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# Implications of the 2023 Flood on the Lower Diamond Fork River, UT

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WATS Capstone Senior Undergraduate Research Thesis

Spring 2024

# Implications of the 2023 Flood on the Lower Diamond Fork River, UT

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Pictured: Channel of the Lower Diamond Fork River, June 2023

# The Diamond Fork River:
# Context and Previous Work

## A Strategic Near-Urban Fishery

The lower Diamond Fork River is located on publicly accessible land owned by the Utah Reclamation Mitigation and Conservation Commission and the United States Forest Service. It is located a 30 minute drive away from the Provo-Orem Metropolitan Area and the stream runs parallel to the Diamond Fork Road, giving anglers convenient access to several miles of publicly fishable stream. The focus of this study is the lower Diamond Fork River between US Highway 6 and the Diamond Fork Campground, UT  (Figure 1).

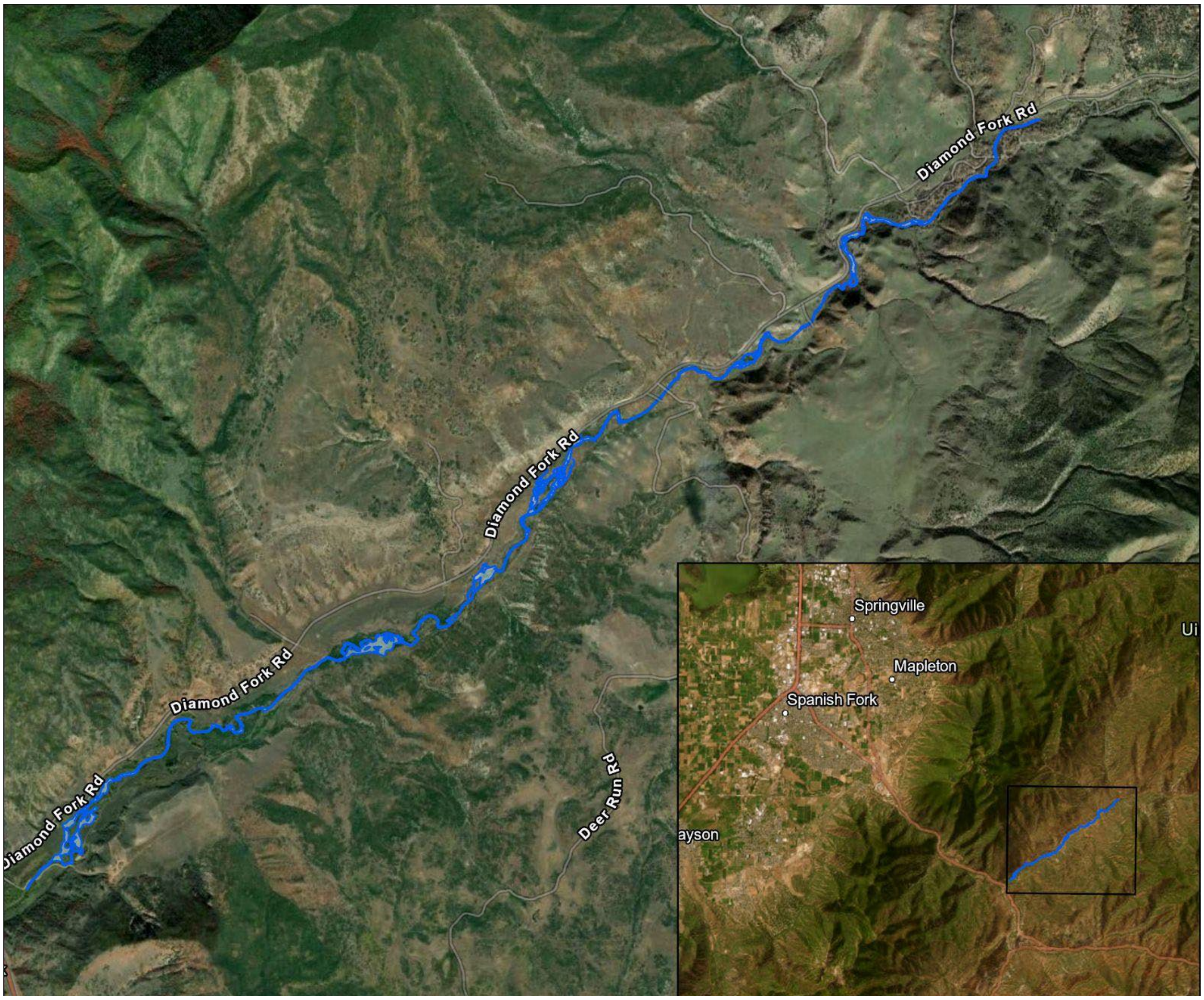

Figure 1: Location of the Study Site (blue) Southeast of Spanish Fork, UT

## A Historically Altered Flow Regime

The Diamond Fork River is an area of active study due to a history of hydrologic change from transbasin diversions that significantly augmented streamflows from 1916 to 2003. Previous research has investigated the effects of long-term artificial hydrologic disturbance to the river channel. Utah State University has authored publications regarding geomorphic responses to this historical hydrologic regime (Jones, 2018; Stout, 2019; Wilcock *et al*., 2019; Wagner, 2024).

During the previous diversion flow regime, the lower Diamond Fork became considerably wider and developed broad braid plains. Large flood events in the 20th Century caused channel widening, followed by gradual channel narrowing during lower magnitude flood years (Jones, 2018). Diversion flows were fully excluded from the Diamond Fork in 2004. Chanel narrowing has occurred over the past two decades, although the channel remains wider than comparable channels in adjacent watersheds (Jones, 2018; Wagner, 2024)

## Known Aquatic Habitat Concerns

Previous work on the Diamond Fork River has identified concerns like channel narrowing and lack of channel diversity as limiting habitat factors for a thriving salmonid fishery. Stout (2019) and Wilcock *et al*. (2019) summarized these main habitat concerns for Brown Trout and Bonneville Cutthroat Trout. One limiting factor is a lack of pool habitat. Pools are important for trout because they increase fish metabolic growth rates and provide refuge from predators. They found pools in the Diamond Fork had an aerial coverage of 12%, short of an ideal 50% pool coverage optimal for trout survival and growth rates. They found entire reaches to be devoid of pools and they noted that most pools formed on the outside of river bends. In addition, the highest percentage of pools were found in reaches with lower slope, higher sinuosity, and lower channel width. During analysis of the 2011 flood, sections of the channel that were the most reshaped or exposed by the flood contained significantly more pools compared to sections of the river less modified by the flood (Stout, 2019).

## Ongoing Restoration Projects

Several ongoing and proposed projects have recommended changes to the Diamond Fork River to improve aquatic habitat. A 2008 report detailed potential actions including excavated wetland depressions, french drain channels, new wetland channels, and more (Allred *et al*. 2008). More recent actions have included installing instream post-assisted log structures and the addition of wood features to certain stream areas.

## 2023 Flood

In 2023, snowpack levels in Utah broke the state record for the highest snowpack ever recorded. This produced a large flood in many Utah rivers, including on the Diamond Fork River. The 2023 flood was not only one of the largest floods in recorded history for the Diamond Fork River, importantly, it was one of only several large floods that have occurred during the "modern" managed flow regime. The modern flow regime is defined by the Central Utah Project Completion Act directing Central Utah Project streamflow augmentation largely away from the Diamond Fork River in 2003.

According to the USGS stream gage "Diamond Fork Abv Red Hollow NR Thistle, UT - 10149400", the Diamond Fork peaked at 970 CFS on 5/14/2023. Other notable spring snowmelt floods on the Diamond Fork River since 2003 include the 2011 flood (890 CFS).

High resolution before-and-after drone imagery was obtained in order to document channel change over the 2023 flood. The 2023 flood occurred 20 years after the removal of diversion flows from the river, thus the river channel is more adjusted to the modern flow regime. Additionally, because future aquatic habitat enhancement work is planned on the Diamond Fork River, information from 2023 is relevant to informing that restoration work.

**2023 High-Resolution Drone Flights**

During the spring of 2023, USU faculty Curtis Gray and Peter Wilcock acquired high resolution imagery from drone flights on the Lower Diamond Fork River in anticipation of changes to the river from a record high snowpack runoff. These flights provided an imagery mosaic of the channel and valley bottom spanning the road bridge closest to Highway 6 to slightly upstream of the Diamond Campground bridge. Each pixel in the imagery represents ~2 square inches on the ground, so features can be seen at very high resolution.

At the USGS gage, Diamond Fork Above Red Hollow (Figure 2), average daily streamflow during pre-flood imagery collection (04/23/23) was 97 CFS, while average daily streamflow during post-flood imagery (06/09/23) was 170 CFS. The gage is upstream of several tributaries that add flow to the channel, making flow for the study imagery close to equivalent. This imagery set provided a unique opportunity to study how the Lower Diamond Fork riverscape is affected by a large flood.

Figure 2: USGS Diamond Fork at Red Hollow (blue marker).

The gage is located upstream of the study reach, with several tributary streams entering after the gage.

# Research Questions:

This research was conducted with three primary research questions in mind regarding the Lower Diamond Fork River:

1. Where does a large flood in the post-CUPCA flow regime era most modify the channel/aquatic habitat in the Lower Diamond Fork River?
2. Did the 2023 flood improve channel conditions conducive to trout habitat?
3. How can ongoing restoration actions synergize with the dynamic flooding regime of the Diamond Fork River?

Pictured: Braided Channels of the Diamond Fork River, November 2023

# Research Methods

The 2023 before-and-after flood drone flight imagery was used as the primary resource to address questions about flooding and aquatic habitat on the Diamond Fork over the 2023 flood. Here are the steps taken to make this imagery useful and gain insights from it.

- **Georeferencing Drone Imagery**
- **Delineating a Wetted Channel**
- **Classifying Instream Habitat Features**
- **Quantifying Channel Planform Statistics**
- **Quantifying Valley Bottom Statistics**

**Georeferencing Drone Imagery:**

Using ArcGIS Pro, the drone imagery sets were georeferenced to the ArcGIS pro basemap, composed of the following imagery: Maxar (Vivid) imagery captured on Jul 1, 2022 and Maxar (Vivid) imagery Nov 3, 2021. Georeferencing was completed by identifying 56 control points on the basemap imagery (Figure 3; Figure 4).

Figure 3: Control Points (pink) Overlaying the 06/09 Drone Imagery on the Lower Diamond Fork River.

Figure 4: A Control Point (pink) Located at Child's Bridge,  04/23 (left) and 06/09 (right)

*Guidelines for selecting control points:*

- features that cannot not move due to time, geomorphic change, or flooding (rocks, notable shrubs, concrete corners, culvert edges)
- features as close as possible to the water surface, but not the water surface/channel edge
- relatively equal amounts of control points on each side of the stream
- relatively equal spacing between control points

At these 56 control points, a “spline” transformation was used to calibrate the imagery to the points. At the control points, spatial error is zero, whereas error increases further from control points due to distortion naturally present in the original imagery. At 10 test points on features in the stream channel (not the 56 control points), original imagery spatial error ranged from 2-5m. After the georeferencing process, spatial error at the test points decreased to 0.1-2m.

**Delineating the Wetted Channel**

With the georeferencing complete, the two sets of imagery are now georeferenced and can be used to directly compare the pre and post-flood channels of the Lower Diamond Fork River. Wetted water surface delineation was conducted by manual digitization of visible and inferred wetted channel area. This information was stored in several polyline shapefiles.

Wetted water surface delineation was the preferred method of delineating the channel compared to mapping a bankfull channel. Having high resolution imagery in the absence of an equally high-resolution Digital Elevation Model, only the water surface was what was visible and reliable to map. Guessing the extent of the bankfull channel would have caused significant and subjective mapping error by the user.

A potential source of error in delineating the channel was also avoided by mapping the channel manually. Due to prevalence of vegetated banks overhanging the wetted surface of the Diamond Fork River (particularly in the 06/09 imagery), a spectral analysis based method of delineating the wetted surface was unreliable. Using manual delineation, context clues could be used to infer the existence of a wetted stream channel underneath overhanging vegetation or shadows. Spectral based identification methods were inaccurate in determining the true wetted surface under these common conditions.

The manual channel delineation has points at a resolution of approximately 1 point per meter of water surface. The maximum pixel dimension in the imagery is .06m, so each click spans an average of 17 pixels. This is a high density of points generated and is a high resolution manual delineation of the water surface (Table 1; Figure 5).

Table 1: Manual Wetted Surface Delineation Statistics

|  | Polygon Points | Wetted Polygon Perimeter (m) | Average Segment Length (m) |
|---|---|---|---|
| Pre-Flood | 28,123 | 27,590 | .98 |
| Post-Flood | 33,462 | 34,536 | 1.03 |

Figure 5: An Example Polygon/Polyline from the Manual Water Surface Delineation Overlaying USU Imagery, Diamond Fork River 06/09/23.

**Classifying Instream Habitat Features**

In order to classify instream aquatic habitat features, Bartelt (2021) suggests the following categories are useful in differentiating fish habitat:

- Overflow – overflow inundation onto the floodplain
- Free flowing – not obstructed by a channel-spanning structural element. The free flowing class could be broken further into uniform, convergent, divergent, eddy and wake classes for studies more focused on in.
- Ponded/pooled – backwater ponding upstream of a structural element.

Legleiter (2013) used spectral-based depth retrieval methods to map water depth on the Snake and Laramie Rivers in Wyoming using publicly available imagery. An unsuccessful attempt was made to use these methods on the Diamond Fork imagery to differentiate between free flowing and ponded habitat. Legleiter relied upon low water turbidity conditions that allowed light to penetrate to the bottom of the streambed in order to differentiate spectral signature at every depth. The Diamond Fork drone imagery available was taken at a time when turbidity conditions prevented light penetration of the entire water column, thus attempting to use this process eventually failed. An attempt was made to delineate pools using image segmentation, which groups pixels of similar spectral characteristics together and classifies them, detailed below. Unfortunately, these methods were discarded in the final results as they did not produce credible findings regarding pool extent.

Because of water clarity issues and time limits regarding potential fieldwork on the river, two habitat types were distinguished in this work: overflow habitat and free flowing+ponded combined habitat when comparing the pre and post-flood imagery. Without Digital Elevation Models or pre-and post-flood site measurements to compare water depth, it was determined there was not a quantitative or rigorous way to differentiate pools from free-flowing stream areas.

### Classifying Overbank Habitat Features

Differentiation of overbank flow areas was possible using image segmentation. The imagery was clipped to the polygon extent of the delineated wetted area. Imagery symbology was set to "ESRI" to allow for maximum contrast between features. Band symbology was adjusted to increase contrast. This gave the maximum differentiation between water and non-water objects. For the 04/23 images, the best bands for differentiation of pixels was Red=Band 1, Green=Band 2, Blue=Band 2. For the 06/09 images, band symbology was set to Red=Band 1, Green=Band 3, Blue=Band 3.

Using Spectral Detail 19, Spatial Detail 20, Minimum Segment Size 999, zoom 1:686, image segmentation was performed in ARCGIS. Segmentation parameters were adjusted and it was determined that this scale of segmentation was best able to preserve detail in the imagery while differentiating between large scale instream-habitat features. The main goal of the first segmentation was to identify overflow inundation areas. The raster to polygon tool was used to create polygons of the segmented image. These polygons were then classified by hand into overflow and free-flowing. At the end of this process, the original wetted surface polygon was now classified into pixel-level-accurate polygons that characterized whether the wetted surface was free flowing or overbank flow area.

### Quantifying Channel Planform Statistics

Metrics important to river channel geometry and planform were quantified to gain insights into the channel form and aquatic habitat quality. If possible, these metrics were measured along 5m transects across the stream channel. First, several products were generated using the Channel Planform Statistics Toolbox (Lauer 2006) in ArcMap with the manually delineated mainstem wetted channel layers as an input:

- calculated stream centerlines
- 5m interval perpendicular transects

From the stream centerlines, a difference-polygon was calculated to find the average centerline migration distance. With the 5m transects, average stream width was calculated across each 5m polygon. Width variability was calculated using the standard deviation of the width values of each 5m transect. Change-in-width was calculated by using a "nearest" spatial join to find the difference in width values between the most equivalent transects from 04/23/23 to 06/09/23 (Figures 6, 7).

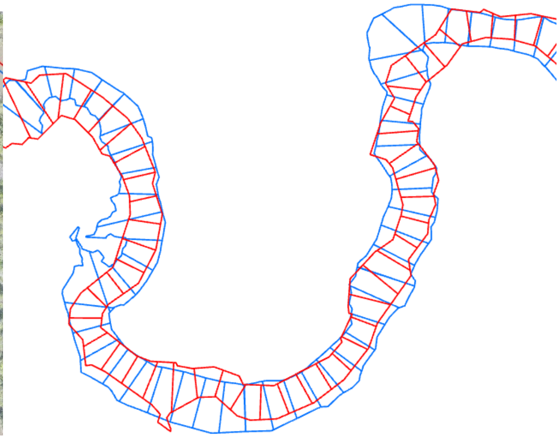

Figure 6: (Left) Channel Centerlines with 06/09/23 Imagery Basemap. Red Pre-Flood + Blue Post-Flood

Figure 7: (Right) 5m Channel Transects. Red Pre-Flood + Blue Post-Flood

**Quantifying Valley Bottom Statistics**

A valley bottom boundary was manually drawn from a Digital Elevation Model of the Diamond Fork River generated from the 2017 NCALM lidar. A centerline was computed for the valley-bottom polygon and the valley bottom was divided using 100m perpendicular transects. Average elevation of these transects was calculated and the aerial coverage of overbank flow area was calculated for each of these transects. Valley bottom slope was calculated for each transect as well.

# Results

**Valley Bottom Features**

Some features like bridges or culverts either confine the valley bottom width or were placed there because of valley bottom geometry (Figure 8). These features are important landmarks in the study site.

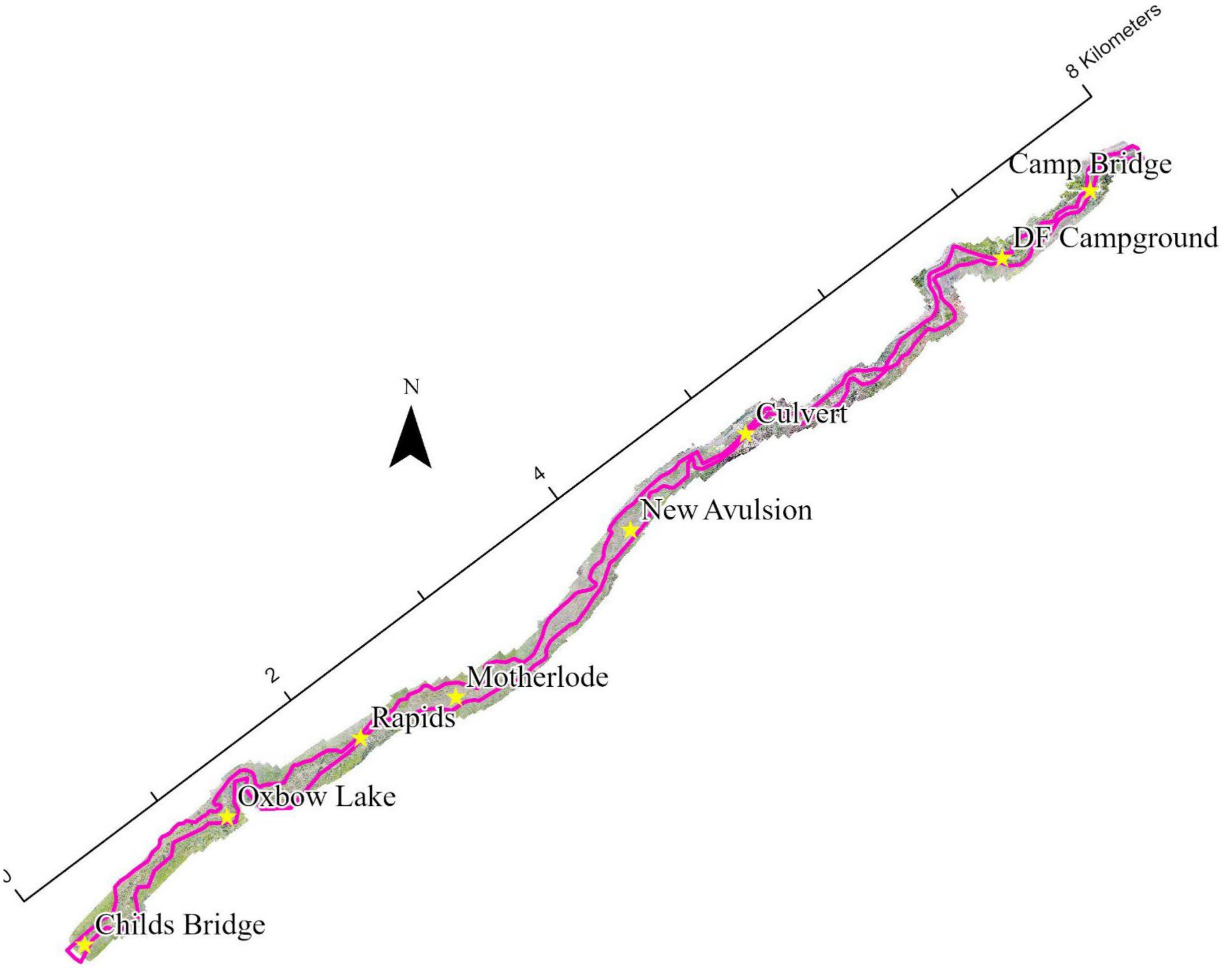

Figure 8: Important Features Along the Lower Diamond Fork Valley Bottom
Important instream features are listed in their respective locations.

The study reach has a higher average slope close to the Diamond Fork Campground at the upstream to the culvert, and experiences a lower slope near the motherlode and oxbow reaches (Figure 9). The valley bottom generally increases in width going from upstream to downstream in the study site.

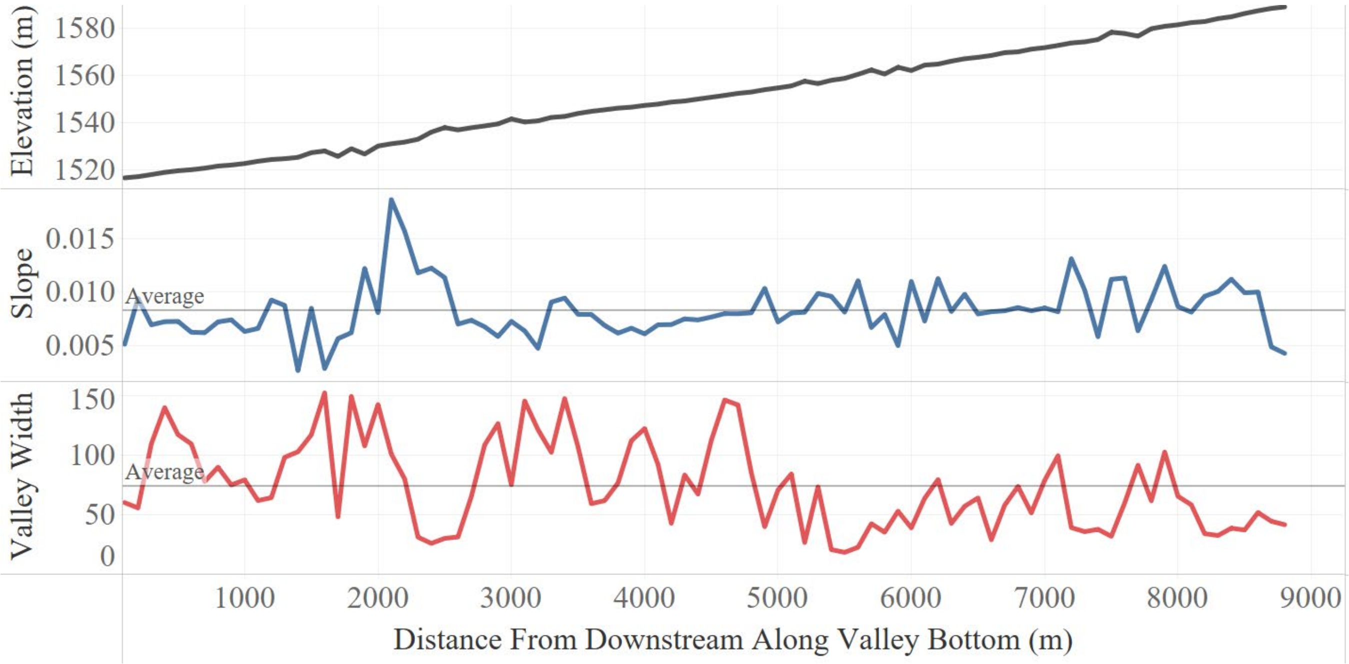

Figure 9: Valley Bottom Characteristics, Lower Diamond Fork River.

A valley bottom longitudinal profile shows elevation, stream slope and valley width along 100m transect measurements along the valley bottom centerline. Distance from downstream was calculated along the valley-bottom centerline from Child's Bridge.

The Lower Diamond Fork River is characterized by a moderate slope and an active floodplain across a relatively wide valley bottom (Table 2)

Table 2: Study Reach Valley Bottom Statistics

| | |
|---|---|
| Average Reach Slope | .00826 |
| Average Reach Elevation (m) | 1552 |
| Average Valley Bottom Width (m) | 73 |

### Channel Migration and Widening

Drivers of centerline migration were primarily meander-expansion and new-channel-avulsion (Figure 10). Meander cutoffs also led to centerline migration through channel straightening (Figure 11).

Figure 10, Channel Centerline Migration through New Channel Avulsion. Pre flood imagery (left) and post-flood imagery (right) located at the same site, ~5500 meters upstream of Childs bridge along the post-flood stream centerline.

Figure 11. Two Meander Cutoffs, Pre-flood (red) and post-flood(blue) centerlines

Because there was inevitable georeferencing error averaging about .5 meters, centerline migration values less than 1m are likely just attributable to imperfect georeferencing, while values larger than 1 meters represent a significant channel migration (Figure 12).

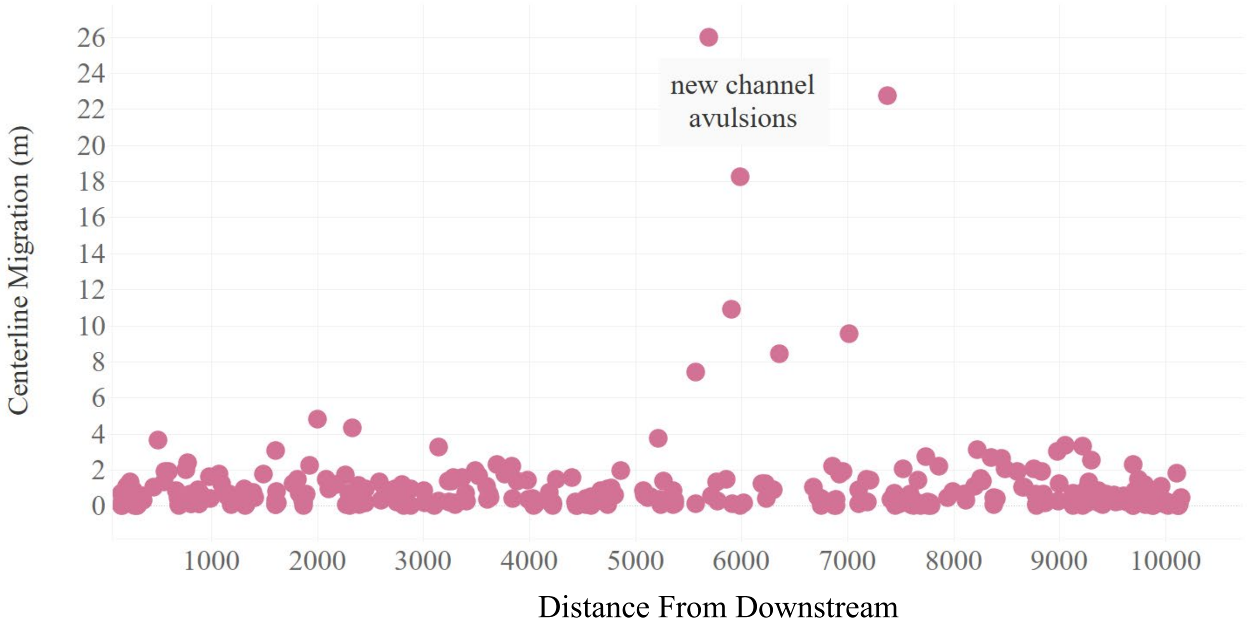

Figure 12: Channel Centerline Migration, Lower Diamond Fork River.

Distance from downstream was calculated along the post flood stream centerline from Child’s Bridge.

10% of the 5m transects surveyed had an average channel centerline migration of 1.9 meters or higher (Table 3). 1% of the transects surveyed migrated by 14.9 meters or more. The 99th percentile for centerline migration is 14.9m. This is likely attributable solely to new channel avulsion.

Table 3: Centerline Migration 5m Transect Percentile Distributions

| 5m Transect Percentile | Centerline Migration (m) |
|---|---|
| 90 | 1.9 |
| 95 | 2.9 |
| 99 | 14.9 |

Braid plain and gravel bar formation was responsible for most of the significant increases in channel width, shown in orange (Figure 13).

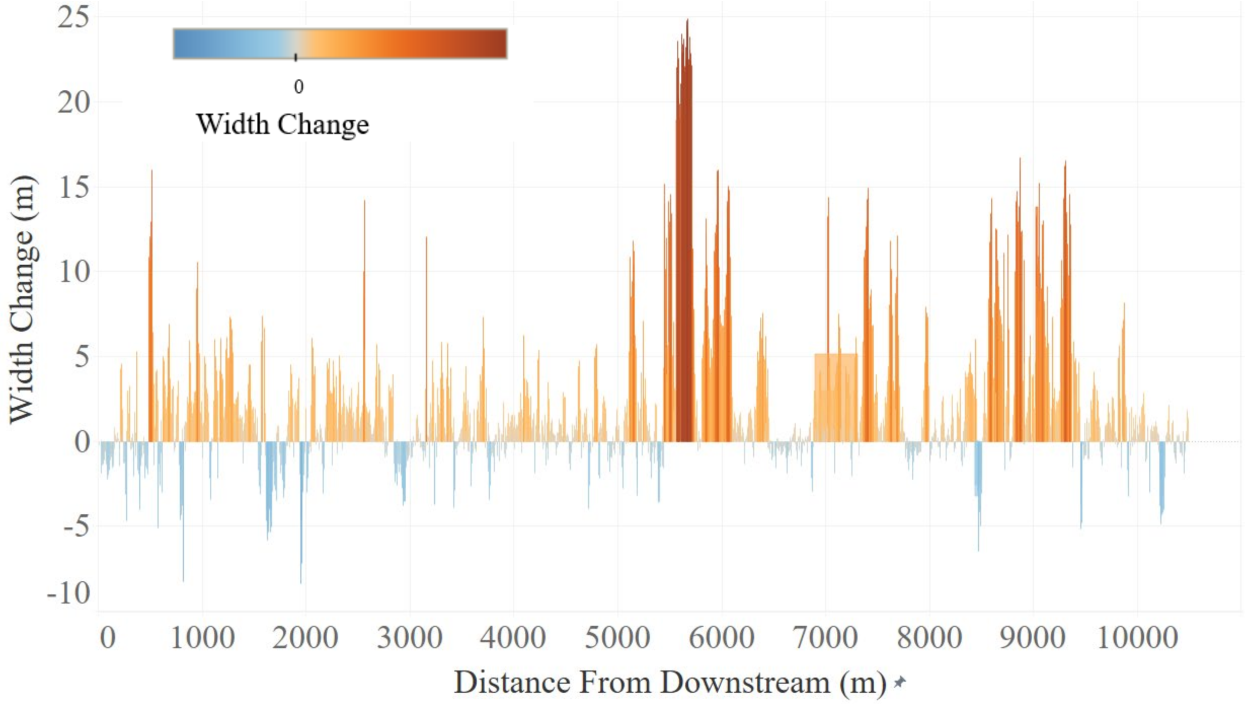

Figure 13: Change in Channel Width, Lower Diamond Fork River. Orange reflects increases in width, blue reflects decreases in channel width. Distance from downstream was calculated along the post-flood stream centerline from Child's Bridge.

Narrowing occurred in 25% of the transects sampled, while the median transect increased in width by 1m (Table 4). 10% of transects increased in width by 7.4 meters or more, which can be explained by gravel bar braid plain development.

Table 4: Channel Width Change 5m Transect Percentile Distributions

| 5m Transect Percentile | Pre-Post Flood Width Change (m) |
|---|---|
| 25 | -.13 |
| 50 | 1.0 |
| 75 | 3.2 |
| 90 | 7.4 |
| Average | 2.3 |

The 2023 flood increased wetted stream area, overbank flow area, mainstem wetted width, and normalized width-standard-deviation, all measures of channel complexity (Table 5).

Table 5: Pre and Post-Flood Channel and Floodplain Geometry

| | Pre-Flood | Post-Flood |
|---|---|---|
| Total Wetted Area (m2) | 124,000 | 171,000 |
| Total Overbank Flow Area (m2) | 34,000 | 67,000 |
| Average Mainstem Wetted Width (m) | 8.0 | 10.2 |
| Wetted Width Standard Deviation (m) | 1.94 | 4.35 |
| Normalized Width Standard Deviation (% of width) | 24% | 43% |
| Stream Centerline Length (m) | 10,500 | 10,400 |

While post-flood width standard deviation is much higher than pre-flood (43% to 24%), most of this is driven by significant width increases above 16m total channel width (Figure 14).

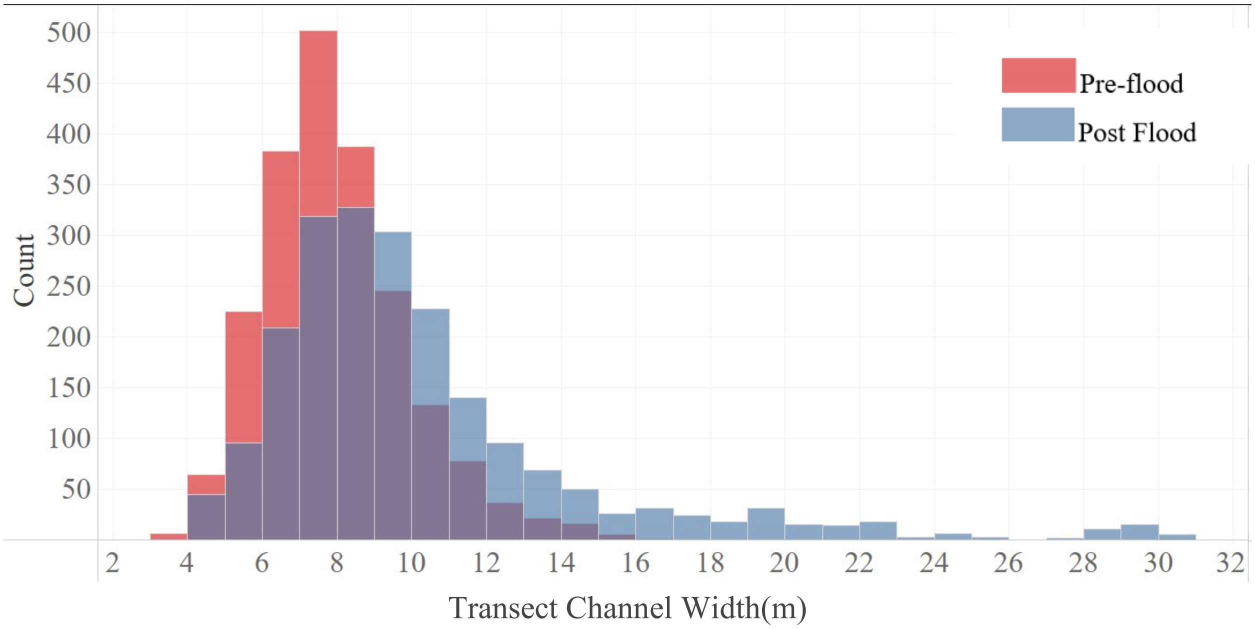

Figure 14: 5m Transects Width Distribution, Pre/Post Flood

In most cases, the widest channel values are not a single-thread channel, but instead represent the overall span of a multithreaded channel with many bars in the center (Figure 15).

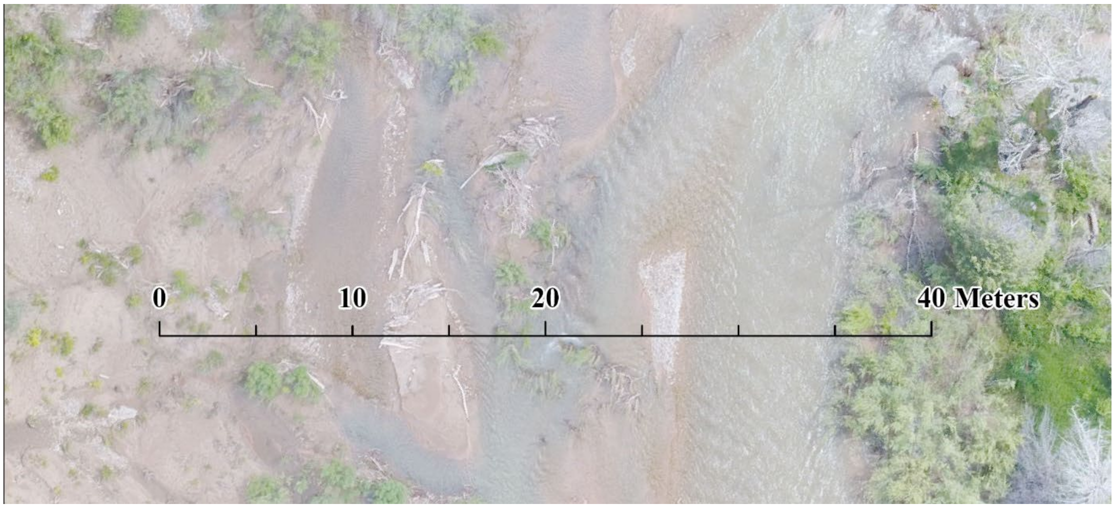

Figure 15. A Wide Multithreaded Channel with Gravel Bars.

**Overbank Flow**

The lower half of the river (<5000m) had a significantly more dynamic change in overbank flow area and a net increase in overbank flow area, displayed by the red bubbles (Figure 16). It is important to note that some 100m transects experienced a decrease in overbank flow area however, noted by the blue bubbles. The upper half of the stream did not experience significant changes in overbank flow area.

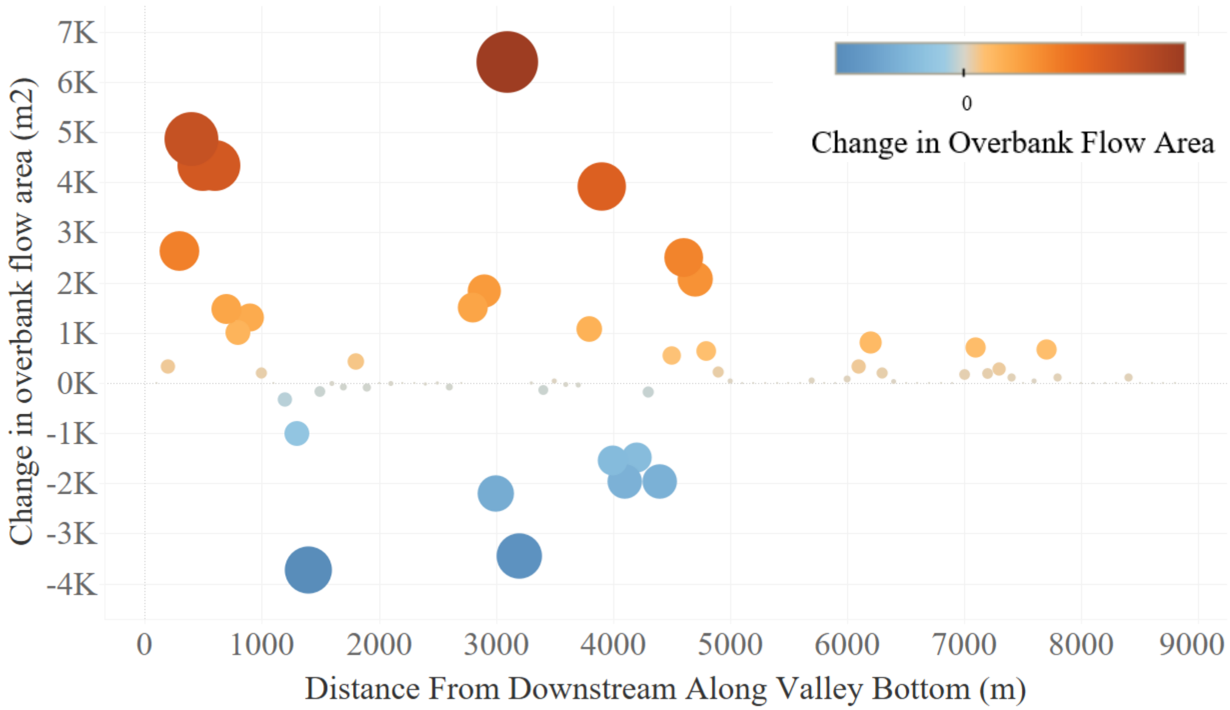

Figure 16: Change in Overbank Flow Area, Lower Diamond Fork River. Distance from downstream was calculated along the valley-bottom centerline from Child's Bridge.

Almost all changes in overbank flow area occurred in areas with below-average slopes with above-average valley width (Figure 17). It seems both of these are necessary for the development of extensive overbank flow on the Lower Diamond Fork, as neither slope nor valley bottom width alone predicted increases or decreases in overbank flow during the 2023 flood.

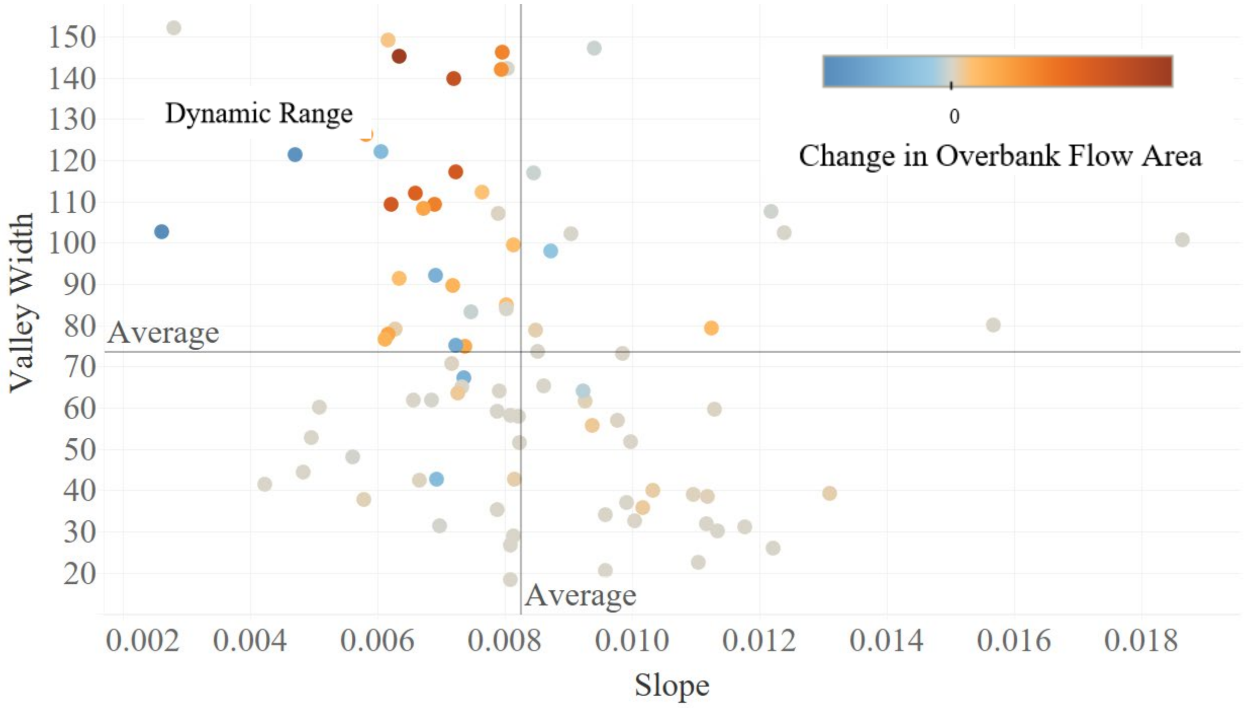

Figure 17: “Dynamic Range” of Slope and Valley Bottom Width, Lower Diamond Fork River. The colored upper-left quadrant represents where changes in overbank flow were most dynamic during the 2023 flood.

# Conclusions

Where does a large flood in the post-CUPCA flow regime era most modify the aquatic channel habitat in the Lower Diamond Fork River?

- Reaches that already had indicators of good trout habitat like width, bars, and overbank flow experienced the largest increases in those same metrics. Reaches with poor habitat indicators (straight, few pools and overbank flow) did not experience much change
- Reaches with below average slope and above average valley bottom width were the most dynamic regarding increases and decreases in overbank flow. Overall, these reaches experienced an increase in overbank flow.
- The 2023 flood increased overall channel width (including bars and braid plains)
- The upstream half of the river experienced relatively larger channel width increases, the downstream half experienced relatively more overbank flow increases

Did the 2023 flood improve channel conditions conducive to a trout fishery?

- The greatest increases in channel width seemed to be driven by bar/braid plain development, which was noted in previous literature to be a good indicator of pool habitat for trout
- Most of the channel centerline migration happened in areas with existing meanders/bends, not in areas with a straight channel. Thus, meander expansion from the flood likely improved pool habitat where pool conditions were already suitable and had little effect in areas where pools were not previously present.
- Thus, the flood increased overall channel diversity and likely improved pool-riffle habitat that already existed

How can ongoing restoration actions synergize with the dynamic flooding regime of the Diamond Fork River?

- Imagery suggests some overbank flow areas are stagnant water, but most of the overbank flow is concentrated enough to flow through vegetation and reenter the river after traveling across the floodplain.
- Areas inundated by overbank flow naturally in the 2023 flood provide an opportunity for restoration actions to develop channel complexity. Actions to maintain these concentrated overbank flow channels are suggested to improve fish habitat
- Areas with valley bottom width and slope conditions approaching the “dynamic range” (Figure 17) might be prime targets for actions targeted at increasing channel diversity

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