DESIGN BASIS REPORT
LACEY MEADOWS RESTORATION DESIGN
SIERRA AND NEVADA COUNTIES, CALIFORNIA

Prepared for:

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December 2021

August 19, 2020 (*Revised December 1, 2021*)

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1 INTRODUCTION AND PURPOSE

In 2012, The Truckee Donner Land Trust (TDLT) acquired 3,000 acres which included the majority of Lacey Creek and the Upper and Lower Lacey Meadows. Much of the surrounding lands are managed by U.S. Forest Service, Tahoe National Forest (TNF). At that time, Truckee River Watershed Council (TRWC) contracted with Balance Hydrologics (Balance) to complete a watershed assessment of the Lacey Meadows watershed above Webber Lake (Hastings and others, 2013). Channel and meadow degradation were described, and restoration opportunities were identified in both the Upper and Lower Lacey Meadows. In 2014, UC Davis and American Rivers researchers classified the 515-acre Lower Meadow as “moderately degraded” (UC Davis, 2019). In 2019, TRWC contracted with Balance to develop restoration design plans for both meadows.

The purpose of this report is to: (1) describe the current condition of Lacey Meadows, (2) describe additional investigations and analyses that have been completed to support restoration design, (3) outline site-specific restoration design constraints and opportunities, (4) present conceptual designs, and (5) establish a scientific basis for those designs, which are intended to enhance montane meadow functions and habitats.

Subsequent coordination with TRWC, landowners, and possibly other stakeholders will be required as the restoration design advances. This report should always accompany the design documents and can be used to facilitate understanding of the project goals and objectives and overall restoration approach.

Summary of project goals:

- Restore meadow surface-groundwater interactions
- Manage grazing impacts
- Enhance meadow vegetation diversity and abundance
- Enhance summer-fall baseflow

2 LOCATION AND PHYSICAL DESCRIPTION

Lacey Creek is a headwater stream that drains a 9.6 square mile watershed on the east side of the Sierra Nevada crest and is the hydrologic support for Upper and Lower Lacey Meadows. The watershed ranges between 8,336 feet elevation and 6,785 feet elevation at Webber Lake. Lacey Creek is a tributary to the Little Truckee River and the Truckee River. The Project includes approximately 3.5 miles of Lacey Creek through both the Upper and Lower Lacey Meadows (**Figure 2-1**).

Throughout this document and the design plans, Lacey Creek is referenced using reach classifications assigned in 2012 (Hastings and others, 2013). This project includes the following reaches identified below in **Table 2-1** and shown in **Figure 2-2** and **Figure 2-3**.

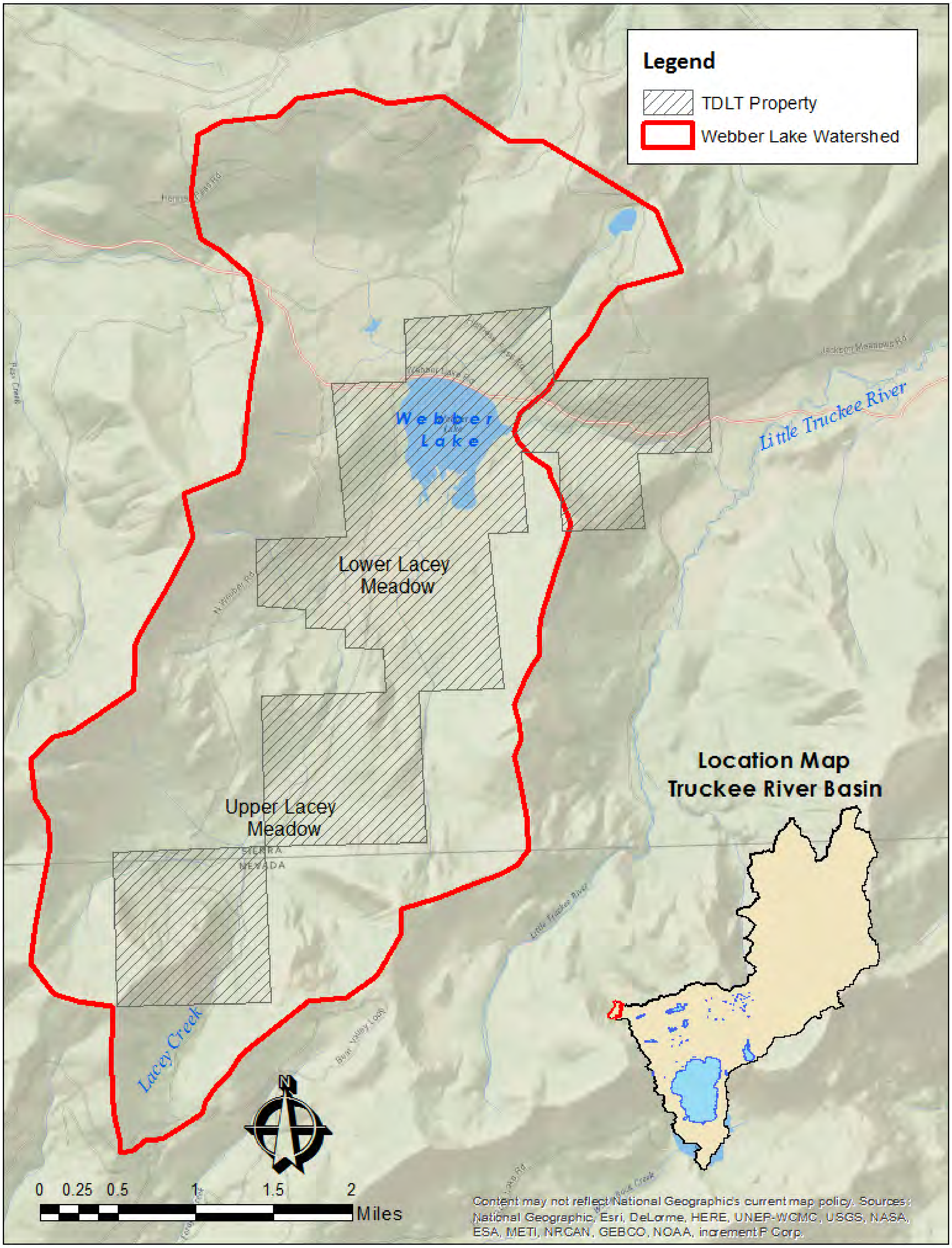

Figure 2-1 Project Watershed Map, Including Upper and Lower Lacey Meadows, Sierra and Nevada Counties, California.

Table 2-1 Lacey Creek Reach Classification with Descriptions.

Location	Reach	Condition and Design Comments
Reaches listed alphebetically; if a letter is not listed, there are no restoration actions proposed for that reach		
Lower Lacey Meadow		
	B	Heavily incised; restoration features downstream of Webber Lake Road crossing presented as optional; baseflow maintained in existing channel
	C	Key reach with evidence of distributary channels; key design elements
	D	Active alluvial fan reach; encourage reduced flow velocities and flow dispersal
	West Tributary	Headcutting from Webber Lake base level changes
	Southeast Tributary	Minor to moderate incision; encourage channel aggradation and overbank flow
	Southwest Tributary	Historical channel modifications; incised; restore flow pathway and encourage channel aggradation
Upper Lacey Meadow		
	F	Downstream of confluence of Reaches G(a+b); incised; encourage channel aggradation and overbank flow
	G (a)	Relocated, existing channel; disconnected from meadow; straight, steep, discourage flow and a sink for groundwater drainage
	G (b)	Former primary channel; incised, evidence of modifications; currently disconnected from existing channel from old gravel push-up dam; restore partial flow; encourage channel aggradation; requires road repair and maintenance (Webber Lake Road)
	H	Braided channel; active alluvial fan; main channel incised and straightened, artificial levee; remove modifications, encourage channel aggradation, and arrest knickpoint erosion in adjacent meadow
	I (a)	Active alluvial fan; former primary channel; partially abandoned, moderately incised in lower segment; restore flow; encourage channel aggradation and distributary flow
	I (b)	Former road; stream capture, currently primary channel, incised; old fill/levee, remove modifications and discourage as primary channel
	J	Active alluvial fan; recieves road runoff; incised (including small triburary to J); encourage channel aggradation, distributary flow

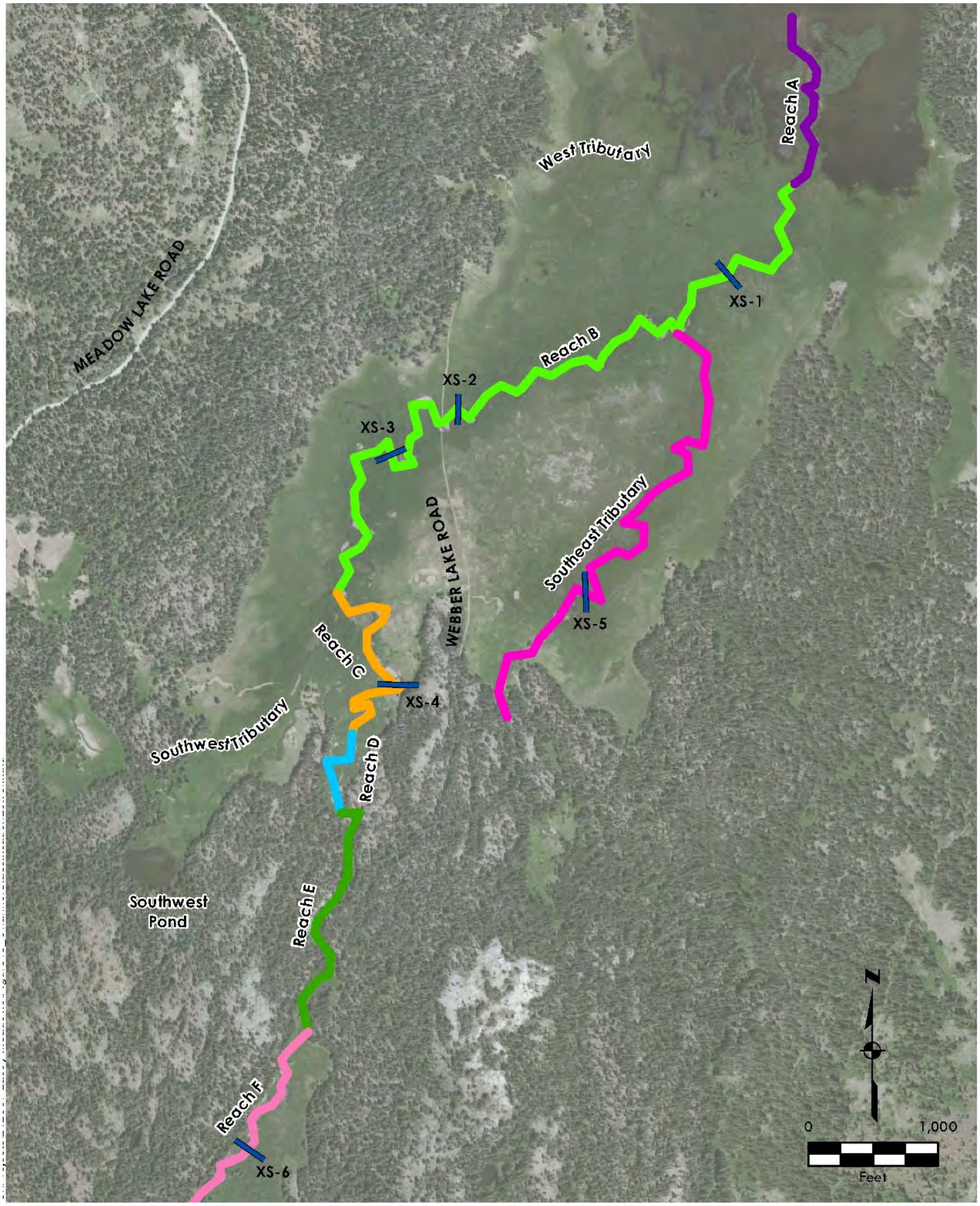

Figure 2-2 Lacey Creek Reach Classification, Lower Lacey Meadow.

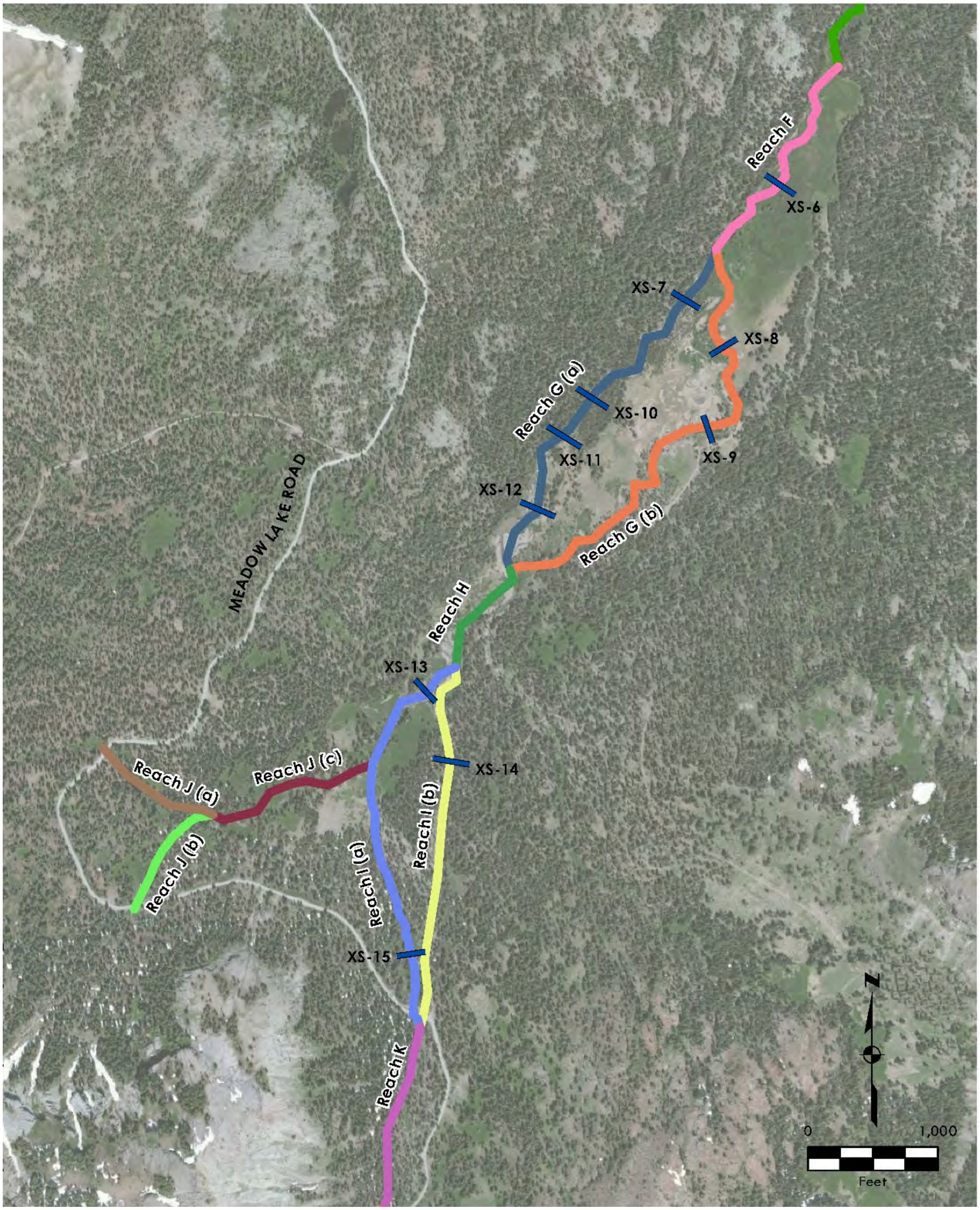

Figure 2-3 Lacey Creek Reach Classification, Upper Lacey Meadow.

The uplands above Lacey Meadows are primarily characterized by highly erosive pyroclastic volcanic rocks, including tuffs, mudflows, and andesitic rocks. Hillslope rilling, gullying and landslides are common. Easily friable or erodible geology in the upper watershed and steep headwater channels provides abundant sediment supply to the stream corridor. In a high sediment supply system, Lacey Creek forms alluvial fans as it enters both the Upper and Lower Meadows. Alluvial fans are common and dynamic landforms of the eastern Sierra; therefore, the entire fan should be considered to be included in the restoration approach, with many areas that could support an active channel.

Further downstream, both the Upper and Lower Lacey Meadows are alluvium-filled valleys derived from glacial and fluvial erosion and deposition. Lacey Creek appears to have undergone period(s) of incision, as evidenced by relatively low width/depth ratios, exposed roots along banks, and absence of overbank flows (**Figure 2-4**). Glacial moraines (i.e., unconsolidated deposits ranging from sand to boulders) are present in each meadow and influence channel patterns, slope, and vegetation. A well-defined moraine bisects the Upper Meadow and its architecture and influence is considered as part of the restoration design.

The Lacey Meadows Assessment (Hastings and others, 2013) characterized both Upper and Lower Lacey Meadows as a montane meadow (333 acres) with areas of montane riparian scrub (74.7 acres), dry montane meadow (36 acres) and montane wetland shrub (2.5 acres); however, a comparison of meadow acreage over the last 50+ years shows a decrease of roughly 40 acres, primarily due to meadow desiccation and encroachment of lodgepole pines. While both meadows provide some groundwater storage and, in most years, support late summer baseflow, the potential for additional storage and baseflow support is obvious. A more detailed description of geology and soils in the watershed are provided in the Lacey Watershed Assessment (Hastings and others, 2013).

Sediment and wood transport are key physical functions provided by Lacey Creek in Upper Lacey Meadow, and induce channel migration and aggradation, especially across the alluvial fans at the Upper end of the Meadow. In lower-gradient reaches, Lacey Creek exhibits active bank erosion and dynamic bar movement, further promoting wood recruitment by undermining and felling trees in areas adjacent to the upland forest. Instream wood provides roughness that encourages local and reach-wide deposition (**Figure 2-5**). These processes are common in at the heads of each meadow and are analogs for restoration elements that can be used to reverse channel incision.

Figure 2-4 Example of Channel Incision and Meadow Desiccation in Upper Lacey Meadow, Reach G (b).

Figure 2-5 Example of Wood Recruitment and Sediment Deposition or Channel Aggradation in Lacey Creek, Upper Lacey Meadow, Reach H.

3 WATERSHED DISTURBANCES RELEVANT TO DESIGN

Current and historical land uses are well documented in the Lacey Meadows Assessment (Hastings and others, 2013). We briefly summarize some of the key disturbances that have affected stream and meadow condition and are considered in the restoration design.

In Lacey Creek watershed, roads are primarily responsible for road capture, excess runoff, meadow dissection and degradation, and hillslope and in-channel erosion. We illustrate examples of these impacts in **Figure 3-1**, **Figure 3-2**, **Figure 3-3** and **Figure 3-4**.

Channel modifications and manipulations of natural stream patterns in montane meadows were common practices over the last century or more. In Upper Lacey meadow, there is both field and photographic evidence that these channel modifications occurred. Gravel piles or push-up dams observed in remnant channels suggest they were placed to dam channels and divert flow (**Figure 3-5**). Similarly, a review of historical aerial imagery between 1952 and 1966 suggests that channel avulsion was encouraged to divert the channel from the upper meadow (**Figure 3-6**). The location of the channel avulsion in the imagery corresponds to the presence of an old gravel push-up dam immediately upstream used to block flows to the meadow, probably to support drier conditions in the meadow for grazing (**Figure 3-7**). Lacey Creek was also modified in other ways using large rock and logs for flow deflection or diversion (**Figure 3-8**).

Sheep grazing is a part of the historical and on-going land use of both the upper and lower meadow. Sheep tend to congregate near the creek for a source of drinking water. In the process, bank trampling is often a consequence (**Figure 3-9**) and accelerates bank erosion and channel migration.

Cumulatively, these upland and meadow disturbances have resulted in channel downcutting or incision, further promoting meadow desiccation and conversion. A comparison of meadow acreage in Lacey Meadows between 1955 and 2009 showed a 38-acre reduction in meadow acreage (Hastings and others, 2013).

Lacey Creek discharges to Webber Lake, a natural feature, but the volume and water levels are regulated by a low-head dam. Removable fish screens were used on the dam for decades to minimize stocked fish from migrating downstream. Debris in the lake often accumulated on the fish screens and exacerbated fluctuations in water levels. Rapid and large fluctuations in lake levels promoted base level changes for the outlet of Lacey Creek, often resulting in a change in shoreline location of almost 0.4 miles. Base level changes in an alluvial system such as Lacey Creek has resulted in knickpoint erosion and headcut migration (**Figure 3-10**). Under current management, the fish screens are no longer used (Svahn, J., pers. comm, 2019), but observed leakage under the dam continues to influence lake level fluctuations to a larger degree than under natural conditions.

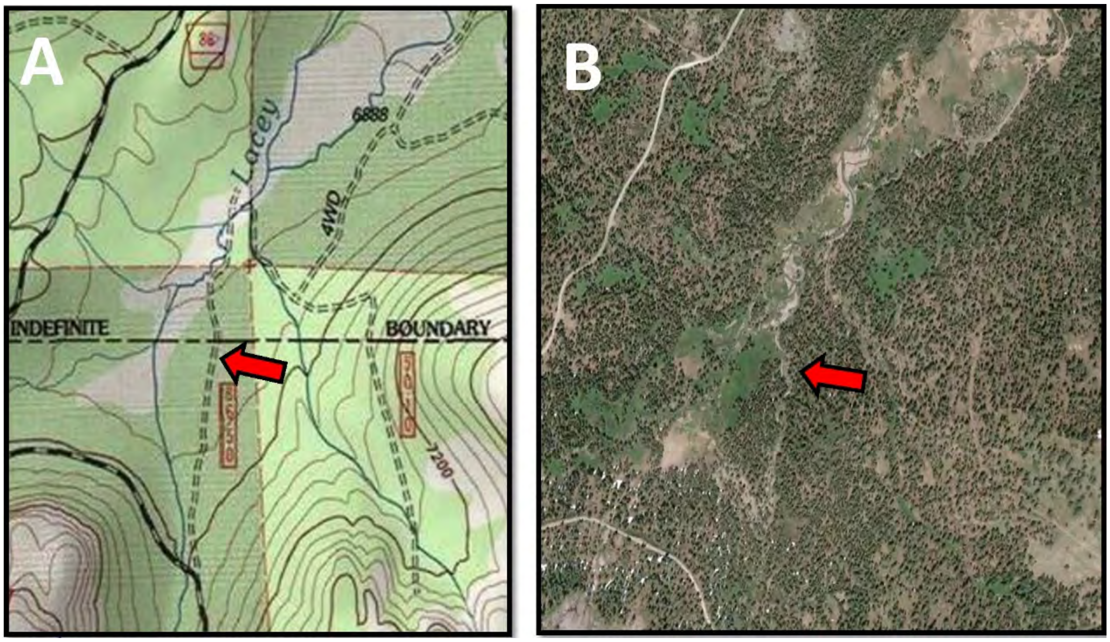

Figure 3-1 Former Roads Shown in a Historical 1940 Topographic Map (A); Current Conditions Showing Road Capture Lacey Creek and Tributaries (B).

Figure 3-2 Example of Road Capture from Webber Lake Road.

Figure 3-3 Example of Road Runoff Concentrated in a Natural Channel, Upper Lacey Meadow, Reach I (a).

Figure 3-4 Evidence of Meadow Dissection and Degradation, Lower Lacey Meadow along Webber Lake Road.

Figure 3-5 Example of a Gravel Push-up Dam Located in a Historical Channel of Lacey Creek, Upper Lacey Meadow, Reach G (b).

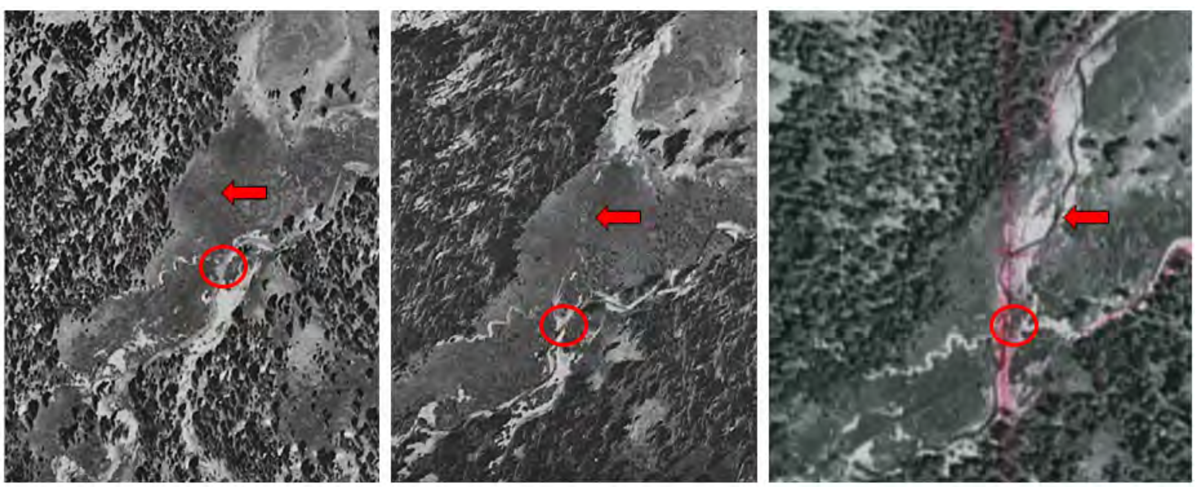

Figure 3-6 Historical Aerial Imagery Showing Channel Modifications over Time from either a Cattle Trail, a Road, or Influence from an Instream Diversion Structure (1952, 1962, 1966, left to right), Reach G (a). Red circles indicate same location in each image.

Figure 3-7 Former Main-Channel Blocked by a Push-up Dam, Lacey Creek, Upper Lacey Meadow. This dam encouraged channel avulsion to the northern side of the meadow and through the forest [Reach G(a)], depriving meadow of hydrologic support.

Figure 3-8 Example of an Old Rock and Log Dam or Diversion Structure, Lacey Creek, Lower Lacey Meadow, Reach B.

Figure 3-9 Example of Bank Erosion from Sheep, Lower Lacey Meadow, Southeast Tributary.

Figure 3-10 Example of Headcut Erosion from Fluctuating Webber Lake Water Levels, Lower Lacey Meadow, West Tributary.

4 ADDITIONAL INVESTIGATIONS & ANALYSIS COMPLETED FOR DESIGN

Additional investigations have been carried out as part of this design process in order to understand historical and on-going stressors, impacts, and to some extent, quantify the magnitude of impairment to support restoration design. In the summer and fall of 2019, Balance geomorphologists and engineers conducted more detailed channel and road reconnaissance, characterized soils within the meadows, began a monitoring program of baseline streamflow, groundwater levels, and Webber lake levels. Together the findings from these additional investigations were used to conduct additional analyses and reconstruct a functioning condition for Lacey Creek and identify restoration goals and outcomes for a restoration design. We briefly describe our findings below.

4.1 Road Reconnaissance (with Direct Impacts on Meadows)

Approximately 22 miles of roads were identified in the watershed with at least 107 stream crossings (Hastings and others, 2013). Efforts to mitigate or restore upper watershed, road-related impacts are outside of the scope for Lacey Meadows restoration design. However, in recent years, TNF has completed drainage improvements along Meadow Lake Road, and additional improvements are scheduled (Westmoreland, R., pers. comm., 2019). For the purposes of restoration design, Balance conducted additional road reconnaissance and identified a half dozen priority road induced impacts that, if addressed, could provide measurable benefits for meadow condition. These road-related impacts are mostly associated with Webber Lake Road and old, abandoned timber harvest roads.

4.2 Soil and Groundwater Investigation

In October 2019 and again in September 2020, Balance geomorphologists worked with a local contractor to excavate trenches between 4 and 9 feet deep in both the Upper and Lower Meadows to characterize subsurface soils at locations where grading of pilot channels is proposed and observe groundwater conditions. Many of the trenches were used to install piezometers for monitoring groundwater conditions over time (**Figure 4-1** and **Figure 4-2**). In this section, we describe subsurface conditions and preliminary recorded groundwater levels for the periods of record (Upper Meadow: fall 2019 through fall 2021; Lower Meadow: fall 2020 through fall 2021).

Figure 4-1 Locations of Soil Trenches and Groundwater Piezometers, Upper Lacey Meadow

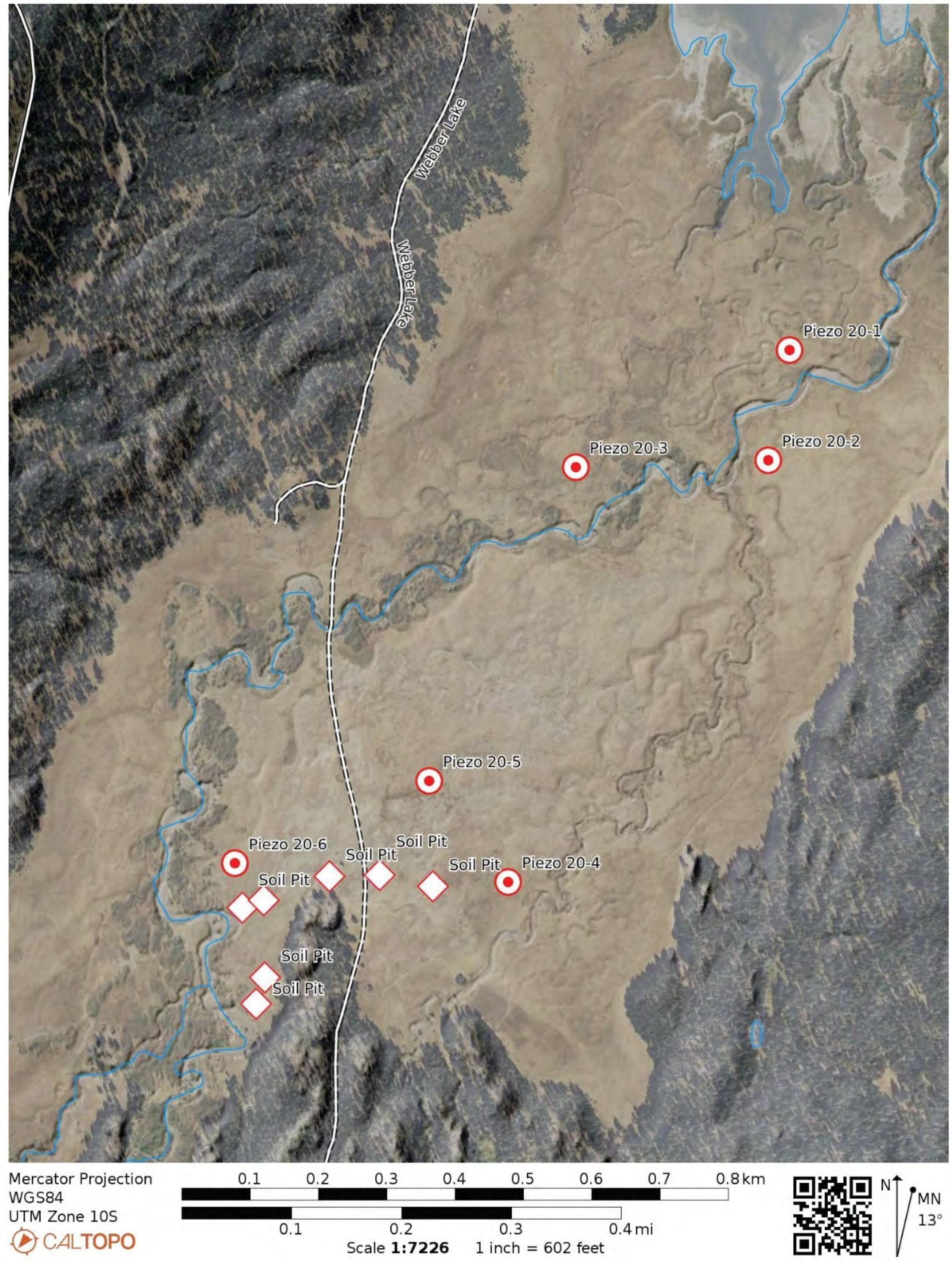

Figure 4-2 Locations of Soil Trenches and Groundwater Piezometers, Lower Lacey Meadow

4.2.1 Upper Lacey Meadow

Based on soil trenches, soil stratigraphy in the downstream direction suggests a fluvial surface of rounded gravels and cobbles consistently 0.5 to 2.0 feet below the meadow surface which could have supported an active channel historically (**Figure 4-3**). However, gravels and small cobble exposed in excavations were notably smaller (median size estimated to be between 23 mm and 90 mm) when compared to those observed in the active channel (median size estimated to be between 90 mm and 128 mm). These observations may suggest that the historical Lacey Creek functioned as a braided or multiple threaded channel such that flow was dispersed with less transport capacity instead of a single, deeper channel that concentrated flow and had the ability to transport larger materials.

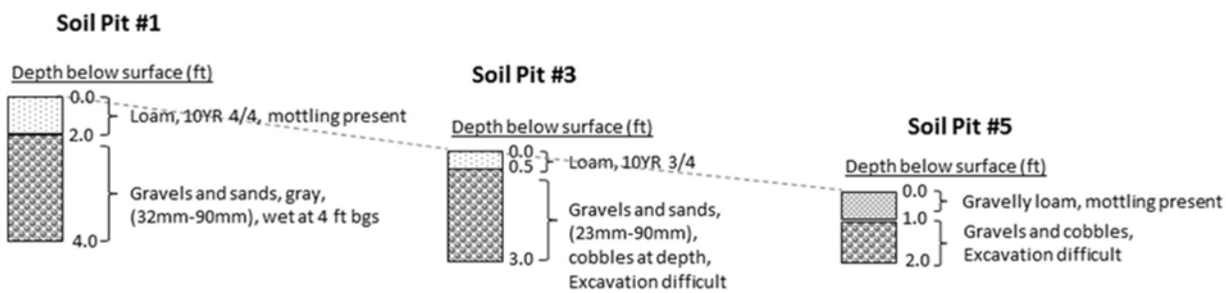

Figure 4-3 Subsurface Stratigraphy of Selected Soil Pits in the Downstream Direction in a Remnant Channel, Upper Lacey Meadow.

Shallow groundwater in the spring months was relatively rare and recorded within 12-inches of the surface for periods of less than 7 continuous days. We also observed that groundwater levels fell to depths greater than 10 feet below ground surface in some piezometers for periods of 5 to 6 months of the year. The range of groundwater levels recorded may be influenced by the timing of melt in high-elevation snow pack, soil texture, as well as the current location and incised condition of Lacey Creek in the Upper Meadow. Relocation of Lacey Creek and rewatering of the meadow will likely increase groundwater levels and increase the duration of higher groundwater levels through the year in the Upper Meadow.

4.2.2 Lower Lacey Meadow

Based on soil trenches, soil stratigraphy in locations proposed for pilot channel grading suggests a fluvial surface of rounded gravels and cobbles consistently 1.0 to 2.0 feet below the meadow surface (**Figure 4-4**). Similar to the Upper Meadow, gravels and cobble exposed in excavations were relatively smaller when compared to those observed in the active channel. These observations may suggest that the historical Lacey Creek functioned as a braided or multiple threaded channel in the Lower Meadow as well.

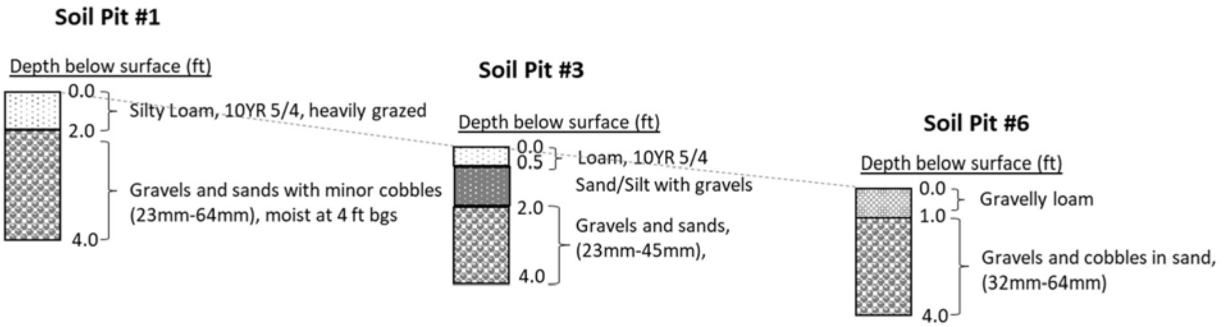

Figure 4-4 Subsurface Stratigraphy of Selected Soil Pits in the Downstream Direction of Areas Where Grading is Proposed, Lower Lacey Meadow.

Similar to the Upper Meadow, shallow groundwater in the Lower Meadow exhibited limited near-surface saturation and wide range of groundwater levels over the period of record. For example, we did not record groundwater levels within 12-inches of the surface in most piezometers and we recorded groundwater levels fell to depths greater than 8 feet below ground surface in some piezometers for periods greater than 6 months of the year. The absence of groundwater levels at the surface or sustained higher levels may be influenced by the incised condition of Lacey Creek in the Upper Meadow. Rewatering of the meadow by design will likely increase groundwater levels and the duration of higher groundwater levels through the year in the Lower Meadow.

4.3 Hydraulic Modeling of Existing Conditions

Balance used estimated hydrology, 2013 LiDAR-based topography, and site-specific estimates of hydraulic roughness to develop a 2-dimensional hydraulic model in HEC-RAS using a range of streamflow rates. Balance installed streamflow gaging stations in Lacey Creek in 2019 (above Upper Meadow and above Lower Meadow); however, two consecutive below-average years (WY2020 and WY2021) have limited our recording, measuring, or understanding of high flows in Lacey Creek. Therefore, hydrology of Lacey Creek was estimated from indirect peak flow measurements computed from bankfull indicators and WY2017 high-water marks along with correlation to other regional gages (Trustman and others, 2020). WY2017 annual peak flow in the Truckee River Basin was estimated to be between a 5-year and 10-year recurrence flood based on regional gages. **Table 4-1** provides a range of estimated flows for Lacey Creek at two locations: (1) the Upper Meadow and (2) the Lower Meadow. Perazzo Creek is an adjacent gaged watershed and shown for reference.

Table 4-1 Range of Streamflow Used for Hydraulic Model of Existing Conditions, Lacey Creek, Upper and Lower Lacey Meadows.

Location	Watershed Area	Average summer baseflow	Bankfull streamflow (1.5-2 yr flood)[3]	WY2017 Peak Flow[4]	10-yr flood[5]
	(sq. miles)	*(cfs)*	*(cfs)*	*(cfs)*	*(cfs)*
Lacey Creek above Upper Lacey Meadow	3.7	0-0.2	45-185	300-340	550
Lacey Creek above Lower Lacey Meadow	4.8	0-0.5	65-220	350-400	650
Perazzo Creek above Perazzo Meadows[2]	6.1	0.2-0.8	140	500	--

Notes:
1. Lacey Creek above Webber Lake represents the outlet of Lacey Creek to Webber Lake; USGS streamstats were computed for this location only.
2. Perazzo Creek above Perazzo Meadows: an adjacent watershed of similar size and elevation with similar geology, climate, and land-use. Gaging station maintained and operated by Balance Hydrologics, Inc. since 2011; baseflows computed from WY2011-WY2021; bankfull estimated from channel geometry, high-water marks, and stage-discharge rating curve
3. Bankfull estimates based on Manning's equation and Continuity equation with parameters measured directly in the field or published literature
4. WY2017 peak flow for Lacey Creek was approximated using two methods: a) WY2017 peak flow (unit discharge) at Perazzo Creek above Perazzo Meadows; and b) Manning's Equation using field measurements of channel geometry and slope of high-water marks and estimated hydraulic roughness values. Regionally, this event was equivalent to a 5-year flood.
5. 10-yr estimates are average values computed using USGS Streamstats : http://water.usgs.gov/osw/streamstats/ssonline.

A synthetic hydrograph using estimated flows from **Table 4-1** was developed for Lacey Creek at the Upper and Lower Meadow to develop and run a two-dimensional hydraulic model (HEC-RAS 2D). Results from the model were examined under existing conditions (2013 LiDAR topography) to evaluate degree of channel incision.

In **Figure 4-5**, water depths are shown for the estimated peak flow for WY2017 (~400 cfs) for Lacey Creek at the entrance to the Upper Meadow using a digital elevation surface developed from LiDAR-based topography (USFS, 2013). In most montane meadow systems, overbank flow or meadow wetting occurs annually during annual peak flow. However, model output shown in **Figure 4-5** indicates that a peak flow with an estimated 5- to 10-year recurrence is contained within the existing channel, illustrating the incised condition of Lacey Creek in the Upper Meadow.

Former remnant channels that may have supported more dispersed flow across the Upper Meadow are also visible in **Figure 4-5**. The upstream-most remnant channel (Reach Gb) is currently blocked by a historical push-up gravel dam (see **Figure 3-7**). Under peak flow inundation extents shown in **Figure 4-5**, the remnant channel is disconnected from the water surface by over 2 feet. This area could be restored to promote flow into the existing remnant channel.

A second remnant channel, further downstream and shown in **Figure 4-5**, is also perched above the peak flow water surface by roughly 1 to 2 feet. Soils investigations identified a remnant gravel-dominated subsurface channel 1.5 to 2 feet below the existing meadow surface along this feature which could be exposed and used as a secondary flow pathway for rewetting the Upper Meadow.

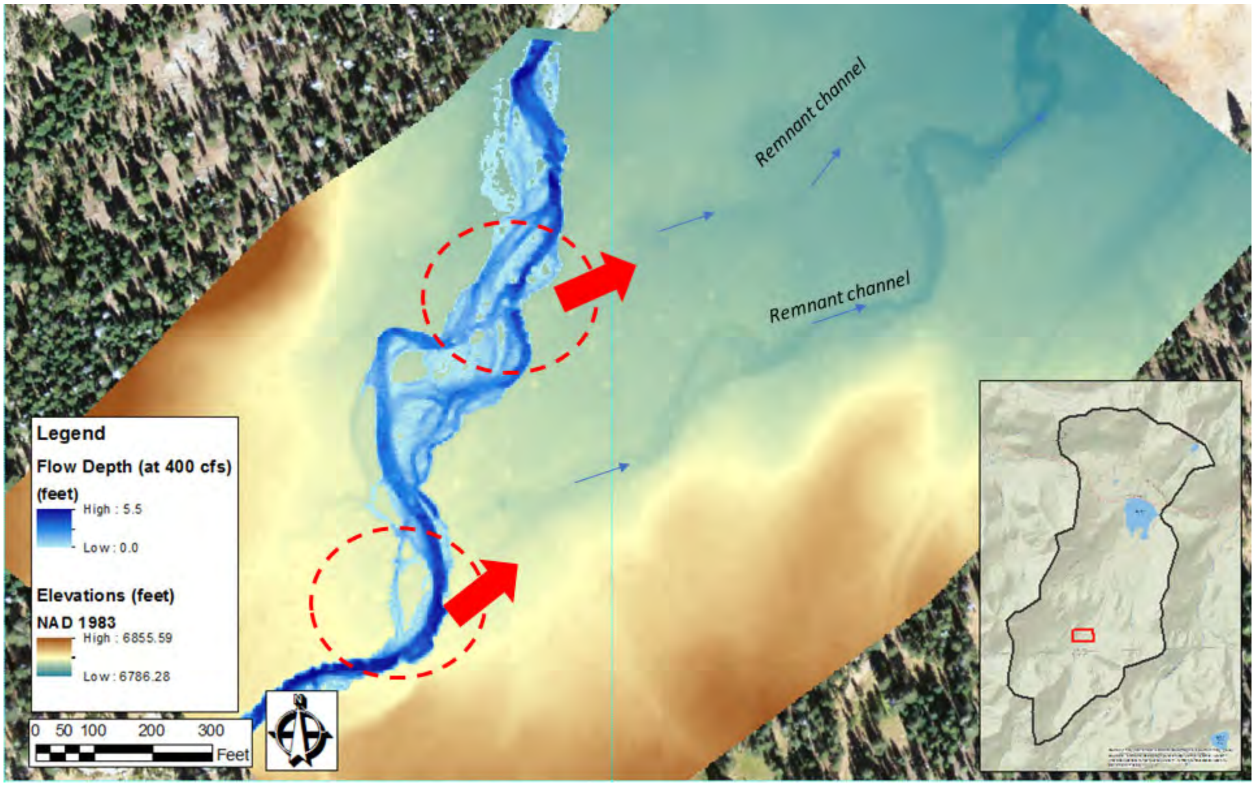

Figure 4-5 **Hydraulic Model Results for WY2017 Peak Flow (estimated 400 cfs) in Existing Channel, Upper Lacey Meadow.** Red arrow indicates preferred rewetting of meadow, while dashed circles identify areas proposed for encouraging overbank channel flow; flow direction is from the bottom to the top of the page.

In **Figure 4-6**, we illustrate estimated peak flow for WY2017 (~400 cfs) for Lacey Creek at the entrance to the Lower Meadow using a digital elevation surface developed from LiDAR-based topography (USFS, 2013). Similar to the Upper Meadow, a peak flow with an estimated 5- to 10-year recurrence is mostly contained within the existing channel and illustrates the incised condition of Lacey Creek in the Lower Meadow.

In **Figure 4-6**, we also identify a former remnant channel that may have supported more dispersed flow across the Lower Meadow. Under peak flow shown in **Figure 4-6**, the remnant channel is disconnected from the water surface by less than 1 foot. This area could be restored to promote flow into the existing remnant channel.

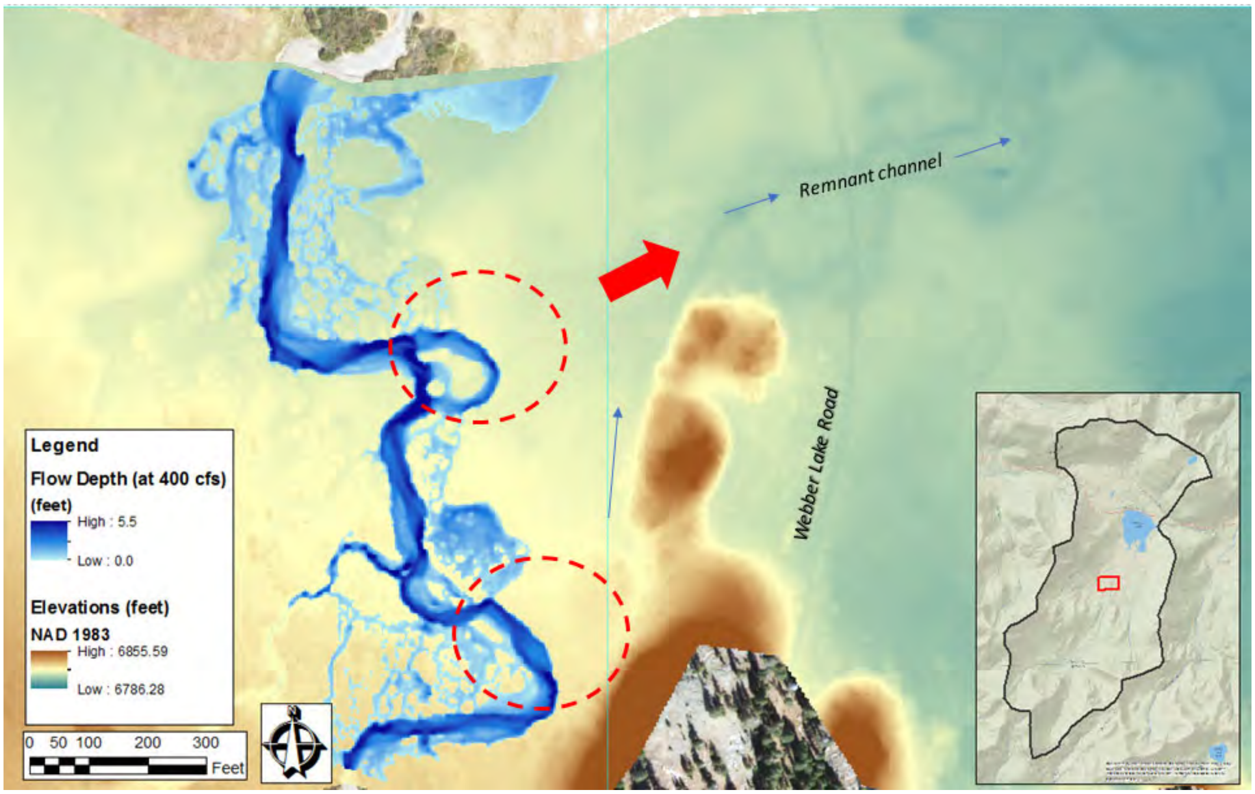

Figure 4-6 **Hydraulic Model Results for WY2017 Peak Flow (estimated 400 cfs) in Existing Channel, Lower Lacey Meadow.** Red arrow indicates remnant channel, while dashed circle identifies area proposed for splitting channel flow; flow direction is from bottom to top of page.

4.4 Webber Lake Water Surface Changes

Webber Lake is a natural water body; however, its outlet is modified by a low-head dam constructed in 1915. From 1985 through 2017 seasonal installation and operation of fish screens on the dam have at times inadvertently augmented lake water levels by an additional 1.0 to 2.0 feet. The screens were frequently blocked by in-lake vegetation that drifted to the outlet, effectively increasing water levels in the lake. Together, the dam and fish screens have augmented the natural range of water levels in Webber Lake by over 3.0 feet. The result is a seasonally fluctuating base level for Lacey Creek and tributaries to the lake. A migrating base level changes processes such as soil wetting, drainage, and groundwater levels in Lower Lacey Meadow, and alters the location of sediment deposition and delta formation in Lacey Creek. A peak flow event occurring during rapid changes in base level, such as from a high lake stage to a lower lake stage, could result in bank failures, knickpoint creation and headcutting—features that are observed today in secondary channels in Lower Lacey Meadow near Webber Lake (see **Figure 3-10**).

Balance instrumented Webber Lake and recorded water levels between April 14 and October 1, 2019 to capture the changes from peak snowmelt runoff and baseflow recession through the dry season (**Figure 4-7**). WY2019 was an above average year with 164 percent of the median snow water equivalent (SWE) for the Little Truckee River watershed (NRCS, 2019). The snowmelt runoff period was followed by a dry summer with limited precipitation between July and October. Fish screens were not used in WY2019 (Svahn, J., pers. comm., 2019). Therefore, lake levels are affected by surface and groundwater inflows and outflows, evaporation, and dam leakage.

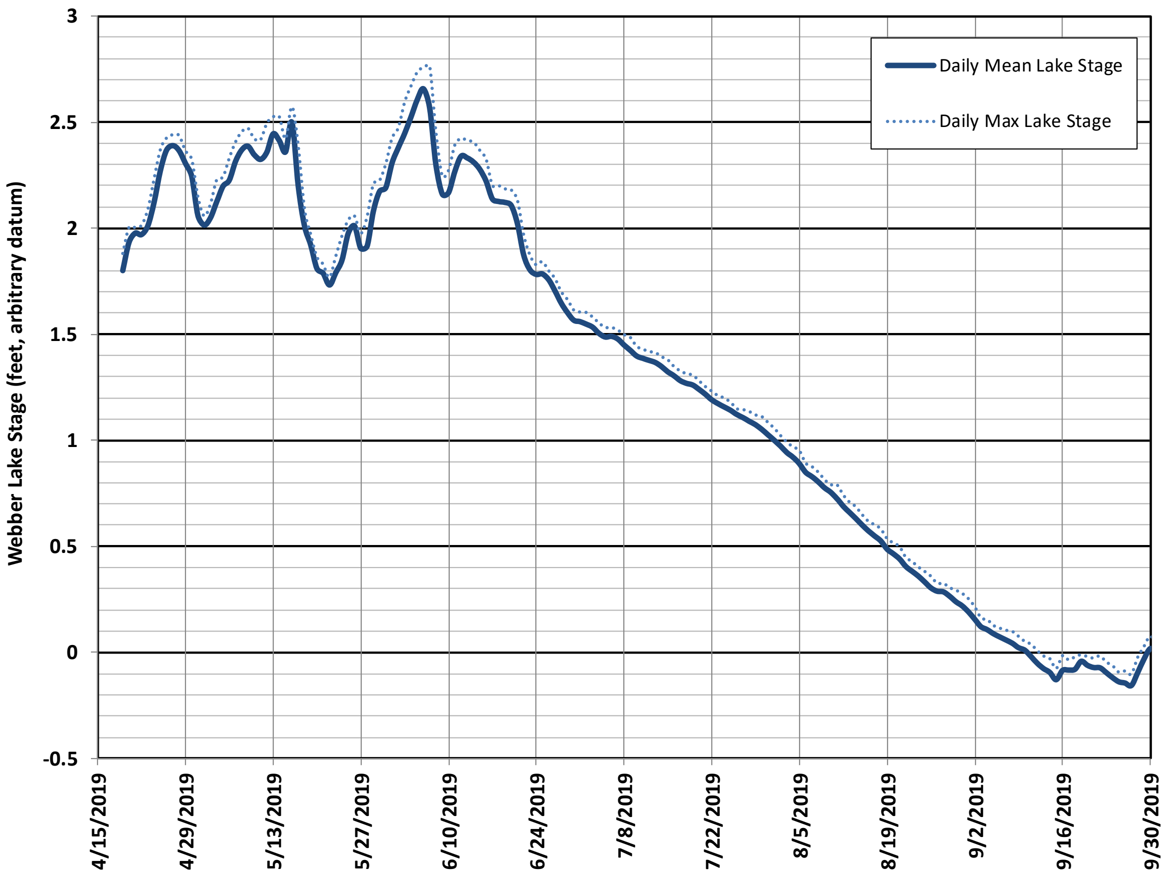

Figure 4-7 Water Levels for Webber Lake, April 17-October 1, 2019.

5 PROJECT CONSTRAINTS AND OPPORTUNITIES

Below we provide a summary of project constraints and opportunities identified from our field observations and limited analysis for conceptual design. Future coordination, observations or management decisions may reduce the listed constraints:

5.1 Project Constraints

- The project is in a rural area with distances to resources and supplies that may be costly for importing materials. Design elements were carefully considered to utilize on-site resources during implementation.

- The project is located near 7,000 feet elevation; wet years could: a) limit the length of construction season with snow cover; and b) potential need to dewater the channel during high-volume runoff. For instance, in July 2019 after an above-average snowpack, we measured over 20 cfs in Lacey Creek, downstream of the Upper Meadow. This flow rate may require expensive stream diversion and dewatering strategies to facilitate project implementation. In contrast, streamflow in Lacey Creek was measured to be less than 3 cfs in July 2020, a year with below-average snowpack.

- Sheep grazing leases will continue into the near future under the TDLT. Project success may be dependent on temporary grazing enclosures or minimizing sheep access to restored areas. Wacker and Wolf (2020) have prepared a grazing management plan with recommended actions to improve meadow condition and protect future restoration activities. The TDLT maintains recreational uses along Webber Lake and in the Lower and Upper Meadows which provide revenue and public access. The restoration design in the Lower Meadow was designed to minimize disturbances (visual, noise, temporary impacts) to the public given its proximity to recreational infrastructure (i.e., campground, boat docks).

- The design is developed to maintain baseflow in the existing channel through the Lower Meadow and support existing instream and riparian habitats; however, dispersion of flows across the meadow may increase evapotranspiration rates and recharge, which may affect the amount of surface flow in some existing channels. If existing instream or riparian habitats begin to show reduction in vigor, value or health, adaptive management strategies may be necessary to modulate flow in the existing channel.

- Lacey Creek is an actively meandering channel in alluvial fill valleys with abundant sediment deposition and movement. These designs were developed from topography generated from 2014 LiDAR data. Channel position, widths and depths have changed in many locations as the result of high flows since that time. Because of these changes, we anticipate the need for the design geomorphologist and/or engineer to be on-site during construction to field fit the design to the conditions observed during implementation.

- We recognize that both Meadow Lake Road and Webber Lake Road will continue to be maintained and used for public access. Impacts on the meadow hydrology and sediment supply will likely continue from these roads unless additional drainage improvements are completed. While some design elements address some of these issues, others will remain unmitigated.

5.2 Project Opportunities

- The project area is within an open space and allows for consideration of full-scale restoration or rejuvenation of an alluvial channel system in some reaches.

- There is limited to no infrastructure downstream of the project area, with limited risk for restoration using a design that rejuvenates geomorphic processes and allows for some stochastic effects.

- The existing channel promotes higher than regional-average sediment supply. This is primarily the result of erosive watershed geology and soils. This abundant supply is considered to be an opportunity to aggrade an incised network of channels and restore surface-groundwater connectivity.

- Channel segments proposed for fill can first be excavated for a source of channel-bed materials (i.e., gravels, cobble) for construction of or augmenting riffles in other segments.

- A Timber Harvest Plan (THP) has been prepared by others for TDLT for the project area (CDFFP, 2019) The THP proposes a number of temporary and long-term improvements to existing access routes for timber harvest. In is the intention of the landowner to implement the THP in the near future. Doing so may provide improvements to road-related sources of excess runoff and sediment.

6 DESIRED OUTCOMES

In this section, we integrate our findings into restoration actions using site-specific desired outcomes. Below, we identify 5 distinct outcomes for Lacey Meadows Restoration:

6.1 Functioning Meadow Hydrology

The restoration design should promote groundwater recharge and encourage a high-water table. Reversal of channel incision is a key objective to support more frequent channel-floodplain connectivity that supports groundwater recharge and storage. An increase in rain-on-snow and heavy summer rain events may lead to periods of uncharacteristically high flows, which may incise the stream channel and decrease groundwater elevations in meadows with channels present; although this may be less likely to occur in systems characterized by an anastomosing or multi-channel stream network (Cluer and Thorne 2013). Ultimately, if these functions are achieved, the meadow will support a more robust, diverse, and vigorous plant community and habitat, provide colder and more persistent baseflow longer into the dry season, and provide resiliency to climate vulnerabilities.

6.2 Healthy Meadow Soil

Recent subsurface investigations identified evidence that groundwater can fluctuate in the Upper Lacey Meadow by as much as 5 feet. During periods when soil and groundwater are lacking, grazing can further impact soil health through compaction and loss of vegetation cover. Reduced water availability and vegetation cover may decrease the ability of the soil to sequester carbon (Vernon and others, 2019). Restoring functioning meadow hydrology and managing grazing impacts will provide for desired restoration outcomes that restore meadow soil and health.

6.3 Meadow Plant Species

Project biologists have identified Lacey Meadows to have fair to good vegetation cover, but identify limitations on meadow hydrology, and depth to groundwater as the key limiting factor in the potential for passive revegetation approaches. In some areas, grazing has impacted the abundance and diversity of plant species and a grazing plan is under preparation to address these impacts. Furthermore, the Lower Meadow supports only limited willow riparian cover. Enhancement of willow riparian cover could reduce stream temperatures and provide cover for fish. Willow recruitment will be facilitated if the channel-floodplain connectivity is improved; however, increased willow plantings would also be beneficial (Wacker, M., pers. comm., 2019).

6.4 Meadow Habitat

Healthy meadows provide habitat for diverse terrestrial and aquatic species. The Lacey Meadows Assessment (Hastings and others, 2013) identified many special status or state-listed endangered species in urgent need of conservation action. As a result, one of our desired restoration outcomes is that the meadow supports diverse native meadow-dependent terrestrial and aquatic species, including birds, amphibians, and fish. Maintaining areas with ponded slow-moving water through design elements can help maintain and enhance water availability.

6.5 Baseflow Hydrology

It is well documented in the literature that incised channels in meadow environments modify the functions of surface-groundwater interactions and alter the hydrologic regime of the system (USDA, 2015). Restored meadows in the Sierra Nevada have shown to increase channel and meadow connectivity, increase groundwater storage, reduce winter and spring flows, but increase summer and fall baseflow (Ohara and others, 2013; Liang and others, 2007; Swanson and others, 1987). Restoring Lacey Meadows surface-groundwater interactions are predicted to enhance summer baseflow and restore this intermittent to a perennial channel.

7 DESIGN BASIS

7.1 The State of Meadow Restoration in the Sierra Nevada

Meadow restoration has evolved over the years, differs from region to region, even site to site, and has changed over time in response to lessons learned. What is important is that restoration design does not impose a template that can be applied to any location, regardless of climate, vegetation, geology, and/or land-use.

Meadow restoration in the Sierra Nevada has been a priority over the last couple decades or more (NRCS, 2010). While restoration approaches have evolved and changed results have shown inconsistency in measured response variables highlighting that success is not yet consistent across projects (Pope and others, 2015). For over 20 years, one particular method (plug and pond) was used across the northern Sierra Nevada as a ‘template’ for meadow restoration. While the plug and pond approach promises to mitigate effects of climate change by increasing groundwater storage capacity, conceptual models and restoration designs do not recognize how climate change may impact the interacting factors that confer meadow stability. Plug and pond introduces novel features and processes into meadow floodplains and addresses interactions between the channel depth and groundwater, but not geomorphic processes that sustain shallow channel morphologies (Natali and Kondolf, 2018). As such, this approach is only considered in locations where other factors may deem its appropriate.

Over the last decade, restoration approaches have adopted a better understanding of working with natural processes and critters who support them. These approaches have been implemented across western states and include analogs that mimic beaver dams (Castro and others, 2015). Use of beaver dam analogs typically require an active beaver colony, willow or cottonwood riparian vegetation and frequent and long-term management to achieve restoration goals. Stream restoration through a meadow should focus on processes aiming to reestablish normative rates and magnitudes of physical, chemical, and biological processes that create and sustain river and floodplain ecosystems (Beechie and others, 2010). Process-based restoration, then, focuses on correcting anthropogenic disturbances to the processes, such that river-floodplain ecosystems progresses along a recovery trajectory with minimal correction intervention (Sear 1994, Wohl and others, 2005).

The restoration approach presented for Lacey Meadows is based on an understanding of anthropogenic disturbances in the watershed, an appreciation for sediment transport and depositional processes, and recognition that beavers are not currently part of the river processes in Lacey Creek. Furthermore, the remote location and access constraints to Lacey Meadows requires a restoration approach that minimizes the need for a large footprint, import of materials, and multiple vehicle trips across a sensitive landscape. Finally, design elements are considered in context with current knowledge in restoration science, effectiveness, and goals driven by ecological business plans and voter approved propositions.

7.2 Design Elements

We used the Lacey Meadows Assessment (Hastings and others, 2013) and supplemental data collected under this contract to support restoration designs for creek and meadow restoration in both Upper and Lower Lacey Meadows. Legacy impacts and cumulative watershed disturbances outlined in this report are primarily responsible for the degraded condition of Lacey Meadows. This condition can be reversed or, at a minimum, current conditions can be enhanced through a process-based restoration approach. General criteria used for developing restoration designs included: (1) geomorphic context, (2) ability to enhance or restore impaired functions and processes, and (3) constructability. With careful planning, implementation, and monitoring, desired outcomes can be achieved with long-term success through adaptive management.

7.2.1 Instream Wood Structures

Lacey Creek is a dynamic channel system with multiple channels, typical of a headwater stream in a post-glacial alluvial valley. Sediment and wood transport are dominant processes, and trees are naturally and easily recruited from upstream areas as well as along the margin of the meadow. As such, we have prioritized use of instream wood and wood-based structures in this design to encourage aggradation of the incised channel. Sediment aggradation is intended to increase the frequency of overbank flow, enhance groundwater levels, and rewet meadow habitats at strategic locations or locations where remnant channels exist.

The instream wood structures are minimally engineered, meaning they do not include cabling, large ballast boulders, or other mechanical anchoring that is not natural to the system. The structures will be secured by stakes or log posts driven into the channel bed, embedding logs into the bed and banks, bracing against existing bank vegetation, and/or pinning by adjacent logs. It is possible that the structures will shift, or mobilize entirely if streamflow levels are high enough. In general, the risk is greatest in the first few years after implementation and decreases as logs are buried by sediment deposits and bank vegetation matures. Regardless, movement of logs and smaller woody debris would not represent a failure of the project since wood transport is a natural process. Mobilized wood will deposit to form new debris jams and will likely encourage depositional process in a similar manner as the designed wood structures. To minimize transport distance and encourage mobilized wood to stay within the project reach, dimensions of logs are specified as relative to the channel geometry consistent with guidance from literature (ODF/ODFW, 2010, Roni and others, 2015, Merten and others, 2010).

We have included five (5) different types of instream wood structures: (1) bundles, (2) small log jams, (3) large log jams, (4) staked small debris jams, and (5) staked large debris jams. We briefly describe these below:

(1) <u>Bundles</u>

Bundles will include pieces of trees less than 9-inches diameter and include branches. The bundles will measure between 8- and 16-feet in length, 18-inches to 24-inches in diameter and secured using natural fiber twine. Bundles will be placed in the channel and secured using 6- to 9-inch diameter stakes, driven a minimum of 3 feet into the channel bed. Bundles are appropriate for smaller channels or tributaries to Lacey Creek.

(2) <u>Small log jam</u>

Small log jams include 1 to 2 key logs, typically characterized by a diameter between 12 and 18 inches and rootwad intact. Rootwads will be embedded or partially buried in the banks to mimic channel bank tree-fall. Additional smaller trees or logs are included to create a channel-spanning structure. The structure is finished by packing branches and slash harvested from smaller trees to fill gaps to the maximum extent possible. Finally, willow stakes cut to a minimum of 2.5 feet length will be installed along both sides of the debris jam to encourage bank root strength. Small log jams are appropriate for tributaries to Lacey Creek or in the mainstem channel in combination with large log jams located upstream and downstream. At locations where access by heavy machinery is difficult or would impact sensitive meadow areas, small log jams will be constructed by felling trees next to the channel, then trimming and packing the felled tree by hand with smaller material.

(3) Large log jam

Large log jams include a minimum of 2 key logs, typically with a diameter greater than 18 inches and rootwad intact. Additional smaller trees or logs are included to create a channel-spanning structure. The structure is also packed with smaller branches and slash harvested from smaller trees. Large log jams are appropriate for Lacey Creek where flow diversion is required to return flows to historical channels. These structures are beneficial when they can be anchored against existing live, bankside trees. In the absence of natural anchors, log posts will be used to secure the log jam and also encourage additional racking of instream wood.

(4) Staked small jam

These structures are used in tributaries to Lacey Creek or smaller channels and induce aggradation of an incised channel and improve channel-floodplain connectivity. These structures are channel spanning features with post rows securing vegetation debris. Debris can be a mixture of nearby willow and pine branches. These features will typically be constructed in series (2 to 4 in a channel segment). These structures can be effective if constructed as specified and include downstream-oriented branches/debris. This design element minimizes downstream bed scour and undercutting of the posts. These structures are intended to fail under high-flow events to minimize bank scour or channel diversion. Failure includes removal of some or all of the posts and debris by higher flows. As such, they will likely require maintenance or rebuilding every 2 to 5 years.

(5) Staked large jam

These structures are used in the mainstem of Lacey Creek to induce aggradation of an incised channel and improve channel-floodplain connectivity. These structures are designed to be wider and longer than the staked small jams with similar architecture including post rows and woven or packed vegetation debris. The staked large jams also include larger support posts embedded deeper into the channel bed since the large jams will experience higher drag forces compared to the small jams. Debris can be a mixture of nearby willow and pine branches. These structures are constructed in series (4 to 5 in a channel segment). These structures are also intended to fail under high-flow events to minimize channel avulsion or major bank failures. As such, they will likely require maintenance or rebuilding every 2 to 5 years.

7.2.2 Log and Boulder Structures

The Upper Meadow is bisected by a glacial moraine characterized by cobble and boulder materials. At the location where former and remnant channels cross the moraine, we have prioritized design elements composed of both instream wood and boulders to mimic existing roughness elements. Boulders will be strategically placed to secure wood in the channel and encourage additional racking of wood. In some cases, boulders are leveraged to improve the stability of log structure, and this is the only location where ballast boulders are proposed since it is the only location where boulders naturally occur in high concentrations.

7.2.3 Pilot Channels

Multiple active channels once characterized both Upper and Lower Lacey Meadows as evidenced by remnant channels in the meadows observed in the field, historical imagery, and on LiDAR-based imagery (see **Figure 4-5** and **Figure 4-6**). Grading of pilot channels is proposed where there is opportunity to direct a portion of the total streamflow toward remnant channels with relatively little disturbance. Pilot channels are paired with either an instream wood structure or a debris riffle to minimize disturbance. In general, an in-channel structure is proposed within Lacey Creek to increase flow depths which in turn decreases the required pilot channel excavation depth to redirect streamflow toward remnant channels. The threshold for pilot channels becoming active varies; in some locations the pilot channel is intended to be the low flow channel and in other locations the pilot channel is perched above Lacey Creek such that it is active during periods of elevated flow.

In the Upper Meadow, three pilot channels are proposed:

- Near the upstream extent of the project on Reach I(b) a small pilot channel will be notched through an existing levee feature on the left bank to direct a portion of elevated flows toward Reach I(a). Low flows will continue over a debris riffle and through Reach I(b).
- At the downstream end of Reach H “Pilot Channel 1” will be the new low flow channel and direct the existing Lacey Creek channel from its current single-channel planform and alignment through Reach G(a) and restore it to Reach G(b), the interpreted historical alignment through the meadow. A debris riffle is proposed just downstream of Pilot Channel 1 which will allow a portion of elevated flows to continue down Reach G(a).

- Approximately 400 feet downstream of Pilot Channel 1, “Pilot Channel 2” is proposed to direct streamflow away from Reach G(a) and onto the meadow surface and through remnant channels. A debris riffle is proposed just downstream of Pilot Channel 2 which will allow high flows to continue down Reach G(b).

In the Lower Meadow, field evidence suggests Lacey Creek and its tributaries were modified, presumably to dewater the meadow for improvement of sheep pasture. We have designed instream structures at two locations in the channel to partially divert flows into remnant channels:

- On Lacey Creek Reach C, “Pilot Channel 1” will direct elevated flows toward remnant channel in the Lower Meadow, eventually discharging to the Southeast Tributary. Hydraulic modeling showed that Pilot Channel 1 will become active between 150 and 200 cfs, the approximate bankfull flow rate. A large log jam is proposed downstream of Pilot Channel 1 that is anticipated to elevated depths and encourage flow into Pilot Channel 1.
- Approximately 600 feet downstream of Pilot Channel 1, “Pilot Channel 2” is proposed as a redundant feature to direct flow into the same remnant channel system as Pilot Channel 1. Similar to Pilot Channel 1, Pilot Channel 2 will have a large log jam just downstream and modeling showed that it would become active around the bankfull flow rate.

7.2.4 Debris Riffles

In Upper Lacey Creek, debris riffles are proposed to encourage the existing alignment of Lacey Creek away from Reach G(b) and through Reach G(a) and/or the meadow surface while allowing a portion of high flows to continue down Reach G(b) to decrease risk of erosion within reaches that have not experienced persistent surface water for several decades. The multi-channel concept is consistent with our interpretation of the historical planform of the system and will help to disperse streamflow and enhance groundwater levels. The debris riffles emulate a log jam that has been buried by sediment deposits, and address access constraints and limited fill sources through strategic location near pilot channels to leverage excavated material and minimize haul distances. The debris riffles consist of a log “core” to provide stability which is then backfilled with material to seal spaces between log pieces. The structure is finished with a surface layer of salvaged riverbed material. In some installations, log posts are proposed throughout the debris riffle for additional stability. Apart from redirecting flows, the debris riffles are anticipated to raise baselevels in Lacey Creek to minimize drainage of groundwater from the meadow, which we anticipate will be restored to near the surface during the spring and early summer.

7.2.5 Road-Related Design Elements

The proposed design does not address the road-related issues in the upper watershed; however, the design does address road capture along Webber Lake Road where these conditions continue to degrade channel and meadow conditions. At these locations we have planned minor grading to restore natural flow pathways to the meadow while maintaining historically significant Webber Lake Road.

7.2.6 Knickpoint Repair and Head Cutting Related to Webber Lake

Finally, through observations and monitoring, we identified that historical operations of the Webber Lake dam and resulting lake water-level fluctuations likely impacted meadow condition in the lower portions of the Lower Meadow, primarily along lake tributaries (e.g., West Tributary). A Lake-Level Management Plan (Hastings, 2020) may address some of these issues, but additional meadow restoration elements are proposed to limit further degradation. These elements include live willow structures, intended to encourage soil-root strength, and minimize further propagation of head cutting.

8 LIMITATIONS

This report and its contents have been developed solely for restoration of Lacey Meadows for the exclusive use of TRWC. Data, interpretations and analyses developed for this report may not be directly applicable to other uses. Balance Hydrologics should be consulted prior to applying the contents of this report to future projects, dam operations, or for other purposes not specifically cited in this report.

As is customary, we note that readers should recognize that interpretation and evaluation of physical factors affecting the hydrologic and geomorphic context of any site is difficult and an inexact art. Judgements leading to conclusions and recommendations are generally made with an incomplete knowledge of the conditions present, and are based on observations made after a year with and extremely large snowpack and late runoff. More extensive studies or increased level of design can reduce the inherent uncertainties associated with such studies.

We have used standard environmental information such as precipitation, streamflow, topographic mapping in our analyses and approaches without verification or modification, in conformance with local customs. New information or changes in regulatory guidance could influence the plans or recommendations, perhaps fundamentally. As updated information becomes available, the interpretations and recommendations contained in this report may warrant change. To aid in revisions, we ask that readers or reviewers advise us of new plans, conditions, or data of which they are aware.

Data developed or used in this report were collected and interpreted solely for developing an understanding of the hydrologic and geomorphic context at the site as an aid to conceptual planning and restoration design. They should not be used for other purposes without great care, updating, review of sampling and analytical methods used, and consultation with Balance staff familiar with the site.

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