# Stream Restoration Plan

# Middle Fork Lake Creek
# at Lake Creek Lodge

August 2005

**Prepared By:**
Louis Wasniewski
Assistant Forest Hydrologist
Deschutes National Forest
Bend, Oregon

**Prepared For:**
Upper Deschutes Watershed Council
Bend, Oregon

**In Partnership With:**

Lake Creek Lodge

US Fish and Wildlife Service

Oregon Dept. of Fish and Wildlife

# 1.0 Introduction

Approximately 725 feet of Lake Creek was channelized with concrete and rock retaining walls in the 1920s during the initial development of the Lake Creek Lodge property. As part of this channelization, a large pond was created for swimming, fish stocking and other recreational activities, and several small weirs were installed to provide for the filling of the pond. In its current condition, the channelized section of the creek supports little riparian vegetation, provides very poor fish habitat, causes seasonal fish passage barriers, and contributes to increased temperature through artificial ponding of water.

In 2004, the Upper Deschutes Watershed Council entered into a partnership with Lake Creek Lodge to develop a stream restoration project to remove historic retaining walls and restore fish and wildlife habitat. The Upper Deschutes Watershed Council obtained funding from the Oregon Watershed Enhancement Board (Grant #204-508) to contract with hydrologists and fisheries biologists from the Deschutes National Forest to develop the stream restoration design under Collection Agreement No. 2005-CO-11060120-012. Throughout the design process, technical assistance has been provided by U.S. Fish and Wildlife Service and the Oregon Department of Fish and Wildlife.

This type of partnership has been developed for this project under the Wyden Amendment, which encourages the Forest Service to partner with private landowners on watershed restoration projects. The Middle Fork Lake Creek project fits with this Wyden Amendment because Forest Service Administered Lands are located upstream and downstream of the projects area and the Forest Service has a vested interest in improving watershed conditions.

# 2.0 Project Description

The project is located on the Middle Fork of Lake Creek on the Lake Creek Lodge property near the town of Camp Sherman, Oregon (T13S R9E SEC 15) (Figure 1). The Middle Fork of Lake Creek, a major tributary of the Metolius River, flows through the 42-acre Lake Creek Lodge property and enters the Metolius River approximately one mile downstream of the Lodge. Approximately 725 feet of the Middle Fork on the upstream end of the lodge property, which starts just downstream of the 1419 county road, was channelized with concrete and rock retaining walls during the initial property development.

This section of stream does not meet the state temperature standards and is listed as such in Oregon's 2002 303(d) impaired water bodies as directed by the federal Clean Water Act. Despite the stream modification, Middle Fork Lake

Figure 1

Creek is known to support the federally-listed Threatened bull trout. It has been recognized as an important stream in the Metolius Basin for the re-introduction of the Spring Chinook in the upper Deschutes River Basin. Although Chinook have not reached the upper basin for 40 years, the recent re-licensing of the Pelton-Round Butte complex is expected to provide passage into the upper basin. Restoring this portion of Lake Creek represents an opportunity to improve habitat conditions in anticipation of the return of Chinook.

## *2.1 Goals and Objectives*

The overall goal of the project is to restore a naturally functioning stream channel, stream banks and riparian margin along the stream to benefit fish habitat and improve water quality. In addition, the project will provide a natural recreational setting for the lodge and enhance community awareness of channel restoration and naturally functioning streams.

Specific objectives include:

- Removing the artificially created pond and restore the natural stream meander pattern.
- Restoring the channelized reach of the creek, including removal of the concrete and rock retaining walls, removal of the two flashboard weirs, and restoration of the riparian vegetation.
- Increasing fish habitat including pool, spawning, rearing habitat.
- Decreasing stream temperatures to improve water quality and help meet Oregon's State Temperature Standards.

## *2.2 Project Area and Condition Description*

### *2.2.1 Geomorphology/Hydrology*

The project area lies on the east slope of the Cascade Range within the Lower Cascades ecological subsection. The Lower Cascades is bounded by the Upper Cascades to the west and Green Ridge to the east. The volcanic upper slopes of the Cascades were shaped with at least three different periods of glaciation. Ground moraines and deeply eroded volcanic peaks dominate the upper elevations. The Lower Cascade subsection is dominated by gently sloping plains of glacial outwash and by hills and ridges of lava that rise above the outwash plains (USDA Forest Service, 1996).

Lake Creek originates from Suttle Lake and travels easterly through the gentle slopes of the glacial outwash. Water feeding Suttle Lake comes off the west slopes of the Cascades near Hoodoo Ski area and the many lakes that remain from the glaciation. As Lake Creek heads toward the Metolius River it splits into three separate channels. The North Fork of Lake Creek enters the Metolius without joining the other forks. The Middle and South Forks join back together before flowing through the Lake Creek Lodge property and then travels about another mile before entering the Metolius.

## *2.2.2 Bankfull Discharge*

Lake Creek is gauged (14088000) below Suttle Lake where the stream flow is in one channel. The gauge is maintained by the Oregon Water Resources Department. This flow data was used to estimate bankfull flows on the Middle Fork at the project area as well as flood flow estimates. Because the flows at the lodge are split into the North Fork and Middle Fork before reaching the lodge, it made estimating bankfull and flood flows at the lodge more difficult.

To determine bankfull discharge at the gauge a stream cross section survey was conducted by the Deschutes National Forest staff. At this time the bankfull indicators corresponded to a staff gauge reading of 3.11 feet. From the discharge versus water depth (staff reading) rating curve a staff reading of 3.11 feet corresponds to a 132.4 cfs bankfull discharge and a 1.54 return interval.

To determine the bankfull discharge on the Middle Fork at the lodge, three different techniques were used. The first was to estimate bankfull by relating the current flows percentages in both the North Fork and Middle Fork to the current flows at the gauge. These two forks represent the total flow for Lake Creek at the gauge. This method was used because there was no flow addition between the gauge and the Lake Creek Lodge. Discharge was measured on April 5 2005 and the Middle and North Forks had discharges of 45.8 and 21.0 cfs, respectively. This corresponds to a 68.6 % in the Middle Fork and 31.4% in the North Fork as a total of Lake Creek as represented by the gauge. Appling this percentage to the gauge bankfull discharge, the calculated bankfull flow at the lodge would be 90.8 cfs.

The other two techniques used the Manning Equation ($V=1.4865*R^{2/3}*S^{1/2}/n$) and Q=A*V.

Q=Discharge ($ft^3/sec$)
A=Cross Section Area ($ft^2$)
V=Velocity (ft/s)
R=Hydraulic radius (ft) = Area/Wetted perimeter
S=Water slope (ft/ft)

The bankfull discharge (Q) was calculated using two different methods of estimating the roughness coefficient “n”. One method used measured discharge, velocity, and area to back calculate the roughness coefficient ‘n”. The other method used the Friction Factor or mean depth divided by the 84 percentile stream substrate size relationship (d/D84) to estimate “n”.

$$\text{Friction Factor} = 2.83 + 5.7\log(d/D84)$$

Then the Friction Factor times shear velocity equals velocity which is used in the Manning’s equation to back calculate Manning’s Roughness Coefficient (n).

Shear velocity = $32.2 * R * S^{1/2}$
32.2 = Gravitational acceleration (ft/$s^2$)

The discharge taken on April 5, 2005 corresponded “n” of 0.066 and a bankfull flow of 81.6 cfs on the Middle Fork at the lodge. Within the restoration reach the pebble count information (D84) and the mean cross section depth (d) was used to calculate relative roughness “n”. The “n” value computed to be 0.044 and a bankfull flow of 121.7 cfs from the d/D84 relationship. Both methods used WinXSPRO version 3.2 software to compute bankfull discharge from the roughness coefficients and other site conditions variables (Hardy *et. al*., 2005).

Jeremy Giffin of the Oregon Water Resource Department indicated that the upstream splitting of the North Fork and Middle Fork did not divide flows evenly as flows increased (personal communication April 7, 2005). The Middle Fork would take more water as flows increase due to a bottle neck effect on the North Fork. At a 1.5 year return interval flow or bankfull it is believed that the bottle neck does not have that large of an effect, but would have a large effect on large flood flows. Therefore, bankfull discharge on the Middle Fork at the lodge is estimated at 90 cfs.

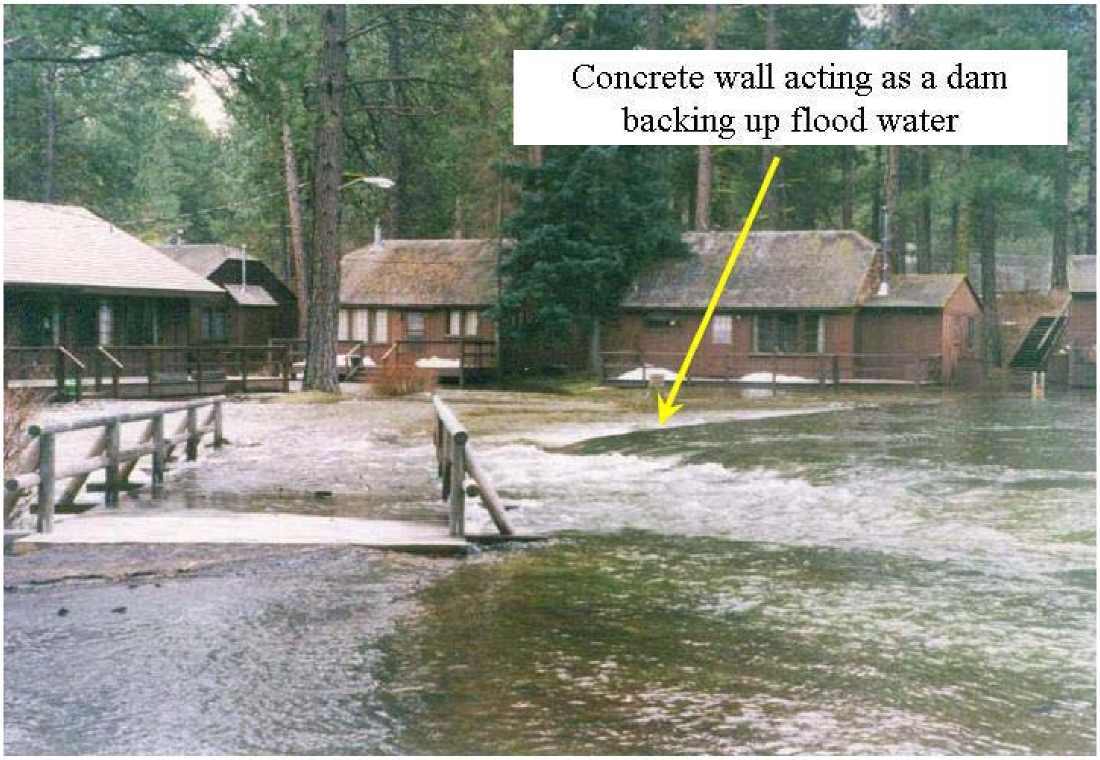
### *2.2.3 Flood Flows*

The largest flow on record at the gauge was 589 cfs that occurred on February 10, 1996 as a result of a warm weather and a rain on snow event. This same flooding also occurred at Lake Creek Lodge where the floodplain was accessed, however, no water had entered the cabins. Pictures during the flood were taken by the lodge and were very useful in several areas of the design (Photograph 1).

**Photograph 1: 1996 flood at Lake Creek Lodge. Photo provided by Lake Creek Lodge.**

The techniques used in determining bankfull flows were also used to estimate the 1996 flood flows at the lodge on the Middle Fork. The percentage of the gauge flows based on the Middle Fork (68.6 %) and North Fork (31.4 %) flow of April 5, 2005 would estimate the flood flows to be 404 cfs at the lodge. However, due to the non-linear relationship of the splitting of flow at the North Fork and Middle Fork split, it is believed the 404 cfs is an underestimate of the flow. From the flood flow pictures the water surface elevation was surveyed to recreate a flood cross sectional area and slope. These variables were used in the WinXSPro software along with a roughness coefficient similar to the ones used above to help estimate flood flows at the lodge. Using this technique with a roughness coefficient of 0.066 corresponded to a discharge of 488 cfs which is 81% of the gauge flow and more realistic to what was probably flowing by the lodge. In addition, the flood survey work at the lodge revealed that the flows had a width of 195 feet, mean depth of 1.1 feet, and a cross sectional area of 222 sq. feet.

When reviewing the flood photographs taken by the lodge it was interesting to see the affect of the created pond and cement / rock retaining walls. The downstream end of the pond wall acted as a spill-way backing up water and raising the flood elevation upstream (Photograph 2).




**Photograph 2: 1996 flood showing the effects of the concrete wall on the down stream end of the pond.**

### *2.2.4 Stream Classification and Reference Reach Conditions*

In order to recommend specific restoration treatments, it is necessary to classify the stream reach since different stream types do not respond the same for similar treatments. A classification system (Rosgen, 1996) was used to classify the entire reach. A visual summary of the classification system is shown in Figure 2. In addition, the stream classification or stream type allows the same stream type to be identified in an undisturbed stable state and to be used as a reference condition. These reference conditions can be surveyed to determine physical characteristics that can be incorporated into the design to rehabilitate the disturbed channel back to a naturally functioning state.

A reference reach was identified about 500 feet downstream of the restoration reach that was stable and contained excellent pool habitat, which is a desired feature for the restoration reach. The location of the restoration and reference reaches are shown in Figure 3.

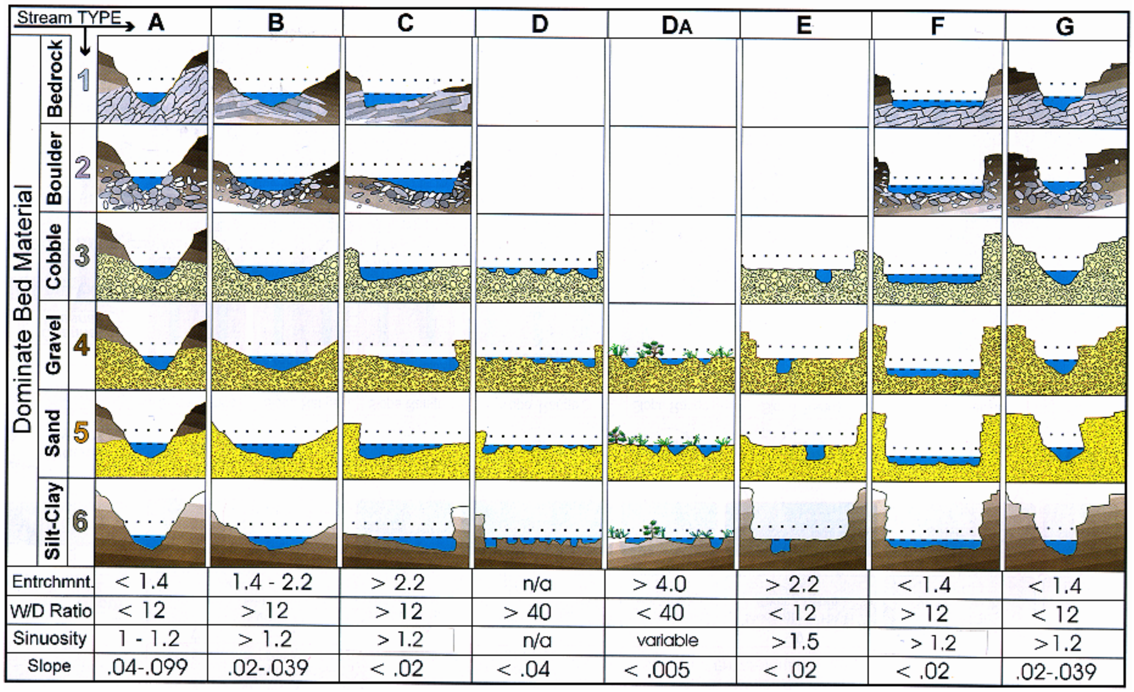



**Figure 2: Delineative Criteria and Characteristics for the Major Stream Types (Rosgen, 1996).**

The proposed restoration reach measures 724 feet and the reference reach measured 824 feet. Both reaches classified out as a Rosgen $C_4$ stream type with signs of an "E" type channel as shown in table 1. More details of the survey physical parameters can be viewed in appendix A. The number following the stream type letter denotes the dominate bed material as shown in Figure 2 and Table 1.

**Table 1: Stream classification of the restoration and reference reaches.**

| **Classification Variables** | **Restoration Reach** | **Reference Reach** |
|---|---|---|
| Entrenchment Ratio | 11.4 | 12.5 |
| Width/Depth Ratio | 26 | 18 |
| Sinuosity | 1.85 | 1.36 |
| Slope | 0.005 | 0.0055 |
| Dominate Bed Material ($D_{50}$) | Coarse Gravel (55.2) | Coarse Gravel (51.8) |
| **Stream Class** | **$C_4$** | **$C_4$** |

Figure 3

The primary morphological features of the “C” stream type are the sinuous, low relief channel, the well developed floodplains built by the river, and characteristic “point bars” within the active channel. These streams have a well-developed floodplain (slightly entrenched), are relatively sinuous (>1.2) with a channel slope of 2% or less, and width to depth ratios generally exceed 12. Bed form morphology is indicative of a riffle/pool configuration. These streams can be significantly altered and rapidly de-stabilized when the effect of imposed changes in bank stability, watershed condition, or flow regime are combined to exceed channel stability threshold.

The width/depth ratio bumped the restoration and reference reaches into a C type channel; however, these reaches do contain E type characteristics. The predominantly higher vegetated point bars and the riffle feature replaced with deeper glide features are characteristic of an E channel type. These are important indicator in designing a channel to access its floodplain rather than being incised and using point bar flood areas.

## 3.0 Proposed Restoration

The proposed project focuses on restoring the 724 feet of channelized stream to natural pattern, dimension, and profile as indicated by the reference reach. To create a stable functioning stream system the following are proposed:

- The cement and rock walls lining the channel and pond would be removed and reverted back to vegetated banks.
- The pond channel would be converted back to meander with a stable radius of curvature.
- The bypass channel would be converted to a high flow flood channel with flood of > 5 year return interval accessing this area.
- The lodge access bridge would be full spanning removing the center pier to allow for a deeper pool to be created and maintained.
- Bank stability on the outside of meanders would be enhanced by whole tree wood complexes which would also increase pool numbers, depth and volume.
- A native riparian vegetation corridor would be established along the stream channel replacing the turf growing to the waters edge.

More specifically, the restoration reach has been broken down into three areas as shown by Figure 4. These areas will be discussed individually below as to how they will meet the project objectives. Figure 4 also indicates the extent of the native riparian zone. This zone already contains areas of existing native riparian vegetation that would be left as is or enriched with additional plant species (See discussion in Section 5.0). The riparian zone would increase bank stability, flood plain roughness (i.e., minimize flood damage), wildlife habitat, plant diversity, stream shading decreasing stream temperature, and improve the natural setting for a lodge experience.

Figure 4

**MF Lake Creek Restoration Project**
**Location of Specific Design Areas**

### *3.1 Area 1*

Area 1 is located under the 1419 county road bridge and extends downstream through the first meander (Figure 5). This area is further divided into two sites: site 1 is under the bridge and site 2 is the first meander. Under bridge the channel maintains a riffle feature that is wide and shallow, having a width of 36 feet that is 180% wider than the average reference width of 20 feet. To create a narrower and deeper channel and improve fish habitat and still maintain flood capacity the channel would be narrowed to approximately 20-25 feet. The existing cross sectional area is 41.9 $ft^2$ and a mean depth of 1.2 ft. By changing the bankfull width to 20 or 25 feet the cross sectional area would be 27.6 or 30.4 $ft^2$, respectively. This is much closer in the reference condition range of 21 to 24 $ft^2$ (Figure 6)

To do this it is proposed to use 2-3 foot diameter boulders, whole trees with root wads, and coarse gravel /cobble fill river rock. The whole trees would be used to push the boulders upstream without damaging the bridge. The trees would be trenched 50-80% into the bank or bed as shown in Area 1 Details. Coarse gravel / cobble river rock would be either hand placed using five gallon buckets or excavator.

The two concerns with narrowing the channel are decreases in flood capacity of the bridge and increases in shear stress on the first meander downstream. Bridge flood capacity calculations were computed based on the narrowing of the channel and compared to the 1996 flood. The 1996 flood estimated at 490 cfs maintained a 2.9 foot of free-board under the bridge deck. The total capacity of the bridge with water flowing up to the bottom of the bridge deck is estimated at 1900 cfs, a 3.9 fold increase from the 1996 flood. Flood flow estimates for changes in channel width are shown in Table 2. Prior to restoration Jefferson County needs to approve channel narrowing and the corresponding flood effect to the 1419 county road bridge. Upon Jefferson County's input site 1 can be modified.

**Table 2: Comparison of flood flows and freeboard with changes in bankfull width.**

| Bankfull Channel Width* | Discharge (cfs) | Freeboard (ft) |
|---|---|---|
| 35.9 | 488 (est. 1996 flood) | 2.89 |
| 35.9 | 88 (est. bankfull flow) | 4.18 |
| 20 | 369 | 2.89 |
| 25 | 395 | 2.89 |
| 35.9 | 1900 | 0.0 |
| 20 | 1685 | 0.0 |
| 25 | 1743 | 0.0 |
| 20 | 488 | 2.55 |
| 25 | 488 | 2.63 |

* Bridge width from piling to piling is 46 feet and during flood events it spans the total width.

The other concern is the increase in shear stress on the banks on the next meander downstream. The meander log jam complex shown in the Area 1 detail as site 2 is designed to handle increases in shear stress. This structure is also designed to increase bank stability and increase pool volume and fish habitat complexity. The existing larch trees would be retained and the log jam built around them to maintain the live tree excellent bank holding capacity.

**Figure 5.  Area 1 Details**

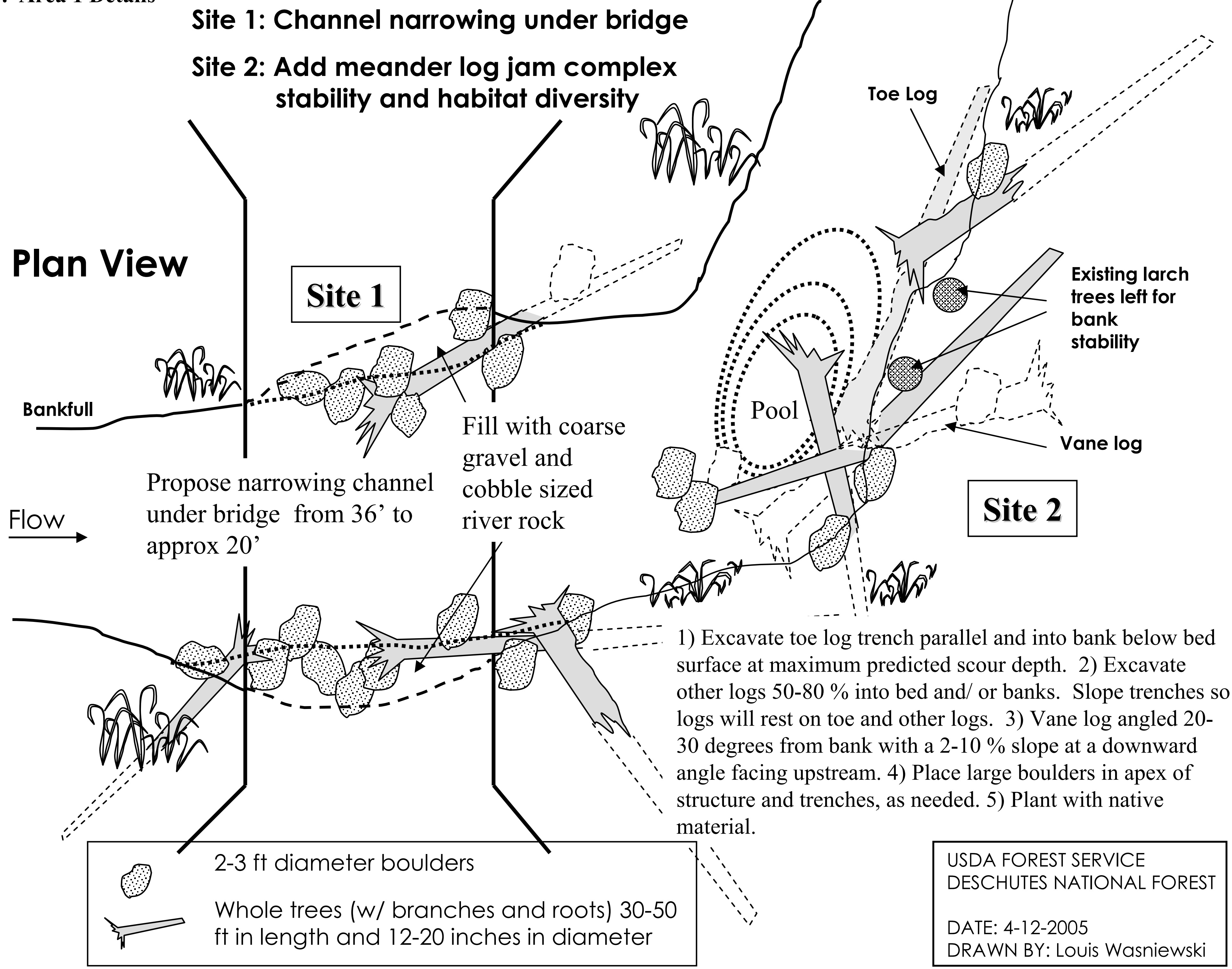
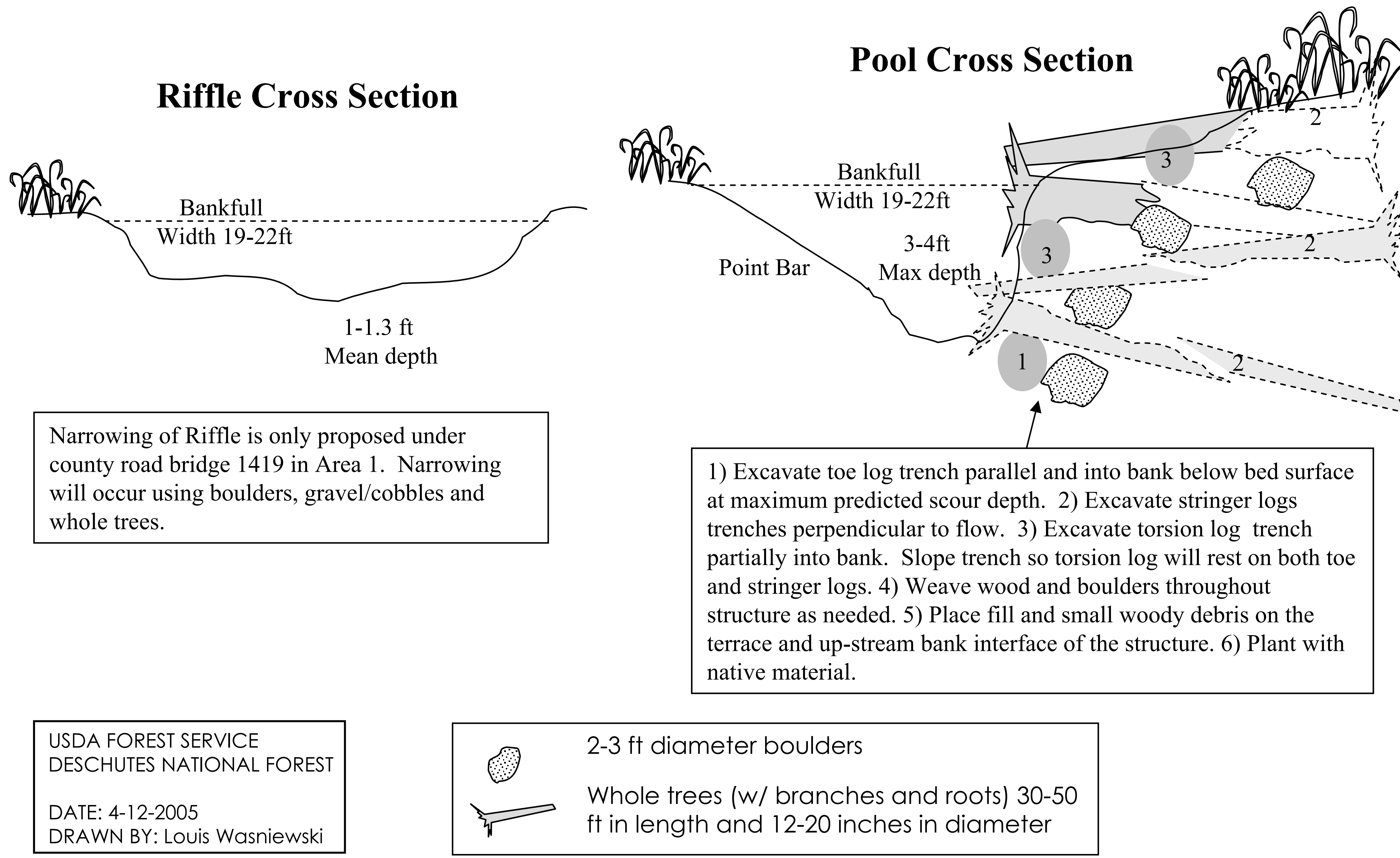


**Figure 6. Typical Riffle and Pool Cross Sections**



### *3.2 Area 2*

Area 2 is located in the vicinity of the existing pond, bypass channel, and access bridge (Figures 7 and 8). This area would undergo the biggest change of all the areas due to the conversion of the pond to a stream channel. The Area 2 is subdivided into 3 additional sites (sites 3, 4, 5) as shown in the Area 2 Details. Site 3 is the conversion of the pond to a channel, site 4 is bridge modification and pool formation, and site 5 is the conversion of the bypass channel to a flood plain and a flood channel.

In order to convert the pond to a 19-21 feet wide channel, as indicated by the reference conditions, the pond would have to be filled with an estimate 1,170 yards of material. This fill would form a point bar extending out from the existing islands to form a channel radius of curvature of approximately 32 feet, which falls in the range of 20 to 48 feet (average 34 feet) as indicated by the reference reach. A mixture of coarse gravel and cobble size substrate would be needed to fill and seed the new channel bed and the margins of the point bar. This amount is estimated at 140 yards and may vary depending on existing pond material. The size mixture would be developed off of the substrate particle size sampled on the restoration and reference reaches.

Currently in the pond there is 2-3 feet of "muck" that will need to be removed. It is proposed to expand an existing wetland by 0.23 acres (9,956 $ft^2$) to acquire the necessary fill material (Figure 8). The existing ground at the proposed wetland site would be excavated an average of 3.25 feet with a max depth of 5 feet to tie into the existing wetland then taper up to ground level. The "muck" will be used in the point bar and wetland creation as a top dressing to promote riparian and wetland vegetation growth.

The cement and rock retaining wall around the pond and bypass channel would be removed and hauled off site. To create bank stability in the outside meander through the old pond, two log jam complexes would be constructed (Area 2 Details). These structures would help dissipate stream energy, and maintain constructed pools and essential fish habitat. Other bank locations would be planted with riparian vegetation to provide the necessary bank stability.

The formation of the channel through the pond required a reference evaluation of riffle, run, pool, and glide slopes, lengths, widths, and depths so that a stable channel could be constructed. A longitudinal profile of the proposed channel and the sequencing of channel features are shown in figure 9. This proposed channel will lengthen the current channel by 97.8 feet. The first riffle slope is proposed to have a steeper riffle (1.5%) then the second (1.0%) which leads into the pool under the lodge access bridge (site 4). This is designed appropriately to increase stream power on the first riffle to maintain two deeper pools and then less stream power (less steep riffle) to form and maintain a good pool under the bridge while still providing protection for the bridge abutments. The riffle slope

**Figure 7. Area 2 Details**

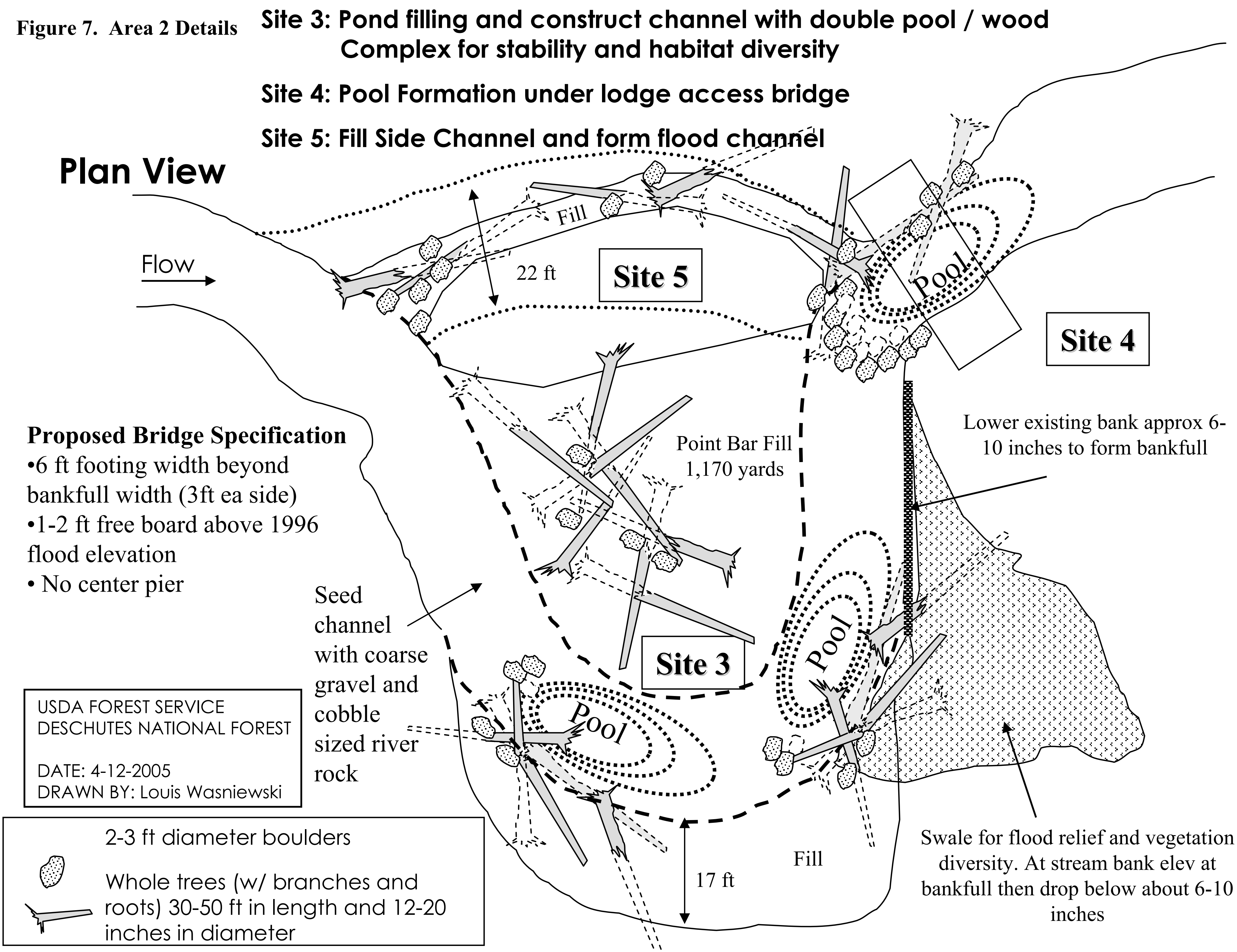


**Figure 8. Area 2 Details – Cross Section**

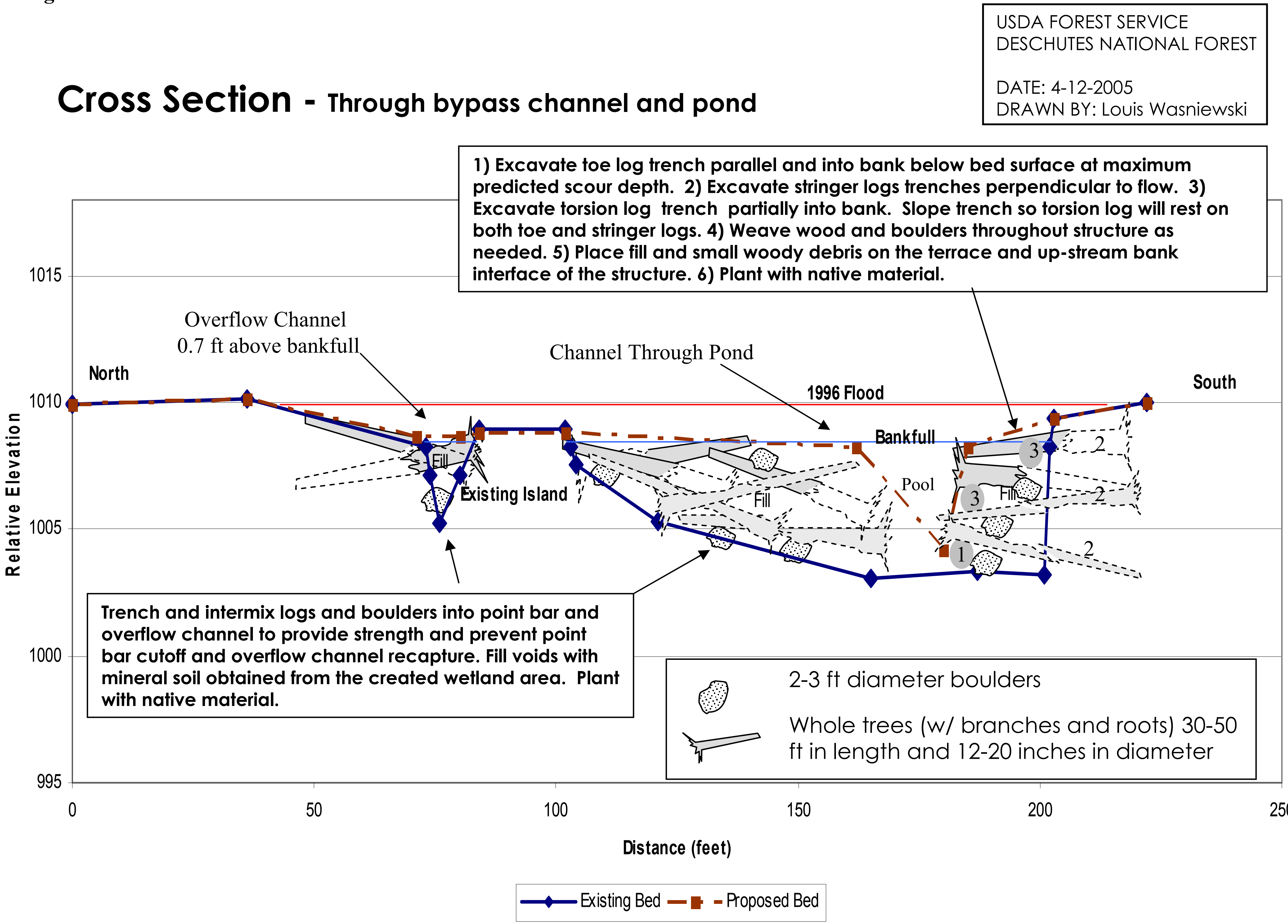
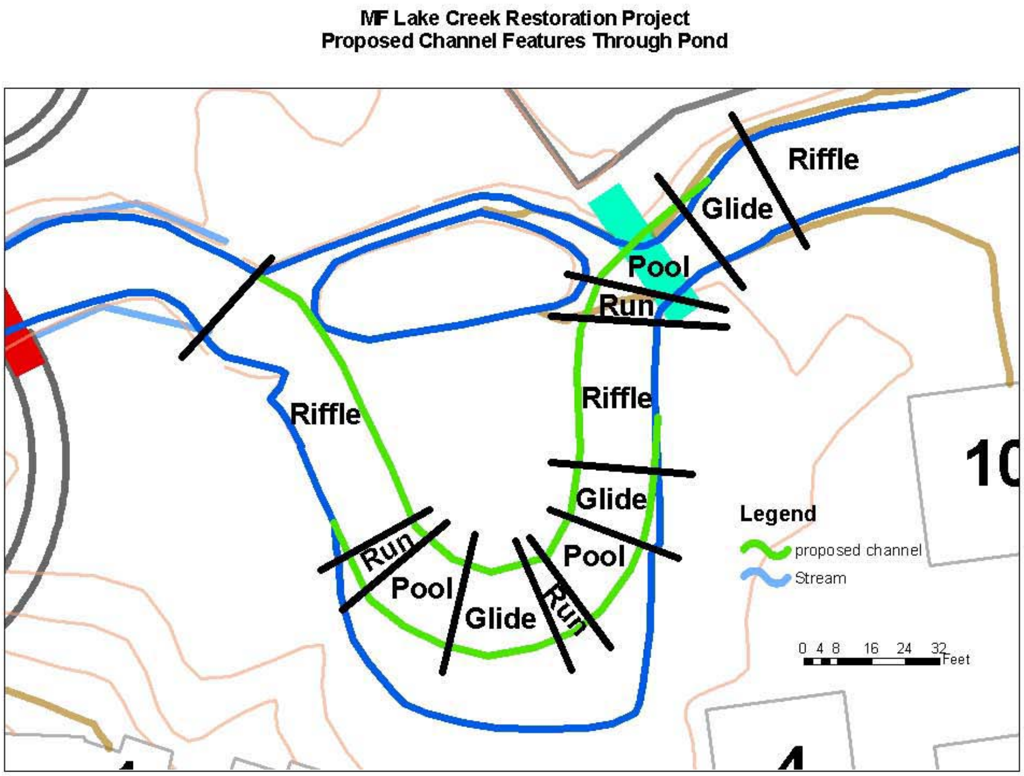
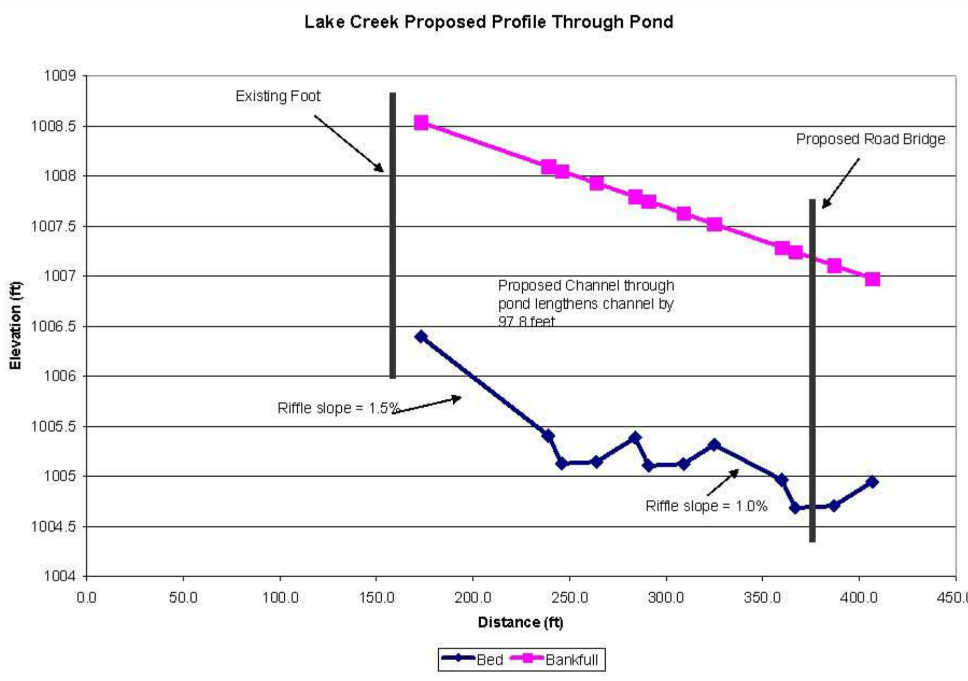


**Figure 9: A longitudinal profile of the proposed channel and the sequencing of channel features in Area 2**



reference conditions indicated a range of 1% to 5.9%. The 5.9% was the steepest and maintained the deepest downstream pool within the reference reach of 4.2 feet measured to bankfull. It is proposed in site 4 to modify the bridge to meet the following specifications which would also pertain to the upstream proposed bike/foot bridge:

- Bridges are to have no center pier. Currently there is a center pier on the lodge access bridge. The center pier reduces flood capacity, creates more of a flood damming effect, and reduces the pool formation potential.
- Bridge abutments are recommend to be set back 3 feet from bankfull. This means the width from abutment to abutment would be 6 feet wider than bankfull width.
- Bridges are recommended to have 1-2 foot free board above the 1996 flood elevation.

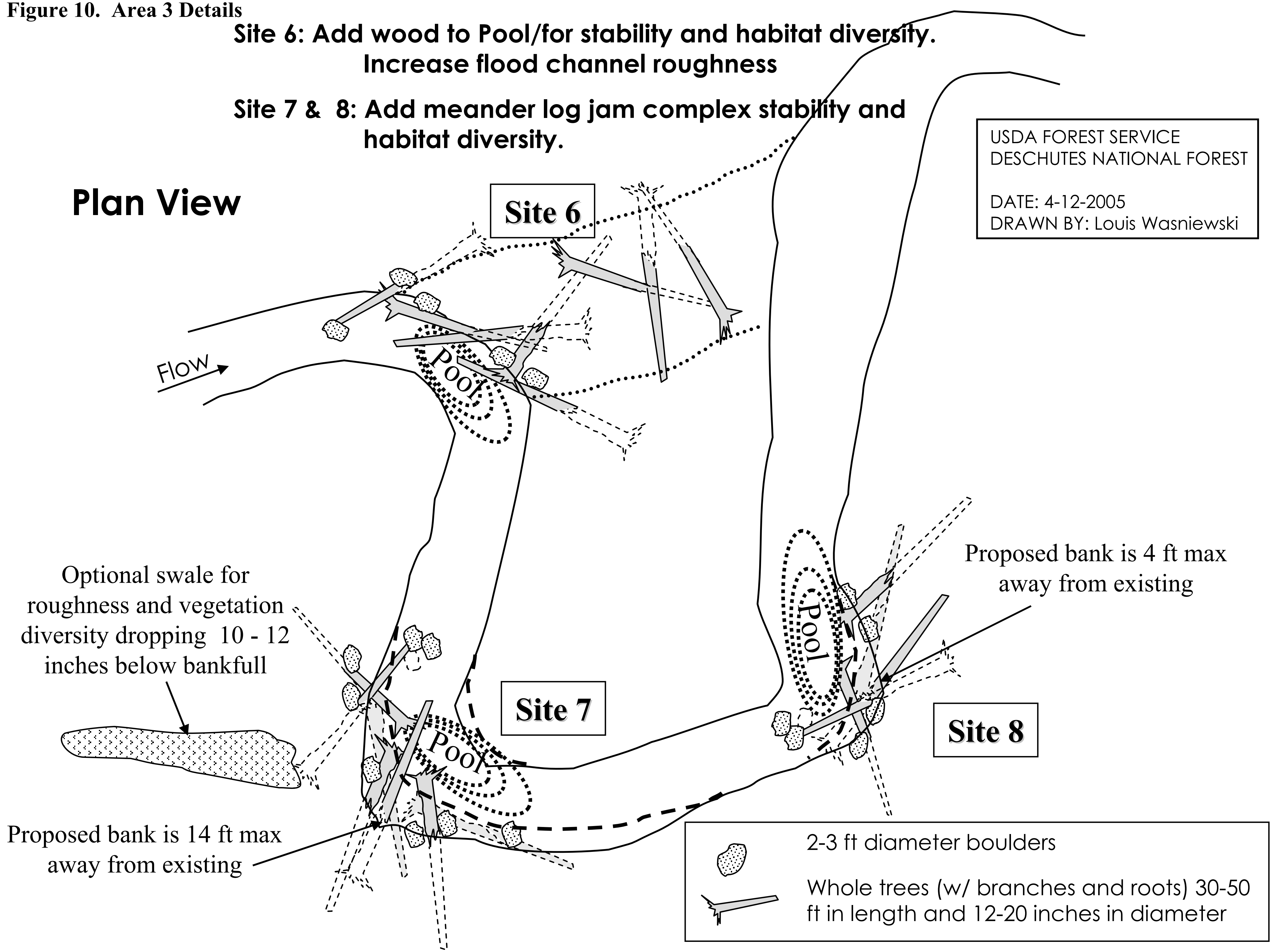
The current pond bypass channel (site 5) would be rehabilitated to a 22 foot wider floodplain / flood channel (Area 2 Details). Whole trees and rocks would be used to harden the flood channel to prevent recapture during large stream flow events. Soil form the created wetland would also be used as side channel fill in and around the rocks and trees. Buried trees would have roots or tops exposed about 1-2 feet above the surface to maintain a low and safe profile while creating a natural floodplain appearance. The structure above the lodge access bridge (site 4) would also act as a elevation control to prevent a headcut from moving up through the flood channel. This same structure would also help direct flood flows under the bridge protecting the abutments.

## *3.3 Area 3*

Area 3 contains the last three meanders (sites 6, 7, and 8) of the restoration reach as shown in Area 3 Details in figure 10. It predominantly focuses on creating bank stability and pool habitat complexity on the outside meanders that have signs of erosion. Site 6 does not have signs of erosion due to boulder rip-rap that was placed along the banks due to flooding and meander cutoff concerns. In order to increase pool complexity some of the rip-rap will be replaced with whole trees. Whole trees are also proposed to be placed in the floodplain to provide additional floodplain roughness and protection from a meander cutoff. These buried trees would have roots or tops exposed about 1-2 feet above the surface to maintain a low and safe profile while creating a natural floodplain appearance.

Site 7 and 8 are proposed to have log jam complexes constructed to restore the eroded banks. Site 7 and 8 would add a maximum of 14 and 4 foot of bank, respectively. Material excavated from the pool would be used to build the bank as well as additional material from the created wetland. Riparian plants would be planted in all three sites to provide the long-term root holding stability that natural occurs along this stream.

Figure 10.  Area 3 Details



## 4.0 Restoration Material

The proposed restoration is calling for whole trees, boulders, and gravel/cobble size river rock to be used in order achieve the restoration objectives. A preliminary estimate of the numbers and volumes of material have been made to assist the Upper Deschutes Watershed Council and partners to develop a preliminary cost estimate. Table 3 below shows the numbers and volumes by site as displayed in each of the three area details. Suggested stockpile locations are shown on Figure 11 along with the proposed disturbance zone.

**Table 3: Material list by site**

| Site | No. Boulders (2-3 ft. dia.) | No. Whole Trees (12-20 in. dia. & 30-50 ft in length) | Yards Gravel/Cobble River Rock |
|---|---|---|---|
| 1 | 35 | 4 | 2-4 |
| 2 | 8 | 5 | |
| 3 | 8 | 24 (includes pt bar) | 140 |
| 4 | 38 | 5 | |
| 5 | 9 | 8 | |
| 6 | 8 | 8 | |
| 7 | 8 | 8 | |
| 8 | 8 | 5 | |
| **Total** | **122*** | **67 (plus 10 extras = 77)** | **142-144** |

* On site material will probably provide around 20 boulders

## 5.0 Riparian Plantings

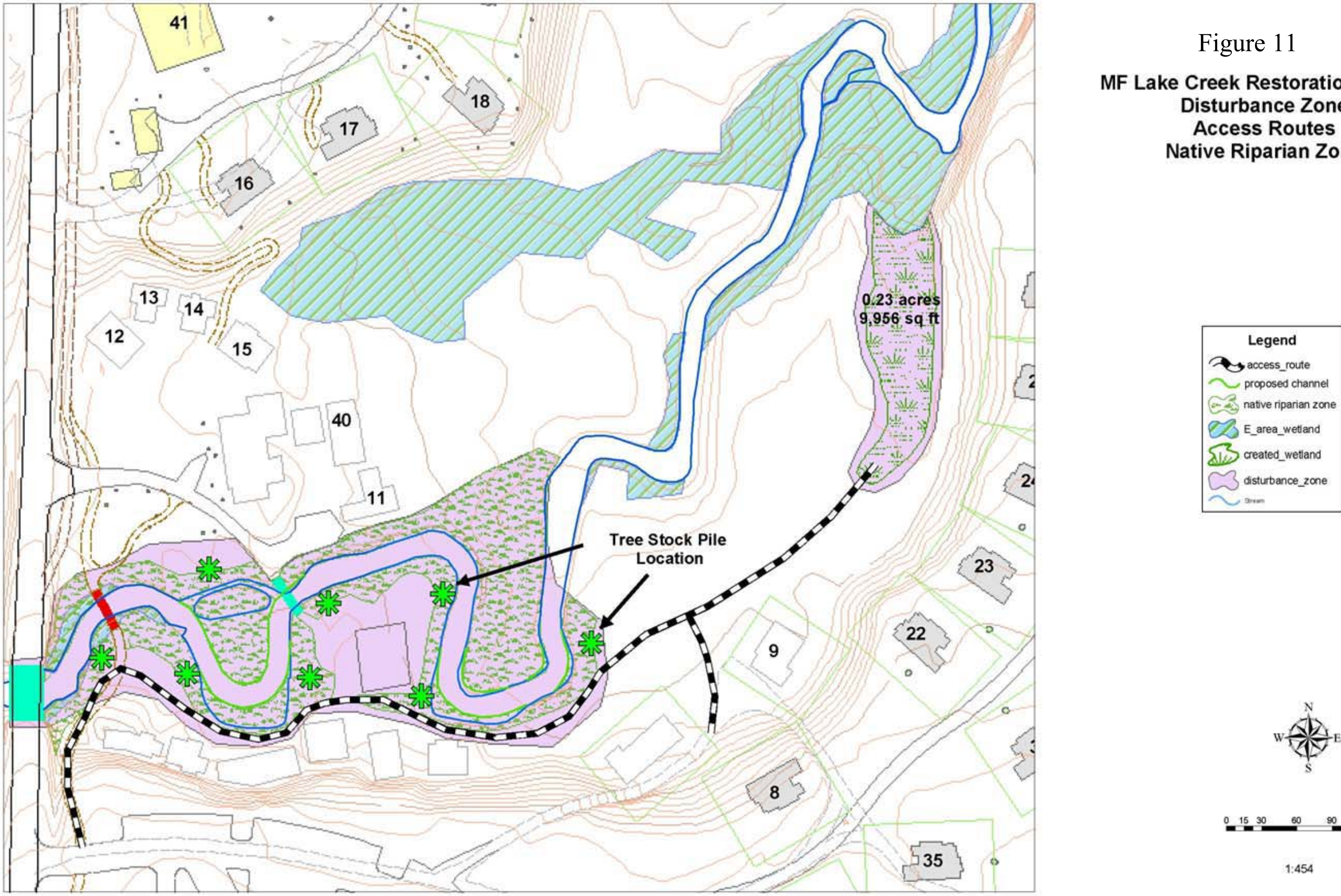
As discussed is Section 3.0, native riparian vegetation will be restored through the area shown on Figure 4. The species shown in Table 4 will be planted in clusters that mimic the natural distribution observed in other portions of the property. As needed, gaps will be left open to facilitate view corridors for cabin guests and river access for recreational users. During the establishment phase, cages and fencing will be used to protect plants from recreational and wildlife impacts.

**Table 4: Riparian Plant Materials**

| **Common Name** | ***Scientific Name*** | **Size** | **Quantity** |
|---|---|---|---|
| Dogwood | *Cornus sericea* | 5 gallon | 75 |
| Alder | *Alnus incana* | 5 gallon | 75 |
| Willow | *Salix sp.* | 5 gallon | 100 |
| Aspen | *Populus trichocarpa* | 5 gallon | 40 |
| Spirea | *Spirea douglasii* | 5 gallon | 40 |
| Nootka rose | *Rosa nutkana* | 2/5 gallon | 30 |
| Woods rose | *Rosa woodsii* | 2/5 gallon | 40 |
| Blue elderberry | *Sambucus cerulea* | 5 gallon | 40 |
| Misc. Currant | *Ribes spp.* | 5 gallon | 40 |
| Serviceberry | *Amelanchier alnifolia* | 5 gallon | 40 |
| Snowberry | *Symphoricarpos albus* | 2 gallon | 20 |
| Oceanspray | *Holodiscus sp.* | 5 gallon | 20 |
| Mockorange | *Philadelphus sp.* | 5 gallon | 20 |
| Ninebark | *Physocarpus capitatus* | 2 gallon | 20 |
| Sedge | *Carex spp.* | 6 cu in plugs | 4000 |
| | | | |
| **Totals** | | | **4600** |

Figure 11

**MF Lake Creek Restoration Project**
**Disturbance Zone**
**Access Routes**
**Native Riparian Zone**



# 6.0 References

Hardy, Thomas, Palavi Panja, and Dean Mathias. 2005. WinXSPRO A Channel Cross-Section Analyzer. Institue for Natural Systems Engineering, Utah Water Research Laboratory, and Utah State University. Modified from Earlier Versions Prepared by: Grant et. al. 1992 and WEST, Inc 1998. User Guide USDA Forest Service General Technical Report RMRS-GTR-147.

Rosgen, D.L. 1996. Applied River Morphology. Wildland Hydrology. Pagosa Springs, Colorado

USDA Forest Service. 1996. Metolius Watershed Analysis. Sisters Ranger District, Deschutes National Forest, Sisters, Oregon.

**Appendix A:**
**Morphological Characteristics of the existing and Proposed Channel with Reference Reach Data Restoration Site: 724 feet of MF Lake Creek nr Lake Creek Lodge**
**Reference Reach (Name of Stream & location): MF Lake Creek downstream of restoration reach**

| Variables | | Existing Channel | | Proposed/ Reference Reach | |
|---|---|---|---|---|---|
| | | Mean | Range | Mean | Range |
| 1 | Stream Type | $C_4$ ($E_4$) | | $C_4$ ($E_4$) | |
| 2 | Bankfull width ($W_{bkf}$) | 29.6 | 23-37 | 20.05 | 19.1-21 |
| 3 | Bankfull mean depth ($d_{bkf}$) | 1.15 | 1-1.3 | 1.15 | 1-1.3 |
| 4 | Width/Depth ratio ($W_{dkf}/d_{bkf}$) | 26 | 18.7-30.7 | 18 | 15.1-21 |
| 5 | Bankfull X-sect. Area ($A_{bkf}$) ($ft^2$) | 34 | 29-44.6 | 22.5 | 21-24.1 |
| 6 | Bankfull mean velocity ($v_{bkf}$) (ft/s) | 2.2 | | 4.03 | |
| 7 | Bankfull discharge, cfs ($Q_{bkf}$) | 90.8 | | 90.8 | |
| 8 | Estimated 1996 Flood flows, cfs | 405-490 | | 405-490 | |
| 9 | Estimated 1996 Flood X-sect. Area | 222 | | 222 | |
| 10 | Bankfull Max. depth ($d_{max}$) (ft) | | | 1.7 | 1.6-1.8 |
| 11 | Width of flood prone area ($W_{fpa}$) (ft) | 250 | 166-400 | 250 | 200-400 |
| 12 | Entrenchment ratio ($W_{fpa}/W_{bkf}$) | 11.4 | | 12.5 | 8.7-19 |
| 13 | Valley Width (ft) | | 200-440 | | 200-440 |
| 14 | Meander length ($L_m$) | 198 | 184-207 | 195 | 140-253 |
| 15 | Radius of curvature ($R_c$) (ft) | 28.9 | 16-48 | 33.9 | 20-48 |
| 16 | Belt width ($W_{blt}$) (ft) | 134 | 112-166 | 112 | 53-173 |
| 17 | Sinuosity (str. Length/valley dist.(k)) | 1.85 | | 1.36 | |
| 18 | Valley slope (ft/ft) | 0.008 | | 0.008 | |
| 19 | Average slope ($S_{avg}=S_{valley/k}$) (ft/ft) | 0.005 | | 0.0055 | |
| 20 | Max pool depth ($d_{pool}$) (ft) | | | 3.7 | 2.9-4.2 |
| 21 | Pool width ($W_{pool}$) (ft) | | | 19.5 | 18-21 |
| 22 | Pool Length (ft) | | | 26.2 | 16.5-31.1 |
| 23 | Pool to pool spacing (p-p) | | | 79.7 | 50.9-123.3 |
| 24 | Riffle slope ($S_{riff}$) (ft/ft) | | | 0.0028 | 0.01-0.059 |
| 25 | Riffle Length (ft) | | | 28.4 | 13.7-41.0 |
| 26 | Run slope (ft/ft) | | | 0.078 | 0.032-0.125 |

| | Variables | Existing Channel Mean | Existing Channel Range | Proposed/ Reference Reach Mean | Proposed/ Reference Reach Range |
|---|---|---|---|---|---|
| **27** | Run Length (ft) | | | 13.5 | 7-24.5 |
| **28** | Glide Slope (ft/ft) | | | -0.0355 | -0.0014--0.0828 |
| **29** | Glide Length (ft) | | | 28 | 18.8-51.8 |
| | | | | | |
| **Particle Size Distribution of Channel Material (mm)** | | | | | |
| **30** | $D_{16}$ | 6.7 | | 20.4 | |
| **31** | $D_{35}$ | 38.57 | | 38.05 | |
| **32** | $D_{50}$ | 55.2 | | 51.8 | |
| **33** | $D_{84}$ | 96 | | 88 | |
| **34** | $D_{95}$ | 123 | | 130 | |