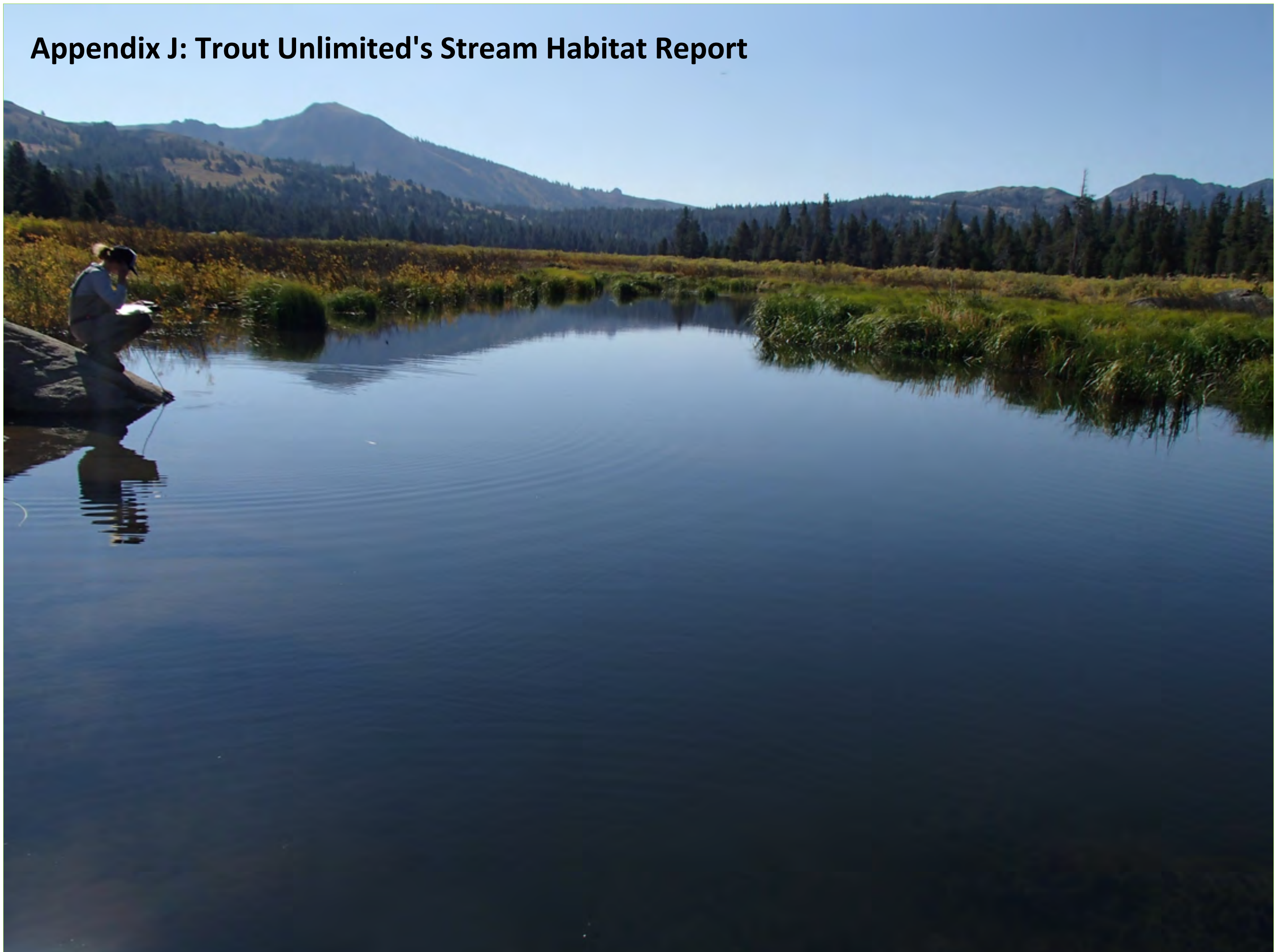
Appendix J: Trout Unlimited's Stream Habitat Report



Faith Meadow Baseline Stream Habitat Condition Inventory and Assessment

West Fork Carson River, Alpine County, California

Prepared by Sabra Purdy, Trout Unlimited, 2018

Report Commissioned by American Rivers from a Grant from the National Fish and Wildlife Foundation

Introduction

Montane meadows are among the most vulnerable and sensitive ecosystems in the Sierra Nevada and have suffered disproportionately from the historic land uses. The result has been widespread degradation of meadows including major erosion, unstable stream banks, entrenched and incised channel, dropped water tables, conversion to upland vegetation types, loss of ground water storage, loss of floodplain access, reduced wetland and meadow habitats, decreased biodiversity, changes in hydrology, channel geomorphology, and in-stream habitat.

The losses of wetland and montane wet meadow habitats in the Sierra Nevadas have been profound and resource managers, academic institutions, non-profits, and other stakeholders have identified meadow restoration as a management priority and numerous cooperative efforts have been directed towards advancing the science of meadow restoration and increasing the number, pace, and benefits of restored meadows(NFWF 2010; Henery et al. 2011; Merrill et al. 2007; Moyle, Israel, and Purdy 2008; Purdy, Moyle, and Tate 2012; Viers et al. 2013; Weixelman et al. 2011).

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 upper Carson River has an history of intensive livestock grazing, timber harvest, and mining, all of which have contributed to significant anthropogenic impacts to the watershed. The West Fork Carson River is a significant river and while mid-summer baseline flows average 80 cfs, in wet years such as 2016/2017 flows can reach well over 2000 cfs. The dynamic power of such high flows in an incised and entrenched channel can create mass erosion in soft and vulnerable meadow alluvium. Substrate in faith meadow tends to be dominated by sand and gravel with some areas where glacial eratics of much larger size have been deposited. Beavers are present and very active within the system but dams seldom persist in any given location for more than a few years since there is nothing to anchor them and they are vulnerable to high flows. Despite the impacts to the system, Faith Meadow retains a significant amount of functionality, though some functions are limited by its condition. It is extremely aesthetic and sees heavy recreational use and is highly visible to the public. Any projects that endeavor to improve the habitat conditions at Faith Meadow will be under 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.

This study was conducted as an effort to gather 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. This data provides a strong basis to inform restoration design and provide baseline information to which the outcomes of restoration efforts can be quantitatively compared.

Figure 1.Topo Map depicting Faith Meadow showing the location of stream channel surveys in red.

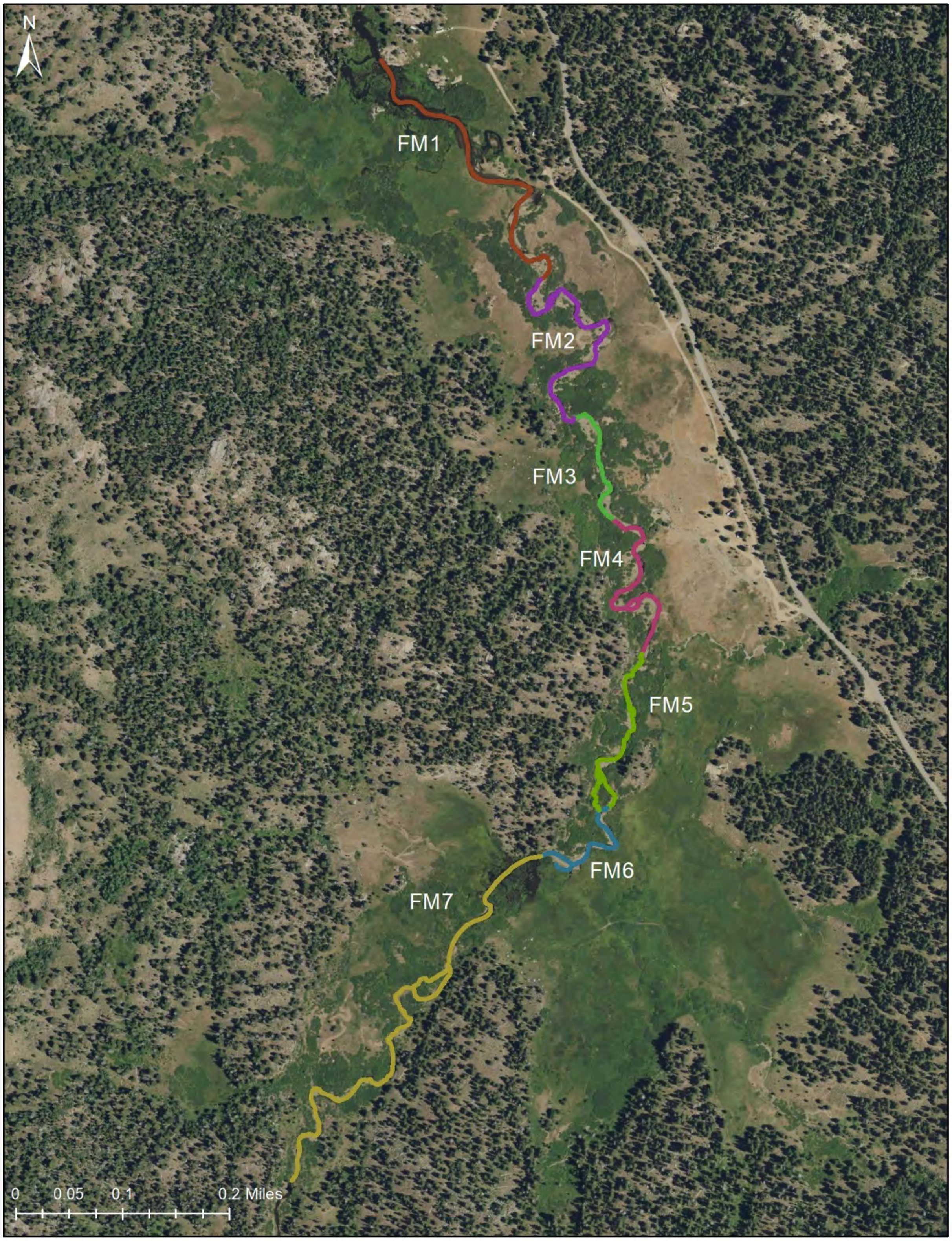


Figure 2. Map of the 7 survey reaches in Faith Valley meadow starting downstream at FM1 and ending at FM7 at the upper (south) end of the meadow.

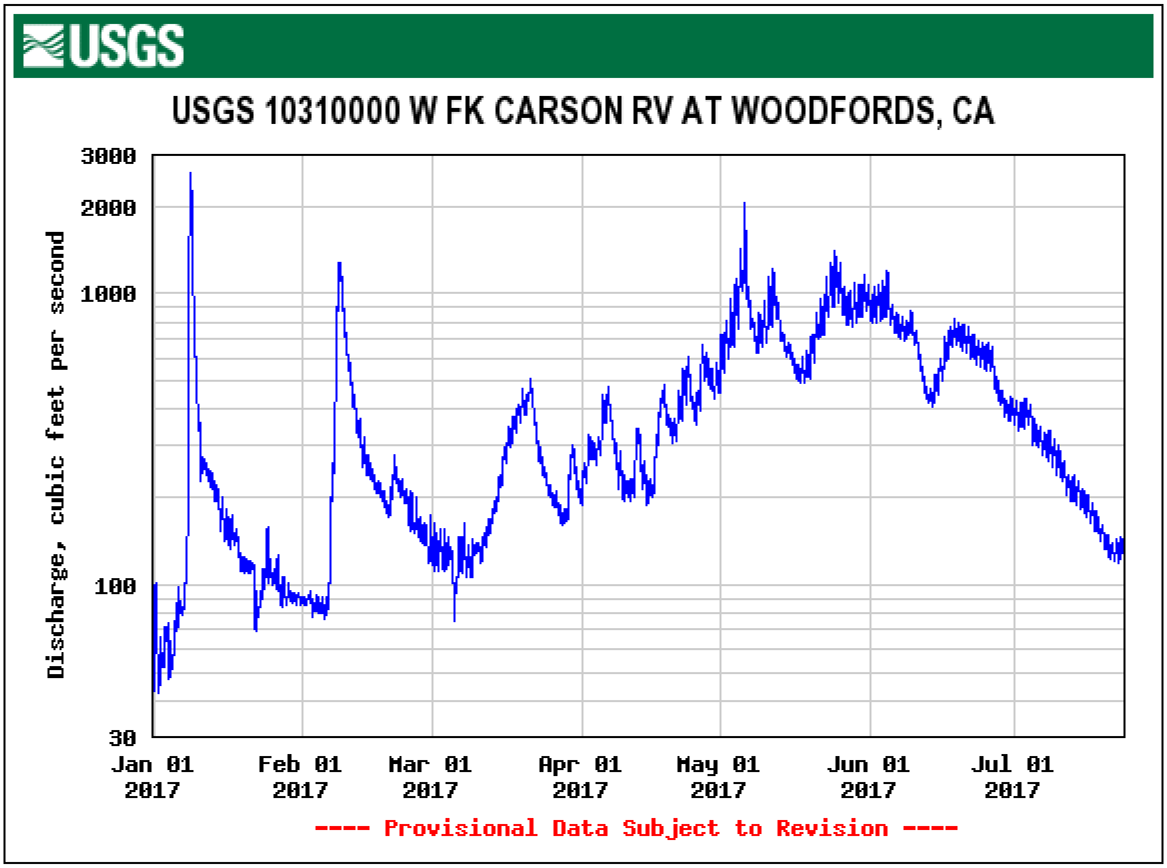


Figure 3. Flow data for the East Fork Carson River at Woodfords. This location is ~13 miles downstream of Faith Meadow with a number of tributaries contributing to flow, but provides a reference for the high flow events that can occurred in 2017, a heavy precipitation year. Source: USGS National Water Information System.

Methods

Baseline monitoring and habitat condition assessment was conducted in 2016 by Sabra Purdy and field assistant, Erin Smith, with technical and administrative support from Rene Henery and Kurt Fesenmeyer of Trout Unlimited. We used a modified version of the USDA Forest Service Stream Inventory Protocol (USFS 2010). This protocol centers on quantifying the instream habitat types that reflect the condition of the stream and drive the ecological conditions that support biodiversity and maintain biotic community structure. The stream is surveyed from downstream to upstream. Each instream habitat unit is identified and categorized in a hierarchical naming convention according to the USFS protocol (Table 1). 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
- GPS waypoint at the bottom and top 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)
- Woody debris count
- Water Quality parameters (Temperature, Dissolved Oxygen, % Oxygen saturation, pH, Electroconductivity)
- Percent shade cover at upstream end of each unit (solar pathfinder)
- Fish Presence
- 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, hardwoods, and conifers by type)

In addition to collecting this data at the channel unit scale, we identified and georeferenced active headcuts, the location and condition of beaver dams and beaver use and conducted visual encounter surveys for reptiles and amphibians.

Table 1. Hierarchy of Channel Unit Types, Coding, and Description

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
		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

Results

We broke Faith Meadow into 7 reaches over the course of surveys ranging from 251 to 840 m (Table 2). Each reach took approximately 1 day to survey. Reach lengths varied, but long reaches generally contained beaver dams that caused extensive areas of inundation making for a large single channel unit. Reach FM1 was 532 m long and consisted of 88.3% Slow Water habitats. Within the Slow Water habitat types, 39.8% were scour pools (either Lateral Scour, Mid-Channel Scour, or Plunge Pools) and 48.5% were dam pools created by either Beaver dams or debris dams (almost exclusively beaver dams). Reach FM1 contained only 11.7% fast water habitats of which 5.7% were turbulent (Riffles) and 6.0% were non-turbulent (Runs). FM1 contained 14 channel units. There were 3 riffles, 2 runs, 1 beaver dam pool, 1 mid-channel scour pool, and 7 lateral scour pools. A tributary entered the first unit on the left bank.

FM2 was 462.1 m long. Slow water habitats accounted for 65.5% of the reach and all were scour pools of some type. Fast water habitats made up 29.4% of the reach of which 23.7 % were riffles and 23.7% were runs. FM2 contained 24 channel units. There were 10 lateral scour pools, 3 mid-channel scour pools, 2 runs, 8 riffles, and 1 side channel.

FM3 was 260.4 m long with 71.0% slow water habitats all of which were scour pools (though there was evidence in many places of beaver dams being present in the recent past but blowing out in high flow events which could change a dam pool into a scour pool). Fast water habitats made up 29.0% of the reach, all of which were riffle habitats. FM3 contained 15 channel units. There were 5 mid-channel scour pools, 4 lateral scour pools, and 6 riffle units.

FM4 was 372.5 m long with 42.8% slow water habitats and 51.8 fast water habitats. All slow water habitats were scour pools. Fast water habitats were 25.8% riffles and 26.0% runs. FM4 contained 26 channel units. There were 7 lateral scour pools, 2 mid-channel scour pools, 7 runs, 9 riffles, and 1 side channel.

FM5 was 397.1 m long with 38.0% slow water habitats, 46.9% fast water habitats, and 15.1% other habitat types. Slow water units consisted of 30.2% scour pools and 7.8% dam pools. Fast water units consisted of 30.6% riffles and 16.3% runs. FM5 contained 25 channel units. There were 2 convergence pools, 2 mid-channel scour pools, 1 beaver dam pool, 2 lateral scour pools, 1 plunge pool, 8 riffles, 4 runs, 3 tributaries, and 2 side channels.

FM6 was 251.5 m long with 42.7% slow water habitats, 42.1% fast water habitats, and 15.2% other channel habitat types. The slow water units were all scour pools. The fast water units consisted of 19.1% riffles and 4.8% runs. FM6 contained 12 channel units. There were 4 lateral scour pools, 2 mid-channel scour pools, 1 run, 3 riffles, 1 fast water unit (mostly run but with some turbulent sections), and 1 side channel.

FM7 was 839.5 m long with 56.8% slow water habitats, 37.0% fast water habitats, and 6.2% other channel habitat types. The slow water habitats were 31.7% scour pools and 25.0% dam pools. The fast water units were 35.7% riffles and 1.3% runs. FM7 contained 32 channel units. There was 1 (very large) beaver dam pool, 12 lateral scour pools, 5 mid-channel scour pools, 12 riffles, 1 run, and 1 side channel.

Table 2. Channel Habitat Metrics for all 7 reaches at Faith Meadow

Channel Habitats	**FM1**	**FM2**	**FM3**	**FM4**	**FM5**	**FM6**	**FM7**
Reach Length	532.0	462.1	260.4	372.5	397.1	251.5	839.5
% Slow Water Units by Length	88.3	65.5	71.0	42.8	38.0	42.7	56.8
% Fast Water Units by Length	11.7	29.4	29.0	51.8	46.9	42.1	37.0
% Scour Pools	39.8	65.5	71.0	42.8	30.2	42.7	31.7
% Dam Pools	48.5	0.0	0.0	0.0	7.8	0.0	25.0
% Turbulent Units (Riffles)	5.7	23.7	29.0	25.8	30.6	19.1	35.7
% Non-Turbulent Units (Runs)	6.0	5.7	0.0	26.0	16.3	4.8	1.3
% Other Habitat Types	0	5.1	0	5.4	15.1	15.2	6.2
Tributary Count	1	0	0	0	3	1	0
Side Channel Count	0	1	0	1	2	1	1

The lengths of types of channel units as well as their relative frequency in the reach are a good indicator of gradient and habitat heterogeneity. Fast water units act as the grade control structures in a meadow (Rosgen 1996). They will occur with greater frequency or be longer as gradients increase. In low gradient systems, pools tend to dominate, often with just a small "crest" at the downstream end of the pool that separates it from the next pool. If slow water units average longer or occur more frequently than fast water units such as is distinctly the case in FM1, FM2, FM3 and FM7, this part of the reach is very low gradient (generally <2% slope). As the ratio of lengths between fast water and slow water units is more equivalent, the slope is increasing compared to other reaches which was the case in FM4 and FM5. FM6 was the highest gradient reach with the average length of slow water units being significantly less than the average length of fast water units.

Bankfull is the average maximum annual flow at a return interval of 1.5 years and is often synonymous with the "ordinary high water mark" (Rosgen 1996). Though large flood events often transport large amounts of sediment and can cause drastic changes in the stream channel geomorphology, it the bankfull flow that mobilizes bed material and governs the majority of sediment transport and channel formation due to the frequency at which those flows occur (Rosgen 1996). In an intact meadow system with minimal erosion and incision impacts, bankfull elevation is the elevation at which the stream leaves the channel and engages with the floodplain. In incised or entrenched systems, bankfull elevation and the historic floodplain terrace are not the same and bankfull is an indication of the new, inset floodplain and stage regime. The bankfull elevation is identified by a number of indicators. These include terracing, a change in bank angle, a shift from hydric to mesic or upland vegetation, undercut banks, scour lines, exposed plant routes, the presence of a floodplain, and other marks made by the common high-water line. This is a useful indicator to base measurements on because it remains essentially the same over the short term, whereas wetted widths and depths vary widely with changes in flow. This also allows us to identify and measure channel characteristics in dry channels.

The table below shows the minimum, maximum, and average bankfull widths, minimum, maximum and average bankfull depths (from cross sections), minimum, maximum, and average wetted widths, and average bankfull elevation above the surface of the water. These numbers are helpful in generating understanding of the channel geomorphology that is created by consistent bankfull flows and can help inform restoration design process. Reaches with wider bankfull average and maximum widths generally contained large beaver dam pools that broadly inundated the adjacent floodplain (FM1 and FM7). For all other units (FM2, FM3, FM4, FM5, FM6), bankfull width was fairly consistent for both fast and slow water units with the fast water units generally averaging wider than the slow water units (with the exception of FM5). Bankfull elevation above the surface of the water ranged from 0.19 m to 0.29 m. The two reaches with large intact beaver dams (FM1 and FM7) at the time of our surveys had an increased water surface elevation due to those dams which decreased the difference between the bankfull elevation and the surface of the water (0.23 m and 0.19 m respectively), whereas reaches without large channel spanning beaver dams ((FM2, FM3, FM4, FM5, FM6) consistently ranged from 0.26 m to 0.29 m above the surface of the water.

Table 3. Channel Unit average lengths, bankfull widths, bankfull depths, wetted widths, and bankfull height above the surface of the water.

Channel Unit Dimensions	**FM1**	**FM2**	**FM3**	**FM4**	**FM5**	**FM6**	**FM7**
Avg. Length Slow Units	52.2	23.3	20.6	17.7	18.9	17.9	26.5
Avg. Length Fast Units	12.5	13.6	12.6	12.1	15.5	21.2	23.9
Avg. Bankfull Width Slow	14.0	6.4	7.2	7.3	7.6	8.8	9.0
Max. Bankfull Width Slow	40.0	8.5	10.1	11.6	10.5	11.9	40.0
Min. Bankfull Width Slow	3.8	3.6	5.4	4.2	6.0	4.3	5.2
Avg. Bankfull Width Fast	14.7	8.3	8.8	8.4	6.2	7.9	8.2
Max. Bankfull Width Fast	21.9	12.0	10.9	13.1	7.9	10.6	12.3
Min. Bankfull Width Fast	9.7	5.3	6.7	4.1	3.7	3.5	5.0
Avg. Wetted Width Slow	10.9	4.7	6.4	5.7	6.6	5.7	7.3
Max. Wetted Width Slow	40.0	7.6	9.3	8.3	9.0	8.4	40.0
Min. Wetted Width Slow	4.4	2.7	4.9	3.5	4.3	2.5	2.9
Avg. Wetted Width Fast	4.3	2.5	4.1	2.9	3.2	3.7	5.0
Max Wetted Width Fast	5.7	4.5	6.1	4.4	5.0	7.3	7.1
Min. Wetted Width Fast	3.2	1.4	2.5	1.6	1.8	1.7	2.5
Avg. Bankfull Depth Slow	0.7	0.8	0.7	0.8	0.8	0.7	0.7
Avg. Bankfull Depth Fast	0.2	0.3	0.3	0.3	0.3	0.3	0.3
Avg. Max. Bankfull Depth	1.0	0.8	0.9	0.8	0.8	0.8	0.9
Avg. Max. Bankfull Depth Slow	1.3	1.1	1.1	1.2	1.1	1.1	1.2
Maximum Bankfull Depth Slow	2.5	1.7	1.4	1.4	1.4	1.4	3.0
Avg. Max. Bankfull Depth Fast	0.5	0.5	0.6	0.6	0.6	0.5	0.6
Max Bankfull Depth Fast	0.7	0.7	0.8	0.8	0.8	0.6	0.8
Average Bankfull Height above Water	0.23	0.29	0.28	0.29	0.26	0.29	0.19

Like almost all meadows in the west, Faith Valley meadow's stream channel has significantly incised since pre-settlement times and in most of the meadow, the stream bank erosion has disconnected the stream from the floodplain in normal years and can only access the floodplain in extremely high flow events. This incision or entrenchment is demonstrated by the difference in elevation between the historic floodplain and the current bankfull elevation. All of the reaches we surveyed in Faith Valley showed significant incision ranging from an average of 0.4 m to 1.1 m with a maximum elevation of 1.5 m above the bankfull indicator. The width from terrace to terrace of the historic floodplain ranged from 21.0 m in FM6 (the most confined reach) to 45.0 m in FM1. These measurements taken together provide a cross-sectional area of the channel erosion that has taken place between the time the lip of the historic floodplain was bankfull to the present. Unstable bank metrics are closely related to the difference between the historic floodplain and bankfull and often the height of instability is equal or very close to the height of the floodplain. However, an entrenched channel is not necessarily actively eroding, though it continues to drive other problems of hydrologic connectivity. We quantified the linear length of unstable banks in each unit and calculated that as a percent of bank length (unit length x 2) in the reach. Percentages ranged from 8.7% of the reach (FM7) to 34.7% of the reach (FM2). Average height of unstable banks ranged from 0.4 m (FM7) to 0.9 m (FM2). We calculated the surface area of exposed unstable banks (m^2/m) in each reach which ranged from 0.1 m^2/m (FM7) to 0.6 m^2/m (FM2). These metrics consistently point to FM2 being the most degraded reach in the meadow in terms of lack of floodplain connectivity and ongoing active erosion. Flood prone width is a measure of the width of commonly inundated parts of the floodplain above bankfull. This is calculated as the width measured at a depth of twice the maximum bankfull depth in fast water units. This formula is often corroborated by geomorphological features such as terraces, a change in bank angle, a change in vegetation, presence of flood deposits and detritus, scour lines, or a combination of indicators.

Table 4. Historic Floodplain elevation, width between historic floodplain terraces,

Historic Floodplain Access and Unstable Banks	**FM1**	**FM2**	**FM3**	**FM4**	**FM5**	**FM6**	**FM7**
Average Historic Floodplain above Bankfull	0.9	1.1	1.1	1.1	0.8	0.6	0.4
Max. Historic Floodplain above Bankfull	1.1	1.4	1.5	1.4	1.1	1.1	0.7
Average Width at Historic Floodplain Terrace	27.6	18.7	19.8	20.9	17.2	12.6	14.9
Max. Channel Width at Historic Floodplain	45.0	27.0	27.0	34.0	35.0	21.0	40.0
Avg. Flood Prone Width	23.5	14.2	14.4	14.7	13.0	11.4	34.2
Length Unstable Banks (m)	225.2	304.3	61.5	186.8	117.5	142.0	137.8
% Unstable Banks	21.2	34.7	11.8	26.5	17.4	33.3	8.7
Surface Area of Unstable Banks (m^2/m)	0.3	0.6	0.2	0.4	0.2	0.4	0.1
Avg. Height Unstable Banks above Bankfull	0.7	0.9	0.7	0.7	0.6	0.5	0.4
Max. Height Unstable Banks above Bankfull	1.1	1.3	1.0	1.1	0.9	0.9	0.9
Surface Area of Unstable Banks (m^2/m) Slow	0.3	0.6	0.2	0.6	0.2	0.2	0.1
Avg. Height Unstable Banks above Bankfull Slow	0.8	0.9	0.7	0.7	0.6	0.5	0.4
Max. Height Unstable Banks above Bankfull Slow	1.1	1.2	1.0	1.1	0.9	0.7	0.6
Surface Area of Unstable Banks (m^2/m) Fast	0.5	0.6	0.2	0.3	0.2	0.7	0.1
Avg. Height Unstable Banks above Bankfull Fast	0.6	0.9	0.5	0.7	0.6	0.6	0.5
Max. Height Unstable Banks above Bankfull Fast	1.0	1.3	0.7	1.1	0.9	0.9	0.9

Faith Valley meadow contains few areas where the forest encounters the floodplain. It is mostly open herbaceous cover and riparian willows along the channel margins. Consequently, there is little in the way of large woody debris inputs into the system except in FM7, the uppermost reach that is closest to the forest above. Overall, the stream substrate in Faith Valley was dominated by sand and gravels. Slow water units had a higher proportion of sand, and generally finer gravel, while fast water units had a much higher proportion of gravel to sand. Larger substrate sizes occurred sporadically and were generally associated with the presence of moraines adjacent to the channel such as FM5 and FM7 where there were boulders in and along the channel in higher numbers than in FM1, FM2, FM3, FM4, and FM6. The predominance of fine and small sediments in Faith Meadow means that the bedload is highly mobile, unconsolidated, and prone to erosion. This is an important factor in restoration design since the installation of hard structures such as boulders, log barbs or rip rap has a high potential to cause localized scouring and possible erosion in undesired locations.

Table 5. Woody Debris and Substrate composition all units.

Woody Debris and Substrate	**FM1**	**FM2**	**FM3**	**FM4**	**FM5**	**FM6**	**FM7**
Large Woody Debris Count	0	0	0	0	0	0	3
% Clay/Silt/Sand Slow Units	41.7	42.8	40.0	43.0	32.5	44.2	25.2
% Gravel Slow Units	51.4	54.8	55.2	51.8	43.8	51.3	37.5
% Cobble Slow Units	1.9	0.4	0.0	0.0	7.1	4.5	28.9
% Boulder Slow Units	3.9	2.0	4.8	5.2	16.6	0.0	7.8
% Bedrock Slow Units	1.1	0.0	0.0	0.0	0.0	0.0	0.6
% Clay/Silt/Sand Fast Units	19.0	21.0	19.0	21.3	17.1	36.8	8.2
% Gravel Fast Units	81.0	76.5	77.1	76.8	57.6	59.4	41.2
% Cobble Fast Units	0.0	1.1	0.3	0.3	15.1	3.2	42.7
% Boulder Fast Units	0.0	1.4	3.6	1.8	10.3	0.6	7.8
% Bedrock Fast Units	0.0	0.0	0.0	0.0	0.0	0.0	0.2

Water quality measurements in Faith Valley were taken with a handheld YSI multimeter that cataloged water temperature, dissolved oxygen, percent oxygen saturation, pH, and conductivity. All of the water quality parameters we measured were well within the tolerances for temperature, dissolved oxygen, pH, and conductivity for species such as salmonid fishes and sensitive macroinvertebrates such as those from the orders of Ephemeroptera, Plecoptera, and Trichoptera—the mayflies, stoneflies, and caddisflies whose presence is used as an indicator of water quality. Average instream temperatures ranged from 8.7 °C (FM7 in early October) to 16.5 (FM1 when surveys commenced in September). Temperature limits for salmonid fishes are commonly agreed upon as 22 °C. Some species can tolerate higher temperatures for short periods of time, though there may be sub-lethal impacts to metabolic functions, feeding, predator avoidance, and breeding (Moyle 2002; Viers et al. 2013; Viers and Rheinheimer 2011; Kiernan and Moyle 2012). Oxygen saturation parameters for salmonid species and sensitive macroinvertebrates suggest a minimum of 4 mg/L (mean preferred dissolved oxygen is 6.5 mg/L) with fishes showing active avoidance of areas less than 5 mg/L, and lethal effects at 3 mg/L (Kemker 2013). Most salmonid species eggs will die if dissolved oxygen gets below 6 mg/L. Average pH ranged from 6.8 to 7.3 which is very close to neutral and should have no negative impacts on fishes at any stage of development (Moyle 2002). Conductivity is a measure of the dissolved conductive mineral levels in the water from dissolved salts and inorganic materials such as alkalis, chlorides, sulfides and carbonate compounds (Kemker 2013). Conductivity levels were very low ranging from 27.3 µS to 71.6 µS typical of a clean, headwater stream with granitic and volcanic parent material. Typical values for snowmelt water are ~2-42 µS while freshwater streams typically range from 100-1000 µS showing demonstrating the snowmelt and groundwater origins of the West Fork Carson River (Kemker 2013).

Slope was calculated using GIS techniques and may have a higher level of error than direct field measurements. Slope is calculated as a percentage. Sinuosity was calculated from aerial imagery and is the ratio of stream channel length to down-valley distance. Many meadow streams show decreased sinuosity from historic conditions which means that available instream habitat is reduced, riparian habitat is reduced, stream velocity can be higher, and shear stress and potential for erosion can be higher. Intact and highly functional meadow ecosystems typically have very sinuous channels, while impacted meadows may become straighter due to human interventions, captured cow paths, and roads and culverts.

Table 6. Water Quality Metrics, Slope, and Sinuosity.

Water Quality Metrics, Slope, and Sinuosity	**FM1**	**FM2**	**FM3**	**FM4**	**FM5**	**FM6**	**FM7**
Avg. Water Temperature (°C)	16.5	15.2	13.7	14.3	12.7	12.1	8.7
Avg. Dissolved Oxygen (mg/L)	6.6	6.7	7.3	7.4	6.8	6.7	8.4
Avg. % Oxygen Saturation	68.0	67.0	70.6	72.4	64.3	62.5	72.2
Avg. pH	7.3	7.4	7.0	7.0	7.0	6.8	7.5
Avg. Conductivity (µS)	56.7	55.8	58.1	71.6	61.3	62.6	27.3

% Slope	0.8	0.1	0.7	1.3	0.4	0.0	0.0
Sinuosity (Reach length/Valley length)	1.3	2.2	2.2	1.8	1.7	1.9	1.4

We measured percent shade using a solar pathfinder in the center of the channel at the upstream end of each channel unit. Riparian shade is a measure of shade coming from riparian sources such as willows, aspens, and alders. Total shade is a measure of all shade affecting that location including conifers, mountains and hills, as well as any man-made structures that might occur such as bridges or culverts. We estimated canopy cover within 10 m of both stream banks on each channel unit. For understory species we used three general categories, sedges and rushes, grasses and forbs, and no vegetation/bare soil. These 3 categories, while simplistic, provide a good indication of soil moisture gradients and access to groundwater. As a generalization, sedges and rushes dominate in more hydric conditions with increased access to groundwater and prolonged periods of saturation. Grasses and forbs dominate in more mesic conditions where soils may be saturated temporarily during periods of high flow and snowmelt but become drier over the course of the season. Bare ground can indicate xeric soil moisture conditions, disturbance from human activities, rodents, and cattle, or the presence of rocky substrates along the channel or significant overstory canopy cover creating shade, (not considered a disturbance). This is taken into account when interpreting the data. Overstory vegetation data estimates the percent cover of all woody species found within 10 m of each channel unit on both sides of the channel. Of particular interest are willow and deciduous shrub coverage (as essential riparian bird habitat and an indicator of ground water connectivity), conifers (due to the potential for conifer encroachment on impacted meadows with lower water tables), and sagebrush (also an indicator of transformation of meadow habitat to upland types and hydrologic disconnection on the floodplain).

FM1 and FM6 had the highest percentage of sedges and rushes 30.6% and 40.6% average cover respectively. This was likely a response to inundation from functional or recently blown out beaver dams as well as increased soil moisture from tributaries and decreased entrenchment when compared to other reaches. Across all reaches, average cover of sedges and rushes ranged from 7.7% to 40.6% and averaged 22.1%. Grasses and forbs ranged from 35.4% cover (FM2) to 49.8% cover in FM7 and averaged 43.0% across all reaches. FM7 became increasingly rocky and confined between moraines as we went upstream, reducing the flood prone width and increasing the presence of upland species. Bare ground ranged from 15.3% (FM6) to 46.9% in FM2 and averaged 34.9% in all reaches. Bare ground occurs frequently on the point bars above bankfull elevation where higher flow events deposit mobilized bedload. These areas typically have some recruitment of willows, but the sediment is highly mobile, lacking in organic matter, and unconsolidated and does not tend to recruit grasses, forbs, rushes and sedges. In our observations, vigorous recruitment of herbaceous species occurs most effectively when beaver dams or debris dams are present creating slow water depositional zones that catch and accrete sediments and allow for colonization by hydric sedges, grasses, and rushes in emergent marsh-type habitat. Over time as more sediment accretes, sod begins to form and undercut banks eventually develop. Areas of point bar deposition that do not have regular long-term inundation persistently remain largely uncolonized by herbaceous vegetation.

Overstory vegetation was dominated by riparian willows ranging from 28.6% cover in FM4 to a high of 60.9% in FM3 with an average of 40.4% cover across all reaches. Conifer cover was limited largely to areas where the stream channel got close to a lateral or terminal moraine, though young conifer recruitment was occurring along stream margins in some locations. Conifer cover ranged from 0.3% in FM6 to 3.9% in FM7 with an average of 1.4% cover across all reaches. Sagebrush cover was similarly limited indicating that there is still adequate access to ground water for herbaceous species to maintain in most of the reaches. Like conifers, sagebrush cover also increased with proximity to moraines due to the increase in elevation from groundwater. Sagebrush cover was 0% in FM1, FM2, FM3, FM4, and FM6. It was 0.2% in FM5 and 1.7% in FM7. Outside the 10 m riparian zone, sagebrush occurred regularly.

Table 7. Vegetation Cover in the riparian zone and shade measurements.

Riparian Vegetation Cover and Shade	**FM1**	**FM2**	**FM3**	**FM4**	**FM5**	**FM6**	**FM7**
% Riparian Shade	0.5	1.1	7.7	3.7	2.0	0.6	1.0
% Total Shade	0.9	1.9	7.7	4.3	2.5	0.6	4.1
% Understory Sedges/Rushes	30.6	17.7	7.7	21.0	15.8	40.6	20.9
% Grasses/Forbs	37.4	35.4	49.3	38.0	47.4	44.1	49.8
% Understory No Veg/Bare Ground	32.0	46.9	43.0	41.0	36.8	15.3	29.2

% Overstory Conifers	3.8	0.5	0.4	0.4	0.7	0.3	3.9
% Overstory Deciduous (Riparian Shrubs)	38.6	30.3	60.9	28.6	43.2	35.8	45.3
% Overstory Sagebrush	0.0	0.0	0.0	0.0	0.2	0.0	1.7

Discussion

Faith Valley Meadow has some significant ecological problems including loss of hydrologic function, disconnection of the floodplain, incision and entrenchment of the stream channel, significant sediment losses from unstable, eroding banks, loss of wet meadow habitat, and non-native species invasions. However, Faith Valley continues to maintain substantial meadow function. There is a great deal of habitat heterogeneity both instream and in the riparian corridor and floodplain. Active beaver populations continually build dams here, which largely have beneficial geomorphologic and hydrologic benefits. When these beaver dams persist for a number of years, we see an elevated water table (and a likely increase in water stored in meadow soils, remarkable recovery and recruitment of hydric vegetation such as sedges, rushes and hydric grasses, multiple stream channels (increasing the overall wetted habitat in the meadow), complex habitats becoming accessible creating new habitat for aquatic species, slower velocity water and access to the floodplain which can become a refuge for fishes in high flow events, and an accretion of sediments and elevation of the stream bed over time. However, due to the larger size of the W. Fork Carson River and the incised nature of the channel, beaver dams are under a tremendous amount of shear stress, particularly at the margins of the channel where they connect to the bank. In high flow events, these dams regularly fail. When this occurs in the center of the channel, the benefits of the intact beaver dam often remain in place including narrowing the channel and slowing flow, the revegetation of the banks, and the elevation of the stream bed through accreted sediments. Post-dam failure, the habitat continues to evolve over time depending on how much and where in the dam the failure occurred. We frequently observed that dams that had failed mid-channel evolved from dam pool to scour pool. In situations where a low channel spanning dam was overtopped more broadly, we might see the accreted sediments forming a riffle crest. However, when the dam failed at the channel margins where it met the banks (end cutting), there was often a significant amount of erosion and ongoing destabilization that occurred to the banks. We also observed that the longer a dam persisted, the more stable and long term the habitat benefits.

The riparian vegetation in Faith Valley is generally in very good condition. Willows were dense, with multiple seral stages ranging from new colonization on the gravel bars to later seral stage willows long established. These provide ample food and dam-building material to the resident beaver populations in the system and utilization appears to be sustainable. This riparian habitat is also critical to bird species, in particular, the Endangered (State) and Forest Service Species of Special Concern, Willow Flycatcher (*Empidonax trailii*). The Willow flycatcher depends on wet meadow and riparian shrub habitats for forage, breeding, and nesting. Inundation is of particular importance because it helps deter nest predators (Craig and Williams 1998). Frequent inundation also supports expanded recruitment of willows and other riparian species. Healthy riparian vegetation is essential to meadow function and the support of biodiversity. In areas where entrenchment is high, riparian species recruitment on the terrace becomes limited. While larger, older willows may still be able to access the water table, new recruitment is limited on the terrace due to lack of access to water.

The West Fork Carson River historically supported Lahontan Cutthroat Trout (federally threatened). However, habitat degradation and overfishing combined with introductions and long-term stocking of non-native fishes such as Brook Trout (*Salvelinus fontinalis*), Rainbow Trout (*Oncorhynchus mykiss*), and Brown Trout (*Salmo trutta*) early in the 20th century led to the near complete extirpation of this species from its historic range in the Carson (Moyle, Katz, and Quinones 2011; Moyle, Israel, and Purdy 2008; Moyle 2002). More recent stocking and reintroduction efforts have had little success in building a self-sustaining population of Lahontan Cutthroat Trout in the mainstem Carson, but has established a put-and-take fishery for recreational angling and introductions into historically fishless headwaters areas of the region show some success (Moyle, Katz, and Quinones 2011). Instream habitat conditions in Faith Valley have many of the components necessary for all life history stages of salmonid species including forage (invertebrate production), spawning habitat (requires flow, temperature, and gravel size to be within narrow parameters), rearing habitat (requires low velocity areas, warmer temperatures, cover from predators, and food resources), cover (undercut banks, overhanging willows, occasional large wood), and habitat heterogeneity (side channels, back waters, pools, undercut banks, boulders).

However, the entrenched channel and loss of floodplain connectivity in most of the reaches has direct adverse impact fish habitat. In high flow events, if the channel is disconnected from its floodplain, there is little instream habitat for velocity refuge. Fish may be swept downstream or become exhausted trying to maintain position. With a connected floodplain that becomes inundated during high flow events, fish can escape onto the floodplain. Additionally, inundated floodplains support tremendous macroinvertebrate and zooplankton production which makes them an excellent area for juvenile rearing and adult foraging (Viers et al. 2013; Bayley and Guimond 2008). Water quality parameters at the time of our surveys indicated that Faith Valley maintains suitable habitat for salmonid fishes but long-term temperature studies would be necessary to identify trends or time when temperatures exceed accepted limits. Other water quality parameters such as dissolved oxygen, pH, and conductivity have varied relationships to temperature (dissolved oxygen being most sensitive) but all were well within the ideal range for sensitive aquatic species and are not likely the limiting factor for fish recruitment.

Conclusion

Faith Valley is classic example of an impacted meadow ecosystem that still maintains significant functionality. In particular, its riparian habitat and heterogeneous vegetation in response to moisture gradients, soil organic matter, nutrients, and substrate provide a rich base for restoration efforts. This meadow, with its aesthetic and recreational values as well as visibility will mean that any restoration efforts will be closely scrutinized by stakeholders and the public. Because of its comparatively high function and the rapid positive response to beaver dams in the system, this meadow is an excellent candidate for ecological restoration practices that maximize the utilization of existing fluvial processes to facilitate long-term, self-sustaining, resilient, complex, and dynamic habitats. With beaver dams in place, the reconnected floodplain quickly responds to elevated water tables and sediment deposition. Hydrologic processes, habitat complexity, and volume of occupiable habitat all benefit. However, due to the historical impacts that have occurred here and the volume of water that the West Fork Carson conveys, beaver dams have a difficult time persisting for long enough to realize their full habitat benefits. After the extreme winter of 2017, the large beaver dams at both FM1 and FM6 blew out. That loss has some notable impacts in the system including the formation of headcuts, the loss of inundated areas, and loss of accreted sediments. Consequently, additional restoration treatments such as beaver dam analogs or other bioengineered structures that act in conjunction with existing beaver dams will be very helpful. It is essential that structures (be they beaver or man-made) occur frequently enough that they maintain continuity in the longitudinal profile of the stream thus reducing the stress on individual structures and providing redundancy in case of failure. The adjacent upland forests have significant overgrowth and fuel overloading. It could make sense to try to utilize some local materials for beaver dam analogs or man-made debris dams which would lower the cost of the project and provide additional ecological benefit to the adjacent forest by reducing fuel load and potential fire intensity. Additional restoration actions that would complement stabilization of existing beaver dams and building human-made analogs include riffle augmentation. This could be particularly beneficial since Faith Valley (particularly FM1-FM3) were dominated by slow water units at the time of our survey and riffle augmentation as opposed to debris dams maintains fast water habitats. We recommend that any restoration activity maximize existing instream habitat components, minimize homogenization of habitat, and minimize the use of heavy equipment in the stream and fragile riparian habitats. Additionally, we suggest that restoration methods be focused on restoring and utilizing ecological processes and avoid hard structures such as rip rap, boulder vanes, log barbs, or other engineered structures that are designed to stabilize banks or reduce erosion. Instead, we hope that the focus of the design basis is on elevating the stream bed and water table, thus reducing shear stress on exposed banks and eliminating the need for expensive bank stabilizing structures that do not allow for dynamic stream channel formation and hydrologic processes to occur. The habitat and condition of Faith Valley, while impacted, are extremely valuable and maintain important ecosystem functions and services. It is essential that any restoration activities do not negatively impact the existing functionality of the system.

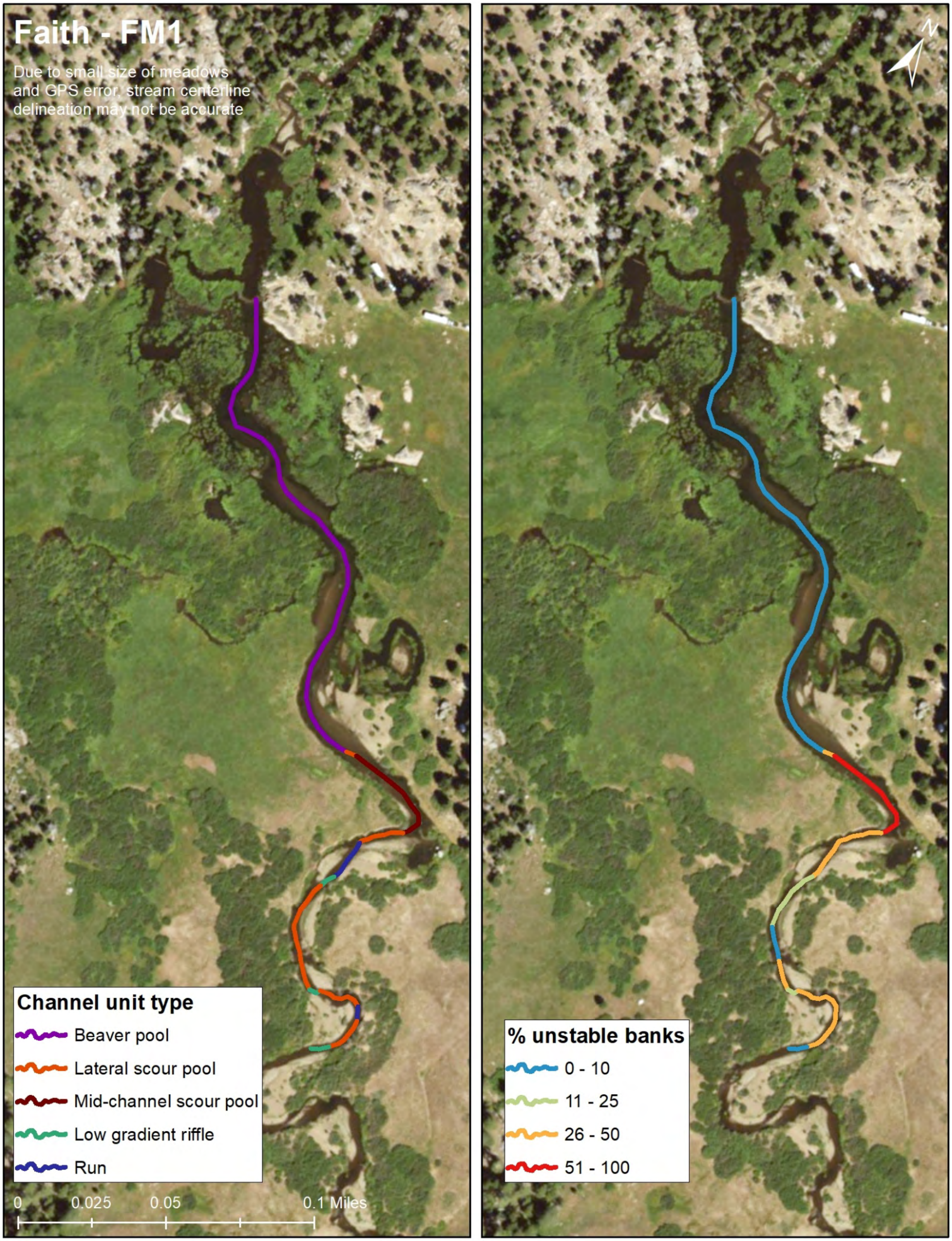


Figure 4. Map of Channel Unit Types and Unstable Banks in FM1.

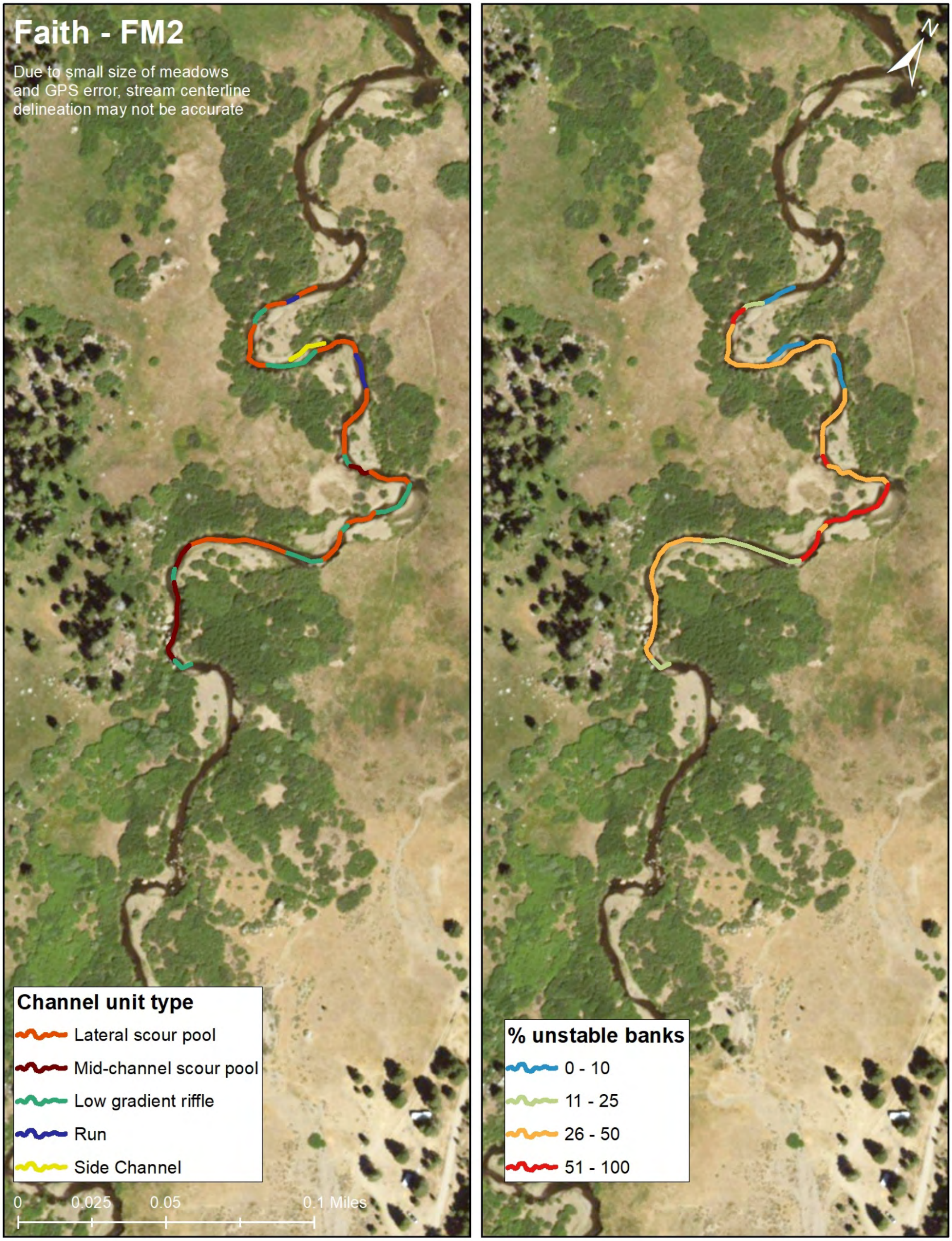


Figure 5. Map of Channel Unit Types and Unstable Banks in FM2.

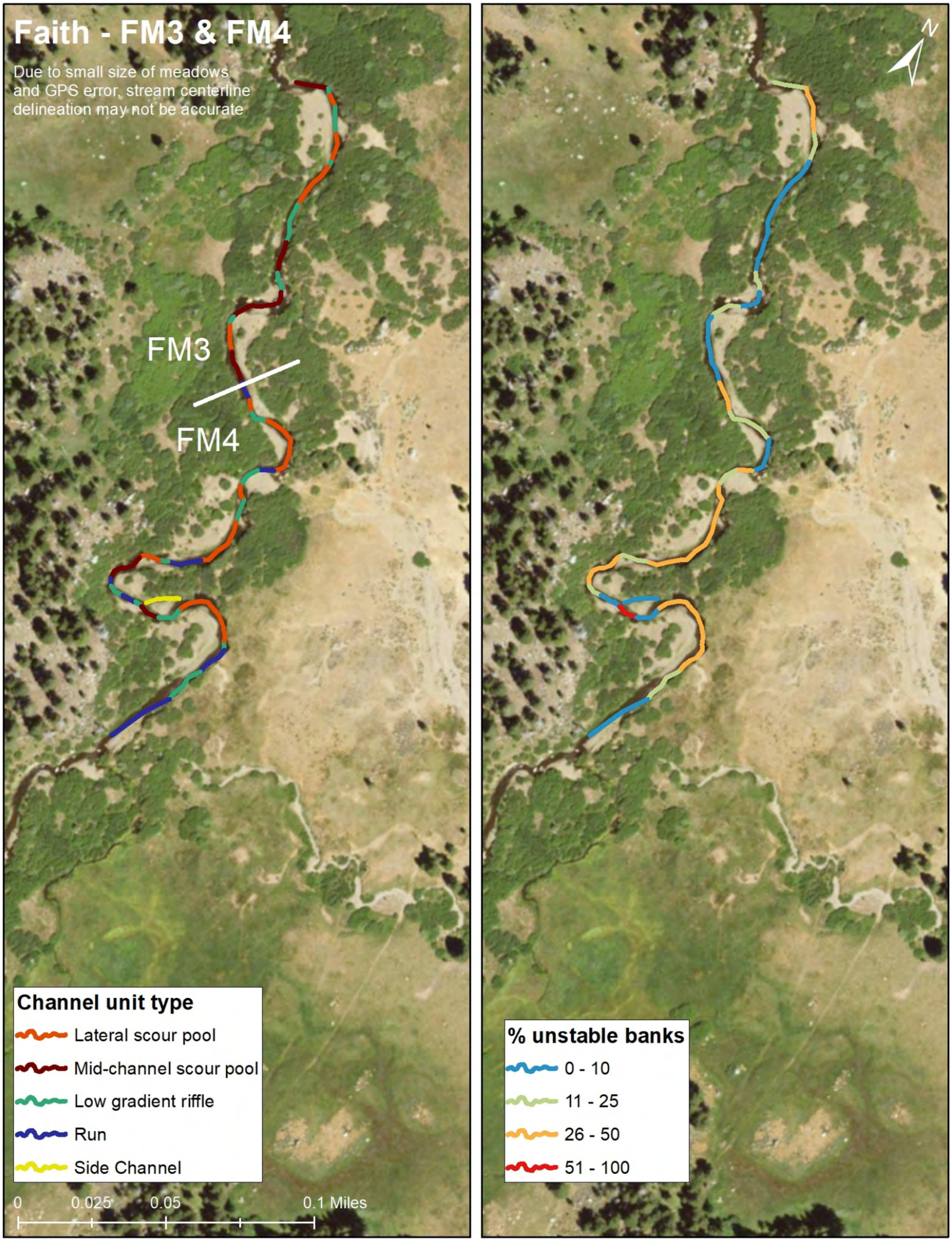


Figure 6. Map of Channel Unit Types and Unstable Banks in FM3 and FM4.

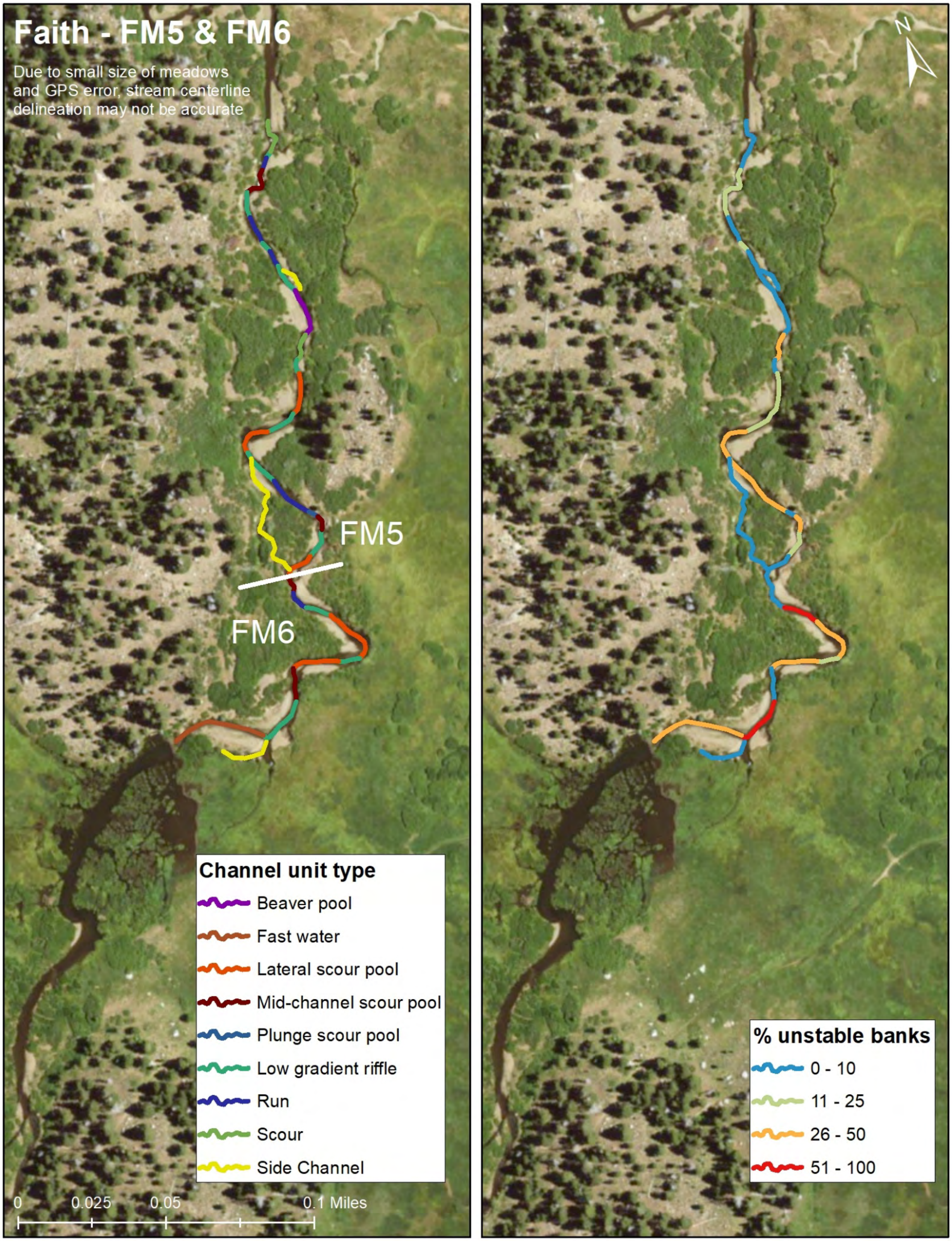


Figure 7. Map of Channel Unit Types and Unstable Banks in FM5 and FM6.

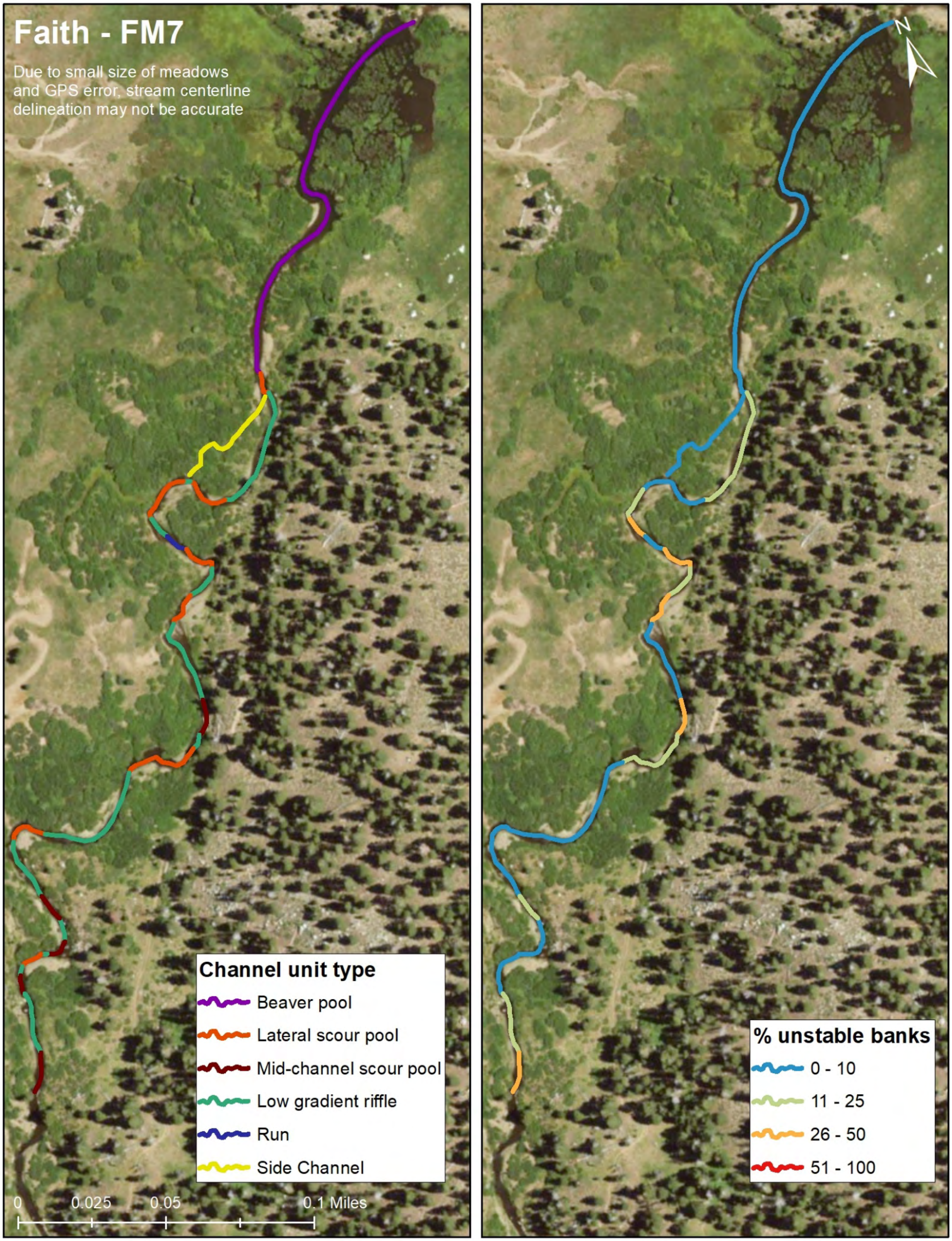


Figure 8. Map of Channel Unit Types and Unstable Banks in FM7.

Photos

Figure 9. Beaver Dam at the base of FM1. This dam backs water up for hundreds of meters and created a large area of inundation laterally that resulted in a tremendous vegetation response. This dam did not survive the winter of 2016/2017 resulting in a much narrower area of inundation and lower water surface elevation exposing much of the previously inundated floodplain and channel. FM1, SDBV1.

Figure 10. Aerial view of FM1, channel unit SDBV1. Note the intact beaver dam near the rocky outcropping adjacent to the channel in the left part of the photo. Note the complex backwater habitat and inundated area on the left side of the channel and the influence of the beaver dam on the tributary on the bottom right part of the photo. Note the lush herbaceous vegetation and willows and inundated oxbow/backwater habitats on the right bank. There is a second beaver dam ~75 m downstream as well. Both washed out in the 2017 floods.

Figure 11. Just upstream of the inundated area from SDBV1 the stream channel becomes entrenched with unstable cutbanks and fresh sediment deposition on the point bars. This location also has a lateral moraine on the right bank (the boulders in the upper right corner of the photo). FM1, SSMC3.

Figure 12. Area of instability and disconnection from the floodplain. Inset floodplain development is occurring, but small substrates are highly mobile. This section rarely overtops its banks and vegetation on the terrace has shifted to mesic/xeric grasses rather than hydric sedges. FM1, SSLS4.

Figure 13. 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 end-cut. FM1, SSLS8.

Figure 14. A typical point bar with sparse herbaceous vegetation above bankfull but healthy willow colonization occurring. Note the eroding remnant of a beaver-stabilized bank on the right edge of the photo. FM1, SSLS9.

Figure 15. Though entrenched, this section of the streambank has been stabilized by a downstream beaver dam that has since been washed out. Note the tell-tale "pillow-shape" of the banks with excellent herbaceous vegetation recruitment, stability and developing undercut banks. These types of banks are common in places where beaver dams have been able to persist for a long enough duration to support this kind of vegetation colonization and reduction of erosion. FM1, SSLS9.

Figure 16. Another area where a now-gone beaver dam has improved the conditions of the stream channel. Here, the accreted sediments have resulted in an emergent marsh type habitat on the left side of the photo (river right) where dense sedges (Carex spp.) inhabit the inundated zone below bankfull protecting the entrenched but no longer eroding bank behind it. Upstream however, the cutbank and terrace continue to erode and floodplain access is restricted. FM2, SSLS10.

Figure 17. Visible remnants of a former beaver dam on the channel margin are all that remain (lower left of photo) of a beaver dam, but the accumulated sediments remain in the channel leading to the formation of a riffle crest. Note the point bar with willows, but very little understory vegetation on the exposed gravel. FM2, FTRF7.

Figure 18. A former cutbank still shows scars from the bad old days when it was actively eroding. The new gravel bar that protects it and allowed it to stabilized appears to be sediments that accreted behind an old beaver dam (now just a remnant). However, the historic floodplain is still largely disconnected from the stream and the difference in elevation is creating a headcut that is moving into the meadow. Note the dry vegetation and soil. FM2. Near SSLS16.

Figure 19. Inset floodplain formation is occurring along an old cutbank but an active headcut is working into the historic floodplain. Note the greener, more hydric-type vegetation at the base of the old cutbank with the dry vegetation and crumbling sod on the terrace. FM2. Near SSLS16.

Figure 20. Gravel bar formation in the inset floodplain. This is a sign of some recovery. However, the historic floodplain remains disconnected from the stream. FM2, FTRF11.

Figure 21. Actively eroding banks occur in many areas of Faith Valley with a disconnected floodplain and ongoing bank fracturing, channel widening, and sediment losses. FM2. SSLS18.

Figure 22. When the stream channel approaches a moraine, large boulders are often found in the channel and conifers come into the riparian zone. FM2. SSMC22.

Figure 23. A tiny remnant of beaver dam (bottom right of photo) is all that remains, but the stabilizing effect on the stream banks and recruitment of vegetation remain after it has blown out. The longer these structures persist, the more resilient the habitat becomes. FM3, FTRF18.

Figure 24. More glacial-origin boulders in the stream near a moraine. These boulders can also help stabilize the channel in some locations. FM3, SSMC27.

Figure 25. More eroding cutbanks with a disconnected floodplain. FM4, FTRF34.

Figure 26. A small beaver dam on a tributary backs water up, encourages wet-meadow vegetation and accretes sediment. The floodplain near the top of the photo is more accessible than in many areas of Faith Valley and has dense sedge and active willow colonization. FM5. TRIB2.

Figure 27. A small beaver dam on a side channel. There are many remnants of old dams in this area which have helped with reconnecting the floodplain and encouraging vegetation growth in this section. FM5, SIDES2.

Figure 28. This side channel formed from a beaver larger beaver dam (partially intact) upstream. Beaver dams often increase channel complexity once the stream accesses the floodplain and a multi-thread channel is formed. FM5, SIDES3.

Figure 29. The center of this beaver dam failed but the sides along the stream banks remain intact. Though the water table is lowered again, the bank protecting benefits of the beaver dam still persist at this unit. FM5, FNRN48.

Figure 30. At this partially blown beaver dam, the habitat has shifted from dam pool to scour pool. Note the evidence of the former area of inundation and the bankfull indicator when the dam was intact. The water table has dropped and headcuts occur where tributaries enter the stream. FM5, SSMC48.

Figure 31. After the downstream beaver dam failed, more stream channel and bare sediments are exposed and the stream channel becomes re-entrenched. FM6, SSLS49.

Figure 32. A headcut moves up a side channel after the downstream beaver dam failed. This side channel was formed by the large beaver dam above with a multiple-thread channel coming down. FM6, SIDEF2.

Figure 33. This enormous, channel spanning beaver dam has exerted a huge amount of influence on the stream and floodplain in this section of Faith Valley Meadow. FM7, SDBV55.

Figure 34. A peek into the large dam pool at FM7, SDBV55. Note the emergent sedge marsh and dead conifers.

Figure 35. The large beaver dam at SDBV55 has created an area of inundation of ~16,000 square meters. The vegetation response to saturated soils is very positive. This type of habitat is excellent rearing habitat for juvenile fishes, has tremendous primary and secondary production, and is contributing to ground water recharge. It also provides velocity refuge for all fishes during high flow events. This dam failed in winter 2017. FM7, SDBV55.

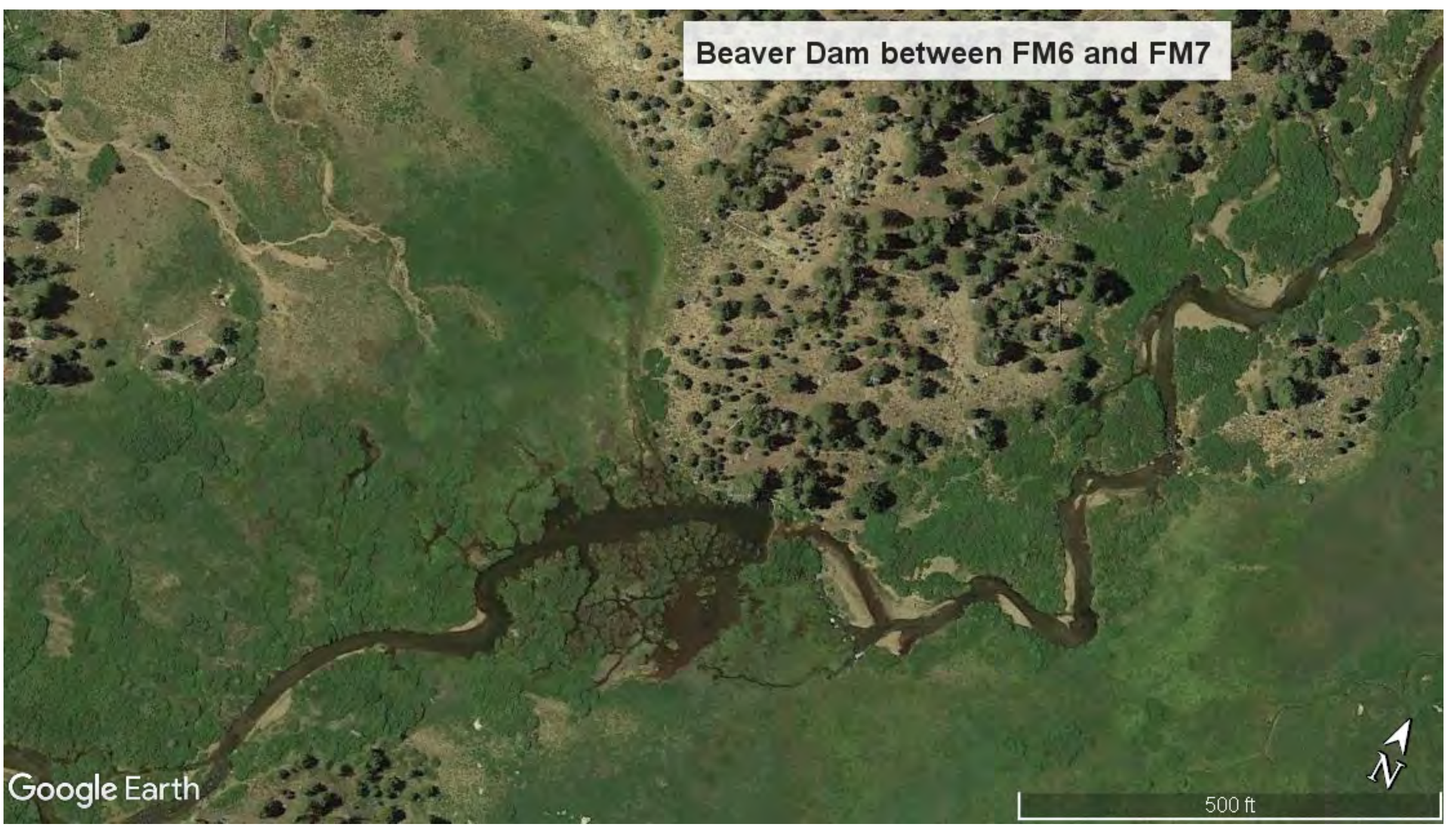


Figure 36. Aerial imagery of the large beaver dam that divides FM6 and FM7. The area of inundation is quite large, continuing on the northwest side all the way to the tan colored moraine area.

Figure 37. The beaver lodge at SDBV55.

Figure 38. Upstream of SDBV55, the character of the stream changes noticeably. Note the larger substrate size, decreased height between bankfull and the floodplain, and very healthy riparian willow forests. Larger-sized substrate is less vulnerable to erosion than smaller substrate. Additionally, meadows typically become incised and eroded from downstream to upstream (headcutting), thus the upstream reaches are often less entrenched than the downstream reaches. FM7, FTRF54.

Figure 39. While erosion is generally less in FM7 than in the other reaches, the stream still shows legacy impacts (likely from grazing) and has inset floodplain development. Conifers here show the location of the nearby moraine. FM7, FTRF58.

Figure 40. In some locations, the stream actually cuts into the moraine creating a taller cutbank and potentially creating more erosion than in other areas. This is not an indication of increased impact, it is simply part the geomorphological process near moraines. Note the larger glacial boulders in the stream as well. The stream does not appear to be actively eroding the right bank here (see the willow and sedge colonization) but this zone is vulnerable to erosion in high flow events. FM7, SSMC63.

Figure 41. The riparian zone becomes more forested, and less meadow-like in upper FM7. Note the substrate dominated by cobble rather than gravel. FM7, FTRF64.

Figure 42. Near the top of FM7, bedrock emerges from the stream bed. The forest is closer to the stream margins on both sides of the channel. Entrenchment is minimal and the floodplain is easily accessed by the stream. Immediately upstream from here there is a series of open willow shrubfields punctuated by close forest zones.

References

Bayley, Suzanne E., and Julie K. Guimond. 2008. 'Effects of river connectivity on marsh vegetation community structure and species richness in montane floodplain wetlands in Jasper National Park, Alberta, Canada', *Ecoscience*, 15: 377-88.

Craig, D. , and P. L. Williams. 1998. 'Willow Flycatcher (Empidonax traillii). In The Riparian Bird Conservation Plan: a strategy for reversing the decline of riparian-associated birds in California', California Partners in Flight. http://www.prbo.org/calpif/htmldocs/riparian_v-2.html.

Henery, Rene, Sabra Purdy, Jack Williams, Jenny Hatch, Kurt Fesenmyer, Mark Drew, David Lass, and, and Curtis Knight. 2011. "Meadow Restoration to Sustain Stream Flows and Native Trout: A novel approach to quantifying the effects of meadow restorations to native trout." In.: A collaborative report to National Fish and Wildlife Foundation by Trout Unlimited, California Trout, University of Nevada, Reno, and University of California, Davis.

Kemker, Christine. 2013. '"Dissolved Oxygen." Fundamentals of Environmental Measurements.', Fondriest Environmental, Inc. Web. < http://www.fondriest.com/environmental-measurements/parameters/water-quality/dissolved-oxygen/ >.

Kiernan, J.D., and P. B. Moyle. 2012. 'Flows, droughts, and aliens: factors affecting the fish assemblage in a Sierra Nevada, California, stream.', *Ecological Applications*, 22: pp. 1146-61.

Merrill, A.G., C. Monahan, S.E. Purdy, P.B. Moyle, and D.A. Weixelman. 2007. "Sierra Meadows: Historical Impact, Current Status and Trends, and Data Gaps." In. University of California, Davis Center for Watershed Science: U.S. Environmental Protection Agency.

Moyle, P. B. 2002. *Inland fishes of California. Second edition. University of California Press, Berkeley, California, USA.*

Moyle, P. B., J. A. Israel, and S. E. Purdy. 2008. *Salmon, Steelhead, and Trout in California: Status of an Emblematic Fauna*.

Moyle, P. B., J. V. E. Katz, and R. M. Quinones. 2011. 'Rapid decline of California's native inland fishes: A status assessment', *Biological Conservation*, 144: 2414-23.

NFWF. 2010. 'National Fish and Wildlife Foundation Sierra Nevada Meadow Restoration Business Plan'. http://www.nfwf.org/sierranevada/Documents/Sierra_Meadow_Restoration_business_plan.pdf.

Purdy, S.E., P. B. Moyle, and K. W. Tate. 2012. 'Montane meadows in the Sierra Nevada: comparing terrestrial and aquatic assessment methods', *Environmental Monitoring and Assesment*, 184: pp. 6967-86.

Rosgen, D. 1996. *Applied River Morphology* (Wildland Hydrology Books: Pagosa Springs, CO).

USFS. 2010. "USDA Forest Service Stream Inventory Handbook Level I & II." In.: Pacific Northwest Region 6.

Viers, J.H., S.E. Purdy, R.A. Peek, A. Fryjoff-Hung, N.R. Santos, J.V.E. Katz, J.D. Emmons, D.V. Dolan, and and S.M. Yarnell. 2013. "Montane Meadows in the Sierra Nevada: Changing Hydroclimatic Conditions and Concepts for Vulnerability Assessment." In, 63. Center for Watershed Sciences University of California, Davis.

Viers, Joshua H., and David E. Rheinheimer. 2011. 'Freshwater conservation options for a changing climate in California's Sierra Nevada', *Marine and Freshwater Research*, 62: 266-78.

Weixelman, D.A., B.A. Hill, D.J. Cooper, E.L. Berlow, J.H. Viers, S.E. Purdy, A.G. Merrill, and S.E. Gross. 2011. "A Field Key to Meadow Hydrogeomorphic Types for the Sierra Nevada and Southern Cascade Ranges in California." In, 34. Gen. Tech. Rep. R5-TP-034, Vallejo, Ca: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region.