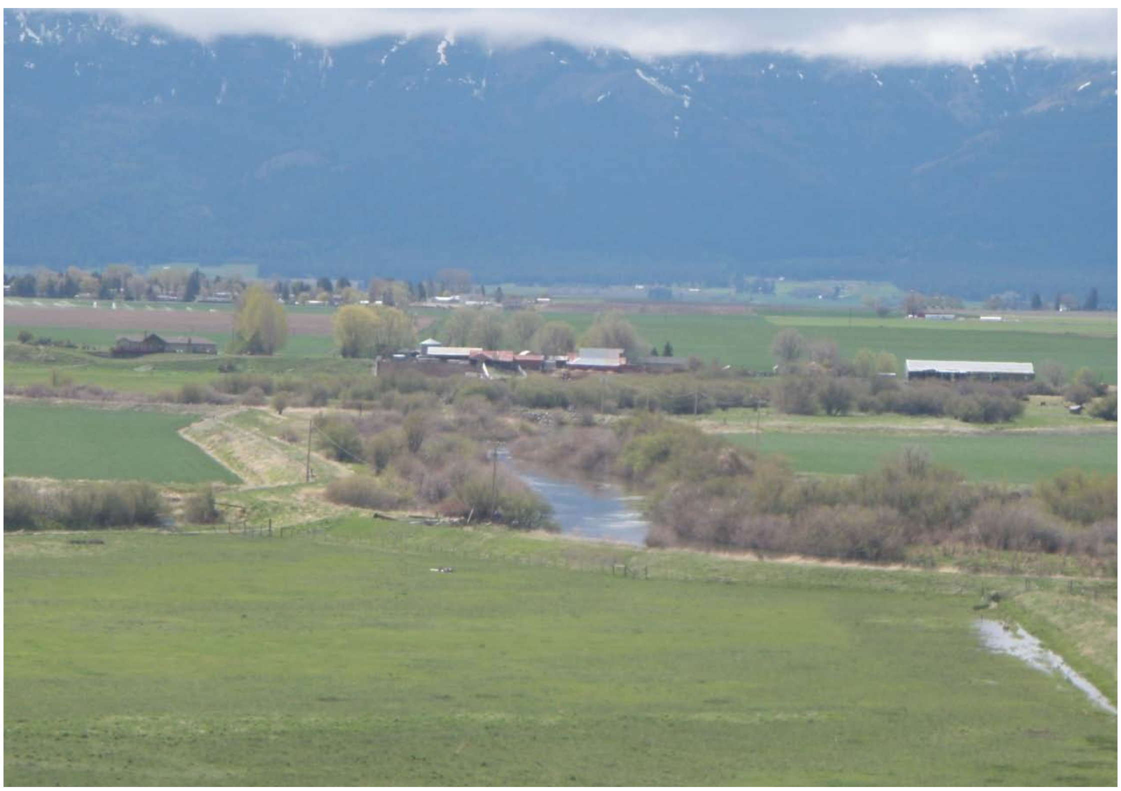
# APPENDIX D – HYDRAULICS

RECLAMATION
*Managing Water in the West*

# Catherine Creek Tributary Assessment Hydraulics Appendix

**Grande Ronde Project, OR**
**Pacific Northwest Region**
**SRH Report 2012-05**



**U.S. Department of the Interior**
**Bureau of Reclamation**

**December 2011**

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Photo taken on Grande Ronde River near station 25,265 on April 27, 2010.

**U.S. Department of the Interior**
**Bureau of Reclamation**

**December 2011**

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## Grande Ronde Project, OR
## Pacific Northwest Region
## SRH Report 2012-05

Peer Review Certification: This document has been peer reviewed per guidelines established by the Technical Service Center and is believed to be in accordance with the service agreement and standards of the profession.

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# Executive Summary

Reclamation's Sedimentation and River Hydraulics Group at the Technical Service Center developed a one dimensional (1D) hydraulic model to analyze the Catherine Creek Assessment area hydraulic conditions during flood flows. Approximately 60 miles of channel were modeled including a portion of Catherine Creek, Grande Ronde River, and State Ditch.

A steady-flow model was developed to examine the existing hydraulic conditions of Catherine Creek. Steady flow model input consists of a channel geometry, infrastructure dimensions and operating conditions, input discharge, a downstream boundary condition, and roughness values. Terrain models were developed as topographic input to the hydraulic model based on LiDAR data above wetted channel areas and bathymetric surveys within the wetted channel areas. A total of 803 cross-section lines spaced approximately 450 feet apart were applied to cover the 60 river miles modeled across the three streams. Levee elements were assigned manually in HEC-RAS. Twenty-nine bridges and nine diversions were included in the HEC-RAS model.

Thirteen model flood flow discharges were simulated in the HEC-RAS model, including the 1.5-, 2-, 10-, 50-, and 100-year flood events. The downstream boundary was set to a normal depth slope of 0.3%. Roughness values were determined using a combination of pebble counts, vegetation and agricultural land use, and professional judgment. The model was compared with measured data from June, 2010 and October, 2010.  Comparison between the measured and modeled water surface were variable; Manning's roughness was not adjusted in the model but sensitivity analyses were performed. Several limitations exist with the current 1D model including levees and levee overtopping, missing low flow channel data, and the extent of the LiDAR data.

Four reaches on Catherine Creek were analyzed for the present conditions. Reach 1 (RM 0 - 22.5) can be described as a wide, unconfined valley with an average slope of approximately 0.006%. The channel capacity of the reach is highly variable, with most locations exhibiting bankfull conditions at flows between the 1.5- to 2-year discharges. Average in-channel velocities are very low and are typically around 1.3 ft/s at discharges with recurrence intervals between 1.5 and 100 years. Similarly, shear stresses are very low, indicating the potential to transport only sand sized sediment under flood conditions. Levees are present along most of the reach, limiting floodplain access. In most locations, levees are overtopped at flows equal to or less than the 10-year discharge. There are four disconnected oxbows (RM 10.2, 14, 16.3, and 17.5) in this reach where the levee is overtopped at less than a five year flood. The most notable hydraulic controls in this reach are Elmer Dam at RM 13.1 and the Old Grande Ronde River, which is

located in the upstream extent of the reach at RM 22.5. Bridges within the reach, including Booth Lane, Market Lane, and Highway 237, exert local controls at flows exceeding the 100-year discharge but do not appear significant at lower discharges.

Reach 2 is also a wide, unconfined valley with an average slope of approximately 0.04%. A noteworthy break in slope occurs at the confluence of Ladd Creek near RM 31.4, which coincides with changes in hydraulic properties. Channel capacity throughout the reach is variable, with bankfull conditions occurring in most cross sections around 1.5 to 2-year discharges. In-channel velocities below Ladd Creek are generally around 1.7 ft/s. Upstream from Ladd Creek, velocity increases with discharge and averages 3.1 ft/s. Shear stresses in Reach 2 are slightly higher than those in Reach 1, with reach averages ranging from approximately 0.10 to 0.17 $lb/ft^2$ for discharges between the 1.5- and 100-year recurrence intervals. Levees within Reach 2 are overtopped less frequently than Reach 1 and only 50% of the cross section levees are overtopped at the 100-year discharge. Notable hydraulic controls in this reach include Upper and Lower Davis Dams, Ladd Creek, Wilkinson Lane Bridge, and a Beaver Dam located at RM 24.9. Similar to Reach 1, most bridges in the reach impart some hydraulic control at the 100-year discharge, but their influence appears to be localized.

The downstream end of Reach 3 (RM 37.2 - 40.8) and the upstream end of Reach 2 act as a hydraulic transition zone at the base of the Catherine Creek alluvial fan. The confinement of the valley within Reach 3 increases from downstream to upstream. Average bed slope within this reach is 0.59%. Channel capacity in this reach is high compared to downstream Reach 1 and 2 and also compared with upstream Reach 4. Over 60% of cross sections require a flow of 100-year recurrence interval or greater to exceed the channel banks. Reach-averaged channel velocities range from 4.6 ft/sec for the 1.5 year flood to 6.6 ft/sec for the 100-year flood. Shear stresses in the reach range from about 1 $lb/ft^2$ for a 1.5-year discharge to 1.75 $lb/ft^2$ for a 100-year discharge, indicating some potential to transport gravels at higher discharges. Less than 30% of cross sections with levees indicate levee overtopping for flows less than a 500-year discharge. Several of the bridges, such as Main Street Bridge at RM 40 exert hydraulic control on the larger flood flows.

Reach 4 (RM 40.8 – 45.8) is an unconfined valley reach with an average channel slope of 0.83%. The channel capacity for most locations of the reach is between a 5 and 10-year discharge. The reach averaged velocity in Reach 4 is approximately 4.8 ft/sec for the 1.5year discharge and 6.7 ft/sec for the 100-year discharge. Average in-channel shear stresses in the reach range between 1.1 $lb/ft^2$ for a 1.5-year discharge to about 1.8 $lb/ft^2$ for a 100-year discharge. Similar to Reach 3, levees present in Reach 4 typically require a discharge of 500-year recurrence interval to overtop. Some localized overtopping of less formidable levees may occur during more frequent floods. The most significant hydraulic control within the reach is the Medical Springs D2 diversion structure.

Within the reaches simulated, Grande Ronde River and Reaches 1 and 2 of Catherine Creek have experienced the greatest degree of impact to flood processes. Conversion of floodplain to agricultural land use has resulted in greatly reduced access to high flow habitat, including inundated floodplains and side channels. Constriction of flows between levees has also likely resulted in increased velocities within the channel banks and reduced high flow refugia along the channel margins during more frequent discharges. Overbank areas that do remain accessible between the levees are expected to have reduced complexity compared with unimpaired conditions. Within Reaches 3 and 4 of Catherine Creek, the greatest impacts to river processes results from the presence of low-head diversion structures and bridges. However, the impacts of the structures on floodplain access are less severe since the floodplain extent is much narrower and slope is higher when compared with downstream reaches.

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# 1. Introduction

## 1.1. Purpose

An assessment is being conducted by Bureau of Reclamation's (Reclamation) Pacific Northwest Regional Office (PNRO) to define the existing habitat conditions, limiting factors, present use and habitat potential within the Catherine Creek Tributary Assessment Area for Endangered Species Act (ESA) listed salmonids such that project locations can be identified and prioritized for implementation. To help meet the assessment objective, Reclamation's Sedimentation and River Hydraulics Group at the Technical Service Center developed a one dimensional (1D) hydraulic model. The model was used to analyze the Catherine Creek Assessment area hydraulic conditions during flood flows.

### 1.1.1. Objectives

The objectives of the model were to:

1. Determine what areas are being inundated for discharges with recurrence intervals ranging between 1.05 to 500 years.
2. Evaluate flood storage, water surface elevations, velocities, and shear stresses.
3. Qualitatively compare with historic conditions.
4. Investigate the flow and stage at which inundation of each disconnected oxbow occurs.

## 1.2. Location

The Grande Ronde River Basin drains the Blue and Wallowa Mountains. The Grande Ronde River enters Grande Ronde Valley from the west and exits towards the north. Catherine Creek is a major tributary to the Grande Ronde River and enters Grande Ronde Valley from the south and combines with Grande Ronde River at the end of a reach known as State Ditch. Upstream of Union, OR, Catherine Creek is a mountainous stream with a narrow valley and slopes approaching 1%, while downstream of Union the river meanders across a wide valley with a nearly flat slope of less than 0.006%.

Approximately 60 miles of channel were modeled (see Figure 1). The model includes a substantial portion of Catherine Creek and a reach of the Grande Ronde River which contains State Ditch. On Catherine Creek, the upstream point of the model is at river mile (RM) 46.6 near Brinker Creek Road Bridge and the downstream point is the confluence with State Ditch at RM 0. The modeled section of State Ditch is from Peach Road Bridge to the confluence with Catherine Creek, a distance of approximately 5.5 miles. Downstream of the confluence of Catherine Creek and State Ditch, 12.6 miles of the Grande Ronde River are modeled. The downstream extent of the model is the canyon known as Rhinehart Gap.

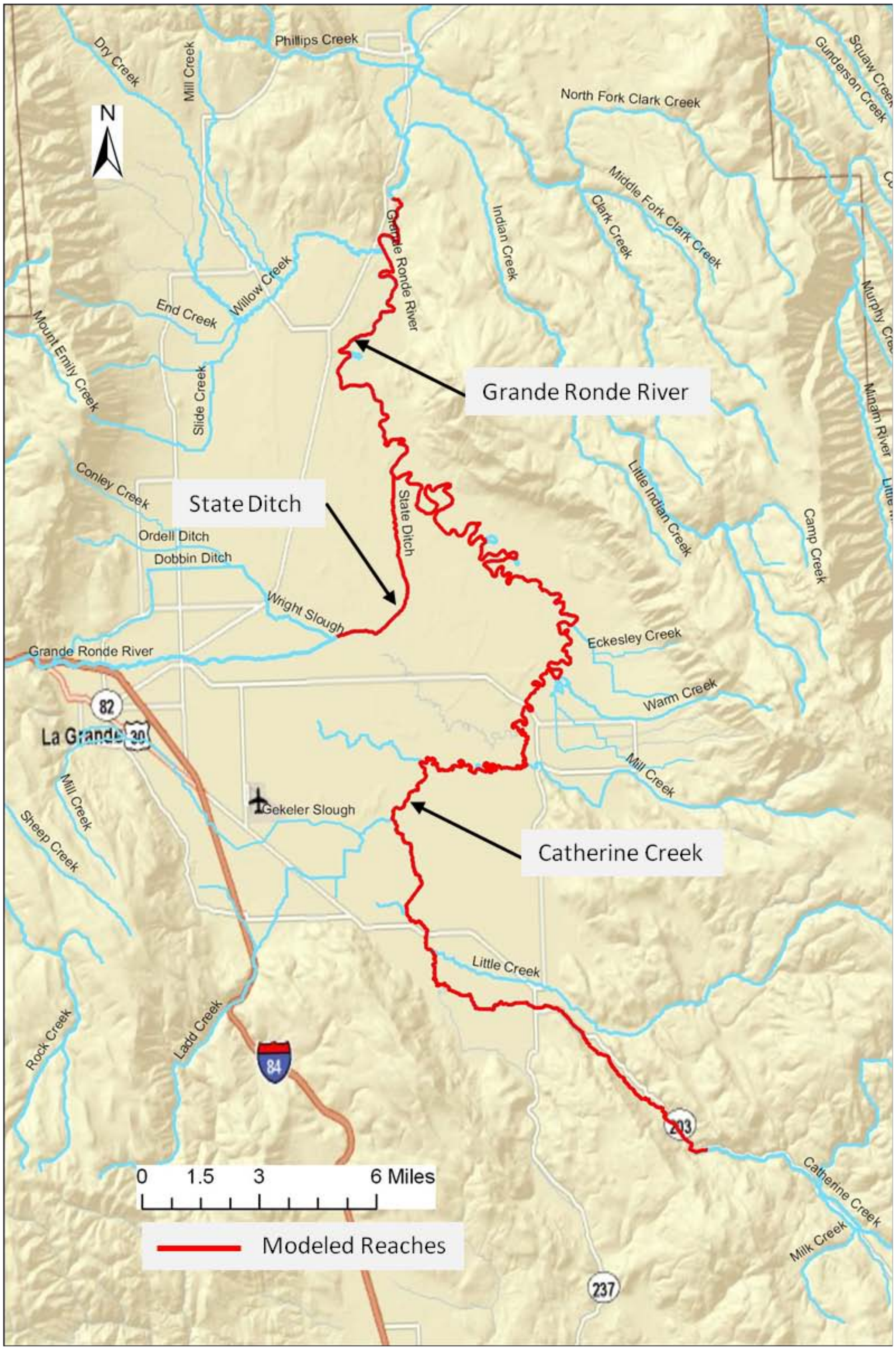


Figure 1. Overview map of Catherine Creek and Grande Ronde River which includes State Ditch.

# 2. Historic Conditions

European settlement began in the Grande Ronde Basin in the mid-1800s. Prior to that point, several Native American tribes, Nez, Perce, and Umatilla, lived in the basin (Duncan 1998). In 1846, a group of Europeans described the River:

*"Grand Round River, which comes in from the West, runs nearly to the middle of the plain in several channels, joins with another branch, bears away to the left and leaves the plain at its Northern extremity, through a now gap…Numerous small creeks and rivulets, run through all parts of the valley, from the surrounding Mountains"* (Beckham 1995)

Others that visited the valley during this time period noted the rich soil and good grass in the valley. From 1811-1908, the Grande Ronde River was described as cold and clear, offering habitat for salmon, crayfish, and beavers. In the Grande Ronde Valley, dense vegetation (cottonwood, hawthorn alder, etc.) was present shading the river channel (Beckham 1995). It is assumed that Catherine Creek downstream of RM 37 would have similar characteristics to Grande Ronde River in the Grande Ronde Valley, where river and valley characteristic are similar.

Once Europeans arrived, the Basin was quickly altered. In 1869, a minor pilot channel was constructed along State Ditch (USACE 1957). The channel was initially 6 feet wide and 3 feet deep (Duncan 1998). The purpose of the channel was to reduce annual spring flooding; the ditch replaced 33 miles of river with 4 miles of straightened channel. Other projects were also occurring to drain wetlands. Tule Lake was drained (approximately 2,300 acres of wetland) in 1870 and Catherine Creek was relocated since it originally drained into Tule Lake (Beckham 1995). Irrigation companies were documented as early as 1904. Later projects were also implemented to protect property from flooding.

*"Local farmers have in several cases excavated channel cut-offs across narrow reaches of stream meanders, and constructed low earth levees."* (USACE 1957)

In addition to stream channelization changes, other land use changes were also occurring, primarily mining, livestock grazing, road building, and timber harvest. Mining has occurred in the headwaters of Grande Ronde River since 1870, and dredge mining was extensive in the early 1900s (McIntosh, 1994). Livestock have been grazing the Grande Ronde River basin since the 1880s. From 1911 to 1990 a decline in domestic livestock occurred mainly due to the sheep industry collapse. However, elk grazing has increased, leading to a similar grazing intensity as in1945 (McIntosh, 1994). Logging activities began in the 1880s as well, and has increased since 1941. Road construction began in the 1920s, and has increased over time (McIntosh, 1994).

The land use changes described above directly and indirectly contributed to the condition of Catherine Creek and Grande Ronde River. Unfortunately, there is little more than anecdotal information to describe the Basin from the late 1800s and early 1900s. In 1941, a Bureau of Fisheries survey collected information on pools and substrate composition of the Grande Ronde River and Catherine Creek. In 1990, portions of the streams were resurveyed. Based on the repeated surveys, the total pools/km has declined by 78% in the Grande Ronde River and 67% on Catherine Creek (McIntosh 1994). The frequency of large pools also dropped 73% and 61%, respectively. Stream flow and discharge records were also examined and showed an increase in base discharge at the gage near La Grande, OR and near Union, OR (McIntosh 1994). Based on the analysis, the average timing of peak flows also shifted to earlier in the year at the La Grande gage from April 10th to March 11$^{th}$. Changes in base discharge and peak discharge are attributed to timber harvest practices that have reduced evapotranspiration (McIntosh 1994). The cleared areas have greater snowfall accumulations as well as faster snowmelt.

In the present-day Grande Ronde Basin, the summers are typically hot and dry while the winters are cold and wet. Peak flows occur in April or May, while August and September are low flow months (UGRRSLAWQAC 1999). Irrigation withdrawals have reduced low flows in the summer months. Below Union, flow reductions due to water withdrawal are about 25% in June and approximately 50% by mid July (Nowak 2004).

The amount of residence time of water in the valley and the mechanism by which water is transported downstream appears to have changed from the early European settlement days. As stated earlier, multiple channels and creeks historically ran across the valley.

*"During presettlement times an estimate 72,000 acres in the middle valley were subject to flooding; up to 60 percent of the valley flood might be inundated for as long as five months. In the 1894 flood, 50,000 acres were covered with floodwaters; in the 1949 flooding, only 5,900 acres were inundated."* (Duncan 1998).

Currently, most of the water is transported through a few channels (Catherine Creek and State Ditch), and most of the valley is not inundated throughout the year.

In 1971, the United States Army Corps of Engineers (USACE) evaluated channel capacity on Catherine Creek. Upstream of Union, the flow on Catherine Creek would get out of bank at approximately 1,000 $ft^3$/sec. Through the town of Union, the capacity of Catherine Creek was 800 to 1,000 $ft^3$/sec. It was noted that in the past this capacity was as little as 600 $ft^3$/sec. From the Highway #203 bridge to the Old Grande Ronde confluence, the capacity of Catherine Creek was around 600 $ft^3$/sec. From the Old Grande Ronde River confluence to the confluence with State Ditch, the capacity ranged from 600 to 1,000 $ft^3$/sec. Below State Ditch, the capacity of Grande Ronde River was 1,000 to 2,000 $ft^3$/sec.

During the pre-settlement era, it appears that a large portion of the Grande Ronde Valley was inundated and could be classified as wetlands or wet meadow. After settlement, anthropogenic influences, such as stream channelization, levee development, and agriculture, changed the valley into a few channels that are locked in place where land on both banks has been protected from floods. The channelization has reduced the total length of the river in locations such as State Ditch. A loss of pools from the 1940s to the 1990s has been documented, and riparian area along the channel has declined. Peak spring runoff is occurring earlier than in the 1940s, potentially due to timber harvest, and the summer months are characterized by reduced low flows due to irrigation withdrawals.

# 3. Methods

A steady-flow model was developed to examine the existing hydraulic conditions of Catherine Creek from RM 0 to RM 46.6. Steady flow model input consists of a channel geometry, infrastructure dimensions and operating conditions, input discharge, a downstream boundary condition, roughness values, expansion and contraction coefficients, and computation parameters. Each model input is described in detail below. The hydraulic model was simulated as a steady-state subcritical flow model.

## 3.1 Model Geometry

### 3.1.1 Development of Topographic Data

Topographic data were used to generate cross sections for the model in HEC-RAS. Terrain models were developed for topographic input to the model based on LiDAR data above the wetted channel perimeter and bathymetric surveys within the wetted channel. LiDAR were acquired in four geographic areas within the tributary assessment area. In October 2007, LiDAR data were collected along the Grande Ronde River and State Ditch (combined into a geographic area referred to as “Willow”) and also along Middle Catherine Creek from River Mile (RM) 23.7 to 42.5 (Watershed Sciences, 2007). In 2009, LiDAR were collected along Upper Catherine Creek from RM 42.5 to 52 and Lower Catherine Creek from RM 0 to 23.7 (Watershed Sciences, 2009).

Because bare-earth LiDAR cannot penetrate the water surface and adequately represent bed elevations in the wetted area of the channel, bathymetric surveys were conducted. Surveys were conducted between October 28th and November 2, 2010 along 8 miles of State Ditch upstream of the confluence with Catherine Creek, along approximately 11.7 miles of the Grande Ronde River downstream from the State Ditch confluence, and from RM 0 to 36.5 along Catherine Creek. Two sections of Catherine Creek, from RM 32 to 34.5 and from RM 27 to RM 30, could not be accessed to measure bathymetry.

The bathymetric survey data were collected using a Sontek River Surveyor M9 Acoustic Doppler Profiler (ADP). Horizontal and vertical position information for the survey was achieved by linking the ADP to a Trimble R8 GPS system operating with a Real Time Kinematic (RTK) survey. Horizontal and vertical accuracies are typically within +/- 0.5 feet.

The GPS and ADP were mounted on an aluminum frame raft with inflatable pontoons and connected to a field computer, which processes information from both instruments. The GPS receiver on the raft was mounted in close proximity to the ADP mounting pole and was set to export the GGA NMEA data string. This data string exports the GPS position data directly to the computer. During the boat surveys, GPS observations were taken to measure the water surface elevation every 20 feet. These measurements were later used to assign a water surface elevation to each ADP measurement.

Data collected in the data controller (on the boat) and in the base station receiver were downloaded to Trimble Business Center (TBC version 2.2). Data logged at the base stations were submitted to OPUS (http://www.ngs.noaa.gov/OPUS/) for post processing. The control point coordinates were adjusted based on these results where necessary. Horizontal positions were reported in NAD 83 State Plane Oregon North International Feet; and vertical positions were reported in NAVD 88 ft. Elevations were derived from GEOID 09. After these adjustments were made, the water surface observations were exported in shapefile format for further use in ArcMap (Version 9.3.1, ESRI, Redlands, CA).

Once the ADP bathymetry data and the GPS water surface elevation data were imported into ArcMap, bed elevations for the ADP measurements were determined. The GPS water surface elevations were used to create a water surface Triangulated Irregular Network (TIN). Using the Functional Surface Tool in 3D analyst, the ADP bathymetry points were assigned a water surface elevation based on each point's position relative to the water surface TIN. Once this process was completed, fields for horizontal position (x,y), water surface elevation, and bed elevation were created and populated in the attribute table of the new 3D feature class.

In addition, the Pacific Northwest Regional Office conducted detailed RTK topographic surveys within the channel from RM 36.8 to 37.9. No additional processing of these data points was required to extrapolate ground elevations. These surveys were combined with the boat surveys for development of the in-channel surface.

### 3.1.2 Combining LiDAR and survey data

Several processing steps were necessary to combine the LiDAR data with the bathymetry data. First, a terrain surface of just LiDAR was developed for each of the 4 geographic areas (Willow, Lower Catherine, Middle Catherine, Upper Catherine). Since no topographic survey data were collected in Upper Catherine Creek, the final terrain model upstream of RM 42.5 consists only of the processed LiDAR data.

The next task required delineating polygons of the wetted area in ArcMap using a hillshade of the LiDAR and rectified aerial photographs. The LiDAR data were removed from this area within each terrain model if survey data were available to better represent the in-channel surface. This first required converting several LiDAR tiles from multi-point features to single part features, selecting the points intersecting the wetted channel polygons, and deleting the points from the feature class. Within the polygons where in-channel data were collected, the Spline With Barriers tool within ArcMap was used to rasterize the channel surface. Raster cell sizes ranged between 3 and 5 feet depending on the width of the channel and the necessary cell size to represent the width of the channel. These rasterized cells were converted to points. To avoid triangulation issues adjacent to the wetted channel polygons, points located within one cell size (3-5 ft) from the wetted channel polygon were deleted.

Within the two sections of Catherine Creek (from RM 32 to 34.5 and from RM 27 to RM 30) where bathymetry was not collected, channel data were developed by delineating a line along the channel and linearly interpolating elevations along the line based on upstream and downstream surveyed elevations. The Spline with Barriers technique was applied in this area using the interpolated points to develop the rasterized surface as described previously. Although these linearly interpolated data poorly represent the bed through these reaches, they are the best method for representing the bed elevations within the scope of this project.

Comparison of the LiDAR data within the channel with the surveyed data just upstream illustrated the need to lower the bed elevations in these reaches below the elevations captured by the LiDAR (Figure 2). Additional survey data should be collected in these reaches for refined future analyses.

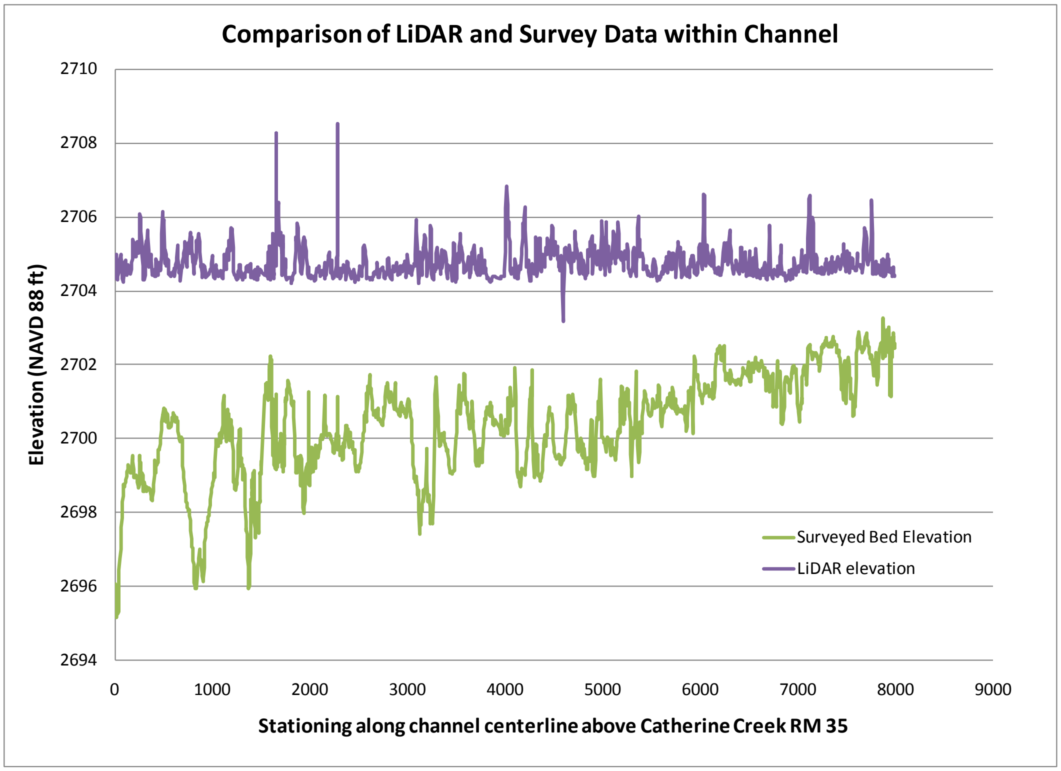


Figure 2. Comparison of LiDAR data within the channel and surveyed bed elevations.

The downstream boundary of the hydraulic model is approximately 6,000 ft downstream of the coverage of the bathymetric surveys. Within this section of the model, the bed elevations are only represented by LiDAR data. Additional surveys will be needed in this reach for refined future analyses. Manipulation of the bed elevations at this downstream end are discussed in Section 3.1.6. Sensitivity analyses were conducted to evaluate the longitudinal extent of the downstream boundary condition and are also discussed in Section 3.1.6.

Final terrain surfaces for the State Ditch, Grande Ronde River below State Ditch, Lower Catherine Creek, and Middle Catherine Creek were developed using the points within the channel developed from the spline with barriers models, the polygons delineating wetted channel areas (soft edges), and the LiDAR data outside of the wetted channel areas.

### 3.1.3 Cross Section Development

HEC-GeoRAS is a custom interface between HEC-RAS and Geographic Information System (GIS) that provides tools to process geospatial data for use with HEC-RAS. The HEC-GeoRAS program (version 4.2.93 for ArcGIS 9.3) was utilized to delineate cross sections, banklines, flowpaths, and a centerline along the modeled reaches. A total of 803 cross-section lines spaced approximately 450 feet apart were applied to cover the 60 river miles modeled across the three streams. Figure 3 shows a portion of the cross sections delineated upstream of Union, OR near RM 44. Figure 4 shows a portion of the cross sections delineated on Catherine Creek near RM 10. A module within HEC-GeoRas was then utilized to convert all of the delineated line work and topographic information into a HEC-RAS format. The stream channel is extremely sinuous and the dominant flow paths may be different at bankfull and flood flows. There was an attempt to represent the main channel flow paths and overbank flow paths as accurately as possible. However, because of the complex stream channel alignment, this is difficult and it may be necessary to alter the over bank representation to better represent flood flows.

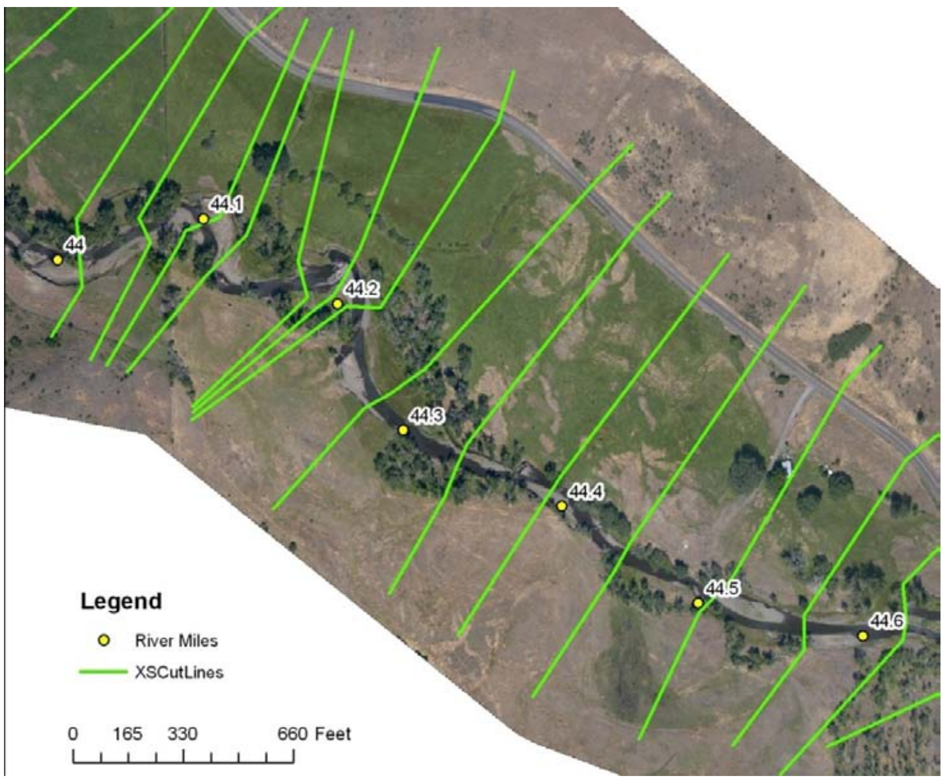

Figure 3. Example portion of upper Catherine Creek with delineated cross sections.

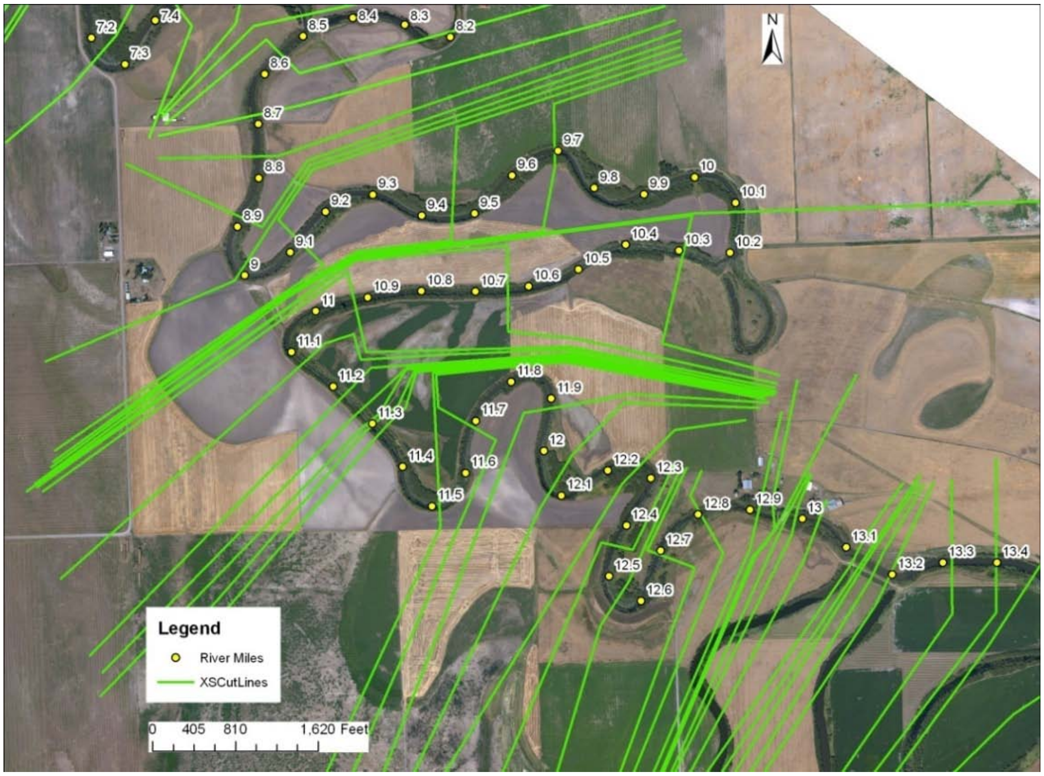

Figure 4. Example portion of lower Catherine Creek with delineated cross sections.

Banklines were manually adjusted where necessary in HEC-RAS to ensure that the top of bank was captured. Levee elements were also assigned manually in HEC-RAS. Levee elements do not allow flow to be conveyed outside of the levee station until the levee elevation is exceeded (Brunner 2008). They were assigned at bank locations or manmade levees as appropriate. Although multiple levees were often present along a single cross section, HEC-RAS does not allow the assignment of more than one levee on each side of the channel. Therefore, the closest, visibly unbreached levee to the main channel was assigned. More detailed explanation of the limitations of the levee assignments and potential impacts to model results are provided in Section 5.1.

### 3.1.4 Infrastructure

Anderson Perry and Associates, Inc. (AP) surveyed 52 structures in the Grande River Basin in 2010 including four river cross sections at each structure. Twenty-nine bridges and nine diversions were included in the HEC-RAS model (Table 1). Each of these structures is discussed in more detail below. The bridge structure dimensions from the AP survey were manually input to the HEC-RAS model. LiDAR data were utilized to incorporate the bridge deck and road surface information when necessary. For the diversion structures, only the grade control features were incorporated into the model geometry as weirs. Fish ladders, gates, and flow diversions were not included in the model.

Table 1. Bridge and diversion structures included in the HEC-RAS model.

| Name | River | Model Station (ft) | River Mile (mi) |
|---|---|---|---|
| Brinker Creek Road Bridge | Catherine Creek | 246853.4 | 46.5 |
| Hwy 203 #B1 (Private Bridge) | | 241903.4 | 45.6 |
| Medical Springs #D2 | | 225243.4 | 42.5 |
| Hwy 203 #B2 (Private Bridge) | | 223943.1 | 42.3 |
| Medical Springs #D3 | | 223510.4 | 42.2 |
| Swackhammer Diversion | | 215110.1 | 40.7 |
| Hwy 203 #B3 | | 215421.6 | 40.6 |
| Bellwood Bridge | | 212546.1 | 40.1 |
| Main St. Bridge | | 212028.1 | 40.0 |
| Godley Diversion | | 211803.1 | 39.9 |
| Townley Dobbin Diversion | | 211140.1 | 39.8 |
| 5TH St Bridge | | 210396.1 | 39.7 |
| Hempe-Hutchinson Diversion | | 209911.1 | 39.6 |
| 10TH St. Bridge | | 209060.1 | 39.5 |
| Pond Slough (Private Bridge) | | 199263.8 | 37.6 |
| Miller Bridge | | 192511.1 | 36.5 |
| HWY 203 #B4 Bridge | | 186024.7 | 35.3 |
| Upper Davis Diversion | | 184402.1 | 35.0 |
| Lower Davis Bridge | | 181367.1 | 34.4 |
| Lower Davis Diversion | | 181252.4 | 34.4 |
| Woodruff Bridge | | 178262.1 | 33.8 |
| Wilkinson Bridge #1 | | 168313.1 | 32.0 |
| Godley Lane Bridge #1 | | 139058.1 | 26.6 |
| Gekeler Bridge #1 | | 123575 | 23.7 |
| HWY 237 Bridge #1 | | 110275 | 21.3 |
| Booth Lane Bridge #1 | | 78300 | 15.3 |
| Elmer Dam | | 66934 | 13.1 |
| Elmers Bridge #1 | | 65975 | 13.0 |
| Elmer Bridge #2 | | 56900 | 11.3 |
| Market Lane Bridge #1 | | 34985 | 6.5 |
| Alicel Bridge #1 | Grande Ronde River | 66200 | NA |
| McKennon Lane Bridge | | 49950 | NA |
| Hull Road Bridge | | 34700 | NA |
| Striker Lane Bridge | | 29300 | NA |
| Rinehart Lane Bridge | | 6800 | NA |
| Booth Ln Bridge #2 | State Ditch | 17350 | NA |
| Market Lane Bridge #2 | | 9100 | NA |
| Ruckman Lane Bridge | | 5220 | NA |

Model cross sections were delineated in HEC-GeoRAS along each field surveyed cross section location upstream and downstream of bridges and diversions. The cross section channel topographic information initially derived from the LiDAR terrain model was replaced in HEC-RAS within the channel by the surveyed information. Figure 5 shows an example of a surveyed cross section and its replacement in the HEC-RAS model. The differences between the terrain model and the surveyed cross sections are considered small outside of the channel, which verifies the methods used to develop the terrain model.

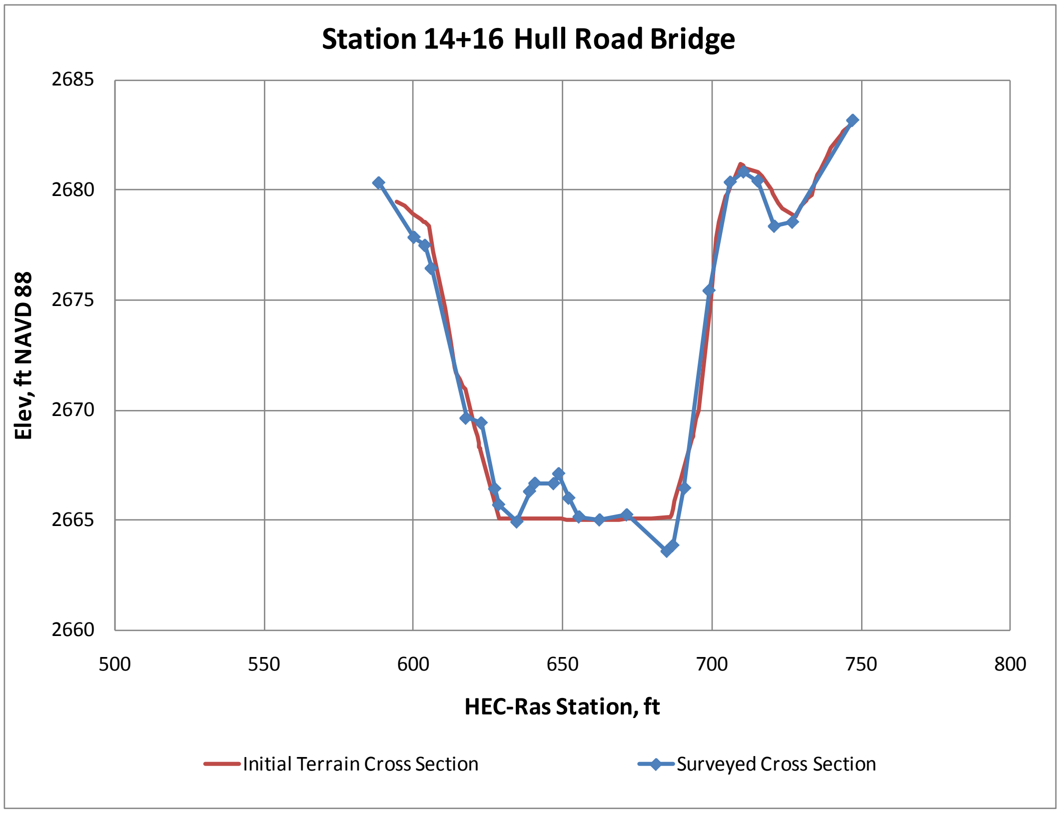


Figure 5. Example of channel cross section near bridge that was modified to include AP survey data.

**Bridges**

Twenty-nine bridges were included in the model. Information utilized in the model is documented in Table 2. In all cases, the energy equation was used for all flows. If bridges were skewed from the channel centerline, they were projected onto the upstream and downstream cross sections to account for the angle. The bridge opening and pier thickness in Table 2 are the projected values. All information was based on survey information, ground photographs, aerial photographs, and terrain models. In the adjacent upstream and downstream cross sections, ineffective flow areas were set where the road leading to and from the bridge was higher than the surrounding ground elevations. Ineffective flow areas are locations where water will likely pond and the velocity is zero in the downstream direction, as is the case with water being ponded behind a road embankment (Brunner 2008).

Table 2. Information used to incorporate bridge geometry in HEC-RAS model.

| Bridge Name | Bridge Opening (ft) | Width (ft) | Piers | Pier Thickness (ft) | Top Deck Elevation (ft) | Low Chord Elevation (ft) |
|---|---|---|---|---|---|---|
| Brinker Creek Rd. | 53 | 10 | NA | NA | 3,087.0 | 3,084.5 |
| Hwy 203 #B1 | 58 | 20 | NA | NA | 3,042.3 | 3,039.8 |
| Hwy 203 #B2 | 56 | 13 | NA | NA | 2,889.7 | 2,888.5 |
| Highway 203 #B3 | 76 | 54.9 | 2 | 2 | 2,827.8 | 2,826.2 |
| Bellwood | 67 | 29.6 | NA | NA | 2,797.7 | 2,795.4 |
| Main St. | 46 | 63 | NA | NA | 2,792.9 | 2,789.5 |
| 5th St | 69 | 28.2 | NA | NA | 2,782.4 | 2,780.2 |
| 10th St. | 47 | 28 | NA | NA | 2,771.9 | 2,769.8 |
| Pond Slough | 38 | 14 | NA | NA | 2,722.1 | 2,719.7 |
| Miller | 98 | 31 | NA | NA | 2,717.5 | 2,714.3 |
| Highway 203 #B4 | 92 | 41 | 2 | 2 | 2,711.3 | 2,709.4 |
| Lower Davis | 60 | 17 | NA | NA | 2,708.2 | 2,706.6 |
| Woodruff | 57 | 29.5 | NA | NA | 2,706.2 | 2,704.9 |
| Wilkinson #1 | 88 | 28 | 1 | 1.5 | 2,703.3 | 2,701.7 |
| Godley Lane #1 | 81 | 22 | 1 | 1.5 | 2,697.9 | 2,696.3 |
| Gekeler #1 | 84 | 28 | NA | NA | 2,697.0 | 2,693.2 |
| Highway 237 #1 | 131 | 42 | 2 | 3 | 2,698.0 | 2,695.8 |
| Booth Lane #1 | 124 | 36 | 2 | 2 | 2,691.5 | 2,689.5 |
| Elmer #1 | 130 | 21 | NA | NA | 2,694.6 | 2,692.0 |
| Elmer #2 | 119 | 18 | 4 | 1 | 2,688.7 | 2,687.4 |
| Market Lane #1 | 108 | 35 | NA | NA | 2,691.9 | 2,685.4 |
| Alicel #1 | 147 | 33.5 | 1 | 2 | 2,695.3 | 2,692.3 |
| McKennon Lane | 192 | 29 | 1 | 2.5 | 2,695.9 | 2,691.2 |
| Hull Road | 169 | 36.22 | 1 | 3 | 2,694.6 | 2,689.6 |
| Striker Lane | 140 | 28.5 | NA | NA | 2,689.7 | 2,685.0 |
| Rinehart Lane | 194 | 32 | 1 | 3 | 2,688.3 | 2,687.7 |

| Bridge Name | Bridge Opening (ft) | Width (ft) | Piers | Pier Thickness (ft) | Top Deck Elevation (ft) | Low Chord Elevation (ft) |
|---|---|---|---|---|---|---|
| Booth Ln #2 | 114 | 36 | 2 | 1.3 | 2,705.1 | 2,703.4 |
| Market Lane #2 | 101 | 28 | NA | NA | 2,701.0 | 2,696.7 |
| Ruckman Lane | 120 | 28 | NA | NA | 2,698.4 | 2,694.1 |

**Diversions**

Nine diversion dams were included in the HEC-RAS model. Only the grade control portion of a diversion dam was included. For example, Medical Springs Diversion #D2 is a series of notched weirs (shown in Figure 6). To include this structure, the four adjacent cross sections were adjusted in a similar manner to the bridge cross sections. Then, the highest weir (typically the most upstream) elevations, width, and dimensions were input as an inline weir structure in HEC-RAS. The highest weir acts as a water surface control and the other weirs would have only a small local effect on the hydraulics.

Figure 6. Medical Springs #D2 Diversion (aka Catherine Creek Adult Collection facility, CCACF) looking upstream. Photo courtesy of AP, taken on November 16, 2010.

Three of the diversion dams (Elmer, Lower Davis, and Upper Davis) have boards placed to increase the backwater behind the dams during the irrigation season. The surveys of all three structures were conducted while boards were in place (see Figure 7). The usage of the boards, such as how many are in place and for what months of the year, is not well documented and highly variable. Therefore, the structures were all modeled assuming that no boards were in place and irrigation was not occurring. Additionally, the primary purpose of the model is to evaluate high flows, during which time the boards would likely be removed. Further refinement of the modeled structures can occur if the operating conditions of the dams are defined.

Figure 7. Photo of Diversion Structure located at station 67045 on Catherine Creek, illustrating the use of boards to increase backwater. Photo from Anderson Perry Surveys, September 28th 2010.

### 3.1.5. Model Discharges

Thirteen model discharges were developed for multiple recurrence intervals using available streamflow gage data. For details of the hydrology analysis performed to develop the discharges, refer to Appendix A. Table 3 below shows the flow change locations in the model and associated flow magnitudes for the 1.5-, 2-, 10-, 50-, and 100-year flood, which represent the discharges used in this modeling effort.

Table 3. Flow changes locations and discharges for various flood return intervals.

| Hydraulic Model Station (ft) | RM (mi) | Description | Flood return interval (Q xx) discharges ($ft^3/sec$) | | | | |
|---|---|---|---|---|---|---|---|
| | | | Q1.5 | Q2 | Q10 | Q50 | Q100 |
| 247207.5 | 46.7 | Catherine Creek near Union, stream gage | 645 | 760 | 1,228 | 1,628 | 1,796 |
| 209189.3 | 39.5 | Catherine Creek at Union, stream gage | 677 | 797 | 1,288 | 1,707 | 1,884 |
| 194813.4 | 36.9 | Catherine Creek below Pyles Creek | 941 | 1,109 | 1,791 | 2,374 | 2,619 |
| 189174 | 35.9 | Catherine Creek below Little Creek | 973 | 1,146 | 1,851 | 2,454 | 2,708 |
| 165306.4 | 31.4 | Catherine Creek below Ladd Creek | 1,325 | 1,562 | 2,522 | 3,344 | 3,689 |
| 153863.5 | 29.4 | Catherine Creek below McAlister Slough | 1,355 | 1,598 | 2,580 | 3,421 | 3,774 |
| 125641.6 | 24.1 | Catherine Creek below Mill Creek | 1,546 | 1,822 | 2,942 | 3,900 | 4,303 |
| 116101 | 22.5 | Catherine Creek below Old Grande Ronde River Channel | 1,632 | 1,924 | 3,107 | 4,119 | 4,544 |
| 80916.28 | 15.8 | Catherine Creek below Eckesley Creek | 1,763 | 2,078 | 3,356 | 4,450 | 4,909 |
| 66414.06 | 0 | Grande Ronde River below Catherine Creek | 4,456 | 5,376 | 9,547 | 13,672 | 15,564 |
| 12225.36 | NA | Grande Ronde River below Willow Creek | 4,779 | 5,757 | 10,162 | 14,488 | 16,464 |
| 28848.65 | NA | State Ditch | 2,692 | 3,297 | 6,190 | 9,222 | 10,655 |

### 3.1.6. Model Boundaries

The downstream boundary condition is located on the Grande Ronde River approximately 12.6 miles downstream of the confluence of Catherine Creek and State Ditch. No in-channel data were collected downstream of the Rinehart Bridge, which is located at about station 6800. As a result, the initial bed elevations used in the downstream-most 9 cross sections of the model were extracted directly from the LiDAR and were several feet higher than elevations surveyed in upstream cross sections. This led to a drastic change in slope at the downstream boundary and caused unrealistic backwater up to 6 miles upstream for low flows (approximately 96 $ft^3/sec$) (Figure 8). To remedy this problem, bed elevations within these 9 cross sections were dropped on average 2 feet to create a low flow channel with a slope of about 0.02%, which is consistent with localized slopes within the reach. An example of the modifications made to cross sections is shown in Figure 9. In the future, it is recommended that additional topographic data be collected in the channel for the downstream 6,800 feet of the model.

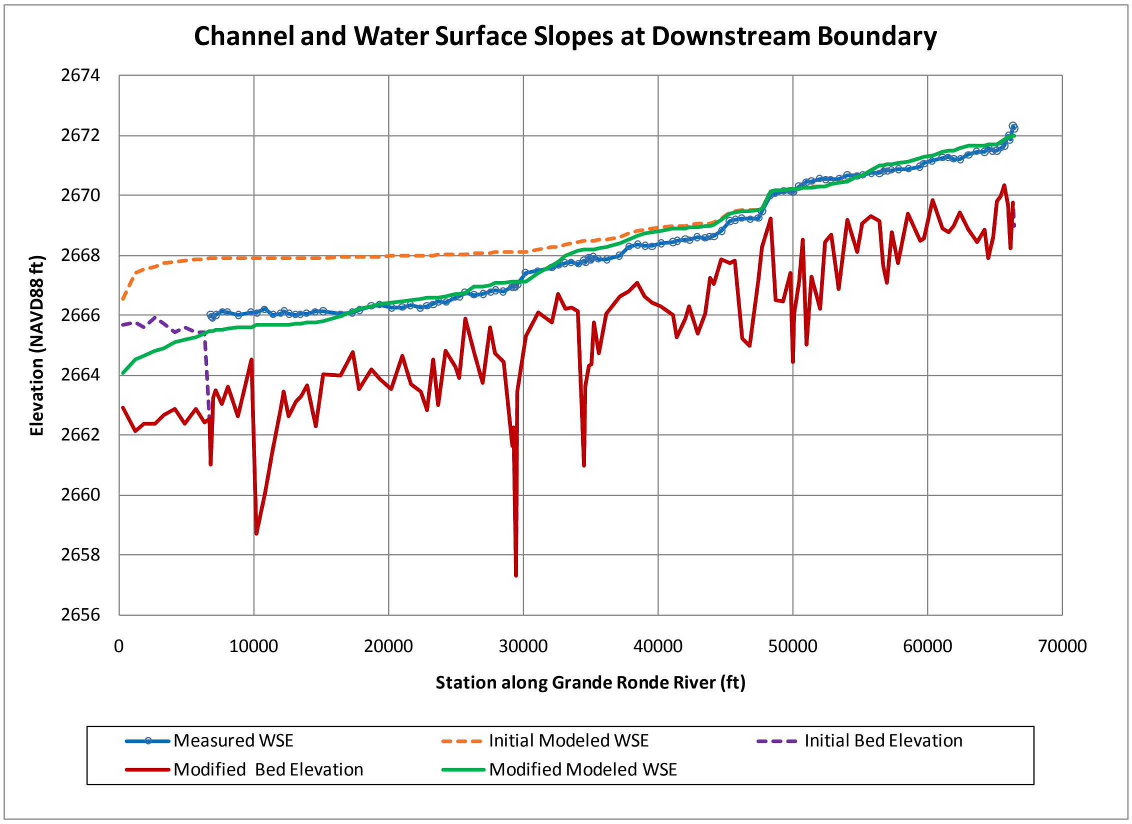


Figure 8. Illustration of changes to bed elevation at downstream end of model and resultant changes in water surface profile for a flow of 95 cfs.

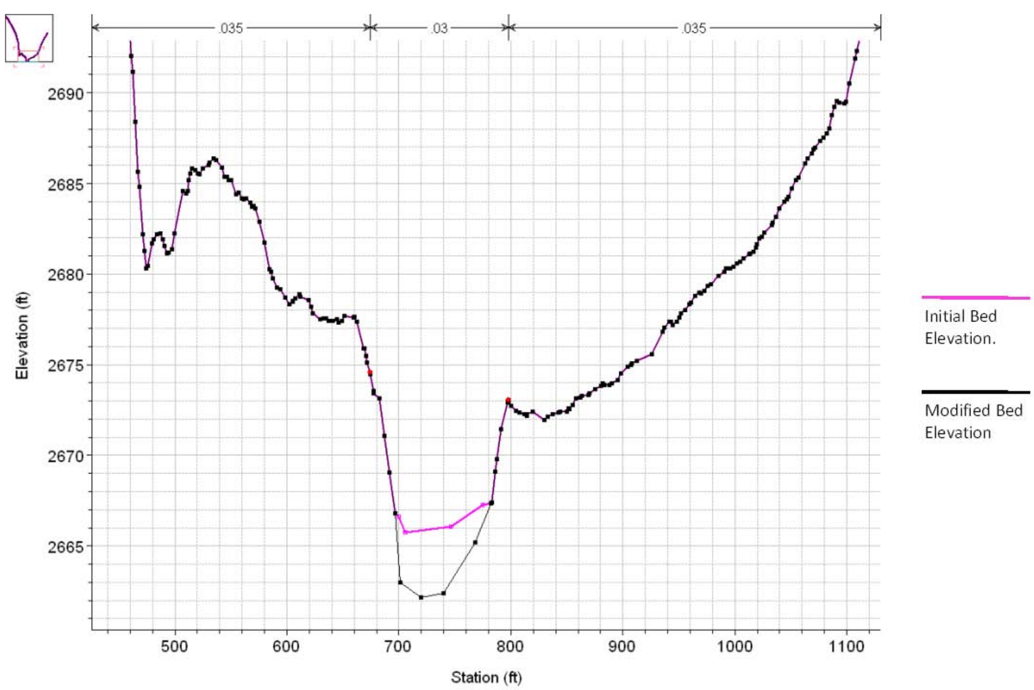


Figure 9. Example of channel bed modification to downstream-most 9 cross sections. Cross section shown is at station 1198.25.

No data regarding a stage/discharge relationship is currently available at the downstream end of the model; therefore, it was assumed that the boundary condition operates under normal depth conditions. The downstream boundary normal depth slope was varied for the June, 2010 discharge (see Section 3.2.1) to determine the slope that most closely simulates the high water marks. Figure 10 shows the results of several different slopes. Once the slope was greater than 0.3%, the water surface elevation values changed very little and only in the downstream most mile. Although the 0.3% slope does appear to be overestimating the water surface elevation, the modeled water surface elevations are within 1 foot of the measured high water marks. Therefore, a slope of 0.3% was used for all additional simulations. Assuming normal depth may not be an accurate assumption at the boundary; a rating curve would be ideal to capture the hydraulics at this location. If more data become available, this downstream boundary condition can be refined and extended.

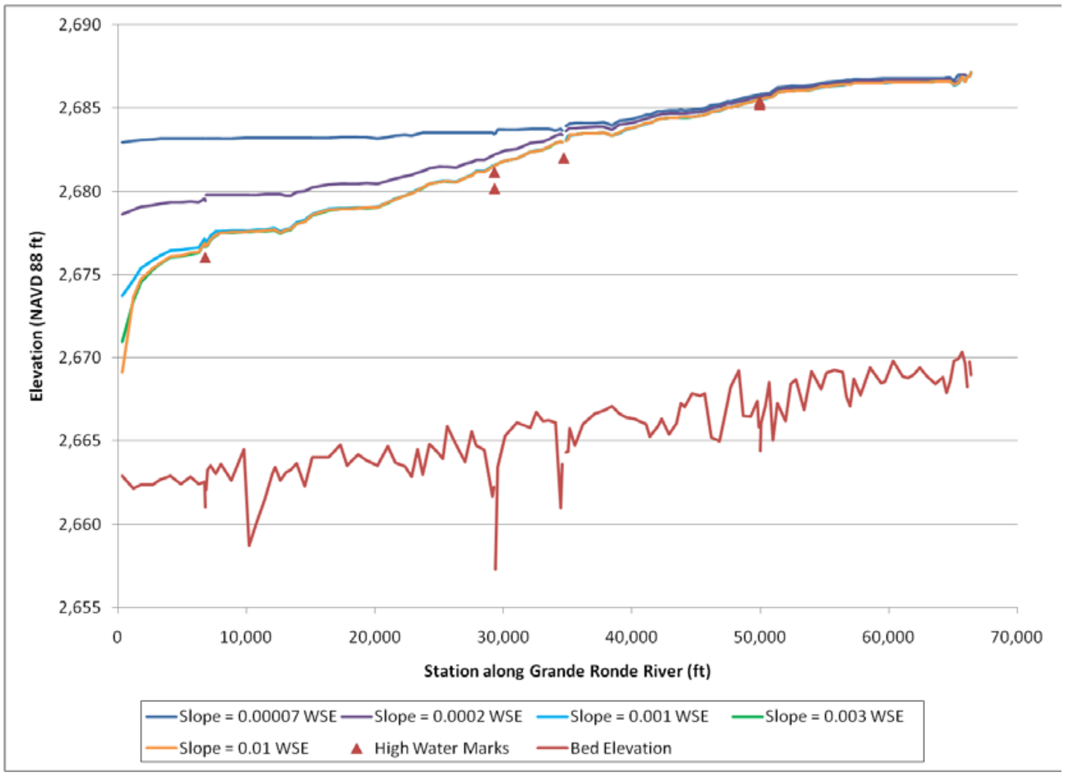


Figure 10. Comparison of different downstream boundary condition slopes for the June, 2010 discharge.

Based on the results of the boundary condition variation, the model appears highly sensitive to the downstream boundary condition. Using a slope of 0.007% results in backwater at the downstream boundary upstream to Grande Ronde River station 66,200 or approximately 500 feet downstream of the confluence of State Ditch and Catherine Creek. Although this slope is not recommended for input at the downstream model boundary, it illustrates that the boundary condition is not likely to impact model results in Catherine Creek or State Ditch.

### 3.1.7. Roughness Values

Roughness values were determined using a combination of pebble counts, vegetation, agricultural land use, and professional judgment. Pebble counts were collected by the Technical Service Center along State Ditch in November 2010 and by PNRO along Catherine Creek upstream of Pyles Creek confluence at RM 36.9 in summer 2010 (Rob McAffee, personal communication). The Manning's-Strickler equation was used to estimate grain roughness based on the pebble counts in these areas. The Manning's roughness values within the channel were then increased slightly to account for other components of form roughness present, such as vegetation along the channel banks and large woody debris within the channel. In modeled reaches where no bed material data were available other than visual observations, Manning's roughness coefficients were estimated based on similar values used in other rivers with similar bed material conditions. Roughness coefficients for floodplain areas were delineated based upon the presence of vegetation cover or agricultural land use. Both floodplain and in-channel roughness values were consistent with guidance presented by Chow (1959). Table 4 below summarizes the Manning's n values used.

Table 4. Hydraulic roughness values used in the HEC-RAS model.

| **River** | **Hydraulic Model Station (ft)** | | **Manning'n value** | | |
|---|---|---|---|---|---|
| | From | To | Left | Channel | Right |
| Catherine Creek | 247207.5 | 194387.8 | 0.075 | 0.045 | 0.075 |
| Catherine Creek | 194387.8 | 709.4 | 0.035 | 0.030 | 0.035 |
| Grande Ronde | 66414.1 | 302.5 | 0.035 | 0.030 | 0.035 |
| State Ditch | 28848.7 | 22875.8 | 0.035 | 0.030 | 0.035 |
| State Ditch | 22875.8 | 54.1 | 0.035 | 0.040 | 0.035 |

For the floodplain areas, except the upstream end of Catherine Creek, the roughness was determined assuming the area was agricultural land with crops such as mint. Figure 11 shows an example of the land adjacent to Catherine Creek.

Figure 11. Example of the floodplain along Catherine Creek. Photo taken April 27, 2010.

At the upstream end of Catherine Creek, agricultural areas are more sparse, and more trees and high relief areas are present (Figure 12). The roughness in the floodplain was increased for this area from 0.035 to 0.075.

Figure 12. Example of the floodplain along the upstream portion of Catherine Creek in Reach 4. Photo taken April 28, 2010.

Attempts were made to validate the in-channel portion of the model using high flow and low flow discharge and water surface information. Sensitivity analyses were performed to better understand how potential variability in Manning's roughness may impact model results (Section 3.2.7). In the future, aerial photography could be used to delineate land cover to capture variability in roughness across the floodplain. However, the level of effort to accomplish these tasks may be more efficiently performed at a more detailed level of investigation and input to a two dimensional (2D) model.

### 3.1.8. Other computational parameters

Coefficients of expansion and contraction of 0.3 and 0.1, respectively, were used at all sections except upstream and downstream of the bridges. For these cross sections 0.5 was used for the coefficient of expansion and 0.3 for the coefficient of contraction. For the bridges, the weir coefficient used varied between 2.6 and 3.05. A weir coefficient of 3.05 was used for all of the diversion structures. These values could be further calibrated in the future if more measured water surface elevation data become available.

## 3.2. Model Comparison

Two basic data sets were available to calibrate the model: high water marks were available from a flood that occurred in June 2010, and a water surface profile was measured in October 2010.

### 3.2.5. June 2010 Water Surface Elevations

In June 2010, a flood occurred in which discharge measurements were collected after the peak, but PNRO placed 21 high water marks at 11 bridges on Catherine Creek, 6 high water marks at 4 bridges on Grande Ronde River and 1 mark on a bridge on State Ditch. The marks were all placed on June 4$^{th}$ and June 5$^{th}$. Discharge data corresponding to these dates were extracted from the three Oregon Water Resources Department (OWRD) stream gages: Catherine Creek near Union, Catherine Creek at Union, and Grande Ronde River near Perry. The highest mean daily flow occurred on June 4$^{th}$ (see Table 5).

Table 5. Discharge values at OWRD gages on June 4, 2010.

| **Gage Description** | **Hydraulic Model Station** | **Mean daily flow on June 4, 2010 (ft$^3$/sec)** |
|---|---|---|
| Catherine Creek near Union | 247,208 | 1,230 |
| Catherine Creek at Union | 209,189 | 1,290 |
| Grande Ronde River near Perry | NA (upstream on State Ditch) | 4,180 |

Three discharge measurements were collected on June 7$^{th}$ after the peak, and three water surface elevation markers from June 7$^{th}$ were surveyed by Anderson Perry. The discharge measurements were collected at bridge locations: Market Lane Bridge on State Ditch, Godley Road Bridge on Catherine Creek and Booth Lane on Catherine Creek. The measurements were collected using a Teledyne RDI StreamPro Acoustic Doppler Current Profiler (ADCP). At least six transects were collected at each location, processed using WinRiver software, and averaged to calculate the flow. The discharge measurements confirmed that the gage discharge data were reasonable (Table 6), however there were not enough water surface elevation markers collected to use the June 7th discharge data independently.

Table 6. Measured discharge values collected on June 7, 2010.

| **Discharge Measurement location** | **Hydraulic Model Station** | **Flow Measured on June 7, 2010 ($ft^3$/sec)** |
|---|---|---|
| Godley Road Bridge on Catherine Creek | 15,220 | 821 |
| Booth Lane Bridge on Catherine Creek | 78,063 | 1,060 |
| Market Lane at State Ditch | 8,897 | 2,600 |

Appendix A contains area and precipitation volume ratios developed for the tributaries. Using the gages and the ratios developed, the discharges for June 7, 2010 in Table 7 were calculated. These computed discharges were used to simulate the water surface elevations resulting from the June 2010 flood.

Table 7.Discharge values used in HEC-RAS model for June, 2010 simulation.

| **Hydraulic Model Station (ft)** | **RM (mi)** | **Description** | **June, 2010 Peak Discharge (ft3/sec)** |
|---|---|---|---|
| 247207.5 | 46.7 | Catherine Creek near Union, stream gage | 1,230 |
| 209189.3 | 39.5 | Catherine Creek at Union, stream gage | 1,290 |
| 194813.4 | 36.9 | Catherine Creek below Pyles Creek | 1,794 |
| 189174 | 35.9 | Catherine Creek below Little Creek | 1,854 |
| 165306.4 | 31.4 | Catherine Creek below Ladd Creek | 2,526 |
| 153863.5 | 29.4 | Catherine Creek below McAlister Slough | 2,584 |
| 125641.6 | 24.1 | Catherine Creek below Mill Creek | 2,947 |
| 116101 | 22.5 | Catherine Creek below Old Grande Ronde River Channel | 3,112 |
| 12225.36 | NA | Grande Ronde River below Willow Creek | 7,292 |
| 28848.65 | NA | State Ditch | 4,180 |

Comparisons of the measured high water marks versus modeled water surface elevations on Catherine Creek are presented in Figure 13 through Figure 16. Results suggest that the model provides conservative estimates of water surface elevations based upon the input data. All but one location have the modeled water surface elevations within 2 feet of the measured high water marks. Five of the eleven locations have modeled water surface elevations within 1 foot of the measured high water marks.

In an attempt to better match the high water marks, Manning's n values were reduced in the lower section of Catherine Creek (station 709.4 to 194387.8) to 0.031 on the floodplain and 0.026 in the channel. An example of the changes resulting from the reduced Manning's values is shown in Figure 13. From this analysis, it was determined that the disagreement between the high water marks and the modeled elevations is not a function of roughnesss alone. To match just a few of the high water marks exactly, roughness coefficients would need to be reduced to unreasonable values. The differences are more likely due to (1) uncertainty of the high water marks relative to discharge values, (2) the simplified representation of in-channel topography, or (3) lack of representation of localized hydraulics at bridges (where the high water marks were collected). Based on professional judgment, the Manning's n values were not adjusted from the values in Section 3.1.7 for the remainder of the analysis. Sensitivity analyses were performed to better understand how potential variability in Manning's roughness may impact model results (Section 3.2.7).
The Grande Ronde River comparison was shown above in Figure 10 and the modeled water surface elevations are within 1 foot of the measured high water marks. For State Ditch, one high water mark was collected at Booth Lane Bridge and had an elevation of 2,694.3. The modeled water surface elevation at this station was 2,694.2 or within a tenth of a foot of the high water mark.

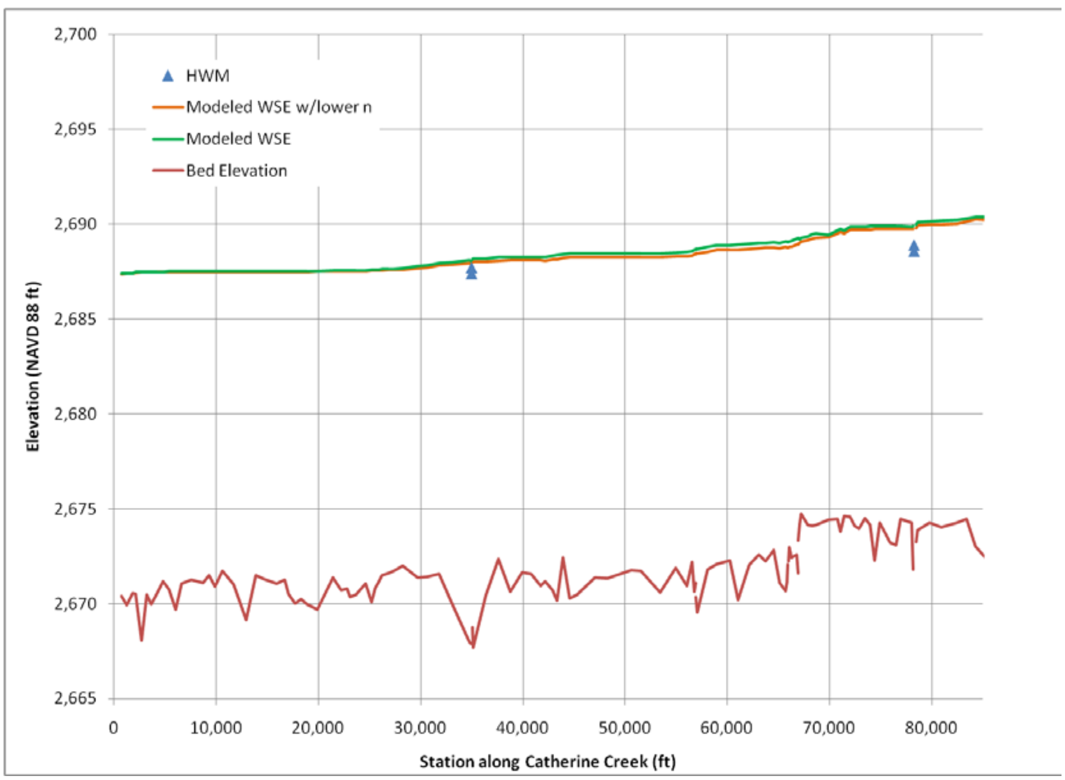


Figure 13. Modeled water surface elevations versus measured high water marks for Catherine Creek (RM 0 to 16.3).

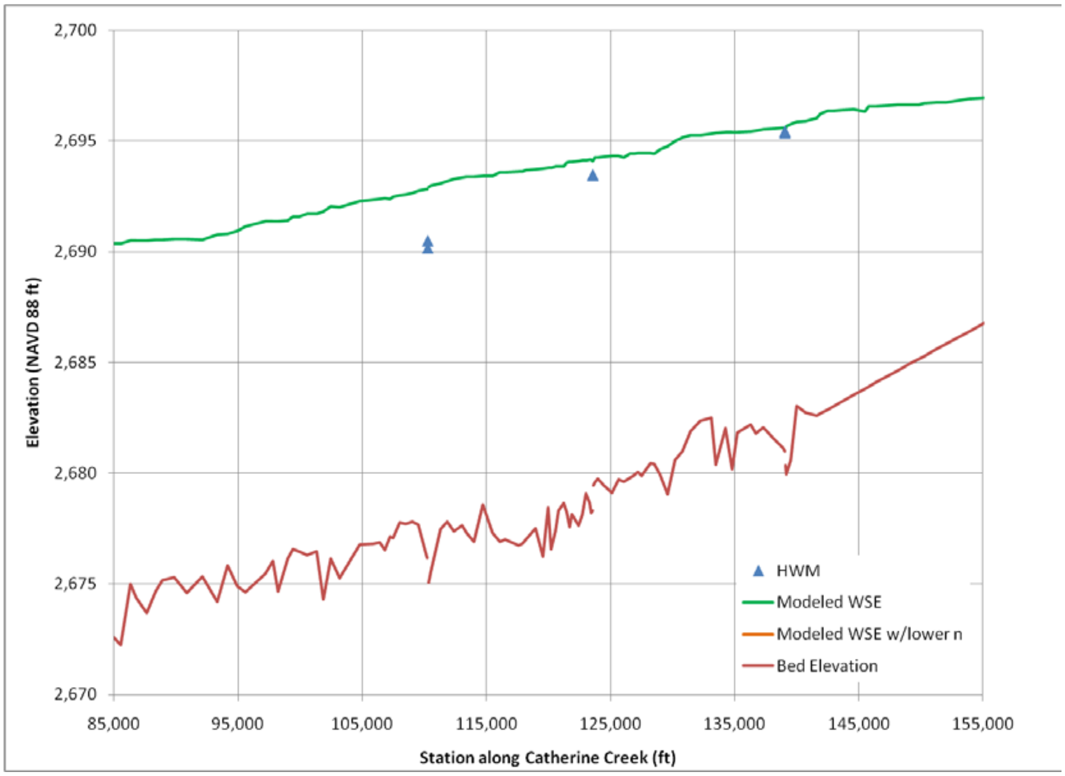


Figure 14. Modeled water surface elevations versus measured high water marks for Catherine Creek (RM 16.3 to 29.6).

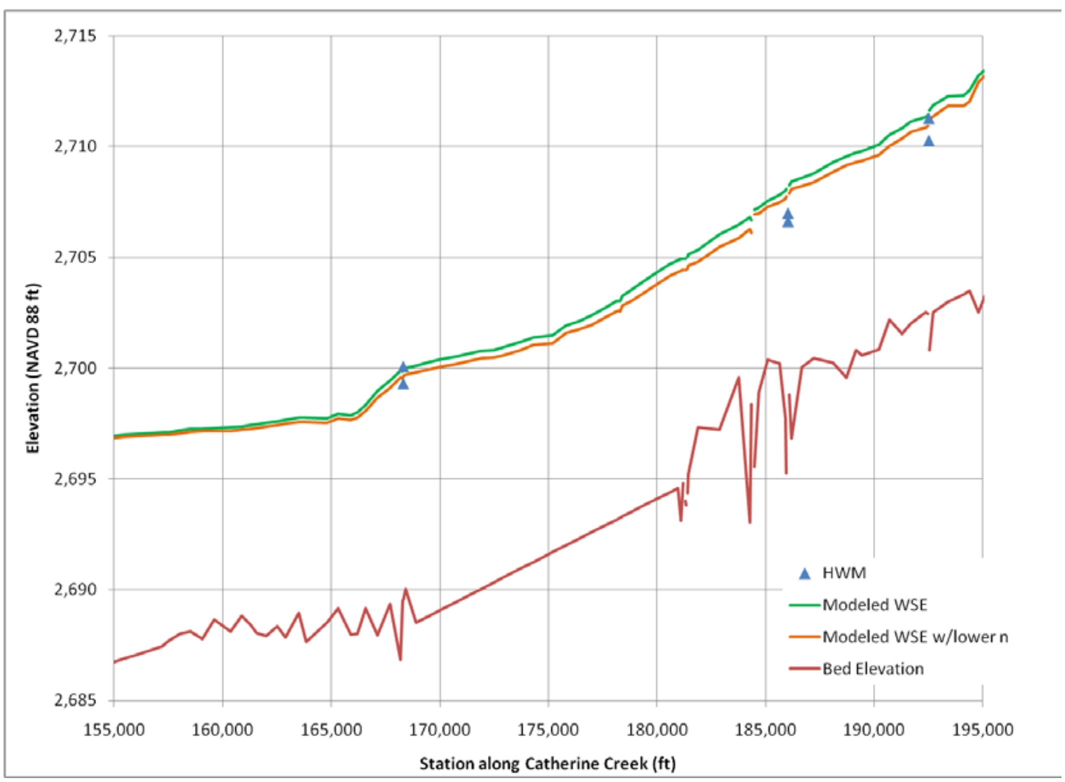


Figure 15. Modeled water surface elevations versus measured high water marks for Catherine Creek (RM 29.6 to 36.5).

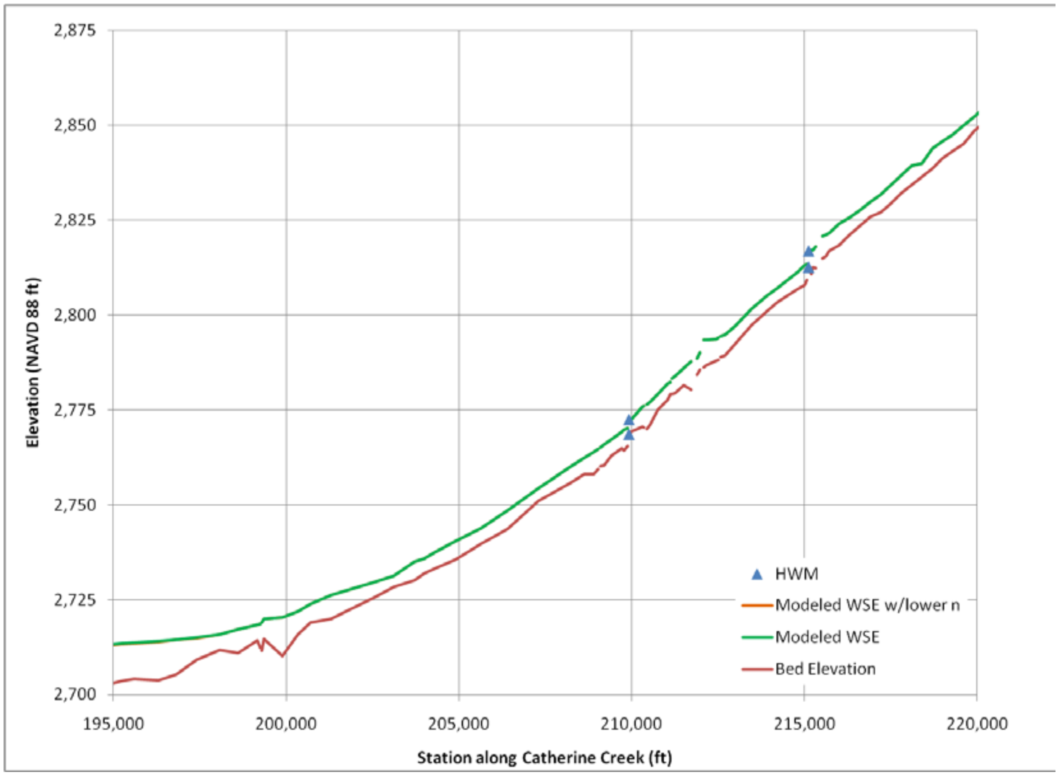


Figure 16. Modeled water surface elevations versus measured high water marks for Catherine Creek (RM 36.5 to 46.6).

### 3.2.6. October 2010 Water Surface Elevations

Although the model produced for this Tributary Assessment is intended to be a tool for investigating high flows, uncertainties were associated with the discharges at which the high water marks were collected as described in Section 3.1.2. In addition, high water marks within a close proximity sometimes varied by over 1 foot in elevation. A comparison of the model results to measured low flow water surface elevations collected during October and November 2010 was performed to evaluate the validity of the in-channel Manning's roughness coefficient and the downstream boundary conditions.

Water surface profiles were collected by boat between October 29$^{th}$ and November 2$^{nd}$, 2010. Discharge data corresponding to these dates were extracted from the three OWRD stream gages: Catherine Creek near Union, Catherine Creek at Union, and Grande Ronde River near Perry. Discharges and surveyed reaches are shown by date in Table 8. Aside from discharge, all model parameters as described in Section 3.1.8 remained the same.

Table 8. Discharges and water surface elevation survey extent by day.

| River | Upstream RS | Downstream RS | River Miles | Date Surveyed | Discharg e (cfs) |
|---|---|---|---|---|---|
| Catherine Creek | 192460 | 157500 | 36.5 - 30.0 | 10/29/2010 | 33 |
| Catherine Creek | 140685 | 84300 | 27- 16.3 | 10/30/2010 | 33 |
| Catherine Creek | 84300 | 0 | 16.3-0 | 11/2/2010 | 44 |
| State Ditch | 29072 | 0 | NA | 10/31/2010 | 46 |
| Grande Ronde | 66103 | 6791 | NA | 11/1/2010 | 96 |

As discharge in a channel increases, the roughness associated with the channel generally decreases. Therefore, the Manning's roughness used to model high flows is generally not going to be the same as the Manning's roughness that will best match water surface elevations at low flows. Manning's roughness was not modified to match low flows in this model since its primary function is to predict high flow inundation patterns. However, the comparison is useful in understanding the model limitations and in determining additional data needs and model changes for future evaluation of lower flows.

In addition, multiple diversion dams within the system alter the hydraulics of the channel at low flows, particularly when stop logs or boards are in place to prevent flow over the weir, as was the case when the low flow surveys were collected. The model was developed with the consideration that no boards were in place because the operations of the diversion structures will likely change during high flows, when stop logs are less necessary to create the needed head for diversion.

Comparisons of the modeled versus measured water surface elevations are presented in Figure 17 through Figure 21. Within the Grande Ronde River from the downstream model boundary to the confluence with State Ditch and Catherine Creek, measured and modeled water surface elevations are very close and are generally within 0.3 feet at a discharge of 96 $ft^3$/sec (Figure 17). One reason for similarities between the measured and modeled water surface elevation was the adjustment of the in channel bed elevations near the downstream boundary (Grande Ronde station 0 to 6800). The comparison between measured and simulated water surfaces at low flow show that the major hydraulic controls in the reach are captured by the topographic information.

Within State Ditch, the comparison illustrates that the modeled water surface elevations are lower than the measured water surface elevations, typically by less than 0.5 feet but up to 1 foot in some localized areas (Figure 18). Increasing the Manning's n for lower flows will improve the agreement to the low flow data, but also results in greater discrepancies at high flow. Despite the underestimation of water surface elevations at low flows, the model is within 1 foot of the measured values for the majority of the reach.

In the downstream 12.5 miles of Catherine Creek, the match between the measured and modeled water surfaces is excellent, with maximum differences of 0.3 feet (Figure 19). However, the diversion structure located at stations 67045 (Elmer Diversion Dam, Figure 7) had boards in place that were not included in the model. Therefore, simulated water surfaces at the diversion and in the upstream backwater, which extends nearly 8 miles upstream, do not match the measured. Upstream of the backwater of Elmer Dam, the model is consistent with the measured water surface elevation up to station 130806 (RM 24.9), where a beaver dam was present during the data collection trip (Figure 22). Upstream of the backwater influence of the beaver dam, the modeled water surface is slightly higher than the measured water surface from approximately station 158000 to 167700, a distance of 1.8 miles. The maximum difference in this section is approximately 0.8 feet. Some of the difference may be attributable to flow diversions at two upstream dams; however, no gage records or measured discharges are available for verification.

On October 29$^{th}$, a 2.5 mile section of river from station 167700 to 181000 was not surveyed due to access constraints (Figure 21). Within this channelized reach, no data are available for comparison and major hydraulic controls may not be adequately represented in the topography. At the upstream end of the surveyed data on October 29$^{th}$, two diversion structures were present: Lower and Upper Davis Diversion Dams. They were both surveyed by Anderson Perry and included in the model. Each of these structures had boards in place that were not present in the model, and therefore comparison in this section of the model is not applicable. However, the modeled water surfaces are substantially lower, with differences exceeding 5 feet at the Upper Davis Dam diversion structure. This may indicate that downstream controls were not surveyed that could be impacting upstream water surface elevations within the vicinity of Lower Davis Dam. More topographic data are necessary to verify the accuracy of model results in this area.

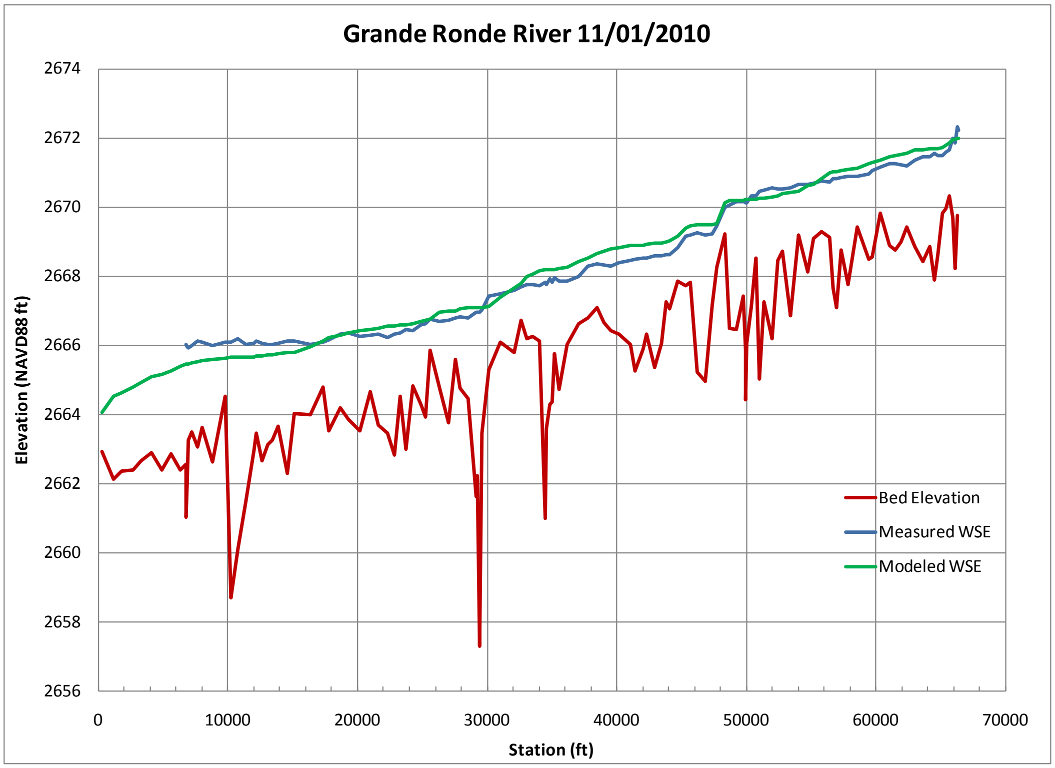


Figure 17. Measured versus modeled water surface elevations for Grande Ronde River downstream of State Ditch, measured on 11/01/2010.

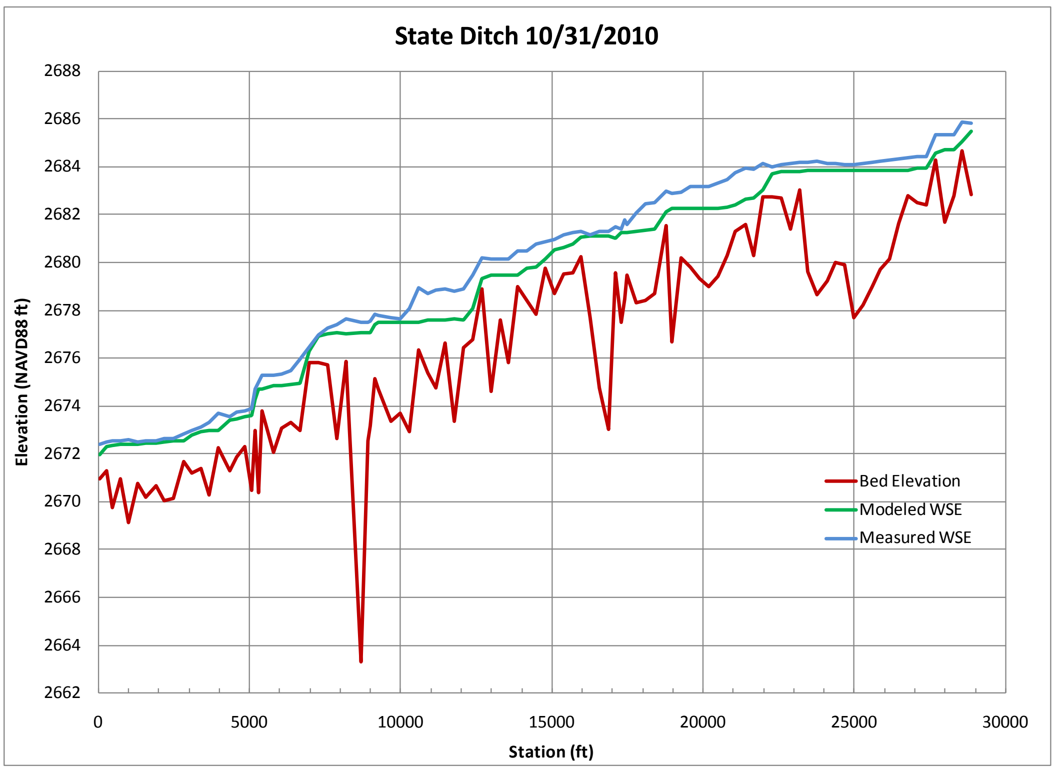


Figure 18. Measured versus modeled water surface elevations along State Ditch, measured on 10/31/2010.

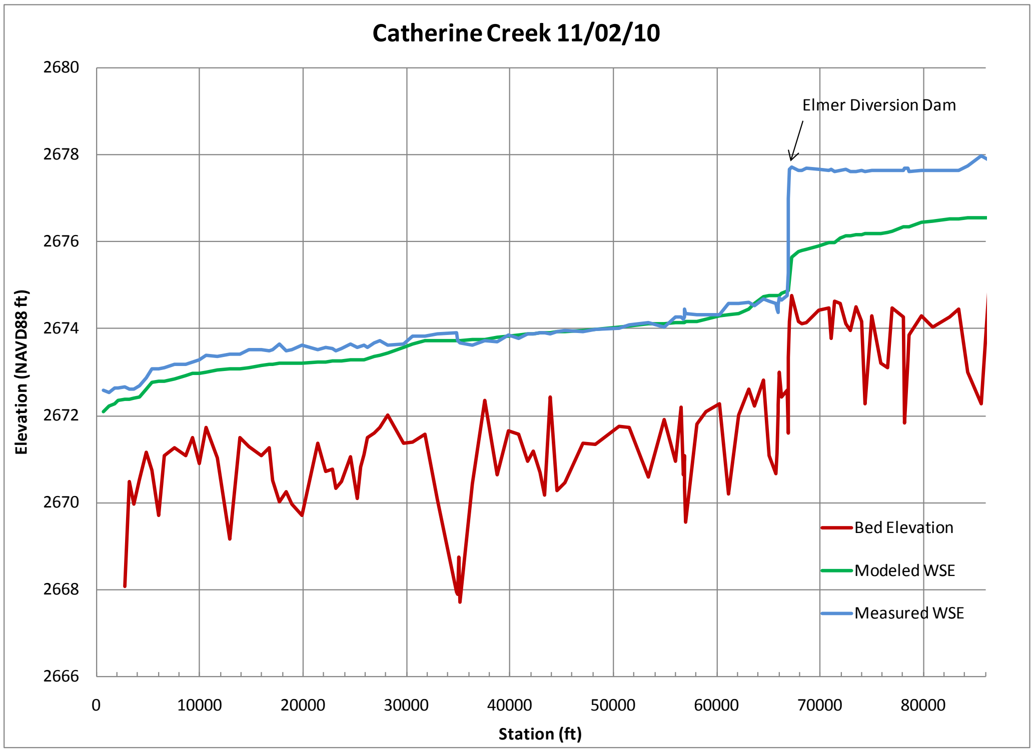


Figure 19. Measured versus modeled water surface elevations for Catherine Creek RM 0 to RM 16.3, measured on 11/02/2010.

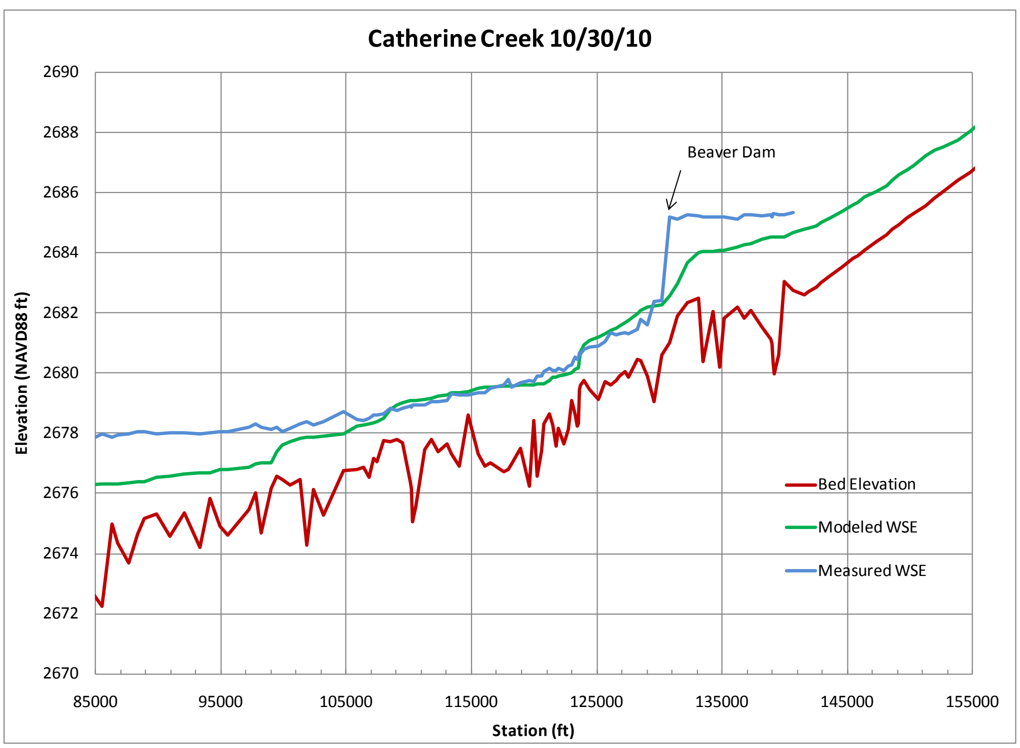


Figure 20. Measured versus modeled water surface elevations for Catherine Creek RM 16.3 to RM 29.6, measured on 10/30/2010.

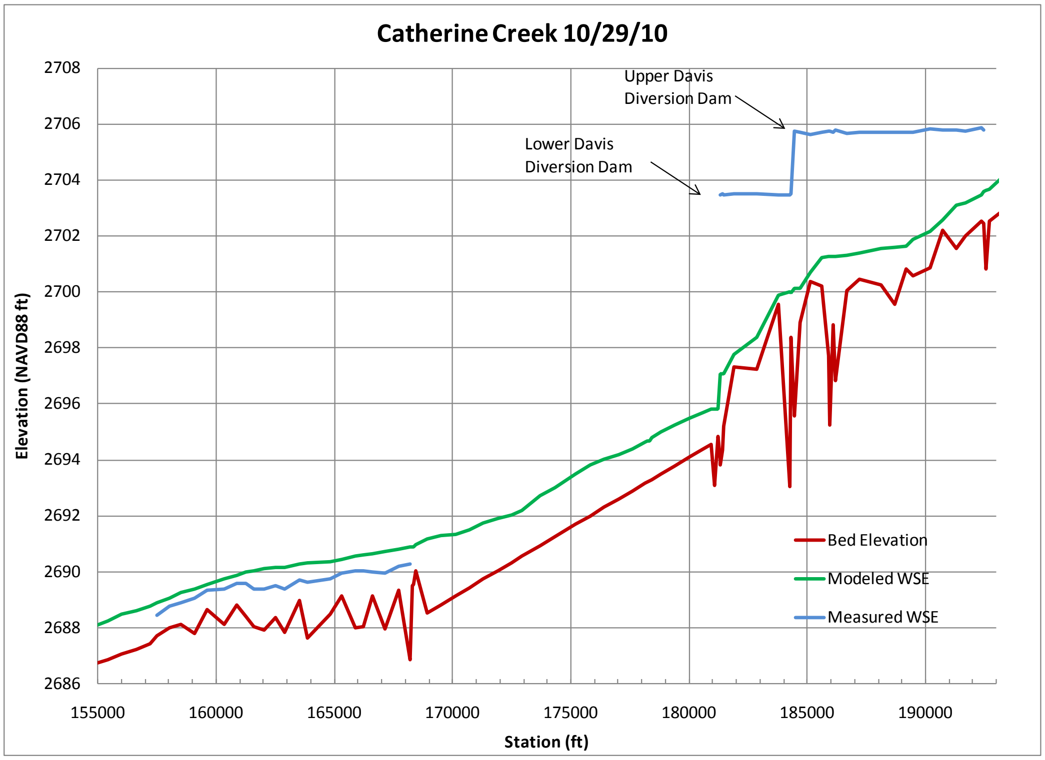


Figure 21. Measured versus modeled water surface elevations for Catherine Creek RM 29.6 to RM 36.5, measured on 10/29/2010.

Figure 22. Photograph of Beaver Dam located at RM 24.9 taken October 30, 2010.

### 3.2.7. Hydraulic Roughness Sensitivity

Within this Tributary Assessment, Manning's n values were selected based upon field observations, professional judgment, and surveyed high water marks as discussed in Section 3.1.7 and 3.2.1. However, some uncertainties are associated with the high water marks and with the simulation of the water surface elevations. For example, high water marks within a close proximity sometimes varied by over 1 foot in elevation. In addition, it is difficult to confirm that the high water marks do represent high water since they were placed during the flooding and in some locations, based on field observations, appeared to potentially be lower than the true high water mark. Hydraulic roughness sensitivity analyses were conducted using the 1.5-year and 10-year discharges. These discharges were selected to represent changes associated with in-channel roughness values and floodplain roughness values. For the 1.5-year discharge, the majority of flow was conveyed within the channel for most cross-sections. Using the 10-year discharge, floodplain flows dominated in areas where overbank flooding is not precluded by topographic influences (high levees or terraces), and most cross sections were capable of containing flows based upon available terrain data. During the sensitivity runs, the Manning's roughness values of the channel and floodplain were increased and decreased by 0.005 to investigate potential modifications to the results from differing hydraulic roughness coefficients.

The sensitivity simulations predicted high sensitivity to Manning's n for reaches with low slopes, including Grande Ronde River, State Ditch, Catherine Creek Reach 1 and the downstream 10-miles of Reach 2. Within these reaches, increases or decreases of 0.005 in the in-channel or overbank roughness values result in differences of +/- 1 foot in the water surface for the 1.5-year discharge and differences of +/- 0.5 to 0.75 feet for the 10-year discharge. In reaches 3 and 4 of Catherine Creek, the sensitivity to changes in Manning's n is greatly reduced. In reach 3, modifications to the roughness results in a maximum increase or decrease of 0.5 feet for the 1.5-year discharge and 0.25 feet for the 10-year discharge. Within Reach 4, maximum differences in water surface are +/- 0.25 feet for the 10-year discharge. Variations in Manning's n values appear to impart less influence in areas of steeper slopes and as flows increase. Plots of the water surface elevations resulting from the variations in Manning's n for Reaches 1 and 2 of Catherine Creek are shown below (Figure 23 to Figure 26).

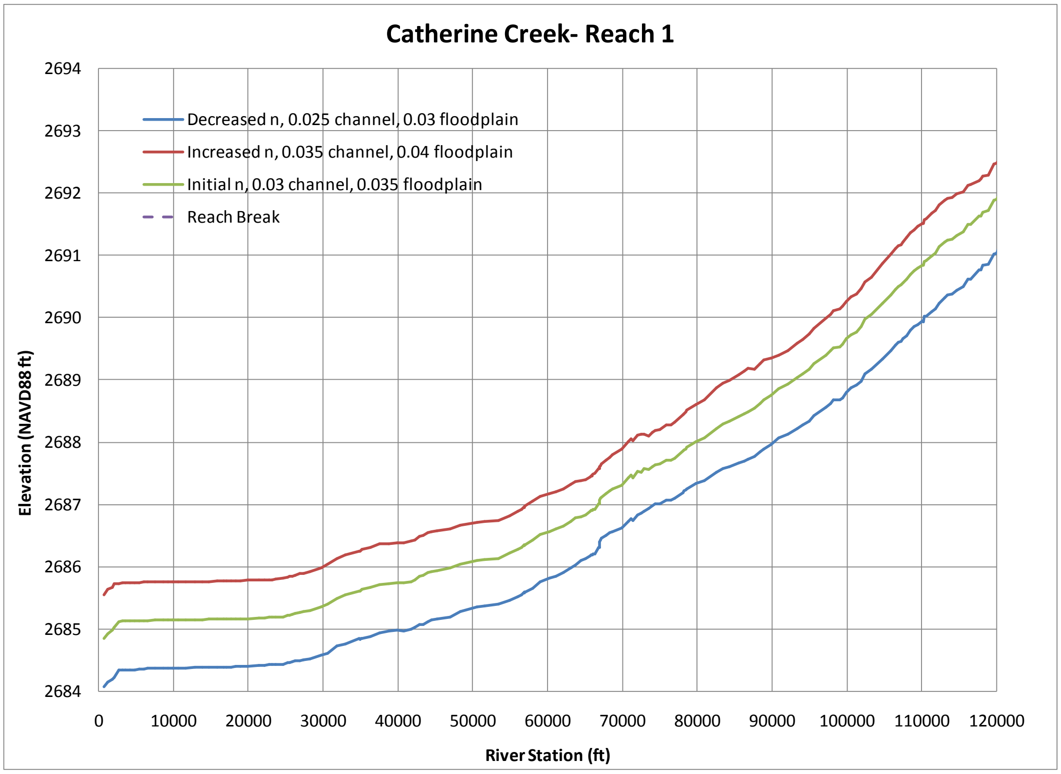


Figure 23. Sensitivity to Manning's n at a 1.5 year discharge for Reach 1 of Catherine Creek.

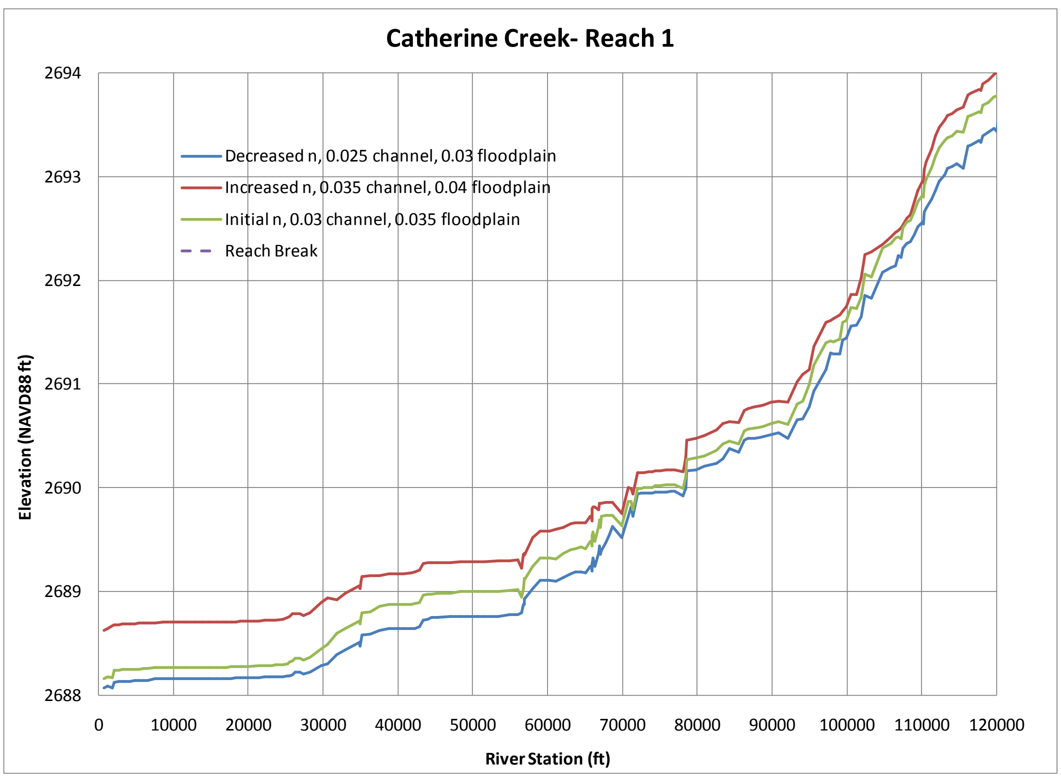


Figure 24. Sensitivity to Manning's n at a 10- year discharge for Reach 1 of Catherine Creek.

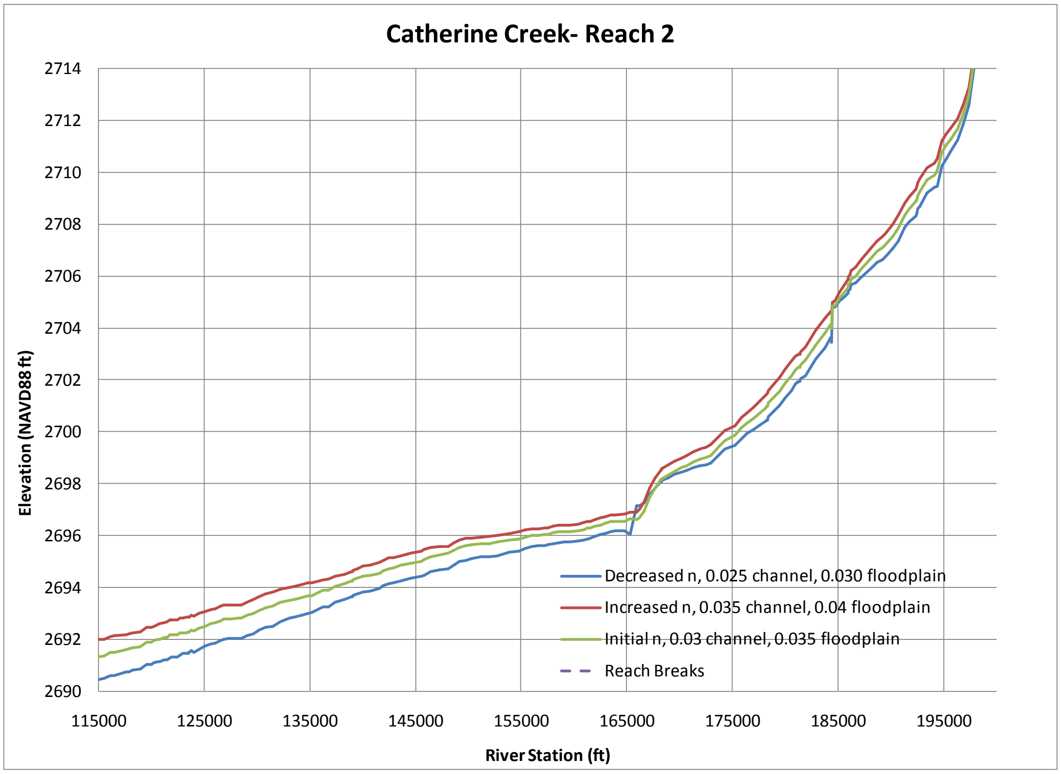


Figure 25. Sensitivity to Manning's n at a 1.5-year discharge for Reach 2 of Catherine Creek.

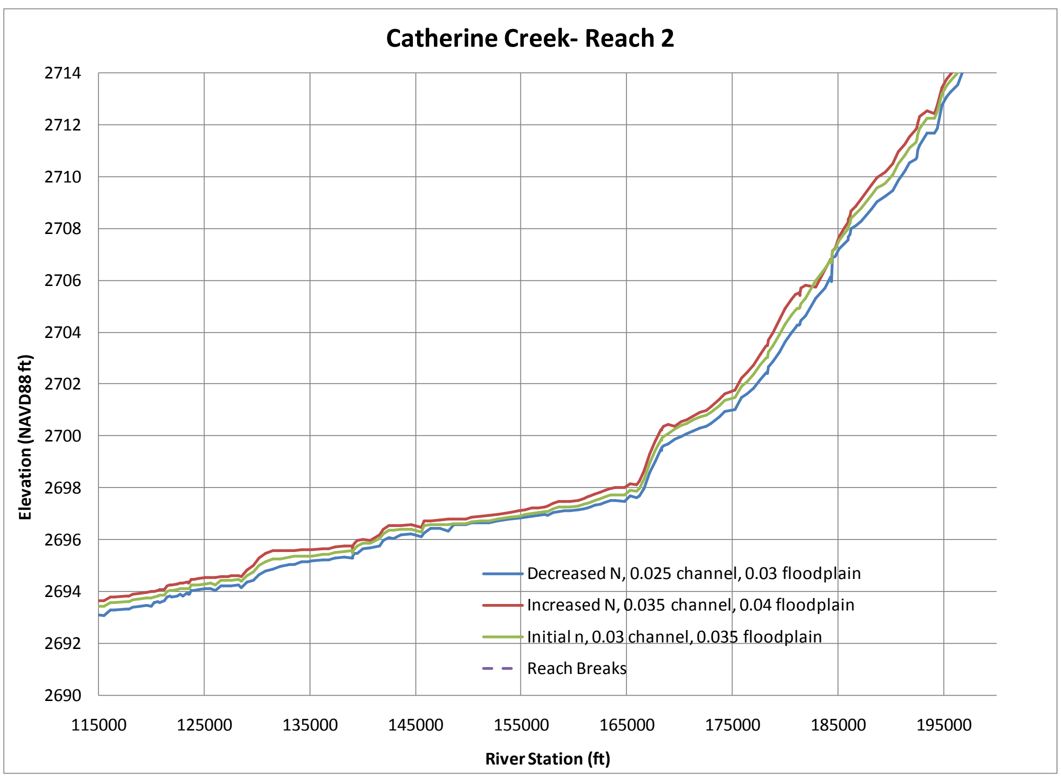


Figure 26. Sensitivity to Manning's n at a 10- year discharge for Reach 2 of Catherine Creek.

# 4. Present Conditions based on Model Results

In Appendix C, channel reach breaks along Catherine Creek were delineated based on the common geomorphic characteristics. There were seven reach breaks defined, four of which are included (reaches 1-4) in this hydraulic model. Only these four Catherine Creek sections are included in the present conditions analysis of the hydraulic model presented below. These reach breaks could be further refined based on the model results, which often had high variability within a reach. As an example, there is a slope break in Reach 2 at Ladd Creek. In addition there are other changes to channel capacity and velocity characteristics at this location. The refining of reach breaks may be useful for future analyses. Table 9 below briefly describes each reach. Figure 27 shows the longitudinal location of the reach breaks along Catherine Creek.

Table 9. Catherine Creek Reach break description.

| Reach | River Miles (RM) | Model Station (ft) | Description |
|---|---|---|---|
| 1 | 0 – 22.5 | 0 – 116514.9 | Historically the Grande Ronde River which included Catherine Creek. Reach break occurs at historic confluence with the “Old” Grande Ronde River. |
| 2 | 22.5 – 37.2 | 116514.9 – 196810.7 | Reach break occurs at the lower end of an alluvial fan where the substrate,bank material, and valley slope change. |
| 3 | 37.2 – 40.8 | 196810.7 – 216006.4 | Encompasses the Catherine Creek alluvial fan and all of the Town of Union, OR. |
| 4 | 40.8 – 45.8 | 216006.4 – 242735.5 | Upstream of Union, OR in narrow valley reach with floodplain and steeper channel slope. |

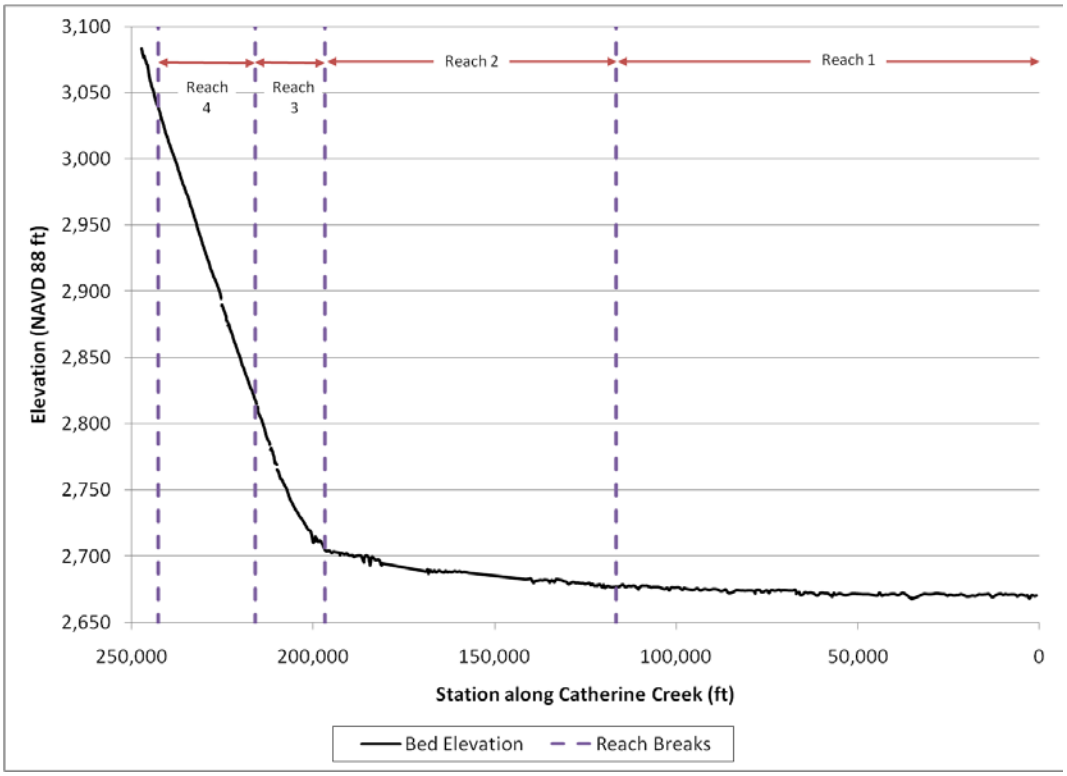


Figure 27. Reach break delineation for Catherine Creek.

## 4.1. Channel Slope and Water Surface Profiles

Results for computed water surface elevations at the 1.5-, 10-, and 100-year discharges are presented in Figure 28 through Figure 31. The average bed slope increases from Reach 1 to Reach 4. This is expected as you move from the valley up into the mountains. Figure 28 shows the results from Reach 1. The bed slope in this area can be divided into three sections. The slope of the bed is fairly constant at 0.004% until Elmer Dam at RM 13.1. There is a flat slope section behind Elmer Dam until Booth Lane which is likely due to sediment deposition upstream of the dam. From Booth Lane until the Old Grande Ronde River confluence (RM 22.5) the slope is constant at 0.01%, but steeper than in the other two sections. Elmer Dam provides a major hydraulic control at all flows simulated. The bridges in this reach appear to exert local hydraulic control at the 100-year flood, but not typically at the lower floods. Old Grande Ronde River is a slope break between the reaches. The slope steepens upstream of the confluence.

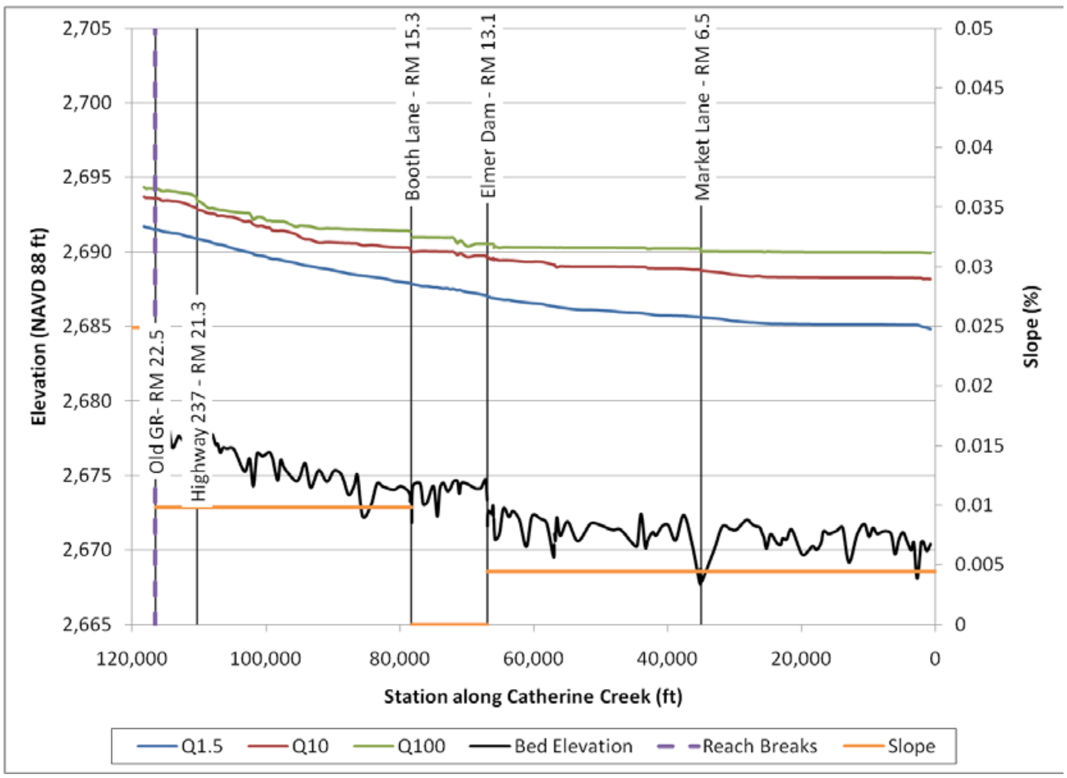


Figure 28. Computed water surface elevation for reach one on Catherine Creek.

Reach 2 is shown in Figure 29. The bed slope is fairly constant below Ladd Creek, 0.02%, although a portion of channel bottom had to be interpolated in this section and there could be hydraulic controls in this area, such as McAlister Slough, that are not included in the bed profile. Upstream of Wilkinson Lane Bridge, the bed slope steepens until Reach 3 to 0.05%. The bridges in Reach 2 act similarly to the bridges in Reach 1; they exert local hydraulic control on the river at higher flood flows. A beaver dam at RM 24.9 (station 130806) also acts as a hydraulic control. The influence can be seen in the 10- and 100-year profiles. Sediment deposition upstream of the dam is notable in the bed profile.

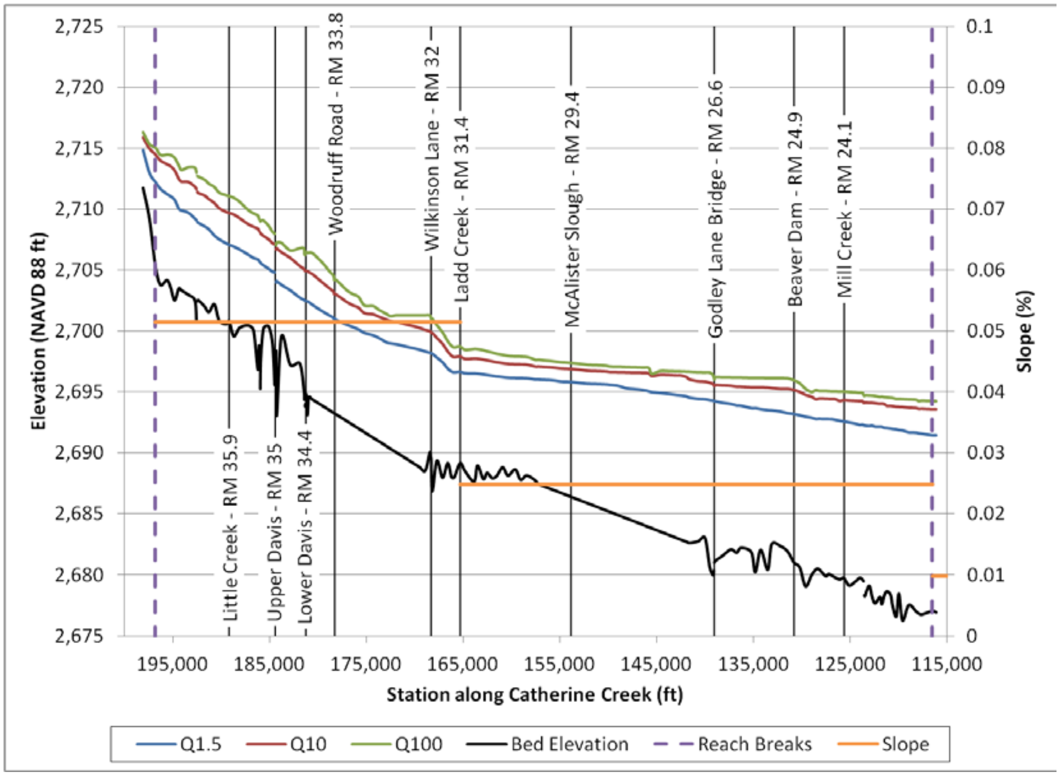

Figure 29. Computed water surface elevation for reach two on Catherine Creek.

Reach 3 is shown in Figure 30 and is the most upstream section of Grande Ronde Valley. The average slope in this reach, 0.59%, is steeper than in Reach 1 or Reach 2. However, variation in the slope throughout the reach is visible. Several of the bridges exert hydraulic control on flood flows. For example, Main Street Bridge at RM 40 raises water surface elevations at the two-year flood. There are two locations where the 100-year water surface elevation is lower than the 10-year water surface elevation: stations 203705 and 201306.4. At station 201306.4, the 100-year water surface elevation is at critical depth. For station 203705, the reason for the water surface elevation discrepancies between the 10-year and 100-year discharge is unclear, but could be related to levee overtopping. This could be investigated further in the future.

Reach 4 is shown in Figure 31 and is the upstream end of Union, OR. The slope in this reach, 0.83%, is steeper than in Reaches 1, 2 or 3. The CCACF diversion acts as a control on the water surface, causing an increase of approximately half a foot in water surface elevation at all flood flows.  State Diversion also increases the water surface, ranging from a three to six inch increase depending on the flood.

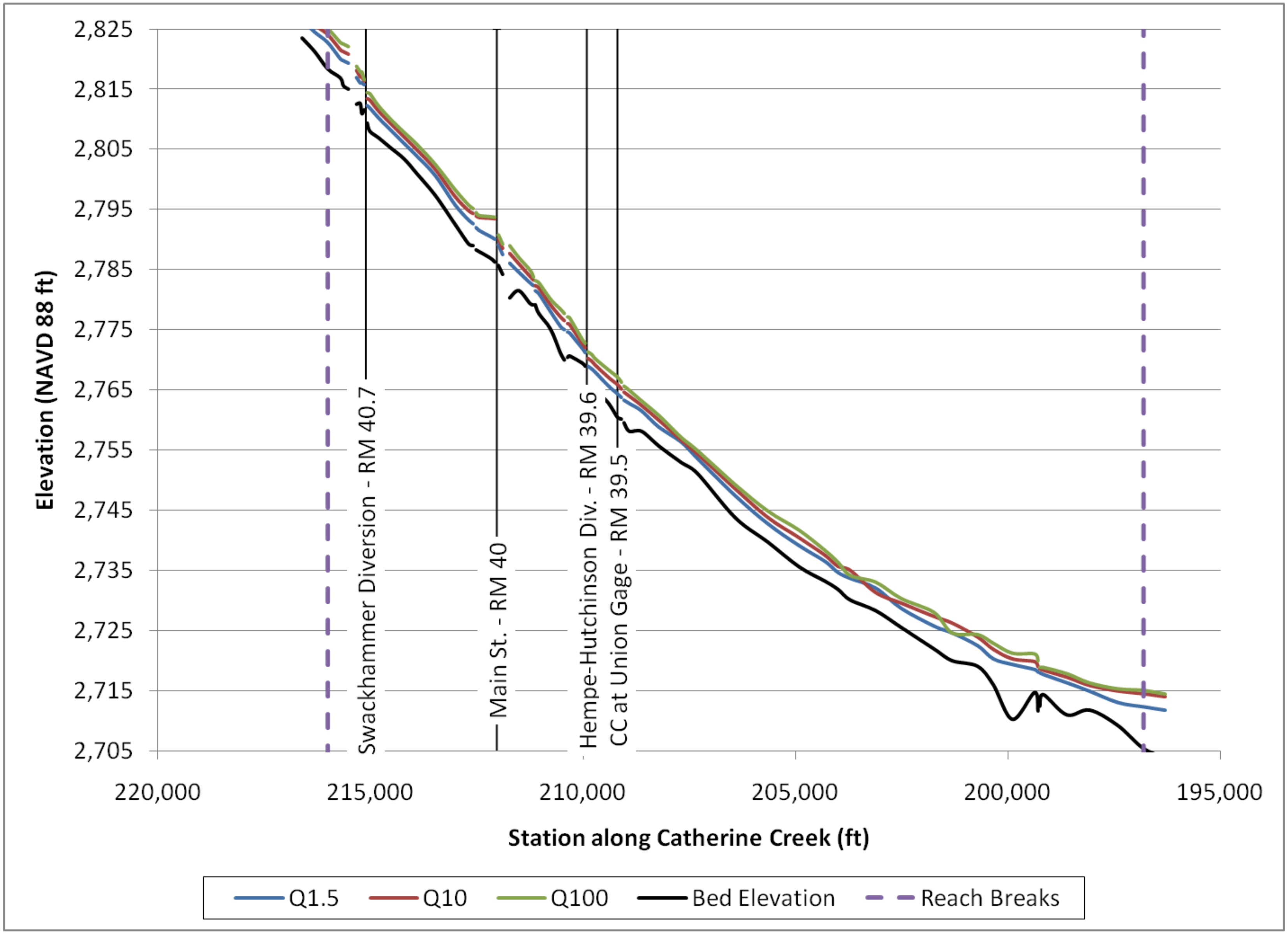


Figure 30. Computed water surface elevation for reach three on Catherine Creek.

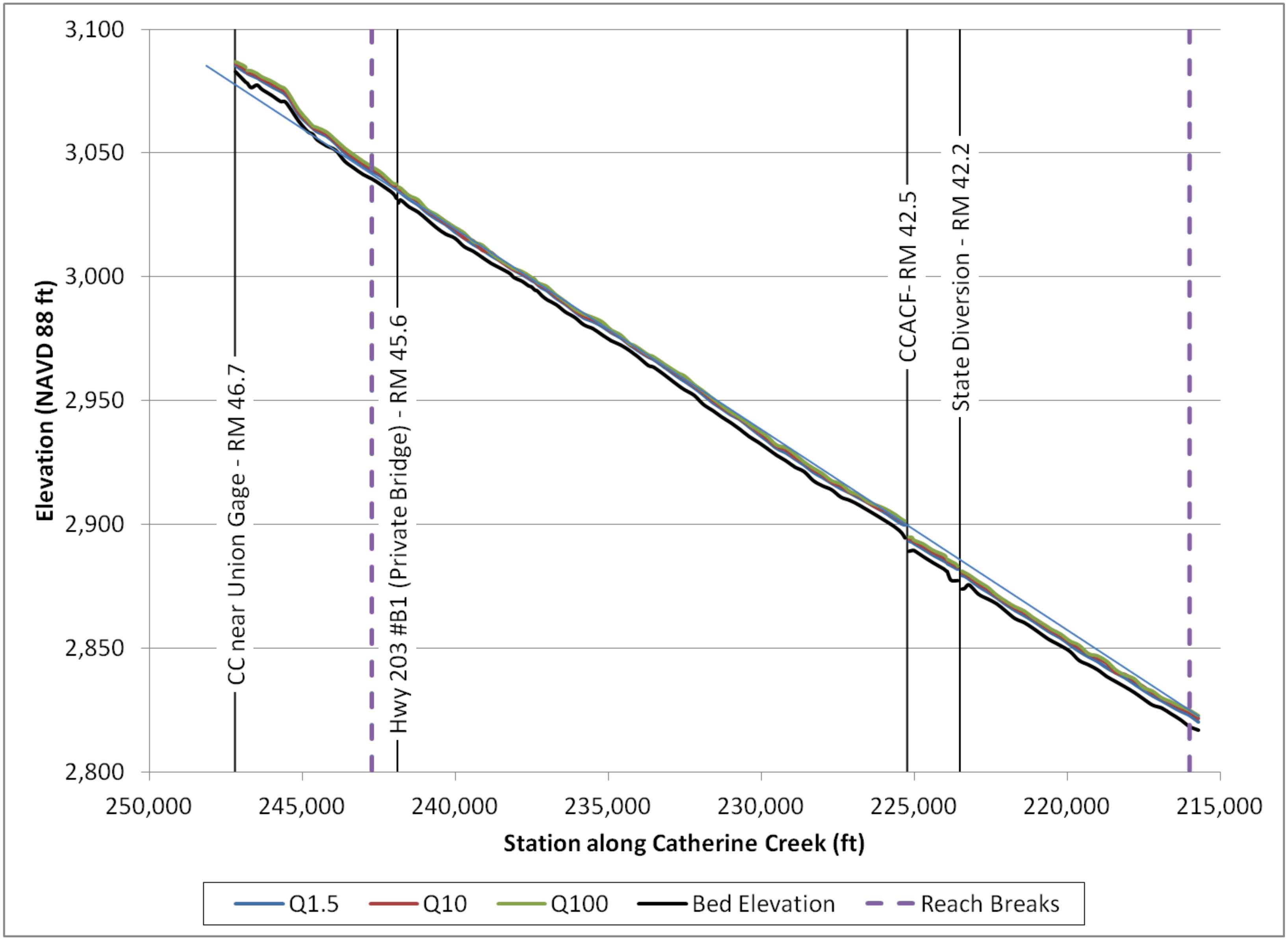


Figure 31. Computed water surface elevation for reach four on Catherine Creek.

## 4.2. Channel and Levee Capacity

### 4.2.5. Channel Capacity

Channel capacity was determined for each reach based upon the flow that overtops the channel banks as they are defined in the HEC-RAS model. Comparisons of channel bank elevations and water surface elevations for each reach are illustrated in Figure 32 to Figure 35. Using all high flow discharges evaluated, a histogram of the return period of the flood that overtops the bank elevation was used to define the most frequent channel capacity (Figure 36 to Figure 39). Within each reach, differences in capacity are expected due to the local topography of the cross section, the morphology of the reach (pool or riffle), and the user-defined bank and levee points. However, the reach-averaged conditions are useful in defining the discharge required to overtop most of the channel banks within the reach. Due to the length of the downstream reaches, some localized areas of higher or lower capacity may not be apparent in the reach-averaged conditions. More detailed analyses of the lower reach breaks could increase the resolution of the channel capacity.

Within Reaches 1 and 2, 63% and 55% of the cross sections have channel capacity equal to or below the 2-year discharge, respectively (Figure 36 and Figure 37). Within these reaches there are some spatial variations. The downstream five miles of Reach 1 appear to exceed the bankfull discharge on a more frequent basis than other portions of the reach. The upstream end of Reach 2 (upstream of Ladd Creek) generally has a higher capacity than the downstream end.

Within Reach 3, channel capacity at most cross sections is equal to or exceeds the 100-year discharge. Approximately 40% have a channel capacity between a 1-year and 50-year discharge and less than 30% of the cross sections have a channel capacity between a 1-year and 10-year discharge (Figure 38). A large portion of this reach is highly confined between artificial levees and high banks. In addition, the channel banks are coincident with the tops of levees in many of these cross sections, resulting in similarities between the channel and levee capacity.

Reach 4 channel capacity is most frequently between a 5-year and 10-year discharge. Sixty-five percent of cross sections have a channel capacity at or below the 10-year discharge, 42% of the cross sections have a capacity between the 5 or 10-year discharge(Figure 39).

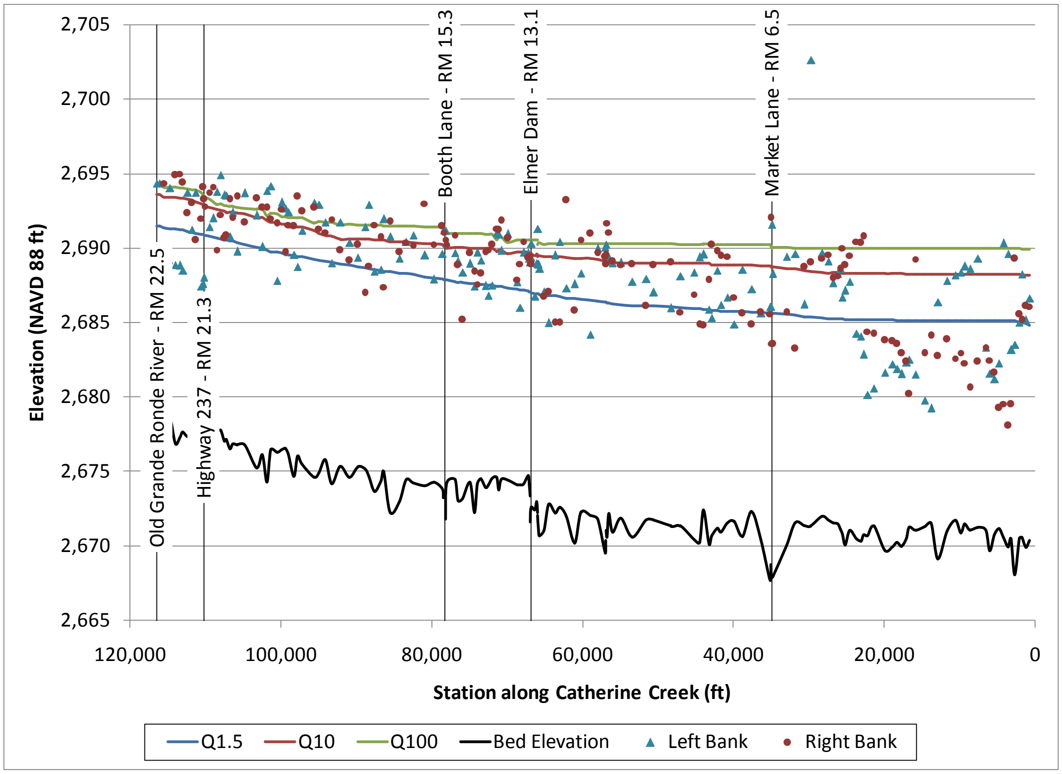


Figure 32. Comparison of bank elevations with flood discharges for Reach 1 of Catherine Creek.

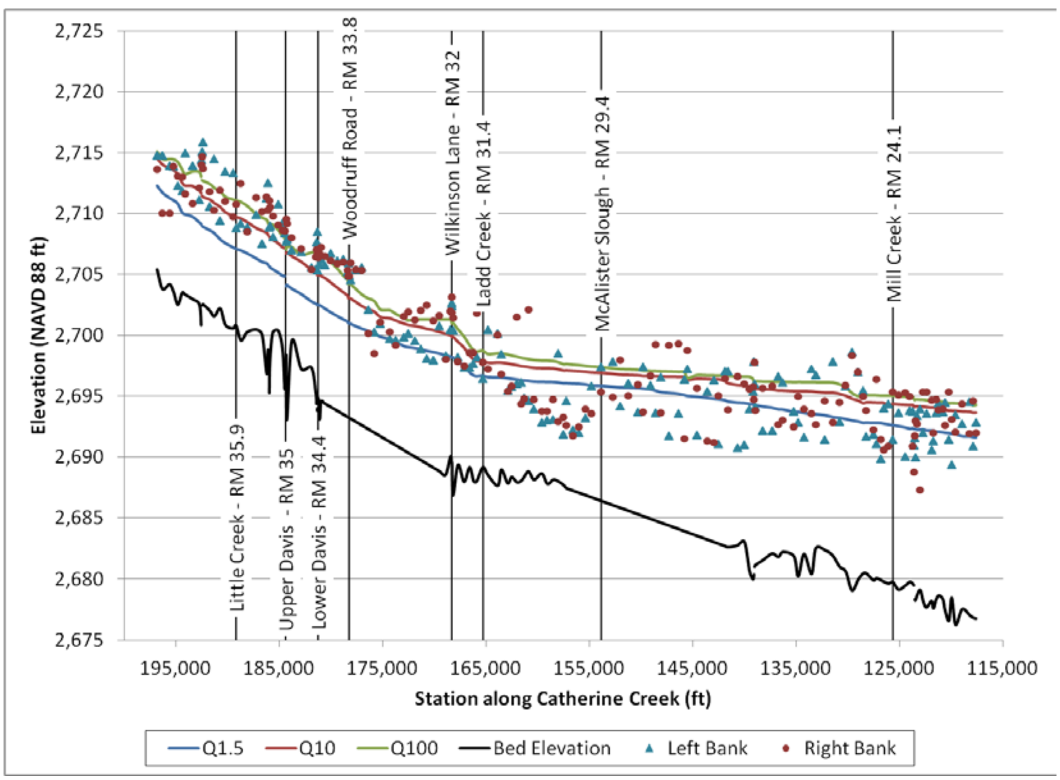


Figure 33. Comparison of bank elevations with flood discharges for Reach 2 of Catherine Creek.

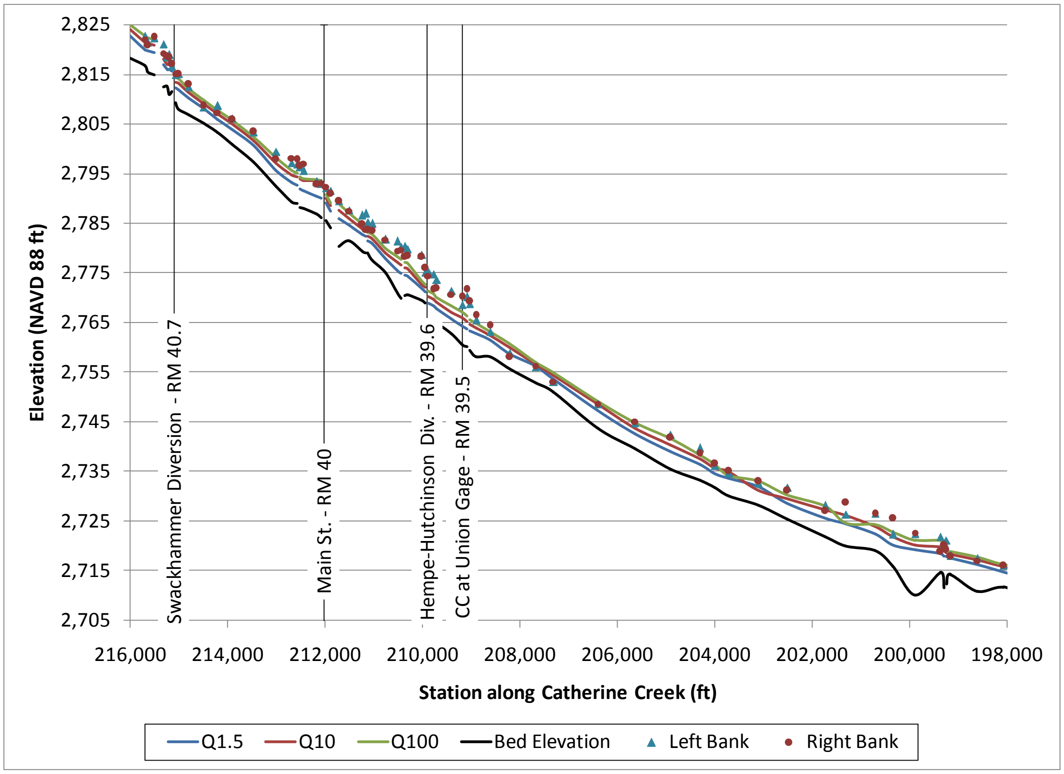


Figure 34. Comparison of bank elevations with flood discharges for Reach 3 of Catherine Creek.

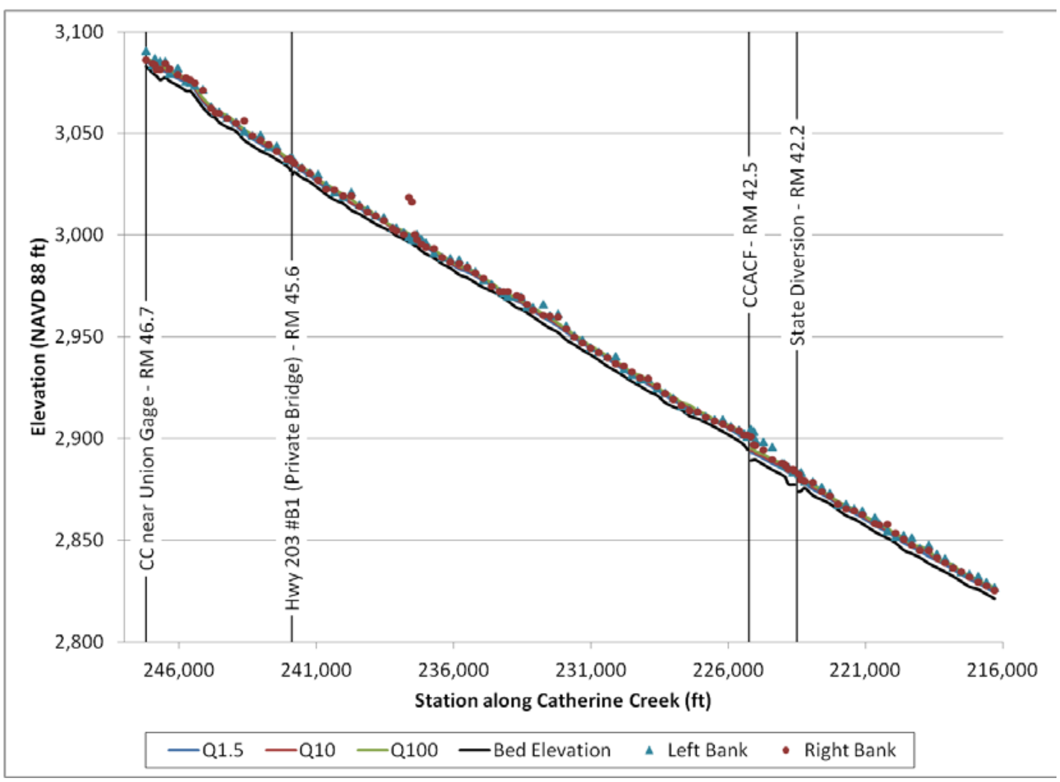


Figure 35. Comparison of bank elevations with flood discharges for Reach 4 of Catherine Creek.

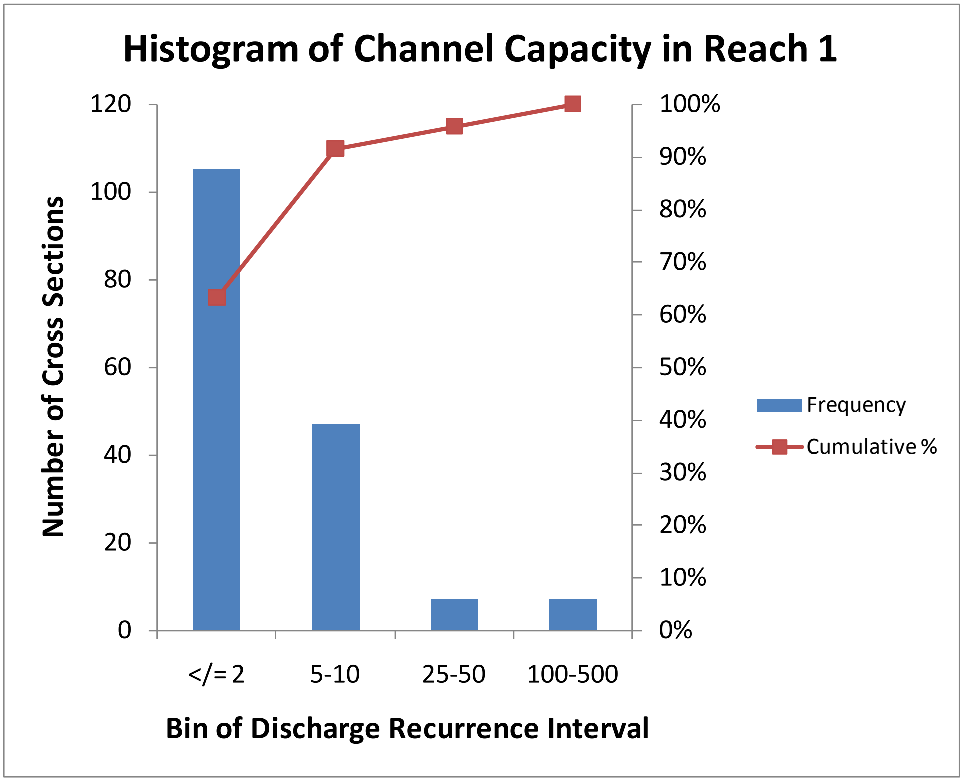


Figure 36. Distribution of channel capacity recurrence intervals for cross sections in Reach 1.

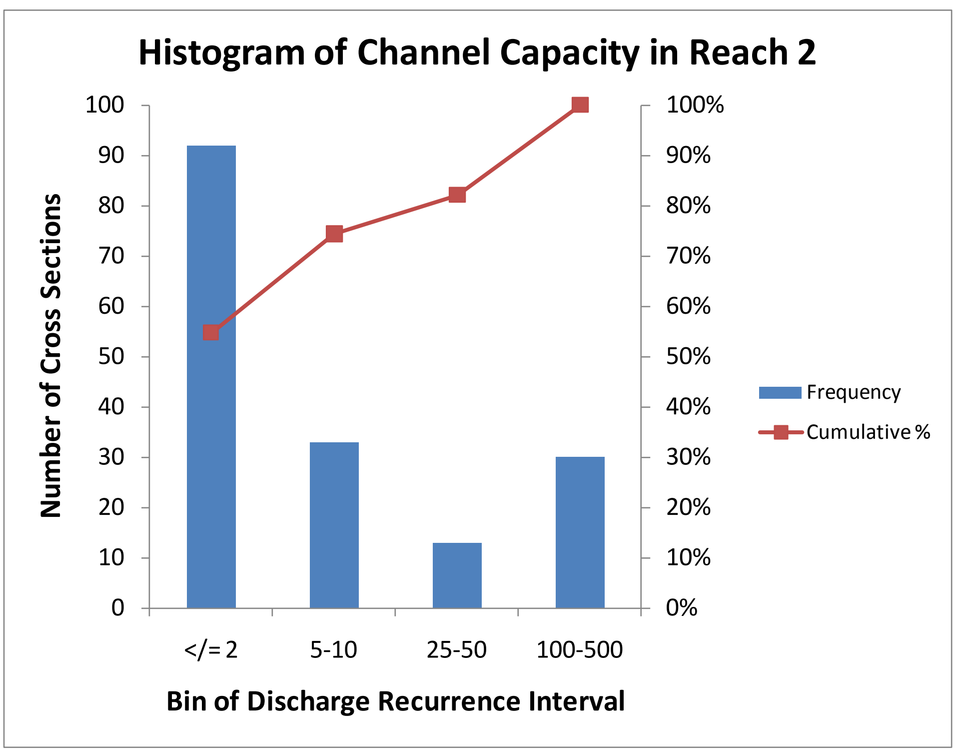


Figure 37. Distribution of channel capacity recurrence intervals for cross sections in Reach 2.

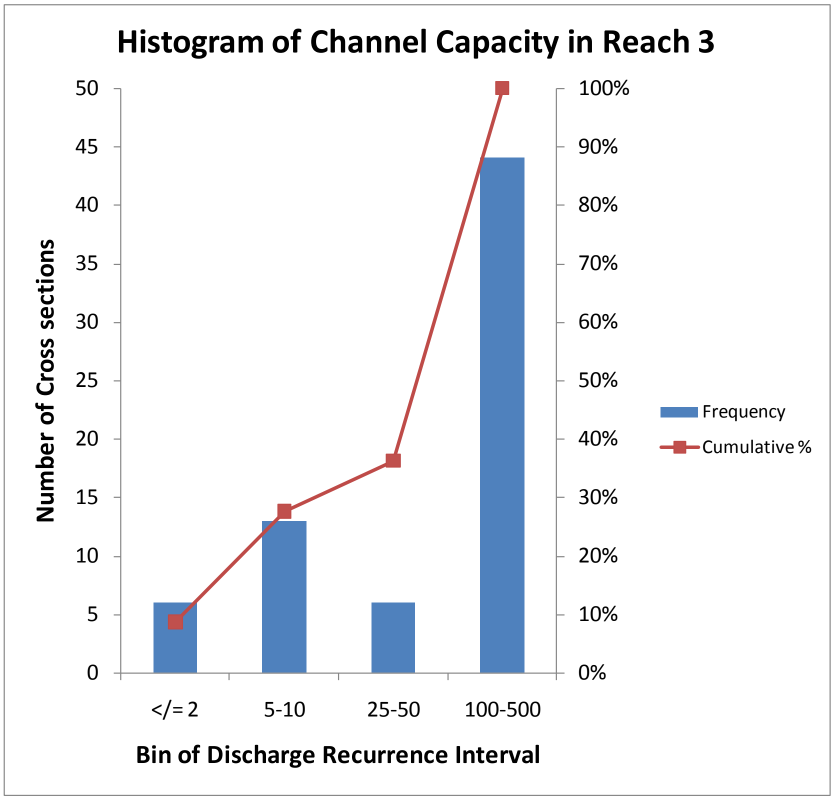


Figure 38. Distribution of channel capacity recurrence intervals for cross sections in Reach 3.

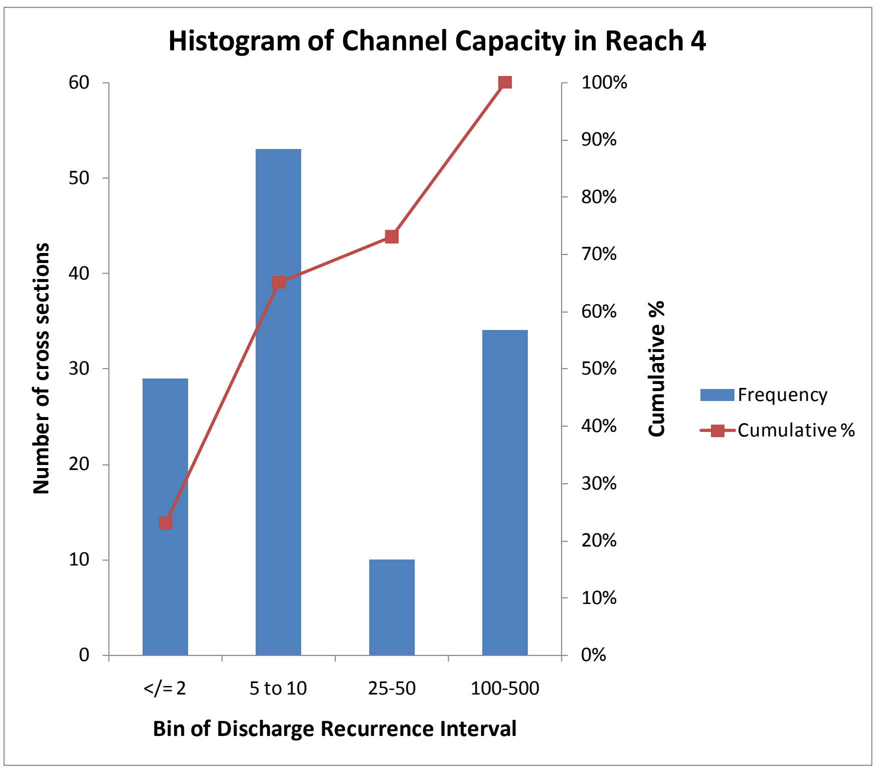


Figure 39. Distribution of channel capacity recurrence intervals for cross sections in Reach 4.

Bankfull discharge is similar to the channel capacity because it is a commonly used as a measure of the flow at which discharge begins to overtop the channel banks. However, bankfull stage is often determined based upon surveyed elevations of visual observations in the field indicating the top of bank, many of which are not purely topographic in nature. In this analysis, surveyed elevations of the bankfull elevation are not available, and instead channel bank elevations as determined in each cross section are utilized as a surrogate to the surveyed bankfull elevations. This surrogate allows for a rough approximation of expected bankfull conditions, but is not representative of the true bankfull stage as defined by Dunne and Leopold (1978).

Within Reaches 1 and 2, a more detailed investigation into the histograms for channel capacity was performed for flows with recurrence intervals ranging between 1.05 and 2.33 years (example shown in Figure 40). The distribution of discharges overtopping the channel banks within these reaches is sorted. High variability exists within the reaches and may warrant additional reach breaks at refined levels of analysis. For example, the downstream five miles of Reach 1 appear to exceed the bankfull discharge on a more frequent basis than other portions of the reach. While confidently describing Reaches 1 and 2 as having a specific discharge associated with the bankfull condition is difficult due to high variability, results indicate that over half of the cross sections in each reach have water surface elevations consistent with the channel banks at a 1.5-year discharge. Reach 3 and 4 bankfull discharge appears coincident with the channel capacity as described previously.

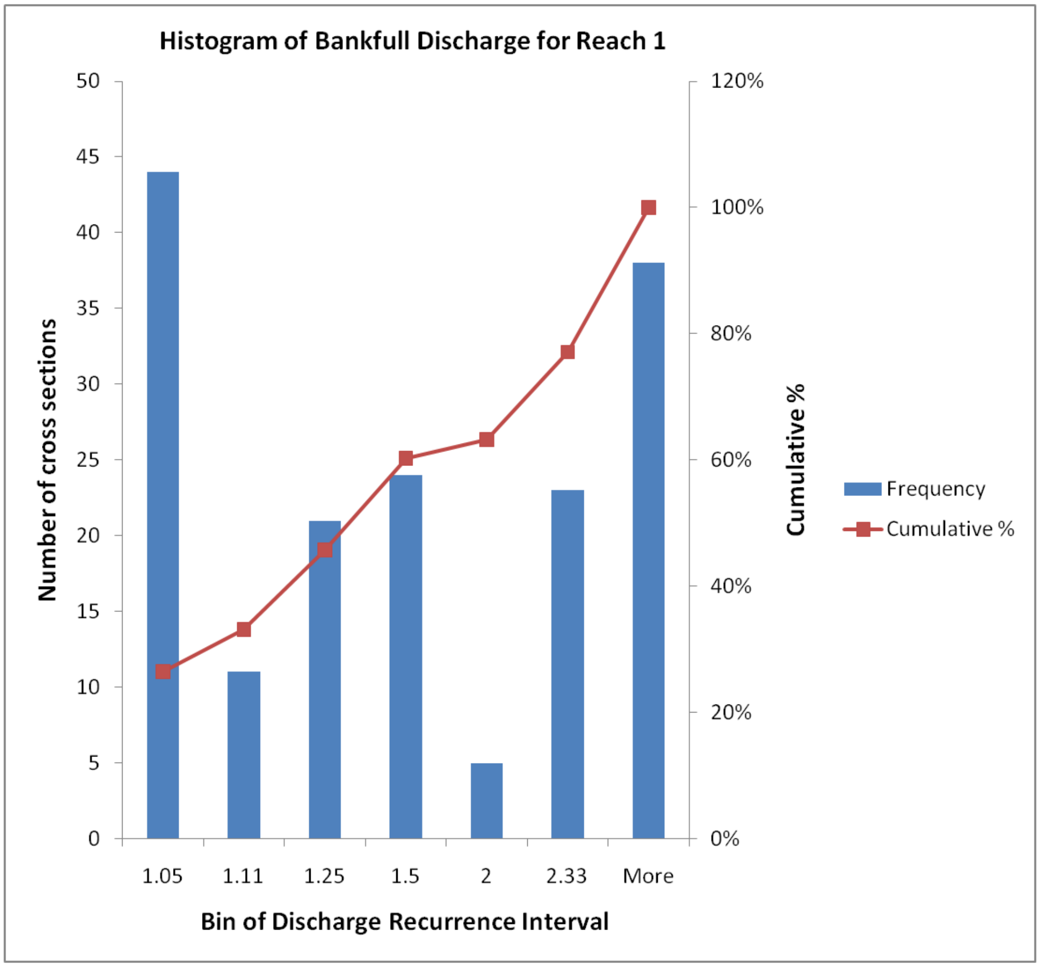


Figure 40. Plot of the distribution of bankfull discharges for cross sections in Reach 1.

### 4.2.6. Levee Capacity

Levee capacity was determined in each cross section by analyzing the flow that overtops the lower of the left or right levee. Cross sections had levees assigned where topographic features were present that prevented flows from accessing floodplain areas. In cross sections where a defined levee was not present, levee elements were often assigned in HEC-RAS to keep flow from accessing lower elevation floodplain areas without first filling the channel to capacity. The analysis of levee capacity includes all levees as assigned in HEC-RAS.

Each reach of Catherine Creek was investigated individually. Histograms indicating the distribution of cross sections at which flows begin to overtop the levees are provided in Figure 41 and Figure 42. Levees in Reach 1 are overtopped at the greatest frequency, with more than 80% of cross sections experiencing levee overtopping at discharges of 10-years or less. Levees at the downstream end tend to be overtopped on a less frequent basis than levees at the upstream end. A comparison of the water surface profiles and levees elevations for the left and right banks is shown in Figure 43 and Figure 44. Levees that correspond with the bank elevations are notable in the plots.

Levees in Reach 2 tend to be overtopped at less frequent recurrence intervals than Reach 1. Less than 40% of cross sections levee are overtopped at flows equal to or less than the 10-year discharge. Nearly 50% of cross sections indicate that levees are not overtopped until flows exceeding the 100-year discharge are experienced. In general, cross sections upstream of Ladd Creek (RM 31.4) require smaller discharges to overtop the levees. Comparisons of the levee elevations and the water surface profiles for Reach 2 are shown in Figure 45 and Figure 46.

Within Reach 3 and 4, levees are typically not overtopped at flows less than 50-year discharge. More than 70% of cross sections in each reach do not experience levee overtopping at flows less than the 500-year discharge. A comparison of Reach 3 levee elevations and water surface elevations is shown in Figure 47. Localized areas of more frequent overtopping may be present, but more detailed investigations of individual reaches is necessary to identify specific locations of levee overtopping.

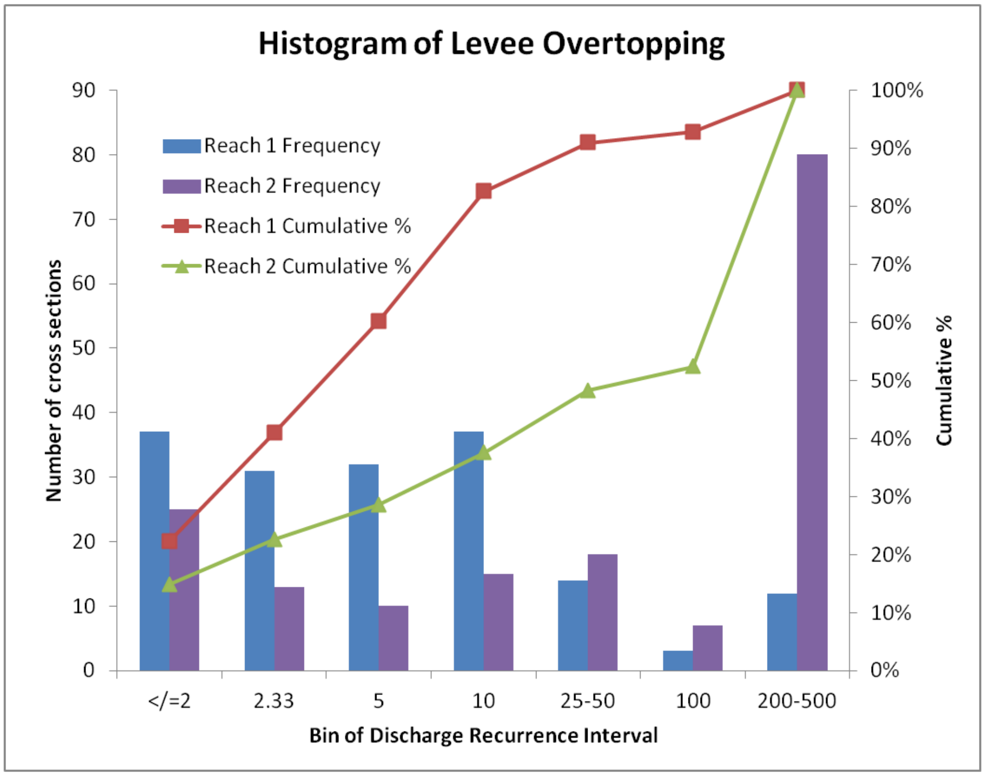


Figure 41. Distribution of the number of cross sections overtopping levees at specific recurrence interval discharges within Reaches 1 and 2.

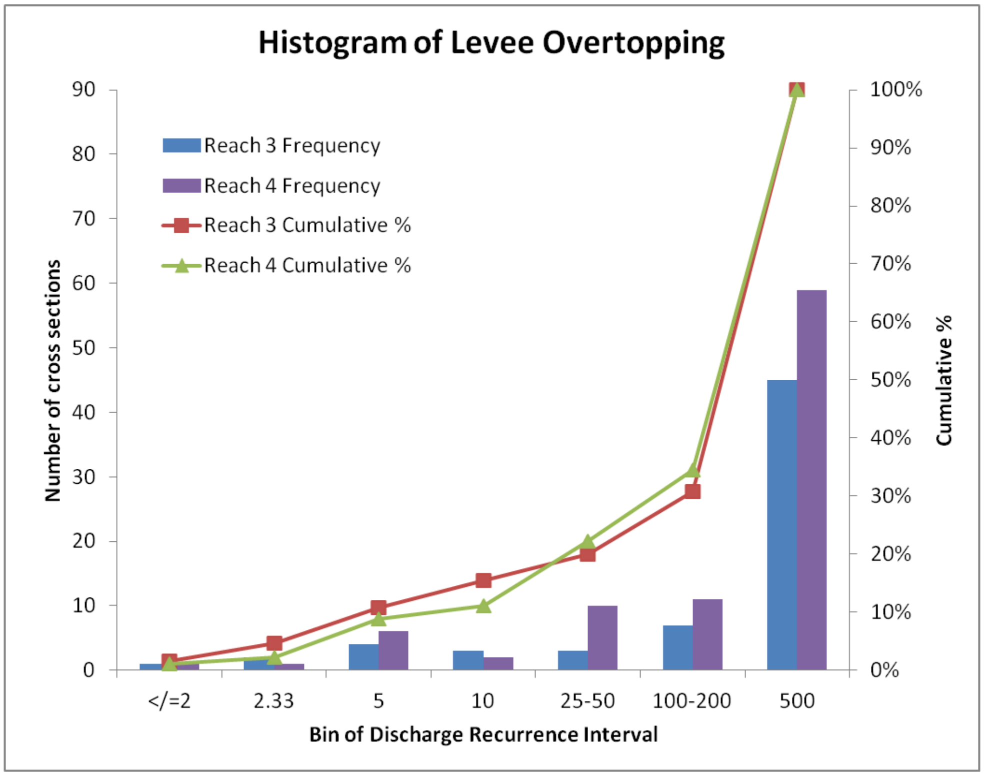


Figure 42. Distribution of cross sections overtopping levees at specific recurrence interval discharges within Reaches 3 and 4.

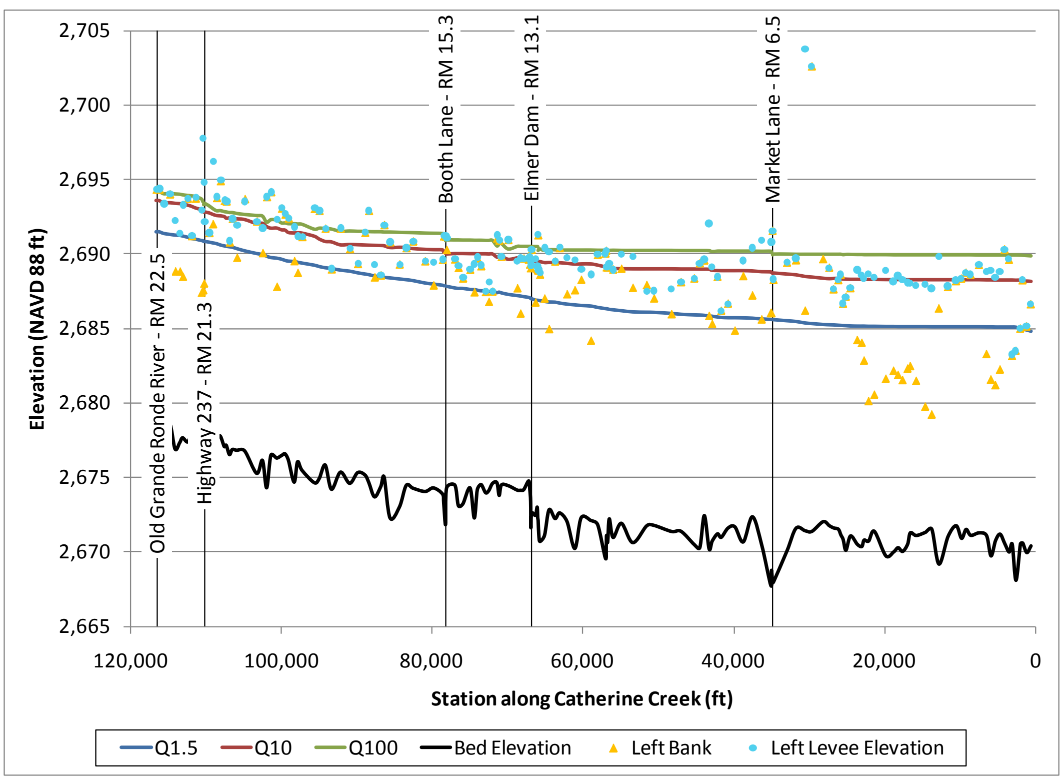


Figure 43. Reach 1 water surface profiles compared with levee and bank heights along the left bank.

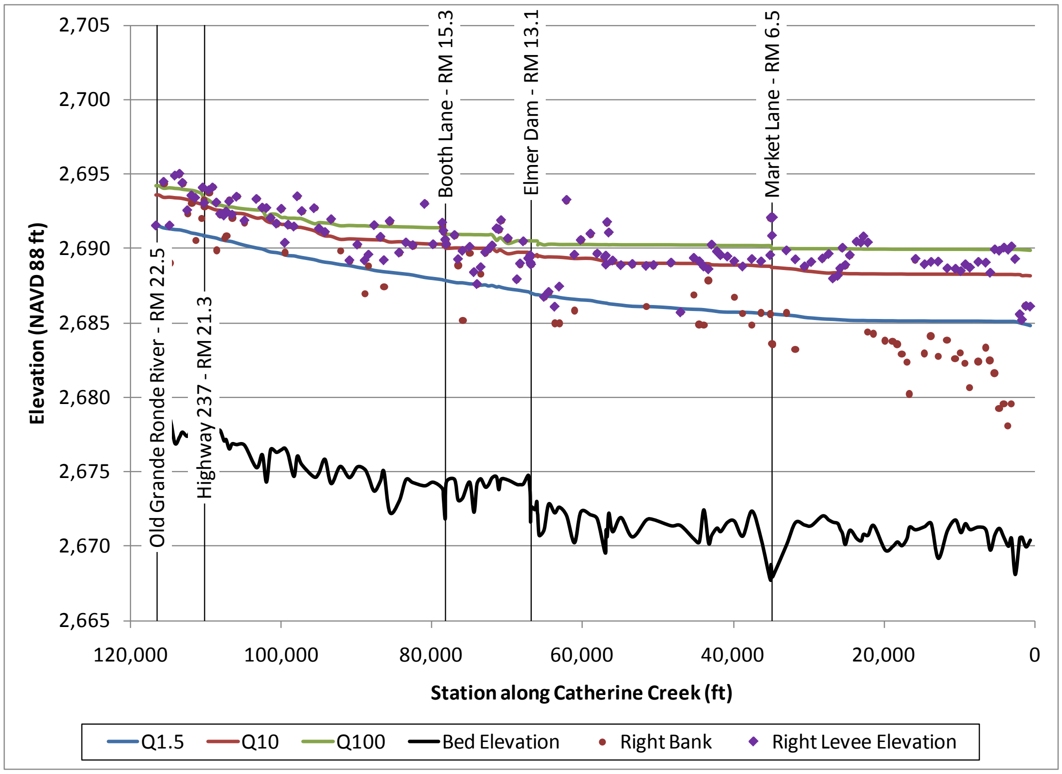


Figure 44. Reach 1 water surface profiles compared with levee and bank heights along the right bank.

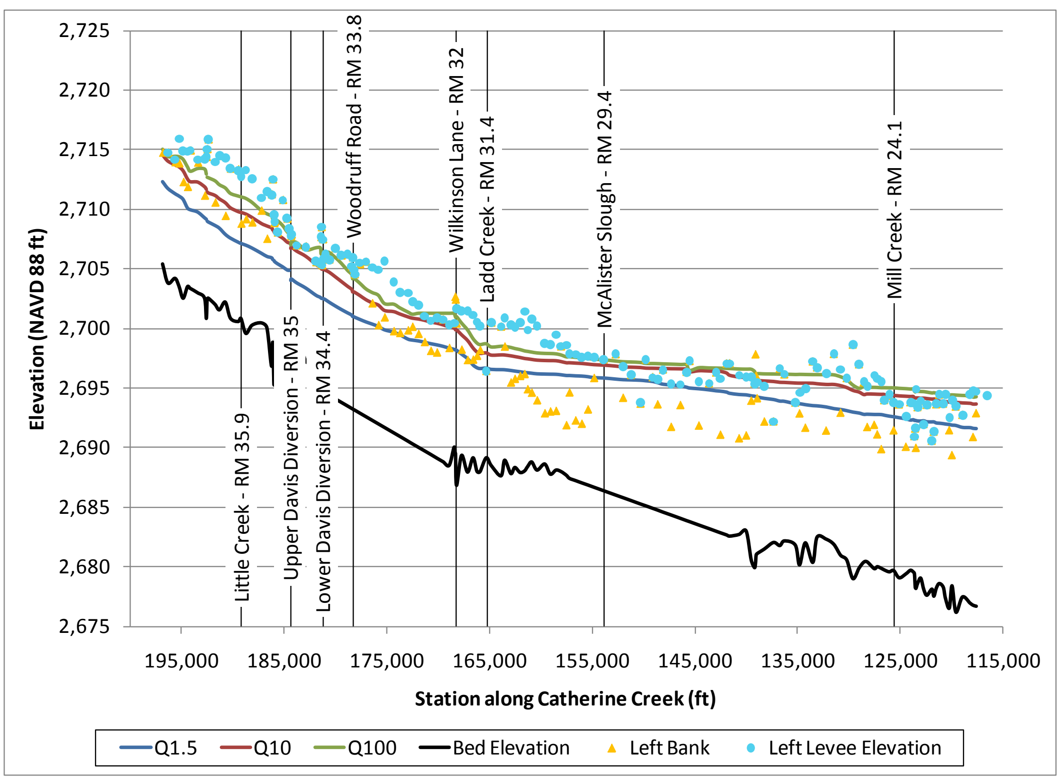


Figure 45. Reach 1 water surface profiles compared with levee and bank heights along the left bank.

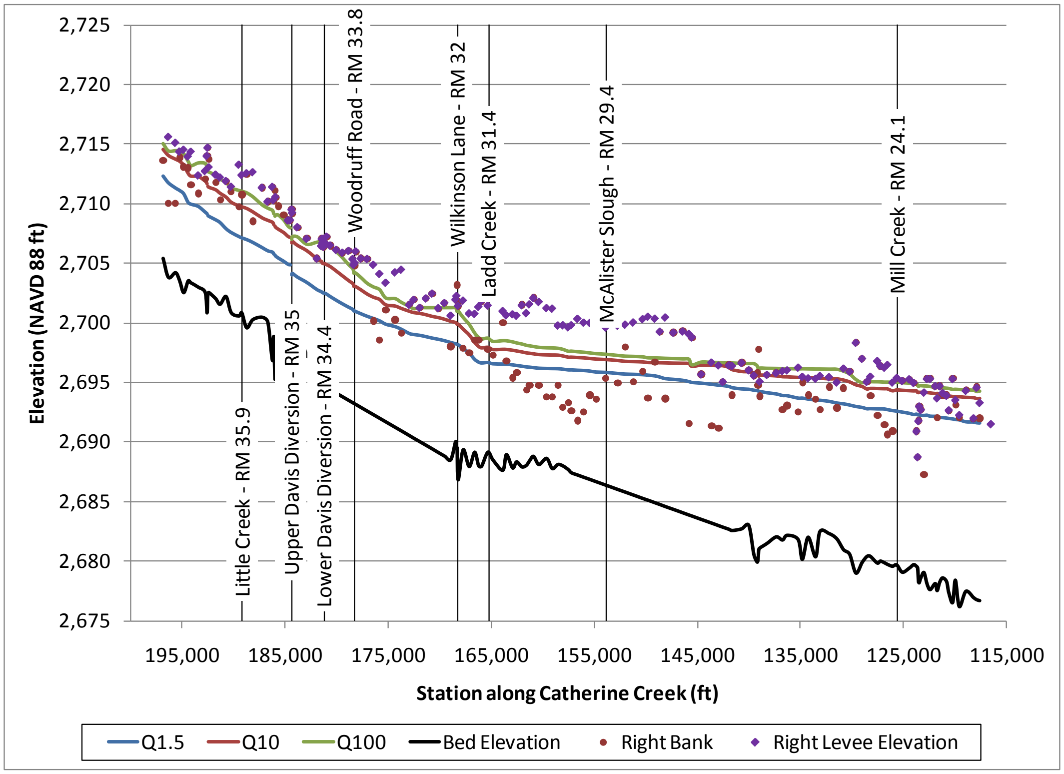


Figure 46. Reach 2 water surface profiles compared with levee and bank heights along the right bank.

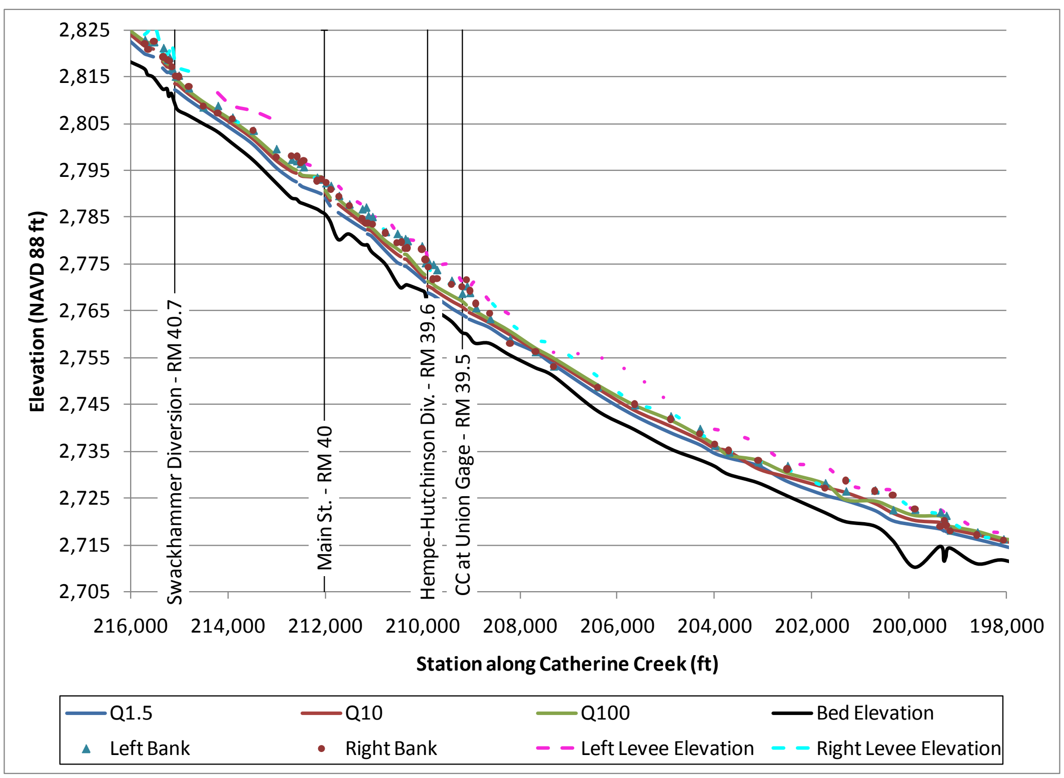


Figure 47. Reach 3 water surface profile compared with levee elevations.

## 4.3. Flood Depth Maps

Maps were developed to illustrate depths of potential flooding within the bounds of the modeled cross sections for the 100-year discharge. Figure 48 shows an example of an area where the flow was out of bank. A full suite of maps illustrating depths within the cross section boundaries are shown in Attachment A.

The process used to create the maps included creating a TIN of the water surface elevations derived from the HEC-RAS model for the 100-year discharge, subtracting the water surface TIN from the terrain models, and manually adjusting the wetted areas to account for the effects of levees or other high points in the terrain that would prevent water from reaching certain overbank areas.  Areas that were not directly connected to the channel, i.e. “islands” of water, were removed from the inundation mapping since there was no direct pathway for the water to reach these locations. In addition, wetted areas outside of the cross section extents were removed since the accuracy of the inundation in these areas is uncertain.

The impacts of the levees were investigated in more detail.  If a levee was overtopped by at least one foot of water, the area behind the levee was not manipulated and was permitted to remain flooded. Flow was allowed to inundate the area both upstream and downstream of the point of overtopping to the extent of the cross section unless another feature was present within the cross section that prevented inundation. As a result, water surface elevations are likely overestimated since the volume of water available to inundate an area was assumed to be infinite.  The area behind a levee was not included as a possible inundation area if a levee parallel to the river was not overtopped by at least one foot, and an upstream and downstream road or levee perpendicular to the river was not overtopped by one foot (essentially enclosing an area). Levees directly adjacent to the channel and further out in the floodplain were considered. Although the valley is very flat, a 1-foot criterion was selected for overtopping because the volume of water required to submerge the areas behind the breached levees is large. Actual depths of inundation are highly uncertain behind levees because the model is a steady state 1D model, and flood storage impacts within the floodplain are not simulated.

Several limitations apply to the depth maps. First, the spatial extent of the flooding was restricted to the extent of each cross section. However, actual inundated areas during a 100-year discharge may extend several miles beyond the length of the cross section.  Therefore, these maps may not represent the likely extent of a100-year flood. Backwater areas included in the maps may not have water at the location and depth indicated. Although attempts were made to capture hydraulic controls in selecting placement of the cross sections, the model can not accurately predict levee overtopping between cross sections.  The wetted areas presented in the maps provide potential depths of flow as constrained by the 1D modeling effort limitations. To evaluate inundation outside of levees for various discharges, additional data are needed. First, topographic data beyond the terrain models could be collected extending to the valley walls. This would allow for a separate model with cross sections extending across the entire valley and spaced at a greatly reduced frequency from the present model. Finally, an unsteady flow model would be needed to evaluate flood storage impacts, and unsteady two-dimensional models would improve understanding of lateral flood processes and flow patterns between cross sections.

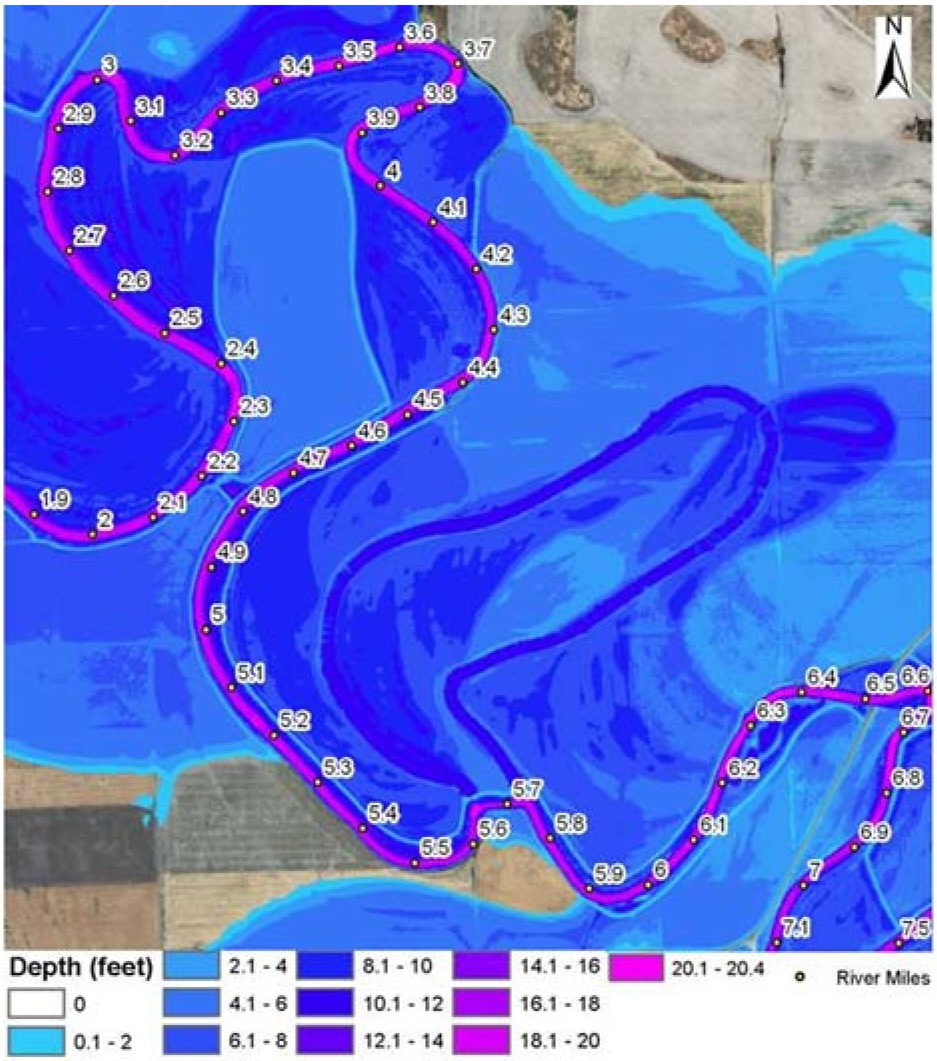


Figure 48. Potential flooding depths within the bounds of the modeled cross sections for the 100-year discharge in a portion of Catherine Creek Reach 1.

### 4.3.5. Oxbow Inundation

Eighteen disconnected oxbows were delineated on Catherine Creek between RM 0 and RM 39. An oxbow was selected for delineation if it appeared cut-off from the main channel but frequently inundated. For each oxbow, the closest upstream cross section was examined. In that cross section, the levee elevation was determined and the flood frequency discharge at which the levee was first overtopped was recorded. Although the levee elevation in the upstream cross section may not be the same elevation as the levee right at the location of the oxbow, it was assumed that if flow overtopped a levee just upstream, it was likely to inundate the oxbow as well. Table 10 below provides a location of each oxbow and the stage and discharge that overtopped the closest upstream cross section.

Table 10. Description of disconnected oxbows and the discharge recurrence interval that causes overtopping.

| **River Mile** | **Bank** | **Discharge recurrence interval (yr)** | **Water surface elevation of upstream cross section at overtopping flow** |
|---:|---|---:|---:|
| 5.7 | Right | 25 | 2689.2 |
| 6.6 | Right | 25 | 2689.4 |
| 8.5 | Right | 100 | 2690.2 |
| 10.2 | Right | 1.5 | 2686.1 |
| 13.2 | Left | 10 | 2689.7 |
| 13.7 | Left | 10 | 2689.9 |
| 14 | Left | 1.5 | 2687.5 |
| 14.8 | Right | 5 | 2689.9 |
| 16.3 | Left | 2.33 | 2689.5 |
| 17.5 | Right | 2 | 2689.5 |
| 19.6 | Right | 25 | 2692.0 |
| 23.4 | Left | 1.25 | 2691.4 |
| 23.6 | Left | 5 | 2693.9 |
| 25 | Left | No overtopping | NA |
| 26.7 | Left | 25 | 2696.1 |
| 27.1 | Left | No overtopping | NA |
| 37 | Right | No overtopping | NA |
| 38.1 | Left | No overtopping | NA |

There are five oxbows (RM 10.2, 14, 16.3, 17.5, and 23.4) where there is likely to be overtopping at less than a five year flood. Oxbows at RM 16.3 and RM17.5 are shown in Figure 49. Figure 50 shows the oxbow at RM 14. Four of these oxbows are located in Reach 1, and one is in Reach 2. These oxbows are of the greatest concern for fish stranding since they are most frequently overtopped. The greatest frequency at which a flood overtops an oxbow is 1.25 years. Based on this result, the delineated oxbows are not overtopped by non-flood flows, and flooding of the oxbows may only occur once or twice per year. However, the entrance and exit conditions of the oxbow connections were not closely evaluated to determine if fish passage into or out of the oxbows by means other than overtopping is possible.

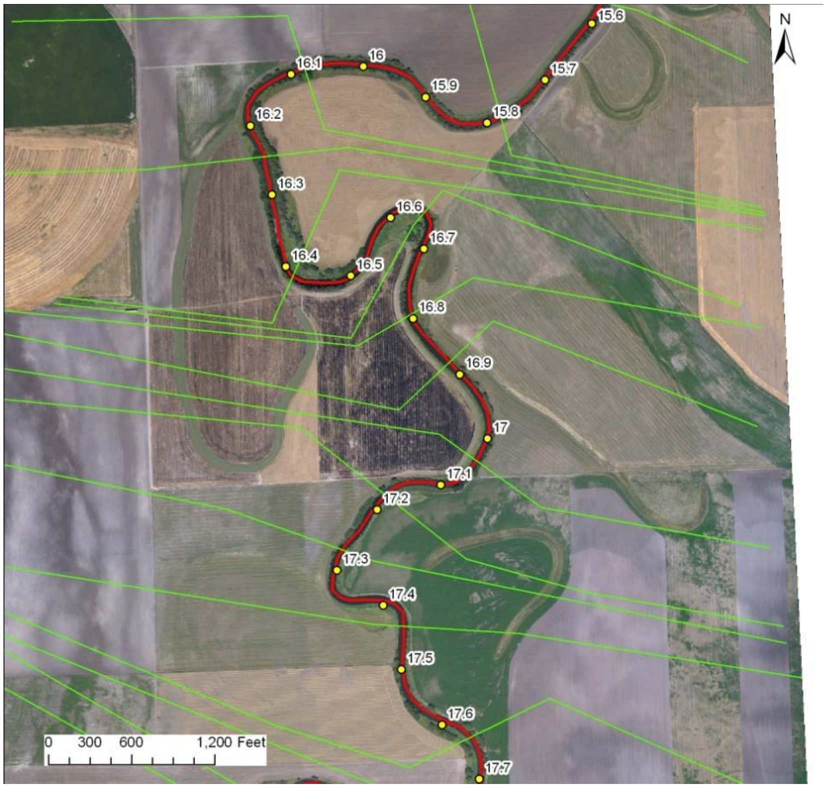


Figure 49. Oxbows at RM 16.3 and RM 17.4 that are inundated by the 2.33 and 2 year floods respectively.


Figure 50. Oxbow at RM 14 that is inundated by the 1.5- year flood.

The Old Grande Ronde River confluence is also an area that can be overtopped, experience backwater conditions, and provide a potential fish stranding concern. A levee exists where the Old Grande Ronde River was disconnected from Catherine Creek. In addition, there is a levee that extends along the eastern side of the Old Grande Ronde River (Figure 51). Based on the levee elevation surrounding the Old Grande Ronde River, the levee would be overtopped with a 1.5-year flood. The Old Grande Ronde river channel geometry and confluence were not included in the HEC-RAS model. Therefore, information regarding storage or extent of flow backwatering into the Old Grande Ronde River is not available.

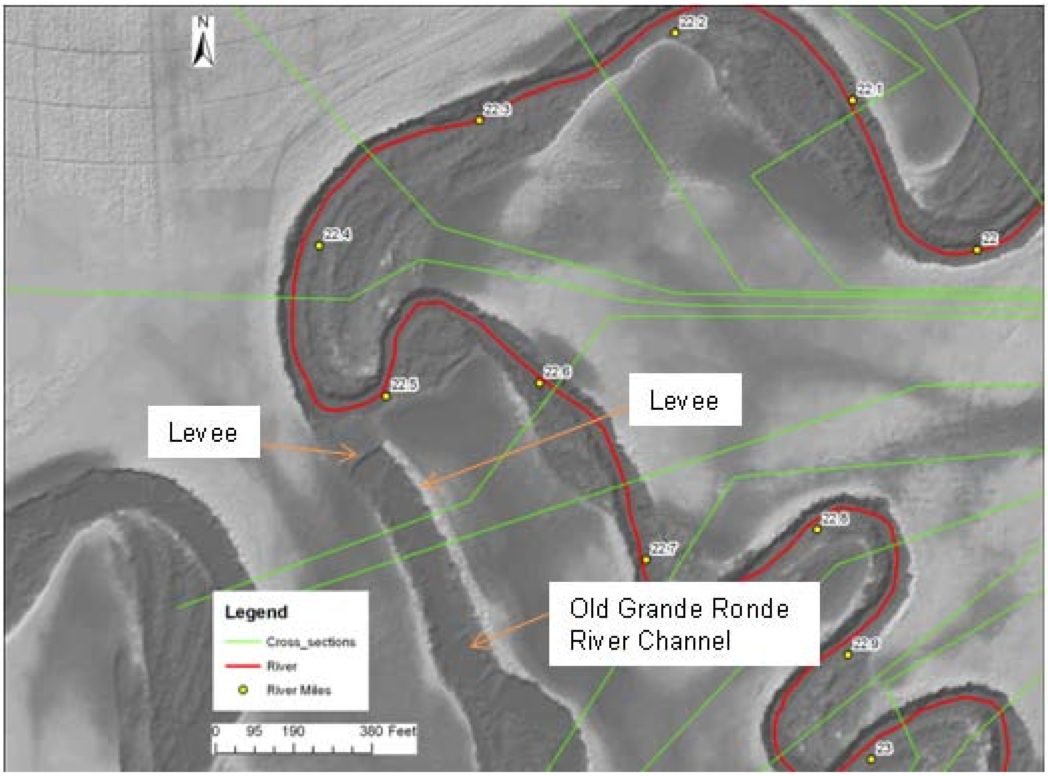


Figure 51. Existing elevation at Old Grande Ronde River confluence with Catherine Creek.

## 4.4. Velocity

Results for computed cross-section averaged in-channel velocities at the 1.5-, 10-, and 100-year discharges are presented in Figure 52 through Figure 55. In Reach 1 (Figure 52), velocities are fairly constant across all flood flows presented (approximately 1.3 ft/sec). This is likely because flows get out of bank at low elevations, and therefore at higher floods, the velocity does not increase because the amount of flow in the channel is not greater. Reach 2 (Figure 53) shows similar results of velocities being fairly constant (approximately 1.7 ft/sec) with increasing discharge until Ladd Creek. The velocities become more stratified (higher velocities for greater discharges) upstream of Ladd Creek. The reach-averaged velocity increases from approximately 2.7 ft/sec for the 1.5-year flood to 3.3 ft/sec for the 100-year flood.

In Reach 3 (Figure 54), the channel velocity increases to approximately 4.6 ft/sec for the 1.5 year flood to 6.6 ft/sec for the 100-year flood. In addition, the flow is staying in the channel at greater discharges so the velocities are increasing with greater discharges. Velocities in Reach 4 (Figure 55) act similarly to velocities in Reach 3 whereby velocity increases with discharge. The reach-averaged velocity is slightly higher in Reach 4 at approximately 4.8 ft/sec for the 1.5 year flood to 6.7 ft/sec for the 100-year flood.

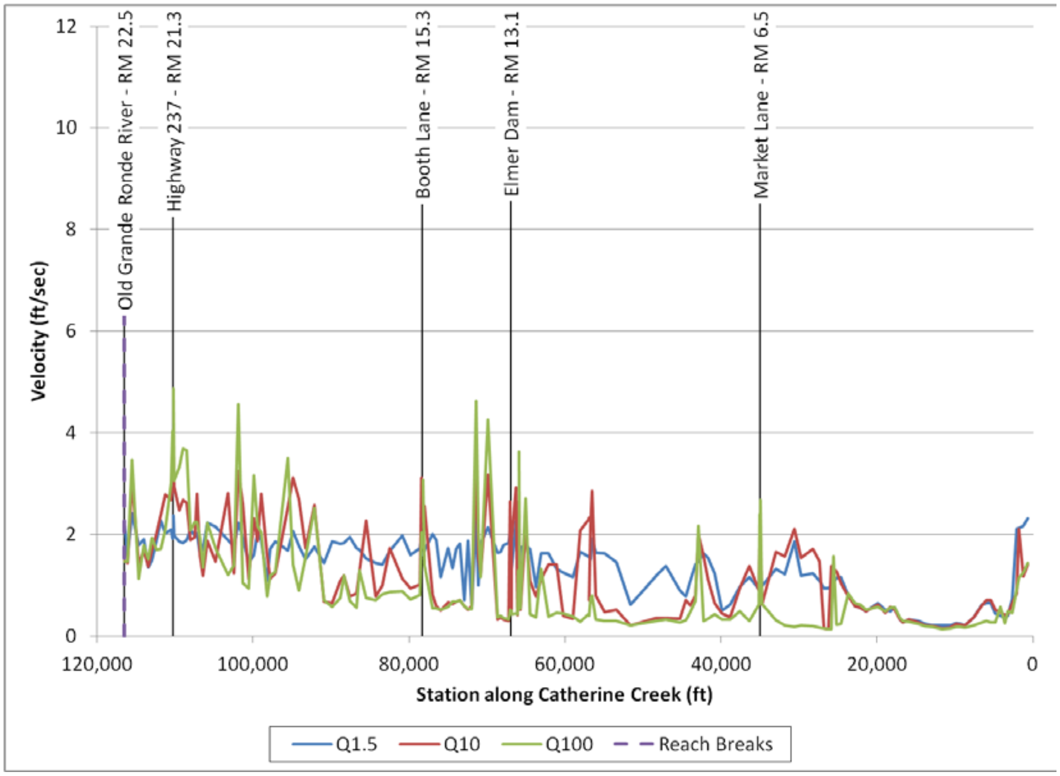


Figure 52. Computed cross-section average in-channel velocity for Reach 1 on Catherine Creek.

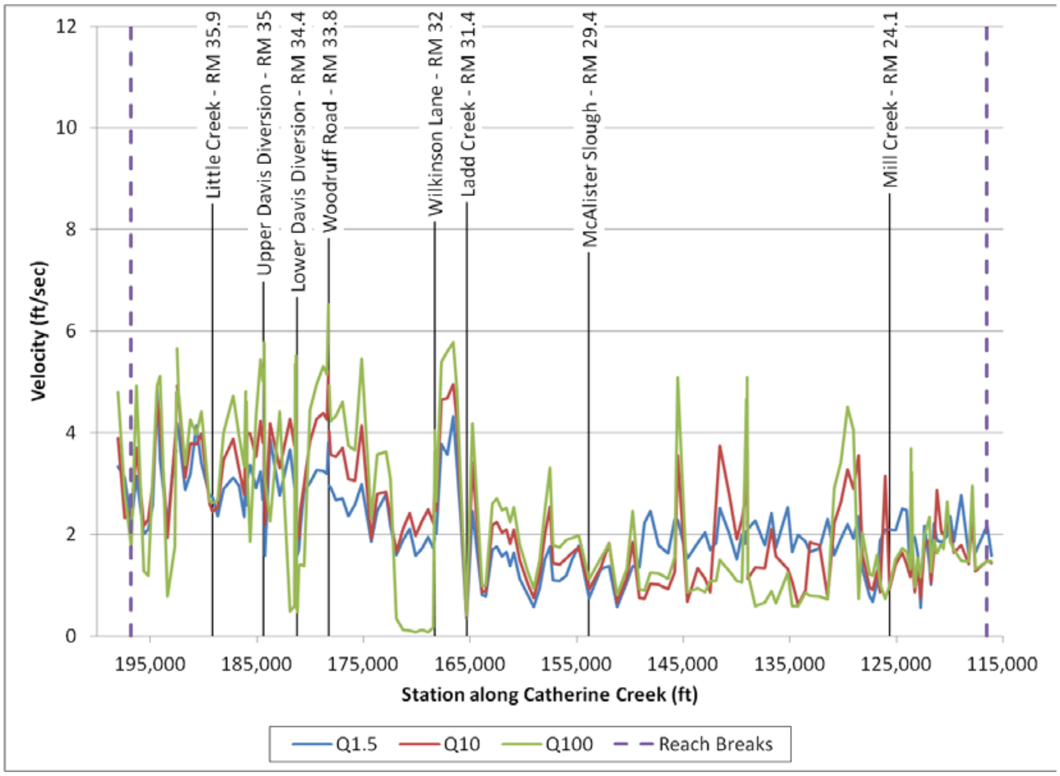


Figure 53. Computed cross-section average in-channel velocity for Reach 2 on Catherine Creek.

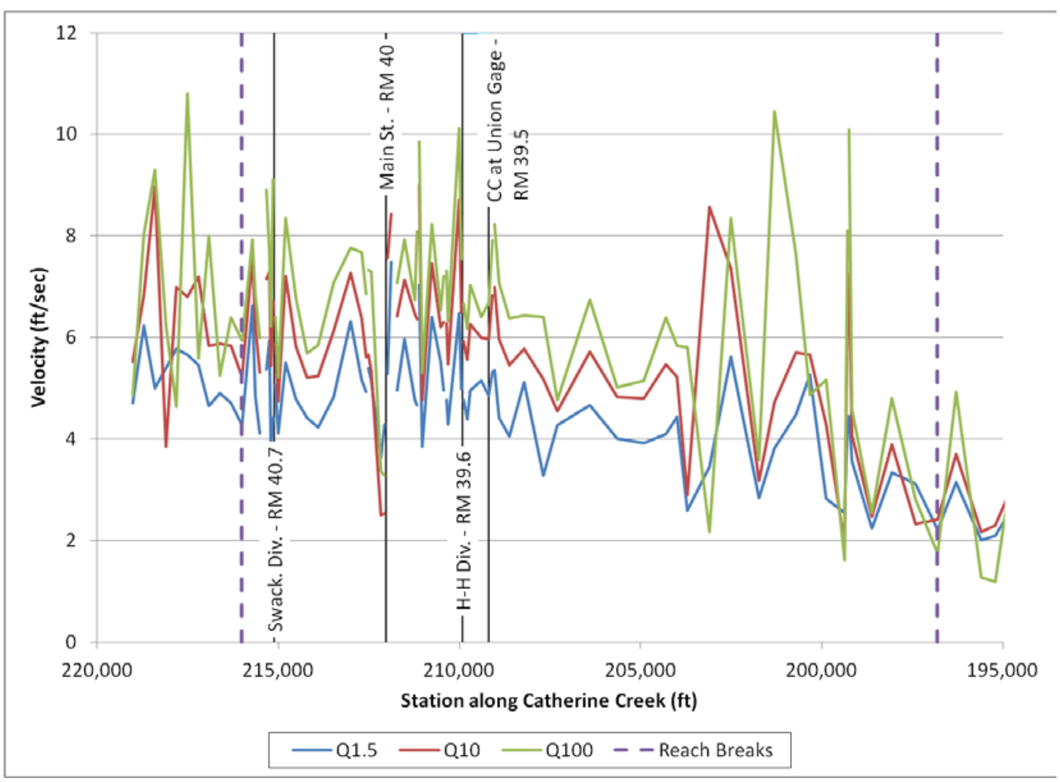


Figure 54. Computed cross-sectional average channel velocity for Reach 3 on Catherine Creek.

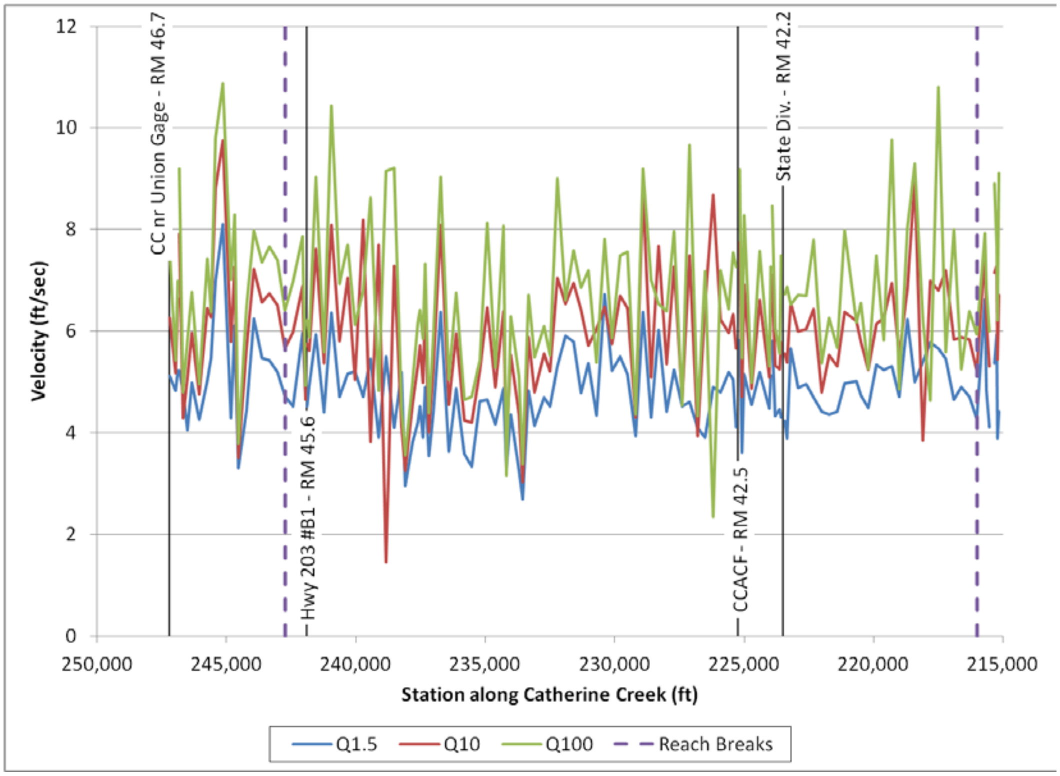


Figure 55. Computed cross-section average in-channel velocity for Reach 4 on Catherine Creek.

## 4.5. Shear Stress

In Figure 56 the in-channel shear stress was averaged for each reach on Catherine Creek. The shear stress for Reaches 1 shows no significant change with discharge. This is likely due to flow getting out of bank at low flood frequencies. There is a slight increase with discharge in Reach 2. Reaches 3 and 4 do show larger increases in shear stress for increases in discharge. This is caused by more flow staying in the channel at greater discharges. The magnitude of the in-channel shear stress much smaller in Reaches 1 and 2 than in Reaches 3 and 4. Although the reach-averaged shear stress provides an overview of what is happening in channel, high variability is present within the reaches. As an example, Figure 57 shows the variability of shear stress among cross sections in Reach 4.

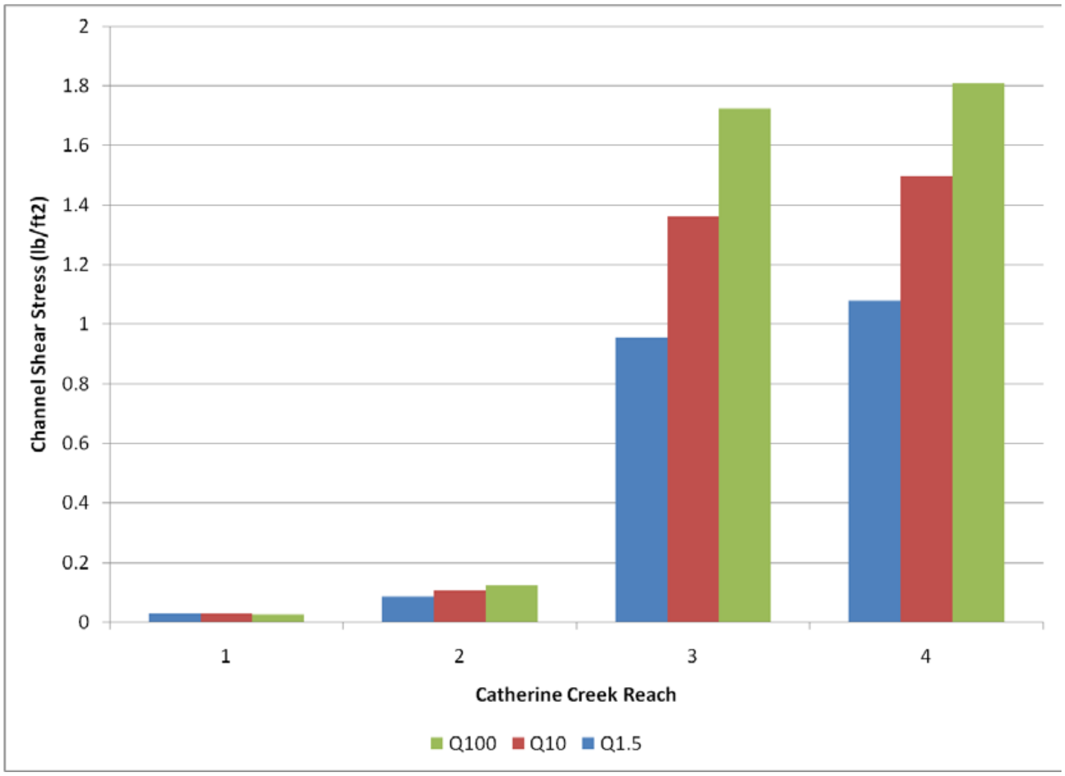


Figure 56. Reach averaged channel shear stress on Catherine Creek.

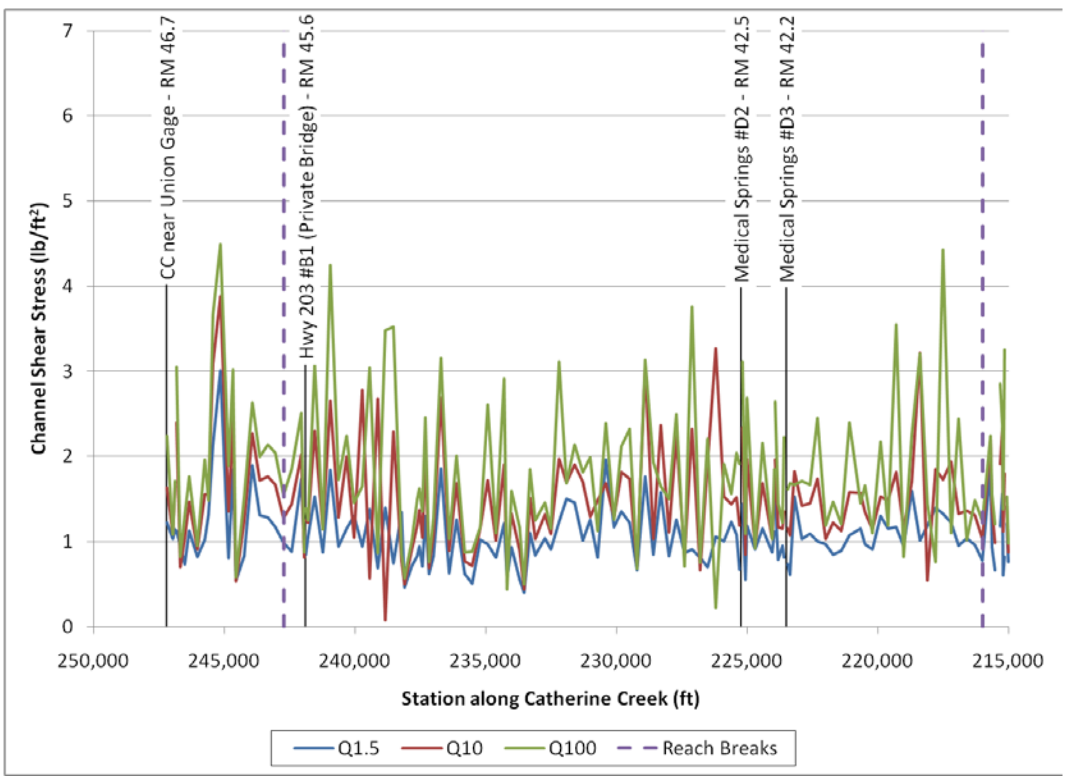


Figure 57. Channel shear stresses in Reach 4 on Catherine Creek.

# 5. Discussion and Summary

Hydraulic modeling conducted for this assessment provides a large-scale evaluation of impacts to flood processes along the Grande Ronde River and Catherine Creek. The information presented in this report documents current reach-averaged channel and levee capacities, velocities, and shear stresses that are experienced during floods on Catherine Creek. Results from the modeling effort can be used to verify hypotheses related to other disciplines, such as biology, geomorphology, and vegetation, and can be integrated with other disciplines to form conclusions related to flooding potential and resultant impacts to habitat.

## 5.1. Hydraulics Related to Flooding and Potential Habitat Impacts

Patterns in hydraulic properties of Catherine Creek help evaluate flood processes, including the potential for inundation of lands adjacent to channel. From upstream to downstream, in-channel velocities and shear stresses tend to decrease under current conditions. This corresponds to changes in valley confinement, channel slope, and sediment sizes. Upstream Reach 4 is situated in a narrow valley with a slope of approximately 0.83%, while the downstream-most reach of Catherine Creek, Reach 1, is in an expansive and flat valley floor with an average channel slope of 0.006%. Because of the wide, flat valley and channel, the natural potential for flooding of adjacent lands is much greater in Reaches 1 and 2 than in Reaches 3 and 4. With the installation of levees, the potential for flooding changes from pre-settlement conditions in association with the hydraulics between the levee bounds. Hydraulic modeling predicts that levee overtopping typically does not occur in Reaches 3 and 4 at discharges less than the 50-year recurrence interval and in most locations requires discharges near the 500-year recurrence interval to occur. On the contrary, Reaches 1 and 2 experience substantial levee overtopping at flows coincident with the 10-year recurrence interval or less. Levees at the downstream end of Reach 1 tend to be overtopped on a less frequent basis than levees at the upstream end of Reach 1. Within each reach, however, localized areas may experience levee overtopping at much smaller discharges than modeled either due to a short section of lower levees or due to overtopping of upstream levees.

Evaluation of the hydraulic modeling results indicates that the Grande Ronde River and Reaches 1 and 2 of Catherine Creek have experienced substantial impacts to flood processes over time. Conversion of floodplain to agricultural land use has resulted in greatly reduced access to high flow habitat, including inundated floodplains and side channels. Constriction of flows between levees has also likely resulted in increased velocities within the channel banks and reduced high flow refugia along the channel margins during more frequent discharges. Overbank areas that do remain accessible between the levees are expected to have reduced complexity compared with unimpaired conditions. The overbank areas are hypothesized to have been wetlands pre-settlement, but now are primarily agricultural areas with little diversity. Fish may become stranded where levees are overtopped and access to the channel on the receding limb of a flood is prevented. This occurs during floods with greater than 10-year recurrence intervals. Stranding may also occur in disconnected oxbows that become inundated during high flows but lack a point of exit once flows recede.

Within Reaches 3 and 4 of Catherine Creek, the model illustrates that the presence of low-head diversion structures and bridges impact current river processes and impact localized hydraulic controls on water surface elevations. However, the impacts of the structures on floodplain access are less severe since the floodplain extent is much narrower when compared with downstream reaches. Addition topographic features and anthropogenic activities, such as clearing of large wood and river channelization, may impact hydraulics and resultant habitat, but additional hydraulic modeling of historical conditions coupled with analysis of historical photography and channel geometries and slopes would be needed to verify this.

## 5.2. Summary of Reach-averaged Hydraulics

A summary of the notable hydraulic characteristics of each reach is provided below:

Reach 1 can be described as a wide, unconfined valley with an average slope of approximately 0.006%. The channel capacity of the reach is highly variable, with most locations exhibiting bankfull conditions at flows between the 1.5- to 2-year discharges. Average in-channel velocities are very low and are typically around 1.3 ft/s at discharges with recurrence intervals between 1.5 and 100 years. Similarly, shear stresses are very low, indicating the potential to transport only sand size sediment under flood conditions. Levees are present along most of the reach, limiting floodplain access. In most locations, levees are overtopped at flows equal to or less than the 10-year discharge. There are four disconnected oxbows (RM 10.2, 14, 16.3, and 17.5) in this reach where the levee is overtopped at less than a five year flood. The most notable hydraulic controls in this reach are Elmer Dam at RM 13.1 and the Old Grande Ronde River, which is located in the upstream extent of the reach at RM 22.5. A change in slope occurs at the Old Grande Ronde River. Bridges within the reach, including Booth Lane, Market Lane, and Highway 237, exert local controls at flows exceeding the 100-year discharge but do not appear significant at lower discharges.

Reach 2 is also a wide, unconfined valley with an average slope of approximately 0.04%. A noteworthy break in slope occurs at the confluence of Ladd Creek near RM 31.4, which coincides with changes in hydraulic properties. Channel capacity throughout the reach is variable, with bankfull conditions occurring in most cross sections around 1.5 to 2-year discharges. In-channel velocities below Ladd Creek are generally around 1.7 ft/s. Upstream from Ladd Creek, velocity increases with discharge and averages 3.1 ft/s. Shear stresses in Reach 2 are slightly higher than those in Reach 1, with reach averages ranging from approximately 0.10 to 0.17 lb/ft$^2$ for discharges between the 1.5- and 100-year recurrence intervals. Levees within Reach 2 are overtopped less frequently than Reach 1 and only 50% of the cross section levees are overtopped at the 100-year discharge. Notable hydraulic controls in this reach include Upper and Lower Davis Dams, Ladd Creek, Wilkinson Lane Bridge, and a Beaver Dam located at RM 24.9. Similar to Reach 1, most bridges in the reach impart some hydraulic control at the 100-year discharge, but their influence appears to be localized.

The reach break between Reach 2 and Reach 3 is a transition zone at the base of the Catherine Creek alluvial fan that results in hydraulics changes. The confinement of the valley within Reach 3 increases from downstream to upstream. Average bed slope within this reach is 0.59%. Channel capacity in this reach is high compared to downstream Reach 1 and 2 and also compared with upstream Reach 4. Over 60% of cross sections require a flow of 100-year recurrence interval or greater to exceed the channel banks. Reach-averaged channel velocities range from 4.6 ft/sec for the 1.5 year flood to 6.6 ft/sec for the 100-year flood. Shear stresses in the reach range from about 1 lb/ft$^2$ for a 1.5-year discharge to 1.75 lb/ft$^2$ for a 100-year discharge, indicating some potential to transport gravels at higher discharges. Less than 30% of cross sections with levees indicate levee overtopping for flows less than a 500-year discharge. In other words, an extreme event is necessary for levee overtopping to occur in most locations within the reach. Four of the bridges on Catherine Creek exert hydraulic control, greater than half a foot, on floods that are more frequent than the 100-year event. For Reach 3, Main Street Bridge exerts control for a 2-year event and Pond Slough and Hwy 203 #B3 exert control for a 25-year event. Hwy 203 #B2 exerts control for a 50-year event in Reach 4.

Reach 4 is a confined valley reach with an average channel slope of 0.83%. The channel capacity at most locations is between the 5 and 10-year discharge. The reach averaged velocity in Reach 4 is approximately 4.8 ft/sec for the 1.5year discharge and 6.7 ft/sec for the 100-year discharge. Average in-channel shear stresses in the reach range between 1.1 lb/ft$^2$ for a 1.5-year discharge to about 1.8 lb/ft$^2$ for a 100-year discharge. Similar to Reach 3, levees present in Reach 4 typically require a discharge of 500-year recurrence interval to overtop. Some localized overtopping of less formidable levees may occur during more frequent floods. The most significant hydraulic control within the reach is the CCACF diversion structure.

## 5.3. Limitations

Several limitations exist with the current 1D model. In some cases, these limitations result from 2D and three dimensional (3D) processes that are not possible to capture with a 1D model. The 1D model cannot capture complex floodplain hydraulics, which is important for a basin where there is often water outside the channel.  The model can also not represent the effects an upstream cross section has on a downstream cross section, especially in the case of levee breaching. Additional information could be collected and applied to improve the 1D model results, but additional data will not impact the ability of the 1D model to replicate 2D and 3D processes. More in channel bathymetry, topographic data extending to the valley walls, and information regarding oxbow connections to the main channel could be collected to improve the model results. This section details the limitations of the current model used for this hydraulic analysis and describes additional data that could be collected to improve the model results.

### 5.3.5. One-dimensional model

Numerical modeling, such as done here with HEC-RAS, provides a useful tool for analyzing hydraulics in a channel resulting from channel geometry, flow rate, and the presence of structures (weirs, culverts, bridges). The objectives of each modeling effort help determine the type of model used to investigate significant flow patterns and represent the important processes. One-dimensional models are capable of simulating longitudinal changes in hydraulics while neglecting vertical and lateral variation. 2D models incorporate lateral differences in velocity and water surface elevation, and 3D models add the vertical components of velocity non-parallel to the stream bed. Interpretation of channel hydraulics with lower dimensional methods requires understanding the limitations of the model results.

A 1D model was selected to represent large-scale high flow inundation patterns of 60 river miles of Catherine Creek, State Ditch, and the Grande Ronde River. While State Ditch is fairly uniform in channel dimensions and levees widths, about 50 miles of the modeled reaches of Catherine Creek and Grande Ronde River are highly sinuous with broad floodplains and a myriad of disconnected oxbows, abandoned or breached levees, and more distant formidable levees. With complex floodplain hydraulics, a 2D model is necessary to capture lateral variations in water surface and velocities. However, the 1D model can provide useful information as to initial levee overtopping and approximate flows at which disconnected oxbows are inundated. The 1D model results for this analysis will be valid for discharges that result in flows remaining between the levees. However, once flows overtop the levees, the velocities and shear stresses within the channel and floodplain lose validity.  Several limitations apply to the depth maps; these are discussed in detail in Section 4.3.

### 5.3.6. Levee Overtopping

Within HEC-RAS, one levee element can be used to contain flow on each side of the channel. The program does not allow flow to access areas outside of the defined levee element until a water surface elevation is reached that overtops the elevation set for the levee. In the model developed here, levee elements were used to represent the closest visibly unbreached levee on each side of the channel. In the absence of a levee, levee elements were often placed adjacent to the channel bank within the cross section to keep flow from accessing lower swales, side channels, or floodplain areas without overtopping the channel banks first. The 1D model cannot represent the effects that the upstream section may have on the downstream section. For example, an upstream cross section may show levee overtopping at a 10-year discharge. However, the next downstream cross section could result in all flow being conveyed between the levees with no levee overtopping. Once flow overtops the levee in an upstream cross section, flow will be conveyed outside of the levee in downstream cross sections unless there is a mechanism for flow to be conveyed back to the channel. These complex flow patterns require a 2D model to adequately capture processes occurring between the cross sections. Once levees are overtopped, hydraulics outside of the levees may not be accurate. Because of this model limitation, reach-averaged hydraulics are applied to define the extent of inundation and cross-section averaged hydraulic parameters (water surface elevations, velocities, and shear stresses). Caution should be used in interpreting the results to represent absolute values for each hydraulic parameter.

### 5.3.7. Low Flow Channel

In-channel topography data were collected in reaches where access was granted. In areas where access was not possible, LiDAR was often used to estimate the low flow channel elevations. Modified LiDAR data were utilized to represent the bed surface in the downstream-most 1 mile of the Grande Ronde River just above Rhinehart Gap and also upstream of RM 37.9. Within these areas, the modeled bed elevation is likely different than the true bed elevation. In addition, two short sections of Catherine Creek from RM 32 to 34.5 and from RM 27 to RM 30 could not be accessed for surveys. Within these reaches, the bed elevations were linearly interpolated from upstream and downstream bed elevations. Model results within the areas where modified LiDAR or linear interpolation was performed to develop the in-channel surface are not likely providing accurate estimates of flows less than the 2-year discharge. However, once a high percentage of flows are conveyed overbank, the percentage of discharge conveyed in low flow channel becomes less important. Therefore, model results of higher discharges are likely minimally affected by the bed elevations. Additional data could be collected in these reaches to improve model results for more frequent floods. Sensitivity tests could also be run to evaluate the impacts of the low flow channel bed elevations on model results.

### 5.3.8. LiDAR Extent

Another limitation of the model results from the limited extent of LIDAR data. In many cross sections along the Grande Ronde River, State Ditch and Catherine Creek, the LiDAR does not extend far enough across the floodplain to capture all of the high flow discharges evaluated. In a few cross sections, the model does not contain 10-year discharge. A greater number of cross sections do not contain discharges in excess of a 50 to 100 year recurrence interval. At these locations, the model creates vertical walls along the boundaries of the cross sections. In reality, flows would likely extend much farther across the channel floodplain until a true topographic feature were encountered that limits the inundation extent. The model likely overestimates the water surface elevations for discharges exceeding the lateral cross section extent. Additional data, such as a USGS DEM data, could be utilized and cross sections elongated to contain all of the discharges. This would be a considerable effort, and may only be warranted in areas where more detailed investigations are needed.

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# APPENDIX E – HYDROGEOLOGY

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# 1. Summary – Hydrogeology of the Grande Ronde Valley

Low summer flows and increased temperatures in the lower reaches of Catherine Creek may potentially impede spawning in Catherine Creek and contribute to declining populations of salmon and steelhead in the Columbia Basin. Two potential solutions to enhancing flow and temperature issues is to substitute surface water for irrigation with groundwater, and promote cooler groundwater return flows (from natural flows and irrigation returns) to lower the summer streamflow temperature. Ferns et al. (2002) discusses geologic and general hydrogeologic conditions throughout the upper Grande Ronde Valley and much of the following descriptions are garnered from that report.

## 1.1 Geologic Setting

The Grande Ronde Valley is a broad, flat alluvial plain surrounded by bedrock highlands. The valley is ringed by young faults that have resulted in the valley being lowered relative to the highlands by almost 3,000 feet on the west and 2,400 feet on the east. Downfaulting of the valley has resulted in a structural trap that is being filled by the deposition of alluvial sediments. Large alluvial fan-deltas form gently sloping surfaces where the Grande Ronde River, Catherine Creek, Mill Creek, and Ladd Creek enter the valley. The shape and gradient of these streams change at the fan-delta - alluvial plain interface; shifting from a braided morphology on the fan to a meandering morphology on the plain. As a result, there is a decrease in channel deposit grain size from gravel and sand to clay and silt and a broader distribution of the alluvial channel deposits into the meander zone (Figure 1).

The alluvial deposits vary in gradation, composition, and permeability; depending on their location within the valley and the energy under which they were deposited (e.g., higher energy stream deposit on the fan-delta or lower energy channel deposit on the alluvial plain). Alluvium, composed of moderately to well-sorted gravel, sand, and silt, is found in the active stream channels and on adjoining floodplains of the Grande Ronde River, Mill Creek, Catherine Creek, and Ladd Creek. The alluvial deposits are constantly reworked by the river, and are probably 15 to 30 feet thick (Ferns et al. 2002). They interfinger with fan-delta deposits and are hydraulically connected to older, deeper abandoned channels (Figure 1).

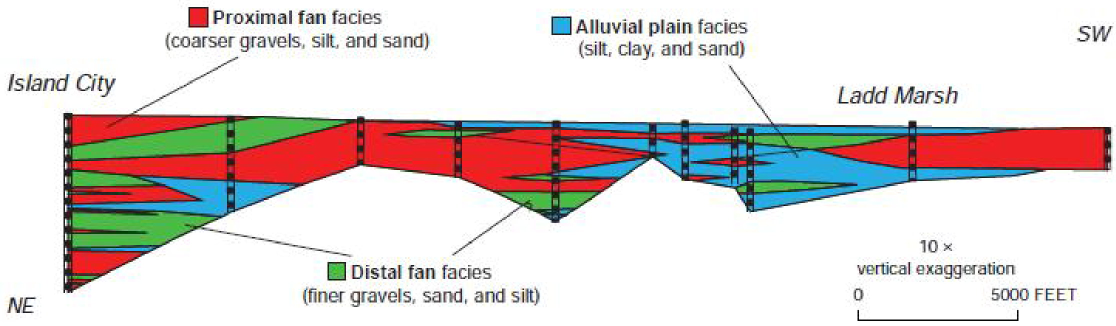


**Figure 1. Interpretive cross section in the Grande Ronde Valley (Ferns et al. 2010).**

## 1.2 Groundwater

Groundwater bearing stratum in the Grande Ronde Valley can be separated into three general hydrogeologic zones; the near surface groundwater zone within the current Catherine Creek alluvial plain (+ 50 feet depth); the shallow aquifer within the fan-delta and alluvial plain sediments (+ 700 feet depth); and the deep (volcanic) bedrock aquifer (+ 3,000 feet depth). The geologic units that make the best aquifers in the Grande Ronde Valley occur at two levels, the shallow fan-delta sediments that underlie the Grande Ronde and Catherine Creek fan deltas, and the deep volcanic bedrock (Figure 2). The shallow fan-delta and bedrock aquifers are utilized for water supply wells (irrigation and municipal) in the area; the near-surface groundwater zone is utilized primarily for residential wells.

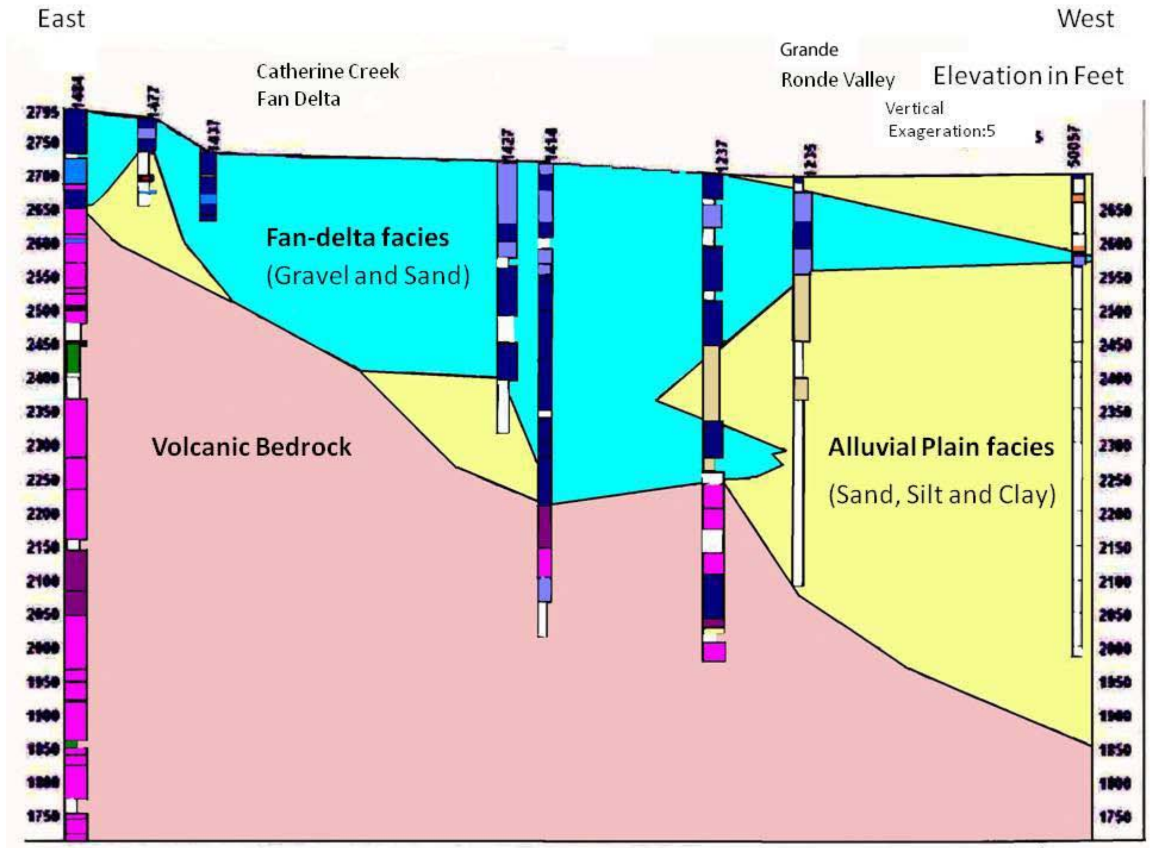


**Figure 2. Profile from east to west across the Catherine Creek fan delta (Ferns et al. 2010).**

## Near-surface Groundwater

The interaction of groundwater with surface water along Catherine Creek, and its tributaries, generally occurs within the upper 50 feet of the ground surface. The fine-grained clay and silt deposits in the alluvial plain have very low permeability and capacity for storing groundwater (Ferns et al. 2002), and are poorly connected to the active river channels. Wells produce moderate amounts of water from gravel and sand lenses at shallow depths within the fine-grained alluvial plain sediments, but the water bearing lenses are generally random and unpredictable making the unit variable as a potential aquifer (Ferns et al. 2002).

For a detailed discussion of the interaction between Catherine Creek streamflows and the near surface groundwater using forward looking infrared data (FLIR) and thermal profile information, refer to the “Groundwater – Surface Water Interaction” and “Thermal Profile of Catherine Creek” sections of this report.

## Shallow Aquifer

The depositional history of the Grande Ronde Valley during the Pleistocene and Quaternary that formed the fan delta sediments was dominated by three episodes of alpine glaciation in the adjacent Elkhorn and Wallowa Mountains (Ferns et al. 2002). Both the Grande Ronde River and Catherine Creek carried glacial outwash material into the valley, producing terrace and fan deposits as braided streams flowed across the valley (Ferns et al. 2002). The most productive shallow cold-water wells are those that intersect the well-sorted gravel and sand deposits that extend beneath the Grande Ronde and Catherine Creek fan deltas (Figure 2).

The Grande Ronde River fan-delta enters the valley from the west at La Grande and includes gravel, sand, and silt deposits that grade laterally into silty sand and silt alluvial plain deposits in the basin. Grande Ronde fan-delta gravel deposits are relatively free of clay (Ferns et al. 2002). Fan-delta gravel is as much as 540 feet thick and has been the most important shallow aquifer in the Grande Ronde Valley.

The Catherine Creek/Little Creek fan-delta enters the south end of the valley and merges with the alluvial plain to the north. The fan-delta deposits appear to contain a relatively higher proportion of clay and silt than the Grande Ronde fan-delta, which may have resulted from the introduction of glacial flour during glaciation of the upper drainage basin (Ferns et al. 2002). Catherine Creek fan-delta gravel has a maximum thickness of 500 feet (Ferns et al. 2002). At Union, the unit is at least 290 feet thick and has historically been an important source of groundwater for the city. For much of its extent, the Catherine Creek fan-delta appears to lie directly on bedrock, unlike the Grande Ronde fan-delta, which overlies older alluvial plain deposits.

Mill Creek fan likely has relatively low permeability (Ferns et al. 2002). The proximal end of the fan at Cove appears to contain interbedded clays and poorly sorted clayey gravels with limited permeability. The existence of localized low permeability deposits in the subsurface may influence groundwater flow direction and gradients.

Ferns et al. (2002) describes the location and connectivity of permeable, water-bearing gravel channels within the fan-deltas as random and unpredictable. The abandoned, alluvial filled channels are thought to provide preferential groundwater flow back to the active channels providing groundwater discharge that may influence surface water temperatures. Geologic factors controlling the deposition of alluvial sediments, including rapid lateral and vertical facies changes, influence the distribution of permeable zones in the subsurface.

### Deep Bedrock Aquifer

The Grande Ronde Member of the Columbia River Basalt Group is the most extensive aquifer in the valley; wells in the deep aquifer generally produces warmer water, and in places providing artesian flow of more than 2,000 gallons per minute (Ferns et al. 2002). In the southern Grande Ronde Valley and Lower Catherine Creek areas, the aquifer is tapped only by municipal wells at LaGrande and Union, the city of Imbler and about half-dozen irrigation wells produce from the Grande Ronde Basalt in the northern part of the valley (Ferns et al. 2002). Even though the deep volcanic aquifer has potential for high initial production rates, the low vertical permeability could potentially limit recharge (Ferns et al. 2002).

## 1.3 Historic Conditions

Ladd Marsh is the remnant of an extensive area of marsh and shallow lake deposits that covered more than 52 $km^2$ of the valley floor prior to construction of the State Ditch (Ferns et al. 2002). Historically, extensive ponding of surface water would have provided more opportunity for infiltration to shallow groundwater aquifers and maintenance of a higher water table that would slowly discharge back to the streams during low flow periods of late summer and fall. There are limited data available that describe annual and long-term water level fluctuations in the Grande Ronde Valley. Figure 3 shows long-term monitoring from 1936 to 1958 of an unconfined aquifer well (well 3/38 – 25B1) located on the La Grande alluvial fan. In addition to seasonal and annual fluctuations, the well also records a water table rise from 1939 into the 1940s, presumably from increased precipitation.

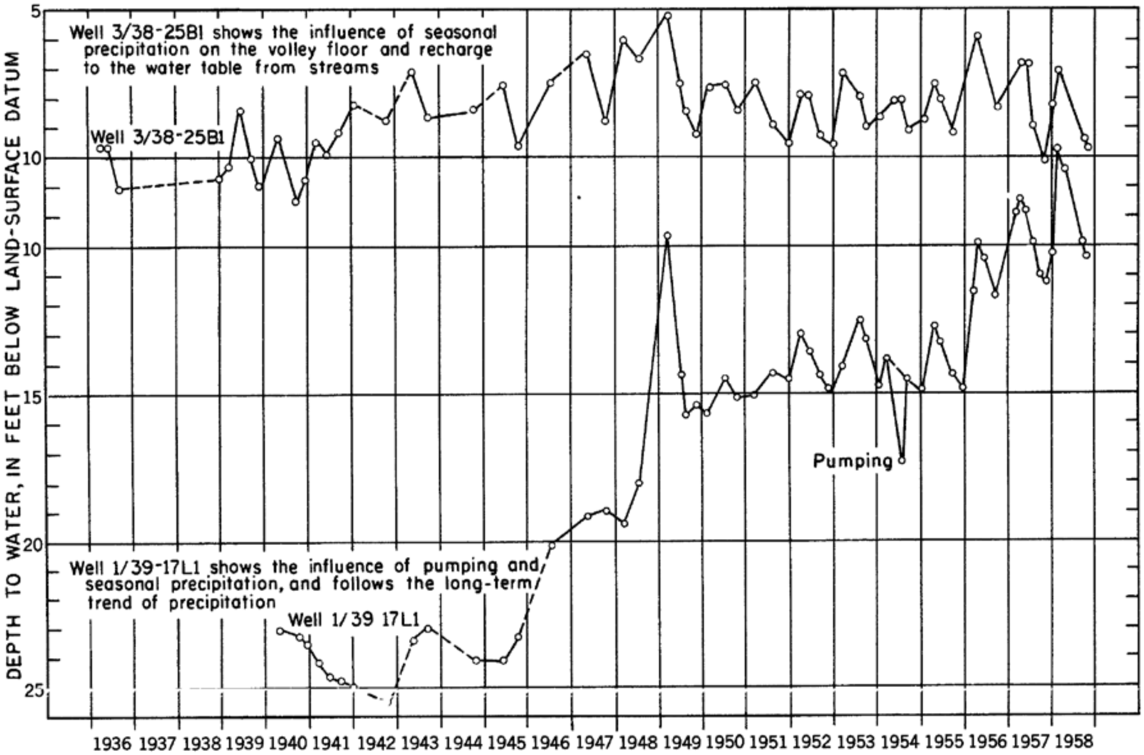


**Figure 3. Hydrograph showing water levels in well 3/38-25B1 near the La Grand airport and well 1/39 – 17L1 about 1 mile north of Imbler (Hampton and Brown 1964).**

Since the Hampton and Brown study, many groundwater wells have been installed for irrigation supply. Most of the larger producing wells in the valley are completed in the deep, basalt aquifers and their impact on shallow water tables and streamflow is unknown. Figure 4 shows groundwater wells that have water right certificates/permits within close proximity to Catherine Creek; they are mapped by ¼, ¼ section. Total water usage, pumping amounts, and water levels are not known. Most of these wells supply water to fields that are also near Catherine Creek and an unknown quantity of the pumped water probably becomes return flow. Seepage investigations that measure streamflow of designated reaches, along with all known diversions, are necessary to determine losing and gaining reaches of Catherine Creek.

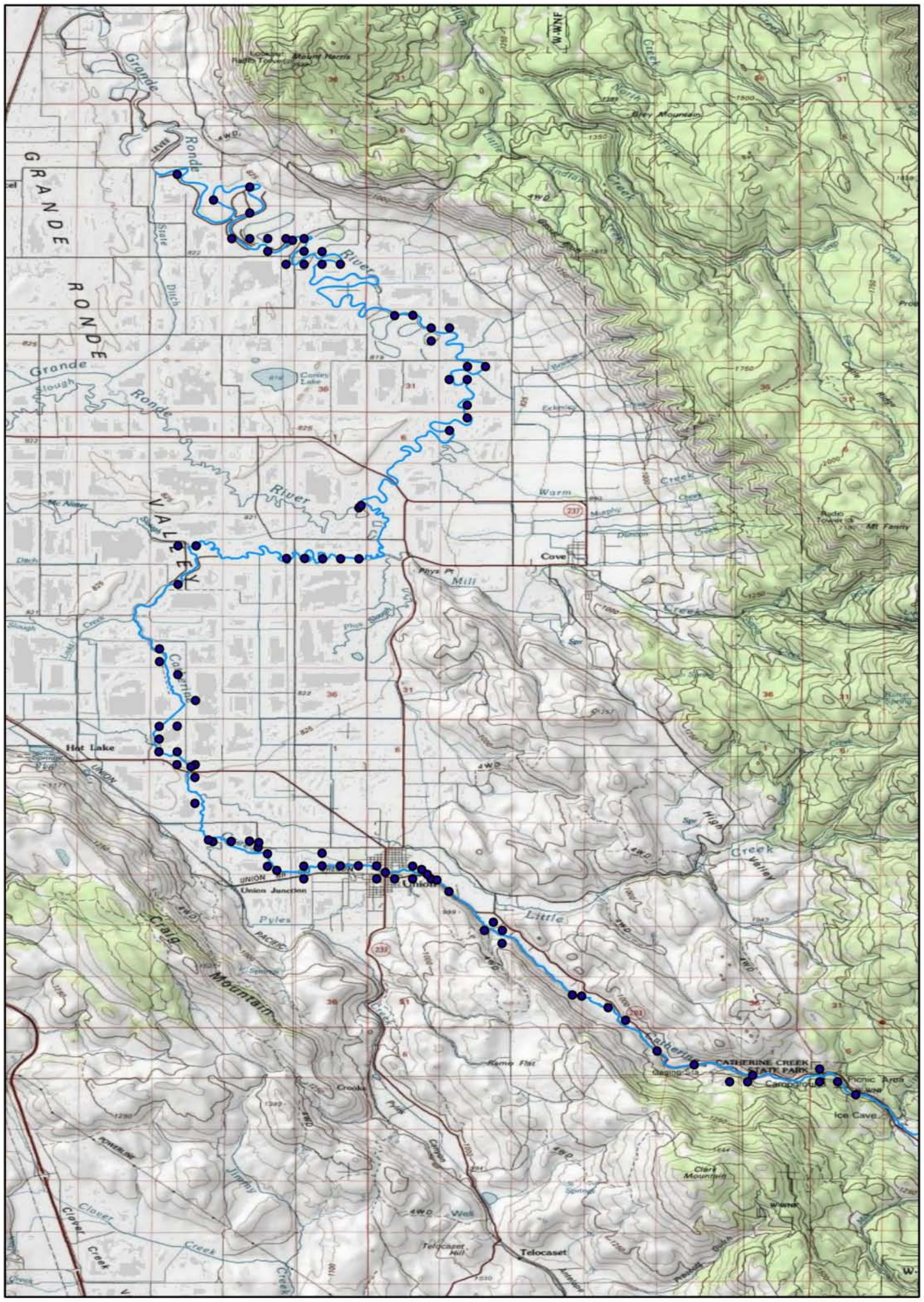


**Figure 4.** **Location of groundwater irrigation wells within ¼ mile of Catherine Creek.**

### 1.3.1 Groundwater – Surface Water Interaction

Various methods are available to measure and quantify the interaction between streamflows and the surrounding aquifer. Measuring the gains and losses of streamflow along stream reaches (called seepage investigations) provides a synoptic view of areas where groundwater is contributing flow or where there are surface water losses to the aquifer. Water chemistry parameters can sometimes be used to indicate the contribution of groundwater to the stream. Since groundwater is often a different temperature than surface water in a stream, tracking temperature along a continuous longitudinal profile of the stream indicates specific locations where groundwater enters the stream. Tracking temperature can be accomplished by FLIR (Watershed Sciences 2000), by ground-based infrared thermography (Schuetz and Weiler 2011), and by conducting a thermal profile with a temperature logger (Vaccaro and Maloy 2006). Each of these methods has advantages and disadvantages for a specific scale of study and provides important information that, when combined with other data, gives insight into the complexity of stream temperature dynamics. A FLIR survey was conducted in August 1999, and covered the entire Grande Ronde River basin (Watershed Sciences 2000). A repeat FLIR survey was conducted over portions of the basin during winter 2011. The FLIR survey has the advantage of covering an entire stream basin in a relatively short period. A potential disadvantage, however, is that the method measures surface radiance and cannot precisely locate groundwater discharge until manifested at the water surface. Thermal stratification of the stream or mixing of surface and groundwater can mask the groundwater signature; these conditions are affected by channel morphology, streamflow volume, and velocity.

Watershed Sciences (2000) describes Catherine Creek as thermally stratified from the mouth (at the confluence with the Grande Ronde River at State Ditch) upstream to Davis Dam. This was interpreted by the mixing seen at the stream bends and the magnitude of thermal differences in the surface patterns (Watershed Sciences 2000). Thermal stratification would prevent the FLIR from identifying areas of groundwater discharge that occur near the bottom of the streambed.

### 1.3.2 Thermal Profile of Catherine Creek

## Method

A thermal profile documents the longitudinal temperature gradient of a stream and is a relatively direct method to evaluate river-aquifer exchanges. A thermal profile was conducted on Catherine Creek during July 2010 to define the spatial variation of temperature due to groundwater contributions. A reduced area was also profiled during March 2011. A total of 42.1 miles of Catherine Creek were profiled. The U.S. Geological Survey (USGS) developed the method used at Catherine Creek in 2001 in the Yakima River Basin, Washington. The method was shown to document the longitudinal distribution of a river's temperature regime and areas of groundwater discharge (Vaccaro and Maloy 2006).

The thermal profiling method consists of towing a temperature probe from a watercraft (e.g., inflatable kayak or small motorized boat) that measures temperature near the river bottom while concurrently logging spatial coordinates with a Global Positioning System (GPS). Profiling is accomplished during seasonal low flows, when the stream is more confined in the main channel and groundwater discharge is a larger proportion of the total streamflow. Data are collected at a one to three-second sample rate, depending on flow velocity, reach length, and datalogger capacity. The profile is conducted during the diurnal warming part of the daily sinusoidal streamflow-temperature regime. Portable temperature loggers are placed at the upstream and downstream ends of the profiled reach to provide additional information on the diurnal temperature change in water entering and leaving the reach.

Groundwater discharge areas are identified by locating deviations from the diurnal heating pattern. Broad discharge areas are typified by stabilization, cooling, or declining rate of change in temperature increases. Localized discharge (springs, alluvial aquifer discharge, or re-connecting side channels) is exhibited by short temporal variations in the thermal profile. These represent "patches"; the size and longitudinal distance between patches are important for most life-history stages of salmonids (Vaccaro 2011). After identifying potential groundwater discharge areas by thermal profiling, a more detailed study using other methods could be employed, such as mini-piezometers, to measure vertical gradient between the stream and shallow aquifer.

## Equipment and Conditions

Onset StowAway® TidbiT™ temperature loggers were deployed at fixed locations along Catherine Creek to record water temperature through time during the thermal profile. The reported accuracy of the Onset StowAway is +/- 0.2ºC (Onset User's Manual). A comparison of air temperature at the Imbler Agrimet station with the Catherine Creek water temperature at Elmer Bridge shows virtually no lag time between the daily high air temperature and the maximum daily water temperature (Figure 5). The daily maximum water temperature generally occurred between noon and 1:00 PM. Although the air temperatures ranged from 90.7ºF to 42.1ºF during the period July 19 to 25, 2010, the water temperatures ranged from 76.9ºF to 69.5ºF, with an average of 72.4ºF.

Streamflows steadily decreased from 86 to 68 cfs during the summer thermal profile (Figure 5) (OWRD 2011).

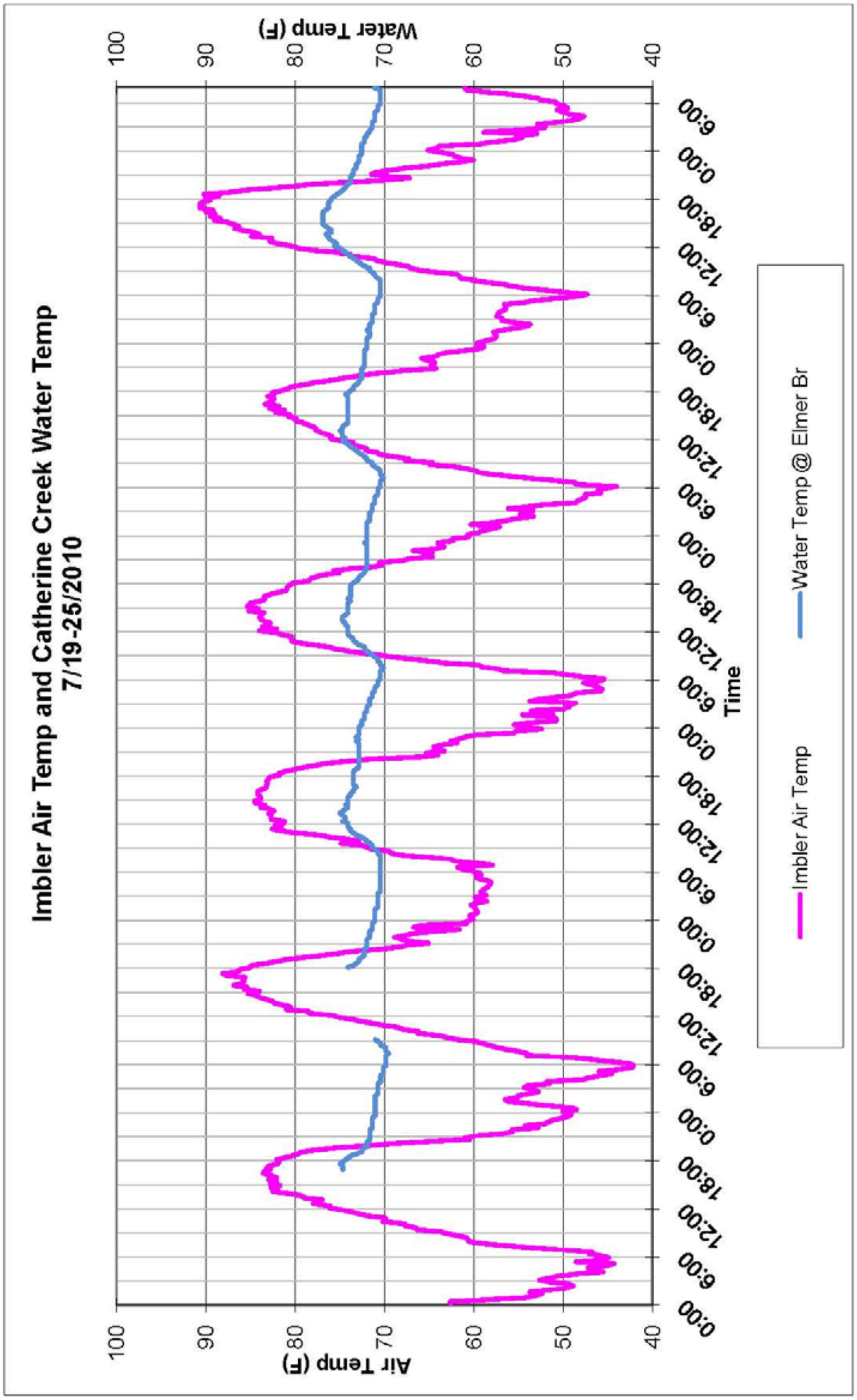


**Figure 5.** **Air temperature at Imbler; Catherine Creek water temperature at Elmer Bridge, July 19 to 25, 2010.**

An integrated temperature sensor and datalogger, designed for groundwater monitoring (Levelogger Gold Model 3001 manufactured by Solinst®) was used to record water temperatures during the thermal profile. Probe accuracy is rated at 0.1ºC for temperature. The probe was housed in a rugged plastic pipe container that provided protection yet allowed the free flow of water around the probe (Figure 7). A handheld Garmin® GPS unit, model Colorado 400T, received and stored location information along the route. Each GPS data point is time stamped and latitude, longitude, length, speed, and course are recorded. At the start of the profile, the internal clock of the temperature probe was closely synchronized to the GPS, and then temperature and location were recorded every 3 seconds. At the end of each day's profile, the data files were processed and combined in an Excel spreadsheet. The data file was then converted to an ArcGIS point coverage.

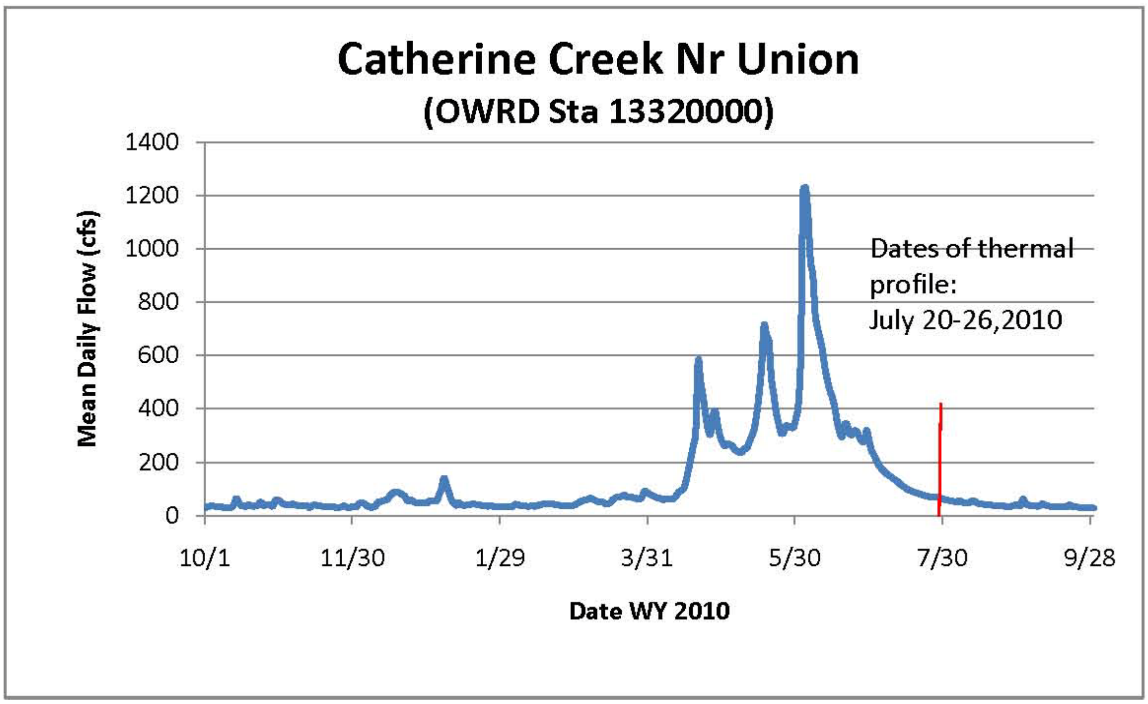


**Figure 6. Mean daily flow, Catherine Creek near Union, OWRD Sta. 13320000.**

**Figure 7. Equipment used during thermal profiling.**

The difference in temperature from one measurement point to another was generally very small (less than 0.01ºC) but it is the trend of water temperature changes and their locations, rather than the absolute temperatures that are of interest in determining groundwater discharge locations. A shape file was created of the temperature differences from one reading to the next, highlighting areas where point-to-point changes exceeded 0.002ºC. The temperature differences less than 0.002ºC was not used in order to eliminate “probe noise.”

Most of the profile was conducted from a two-person inflatable kayak. The lowest reach (RM 1.5 to 6.5) and the March 2011 profiles were completed from a motorized john boat. The upper reaches (above the town of Union) were completed by wading, due to obstacles in the river and velocities that jeopardized control of the boat while towing the probe.

### 1.3.3 Results

Surface-aquifer exchanges vary temporally and by physical setting. Thermal profiling of Catherine Creek shows that water returns from sloughs and old oxbow lakes may provide preferential return flow back to the stream during the summer. These are areas where coarser sediments may be found within the generally finer grained floodplain. Studies in the Yakima Basin, Washington, showed similar results (Vacarro 2011) with the conclusion that wetting-up side channels and sloughs was more important than bank storage in supplying cool water to the shallow groundwater system. Some of the temperature graphs show areas where the temperatures stabilize or deviate from the expected thermal response of streamflow during the diurnal heating period. These are indicative of localized discharge (springs, surface-water inflows, and/or alluvial aquifer discharge from re-connecting channels). They represent "patches" and may be preferred areas of thermal refuge for salmonids.

The geometry of the stream channel and point source water returns may also affect the thermal response recorded during the thermal profiling. The information from the profiles should be considered one source of data and used in conjunction with other information, such as seepage investigations, measured hydraulic gradients and groundwater level information.

## Reach 1 – RM 0.0 to 22.5

Reach 1 was profiled over the following days:

| River Mile | Date Profiled | Figure # of Temperature vs Time graph |
|---|---|---|
| RM 1.5 – 6.5 | July 21, 2010 | Fig. 7 |
| RM 6.5 - 13.0 | July 20, 2010 | Fig. 8 |
| RM 13.2 - 20.5 | March 10, 2011 | Fig. 9 |
| RM 21.4 - 22.5 | July 23, 2010 | (included in Fig. 12) |
| RM 18.8 - 21.2 and 22.3 – 22.5 | March 11, 2011 | Fig. 10 |

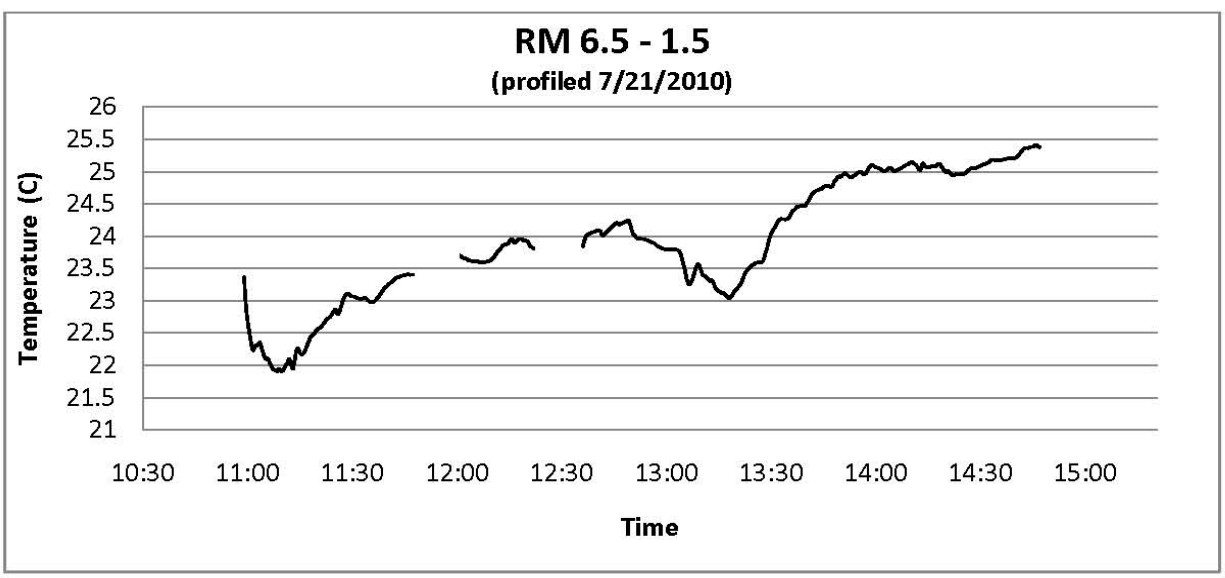


**Figure 8. Temperature vs. time. Reach from Market Lane to RM 1.5.**

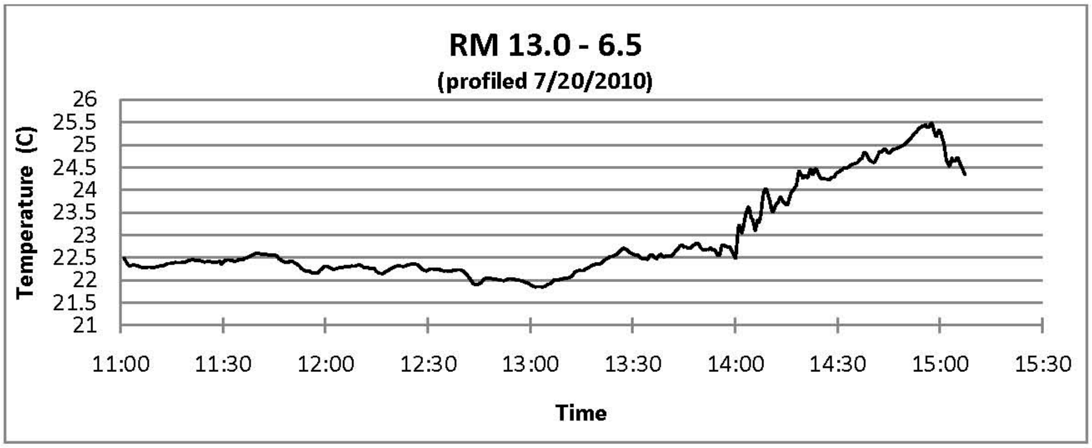


**Figure 9.** **Temperature vs. time. Reach from Elmer Dam to Market Lane.**

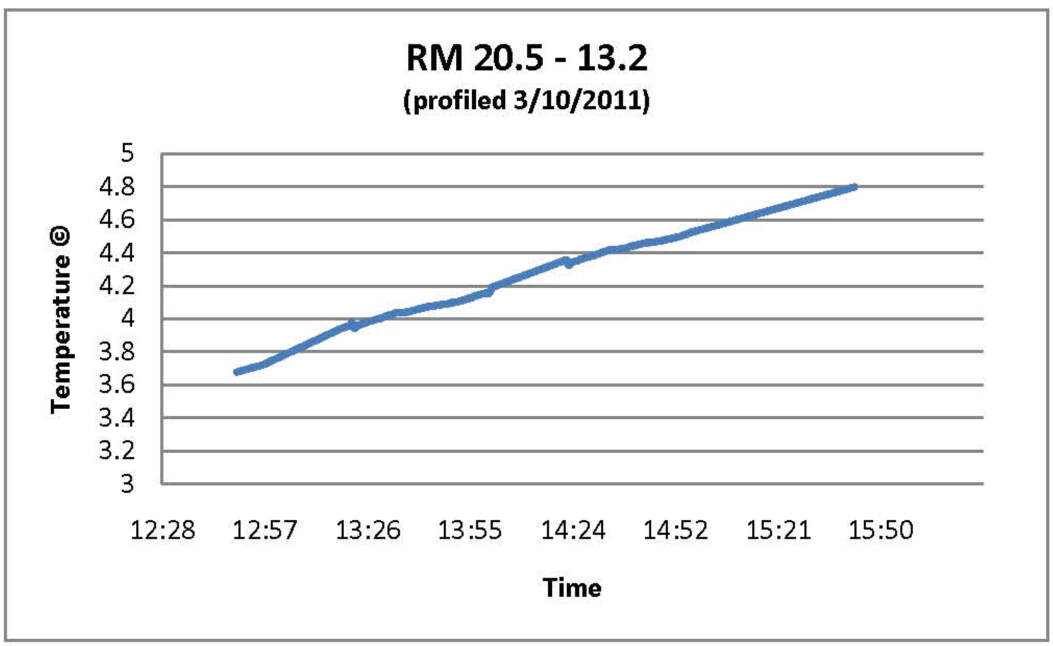


**Figure 10.** **Temperature vs. time. Reach from RM 20.5 to Elmer Dam.**

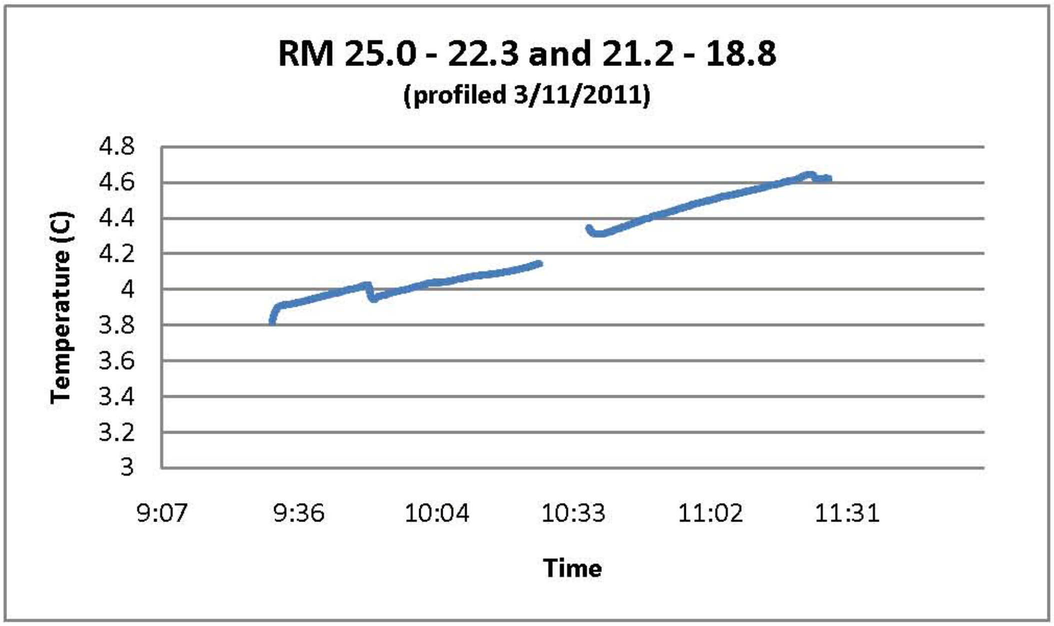


**Figure 11.** **Temperature vs. time. Reach from RM 25.0 to 22.3 and 21.2 to 18.8.**

Figure 12 shows locations where patches of cooler temperatures were detected. The areas are generally at the downstream end of bends of the river and at the downstream entrance of old oxbow channels. Although these temperature variations may indicate groundwater discharge, the stream geometry and/or mixing due to the river bend may also influence temperatures. The old oxbow channels are likely coarser grained alluvial materials than the surrounding floodplain sediments and may provide preferential flow to the active channel. A portion of reach 1 that was not profiled during the summer due to the backwater of Elmer Dam was profiled during March 2011. This area includes three large disconnected oxbow lakes adjacent to the stream from RM 13.1 to 14.1 yet no temperature changes were discerned during the March profile. This may indicate a seasonal component to the discharge or may be related to the very cool and decreasing temperature conditions that occurred during the March profile. In addition, no temperature variation was detected at the confluence with Warm Creek (RM 19) during the March 2011 profile.

| River Mile | Approximate Temperature Change Detected ($^{o}$C) |
|---|---|
| 1.6 – 1.8 | 0.15 |
| 3.3 – 3.5 | 0.8 |
| 6.5 – 6.7 | 0.8 |
| 7.6 – 7.7 | 0.2 |
| 9.0 – 9.1 | 0.4 |

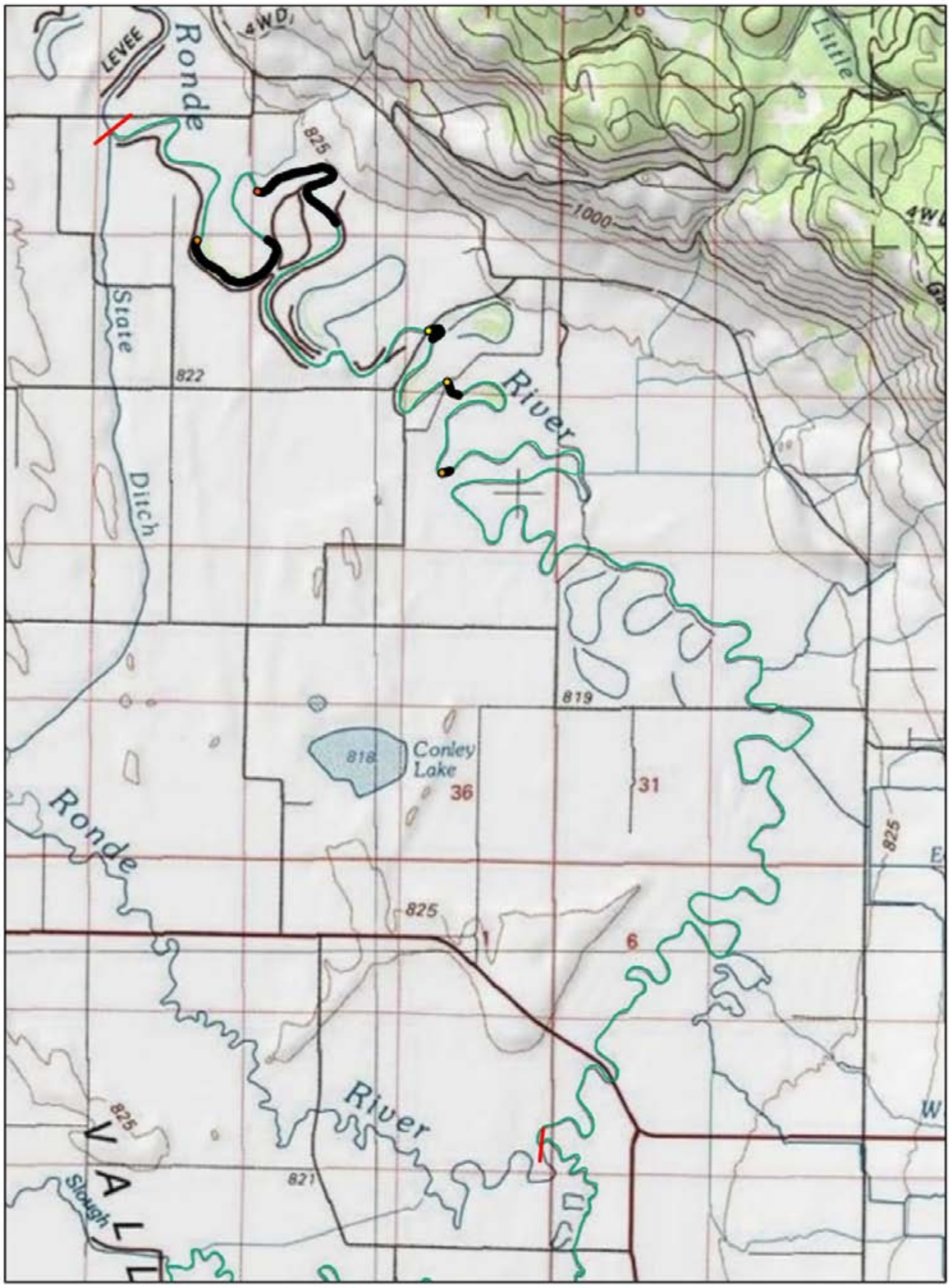


**Figure 12.** **Reach 1 (RM 0.0 to 22.5). Location in reach 1 where cooler temperatures were detected during thermal profile.**

## Reach 2 – RM 22.5 to 37.2

Reach 2 was profiled over the following days:

| River Mile | Date Profiled | Figure # of Temperature vs Time graph |
|---|---|---|
| RM 22.5 - 26.9 | July 23, 2010 | Fig. 12 |
| RM 22.5 – 25.0 re-profiled | March 11, 2011 | See Fig. 10 |
| RM 26.9 – 33.9 | July 22, 2010 | Fig. 13 |
| RM 36.6 – 37.2 | July 23, 2010 | Fig. 14 |

RM 33.9 to 36.6 includes the backwater behind the Davis Dams and was not profiled.

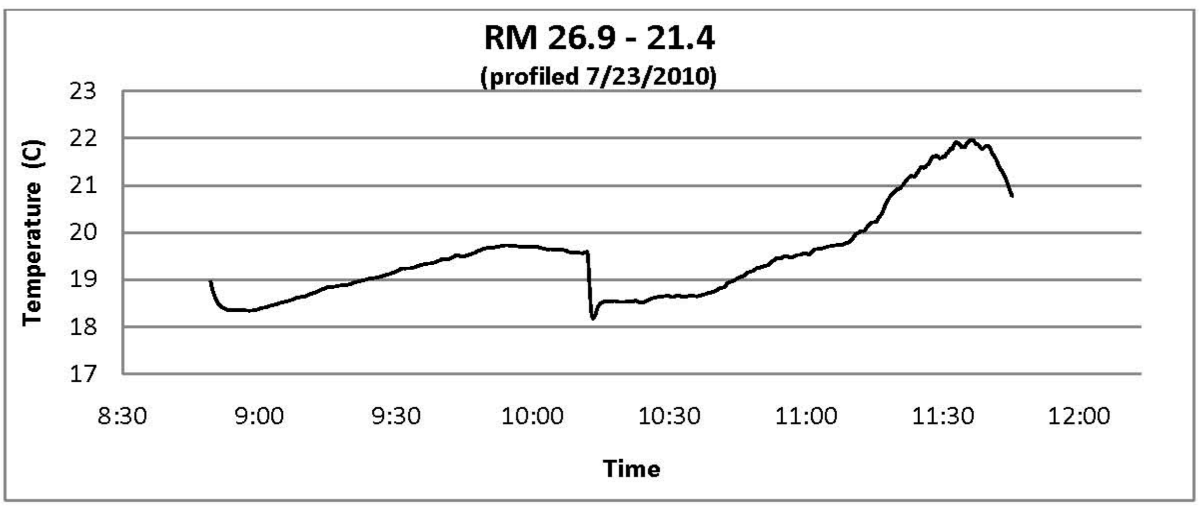


**Figure 13. Temperature vs. time. Reach from Godley Lane to Highway 237 Bridge.**

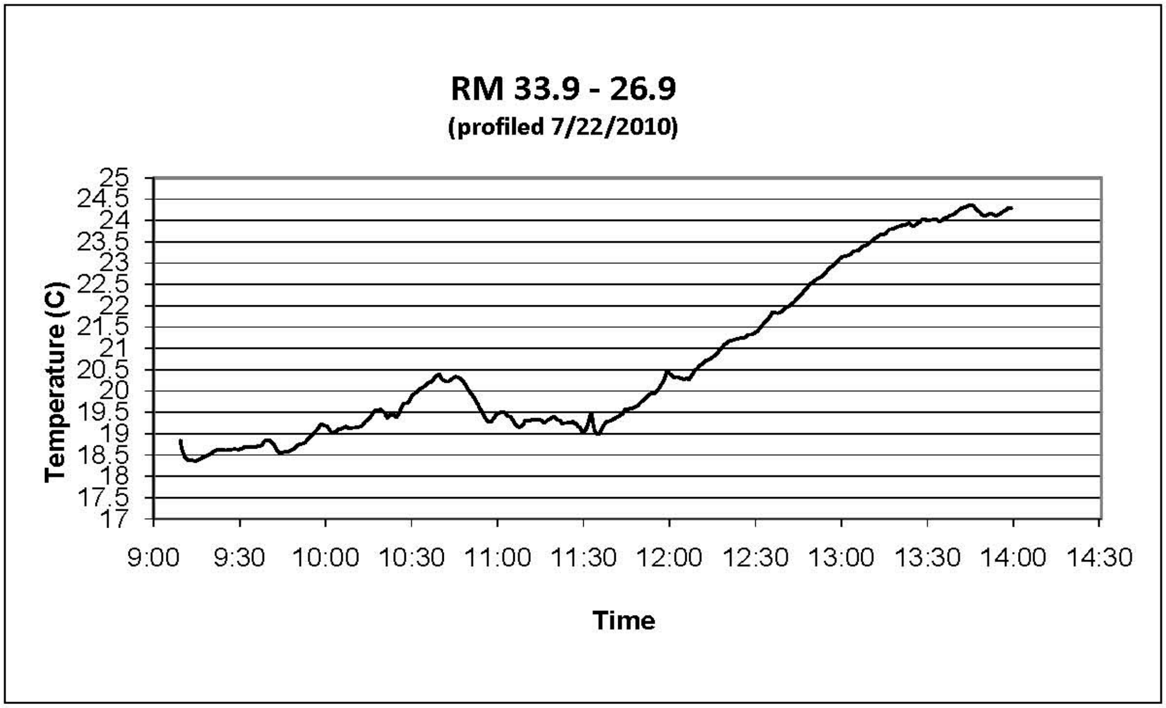


**Figure 14.** **Temperature vs. time. Reach from Woodruff Road to Godley Lane.**

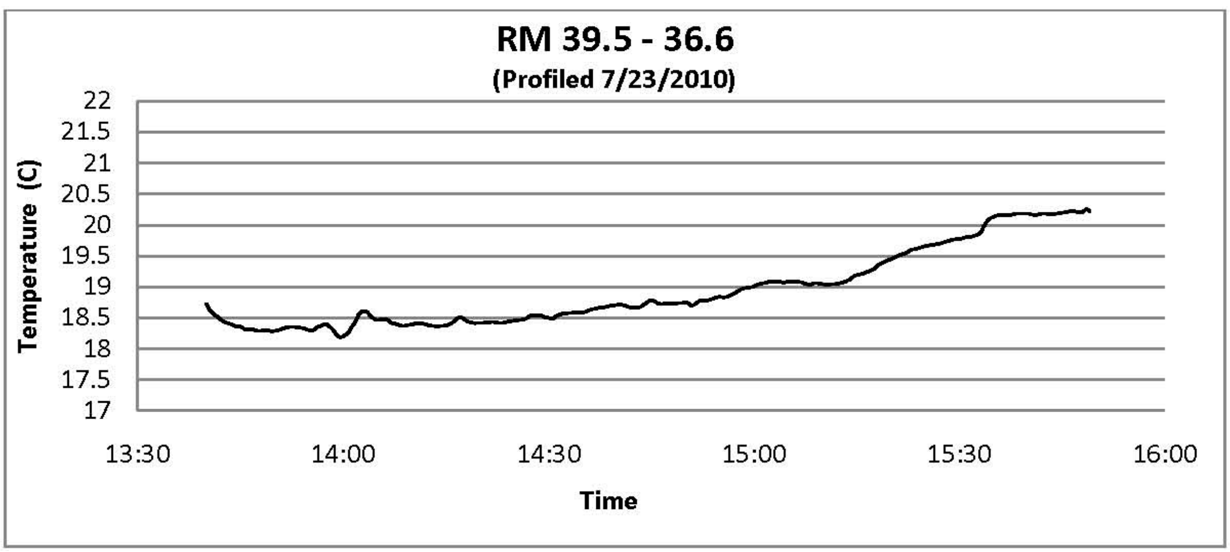


**Figure 15.** **Temperature vs. time. Reach from Union to Miller Lane.**

Figure 16 shows locations in reach 2 where patches of cooler temperatures were detected. The area at RM 24.1 (near the confluence with Mill Creek) also indicated cooler than ambient temperatures during the re-profile of this reach in March 2011.

| River Mile | Approximate Temperature Change Detected (degree C) |
|---|---|
| 24.0 – 24.3 | 0.35 (confluence w/ Mill Creek) |
| 26.9 – 27.0 | 0.08 |
| 31.3 – 31.4 | 0.13 (confluence w/ Ladd Creek) |

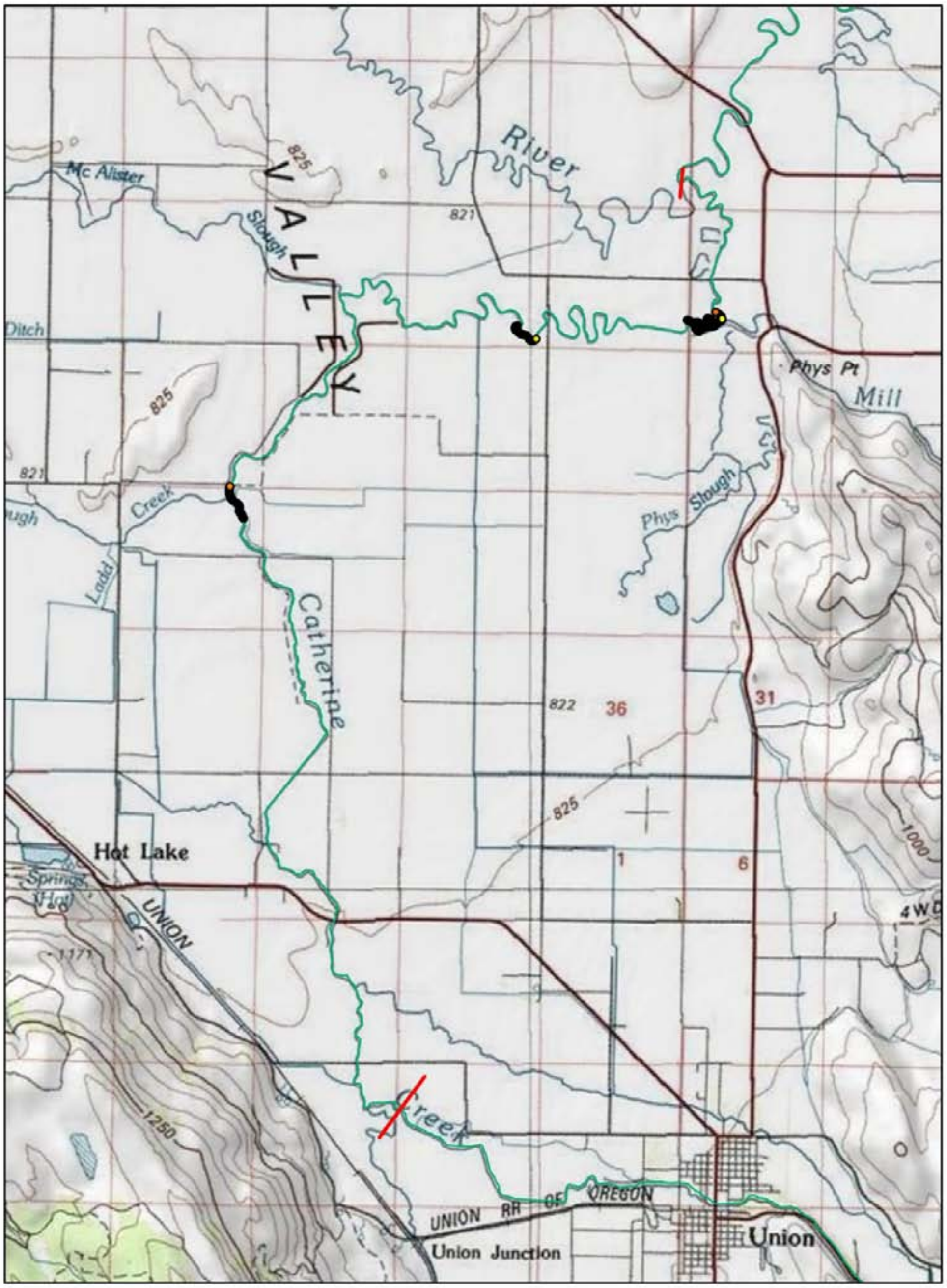


**Figure 16. Reach 2 (RM 22.5 to 37.2). Locations in reach 2 where cooler temperatures were detected during thermal profile.**

Two of the areas where cooler temperatures were detected are associated with surface water inflows into Catherine Creek.  The area at RM 27 appears to be associated with old drainage channels that are shown as surface depressions on the 24:000 scale topographic map near Godley Lane.

## Reach 3 – RM 37.2 to 40.8

Reach 3 was profiled over the following days:

| River Mile | Date Profiled | Figure # of Temperature vs Time graph |
|---|---|---|
| RM 37.2 – 39.5 | July 23, 2010 | Included in Fig. 14 |
| RM 40.7 – 40.8 | July 26, 2010 | See Fig. 17 |

RM 39.5 to 40.7 includes the town of Union and was not profiled.

| River Mile | Approximate Temperature Change Detected (degree C) |
|---|---|
| 37.5 – 37.6 | 0.05 |
| 39.2 – 39.3 | 0.14 |

Figure 17 shows locations in reach 3 where patches of cooler temperatures were detected.

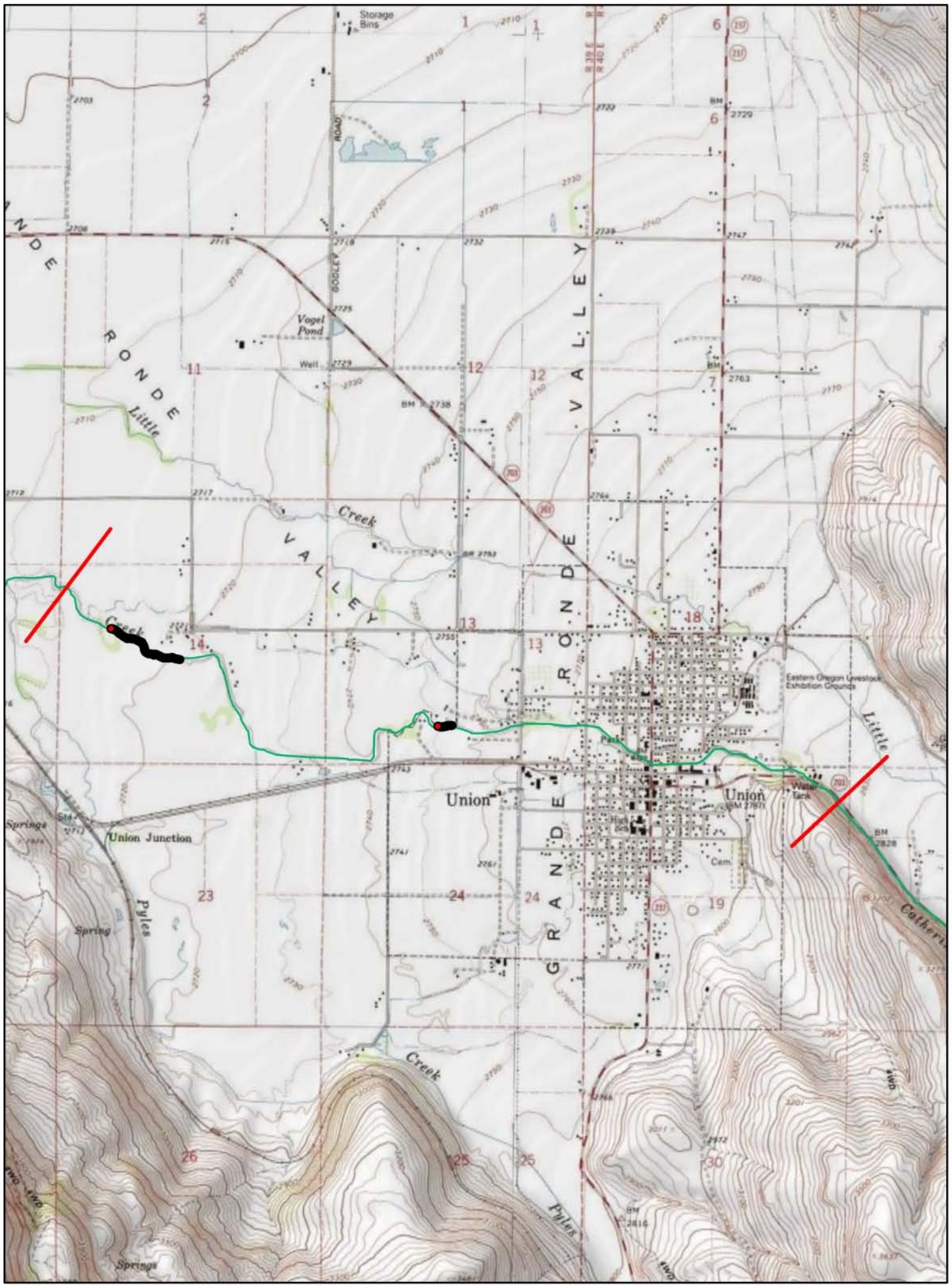

**Figure 17. Reach 3 (RM 37.2 to 40.8). Locations in reach 3 where cooler temperatures were detected during thermal profile.**

## Reach 4 – RM 40.8 to 45.8

Reach 4 was profiled over the following days:

| River Mile | Date Profiled | Figure # of Temperature vs Time graph |
|---|---|---|
| RM 40.8 – 42.4 | July 26, 2010 | Fig. 17 |
| RM 45.0 - 45.8 | July 25, 2010 | See Fig. 19 |

RM 42.4 to 45.0 was not profiled due to accessibility, stream obstacles, and low flow conditions. Reach 4 was profiled by wading the stream and towing the probe. Only one area showed a cooler water trend and was of relatively low resolution. The temperature change may be due to an unknown point source or surface returns at this location.

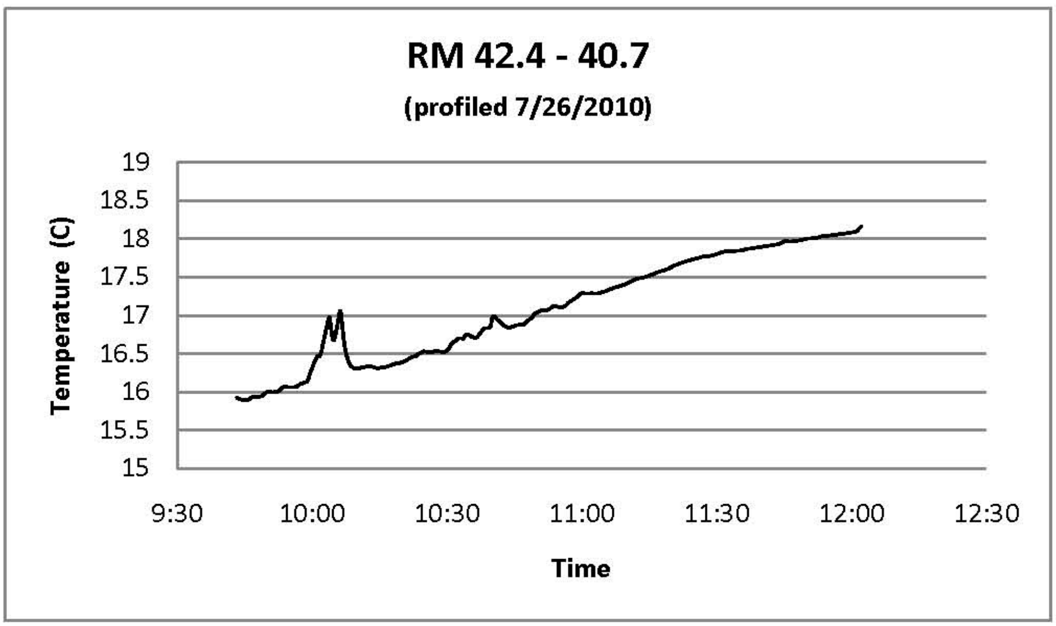


**Figure 18. Temperature vs. time. Reach from Fish Trap to Union.**

| River Mile | Approximate Temperature Change Detected (degree C) |
|---|---|
| 41.7 – 41.8 | 0.15 |

Figure 19 shows locations in reach 4 where patches of cooler temperatures were detected.

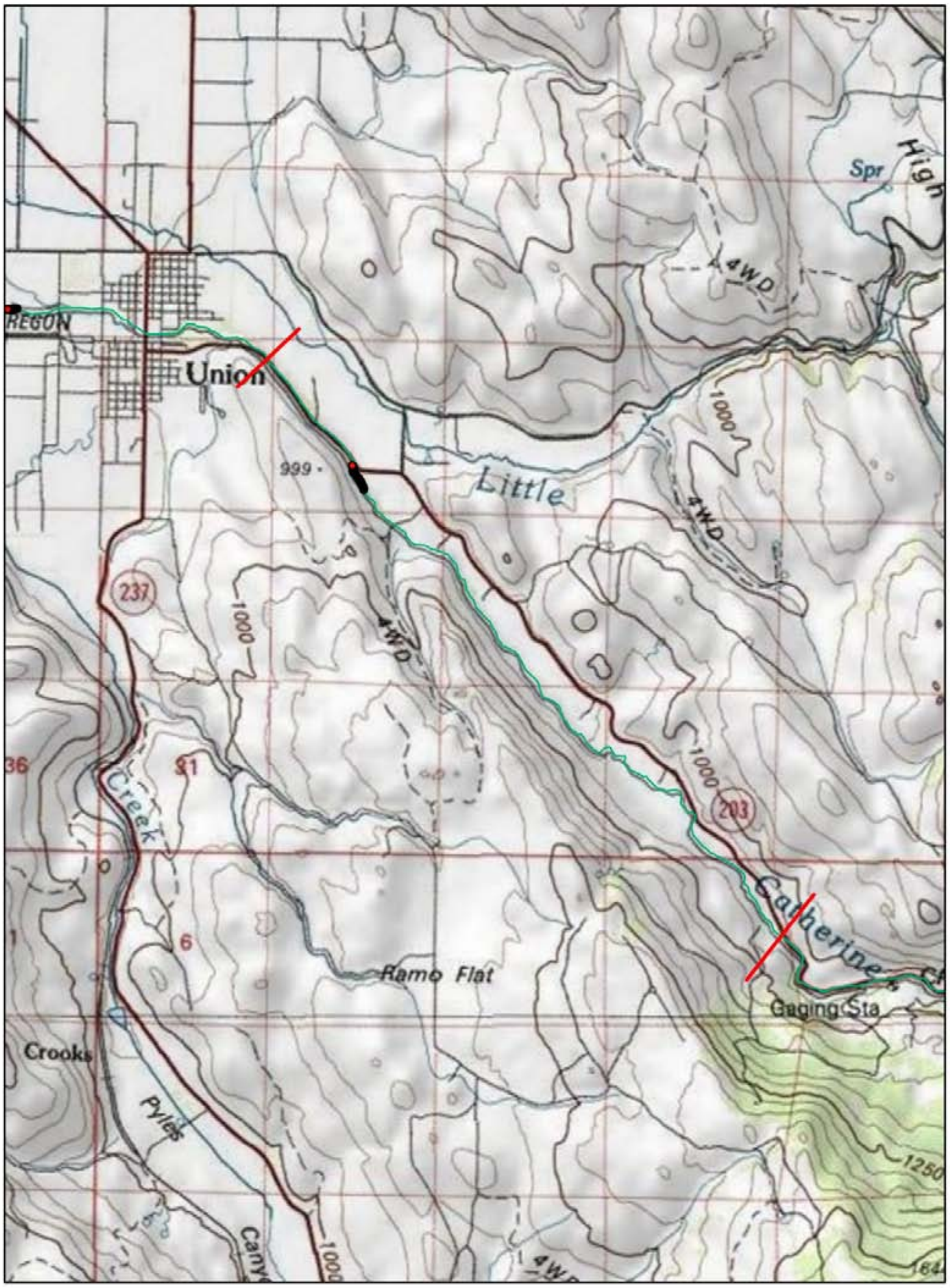


**Figure 19. Reach 4 (RM 40.8 to 45.8). Locations in reach 4 where cooler temperatures were detected during thermal profile.**

## Reach 5, RM 45.8 to 50.1

RM 45.8 to 48.8 in reach 5 was profiled on July 25, 2010 (Figure 20). No areas were detected with cooler temperature patterns in reach 5.

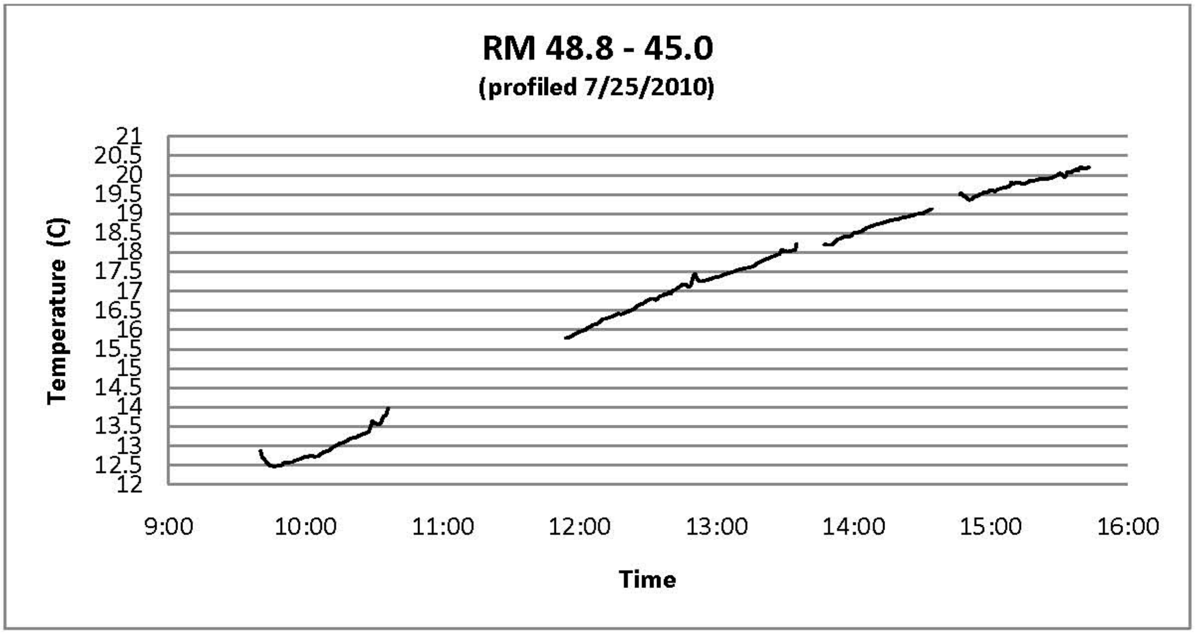


**Figure 20. Temperature vs. time. Reach from Catherine Creek State Park to RM 45.0.**

This area of the river is underlain by bedrock and landslide debris, the riverbed is composed of cobble, and boulder sized rocks. The boulders and shallow rocks prevented safe operation of the inflatable kayak with the probe in tow so the profile was completed by wading in the stream. The lack of any temperature trends may be due to the mixing of the water and movement of the probe within the stream but also may be the lack of groundwater discharge in this reach due to the shallow bedrock foundation.

Reaches 6 and 7 (RM 50.1 to 54.9) were not profiled.

# 2. Conclusions

Complex and highly variable characteristics represent the surface water - groundwater relationship; including geology, groundwater levels, temperature, surface water bodies and abandoned channels, alluvial aquifer flow, and irrigation. In a natural system, surface water flows during spring run-off would exceed the riverbanks and inundate the surrounding floodplain. Groundwater levels would rise to the extent that they may intercept the land surface in depressions and sloughs. As the flows decrease during the summer and fall, groundwater plays an increasingly important role in supplying water (base flow) to streams and tempering the surface water flows with cooler return flows. In a highly modified basin, such as the Grande Ronde and Catherine Creek, the surface water has been channelized and levied to reduce flooding, ponding, and increase agricultural land and production. In addition, pumping wells have been constructed that lower groundwater levels and intercept water that, under natural conditions, would have discharged to the stream.

Thermal profiling of Catherine Creek shows that water returns from sloughs and old oxbow lakes may provide preferential flow back to the stream during the summer. Some of the temperature graphs show areas where the temperatures stabilize or deviate from the expected thermal response of streamflow during the diurnal heating period. These are indicative of localized discharge (springs, surface-water inflows, and/or alluvial aquifer discharge from reconnecting channels). These represent "patches" and may be preferred areas of thermal refuge for salmonids.

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# 1. Introduction

Appendix F describes historical and existing biological use of Endangered Species Act (ESA) listed species within the assessment area as well as limiting factors by geomorphic reach. A number of fish species inhabiting streams in the Grande Ronde basin and Catherine Creek subbasin have been listed under the ESA. Those relevant to this Tributary Assessment (TA) include populations of spring/summer Chinook salmon and summer steelhead. Spring Chinook salmon are part of the Snake River Spring/Summer Chinook Evolutionarily Siginificant Unit (ESU) which has five major population groupings (MPG) including: Lower Snake River, Grande Ronde/Imnaha, South Fork Salmon River, Middle Fork Salmon River, and the Upper Salmon River group. The Catherine Creek population is a spring run and one of seven remaining Chinook salmon populations in the Grande Ronde/Imnaha MPG (Interior Columbia Technical Recovery Team [ICTRT] 2010). Catherine Creek summer steelhead are part of the Upper Grande Ronde steelhead population of the Grande Ronde MPG of the Snake River steelhead Distinct Population Segment (DPS).

# 2. Spring Chinook Salmon

## 2.1 Historic Conditions

Historically, the Grande Ronde basin supported an abundance of salmonids including spring, summer and fall Chinook salmon, sockeye salmon, coho salmon, and summer steelhead (Favrot et al. 2010). Favrot et al. (2010) further state that “during the past century, numerous factors have led to a reduction in salmonid stocks such that the only viable populations remaining are spring Chinook salmon and steelhead.” Spring Chinook salmon populations in the Grande Ronde have declined in size and are substantially depressed from historic levels.

Figure 1 illustrates the current and historic spring Chinook distributions in the Grande Ronde basin. According to the Northwest Power and Conservation Council (NPCC) (2004), changes in Chinook distribution are “somewhat subtle and difficult to map.” Some areas historically used for Chinook spawning are now used primarily for seasonal rearing and migration due to human modification of the habitat which limits its use for spawning (NPCC 2004).

According to NPCC (2004), it is estimated that prior to the construction of the Snake and Columbia River dams, more than 20,000 adult spring Chinook salmon returned to spawn in the Grande Ronde basin annually. Spring Chinook spawning escapement in the basin was estimated at 12,200 fish in 1957 (NPCC 2004). Recent escapement levels have numbered fewer than 1,000 fish. Estimated escapements for the Grande Ronde basin during 1979 to 1984 ranged from 474 to 1,080 (Howell et al. 1985). These low levels prompted listing of spring Chinook salmon under the ESA, including Grande Ronde spring Chinook salmon in 1992.

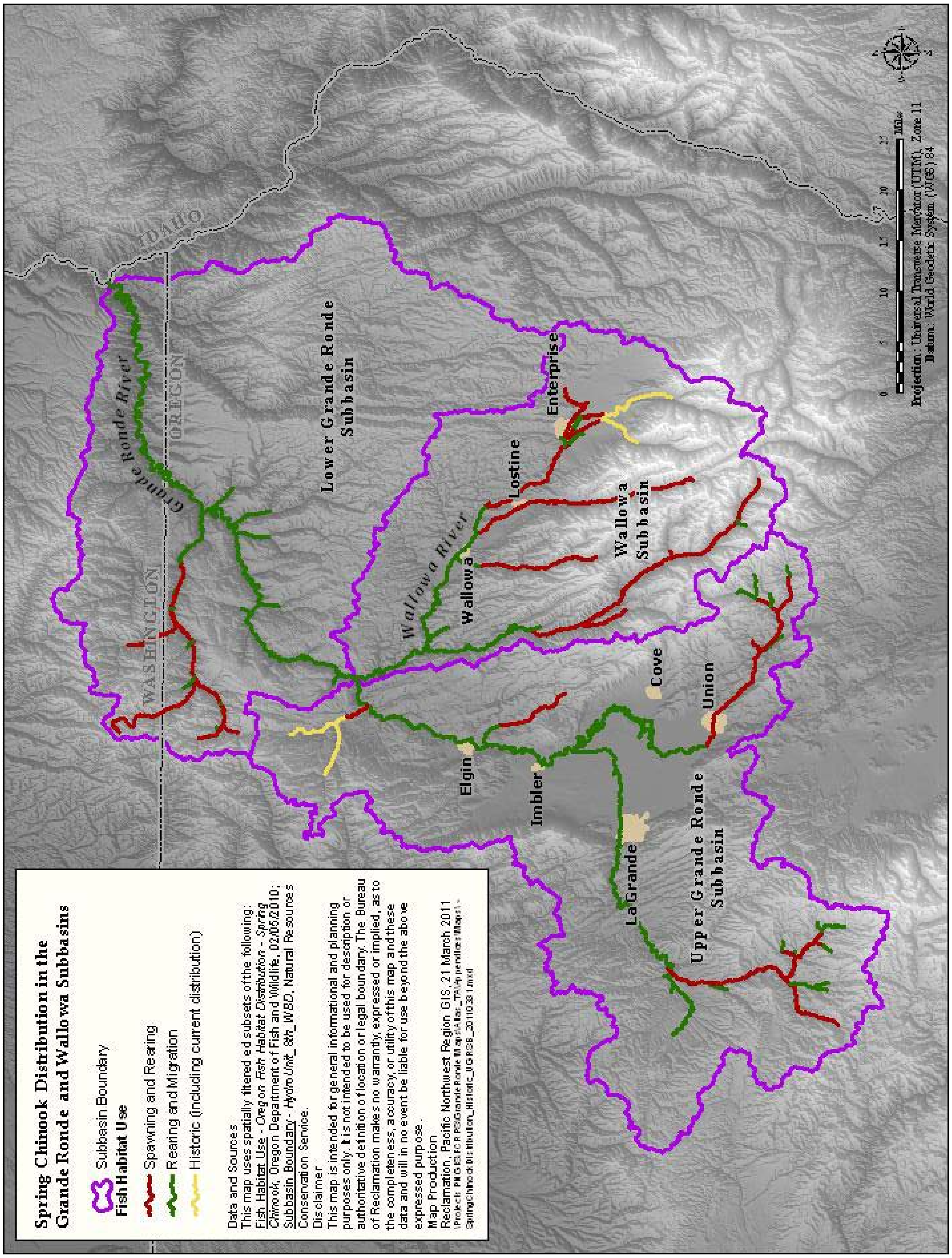


**Figure 1.** **Spring Chinook salmon distribution in the Grande Ronde and Wallowa subbasins.**

## 2.2 Present Conditions

### 2.2.1 Population

Catherine Creek supports a depressed population of ESA-listed Snake River spring/summer Chinook salmon. Recent population estimates vary from year to year but remain at very low levels when compared to historic estimates. Figure 2 shows abundance (number of adult spawning in natural production areas) of spring Chinook salmon in Catherine Creek ranging from 27 in 1994 to 2,947 in 1960. Abundance estimation methods have varied through time. Prior to 1998, spawner abundance estimates were based on redds observed during spawning ground surveys conducted annually since 1955. From 1998 to present, spawner abundance was estimated based on weir counts, mark-recapture estimates, and redd counts with adjustments for pre-spawning mortality estimated from carcass recoveries (Feldhaus 2011).

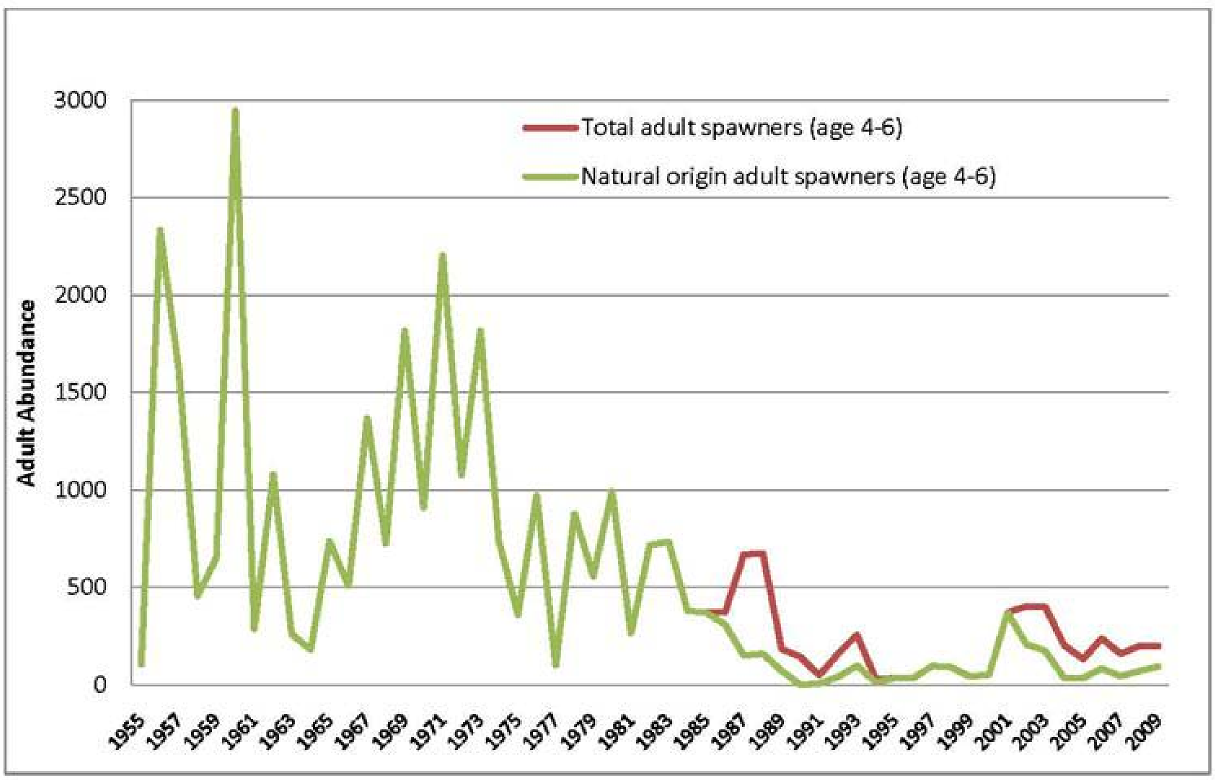


**Figure 2. Catherine Creek Spring Chinook Salmon population spawner abundance estimates (1955-2009).**

### 2.2.2 Life History

Most Grande Ronde adult spring Chinook salmon pass Bonneville Dam and enter the Columbia Basin in April and May (NPCC 2004). By June or July, the adults are holding in the Grande Ronde basin near spawning tributaries. Spawning usually occurs in August and September (NPCC 2004).

Following spawning, eggs incubate in the gravel over the winter and fry emerge between March and May. Spring Chinook salmon juveniles usually rear in the Grande Ronde basin for one year before migrating to the ocean as smolts from March through May. Some juveniles begin their downstream migrations June through October of their first year (NPCC 2004), then continue to rear in freshwater prior to smolting the following spring. Studies have shown that smolts from the Grande Ronde basin arrive at Lower Granite Dam about mid-June. Adult spring Chinook salmon return at ages 3 to 6 (after 1 to 4 years in the ocean), although age 4 is the dominant age class among spawners (NPCC 2004).

Naturally-produced age-0 fall migrants account for 78 percent of the fish (Yanke et al. 2008) that leave during the fall to overwinter downstream of Davis Dam in lower Catherine Creek. In the spring, they migrate out of Catherine Creek and the Grande Ronde watershed to migrate to the ocean as age-1 juveniles. Another group of naturally-produced juvenile Chinook overwinter in upper Catherine Creek and associated tributaries and then leave Catherine Creek at age-1 in the spring for the ocean. They return from the ocean to their natal streams 2 to 3 years later from June through August as 3- and 4-year old adults. Spawning occurs in the reaches above Davis Dam in August and September. The majority of Chinook salmon spawning occurs from Union, Oregon to the confluence of north fork Catherine and middle fork Catherine creeks (Figure 3).

The ICTRT identified two major spawning areas and two minor spawning areas within the Catherine Creek spring Chinook population (Figure 3). According to ICTRT (2010), 50 percent of the historic major spawning areas are occupied and none of the minor spawning areas are occupied.

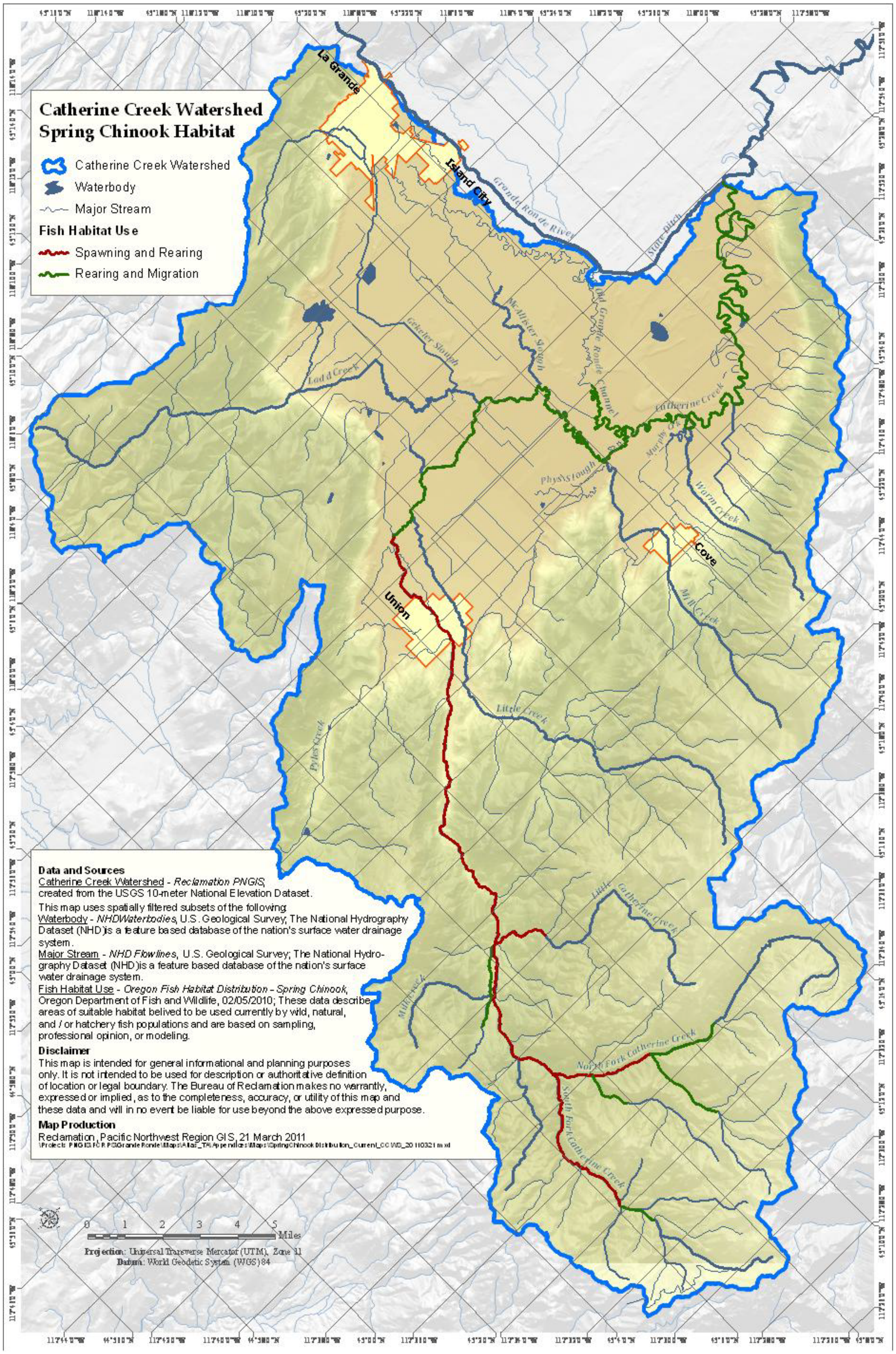


**Figure 3. Catherine Creek watershed spring Chinook habitat.**

## 2.3 Artificial Production

As a result of dramatic declines of Grande Ronde salmon and steelhead populations, the Nez Perce Tribe, Oregon Department of Fish and Wildlife (ODFW), and the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) have implemented conservation hatchery and supplementation programs that functioned within the framework of regional programs. The Lower Snake River Compensation Plan, Northeast Oregon Hatchery program, Grande Ronde Endemic Supplementation program, and Captive Broodstock programs have been integrated together in the Grande Ronde basin in an attempt to improve salmon and steelhead populations and prevent extinction of the Catherine Creek Chinook salmon population. According to NPCC (2004), ESA listings, continued declines in natural production, poor performance of hatchery programs (especially for spring Chinook), and increasing concerns about hatchery/wild interactions have contributed to changes in hatchery mitigation programs. Although agencies are continuing to pursue mitigation goals in the long term, they are placing increasing short-term emphasis on use of hatcheries for conservation and recovery of ESA-listed species (NPCC 2004). Annual adult mitigation, broodyear specific smolt-to-adult return and total survival rates, and annual smolt production goals were established to compensate for the estimated annual loss of 48 percent of the basin adult production.

According to Carmichael et al. (2010), the low productivity of naturally spawning fish and low abundance of natural-origin adults are significant challenges limiting the success of the Catherine Creek spring Chinook salmon hatchery program. These factors limit smolt production. Carmichael et al. (2010) also states: "There are no short-term or simple solutions for improving productivity.…Productivity can only be enhanced by improving survival across the entire life cycle." Two challenges faced by the Catherine Creek Spring Chinook Salmon Hatchery program include low smolt-to-adult survival and high smolt mortality between the release location on Catherine Creek and Lower Granite Dam (Carmichael et al. 2010). Work is presently underway by the ODFW to identify the location and potential causes of mortality that occurs in the Grande Ronde Valley low gradient habitat.

## 2.4 Limiting Factors and Threats

NPCC (2004) indicated that the carrying capacity and survival of anadromous fish have been reduced within the Grande Ronde basin by land management activities which have contributed to riparian and instream habitat degradation. Favrot et al. (2010) states "stream conditions in Catherine Creek, below the city of Union, consist of highly modified meandering and channeled reaches of stream flowing through agricultural land." Many low-elevation portions of the Catherine Creek watershed and Grande Ronde Valley historically were composed of expansive wet meadow, emergent wetland, and open water complexes (NPCC 2004). Pioneer farmers drained these wetlands in the late 19th century which contributed to decreases in water quality, base flows, and large wood inputs (NPCC 2004). Most notable of these wetlands was Tule Lake, a 20,000-acre complex within the Ladd Creek drainage, of which only a small portion remains as part of the Ladd Marsh Wildlife Area (NPCC 2004).

Results from McIntosh et al. (1994) comparing historic and current stream habitat conditions in the upper Grande Ronde River Valley indicated that from 1934 to 1992, pool frequency decreased by 66 percent in managed (non-wilderness) watersheds, substrate composition shifted towards finer substrates, and habitat diversity decreased significantly.

Catherine Creek is on the 303(d) Stream List based on concerns of high temperatures, habitat and flow modifications, and low dissolved oxygen (NPCC 2004). Lower sections of Catherine Creek downstream of Union are heavily silted due to extensive erosion associated with agricultural, forest management practices and mining activities (Yanke et al. 2008). This reach of Catherine Creek is currently listed as an Oregon Water Resources Department (OWRD) flow restoration priority, as irrigation withdrawals in the Grande Ronde Valley generally reduce Catherine Creek flows by up to 90 to 95 percent during irrigation season (Favrot et al. 2010).

Favrot et al. (2010) reported that winter rearing habitat quantity and quality in Grande Ronde Valley may be important factors limiting spring Chinook salmon smolt production in Catherine Creek. Alterations to lower Catherine Creek (e.g., isolated oxbows, irrigation diversions, artificial levees) may degrade the ability of spring Chinook salmon to successfully emigrate into the Grande Ronde River (Favrot et al. 2010).

Within the Grande Ronde basin and Catherine Creek, riparian and instream habitat degradation has severely affected spring Chinook salmon production potential (NPCC 2004). Water withdrawals for irrigated agriculture, human residential development, livestock overgrazing, mining channelization, low stream flows, poor water quality and road construction are major problems affecting salmon production. According to NPCC (2004), “many of these impacts have been reduced in recent years with management practices becoming more sensitive to fish and aquatic habitats.” However, the effects of some past management activities remain.

## 2.5 Overview By Reach

Lower Catherine Creek flows through a low gradient unconfined valley. This area has been highly modified (NPCC 2004). In the late 1800s, the State Ditch was constructed as a flood control cut-off channel. This portion of Catherine Creek has been diverted into the old main Grande Ronde channel (Figure 4). There is extensive agricultural use and water diversions throughout lower Catherine Creek. This reach, as previously mentioned, is listed as an OWRD flow restoration priority. Most of the impacts to Catherine Creek occur below the town of Union where there is extensive agriculture that has impacted the riparian area, reducing shade and confining the channel (NPCC 2004). Water withdrawals also result in flow reductions of about 25 percent starting in June, 50 percent by mid-July, and 90 to 95 percent from the third week of July through the end of September.

In an effort to collect further information on habitat conditions for Catherine Creek, the ODFW utilized its aquatic inventory program that is designed to provide quantitative information on habitat condition for streams throughout Oregon. Aquatic habitat surveys were conducted on Catherine Creek in 1991, 1995, and 2010. All surveys described the channel morphology, riparian characteristics, and features and quality of instream habitat during summer flow, following the methods described in Moore et al. (2010). Different portions of Catherine Creek were surveyed in 1991 and 1995. The 2010 survey began at the confluence of Catherine Creek and State Ditch while the 1991-95 survey did not encompass the lower 11 miles (Kavanagh, Jones, and Stein 2011).

According to Kavanagh et al. (2011), Catherine Creek has changed little between the two surveys: "The lower section of the creek continues to be a meandering stream constrained by terraces and agricultural activities with little undercut, riparian shading, or large wood.….The substrate and bank material is fine sediment, some of which is actively eroding.…Active erosion may have decreased since 1995 due to increased shrub growth."

The middle section of Catherine Creek transitions from an agriculture landscape to a reach with agriculture and urban land uses. Catherine Creek has five dams and diversions in this section (Kavanagh, Jones, and Stein 2011). Streamside shade, coarse substrate, and stream gradient increases in the middle reach. The upper reach changes dramatically with an increase in the number of multiple channels. The channel geomorphology and dimensions, habitat types, and substrate composition changed little between survey years (Kavanagh, Jones, and Stein 2011). Approximately half the amount of wood was observed during the 1991-95 survey in contrast to the 2010 survey, although the amount of overall wood was still low. The percent of pools was similar for both surveys (Kavanagh, Jones, and Stein 2011).

Kavanagh et al. (2011) utilized the HabRate model (Burke, Jones, and Dambacher 2010) to integrate habitat attributes as a method to assess overall habitat quality relative to freshwater life stages of Chinook and steelhead. For spring Chinook salmon, the availability and quality of spawning habitat in Catherine Creek did not change in the three sections surveyed between 1991-95 and 2010. HabRate indicated that spawning habitat is poor in the lower section and fair in the middle and upper sections of Catherine Creek. The abundance of fines and lack of coarse material lowers the quality of the few riffles that are present in the lower section (Kavanagh, Jones, and Stein 2011). Riffles are prevalent in the middle and upper sections and the substrate has few fines and more gravel, but with little cobble (Kavanagh, Jones, and Stein 2011). Kavanagh et al. (2011) rated the lower section (mouth to Davis Dam) fair for 0+ summer rearing and overwintering for spring Chinook salmon. Pools in this section were nearly non-existent, and availability of instream cover was poor. The few pools that were present had good complexity. The middle (Davis Dam to Brinkler Creek) and upper (Brinkler Creek to North and South Forks Catherine Creek) sections also rated fair for rearing and overwintering (Kavanagh, Jones, and Stein 2011). These sections lacked suitable pool area, undercut banks, large wood, and cobble substrate.

Table 1 below provides information of fish usage by life stage and limiting factors on a reach-by-reach basis for spring Chinook salmon. The limiting factors were determined following a Habitat Work Session meeting conducted on February 10, 2011, in La Grande, Oregon.

There are multiple physical variables that control the lack of habitat availability. For example, lack of juvenile rearing habitat can imply insufficient off-channel habitat, in-channel habitat complexity produced by large woody debris, pool-forming elements, protective cover, velocity refugia, or other variables. In general, impacts to juvenile Chinook salmon in this reach are attributed to low flow, high water temperatures, lack of protective cover, lack of pools, juvenile outmigration delays, and entrainment into unscreened diversions as a result of high flow events.

**Table 1. Spring Chinook salmon fish usage by life stage and limiting factors on a reach-by-reach basis.**

| Reach | RM | Life Stage Usage | Limiting Factors |
|---|---|---|---|
| 1 | 0 to 22.5 | Migration, juvenile rearing | Low flows<br>High water temperatures<br>Predation<br>Protective cover<br>Outmigration delays<br>Silt substrate |
| 2 | 22.5 to 37.2 | Migration, juvenile rearing | Passage delays<br>Turbidity/siltation<br>Lack of juvenile rearing habitat<br>Protective cover<br>High summer water temperatures<br>Overgrazing<br>Entrainment<br>Predation<br>Productivity |
| 3 | 37.2 to 40.78 | All | Low summer flow/fish passage<br>Lack of juvenile rearing habitat<br>High summer water temps<br>Anchor ice<br>Overgrazing<br>Flooding |
| 4-7 | 40.78 to 54.9 | All | Lack of juvenile rearing habitat<br>Lack of adult holding habitat<br>Anchor ice<br>Lack of deep pools |

The following issues were summarized following the February 10, 2011 Habitat Work Session for Catherine Creek:

### Reach 1 – Mouth of Catherine Creek (RM 0) to Old Grande Ronde Channel (RM 22.5)

1. Possible juvenile Chinook salmon outmigration delays from the mouth of Catherine Creek to Elmer Dam resulting from high flows in Grande Ronde River backing up lower Catherine Creek flow.

2. Isolated unscreened oxbows that are operated for storage can strand/delay juvenile Chinook salmon migration.

3. Instream structure is very limited.

### Reach 2 – Old Grande Ronde Channel (RM 22.5) to Pyles Creek (RM 37.2)

1. Low flow delays for late adult spring Chinook migrants.

2. Juvenile Chinook salmon entrainment into overflow ditch near Sherman property.

3. Heavy livestock use impacting riparian zone.

4. Should stop logs remain in place at Davis Dam during late fall early winter to provide habitat for juvenile Chinook salmon?

5. Lower Little Creek providing winter refugia for juvenile Chinook salmon.

Agriculture dominates reaches one and two of Catherine Creek. Extensive irrigation diversions, which alter natural streamflows and channels, exist within the mainstem and several of the tributaries within this reach (NPCC 2004). Historically, many of the stream channels in this reach had a high sinuosity; however, this sinuosity has been reduced as a result of agriculture and road development (Lovatt 2003). McIntosh et al. (1994) reported a 61 percent decrease in frequency of large pools in the mainstem of Catherine Creek. Overall, limiting factors include low summer flows, elevated summer temperatures, poor water quality (low dissolved oxygen levels), low abundance of pool habitat, poor passage for returning adults, excess sediment, substandard streambank and riparian conditions, and a lack of habitat diversity (Huntington 1994; GRMW 1995; NPCC 2004).

StreamNet (2006) indicates that the main stem of Catherine Creek within this reach is being used by spring Chinook salmon primarily for rearing and migration. Spring Chinook have been documented using the lower 2 to 3 miles of Gekeler Slough for rearing (StreamNet 2006) and lower Little Creek for rearing (Favrot et al. 2010). Of the limiting factors indicated above, poor water quality, low abundance of pool habitat, and lack of protective cover limit winter rearing for juvenile Chinook.

### Reach 3 – Pyles Creek (RM 37.2) to Swackhammer Dam (RM 40.8)

1. Low flow issues in summer as juvenile Chinook salmon move upstream to cooler water.
2. Anchor ice formation in shallow riffles.
3. Heavy livestock use near sewage treatment plant to Hefner property.
4. Fish passage criteria being met at diversion dams?

### Reach 4-7 – Swackhammer Dam (RM 40.8) to Forks (RM 54.9)

1. Limited pools.
2. Riparian conditions needing improvement.

From Pyles Creek upstream to the confluence of Catherine Creek's North and South Forks, rural residences and Highway 203 constrain portions of Catherine Creek (NPCC 2004), reducing the number of pools, and creating long shallow runs. Irrigated agriculture and logging dominate this portion of the watershed (NPCC 2004), which is primarily in private ownership. Agriculture, grazing, irrigation diversions, the highway, and impacts from residences within the riparian area are the primary threats within this reach (GRMW 1995; NPCC 2004). Limiting factors include low summer flows, excess fine sediment, elevated summer temperatures, poor water quality (low dissolved oxygen levels), low abundance of pool habitat, poor passage for returning adults, substandard streambank and riparian conditions, and reduced channel complexity (GRMW 1995; Huntington 1994; NPCC 2004).

As mentioned previously, this reach is used for spawning and rearing by spring Chinook salmon. Of the limiting factors outlined above, low summer flows and elevated water temperatures likely limit summer rearing while excess sediment/substrate embeddedness may limit survival during incubation. Additionally, poor spawning conditions created by excess sediment and barriers that may prevent returning adults from accessing upstream spawning habitat may limit spawning success.

## 2.6 Discussion

The decline in the Catherine Creek spring Chinook salmon population has been primarily attributed to passage problems at Columbia and Snake River dams (NPCC 2004). These fish must pass a total of eight dams; four on the Columbia River and four on the Snake River, during up and downstream migrations. Out of subbasin harvest and habitat degradation have also contributed to the population decline. However, recent information by Favrot et al. (2010) indicates that winter rearing habitat quantity and quality in the Grande Ronde Valley may be more of an important factor in limiting spring Chinook salmon smolt production for Catherine Creek. According to ICTRT (2010), there are currently two primary life history stages pathways for the freshwater juvenile life stages: fish rear from fry to smolt in the upper reaches of Catherine Creek or fish leave the upper reaches of Catherine Creek in the fall and overwinter in the Grande Ronde Valley reaches, including lower Catherine Creek. There is speculation that there have been reductions in the variation of juvenile pathways such as the loss of ability of fry and summer parr to move downstream from the upper rearing reaches into the Grande Ronde Valley. Favrot et al. (2010) indicated that early migrant survival (fish overwintering in the Grande Ronde Valley) to Lower Granite Dam is typically lower for the Catherine Creek population than other Chinook salmon populations in the Grande Ronde basin. Previous research estimated that travel times through the Grande Ronde Valley reach (lower Catherine Creek included) were considerably greater than any other reach, and accounted for 42 percent of the mortality incurred in freshwater for naturally-produced Chinook salmon (Monzyk et al. 2009). Research is underway that will provide a better understanding of the timing, location, and source of mortality for this depressed population of spring Chinook salmon.

Catherine Creek adult spring Chinook salmon migration and spawn timing has likely shifted and has reduced variability relative to historic timing as a result of lower flows and temperature changes (warmer water) in the summer season (ICTRT 2010). Significant changes in habitat attributes have occurred in Catherine Creek relative to historic conditions. Flow and temperature patterns are altered with much reduced flow in summer and increased temperatures. These factors have significantly influenced adult and juvenile migration opportunity as well as availability of adult holding habitat. Selective pressures against fry and summer downstream movement and late adult migration are likely significant and affect 25 percent or greater of the individuals that historically expressed these traits (ICTRT 2010).

The primary in-basin factors limiting spring Chinook salmon populations in the Catherine Creek and middle Grande Ronde River systems are water temperature, sediment, altered hydrologic function, predation, food, and habitat complexity (GRMW 1995; Huntington 1994; NPCC 2004). Altered hydrologic function primarily is the result of irrigation water management, which results in reduced instream flows during critical summer months, contaminated return water, elevated stream temperatures, and passage barriers. Habitat complexity issues primarily are due to reduced wetted widths and a lack of pools and large woody debris (GRMW 1995; Huntington 1994; Kavanagh, Jones, and Stein 2011; NPCC 2004). Some reaches of Catherine Creek have been channelized and armored to accommodate road construction, homesteads, and irrigated agriculture.

Key questions that are critical towards recovering Catherine Creek spring Chinook salmon are:

1. Are habitat conditions for juvenile spring Chinook salmon (Age 0- fry) in rearing areas upstream of Pyles Creek limiting to where those conditions are forcing these fish downstream earlier than what they experienced historically?
2. Are habitat conditions downstream of Pyles Creek unfavorable for the above indicated early migrants?

## 2.7 Spring Chinook Population Risk Assessment

Ecosystem Diagnosis and Treatment (EDT) is a system for rating the quality, quantity, and diversity of habitat along a stream, relative to the needs of a focal species such as Chinook salmon. The methodology includes a conceptual framework for decision making and a set of modeling tools used to organize environmental information and rate the habitat elements with regard to the focal species. EDT can identify the potential for a stream under a set of conditions such as those that occur presently or those that might occur in the future. The result is a scientifically-based assessment of conditions and a prioritization of restoration needs.

EDT analysis for Catherine Creek identified impacts for the "middle" reach. The highest priority impacts were dams, riparian function, lack of wood, high water temperature, competition with hatchery fish, low flow, predation and sediment (NPCC 2004). Life history stages most affected were the age 0 inactive, age 0 active and age 1 migrants. NPCC (2004) stated, "EDT rated the middle Catherine Creek geographic area as an overwhelming priority for restoration (with a predicted 5,000+ percent increase) for spring Chinook salmon abundance."

# 3. Summer Steelhead

The Upper Grande Ronde River summer steelhead population is part of the Snake River Basin Steelhead DPS that includes all naturally spawned populations of steelhead in streams in the Snake River basin of southeast Washington, northeast Oregon, and Idaho (62 FR 43927), and were federally listed as threatened in 1997 and reaffirmed on January 5, 2006. Critical habitat for Snake River Basin steelhead, including Catherine Creek, was designated in 2006.

## 3.1 Historic Conditions

The Grande Ronde basin historically produced large runs of summer steelhead (NPCC 2004). The size of those runs is unknown but an estimate of nearly 16,000 to the mouth of the Grande Ronde River was given for 1957, prior to construction of the lower Snake River dams (NPCC 2004). The ICTRT (2010) classified the Upper Grande Ronde River steelhead population as "Large" based on historical habitat potential. A steelhead population classified as "Large" has a mean minimum abundance threshold of 1,500 naturally produced spawners.

## 3.2 Present Conditions Summer Steelhead

### 3.2.1 Population

Recent estimates have estimated the upper Grande Ronde River summer steelhead escapement at about 1,800 fish (NOAA Fisheries 2006). The watershed is currently managed for wild fish production only with no hatchery fish released to the stream.

NPCC (2004) indicated that the current condition of Snake River summer steelhead population abundance, growth rate/productivity, spatial structure, and diversity are as follows:

- The abundance of returning adults is uncertain due to a lack of data for adult spawners. Dam counts are currently 28 percent of the interim recovery target for the Snake River basin (52,000 natural spawners).
- Diversity within the Snake River population is of concern. Displacement of natural fish by hatchery fish (declining proportion of natural-origin spawners) is a concern and efforts are underway to reduce this. There is also evidence of homogenization of hatchery stocks within the basins, and some stocks exhibiting high stray rates.

### 3.2.2 Life History

Steelhead spawn in cool, clear streams with suitable gravel size, depth, and current velocity. Intermittent streams may also be used for spawning. Steelhead enter streams and arrive at spawning grounds weeks or even months before they spawn and are vulnerable to disturbance and predation during that time (NPCC 2004). Steelhead eggs may incubate for 1.5 to 4 months prior to hatching, depending on water temperature. Juveniles rear in freshwater from 1 to 4 years and then migrate to the ocean as smolts. Summer rearing takes place primarily in the faster parts of pools, although young-of-the-year are abundant in glides and riffles. Winter rearing occurs more uniformly at lower densities across a wide range of fast and slow habitat types (NPCC 2004). Productive steelhead habitat is characterized by complexity, primarily in the form of large and small wood.

Most summer steelhead rear for two years in the Grande Ronde River system before migrating to the ocean.  Most smolt migration occurs from April through June (NPCC 2004).  Juveniles may move upstream to find cool water refugia during the summer (NPCC 2004).

Adult summer steelhead spend 1 to 3 years in the ocean before returning to spawn.  Those returning to the Grande Ronde pass Bonneville Dam during July and John Day Dam primarily during August through October (NPCC 2004).  According to NPCC et al. (2004), Grande Ronde River summer steelhead migrate through the lower Snake River during two periods; a fall movement that peaks in mid-to-late September and a spring movement that peaks during March and April.  Some adult summer steelhead enter the lower Grande Ronde River as early as July but most adults enter from September through March.

Wild adult summer steelhead returning to the Grande Ronde are generally 4 years of age at maturity, having spent 2 years in freshwater, 1.5 years in the ocean, and 0.5 year migrating to the subbasin and holding there until spawning.  Spawning occurs from March through mid-June, with peak spawning taking place from late April through May (NPCC 2004).  Fry emerge from May through July (NPCC 2004).

Summer steelhead are presently distributed throughout the Grande Ronde basin and in Catherine Creek (Figure 5).  Figure 4 represents adult summer steelhead that were passed above the Catherine Creek weir trap from 2003 through 2010.

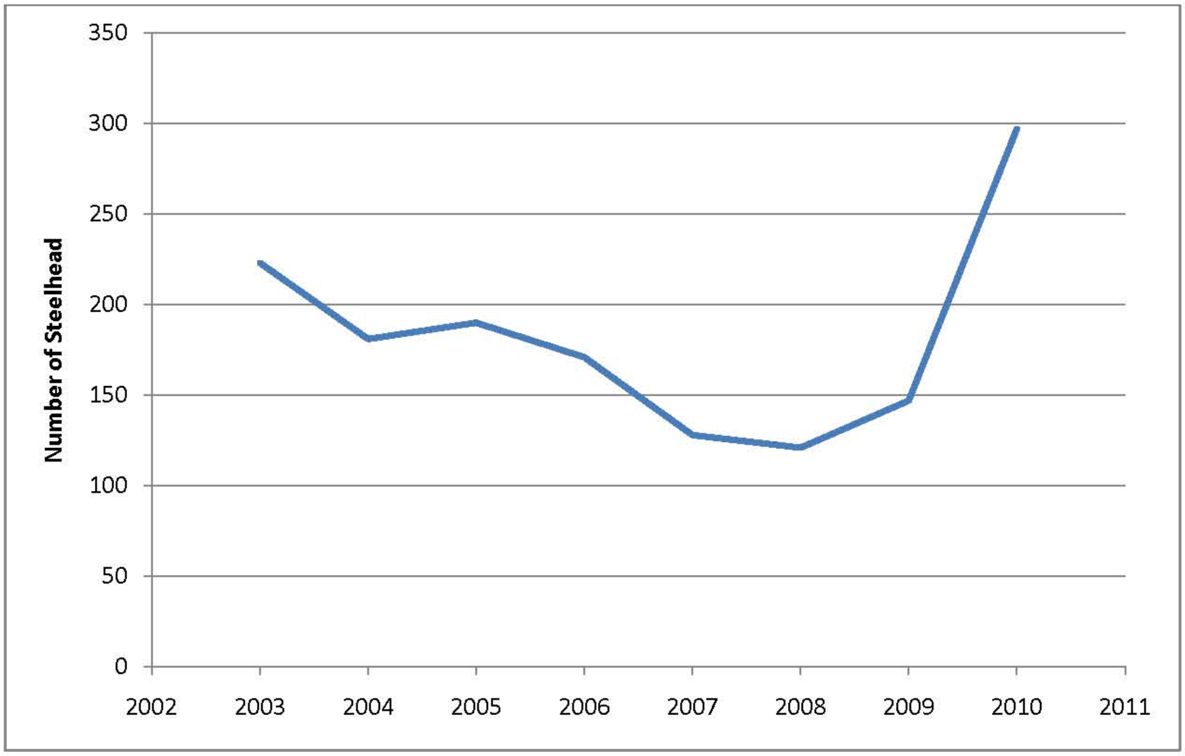


**Figure 4. Adult steelhead passed above Catherine Creek weir 2003 through 2010.**

Summer steelhead spawn and rear upstream of the town of Union. Steelhead utilize Catherine Creek downstream from Union for migration and rearing. Approximately one-third overwinter in downstream areas and are considered early migrants (Yanke et al. 2008).

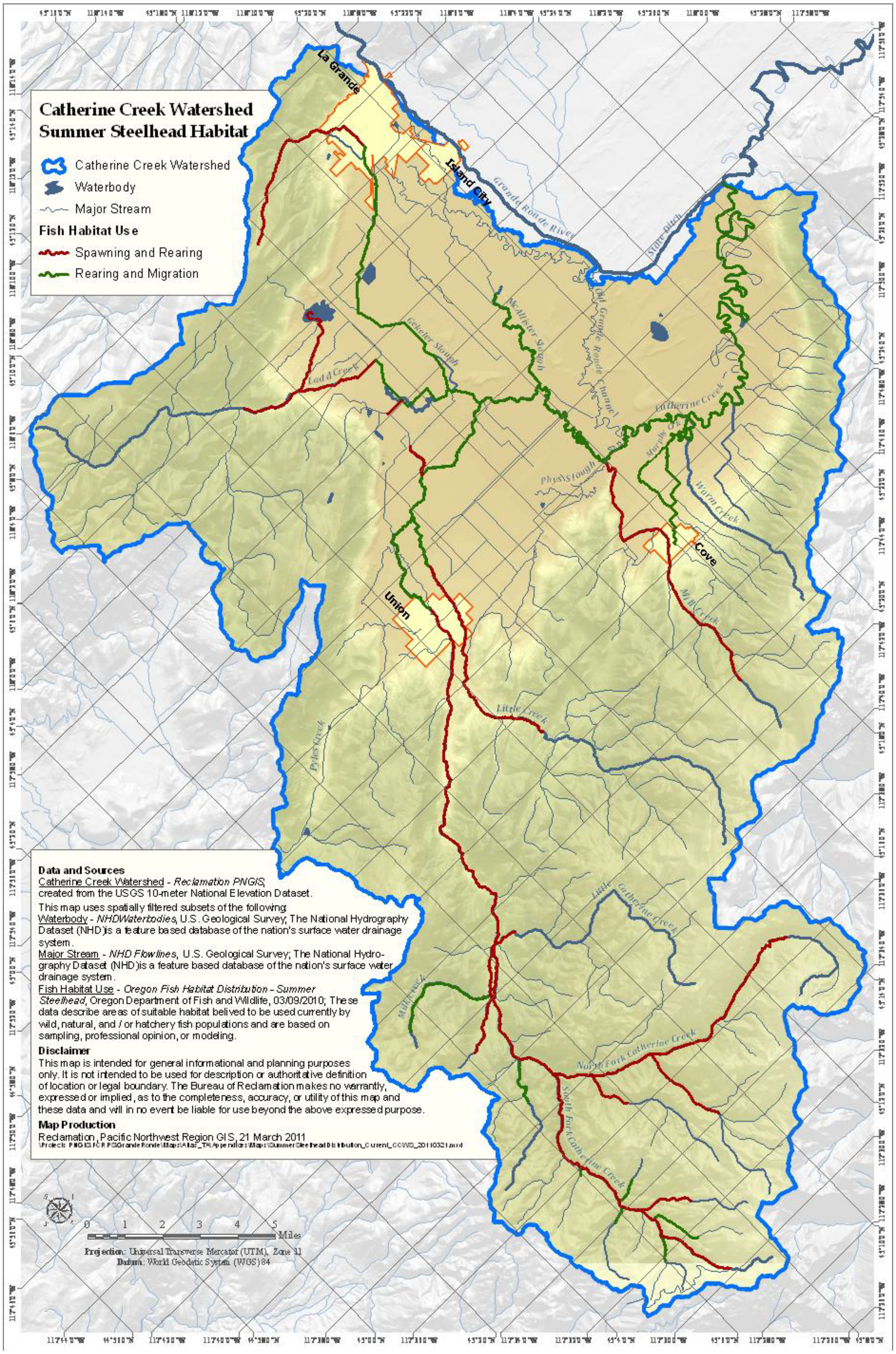


**Figure 5. Catherine Creek watershed summer steelhead habitat.**

### 3.2.3 Steelhead Population Risk Assessment

The EDT model attribute summary indicated that sediment and habitat quantity are the largest and most widespread impacts on the Upper Grande Ronde summer steelhead population (NPCC 2004). Limiting factors identified previously for Catherine Creek spring Chinook salmon are likely applicable to summer steelhead found in Catherine Creek. Those would include habitat quantity and quality, sediment conditions, water quality, and water quantity.

Kavanagh et al. (2011), following their 2010 aquatic habitat survey, found that for summer steelhead HabRate values remained about the same between 1991 to 1995 and 2010 (Kavanagh et al. 2010). The lower section of Catherine Creek contained poor habitat for steelhead spawning, incubation and emergence. Habitat quality for summer and winter rearing for age-0 and age-1 juvenile steelhead was also poor in the lower section and fair in the middle and upper sections. Spawning habitat quantity and quality was fair in the middle and upper sections. Conditions were somewhat better in the middle and upper sections as a result of increased habitat complexity.

# 4. Bull Trout

## 4.1 Historic Conditions

There is limited information on bull trout population productivity and abundance in the Grande Ronde basin. Historically, bull trout were distributed throughout the basin, and although they were never abundant as other salmonids, they were certainly more abundant and more widely distributed than they are today (NPCC 2004). As a result of declines in populations, bull trout were listed under the ESA in 1998 as threatened primarily due to habitat threats. Bull trout in the Grande Ronde basin fall into the "Mid-Columbia" recovery unit. In 2010, critical habitat for bull trout was designated by the U.S. Fish and Wildlife Service (USFWS) from the mouth of Catherine Creek to headwater locations. Critical habitat receives protection against Federal agencies carrying out, funding, or authorizing the destruction or adverse modification of critical habitat.

## 4.2 Life History

Bull trout in the Grande Ronde basin have both resident and migratory life history patterns. Resident bull trout complete their entire life cycle in a tributary stream. Migratory bull trout spawn in tributary streams where juveniles rear for up to 4 years before migrating to a river or lake. Migrating bull trout return to spawning tributaries from the end of June into October. Spawning occurs between mid-September and early November. Resident and migratory bull trout can be found together in spawning grounds and can spawn together. Offspring can express either life history. Bull trout can live longer than 12 years and prefer the coldest water (typically l5˚C or less). All life stages of bull trout are associated with complex forms of cover and pools.

Complete historical distribution for bull trout is undocumented. It is thought that bull trout occupied all major tributaries in the upper Grande Ronde (including Catherine Creek) and a seasonal connection existed with the Snake River (Buchanan et al. 1997). Current known spawning and resident distribution of bull trout is spread throughout the headwater streams of the Grande Ronde basin, though most populations are concentrated in the Wallowa River basin (NPCC 2004). Figure 6 shows bull trout distribution in the Catherine Creek watershed. Potential for inter-population connection exists through major migratory corridors and large rivers, however, bull trout use of these rivers is limited by high water temperatures and low flow during the summer months (NPCC 2004). Presence and absence data from Catherine Creek suggest low population densities (NPCC 2004).

Catherine Creek supports both life history forms of bull trout. The fluvial form found in Catherine likely utilize lower reaches downstream of Union as a migratory corridor based on habitat conditions. Distribution (spawning and rearing) of bull trout is restricted to headwater areas and rivers with high quality habitat and water quality, primarily on National Forest lands. Bull trout spawning in Catherine Creek would occur in headwater locations.

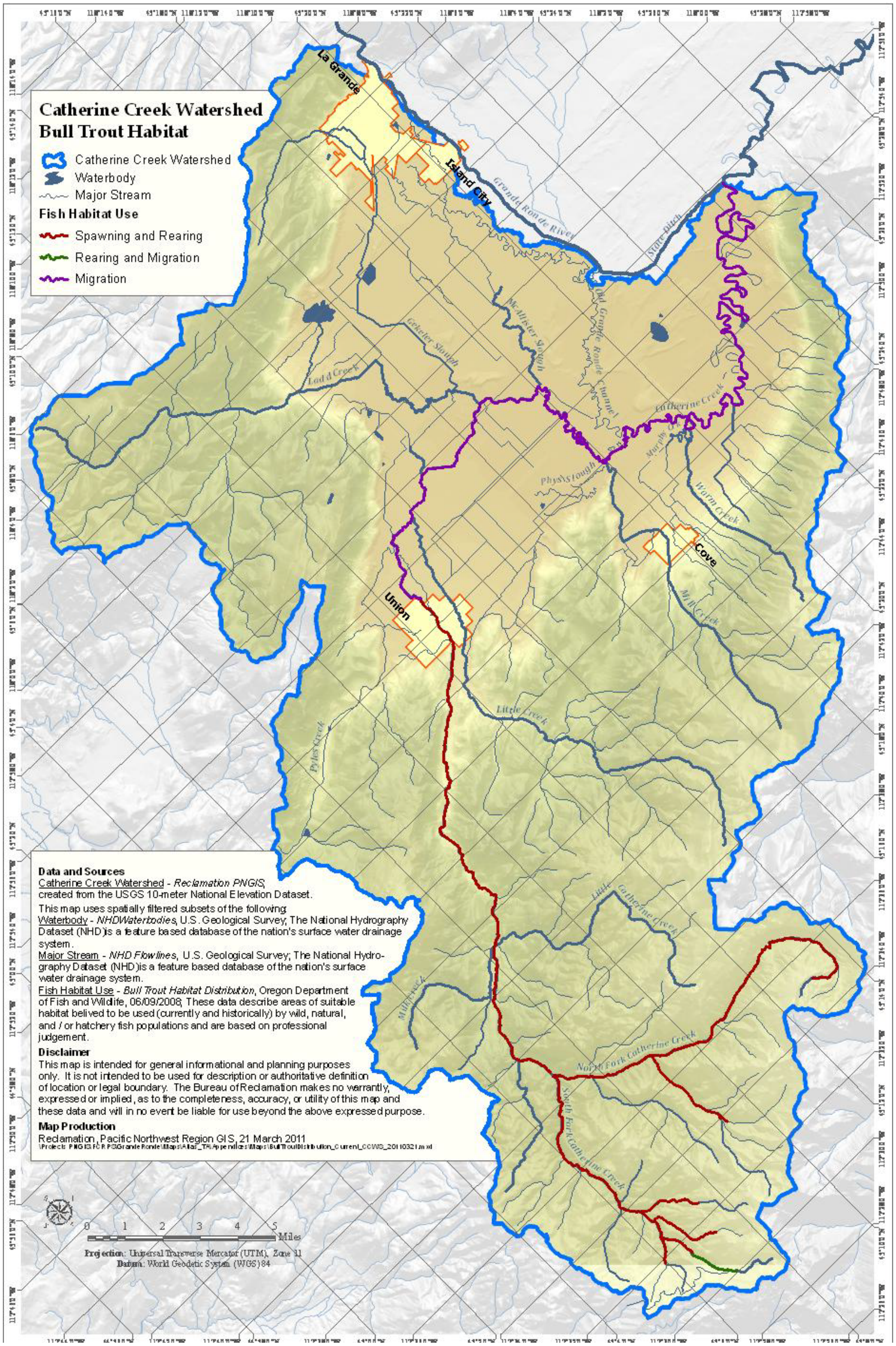


**Figure 6. Bull trout distribution in the Catherine Creek watershed.**

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