1 INTRODUCTION

Lahontan cutthroat trout (LCT, Oncorhynchus clarkia henshawi), a distinctive subspecies of cutthroat trout, is a state and federally listed species endemic to the Lahontan Basin. LCT populations have suffered due to a plethora of stressors including historic over-fishing, habitat loss and fragmentation, water diversions, loss of genetic variation, and interactions with nonnative fishes (e.g., displacement, competition, predation, disease introduction and hybridization). It is estimated that LCT now occupy only 2.2% of historic stream habitat within the Truckee River Basin (Moyle 2002, Stead 2007). The lone remnant native population resides in the upper basin in Independence Lake and Creek (Gerstung 1988).

Efforts are underway to preserve current populations (e.g., the recently constructed Independence Lake Spillway Fish Barrier) as well as expand the range through reintroduction to historic habitat. Some reintroductions of LCT in the Truckee River Basin (e.g., Martis Creek Lake) have failed (Moyle and Vondracek 1985); however, reestablishment efforts were successful in small headwater creeks within the basin, where LCT populations were able to survive in isolation from nonnative trout species (Moyle 2002). It appears that successful reestablishment requires the eradication and exclusion of nonnative trout. Sagehen Creek is under consideration for LCT reintroduction. However, several species of nonnative salmonids reside in or seasonally utilize the creek, migrating upstream from Stampede Reservoir.

A feasibility assessment was undertaken to evaluate the possibility of constructing fish passage barriers for both the long-term exclusion with a permanent barrier and short-term isolation of segments of the stream with temporary barriers to facilitate eradication of nonnative salmonids within the watershed. Permanent barriers would prevent upstream fish migration in perpetuity, while the temporary barriers are envisioned to operate through a finite number of high flow seasons (e.g., 3 years), while the nonnative eradication effort is undertaken. It was desired that the temporary barriers be considered in
a way that they could be reoperated in the future in case additional isolation and eradication efforts are required.

Our assessment began with discussions undertaken with several individuals knowledgeable of Sagehen Creek, the fishes utilizing the creek, and fish barrier design (e.g., Jeff Brown, Peter Moyle, Virginia Boucher, George Heise, among others). Next, a desktop analysis was undertaken that assessed: 1) the bioenergetics of nonnative species of concern to develop physical criteria for successful barriers, 2) conceptual designs for the barriers (type and geometry, e.g., physical barriers, leaping barriers, velocity barriers, or combination barriers), 3) physical opportunities and constraints via topographic analysis and review of soil and geologic information, and 4) hydrologic data to identify the magnitude of design flows for each of the barriers. This effort identified an initial conceptual design for the barriers along with a number of potential barrier locations. A subsequent field effort was undertaken to collect detailed topographic data and assess barrier feasibility at particular locations. Following the field effort, hydraulic modeling was conducted using HEC-RAS. All the data and information were synthesized to assess potential ecological, hydrologic and geomorphic impacts to provide an overall feasibility assessment for barriers on Sagehen Creek.

Three potential permanent barrier locations had previously been identified at or near: 1) The HWY 89 crossing, 2) a Forest Service road crossing upstream of the HWY 89 crossing, and 3) a valley constriction downstream of the HWY 89 crossing. Topographic surveys were performed at these three sites to aid in the conceptual design, hydraulic modeling and overall assessment. Additional potential barrier locations were identified primarily using LiDAR data collected in 2005. Potential locations were distinguished by narrow valley width and a steeply sloping longitudinal profile to help reduce the overall barrier footprint and backwater effect. Conceptual barrier designs were based on the physical abilities of the target species, a conservative estimate of peak hydrology in the basin, and the overall impacts of construction (i.e., cost, footprint size, backwater extent, geomorphic and ecological effects).

2 TARGET SPECIES

A number of nonnative salmonid species perennially or seasonally utilize Sagehen Creek, including naturalized populations of rainbow trout (O. mykiss), brown trout (Salmo trutta), brook trout (Salvelinus fontinalis), and kokanee salmon (O. nerka kennerly). Lake trout (S. namaycush) are also known to inhabit Stampede Reservoir, but are not thought to utilize Sagehen Creek. The physical abilities of the target species have been well documented in various State and Federal design manuals. Table 1 shows the relative swimming speeds of fish taken from the U.S. Department of Transportation, Federal Highway Administration’s technical manual on fish passage through culverts (FHWA, 1990).

For the purposes of determining barrier height, the physical abilities of steelhead trout were considered to be the most conservative. Many of the manuals assess the leaping height and burst speed of steelhead trout rather than the rainbow trout that are present in Stampede Reservoir and Sagehen Creek. For this assessment the steelhead values were used, with a condition factor of 0.75 applied, such that the maximum burst speed considered was 19.9 ft/s. While this likely overestimates the swimming
ability of even the largest land-locked *O. mykiss* (historical observations reach 25 inches in length, David Lass personal comm.), this analysis erred on the conservative size because it only takes the upstream passage of one individual to compromise the entire eradication and repopulation effort. This assumption was discussed and agreed upon in communication with California Department of Fish and Wildlife Senior Hydraulic Engineer, George Heise.

### Table 1: Relative Swimming Speeds of Adult Fish

<table>
<thead>
<tr>
<th>Species</th>
<th>Cruising Speed (ft/s)</th>
<th>Sustained Speed (ft/s)</th>
<th>Burst Speed (ft/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown Trout</td>
<td>0 – 2.3</td>
<td>2.3 – 6.1</td>
<td>6.1 – 12.8</td>
</tr>
<tr>
<td>Steelhead</td>
<td>0 – 4.6</td>
<td>4.6 – 13.8</td>
<td>13.8 – 26.6</td>
</tr>
<tr>
<td>Trout</td>
<td>0 – 2.0</td>
<td>2.0 – 6.6</td>
<td>6.6 – 13.5</td>
</tr>
</tbody>
</table>

Source: FHWA, 1990

The maximum leaping height and distance of steelhead trout can be determined from the maximum burst speed using the principles of projectile motion (Figure 1; Powers 1985). The leaping height of rainbow trout in Stampede Reservoir is assumed to be similar to that of a migrating steelhead trout (burst speed = 19.9 ft/s), represented by the dashed line in Figure 1. Using this information, the maximum leaping height and distance for barrier design was determined to be 6 ft and 12 ft, respectively.

### 3 INITIAL CONCEPTUAL BARRIER DESIGN

Based upon the maximum leaping height and distance identified, an initial conceptual design was developed for the barriers (Figure 2). The design includes a height of 6 ft from the tailwater elevation (under the design high-flow conditions) to the spillway crest, and a length of 12 ft. The barrier was envisioned as a sharp-crested weir, with a steeply sloping apron underneath the spillway to convey supercritical flow to some distance away from the structure. The sloping apron begins at the design tailwater elevation, rising 2 ft vertically over 10 ft horizontally, to prevent the formation of a launch pool at the base of the vertical component of the barrier. Upstream of the apron a vertical (or near vertical) section rises 4 ft to the spillway crest, to achieve the 6 ft design height (maximum leaping height). Including the elevated tailwater conditions during a large magnitude flood (initially estimated to be ~2 ft above the floodplain ground surface) and the 6 ft combined apron and wall height, a structure of ~8 ft in height above the floodplain was envisioned at this phase of the assessment (Sheet A). The geometry of the barrier follows the design of several fish passage barriers which have been constructed in the Sierra previously and have proven to be successful at blocking the upstream migration of *O. mykiss* (e.g., Independence Lake Barrier, Schaeffer Barrier, Templeton Barrier; George Heise, personal comm.).

### 4 POTENTIAL BARRIER LOCATIONS

Seven potential barrier locations are shown in Figure 3. The approximate locations of sites 1 – 3, and 7 were identified based upon previous discussions and refined to reflect specific cross sections based on topographic field surveys and topographic data analysis. Sites 4 – 6 were selected initially through the
desktop analysis of the LiDAR derived Digital Elevation Model (DEM) and subsequently refined during field reconnaissance. Table 2, lists the seven potential barrier locations along with a brief description of the geomorphic setting. Photographs of the seven sites are provided in Appendix A.

<table>
<thead>
<tr>
<th>Barrier Location</th>
<th>Approximate Location</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>0.5 mi downstream of HWY 89</td>
<td>Valley constriction, wide open floodplain, complex side channel features</td>
</tr>
<tr>
<td>Site 2</td>
<td>At HWY 89 Crossing</td>
<td>Channel confined upstream of bridge culvert, small inset floodplain</td>
</tr>
<tr>
<td>Site 3</td>
<td>At USFS Rd Crossing, 0.5 mi upstream of HWY 89</td>
<td>Channel confined upstream of bridge culvert, small inset floodplain</td>
</tr>
<tr>
<td>Site 4</td>
<td>0.5 mi downstream of Research Station</td>
<td>Valley walls relatively confined, open meadow with high water table, soft sandy soils, little bedrock</td>
</tr>
<tr>
<td>Site 5</td>
<td>0.75 mi upstream of Research Station</td>
<td>Valley constriction, steep gradient, confined channel cross section, exposed bedrock</td>
</tr>
<tr>
<td>Site 6</td>
<td>1.75 mi upstream of Research Station</td>
<td>Upper watershed, very steep gradient, deep confined cross section, exposed bedrock</td>
</tr>
<tr>
<td>Site 7</td>
<td>At USFS Rd 11 Crossing</td>
<td>Channel confined on either side of large pipe culvert</td>
</tr>
</tbody>
</table>

The slope of Sagehen Creek changes drastically from the upper watershed above Site 7 to the outlet into Stampede Reservoir downstream of Site 1. The morphology of the stream transitions from a highly laterally confined cascade and step pool morphology at the highest elevations to wide, low gradient, mountain meadows with meandering alluvial channels at the lower elevations. A longitudinal profile of Sagehen Creek with the seven potential barrier locations identified is shown in Figure 4.

5 HYDROLOGY

A flood frequency analysis was performed using data collected at the Sagehen Creek Gage (USGS Gage No. 10343500) and used to design barriers that would function properly during a rare, large magnitude flood event. Peak annual flows from 1954 to 2013 were tabulated and a Bulletin 17B flood frequency analysis was performed using HEC-SSP (USACE, 2009) to calculate peak discharge for the 2, 5, 10, 50, and 100 year return period runoff events (Figure 5).

The permanent barriers were designed for the 100 year return period flood (i.e., 1% chance of occurrence in a given year), as a reasonably conservative design threshold. The temporary barriers were designed for the 10 year return period flood. The 100 year flood (Q100) and the 10 year flood (Q10) at the Sagehen Creek Gage were calculated to be 1,330 cfs and 402 cfs, respectively. However, the catchment areas above each of the seven sites vary compared to the catchment area above the gaging station. In order to account for this difference, design flows were scaled by the ratio of the two...
catchment areas to come up with a design discharge for each barrier location. Using the same methodology, the catchment areas of the largest tributaries feeding into Sagehen Creek were also calculated and scaled using their catchment areas. The design discharges at each barrier location and the major tributaries joining Sagehen Creek are listed in Table 3.

### Table 3: Design Flows and Catchment Watershed Areas

<table>
<thead>
<tr>
<th>Location</th>
<th>Catchment Area (mi²)</th>
<th>Scaling Factor</th>
<th>Q2 (cfs)</th>
<th>Q5 (cfs)</th>
<th>Q10 (cfs)</th>
<th>Q50 (cfs)</th>
<th>Q100 (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sagehen Gage</td>
<td>10.6</td>
<td>1</td>
<td>98</td>
<td>246</td>
<td>402</td>
<td>973</td>
<td>1,338</td>
</tr>
<tr>
<td>Site 1</td>
<td>14.5</td>
<td>1.37</td>
<td>135</td>
<td>337</td>
<td>550</td>
<td>1,331</td>
<td>1,830</td>
</tr>
<tr>
<td>Site 2</td>
<td>14.4</td>
<td>1.36</td>
<td>134</td>
<td>334</td>
<td>546</td>
<td>1,322</td>
<td>1,818</td>
</tr>
<tr>
<td>Site 3</td>
<td>13.2</td>
<td>1.25</td>
<td>123</td>
<td>306</td>
<td>501</td>
<td>1,212</td>
<td>1,666</td>
</tr>
<tr>
<td>Site 4</td>
<td>11.8</td>
<td>1.11</td>
<td>110</td>
<td>274</td>
<td>448</td>
<td>1,083</td>
<td>1,489</td>
</tr>
<tr>
<td>Site 5</td>
<td>7.8</td>
<td>0.74</td>
<td>72</td>
<td>181</td>
<td>296</td>
<td>716</td>
<td>985</td>
</tr>
<tr>
<td>Site 6</td>
<td>5.2</td>
<td>0.49</td>
<td>48</td>
<td>121</td>
<td>197</td>
<td>477</td>
<td>656</td>
</tr>
<tr>
<td>Site 7</td>
<td>1.9</td>
<td>0.18</td>
<td>18</td>
<td>44</td>
<td>72</td>
<td>174</td>
<td>240</td>
</tr>
<tr>
<td>Tributary 1</td>
<td>1</td>
<td>0.09</td>
<td>9</td>
<td>23</td>
<td>38</td>
<td>92</td>
<td>126</td>
</tr>
<tr>
<td>Tributary 2</td>
<td>0.8</td>
<td>0.08</td>
<td>7</td>
<td>19</td>
<td>30</td>
<td>73</td>
<td>101</td>
</tr>
<tr>
<td>Tributary 3</td>
<td>1.2</td>
<td>0.11</td>
<td>11</td>
<td>28</td>
<td>46</td>
<td>110</td>
<td>151</td>
</tr>
<tr>
<td>Tributary 4</td>
<td>1.3</td>
<td>0.12</td>
<td>12</td>
<td>30</td>
<td>49</td>
<td>119</td>
<td>164</td>
</tr>
<tr>
<td>Tributary 5</td>
<td>0.7</td>
<td>0.07</td>
<td>6</td>
<td>16</td>
<td>27</td>
<td>64</td>
<td>88</td>
</tr>
<tr>
<td>Tributary 6</td>
<td>0.2</td>
<td>0.02</td>
<td>2</td>
<td>5</td>
<td>8</td>
<td>18</td>
<td>25</td>
</tr>
<tr>
<td>Tributary 7</td>
<td>1.1</td>
<td>0.10</td>
<td>10</td>
<td>26</td>
<td>42</td>
<td>101</td>
<td>139</td>
</tr>
<tr>
<td>Tributary 8</td>
<td>0.9</td>
<td>0.08</td>
<td>8</td>
<td>21</td>
<td>34</td>
<td>83</td>
<td>114</td>
</tr>
<tr>
<td>Tributary 9</td>
<td>1.9</td>
<td>0.18</td>
<td>18</td>
<td>44</td>
<td>72</td>
<td>174</td>
<td>240</td>
</tr>
</tbody>
</table>

Note: Scaling factor was determined from ratio of catchment area for each site to catchment area above the gaging station.

Daily-averaged flows from 1953 – 2013 were compiled from the USGS Gage data and plotted in terms of probability of exceedance (Figure 6). Using this plot, the total number of days and percent of time where each design discharge was equaled or exceeded by the daily-average flow recorded at the gage is detailed in Table 4.

### Table 4: Design Flow Exceedance Values for the 1953 – 2013 Gage Record

<table>
<thead>
<tr>
<th>Return Interval</th>
<th>Peak Discharge (cfs)</th>
<th>Number of Days Exceeded</th>
<th>Percent of Time Exceeded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q2</td>
<td>98</td>
<td>271</td>
<td>1.2</td>
</tr>
<tr>
<td>Q5</td>
<td>246</td>
<td>12</td>
<td>0.05</td>
</tr>
<tr>
<td>Q10</td>
<td>402</td>
<td>3</td>
<td>0.01</td>
</tr>
<tr>
<td>Q50</td>
<td>973</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q100</td>
<td>1,338</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: Days exceeded represents the total number of days in the period of record where the daily-averaged flow equaled or exceeded the peak discharge.
6 FIELD DATA COLLECTION

Previous discussions with individuals regarding potential permanent barrier locations identified three sites near HWY 89 that may be appropriate for a permanent fish passage barrier. At each of these sites detailed topographic surveys were conducted. The first site assessed was the furthest downstream, located approximately 0.25 mi downstream of HWY 89 at a valley constriction. The second site was just above the HWY 89 crossing where the valley cross section is confined just upstream of twin box culverts that carry the creek beneath the highway. The third site was approximately 0.5 mi upstream of the HWY 89 crossing where the creek crosses under a USFS road through a large culvert.

To assess the suitability of the three potential permanent barrier locations, and to scout out other potential temporary and permanent barrier locations, cbec performed a field data collection and reconnaissance effort. Detailed cross sections were surveyed at each of the three sites using foot-based RTK GPS and total station measurements. Hydraulic control features, thalweg profiles, floodplain elevations, and hydraulic structure dimensions were also surveyed. During the field reconnaissance, four additional sites identified in the desktop analysis as potential barrier locations were assessed based on relative valley width, geomorphic setting and channel slope.

7 HEC-RAS MODELING

A one-dimensional, steady-state, hydraulic model of Sagehen Creek from the upper portion of the watershed to 0.5 mi downstream of HWY 89 was developed using HEC-RAS (Brunner, 2010). Cross sections were sampled every 200 ft from the LiDAR DEM and relevant hydraulic structures and culverts were added based upon surveyed dimensions. The Q2, Q10, and Q100 discharge for each of the sites from Table 3 were modeled to determine design tailwater elevations for each of the potential barrier locations.

Conceptual permanent barrier designs were also modeled in HEC-RAS. An iterative process was used to determine optimal barrier spillway cross sections that could convey Q100 without overtopping or laterally flanking the structure. The model results were used to determine the design headwater elevation and the extent of ponding upstream due to the barrier.

8 REFINED CONCEPTUAL BARRIER DESIGNS

Using the results of the desktop analysis, field reconnaissance and hydraulic modeling, the conceptual barrier designs were refined and evaluated for each potential location. Conceptual permanent and temporary barrier locations were evaluated with the following criteria:

1) Feasibility of constructing a barrier at the proposed location given topography, construction access, and local geomorphic setting,
2) Expected peak hydrology during service life,
3) Overall construction impacts such as cost, footprint size, backwater extent, ecological, hydrologic and geomorphic effects.
The permanent barriers were designed to prevent upstream migration during a 100 year return period discharge event, whereas the temporary barriers were designed to prevent upstream migration for a 10 year return period discharge event. As the details of the designs were refined, a multi-stage spillway, capable of containing the design flow within the spillway cross section without overtopping, the entire structure was incorporated.

As previously noted the permanent barriers (Sites 1 and 3) were designed with a 100 year tailwater elevation, whereas the temporary barriers (Sites 4 - 7) were designed with a 10 year tailwater elevation. Similar geometries were envisioned for the permanent barriers and the temporary barriers; however, the temporary barriers are different from the permanent barriers in two ways. First the vertical portion of the temporary barrier would be composed of an inflatable bladder dam so that it could be deflated and removed once the barrier is no longer needed. Second, the central portion of the temporary barrier, where the channel is located, is proposed as removable concrete blocks or gabions at the thalweg to restore upstream connectivity at the end of the treatment/eradication phase. With the central part of the structure removed, upstream fish passage for native species would be possible, as would the downstream transport of sediment and large woody material. In addition, no impoundment would exist upstream of the structure, which is desirable to minimize hydrologic, geomorphic and ecological effects.

Each site is described in detail below.

8.1 PERMANENT BARRIER SITES

8.1.1 SITE 1

Site 1 is located 0.5 mi downstream of the HWY 89 crossing (Sheets 1 & 2). The narrowest valley section was chosen as the location for the proposed permanent barrier. The crest height of the barrier was designed to be 6 ft above the Q100 tailwater elevation. The predicted backwater effect from the crest was determined by extending the design crest elevation upstream until it intersected with the ground surface. Similarly the Q100 headwater elevation predicted by HEC-RAS was extended upstream to determine the approximate backwater footprint from the 100 year flow.

The barrier geometry consists of a 50 ft wide low flow channel section and a 160 ft wide overflow channel section that is capable of containing Q100. A 10 ft long concrete apron, sloping at 5:1, is projected under the spillway to intersect the Q100 tailwater at the base of the apron. It is assumed that some form of bank protection such as grouted rip-rap will be required at all of the sites at some distance downstream of the spillway and along the channel margins to prevent erosion and undercutting.

8.1.2 SITE 2

Site 2 is located just upstream of the HWY 89 crossing where twin box culverts convey the creek underneath the highway (Sheets 3 & 4). Although the channel upstream of the highway is relatively confined, analysis of the cross sections revealed that there was very little freeboard between the Q100 tailwater elevation and the highway elevation (Sheet 4). Sections 1+00 and 3+25 show that there is less...
than 4 ft of freeboard between the 100 year tailwater elevation and the highway in the existing condition, therefore a structure that would raise the water surface elevation by over 6 ft would require the roadway to be raised in order to prevent overtopping. Section 4+00 is cut along the highway centerline and shows the 100 year tailwater elevation downstream of the culverts. In order for the 6 ft barrier height to be enforced, and accounting for the predicted headwater elevation from HEC-RAS, a roughly ~475 ft section of HWY 89 would need to be raised and modified to accommodate a barrier at Site 2. The backwater from the existing bridge culverts is partially responsible for the elevated tailwater elevations, however, given the narrow channel cross sections upstream of the bridge and the minimal freeboard between the channel and HWY 89, Site 2 was determined to be unsuitable for a permanent barrier given the design constraints.

In the future, if modifications are made to HWY 89 as part of a potential CalTrans project, the feasibility of Site 2 may be revisited with a different type of barrier considered (e.g., a velocity barrier).

### 8.1.3 SITE 3

Site 3 is located 0.5 mi upstream of the HWY 89 crossing (Sheets 5 & 6). The channel is constricted upstream of a USFS road crossing where the creek is conveyed through a large metal pipe culvert. The conceptual barrier design at Site 3 is very similar to that of Site 1. The design incorporates a multi-stage spillway with a 50 ft wide low-flow channel section and a 150 ft wide overflow channel section capable of conveying Q100 without overtopping. Apron dimensions and slope are identical to Site 1. The USFS road that runs along the river-left embankment should not be impacted. The design showed roughly ~3 ft of freeboard between the road and the 100 year headwater elevation with the barrier in place.

### 8.2 TEMPORARY BARRIER SITES

The conceptual design for each of the temporary barriers was essentially the same, only the lateral extent was modified to accommodate each site specific cross section. A detail of the typical temporary barrier conceptual design is shown for Site 5 in Sheet 9. Each temporary barrier consists of a 10 ft wide (in the downstream direction) concrete foundation with a crest elevation 2 ft above the Q10 tailwater elevation. There is a sloping apron that drops down 2 ft and extends downstream 10 ft to match the Q10 tailwater elevation. Above the foundation, the crest height is capable of being raised an additional 4 ft using bladder dams supported by removable stanchions. In the main channel, several removable concrete blocks or gabions would remain in-place during the barrier's service life, and then be removed to restore stream gradient and connectivity at the end of treatment. To ensure that flow is focused over the bladder dams when in use, earthen embankments would extend the non-spillway portions of each structure laterally to the valley walls.

### 8.2.1 SITE 4

Site 4 is located roughly 0.5 mi downstream of the Sagehen Creek Research Station, at a relatively confined section of the valley (Sheet 7). Although the valley is relatively confined, it is still significantly wider than any of the other proposed sites. Site 4 is located in a wide open low gradient meadow with
shallow groundwater. Beaver dams and complex multi-threaded channels are prevalent in this reach. Because of the wide valley and shallow gradient, the barrier at Site 4 would create a significant backwater. Despite the difficulties present, Site 4 was chosen because it is the narrowest section of the valley between Sites 3 and 5, and it may be necessary to divide the main channel up into segments shorter than 2 miles during the treatment phase.

8.2.2 SITE 5

Site 5 was located approximately 0.75 mi upstream of the Sagehen Creek Research Station at a valley constriction (Sheets 8 & 9). The terrain at Site 5 is significantly more confined and steep than at Site 4. Large boulders and exposed bedrock are prevalent in this reach.

8.2.3 SITE 6

Site 6 was located in the upper reaches of the watershed where the channel is highly confined (Sheet 10). The confined topography at Site 6 means that a relatively small barrier should be sufficient. The backwater pool created at Site 6 was significantly smaller than the 5 sites located downstream.

8.2.4 SITE 7

Site 7 is the furthest upstream site, located just upstream of the USFS Road 11 crossing (Sheet 11). The barrier at Site 7 had the smallest footprint of any of the barriers and the concrete foundation was only 30 ft long. The steep, narrow, topography at this site combined with a relatively small contributing watershed upstream, suggest that the design at Site 7 would have a minimal impact.

9 DISCUSSION

The seven barrier designs were evaluated based on their overall cost, construction impact as well as potential geomorphic, hydrologic and ecological impacts. Table 5, lists the total backwater area from the crest elevation, the construction footprint, the estimated volume of concrete required, and an approximate estimate of construction cost. The cost estimates do not include costs associated with design, permitting or construction observation. In recent discussions, George Heise estimated the permanent structures to cost around one million dollars. Mr Heise has more experience with the construction of these types of barriers in mountain environments, so it is possible the conceptual level cost estimates provided in Table 5 are low.

As these designs are conceptual, for the purpose of determining the feasibility of this effort, a future phase of the project should entail additional design, and a value engineering exercise to evaluate various design components. For instance the permanent barriers could be designed as retaining walls rather than concrete gravity dams, which would reduce the amount of concrete; however, this design would require earth to be excavated/imported. The lateral, non-spillway portions of the structures could be constructed as earthen embankments rather than concrete structures, but that would require a local source of fill. The apron portion of the structures could be constructed with grouted riprap as opposed
to concrete, which would likely reduce the cost. The vertical portion of the temporary barriers could be constructed as a flashboard dam rather than a bladder dam, however this would require more closely spaced stanchions that could inhibit the downstream transport of large woody material if not removed when the barrier is no longer utilized. Each of these design considerations and several more should be evaluated in a future phase of the project.

### Table 5: Barrier Impacts, Dimensions and Estimated Costs

<table>
<thead>
<tr>
<th>Barrier Location</th>
<th>Backwater Area (Ac)</th>
<th>Construction Footprint (ft²)</th>
<th>Top Width (ft)</th>
<th>Concrete Volume (CY)</th>
<th>Construction Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>1.82</td>
<td>1,980</td>
<td>192</td>
<td>406</td>
<td>$410,700</td>
</tr>
<tr>
<td>Site 2</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Site 3</td>
<td>1.6</td>
<td>1,930</td>
<td>214</td>
<td>406</td>
<td>$407,000</td>
</tr>
<tr>
<td>Site 4</td>
<td>1.95</td>
<td>3,700</td>
<td>185</td>
<td>616</td>
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<td>30</td>
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**Note:** Construction costs were estimated with a unit cost of concrete formwork including labor of $500 per cubic yard (CY) and a location factor of 1.3 due to the relatively remote access to the sites.

The two permanent barrier designs are very similar in terms of cost and impact due to similar valley widths at each location. The permanent barriers at Sites 1 and 3 have the largest relative backwater areas due to their comparatively high crest heights and shallow valley slopes, although elevating the crest elevations of Sites 4 and 5 using bladder dams would create comparable backwater areas. The major distinction between the two viable permanent sites is that Site 1 is downstream of HWY 89 and Site 3 is upstream. It has been noted that with a barrier located downstream of the highway there is a greater potential concern regarding reintroduction of nonnatives. A site upstream of HWY 89 has been considered by some to have a lower risk of anthropogenic reintroduction of nonnatives.

Each of the proposed permanent barriers would create a pool upstream, which would inundate a portion of the valley floor. The impoundment would halt bedload transport for the period of time while the impoundment filled with coarse sediment. Water passing over the barrier would have a greater capacity to transport sediment, and adjustments to the channel downstream could occur due to the imbalance between transport capacity and sediment load. The permanent barriers should allow the transport of large woody material downstream, however it is possible that pieces would collect along the margins of the impoundment, or at the crest of the structure. The impoundment would also create an elevated groundwater condition upstream of the inundation extent making the floodplain a more hydric environment for a short distance upstream.

The temporary barriers vary significantly in terms of cost and impact. The cost is skewed towards Sites 4 and 5 due to their relatively large concrete footprints and valley widths. Backwatering is not a significant concern if the temporary barriers are operated without the stanchions and bladder dams in-place. If the crest is raised seasonally or permanently during treatment, the backwater inundated area would increase significantly. For the period while the barrier was in operation a portion of the valley floor
would be converted to an impoundment. This impoundment would generate deposition of coarse sediment and the formation of a delta in the pool. There could also be minor adjustments to the channel downstream of the barrier due to the interruption in sediment transport, particularly if large runoff events occur during this period. Changes in vegetation are also likely to occur; however, the changes are likely to be temporary. If the barriers are only utilized for a short period (e.g., three years), it is likely that once the backwatered area is no longer inundated, wet meadow and riparian species would reestablish. Once the removable sections were removed from the channel section, longitudinal connectivity would be restored and the channel should return to a similar condition as the pre-project state. Likewise, the removable sections would allow the downstream transport of large woody material; however there is the chance that large logs could get caught by the portions of the structure which remain on the channel margins and floodplain.

In designing the barriers (both permanent and temporary) a conservative approach has been utilized. When the cost of nonnative eradication and LCT reintroduction are considered, it would be a tragedy if any nonnative fish passed upstream and compromised the effort. However, it is possible smaller barriers could function successfully if within the risk tolerance of the project sponsors. The permanent barriers were designed to the 100 year tailwater elevation. This tailwater condition has the statistical probability of occurring once in a hundred years, and then only for minutes. The flow exceedance analysis shown in Table 4 and Figure 5 indicate how infrequent this elevated flow condition is for the system. The likelihood of upstream migration during these extreme events should also be considered. The larger the design flow, the larger and more costly the structure.

Lastly, the size of the barriers and resulting impoundments as proposed all fall well below the jurisdictional limits of the Division of Dam Safety. Dams shorter than 25 ft, must have a storage volume of less than 50 acre feet.

**10 CONCLUSIONS**

A feasibility assessment was undertaken to evaluate opportunities and constraints for the creation of fish passage barriers on Sagehen Creek to allow for the eradication of nonnative salmonids and the reintroduction of LCT. Conceptual barrier designs were developed based upon published values for maximum swimming speed and subsequent leaping height as well as through consultation with George Heise, a senior hydraulic engineer with the California Department of Fish and Wildlife. The site identification effort primarily utilized topographic and hydrologic data in the selection of potential barrier locations, although data regarding soil type, geology and historic aerial imagery were also referenced. Once potential locations were identified, a field reconnaissance/survey and subsequent hydraulic modeling was undertaken to refine the design of potential structures. The effort yielded two viable permanent barrier locations, as well as four additional locations where temporary barriers could be located. A future phase of the effort should evaluate the duration of temporary barrier employment, as well as the magnitude of flows that should be impassable to fish. Furthermore, a value engineering effort should be undertaken to evaluate the costs and benefits of various barrier designs.
11 REFERENCES


FIGURES
Source: Analysis of Barriers to Upstream Fish Migration (Powers, 1985)

Sagehen Creek Fish Barrier Feasibility Assessment

Steelhead Trout Leaping Curves

Project No. 12-1022
Created By: T.R.A.

Figure 1

SPECIES: Steelhead trout
VFB: 26.5 fps

- WC = 0.75
Cfc = 1.00
Predicted Steelhead leaping curves assume a condition factor of 0.75.
Notes: Source: 2005 LIDAR

Potential Barrier Locations

Legend
Potential Barrier Locations
Type
- Potential Permanent
- Potential Temporary
- Major Tributary

LIDAR DEM
NAVD 88 FT
High: 8763.08
Low: 5812.63

Research Station
SITE 1
SITE 2
SITE 3
SITE 4
SITE 5
SITE 6
SITE 7
USFS Rd 11
HWY 89
USGS Gage

Notes:
Source: 2005 LIDAR

Sagehen Creek Fish Barrier Feasibility Assessment

Potential Barrier Locations

Project No. 12-1022
Created By: T.R.A.
Notes: Source: 2005 LiDAR
Maximum elevation of Stampede Reservoir ~5949 ft

Sagehen Creek Fish Barrier Feasibility Assessment
Sagehen Creek Longitudinal Profile

Figure 4
Notes: Developed using HEC-SSP (USACE, 2009) using peak annual flow data for 1954-2013 from USGS Gage No. 10343500.

Sagehen Creek Fish Barrier Feasibility Assessment

Flood Frequency Plot

Project No. 12-1022
Created by: T.R.A.

Figure 5
Notes: Source: USGS Gage No. 10343500

Sagehen Creek Fish Barrier Feasibility Assessment

Daily Average Flow Exceedance

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Created By: T.R.A.

Figure 6
SHEETS
NOTE: CONCEPTUAL DESIGNS NOT INTENDED FOR CONSTRUCTION.
APPENDIX A
Notes:

Sagehen Creek Fish Barrier Feasibility Assessment

Site 1 Looking Upstream

Project No. 12-1022  Created By: T.R.A.  Appendix A-1

C:\Work\Projects\12-1022_Sagehen\reporting\Appendix_A\Appendix_A1_Site_1_US.docx
12/10/2013
Notes:

Sagehen Creek Fish Barrier Feasibility Assessment

Site 2 Looking Upstream

Project No. 12-1022  Created By: T.R.A.

Appendix A-3
Notes:

Sagehen Creek Fish Barrier Feasibility Assessment

Site 2 Looking Downstream

Project No. 12-1022

Created By: T.R.A.

Appendix A-4
Site 4 Looking Upstream

Notes:

Sagehen Creek Fish Barrier Feasibility Assessment

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Created By: T.R.A.
Appendix A-7
Notes:

Sagehen Creek Fish Barrier Feasibility Assessment

Site 4 Looking Downstream

Project No. 12-1022
Created By: T.R.A.
Appendix A-8
Notes:

Sagehen Creek Fish Barrier Feasibility Assessment

Site 5 Looking Downstream

Project No. 12-1022  Created By: T.R.A.

Appendix A-10
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