U.S. FOREST SERVICE
NATIONAL STREAM AND AQUATIC ECOLOGY CENTER

June 23, 2017

PICKEL MEADOW: STREAM CONDITION and RESTORATION POTENTIAL

Client: Humboldt-Toiyabe National Forest

Location: Pickel Meadow, West Walker River, Mono County, California

Date of Visit: 10/11/2016

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Summary: Pickel Meadow and the West Walker River are impaired by three general circumstances: (1) an alluvial fan at the upstream limit of the meadow which is constrained by a parking lot, terrace features, and a primitive road, with a resulting disconnection of the uppermost, widest, and potentially most productive portion of the meadow; (2) incision within the upper portion of the potential restoration extent, which has likely lowered the groundwater table elevations in the meadow and reduced productivity; and (3) infrequent deep pools and cover for fish. The meadow disconnection by the parking lot, road, and terrace features has resulted in a loss of flow, sediment, and large wood and other organics from the West Walker River. The incision likely occurred some time ago since a wide and hydraulically-effective floodplain has had an opportunity to develop at a lower elevation but this incision has likely resulted in water table levels during low flow to be 6 or 7 feet below certain portions of the meadow surface along the West Walker River.

The following alternatives are suggested for consideration for the West Walker River in Pickel Meadow:

Alternative 1: No action
Alternative 2: Management plus vegetative plantings
Alternative 3: Restoration with current alignment, with vegetative plantings
Alternative 4: Restoration with new alignment, with vegetative plantings
Alternative 5: Restoration with multi-thread channels, with vegetative plantings

Recommendation: It is recommended that Alternative 5 be implemented from the canyon mouth to where the West Walker River becomes semi-confined by high terraces. This alluvial fan restoration would best match the goals of the stakeholders. For the remainder (majority) of the 4.8 mile extent, it is recommended that Alternative 3 be implemented, with the introduction of various features to enhance fish habitat.

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INTRODUCTION

Planning is underway for a collaborative project to restore and enhance the function of Pickel Meadow and the West Walker River (and its tributaries). A field visit with staff from the Humboldt-Toiyabe National Forest, California Trout, and American Rivers was performed to evaluate existing conditions and perceived impairments. This report was written to detail perceptions of the authors on the conditions and restoration potential, and to suggest a course of action.

This reach of the West Walker River (Figure 1) has an overall length of 25,200 feet (4.8 miles), with a contributing watershed area of 84.9 and 113 mi^2 at the proposed upstream and downstream project boundaries, respectively. Average annual precipitation varies from 70 to 30 inches for the contributing watershed, and 29 to 26 inches within Pickel Meadow (PRISM, Daly et al. 2008). This watershed is on the east side of the Sierra Nevada Mountains. Elevations range from 11,800 to 6700 feet, with a shared watershed boundary with a portion of Yosemite National Park. This stream is considered "functioning at risk" within the Forest Service Watershed Condition Framework (Potyondy 2011).

This meadow is immediately adjacent to the U.S. Marine Corps Mountain Warfare Training Center, and is located on both the Humboldt-Toiyabe National Forest and California state lands (managed by the California Department of Fish and Wildlife as the Pickel Meadow Wildlife Area). There are no known endangered, threatened, or sensitive aquatic species currently present within this reach, though brown and rainbow trout are present. Bald eagles are present in the vicinity. In regard to game, deer, waterfowl, mountain quail, and blue grouse are noted to be present by the Department of Game and Fish.

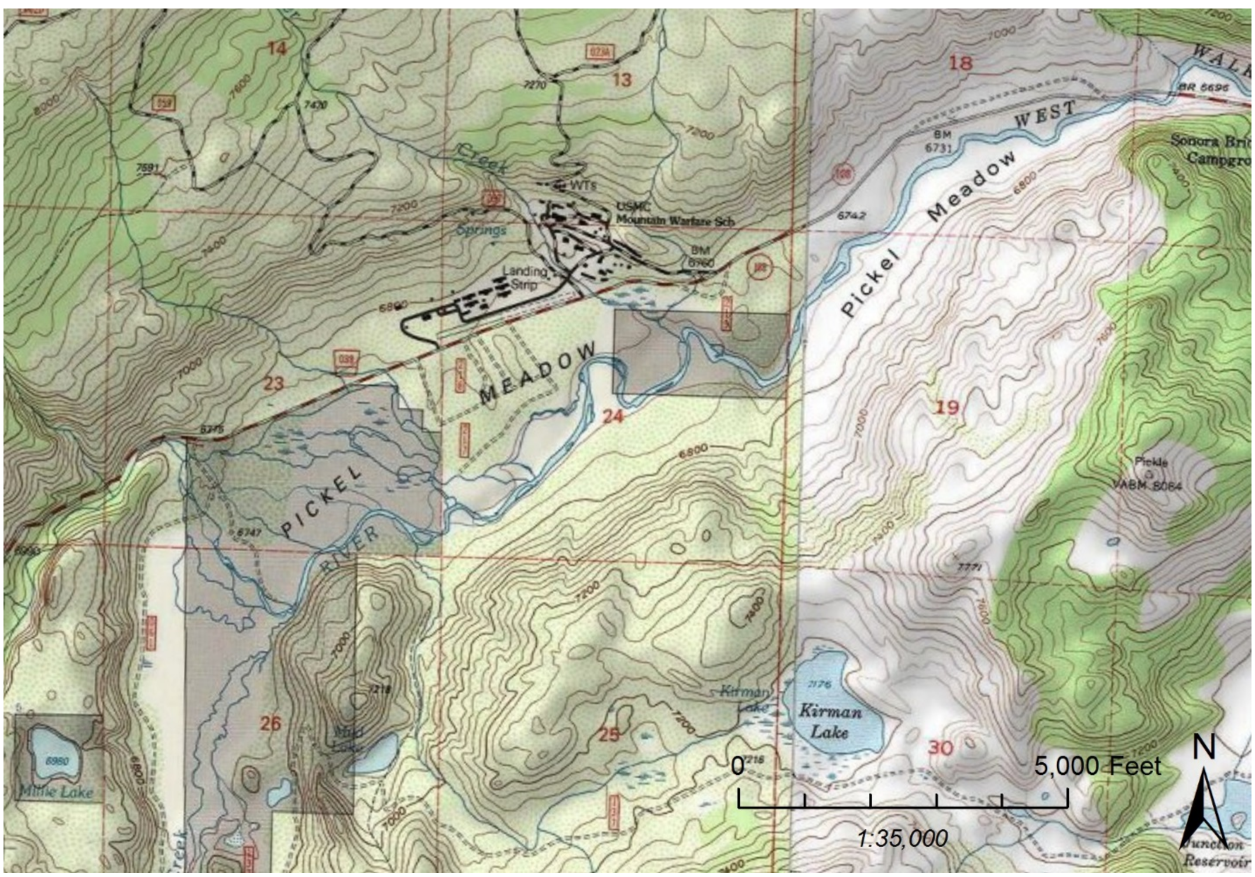

Figure 1: Topography overview, West Walker River and lesser streams at Pickel Meadow.

GOALS and OBJECTIVES

This project has developed a series of goals which were developed collaboratively with a core group of stakeholders. These goals have been defined within a context that requires sensitivity to a number of different land managers and existing or potential values of importance to various stakeholders. With input from land users and land managers, the following goals for Pickel Meadow have been developed:

1. Maintain a stream whose dimension, pattern, and profile are appropriate to sediment supply, landscape setting, and the watershed's climate.
2. Maintain lotic aquatic habitat that will allow for maintenance of a self-sustaining fish population (i.e., provides breeding and rearing habitat).
3. Provide for the expansion of wetland and riparian vegetation (relative to current conditions) within the meadow without the need for irrigation.
4. Eliminate the addition of sediment to the West Walker River due to accelerated erosion within Pickel Meadow.
5. Improve the capability of the meadow to trap fine sediments (sand sized and smaller) during high flows.
6. Ensure the meadow remains a recreational destination for non-motorized activities (e.g., fishing, hiking, wildlife viewing).
7. Ensure the meadow continues to provide opportunity for livestock grazing (in a manner that is compatible with other goals).
8. Maintain terrestrial habitat and associated vegetative communities required by wildlife populations native to the area.

At this time, measureable objectives have not been set. Once existing conditions have been more fully evaluated and design alternatives more thoroughly discussed, discrete objectives pertaining to stream morphology, vegetative communities, and land use can be developed.

FLOW FREQUENCY

Understanding the flow frequency relationship of the West Walker River at the restoration site is necessary for the planning and design work of the proposed restoration project. An abandoned streamgage, with 23 years of record, is present 2 miles upstream of the meadow on the West Walker River (USGS ID 10295200). This streamgage, which was located near the downstream limit of Leavitt Meadow, will likely be of most value for determining the flow frequency relationship at the site. An additional (realtime) streamgage is located downstream of the site (USGS ID 10296000), with substantially increased watershed area. A separate report on this topic will be provided.

A preliminary analysis indicates the 1.25- and 2-year flows to be 850 cfs and 1200 cfs, respectively. At the downstream streamgage the return interval of bankfull flow was determined to be 1.23 years. Following this, bankfull flow in Pickel Meadow may be about 850 cfs.

STREAM and RIPARIAN CONDITION

General Geomorphic Condition

Based upon general geomorphic processes and stream confinement, the overall Pickel Meadow restoration reach was divided into five subreaches of the West Walker River (Figure 2). Specifically, these are:

(1) Transition from upstream canyon to unconfined meadow (remnant alluvial fan)
(2) Unconfined meadow and stream
(3) Semi-confined meadow and stream, by high terraces
(4) Generally unconfined meadow and stream
(5) Fully confined stream, by high terraces

Historic Aerial Imagery

Historic aerial imagery was obtained from the USGS, with images discovered and georeferenced from 1955, 1969, 1984, 1993 and 1998. Recent imagery is also available from DigitalGlobe, at 46 cm resolution (Appendix B). The historic imagery is provided in Appendix C, and is also available in GIS format on request.

Stream centerlines have been delineated from the historic imagery for 1955 through 2016; they are shown in Figure 3 and Figure 4.

In reach 1 (Figure 3), the transitional reach with a remnant alluvial fan, the stream has alternated between being in a single thread and multi-thread form, though has occupied a narrow footprint as the slope and valley confinement changes from canyon to meadow. Terrace features, a parking lot, and a primitive road have limited the development of a more extensive fan since at least 1955, with the widest portion of Pickel Meadow, to the east (reach 2), being isolated from this reach. Reach 1 has been more connected with the Poore Creek portion of Pickel Meadow to the south, with at least two connected lesser stream channels being consistently maintained by fluvial geomorphic processes from 1955 through 2016.

The West Walker River in reach 2 (Figure 3) has had a consistent form from 1955 to 2016 for most of this unconfined portion of Pickel Meadow. Despite the meadow being up to 2500 ft wide within this reach, the stream has consistently flowed in the far southern portion of the meadow. An 1877 survey of the area shows the West Walker River also in this same general location. A small amount of downstream meander migration, as well as a meander bend cutoff as this reach transitions to being semi confined in reach 3, has occurred from 1955 through 2016. This cutoff occurred between 1969 and 1984. More substantial side channel connectivity also existed for a portion of this reach in 1955, but has since been gradually lost.

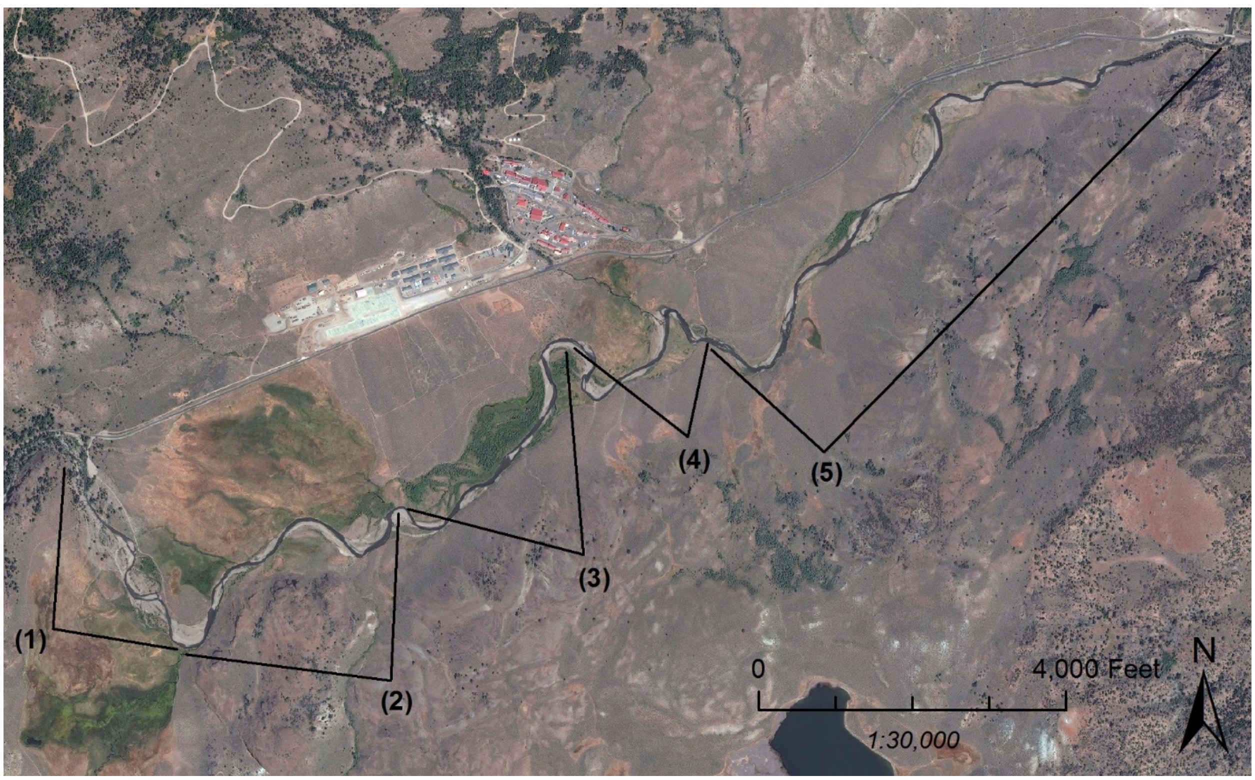

Figure 2: Geomorphic subreaches of the West Walker River in and downstream of Pickel Meadow. Aerial imagery: 8-28-2016.

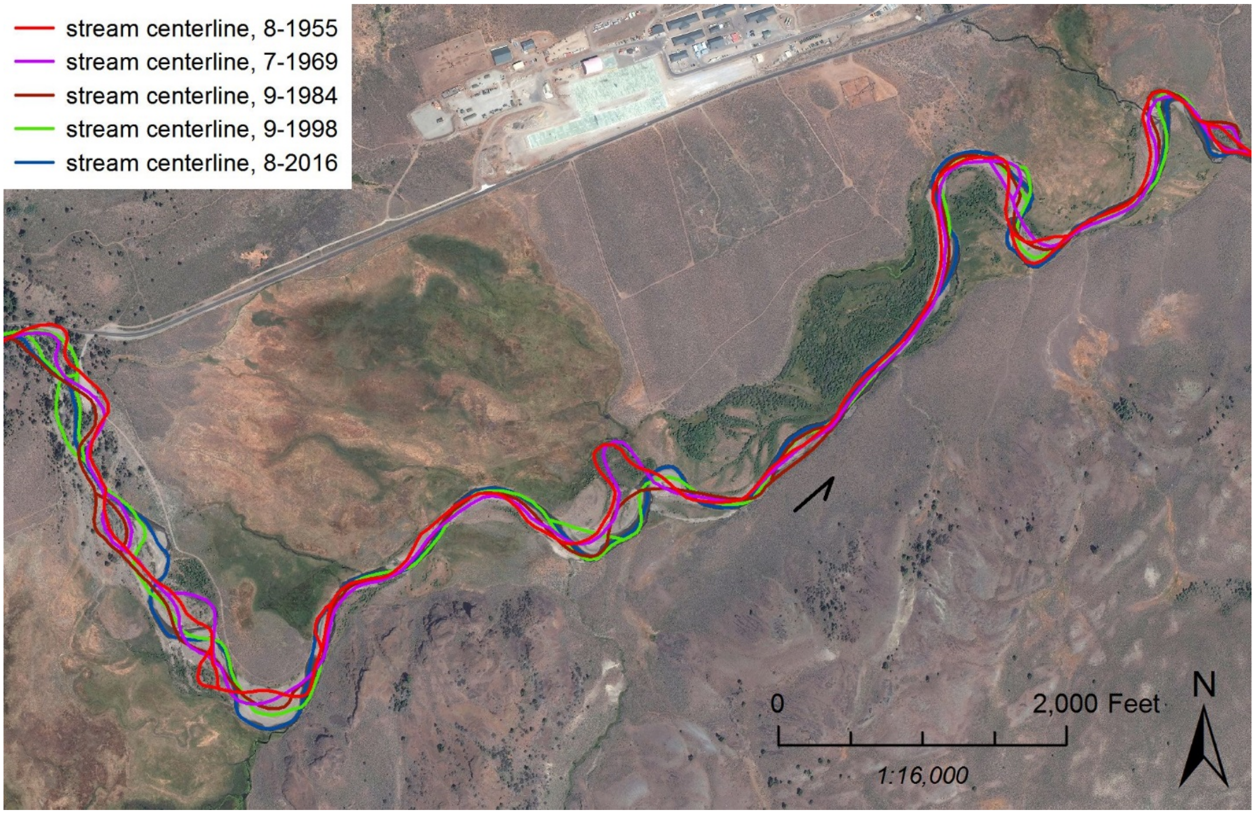

Figure 3: Stream centerlines (1955 through 2016), upstream portion of the West Walker River in Pickel Meadow.

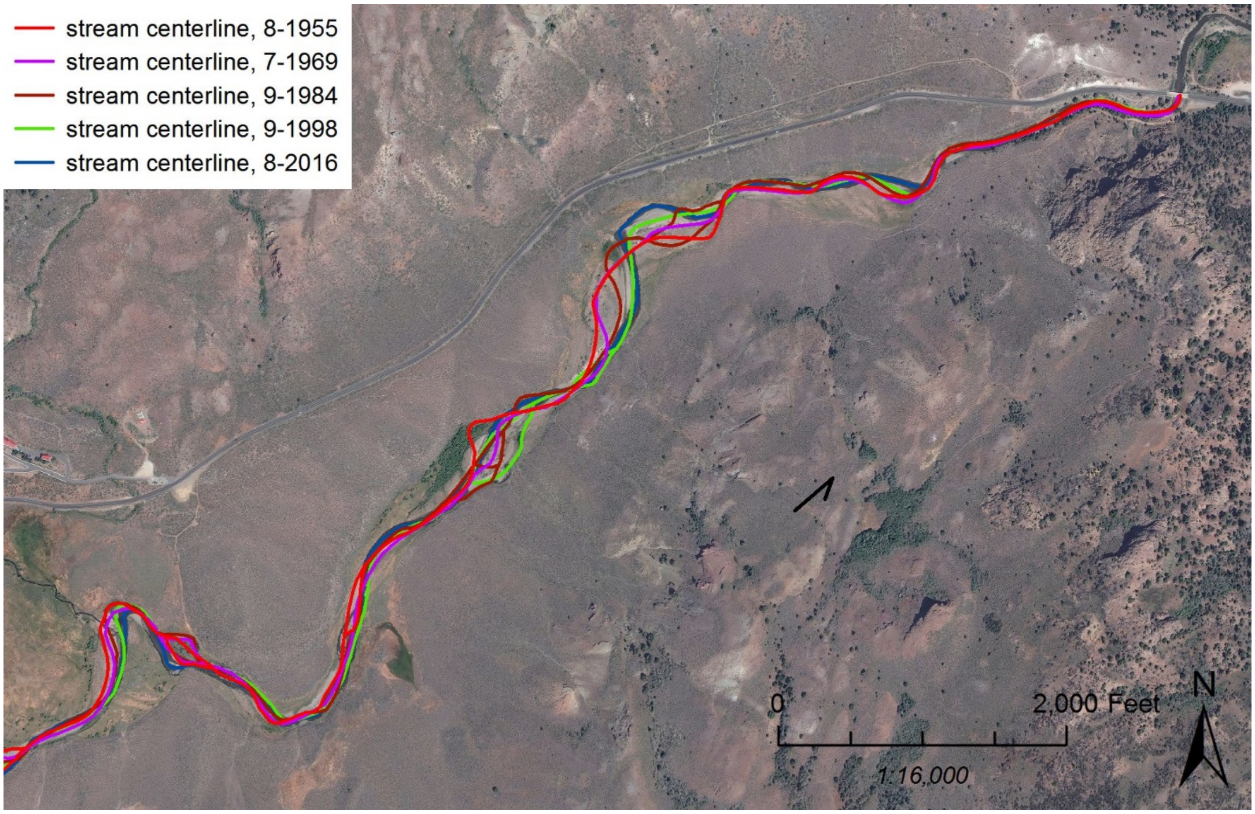

Figure 4: Stream centerlines (1955 through 2016), downstream portion of the West Walker River in Pickel Meadow.

Reach 3 of the West Walker River in Pickel Meadow (Figure 3) is more confined, with terraces limiting active floodplain widths from 550 to 750 ft within the majority of this reach. The meadow widens again in reach 4, to 1600 ft as Silver Creek flows towards its confluence with the West Walker River. The stream has had a consistent form from 1955 through 2016 within reaches 3 and 4, with minimal detected meander migration, though side channel connectivity appears to have been reduced since 1955.

Reach 5 (Figure 4) is substantially more confined by high terraces than the upstream reaches, with floodplain widths ranging from 150 to 500 ft. In the most confined portions of this reach the channel has remained in the same planform, though substantial channel migration has occurred where the channel is less confined, with most of the floodplain in these locations being host to the channel since 1955.

Field Observations

The stream was walked by the authors for the entire potential restoration extent, and joined by other members of the collaborative project for a portion of the inspection. GPS-linked photographs were collected to document condition, with a select few provided here.

The upper part of **reach 1** (Figure 5, Figure 6) is dominated by boulder-size material, in both the channel as well as the floodplain and terrace surfaces. Cobbles and gravels are also present. The large bed material may have been deposited during the flood of January 1997, as well as during previous (undocumented) large floods. The upper portion of this reach is bounded by trees, with shrubs also present. Sporadic large wood deposited within the floodplain was noted, though no material was observed in the channel. Thin to nonexistent soils were noted on the floodplain and terrace surfaces. Impact scars on trees were noted likely from the 1997 flood.

The upper portion of reach 1 is confined on the east by a parking lot, terraces, and a primitive road. Confinement due to this parking lot prevents a direct connection of the West Walker River with the previous extent of its alluvial fan and the widest portion of Pickel meadow (Figure 3, reach 2). The wet conditions of this meadow are supported by ongoing flood irrigation though a culvert buried under the north end of the parking lot. A diversion dam is present on West Walker River at the upstream limit of reach 1, to generate head for this flow diversion.

Figure 5: Upper portion of reach 1 (viewing downstream), with streamside shrubs and trees present. Thin floodplain and terrace soils were observed over deposited alluvium.

Figure 6: Upper portion of reach 1 as it is transitioning from the presence to absence of trees (viewing upstream). Thin floodplain and terrace soils were observed on the right bank (as viewed downstream).

In the middle to lower part of reach 1 (Figure 7), the stream shows instability that appears to be associated with a terrace on the left bank, with more xeric to mesic conditions and with higher and less stable banks, as well as a response to the continued transition from the higher gradient canyon reach to lower-gradient meadow reach. This transition promotes sediment deposition. Cobble-size material appears to be dominant.

The downstream end of reach 1 (Figure 8) has a wide wet meadow present on the right bank, with the confluence of a small stream (Poore Creek) that feeds this meadow. The West Walker River is mildly incised (~1 ft) compared to this meadow surface, but still has 300 ft of active floodplain width present (Appendix A, X-S 2). The high left

Figure 7: Middle to lower portion of reach 1 (viewing downstream), with a terrace on the left bank and meadow on the right bank.

Figure 8: Lower limit of reach 1, with an expansive meadow present on the right (West) bank.

bank along the lower portion of reach 1 continues to this point. This terrace is 5 ft above the bankfull water surface at the lower limit of reach 1.

Proceeding downstream through **reach 2** (Figure 9, Figure 10), the bed material appears to shift from cobble to gravel dominated size material. The largest extent of Pickel Meadow is on the left side of the West Walker River in this reach, with the surface of the meadow adjacent to the current floodplain functioning as a terrace that is 3 to 4 ft above the bankfull elevations. High banks are also present in places on the right (south) bank (Figure 11). However, the current active floodplain is wide, with up to at least 900 ft widths (Appendix A, X-S 3, 4, &5). Minimal willows are present along this reach and no in channel large wood was observed. Minimal pool development was also observed.

The terraces and current and former meadow surfaces along reach 2 show a mix of vegetation types, from hydric, to mesic, to xeric. This is likely due to these surfaces being various elevations above the low flow (dry season) water surface (up to 9 ft).

Figure 9: Reach 2 (viewing downstream).

Figure 10: Reach 2 (viewing downstream).

Figure 11: Reach 2 (viewing upstream), with high banks on the right side of the channel (as viewed downstream; south).

Reach 3 (Figure 12, Figure 13) is semi confined by high terraces (15 to 40 ft above the current floodplain surface). An active floodplain exists within this confinement; it varies in width from about 500 to 800 ft (see Appendix A, X-S 6 for an example). An extensive stand of mature willows is present within this reach, primarily on left (north) bank. Sedges are also widely present. Side channels were also observed within the floodplain of reach 3 (Figure 13), with groundwater connectivity noted.

Mature willows were heavily browsed to about 4 ft; deer appear to be having a high impact here and may pose problems for vegetation recovery during restoration.

Along some portions of reach 3, willow clumps from mass wasting along taller banks may be developing bankfull benches.

Beaver activity, with burrowing and feeding, was noted within reaches 3 and 4. One side channel lodge was observed. One active and several abandoned bank lodges were observed adjacent to the main channel.

Figure 12: Gravel bar, mature willows, and wide floodplain of reach 3, viewing upstream.

Figure 13: Side channel and willows on north bank of reach 3.

Reach 4 (Figure 14, Figure 15) is generally unconfined, with an extensive meadow existing along Silver Creek near the confluence. Unlike the reach 2 portion of Pickel Meadow, the lower portions of this meadow appear to be still connected as active floodplain surfaces of the West Walker River (Appendix A, X-S 8). Fewer willows are present along this reach than in reach 3. Underwater exposed clay lenses, which provide some cover, were observed near the upstream limit of reach 4 (Figure 16).

Figure 14: West Walker River in reach 4, viewing downstream.

Figure 15: Lower portion of reach 4, viewing upstream.

Figure 16: Underwater clay lenses in reach 4 that provide some fish cover (viewing upstream).

Reach 5 (Figure 17) is confined by high terraces (15 to 55 ft high), though active floodplains are still present (Appendix A, X-S 9). Larger bed material sizes (up to boulder sized) are present within portions of this reach.

Figure 17: Reach 5, viewing downstream.

Generally, Pickel Meadow does not have cottonwood present.

A prior project was reportedly built in a portion of the meadow to raise the grade, but was washed out by the 1997 flood.

Bankfull Flow and Incision

Using the preliminary results of the flow-frequency analysis of the upstream streamgage and knowledge that the downstream streamgage has a return interval for bankfull flow of 1.23 years, bankfull discharge may likely be about 850 cfs. Estimates based on geomorphic indicators (or direct measurement at bankfull flow) is required.

As an initial estimate, using existing LiDAR data obtained from the Marine Corps, and ignoring the portion of the channel below the water surface, 9 cross sections were cut (Appendix A) to assess the degree on incision and estimate bankfull flow. Current bankfull indicators were noted in the cross sections and combined with a uniform flow assumption, channel slope, and Manning's *n*. The cross sections were primarily cut in riffle sections to reduce the lost flow area below the water surface at the time of the LiDAR flight, though these estimates are likely low due to unaccounted for low flow area.

Results are provided in Table 1, with the cross section locations, cross section forms, assumed water surface elevations, and on-the-ground photos for these seven sections provided in Appendix C. The preliminary bankfull discharge, as computed by the average, is **860 cfs**. The median value is **790 cfs**.

Once bed material size data are available, the Manning's *n* estimates should be appropriately revised to reflect quantitative tools that use bed material size. The Forest Service Stream Channel Flow Resistance Coefficient Computation Tool can help assist with Manning's *n* estimation.

Table 1: Bankfull discharge estimates of the West Walker River in Pickel Meadow, with key computational values.

ID	Bankfull Discharge (cfs)	Slope (ft/ft)	Manning's n
X-S 2	780	0.0033	0.04
X-S 3	880	0.0021	0.038
X-S 4	720	0.0021	0.038
X-S 5	790	0.0033	0.038
X-S 6	750	0.0014	0.038
X-S 8	1020	0.0024	0.038
X-S 9	1110	0.0021	0.038

In a number of locations, the West Walker River through Pickel Meadow expresses a recovered floodplain surface from a previous incision event (channel evolution model stage 5). Such a recovered floodplain is clearly present at X-S 2, -3, -4, and -5. The lower cross sections also have substantial floodplains, but do not appear to be incised.

CONDITION and RESTORATION POTENTIAL SUMMARY

Generally, the historic aerial imagery indicates that the West Walker River in Pickel meadow has had a relatively stable planform, though with some minor amounts of meander migration noted in places.

Since at least 1955 the upstream portion of the overall reach has been disconnected from its floodplain and meadow due to terrace features, a parking lot, and a primitive road. This disconnection in the upper portion of reach 1 is considered a primary impairment. This confinement prevents a direct connection of the West Walker River with the previous extent of its alluvial fan and the widest portion of Pickel meadow (Figure 3). Elevations within the northwest portion of the meadow indicate that, with the absence of the parking lot and terrace, the northwest portion of the meadow (which appears to currently be xeric to mesic) could be directly connected with the West Walker River and hydric. However, with this barrier, the supply of water is limited to irrigation withdrawals and groundwater flow (likely minimal, through compacted material). Additionally, sediment and wood supply to this upper portion of adjacent meadow is lacking due to the barrier.

The lower portion of reach 1 continues to be transitional, with resulting deposition of sediment and resulting variable geomorphic form. A terrace on the left (East) side of this reach shows xeric to mesic characteristics and unstable banks. At the downstream limit, the top of this terrace is 5 ft above the bankfull water surface, which fundamentally contributes to the dry conditions. These terraces may be a valuable source of alluvial material as borrow (if of appropriate size).

However, the active floodplain surface is 300 ft wide at this downstream limit of reach 1, with this surface continuing and expanding downstream through reach 2 to a width of at least 900 ft. This currently active floodplain is wide and likely sufficient for minimizing unit stream power during floods. Unit stream power is computed as

$$\omega = \frac{\gamma Q S_f}{w}$$

where, in the SI unit system, ω is unit stream power (W/m^2), γ is the specific weight of water (N/m^3), S_f is the friction slope (m/m, frequently assumed to be equal to the water surface or channel slope), and w is the flow width (m). Higher unit stream power is directly proportional to greater sediment transport conveyance capacity.

Importantly, while the current floodplain surface in reach 2 is extensive and likely sufficient, this most extensive portion of Pickel Meadow is elevated compared to this current floodplain surface, with the surface of the lower end of the meadow functioning as a terrace that is 3 to 4 ft above the bankfull flow elevations. Consequently, during low flow in West Walker River this leads to depressed ground water table elevations under the adjacent meadow (6 to 7 feet below meadow surface).

The West Walker River in reach 2 has incised at some point in time and fully developed a new floodplain at a lower grade. Hence, this stream is in stage 5 of the channel evolution model (Figure 18). In these areas, the current substantial floodplain extent has reduced unit stream power and sediment transport conveyance capacity; it is considered relatively recovered from a historic incision episode, but with hydrologic consequences to the adjacent meadow due to the lowered groundwater table elevations.

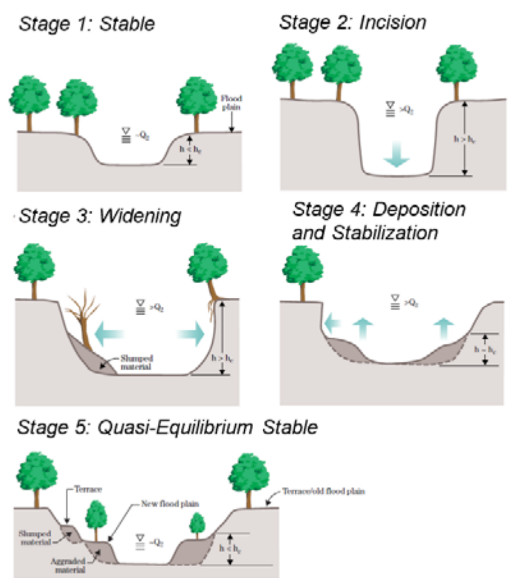

Figure 18: Channel evolution model, with channel cross sections illustrating the 5 channel stages (modified from NRCS 2007).

Additionally, the general lack of willows present in reach 2 may be contributing to enhanced streambank instability and sediment liberation. Though the generally stable planform (since 1955) indicates that bank erosion rates may not be excessive.

The lack of in-channel large wood present, transported from forested hillslopes upstream, may be contributing to what appears to be a lack of extensive pool development. This lack of wood, combined with infrequent willow and other woody cover along streambanks, results in a lack of cover for fish communities.

More substantial side channel connectivity appears to have existed for a portion of reach 2 in 1955, but has since be gradually lost. This may be due to incision that could have occurred since 1955. It could be associated with a downstream meander bend that was cutoff, creating localized increased slope, increasing sediment transport conveyance capacity and channel incision potential. Generally, incision appears to be primarily limited to reaches 1 and 2.

Reach 3 is in decent condition, with an active floodplain of various widths, mature willows, side channels, and groundwater connectivity present. Substantial restoration efforts will not likely be needed, but some management alteration and local features (to add cover, for example) could be considered.

Reaches 4 and 5 are also in generally good condition, though have very limited amounts of cover present. Like reach 3, substantial restoration efforts will not likely be needed, but some management alteration and local features (to add cover, for example) could be considered. Cottonwood planting in reach 5 could also be considered.

A variety of restoration options and features are possible to address the most substantial impairments and proposed goals for Pickel Meadow and the West Walker River. These range from a management and revegetation alternative, to promote vegetative recovery, to more active alternatives such as the introduction of large wood, raising the bed of the West Walker River in places to address minor incision from the current floodplain surfaces, the relocation of the parking lot and removal of adjacent terrace features, and the construction or reconnection of a perennial flow multi-thread stream system in portions of the meadow. Removal of the parking lot alluvial fan confinement and creation or reconnection of multi-thread, perennial flow stream channels would likely best satisfy the goals of the project, most especially goal 3 (providing for the expansion of wetland and riparian vegetation within the meadow without the need for irrigation).

Such a multithread restoration would be a process-based approach, to reestablish baseline conditions that will allow the stream channels and floodplains to evolve through fluvial processes and riparian succession towards more complex and dynamic habitats. In contrast, a form-based approach defines channel pattern, profile, and dimension and uses structural features to minimize channel adjustment. A form-based approach would be in a physical form that is in dynamic equilibrium with its water and sediment load; however, such an approach is less appropriate in this setting, where a canyon transitions to a meadow through an alluvial fan, with resulting reductions in unit stream power and sediment transport conveyance capacity.

However, reestablishment of the West Walker River to a grade high enough in reach 2 to activate the lower end of the primary meadow system will likely not be feasible due to the large amounts of material required to fill the existing active floodplain (Appendix A, X-S 2, 3, & 4). To reestablish the stream at a higher grade, substantial impacts would also be required to existing floodplain vegetation, requiring mitigation.

At least temporary grazing exclusion areas (e.g., a riparian buffer corridor adjacent to the channel) would be needed as a part of restoration efforts.

RESTORATION ALTERNATIVES

Based on the goals and objectives of the proposed project, 5 alternatives are proposed for Pickel Meadow. The alternatives are summarized within each of the following paragraphs.

Alternative 1: No action

This alternative would result in continued impaired conditions (as described in the previous section) and continued need to irrigate the reach 2 portion of the meadow to maintain hydric plant communities. This alternative would not address the proposed goals of the partners and stakeholders.

Alternative 2: Management plus vegetative plantings

This alternative would reduce or eliminate utilization/ browse impacts to riparian vegetation along the greenline of the West Walker River to allow for vegetative recovery though recruitment and plantings. This may be accomplished either through improved livestock management practices (e.g., altered timing, use of off channel water, a period of rest) or through the construction of exclosures which could be removed once stabilizing greenline vegetation was fully established. These exclosures could be limited to riparian buffers along flow channels of West Walker River and the tributaries or could span the entire meadow width. The banks would stabilize over time. A thoughtfully-planned and implemented revegetation plan should be incorporated into this alternative.

Alternative 3: Restoration with current alignment, with vegetative plantings

The current alignment of the West Walker River and its tributaries could be maintained, with enhanced geomorphic, wood, and vegetation features. Riffles could be raised, though this could be problematic to tie into the existing (and extensive) floodplains. Care would also be needed to maintain reasonable consistency in trends and magnitude of sediment transport conveyance capacity, to avoid unexpected deposition or erosion. Large wood material or structures could be added, to encourage pool scour and provide cover. A thoughtfully-planned and implemented revegetation plan along with improved management of greenline vegetation use should be incorporated into this alternative.

Alternative 4: Restoration with new alignment, with vegetative plantings

A new single-thread alignment for the West Walker River could be constructed, potentially with a new channel passing further north across the meadow surface of reach 2 or in another location, potentially utilizing a remnant channel. This approach could maintain higher groundwater table levels under the meadow but could be risky due to the potential of recaputure by the current (and extensive) channel and floodplain. Care would also be needed to maintain reasonable consistency in trends and magnitude of sediment transport conveyance capacity, to avoid unexpected deposition or erosion. Increasing the sinuosity of the new channel could complicate this need. Where a new channel is adjacent to terraces, bankfull benches should be constructed to provide a surface for the growth of stabilizing riparian vegetation. Large wood material or structures could also be added, to stabilize banks, encourage pool scour, and provide cover. A thoughtfully-planned and implemented revegetation plan along with improved management of greenline vegetation use should be incorporated into this alternative. Using existing water rights for irrigation, it may likely be best to establish much of this vegetation before flow was diverted into the new channel, though this would likely take substantial effort.

Alternative 5: Restoration with multi-thread channels, with vegetative plantings

Instead of a new single thread alignment, multi-thread perennial flow stream channels could be constructed (or existing relic channels reconnected) to reestablish an unconstrained alluvial fan through reaches 1 and 2. The current parking lot would be relocated and the primitive road and terrace features eradicated. Multiple channels would be constructed or reconnected to distribute the flow across the meadow surface, with these smaller channels providing flow to maintain higher groundwater levels during low flow. This would best satisfy goal 3: provide for the expansion of the wetland and riparian vegetation within the meadow without the need for irrigation. The channels would likely be allowed to shift over time, as expected in an undisturbed fan and meadow. However, as with alternative 4, this approach could be risky with the potential for recapture by the current channel and floodplain. With reestablishment of an active alluvial fan, the current channel dimensions could potentially be resized for lower discharges in places. Large wood material or structures could also be added, to stabilize banks, encourage pool scour, and provide cover. Soil bioengineering practices could be helpful, and grade control through constructed riffles or other features may be needed, especially in the transition to the primary channel at the lower end of reach 2. A thoughtfully-planned and implemented revegetation plan along with improved management of greenline vegetation use should be incorporated into this alternative. Using existing water rights for irrigation, it may likely be best to establish much of this vegetation before flow was diverted into the new channel, though this would likely take substantial effort.

RECOMMENDED RESTORATION STRATEGY

Considering the variety in geomorphic conditions of the overall 4.8 mile restoration extent, the best restoration alternative for each reach will vary. It is recommended that:

- **Reaches 1 and 2: Implement Alternative 5.** This approach would likely provide the most appropriate dimension, pattern and profile for an alluvial fan transition to a meadow system (goal 1), provide the best ecological conditions for fish populations (goal 2), and provide better hydrologic conditions for the wet meadow (goal 3). This alternative would also encourage more trapping of sediment within the meadow (goal 5), should likely enhance most recreational pursuits (goal 6), would likely increase forage for livestock (goal 7) and wildlife (goal 8).
- **Reaches 3, 4, and 5: Implement Alternative 3.** With the more confined setting of these reaches and minimal observed incision, more aggressive restoration is likely not warranted. Instead, in pursuit of goal 2 (maintenance of self-sustaining fish populations), large wood and vegetation features would likely be the most valuable restoration strategy. Large wood features could consist of log jam placement (mobile), engineered log jams (static), and possibly toe wood and log bank vanes. Vegetation features could consist of willow and sedge plantings, cottonwood and other wood plantings, and soil bioengineering.

DATA and ANALYSIS NEEDS

A number of data needs are provided below. These needs are not all inclusive and would only be required to support project design and analysis of restoration alternatives 3, 4, or 5 prior to alternative selection by the land management agencies:

(1) Meadow and floodplain survey, using LiDAR
(2) In-channel survey (to be combined with LiDAR survey, for a complete DEM)
(3) In-channel bed material gradation
(4) Bankfull discharge measurements (can be replaced with estimated values, as presented in this report)
(5) Historic peak flow estimates, to supplement upstream streamgage record (for infrequent flood magnitude refinement)
(6) Groundwater table monitoring (a few wells were installed in 2016)

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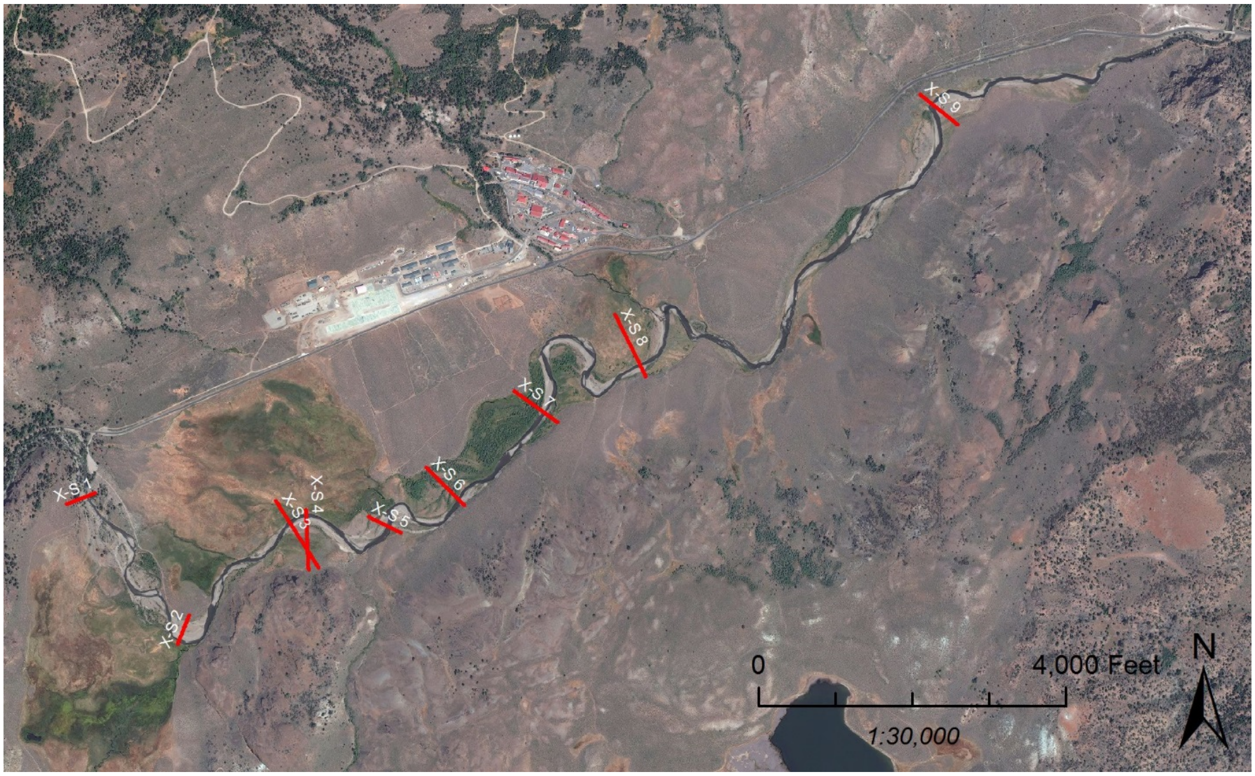
Potyondy, J.P. 2011. Watershed Condition Framework. United States Department of Agriculture Forest Service FS-977, Washington, D.C.

APPENDIX A: Cross Sections



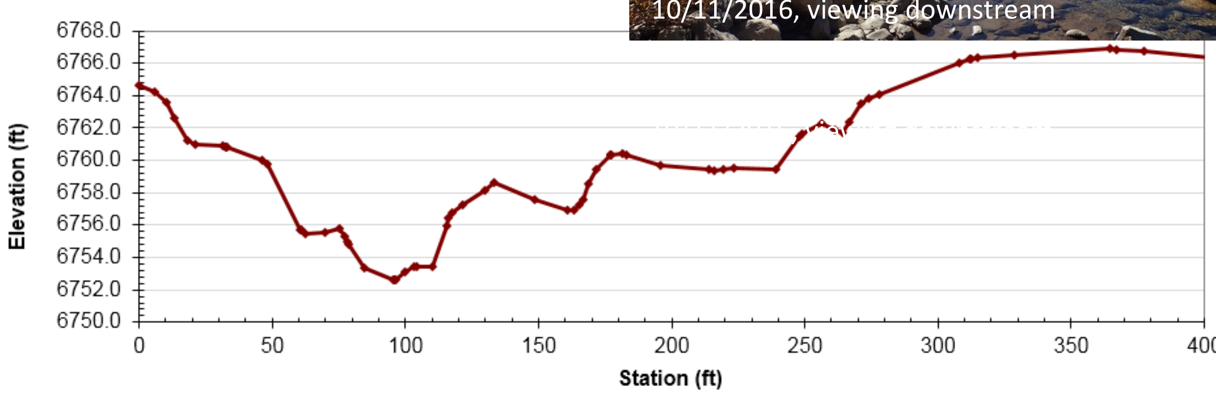
(imagery collected 8/28/2016)

X-S 1

Notes:

Stream is incised, without reasonable bankfull indicators

Large bed material is present within this transition from canyon to meadow on a constrained alluvial fan



X-S 2

Notes:

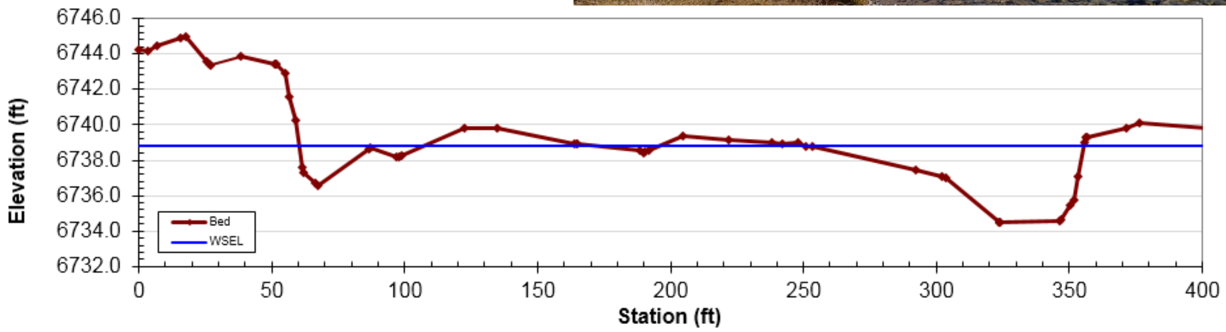
Bankfull indicator: break in cross section slope

Terrace on left edge of floodplain is 5 ft above bankfull water surface

Wet meadow on right bank is 1 ft above bankfull water surface

Active floodplain is 300 ft wide

Q_{bnk} = ~780 cfs



X-S 3

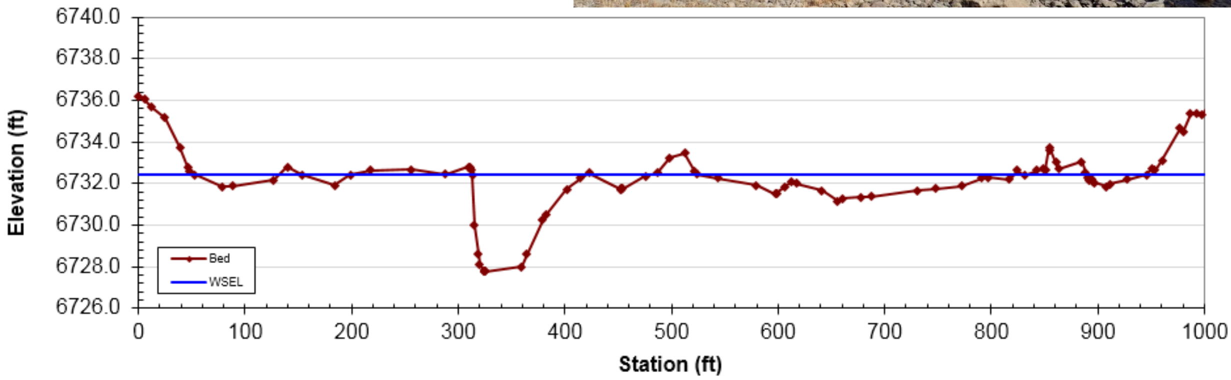
Notes:

Bankfull indicator: break in cross section slope

Terrace/meadow on left side of floodplain is 4 ft above bankfull water surface

Active floodplain is 900 ft wide

Q_{bnk} = ~880 cfs



X-S 4

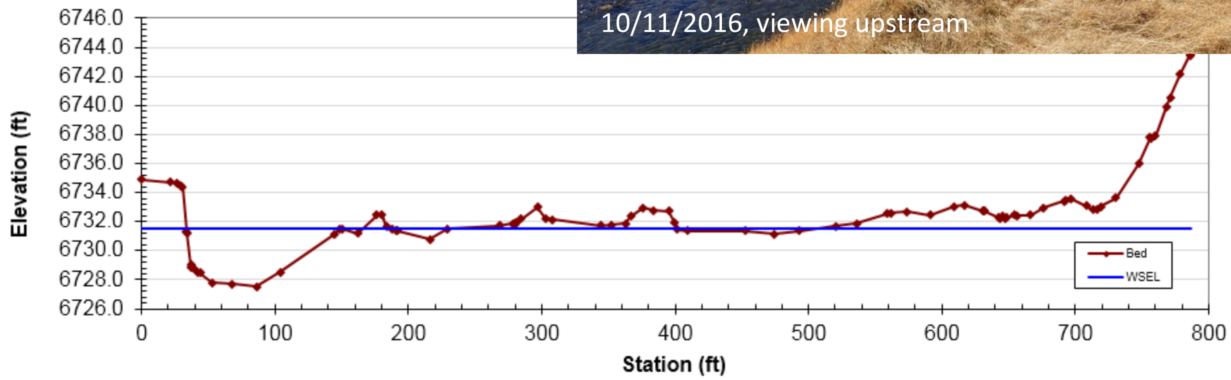
Notes:

Bankfull indicator: break in cross section slope

Terrace/meadow on left edge of floodplain is 3 ft above the bankfull water surface

Active floodplain is 700 ft wide

Q_{bnk} = ~720 cfs



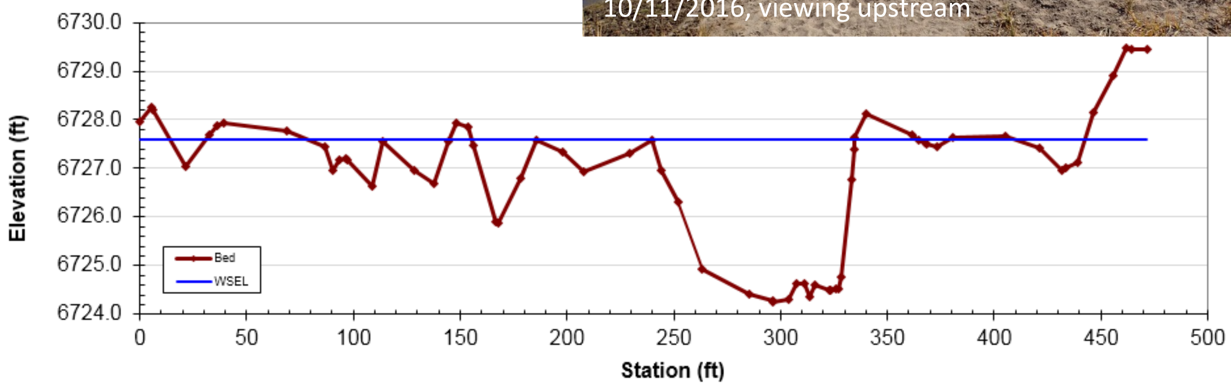
X-S 5

Notes:

Bankfull indicator: break in cross section slope

Floodplain is wide, with X-S 5 across only the primary channel and adjacent floodplain

Q_{bnk} = ~790 cfs



X-S 6

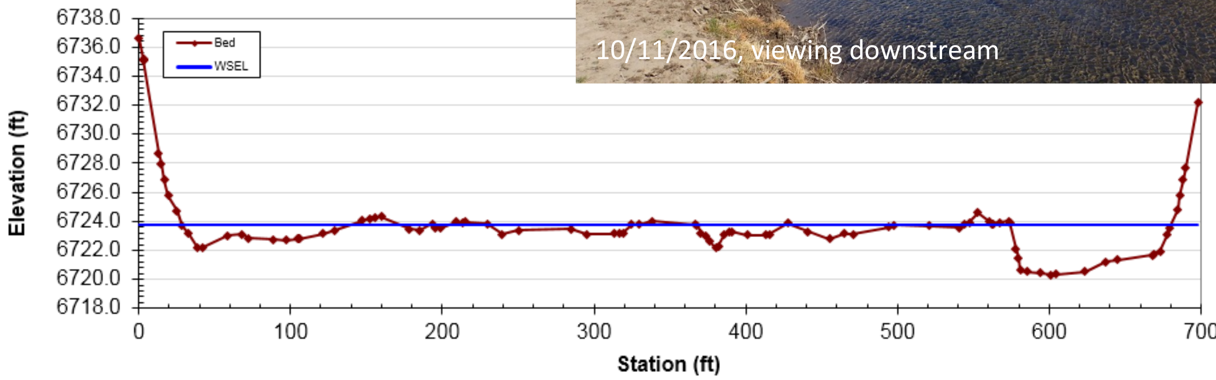
Notes:

Bankfull indicator: break in cross section slope

Semiconfined by high terraces

Active floodplain is 650 ft wide

Q_{bnk} = ~750 cfs



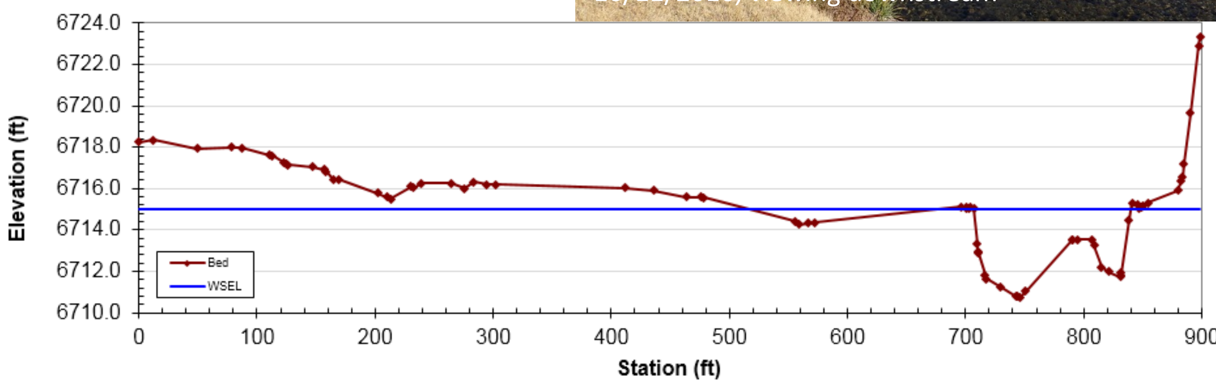
X-S 8

Notes:

Bankfull indicator: break in cross section slope

Floodplain slopes up to a smaller unconfined meadow system (reach 4)

Q_{bnk} = ~1020 cfs



X-S 9

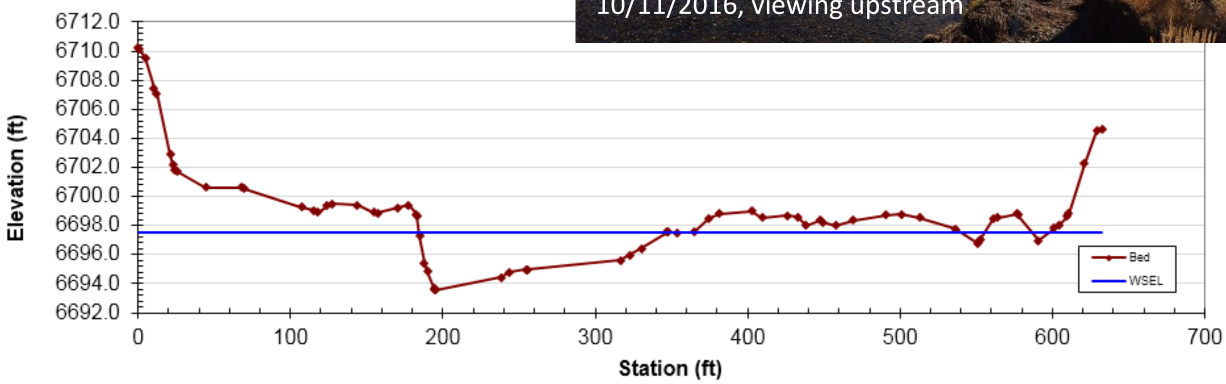
Notes:

Bankfull indicator: break in cross section slope

Floodplain is less connected than upstream sections in less confined locations, though 400 ft wide active floodplain exists

Left bank is a low terrace

Q_{bnk} = ~1110 cfs



APPENDIX B: Aerial imagery (8/28/2016)

Appendix B: Current Aerial Imagery (2016-08-28), Upstream

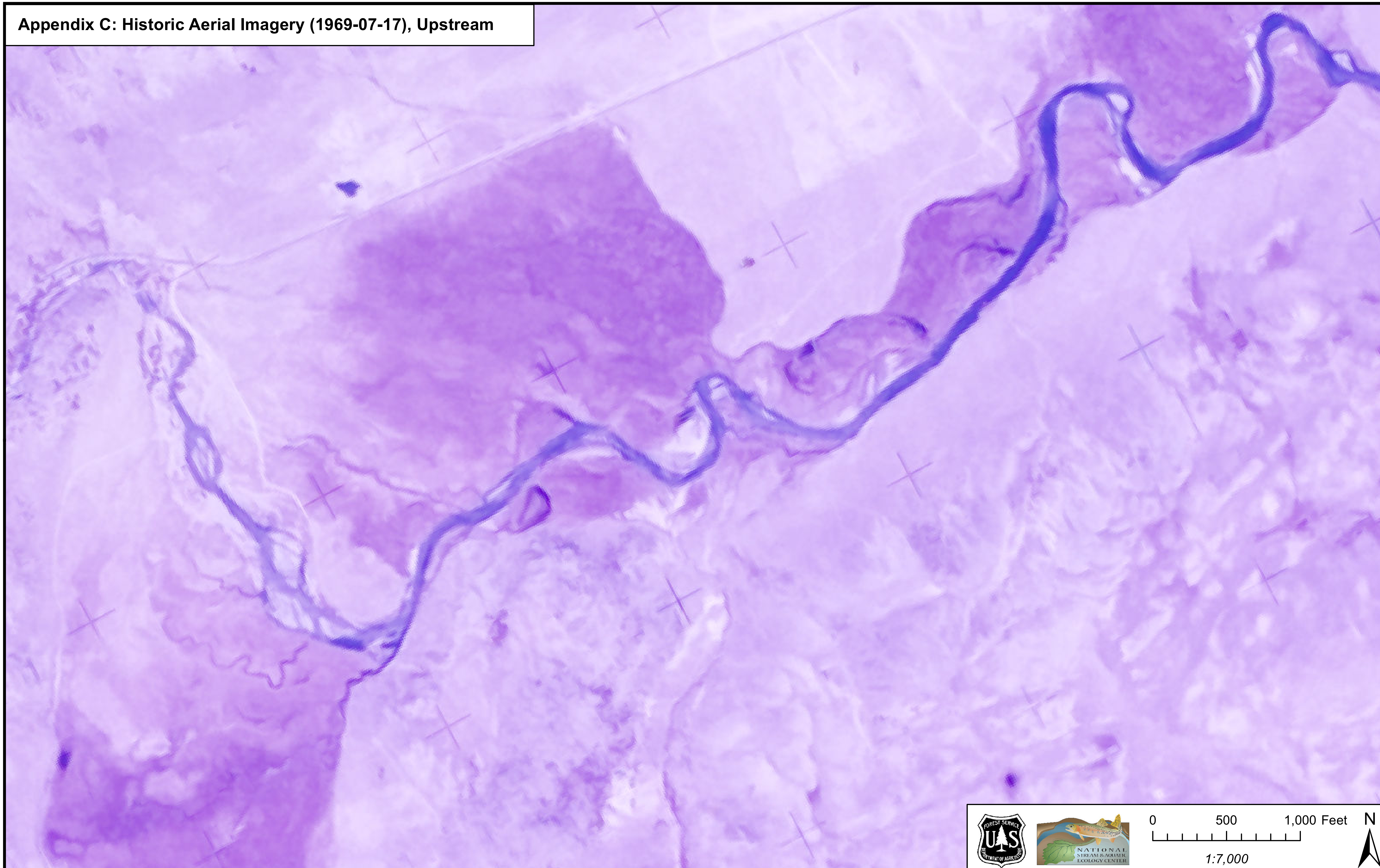
Appendix B: Current Aerial Imagery (2016-08-28), Downstream

APPENDIX C: Historic Aerial Imagery

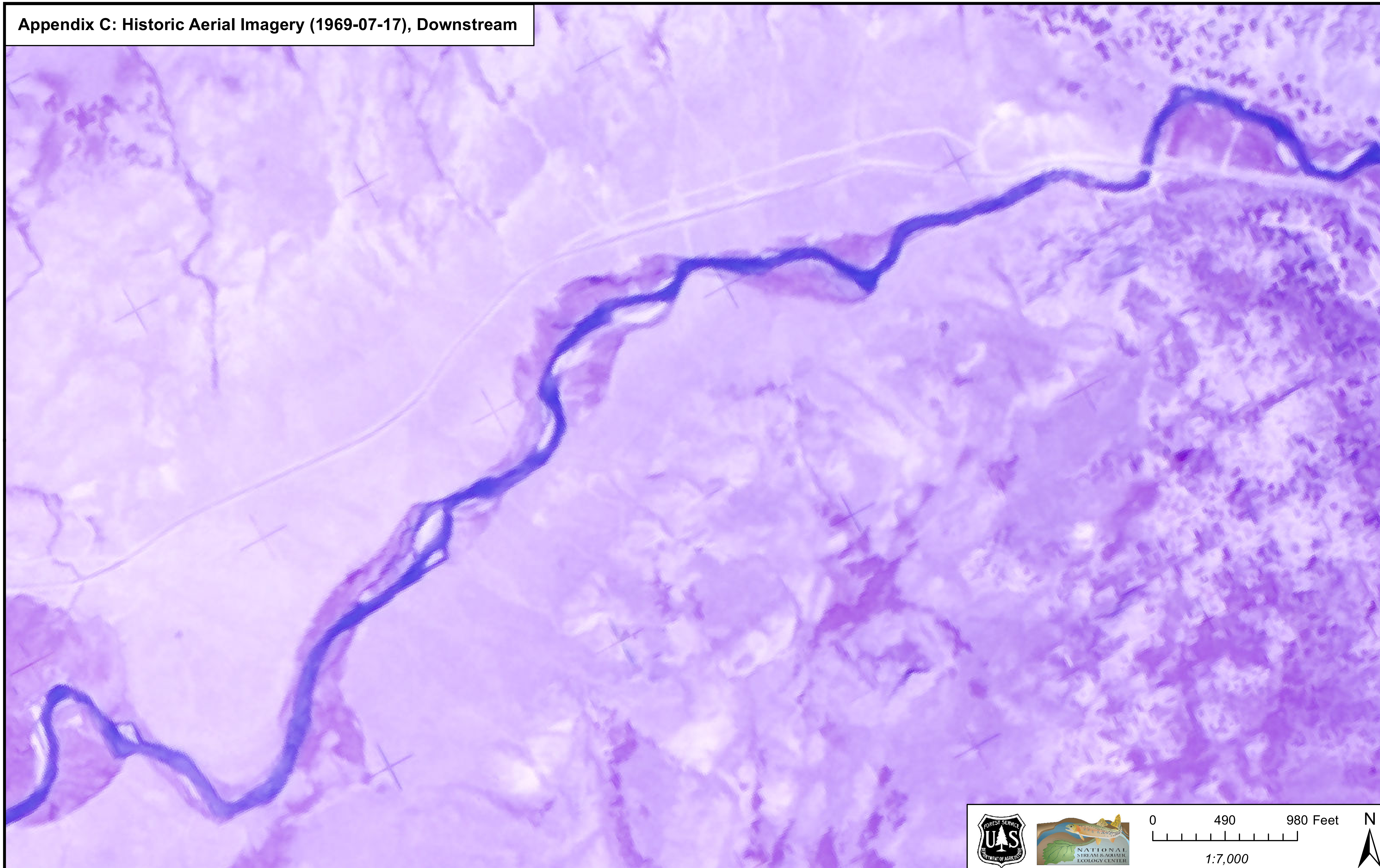
Appendix C: Historic Aerial Imagery (1955-08-31), Upstream

Appendix C: Historic Aerial Imagery (1955-08-31), Downstream

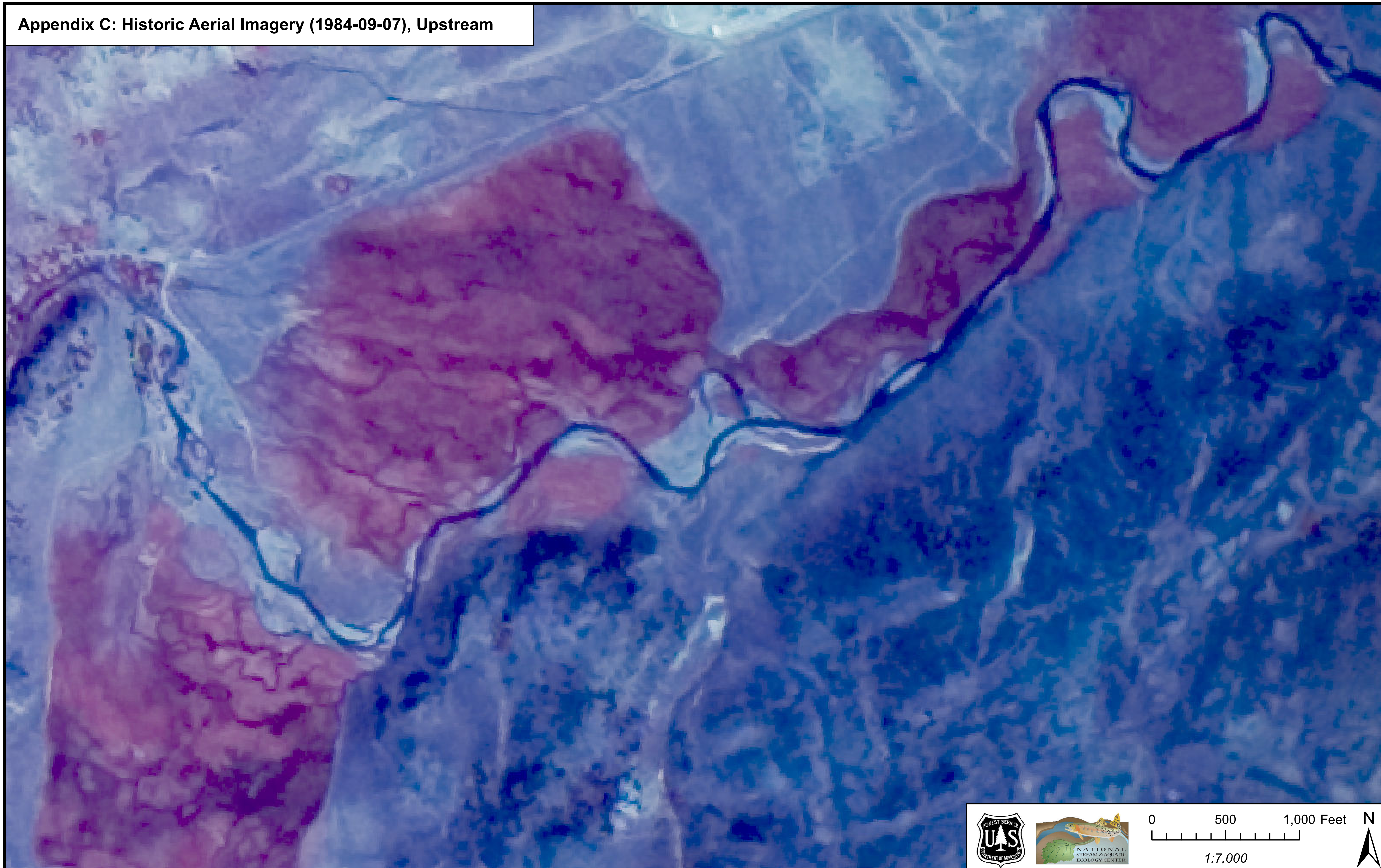
Appendix C: Historic Aerial Imagery (1969-07-17), Upstream



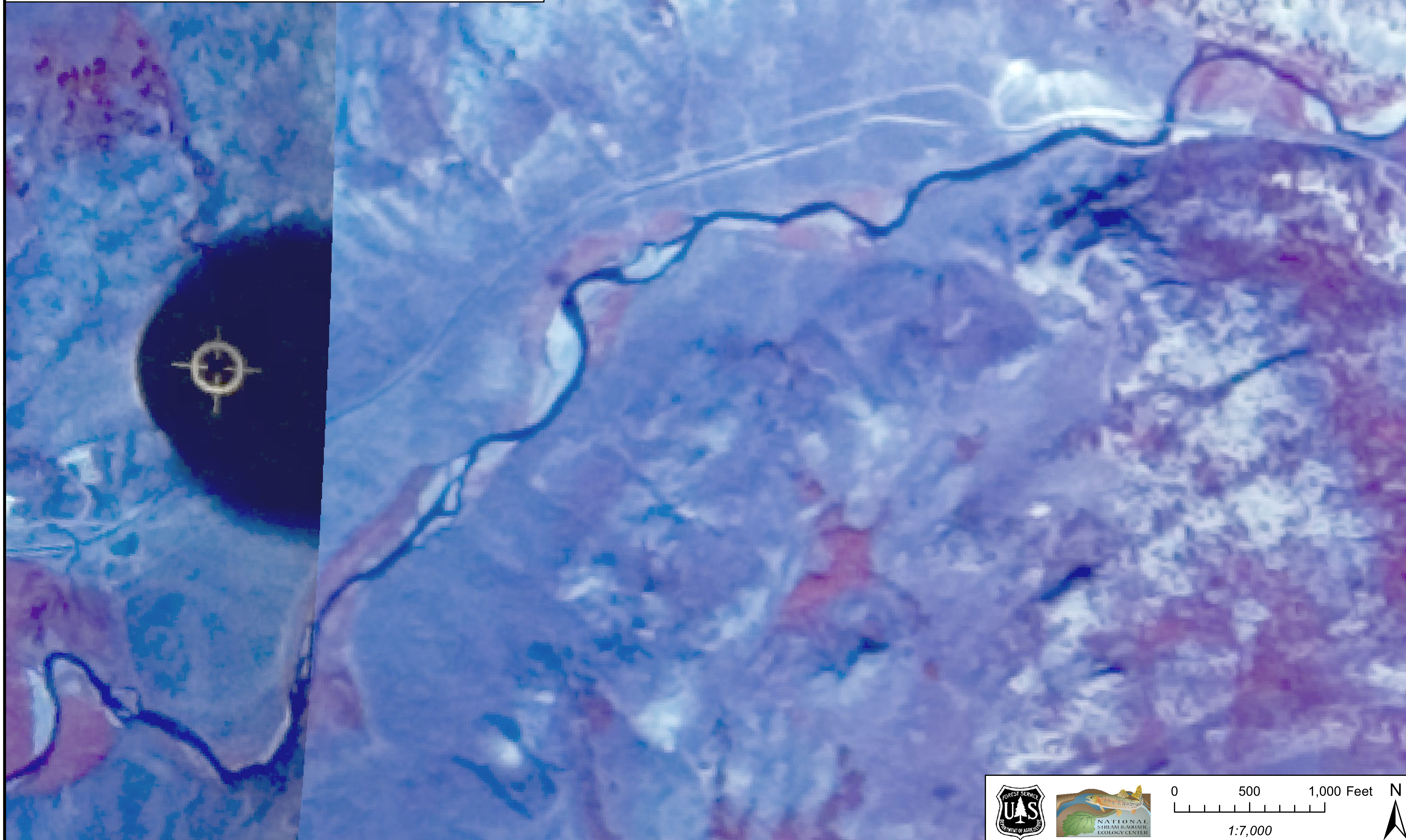
Appendix C: Historic Aerial Imagery (1969-07-17), Downstream



Appendix C: Historic Aerial Imagery (1984-09-07), Upstream



Appendix C: Historic Aerial Imagery (1984-09-07), Downstream



Appendix C: Historic Aerial Imagery (1998-09-18), Upstream

Appendix C: Historic Aerial Imagery (1998-09-18), Downstream