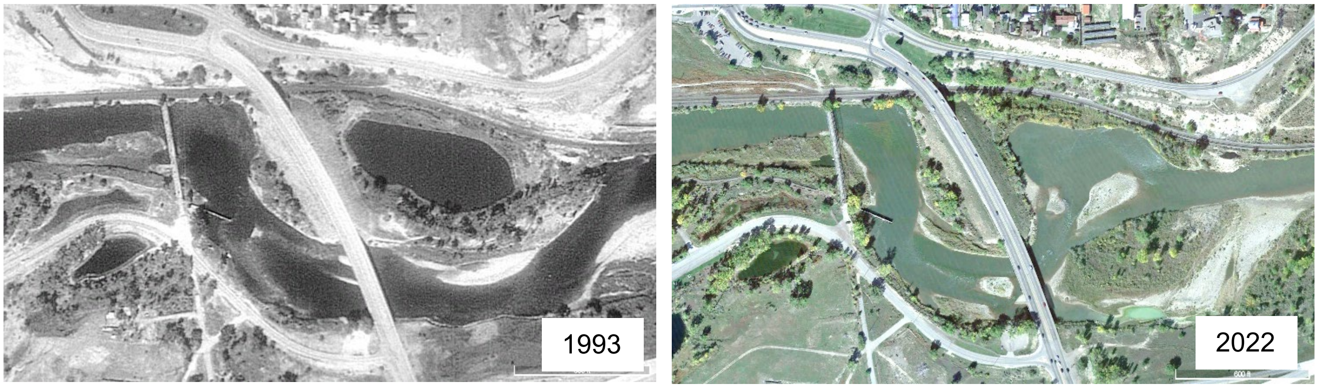


Figure 6-9. Gravel pond upstream of bridge at Rifle, Colorado captured by the Colorado River.

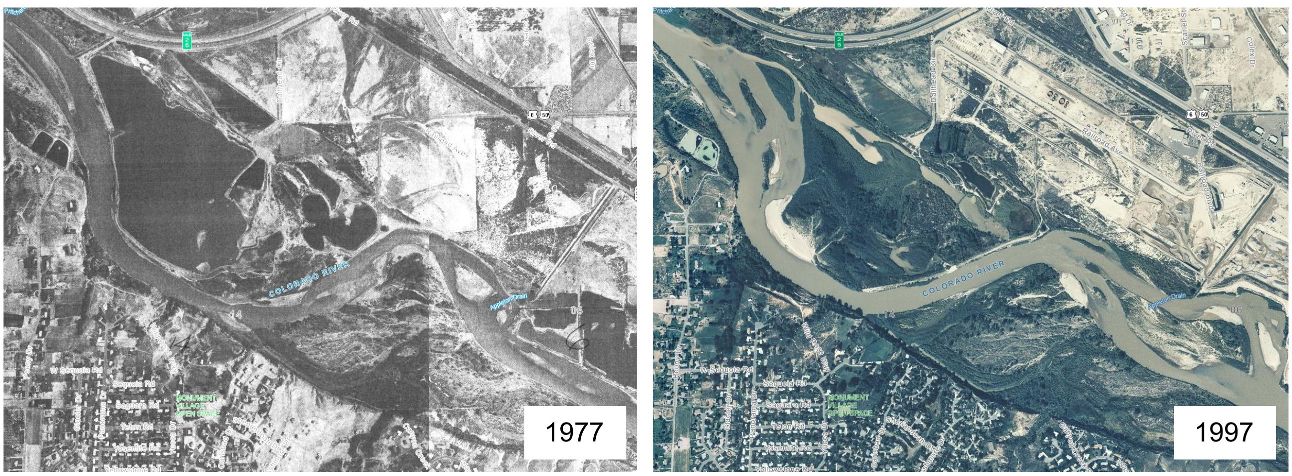


Figure 6-10. Gravel pond located at the (now) Walter Walker State Wildlife Area captured by the Colorado River.

6.2 River – Community Interactions

The following are examples of areas where the rivers of the Grand Valley are interacting with infrastructure and development. Here, we highlight examples of this and provide discussion about potential actions or responses. This does not represent a comprehensive list of areas of interactions or concerns within the Grand Valley River Corridor. Future river corridor master planning and capital improvement planning could provide a more comprehensive assessment of this.

Palisade

The Town of Palisade is located on the outer bend of the Colorado River as it flows out of De Beque Canyon (Figure 6-11). Outer bends of rivers are susceptible to outward channel migration and bank erosion. However, since the earliest aerial imagery taken over 85 years ago, this bank has only moved marginally. That is likely because Palisade is located on a 30- to 40-foot-tall terrace comprised of sand to boulder sized glacial outwash material. Though unconsolidated, this material, along with riparian vegetation, has demonstrated some level of resistance to erosion. Nevertheless, development and utilities located immediately adjacent to the bank and river are still susceptible to fluvial geomorphic hazards from gradual bank erosion and bank failure.

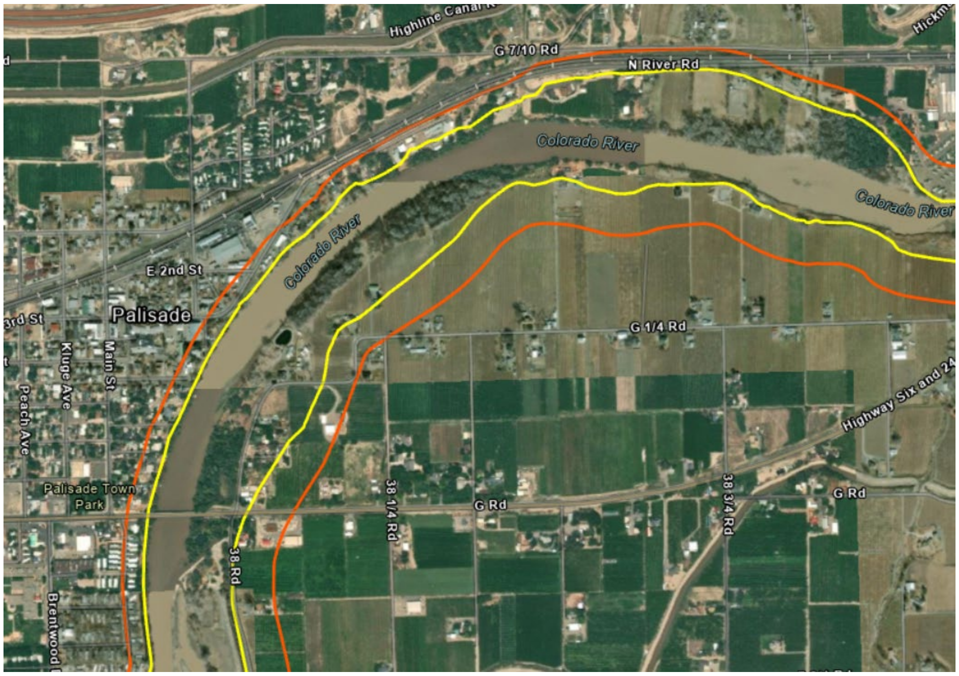


Figure 6-11. The Fluvial Hazard Zone boundaries (ASC and FHB) for the Colorado River at Palisade, CO.

Clifton Area

Dozens of gravel ponds are located in the unincorporated region between Grand Junction and Palisade generally referred to as the Clifton area (Figure 6-12). These ponds are contained within dikes or berms, many of which have not likely been design by an engineer or to withstand a design flood. The dikes constrain the river and could exacerbate bank erosion downstream. Additionally, some utilities (the Riverfront Trail) have been placed on these dikes making them vulnerable to channel migration processes. The gravel ponds are susceptible to river capture under high flow events. This could lead to channel avulsion as well as introduction of non-native and invasive fish species into the Colorado River. As discussed below under Section 6.3 Project Recommendations, some of these ponds may be good candidates for floodplain restoration and reconnection work.

Figure 6-12. Gravel ponds located within the Clifton area constrain flood flows and channel migration.

Down valley channel migration is approaching the 29 Road and bridge (Figure 6-13). Private land located between the river and the road is subjected to bank erosion and other fluvial hazards. The gravel pond located in this area is subject to river capture. River training may be necessary to keep the river from migrating into 29 Road. Alternatively, actions could be taken to allow for channel migration here and adjust infrastructure to accommodate this.

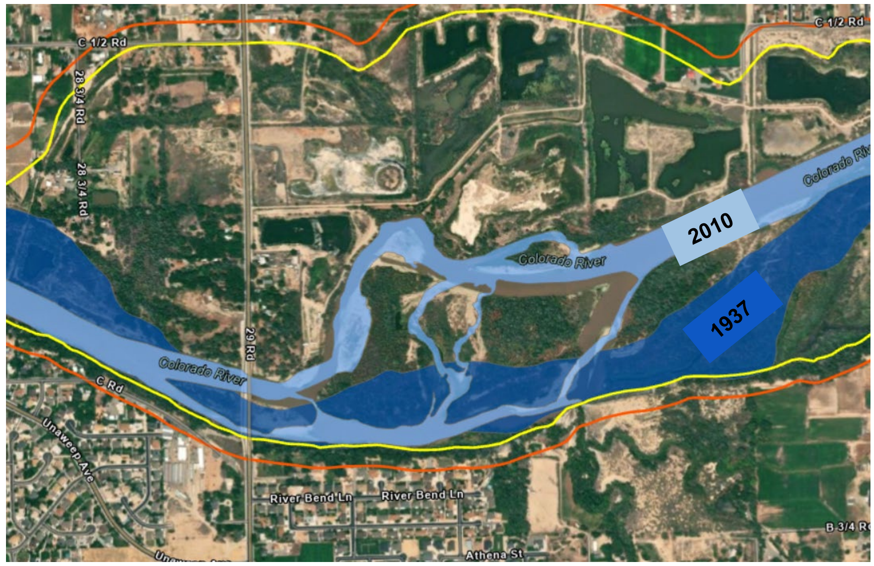


Figure 6-13. Channel migration on the Colorado River towards 29 Road.

City of Grand Junction

As the river enters the City of Grand Junction it becomes more confined in many locations, often due to development, floodplain fill, and riprap. Development is expanding along the river corridor to the east of Las Colonias. A proposed bike path connecting the Riverfront Trail from Las Colonias to 29 road would travel through the ASC / FHB (Figure 6-14). Finding a path that accommodates existing trail easements and avoids traveling along the riverbank would allow for ongoing channel migration and reduce habitat impacts. It would reduce long-term project costs by avoiding costly bank armoring construction and maintenance as well.

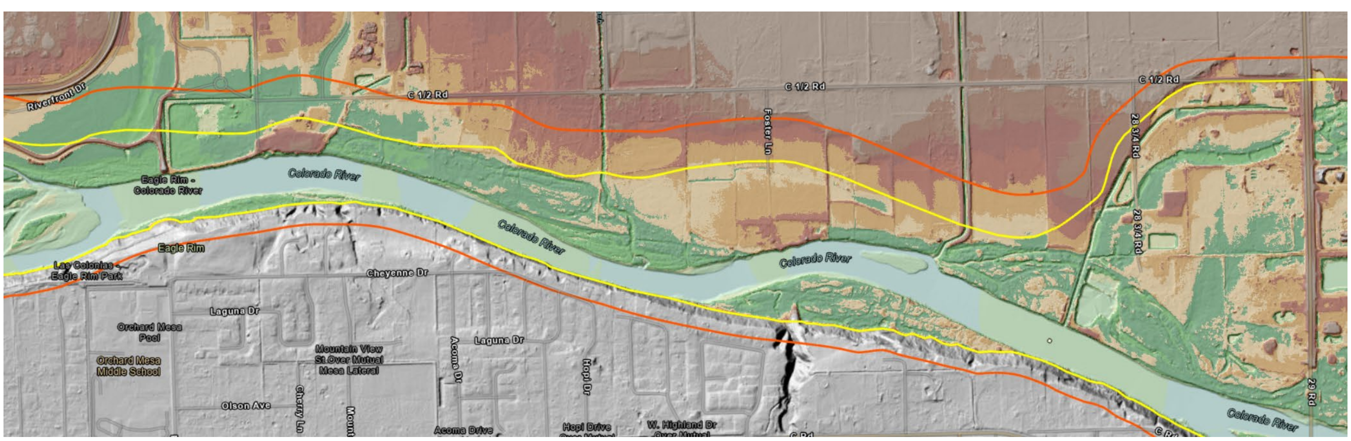


Figure 6-14. Colorado River upstream of Las Colonias in Grand Junction.

The City has recently rip-rapped the northern bank of the Colorado River in to the east of Las Colonias (Figure 6-15). This riprap ends at the top of a meander bend. As such, this bank armoring project may be susceptible to upstream flanking by the river. Construction of bank armoring projects should consider upstream and downstream effects, the channel's tendency to migrate in that location, and future trends in channel movement. This is an example of a bank armoring project that may lead to more riprap because of the engineered hardpoint (eastern terminus of bark armor) installed in an erosive location.

The River Park at Las Colonias represents a reasonably compatible riverfront development due to a considerable buffer from channel migration processes located within the side channel / island complex to the south of the development.

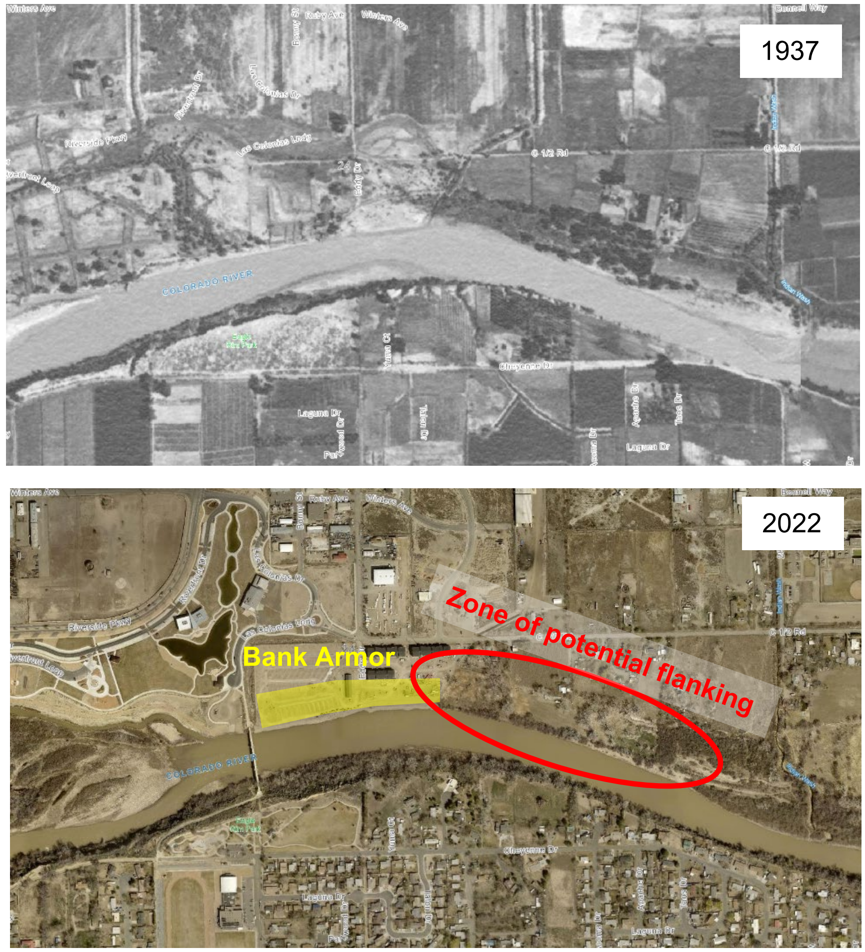
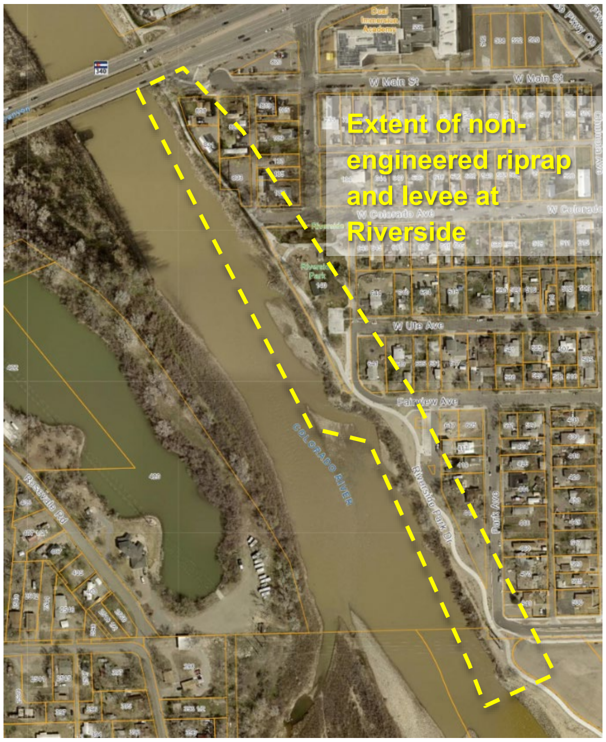


Figure 6-15. Bank armoring east of Las Colonias that ends at apex of outer meaner bend may be subject to flanking by channel migration.

The inlet to the river park side channel is located at an expansion in the channel where sediment naturally deposits (Figure 6-16). Sediment deposition and movement will require ongoing maintenance at the inlet to the river park side channel to maintain its opening at the desired elevation.

Figure 6-16. Channel expansion and deposition at inlet of the River Park at Las Colonias.



Recent riverfront re-development at Las Colonias and west at Dos Rios has involved bank armoring and FEMA-certified levee projects. The Riverside Community currently resides behind a non-engineered levee that was hastily constructed in the 1980s in response to large snowmelt runoff years (Trent Prall, Public Works Director, City of Grand Junction, personal communication). The banks of the river here are haphazardly armored with concrete debris and are steep (Figure 6-17). Currently, the Riverside Community has no designed or safe access to the river. The access and lack of flood protection represents an equity issue for the Riverside Community.

Figure 6-17. Non-engineered bank armoring and levee at Riverside Community.

Downstream of the South Broadway bridge and approaching Connected Lakes, the Colorado River undergoes an expansion following multiple miles of constriction by floodplain encroachment and development (Figure 6-18). Sediment in transport through the constricted reach finds a location to deposit here. This area represents an erodible corridor downstream of a constricted and armored corridor. The channel bifurcates around an island formed from sediment deposited at this expansion. Down valley channel migration has been arrested due to two hard points (Dike Road and a high-tension powerline tower). This is causing dangerous hydraulic conditions for boaters at high and low flows and continued bank erosion. We recommend the City investigate the feasibility of re-routing Dike Road and re-locating the powerline tower to allow for channel migration to progress downstream. This could alleviate the southward bank erosion and allow for natural migration to progress down valley (westward).

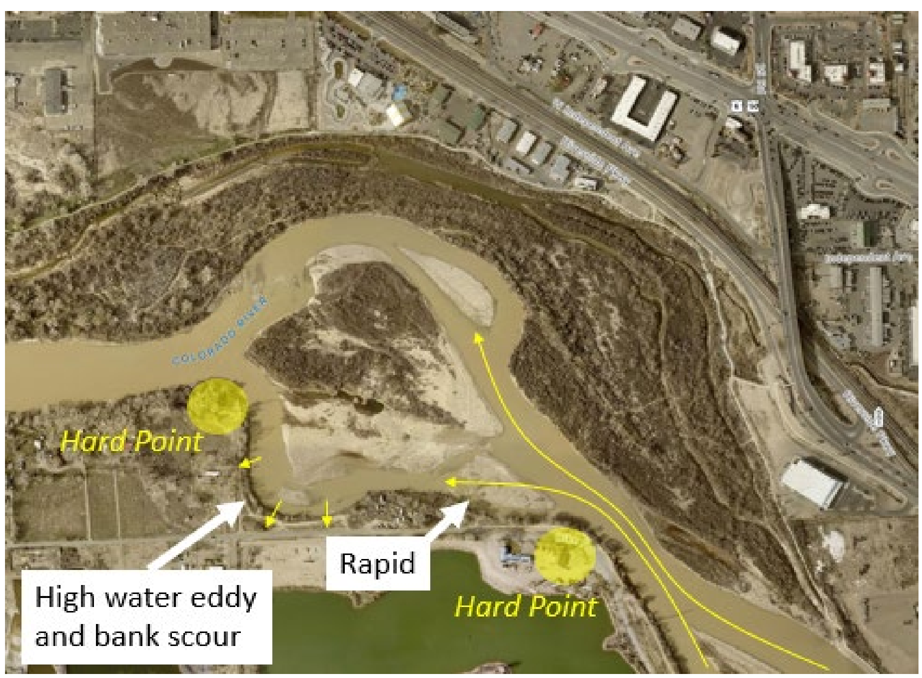


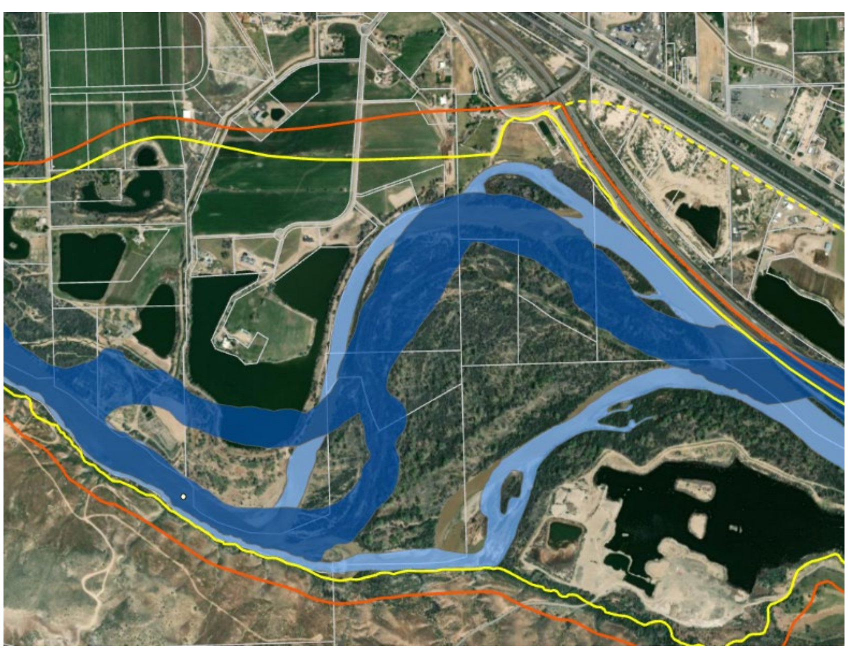
Figure 6-18. Arrested down valley channel migration and artificially forces southward migration at Dike Road near Connected Lakes State Park.

As discussed previously, the Colorado River is migrating down valley towards Redlands Parkway (Figure 6-6). An exploration of river training alternative is recommended here. Implementation of some mitigation measures should take place soon before the river migrates into the road and bridge. This could result in dangerous high flow hydraulics for boaters and threaten the integrity of the Redlands Parkway bridge.

Fruita Area

The floodplain of the Colorado River is constricted by numerous gravel ponds, which may be susceptible to capture by the river during high flow events. Candidate ponds for floodplain reconnection and restoration could be identified and ultimately restored, thereby alleviating this potential hazard.

Figure 6-19. Examples of gravel ponds constricting the floodplain of the Colorado River in the Fruita area.



A subdivision was platted and developed within the migratory pathway of the Colorado River in unincorporated Mesa County from approximately 20 Road to 19 Road. These homes are located within the 100-year floodplain as well as the ASC. The existence of these privately owned parcels likely precludes any restoration of down-valley migration or floodplain habitat (Figure 6-20).

Figure 6-20. Residential subdivision located within the ASC and pathway of down valley channel migration.

Whitewater

The Gunnison at Whitewater has an artificially high sinuosity (channel length to valley length ratio, Figure 6-21). This makes it susceptible to avulsion, or the channel seeking a shorter, steeper route, during a high flow event. We recommend that the middle and downstream-most gravel ponds be explored for floodplain restoration and reconnection feasibility. This would reduce the hazard of avulsion and restore critical habitat for native fish.

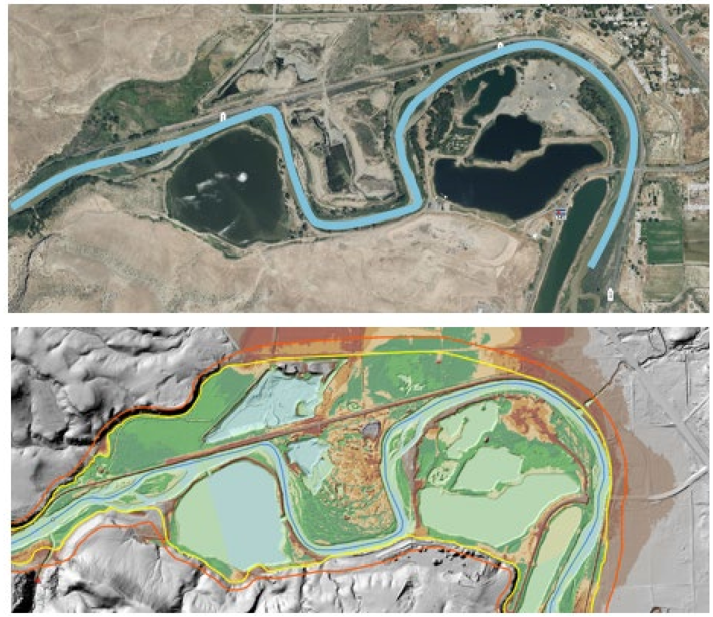


Figure 6-21. Gunnison River at Whitewater with high sinuosity around gravel ponds.

6.3 Project Concepts

Many project ideas have been presented in the previous section, ranging from establishing channel migration zones to getting ahead of and planning for managing migration to protect infrastructure. Here we present additional project ideas not previously discussed. The feasibility of these high level and conceptual recommendations have not been explored in depth.

U.S. Bureau of Reclamation Channel Migration Zone

The Bureau of Reclamation (BOR) manages a wildlife habitat area on the left bank of the Colorado River just downstream of the confluence with the Gunnison River. Historic and contemporary bank armoring projects have been constructed to limit the river's natural tendency to migration southward and westward and potentially undermine a cottonwood forest planted for habitat mitigation purposes (Figure 6-22).

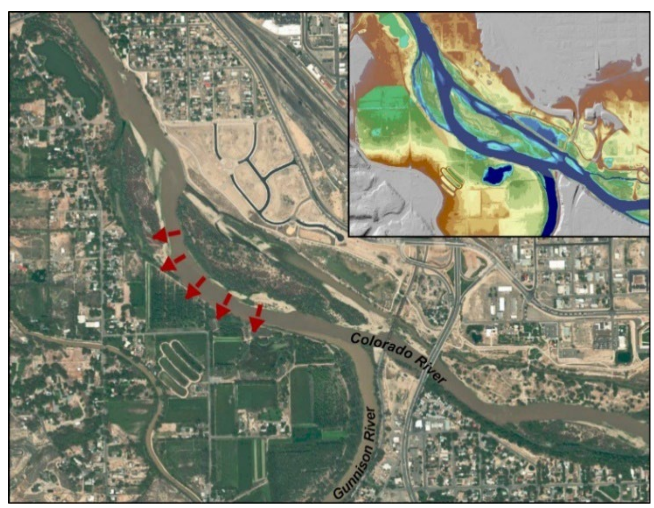


Figure 6-22. Direction of channel migration into Bureau of Reclamation habitat property.

Under this proposed project, we recommend forgoing bank armoring and allowing the river to naturally migrate. To compensate for lost trees, BOR could restore the vegetation on the island across the main channel. As rivers erode their outer banks and migrate down and across their corridors, they typically maintain their channel widths. This means that although bank erosion is occurring on the left bank, accretion or deposition is occurring on the right bank. This accreted surface is where cottonwood trees naturally recruit and establish.

Side Channel Restoration

As the Colorado and Gunnison Rivers migrate across their floodplains, they create new channels and abandon old channels weaving a multi-threaded channel system. Side channels and backwater areas that are seasonally connected to surface flow by the mainstem serve as slow and backwater habitat for native fish (US FWS 1994, Pitlick and Cress 2000). Human activities in the river corridor coupled with impacts to runoff from flow storage, diversion, and aridification in the Upper Colorado River Basin have all reduced channel migration. Active restoration and maintenance of secondary flow pathways or side channels may achieve habitat goals for native and federally listed fish and dissipate erosive energy.

Two proposed side channel restoration sites are depicted in Figure 6-23. Others may exist within the Grand Valley. The first proposed project is through a series of gravel ponds to a former side channel around the Clifton Water and Sanitation District facility. Gravel ponds would need to be reclaimed into floodplain habitat and appropriate measures taken to ensure protection of infrastructure. The second is at Walter Walker State Wildlife Area. A berm and bank armoring hinder down-valley channel migration and flow into an existing side channel. This berm could be removed, and a more direct flow pathway designed.

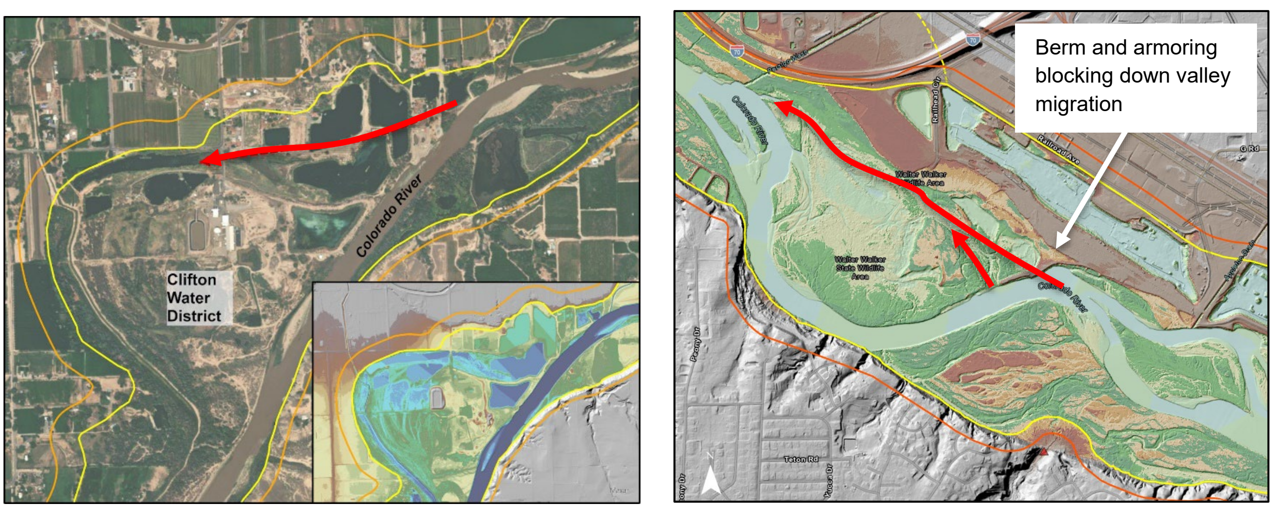


Figure 6-23. Two side channel restoration project candidates. (Left) Reconnection of side channel through gravel ponds and to former side channel around the Clifton Water and Sanitation District Facility. (Right) Side channel restoration and berm removal at Walter Walker State Wildlife Area. Red arrows indicate potential side channel flow paths.

Floodplain Reconnection and Restoration

A more comprehensive approach to re-connecting the rivers with their corridors may occur through floodplain restoration. The Colorado and Gunnison Rivers in the Grand Valley have been losing their hydrologic and geomorphic connection with floodplains from bank armoring and gravel mining. These activities also limit natural channel migration. In Figure 6-24 we present some candidate sites for floodplain reconnection and restoration. Such activities could involve removing bank armoring, re-grading the floodplain to allow for inundation at a desired frequency, constructing preferential flow paths, re-vegetation, and filling gravel ponds with appropriate material. Simple reconnection of the river with an un-restored gravel pond may result in negative consequences including distribution of invasive fish species and un-planned avulsion pathways. As such, reconnection and restoration design should involve hydraulic and hydrologic modeling and appropriate grading and re-vegetation plans. Private property and filling deeply mined gravel ponds with appropriate fill likely present the biggest challenges for floodplain restoration.

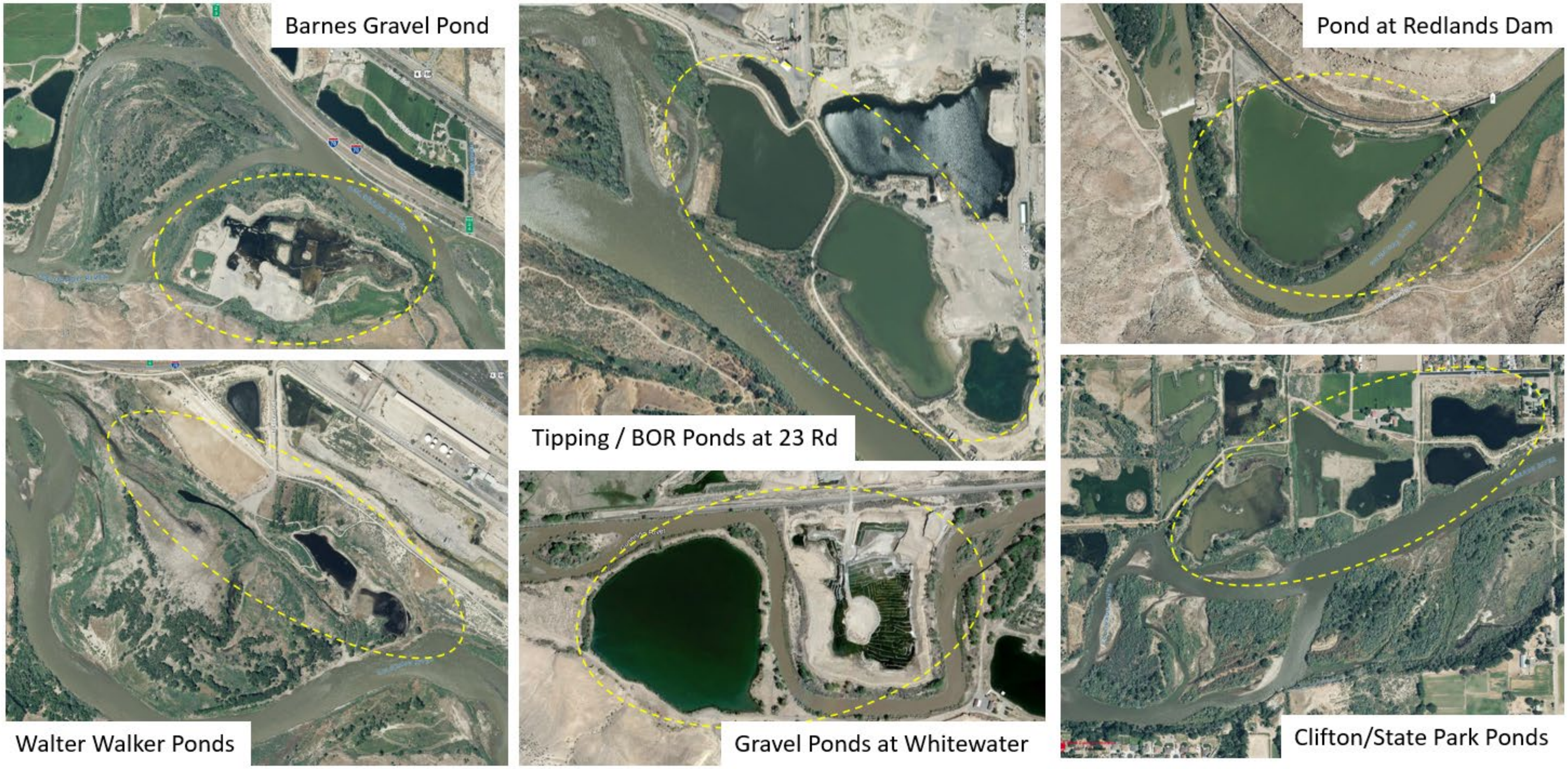


Figure 6-24. Potential floodplain and gravel pond sites where floodplain reconnection and restoration would be beneficial from a channel migration perspective.

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Appendix A: Reach Information Sheets

(See Attached)