Faith Valley Meadow

Post-Restoration Treatment Stream Condition Inventory 2024

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AMERICAN RIVERS

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Introduction

Faith Valley sits upstream of Hope Valley, South of Highway 88 off Blue Lakes Rd on the West Fork of the Carson River. The elevation of Faith Valley Meadow is ~7500 ft (2286 m) and it flows essentially south to north parallel to the Blue Lakes Road. It serves a heavily used trailhead for hikers, equestrians, mountain bikers. It is also an OHV staging area and popular dispersed campsite. The West Fork Carson River watershed has a history of intensive livestock grazing, timber harvest, and mining, all of which have contributed to significant anthropogenic impacts to the watershed. This is particularly pervasive in the meadows and depositional valley bottoms where severe erosion and gully formation remain persistent legacy impacts. The West Fork Carson River is a significant river and while mid-summer baseline flows in Faith Valley average 10 cfs or less, in wet years such as 2017 or 2023, flows can reach well over 2000 cfs. The dynamic power of such high flows in an incised and entrenched channel can create continued bank erosion and channel incision in soft and vulnerable meadow alluvium. Substrate in Faith Meadow tends to be dominated by sand and gravel with some areas where glacial erratic boulders of much larger size have been deposited and overall substrate size increases in the upstream reaches. The floodplains vary from ~200 to ~800 meters at their widest, however, much of Faith Valley's historical floodplain is disconnected from frequent flooding due to streambed elevation loss through incision and channel erosion.

There is a large amount of variability in the floodplain connectivity and channel incision throughout Faith Valley Meadow. There are many snowmelt and spring-fed tributaries (some perennial but most ephemeral) feeding the mainstem bringing in plentiful gravel and sand substrates at high flows. The zones that have both year-round tributary channels and broader valley bottom are the zones that have the greatest potential for inundation and resident beavers continuously build dams in these zones because they are such lucrative, high value areas for inundation. This provides many opportunities for beavers to create a network of tunnels and channels throughout the inundation zone. Beavers continue to be present and very active within the system. Numerous dams are present most of the time, but dams tend to be ephemeral and seldom persist in any given location for more than a few years before they succumb to breaching during high flows. Remnants of beaver dams present and visible in banks and channel geomorphology indicate the existence of hundreds of dams at different times and locations at Faith Valley.

The continuous dam building in the incised channel allows large amounts of sediment aggradation behind longer-lived dams, but due to the concentrated flows in the incised channel, the dams are typically not able to persist for more than 5-10 years. The resulting breach sends a large splay of gravel and sand downstream, rearranging channel habitat significantly depending on the new deposition and typically resulting in a scour pool where the beaver dam breached or flanked. If the dam flanks at the channel margins, that typically results in lateral erosion and forms a lateral scour pool. If the dam flanks near its center, that typically results in a mid-channel scour pool. If the dam fully aggrades with sediment and does not breach, it typically becomes a riffle crest. Beaver dams also drive bedforms and bank shape in the form of bars, emergent marshes, and vegetating banks. The constant cycles of dam building, which raises the water table and increases inundation and channel complexity, followed by dam breaching and sediment mobilization resulting in lower water table and higher, exposed banks form a highly dynamic and changing landscape. We do not currently have physical evidence that beavers were historically present in this system prior to European settlement, but very old beaver dams have been found and dated in the upper Feather River system north of Lake Tahoe and researchers are largely in consensus that beavers were historically widespread in the Sierra Nevada (James and Lanman 2012, Lanman et al. 2012, Purdy 2020). It is likely that beavers historically played a significant role in modulating the dynamics of sediment deposition and erosion, vegetation, inundation and groundwater recharge in the meadows of the West Fork Carson River (Pollock et al. 2003, Pollock et al. 2015).

When intact, these dams fully reconnect the channel to its historical floodplain, returning the system to its highest potential for supporting complex, multithread flow paths with a diversity of depths, velocities, and a high degree of sediment sorting. This provides maximum potential for floodplain connectivity, groundwater recharge, and productivity of mesic and hydric meadow vegetation. Cluer and Thorne (2014) proposed a Stream Evolution Model for depositional systems. They provide an 8 stage model that starts at Stage 0 which is characterized by complex multithread channels and a fully connected floodplain maximizing fluvial processes and biodiversity (Cluer and Thorne 2014). This is the peak state for ecological value in a depositional habitat. Impact from anthropogenic activities drives channelization and incision which reduces connectivity and ecological potential while exacerbating the negative effects including bank erosion, straightening, and homogenization. This is characterized by Cluer and Thorne as the mid-range of the channel evolution model in Stages 3-7 which have diminished functionality and ecological potential. As stream widening and lateral processes occur, the channel can begin to reform a multithread system, however, covers a limited space within the inset floodplain so provides less overall habitat than the Stage 0 condition (Cluer and Thorne 2014).

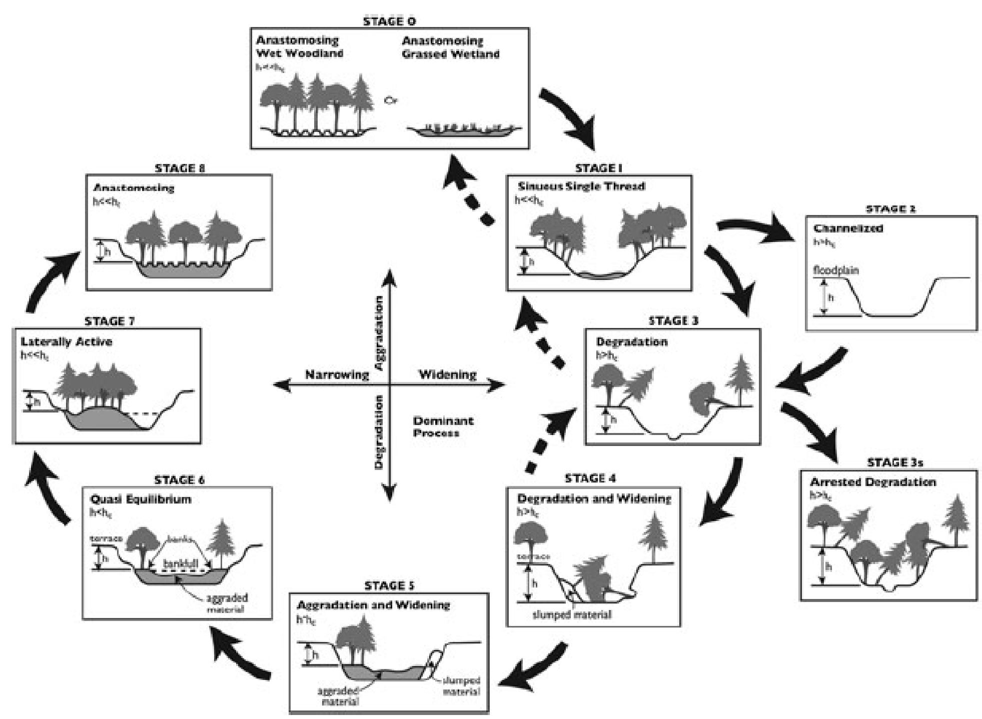

Figure 1. Stream Evolution Model Stages 0 to 8. Stage 0: Full function and floodplain connectivity. Stage 1: Sinuous singe thread channel with some entrenchment but stable and laterally active. Stage 2: Channelization, ditching or constructed channels. Stage 3: Degrading, Incising and abandoning floodplain, can stabilize in this state(3s). Stage 4: Degradation and Widening, Incising with unstable, retreating banks. Stage 5: Aggrading and Widening, Bed rising, banks stabilizing, and berming. Stage 6: Quasi-Equilibrium, Regime channel and proto/inset floodplain established. Stage 7: Laterally Active, widening inset floodplain and increasing sinuosity. Stage 8: Anastomosing, Meta-stable anabranching network within the inset floodplain. From Cluer and Thorne (2014).

Legacy impacts to the system, which began in the 19th century with unregulated grazing as well as active mining and timber harvest throughout the region disrupted much of the structure that creates and maintains low gradient meadow areas as depositional zones that received sediment and spread water across the valley bottom floodplains. The initial loss of vegetation cover due to historic grazing made the soft gravels and fine sediments vulnerable to erosion. Nearly all of the meadows in the Sierra Nevada suffered eras of pronounced channel incision and sediment loss between 1850 and 1930 (Beesley 1996, Kattleman and Embury 1996, Kinney 1996, SNEP 1996). Faith Valley shifts between areas of Stage 0, full connectivity when large beaver dams are intact and bring the channel to the floodplain surface but then instantaneously shifts back to Stage 3-6 when those dams blow out in high flows.

Despite the impacts to the system and the dynamic shifts caused by beaver dam build and breach cycles, Faith Meadow retains a significant amount of ecological function, though some functions are limited by its condition. There is a substantial amount of subsurface groundwater moving from the hillslopes through the meadow and that helps to buffer conversion to upland vegetation types driven by channel incision and the resulting loss of water table elevation in the riparian zones. However, there are significant areas that do not regularly receive inundation, and the groundwater table is below the reach of most of the herbaceous mesic and hydric meadow species' roots. These areas have sparser understory vegetation and larger areas of bare unvegetated soil. While carbon dynamics in meadow soils can be very complicated, it is generally true that dry meadow soils with a fractured sod layer, lots of exposed bare mineral soil, and lack of soil moisture or inundation tend to produce a net source of carbon to the atmosphere. Whereas meadows with frequent inundation and floodplain connectivity tend to have a higher water table elevation, higher soil moisture, more vigorous vegetation, more developed sod (which both retains moisture and resists erosion), and tend to sequester organic carbon in the soil rather than release it to the atmosphere (Povirk et al. 2001, Gill 2007, Reed et al. 2021).

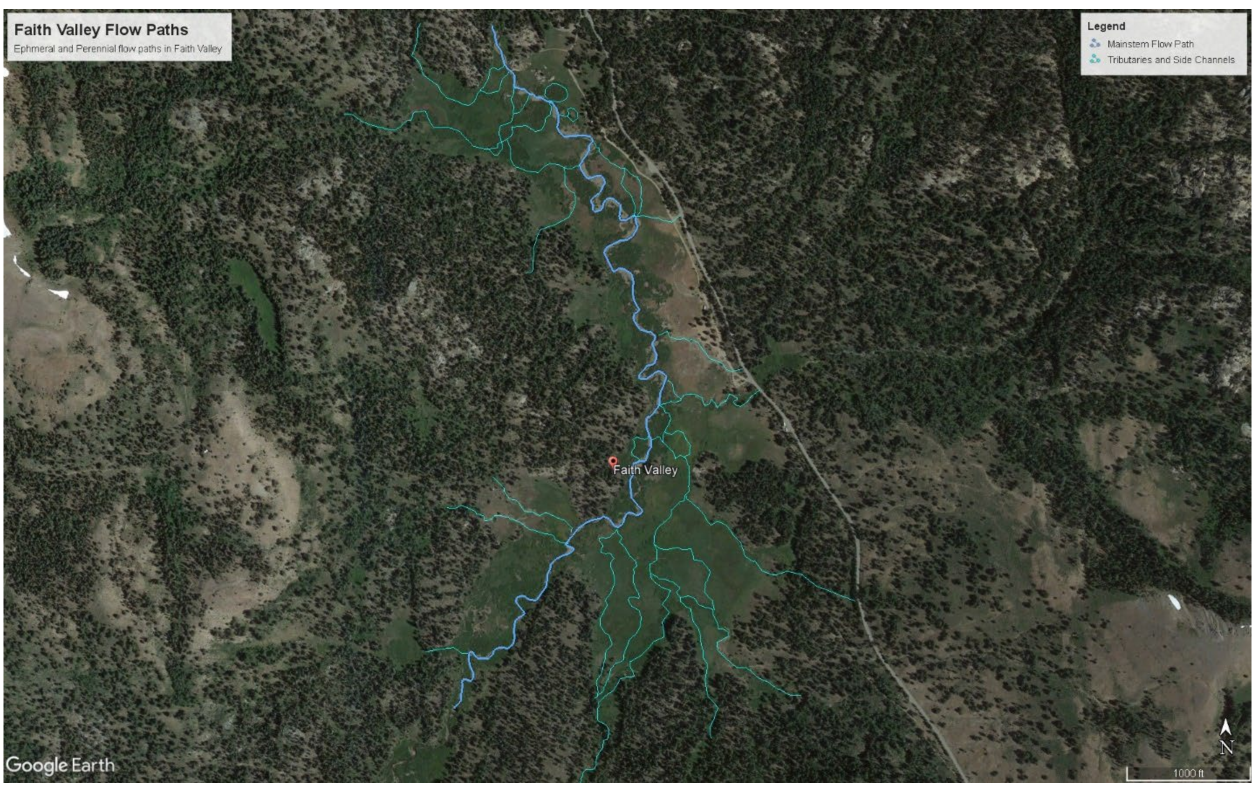

Figure 2. Faith Valley Overview with primary flow path in blue and tributaries and secondary flow paths in turquoise.

We conducted Stream Condition Inventory surveys throughout the meadow gathering quantitative habitat data on stream channel geomorphology and condition, instream habitat types and diversity, riparian vegetation cover, vegetation community structure and condition, floodplain connectivity, substrate, and large woody debris in 2016, prior to treatment implementation and again in 2024 post treatment implementation. This data provides a strong basis of before and after information to which the outcomes of restoration efforts can be compared. While there is a tremendous amount of dynamism in the system and changes in the presence and persistence of beaver dams radically alter the instream habitat composition, there are some definite trends apparent post restoration.

Restoration Treatment

The Faith Valley Meadow Restoration Project was conducted collaboratively by nonprofit organization, American Rivers, and the Humboldt-Toiyabe National Forest. The goal was to restore ~110 acres of meadow habitat in Faith Valley and improve hydrologic impacts from roads at the meadow margins. Constraints around the project included the desire to limit heavy equipment impacts to the existing meadow, protect downstream water rights access to water, and to maintain and enhance the ecosystem function and aesthetic value of the meadow.

Faith Valley is easily accessible from Gardnerville, Carson City, Lake Tahoe, and the western Sierra Foothill communities and sees heavy recreational use and is highly visible to the public. Any management or treatment activities face intense public scrutiny and pressure to deliver a project that does not change the character and aesthetic values of Faith Meadow but does address the impacts and allow natural processes to continue to shape and maintain the meadow ecosystem (Wheaton et al. 2019, Sevier et al. 2024). The final design was developed using Process Base Restoration approaches to facilitate natural biological and hydrogeomorphic processes to recover ecosystem function. Process Based Restoration uses predominantly native materials derived on site (with the exception of posts used to pin the structure in place to better withstand high flows) to create structures that mimic natural forms such as beaver dams, debris jams, log jams, and other organic forcing structures that create diverse instream channel habitats. By replacing lost structural components that work with Process to create and maintain depositional habitats, a broad suite of ecological functions can be supported and improved including groundwater elevation, vegetation cover, habitat complexity, and hydrologic connectivity with the floodplain. The modified Process Based Restoration (PBR) approach using double post brush and willow weave (a type of Beaver Dam Analog) was combined with an engineered grade control structure made of rock and root wads at the downstream end of the meadow. This structure is needed to maintain the streambed at a minimum elevation to protect upstream structures from re-incision. Full channel spanning structures are built in shallow riffle crest areas and are designed to increase pool depth, raise the water surface in the channel, and catch and aggrade sediment. Over time and with multiple iterations as sediment fills in behind structures, the goal is to reconnect the stream with the historical floodplain and increase channel complexity by allowing multiple flow paths to develop. This in turn reduces the shear stress on channel banks and helps slow the rate of erosion and sediment loss.

Project implementation took place in 2022 and 2023, with an initial pilot phase in 2022. Unfortunately, the record setting winter of 2022-2023, which registered the 13th highest recorded flood crest for the West Fork Carson, damaged a number of the initial structures and significantly altered the stream channel in Faith Valley (NOAA 2025). Full implementation in 2023 replaced or enhanced impacted structures. A further season of adaptive management occurred in 2024 for additional repairs and to ensure longer term functionality and resilience. Deep mid-channel scour pools formed at some of the initial structures much the way a center breach in a natural beaver dam can drive deeper scour pool formation which forced crews to relocate replacement structures to new areas where the water was shallowest. This initial phase of implementation, when the incised channel is at its deepest and most confined, is the most vulnerable to impacts from high flows. Rebuilt structures were made in a sturdier BDA approach using larger conifer logs to reinforce the structures and create a longer apron on the downstream side for water to flow down creating a more hydrodynamic structure profile. This should help the structures persist through higher flow events better while still providing fish passage, deeper pools, and a higher overall water surface which improves floodplain connectivity and reduces the height of unstable banks.

Some project goals, like full floodplain connectivity, channel aggradation, and improved meadow plant cover and vigor, will require a longer time frame to realize measurable improvement, however, some indicators are already showing significant improvement compared to pre-treatment surveys in 2016. With iterative, Process Based treatments, effects can be demonstrated even before full aggradation is achieved (Sevier et al. 2024).

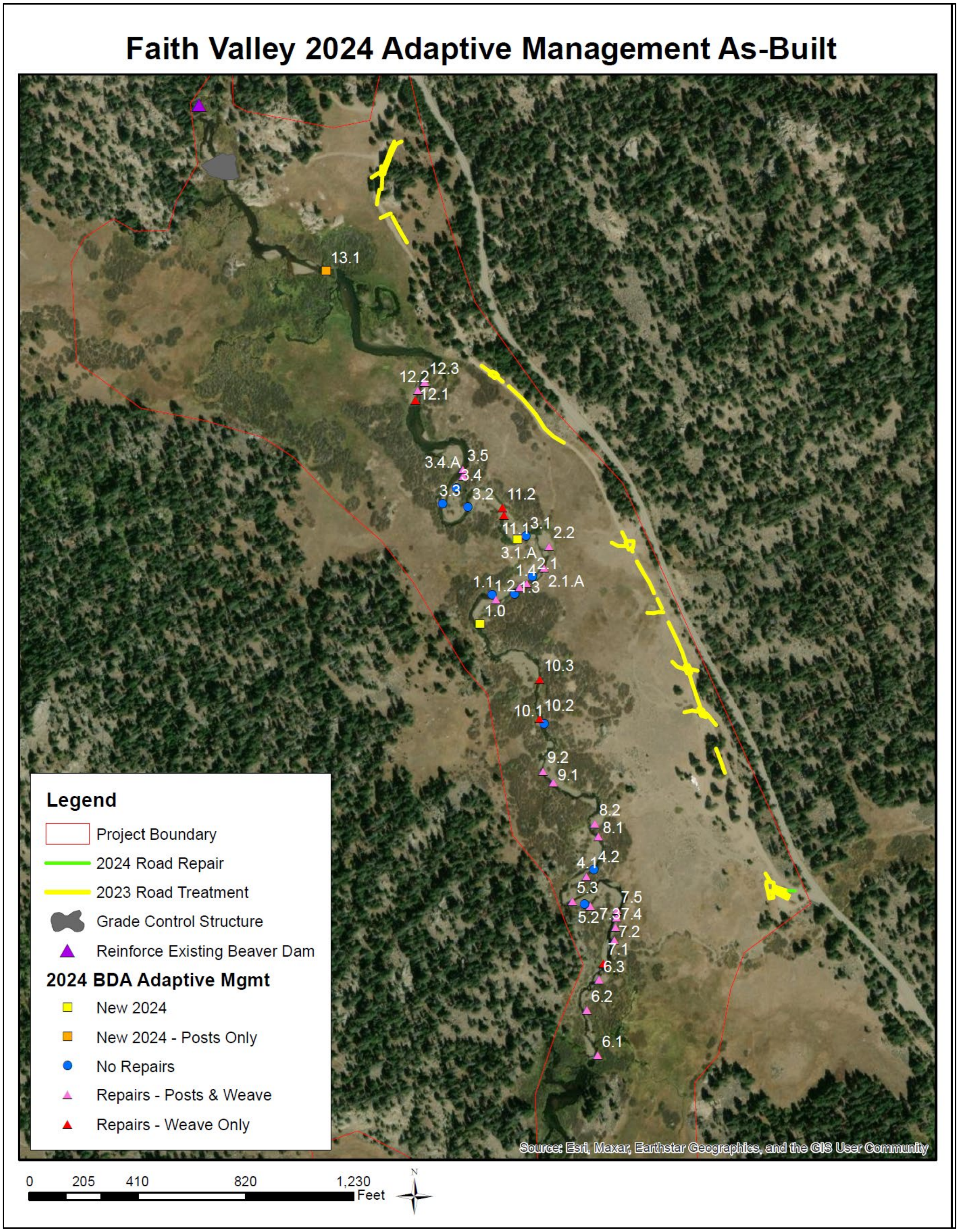

Figure 3. Faith Valley As-Built in 2024. 42 structures have been built to date.

Methods

We used a modified version of the USFS Stream Condition Inventory Protocol to assess the habitat and function of Faith Valley Meadow. This protocol centers on the instream channel unit as the basis of assessment. Each instream habitat unit was identified and categorized in a hierarchical naming convention according to the USFS protocol. These are known as channel units. At the primary level, the channel unit is identified as a fast or slow (pool) unit. At the secondary level, fast water units are subdivided into turbulent and non-turbulent flow and slow water units (pools) are divided into dam pools and scour pools. At the tertiary level, the units are further subdivided by gradient or water depth for fast water units and by the driver that formed the pool for slow water units such as beaver dam pool or plunge pool (Table 1).

At each channel unit, we perform the following measurements and surveys:

- Identify, name and number each channel unit. In addition to the main channel unit types described in Table 1., special habitat units such as side channels, tributaries, braids (riffles with 3 or more parallel flow paths), culverts or artificial structures are also tabulated. Side channel data includes location, photo, length, average width, and maximum depth. Tributary data includes location, photo, and percent contribution to flow. Tributary data is not included if there is no flow at the time of the survey, though it may be noted in the comments.
- GPS waypoint at the downstream and upstream end of each unit
- Unit length
- Length and average height of unstable banks (left and right side)
- Wetted width
- Wetted cross-sectional depths (at 25%, 50%, 75% channel width)
- Bankfull width and cross-sectional depths
- Bankfull elevation above water surface
- Length of Undercut banks (left and right side)
- Flood prone width
- Historic floodplain elevation above current bankfull
- Historic floodplain width (i.e., from left to right side across channel)
- Photographs of every unit depicting channel, stream banks, and riparian vegetation
- Percent substrate particle size composition (bedrock, boulder, cobble, gravel, sand)
- Organic Forcing Structure Count (including debris jams, root wads, willow in the channel, fractured sod clumps, beaver dams or dam remnants
- Percent shade cover at upstream end of each unit (solar pathfinder)
- Fish Presence
- Beaver sign (Dams, breached dams, remnants, chew marks, geomorphic features)
- Dominant Vegetation Seral Stage (left and right side)
- Percent understory vegetation cover (bare soil, grasses and forbs, and sedges and rushes)
- Percent overstory vegetation cover (woody shrubs, sagebrush, riparian hardwoods, and conifers by type)

Table 1. Hierarchy of Channel Unit Codes and habitat type descriptions

First Level (& code)	Second Level (& code)	Third Level (& code)	Channel Unit Code	Channel Unit Description
Fast Water (F)	Turbulent (T)	Cascade (CC)	FTCC	A riffle with stream gradient greater than 10%
		Rapid (RP)	FTRP	A riffle with stream gradient greater than 3% but less than 10%
		Riffle, Low Gradient (RF)	FTRF	A riffle with stream gradient less than 3%
	Non-Turbulent (N)	Run (RN)	FNRN	Unit has a homogenous streambed, no residual depth, laminar flow, and nearly no gradient... a glide
		Sheet (SH)	FNSH	A unit that has hardpan clay or bedrock as its streambed, very shallow flow, noticeable gradient
Slow Water (S)	Dam (D)	Beaver (BV)	SDBV	A dam pool upstream of a beaver dam, generally raises the surface-water elevation and water table. Typically captures sediments and raises stream bed elevation over time. Depositional. May also be used for human constructed Beaver Dam Analogues
		Debris (DD)	SDDD	A dam pool upstream of a woody debris jam. The dam slows water velocity and backs water upstream. Typically, sediments accumulate upstream of debris dam raising the streambed over time. Depositional
		Landslide (LS)	SDLS	A pool upstream of a landslide (typically soil and rock) that creates a dam that slows water velocity and backs water upstream. Typically, sediments accumulate in the dam pool raising the streambed over time. Depositional
	Scour (S)	Convergence (CV)	SSCV	A pool scoured at a channel convergence by the addition of a tributary's stream flow
		Lateral Scour (LS)	SSLS	A pool scoured against a streambank (typically the outside stream bend), the bank forces a change in the direction of streamflow causing scour at the lateral edge
		Mid-Channel (MC)	SSMC	A mid-channel pool scoured underneath woody debris, between boulders or stream banks (where deepest point in the channel is center), or downstream of one or more boulders that have redirected water around them or partially dammed the stream creating a scour depression on the downstream side
		Plunge (PL)	SSPL	A plunge pool is created by a drop in elevation from upstream to downstream as water is directed by one of the following conditions: • A woody debris jam, log, or beaver dam • A waterfall or boulders • A transverse bar of substrate • A human-built dam or culvert A change in jump height is necessary to differentiate from other scour pool types
		Trench (TR)	SSTR	A narrow scour pool through bedrock or hardpan clay parallel to the stream bank. The trench is the deepest part of the pool and instream habitats at the stream margins are generally shallow
Other Habitat Unit Types	Special Cases	Side Channel	SIDE	A separate flow path from the Mainstem separated by a stable island above bankfull height that supports perennial vegetation and is more than a transient bar deposit
		Tributary	TRIB	Flow from a tributary entering the Mainstem channel. If it is dry, it is generally not counted.
		Braid	BRAID	A riffle with 3 or more separate flow paths. This may be through bars or depositional areas.
		Artificial	ARTIF	Artificial structures like culverts, low water crossings, or other non-natural human structures in the channel.

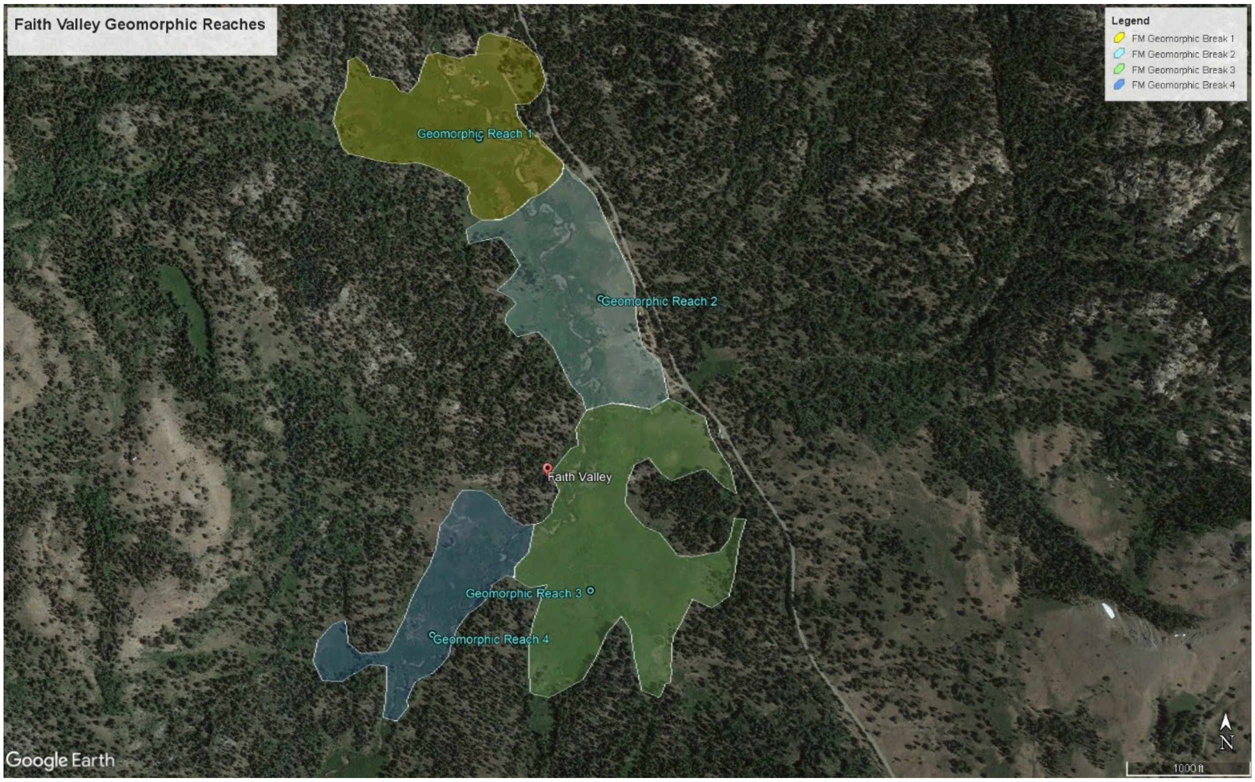

Figure 4. Faith Valley Hydrogeomorphic Reaches separated by characteristics such as valley bottom width, gradient, floodplain connectivity, proximity to hillslopes, and defining geomorphic features.

We broke Faith Valley into 4 hydrogeomorphic reaches that each had distinct characteristics driven primarily by gradient, channel incision, and floodplain connectivity and dimensions. Reach 1 is characterized by a broad valley bottom with numerous tributary channels entering on the left bank. Several oxbow backwaters create sheltered off channel habitat and diversify the channel. Extensive networks of beaver tunnels, channels, and lodges create complex webs of flow paths in the floodplain. Vegetation is lush with robust hydric sedges and willow. In Geomorphic Reach 2, the valley bottom narrows dramatically and the channel becomes more deeply incised with limited floodplain connectivity and actively eroding banks. The vegetation on the historic floodplain is sparser and more mesic with a greater proportion of grasses to sedges and rushes. There is more bare ground with a less developed sod layer and exposed mineral soil. Where the channel gets close to the moraine on the left bank, glacial boulders are found in the channel and on the banks. Upland and forested areas are close to the channel margin on the left bank. Ephemeral channels cover the floodplain terrace on the right bank as well as seasonal tributary flow paths. At Geomorphic Reach 3, multiple tributary channels enter the mainstem on the right bank with complex, multithread channels across the floodplain, an elevated water table and numerous beaver dams in the tributaries create a marshy, well connected wet meadow area. The left bank of the mainstem channel rises quickly into upland habitat with conifer forest. Geomorphic Reach break 4 is located at the site of the massive upstream beaver dam that was present in 2016. The hillslope on the left bank provides a firm boundary with a high point along the channel just upstream and the floodplain on the right bank connects to the large floodplain in Reach 3 with several tributary flow paths and robust hydric vegetation. The consistent building of beaver dams in this general location followed by breaches that lower the water table has created the characteristic “row cropping” of willows where willow sticks placed in dams by beavers then sprout as the waters recede leaving behind telltale rows of willows on a mounded linear surface. The temporal dynamics of disturbance created by periodic inundation and dehydration drive considerable habitat heterogeneity. Upstream of this area, the valley narrows to a pinch point about 40 meters across. This section has more gradient than the downstream reaches and is more confined.

Results

We began the survey at the downstream end of the meadow and worked our way continuously upstream through all four reaches. 2016 marked the 5th consecutive drought year in California with 2015 being a critically dry year. While the West Fork Carson continued to flow, this period of persistent low water years allowed several large beaver dams to be built and persist. At the time of our surveys in 2016, a pair of very large beaver dams at the downstream end of the meadow in Geomorphic Reach 1 inundated a large area where the valley is broad with tributary channels entering from the west side of the meadow. Many small dams or partial dams were in place throughout Geomorphic Reaches 2 and 3 leading to another enormous dam at the division between Geomorphic Reaches 3 and 4 with a low scratch dam continuing for 90 meters across the valley. These dams were all fully functioning at the time of the 2016 surveys and within those areas, the floodplains were fully connected to their maximum potential. All of these dams blew out in the 2017 winter that followed which sent the gravel trapped behind the dams downstream and the streambed became incised again with less lateral connectivity and increased bank height to the historical floodplain and exposed unstable banks. In the following years until implementation, beaver activity continued in tributary channels and banks but most of the mainstem dams were blown out and did not persist.

The grade control structure built at the bottom of the meadow was downstream of the 2016 starting unit, so we extended the survey downstream to its base to include this critical structure. This extended the overall length of Geomorphic Reach 1. While the grade control structure does back water up into the broad valley, upstream, it is not as large as the natural beaver dams that were present in 2016 and consequently inundates less area upstream. After treatment implementation and the winter of 2023's impacts to some of structures, the channel changed significantly. Most of the natural beaver dams and some of the implementation structures were damaged in the high flows.

Channel Habitat and Reach Metrics

Table 2. Reach level metrics including reach length, unit lengths, and percentages and counts of habitat types in Faith Valley in 2016 and 2024

Metric/Reach	Geomorphic Reach 1 (2016)	Geomorphic Reach 1 (2024)	Geomorphic Reach 2 (2016)	Geomorphic Reach 2 (2024)	Geomorphic Reach 3 (2016)	Geomorphic Reach 3 (2024)	Geomorphic Reach 4 (2016)	Geomorphic Reach 4 (2024)
Total Reach Length (m)	532	593	1095.0	1039	648.6	589	839.5	991
Total Reach Length (m, excluding side channels)	532	593	1051.5	1004.3	550.6	543.4	787.5	892
Avg. Unit Length - Slow Water Units (m)	52.17	42.5	22.2	45.2	18.5	33.1	26.5	17.8
Avg. Unit Length - Fast Water Units (m)	12.5	24	12.6	0	17.2	20.9	23.9	17.3
% Slow Water	88.2	71.7	38.5	100	46.9	69.1	60.5	46.5
% Fast Water	11.74	24.3	61.5	0	53.1	26.9	39.5	52.2
% Scour Pools	28.5	34.9	61.5	15.9	41.3	29.8	33.8	47.8

% Dam Pools	48.5	36.8	0.0	84.1	5.6	39.4	26.7	0
% Riffle Units	19.9	13.4	26.7	0	39.1	11.9	38.1	37.3
% Run Units	13.3	10.8	11.7	0	13.9	15	1.4	16.5
Count Scour Pools	8	6	31	3	13	9	17	25
Count Dam Pools	1	4	0	18	1	3	1	0
Count Riffles	3	4	21	0	12	5	12	21
Count Runs	2	1	9	0	5	2	1	6
Count Side Channels	0	0	2	1	3	1	1	1
Count Tributaries	1	1	0	0	3	2	0	1
Total Habitat Unit Count	15	16	63	22	37	22	32	54
Number of Confluences	NA	21	NA	10	NA	6	NA	2
Number of Difluences	NA	11	NA	7	NA	1	NA	6
Cumulative Structures in 2024	0	4	0	34	0	5	0	0

Channel habitats were significantly altered between 2016 and 2024 through a combination of habitat changes due to beaver dam breaches and changes from restoration treatment implementation and scour from runoff in winter 2022/2023. Unit lengths were altered slightly but insignificantly and within expected cumulative sampling differences over large distances. The overall trends over time were pronounced for unit size and type. In 2016, Geomorphic Reach 1 and Geomorphic Reach 4 had larger average unit lengths due to large beaver dams inundating long areas upstream. In 2024, both reaches had more units than in 2016 after dam breaches eliminated large pools and exposed smaller habitat units.

The average size of the slow water units (pools) decreased in GM1 and GM4 due to the loss of large dams while the length of fast water units (runs, riffles, braids) increased in GM1 due to the addition of the grade control structure downstream and the exposure of more units. 42 structures have been constructed to date. GM2 contained the majority of the treatment structures (34 out of 42). This was the most profoundly changed reach between 2016 and 2024. The structures were built consecutively each at the top of the previous structure's zone of inundation so that there were no remaining fast water habitats (riffles, runs, braids) large enough to break out separately in GM2 in 2024. However, the apron on the downstream side of the structures provides the mechanism for gradient drop and those areas, creating a short cascade-like feature that provides an area of faster velocity and allows reoxygenation of water. There were a number of structures that been damaged in 2022/2023 and were not repaired. This was because there had been significant scour around the structures and the remaining posts were so deeply inundated as to be impracticable to try to repair, instead, new structures were built on different riffle crests with post lines remaining in place. They will continue to drive channel evolution since they are a source of scour. Some structures just needed maintenance, and some additional structures were added. There were 4 structures in GM1 and 5 structures in GM3. Most of GM3 has yet to be treated and none of GM4 has been treated and can serve as control reaches until such a time that they are implemented if that occurs.

The furthest upstream structure implemented in GM3 (SDBV34) has been taken over by beavers, as hoped, and they have extended the length of the dam across the channel and increased the inundated area behind it. Ideally, all of the Beaver Dam Analogs built will attract continued beaver activity and further building, and the posts will help them persist in high flow events allowing sediment to aggrade behind them. The aggradation of the streambed reduces the height of unstable banks and reduces the depth of incision, allowing less shear stress on banks and more frequent inundation of the floodplain. Reduced channel depth also increases the elevation of the groundwater table through hyporheic exchange. This can be monitored through groundwater wells and changes in the floodplain vegetation productivity and vigor measured through remote sensing (Silverman et al. 2018). Incremental changes in channel geometry can significantly increase aquatic species, particularly as increases in wetted widths and depths increase habitat volumetrically. Confluence and diffluences which provide a measure of channel complexity through deposition, bar development and island formation, tributaries, multithread channel development, and side channel departures and returns were not tabulated in 2016 but were present in promising number in 2024. That metric could easily be repeated under future monitoring efforts.

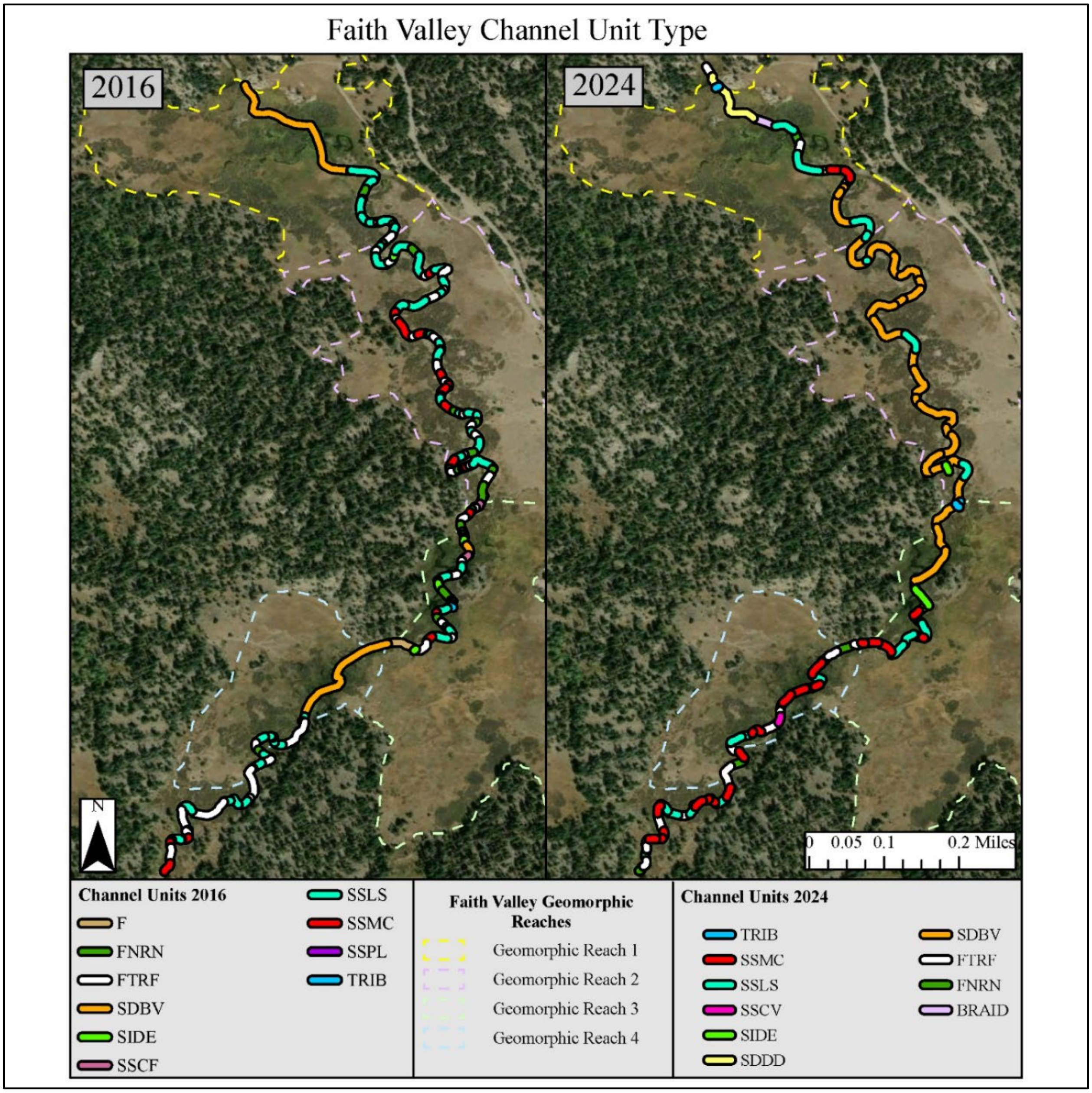

Figure 5. Overview of Channel Habitat Units in 2016 and 2024 in Faith Valley. For more detailed reach level images, see Appendix 1.

Geomorphic Measurements

Table 3. Geomorphic Measurements by Reach 2016 and 2024 (Bankfull Widths, Wetted Widths, and Depth Profiles segregated between slow water and fast water habitat types. Flood Prone Width/Active Valley Bottom, Channel Entrenchment/Incision, Bank Stability, Confluences and Diffluences)

Metric/Reach	Geomorphic Reach 1 (2016)	Geomorphic Reach 1 (2024)	Geomorphic Reach 2 (2016)	Geomorphic Reach 2 (2024)	Geomorphic Reach 3 (2016)	Geomorphic Reach 3 (2024)	Geomorphic Reach 4 (2016)	Geomorphic Reach 4 (2024)
Avg. Wetted Width (m)	8.57	9.5	7.0	11.3	4.5	6.1	6.36	4.2
Avg. Wetted Width Slow (m)	10.9	11.8	5.4	11.3	6.2	7.2	7.3	4.6
Avg. Wetted Width Fast (m)	4.3	6.1	3.0	0	3.4	4.2	5	4
Avg. Wetted Depth	0.46	0.11	0.3	0.71	0.3	0.32	0.43	0.3
Avg. Wetted Depth Slow (m)	0.67	0.62	0.6	0.71	0.63	0.5	0.62	0.5
Avg. Wetted Depth Fast (m)	0.07	0.41	0.1	0	0.14	0.12	0.17	0.1
Avg. Max. Wetted Depth Slow (m)	1.18	1.11	0.8	1.27	0.85	0.97	1	0.7
Max. Wetted Depth Slow (m)	3	1.55	1.4	2.5	1.2	1.85	2.81	1.15
Avg. Bankfull Width (m)	14.22	15.2	7.7	15	7.3	8.93	8.4	6.7
Avg. Bankfull Width Slow (m)	13.97	14	7.0	15	7.45	8.6	8.96	6.1
Avg. Bankfull Width Fast (m)	14.66	17	8.5	0	7	9.4	7.68	7.3
Avg. Bankfull Depth (m)	0.54	0.63	0.5	0.83	0.5	0.36	0.52	0.4
Avg. Bankfull Depth Slow (m)	0.71	0.86	0.7	0.83	0.73	0.46	0.69	0.6
Avg. Max. Bankfull Depth Slow (m)	1.3	1.41	1.1	1.5		1.14	1.18	1
Max. Bankfull Depth Slow (m)	2.5	1.85	1.5	2.65	1.4	1.85	3	1.4
Avg. Bankfull Depth Fast (m)	0.23	0	0.3	0	0.29	0.2	0.3	0.3
Average Floodprone Width	~200	~200	14.5	57.5	12.4	77.8	34.23	22.2
Avg. Height Historic Floodplain above bankfull (m)	0.87	0.42	1.1	0.6	0.73	0.61	0.42	0.5
Max. Height Historic Floodplain above bankfull (m)	1.05	0.85	1.5	1	1.1	0.95	0.7	0.85
Avg. Width Historic Floodplain Terrace across Channel (m)	27.6	22	20.1	22.2	15.6	14.9	14.9	9.8
Max. Width Historic Floodplain	45	42.4	34.0	46.2	35	27.1	40	17.1

Terrace across Channel (m)								
Length Unstable Banks (m)	225.2	248.1	552.5	385	259.5	146	137.8	305.9
% Unstable Banks (% of Total Length)	21.17	20.92	26.27	19.17	23.57	13.43	8.75	17.15
Avg. Unstable Bank Height above Bankfull (m)	0.69	0.64	0.4	0.6	0.26	0.57	0.14	0.5
Max. Unstable Bank Height above Bankfull (m)	0.9	0.85	1.3	1	0.9	0.9	0.85	0.85

Average wetted width and bankfull width increased in all 3 of the implementation reaches (GM1-GM3) following implementation in both fast water and slow water reaches. GM4 saw a slight reduction in widths due to the breach of the large beaver dam present in 2016 and subsequent channelization of the stream below its 2016 levels. Wetted and bankfull depths increased most markedly in slow water units (pools) in GM2 which saw a complete conversion to a series of dam pools post treatment. Flood prone width remained approximately the same in GM1 which was well connected in 2016 and incised slightly following the loss of the large beaver dams in 2017. Flood prone width increased markedly in GM2 and GM3 following implementation as water surface elevations rose and the difference between current bankfull elevation and the historical floodplain was reduced, allowing more frequent inundation at lower flows. The elevated stream bed also reduces shear stresses on exposed banks. The elevation of the historical floodplain above bankfull indicator (channel entrenchment) was reduced in all 3 of the implementation reaches (GM1-GM3) while the opposite occurred in GM4 where no treatment was undertaken. This is the metric that most clearly demonstrates the beneficial effects of the treatment. Unstable bank percentages (length) remained similar to pre-treatment levels in GM1, were reduced slightly in GM2, reduced significantly in GM3, and increased in GM4 due to the loss of the primary beaver dam and the re-exposure of the banks that had previously been inundated by the dam. Average unstable bank height increased slightly in GM3 and GM4, likely due to the loss of beaver dams present in 2016 that were not part of the treatment area but maximum measured unstable bank height was actually decreased in GM1 and GM2 while holding steady in GM3 and GM4.

Instream Habitat Features and Vegetation

Table 4. Substrate Composition, Undercut Banks, Large Wood, Shade, Understory Vegetation Composition, Overstory Vegetation Cover, and Sagebrush encroachment in 2016 and 2024.

Metric/Reach	Geomorphic Reach 1 (2016)	Geomorphic Reach 1 (2024)	Geomorphic Reach 2 (2016)	Geomorphic Reach 2 (2024)	Geomorphic Reach 3 (2016)	Geomorphic Reach 3 (2024)	Geomorphic Reach 4 (2016)	Geomorphic Reach 4 (2024)
% Sand/Silt/Clay (Slow Water Units)	41.7	42.1	42.1	48.8	36.9	48.7	26.2	33.1
% Gravel (Slow Water Units)	51.4	50.4	54.0	48.5	46.5	42.4	38.2	56.3
% Cobble (Slow Water Units)	1.9	5.3	0.2	0.3	6.3	5	26.8	7.6
% Boulder (Slow Water Units)	3.9	1.7	2.1	2	10.2	3.9	8.2	3
% Bedrock (Slow Water Units)	1.1	0.4	0.0	0	0	0	0.6	0
% Sand/Silt/Clay (Fast Water Units)	19	32.7	20.6	0	23.4	20	8.1	16.5
% Gravel (Fast Water Units)	81	56.9	76.8	0	56.6	64.6	41.2	69.6
% Cobble (Fast Water Units)	0	6.9	0.5	0	12.2	13	42.7	11.4
% Boulder (Fast Water Units)	0	2.1	2.1	0	7.9	2.4	7.8	2.1
% Bedrock (Fast Water Units)	0	0	0.0	0	0	0	0.15	0
Length Undercut Banks	7	109.4	188.7	232	39.75	203	80.05	308.6
% Undercut Banks	0.7	9.2	9.0	11.6	3.6	18.7	5.1	17.3
Count Large Woody Material	0	0	0	0	0	1	3	7
% Riparian Shade	0.6	0.75	4.2	1.2	1.4	2.7	2	4.6
% Total Shade	1	3.1	4.5	2.65	1.9	4.8	5.8	8.1
% Understory Grass/Forb	41.04	33.8	38.7	33.9	46.8	37.2	54	50
% Understory Sedge/Rush	17.8	41.1	16.7	32.4	26	37.6	11.6	28
% Understory No Veg/Bare Ground	41.1	25	44.6	33.7	27.2	29.4	34.5	21.9
% Overstory Conifer	4.8	1	2.5	1.4	3.17	1.2	4.2	5.1
% Overstory Riparian Deciduous (Willows, Alder, Aspen)	35.6	29.6	40.5	46.2	40.9	36.1	50.2	49.5
% Overstory Sagebrush	0	2	1.0	2	1	1.5	8.3	4.2

Substrate composition remained essentially unchanged pre- and post-treatment and fell within the range of variation expected for ocular estimation of cover in large areas. Undercut banks appeared to increase in all reaches but may have been poorly detected in 2016 due to deep inundation from the large beaver dams and increased most in GM1, GM3, and GM4, all of which had either large or several beaver dams intact in 2016 that were gone in 2024. Understory vegetation cover of Grasses and Forbs (mesic vegetation indicators) changed very little but Sedge and Rush cover increased in all reaches which may be more of a relic of several good water years following the prolonged drought in the teens coupled with variability from ocular estimates. Using remote sensing tools to track NDVI values over time will provide a helpful tracker of vegetation trajectory as the project matures. It is unusual to detect meaningful change in vegetation composition within one season and we expect a lag in vegetation response following treatments. That coupled with the historical dynamism of water surface and groundwater elevation historically, we may find it difficult to draw a distinct signal from vegetation for some time. However, if the BDAs persist and channel aggradation occurs, we should be able to start to detect a signal as vegetation productivity becomes more robust and is able to be more resilient to the effects of drought (see Figure 8 for historic NDVI and precipitation measurements) (Silverman et al. 2018). Overstory cover (Primarily willows in the meadow and conifers at the upland margins) remained essentially the same. We may see an increase in willow recruitment on the large gravel bars along the channel if the water table elevation increases keep them moister and more hospitable to willow colonization. Emergent vegetation (hydric sedges and other species) within the channel and below bankfull was not quantified by this protocol, but changes would be detectable using NDVI moving forward. These species require fine sediment deposits to colonize so the overall increase in pool habitat from BDAs will encourage more fines recruitment in shallow depositional areas which will in turn help stabilize banks and margins with their dense, mat-forming roots.

Water Quality and Air Temperature

Table 5. Water Quality and Air Temperature Metrics for Faith Valley in 2016 vs. 2024. Dissolved Oxygen Data was not available in 2024 due to meter malfunction and the pH and electroconductivity meter experienced a spectacular though thoroughly fatal drowning incident in GM3 in 2024. Surveys were conducted in September and early October in 2016 and in late September in 2019.

Metric/Reach	Geomorphic Reach 1 (2016)	Geomorphic Reach 1 (2024)	Geomorphic Reach 2 (2016)	Geomorphic Reach 2 (2024)	Geomorphic Reach 3 (2016)	Geomorphic Reach 3 (2024)	Geomorphic Reach 4 (2016)	Geomorphic Reach 4 (2024)
Air Temperature C°	NA	12.8	NA	13.6	NA	18.1	16.6	19.1
Water Temperature C°	16.5	11.2	14.5	11.2	12.5	12.4	8.7	12.1
Dissolved Oxygen (mg/L)	6.6	NA	7.1	NA	6.8	NA	8.4	NA
% Oxygen Saturation	68.0	NA	70.0	NA	63.7	NA	72.2	NA
pH	7.3	7.7	7.1	7.4	7.0	7.7	7.5	NA
Conductivity (μS)	56.7	65.3	62.2	71.3	61.7	75.1	27.2	NA
Flow (cfs)	1.62	2.96	2.3	NA	2.71	3.86	NA	NA

Water quality and air temperature data was taken in 2016 and 2024 at each channel unit when functioning meters were available. The surveys occurred in September and early October 2016 and in late September 2024. While this provides only a brief window in time and does not include the hottest portion of the summer, the data that was collected was within the survival parameters for sensitive taxa such as salmonid fish species and EPT (Ephemeroptera, Plecoptera, Trichoptera) macroinvertebrate groups that are sensitive to temperature, dissolved oxygen, pH, and conductivity. The commonly cited temperature limit for salmon and trout is 22° C for sublethal effects (Moyle 2002). Dissolved Oxygen and % Oxygen saturation requirements should be above 5 mg/L and 80% saturation meaning that oxygen content in the water was low, and was likely even lower in mid-summer (Kemker 2013, Fondriest

Environmental 2014). We saw few trout in either survey and that is likely due to the low flows and questionable oxygen saturation. pH and conductivity were within tolerances for sensitive aquatic species but there could be other factors playing a role also.

Discussion and Conclusions

The restoration efforts at Faith Valley have utilized biogeomorphic structures to leverage the dynamic resources of flow, sediment distribution, vegetation production, and beavers for improved ecosystem function. Faith Valley Meadow is a highly dynamic system with a tremendous amount of variability in flows. Its contributing watershed provides ample sediment inputs and flashy pulses of runoff during high flow events that can transport large amounts of sediment but high flows can also strain beaver dams and structures. Vegetation, while showing the effects of lost groundwater elevation through channel entrenchment and floodplain disconnection, is still robust in many areas, buffered in part by hillslope groundwater processes from the surrounding mountains, and in others by functional hydrology supported by tributary channels, springs, and areas of connectivity. The constant "build and breach" cycle of beaver dams in the system have created an ongoing sequence of localized effects switching between Cluer and Thorne Stage 0 when large, persistent dams achieve full floodplain connectivity and Stages 3-6 after the breach when the channel returns to its incised, less functional state.

The potential alternatives for restoration treatment were limited by several constraints. Full channel fill might have been a proposed approach that would have instantaneously solved the channel incision problem, but the narrowness of the valley in Reaches 2 and 3 with a lack of alternative channel would have made it extraordinarily risky due to the potential for very high flows in the system running over fresh, unvegetated fill material with a very high chance of re-incision. This would also have been a very high-cost option and would require a source of appropriate channel fill material, which can be difficult and costly to acquire. This option would also take an unacceptable toll on the existing positive habitat attributes within the system and been intolerable from the standpoint of avoiding heavy machinery in the meadow or harvesting fill material from the meadow soil.

A second alternative approach using Large Wood Engineered Debris jams could have been a good treatment alternative since the high energy in the system can be challenging for lighter structures. That approach would have put a series stable engineered structures into the channel that would function much like a BDA but have much heavier material keyed into the bank and anchored in place potentially providing greater stability than hand built beaver dam analogs using brush, willow weave, small wood, and 3" posts. However, large wood structures would have required extensive heavy machinery access and required major streambed and bank alteration during construction and some ground disturbance for access. This option would also require sourcing large trees and was not utilized due to a combination of design decisions and regulatory constraints that it would have triggered. The necessary grade control structure at the downstream end of the meadow was the only structure constructed in this manner and had appropriate access and rehabilitation post-implementation.

Using a Process Based Restoration approach in Faith Valley provided both opportunities and limitations. The success of natural beaver dams in the system at generating excellent habitat showed proof of the concept that a Beaver Dam Analog approach would be viable in this system to achieve desired conditions. The ample sediment supply and presence of beavers in the system made this an appealing approach and the function of persistent beaver dams within the system demonstrated the potential efficacy of this type of structure. However, the problems associated with natural beaver dams in a system with this much stream power remain true for BDAs, i.e., they are vulnerable to breaching during high flow events, particularly when there is only a single large structure. The Process Based Restoration

Design Manual recommends an iterative approach to building up stream channels and to avoid building up too large too quickly because the risk of breach increases with more water volume behind a dam and the use of posts helps structures to persist in the face of high flows. The Riverscapes Restoration Principles outline the ideas that drive the PBR approach (Wheaton et al. 2019). While explicit project goals might be focused on channel aggradation and reduced erosion, PBR relies more broadly on the concept of increasing the area accessible for process space, using structure to force complexity and built resilience, of creating more inefficiency in the movement of water through the system, using many small structures to build redundancy and resiliency into the system to reduce dependence on single structures, using natural building materials, and allowing the natural processes at work in the system to drive the evolution of the channel form. Self-sustaining systems are the solution (Wheaton et al. 2019).

LOW-TECH PROCESS-BASED RESTORATION PRINCIPLES FOR STRUCTURALLY-STARVED RIVERSCAPES

Riverscapes Principles

1. Streams need space
2. Structure forces complexity and builds resilience
3. The importance of structure varies
4. Inefficient conveyance of water is healthy

Restoration Principles

5. It's okay to be messy
6. There is strength in numbers
7. Use natural building materials
8. Let the system do the work
9. Defer decision making to the system
10. Self-sustaining systems are the solution

Figure 6. Design Principles for Low-Tech Process Based Restoration Treatments (From Wheaton et al. 2019)

This deference to the system can be difficult in practice when agencies have specific mandates, multiple stakeholders to address, and regulatory or infrastructural constraints that must be accommodated as well as limited durations for funding and permits. The project design reflected the desire for a minimal-impact approach but had the tradeoff that the implementation would take multiple efforts as the channel adjusts, BDAs fill in, and the streambed aggrades. After the winter of 2023, rebuilt structures contained larger wood and longer downstream aprons to help keep material in place and dissipate flows with a more hydrodynamic shape than some of the first-round structures that appeared more vertically oriented. While many of the structures were recently enhanced at the time of our surveys, they appeared sturdy and were functioning well. The design appropriately did not build structures all the way up to the historical floodplain elevation, rather, most structures were <1 m tall with several clustered together in complexes that matched the gradient of the channel and provided redundancy if any single structure were to blow out. Implementation has been phased to allow for adaptive management and enhancement of structures as the channel evolves and fits well into the Riverscapes Restoration Principles (Wheaton et al. 2019). While the long-term goal for restoration in Faith Valley is the full reconnection of the channel to its historic floodplain and reaching the full potential of ecosystem processes and services, there are already measurable benefits being realized just after the first phase of implementation. The surveys in both 2016 and 2024 were conducted during very similar times with late season baseflows making the channel metrics highly comparable. The differences observed between 2016 and 2024 were directly attributable to project implementation, particularly in Geomorphic Reach 2 which contained the majority of structures implemented in Phase 1. The clearest graphics that show the benefits of the project thus far are the channel incision maps which show an overall reduction in channel incision (less distance from the channel to the historic floodplain) as well as channel widening an increase in wetted areas throughout the treatment reaches.

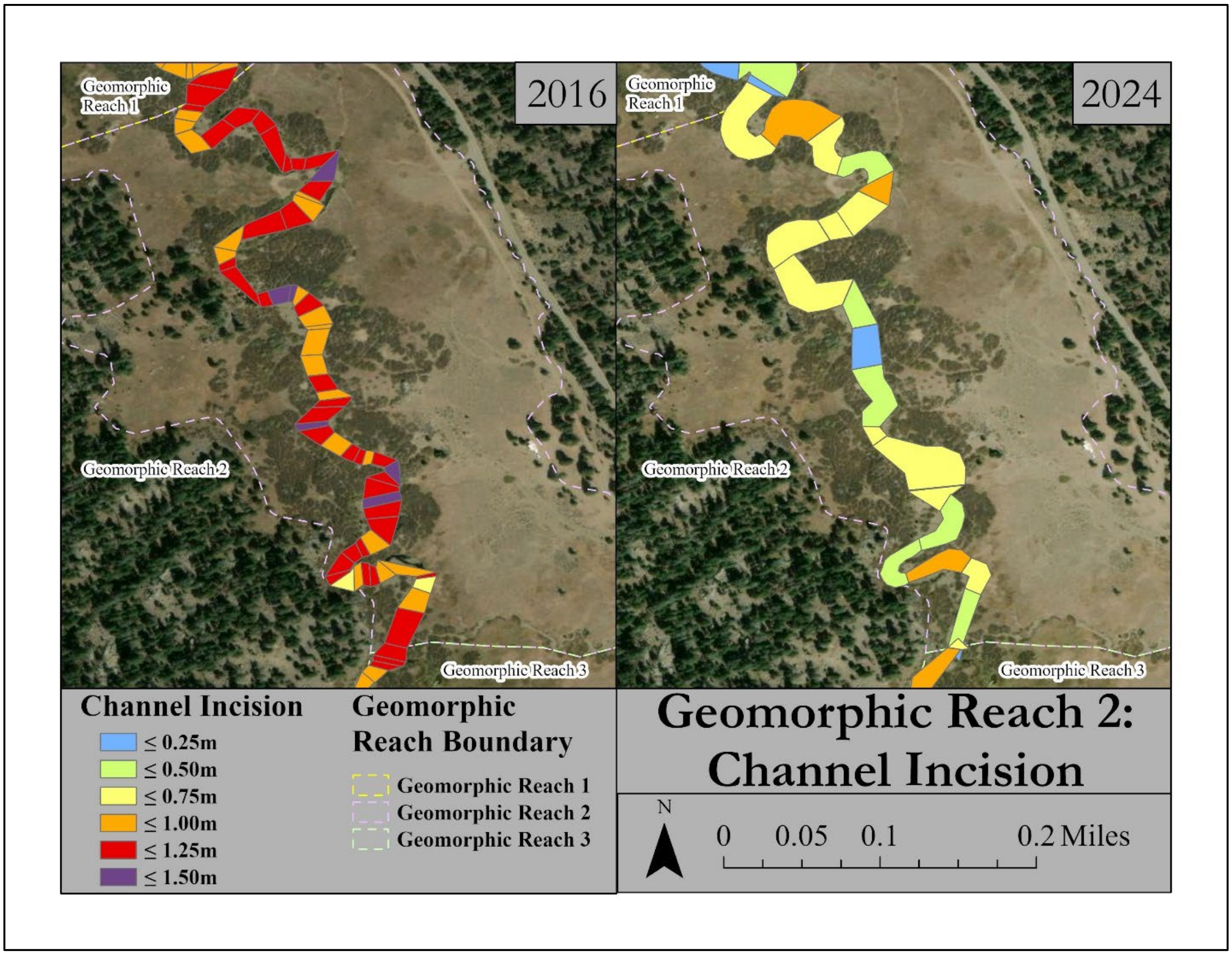

Figure 7. Detail of Channel Incision changes in Geomorphic Reach 2 pre-and post-restoration treatment. The decreases in entrenchment below the historic floodplain are significant throughout the treatment area. The channel widened and wetted area also expanded in this reach post-treatment. Detail maps for the entire project area and other geomorphic reaches are in the appendix.

Benefits from implementation prior to complete aggradation and floodplain reconnection have been documented in other Process Based Restoration Projects where changes in groundwater recharge. Sevier et al. (2024) found that even before full floodplain reconnection was realized, ground water storage increased, baseflow was extended, and pools retained fine sediments building the streambed up to the meadow surface. This quantification of interim benefits couples with other improvements to habitat including deeper pools, fine sediment deposition behind dams leading to emergent marsh development driving increased vegetation productivity and reduced erosion. Elevated water surfaces reduce shear stress on erosible stream banks and encourage vegetation development.

Table 6. Scores for the physical and vegetative attributes for each stage in the Stream Evolution Model. Scores are based on an ordinal scale where 3 = abundant and fully functional, 2 = present and functional, 1 = scarce and partly functional and 0 = absent or dysfunctional (From Cluer and Thorne 2014).

Hydrogeomorphic Attributes Table

Stage	0	1	2	3	3s	4	4-3	5	6	7	8
Physical Channel Dimensions											
Wetted Area Relative to Flow	3	2	1	1	1	0	0	1	1	2	2
Shoreline Length and Complexity	3	2	1	1	1	0	0	1	1	2	2
Channel and Floodplain Features											
Bedforms and bars	2	3	1	0	0	1	0	2	3	3	2
Islands	3	1	0	0	0	0	0	0	0	1	3
Local Confluence/Diffluences	3	1	0	0	0	0	0	0	0	1	3
Stable banks	3	2	2	2	2	0	0	1	2	2	3
River cliffs	2	2	0	1	2	2	2	2	1	2	2
Riparian Margins	3	2	1	1	1	0	0	1	2	2	3
Floodplain Extent and Connectivity	3	3	1	0	0	0	0	1	2	2	2
Side channels	3	2	0	0	0	0	0	0	1	2	2
sediment storage	3	2	1	0	0	0	0	0	1	2	3
Connected Wetlands	3	2	1	0	0	0	0	0	0	1	2
Substrate											
Substrate Sorting	2	3	0	0	1	0	0	1	1	2	2
Substrate Patchiness	3	3	0	0	1	0	0	1	2	3	3
Hydraulics											
Hydraulic Diversity	3	2	0	0	1	0	0	1	1	2	3
Marginal Deadwater	3	2	0	0	0	0	0	0	1	2	3
Vegetation											
Aquatic plants	3	2	1	0	0	0	0	1	2	2	3
Emergent Plants	3	1	1	1	1	1	0	2	2	1	3
Riparian plants	3	2	0	0	1	0	0	1	1	2	3
Floodplain plants	3	3	2	0	0	0	0	0	1	2	3
Woody debris	3	1	0	1	1	2	1	2	2	1	3
Leaf litter	3	2	0	1	2	0	0	1	2	2	3
Hydrological Regime											
Flood pulse	1	1	2	3	3	3	3	2	2	1	1
Flood attenuation	3	2	1	0	0	0	0	0	1	2	3
Base flow	2	3	1	0	0	0	0	0	1	3	2
Hyporheic connectivity	3	3	2	0	0	0	0	1	2	3	3
Results											
possible	78	78	78	78	78	78	78	78	78	78	78
sum	72	54	19	12	18	9	6	22	35	50	67
ratio	92%	69%	24%	15%	23%	12%	8%	28%	45%	64%	86%

Post-Treatment, Faith Valley Meadow has seen improvements on numerous attributes found in the Stream Evolution Model. Wetted area relative to flow, shoreline length and complexity, Bedforms and Bars, Local confluences and diffluences, bank stability, sediment storage, connected wetlands, marginal dead waters, emergent plants, woody debris, flood pulse, and hyporheic connectivity have all been improved by the restoration treatment. These attributes will continue to improve as the project continues to evolve, and a combination of further treatment and beaver activity works on top of the aggradation initiated by phase 1.

An additional metric that should be applied to the project over time is to calculate the resiliency of vegetation productivity to precipitation. This is available using Landsat data on platforms such as Climate Engine. Vegetation Resiliency calculates the change in vegetation productivity (NDVI) relative to the change in precipitation. When productivity becomes less linked to changes in precipitation it indicates increased resiliency. The equation for this calculation is

$$1 - \frac{\Delta NDVI}{\Delta P}$$

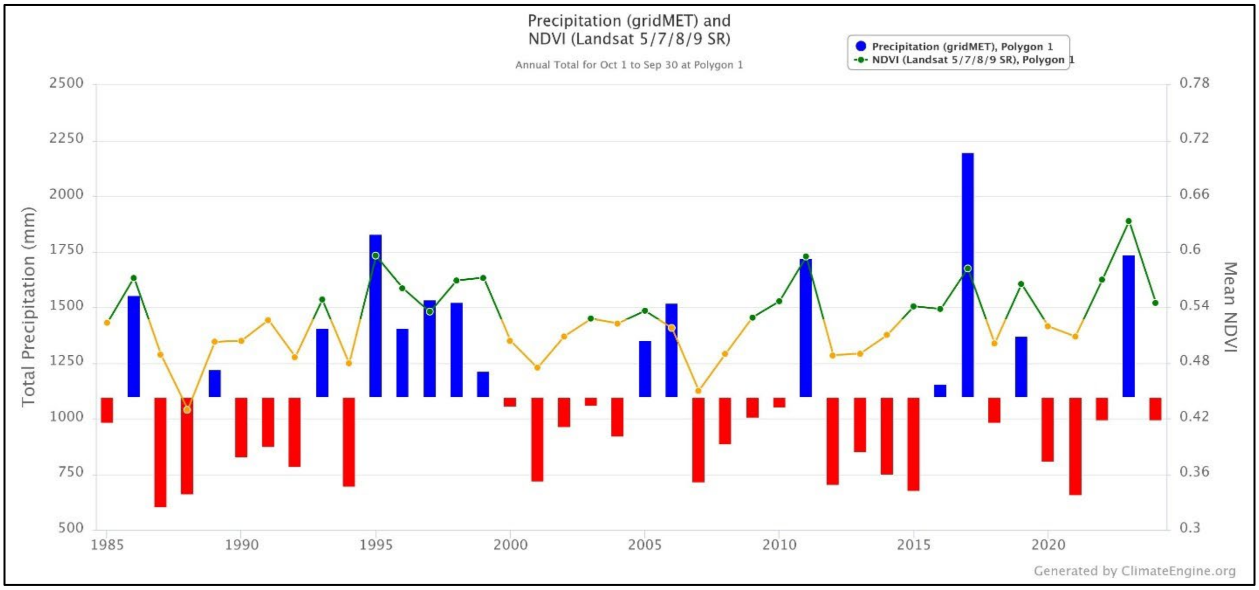

Figure 8. Precipitation and NDVI for Faith Valley Meadow from 1985 to 2024 for the May1-October 1 growing season (shortened due to high elevation and later green up. It is too early in the project to detect a signal from treatment at the time of this analysis, but this relationship should continue to be monitored over time as an easy and effective means of tracking project impact. The trend over time has been that the NDVI results have tracked very closely with precipitation (Generated by ClimateEngine.org, https://climengine.page.link/CdAt)

This project is an excellent test piece for the application of Process Based Restoration approaches in larger stream systems in Sierra Nevada Meadows. Given time, structure, sediment, and vegetation response, there is great potential for the channel in Faith Valley to fully re-aggrade and reconnect the full valley bottom providing a renewal of ecosystem function lost in the past. The current trajectory is positive and the ingredients for success are present in the system, however it is also a challenging system to work in due to the very high energy stream flows that periodically appear. As the project matures and there is more time for response, its effects will become increasingly quantifiable and further iterations of the project can be adaptively managed over time. While future activities may not have current funding, the work that has already been done shows great potential to push the system in a positive trajectory and that should help to make it attractive to funders for additional phases of Process Based treatments.

Appendix 1. Figures

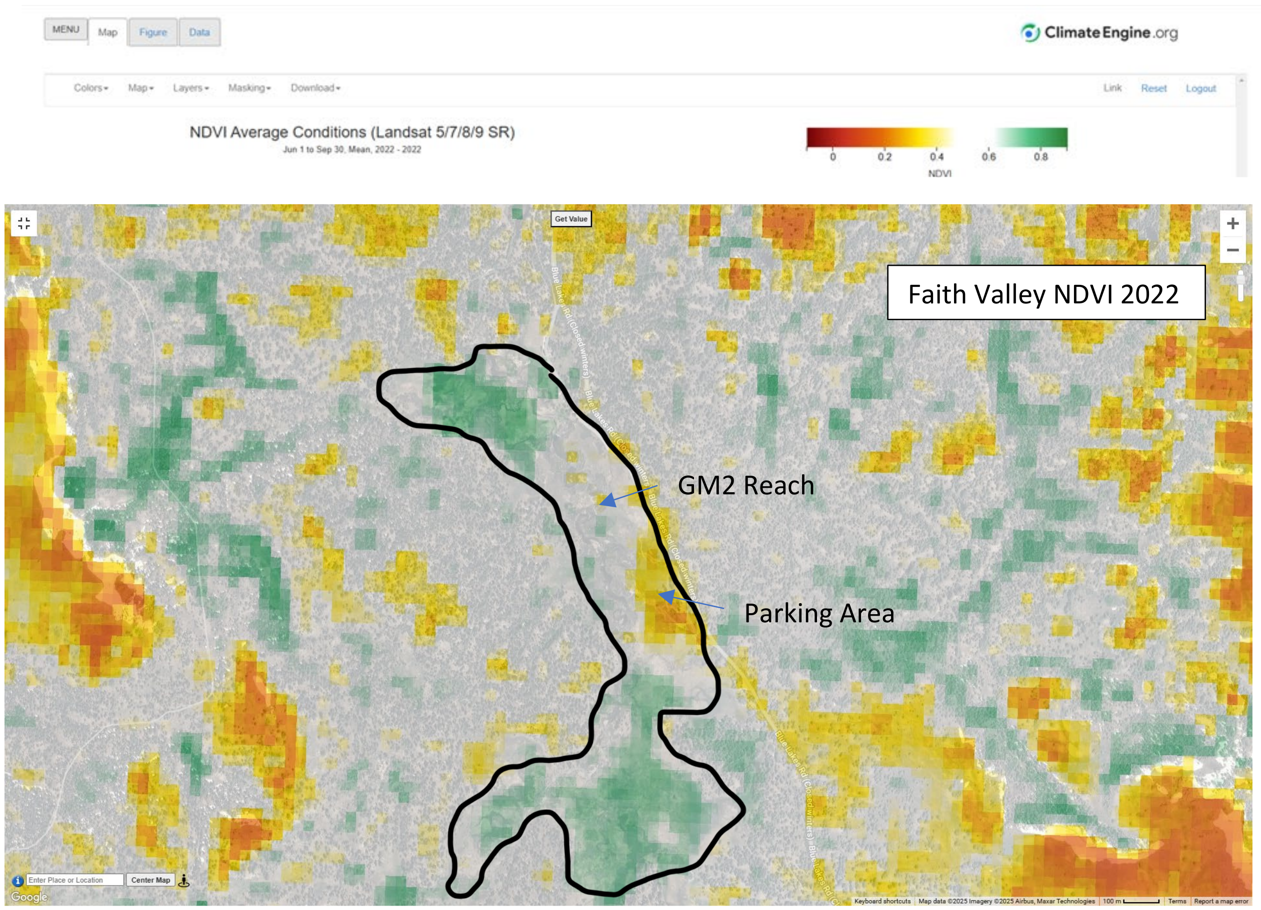

Figure 9. NDVI map for Faith Valley in 2022 (last year available). Comparing this to future results will help demonstrate project impacts on vegetation, particularly in the GM2 reach which has the poorest NDVI Values in Faith Valley Meadow and the least hydrologic connectivity to the floodplain. There is great opportunity for improvement in this section. (Generated by ClimateEngine.org)

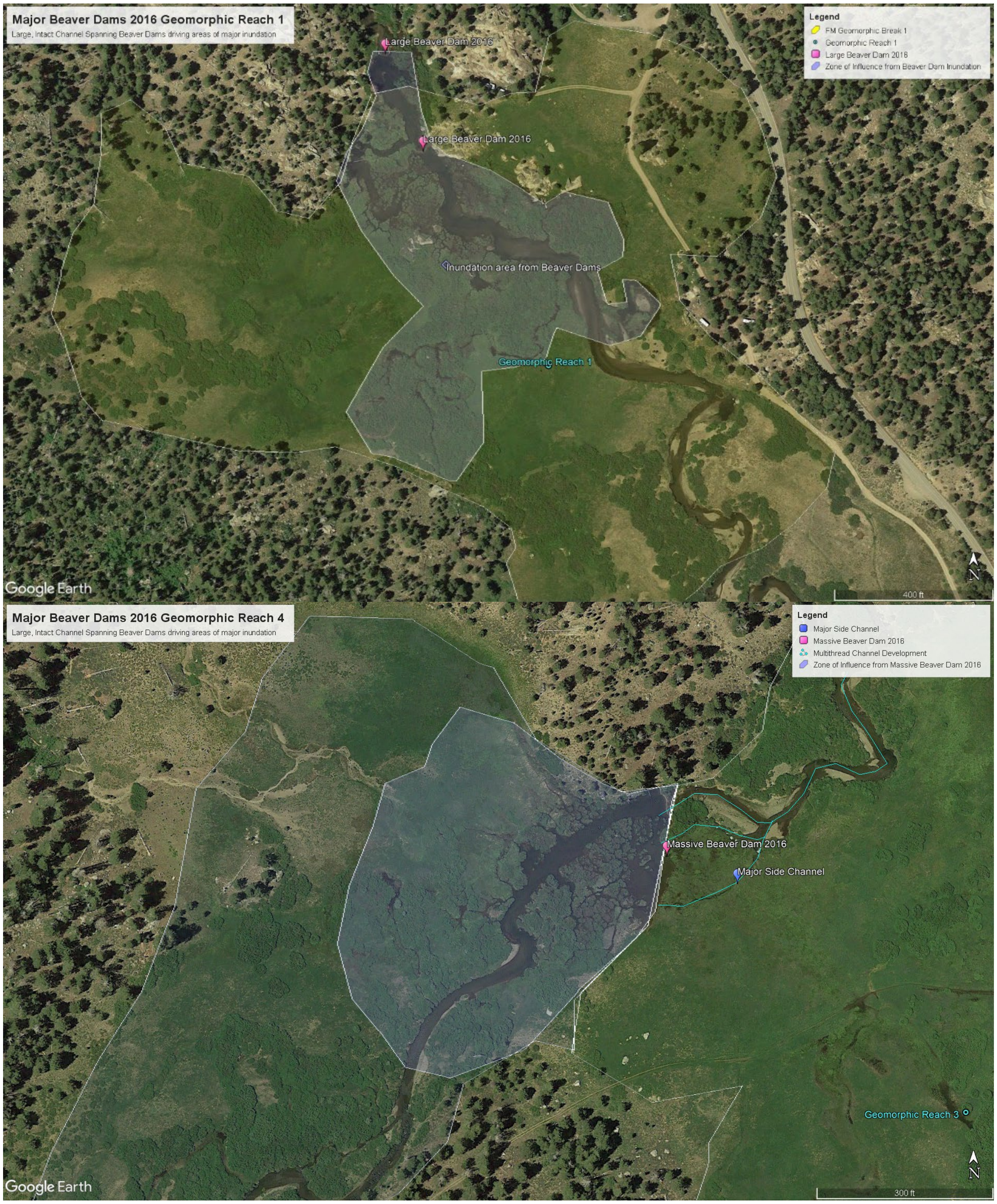

Figure 10. Major beaver dams present in 2016 that breached in the following winter dramatically altering the habitat and areas of inundation. The lower 2 beaver dams in Geomorphic Reach 1 inundated an area of ~ 9.75 acres with the large dam at Geomorphic Reach 4 inundating ~ 5.5 acres. The impacts to groundwater tables extended even further. These inundated areas were significantly reduced after the breaches and the channel became confined again. This is the reference condition for full floodplain connectivity in Faith Valley and represents Stage 0 conditions in the Stream Evolution Model.

Figure 11. The same reaches as depicted in figure 10 after the heavy flows in 2017 completely breached all of the large beaver dams in Faith Valley. Note the reduction of inundated areas and large areas of fresh sediment deposition exposed and redeposited by the blowout. This is a return to Stage 5-7 in the Stream Evolution Model.

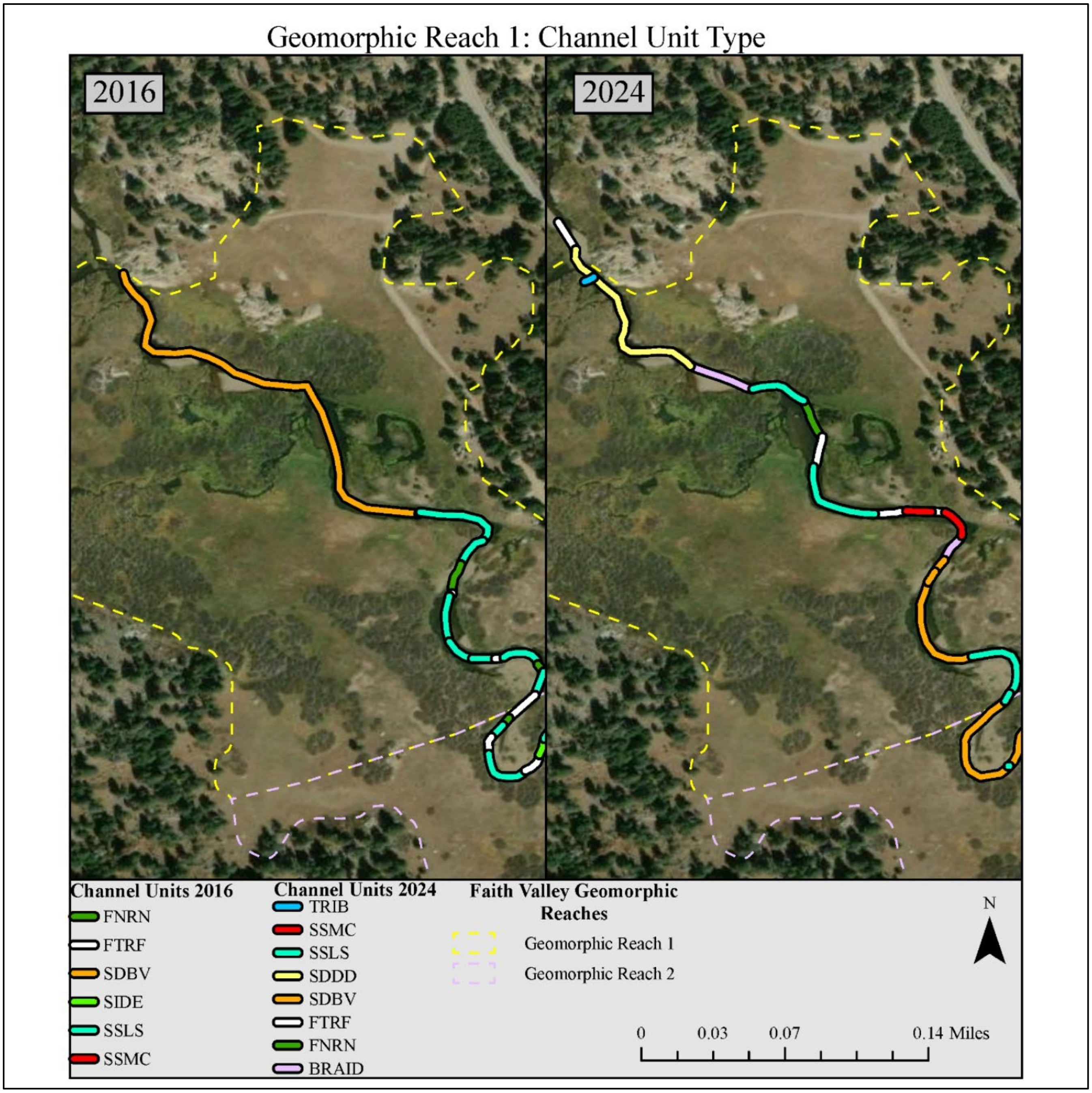

Figure 12. Detail of Geomorphic Reach 1 comparing Channel Habitats in 2016 vs. 2024

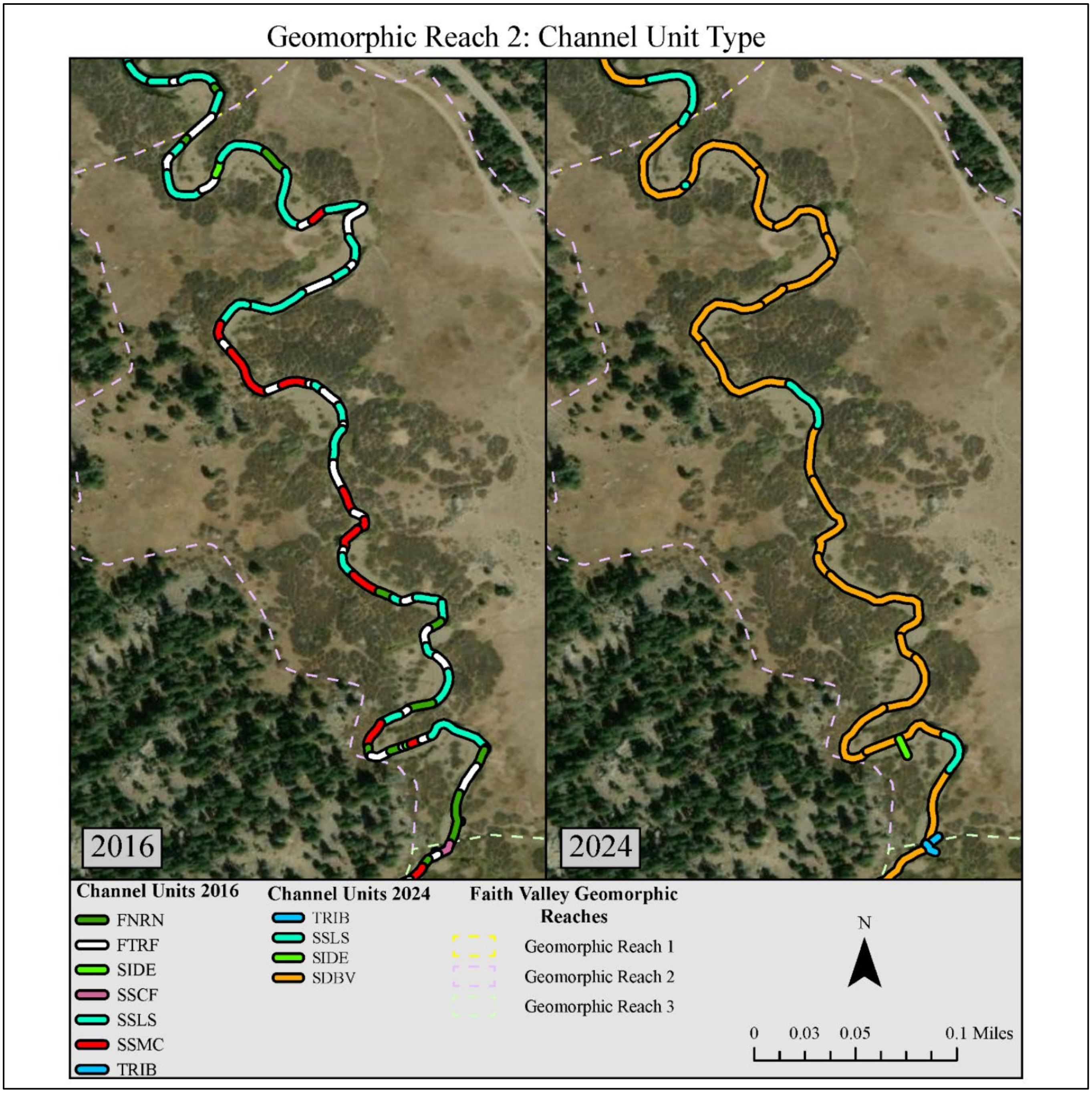

Figure 13. Detail of Geomorphic Reach 2 Channel Units in 2016 vs. 2024. This reach demonstrated the greatest shift in habitat type through the implementation of BDA structures throughout the reach converting almost all of the reach to pool habitat.

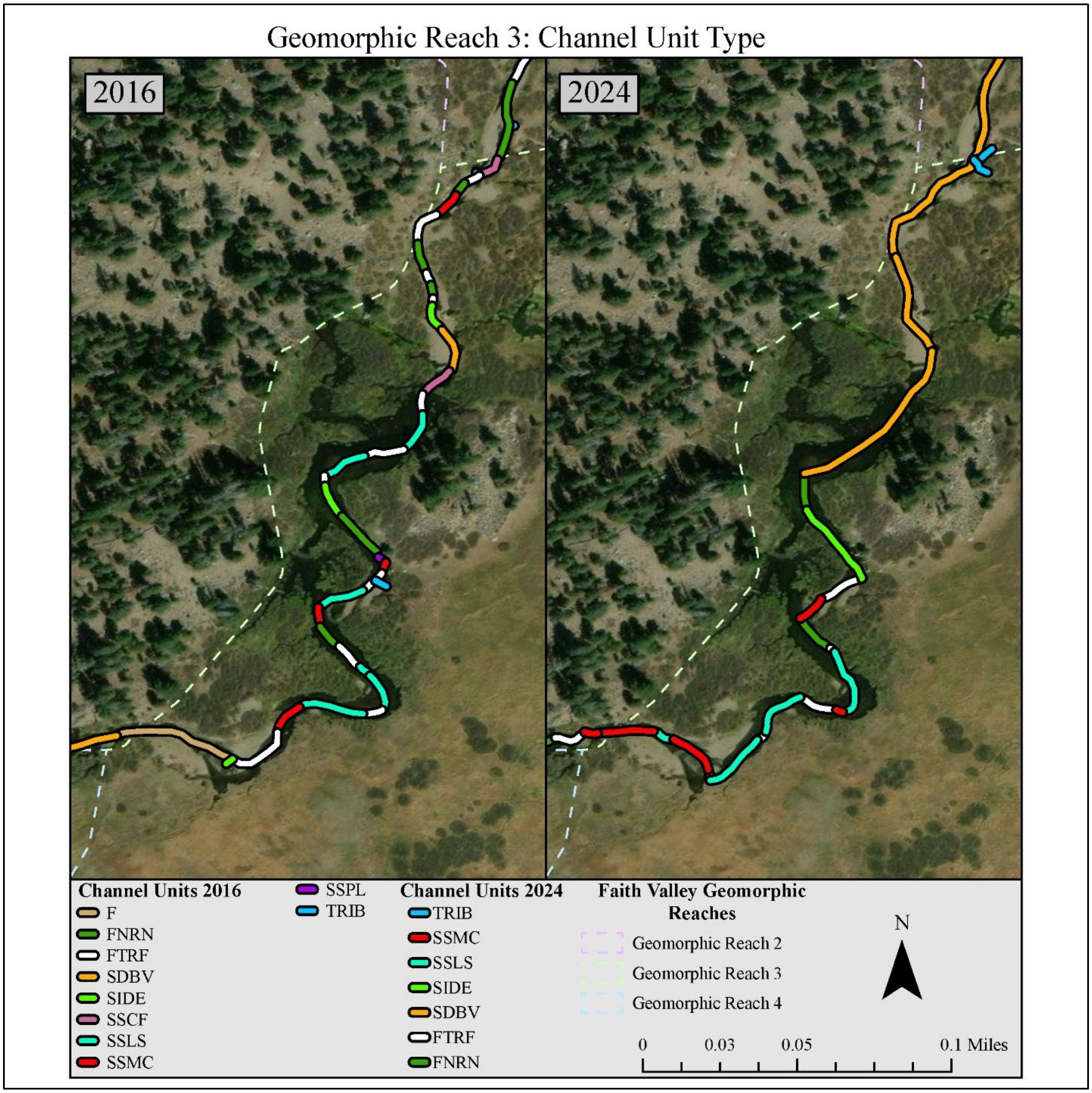

Figure 14. Detail of Geomorphic Reach 3 Channel Units in 2016 vs. 2024. The lower end of GM3 contained several BDA structures whereas the natural beaver dams present in 2016 at the upstream end were breached leaving behind scour pools in 2024. Sediment rearrangement and scour following a beaver dam breach completely reworks the instream channel habitats.

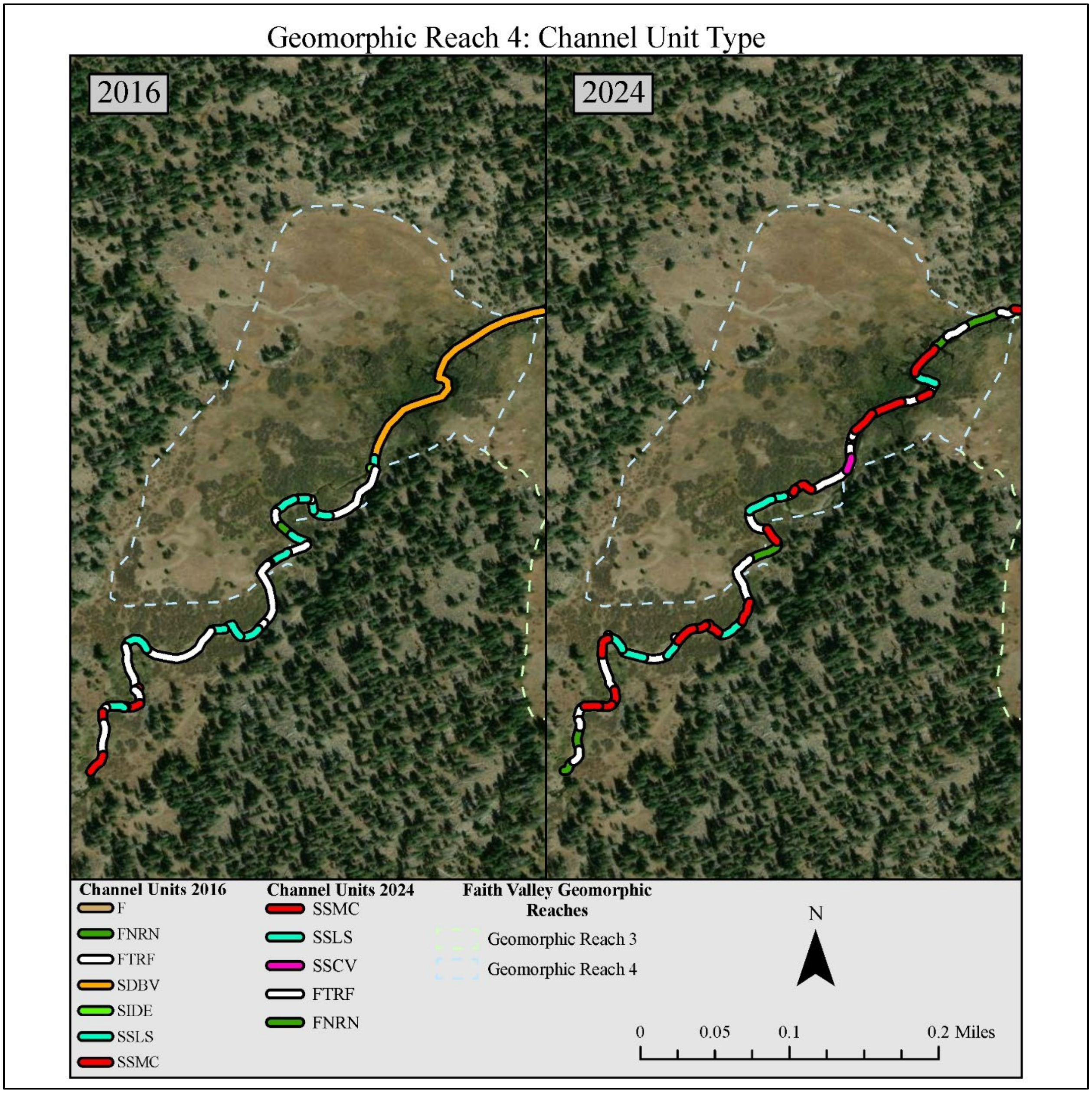

Figure 15. Detail of Geomorphic Reach 4 Channel Units in 2016 vs. 2024. Note the large beaver dam pool present at the downstream end of GM4 in 2016 that breached in 2017 and became many smaller habitat units following the loss of the dam.

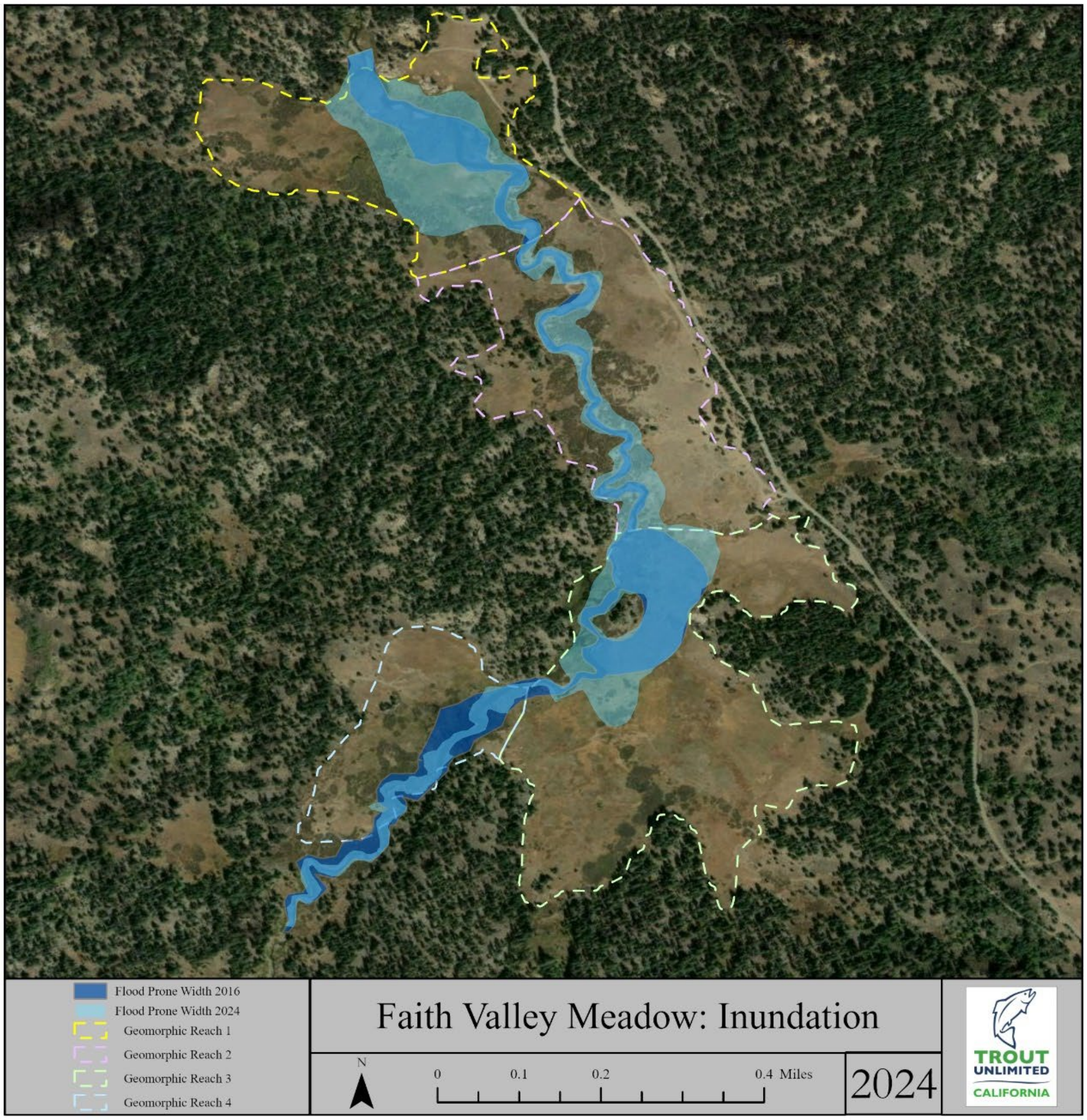

Figure 16.Overview of Inundation areas/Flood Prone widths in 2016 vs. 2024.

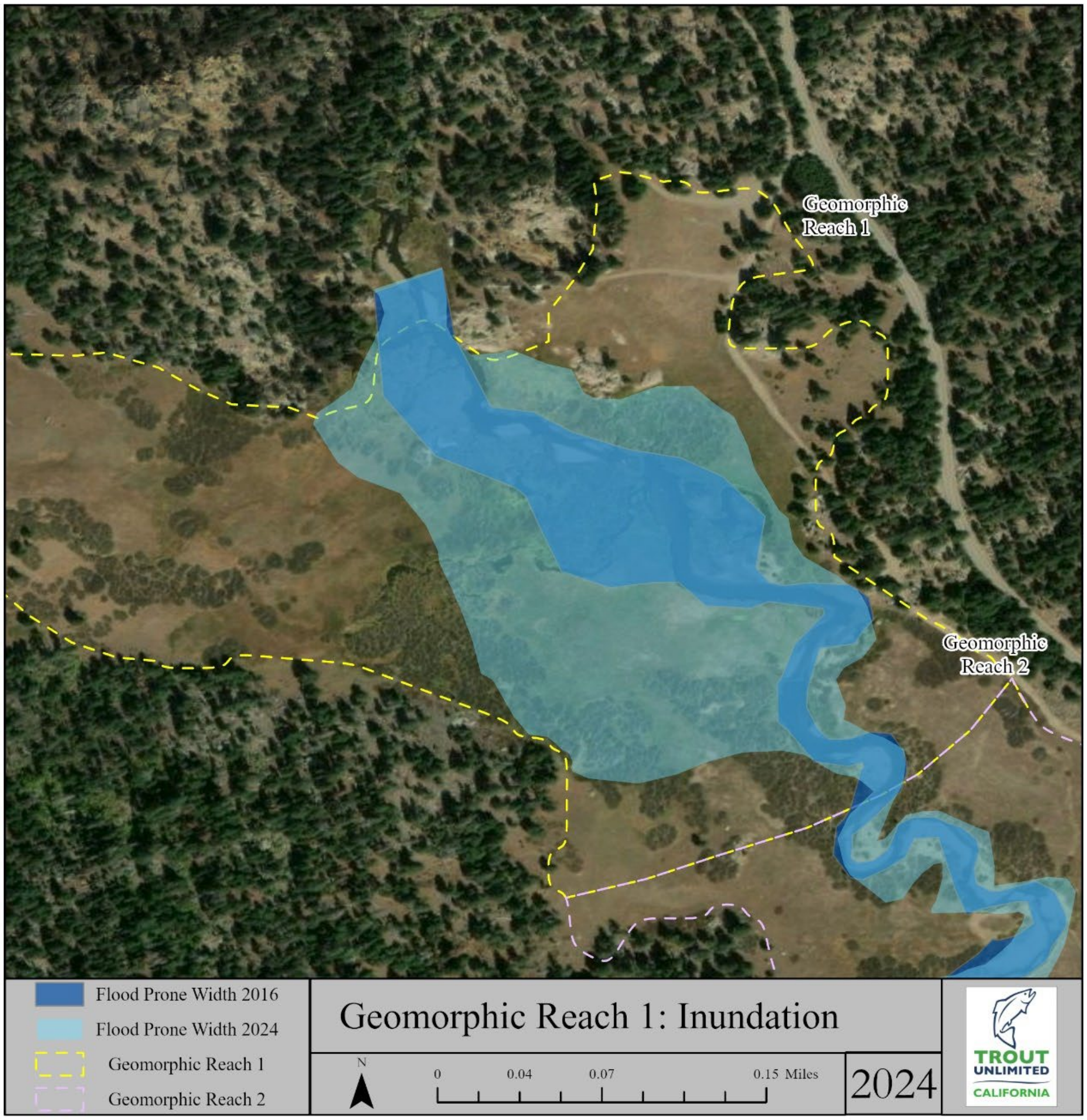

Figure 17. Detail of Geomorphic Reach 1 Inundation Areas and Flood Prone Widths in 2016 vs. 2024. Note the increase in inundation potential in 2024. This was due to increased floodplain connectivity from the structures near the top of GM1 that allowed water to spill into the valley bottom at lower flows than in 2016.

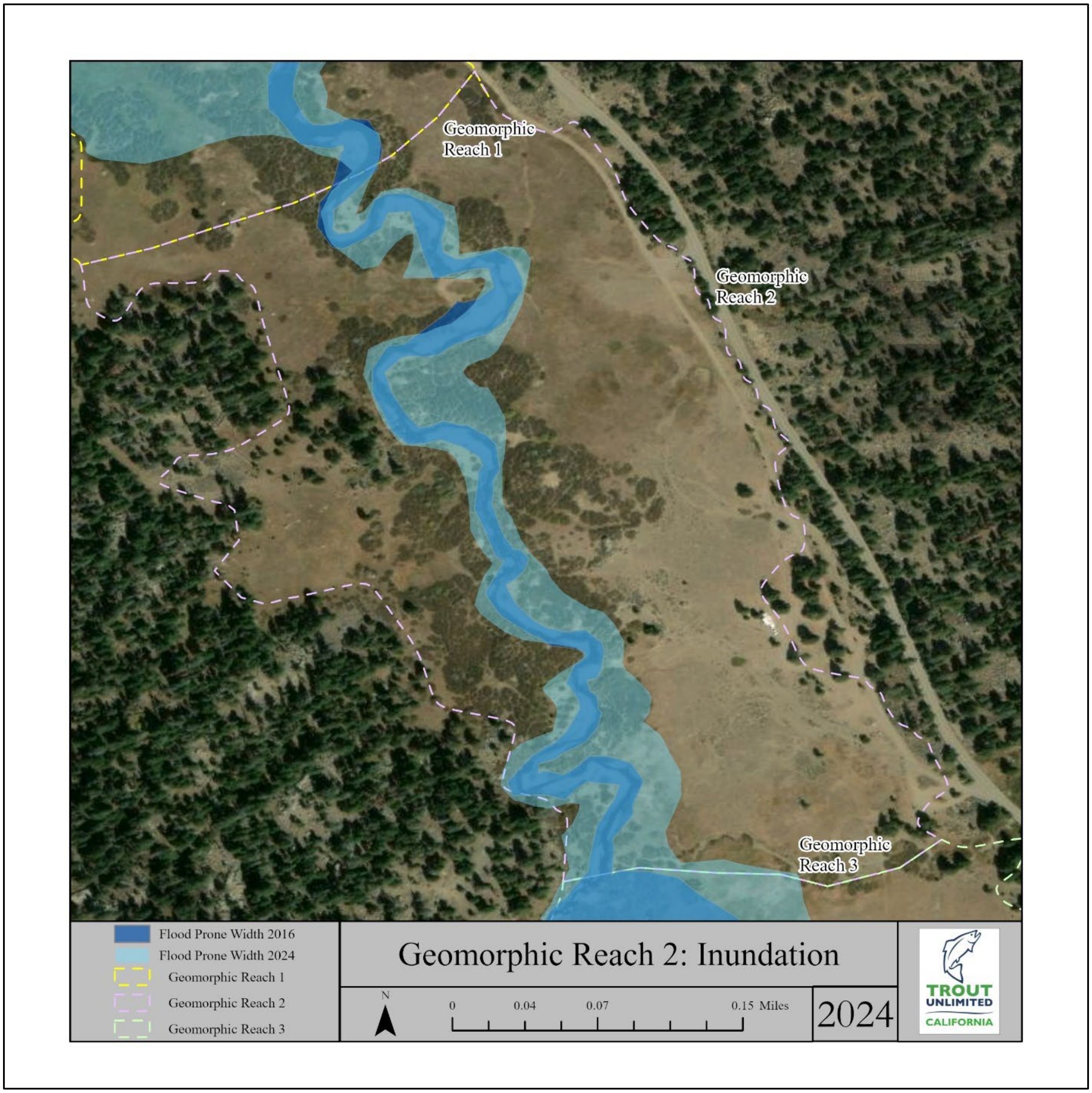

Figure 18. Detail of Geomorphic Reach 2 Inundation Areas and Flood Prone Widths in 2016 vs. 2024. Floodplain connectivity was improved by the implementation of Beaver Dam Analogs in what was the most entrenched portion of the channel in Faith Valley. While it remains entrenched, the treatment set the reach on a trajectory of aggradation and better floodplain connectivity. Subsequent treatments over time coupled with beaver activity on top of BDAs could allow this reach to fully re-aggrade to the historic floodplain.

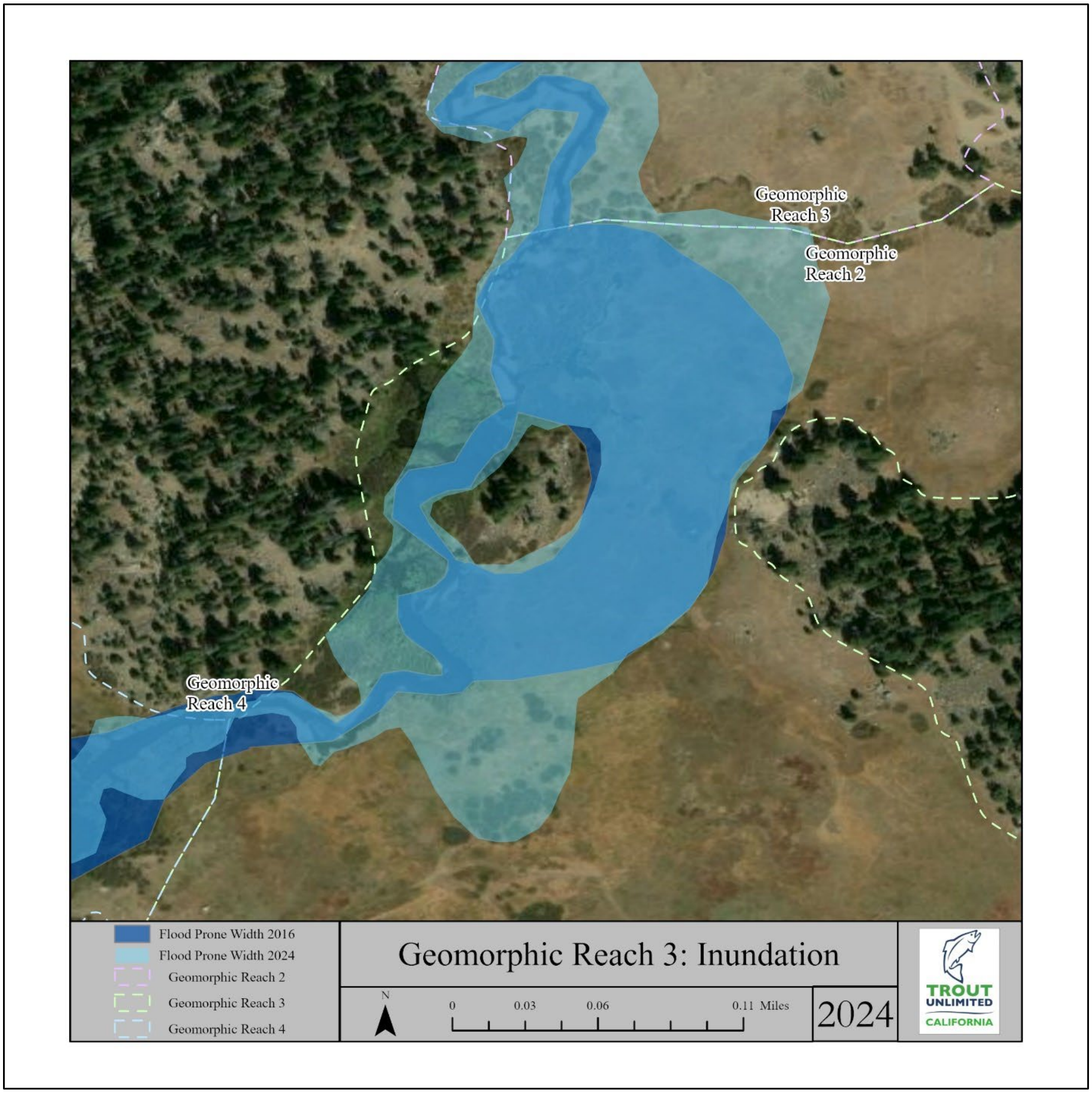

Figure 19. Detail of Geomorphic Reach 3 Inundation Areas and Flood Prone Widths in 2016 vs. 2024. Tributary channels and floodplains throughout this area are well connected and flood frequently. The mainstem has historically been very dynamic as beaver dams are built and are subsequently breached in high flow events. The upstream end of GM3 has not received any restoration treatment.

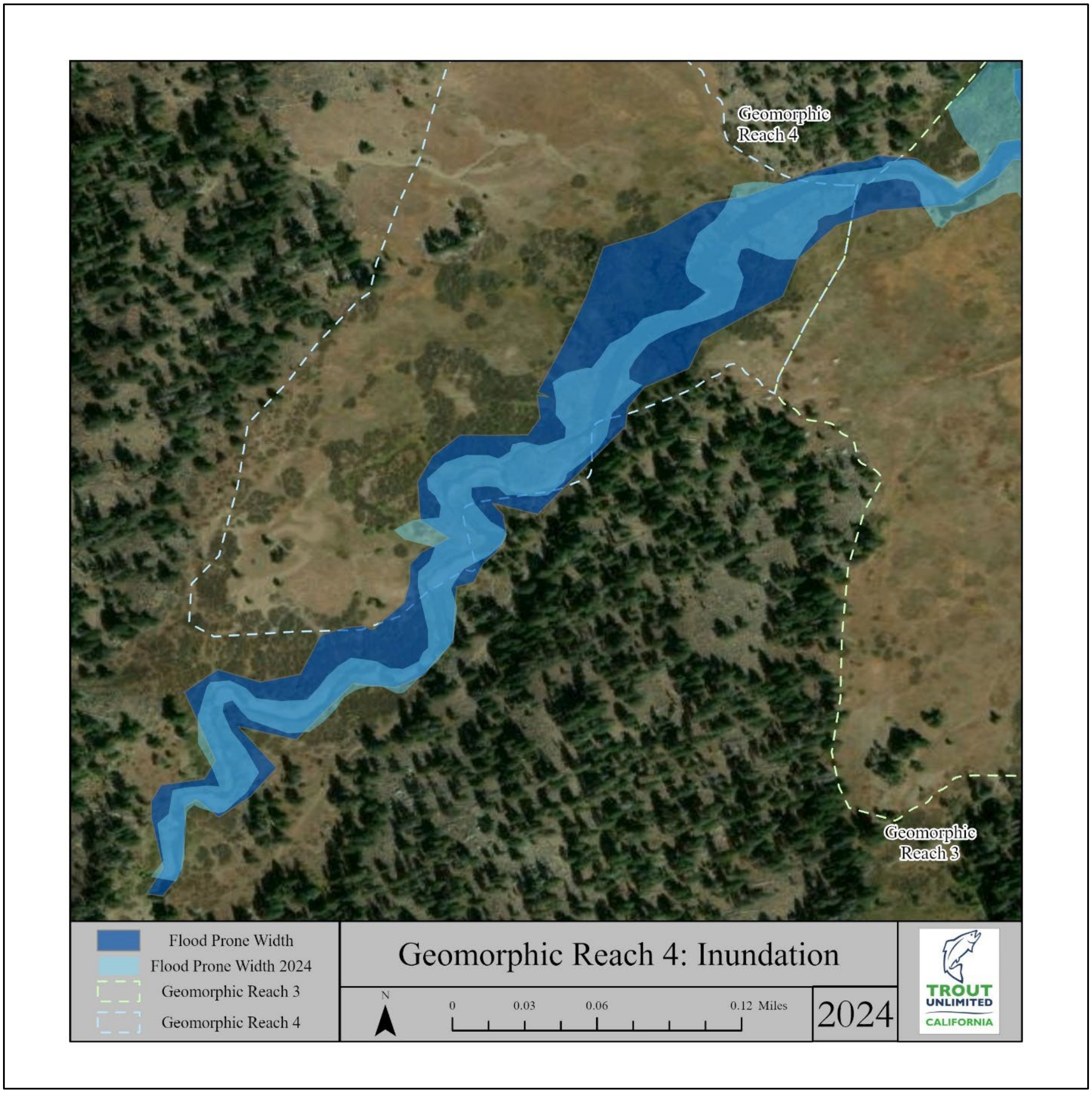

Figure 20. Detail of Geomorphic Reach 4 Inundation Areas and Flood Prone Widths in 2016 vs. 2024. Note that the flood prone width decreased in this reach following the breach of the large dam that was present in 2016.

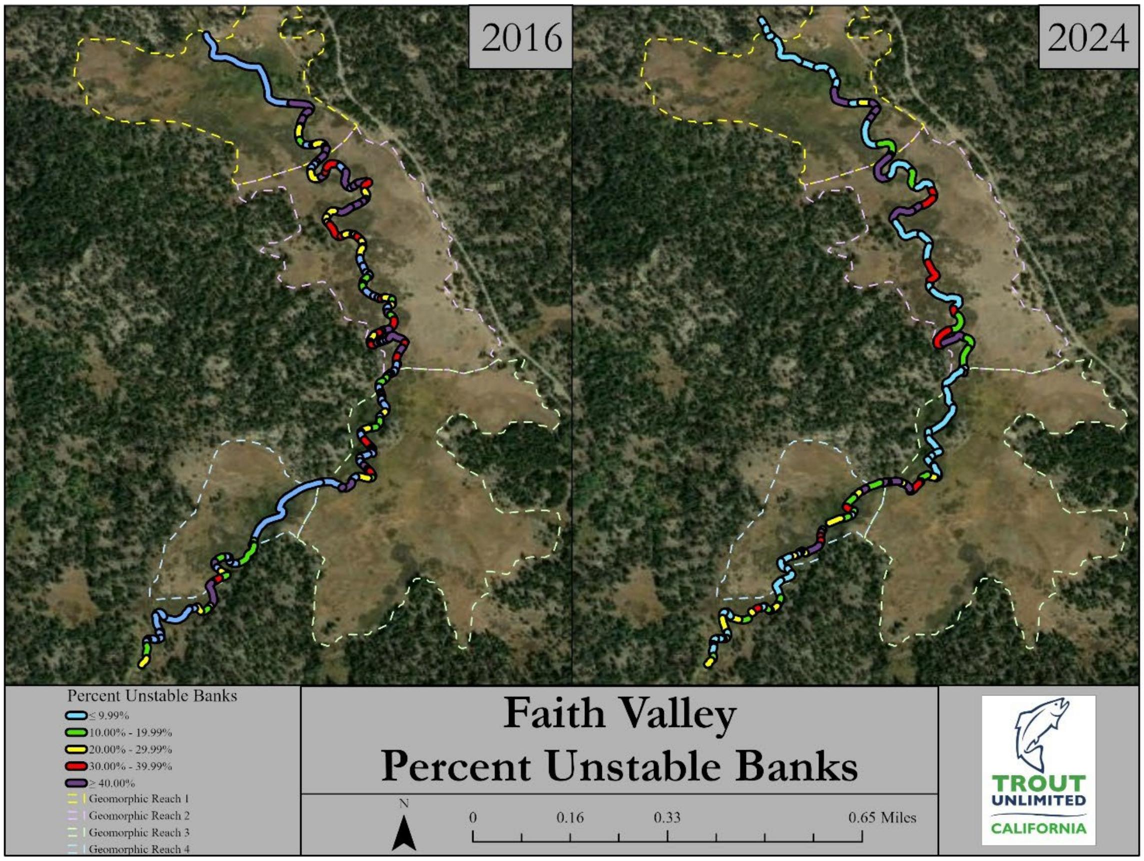

Figure 21. Overview of Bank Stability in Faith Valley in 2016 vs. 2024 by channel unit. Blue indicates <10% unstable banks in the unit, green indicates between 10% and 19.99% unstable banks in the unit, yellow indicates between 20% and 29.99% unstable banks in the unit, red indicates between 30 and 39.99% unstable banks in the unit, and purple indicates >40% unstable banks in the unit.

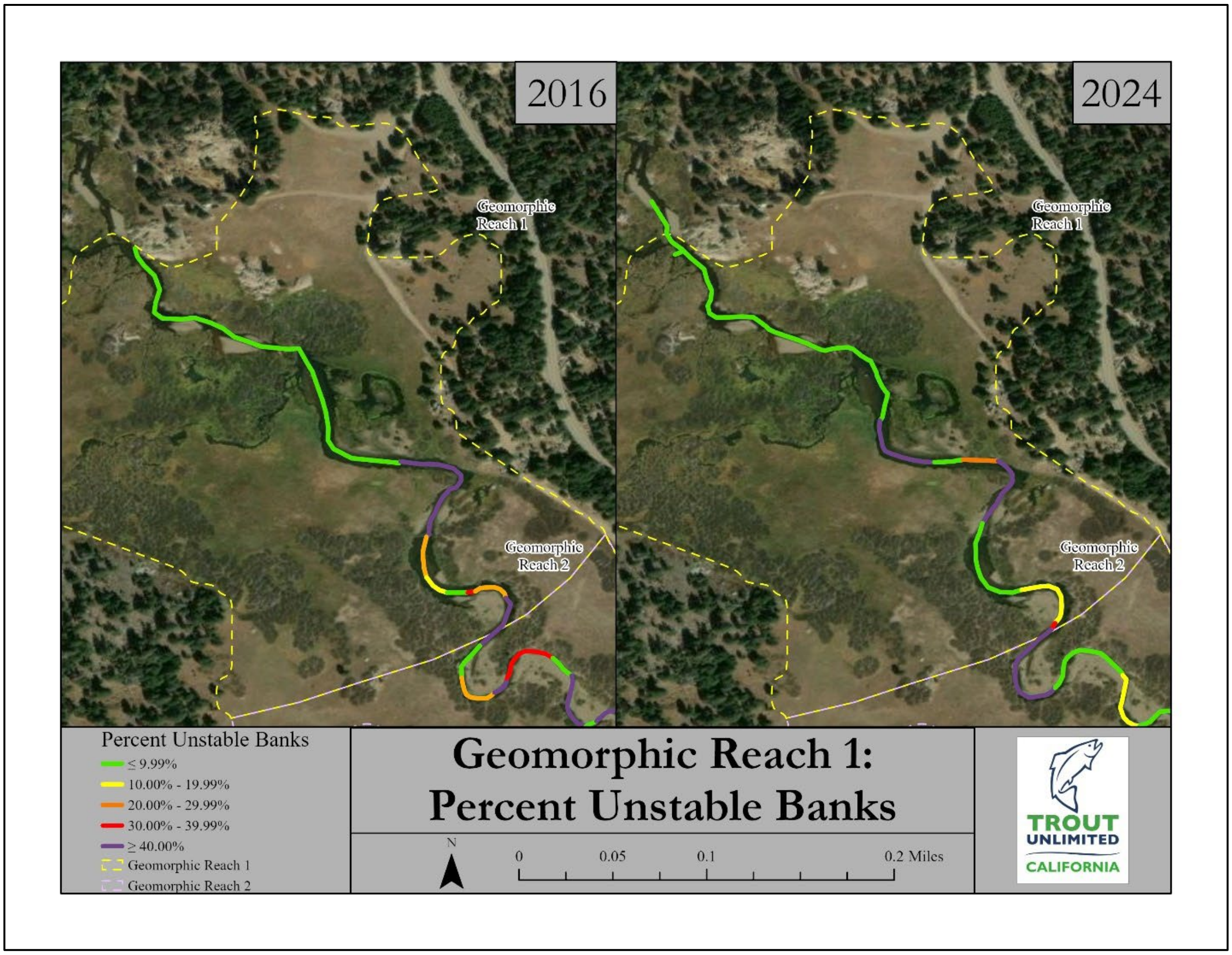

Figure 22. Detail of Bank Stability in GM1 in 2016 vs. 2024 by channel unit. Blue indicates <10% unstable banks in the unit, green indicates between 10% and 19.99% unstable banks in the unit, yellow indicates between 20% and 29.99% unstable banks in the unit, red indicates between 30 and 39.99% unstable banks in the unit, and purple indicates >40% unstable banks in the unit.

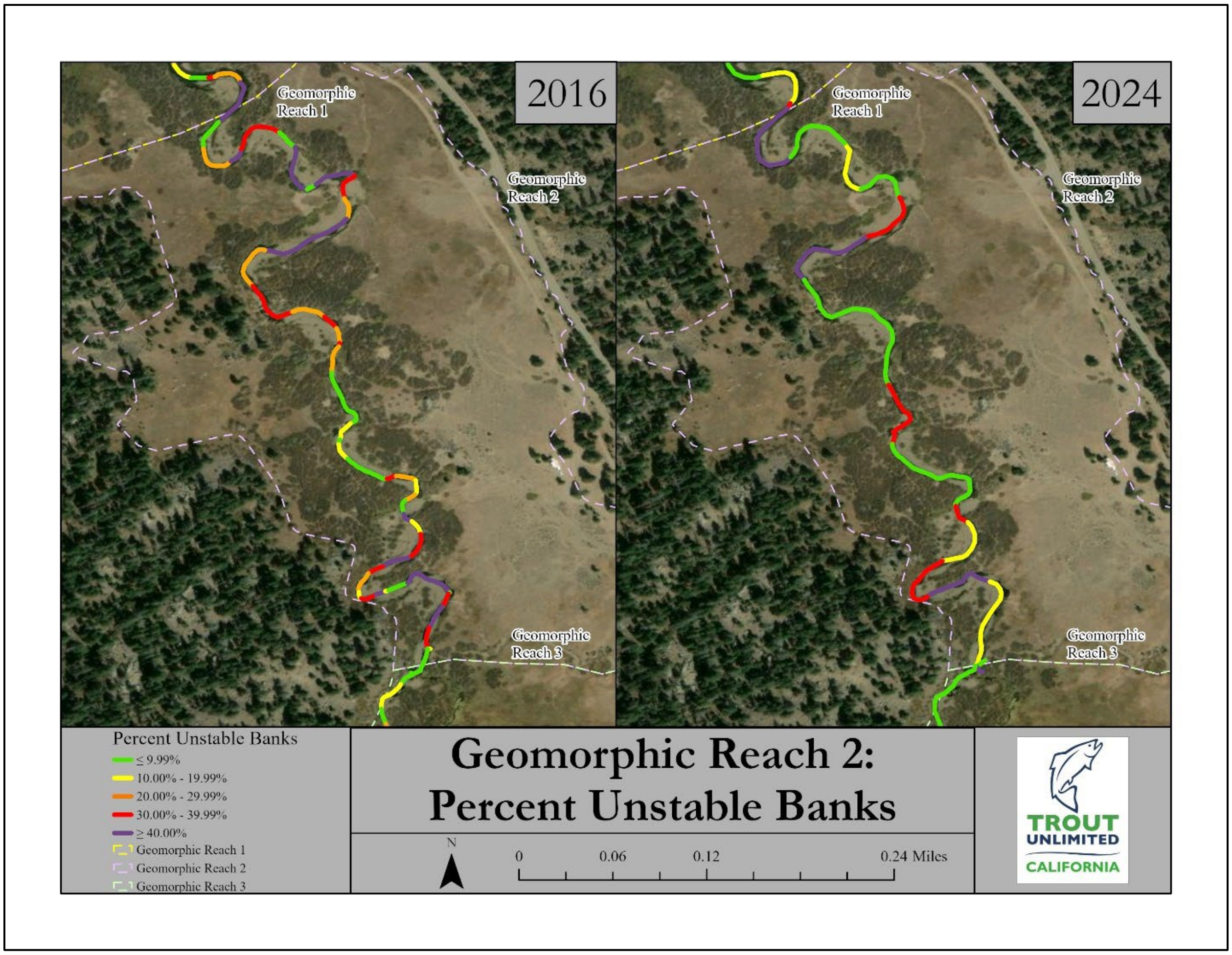

Figure 23. Detail of Bank Stability in GM2 in 2016 vs. 2024 by channel unit. Blue indicates <10% unstable banks in the unit, green indicates between 10% and 19.99% unstable banks in the unit, yellow indicates between 20% and 29.99% unstable banks in the unit, red indicates between 30 and 39.99% unstable banks in the unit, and purple indicates >40% unstable banks in the unit.

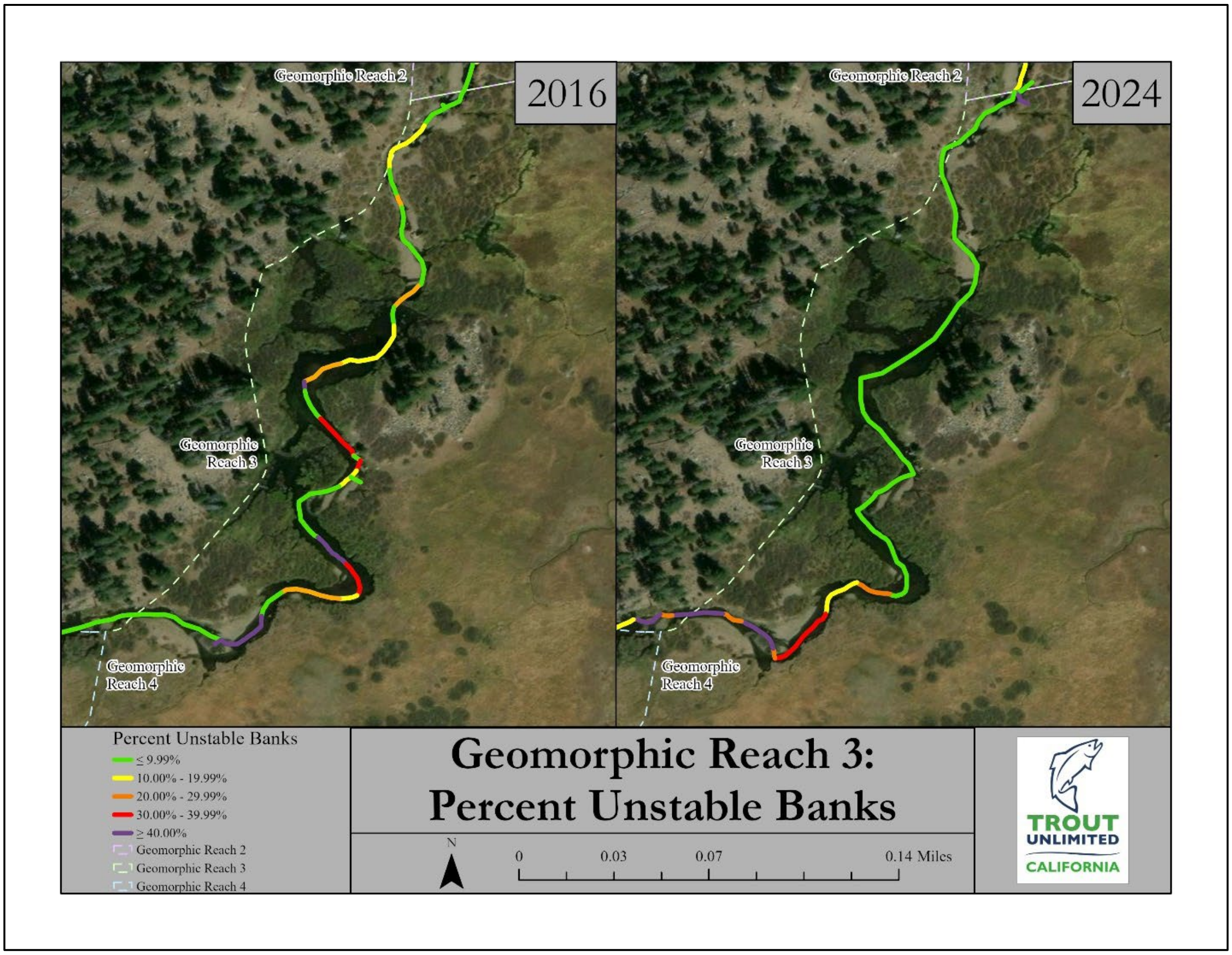

Figure 24. Detail of Bank Stability in GM3 in 2016 vs. 2024 by channel unit. Blue indicates <10% unstable banks in the unit, green indicates between 10% and 19.99% unstable banks in the unit, yellow indicates between 20% and 29.99% unstable banks in the unit, red indicates between 30 and 39.99% unstable banks in the unit, and purple indicates >40% unstable banks in the unit.

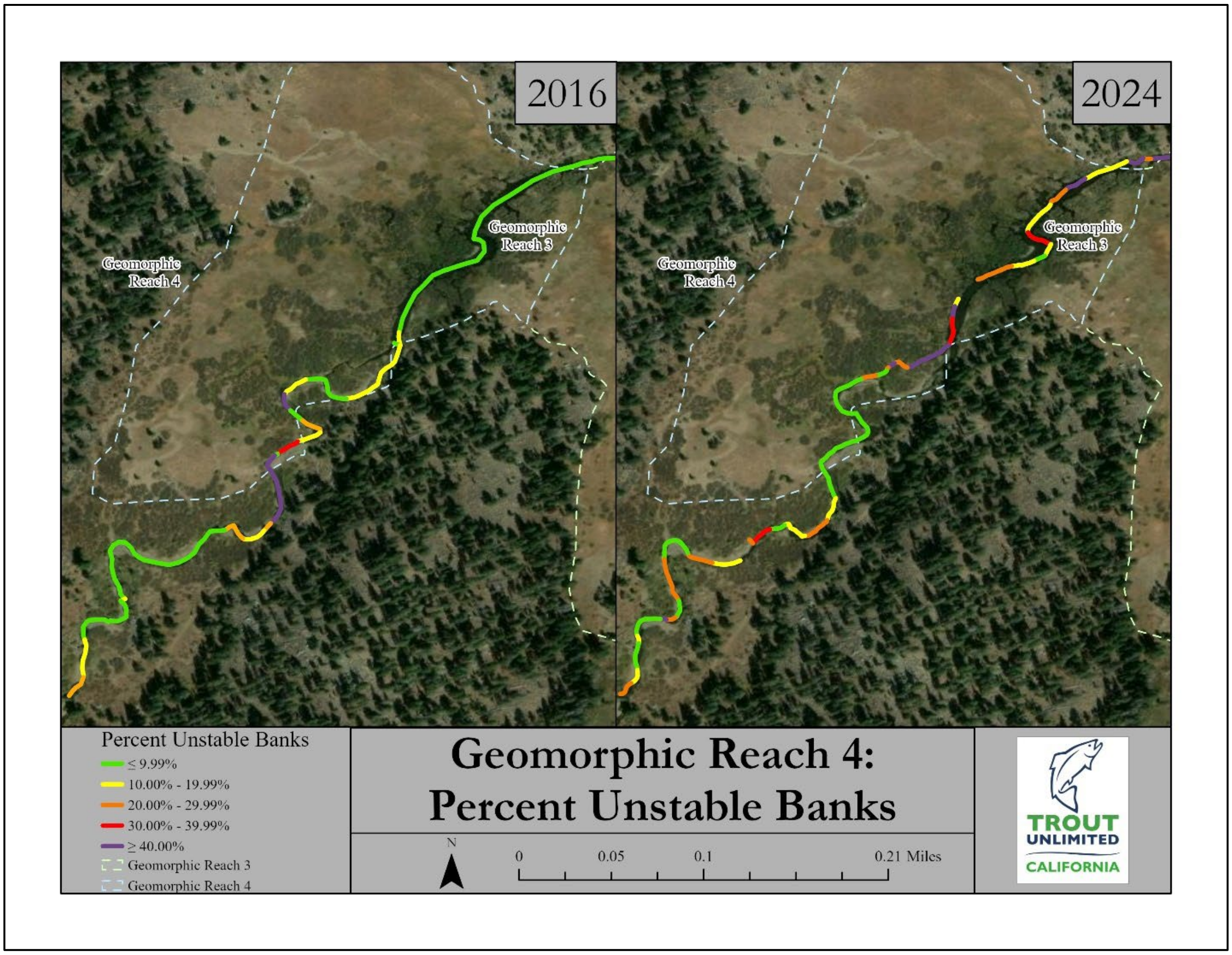

Figure 25. Detail of Bank Stability in GM4 in 2016 vs. 2024 by channel unit. Blue indicates <10% unstable banks in the unit, green indicates between 10% and 19.99% unstable banks in the unit, yellow indicates between 20% and 29.99% unstable banks in the unit, red indicates between 30 and 39.99% unstable banks in the unit, and purple indicates >40% unstable banks in the unit. Note the increased bank instability in this reach due to the loss of the large beaver dam that was present in 2016 as well as the altered flow path.

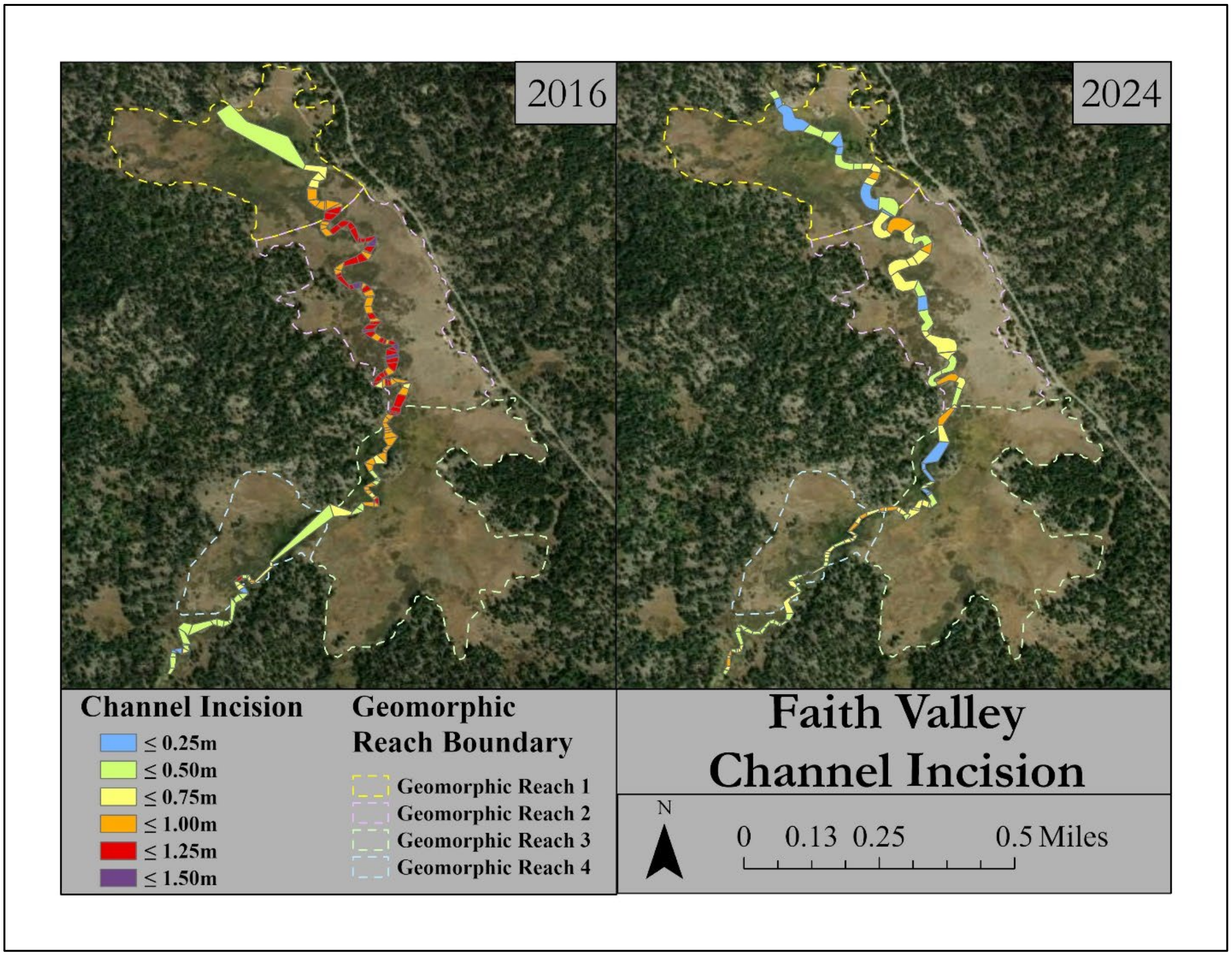

Figure 26. Overview of Channel Incision/entrenchment changes in Faith Valley pre-and post-restoration treatment. The decreases in entrenchment below the historic floodplain are significant throughout the treatment area.

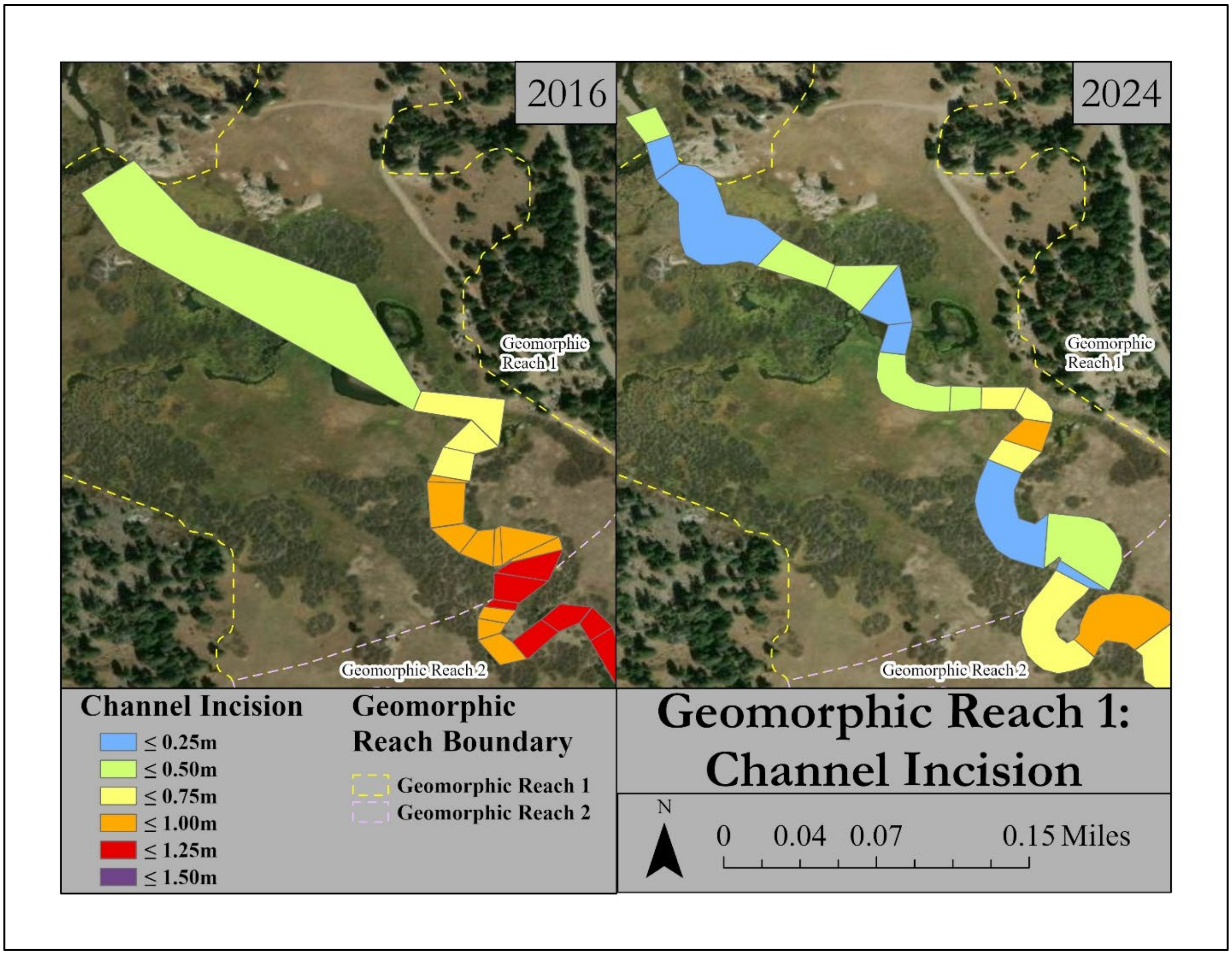

Figure 27. Detail of GM1 changes to channel incision and width pre-treatment (2016) and post-treatment (2024). The overall trajectory is for decreased distance to the historical floodplain surface, i.e., decreased entrenchment.

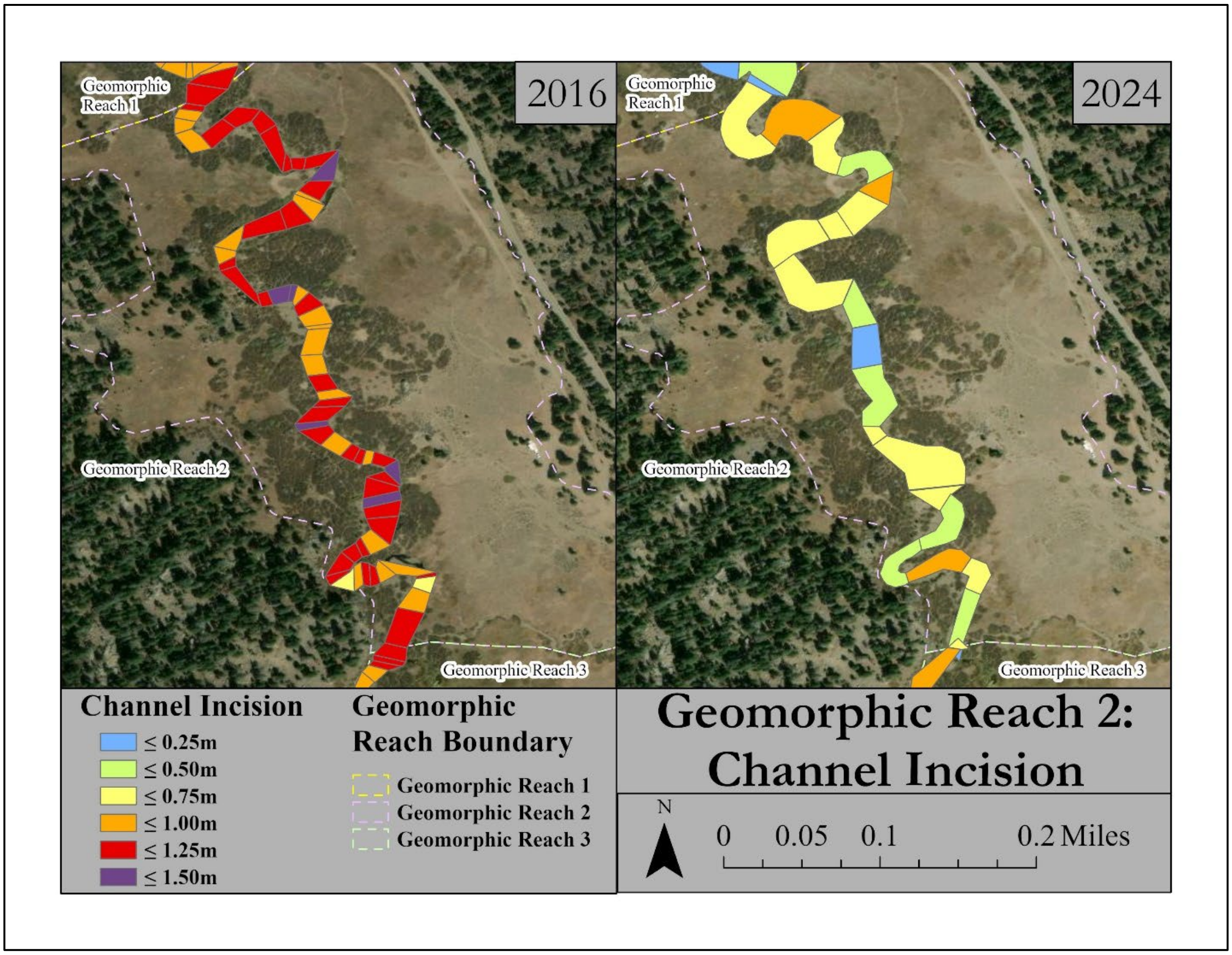

Figure 28. Detail of changes to channel incision and width pre-treatment (2016) and post-treatment (2024). This reach contained the highest number of structures and demonstrated a positive response.

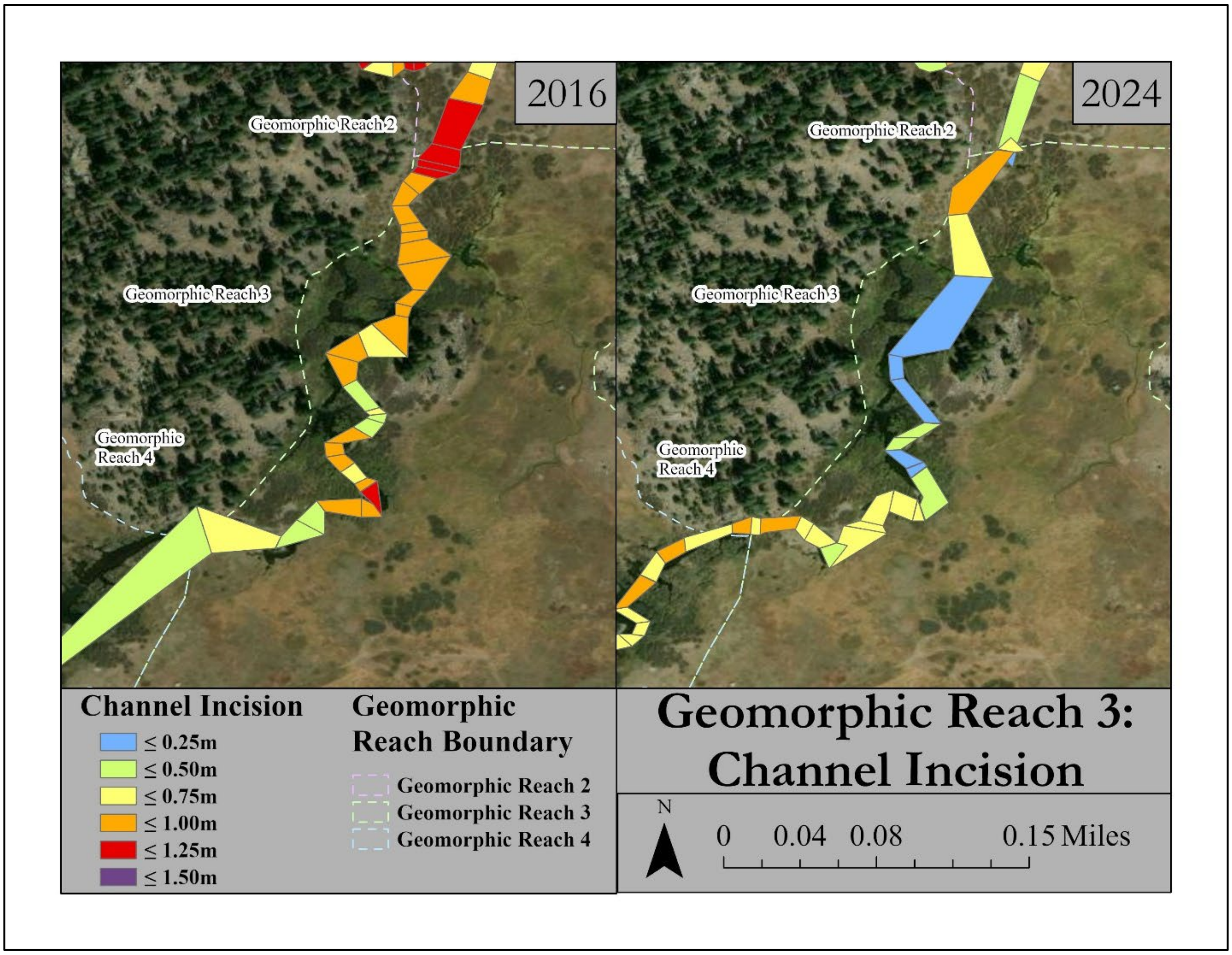

Figure 29. Detail of Channel incision and width in Reach GM3. Structures were built in the downstream section only in this reach (stream flows north). Channel aggradation also occurred from a redistribution of sediments from upstream beaver dam breaches but decreased in the areas around the former dams. This is a great example of the dynamics associated with the build and breach cycles at Faith Valley.

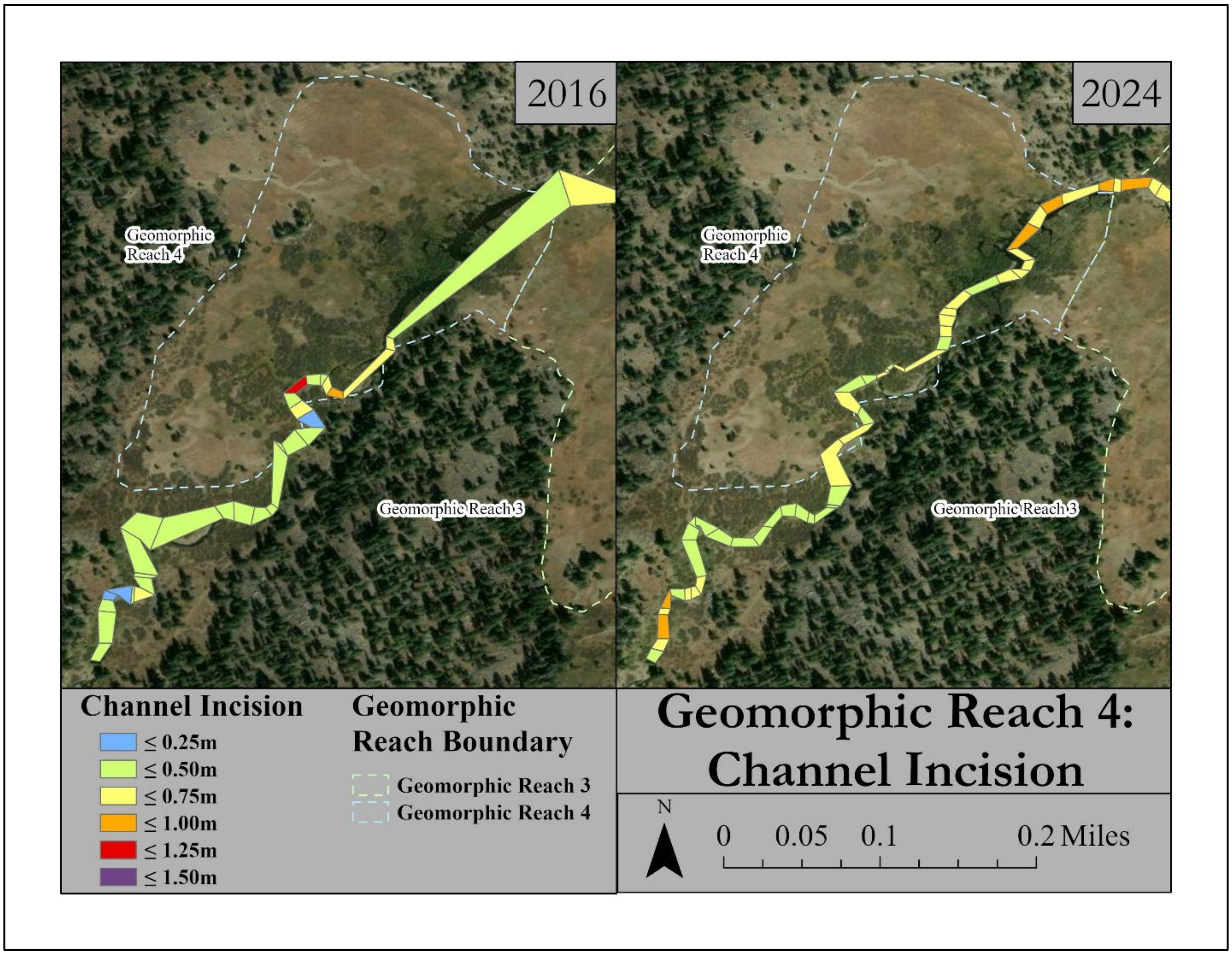

Figure 30. Detail of Channel Incision and width in GM4. The loss of the primary dam at the downstream end of the reach drove the shift of the channel back to a more narrow and more incised state.

Appendix 2: Photos Labeled with geomorphic reach, year and channel unit.

Figure 31. Beaver Dam at the base of GM1 in 2016. This dam backed water up for hundreds of meters and created a large area of inundation laterally that resulted in a tremendous vegetation response throughout the valley bottom. This dam did not survive the winter of 2016/2017 GM1_2016, SDBV1.

Figure 32. This area in GM1 was more fully inundated in 2016 from the large beaver dam at the base, now elevation is controlled by the downstream Grade control structure. While water table is still high, there is less inundated habitat but full floodplain connectivity. Note the dam remnant perched above current water surface on the point. GM1_2024, SSLS2.

Figure 33. The grade control structure built at the downstream end of Faith Valley. The vertical logs coming out of the structure are intended to facilitate future beaver dams or beaver dam analogs by creating a sturdy anchor point. GM1_2024, FTRF1

Figure 34. The area of inundation created by the grade control structure at GM1_2024, FTRF1. While less than the natural dam in 2016, it is unlikely to blow out and will allow for greater aggradation in this reach over time.

Figure 35. Area of incision and bank instability. Note the chunk of sod that has fractured off the bank. There is a beaver dam remnant immediately downstream that contributed to bank erosion when it flanked and eroded laterally. GM1_2016, SSLS8.

Figure 36. Just downstream of the previous photo in 2024 a BDA has been placed to aggrade the channel. The cutbank in figure 35 is visible in this image in the distance. GM1_2024 SDBV7

Figure 37. A cutbank still actively eroding. The historic floodplain is still largely disconnected from the stream GM2_2016. Near SSLS17.

Figure 38. The same area in 2024 post-treatment. There is still some exposed unstable bank, but it is shorter than pre-treatment. The numerous BDAs in this section trap sediment, increase pool depth and inundated area. The flows were approximately the same in both photos. GM2_2024, SDBV17

Figure 39. Looking downstream at the steep high right cutbank and dry vegetation. This section is the most disconnected in Faith Valley Meadow. GM2-2016, SSLS18

Figure 40. The same section of channel as in Figure 35 post-treatment. A complex of structures drives sediment deposition, a higher water table, deeper pools, and slower velocities. Emergent vegetation is beginning to take hold on the left bank gravel bar. Note the partial span of the middle structure which was breached in 2023. It continues to do work in the channel despite being breached. GM_2024, SDBV17

Figure 41. A deep scour pool in 2016 where the channel touches the edge of the moraine and large boulders appear. Note stable well-vegetated banks from earlier beaver dam, now breached. GM2_2016, SSMC22

Figure 42. The same scour pool in 2024. Note the boulder visible in the picture above is now nearly submerged by the effects of a downstream BDA structure. Wetted width and pool depth have increased. Distance from the channel to the historical floodplain is reduced, bringing groundwater closer to the rooting zone of floodplain vegetation. GM2_2024, SDBV20.

Figure 43. A highly distinctive boulder in the channel in 2016 looking downstream with the remnants of a beaver dam creating a riffle crest. Note the other boulders in the background and exposed gravel bar. GM2_2016, SSMC28

Figure 44. The same unit as Figure 43 in 2024 looking downstream at a BDA that has covered the boulders and gravel bar with water. GM2_2024, SDBV23

Figure 45. Looking upstream at a narrow wetted area with gravel deposits in channel. Note the standing dead tree on the bank on the right. GM2_2016, FTRF36

Figure 46. The same area post-treatment. There is now a complex of 5 BDAs in this section working together as a complex to provide redundancy. Note that the material on the dam in the fore is beginning to sprout, this is becoming a living biogenic structure. Emergent vegetation at the margins is colonizing the fine sediments behind the dam. The dead tree on the bank remains standing but we hope that it eventually falls into the channel to add some large woody debris. GM2_2024, SDBV31

Figure 47. A natural pool made from a remnant beaver dam in 2016. The area shows lots of indications of earlier dams and beaver associated geomorphology. GM3_2016, SDBV43

Figure 48. The same area post-treatment in 2024 with a large BDA creating a lot of inundated area upstream. There are active beavers in this area that have been adding onto the BDA and creating additional dams in the side channel created by the BDA. GM3_2024, SDBV34

Figure 49. Breached Remnant beaver dam in 2016. The highwater mark from when the dam was intact is clearly visible. Even remnant dams provide structure and habitat complexity. GM3_2016, SSMC 48

Figure 50. Beaver dam remnants and old beaver channels revealed by the loss of the large dam pictured in Figure 49. Remnants cover this entire reach indicating that beavers continuously build dams in this area. GM4_2016, FNRN50

Figure 51. Massive beaver dam at the split between GM3 and GM4 in 2016 creating more than 5 acres of Stage 0 inundated habitat. This dam blew out in 2017. GM4_2016, SDBV55

Figure 52. The former beaver pond (SDBV55) in 2024 after the dam breached revealing a complex of dam remnants and exposed beaver tunnels and lodges. The stream went back to Stage 5-7 with an entrenched channel and exposed unstable banks. GM4_2024, FTRF15

Figure 53. Drowned trees and a fully connected floodplain in the large beaver dam pond. GM4_2016, SDBV55

Figure 54. Beavers extended this large dam for 90m across the floodplain, inundating the entire valley bottom. Multiple flow paths from the dam worked across the valley. However, headcuts were forming on the side channels when they returned to the mainstem below due to dam breaches downstream. GM4_2016, SDBV55

Figure 55. Upstream of the large beaver pond area the stream becomes increasingly steeper and more confined with larger average substrate size and a narrower valley bottom. More alders are found in this reach due to the coarser sediment. There were also more fish present in this zone than in the lower reaches of Faith Valley. GM4_2024, FTRF33

Figure 56. The final unit of GM4 where large wood recruitment drives sediment sorting, scour, and deposition. The End. GM4_2024, FNRN39

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