APPENDIX A – HYDROLOGY

RECLAMATION
Managing Water in the West

HYDROLOGY REPORT
CATHERINE CREEK TRIBUTARY ASSESSMENT – GRANDE RONDE RIVER BASIN
Tributary Habitat Program, Oregon

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region
Geology and Fluvial Analysis Group
Boise, Idaho

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U.S. DEPARTMENT OF THE INTERIOR

Protecting America's Great Outdoors and Powering Our Future

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Cover Photograph: View looking east (downstream) along Catherine Creek, Reach 2 at river mile 26.0, in the Cove area, Mt. Fanny (upper left) and Phys Point (upper right) can be seen in the background. **Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – July 29, 2010.**

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1. Summary

Catherine Creek is a large, snowmelt-dominated creek that drains part of the Wallowa Mountains of Oregon. The headwaters are steep and mountainous while the lower reaches have an exceptionally low gradient (1.9 ft/mile). Historically, the low gradient reaches were meandering and tortuous and routed through abundant wetlands, rivulets, and shallow lakes through the Grande Ronde Valley. Here the creek has been channelized and deepened to improve the local land drainage and reduce flooding for agricultural and urban use. Similarly, the lower end of the Grande Ronde River within the Grande Ronde Valley, below La Grande, Oregon has been redirected and channelized, moving the Catherine Creek-Grande Ronde River confluence downstream 22.5 miles and shortening the Grande Ronde River by 33 miles. The lowest reach of Catherine Creek is now in an oversized channel (the historic Grande Ronde River) which once had a 1.5-year return interval discharge of approximately 6,400 cfs and is now only 1,760 cfs. The modifications that have occurred have led to lower baseflows during the summer months as well. Studies have been conducted to determine how altering Rhinehart Gap, a natural constriction marking the end of the Grande Ronde Valley downstream of Catherine Creek, might further improve runoff efficiency during high flow events. Numerous diversion dams and pumps along the length of the creek remove water during the summer at a time when the creek naturally has the lowest flows, which can lead to dry or nearly dry sections of creek. Changes in climate have also occurred leading to decreased water yield in the basin and an earlier release of snowpack. This adds further stress to the system as the irrigation season is extended while the water supply is reduced.

2. Introduction

2.1 Purpose

Reclamation and Bonneville Power Administration (BPA) contribute to the implementation of salmonid habitat improvement projects in the Grande Ronde subbasin to help meet commitments contained in the 2010 Supplemental Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) (NOAA Fisheries 2010). This BiOp includes a Reasonable and Prudent Alternative (RPA), or a suite of actions, to protect listed salmon and steelhead across their life cycle. Habitat improvement projects in various Columbia River tributaries are one aspect of this RPA. Reclamation provides technical assistance to States, Tribes, Federal agencies, and other local partners for identification, design, and construction of stream habitat improvement projects that primarily address streamflow, access, entrainment, and channel complexity limiting factors. Reclamation's contributions to habitat improvement are intended to be within the framework of the FCRPS RPA or related commitments.

The hydrologic assessment as a part of the Catherine Creek Tributary Assessment (TA) described here will provide scientific information that can be used to help identify, prioritize, and implement sustainable fish habitat improvement projects and to help focus those projects on addressing key limiting factors to protect and improve survival of salmon and steelhead listed under the Endangered Species Act (ESA). The TA represents the initial phase of a work process adopted by Reclamation to provide specific technical details, which serve as guidance for project identification, viability of existing habitat, and project needs for rehabilitation of ESA-listed steelhead trout and spring Chinook. The TA will be provided to regional and local implementers of habitat rehabilitation projects to guide efforts towards a common goal of increased abundance and productivity of ESA-listed steelhead trout and spring Chinook.

The specific objectives of this hydrologic assessment as part of the TA include the following:

1. Identify the present condition surface water hydrologic patterns and influences of Catherine Creek utilizing available data.
2. Identify the historic conditions surface water hydrologic patterns and influences utilizing available data and historic accounts.
3. Identify any changes to historic hydrologic conditions that are well understood to include anthropogenic alterations and natural changes.
4. Estimate recent climate change effects on the hydrology of the region.

2.2 Physical Setting and Location

The Catherine Creek TA focuses on the “valley segment” of Catherine Creek from its confluence with the Grande Ronde River at State Ditch to near its headwaters at the U.S. Forest Service (USFS) boundary at the confluence of the North and South Forks of Catherine Creek (Figure 1). This reach is approximately 55-miles long and is located within three distinct geomorphic valley types including headwater, alluvial fan, and valley bottom. Several tributaries are also of interest within this area, most notably larger tributaries within the valley segment to include Mill Creek, Ladd Creek, Little Creek, and Pyles Creek. The study area is roughly bounded by the 100-year floodplain.

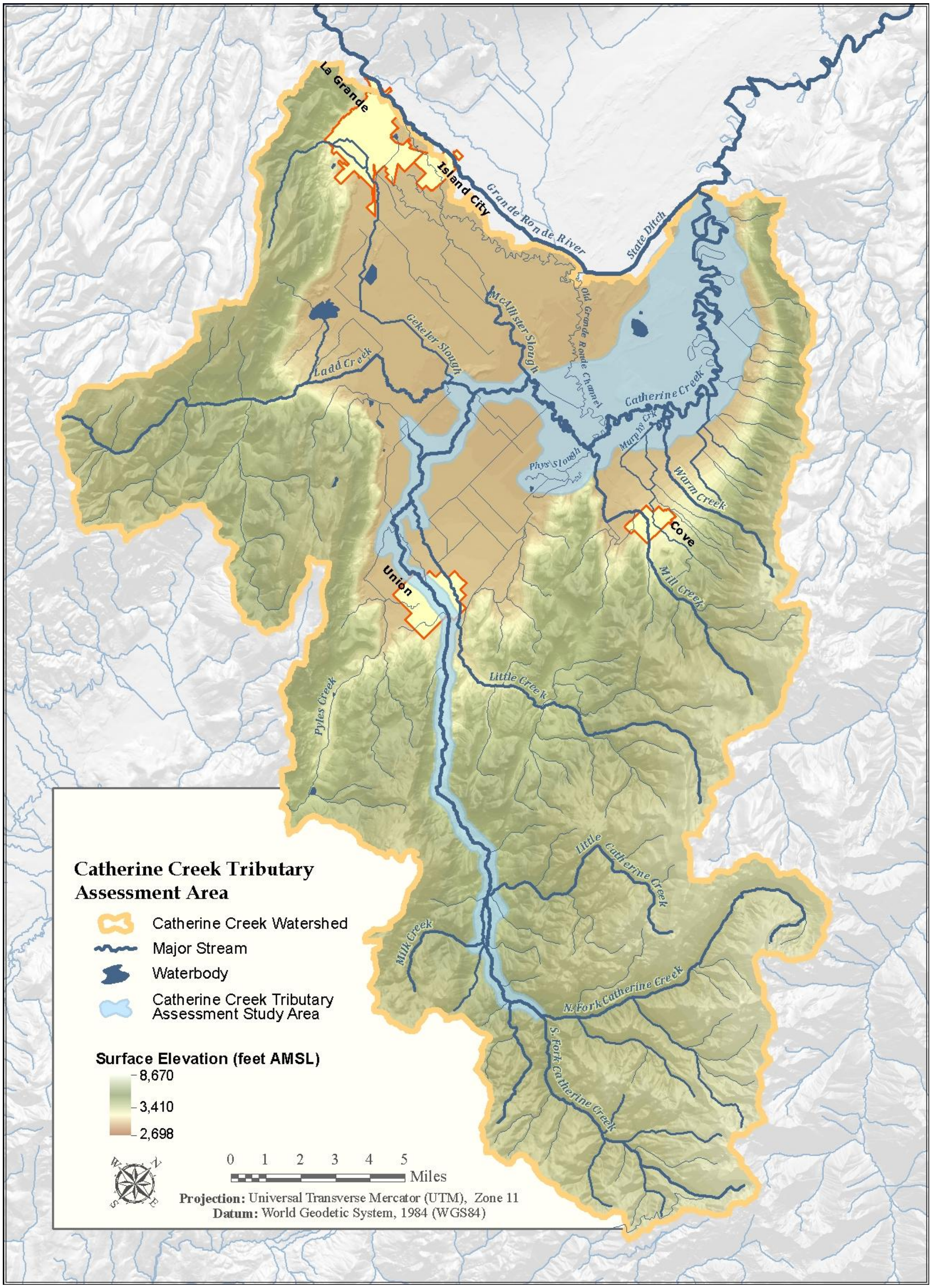


Figure 1. **Catherine Creek watershed with the Tributary Assessment study area identified to encompass the lower 55-miles of Catherine Creek.**

Catherine Creek is a large tributary of the Grande Ronde River, draining 402 square miles (mi^2) (Figure 2). At its confluence with Catherine Creek, the Grande Ronde River drains 735 mi^2 not including Catherine Creek. The majority of Catherine Creek and the Grande Ronde River to this point are contained within Union County in northeast Oregon and are in the Blue Mountains Ecoregion (Omernik 1995). Catherine Creek drains steep mountainsides with elevations over 8,671 feet before crossing the wide and flat Grande Ronde Valley where it meets the Grande Ronde River at an elevation of 2,677 feet above sea level. The Grande Ronde River continues downstream for 105 miles through narrow and steep mountain valleys, eventually flowing through the southeast corner of Washington State before joining the Snake River upstream of Lewiston, Idaho, and Clarkston, Washington.

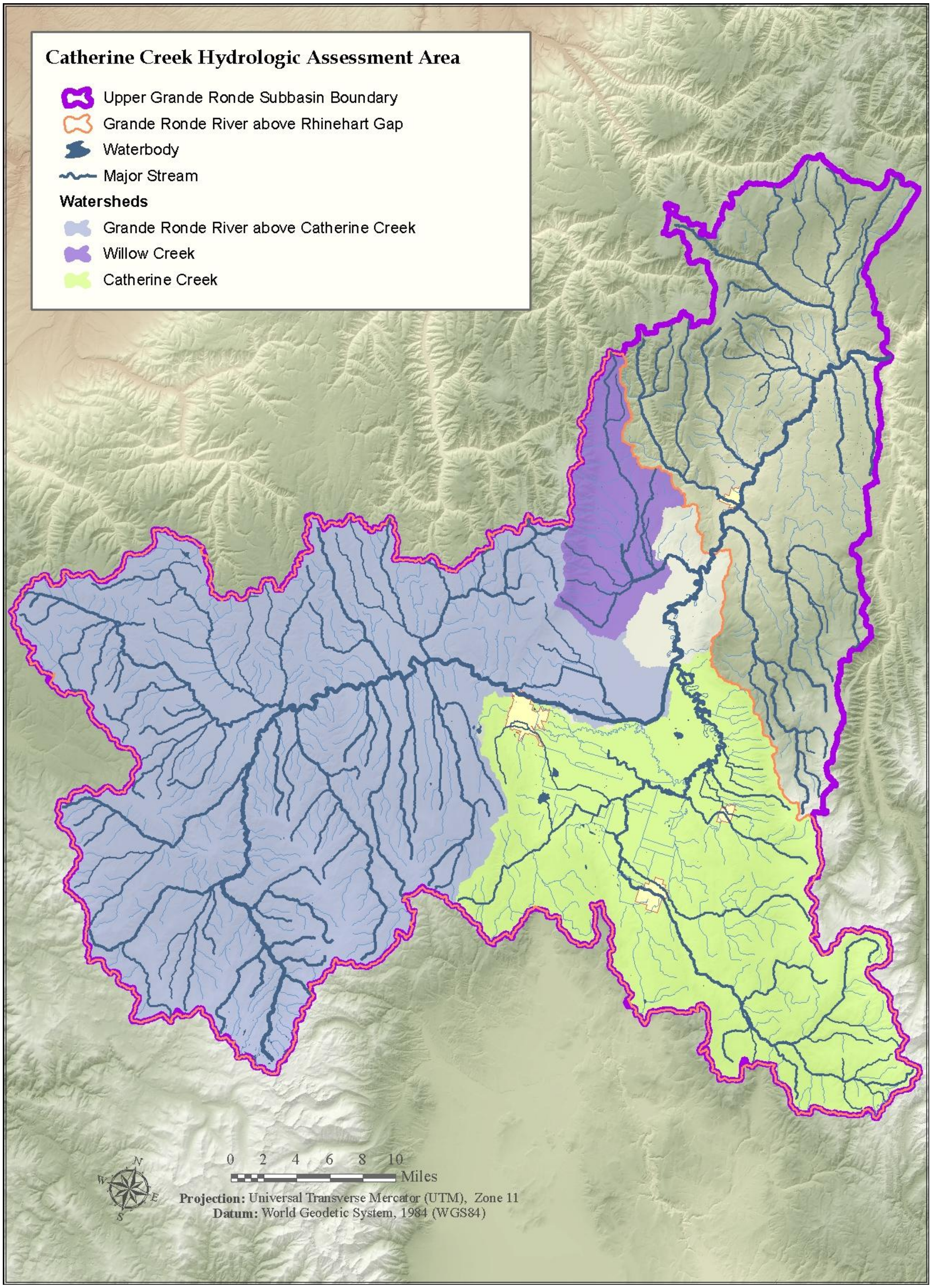


Figure 2. Grande Ronde River and Catherine Creek watersheds.

There are four major tributaries to Catherine Creek within the study area including Little Creek, Mill Creek, Pyles Creek, and Ladd Creek in addition to the upper Catherine Creek watershed (Figure 3). The stream gage "Catherine Creek near Union" is used here to represent the upper Catherine Creek watershed. These watersheds drain most of the higher terrain in the Catherine Creek watershed, are steep, and receive a majority of the precipitation. The Grande Ronde River above the confluence with Catherine Creek and Willow Creek are two other major watersheds used in this analysis to provide a hydrologic assessment of Catherine Creek within the Grande Ronde Valley, above Rhinehart Gap. Figure 3 depicts the delineated area of each of the major watersheds used for this assessment.

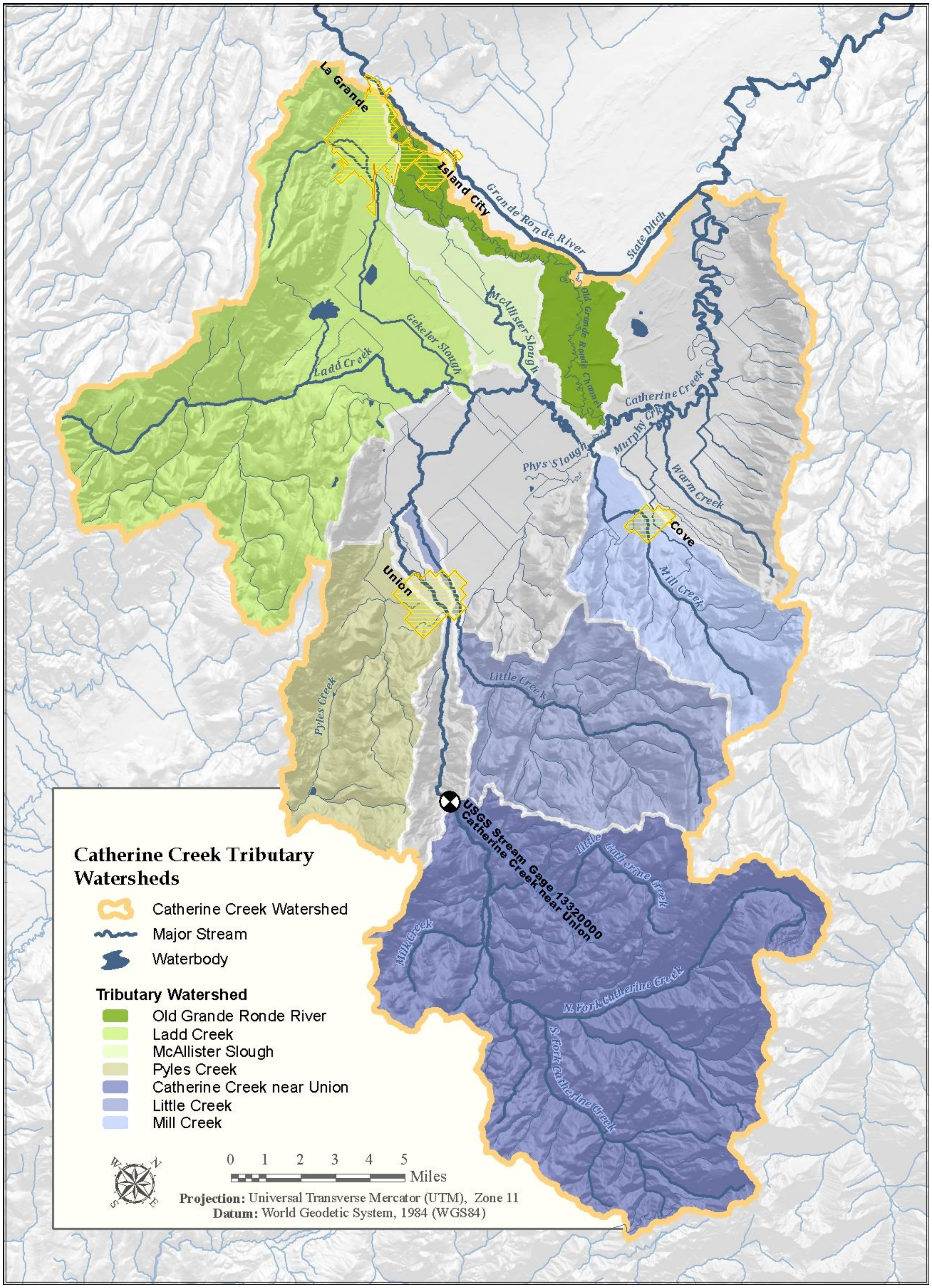


Figure 3. Catherine Creek watershed and smaller tributaries, Catherine Creek near Union gage, including Rhinehart Gap.

Three miles downstream of the Catherine Creek-Grande Ronde River confluence the Grande Ronde River flows through a narrow, confined valley known as Rhinehart Gap. Because of the profound effect Rhinehart Gap has on controlling floodflow stages well into the lower reaches of Catherine Creek, this area of the Grande Ronde River has been included as part of this hydrologic analysis in support of the hydraulic assessment of Catherine Creek.

The remaining areas above Rhinehart Gap that are not included in the preceding watersheds are broad, low relief areas with low relative precipitation. Two of the low relief areas have substantial channels apparent, McAllister Slough and the Historic Grande Ronde River. There are also a number of short, steep creeks, with low contributing areas that drain USFS lands in the northeast corner of the watershed, which are not directly included in the following analyses (Figure 3). Many of these creeks are associated with springs near the valley bottom that provide irrigation water. Figure 4 depicts the numerous springs and creeks within this area, several of which are located within the Mill Creek watershed. Mill Creek was the only tributary in this area that was included in this analysis.

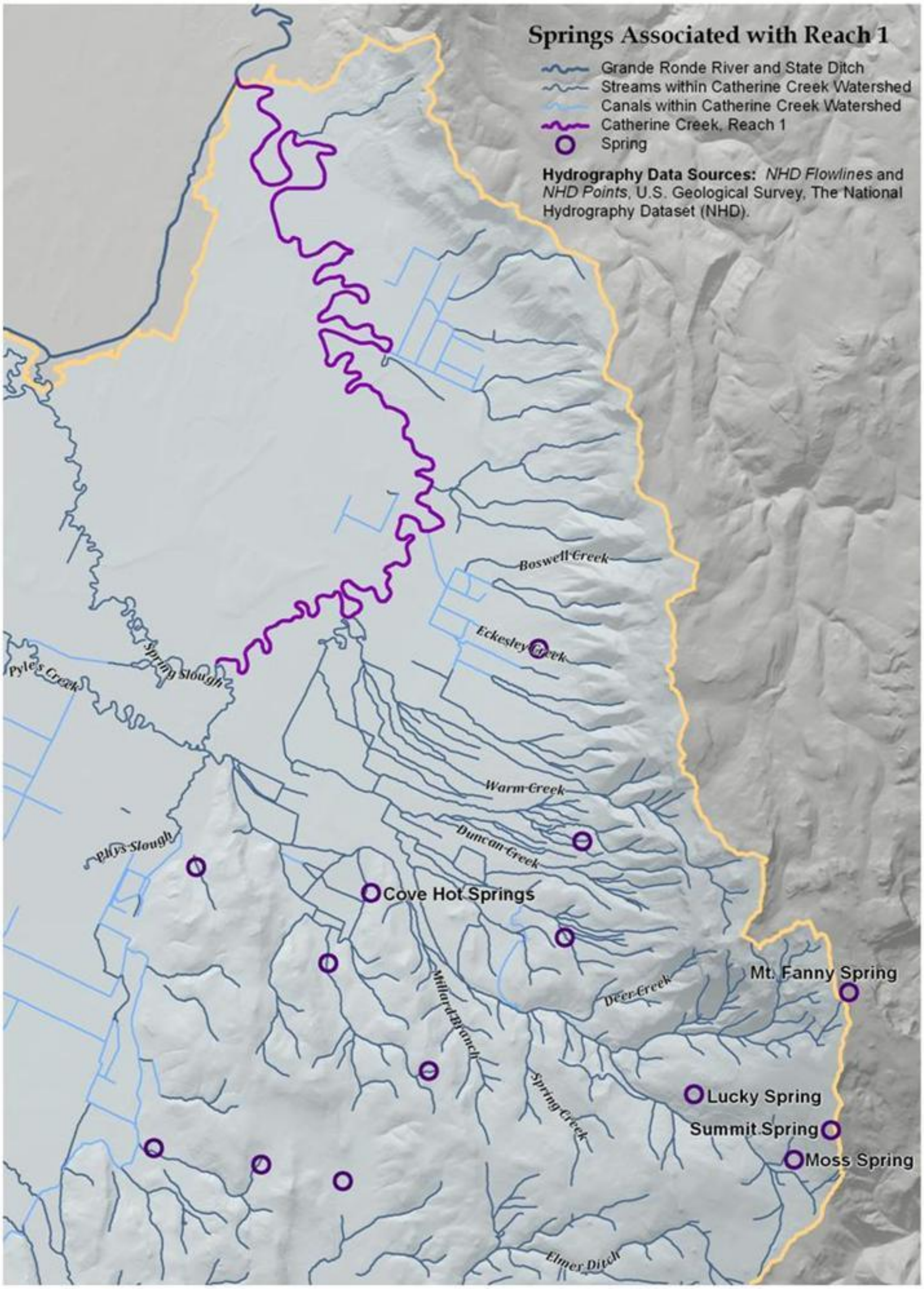


Figure 4. **Springs and creeks draining to reach 1 of Catherine Creek.**

2.2.1 Climate

The hydrology of Catherine Creek and surrounding watersheds is dominated by a spring snowmelt regime. Peak flows generally occur in May (Catherine Creek near Union gage has an average peak date of May 13), but can occur from April through June. Flood peaks for the Grande Ronde River tend to occur earlier, having snowmelt peaks as early as February in some years. Late fall, winter, and early spring rain-on-snow events can also develop into substantial peak flow events that can approach the magnitude of the annual snowmelt peak, but the highest annual peak discharge is typically a result of the spring melt. Winter freeze-thaw events are common in the region and can contain large quantities of ice potentially causing locally damaging floods and promote scour and bank erosion. Due to the high variation in elevation among tributaries, including the Grande Ronde River, runoff timing, and magnitudes can vary substantially.

Summers are relatively dry with low flow conditions occurring in August and September. Precipitation in the summer accounts for a very small percentage of the annual yield. Summer precipitation events are typically the result of small, localized thunderstorms that may or may not lead to noticeable changes in flow in small creeks. However, flash floods have occurred which have caused documented flooding and fish kills (Gildemeister 1998).

3. Methods

3.1 Hydrologic Analysis

3.1.1 Stream Gages

Multiple locations within and near the study area have had stream gages in the past (Figure 5). However, only three stream-discharge gages are active in the Catherine Creek assessment area including Catherine Creek near Union, Oregon (13320000), Catherine Creek at Union, Oregon (13320300), and Grande Ronde River near Perry, Oregon (13318960). General stream gage information, including years of operation, is presented in Table 1. Data from these gages was used to compute summary statistics including exceedance flows, average annual hydrographs, peak return interval discharges, water yield, and baseflows.

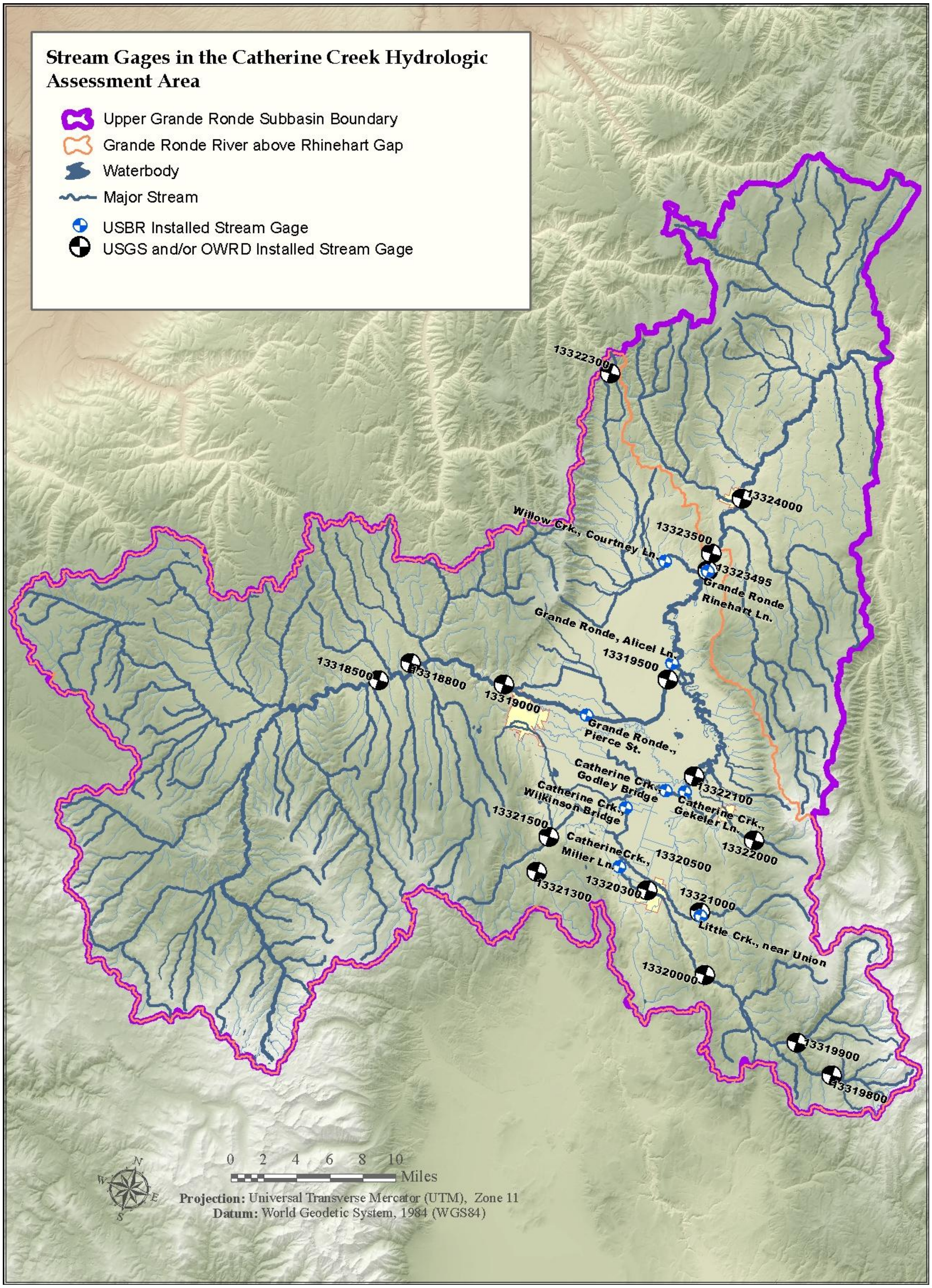


Figure 5. Stream gages in the Catherine Creek area. Reclamation gages were installed in 2010.

Table 1. Active and discontinued stream gages in the assessment area indicating the type of data available and the range of years the gage was active. (Note – Data may not be continuous; peak data refers to the annual maximum instantaneous discharge; and years are calendar years).

Station Number	Station Name	15-minute Data	Daily Mean Data	Peak Data	Start Year	End year	Active ?
13318500	GRANDE RONDE RIVER NEAR HILGARD, OR	no	yes	no	1937	1956	No
13318800	GRANDE RONDE R AT HILGARD, OR	no	yes	no	1966	1981	No
13319000	GRANDE RONDE R AT LA GRANDE, OR	no	yes	yes	1903	1989	No
13318960	GRANDE RONDE R NR PERRY, OR	yes	yes	yes	1997	2009	Yes
13319500	STATE D NR ALICEL, OR	no	no	no	1918	1918	No
13319700	*S CATHERINE CR D NR MEDICAL SPRINGS, OR	no	yes	no	1966	1984	No
13319800	S FK CATHERINE CR NR MEDICAL SPRINGS, OR	no	yes	no	1926	1927	No
13319900	N FK CATHERINE CR NR MEDICAL SPRINGS, OR	no	yes	no	1992	1999	No
13320000	CATHERINE CR NR UNION, OR	yes	yes	yes	1911	2009	Yes
13320300	CATHERINE CR AT UNION, OR	yes	yes	yes	1996	2009	Yes
13320400	LITTLE CR AT HIGH VALLEY NR UNION, OR	no	no	yes	1948	1979	No
13320500	LITTLE CR AT SERLAND RANCH NR UNION, OR	no	no	no	--	--	No
13321000	LITTLE CR NR UNION, OR	no	no	no	1918	1918	No
13321300	LADD CANYON NR HOT LAKE, OR	no	no	yes	1953	1972	No
13321500	LADD CREEK NEAR HOT LAKE, OR	no	no	no	1918	1918	No
13322000	MILL CR NR COVE, OR	no	no	no	1918	1921	No
13322100	GRANDE RONDE R NR COVE, OR	no	no	no	1955	1981	No
13322300	DRY CREEK NEAR BINGHAM SPRINGS, OR	no	no	yes	1965	1979	No
13323495	GRANDE RONDE R NR IMBLER, OR	no	yes	no	1997	2003	No
13323500	GRANDE RONDE R NR ELGIN, OR	no	yes	yes	1955	1981	No
13324000	GRANDE RONDE R AT ELGIN, OR	no	no	yes	1904	1919	No

* Gage is on a ditch that carries water out of S Catherine Ck to the Powder River watershed.

Table 2. Watershed characteristics for stream gages.

Station Number	Station Name	Area [sq mi]	Maximum Elevation [ft]	Mean Elevation [ft]	Minimum Elevation [ft]
13320300	CATHERINE CR AT UNION OR	111	8671	5149	2763
13320000	CATHERINE CR NR UNION OR	103	8671	5271	3097
13322300	DRY CREEK NEAR BINGHAM SPRINGS OR	1.4	4776	4443	3919
13324000	GRANDE RONDE R AT ELGIN OR	1411	8671	4221	2641
13318800	GRANDE RONDE R AT HILGARD OR	543	7933	4672	3002
13319000	GRANDE RONDE R AT LA GRANDE OR	686	7933	4582	2833
13322100	GRANDE RONDE R NR COVE OR	357	8671	4095	2683
13323500	GRANDE RONDE R NR ELGIN OR	1251	8671	4219	2667
13323495	GRANDE RONDE R NR IMBLER OR	1248	8671	4221	2669
13318500	GRANDE RONDE RIVER NEAR HILGARD OR	496	7933	4742	3059
13321300	LADD CANYON NR HOT LAKEOREG	16	4989	4120	3532
13321500	LADD CREEK NEAR HOT LAKEOR	40	5790	4310	2901
13320400	LITTLE CR AT HIGH VALLEY NR UNION OR	16	6771	5093	3217
13320500	LITTLE CR AT SERLAND RANCH NR UNION OR	0.7	3893	3472	3049
13321000	LITTLE CR NR UNION OR	31	6771	4520	2987
13322000	MILL CR NR COVE OR	12	7137	5456	3482
13319900	N FK CATHERINE CR NR MEDICAL SPRINGS OR	34	8652	5957	3712
13319800	S FK CATHERINE CR NR MEDICAL SPRINGS OR	16	8671	6050	4482
13319500	STATE D NR ALICEL OR	734	7933	4481	2678

Stream gage data were extrapolated from existing stream gages to other locations along Catherine Creek in order to develop input boundary conditions for the TA hydraulic model (Appendix D—Hydraulics). The hydraulic model was run with peak recurrence flow discharges and the model was set up to include changes (increases) in discharge with distance downstream.

The upstream gage data was extrapolated to downstream locations by delineating watersheds along Catherine Creek at points with substantial discharge changes including Catherine Creek below Pyles Creek, Catherine Creek below Little Creek, Catherine Creek below Ladd Creek, Catherine Creek below McAllister Slough, Catherine Creek below the "Old" (Historic) Grande Ronde River Channel, Catherine Creek below Mill Creek, and Catherine Creek at the State Ditch confluence. The extrapolation was done by multiplying the average annual precipitation ratio for the watersheds (ratio of the average annual precipitation volume for the watershed at the point of interest to the average annual precipitation volume for the watershed at the stream gage) and the known discharge from the stream gage. The average annual precipitation volume was calculated using average annual precipitation data from the Parameter-elevation Regressions on Independent Slopes Model (PRISM 2006) developed by Oregon State University as shown in Figure 6 and polygons of delineated watershed areas using a geographical information system (ESRI's ArcMap v.9.3). The watershed areas were delineated from 10-meter (m) digital elevation models (DEMs) using ESRI's ArcMap v.9.3.

The upstream gages data were adjusted to downstream locations using only the precipitation volume technique and do not account for downstream attenuations in flows or water withdrawals. All spatial adjustments of data to downstream locations for statistical analyses were performed in the same way.

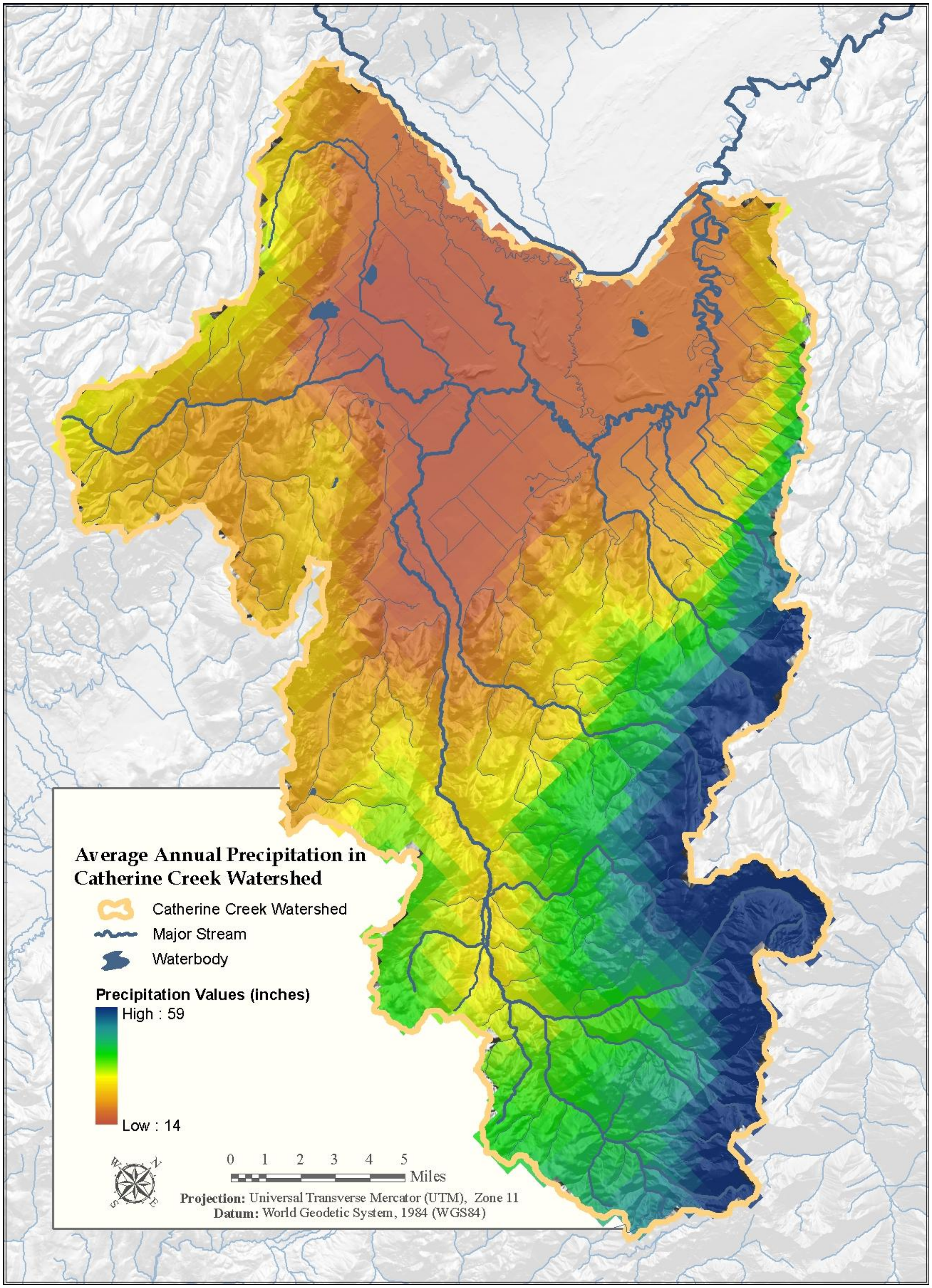


Figure 6. Catherine Creek watershed/PRISM data – average annual precipitation in the Catherine Creek watershed.

As part of this assessment, Reclamation installed nine surface water gages in the assessment area in the fall and winter of 2010 (Table 3). Each gage consists of a logging device, which contains either a pressure transducer or radar and temperature probe that measures water surface stage and temperature hourly. The main goal of the gage network is to provide stage data for hydraulic and water temperature models. At the time of this writing, none of the gages have rating curves established but several of those that do not experience backwater conditions may be developed in the future for discharge estimation. Discharge measurements are planned during 2011 and 2012 to eventually have additional discharge information throughout Catherine Creek within the Grande Ronde Valley. Uses will include the further refinement of the hydraulic model and to provide increased knowledge of conditions for future project implementation and monitoring.

Table 3. Reclamation stream gages installed in 2010. All stream gages measure water stage. The Grande Ronde River at Pierce and Rhinehart Lane measure air temperature while all others measure water temperature.

Stream Gage	Gage Type	RM
Catherine Creek at Geckler Lane	Pressure Transducer/Water Temperature	23.7
Catherine Creek at Godley Road	Pressure Transducer/Water Temperature	26.6
Catherine Creek at Miller Lane	Pressure Transducer/Water Temperature	36.5
Catherine Creek at Wilkinson Lane	Pressure Transducer/Water Temperature	31.9
Grande Ronde River at Alicel Lane	Pressure Transducer/Water Temperature	--
Grande Ronde River at Pierce Road	Radar/Air Temperature	--
Grande Ronde River at Rhinehart Lane	Radar/Air Temperature	--
Little Creek near Union	Pressure Transducer/Water Temperature	--
Willow Creek at Courtney Lane	Pressure Transducer/Water Temperature	--

Published discharge data was collected from the U.S. Geological Survey (USGS) and Oregon Water Resources Department (OWRD) websites (2011). Stream gaging in the study area is limited and only the Catherine Creek near Union, Oregon (13320000) gage has a long-term record. Gage 13320000 contains published flow records spanning the period between 1911 and 2009. Available data from gage 13320000 was summarized, analyzed, and subsequently used to develop synthetic discharges for the hydraulic model of Catherine Creek, which extends beyond the confluence with the Grande Ronde River and terminates at Rhinehart Gap.

3.1.2 Flood Frequency Analyses

Flood frequency analyses were carried out following the guidelines set forth in Bulletin 17B (IACWD 1982), including the use of log-Pearson type III distributions for gages with sufficient record. Published regression equations were used for streams with insufficient (sample size less than 10) or nonexistent gage records (OWRD 2006). OWRD (2006) developed peak flow return interval discharge regression equations (Table 4) for ungaged streams in Eastern Oregon following the U.S. standard protocol described in Bulletin 17B (IACWD 1982). Where the record is sufficient, a log-Pearson type III analysis was completed using the USGS software program PeakFQWin (Flynn, Kirby, and Hummel et al. 2006) on the historic (systematic) record. The period of record for all analyses included data through water year 2009 when available.

Table 4. Peak flow regression equations for northeastern Oregon (OWRD 2006). Area is in square miles and discharge is in cfs.

Return Interval Discharge	Equation	Standard Error [percent]	Average Standard Error of Sampling [percent]	Average Prediction Error [percent]	Equivalent Years of Record
Q(2)	=21.83*Area^0.7546	56.8	10.9	58.2	1.3
Q(5)	=36.8*Area^0.7459	47.3	10.1	48.6	2.5
Q(10)	=47.68*Area^0.7431	44.8	10.2	46.1	3.6
Q(25)	=61.9*Area^0.7415	44.3	10.7	45.8	5.2
Q(50)	=72.81*Area^0.7408	45.1	11.2	46.8	6.1
Q(100)	=84.03*Area^0.7402	46.7	11.8	48.5	6.8
Q(500)	=111.9*Area^0.7388	52.2	13.3	54.3	7.7

Bulletin 17B (IACWD 1982) includes a technique for determining peak discharges using a weighted average from log-Pearson III type analyses and regional regression equations (Wiley, Atkins Jr., and Tasker 2000), which is useful when gages contain a minimal period of record and extension of the record is desired to estimate floods of low frequency. The following equation was applied to all stream gages where the systematic record was at least 10 years to provide a reasonable estimate of Q_s (Wiley, Atkins Jr., and Tasker 2000):

$$Q_W = \frac{(Q_S N + Q_R E)}{(N + E)}$$

Q_W	weighted average discharge
Q_S	discharge from the log-Pearson III analysis
Q_R	discharge from the regression equation
N	number of years of peaks
E	equivalent years of record

3.1.3 Significant Tributary Hydrology

There are four major tributaries to Catherine Creek within the study area and below gage 13320000 (upper Catherine Creek) including Pyles Creek at river mile (RM) 36.9, Little Creek at RM 35.9, Ladd Creek at RM 31.4, and Mill Creek at RM 24.1. The average annual precipitation volume for each of the five watersheds (upper Catherine Creek, Pyles Creek, Little Creek, Ladd Creek and Mill Creek) was calculated using average annual precipitation data from PRISM 2006 clipped by polygons of delineated watershed areas using a geographical information system (ESRI's ArcMap v.9.3). Watershed areas were delineated from 10-m DEMs using ESRI's ArcMap v.9.3. Average annual precipitation depth data was multiplied by watershed area to determine average watershed annual precipitation volume. Finally, the ratio of the annual precipitation volume for each watershed to the annual precipitation volume of the upper Catherine Creek watershed at the stream gage 13320000, Catherine Creek near Union, was used to scale the long-term (87 years) Catherine Creek discharge gaging record to each tributary.

3.1.4 Climate Analysis

Four climate stations in or near the study area were used to evaluate historic trends for average monthly temperatures, precipitation, and snowfall.

Climate data was compiled from the National Ocean and Atmospheric Administration Cooperative Observer Program (NOAA COOP) website (2011) for two climate stations located within the study watershed, Cove and Cove 1E, to develop a record of weather from 1948 to 2009. These stations are both near the town of Cove, Oregon in the Mill Creek watershed. These stations are located in the lower valley of Catherine Creek and were used to represent the lower elevations of the watershed. Average monthly temperatures, precipitation, and snowfall were calculated to determine overall average values and to evaluate trends over time.

Climate station data from two Natural Resource Conservation Service (NRCS) SNOTEL sites were analyzed to evaluate historic trends of monthly average temperature, precipitation, and snowfall for areas representing the high elevation zone of Catherine Creek. The "Moss Spring" station was established in 1981 and is located near the eastern edge of the Mill Creek watershed divide in the Wallowa Mountains. The Taylor Green site was established in 1979 and is located in the South Fork of Catherine Creek watershed near the southern watershed divide. Climate stations in or near the Catherine Creek watershed including those utilized and discussed are shown in Figure 7.

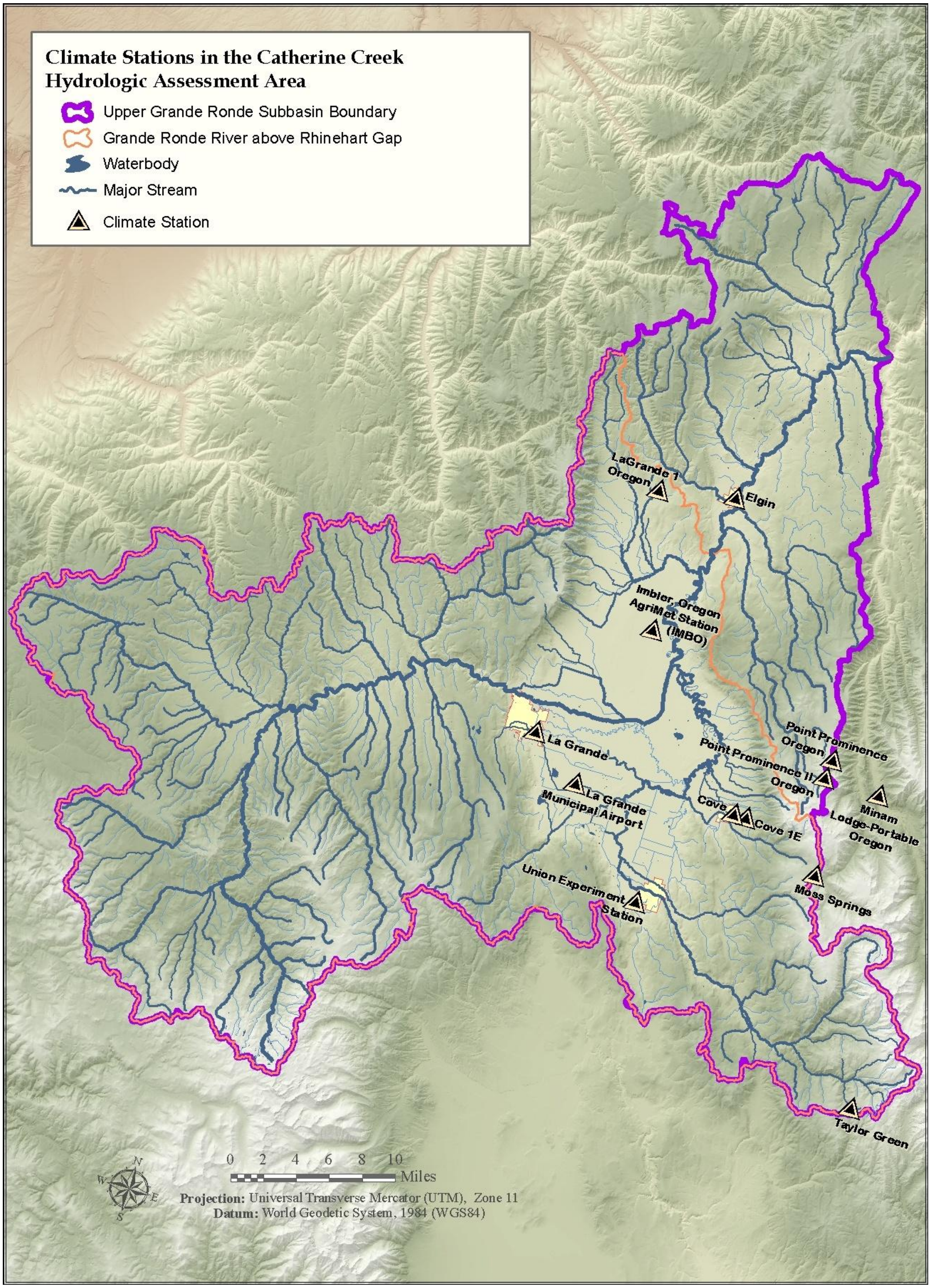


Figure 7. Climate stations in or near the Catherine Creek watershed.

4. Historical Conditions

Native Americans lived in the Grande Ronde area for thousands of years before explorers came through the area in approximately 1811 (Gildemeister 1998). The Grande Ronde Valley was covered in grasslands, wetlands, and a lake known as Tule Lake which was reported to be anywhere from 1,600 acres (Gildemeister 1998) to 20,000 acres (Duncan 1998) depending on source. Beckham (1995) recounts many early pioneers' and explorers' notes on the Grande Ronde Valley. In general, they documented the valley bottom as having the following characteristics: woody trees were only present along the banks of the creeks and rivers; springs were common along the margins of the valley; camas covered much of the valley bottom; while willows, alders, and cottonwoods lined the creeks and rivers (Duncan 1998; Beckham 1995). Areas adjacent to the creek had an abundance of willows and patches of cottonwoods and the soil was "excellent" but swampy in most places along the flat valley (Beckham 1995). The streambanks were noted to be "high and muddy" (Beckham 1995).

Homesteading began in the Grande Ronde Valley in 1860 and the city of La Grande was founded in 1862 (Gildemeister 1998). Duncan (1998) notes that soon after settlement began water became the "center…of nearly…every economic activity of significance." Agriculture and mills became commonplace in the valley which required both water and flood control. One of the earliest projects in the Grande Ronde Valley to drain the land for agriculture was the construction of State Ditch which began in 1870 (Gildemeister 1998). Initially 6 feet wide and 3 feet deep, it was designed to reduce flooding by diverting some of the Grande Ronde River water in a more direct route (north) through the valley (Gildemeister 1998). The ditch-diverted water from the Grande Ronde River and, taking a shorter course by approximately 33 miles, delivered it back to the Grande Ronde River further down the valley below the confluence of the Grande Ronde River and Catherine Creek. Over time, the ditch took a larger portion of the total Grande Ronde River; presently it conveys the total flow of the Grande Ronde (Flow Technologies 1997). No information has been found that indicates when the full flow of the Grande Ronde River began coursing down State Ditch.

In 1870, a "mammoth" canal was dug to divert Catherine Creek before it entered Tule Lake near the current area of Ladd marsh (Beckam 1995; Gildemeister 1998). The lake was owned by the State of Oregon after being acquired through the Swamp Lands Act, which opened it to "reclamation." The canal brought the creek east of the lake and connected it directly downstream (north) of the lake, expediting water through the valley.

One of the earliest documented pumps for water diversion was placed in the Grande Ronde River for the city of La Grande in 1892 (Beckham 1995). Since this time, pumps and further diversion dams have been placed throughout Catherine Creek for surface water diversion. Since most water withdrawals are for irrigation and occur during the warm summer irrigation period when creeks are flowing at or near baseflow, it is assumed that discharge during these periods were higher than they are now. Therefore, it is also understood that the rate of decrease in discharge, as peak flows recede and the irrigation season begins, is likely higher now than was historically before irrigation became common.

Historical accounts describing the Catherine Creek watershed above the town of Union were not found. Several of the lower valley descriptions, however, make some general comments regarding the vegetation that was observed further up on the mountainsides: pine, cedar, larch, and birch (Beckham 1995). Timber harvest has varied considerably in Union County but show a generally increasing trend between 1896 and 1990 (McIntosh 1992). On average 36-million board feet were harvested per year prior to 1941, rising to an average of 98 million between 1941 and 1990 (McIntosh 1992).

In 1955, Reclamation completed a report focused on storing spring high flow waters in reservoirs and irrigating more of the high quality soils in the valley bottom (McKay, Dexheimer, and Nelson 1955). A dam was to be located just below the Little Catherine Creek and Catherine Creek confluence near RM 50.1 and was to have an outlet capacity of 2,000 cfs. The 100-year flood was estimated to be 2,230 cfs at the time. A second dam was to be on the Grande Ronde River above the confluence with Spring Creek. The study underscores two relatively constant concerns in the Grande Ronde Valley that hold true today: flooding and limited irrigation water. The project plan was to develop enough storage to irrigate 58,754 acres using 189,000 acre-feet of water as part of the two dam projects and provide additional storage for flood control. The Catherine Creek project was to provide water for 13,471 acres of irrigated land while the Grande Ronde River project was to supply water for 45,283 acres.

A project to assess the potential to develop groundwater resources was undertaken by Reclamation in 1966 (Ham 1966). The report suggests that groundwater resources within the Grande Ronde Valley could be developed with safe yields of 25,000 to 40,000 acre-feet and that the withdrawals would benefit soil drainage. An exception is the Sand Ridge area, which does not have an adequate shallow aquifer for development (Reclamation 2002).

The U.S. Army Corps of Engineers (USACE) (1996) conducted a flood control study to determine the benefits of excavating within Rhinehart Gap (RM 102 on the Grande Ronde River) to increase the flow capacity and reduce upstream backwater effects. They developed annual peak return flow discharges based on the USGS gages Grande Ronde River at Elgin (13324000), Grande Ronde River near Elgin (13323500), and Grande Ronde River at La Grande (13319000). Final return interval discharges for the computed 2, 10, 50, and 100-year discharges were 4,490; 7,360; 9,910; and 11,000 cfs, respectively. The study determined that flood reductions in the Grande Ronde Valley were possible through excavation within the Rhinehart Gap reach. Excavating 700,000 cubic yards of material could potentially reduce the 100-year discharge ponding elevation in the Grand Ronde Valley by approximately 4 feet and a 3-foot reduction could potentially be obtained with

330,000 cubic yards of excavation. No work on this has been completed to date and excavation would likely require relocating the highway and rail line within this area.

Discharge measurements have been limited historically; however, several major floods were documented to have occurred prior to any established stream gages in the basin. Pre-settlement flooding of the Grande Ronde Valley was annual and could inundate as much as 72,000 acres (Duncan 1998) or more. Flooding could last as long as 5 months and proceed into summer. The flood of 1894 reportedly inundated 50,000 acres in the Grande Ronde Valley with a flow of 9,500 cfs from the Grande Ronde River. Major flood events that occurred and were documented before 1911, when stream gages began operation, are provided in Table 4. As early as 1865, floods began inundating the city of La Grande (Figure 8). Multiple debris flows and flash floods were also reported by Gildemeister (1998), which further documents large numbers of Chinook salmon killed in the upper headwater areas.

Table 5. Documented historic floods prior to stream gaging (1911) in the Grande Ronde Valley.

Year	Discharge [cfs]*	Notes
1865	10,000	Grande Ronde River (Gildemeister 1998)
1865	3,000	Catherine Creek (USACE 1950)
1876	9,000	Grande Ronde River (Gildemeister 1998)
1876	2,500	Catherine Creek (USACE 1950)
1881	10,000	Spring flood on Catherine Creek, December flooding on Grande Ronde River (Gildemeister 1998)
1882	2,600	Catherine Creek (USACE 1950)
1891	unknown	July thunderstorm on Catherine Creek (Gildemeister 1998)
1893	1,500	Catherine Creek (USACE 1950)
1894	9,500	April 1st Grande Ronde River
1895	2,000	Catherine Creek (USACE 1950)
1907	unknown	5-7 foot wall of debris at Oro Dell, Grande Ronde River (Gildemeister 1998)
1908	unknown	Dam at Perry partially destroyed, Grande Ronde River
1908	1,600	Catherine Creek (USACE 1950)
* cfs – cubic feet per second		

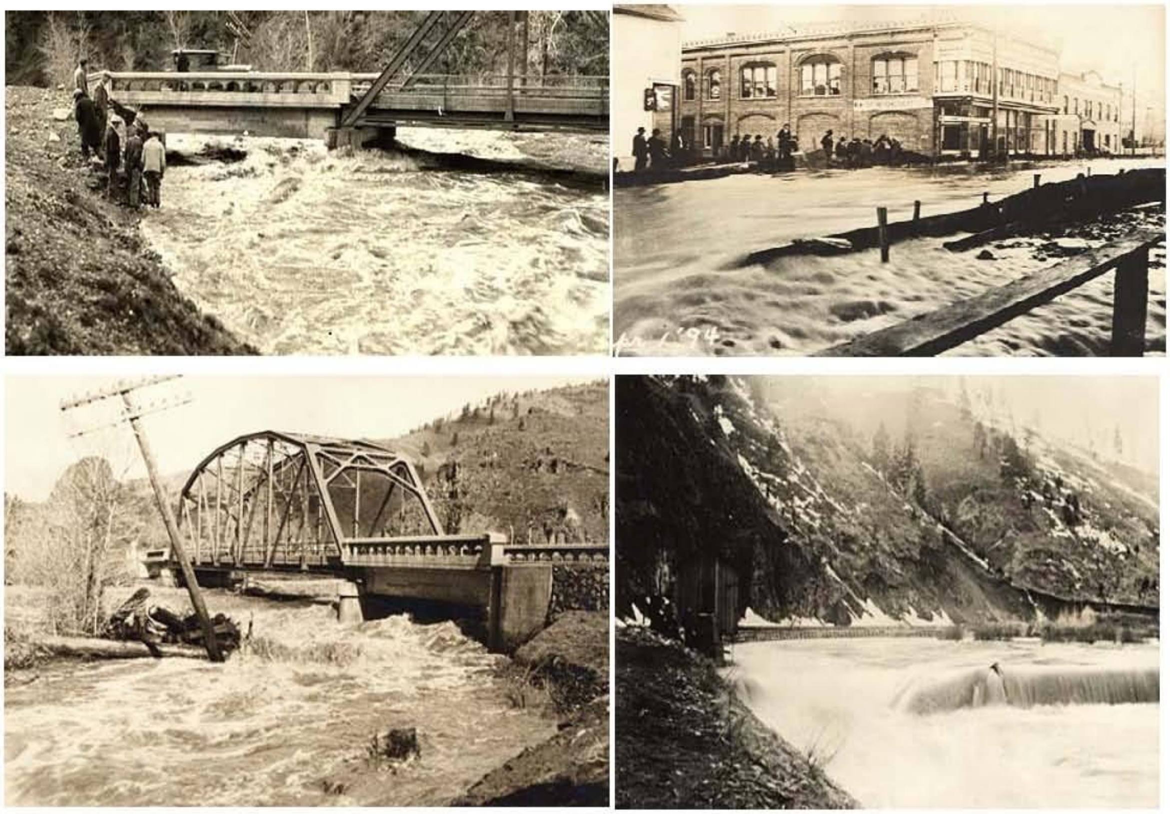


Figure 8. The Grande Ronde Valley endured a large flood in the spring of 1894. The top right picture shows downtown La Grande, Oregon, on April 1. Oregon State Planning Board Records, Oregon State Planning Board Photograph Box, Grande Ronde Flood Photographs, OPB0002.

4.1 Historic Changes

Since being settled in the 1800s, the Grande Ronde Valley has gone through many changes, which has affected the local hydrology. Land cover has changed from a landscape of meandering channels with shallow lakes and wetlands to a valley floor where water is channelized, piped, and ditched. The find sediments in the valley bottom, with low infiltration and conductivity, have been drained for agriculture. Wetlands have been drained and Catherine Creek has been channelized to encourage drainage. Small urban areas, such as towns of La Grande, Union, and Cove have increased the impervious areas in the basin along with the several highways and other surface roads that are weaved throughout the watershed. The combination of land use changes since settlement and redirection of water have likely decreased the amount of water storage in the watershed and developed somewhat higher peak discharges.

Interpreting and understanding the historic hydrologic conditions of Catherine Creek is a difficult task given that little information exists regarding historic climate and hydrologic data prior to the beginning of the 20^{th} Century. However, inferences can be made based upon know historic changes to physical processes for which we have known hydrologic relationships. For example, we know that several sections of lower Catherine Creek were channelized to drain the valley bottom more rapidly after peak runoff and to reduce flooding for agricultural purposes. In areas where levees are not overtopped, channelization would decrease the amount and area of standing water available on flood plains to infiltrate valley soils. In areas where levees are overtopped, channelization may increase the amount of time flood plains are inundated. Deep channelized sections within Catherine Creek likely drain adjacent lands quicker and lower the adjacent water table, which would reduce soil moisture deeper than would otherwise occur. With the number of alterations that have occurred in the Grande Ronde Valley, it is difficult to say how baseflows have been affected. However, further study would be needed to determine if baseflows have been substantially reduced.

Physical changes to the Grande Ronde Valley have likely had dramatic effects upon the annual hydrograph exiting the valley in terms of flood peaks, baseflow, and temperature. Historic descriptions of the valley as swampy with lakes, replete with beaver, "snaking" channels, full of springs and rivulets, describes a valley that is generally wet with soils that are moist a substantial part of the year. These conditions capture spring snowmelt peaks and dissipate floods over the valley bottom. This would tend to attenuate flood peaks downstream of the valley while increasing the duration of flooding within the valley. A portion of the floodwaters would be stored in the wetlands and released slowly over the summer and possibly into fall. Stored water in a wetland system and through hyporheic exchange with valley soils would likely have provided cooler temperatures with increased survivability of salmonids in the warm months possibly into the late summer.

Other changes that have occurred which are likely to have a hydrologic influence on Catherine Creek include logging, road construction, surface water diversion and storage, groundwater diversion, and land use (i.e., wetlands and grasslands to agricultural land and urban areas). The magnitude of change caused by these drivers is difficult to quantify. However, they can be lumped as to their typical cumulative effects to the shape of the hydrograph in both magnitude and timing. Logging and road construction likely resulted in increased and shorter duration peak flows. Diversions and storage likely decreased instream flows and lowered baseflows during the dry season relative to the historic regime. Other techniques can be used to attempt to quantify the cumulative effects of these alterations through spatially explicit hydrologic modeling; however, this is outside the scope of this TA.

5. Present Conditions

The present condition of Catherine Creek and the Grande Ronde Valley is quite different from the historical condition. Duncan (1998) compares what humans have done to the water in the Grande Ronde Valley to “moving the living room furniture.” While some of the difference has been due to direct changes made for altering how water is stored and moves throughout the watershed, there has also been a substantial amount of indirect change to the local hydrology. For instance, there is currently an additional 5.5 percent of the watershed (estimated from National Land Cover Database [NLCD] 2006) which is impervious surface due to human activity (e.g., buildings and roads), whereas historically, there was little impervious surface. The conversion of grasslands, wetlands, riparian areas, and other types of natural features to agriculture has likely had measureable changes to evapotranspiration rates, infiltration, interception, groundwater storage, and surface runoff. Forestry practices, including road building, culvert placement, harvesting, planting, and forest fuels management also has likely affected watershed hydrology.

Current land cover (land use) mapping in the Catherine Creek watershed illustrates the extent of urban and agricultural land uses that have altered the local hydrology (Figure 9). The percentages of various land cover classifications for the Catherine Creek watershed are shown in Table 6. Agricultural lands are situated in the lower portions of the watershed along with the majority of “developed” area. Forested lands include most of the headwater areas of the upper Catherine Creek watershed.

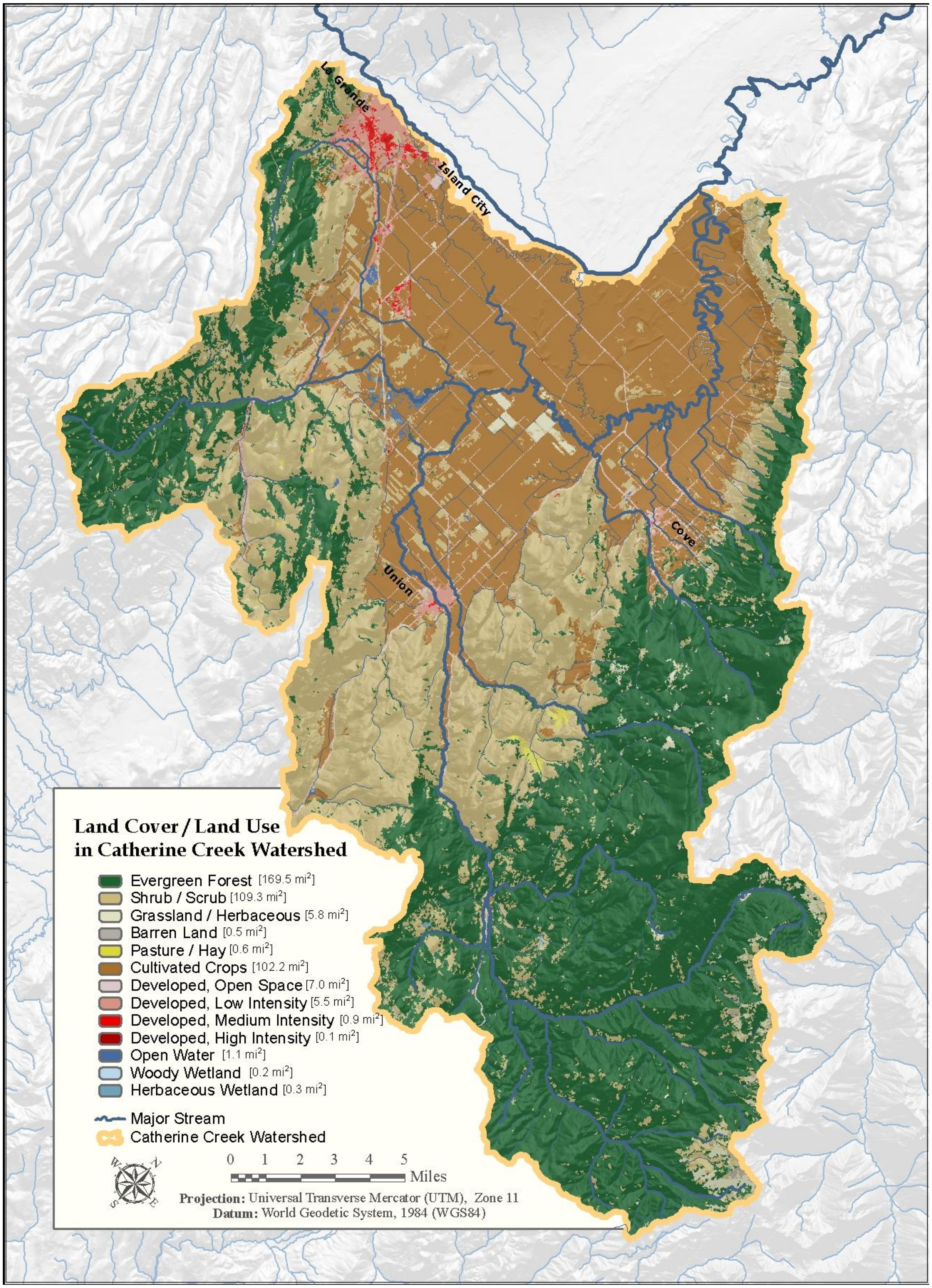


Figure 9. Land cover classes in the Catherine Creek watershed using the National Land Cover Database (NLCD) (2006).

Table 6. Land cover proportions using NLCD (2006) in the Catherine Creek watershed.

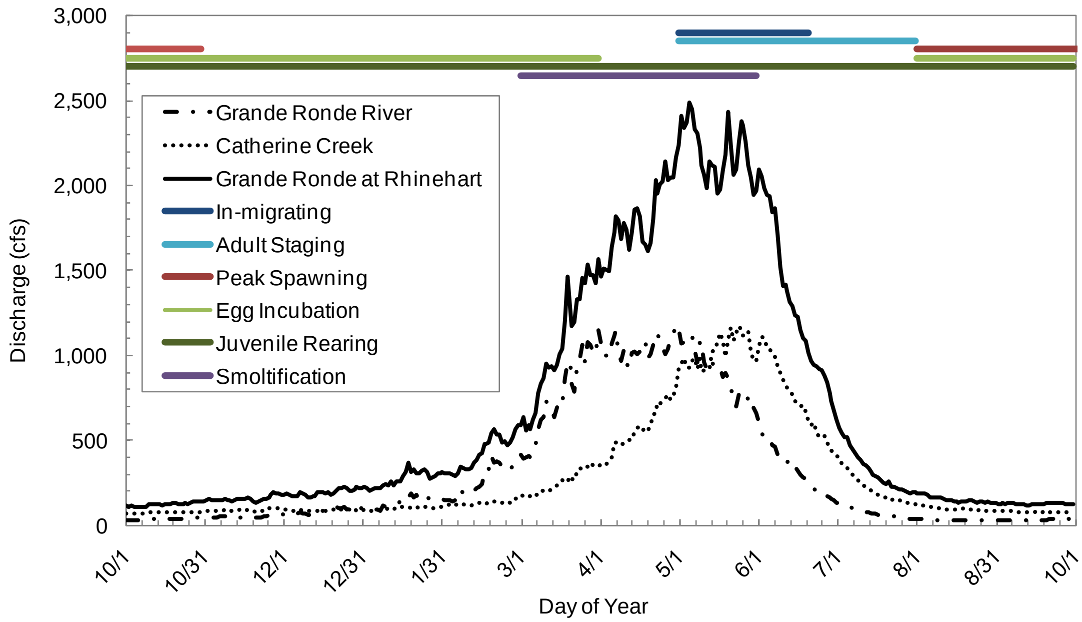
Description	Area [mile^2]	Area [percent]
Open Water	1.1	0.3%
Wetlands	0.5	0.1%
Developed	13.5	3.4%
Barren Land	0.5	0.1%
Forest	169.5	42%
Shrub / Scrub	109.3	27%
Agriculture	108.6	27%

The cumulative effects of watershed management practices in the upper watershed are likely of importance to hydrologic impacts to Catherine Creek; however, this is beyond the scope of this document. Within the study area, changes to hydrology have mostly occurred in accordance with land use changes in the Grande Ronde Valley. Channelization, levee construction, ditching, piping, well drilling, and draining of wetlands and lakes has likely altered the Catherine Creek hydrograph as it progresses through the valley. For most flow conditions, Catherine Creek now flows downstream through the valley much more expediently than in historic times. However, some large-scale physical conditions have not changed. Rhinehart Gap and the low gradient valley persist and still control large floods in the valley. Historically, annual floodwaters would have likely been temporarily stored in the valley bottom and released slowly through the drier months. Presently, Rhinehart Gap along with the flat slope of the valley cause large floods to be stored in the valley as well; however, it is assumed here that storage and release of floods occurs in different locations and with different timing due to alterations of the valley. In some locations, large flood events may store floodwaters longer than historically due to over-topping of streamside levees and trapping of floodwaters behind them. Along Highway 203 upstream of Union and throughout the lower valley, multiple sub-reaches of Catherine Creek have been straightened through channelization efforts. In addition, an extensive network of levees in the lower reaches further advance water through the valley by eliminating floodplain and shallow subsurface storage. Finally, surface water diversions out of Catherine Creek and its major tributaries (both pumps and gravity) occur throughout the valley for mostly agricultural purposes. These diversions deplete and at times, can eliminate summer low flows within Catherine Creek that was likely a perennial stream historically throughout its length. Surface water diversions feed a network of pipes and ditches throughout the valley where water is diverted, used, pumped, and re-used until minimal water is left to return to Catherine Creek due to clearing of land and likely increased evapotranspiration within the valley.

5.1 Hydrologic Results

5.1.1 Mean Annual Hydrograph

Estimated mean annual hydrographs for Catherine Creek and the Grande Ronde River at their confluence, and for the Grande Ronde River below their confluence (at Rhinehart Gap) are superimposed on Chinook salmon life stage usage (Appendix F) in Catherine Creek (Figure 10). The data used to develop the Catherine Creek hydrograph (Catherine Creek near Union, Oregon) is above most major diversions and over-estimates low summer flows when used to extrapolate flows downstream. Because the water of Catherine Creek is withdrawn for irrigation purposes, flows below Lower Davis Dam at RM 34.4 are frequently very low and even near zero during the irrigation season (approximately June through September). The Catherine Creek at Union, Oregon stream gage has a shorter period of record (1996 to present) and so was not used to develop long-term estimates of downstream and tributary hydrology; however, this stream gage better represents the low flow conditions typically experienced at and below the town of Union. There are however, three storage and diversion dams (Upper Davis, Lower Davis, and Elmer) and numerous pumped diversions below the stream gage which have further capacity to reduce irrigation season discharges. Comparing the “near Union” to the “at Union” stream gage (Figure 11) over the same period (water years 1999 to 2009) illustrates the impact of diversions on irrigation season discharges between these two stream gages.



exceedance) for Catherine Creek and Grande Ronde River at their confluence with Chinook salmon life stage usage. Grande Ronde River is estimated using data combined from two USGS gages, Grande Ronde at La Grande (13319000), and Grande Ronde at Perry (13318960). Catherine Creek is estimated from the Catherine Creek near Union gage (13320000). Note – data used to develop Catherine Creek is above most major diversions and does not properly reflect low summer flows which may be zero during the irrigation season.

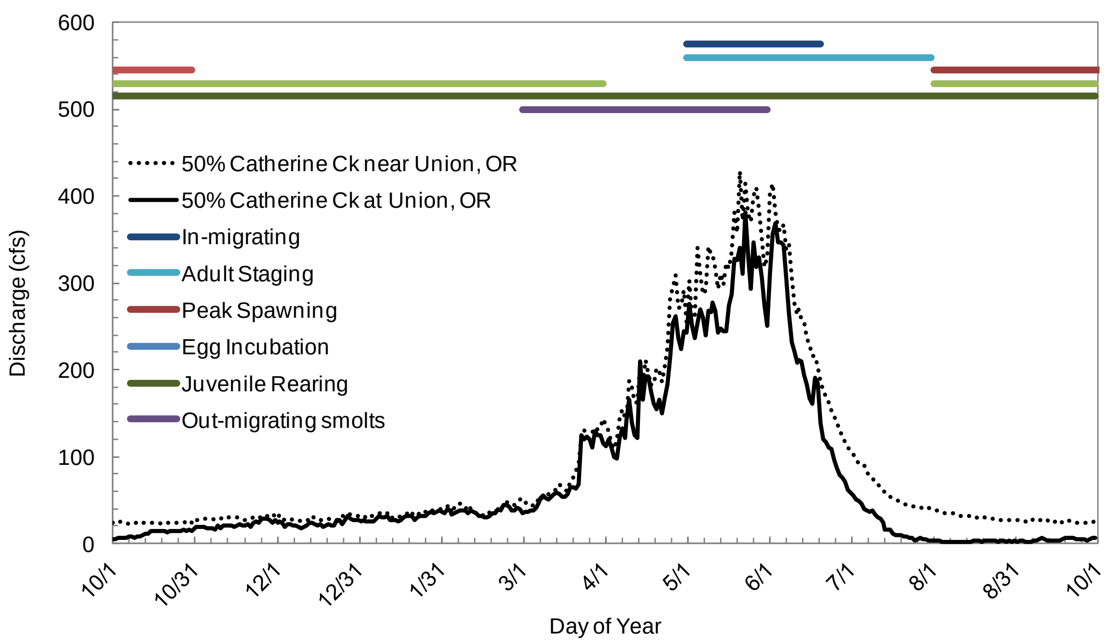


Figure 11. Estimated mean annual hydrograph (based on daily data and the 50 percent probability exceedance) for Catherine Creek with Chinook salmon life stage usage. Two stream gaging stations are shown, Catherine Creek near Union gage and Catherine Creek at Union gage. Catherine Creek near Union is above most major diversions while the "near Union" stream gage includes substantial diversions.

5.1.2 Exceedance Flows

Estimated mean daily exceedance flow hydrographs for Catherine Creek at the confluence with the Grande Ronde River and for the Grande Ronde River at Rhinehart Gap are presented in Figures 12 and 13, respectively. The data used to develop the exceedance flows are from upstream gages (Catherine Creek near Union [13320000] and Grande Ronde near Perry [13318960]) and the data do not account for most water withdrawals, and therefore, overestimate July through October flows. The 50-percent exceedance value represents the average annual hydrograph while the 5-percent exceedance and 95-percent exceedance values represent less frequent low and high mean daily flows that can be expected. Relative to the Grande Ronde, Catherine Creek has a sharper spring peak with a shorter window of time for peak flows. Being of higher elevation, it appears that Catherine Creek is also less affected by winter and early spring peaks, which indicates that the Grande Ronde may have earlier snowmelt and a stronger rainfall influence than Catherine Creek.

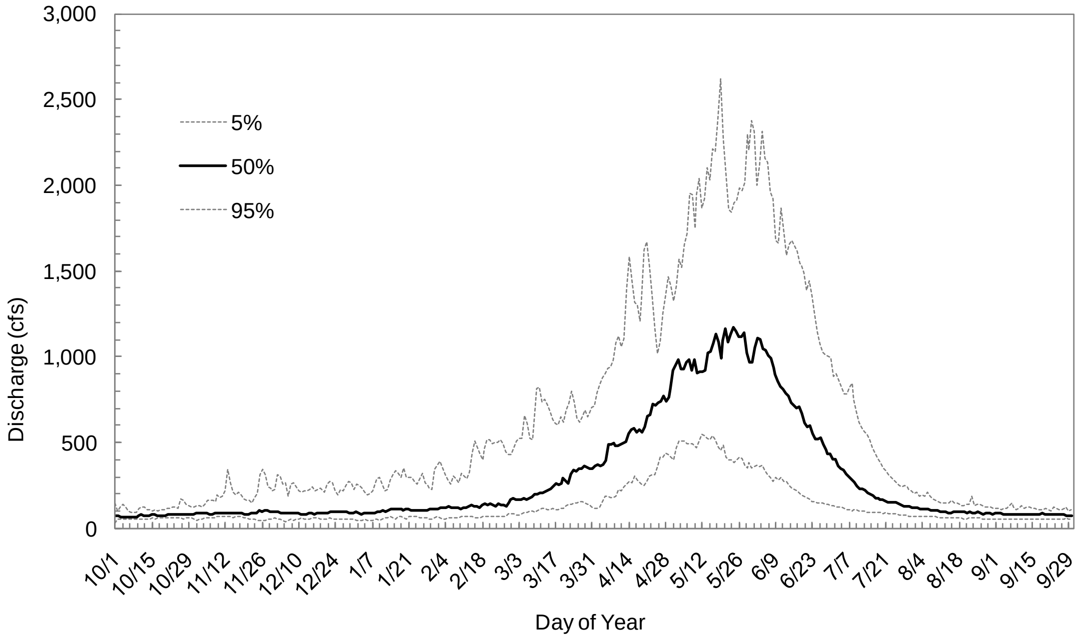


Figure 12. Estimated mean daily flow percent exceedance values for Catherine Creek at the confluence with the Grande Ronde River. Note – the data used to extrapolate this graph are from the Catherine Creek near Union (13320000) stream gage and the data do not account for all water withdrawals, and therefore, overestimate July through October flow. The 50 percent value represents an average annual hydrograph.

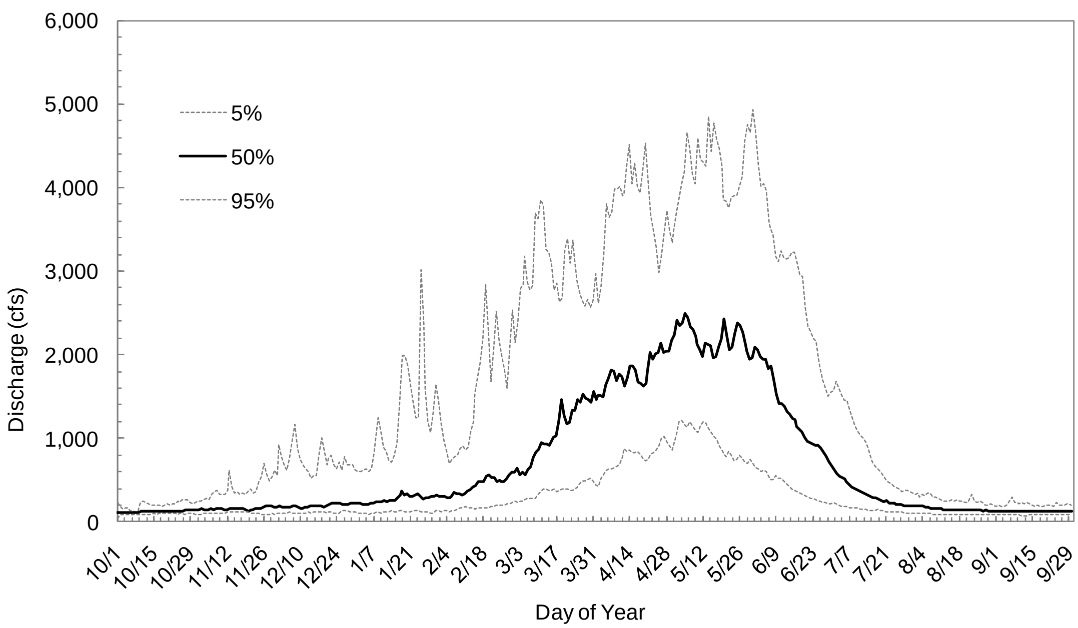


Figure 13. Estimated mean daily flow percent exceedance values for the Grande Ronde River at Rhinehart Gap. Note – the data used to extrapolate this graphy are from upstream gages (Catherine Creek near Union [13320000] and Grande Ronde near Perry [13318960]), and the data do not account for all water withdrawals, and therefore, overestimate July through October flows. The 50 percent value represents an average annual hydrograph.

5.1.3 Peak Flow Events

There are three general types of peak flow events in Catherine Creek that produce large floods. The most common cause is the annual spring snowmelt events that typically occur from April through June. In 87 years of record, only one annual peak discharge was not a result of the spring melt. Winter melt and fall through early spring rain and rain-on-snow events can cause notable peak flow events in Catherine Creek. However, it appears that the maximum annual flood has nearly always been from snowmelt in the spring. Rain driven events are usually of shorter duration, often less than a day but sometimes lasting several days and can lead to local flooding. Winter melt and rain-on-snow events can cause significant local damage due to ice break-up commonly found in the study area during extreme cold conditions.

In the spring, Catherine Creek typically has a later peak runoff than the Grande Ronde River. A comparison of peak flows showed that peaks in the Grande Ronde can be hours to months earlier than Catherine Creek. This may be partially attributable to the slightly lower average watershed elevation of the Grande Ronde River, above the Grande Ronde Valley, relative to the Catherine Creek watershed. Due to the timing differences between the two hydrographs, landowners in the lower Grande Ronde Valley have occasionally noticed that the lower reaches of Catherine Creek can have reverse flow upstream of the Grande Ronde confluence.

Annual flood peak discharges were calculated for each historic stream gage as described in "Methods." Annual flood peak discharges as return interval discharges are presented in Table 7 for all historic stream gages within the study area. The return interval discharges presented include those calculated statistically from the systematic record, those calculated from regression equations, and a weighted average peak discharge (of the two methods) following OWRD (2006). For gages where an insufficient or non-existent gage record prevents a statistical inference, only the regression equation results are presented. At stream gages where at least 20 years of record exist under recent climitalogical conditions, the systematic record provides the preferred estimate of peak flows. Where fewer peaks are available, or when the data is not recent, then the preferred estimate may come from the weighted estimate. Where no, or very few, systematic data are available, the regression equation estimates may be the only option.

Table 7. Annual peak discharges for all historic gages in the study area specified as return intervals.

Station Number	Station Name	Peak Data	Q1.5	Q2	Q5	Q10	Q25	Q50	Q100	Q500	Basis
13318500	GRANDE RONDE RIVER NEAR HILGARD, OR	no		2,190	3,080	3,740	4,640	5,360	6,110	7,940	W '06
""	""			2,190	3,010	3,590	4,360	4,950	5,570	7,130	S '06
""	""			2,360	3,770	4,790	6,160	7,220	8,300	10,900	R '06
13318690	GRANDE RONDE RIVER NR PERRY, OR	yes		3,038	4,552	5,706	7,317	8,600	9,945	13,354	W
""	""		2,519	3,046	4,504	5,587	7,089	8,307	9,609	13,030	S
""	""			2,979	4,745	6,037	7,756	9,081	10,440	13,776	R
13318800	GRANDE RONDE R AT HILGARD, OR	no		2,360	3,290	3,990	4,950	5,700	6,480	8,360	W '06
""	""			2,340	3,200	3,790	4,560	5,150	5,750	7,230	S '06
""	""			2,530	4,040	5,140	6,610	7,740	8,890	11,700	R '06
13319000	GRANDE RONDE R AT LA GRANDE, OR	no		3,233	4,872	6,078	7,736	9,063	10,468	14,068	W
""	""		2,643	3,237	4,874	6,077	7,729	9,053	10,460	14,080	S
""	""			3,015	4,802	6,109	7,849	9,190	10,565	13,941	R
13319500	STATE D NR ALICEL, OR	no		3,173	5,051	6,424	8,252	9,662	11,107	14,655	R
13319800	S FK CATHERINE CR NR MEDICAL SPRINGS, OR	no		176	290	373	482	566	652	865	R
13319900	N FK CATHERINE CR NR MEDICAL SPRINGS, OR	no		238	390	500	646	759	874	1,159	R
13320000	CATHERINE CR NR UNION, OR	yes		750	1,013	1,182	1,394	1,550	1,702	2,049	W
""	""		645	751	1,008	1,167	1,357	1,492	1,621	1,907	S
""	""			722	1,168	1,494	1,925	2,257	2,598	3,437	R
13320300	CATHERINE CR AT UNION, OR	yes		893	1,363	1,700	2,150	2,502	2,866	3,775	W
""	""		728	907	1,390	1,736	2,199	2,560	2,934	3,865	S
""	""			764	1,236	1,580	2,036	2,387	2,747	3,634	R
13320400	LITTLE CR AT HIGH VALLEY NR UNION, OR	yes		119	192	245	317	371	424	548	W
""	""		90	116	182	227	282	322	361	449	S
""	""			180	296	381	492	578	666	883	R
13320500	LITTLE CR AT SERLAND RANCH NR UNION, OR	no		17	29	38	49	58	67	89	R
13321000	LITTLE CR NR UNION, OR	no		290	474	608	785	921	1,061	1,406	R
13321300	LADD CANYON NR HOT LAKE, OR	yes		92	130	153	180	201	222	272	W
""	""		78	96	141	170	205	231	256	314	S
""	""			37	62	80	103	122	140	187	R
13321500	LADD CREEK NEAR HOT LAKE, OR	no		353	577	740	955	1,120	1,290	1,709	R
13322000	MILL CR NR COVE, OR	no		141	232	299	387	454	523	695	R
13322100	GRANDE RONDE R NR COVE, OR	no		1,843	2,952	3,762	4,839	5,668	6,519	8,610	R
13322300	DRY CREEK NEAR BINGHAM SPRINGS, OR	yes		36	47	55	67	75	85	107	W
""	""		32	37	47	54	62	68	74	88	S
""	""			28	46	60	78	92	106	141	R
13323495	GRANDE RONDE R NR IMBLER, OR	no		4,738	7,506	9,533	12,236	14,321	16,457	21,698	R
13323500	GRANDE RONDE R NR ELGIN, OR	yes		3,440	4,804	5,787	7,151	8,186	9,226	11,621	W
""	""		2,876	3,375	4,543	5,267	6,131	6,742	7,329	8,628	S
""	""			4,744	7,516	9,545	12,251	14,339	16,478	21,725	R
13324000	GRANDE RONDE R AT ELGIN, OR	yes		4,947	7,579	9,435	11,907	13,786	15,693	20,198	W
""	""		3,928	4,915	7,417	9,072	11,130	12,630	14,110	17,460	S
""	""			5,197	8,225	10,442	13,400	15,682	18,020	23,754	R

Annual peak return interval discharges were calculated for points along Catherine Creek and its major tributaries within the study area utilizing the historic period of record at the Catherine Creek near Union gage (13320000) and adjusting for additional area and precipitation volume as described in "Methods." For this analysis, all available data were used through water year 2009. Flow locations along Catherine Creek were used to supply model flow boundary conditions for HEC-RAS hydraulic analysis (see Appendix D – Hydraulics).

Tributary peak flows were developed based upon gage 13320000 and adjusted for drainage area and precipitation volume as described in "Methods." Peak flows for the four major tributaries to Catherine Creek within the study area including Little Creek, Mill Creek, Pyles Creek, and Ladd Creek are also included in Table 8. Peak flows along Catherine

Creek were not adjusted for timing of hydrographs or flood routing and were assumed to peak at the same time, which may greatly overestimate peak flows within the valley.

Table 8. Peak flow data for major tributaries and at flow change locations along Catherine Creek. Data extrapolated from Catherine Creek near Union stream gage. Peak flows along Catherine Creek were not adjusted for timing of hydrographs or flood routing and were assumed to peak at the same time, which may greatly overestimate peak flows within the valley.

	RM	Peak Flow	Peak Flow	Peak Flow	Peak Flow	Peak Flow	Peak Flow	Peak Flow	Peak Flow
Location		**Q1.5**	**Q2**	**Q5**	**Q10**	**Q25**	**Q50**	**Q100**	**Q500**
	[miles]	[cfs]	[cfs]	[cfs]	[cfs]	[cfs]	[cfs]	[cfs]	[cfs]
Catherine Ck below Pyles Ck	36.9	941	1,109	1,523	1,791	2,126	2,374	2,619	3,188
Catherine Ck below Little Ck	35.9	973	1,146	1,574	1,851	2,198	2,454	2,708	3,295
Catherine Ck below Ladd Ck	31.4	1,325	1,562	2,144	2,522	2,995	3,344	3,689	4,490
Catherine Ck below Mill Ck	24.1	1,546	1,822	2,501	2,942	3,493	3,900	4,303	5,237
Catherine Ck below Old Grande Ronde River Channel	22.5	1,632	1,924	2,641	3,107	3,689	4,119	4,544	5,530
Catherine Ck below Eckesley Ck	15.8	1,763	2,078	2,854	3,356	3,985	4,450	4,909	5,975
Grande Ronde River below Catherine Ck	NA	4,456	5,376	7,818	9,547	11,858	13,672	15,564	20,317
Grande Ronde River below Willow Ck	NA	4,779	5,757	8,342	10,162	12,589	14,488	16,464	21,413
Little Ck	NA	189	223	306	359	427	477	526	640
Ladd Ck	NA	292	344	473	556	660	737	813	990
Mill Ck	NA	191	226	310	364	433	483	533	649
Pyles Ck	NA	146	172	237	279	331	369	407	496
NA – not applicable.									

5.1.4 Low Flows

The September 95 percent exceedance probability discharge and the lowest September discharge in the daily discharge record for both stream gages on Catherine Creek were calculated (Table 9). September generally has the lowest flows of the year but they can also occur in August. The 95 percent exceedance probability describes the discharge that is equaled or exceeded at least 95 percent of the time. Low flow metrics were not extrapolated to downstream locations because of the error that would be introduced as a result of the complex water withdrawal system that has a significant effect on low flows.

Table 9. Low flow metrics for Catherine Creek stream gages.

	Catherine Creek Near Union, OR		Catherine Creek At Union, OR		
	Low Flow	Low Flow	Low Flow	Low Flow	
Location	95% Sept. Exceedance	Minimum flow	95% Sept. Exceedance	Minimum flow	
	[cfs]	[cfs]	[cfs]	[cfs]	
Catherine Ck near Union*	19	8	--	--	
Catherine Ck at Union*	--	--	2	0	

The Catherine Creek near Union, Oregon stream gage and the Catherine Creek at Union, Oregon stream gage were both used to develop estimates of the low flows. Because the “near” union stream gages is above most water withdrawals, it better indicates the “natural flow” condition, which describes the amount of, water that would be discharging under natural, or non-diversion conditions. The “at” Union stream gage is below many of the diversions and better indicates existing conditions during the irrigation season. A comparison of September flows between the “near” and “at” Union stream gages indicates that flows are regularly less than 25 percent of the natural flow during the irrigation season and can even be zero in locations below senior water rights such as Lower Davis Dam. In reach 1, which historically contained the Grande Ronde River, the change has been even more significant due to the loss of Grande Ronde River baseflows through efforts that created the State Ditch.

Because many more diversions are located below the Catherine Creek at Union, Oregon stream gage, any extrapolation to downstream locations would provide optimistically high values; therefore, no such extrapolation was completed as part of this assessment.

5.2 Diversion Dams and Inter-basin Transfers

There are nine inline diversion dams along Catherine Creek within the assessment reaches that include many pumps, which draw off surface water from Catherine Creek. This assessment only discusses the main diversion dams.

Reach 1 includes Elmer Dam (RM 13.1) which can create a backwater approximately 14.6 miles long (to near Godley Lane at RM 26.7) given the extremely low gradient of this reach. The Elmer Dam Reservoir services several pumps to irrigation agricultural lands in the area with water rights totaling approximately 29 cfs. Additionally, there are water rights for another 298 acre-feet of water. The water is pumped from the resulting reservoir at multiple locations with a total capacity of approximately 20 cfs.

In reach 2, Upper Davis Dam (RM 34.4) and Lower Davis Dam (RM 34.8) backwater Catherine Creek over 2 miles, to near the mouth of Pyles Creek. Lower Davis has a total water right of approximately 47 cfs and Upper Davis has approximately 60 cfs. Surface diversion ditches and pumps are used to withdraw water at these locations. Both dams were completely reconstructed in 2011 and are equipped with radial gates and vertical slot fish ladders.

There are four diversion dams in reach 3. Swackhammer diversion located at RM 40.6 was reconstructed in 1995 for improved fish passage and further modified in 2005. The water rights associated with it are approximately 30.5 cfs, but the ditches have a limited capacity and diversions are limited to less than 24 cfs (Hattan 2011). The Godley diversion located at RM 40 was originally constructed in 1950 with modifications made in 1990 for improved fish passage. The Grande Ronde Model Watershed (GRMW) added a step-pool fishway in 2011. It has a total water right of just over 17 cfs. The Townley-Dobbin Diversion located at RM 39.9 was completely reconstructed in 2010 to include a step-pool fishway and has a water right of approximately 4.5 cfs. The Hempe-Hutchinson Diversion located at RM 39.6 was partially reconstructed in 1994 and retained a previously built fishway. It has a water right of approximately 31 cfs but may only have the capacity to divert around 15 cfs (Hattan 2011).

Two diversions dams are located in reach 4. The Catherine Creek Adult Collection Facility (CCACF) operated by the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) is located at RM 42.2 and the “State” Diversion is located at RM 42.5. CCACF was totally reconstructed in 1995 and fish passage facilities were added around 2000. A vertical slot fish passage facility was added to the State Diversion in 2007. CCACF has a total potential diversion capacity of 4.75 cfs although less is generally withdrawn (Hattan 2011). State Diversion has water rights for over 13 cfs; however, ditch capacity typically limits the discharge to not more than approximately 10 cfs (Hattan 2011).

There are several inter-basin transfers out of the Catherine Creek watershed including the South Fork Catherine Creek Ditch and the Trout Creek Ditch. These are both in the headwaters of Catherine Creek and both divert water into the Powder River watershed. OWRD operated a flow gage on the South Fork Ditch (South Catherine Creek Ditch near Medical Springs, Oregon, 13319700) from 1966 to 1984. The gage data indicate a maximum withdrawal of 32 cfs early in the season, which tapers off until late July or early August when the diversion is stopped. The water rights for this ditch have a priority date of 1918, which is a relatively junior water right in comparison to water rights downstream.

5.3 Reclamation Stream Gages

Only a brief period of data has been collected and downloaded from the stream gages Reclamation began installing in September 2010. Some of these gages will be useful in evaluating streamflows throughout the assessment area in the future, while others will be used for calibration of hydraulic models. At the time of this assessment, rating curves to estimate discharge have not been developed and still require several discharge measurements to be collected at to develop such curves. Once discharges and water surface stage relationships are developed, the stream gages will provide important information on the amount, temperature, and timing of water as it travels downstream. The stream gages will further provide valuable data to calibrate and validate hydraulic models for assessing current and proposed project conditions.

5.4 Climate Results and Climate Change

Until recently, climate was considered to be relatively consistent over time (known as stationarity). Current research into climate change has led to long-term historical studies of climate that illustrate the dynamic nature of climate over time (non-stationarity) (Milly et al. 2008). For instance, Nelsen et al. (2010) discovered that the early 20th century was a particularly wet period in the Pacific Northwest. This coincides with the beginning of much of the stream discharge and weather data collection in the region. This also coincides with the earliest memories of many locals when recounting past conditions.

It is useful to analyze time series of hydrologic data to understand past and current conditions. According to Mote et al. (2005), the upper Grande Ronde region has seen a 20 to 80 percent decrease in the April 1 snow water equivalent (SWE) from 1950 to 1997 or more than a 15 cm decrease between 1950 and 1999 (Regonda et al. 2005). Regonda, et al. (2005) further demonstrates the relationship of SWE to precipitation and SWE to November through March temperature. They found that while an increase in winter temperature does have some effect on reducing SWE, it mainly correlates to a reduction in winter precipitation. This suggests that the decrease in SWE is not a problem due to a lack of water storage as snowpack, but simply that there is less precipitation overall as a result of climate change.

Using stream discharge data from gages in and around Catherine Creek with data from water years 1948 to 2010, the annual water yield and 50-percentile flow dates were calculated (Table 10) for each water year similar to the work of Stewart, Cayan, and Dettinger 2005. The 50-percentile flow date can be considered an estimate of the annual peak flow date in snowmelt regimes such as those in the Grande Ronde. This analysis indicates that there has been a reduction in annual water yield of approximately 13 percent in Catherine Creek above Union and 8 percent in the Grande Ronde River above La Grande since 1948. Additionally, there has been a reduction of approximately 15 percent in the annual water yield of the Grande Ronde River watershed as measured above Troy, Oregon since 1948. Further, the 50-percentile date for flow has shifted earlier. It occurs approximately 11 days earlier in Catherine Creek (near Union) and 6 days earlier in the Grande Ronde (at La Grande) than it did in 1948.

Table 10. Change in the annual water yield and fifty percentile discharge date between water years 1948 and 2010.

Station Name	Station Number	Decrease in Annual Water Yield [percent]	Decrease in Arrival of 50 Percentile Date [Days]
Catherine Creek near Union, OR	13320000	13	11
Grande Ronde River at La Grande, OR	13319000	8	6
Grande Ronde River at Troy, OR	13333000	15	4
Imnaha River near Imnaha, OR	13292000	16	7
Bear Creek near Wallowa, OR	13330500	14	4

6. Discussion

Peak flows in the Grande Ronde Valley are exacerbated by the extreme low gradient (approximately 0.006 percent) in the lower valley, the constriction at Rhinehart Gap, and the confluence of two rivers (Catherine Creek and Grande Ronde River) that have distinct differences in the timing of peak flows. As a result, spring flooding can be more substantial and last longer than typically experienced on other creeks and rivers in the area.

Unlike typical rivers which only flood as a result of their own discharge, flooding in reach 1 of Catherine Creek can be a result of high discharges coming down Catherine Creek, the Grande Ronde River, or both simultaneously. Peak flows can occur from January through early June on Catherine Creek with peak flows typically occurring in April or May. The average peak flow date is May 12. The Grande Ronde River peak flows tend to occur earlier and over a much broader range of dates, typically December through May with an average peak flow date of March 6. Further, because Catherine Creek high flows tend to have a long duration such that high flows (not necessarily the peaks) in both Catherine Creek and the Grande Ronde often happen simultaneously, flooding in the lower Grande Ronde Valley is often substantial and can occur over an extended period of time.

Climate induced patterns in peak flow event timing suggest that peak flows are happening early in the year by as much as 11 days on Catherine Creek and 6 days on the Grande Ronde. This tends to result in less water being available in the summer and an extended irrigation season with higher subsequent demand. In addition, climate change may lead to higher probabilities for having winter rain-on-snow events, which result in early season flood events, and less water stored as snow throughout the spring. Winter rain-on-snow events can also develop large peak flows which can lead to flooding that is exacerbated by ice jams.

Winter disturbance (i.e., flood) events in Catherine Creek may have important consequences for flooding and salmonid survival. During frigid winter periods, ice build up on the creek is typical and can be followed by high winter flow events that break up and carry ice downstream. Thick surface layers of ice alone could be a limiting factor for fish survival and when combined with high flow events could result in fatalities to overwintering juvenile fish. Ice flows can also cause substantial scouring of the creek bottom leading to the direct mortality of incubating eggs. The relative commonality of such events in Catherine Creek points to a data gap in our knowledge as to this potential stress on ESA-listed salmonids within Catherine Creek.

A changing climate is important to consider in view of hydrologic conditions especially when dealing with already over-allocated resources and temperature sensitive salmonids. With an expected increase in average temperatures and an associated reduction in regional snowpack, the challenges facing natural resources, including salmon and other stream dependant species, will continue to grow (Mote et al. 2003). Battlin et al. (2007) modeled the relationship between Chinook salmon and climate change in the Snohomish River basin in Western Washington River and found that a mean increase of 1.5°C by 2050 could reduce the population by 40 percent. However, they also concluded that river restoration that included large increases in juvenile rearing habitat could limit the decline to 5 percent. Although it is not appropriate to directly transfer these numbers to Catherine Creek, it does underscore the importance of improving salmonid conditions through habitat restoration to improve the biological resilience of the creek.

Low flow issues are most apparent during the summer irrigation season. Improving summer discharges for fishery benefits will require both increasing our understanding of the quantity and timing of water as it moves through the assessment area and working with watershed stakeholders to find conservation improvements. Improving our knowledge of the system will require increased knowledge and mapping of local sources and sinks within Catherine Creek. Gages placed by Reclamation throughout the study area will provide much improved knowledge over time. However, many data gaps still exist for improving our knowledge of hydrologic conditions throughout the assessment area. There are several sources and sinks that affect summer hydrology that are unknown at a level of detail necessary to determine the type of actions necessary to improve flows including:

- Where can the creek go dry in the summer?
- Where are all the pumps along the river, how much do they divert and when?
- Do irrigation return flows contribute to baseflows, and if so, where and how much?
- How do the oxbows used for storage function in a typical year?

7. References

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8. Geospatial Data Source and Description

Average Annual Precipitation – PRISM Precip_Annual, PRISM Climate Group at Oregon State University. This data contains spatially gridded average annual precipitation for the climatological period 1971-2000.

Catherine Creek Tributary Assessment Study Area – GRCC_StudyAreaBoundaries, Reclamation PNGIS. This data set was digitized based on FEMA 100-year flood plain.

Catherine Creek Watershed – CatherineCreekWatershed, Reclamation PNGIS. This data set was created from the USGS 10-meter National Elevation Dataset.

City Limits – City Civil Divisions, NAVTEQ. NAVTEQ incorporated and enhanced data from a number of sources to produce a geospatial dataset of boundaries for medium and larger sized U.S. cities.

Climate Station – climate_stations, NOAA National Weather Service COOP, NRCS Snotel, Reclamation Agrimet, USFS/BLM RAWS. This data set was created from geographic coordinates obtained online from NOAA, NRCS, Reclamation, USFS and BLM websites.

Catherine Creek Hydrologic Assessment Area – gr_nre, Reclamation River Systems Analysis Group. This data set was created from the USGS 10-meter National Elevation Dataset.

Land Cover/Land Use – NLCD 2006 Land Cover, U.S. Geological Survey. The National Land Cover Database (NLCD) is public domain information on land use and land cover.

Major Stream – NHD Flowlines, U.S. Geological Survey. The National Hydrography Dataset (NHD) is a feature based database of the nation's surface water drainage system.

Spring – NHD Points, U.S. Geological Survey. The National Hydrography Dataset (NHD) is a feature based database of the nation's surface water drainage system.

Surface Elevation – 10-meter digital elevation model (DEM) and hillshade, Reclamation PNGIS. This data set was created from USGS National Elevation Dataset 1/3 arc-second FLT (binary) files.

Tributary Watershed – SignificantWatersheds_CCW, Reclamation PNGIS. This data set was created from the USGS 10-meter National Elevation Dataset.

Upper Grande Ronde Subbasin Boundary – HydroUnit_8th_WBD, Natural Resource Conservation Service. This data set is a complete digital hydrologic unit boundary layer to the Subbasin (8-digit) 4th level for the entire United States.

USBR Installed Stream Gage – StreamGages_UGRSB, Reclamation River Systems Analysis Group. This data set was created from recorded location coordinates.

USGS and/or OWRD Installed Stream Gage – StreamGages_UGRSB, Reclamation River Systems Analysis Group. This data set was created from geographic coordinates obtained online from USGS and OWRD websites.

Watersheds – gr_cc, wc_cl, and CatherineCrkWshed, Reclamation River Systems Analysis Group and PNGIS. These data sets were created from the USGS 10-meter National Elevation Dataset.

Waterbody – NHDWaterbodies, U.S. Geological Survey. The National Hydrography Dataset (NHD) is a feature based database of the nation's surface water drainage system.

Disclaimer

Maps contained in this report are intended for general informational and planning purposes only. They are not intended to be used for description or authoritative definition of location or legal boundary. Reclamation makes no warranty, expressed or implied, as to the completeness, accuracy, or utility of the maps and associated data and will in no event be liable for use beyond the above expressed purpose.

APPENDIX B – WATER QUALITY

RECLAMATION

Managing Water in the West

WATER QUALITY REPORT
CATHERINE CREEK TRIBUTARY ASSESSMENT – GRANDE RONDE RIVER BASIN

Tributary Habitat Program, Oregon

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region
Boise, Idaho

February 2012

U.S. DEPARTMENT OF THE INTERIOR

Protecting America's Great Outdoors and Powering Our Future

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

MISSION OF THE BUREAU OF RECLAMATION

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Cover Photograph: View looking east (downstream) along Catherine Creek, Reach 2 at river mile 26.0, in the Cove area, Mt. Fanny (upper left) and Phys Point (upper right) can be seen in the background. **Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – July 29, 2010.**

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1. Summary

Several water quality parameters currently limit fish survival and reproduction in Catherine Creek. Land management activities have contributed to riparian and instream habitat degradation with the primary issues being temperature, sediment, water withdrawal, and riparian condition (Nowak 2004). An extensive literature search was conducted to gather information and data pertaining to water quality in Catherine Creek. Water quality in this tributary is being assessed to provide information for implementing salmonid habitat improvement projects to meet commitments in the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) (NOAA Fisheries 2008).

Catherine Creek is comprised of an upstream high gradient reach and a downstream low gradient reach with the transition in gradients occurring near Pyles Creek, which joins Catherine Creek in the town of Union. Below Union, Catherine Creek is a highly modified meandering channel that flows through heavily irrigated agricultural land (Favrot et al. 2010). The lower reaches are characterized by floodplains and old lakebeds (NRCS 2005). As elevation begins to increase above Union, land use changes from cultivated crops to more pasture and rangeland within grasslands and shrublands (Bach 1995). Grazing also occurs in the high gradient reaches of the subbasin, where mixed conifer forests on steeper slopes are the dominant vegetation type.

Spring- run Chinook salmon and steelhead trout spawn at high elevations in the headwater tributaries of Catherine Creek (NOAA Fisheries 2008). Spawning is complete by the second week of September. The majority of juvenile spring Chinook salmon and steelhead move out of natal rearing areas to overwinter in downstream areas of Catherine Creek, while fewer remain in the upper reaches through the winter before migrating toward the ocean as smolts the following spring or later (Yanke et al. 2008).

The Grande Ronde Basin historically produced large runs of native spring Chinook salmon (Bach 1995). Historical information from 1811 to 1908 characterized the Grande Ronde River through the Grande Ronde Valley as being: 1) cold, clear, and a consistent source of water in all seasons; 2) habitat for salmon and crayfish; and 3) habitat for beaver, with Tule Lake being created by beaver dams (Beckham 1995). Historical accounts on riparian conditions describe the Grande Ronde and its tributaries as lined and shaded with dense vegetation that included species such as cottonwoods, willows, hawthorn, alder, and rosebush (Beckham 1995; Duncan 1998; ODEQ 2000).

European settlers moved into the area in the mid-1800s and significant timber harvest, livestock grazing, and agricultural production began (Bach 1995). Wetlands and floodplains were drained and transformed into productive farmland. Large-scale changes

in vegetation occurred as early as the 1870s with the introduction of livestock (ODEQ 2000). Logging has increased steadily in the Grande Ronde Basin since 1896, with demand and production of timber surging in the period following World War II (McIntosh et al. 1994; Duncan 1998). Following this surge, intensive road building took place in remote areas, particularly from the 1970s onward (Duncan 1998).

As a result of land use practices, a number of water quality parameters in Catherine Creek exceed standards established by the Oregon Department of Environmental Quality (ODEQ). Due to water quality standards violations, Catherine Creek is included on Oregon's 1998 Section 303(d) list as shown in Table 1 (ODEQ 2000). Temperatures exceed standards throughout the entire stream; however, most of the water quality standard violations occur on the lower reaches of Catherine Creek, from the mouth to Catherine Creek Adult Collection Facility (CCACF) (reaches 1, 2, 3, and the lower segment of reach 4). The CCACF is referred to as "Union Dam" in the ODEQ TMDLs. The exception is sedimentation, which only exceeds ODEQ standards in the North and South Forks of Catherine Creek. Although these upper tributaries are not specifically included in this assessment, they contribute sediment to the lower reaches of the creek, where siltation has degraded salmonid habitat.

Table 1. Reaches in Catherine Creek included in the 1998 Section 303(d) list for violating water quality standards (ODEQ 2000).

Parameter	Boundary
Temperature	Mouth to CCACF CCACF to N.F./S.F. Catherine Cr. N. Fork, Mouth to Middle Fork S. Fork, Pole Cr. to S. Catherine Ditch Diversion
Aquatic weeds or algae	Mouth to CCACF
DO	Mouth to CCACF
Flow modification	Mouth to CCACF
Habitat modification	Mouth to CCACF
Nutrients	Mouth to CCACF
pH	Mouth to CCACF
Sedimentation	N. Fork, Mouth to Middle Fork
Sedimentation	S. Fork, Mouth to South Catherine Ditch Diversion

A number of factors limiting water quality in Catherine Creek have been identified and include (GRMWP 1994; Nowak 2004; NOAA Fisheries 2008):

- Substandard riparian conditions
- Low summer flows
- High summer temperatures
- Limited dilution flows
- Excess sediment
- Streambank erosion

Temperature data are probably the most comprehensive of water quality data for Catherine Creek and exist in the form of continuous monitoring data and thermal imagery. Existing temperature data confirms that summer temperatures typically exceed the ODEQ standard of 64.0^{0}F, which was established based on optimal temperatures for salmonid species. Temperatures are particularly high in the lower reaches of the creek, where they can reach 80^{0}F in August (Justice, McCullough, and White 2011b; McCullough et al. 2011; Watershed Sciences 2000). The only sections of the creek that did not consistently exceed 64.0^{0}F were the North and South Forks and the very upper reaches of main stem Catherine Creek (Justice, McCullough, and White 2011b; McCullough et al. 2011; Watershed Sciences 2000; ODEQ 2000).

Sediment is only included on the Section 303(d) list for the North and South Forks, although there appears to be a problem throughout the stream in regards to salmonid habitat. The estimated percent function is egg survival to emergence of 30 percent of potential due to fine sediment levels (CRITFC 2009). Bank stability was below reference condition levels along 85 percent of Catherine Creek and levels of fine sediment in the streambed were above reference criteria along 79 percent of the stream (Huntington 1994). Surface sediment fines were found to be highest at the mouth of North Fork and lowest in the upper reaches of South Fork out of five sites sampled in Catherine Creek (Justice, McCullough, and White 2011a; McCullough et al. 2011).

Data on nutrients, pH, DO, ammonia toxicity, and bacteria were only found for the segment of the stream below RM 43, just upstream of Union. This lower portion of Catherine Creek typically exceeds the ODEQ standard of 6 µ/L of orthophosphate as P (USWCD nd; Miles nd; ODEQ 2007). Dissolved inorganic nitrogen (DIN) levels standards of 26 µ/L are usually only exceeded below the town of Union, but not upstream or further downstream, which is probably due to excessive algal and aquatic weed growth consuming nitrogen (USWCD nd; Miles nd). Bacteria levels also occasionally exceed ODEQ standards, which require that a 30-day log mean for a minimum of five samples cannot exceed 126 organisms per 100mL, particularly just downstream of Union. The Union Wastewater Treatment Plant (WWTP) stopped discharging effluent into Catherine Creek during summer months in 2001 per ODEQ recommendations. Ammonia levels appeared to decrease but the excessive nutrient and bacteria levels detected below town suggest that the urban land use area that the stream flows through is a significant NPS of nutrient and bacteria loading. Catherine Creek has large diel fluctuations in pH and DO with levels very near violations of water quality standards due to considerable aquatic plant and algae activity (Miles nd).

Flow and habitat modification are parameters included on Oregon’s 1998 Section 303(d) list for violating water quality standards on Catherine Creek. Flow and habitat (i.e., riparian condition) modifications are not the direct result of a pollutant load, although they are closely related to water quality conditions. Water quality standard violations occur from June to September when flows in Catherine Creek are lowest. Water withdrawals for irrigation reduce flows starting in June. Between mid-July and late September irrigation demand often exceeds the water supply in Catherine Creek, reducing summer flows that are already naturally very low late season. This results in insufficient flows to support anadromous fish migration and to meet water quality standards (Huntington 1994; ODEQ 2000; Reclamation 2002). While not the only issue, riparian habitat degradation has been identified as the most serious problem in the subbasin (Nowak 2004). Riparian vegetation is especially sparse and provides little shade cover in lower Catherine Creek (Favrot et al. 2010). Stream shade was below reference condition levels along 56 percent of miles surveyed on Catherine Creek (Huntington 1994).

Most water quality problems in the Grande Ronde subbasin derive from past forestry, grazing and mining activities as well as current improperly managed livestock grazing, cumulative effects of timber harvest and road building, water withdrawals for irrigation, agricultural activities, industrial discharge, and urban and rural development (Nowak 2004). The landscape has been drastically altered by human activities since the mid-1800s due to large-scale disturbances to the riparian vegetation (ODEQ 2000).

Long-term degradation of riparian areas has reduced shade, which has led to chronic stream temperature problems in Catherine Creek (Huntington 1994). Solar radiation loading was determined to be the primary source of elevated stream temperatures in the Grande Ronde River (ODEQ 2000). Poor riparian vegetation conditions have also contributed to bank erosion, sedimentation, and nutrient loading.

Although flows are naturally low in summer due to the local climate, water withdrawal for irrigation has caused severe water depletions in Catherine Creek. Low summertime streamflows have caused temperatures to increase. Nutrients and bacteria entering the stream are less diluted. These conditions have led to increased algal growth, which in turn affects DO concentrations and pH levels.

Riparian and instream habitat degradation has severely affected spring Chinook salmon production potential in the subbasin (Nowak 2004). Significant changes in many salmonid habitat attributes have occurred in Catherine Creek relative to historic conditions (NOAA Fisheries 2008).

Overall changes in water temperatures between historic and existing conditions appear to have had the greatest contribution in reducing spring Chinook productivity (Duncan 1998). Flow and temperature patterns have been altered with much reduced flow caused by irrigation withdrawals in summer and increased temperatures due to low flows and the loss of streamside shade (Duncan 1998; NOAA Fisheries 2008). These factors have significantly influenced adult and juvenile migration opportunity and created heat sinks in what would be prime rearing habitat. Lower flows and warmer water temperatures have likely shifted and reduced variability of adult migration and spawn timing relative to historic timing (NOAA Fisheries 2008). The opportunity for fry and summer parr downstream migration in Catherine Creek has also been reduced. Lower than optimum winter temperatures resulting from the disconnect between streams and moderating groundwater supplies may adversely affect overwintering juvenile fish (Duncan 1998).

2. Introduction

2.1 Purpose of Study

Catherine Creek is a known spring Chinook salmon and steelhead-spawning tributary of the Grande Ronde River and is a highly regulated stream (Favrot et al. 2010). Land management activities have contributed to riparian and instream habitat degradation with the primary issues being high temperatures, sediment, water withdrawal, and riparian condition (Nowak 2004).

Several water quality parameters currently limit fish survival and reproduction in Catherine Creek. Catherine Creek has low survival rates of juvenile spring Chinook salmon emigrants in comparison to the Snake and Columbia River systems (Favrot et al. 2010). Water quality in this tributary is being assessed to provide information for implementing salmonid habitat improvement projects to meet commitments in the 2008 FCRPS BiOp (NOAA Fisheries 2008).

For the purposes of this assessment, water quality parameters are addressed under four headings: temperature; sediment; nutrients; and flow and riparian conditions. Discussions on nutrients include nitrogen, phosphorous, dissolved oxygen (DO), pH, and algal growth because these parameters are so closely linked. Physical attributes of flow and riparian conditions, though not specifically water quality issues, are directly related to water quality conditions and are therefore discussed briefly. Optimal water quality conditions for salmon are summarized in Table 2. Water quality parameters and their effects on the life cycle of cold-water fish, such as salmon and steelhead are discussed below.

Table 2. General water quality habitat requirements for salmon (WCSRSC 1999).

Parameter	Optimal Habitat Condition for Salmon
Temperature	[1] Adult migration: 38 - 68ºF Spawning and incubation: 40 - 57º Rearing 39 - 68ºF (juvenile fish prefer 54 -57ºF)
Dissolved oxygen	[1] Adult migration: > 7.0 ppm Spawning and incubation: > 8.0 ppm Rearing: > 7.0 ppm
pH	Oregon State Standard of 6.5 – 8.5
Turbidity	[1] Turbidity should be limited and not sustained
Surface fines on stream bottom	[2] Good = < 20 percent Fair = 10 – 20 percent Poor = > 20 percent
Cobble embeddedness	[2] Good = < 20 percent Fair = 20 – 35 percent Poor = > 35 percent
Streamflow	Streamflow should provide access to adequate spawning gravel, and stream depth should be no less than 7 inches [1] Spawning velocity: 1.0 to 2.5 ft/s Adult migration velocity: maximum of 8.0 ft/s

[1]Bjornn and Reiser 1991 [2]BLM 1993

2.1.1 Temperature

Stream temperature is largely a function of riparian vegetation and the amount of stream shading it creates. Water temperature tends to be a parameter that generally increases downstream, with an irregular pattern of variation occurring at tributary junctions, entry points for seeps, and zones of groundwater-surface water exchange (CRITFC 2009). Variability in stream temperatures may be important for the existence of cold-water fish in relatively warm water streams. Variations in the spatial distribution of water temperature affect the spatial distribution and potential survival of summer-rearing juveniles (CRITFC 2009). Cold-water fish commonly inhabit cooler reaches when many portions of streams maintain stressful and/or lethal warm water temperatures (McIntosh et al. 1995; ODEQ 2000).

Groundwater inflow has a cooling effect on summertime stream temperatures (ODEQ 2000). Subsurface water is insulated from surface heating processes and most often groundwater temperatures fluctuate little and are cool (45°F to 55°F). Groundwater inflow not only cools summertime stream temperatures, but also augments summertime flows. Many land use activities that disturb riparian vegetation and associated floodplain areas affect the connectivity between river and groundwater sources. Reductions or elimination of groundwater inflow will have a warming effect on the river. The disconnect between streams and moderating groundwater supplies can also lower winter temperatures. Winter temperatures are critical to timing of egg hatch and the availability of food for emerging juvenile fish and, if too low, may adversely affect overwintering fish (Duncan 1998).

Stream temperature often controls the distribution of fish and other aquatic organisms and affects salmonids during all life history stages (Bach 1995). Water temperature appears to be a migration stimulus associated with movement during fall migration and overwinter rearing (Favrot et al. 2010). For Chinook salmon, adult migration, spawning, egg incubation, and rearing are all subject to reduced success at temperatures that are not optimal. A desired temperature range for each of these life cycles is shown in Table 2. The upper limit for growth of most salmonid species is around 66°F (Bach 1995). Temperatures in the mid- to high- 70°F range cause death of cold-water fish species during exposure times lasting a few hours to a day (ODEQ 2000). The incipient lethal limit (i.e., the temperature at which fish mortality is caused) for Chinook salmon appears to be 77°F (ODEQ 2000), when the regulation of vital processes such as respiration and circulation break down (ODEQ 2000). The Environmental Protection Agency (EPA) and National Marine Fisheries Service (NOAA Fisheries Service) reported 50 percent mortality to adult salmon and steelhead trout with a constant water temperature of 70°F (ODEQ 2000). The sub-lethal limit causes a more delayed thermally induced mortality and occurs weeks to months after the onset of elevated temperatures (mid-60°F to low-70°F).

2.1.2 Sediment

Streambed material classification defines fines as sand, silt, and organic material that have a grain size of 0.25 inches or less (ODEQ 2000). Human disturbances, such as grazing, road construction, and vegetation removal, may lead to increased delivery of fine sediment to streams (CRITFC 2009). Controlling erosion not only reduces the amount of sediment that enters streams, but also affects the amount of pesticides, fertilizer, and other substances that move into the Nation's waters (NRCS 2005). Fine sediments can adversely affect fish and other aquatic organisms. Increased fine sediment deposition in spawning gravel can impair the success of juvenile emergence from gravel redds (ODEQ 2000). Sedimentation may affect egg survival through entombment or through reduction of intergravel DO delivery. Other impacts to salmonids caused by sedimentation include mortality, reduced growth or disease resistance, modified natural movements and migration, and reduced abundance of food organisms (ODEQ 2000).

Increases in bed sediments alter habitat complexity for aquatic species. Landscape and bank mass failures that lead to increased sediments are often accompanied by channel widening and braiding resulting in increased bank erosion and decreased pool riffle amplitude (ODEQ 2000). Pool volumes can also be reduced, which can affect the thermal buffering capacity of a reach (CRITFC 2009).

2.1.3 Nutrients

Among other factors, elevated nutrient levels in streams can lead to excessive algal growth (ODEQ 2000). In turn, growth of algae can result in significant diel fluctuations in DO and pH, which may adversely impact aquatic life. During the day, when algae perform photosynthesis and grow, carbon dioxide is consumed and oxygen produced. At night respiration dominates, carbon dioxide is produced, and oxygen consumed. Carbon dioxide affects pH because it combines with water to form carbonic acid. Therefore, during the day as algae consume carbon dioxide the pH increases, while at night as algae produce carbon dioxide the pH declines. This process also affects oxygen concentrations, with DO increasing in the day while algae produce oxygen through photosynthesis, and decreasing at night while respiration consumes oxygen.

Ammonia toxicity is a potential concern in the Upper Grande Ronde subbasin because of elevated pH and temperature levels (ODEQ 2000). Ammonia is present in two states in natural waters: ammonium ion (NH_4^+) and un-ionized ammonia (NH_3). Un-ionized ammonia is much more toxic to aquatic life than the ammonia ion state. Since the fraction of ammonia that is un-ionized increases as pH increases, systems with high pH, such as Catherine Creek, are highly susceptible to ammonia toxicity.

DO and ammonia concentrations and pH levels all affect fish habitat. When DO concentrations get too low, fish begin to suffocate (Bach 1995). Eggs and embryos are particularly sensitive to DO. If a particular segment of a stream develops a low DO saturation that is sustained for an extended period, it can create a barrier to fish passage. DO saturations as low as 75 percent will generally support a diverse population of aquatic organisms; however this is not the most favorable condition for salmonids. For optimal development and hatching, salmonids require DO in excess of 95 percent saturation.

High pH levels (greater than 9.0) can lead to increased fish mortality (Bach 1995). In addition, both high and low pH (above 8.5 and below 6.5) can increase the toxicity of some other compounds. As with DO problems, high pH is often associated with excessive algae growth.

Ammonia can cause a number of problems in aquatic systems. Ammonia is converted to nitrate in a process that consumes oxygen, and thus reduces DO concentrations in the water column (Bach 1995). Ammonia is also a nutrient that contributes to excessive algae growth. Finally, ammonia is toxic to most aquatic animals. Toxicity increases when pH levels exceed 8.5 (Bach 1995).

2.1.4 Flow and Riparian Conditions

Streamflows have a large effect on water quality. When streamflows are low, the thermal buffering capacity of the stream is reduced (CRITFC 2009). Subsequently, stream temperatures increase and DO concentrations are lowered (Bach 1995). In addition, chemicals and toxic substances that enter the stream are not as diluted under low flow conditions.

Water temperature is controlled by solar radiation, which in turn is influenced by riparian condition (CRITFC 2009). Shading from riparian vegetation largely moderates stream temperatures. Riparian vegetation is also important in controlling sedimentation. Roots of riparian plants, particularly woody stemmed species, help to stabilize banks. Vegetation in riparian buffers adjacent to the stream prevents soil runoff.

2.2 Project Area

Catherine Creek is a tributary of the Grande Ronde River in northeastern Oregon that is considered important to Chinook salmon populations within the Columbia River Basin (NOAA Fisheries 2007). Catherine Creek is comprised of an upstream high gradient reach and a downstream low gradient reach with the transition in gradients occurring near Pyles Creek, which joins Catherine Creek in the town of Union. Below Union, Catherine Creek is a highly modified meandering channel that flows through agricultural land (Favrot et al. 2010). The area is heavily irrigated, with approximately 6,800 acres of irrigated farmland within the total 8,000 acres of Catherine Creek's fan (Reclamation 2002). There are three irrigation dams (upper and lower Davis and Elmer Dams) that partially impound water in the stream from late summer to mid winter. The lower reaches are characterized by floodplains and old lakebeds (NRCS 2005). The soils are well drained to somewhat poorly drained. As elevation begins to increase above Union, land use changes from cultivated crops to more pasture and rangeland within grasslands and shrublands (Bach 1995). The middle reaches are characterized by shallow and moderately deep soils on gently sloping to steeply sloping hills and mountains adjacent to forestland (NRCS 2005). Grazing also occurs in the high gradient reaches of the subbasin, where mixed conifer forests on steeper slopes are the dominant vegetation type.

Spring- run Chinook salmon and steelhead trout spawn at high elevations in the headwater tributaries of Catherine Creek (NOAA Fisheries 2008). Spawning is complete by the second week of September. There are currently two primary life history 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 (NOAA Fisheries 2007). "Early" migrant juveniles start moving downstream in autumn between late-September and mid-January with a peak in the fall. "Late" migrants overwinter in streams, leaving upper rearing areas from late-January to late-June with a peak in the spring (Yanke et al. 2008). The majority of juvenile spring Chinook salmon migrate out of upper rearing areas (e.g., 78 percent in 2008) as early migrants, while fewer steelhead (e.g., 36 percent in 2008) leave as early migrants (Yanke et al. 2008).

Microhabitat availability in Catherine Creek is considerably different in the high gradient reaches (i.e., upstream of the mouth of Pyles Creek) than in the low gradient reaches (i.e., downstream from the mouth of Pyles Creek (Favrot et al. 2010). High gradient reaches have shallower depths and faster flows with coarser substrates compared to low gradient reaches. Substrates available in the high gradient reach range from clay to boulder, while available substrates ranged from clay to sand in the low gradient reaches. Low gradient reaches are considerably wider than high gradient reaches; however, both have generally small bank angles. Land use conditions within a 164-foot buffer are similar between high and low gradient reaches. The majority of land use is agriculture, with forested and developed categories less than or equal to 25 percent each.

To the extent possible, water quality conditions will be assessed within seven reaches spanning from the mouth of Catherine Creek at RM 0 to the bifurcation of the North and South Forks of Catherine Creek at RM 54.9. The reaches are designated as follows:

- Reach 1 (RM 0 to 22.5) begins at the mouth of Catherine Creek where it intersects State Ditch to the junction with the Grande Ronde.
- Reach 2 (RM 22.5 to 37.2) continues to the outskirts of Union, just north of the town.
- Reach 3 (RM 37.2 to 40.8) flows through the town of Union.
- Reach 4 (RM 40.8 to 45.8) enters the foothills and proceeds into the canyon.
- Reach 5 (RM 45.8 to 50.1) increases in elevation and becomes a confined channel, ending at the confluence with Little Catherine Creek.
- Reach 6 (RM 50.11 to 52.0) ending at the confluence with Milk Creek.
- Reach 7 (RM 52.0 to 54.9) continues to the mouths of the North and South Forks.

Stream characteristics, grouped by relatively similar reaches and documented by Kavanagh, Jones, and Stein (2011), are described below:

2.2.1 Reaches 1 and 2

The lower reaches of Catherine Creek consist of a continuous homogenous channel, constrained by terraces, which meanders through agriculture land use. The stream is deep (average 3.0 feet), approximately 65.6 feet wide, with little defined habitat. The gradient of the section averages 0.0 percent. Water visibility is low. The stream substrate and streambanks are primarily composed of fine sediment (hardpan clay, silt, some sand), some of which is actively eroding. Shrubs (hawthorn, willow, dogwood) and grasses line the streambank, providing little in the way of shade or woody structure. Oxbows have been cut off from the main stem with only a control structure connecting the creek with the oxbow. Elmer’s Dam (RM 12.4) is a seasonal dam for irrigation. Boards are either placed or removed to control the water height and availability. When all the boards are in place, the water may pool for 69 feet (Kavanagh, Jones, and Stein 2011).

2.2.2 Reaches 3 and 4

The middle reaches transition from an agriculture landscape to a section with agriculture and urban (i.e., town of Union) land uses. The stream is shallower (average 1.6 feet) above the Davis Dam pool and characterized by more defined habitat, a mix of land use influences, and an increase in streamside trees. Catherine Creek is primarily a single channel through these reaches, with little off-channel habitat. The stream habitat includes low gradient riffles as well as scour pools and glides. The substrate is a mix of fine sediments, gravel, and cobble. Large willows and other deciduous trees contribute to shading. Little Creek, Pyles Creek, and Brinkler Creek are named tributaries, which enter these reaches. There are at least five dams/fish ladders/diversions which fish encounter at RM 40.1, 40.3, 40.4, 41.2, and 43.0. Streamside shade, coarse substrate, and stream gradient increase in the middle reaches.

2.2.3 Reaches 5, 6, and 7

Catherine Creek State Park and Whitman National Forest are within the upper reaches of the creek. The surrounding area is forested with deciduous and coniferous trees of all size classes. Trees in the riparian areas shade the creek, add stability to stream banks, and are a source of large wood for the channel. The upper reaches have long stretches of riffles with some rapids and pools; the average depth is 1.2 feet. The average gradient is 1.3 percent. The upper reaches maintain the riffle/pool habitat ratio of the middle reaches; however, the character of the upper reaches changes dramatically with a sharp increase in the number of multiple channels. The secondary and off-channel habitat increases from approximately 1,969 feet in the middle reaches to close to 16,404 feet in the upper reaches. The upper section has the most wood and the most opportunity for large woody debris contribution.

3. Methods

An extensive literature search was conducted to gather information and data pertaining to water quality in Catherine Creek. Readily available literature was obtained and local agencies contacted to prepare this report. A bibliography listing all references used is provided at the end of this report.

4. Historic Conditions

Native Americans inhabited the valleys and canyons of the Grande Ronde for thousands of years before the 19th century arrival of Euro-Americans (Duncan 1998). In pre-settlement times, the middle Grande Ronde River meandered in a wide circle (a “grande ronde”) through an open bowl of valley occupied by grasslands, wetlands, and lakes. Tule

Lake – “a vast lake covered with tules” – was located on the lower reaches of Catherine Creek (Duncan 1998).

The Grande Ronde Basin historically produced large runs of native spring Chinook salmon (Bach 1995). Historical information from 1811 to 1908 characterized the Grande Ronde River through the Grande Ronde Valley as being: 1) cold, clear, and a consistent source of water in all seasons; 2) habitat for salmon and crayfish; and 3) habitat for beaver, with Tule Lake being created by beaver dams (Beckham 1995).

There is very little quantitative data available to describe the historical vegetation conditions in the Upper Grande Ronde basin; however, some qualitative descriptions are documented (ODEQ 2000). Riparian trees and shrubs were undoubtedly more abundant than today. Historical accounts describe the Grande Ronde and its tributaries as lined and shaded with dense vegetation that included species such as cottonwoods, willows, hawthorn, alder, and rosebush (Beckham 1995; Duncan 1998; ODEQ 2000). In fact, the first name for the Grande Ronde Valley was Kup-Kup-Pa, or “Place of the Cottonwood” (ODEQ 2000).

European settlers moved into the area in the mid-1800s and significant timber harvest, livestock grazing, and agricultural production began (Bach 1995). Wetlands and floodplains were drained and transformed into productive farmland. Fred Nodine, a farmer and land developer, began draining Tule Lake in 1870 (Beckham 1995; Duncan 1998). Water was withdrawn from an estimated 2300 acres of wetland and the land was placed under cultivation within 20 years. This project involved turning Catherine Creek, carrying it around the eastern side of the lake in a new channel, and finally turning it into one of the lake’s numerous outlets (Duncan 1998). A huge canal was constructed in order to do this. In 1860s, the first excavations for what would become State Ditch took place in the area west of Tule Lake. During pre-settlement times, an estimated 72,000 acres in the valley were subject to flooding and up to 60 percent of the valley floor might be inundated for as long as 5 months (Duncan 1998). In 1894, around 50,000 acres were flooded; in 1949 flood, only 5,900 acres were inundated.

Historical accounts indicate that large-scale changes in vegetation occurred as early as the 1870s with the introduction of livestock (ODEQ 2000). By the 1880s, there were signs of overgrazing in parts of the upper Grande Ronde basin (McIntosh et al. 1994; Duncan 1998). In the early 1900s, domestic livestock peaked. Records from Wallowa-Whitman National Forest from 1911 to 1990 indicate that over that period, grazing by livestock declined 78 percent, which was largely due to the collapse of the sheep industry in northeast Oregon (McIntosh et al. 1994).

Logging began in the upper Grande Ronde basin in the late 1880s. Harvest has increased steadily since 1896, with demand and production of timber surging in the period following World War II (McIntosh et al. 1994; Duncan 1998). Following this surge, intensive road building took place in remote areas, particularly from the 1970s onward (Duncan 1998). Miles of road doubled from 1954 to 1978, and doubled again from 1978 to 1989 (McIntosh et al. 1994). Harvest in the early part of the century was restricted to riparian areas and adjacent hillslopes. More recently, logging has occurred in higher elevation and headwater sections as road construction increased access (McIntosh et al. 1994).

From 1934 to 1946, the Bureau of Fisheries (BOF) conducted stream surveys in the Columbia River Basin that included the Upper Grande Ronde Basin (McIntosh, Clarke, and Sedell 1990). Catherine Creek was surveyed August 9 to 12, 1941. Although the Upper Grande Ronde Basin had already experienced considerable human-induced disturbance at the time of the surveys, these are the earliest and most comprehensive records available on the condition and extent of anadromous fish habitat prior to hydropower development in the Columbia River Basin. These documents therefore provide baseline data for future fish habitat restoration throughout the watershed.

BOF surveys were conducted at five stations. Although these stations do not clearly correspond to the current assessment reaches, an attempt will be made to discuss stream conditions at the time of the surveys in terms of the current reach designations. Throughout the entire stream, 29 diversions and 19 “artificial obstructions” (i.e., dams) were noted. Apparently, the entire surveyed portion of the stream was inaccessible to spawning during low water because Lower Benson Dam (currently at the confluence with the Grande Ronde between reach 1 and 2) became impassible, even though it was equipped with a makeshift fish ladder. Width and depth of the creek varied from 45 feet and 30 inches, respectively, at the lower reaches (1 and 2) to 20 feet and 10 in at the confluence with the North and South Forks (reach 7). Substrate was predominately mud and sand within present day reaches 1 and 2. Above Union, substrate became coarser, dominated by medium sized rubble (3 to 6 inches) at all of the upper stations BOF surveyed. Stream temperature data collected mid-August ranged from 74^0F in the lower reaches to 59^0F at the confluence with North and South Forks.

BOF records on stream characteristics in the lower reaches (reach 1 and 2) noted that rubble was present for only four miles below the town of Union, but that scarcely any of the rubble in this section was usable because of heavy silt on the riffles. From this point to the mouth of the stream, the bottom contained nothing but mud and an occasional large stone. There were many good pools below Union, but they were probably unsuitable for salmon because of the high water temperatures in summer, which reportedly reached into the 80^0F range. Carp appeared as soon as mud comprises most of the bottom, and continued in abundance to the mouth of the stream. This portion of the river meandered through a broad floodplain continuous with that of the Grande Ronde River. Gradient was documented as very shallow, being only one to a few feet per mile.

Above the town of Union (reaches 4 to 7), BOF records note that the gradient begins to get steeper and that all spawning activities of salmon and steelheads occurred here.

Between Union and BOF Station D (reaches 4 and 5), the report describes two agricultural valleys, the lower and larger one continuing almost to Union, separated by a narrow V-shaped valley. In these valleys, especially the lower one, some good spawning riffles and fair resting pools occurred. The V-shaped valleys were described as having a gradient too steep to permit good spawning areas for the most part.

The 1941 survey reported that steelhead and Chinook ran in Catherine Creek. According to a local sportsman, the run of steelheads appeared to have been increasing over the past 4 years, while that of the Chinook has been steadily decreasing. The Chinook appeared from May 10 to June 1 and spawned in late August or early September.

BOF identified a number of factors that contributed toward making conditions in Catherine Creek unfavorable for migratory fish at the time. The majority of issues were related to dams and diversions. Of the 19 irrigation dams on Catherine Creek, 11 were fish barriers at low water and some of the dams were even impassible at high water. Snagging and gigging were still allowed in the stream, and fishing was popular below each dam as fish were temporarily blocked. Diversions not only had large impacts on flows, but only 2 of 29 were screened and many fish were said to swim down the ditches in spring. High stream temperatures were a problem by 1941, with summer water temperatures reaching the low 80^{o}F range in August. It was noted that temperature conditions were possibly a result of timber removal in the headwaters of the tributaries. Finally, sedimentation caused by erosion appeared to be an issue. Flash floods caused by cloudbursts in the headwaters brought down mud and muddy water, which could be very harmful to Chinook runs.

5. Existing Conditions

A number of water quality parameters exceed standards established by ODEQ. ODEQ developed a Total Maximum Daily Load (TMDL) for all streams in the Upper Grande Ronde subbasin that addresses salmonid fisheries concerns (ODEQ 2000). The TMDL analyzes the factors affecting water quality and identifies the amount of pollution that can be present without causing state water quality standards to be violated. Load allocations associated with this TMDL are designed to reduce the input of pollutants into streams. Water quality conditions are typically a result of interactions between variables. The standards of concern include stream temperature, DO, and pH. The pollutants responsible for these water quality problems include excess heat, nutrients, and sediments. In turn, excess heat is caused by limited shade and low flows. Pollutants that enter the streams are a result of human induced changes to streamside vegetation and to the stream channel (ODEQ 2000).

As a result of water quality standards violations, Catherine Creek is included on Oregon's 1998 Section 303(d) list shown in Table 3 (ODEQ 2000). Catherine Creek is on the

303(d) Stream List based on primary concerns of high temperatures, habitat and flow modifications, and low DO (Nowak 2004). Most of the water quality standard violations occur on the lower reaches of Catherine Creek, from the mouth to CCACF at RM 42.5 (reaches 1, 2, 3, and the lower segment of reach 4). The CCACF was referred to as "Union Dam" in the ODEQ TMDLs. The exception is sedimentation, which only exceeds ODEQ standards in the North and South Forks of Catherine Creek. Although these upper tributaries are not specifically included in this assessment, they contribute sediment to the lower reaches of the creek, where siltation has degraded salmonid habitat. Temperatures exceed standards throughout the entire stream.

Table 3. Reaches in Catherine Creek included in the 1998 Section 303(d) list for violating water quality standards (ODEQ 2000).

Parameter	Boundary
Temperature	Mouth to CCACF CCACF to N.F./S.F. Catherine Cr. N. Fork, Mouth to Middle Fork S. Fork, Pole Cr. to S. Catherine Ditch Diversion
Aquatic weeds or algae	Mouth to CCACF
DO	Mouth to CCACF
Flow modification	Mouth to CCACF
Habitat modification	Mouth to CCACF
Nutrients	Mouth to CCACF
pH	Mouth to CCACF
Sedimentation	N. Fork, Mouth to Middle Fork
Sedimentation	S. Fork, Mouth to South Catherine Ditch Diversion

Stream shade and bank stability are two indicators of riparian health that are deficient in Catherine Creek and are particularly acute below the town of Union (GRMWP 1994). Below Union, Catherine Creek has been severely altered and mostly functions only seasonally as salmonid habitat due to channel modifications and severe flow depletion. By early summer, passage conditions are poor for adult salmon and downstream migrant juveniles face unscreened or poorly screened diversions. Juvenile fish may overwinter within these reaches, but habitat has been much reduced by channelization. The lower reaches are unsuitable for juvenile salmon during summer due to high water temperatures. General issues and concerns with respect to water quality are listed by reach in Table 4.

Table 4. Water quality issues in Catherine Creek by reach (GRMWP 1994).

Reach	Boundary	Issues
1 and 2	Mouth to Union	Substandard riparian conditions Low summer flows High summer temperatures Poor water quality – limited dilution flows Streambank erosion
3 and 4	Union to State Park	Low summer flows High water temperatures Locally substandard riparian conditions Streambank erosion
5 through 7	State Park to N and S Forks	Locally substandard riparian conditions Fine sediment
	North and South Forks	Fine sediment Streambank erosion Locally substandard riparian conditions

The FCRPS BiOp (NOAA Fisheries 2008) identified the major factors that have limited the functional use of tributary habitat by Snake River spring-summer Chinook salmon, which includes headwater tributaries of the Grande Ronde:

- Physical passage barriers (culverts; push-up dams; low flows)
- Reduced tributary streamflow, which limits usable stream area and alters channel morphology by reducing the likelihood of scouring flows (water withdrawals)
- Altered tributary channel morphology (bank hardening for roads or other development and livestock on soft riparian soils and streambanks)
- Excess sediment in gravel (roads; mining; agricultural practices; livestock on soft riparian soils and streambanks, and recreation)
- Degraded tributary water quality including high summer temperatures and in some cases, chemical pollution from mining (water withdrawals; degraded riparian condition)

From this list, reduced flows, excess sediment, and high summer temperatures (among other water quality issues) are all factors that impact water quality conditions in Catherine Creek. These limiting factors were also identified in the *Grande Ronde Subbasin Plan* (Nowak 2004), which used the Ecosystem Diagnosis and Treatment (EDT) model to analyze habitat attributes within the Grande Ronde subbasin. The plan recognized four attributes as being the most limiting: sediment, temperature, flows, and channel condition (i.e., Key Habitat Quantity and Diversity). Although EDT identified other factors, these four were determined to be the most important to address, with all other limitations dependent upon these. The EDT model was also used to analyze factors limiting survival for each spring Chinook population (Watershed Professionals Network 2004). Table 5 shows limiting factors listed for Catherine Creek.

Table 5. EDT identified the highest priority Geographic Areas for restoration and key factors limiting survival for each Grande Ronde subbasin spring Chinook population (Watershed Professionals Network 2004).

Geographic Area	Key Limiting Factors
Mid Catherine Creek	Habitat Diversity, Key Habitat Quantity, Temperature
South Fork Catherine Creek	Sediment
North Fork Catherine Creek	Habitat Diversity, Key Habitat Quantity, Sediment

Existing water quality data is discussed by parameter and by reach. Most of the data comes from completed activities; however, data collection is still ongoing in some cases. The Columbia River Inter-Tribal Fish Commission (CRITFC) has begun monitoring recovery trends in key spring Chinook habitat including Catherine Creek (CRITFC 2009; McCullough et al. 2011) and results of some of their studies are included here. The monitoring project is proposed for 10 years and therefore, will continue to provide water quality data for Catherine Creek. The Grande Ronde Model Watershed Program (GRMWP) will be conducting a channel reconstruction project just below Union around RM 37near the break between reaches 2 and 3 (Kuchenbecker 2011). Water quality monitoring data will likely be collected in association with the project.

5.1 Temperature

Oregon's water temperature standards are determined based on the biological temperature limitations of sensitive indicator species by stream (ODEQ 2000). In Catherine Creek, a temperature standard of 64^{0}F was established for downstream reaches 1 through 3 using salmonid rearing requirements as criteria (Table 6). In the upper reaches 4 to 7, bull trout was the indicator species used to establish a temperature standard of 50^0 F (although literature always uses 64^0 as standard). A 7-day moving average of daily maximums (7-day statistic) was adopted as the measure for stream temperature.

Table 6. The 1998 Section 303(d) listed segments and applicable numeric temperature criterion for Catherine Creek. (ODEQ 2000)

Segment	Criterion
Mouth to CCACF	Rearing(7/1 – 9/30); 64ºF
CCACF to N.F./S.F. Catherine Cr.	Oregon Bull Trout; 50ºF
N. Fork, Mouth to Middle Fork	Oregon Bull Trout; 50ºF
S. Fork, Pole Cr. to S. Catherine Ditch Diversion	Oregon Bull Trout; 50ºF

Stream temperatures exceed State water quality standards in summer and early fall months from June through September (ODEQ 2000). High stream temperatures correlate with low flows caused by water withdrawals for irrigation during this time. High temperatures can impact anadromous fish survival during egg depositing, rearing, and early migration periods (Yanke et al. 2008). Temperatures that are too low can impact winter incubation (CRITFC 2009).

Water temperature was estimated to currently function at 20 percent, which is expected to increase to 30 percent function in 10 years (CRITFC 2009).

Two types of temperature data exist for the Grande Ronde River and tributaries: continuous measurements (i.e., temporal) and thermal imagery (i.e., spatial) (ODEQ 2000). A range of temperature data exists for Catherine Creek - mostly temporal - that covers various periods. Temporal data is presented by reach in the sections below. Spatial data – in the form of forward-looking infrared radiometer (FLIR) and thermal infrared (TIR) imagery – is discussed on a streamwide basis and also examined by reach.

FLIR longitudinal temperature profiles were collected by Watershed Sciences for ODEQ on Catherine Creek, North Fork Catherine Creek, and South Fork Catherine Creek between 1:38 PM and 2:57 PM on August 21, 1999 (ODEQ 2000; Watershed Sciences 2000). As would be expected, stream temperatures increased continuously downstream (Figure 1). Table 7 lists the average median temperature by reach. Temperatures by the number of miles and percentage of stream they occurred along 53.8 miles of Catherine Creek (from the confluence of the North and South Forks to the mouth at State Ditch) are shown in Table 8. Within the Catherine Creek system, 29 percent of temperatures were below the sub-lethal limit of 64°F (ODEQ 2000). These cold-water areas were exclusively in the North and South Forks and the uppermost 3.6 miles of Catherine Creek (reaches 6 and 7). Almost no cold-water "refugia" areas were observed in the 1999 FLIR temperature profiles for Catherine Creek. Thermal stratification was an intermittent process in the Grande Ronde River and several tributaries. In Catherine Creek, these conditions were due to the impounding of water by dams in the lower reaches.

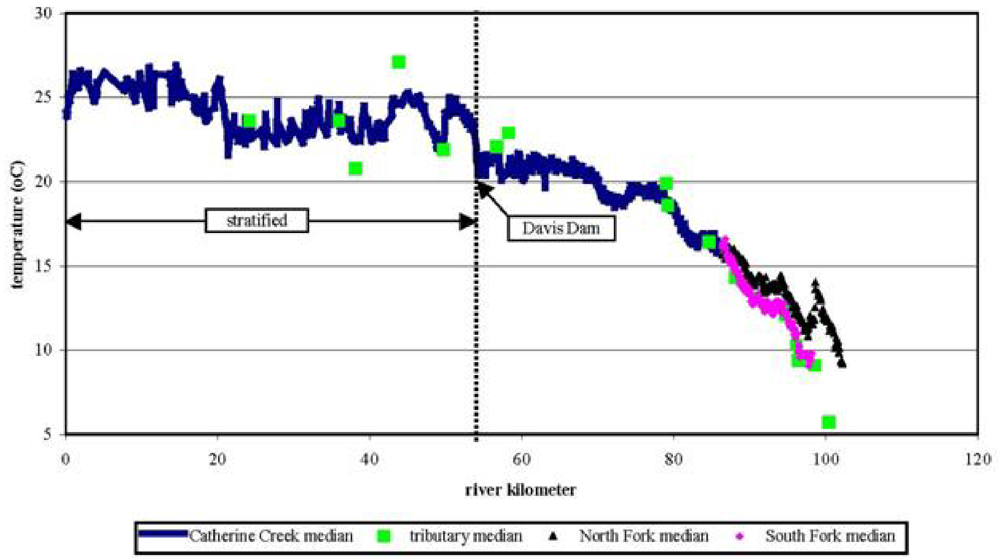


Figure 1. Longitudinal temperature profile of the Catherine Creek, North Fork, and South Fork Catherine Creek (Watershed Sciences 2000).

Table 7. Average median temperature °F by reach in Catherine Creek, August 1999.

Reach	1	2	3	4	5	6	7
Average median temperature °F	76.1	73.2	69.6	68.2	66.7	62.1	61.5

Table 8. Temperatures in Catherine Creek, August 1999 (ODEQ 2000).

Temperature (°F)	Distance (miles)	Percentage of total	Mode of thermal mortality
59.5 – 64.0º	3.6	6.7 percent	
64.0 - 68.5º	7.0	13.0 percent	Sub-lethal
68.5 – 73.0º	9.4	17.4 percent	Sub-lethal
Thermally stratified	33.8	62.9 percent	

Ten tributaries contributing flow to the main stem of Catherine Creek were detected (Watershed Sciences 2000). Four were contributing warmer flow, four were cooler, and two were the same as the main stem. Tributary temperatures did not appear to influence main stem temperatures, however (ODEQ 2000).

CRITFC contracted with Watershed Sciences to provide thermal infrared (TIR) imagery for Catherine Creek in August 2010 (Watershed Sciences 2010; McCullough et al. 2011). These data will be used to establish baseline conditions and direct future ground level monitoring by CRITFC. Approximately 31 miles were surveyed from the mouth at the

Old Grande Ronde River (at the boundary between reach 1 and 2) upstream to the confluence of North and South Fork Catherine Creek (upstream boundary of reach 7). Seven tributaries, one seep, five ponds/sloughs, and two canals were sampled in the imagery. Six active diversions and two dams were seen in the imagery. Bulk water temperatures ranged from 59.4°F near the North and South Fork confluence (RM 53.8) to 88.5°F at RM 29.7 along the low water reach below Ladd Creek in reach 2.

A thermal profile comparison between the 1999 ODEQ FLIR analysis and the 2010 CRITFC TIR analysis for Catherine Creek is shown in Figure 2 (Watershed Sciences 2010; McCullough et al. 2011). Air temperatures were 3 to 5°F warmer during the period of the 1999 flights.

The thermal profile comparison for Catherine Creek shows slightly higher water temperatures in 1999 upstream of the dams and significantly lower, more stable temperatures downstream of the dams (Figure 2). This suggests that flows were higher downstream of the dam in 1999. No discharge data was found near the survey for the 1999 flight; however, the downstream flow gage at Troy, Oregon showed higher flow rates in 1999. It is unclear how well the gage, located 35 miles downstream, reflects the upper Grande Ronde flow rates. With the more stable temperatures in 1999, the impact of Ladd Creek as a cooling point source is more obvious.

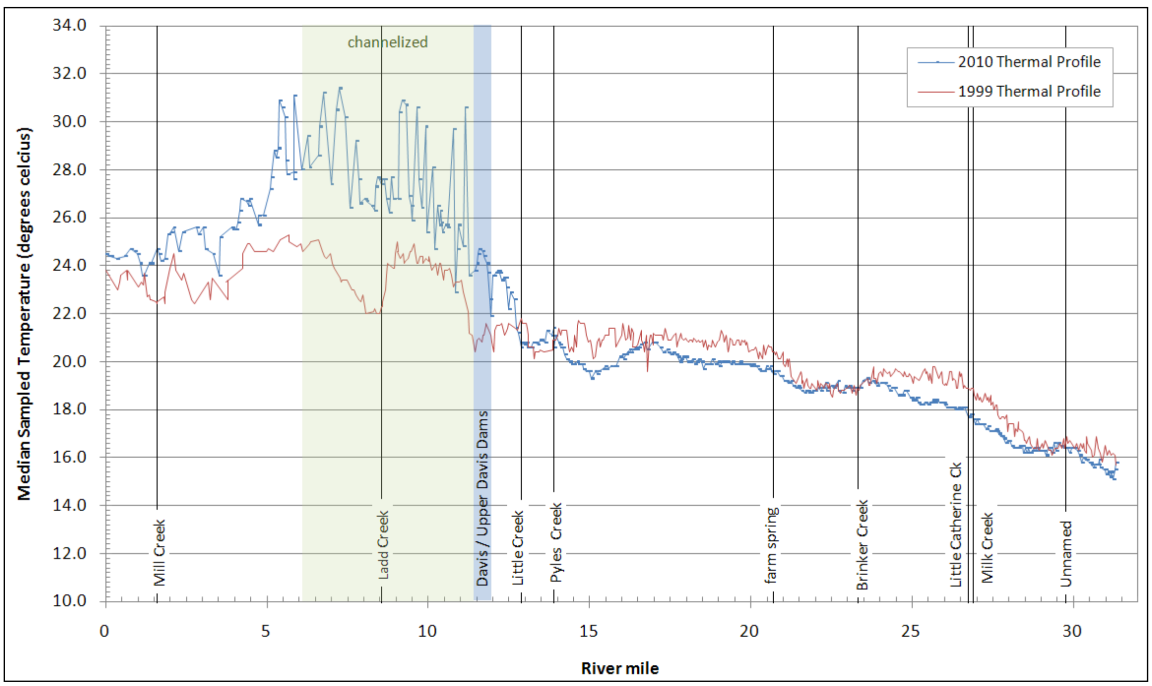


Figure 2. A comparison of the 1999 and 2010 thermal longitudinal profiles for Catherine Creek. Note that RM 0 in the graph is the confluence with Catherine Ck. and Old Grande Ronde River (Watershed Sciences 2010).

In association with the 2010 TIR survey, continuous stream temperature data were collected to provide a ground truth for temperature measurements (Justice, McCullough, and White 2011b; McCullough et al. 2011). Temperature data were collected at 27 sites in Catherine Creek and selected tributaries of Catherine Creek. Average summer stream temperatures (mean from 15 July to 15 September) ranged from 45.3 to 70.2°F with a mean of 57.2°F. Maximum weekly maximum temperatures (MWMT) ranged from 52.5°F in upper North Fork Catherine Creek to 80.6°F in lower Catherine Creek at the Booth Road Bridge in reach 1. Stream temperatures peaked between the last week of July and first week of August at most sites. Of all the sites sampled, only headwater tributaries including Middle Fork Catherine Creek, North Fork Catherine Creek, South Fork Catherine Creek, and upper Milk Creek met the ODEQ water temperature standard of 64.0°F MWMT (ODEQ 2000). The number of days that maximum temperatures exceeded 75.2°F in the Catherine Creek basin ranged from 0 to 29 (mean = 2).

Reclamation funded more recent FLIR flights on Catherine Creek in March 2011. These data were not available at the time of this report documentation. Reclamation also measured temperatures along Catherine Creek in summer 2010 (Didricksen 2011). See the Groundwater section of this report for thermal profiling of the temperature data collected.

5.1.1 Reach 1

In 1997, stream temperature data was collected by the Union Soil and Water Conservation District (USWCD) at six sites on Catherine Creek from June 1 to September 30 (Ballard 1999). The site in reach 1 at approximately RM 21.5 shown in Figure 3 (i.e., Highway 237) exceeded the ODEQ standard of 64.0^{0}F in the beginning of August. Temperatures at this site were only recorded for August and September of that year.

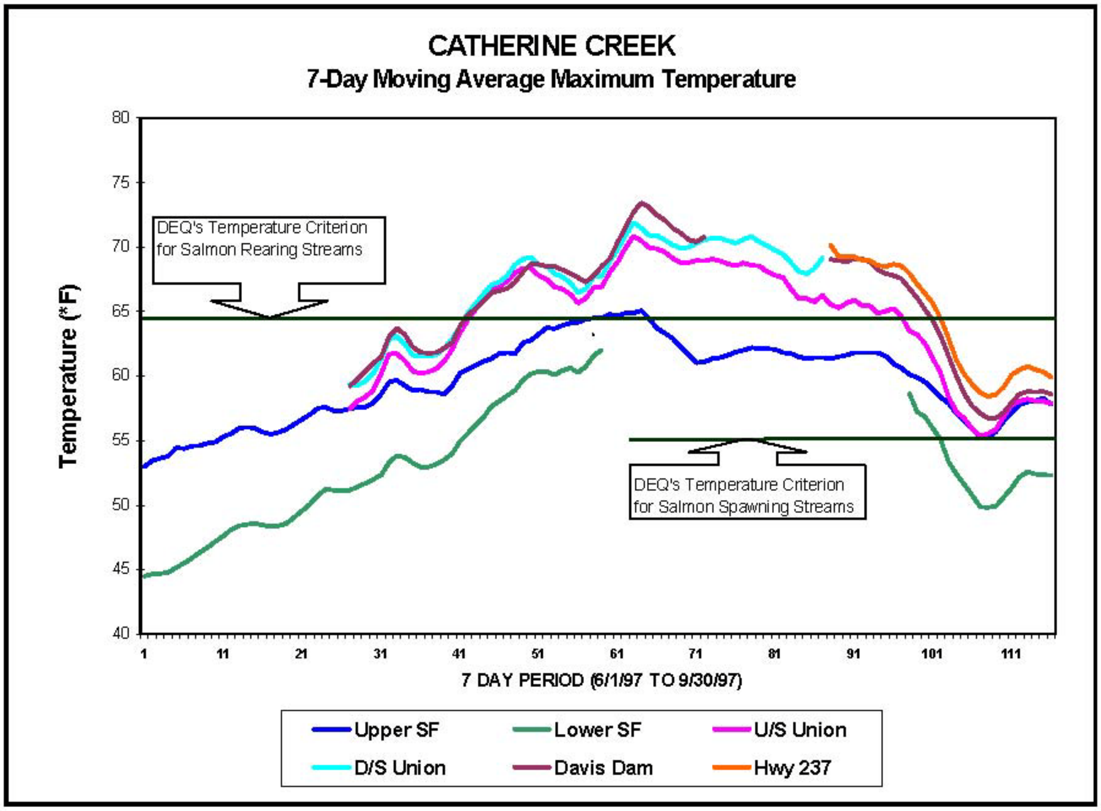


Figure 3. Stream temperatures from six sites in Catherine Creek, June to September 1997 (Ballard 1999).

USWCD has conducted monitoring on Catherine Creek to assess conservation/restoration project effectiveness as a requirement for OWEB grant agreements (USWCD nd; Miles nd). Temperature data were collected within reach 1 in 2000, when onset temperature loggers were deployed at three sites: upstream of Union at RM 43 (reach 4), downstream of Union at RM 38 (reach 3), and under the Hwy. 237 bridge at RM 21 (reach 1). Sites were chosen to provide representative data on long-term stream temperature patterns in relation to land uses (Miles nd). In reach 1, RM 21 falls within agricultural land uses.

Seven-day moving averages of daily maximums were calculated and plotted in Figure 4. Concerning the monitoring point located within reach 1, stream temperature exceeded the ODEQ basic absolute criteria (7-Day Statistic ≤ □64°F) in 2000 at RM 21 for all of August into the end of September.

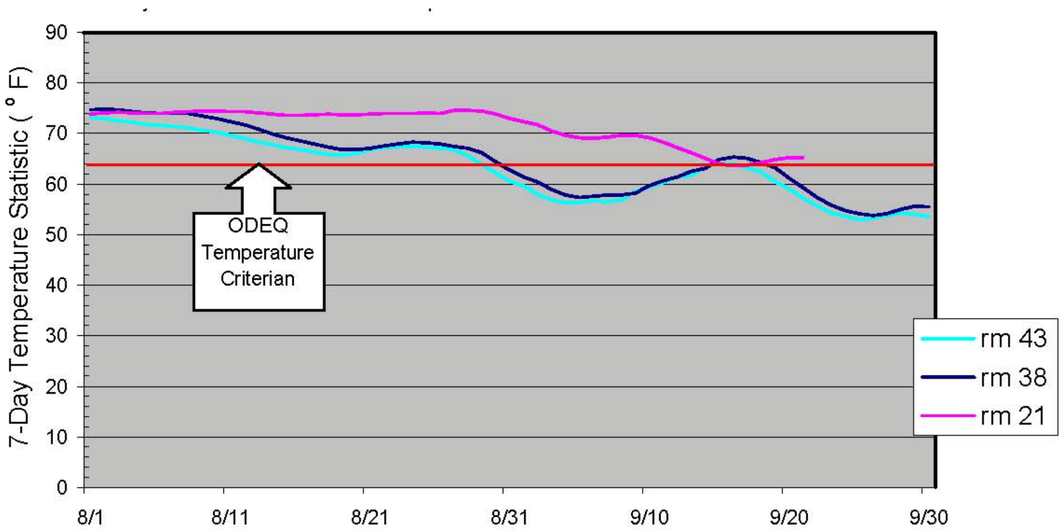


Figure 4. Catherine Creek 2000, 7-day moving average of daily maximum stream temperature (USWCD nd).

Based on 1999 FLIR data, the average median temperature within reach 1 was 76.1°F Table 6). Surface water temperatures below Davis Dam always exceeded the maximums recorded above the dam, reaching a maximum of 80.4^{0}F at RM 9.0 (Figure 1) (Watershed Sciences 2000). Below Davis Dam (reaches 1 and 2), thermal stratification of the water column was a common feature due to low, stagnant streamflows. Thermal stratification was identified because FLIR temperature increases downstream of Davis Dam did not match temperatures measured by continuous monitors at the bottom of the water column. Therefore, caution should be used when interpreting FLIR water temperature data in reaches 1 and 2 because it likely does not reflect water column temperatures below the stratified surface layer (ODEQ 2000). At the mouth of Catherine Creek, the deviation from Grande Ronde temperature was -1.4^{0}F. Figure 5 shows the difference in the Catherine Creek tributary temperatures where it joins with the State Ditch and Old Grande Ronde as captured with FLIR photography.

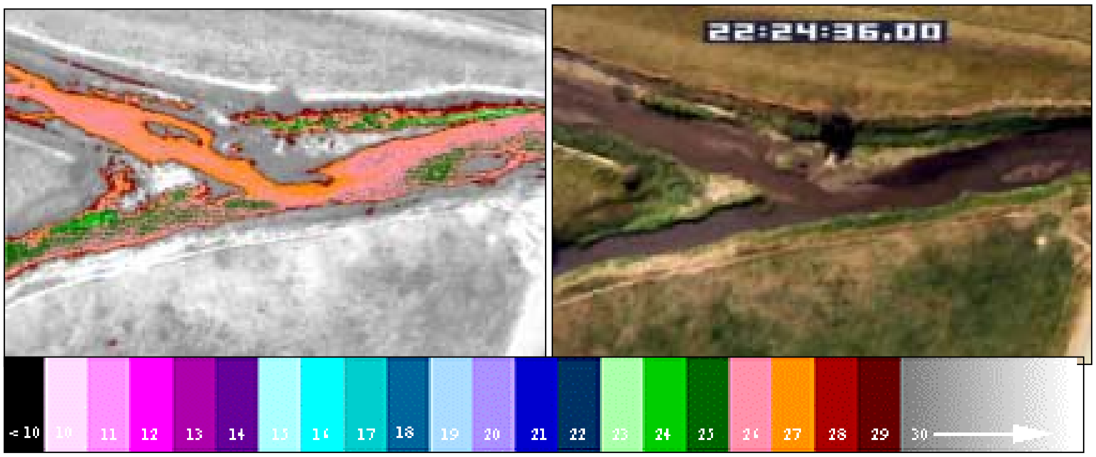


Figure 5. Downstream end of the State Ditch at confluence with old Grande Ronde River channel. The state ditch is flowing in diagonally from the top left corner while Catherine Creek is flowing in from the bottom left corner. Alicel Road is just visible in the bottom right of the image (August 22, 1999 at 3:24 pm) (Watershed Sciences 2000).

In association with the 2010 TIR survey, continuous stream temperature data were collected at 27 sites in Catherine Creek and selected tributaries to provide a ground truth for temperature measurements (Justice, McCullough, and White 2011b; McCullough et al. 2011), although reach 1 was not actually surveyed for TIR data. A summary of stream temperatures collected during continuous monitoring at the Booth Road bridge site in reach 1 is shown in Table 9. A MWMT of 80.1°F exceeded the ODEQ temperature standard of 64.0°F. The warmest temperatures observed from the 27 monitoring sites were at the Booth Road Bridge. This site also had the highest cumulative days exceeding 75.2°F of all sites monitored.

Table 9. Summary of stream temperatures °F in reach 1 of Catherine Creek during the summer of 2010 (July 15 through September 15) (Justice, McCullough, and White 2011b).

		Temperature °F (°C)					Consecutive Days Daily Max Exceeded[6]			
Approximate RM	**Site Description**	**Avg[1]**	**Max[2]**	**Min[3]**	**MWAT[4]**	**MWMT[5]**	**60.8°F**	**64.4°F**	**68°F**	**75.2°F**
16.0	Booth Rd bridge	70.2	81.1	59.4	75.9	80.1	67	59	48	29

[1] average daily temperature; [2] the highest instantaneous temperature recorded; [3]the lowest instantaneous temperature recorded; [4]maximum weekly average temperature; [5]maximum weekly maximum temperature; [6]the greatest consecutive number of days that the daily maximum temperature exceeded thresholds of 60.8, 64.4, 68 and 75.2°F

5.1.2 Reach 2

Monitoring data from ODEQ's web database (ODEQ 2007) provided temperature data collected from various times for Catherine Creek (Table 10 and Table 11). Typically, anywhere from one to five temperature measurements were taken per month. Less often, data were collected at a site continuously over 1 to 3 days. Therefore, values shown in the table may be an average of a few to numerous temperatures collected. From 1961 to 1968, samples were collected every year at the confluence of Catherine Creek and Grande Ronde River, but during various months in each year. As is still the case, temperatures consistently exceeded 64.0°F (the current standard) in July and August. More recent data collected from June to October in 1991 to 1993 at the Grande Ronde confluence and upstream in reach 2 also showed that standards were violated in July, August, and sometimes in September.

Table 10. ODEQ temperature data at the confluence of Catherine Creek and old Grande Ronde River, which is located at the break between reaches 1 and 2.

Year	Avg. Temperature F◦ by month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1961						75.2	77.0					
1962							75.2 (24)			48.2		
1963	35.6			42.8			69.8					
1964	33.8					51.8		68.0			46.4	
1965			44.6		59.0			68.0				
1966			39.2						64.4			
1967		32.0						71.6				32.0
1968				44.6				79.7				
1991							72.5		68.0			

Table 11. ODEQ temperature data in reach 2.

Station Location	Year	Avg. Temperature F◦ by month				
		Jun	Jul	Aug	Sep	Oct
Gekeler Rd	1991	59.0				
Godley Rd	1991		72.9		68.5	
	1992				55.9	
Wilkerson Ln	1991	56.3	71.6		75.7	
	1992				56.3	
Hwy 203 & Hawkins	1991		69.8		38.9	
	1992				54.5	
	1993				65.8	
Miller Rd	1991		71.2		63.3	
	1992				58.1	
	1993			68.0	61.3	50.4

In 1997, stream temperature data was collected by the USWCD at six sites on Catherine Creek from June 1 to September 30 (Ballard 1999). The site in reach 2 at Davis Dam shown in Figure 3, exceeded the ODEQ standard of 64.0^{0}F from approximately mid-July to mid-September.

During the summer of 1999, ODEQ deployed a Vemco thermistor at Godley Lane on Catherine Creek (ODEQ 2000). The calculated 7-day temperature statistics for this station using the 1999 data is presented in Table 12. Temperatures taken in August were well over the standard.

Table 12. Calculated 7-day temperature statistics for reach 2 using summer 1999 data (ODEQ 2000).

	Max temp		7-day statistic	
Temperature site	**Date**	**Degrees F**	**Date**	**Degrees F**
Catherine Cr. at Godley Rd (RM 26.5)	08/28/99	80.8	08/23/99	77.8

USWCD has conducted monitoring on Catherine Creek to assess conservation/restoration project effectiveness as a requirement for OWEB grant agreements (USWCD nd; Miles nd). Temperature data were collected within reach 2 in 2001, 2004, and 2006. To monitor stream temperature patterns in 2001 and 2004, the USWCD deployed temperature loggers at four sites: RM 43 (reach 4), RM 38 (reach 3), above the Mill Ck. confluence at RM 24 (reach 2), and the mouth at the confluence with the Grande Ronde River (boundary between reach 1 and 2). In 2006, temperature data were collected at three locations (RM 43, RM 38, and at the mouth). Sites were chosen to provide representative data on long-term stream temperature patterns in relation to land uses (Miles nd). The site at the mouth was selected to represent the lower boundary of intensive agricultural land uses in the Grande Ronde Valley. The site at RM 24 falls within agricultural land uses and was selected to isolate the stream temperature pattern of that Catherine Creek reach from the influence of Mill Creek, a major tributary.

Seven-day moving averages of daily maximums were calculated and plotted in Figures 6 through 8 (USWCD nd; Miles nd). Concerning the monitoring plot located at RM 24, stream temperature exceeded the ODEQ basic absolute criteria (7-Day Statistic ≤ □64°F) from the end of June through September in 2001 and from the end of June to the end of July in 2004 (the only timeframe that data exists for RM 24 in 2004). At the mouth (i.e., confluence with Old Grande Ronde), temperatures were in violation of ODEQ standards from the end of June through September in 2001 and 2004 and from July to early September in 2006.

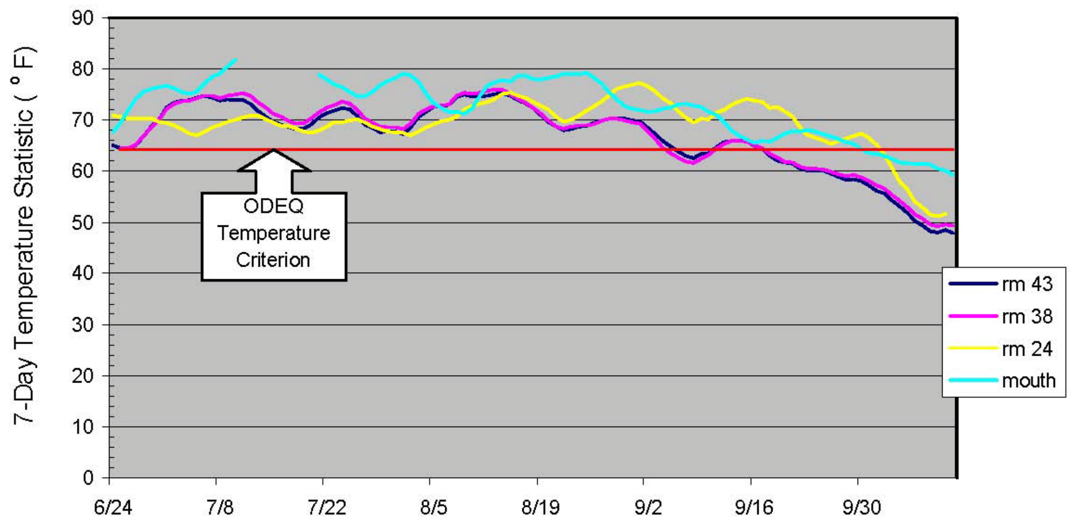


Figure 6. **Catherine Creek 2001, 7-day moving average of daily maximum stream temperature (USWCD nd).**

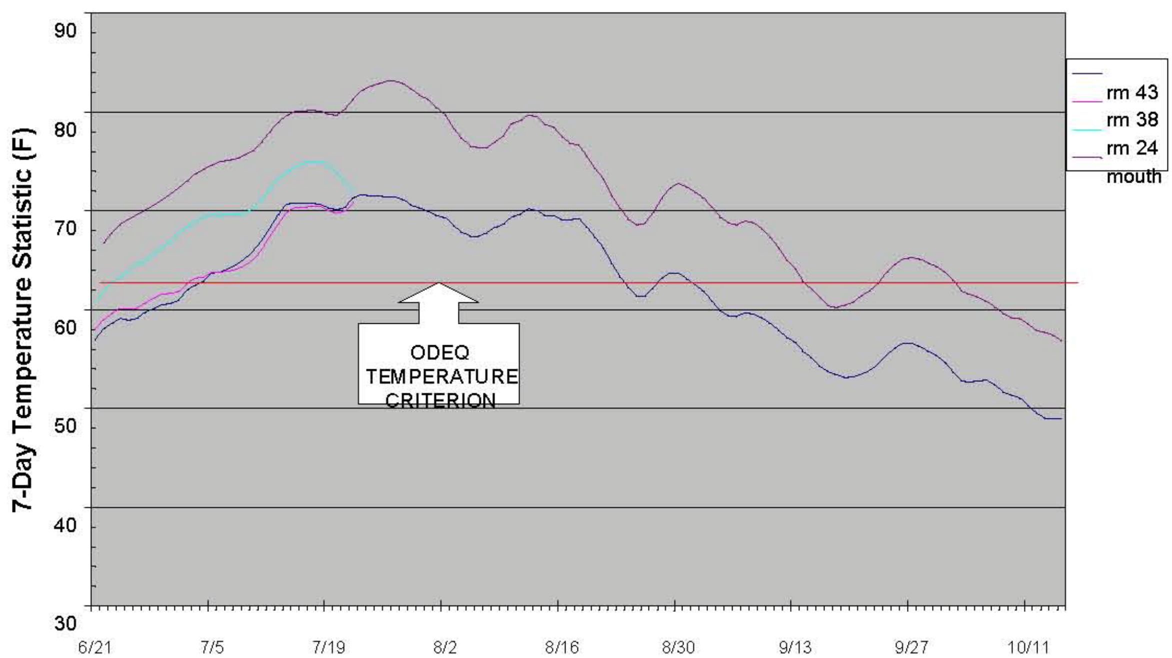


Figure 7. **Catherine Creek 2004 7-day moving average of daily maximum stream temperature. (Data screening protocols removed points from the final data sets of RM 38 and RM 24) (Miles nd; USWCD nd).**

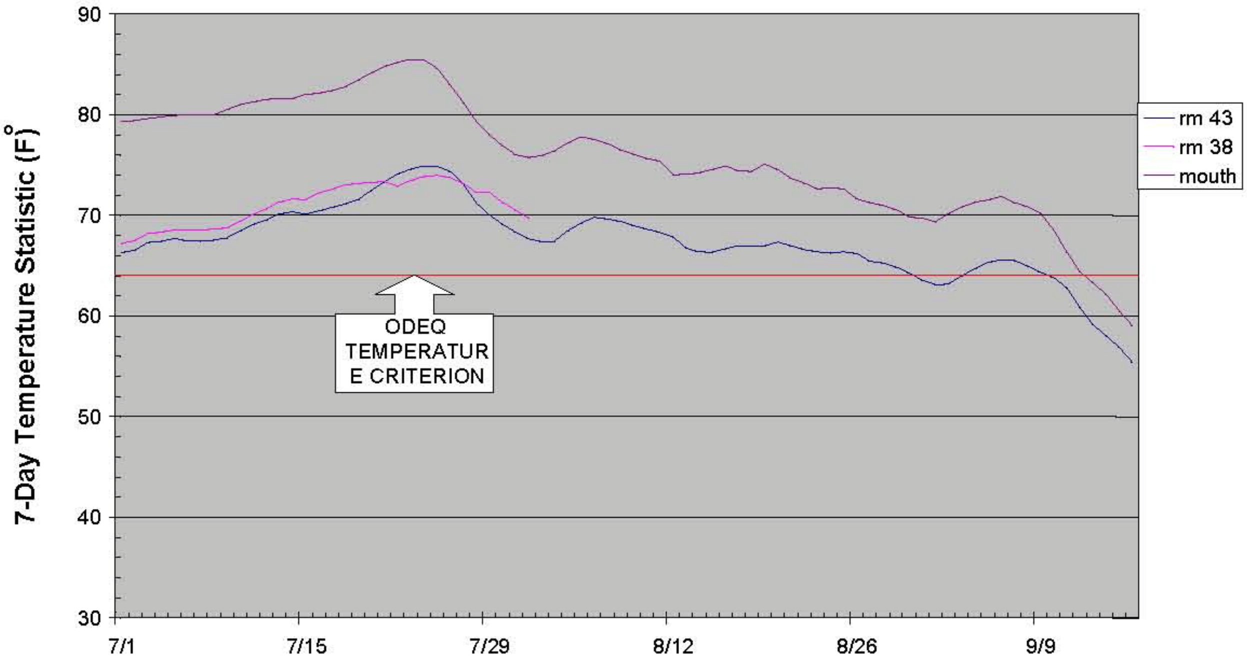


Figure 8. Catherine Creek 2006 7-day moving average of daily maximum stream temperature. (Data screening protocols removed points from the final data sets of RM 38) (Miles nd; USWCD nd).

The 1999 FLIR data indicated that the average median temperature in reach 2 was 73.2^{0}F (Table 7). Surface water temperatures below Davis Dam (which is located in the upper section of reach 2 at RM 33.8) always exceeded the maximums recorded above the dam (Figure 1) (Watershed Sciences 2000). Below Davis Dam (reaches 1 and 2), thermal stratification of the water column was a common feature due to low, stagnant streamflows. Thermal stratification was identified because FLIR temperature increases downstream of Davis Dam did not match temperatures measured by continuous monitors at the bottom of the water column. Therefore, caution should be used when interpreting FLIR water temperature data in reaches 1 and 2 because it likely does not reflect water column temperatures below the stratified surface layer (ODEQ 2000). From RM 41.6 (reach 4) to Davis Dam in reach 2, stream temperatures were relatively constant, fluctuating between 67.3 and 70.9^{0}F (Watershed Sciences 2000).

The lower boundary of the 2010 TIR data was the confluence with Old Grande Ronde River where reach 2 begins. Data indicated that as the stream gradient flattened downstream of RM 37.6 in the lower portion of reach 3, temperatures began to increase (Figure 2) (Watershed Sciences 2010; McCullough et al. 2011). A short stretch of cooling was seen downstream of Pyles Creek (RM 36.4), though it appeared to be contributing warmer surface water (72.7°F). A significant point source warming (75.7°F) was seen at the confluence with Little Creek at RM 35.4.

When Catherine Creek reaches Upper Davis Dam (RM 34.5) and Davis Dam (RM 33.9), a significant amount of flow is diverted out of the main channel. The low flows seen below the dams resulted in highly variable temperatures and potentially stratified water conditions (Watershed Sciences 2010; McCullough et al. 2011). The river is also highly channelized for 4.8 miles below the dam. The increase in the warming rate downstream of the Davis Dams indicates that these diversions do have an impact on the temperature profile of the stream. The Ladd Creek confluence appeared to have a significant impact on bulk water temperatures, though it was not contributing enough surface water for accurate sampling.

Near RM 29.1, the river resumes a more natural meandering flow, and water levels begin to rebound below RM 27.9. In this more natural flow regime, a 6.4°C temperature decrease is seen in the lower 5 miles of reach 2 (Figure 9).

5.1.3 Reach 3

At the time TMDLs were developed for the Upper Grande Ronde Basin, the Union Waste Water Treatment Plant (WWTP) in the town of Union was identified by ODEQ as an NPDES permitted facility that discharged surface water during critical summertime temperature period (ODEQ 2000). System potential temperatures and waste load allocations were derived by ODEQ for all point sources. At the time the loading capacities were determined, no data existed for August discharge temperatures at the Union WWTP. A new plant was built in 2001, when the town of Union removed its wastewater discharge during low flows (Ramondo 2011). The current discharge schedule is from October 1 to approximately June 1 to June 15. Certain specifications must be met, however, in order for the plant to discharge effluent: 1) Catherine Creek flows must be at least 17 cubic feet per second (cfs); 2) stream temperatures cannot exceed 57.2^{0}F; and 3) effluent temperatures must be below 55.3^{0}F. These specifications are not always met during the allowable time frame. For example, in 2010 the creek temperatures and flows did not meet criteria required for the plant to discharge into the creek until November (Ramondo 2011). Union WWTP monitors daily stream temperature about 0.5 miles above the plant.

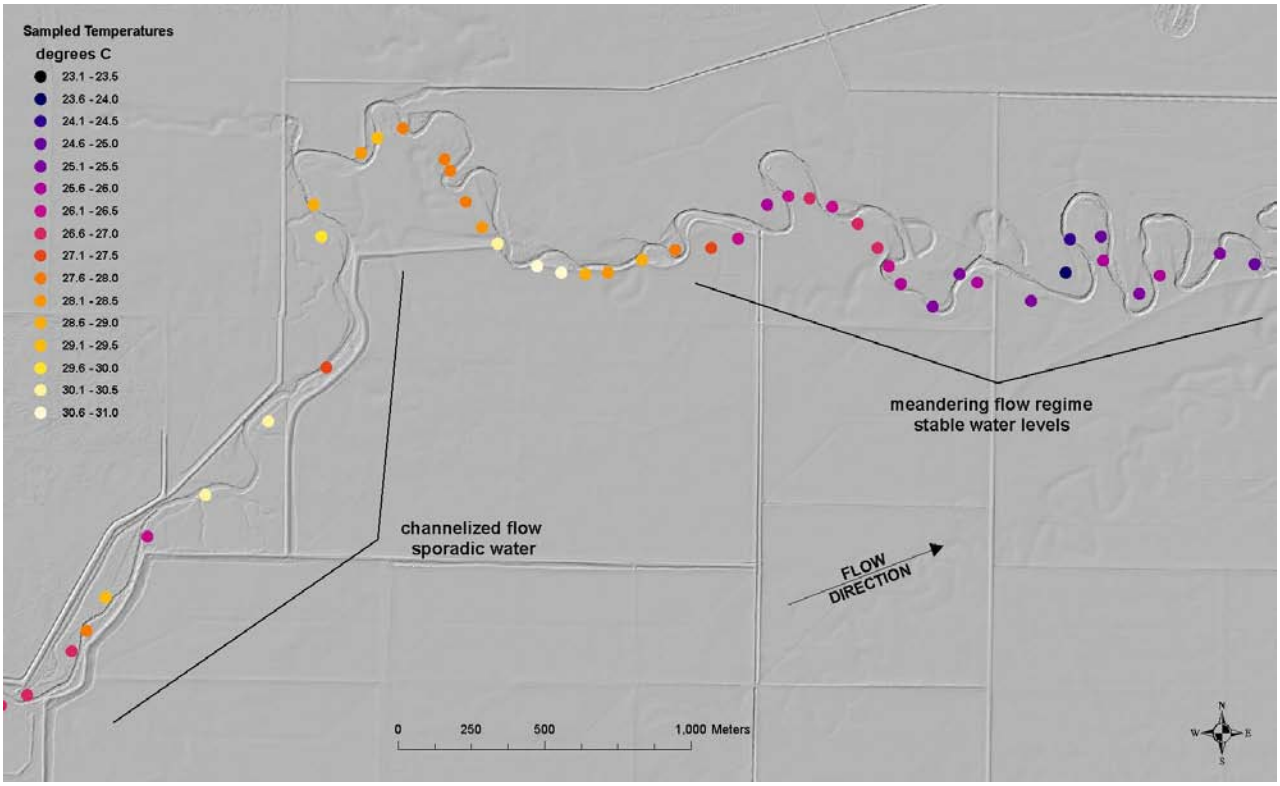


Figure 9. LiDAR bare earth hillshade that shows the transition between the confined, channelized river and the sinuous meandering channel near RM 29.1. Along this portion of Catherine Creek, water levels begin to rebound and a 6.4°C temperature decrease is seen in the lower 5 miles of reach 2 as the river returns to a more natural flow regime. The point color ramp is exaggerated for this image (Watershed Sciences 2010).

Temperature data from ODEQ's web database (ODEQ 2007) collected within reach 3 of Catherine Creek are shown in Table 13. Temperature was measured at some time between June and October from 1991 to 1993, with the most consistent data from the month of September. Three of the collection sites were located directly downstream of the WWTP and two were located upstream of the plant. Unfortunately, there is not enough data to determine if the WWTP was influencing stream temperatures during critical periods of low flow and high temperatures. In August, all temperatures exceeded the ODEQ standard of 64.0^{0}F.

Table 13. ODEQ temperature data in reach 3.

Station Location	Year	Avg. Temperature F° by month				
		Jun	Jul	Aug	Sep	Oct
At Union WWTP outfall	1991	64.4	63.1		63.5	
	1992				60.4	
	1993				60.8	
100 feet downstream of Union WWTP	1993				61.3	
0.25 miles downstream of Union WWTP	1991					50.0
	1993				63.9	50.4
0.5 miles downstream of Union WWTP	1993			71.2		
5th St in Union	1993				60.4	50.9
Highway 203 (E of Union)	1991	53.6	72.9		64.9	
	1992			64.4	54.9	
	1993			70.7	59.0	

In 1997, stream temperature data was collected by the USWCD at six sites on Catherine Creek from June 1 to September 30 (Ballard 1999). Results from two sites presumed to be in reach 3 – upstream and downstream of Union - are shown in Figure 3. Temperatures exceeded the ODEQ standard of 64.0^{0}F from approximately mid July to early September, although there is not a complete record for the upstream site.

Temperature data were collected by USWCD downstream of Union at RM 38 in reach 3 in 2000, 2001, 2004, and 2006 (USWCD nd; Miles nd). Sites were chosen to provide representative data on long-term stream temperature patterns in relation to land uses (Miles nd). The site at RM 38 was selected to represent a transition between urban land uses upstream and predominantly agricultural uses downstream. It was also important that this site be near the location of the OWRD gauging station so that data could be correlated to flow rate and total discharge.

Seven-day moving averages of daily maximums were calculated and plotted in Figures 4, 6, 7, and 8. With regards to the monitoring plot located at RM 38 within reach 3, stream temperature exceeded the ODEQ basic absolute criteria (7-Day Statistic ≤64^{0}F) through August and a few days in mid-September in 2000 and 2001 and in July in 2004 and 2006 (the only timeframe that temperature data exists for RM 38 in 2004 and 2006).

Continuous and FLIR temperatures collected in August of 1999 correlated well upstream of Davis Dam (reaches 3 to7) (ODEQ 2000). These data indicated that from RM 41.6 (reach 4) to Davis Dam RM 33.8 (reach 2), which encompasses reach 3, stream temperatures were relatively constant, fluctuating between 67.3 and 70.9^{0}F (Figure 1)

(Watershed Sciences 2000). The average median temperature in reach 3 was 69.6^{0}F (Table 6).

Temperature data collected in the August 2010 TIR surveys showed a gradual increase from the mouth of the North and South Forks (RM 53.8) downstream to RM 39.4 (reach 3) from 59.4°F to 69.4°F (Figure 2) (Watershed Sciences 2010; McCullough et al. 2010). At RM 38.8 in reach 3, bulk water temperatures decreased 2.7°F from 69.4°F to 66.7°F over 1.88 miles. It was unclear what causes this decrease in temperatures as the stream flows through Union, Oregon. No significant inflows or outflows, no changes in stream gradient, morphology or vegetation type were identified along this reach. The diversion at RM 39.9 did not appear to have a quantifiable effect on temperatures in Catherine Creek.

In association with the 2010 TIR survey, continuous stream temperature data were collected at 27 sites in Catherine Creek and selected Catherine Creek tributaries to provide a ground truth for temperature measurements (Justice, McCullough, and White 2011b; McCullough et al. 2011). A summary of stream temperatures collected during the 2010 continuous monitoring at a site east of Union in reach 3 is shown in Table 14. A MWMT of 71.2°F exceeded the ODEQ temperature standard of 64°F. The daily average, maximum, and minimum stream temperatures at this site are graphed in Figure 10.

Table 14. Summary of stream temperatures in reach 3

		Temperature °F					Consecutive Days Daily Max Exceeded[6]			
Approx RM	Site Description	Avg[1]	Max[2]	Min[3]	MWAT[4]	MWMT[5]	60.8°F	64.4°F	68°F	75.2°F
40.5	East of Union	60.4	72.7	47.3	65.3	71.2	48	43	12	0

[1] average daily temperature;
[2] the highest instantaneous temperature recorded;
[3]the lowest instantaneous temperature recorded;
[4]maximum weekly average temperature;
[5]maximum weekly maximum temperature;
[6]the greatest consecutive number of days that the daily maximum temperature exceeded thresholds of 60.8, 64.4,68, 75.2°F

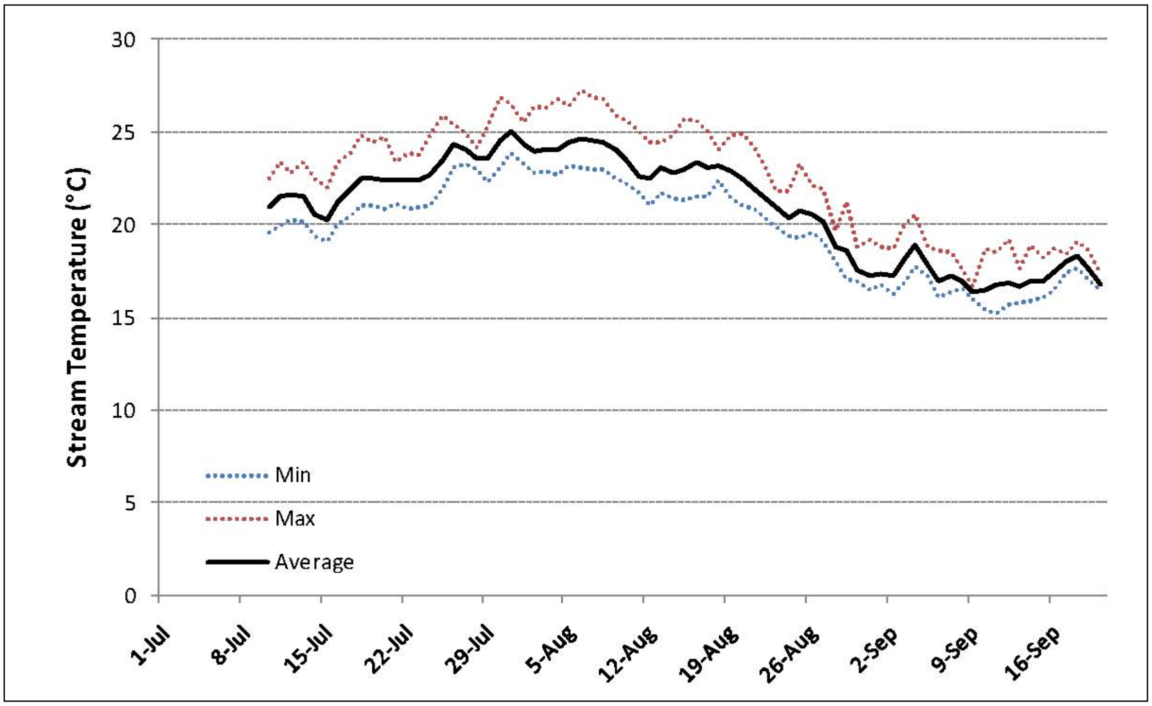


Figure 10. Daily average, minimum, and maximum stream temperatures (°C) in Catherine Creek at the east end of Union in reach 3 from 10 July to 20 September, 2010 (Justice, McCullough, and White 2011b).

5.1.4 **Reach 4**

Temperature data from ODEQ's web database (ODEQ 2007) collected within reach 4 of Catherine Creek is shown in Table 15. Temperature was measured in August and September 1992. The ODEQ temperature standard of 64.0^0F was slightly exceeded in August.

Table 15. ODEQ temperature data in reach 4.

Station Location	Year	Avg. Temperature ^{0}F by month	
		Aug	Sept
RM 41.5 (E Of Union)	1992	64.4	62.6

ODEQ deployed a Vemco thermistors upstream of Union in reach 4 during the summer of 1999 (ODEQ 2000). Calculated 7-day temperature statistics for these stations using the 1999 data is presented in Table 16. Temperatures in August were well above the ODEQ standard of 64.0^0F.

Table 16. Calculated 7-day temperature statistics for reach 4 using summer 1999 data (ODEQ 2000).

	Max temp		7-day statistic	
Temperature site	**Date**	**Degrees F**	**Date**	**Degrees F**
Catherine Cr. upstream Union	08/06/99	75.2	07/31/99	71.7

Temperature data were collected by USWCD upstream of Union at RM 43 in reach 4 in 2000, 2001, 2004, and 2006 (USWCD nd; Miles nd). Sites were chosen to provide representative data on long-term stream temperature patterns in relation to land uses (Miles nd). The site at RM 43 was selected to represent a transition between forestry and grazing land uses upstream and urban land uses downstream. Seven-day moving averages of daily maximums were calculated and plotted in Figures 4, 6, 7, and 8. With regards to the monitoring plot located at RM 43 within reach 4, stream temperature exceeded the ODEQ basic absolute criteria (7-Day Statistic 64^{0}F) through August in 2000 (no data for July), in July and August in 2001, from the beginning of July until the end of August in 2004, and July through September in 2006.

Yanke et al. (2008) conducted fish studies in Catherine Creek below spawning and upper rearing areas upstream of the town of Union where traps were place and temperatures measured. A cohort of juvenile spring Chinook salmon were examined from brood year (i.e., the year eggs were fertilized) 2006. Temperature statistics were correlated with Chinook life history phases for the period between 2006 and 2008. Daily mean water temperature typically fell within DEQ standards while the 2006 brood year (BY) of spring Chinook salmon occupied the Grande Ronde River subbasin (1 August 2006 to 30 June 2008), with the daily mean water temperatures exceeding the standard of 64.0°F for 44 of 650 days in Catherine Creek. Daily mean water temperatures in excess of 64.0°F occurred while eggs may have been being deposited in redds (August 2006), intermittently during parr rearing stages (June to August 2007), and for several days during early dispersal (August to September 2007). Temperatures preferred by juvenile Chinook salmon (50-60.1°F) occurred for 16 percent of the hours logged for Catherine Creek. The temperature considered lethal to Chinook salmon (77°F) was encountered less than 2 of 662 days.

The moving mean of maximum daily water temperature showed that temperatures below the limit for healthy growth (39.9 °F) occurred more often than temperature above the limit for healthy growth 66.0°F in Catherine Creek. Moving mean temperatures exceeded 66.0°F 95 days while this cohort was in-basin. During this period, a total of 26 days (4 August to 7 September 2006) occurred during parental spawning and 69 days (30 June to 6 September 2007) occurred while the majority of young of year were rearing and dispersing. Moving mean temperatures were less than 39.9°F 64 days (12 November

2006 to 4 March 2007) during incubation and emergence, and 97 days (20 November 2007 to 24 February 2008) during dispersal and spring migration.

The 1999 continuous and FLIR temperatures correlated well upstream of Davis Dam in reaches 3 through 7 (ODEQ 2000). Within reach 4, stream temperatures increased slowly downstream from RM 44.7 to about RM 41.6 where they reached a local maximum of 69.8^{0}F (Figure 1) (Watershed Sciences 2000). From that point to Davis Dam (RM 33.8 in reach 2, stream temperatures were relatively constant, fluctuating between 67.3 and 70.9^{0}F). The average median temperature in reach 4 was 68.2^{0}F (Table 6).

The 2010 TIR temperatures showed a gradual increase from the North and South Forks downstream to RM 39.4 in reach 3 from 59.4°F to 69.4°F (Watershed Sciences 2010; McCullough et al. 2010). Localized cooling was seen at three different locations along Catherine Creek including the farm spring at RM 43.2 in reach 4. The spring did not have a visible surface water contribution to Catherine Creek, but subsurface interaction is suggested by the plateaus seen in the longitudinal profile (Figure 2). The diversions at RM 41.8 in reach 4 did not appear to have a quantifiable effect on temperature in Catherine Creek.

5.1.5 Reach 5

Continuous and FLIR temperatures collected in August 1999 correlated well upstream of Davis Dam from reaches 3 to 7, which encompasses reach 5 (ODEQ 2000). From the confluence with the North and South Forks in reach 7, Catherine Creek warms steadily in the downstream direction to Little Catherine Creek at RM 49 in reach 5 (Figure 1) (Watershed Sciences 2000). From RM 49 to 46.6 in reach 5, stream temperatures were relatively constant at just under 68.0^{0}F. At RM 46.6, stream temperatures were cooler over the next several kilometers for no apparent reason. The average median temperature in reach 5 was 66.7^{0}F (Table 6).

Temperature data from the 2010 TIR surveys showed a gradual increase from the Forks downstream to RM 39.4 in reach 3 from 59.4°F to 69.4°F (McCullough et al. 2010; Watershed Sciences 2010). Localized cooling was seen at Brinker Creek, which is located at approximately RM 45.8 where the break between reach 4 and 5 occurs. Brinker Creek did not have a visible surface water contribution to Catherine Creek, but subsurface interaction is suggested by the plateaus seen in the longitudinal profile (Figure 2). The slight inflection seen at the confluence of Little Catherine Creek between reaches 5 and 6 indicates a decrease in the rate of warming which also suggests groundwater interaction.

In association with the 2010 TIR survey, continuous stream temperature data were collected at 27 sites in Catherine Creek and selected Catherine Creek tributaries to provide a ground truth for temperature measurements (Justice, McCullough, and White 2011b; McCullough et al. 2011). A summary of stream temperatures collected during the 2010 continuous monitoring at the site on Hwy 203 in reach 5 is shown in Table 17. A MWMT of 69.6°F exceeded the ODEQ temperature standard of 64.0°F.

Table 17. Summary of stream temperatures °F in reach 5 of Catherine Creek during the summer of 2010 (July 15 through September 15) (Justice, McCullough, and White 2011b).

		Temperature °F					Consecutive Days Daily Max Exceeded[6]			
Approx RM	Site Description	Avg[1]	Max[2]	Min[3]	MWAT[4]	MWMT[5]	60.8°F	64.4°F	68°F	75.2°F
46.0	Hwy. 203	57.7	70.9	44.1	62.4	69.6	44	27	11	0

[1] average daily temperature;
[2] the highest instantaneous temperature recorded;
[3]the lowest instantaneous

5.1.6 Reach 6

Continuous and FLIR temperatures collected in August 1999 correlated well upstream of Davis Dam from reaches 3 to 7 which encompasses reach 6 (ODEQ 2000). From the confluence with the North and South Forks in reach 7, Catherine Creek warms steadily in the downstream direction to Little Catherine Creek at RM 49 in reach 5 (Figure 1) (Watershed Sciences 2000; ODEQ 2000). Further downstream, water temperatures continued to warm between Milk Creek confluence in reach 6 and upstream of Davis Dam (66.0°F to 69.6°F, respectively). The average median temperature in reach 6 was 62.1°F (Table 6).

The 2010 TIR temperatures showed a gradual increase from the North and South Forks downstream to RM 39.4 in reach 3 from 59.4°F to 69.4°F (Watershed Sciences 2010; McCullough et al. 2011). The slight inflection seen in the longitudinal profile (Figure 2) at the confluence of Milk Creek between reaches 6 and 7 indicates a decrease in the rate of warming, which suggests groundwater interaction.

In association with the 2010 TIR survey, continuous stream temperature data was collected at 27 sites in Catherine Creek and selected Catherine Creek tributaries to provide a ground truth for temperature measurements (Justice, McCullough, and White 2011b; McCullough et al. 2011). A summary of stream temperatures collected during continuous monitoring at two sites in reach 6 is shown in Table 18Table 18. Summary of stream temperatures ^{0}F in reach 6 of Catherine Creek during the summer of 2010 (July 15 through September 15) (Justice, McCullough, and White 2011b).

Table 18. Summary of stream temperatures ^{0}F in reach 6 of Catherine Creek during the summer of 2010 (July 15 through September 15) (Justice, McCullough, and White 2011b).

		Temperature °F					Consecutive Days Daily Max Exceeded[6]			
Approx RM	Site Description	Avg[1]	Max[2]	Min[3]	MWAT[4]	MWMT[5]	60.8°F	64.4°F	68°F	75.2°F
50.2	Above Little Ck.	56.1	68.5	43.0	60.4	67.1	43	13	2	0
50.5	Above Milk Ck	55.9	68.4	43.2	60.4	66.9	43	13	2	0

[1] average daily temperature;
[2] the highest instantaneous temperature recorded;
[3] the lowest instantaneous temperature recorded;
[4] maximum weekly average temperature;
[5] maximum weekly maximum temperature;
[6] the greatest consecutive number of days that the daily maximum temperature exceeded thresholds of 60.8, 64.4, 68, and 75.2^{0}F

The MWMTs of 67.1 and 66.9^{0}F exceeded the ODEQ temperature standard of 64.0^{0}F.

5.1.7 Reach 7

In 1997, stream temperature data was collected by the Union Soil and Water Conservation District (USWCD) at six sites on Catherine Creek from June 1 to September 30 (Ballard 1999). Results from two sites upstream of reach 7 in the upper and lower South Fork are shown in Figure 3. Temperatures generally remained below the ODEQ standard of 64.0^{0}F except for a few days in early August in the upper S. Fork, although there is not a complete record for the lower South Fork site.

ODEQ deployed two Vemco thermistors at the mouths of North and South Forks at the upper boundary of reach 7 of Catherine Creek during the summer of 1999 (ODEQ 2000). Calculated 7-day temperature statistics for these stations using 1999 data is presented in Table 18. Seven-day moving averages of daily maximums in August were below ODEQ standards at these sites.

Table 19. Calculated 7-day temperature statistics for reach 7 using summer 1999 data (ODEQ 2000).

	Max temp		7-day statistic	
Temperature site	Date	Degrees F	Date	Degrees F
North Fork Catherine Cr. at mouth	08/19/99	64.4	07/27/99	62.5
South Fork Catherine Cr. at mouth	08/04/99	64.4	07/27/99	62.0

Continuous and FLIR temperatures correlated well upstream of Davis Dam, from reaches 3 through 7 (ODEQ 2000). Based on FLIR data, the temperature below the Catherine Creek forks was 61^{o}F. Rapid stream heating was observed in Catherine Creek between the confluence of Scott Creek and Milk Creek in reach 7. Stream temperatures rose above 64^{o}F within this reach.

From the confluence with the North and South Forks in reach 7, Catherine Creek warms steadily in the downstream direction to Little Catherine Creek at RM 49 in reach 5 (Figure 1) (Watershed Sciences 2000). The average median temperature in reach 7 was 61.5^{0}F (Table 6).

The 2010 TIR temperature data showed a gradual increase from the mouth of the North and South Forks at the upper end of reach 7 downstream to RM 39.4 in reach 3 from 59.4°F to 69.4°F (Watershed Sciences 2010; McCullough et al. 2010). Localized cooling can be seen downstream of the unnamed stream at RM 52.3 in reach 7. The stream does not have a visible surface water contribution to Catherine Creek, but subsurface interaction is suggested by the plateaus seen in the longitudinal profile (Figure 2).

5.2 Sediment

For listing sedimentation standards, the PACFISH target of 20 percent streambed fines was utilized as an indicator of fine sediment impairment to salmonids (ODEQ 2000). Thus, the loading capacity for sedimentation is defined as 20 percent streambed area fines. Sediment levels in Catherine Creek violate 1998 ODEQ standards only within North and South Forks. However, inputs from these upper tributaries contribute to sedimentation in the lower reaches of Catherine Creek.

Roads, grazing, agricultural practices, and urban development are main sources of excessive fine sediment in the Grande Ronde River subbasin (USFWS 2002). Many farmers and ranchers have applied conservation practices to reduce the effects of erosion by water (NRCS 2005). As a result, erosion rates on croplands and pasturelands fell 24 percent, from 2.5 tons/acre/year to 1.9 tons/acre/year, from 1982 to 1997 in the Upper Grande Ronde. However, estimates indicate that 17,700 acres of agricultural lands still had water erosion rates above a sustainable level in 1997.

Sediment in the basin is currently estimated to operate at a percentage function of 30 percent, increasing to 40 percent in 10 years (CRITFC 2009). The estimated percentage function is essentially a current egg survival to emergence of 30 percent of potential due to fine sediment levels that is expected to improve to 40 percent of potential survival after a 10-year restoration program.

In the Upper Grande Ronde subbasin, high fine sediment distributions correlate strongly with non-woody riparian vegetation (i.e., annuals and perennials) (ODEQ 2000). Annual riparian vegetation types have median percent fine sediment distributions approaching 100 percent. Perennial riparian vegetation types have a median percent fine sediment level of 58 percent. Non-woody riparian vegetation communities correlate to fine sediment distributions that would prevent nearly all sac-fry emergence. As such, these survey reaches are degraded to a level that reduces salmonid reproductive fitness to near zero levels.

Woody riparian vegetation classifications correlate to lower fine sediment distributions (median values less than 20 percent fine sediment). Established mature deciduous/mixed/ conifer riparian vegetation correlate to the lowest median percent fine value (16 percent of the streambed substrate).

However, much of the woody riparian communities have high levels of fine sediments which suggests that sources of sediment beyond sources related to riparian vegetation are affecting the sediment distributions in the Grande Ronde River and tributaries.

Streambed substrate gravel occurrence is lowest (median gravel distribution of 21 percent) where riparian vegetation communities are annual and perennial plant species (ODEQ 2000). Woody riparian vegetation corresponds to higher gravel streambed substrate. Data show that established deciduous/mixed/conifer riparian vegetation types correlate with higher median gravel substrate (32 percent). In high gradient reaches of Catherine Creek, the dominant available substrate is gravel, while the substrate most commonly used by salmonids is cobble (Favrot et al. 2010). This indicates that the rate that coarser substrates are selected is higher than the rate that they are available. The predominance of gravel in the upper reaches could be related to geology. An outcrop of gravels is located about 11.5 miles south of Union in the upper watershed of Catherine Creek (Isaacson 2002). The average size of the gravels gets coarser upward, reaching cobble and boulder sizes near the top of the outcrop. Silt was the most available and the most utilized substrate by early migrants in the low gradient reaches (Favrot et al. 2010).

Bank stability problems on Catherine Creek were found to be common along both high- and low-gradient stream reaches, although were most extensive along unconstrained low-gradient reaches (Huntington 1994). On average, high gradient channels had high levels of sediment with mean cobble embeddedness of 48 percent and mean surface fines of 43 percent. Unconstrained low gradient reaches generally had moderate to high levels of sedimentation; mean surface fines were 18 percent. Constrained low gradient channels surveyed had moderate to extremely high levels of streambed sediment with mean surface fines of 51 percent. Huntington (1994) also developed reference conditions (RC) based on salmonid habitat requirements, which were used to compare existing habitat conditions. Habitat quality concerning sedimentation issues along streams surveyed in the Catherine Creek subbasin was frequently below RC levels. Bank stability was below RC levels along 85 percent of the streams surveyed. Levels of fine sediment in the streambed were too high to match RC criteria along 79 percent of stream miles surveyed.

Analysis of sediment size was conducted by CRITFC during the summer of 2010 at five sites in Catherine Creek (Justice, McCullough, and White 2011a; McCullough et al. 2011. Table 20 lists the sites and locations. Surface samples were collected at all sites. Subsurface samples were only collected at two sites in Catherine Creek because the other reaches did not contain suitable spawning gravels. Among the five surface samples in Catherine Creek, the mean percentage of surface fines less than 0.25 inches was 17.4 percent. The average size frequency distribution of streambed particles appeared to be bimodal, with a relatively small peak in particle frequencies occurring at 0.08 inches and a second larger peak occurring between 1.8 and 3.5 inches. Consistent with the surface sediment distributions, the frequency distributions of subsurface particles from 2 sites in Catherine Creek appeared to have a bimodal distribution with a smaller peak occurring around 0.08 inches, and a second larger peak occurring around 2.5 to 3.5 inches.

Table 20. Sediment size sampling sites on Catherine Creek, summer 2010.

Reach	Approximate river mile	Sample date	Sample type
3	40	9/16/2010	Surface, subsurface
6	50.7	7/21/2010	Surface, subsurface
Just upstream of 7 at the mouth of North Fork	-	7/29/2010	Surface
North Fork at confluence with Middle Fork	-	9/16/2010	Surface
South Fork	-	9/14/2010	Surface

Results of the sediment size analysis and soils and erosion hazard ratings are discussed by reach below.

5.2.1 Reaches 1 and 2

Soils are predominately silt loams and silty clay loams. Erosion hazard is slight (NRCS 2009).

5.2.2 Reach 3

Soils are composed of silt loams and silty clay loams. Erosion hazard is mostly slight, with some moderate ratings (NRCS 2009).

The average percentage of surface sediment particles finer than 0.08 inches and 0.25 inches from sampling conducted in summer 2010 are listed in Table 21 (Justice, McCullough, and White 2011a; McCullough et al. 2011). Of the sites sampled, reach 3 had some of the lowest percentages of fine sediment. The surface size sediment distribution for the sample site in reach 3 near Union is graphed in Figure 11. The bimodal distribution, with peaks around 0.08 inches and between 1.3 and 5.0 inches, is apparent in the graph. The percentage of fine sediment in subsurface bulk samples based on four particle sizes is listed in Table 22. The predicted egg to fry survival for reach 3 based on sediment size sampling was 64.4 percent for particle size < 0.03 and 0.27 inches and 76.4 percent for particle size < 0.25 inches (Table 23).

5.2.3 **Reach 4**

Soils are stony and cobbly silt loams (NRCS 2009). Erosion hazards are moderate to slight (NRCS 2009).

Table 21. Percentage of surface sediment particles finer than 0.08 inches and 0.25 inches measured at 5 sites in Catherine Creek during summer 2010 (Justice, McCullough, and White 2011a).

	Percent fines < 0.08 inches			Percent fines < 0.25 inches		
Reach	**Estimate**	**LCI**	**UCI**	**Estimate**	**LCI**	**UCI**
3	9.4	5.0	15.9	13.2	7.9	20.3
6	15.0	10.3	20.9	17.8	12.7	24.0
Mouth of N. Fork	22.9	16.5	30.4	28.6	21.6	36.4
North Fork	13.7	8.4	20.8	19.1	12.7	26.9
South Fork	3.6	1.0	9.0	8.6	4.1	15.4
Average	12.9	8.2	19.4	17.4	11.8	24.6
Min	3.6	1.0	9.0	8.6	4.1	15.4
Max	22.9	16.5	30.4	28.6	21.6	36.4

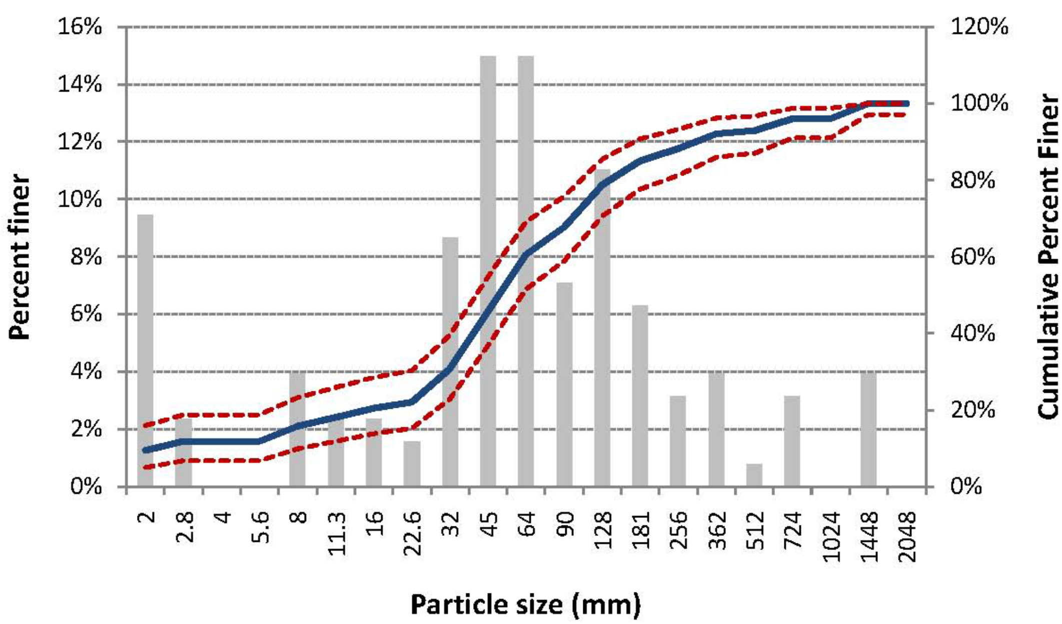


Figure 11. Surface sediment size distribution for Catherine Creek in reach 3 near Union during summer 2010. Dashed lines denote the 95 percent confidence interval for the cumulative distribution (Justice, McCullough, and White 2011a).

Table 22. Percentage of fine sediment in subsurface bulk samples measured in reach 3 of Catherine Creek during summer 2010. Calculations of percent finer are provided for four commonly used particle size criteria including 0.03, 0.13, 0.25, and 0.37 inches (Justice, McCullough, and White 2011a).

Particle size (inches)	Average percent finer	SD	LCI	UCI
< 0.03	8.4	2.6	6.0	10.8
< 0.13	23.4	4.8	18.9	27.9
< 0.25	33.7	6.3	27.8	39.6
< 0.27	42.8	7.7	35.7	49.9

Table 23. . Predicted egg-to- fry survival and associated 95 percent confidence intervals in reach 3 of Catherine Creek during summer 2010 (Justice, McCullough, and White 2011a).

percent fines < 0.03 and 0.27 inches[1]			percent fines < 0.25 inches[2]		
Survival estimate (percent)	LCI	UCI	Survival estimate (percent)	LCI	UCI
64.4	42.9	80.0	76.4	52.5	89.0

[1] Tappel and Bjornn 1983; [2] Irving and Bjornn 1984

5.2.4 Reaches 5 and 6

Soils are stony and cobbly silt loams on steeper slopes. Erosion hazards are mostly moderate, with some very severe (NRCS 2009).

The average percentage of surface sediment particles finer than 2mm and 6 mm from sampling conducted during summer 2010 in reach 6 is listed in Table 21 (Justice, McCullough, and White 2011a; McCullough et al. 2011). Of the sites sampled, reach 6 had the second highest percentages of fine sediment (Table 21). The percentage of fine sediment in subsurface bulk samples based on four particle sizes is listed in Table 24. Despite the relatively high percentages of fine sediment, the predicted egg to fry survival for reach 6 was 79.1 percent for particle size < 0.03 and 0.27 inches and 88.4 percent for particle size < 0.25 inches (Table 25).

Table 24. Percentage of fine sediment in subsurface bulk samples measured in reach 6 of Catherine Creek during summer 2010. Calculations of percent finer are provided for four commonly used particle size criteria including 0.03, 0.13, 0.25, and 0.37 inches (Justice, McCullough, and White 2011a)

Particle size (inches)	Average percent finer	SD	LCI	UCI
< 0.03	6.8	2.5	4.8	8.7
< 0.13	20.6	6.1	15.9	25.3
< 0.25	28.3	7.8	22.3	34.3
< 0.37	34.9	9.8	27.4	42.5

Table 25. Predicted egg-to- fry survival and associated 95 percent confidence intervals in reach 6 of Catherine Creek during summer 2010. (Justice, McCullough, and White 2011a)

	percent fines < 0.03 and 0.37 inches[1]			percent fines < 0.25 inches[2]		
Reach	Survival estimate (percent)	LCI	UCI	Survival estimate (percent)	LCI	UCI
6	79.1	63.8	89.4	88.4	74.6	93.6

[1] Tappel and Bjornn 1983;
[2] Irving and Bjornn 1984

5.2.5 Reach 7

Erosion hazards are moderate and severe (NRCS 2009).

The North and South Forks of Catherine Creek, upstream of reach 7 and located within the Wallowa-Whitman National Forest, are discussed since they exceed sediment standards and contribute to sediment loads downstream.

North Fork

Erosion hazard along the North Fork is mostly very severe with some severe ratings (NRCS 2009).

Although erosion hazards along the North Fork are high, this tributary is not considered to cause significant sediment problems (Platt 2011; Lovatt 2011). The Forest Service does not collect sediment load data on either fork. Land uses adjacent to the North Fork that could contribute sediment to the creek include grazing, logging, and roads. Portions of this tributary are grazed; however, Rosgen type A and B stream channels are relatively stable and the most sensitive areas along the creek are excluded from grazing (Lovatt 2011). Current Forest Service logging practices require a 300-foot buffer along fish-bearing streams (Platt 2011), although past logging may still impact slope stability. The Eagle Cap Wilderness includes the North Fork; therefore, roads are limited but trailheads are located throughout the area.

Surface sediment size sampling was conducted on the North Fork of Catherine Creek during summer 2010 near the confluence with Middle Fork and at the mouth, just upstream of reach 7 (Justice, McCullough, and White 2011a; McCullough et al. 2011). The North Fork had the highest percentages of surface fine sediment out of the five sites sampled (Table 21). Fine sediment was highest at the mouth, near where it joins the main stem of Catherine Creek.

South Fork

Erosion hazard along the South Fork is mostly severe with some severe ratings (NRCS 2009).

Although the North Fork has higher erosion hazard ratings than the South Fork, the South Fork is considered to contribute more sediment to the Catherine Creek system (Platt 2011; Lovatt 2011). This tributary is grazed from the mouth to the headwaters, experiences some logging, and contains many roads. Grazing and logging practices are the same as those described above. The largest sediment contribution in the South Fork comes from roads (Lovatt 2011). More localized issues include a head wall that, as part of a granitic system, breaks out occasionally and adds sediment to Catherine Creek. There is also an irrigation ditch at the headwaters of South Fork that diverts water to the Powder drainage and causes large problems in the form of debris flows and slope failures (Platt 2011). Finally, there was a large fire within this drainage recently that has been causing sediment concerns.

Surface sediment size sampling was conducted in the upper reaches of the South Fork of Catherine Creek during summer 2010 (Justice, McCullough, and White 2011a; McCullough et al. 2011). The South Fork had the lowest percentages of surface fine sediment out of the five sites sampled (Table 21). The relatively low rates of fine sediment may have been a result of sampling high in the watershed, where there was less cumulative sediment input.

The Forest Service is planning to carry out a restoration project in summer of 2011 and 2012 along 4.3 miles of South Fork Catherine Creek (USFS 2009; Platt 2011). A stream bottom road would be removed and woody species planted, among other things, to improve fish habitat. Expected benefits of the project include improved floodplain connectivity; increased quantity and quality of pools; fish cover and habitat complexity; and increased pieces of large woody debris in streams. The project would presumably help control sediment input as well.

5.3 Nutrients

The DO applicable standard is based on Catherine Creek providing habitat for cold-water aquatic life at all times of the year and for salmonid spawning and egg incubation during the fall, winter and spring months from October 1 through June 30 (ODEQ 2000). For periods identified as providing for salmonid spawning and egg incubation, the applicable water column standard is 95 percent of saturation. At 50°F (bull trout temperature criteria), 95 percent saturation converts to 9.7 ppm and at 55.4°F (salmonid spawning temperature criteria) it converts to 9.1 ppm. For periods other than during spawning and egg incubation, standards are specified as 8.0 ppm as a minimum 30-day average, 6.5 ppm as an absolute minimum (Table 26). For pH, targets have been set to 8.7 as an absolute maximum and 6.5 as an absolute minimum. The pH target of 8.7 for Catherine Creek is more stringent than the maximum pH of 9.0 allowed by the Oregon State standard and the DO target of 6.5 ppm is more stringent than the minimum of 6.0 ppm allowed by the standard, which provides for a margin of safety.

Table 26. DO standards for Catherine Creek.

Time period	**ODEQ 1998 Standard**
Oct 1 – Jun 30 (spawning & egg incubation)	95 percent saturation Mouth to CCACF (salmonid temp criteria) = 9.1 ppm CCACF to N & S Forks (bull trout temp criteria) = 9.7 ppm
Jul 1 – Sep 30	8.0 ppm minimum 30-day avg 6.5 ppm absolute minimum

The Grande Ronde River is listed for pH and DO violations due to excessive algal (i.e., periphyton) growth. Water quality modeling using the periphyton model PCM (ODEQ 2000) indicated that the pH standard is more difficult to achieve in Catherine Creek than the DO standard. Because of this, allocations which result in the pH target of 8.7 being met are calculated by the model to result in DO concentrations significantly greater than 6.5 ppm. Such allocations will result in the 30-day average standard of 8.0 ppm being met in all reaches.

Since not all nitrogen and phosphorus in a stream is available for algal growth, nutrient load allocations are provided in terms of the reactive inorganic forms. For nitrogen, this is the dissolved inorganic nitrogen (DIN), which includes ammonia, nitrite, and nitrate. For phosphorus, it is the dissolved orthophosphate (equivalent to soluble reactive phosphorus or SRP). Standards are provided for two sets of conditions (ODEQ 2000): 1) existing riparian conditions with associated high stream temperatures and solar radiation, and 2) site potential riparian conditions of reduced stream temperatures and solar radiation.

The nutrient load allocations presented in Table 27 are designed to achieve pH levels within the range 6.5 to 8.7 and DO concentrations greater than 6.5 ppm under each type of condition. Nutrient load allocations are in terms of percent reductions from current levels and apply to NPS pollution loads. Summer point source refers to the WWTP in Union.

There are two criteria for evaluating ammonia toxicity, chronic (based on a 4-day average occurring once in 3 years) and acute (based on an hourly average occurring once in 3 years). Ammonia toxicity can be calculated from pH and temperature. For a pH of 9.0 and a temperature of 77.0°F, the applicable total ammonia chronic standard (NH_4^+ plus NH_3) is 0.1 mg/L (0.0822 ppm as nitrogen) (ODEQ 2000). The 4-day average ammonia concentration may not exceed this concentration more than once every 3 years on the average. For the same pH and temperature combination, the total ammonia acute standard is 0.72 ppm (0.59 ppm as nitrogen). The 1-hour average ammonia concentration may not exceed this concentration more than once every 3 years on the average.

Table 27. Nutrient load allocations and corresponding loading capacities for Catherine Creek. (ODEQ 2000)

		Loading capacities (Water column concentrations as monthly medians)	
Mile points	**Nutrient load allocations**	**Dissolved Inorganic N ppm as N**	**Dissolved orthophosphate ppm as P**
Current riparian conditions			
Mouth to CCACF	60 percent (60 percent reduction in NPS loads plus summer point source removal)	0.026	0.006
Site potential riparian conditions			
Mouth to CCACF	50 percent (50 percent reduction in NPS loads plus summer point source removal)	0.033	0.007

Continuous monitoring data collected in 1991 and 1992 in the Grande Ronde River was the best data available for computing acute and chronic ammonia toxicity levels (ODEQ 2000). During the summer months of July to September the acute criteria is the controlling factor. During these months, the pH in the Grande Ronde ranges from 7.0 to 10.0. The high pH values result in very low acute toxicity levels. From the continuous data, hourly acute toxic levels were calculated as low as 0.25 ppm. Average daily chronic levels were calculated at 0.50 ppm. Keeping in mind the safety margin, ammonia levels below 0.2 ppm should be protective of the acute criteria during these months.

Catherine Creek experiences DO and pH water quality standards violations related to excessive algal growth (ODEQ 2000). The excessive growth is due to a number of factors including elevated nutrient concentrations, high water temperatures, excessive solar radiation, high width to depth ratios, and inadequate streamflow rates. This excessive periphyton activity causes large diel DO and pH fluctuations, which result in, DO standards violations at night and pH standards violations during the day.

Nutrients enter the system from both point and NPSs, with the non-point nutrient loads being functions of land use. The Grande Ronde Valley, where Catherine Creek is located, is comprised mostly of privately owned agricultural and urban lands. The town of Union WWTP is a significant point source for Catherine Creek and has been shown to be a major contributor to nutrient loads at the time TMDLs were established (ODEQ 2000). At that time, violations of standards for DO and pH were generally not seen above the treatment plant discharge but began to occur immediately below the discharge and continue all the way to the confluence with the Grande Ronde River.

Significant summer ammonia standard exceedances also occurred near the Union WWTP discharge (ODEQ 2000). However, away from the discharge no violations were observed in samples from 1991 to 1993, as shown in Figure 12. The exceedances were caused by high ammonia concentrations in the Union effluent coupled with very poor dilution in Catherine Creek. The poor dilution was due to lack of flow because of irrigation diversions. Even though the Union discharge was recorded at 0.47 cfs, which is small relative to many other treatment plants, it was the dominant source of nutrients to Catherine Creek. Not only was the chronic criteria of 0.082 ppm (as N) exceeded near the discharge, but the acute criteria of 0.6 ppm (as N) was also frequently exceeded. The recommended "No Discharge" allocation for summer months was expected to eliminate these violations.

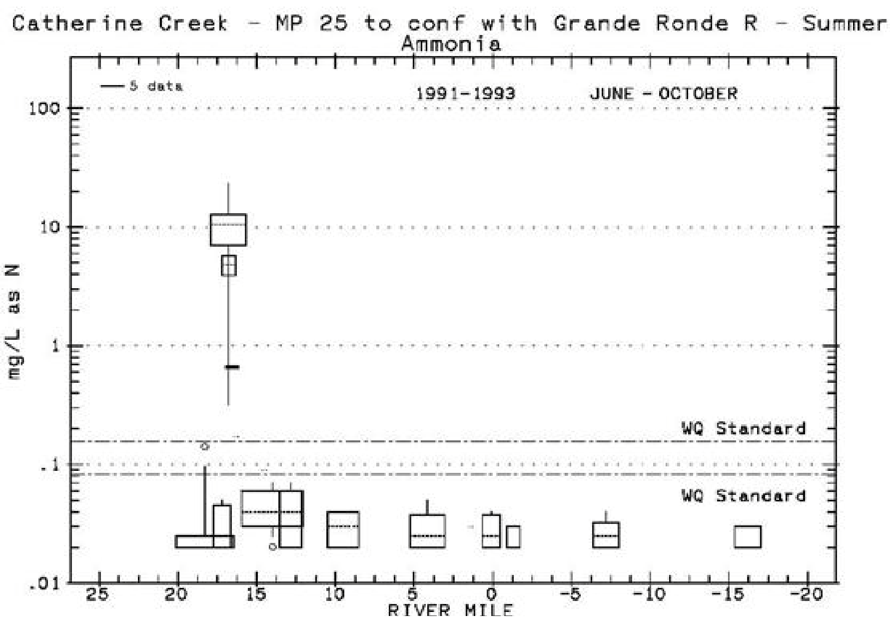


Figure 12. Catherine Creek observed Ammonia concentrations during the summer. Note that RM 0 in the graph is the confluence with Grande Ronde River, which places the WWTP at approximately RM 16 where ammonia exceeds ODEQ standards (ODEQ 2000).

Following the designation of nutrient standards by ODEQ in 1998, a new WWTP was built in 2001. The town of Union stopped discharging effluent during low flows from approximately July 1 to September 30 (Ramondo 2011) per the "No Discharge" allocation for summer months recommended in the TMDLs (ODEQ 2000). The current discharge schedule is from October 1 to approximately June 1 to June 15. Certain specifications must be met, however, in order for the plant to discharge effluent: 1) Catherine Creek flows must by at least 17 cfs; 2) stream temperatures cannot exceed 57.2^{0}F; and 3) effluent temperatures must be below 55.3^{0}F. These specifications are not always met during the allowable period. For example, in 2010 the creek temperatures and flows did not meet criteria required for the plant to discharge into the creek until November (Ramondo 2011). The plant also has a variance, in which it is allowed to discharge from June 16 to June 30 if certain conditions are met; however, Union WWTP has rarely or never discharged during this period.

Currently, effluent is held in storage ponds at the golf course during periods of non-discharge, and the golf course uses the effluent to irrigate. Because the pond nears holding capacity during the summer, and because WWTP meets requirements on effluent standards, the plant may request partial releases be allowed during summer months with issuance of the next permit (Ramondo 2011).

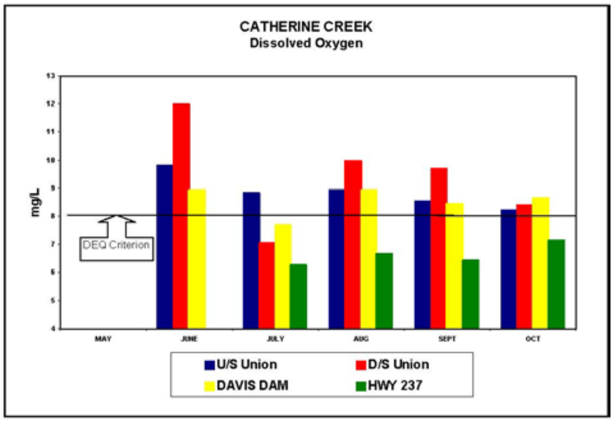
The Union WWTP operator informally collected water quality data from effluent and from a sample site in Catherine Creek, about 15 feet above the discharge point (Ramondo 2011). He found that total suspended solids and E. coli bacteria levels were lower in the effluent than in the stream water, although sampling was carried out in the spring, when runoff into the creek from adjacent lands may have been relatively high.

Monitoring that has been conducted in Catherine Creek, including sampling for pH, DO, nitrogen, phosphorous, and bacteria, is discussed by reach below. No specific information was found regarding these parameters above RM 43 within reach 4.

5.3.1 Reach 1

In 1997, water quality data were collected by the USWCD. These data were collected and analyzed prior to the current ODEQ standards established in 1998 (ODEQ 2000); therefore, standards for this data set were slightly different. Water chemistry and nutrient samples were collected at four sites on Catherine Creek from May through October (Ballard 1999). Samples collected at approximately RM 21.5 in reach 1 (i.e., Highway 237) did not meet ODEQ DO minimum standards in any month, and pH levels were extremely high in August, exceeding the upper pH limit of 9 set at that time (Figure 13). Nitrogen levels did not exceed ODEQ standards during 1997 at the sampling site in reach 1 but phosphorous standards were exceeded in July and August (Figure 14). Ammonia did not reach chronic toxicity levels (Figure 15) in reach 1, nor were bacteria (i.e., E. coli) levels in excess of ODEQ standards, although they were elevated in July relative to other months (Figure 16).

There was a continuous problem with DO throughout the summer of 1997 at the reach 1 site. The combination of low levels of DO, pH levels greater than 9.0, warm stream temperatures, and high levels of nutrients (nitrogen and phosphorus) often creates excessive algae growth (Ballard 1999). In addition to low DO levels, the 1997 data set showed pH levels around 10 in July with high phosphorus levels. Algae growth is a parameter also included on the ODEQ Section 303(d) list for lower Catherine Creek.



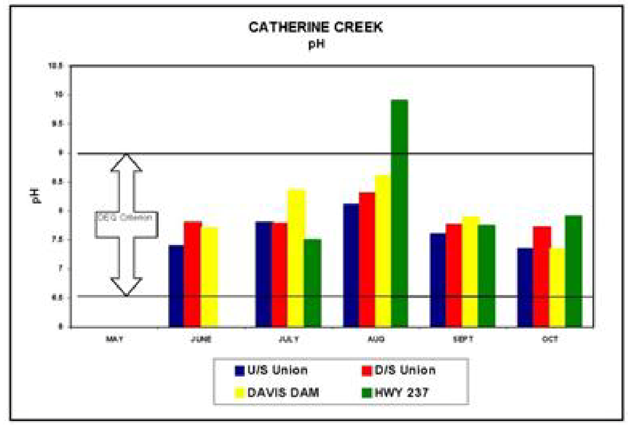
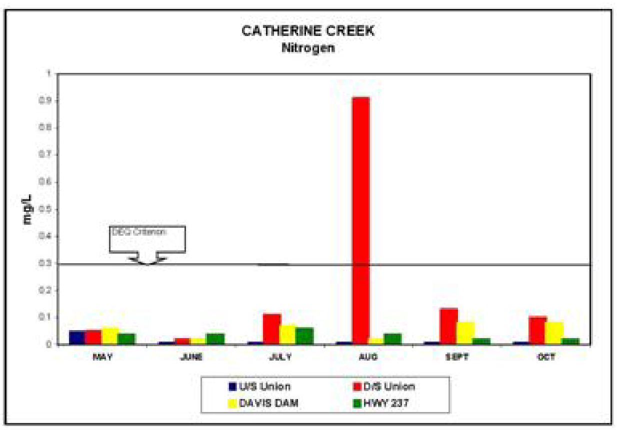


Figure 13. DO (left) and pH (right) levels from four sites in Catherine Creek, May through October 1997 (Ballard 1999).



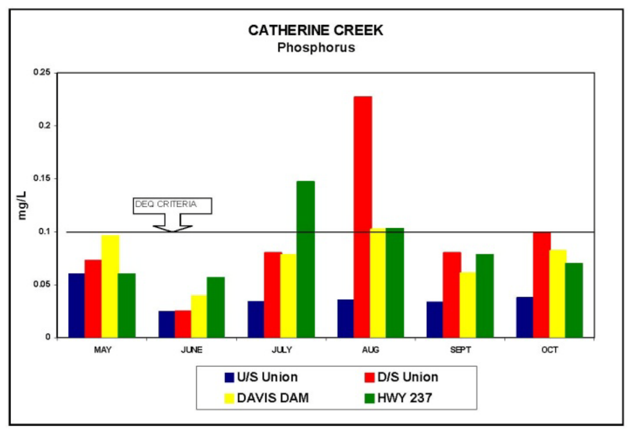


Figure 14. Nitrogen (left) and phosphorous (right) levels from four sites in Catherine Creek, May through October 1997 (Ballard 1999).

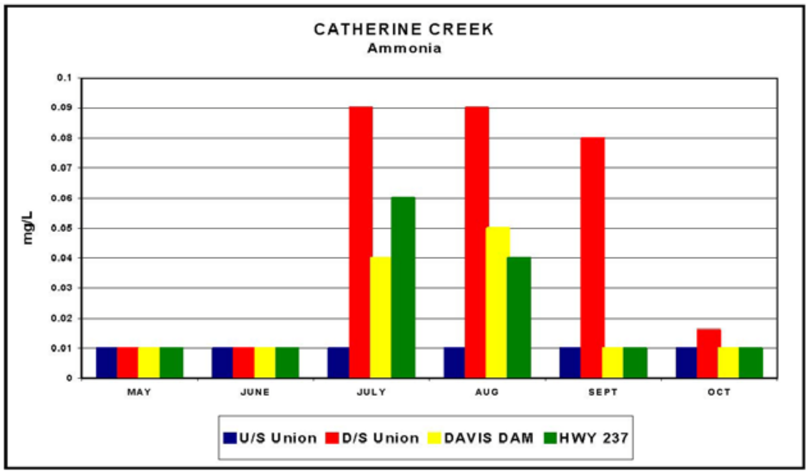


Figure 15. Ammonia levels at four sites in Catherine Creek, May through October 1997 (Ballard 1999).

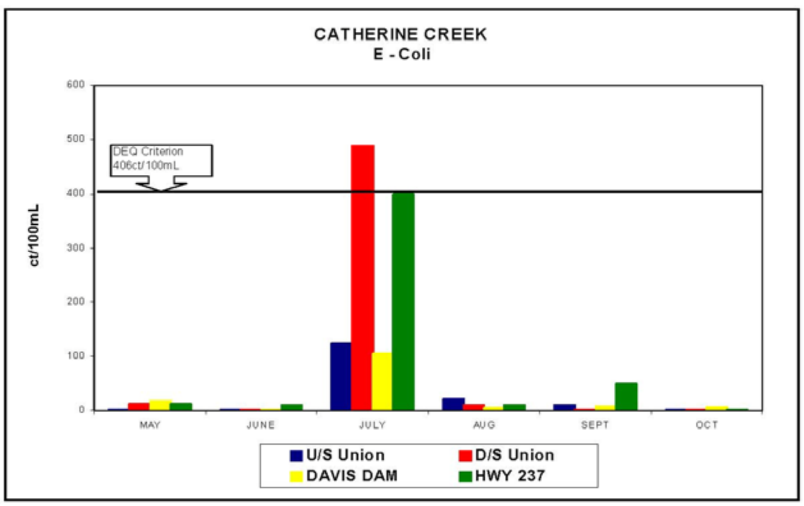


Figure 16. Bacteria levels at four sites in Catherine Creek, May through October 1997 (Ballard 1999).

USWCD collected sets of grab samples at three sites on Catherine Creek over 30-day periods in August from 2004 through 2006 (Miles nd). The three sites were chosen to provide representative data on long-term nutrient loading patterns in relation to land uses, point sources, and NPSs. The site at RM 7 in reach 1 was selected to assess the cumulative effect of intensive agricultural land uses in the Grande Ronde Valley.

Figures 17 and 18 show DIN and orthophosphate results, respectively, from these samples along with three previous years of data (Miles nd). At RM 7, in reach 1, DIN 30-day means were 0.013 ppm as N for 2004, 0.010 ppm for 2005, and 0.026 ppm for 2006, all less than the loading capacity of 0.033 ppm (0.026 ppm) as N for this reach. However, the 30-day means of orthophosphate observations were 17 as P for 2004, 0.014 (114?) ppm for 2005, and 0.125 ppm for 2006 compared to the loading capacity of 6 μg/L set for this reach. These results do not lead to the conclusion that there was a reduction in NPS loading between RM 38 and RM 7 given the high orthophosphate levels of the 2005 and 2006 samples. The evident decrease in DIN levels was most likely due to excessive algal and aquatic weed growth consuming nitrogen.

Samples from these sites were also analyzed for the E. coli bacteria. Results are shown in Figure 19 for sites at RM 7 from 2004 to 2006 and at RM 38 and RM 43 from 2001 to 2006. Samples were collected in August, when streamflows were at their lowest, providing minimal dilution for any contamination. At RM 7 in reach 1 of Catherine Creek, the state chronic standard – which requires that a 30-day log mean for a minimum of five samples cannot exceed 126 organisms per 100 mL – was violated in 2005.

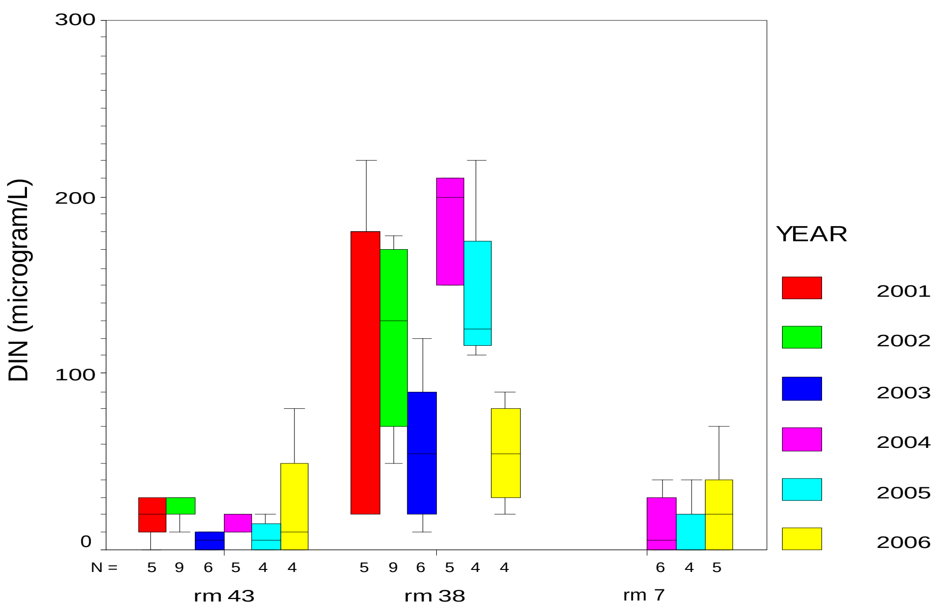


Figure 17. Catherine Creek DIN levels at RM 7, 38, and 43 from 2001 to 2006 (Miles nd; USWCD nd).

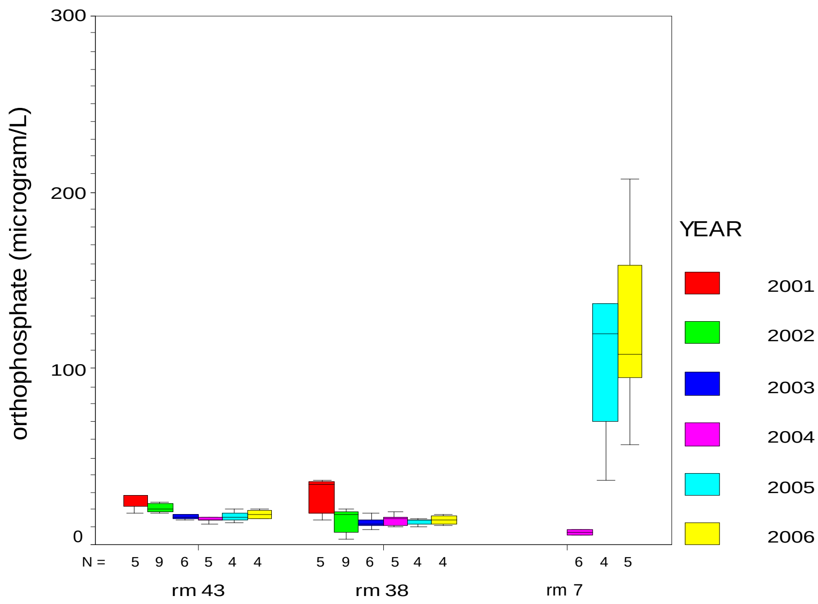


Figure 18. Catherine Creek orthosphosphate levels at RM 7, 38, and 43 from 2001 to 2006 (Miles nd; USWCD nd).

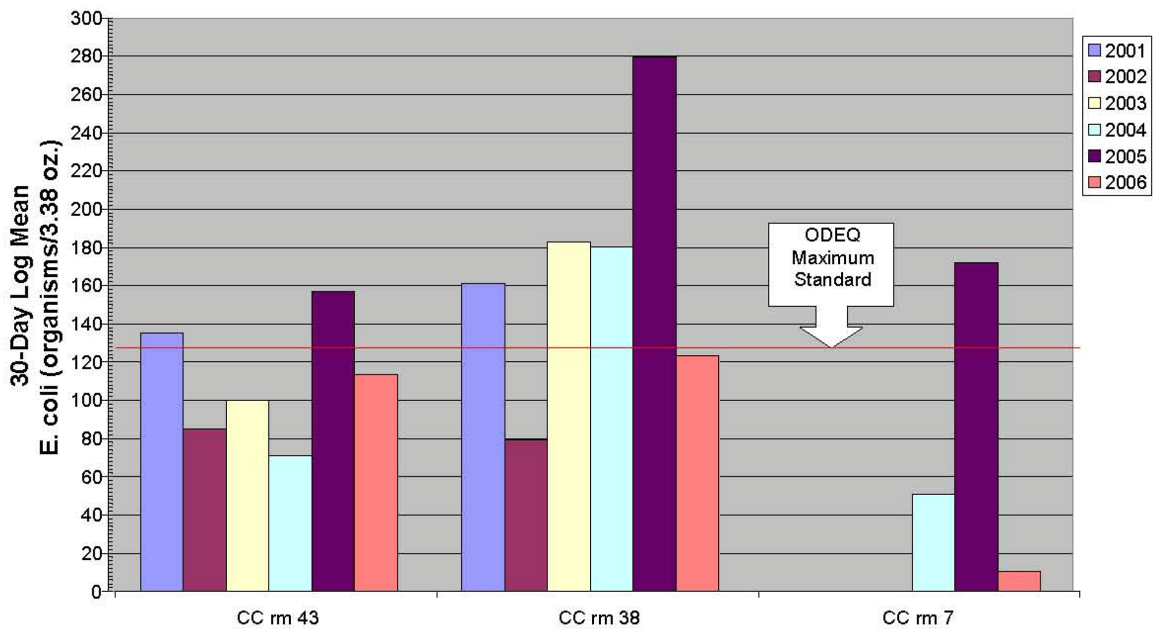


Figure 19. Catherine Creek E. coli bacteria levels at RM 7 from 2004 to 2006, and at RM 38 and 43 from 2001 to 2006 (Milds nd; USWCD nd).

5.3.2 **Reach 2**

ODEQ's web database (ODEQ 2007) provides water quality data collected from various times for Catherine Creek. Parameters collected included DO, pH, N, P, and ammonia. Results for monitoring sites within reach 1 are shown in Tables 27 and 28. Typically, anywhere from one to five measurements were taken per month. Less often, data were collected at a site continuously over 1 to 3 days. Therefore, values shown in the table may be an average of a few to numerous values collected. From 1961 to 1968, samples were collected every year at the confluence of Catherine Creek and Grande Ronde River, but during various months in each year.

Within reach 2, ODEQ DO standards (95 percent saturation and 9.1 ppm for October 1 to June 30) were exceeded at least once in March, May, June, and October in the 1960s (Table 27). Sampling was only done during summer months in the 1990s. From July 1 to September 30, levels fell below the absolute minimum of 6.5 ppm once, but the 30-day average standard of 8.0 ppm could have potentially been exceeded since many measurements were below this value (Tables 27 and 28). The pH values exceeded the standard of 8.7 at one location in September of 1992 and 1993. Nutrient levels of DIN and orthophosphate exceeded the ODEQ standards of 0.026 ppm and 0.006 ppm, respectively, in all samples. Ammonia toxicity standards were never exceeded in reach 2 among these samples.

Based on ODEQ water quality data collected at sampling sites within reach 2 in the early 90s, water quality problems persisted in Catherine Creek all the way downstream to the Grande Ronde River (Bach 1995). These problems likely resulted from a combination of water impoundment and withdrawal and the nutrient load resulting from both treatment plant and downstream nonpoint source contributions. Algae growth resulting from the nutrient load was also a major problem. At the upstream end of reach 2 (approximately RM 35.3), acute pH and high DO problems were observed. At Wilkerson Lane (approximately RM 32.0), chronic pH violations were observed. At Godley Lane (approximately RM 26.0), chronic violations for both pH and high DO were noted. At the confluence of Catherine Creek with Old Grande Ronde River channel, chronic low DO problems were observed.

In 1997, water quality data were collected by USWCD. These data were collected and analyzed prior to the current ODEQ standards established in 1998 (ODEQ 2000); therefore, standards for this data set were slightly different. Water chemistry and nutrient samples were collected at four sites on Catherine Creek from May through October (Ballard 1999). Samples collected at Davis Dam in reach 2 did not meet the ODEQ minimum DO standards in July, although pH levels never exceeded standards (Figure 13). Nitrogen levels did not exceed ODEQ standards during 1997 at the sampling site in reach 2, but orthophosphate standards were exceeded in August (Figure 14). Neither ammonia nor bacteria were at levels in excess of ODEQ standards (Figures 15 and 16).

USWCD collected samples from Grande Ronde River tributaries during peak runoff and irrigation return flows to assess agriculture's contribution to water quality problems circa 2004 to 2006 (Miles nd). This effort was also intended to evaluate effects of implementing the WQMP. Results indicated that certain tributaries, including Mill Creek that joins Catherine Creek in reach 2, were still receiving significant NPS loads of nutrients and bacteria from surrounding agricultural land uses.

Table 28. ODEQ DO, pH, DIN, orthophosphate, and ammonia data at the confluence of Catherine Creek and Old Grande Ronde River located at the border between reaches 1 and 2 (ODEQ 2007).

Year	Avg. Field DO ppm (percent) by month											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1960									9.8 (114)	8.5 (89)	11.2 (99)	12.3 (103)
1961		11 (95)	8.6 (102)	9.8 (95)	8.6 (93)	4.9 (66)	7.5 (101)					
1962							9.1 (126)			7.7 (75)		
1963	12.4 (101)			10.4 (95)			8.0 (102)					
1964	12.2 (101)					9.3 (94)		8.3 (103)			11.5 (109)	
1965			10.8 (101)		9.3 (103)			8.4 (104)				
1966			10.8 (93)						8.7 (103)			
1967		11 (86)						8.2 (106)				12.4 (97)
1968				10.8 (101)				8.5 (117)				
1991							8.3 (105)		6.0 (72)			
Year	**Avg. Field pH by month**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1960									7.5	7.5	7.5	7.3
1961		7.5	7.3	7.4	7.2	7.2	8.4					
1962							8.2			7.3		
1963	8			7.4			7.8					
1964	7.4					7.1		8.4			7.7	
1965			7.6		8.4			8.4				
1966			8.0						8.3			
1967		7.5						7.3				7.5
1968				7.2				8.3				
1991							7.8		7.7			
Year	**Avg. DIN ppm by month**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1966									0.54			
1967		0.24						0.23				0.4
1968				0.14				0.31				
1991							0.09		0.02			
Year	**Avg. Orthophosphate as P ppm by month**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1991							0.06		0.07			

Year	Avg. Field DO ppm (percent) by month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Year	**Avg. Ammonia ppm by month**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1966									0.037			
1967		0.001						0.002				0.001
1968				0.001				0.035				
1991							0.001		0.001			

Table 29. ODEQ DO, pH, DIN, and orthophosphate data in reach 2 (ODEQ 2007).

Station Location	Date	Avg DO mg/L (percent sat)	Avg pH	Avg DIN mg/L	Avg Orthophosphate mg/L	Ammonia mg/L
Gekeler Rd	Jun 1991	9.7 (105)	8.0	0.06	0.025	0.001
Godley Rd	Jul 1991	8.1 (103)	7.9	0.08	0.06	0.002
	Sep 1991	10.2 (122)	8.7	0.04	0.04	0.005
	Sep 1993	11.1 (116)	9.4	0.03	0.07	0.009
Wilkerson Lane	Jun 1991	10.7 (114)	8.0	0.06	0.03	0.001
	Jul 1991	7.8 (97)	7.7	0.13	0.07	0.001
	Sep 1991	9.2 (119)	8.6	0.05	0.08	0.006
	Sep 1992	9.7 (102)	8.6	0.04	0.08	0.003
Hwy 203 & Hawkins	Jul 1991	7.8 (95)	7.8	0.13	0.078	0.002
	Sep 1991	10.4 (127)	8.4	0.05	0.074	0.003
	Sep 1992	12.7 (140)	9.0	0.04	0.07	0.004
Miller Rd.	Jul 1991	9.3 (109)	8.0	0.12	0.08	0.002
	Sep 1991	8.5 (93)	7.9	0.28	0.12	0.002
	Sep 1992	7.3 (100)	8.0	0.19	0.11	0.004
	Aug 1993	7.1 (86)	7.8	0.39	0.1	0.002
	Sep 1993	8.7 (97)	8.0	0.4	0.1	0.002
	Oct 1993	10.3 (101)	7.8	-	-	-

5.3.3 Reach 3

ODEQ's web database (ODEQ 2007) provides water quality data collected during various months from 1991 to 1993 for Catherine Creek. Parameters included DO, pH, N, P, and ammonia. Results for monitoring sites within reach 3 are shown in Table 30. Typically, anywhere from one to five measurements were taken per month. Less often, data were collected at a site continuously over 1 to 3 days. Therefore, values shown in the table may be an average of a few to numerous values collected.

Within reach 3, all but 1 sample taken at the Union WWTP outfall fell below the absolute minimum of 6.5 mg/L for DO and the sample site 100 feet downstream of the wastewater plant may have violated the 30-day average standard of 8.0 mg/L (Table 30). At the time of sampling, the WWTP was still discharging effluent into Catherine Creek. For all other samples collected between 1991 and 1993 in reach 3, DO was above 8.0 mg/L and the pH standards were never exceeded. The DIN standard of 0.026 mg/L and the orthophosphate standard of 0.006 mg/L were violated in all cases. One exception was from a sample collected above the WWTP at Hwy. 203 east of Union in which DIN detection was 0.020 mg/L. Ammonia exceeded the chronic toxicity standard of 0.082 mg/L as N in three samples taken in June and September at the Union WWTP outfall.

Based on ODEQ data from the early 1990s examining pH, DO, and ammonia toxicity, Bach (1995) reported that a sampling site bordering on reach 3 and 4 (approximately RM 40.8 just east of Union) showed chronic pH violations (>8.5 but <9.0). No violations for the three variables were detected at the 5th Street site in the town of Union (RM 39.7), just above the WWTP discharge. A site just below the treatment plant discharge (RM 39.3) showed chronic ammonia toxicity due to the plant discharge.

Table 30. ODEQ DO, pH, DIN, orthophosphate, and ammonia data in reach 3.

Station Location	Date	Avg DO mg/L (percent sat)	Avg pH	Avg DIN mg/L	Avg Orthophosphate mg/L	Ammonia mg/L
At Union WWTP outfall	Jun 1991	6.0 (70)	7.3	13.2	2.3	0.094
	Jul 1991	5.7 (61)	7.4	5.7	2.2	0.014
	Sep 1991	4.3 (43)	7.4	11.3	3.7	0.061
	Sep 1992	6.8 (74)	7.4	12.8	3.2	0.098
	Sep 1993	3.8 (37)	7.4	19.1	-	0.113
100 feet downstream of Union WWTP	Sep 1993	7.7 (86)	8.6	5.15	-	0.068
0.25 mi downstream of Union WWTP	Oct 1991	8.6 (84)	7.5	-	-	-
	Sep 1993	8.4 (96)	7.5	0.99		0.008
	Oct 1993	9.8 (96)	7.5	-	-	-
0.5 mi downstream of Union WWTP	Aug 1993	10.9 (135)	8.6	0.73	0.18	0.023
5th St in Union	Sep 1993	9.1 (101)	7.9	0.04	-	0.001
	Oct 1993	10.6 (106)	7.7	-	-	-
Hwy 203 (E of Union	Jun 1991	10.7 (111)	8.2	0.05	0.012	0.001
	Jul 1991	8.5 (107)	7.8	0.03	0.034	0.001
	Sep 1991	9.2 (98)	7.7	0.095	0.15	0.002
	Aug 1992	8.1 (93)	7.9	0.03	0.03	0.001
	Sep 1992	9.9 (102)	7.9	0.03	0.02	0.001
	Aug 1993	8.2 (101)	8.0	0.04	0.02	0.001
	Sep 1993	9.6 (103)	8.1	0.02	0.02	0.001

In 1997, water quality data were collected by the USWCD. These data were collected and analyzed prior to the current ODEQ standards established in 1998 (ODEQ 2000); therefore, standards for this data set were slightly different. Water chemistry and nutrient samples were collected at four sites on Catherine Creek from May through October (Ballard 1999). Samples collected downstream and upstream of Union (both presumed to be in reach 3) were always within ODEQ water quality standards at the upstream site (Figures 13 to 16). The downstream site, however, violated ODEQ standards for DO and bacteria in July and exceeded standards for nitrogen, phosphorus, and ammonia toxicity in

July and August of 1997. Results suggested that the town of Union was a source of excess nutrients to the stream. At the time, the WWTP was still discharging into Catherine Creek and likely contributed to the violations in water quality downstream of town.

Results of continuous monitoring studies by USWCD in 2002 at RM 38 are shown in Figure 20 (Miles nd). There were large diel fluctuations in temperature, pH and DO with levels very near violations of water quality standards due to considerable plant and algae activity.

USWCD collected sets of grab samples at three sites on Catherine Creek over 30-day periods in August from 2004 through 2006 (Miles nd). In 2001, grab samples were collected at two sites (USWCD nd). Sites were chosen to provide representative data on long-term nutrient loading patterns in relation to land uses, point sources, and NPSs. The site at RM 38 in reach 3 was selected to represent a transition between urban land uses upstream and agricultural uses downstream. It was also important that this site and RM 43 in reach 4 bracketed the section of Catherine Creek that received any discharge from the town of Union WWTP. Previous monitoring showed extreme and varied concentrations at RM 38 when compared to values at RM 43.

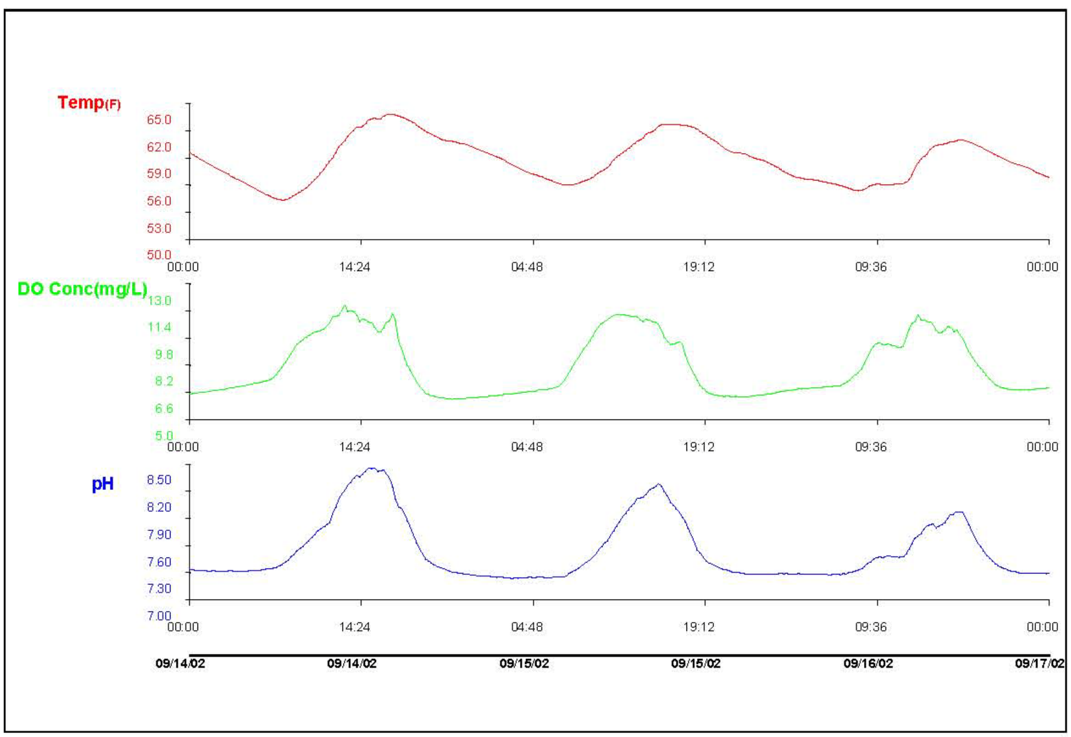


Figure 20. Catherine Creek continuous monitoring for temperature, DO, and pH at RM 38, September 2002.

At RM 38 in reach 3, DIN 30-day means were 188 μg/L as N for 2004, 145 μg/L for 2005, and 55 μg/L for 2006 as shown in Figure 17. All of these values were greater than the loading capacity of 33 μg/L (26 μg/L?) as N for this reach (Miles nd). In 2001, the 30-day median was 180 μg/L as N, which was greater than the loading capacity of 26 μg/L as N (USWCD nd). Figure 18 shows the 30-day mean of orthophosphate observations at RM 38. Levels were 35 μg/L as P for 2001 (USWCD nd), 16 μg/L as P for 2004, 13 μg/L for 2005, and 113 μg/L for 2006, all of which violated the loading capacity of 6 μg/L set for this reach (Miles nd). The sampling site at RM 38 is downstream of the town of Union, including the treated wastewater outfall. Union's WWTP operator maintained there were no discharges to the stream during the sampling periods (Miles nd; USWCD nd).

Previous monitoring in 1999, when grab samples for June through October were collected, also resulted in high nutrient levels at this site (USWCD nd). DIN ranged from 40 to 1340 μg/L as N while orthophosphate ranged from 16 to 265 μg/L as P.

Ammonia toxicity measured at RM 38 in 2001 did not exceed chronic standards (i.e., at 25 °C and at pH 9.0, a 4-day average ammonia concentration may not exceed 0.0822 mg/L as N more than once every 3 years) or the total ammonia acute standard (0.59 mg/L as N) (USWCD nd). Sampling in 1999, however, indicated a potential violation of the chronic standard, which ranged from 0.03 to 0.36 as shown in Figure 21. This was most likely due to high ammonia concentration of the effluent from the Union WWTP and poor dilution in the stream. During 1999, the plant was still discharging wastewater in low flow periods. Although ammonia toxicity sampling before and after discharge was discontinued during summer months is limited, comparisons between 1999 and 2001 appear to indicate that ammonia toxicity problems were improved.

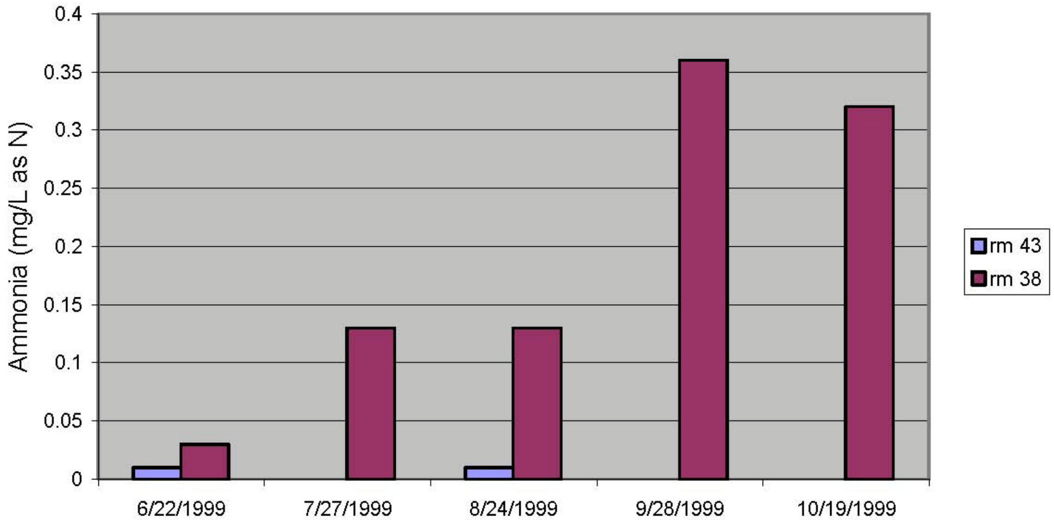


Figure 21. Catherine Creek ammonia levels at RM 43 and 38, June to October 1999.

Bacteria counts at RM 38 violated the state acute standard in 2001, 2003, 2004, and 2005 (Figure 19).

The excessive nutrient levels and E. coli bacteria counts detected at RM 38 in Catherine Creek as compared to upstream (RM 43 in reach 4) from samples collected between 2001 and 2006 suggested that the 60 percent reduction in NPS loads (ODEQ nutrient loading allocations) had not been achieved. Since no discharge from Union's wastewater treatment plant occurred during the sampling period, results indicated that the urban land use area that the stream flows through is a significant NPS of nutrient and bacteria loading.

5.3.4 Reach 4

Results of continuous monitoring studies by USWCD in 2002 at RM 43 are shown in the Figure 22 (Miles nd). As expected, given the high nutrient levels of samples from the RM 43 site and visual observation of abundant algae, pH and DO levels fluctuate significantly. However, these fluctuations were not as pronounced as those documented at RM 38 (Figure 20).

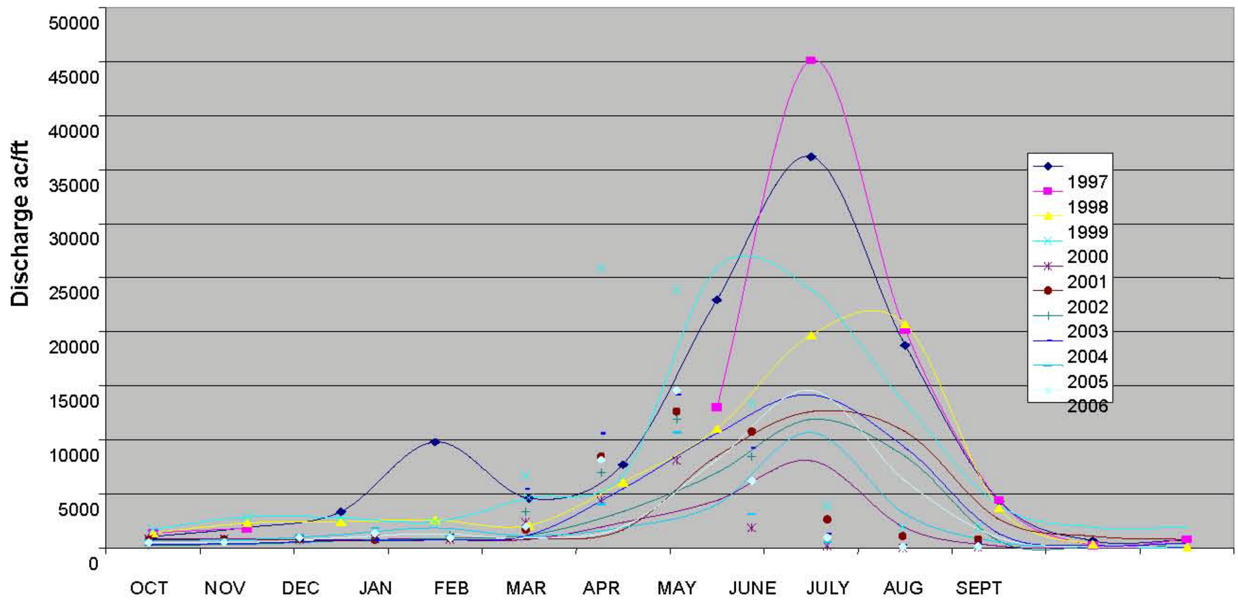


Figure 22. Catherine Creek monthly discharge at 10th Street Bridge in Union for water years 1997 to 2006 (Miles nd).

USWCD collected sets of grab samples at three sites on Catherine Creek over 30-day periods in August from 2004 through 2006 (Miles nd). In 2001, grab samples were collected at 2 sites (USWCD nd). Sites were chosen to provide representative data on long-term nutrient loading patterns in relation to land uses, point sources, and NPSs. The site at RM 43 in reach 4 was selected to represent a transition between forestry and grazing land uses upstream and urban land uses downstream. This site is also located near the upper boundary of the ODEQ Section 303(d) list for most parameters (the CCACF at RM 42.5). It was also important that this site and RM 38 in reach 3 bracketed the section of Catherine Creek that received any discharge from the town of Union WWTP. Previous monitoring showed extreme and varied concentrations at RM 38 when compared to values at RM 43.

At RM 43 in reach 4, DIN 30-day means were 16 µg/L as N for 2004, <10 µg/L for 2005, and 26 µg/L for 2006 as shown in Figure 17. All of these values were less than the loading capacity of 33 µg/L (26 µg/L?) as N for this reach (Miles nd). In 2001, the 30-day median was 20 µg/L as N, which was less than the loading capacity of 32 µg/L (26 µg/L?) as N that DEQ has set for this reach (USWCD nd). Figure 18 shows the 30-day mean of orthophosphate observations at RM 38. Levels were 29 µg/L as P for 2001 (USWCD nd), 15 µg/L as P for 2004, 16 µg/L for 2005, and 17 µg/L for 2006, all of which violated the loading capacity of 6 µg/L set for this reach (Miles nd).

Similar results were found in previous monitoring conducted in 1999. In grab samples collected from June through October, DIN ranged from < 10 to 30 μg/L as N while orthophosphate ranged from 12 to 28 μg/L as P (USWCD nd).

Ammonia toxicity measured at RM 43 in 1999 (Figure 21) and 2001 did not exceed chronic standards (i.e., at 25 ^{o}C and at pH 9.0, a 4-day average ammonia concentration may not exceed 0.0822 mg/L as N more than once every 3 years) or the total ammonia acute standard (0.59 mg/L as N) (USWCD nd). Bacteria counts at RM 43 violated the state acute standard in 2001 and 2005 (Figure 19).

The DIN levels did not exceed ODEQ standards in any of the years USWCD sampled at RM 43. Orthophosphate levels did exceed standards, although results were less varied and generally lower than levels detected downstream. Exceedences in orthophosphate still suggested that the predominant land uses of forestry and grazing upstream of this site had not achieved the 60 percent reductions of NPS loads called for in the TMDL (ODEQ 2000) in order to meet water quality standards for pH and DO. The low DIN levels while orthophosphate levels remained high could be the result of algal growth being nitrogen limited in this reach (Miles nd).

Bach (1995) reported that there were no violations of either pH or DO standards for a sampling site in reach 4 (approximately RM 41.5) based on ODEQ data since 1989.

5.4 Flow and Riparian Conditions

Flow and habitat modification are parameters included on Oregon's 1998 Section 303(d) list for violating water quality standards on Catherine Creek. Flow modification is not the direct result of a pollutant load, although decreased flow does affect beneficial uses (ODEQ 2000). Loading capacities and allocations are not established; however, improved flow is necessary to adequately address water quality standards and habitat below the town of Union on Catherine Creek. Improving in-stream flow is an identified goal in the TMDL and is identified as a high priority in the Water Quality Management Plan (ODEQ 2000). Habitat modification is also not the direct result of a pollutant although it does affect beneficial uses. Because a pollutant is not the cause, the concept of establishing a loading capacity and allocations does not apply. There is the expectation, however, that the improvements to riparian vegetation that will be necessary to meet temperature surrogates will also lead to improvements in habitat.

Annual stream discharge patterns at 10 historic USGS gauge sites in the Grande Ronde Basin all show peak flows occurring in the spring (April to June) and declining flows through summer and early fall (Huntington 1994). Discharge at most sites remains low through winter, before rising again in spring. Peak discharge and flow volume patterns in Catherine Creek are collected by the OWRD at a flow gauging station near the 10th Street

Bridge in Union (Miles nd). Figure 23 shows a hydrograph of monthly Catherine Creek discharge at RM 39 before it enters the valley for the water years 1997 through 2006.

Water quality standard violations occur from June to September when flows in Catherine Creek are lowest. Water withdrawals for irrigation reduce flows starting in June, with flow reduced by about 20 percent (Nowak 2004). In mid-July, flow reduction is about 50 percent and by the 3rd week in July through the end of September, flow is reduced by 90 to 95 percent. Between mid-July and late September, irrigation demand often exceeds the water supply in Catherine Creek, reducing summer flows that are already naturally very low late season. This results in insufficient flows to support anadromous fish migration and to meet water quality standards (Huntington 1994; ODEQ 2000; Reclamation 2002).

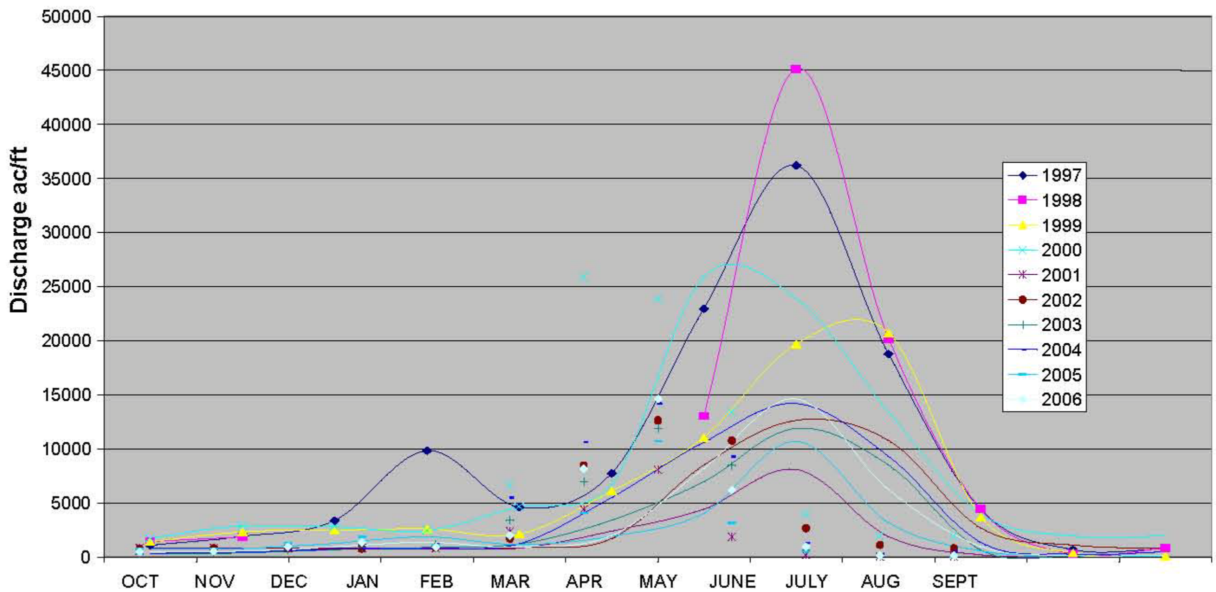


Figure 23. Catherine Creek monthly discharge at 10th Street Bridge in Union for water years 1997 to 2006 (Miles nd; USWCD nd).

There appears to be potential for installing wells to meet irrigation demands during critical periods, although there must be sources for supplemental recharge to replenish the aquifer (Reclamation 2002). More studies are needed to explore this alternative. The GRMWP is conducting preliminary feasibility studies at Hall Ranch in reach 6 (Kuchenbecker 2011). The potential for removing water from Catherine Creek during high flows, injecting that water into an aquifer for storage, and pumping the water back into the creek during low flows will be examined. The capacity of the aquifer to store additional water must be determined. If feasible, this project would not be implemented for some time due to the time and cost involved.

Riparian habitat degradation is considered a major problem in the subbasin (Nowak 2004). Improving the riparian condition of Catherine Creek will lead to improvements in water quality in general ((Nowak 2004; GRWQC 2000; Huntington 1994).

The Grande Ronde Valley bottom (i.e., reaches 1 and 2) has riparian vegetation types composed primarily of annual grasses (ODEQ 2000). However, in some cases where crop cultivation extends to the active channel or where grazing pressure is high, little if any riparian vegetation exists within the Valley bottom (Figure 24). In the upper reaches of Catherine Creek, black cottonwood/mixed conifer and alder communities were identified as the top 2 vegetation communities in providing shade for the creek (Kaufmann et al. 1985).

Riparian vegetation is especially sparse and provides little shade cover in lower Catherine Creek (Favrot et al. 2010). Low shade levels result from a combination of lack of streambank vegetation and/or wide stream channels (ODEQ 2000). Often, low shade levels result from lack of tall streambank vegetation. In many areas that do have tall streambank vegetation but low shade levels, channel widths are too great to effectively shade. Temperature monitoring of stream reaches on Catherine Creek within riparian fencing projects demonstrated that the improved vegetation vigor and density reduced thermal loading of the stream, which suggested a correlation of stream temperature to riparian vegetation's ability to shade the stream (Miles nd).

Figure 24. Grande Ronde River downstream of the Catherine Creek confluence, August 1999. (ODEQ 2000)

Huntington (1993) found that fish habitat conditions related to stream shading in Catherine Creek varied among three major channel types. On average, high gradient channels frequently had high levels of stream shading (mean=74 percent shade). Unconstrained low gradient reaches generally had low levels of stream shading (mean=50 percent). Constrained low gradient channels surveyed had high levels of shading (mean=69 percent). Huntington (1993) also developed reference conditions (RC) based on salmonid habitat requirements, which were used to compare existing habitat conditions. Habitat quality concerning shading along streams surveyed in the Catherine Creek subbasin was frequently below RC levels. Stream shade was below RC levels along 56 percent of miles surveyed.

Favrot et al. (2010) found that early migrant Chinook salmon occupying the high gradient reaches of Catherine Creek most frequently used boulders as cover; fine woody debris was most commonly used as cover in the low gradient reaches, despite cover not being readily available in any of the reaches. Clusters of tumbleweed (*Sisymbrium altissimum*) and American waterweed (*Elodea canadensis*) were commonly available and heavily used as cover in the low gradient reaches, but were not available at higher gradients. The riparian zone of both the high and low gradient reaches used by early migrants was primarily devoted to agriculture, indicating that riparian vegetation – which is ultimately the source of numerous types of cover – may be a limiting factor. In addition, reaches associated with agriculture and minimal riparian vegetation exhibited stream entrenchment, bank erosion, and reduced habitat complexity.

Plans were initiated by CRITFC in 2010 and 2011 to develop a map of potential natural vegetation (PNV) in the Catherine Creek basin (McCullough et al. 2011). The PNV map can provide information about the expected plant and tree community types that are likely to affect riparian shading, food web structure, and possibly streambank stability. This information can in turn help inform the range of possible historical or future riparian scenarios that will likely impact spring Chinook salmon populations in Catherine Creek.

6. Discussion

Most water quality problems in the Grande Ronde subbasin derive from past forestry, grazing and mining activities as well as current improperly managed livestock grazing, cumulative effects of timber harvest and road building, water withdrawals for irrigation, agricultural activities, industrial discharge, and urban and rural development (Nowak 2004). The landscape has been drastically altered by human activities since the mid-1800s due to large-scale disturbances to the riparian vegetation (ODEQ 2000). Riparian species size and composition have decreased from historic conditions (USFWS 2002). Hines (ODEQ 2000) determined that riparian populations of black cottonwood (*Populus trichocarpa*) along the Grande Ronde River declined in number, aerial extent, and average size (a loss of 45 percent, 82 percent, and 70 percent, respectively) from 1937 to 1987. Evidence suggested that changes in vegetative cover in the floodplains are a consequence of intense land use practices in the upper Grande Ronde River subbasin, interacting with such natural variations as climate and precipitation.

Much of the literature identifies degraded riparian conditions as one of the primary problems in the Upper Grande Ronde basin and in Catherine Creek (ODEQ 2000; Huntington 1994; Nowak 2004; NOAA Fisheries 2008). As such, many riparian functions have been historically compromised (USFWS 2002). Long-term degradation of riparian areas has reduced shade, which has led to chronic stream temperature problems (Huntington 1994). Solar radiation loading was determined to be the primary source of elevated stream temperatures in the Grande Ronde River (ODEQ 2000). ODEQ (2000) identified the following anthropogenic sources for elevated summertime stream temperatures in the Upper Grande Ronde subbasin:

1. Riparian vegetation disturbance reduces stream surface shading via decreased riparian vegetation height, width and/or density, thus increasing the amount of solar radiation reaching the stream surface,
2. Channel widening (increased width-to-depth ratios) increases the stream surface area exposed to solar radiation,
3. Reduced summertime saturated riparian soils that reduce the overall watershed ability to capture and slowly release stored water, and
4. Reduced summertime base flows may result from instream withdrawals.

Poor riparian vegetation conditions have also contributed to bank erosion and sedimentation. Riparian vegetation reduces streambank erosion by increasing stream bank stability via rooting strength and near-stream roughness (ODEQ 2000). The species composition and condition of the riparian vegetation determine natural streambank roughness. Rough surfaces decrease local flow velocity, which sequentially lowers shear stress acting on the streambank. Sediment sources, both upslope and instream, are elevated in some portions of Catherine Creek. If the stream channel, riparian zone and/or upslope landscape is in a degraded state, the same high flow events that transport sediments out of the stream channel can introduce large quantities of fine sediment into the channel.

Land uses that include urban, agriculture, and livestock grazing have increased the input of nitrogen and phosphorus into the Catherine Creek system. Nutrients often enter water attached to soil particles and fine organic matter that erodes off adjacent land due to reduced bank stability, streambank roughness, and riparian vegetation. At low concentrations of nutrients algal growth is inhibited, but at high nutrient concentrations algal nutrient demands are fully met and growth is limited only by temperature and available light (ODEQ 2000). As temperature increases, the growth rate increases.

Because Catherine Creek experiences elevated temperatures, algal growth rates are high and the stream is more likely to experience pH and DO violations than those with lower temperatures.

In general, reduced flows are also frequently identified as a limiting factor in the Upper Grande Ronde and in Catherine Creek in reaches 1 through 4 (GRMWP 1994; ODEQ 2000; Nowak 2004; NOAA Fisheries 2008). Although flows are naturally low in summer due to the local climate, water withdrawal for irrigation has caused severe water depletions in Catherine Creek. Low summertime streamflows have caused temperatures to increase. Nutrients and bacteria entering the stream are less diluted. These conditions have led to increased algal growth, which in turn affects DO concentrations and pH levels.

Riparian and instream habitat degradation has severely affected spring Chinook salmon production potential in the subbasin (Nowak 2004). The Grande Ronde Basin historically produced large runs of native spring Chinook salmon and summer steelhead (Bach 1995). The runs have declined substantially since the early 1970s. Water withdrawals for irrigated agriculture, human residential development, livestock overgrazing, mining, mountain pine beetle damage, channelization, low streamflows, poor water quality, logging activity, and road construction are major problems affecting salmon production. Significant changes in many salmonid habitat attributes have occurred in Catherine Creek relative to historic conditions (NOAA Fisheries 2008).

Overall changes in water temperatures between historic and existing conditions appear to have had the greatest contribution in reducing spring Chinook productivity (Duncan 1998). Flow and temperature patterns have been altered with much reduced flow caused by irrigation withdrawals in summer and increased temperatures due to low flows and the loss of streamside shade (Duncan 1998; NOAA Fisheries 2008). These factors have significantly influenced adult and juvenile migration opportunity and created heat sinks in what would be prime rearing habitat. Lower flows and warmer water temperatures have likely shifted and reduced variability of adult migration and spawn timing relative to historic timing (NOAA Fisheries 2008). The opportunity for fry and summer parr downstream migration in Catherine Creek has also been reduced. Lower than optimum winter temperatures resulting from the disconnect between streams and moderating groundwater supplies may adversely affect overwintering juvenile fish (Duncan 1998).

A study comparing historic BOF surveys to present day conditions in the Grand Ronde Basin found that fish habitat has changed since l934 (McIntosh et al. 1994). Pool habitat decreased significantly. Substrate conditions shifted toward smaller substrates in managed watersheds with an increase in fine sediments. Shifts in substrate composition suggest altered sediment supplies. Changes in substrate size can signify impacts of sediment inputs and bedload transport in the stream (McIntosh et al. 1994). Given current and past management practices in Catherine Creek, both have likely occurred (McIntosh et al. 1994). These changes can result in channel-widening leading to increased water temperatures and decreased pool volumes (McIntosh et al. 1994). Increases in the sediments have probably led to lower egg survival and the decrease in pool habitat (McIntosh et al. 1994).

The water quality changes that have occurred in Catherine Creek over time and the effects of those changes on salmonids are discussed at reach level below. Relatively similar reaches are grouped.

6.1 Reach 1 and 2

Unique features in the Grande Ronde Valley, where reaches 1 and 2 are located, must be considered when evaluating water quality (GRWQC 2000). The valley form is flat and wide, offering an unconstrained area for low velocity channel development with significant sediment deposition. As a result, a large floodplain has developed where soils are much deeper than in other parts of the subbasin. The combination of valley and a channel form with high sinuosity creates the potential for erosion and down cutting when banks are destabilized or streams are artificially straightened. In addition, there are a number of land management activities and pollution sources that are unique to the Valley including population centers with both residential and commercial areas and sewage treatment plants. The land has been highly developed for agriculture and livestock management, which are now the predominant land uses in the valley. The river and most of the tributaries in the valley have been channelized and riparian vegetation altered to some extent. This relatively high level of land development means that there are many more potential sources of pollution in the valley than in the rest of the subbasin.

Historically this portion of the subbasin was wet meadows and emergent wetland (Nowak 2004). In developing this area for agricultural production, many acres of previously flooded valley-bottom land were drained and streams were channelized to prevent flooding and manage water delivery (Bach 1995). The historic Tule Lake, remnants of which can be found in the Ladd Marsh Wildlife Area, covered nearly 20,000 acres of the valley before it was drained for agricultural use (Nowak 2004). These wetland areas served an important function in the hydrology of the area by collecting and filtering water for slow release into the system. Beavers were an integral part of these wetland systems; beaver dams created a succession of wetland types from open water ponds to wet meadows. These wet meadows and emergent wetlands have been lost or degraded by conversion to agriculture, road building, livestock introduction, and removal of beavers. Channelization and conversion to agriculture has also dramatically decreased streamside riparian vegetation. The result of channelization and conversion to agriculture has been a dramatic decrease in riparian area, with subsequent loss of rearing habitat for juvenile salmonids (Bach 1995).

Irrigation diversions and water withdrawals have severely depleted summertime flows in Catherine Creek. Low streamflows strand rearing juvenile fish in dry channel beds and result in elevated water temperatures, which can delay spawning (USFWS 2002). Irrigation, particularly flood irrigation, increases runoff, and subsurface drainage from agricultural fields (Bach 1995). When irrigation water is returned to the stream, it carries sediment and nonpoint pollution from agricultural chemicals and may contribute warmer water to the stream, which degrade water quality.

The use of lower Catherine Creek by salmon as habitat for particular lifestages has been significantly reduced from historic. Adult holding has been eliminated in reaches 1 and 2 due to high temperatures and low flows throughout summer (Huntington 1994). The entire creek below Union is not suitable for spawning and incubation with issues that include sedimentation, loss of pools, and high temperatures. The loss of occupancy in the lower reaches of Catherine Creek has affected the entire Grande Ronde River Basin by reducing the current spawner distribution (NOAA Fisheries 2007). Currently 50 percent of the historic MaSAs in the basin are occupied and none of the MiSAs are occupied. Adult migration to areas above town is eliminated after mid July in most years due to water withdrawal and high temperatures in the lower reaches (Huntington 1994). Reaches 1 and 2 are not suitable for summer rearing after early June due to high water temperatures. Loss of habitat prevents juveniles from migrating from Catherine Creek into the Grande Ronde River prior to early fall.

Juvenile fish may overwinter below Union, but capacity for such use of the stream has been much reduced by channelization and loss of habitat complexity (Huntington 1994). Winter rearing habitat quantity and quality in Grande Ronde River Valley may be important factors limiting spring Chinook salmon smolt production for Catherine Creek (Favrot et al. 2010). Rearing of juvenile spring Chinook salmon and summer steelhead is not confined to the areas in which the adults spawn (Yanke et al. 2008). The majority of juvenile spring Chinook salmon and steelhead move out of natal rearing areas to overwinter in downstream areas of Catherine Creek before migrating toward the ocean as smolts the following spring or later. Favrot et al. (2010) found that a considerably larger proportion of fish occupied reaches downstream of lower Davis Dam during winter compared to fall. These movements of spring Chinook salmon and steelhead show that lower river reaches are used for more than migratory corridors.

6.2 Reach 3

Catherine Creek passes through the town of Union in reach 3, where urban land use has led to modifications to the stream. Catherine Creek is a single channel through town with some dams, fish ladders, and diversions located in this stretch. Urban development closely borders the creek and limits the extent of riparian vegetation. Roads and paved areas also contribute to the reduction of riparian vegetation and to the input of sediment and nutrients into the stream. On the outskirts of town within reach 3, agriculture and grazing are the land uses. Water quality issues within reach 3 are the same as those in the lower reaches of Catherine Creek (Table 3) and include elevated temperatures, algae growth, and nutrient input; high fluctuations in DO and pH levels; and low flows and degraded riparian conditions.

In the 1998 TMDLs, ODEQ (2000) recommended that no effluent be discharged from the Union WWTP during summer months in order to mitigate the impact of the point source discharge on Catherine Creek water quality. ODEQ predicted that the likelihood of standards being met would be improved by the implementation of a summer no discharge period, since there would be less periphyton biomass produced which would reduce the likelihood of excessive diurnal DO and pH variation. The Union WWTP ceased summer discharge in 2001 (Ramondo 2011). Based on summer sampling conducted downstream of the WWTP between 2001 and 2006, there were still excessive nutrient levels and E. coli bacteria counts detected, although ammonia appeared to be reduced to non-toxic levels (Miles nd; USWCD nd). The 60 percent reduction in NPS loads (ODEQ nutrient loading allocations) has not been achieved even with no discharge from Union's wastewater treatment plant. It appears that the urban land use area that the streamflows through is a significant NPS of nutrient and bacteria loading.

With regards to currently available salmonid habitat found in reach 3 as compared to historic conditions, the capacity for adult holding from Union to the State Park (in lower reach 5) has been reduced because of loss of pool habitat and high temperatures (Huntington 1994). The quality and quantity of spawning and incubation habitat from Union upstream to State Park has been reduced due to high temperatures, loss of pools and sedimentation. Catherine Creek just upstream from Union in reach 3 is a potential high gradient overwintering reach but is not consistently occupied by early migrants, which indicates that habitat conditions are not conducive to successful overwintering (Favrot et al. 2010). Specifically, the high gradient channelized segment extending approximately 1.1 mi (1.7 km) upstream of Schwackhammer Fish Ladder at RM 40.6 appears to only be utilized as a migration corridor and is avoided as overwintering habitat.

6.3 Reaches 4 and 5

The predominate land use in reaches 4 and 5 of Catherine Creek is grazing on pasture and rangelands. Effects of overgrazing in the late 1800s and early 1900s remain severe throughout the Grande Ronde basin, especially in riparian areas where livestock tend to gather (Duncan 1998). Even lower levels of grazing today continue to cause watershed problems. Unless properly managed, livestock congregate around stream channels, where water and forage are abundant. This causes severe reductions in the amount and diversity of riparian vegetation, and increases soil compaction and streambank erosion. These changes severely reduce riparian function, with subsequent increases in stream temperature, nutrient-loading, sediment deposition in spawning and rearing areas, and alterations in streamflow patterns (Bach 1995). Rangeland can become infested with noxious weeds and annual grasses due to inadequate forage and grazing management, which causes loss of riparian vegetation and increased sedimentation (NRCS 2005).

The highway is adjacent to Catherine Creek in the lower segments of reach 4 and along all of reach 5, which has contributed to the reduction of riparian vegetation (USFWS 2002). Buffer widths between roads and streams are too narrow to filter out all soil movement before reaching the stream.

With regards to currently available salmonid habitat found in reaches 4 and 5 as compared to historic conditions, the capacity for adult holding from Union to the State Park (in lower reach 5) has been reduced because of loss of pool habitat and high temperatures (Huntington 1994). The quality and quantity of spawning and incubation habitat from Union upstream to State Park has been reduced due to high temperatures, loss of pools and sedimentation. USFWS (2002) recommends revegetation in riparian zones associated with habitat in these reaches to restore shade and canopy, riparian cover, and native vegetation that has been lost.

6.4 Reaches 6 and 7

The majority of stream miles in the upper watershed of Catherine Creek are affected by either grazing, logging, fire, roads, or a combination (USFS 1994 as cited in GRWQC 2000,). Most large conifers in the riparian zone were logged off before 1930 (Hug 1961 as cited in Kaufman et al. 1985). Grazed areas were cleared of brush periodically through the 1950s to increase forage for livestock.

In studies conducted on Hall Ranch at RM 50.1 in reach 6, cattle grazing was found to have significantly impacted structure, composition and standing biomass in some vegetation communities, as well as significantly increasing streambank sloughoff (Kaufman, Krueger, and Vavra 1985). Grazing impacts to the riparian ecosystem included forage removal, trampling, and physical damage of vegetation. While grazing enhanced species richness in some communities, it was halted or slowed in others, especially gravel bars dominated by willows and moist meadows (Kaufman, Krueger, and Vavra 1985). The presence of cattle created drier environments in some communities, decreasing the abundance of mesic plants. Kentucky bluegrass (i.e., dry meadow) communities were the most widespread in this reach. Historically, the dominant communities were probably native bunchgrass, sedge, and rushes. Overgrazing is likely the reason for the change in composition (Kaufman, Krueger, and Vavra 1985).

Effects of overgrazing in the late 1800s and early 1900s remain severe throughout the Grande Ronde basin, especially in riparian areas where livestock congregate (Duncan

1998). Even lower levels of grazing today continue to cause watershed problems. Grazing impacts to riparian vegetation severely reduce riparian function , with subsequent increases in stream temperature, nutrient-loading, sediment deposition in spawning and rearing areas, and alterations in streamflow patterns (MacDonald et al. 1991; Platts 1991; Rhodes et al. 1994 as cited in Bach 1995).

Kaufman, Krueger, and Vavra (1985) reported that beaver almost completely removed young black cottonweed communities (dbh<15 cm) in the upper reaches of Catherine Creek. They altered the riparian ecosystem by removing or thinning overstory, causing changes in community composition and structure. The potential effect of continued beaver browing is a decrease in shade cover and altered run-off and bank physiognomy.

The highway is adjacent to Catherine Creek along reach 6, which has contributed to the reduction of riparian vegetation (USFWS 2002). Buffer widths between roads and streams are too narrow to filter out all soil movement before reaching the stream. The highway veers away from the creek in reach 7. Forest Service roads were identified as a major problem in contributing sediment to South Fork of Catherine Creek upstream of reach 7 (Lovatt 2011).

The upper reaches of Catherine Creek have quality that is low relative to reference conditions for five habitat measures: shade, bank stability, sediment, pool frequency, and woody debris (GRWQC 2000). The most affected reaches, at present, are located in large meadow systems high in the watershed. The Forest Service concluded that this has led to unstable banks, higher width to depth ratios and lower water tables than would naturally occur (GRWQC 2000).

7. Recommendations

The following information relating to water quality in Catherine Creek appears to be limited:

- Nutrient and bacteria data upstream of reach 4.
- Comparisons of nutrients before and after WWTP stopped discharging during summer months.
- Current DO concentrations and pH levels throughout stream.
- Lack of sediment loading and source data for entire stream. (Sediment is on the 303(d) list for North and South Forks of Catherine Creek only but is apparently a problem throughout the stream regarding salmonid habitat).
- The extent, species distribution, and density of riparian vegetation canopy and ground cover; linked to riparian site potential (Bach 1995). CRITFC is planning to create a PNV map of the Catherine Creek basin, which may address this data gap.

- Detailed spatial information on land use: irrigated versus non-irrigated agriculture, types of agriculture, extent of grazing and riparian areas excluded from grazing, road locations and densities, timber harvest activities (Bach 1995) to better identify sources of water quality problems

Recommendations for improving water quality, and consequently Chinook and steelhead habitat, in Catherine Creek are provided by parameter below. Much of the literature agrees that addressing riparian condition and streamflow issues would lead to improvements in most other water quality parameters.

7.1 Temperature

Lack of riparian vegetation and shade, as well as low flows, contribute to increases in temperature. To address these problems, provide riparian shading by planting new shrubs and trees, as well as protecting existing shade. Protect (and possibly increase) flow from springs by enhancing groundwater recharge (limit surface runoff from roads, etc.). Plant and/or protect conifers in riparian area to provide thermal cover in winter, but allow for biodiversity with deciduous vegetation. Increase irrigation efficiency and limit amounts of warm irrigation return flows (WCSRCS 1999).

Improving livestock management and distribution will also help to address temperature problems by minimizing impacts to riparian vegetation. Recommendations for managing livestock in riparian areas include using riparian pastures as part of a rotational grazing scheme, creating off-stream water developments and salting sites to deter cattle away from the stream, herding, and fencing where appropriate to exclude livestock from riparian zones (Upper Grande Ronde River Subbasin Local AWQAC 1999). Whitney (2007) found that in most cases, cooler stream temperatures were clearly associated with minimal impact from grazing and other land uses, while higher temperatures were associated with heavier use. The parameters most responsive to disturbance were temperature, DO, and pH.

Slowing the rate of water warming will push the point at which maximum temperatures occur further downstream, adding many miles of fish habitat (Nowak 2004). Improved riparian vegetation along smaller order streams will dramatically reduce the daily maximum stream temperature in Catherine Creek.

7.2 Sediment

Prevent bank erosion and destruction through livestock by fencing riparian area and providing water corridors or alternate water sources (WCSRCS 1999). Protect water corridors with rock of appropriate size. Avoid excessively high peak flows, and resultant bank erosion, by keeping enough watershed vegetation to slow runoff. Plant in critical areas. Manage weeds, which generally have shallow root systems that do not provide soil stability and can result in increased sedimentation.

Methods for avoiding agricultural field erosion include planting buffer strips, planting perennial crops, and planting wind breaks to control wind erosion (Upper Grande Ronde River Subbasin Local AWQAC 1999). Use conservation tillage. Use sediment traps by providing wetlands, filter strips, or settling ponds for irrigation return flows. Limit sediment-laden irrigation return flows (WCSRCS 1999).

Road design and maintenance should be planned to avoid quick runoff and sediment entrainment. If there is a sediment problem that could not be mitigated by road design, maintenance, or relocation, the road could be revegetated, use could be limited, or the road closed (WCSRCS 1999). Wetlands and/or filter strips could be developed to filter runoff from roads and campgrounds.

7.3 Nutrients

Nutrients often enter water attached to soil particles and fine organic matter that washes off adjacent land; therefore, bank stability and riparian vegetation are important. Follow practices that will limit erosion and sedimentation. Healthy riparian areas with deep-rooted woody vegetation have been shown to intercept significant amounts of nutrients and prevent them from reaching surface waters (GRWQC 2000). Sediment and dissolved nutrients can also be transported via roadside and drainage ditches. Dissolved nutrients move easily into surface waters via shallow groundwater and drain tiles. Fertilizer management, cover crops, soil disturbance, and irrigation management on agricultural fields have an impact on the nutrient load (GRWQC 2000). Soil and foliage testing should be encouraged (Upper Grande Ronde River Subbasin Local AWQAC 1999). Plant buffer strips to filter nutrients.

Whitney (2007) found that in most cases, better water quality was seen in study reaches with minimal impact from grazing and other land use activities, while poorest water quality was seen in study reaches with heavy grazing use. The parameters most responsive to disturbance were temperature, DO, and pH.

Methods for preventing bacteria from entering the stream include managing animal waste, planting buffer zones, installing settling ponds and clean water diversions around livestock concentration areas (Upper Grande Ronde River Subbasin Local AWQAC 1999).

7.4 Flow and Riparian Conditions

Increased late season flow would improve almost all of the 303(d) listed parameters – temperature, habitat modification, pH, algae, nutrients, DO, and bacteria – by providing dilution and increased moisture (GRWQC 2000).

Areas with a large number of irrigated acres have the potential for reduced water use through irrigation efficiency or changes in land use (Bach 1995). Irrigation efficiency can be improved by: pump testing, sizing mainlines properly, using proper nozzle sizes, fixing leaks, installing headgates at diversion points and/or improving the existing structures, converting surface systems to buried mainline, monitoring soil moisture levels, and lining or piping irrigation ditches (Upper Grande Ronde River Subbasin Local AWQAC 1999). Alternative sources of water for irrigation could be used, such as city wastewater or deep wells.

While not the only issue, riparian habitat degradation is the most serious problem in the subbasin (Nowak 2004). Improving riparian conditions will improve temperature, bank stability, sediment, and other water quality factors (Nowak 2004; GRWQC 2000; Huntington 1994).

Riparian restoration is probably the most cost effective way to improve fish habitat throughout the basin and is the only way to reduce high water temperatures (Huntington 1994). Establishment and protection of riparian vegetation would likely increase the contribution of LWD into the stream, thereby elevating habitat complexity and cover availability (Favrot et al. 2010). In addition, riparian vegetation is associated with bank stability and reduced erosion.

To improve riparian conditions, it is important to encourage revegetation and protection of existing vegetation on non-forested riparian areas with woody material (e.g., educate landowners on the value of streamside woody plants) (WCSRCS 1999). Livestock use of riparian areas should be carefully controlled in order to assure health of shrub and woody components (Huntington 1994). Restoration measures related to grazing might include temporary fencing of riparian areas, corridors, changes in grazing seasons and duration, development of offstream watering sites, and planting appropriate native shrubs and trees. Results of a study to evaluate the effectiveness of channel restoration efforts in McCoy Creek, a degraded stream in the Upper Grande Ronde basin with characteristics similar to Catherine Creek, showed livestock exclusion by itself may not result in improved habitat and recovery of sensitive aquatic life (Whitney 2007). In most cases, however, better water quality was seen in study reaches with minimal impact from grazing and other land use activities, while poorest water quality was seen in study reaches with heavy grazing use. Cool groundwater influx and shade were important factors affecting water quality.

Higher in the Catherine Creek watershed, catastrophic fires could destroy vegetative cover and consequently result in sediment input to the river. Prescribed burning in forests can help reduce fuel levels and provide fire breaks to prevent large uncontrollable fires. In riparian areas, fuel rearrangement (placing fuels to protect streambank or placing large woody debris in stream to add to stream structure) may be preferable to burning in order to keep the organic material as part of the ecosystem, preserve shade, and prevent sedimentation (Wallow County SRSC 1999).

If funds are limited, restoration should initially emphasize vegetative recovery along unconstrained low-gradient reaches of streams which have greatest capacity for rapid response, are naturally the most dynamic and productive stream channels, and tend to be the preferred spawning or rearing areas of spring Chinook (Huntington 1994). Whitney (2007) found that restoration of meandering wet meadow channels (i.e., reaches 1 and 2) can improve habitat and benefit sensitive aquatic life in a relatively short period (2 to 5 years). Efforts directed toward increasing survival of early migrants during fall migration and overwintering periods would likely be most efficiently directed toward portions bounded by Union and the mouth of Mill Creek (reach 2). Despite channelization and lack of habitat complexity (e.g., pools and cover), several smaller reaches positioned between Union, Oregon, and the mouth of Pyles Creek (lower section of reach 3) were intensely utilized (Favrot et al. 2010).

Riparian recovery along constrained stream channels should also be a high priority because these reaches provide important habitat by providing a source for woody debris and moderating stream temperatures (Huntington 1994). Management practices that enhance the riparian corridor vegetation of Catherine Creek could improve overwinter carrying capacity of early migrants by increasing habitat complexity (i.e., cover) and bank stability (Favrot et al. 2010). Several reaches within the high gradient overwintering reach (e.g., 1.7 km upstream of Swackhammer Fish Ladder at RM 40.6 in reach 3) were not occupied consistently by the early migrant population, indicating that these reaches do not contain habitat conditions conducive to successful overwintering. Employing habitat restoration techniques within these degraded reaches would likely increase overwintering carrying capacity (Favrot et al. 2010).

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APPENDIX C – GEOLOGY AND GEOMORPHOLOGY

RECLAMATION
Managing Water in the West

Geology and Geomorphology Report for the Catherine Creek Tributary Assessment – Grande Ronde River Basin
Tributary Habitat Program, Oregon

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region
Geology and Fluvial Analysis Group
Boise, Idaho

February 2012

Cover Photograph: View looking east (downstream) along Catherine Creek, Reach 2 at river mile 26.0, in the Cove area, Mt. Fanny (upper left) and Phys Point (upper right) can be seen in the background. **Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – July 29, 2010.**

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1. Summary

The primary objectives of this tributary-scale geomorphic assessment are to:

1. Delineate and describe geomorphic reaches based on differing geomorphology that includes:
   - The natural and artificially induced controls on current morphology.
   - Historic conditions.
   - Current channel form.
2. Discuss the conditions and processes noted above as they relate or contribute to the known limiting factors that impede the reproduction and/or survival of Chinook salmon and steelhead.
3. Discuss initial rehabilitation strategies that address the current conditions and limiting factors that affect the reproduction and/or survival of spring Chinook salmon and steelhead.

Seven geomorphic reaches were identified and grouped into three sections within the Catherine Creek Tributary Assessment area. The primary in-basin limiting factors of water quantity (low summer flows), water quality (elevated summer temperatures), poor habitat quantity/diversity (low abundance of pool habitat and lack of habitat diversity), excess fine sediment, and returning adult passage (NOAA Fisheries 2008) are noted to persist across all of Catherine Creek. In order to address the causes of the limiting factors, both short-term and long-term approaches based on a strategy of prioritizing rehabilitation activities described by Roni et al. (2002) should be considered. The short-term strategy should address the immediate need to increase habitat quality and quantity by increasing complexity in the main channel. The long-term focus of rehabilitation efforts should include multiple strategies that: 1) reconnect isolated habitats, 2) restore long-term processes, and 3) restore short-term habitat.

The Grande Ronde Valley and Catherine Creek are within the Blue Mountain physiographic province in northeast Oregon. The valley is a large structural basin situated along the east flank of the Blue Mountain uplift, bordered by the Blue Mountains to the northwest, the Wallowa Mountains to the east, and the Elkhorn Mountains to the south (Carson 2001). Subsidence of the basin opposite the direction of flows has resulted in a low gradient across the basin and infilling by alternating lacustrine and fluvial depositional conditions along the southern portion of the valley creating what is now a broad, flat plain that Catherine Creek meanders through.

The basin is filled with a thick sequence of interbedded silt, sand, and gravel and poorly sorted alluvial fan deposits (Van Tassell 2001) mark the valley margins. Samples from deep-water wells in the valley show mostly river channel, floodplain, marsh, and shallow lake sediments, indicating the basin was never a deep water environment (Carson 2001). Both the Grande Ronde River and Catherine Creek carried glacial outwash from adjacent highlands into the Grand Ronde Valley, producing terrace and alluvial fan-delta deposits as sedimentation rates fluctuated during glacial advances and retreats (Ferns et al. 2010). Pleistocene deposits also include air-fall ash from Cascades volcanic eruptions, and wind-blown loess originating from outburst glacial flood deposits near Pendleton (Ferns et al. 2010).

For this report, the assessment area was divided into three distinct geomorphic areas: the Upper Valley Group, the Alluvial Fan, and the Valley Floor Group. Reaches are unconfined in the Valley Floor Group and range from confined to unconfined in the alluvial fan and upper valley reaches. Catherine Creek is characterized by very high sinuosity in the Valley Floor Group and relatively low sinuosity in the alluvial fan and Upper Valley Group. Substrate ranges from boulder cobble and gravel in the alluvial and upper valley reach to fine sand and silt interbedded with clays in the Valley Floor Group. Riparian vegetation ranges from grass and willows to trees. Overall Catherine Creek and the adjacent riparian and floodplain vegetation have been significantly altered for flood control/conveyance and irrigation storage in addition to agricultural and residential development. Alterations include channel shortening, channelization, and levee construction.

2. Introduction

Declining populations of salmon and steelhead in the Columbia Basin have resulted in attempts to improve habitat in spawning tributaries. This geology and geomorphology report is being prepared as part of a “tributary assessment (TA)” of one of those tributaries (Catherine Creek within the Grande Ronde Watershed of the Snake River basin). The TA represents the initial phase of a work process adapted by the Bureau of Reclamation (Reclamation) to help determine the existing conditions as well as the potential to improve the habitat. This study provides technical information to decision makers tasked with implementing rehabilitation projects that will increase the abundance and productivity of Endangered Species Act (ESA) listed steelhead and spring Chinook on Catherine Creek. In doing so, Reclamation will be working toward meeting tributary habitat commitments contained in the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) (NOAA Fisheries 2008).

2.1 Purpose of Study

The primary objectives of the geomorphic assessment are to understand the geomorphic regimes, delineate geomorphic reaches based on differing physical conditions, characterize watershed conditions and large-scale impacts to geomorphic regimes, and provide information to identify sections that have potential for habitat enhancement and retailed reach assessments. This report was prepared for the purpose of documenting the results of geologic and geomorphic mapping and field verification work performed during the 2010 field season.

2.2 Location

The Catherine Creek TA area focuses on the "valley segment" of Catherine Creek from its confluence with the Grande Ronde River at the State Ditch upstream to near its headwaters at the U.S. Forest Service (USFS) boundary at the confluence of the north and south forks of Catherine Creek. This segment of Catherine Creek is approximately 55-miles long and is located within three distinct geologic regimes: Upper Valley, Alluvial Fan, and Valley Floor. Several tributaries are also of interest within this area, most notably Mill Creek, Ladd Creek, Little Creek, and Pyles Creek. The study area includes the floodplain and Channel Migration Zone of Catherine Creek within this segment as shown in Figure 1.

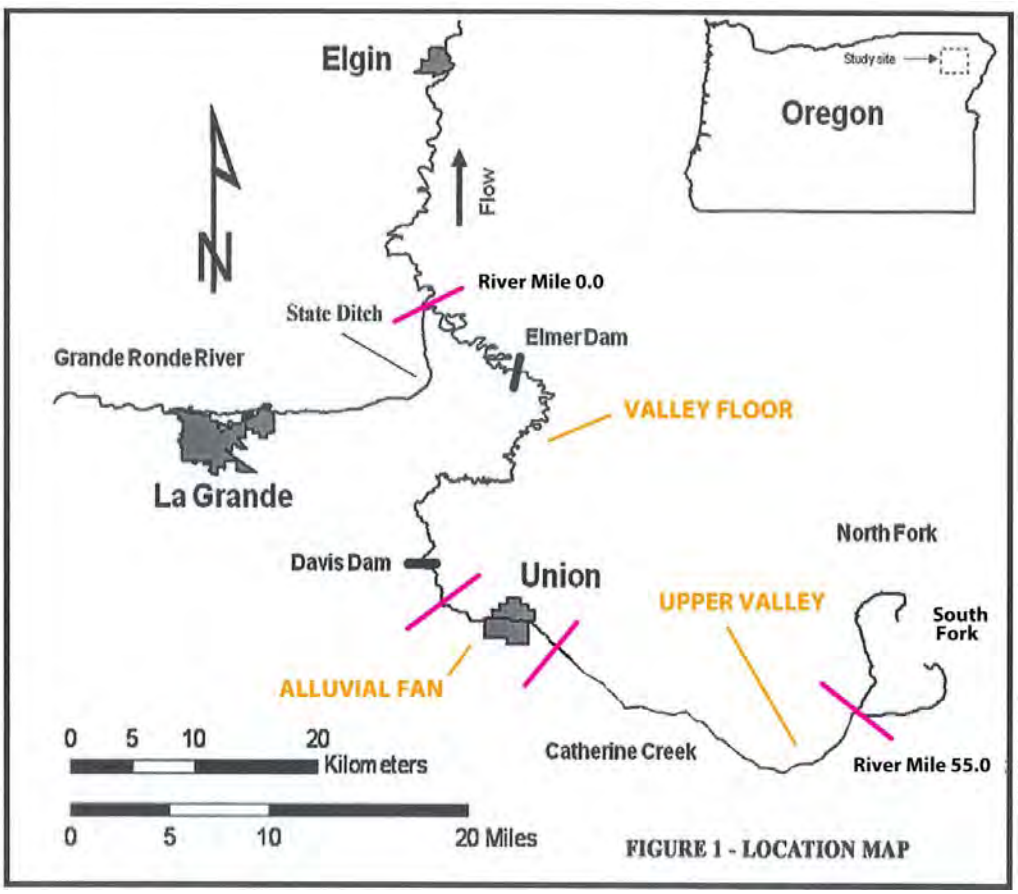

Figure 1. An illustration showing the Grande Ronde Valley and associated features.

2.3 Current Investigations

This report was prepared using historical accounts, ground photographs, maps, aerial photography, LiDAR (Light Deflecting Airborne Radar), USGS 30 meter DEM (Digital elevation Model), existing geologic maps and field mapping performed during the summer of 2010. Catherine Creek reaches were delineated based on physical parameters including geologic and geomorphic characteristics. The findings were compiled into a Geographical Information System (GIS) database.

Field investigations included photographic documentation of geologic and anthropogenic features for the 55-mile segment of mainstem Catherine Creek. Geologic features documented include active channel deposits, bank, and floodplain sediments. Human impacts include channel shortening, channel slope increases, reduced channel migration, and altered sediment transport regime due to mechanical channel straightening and manipulation, and bank stabilization. Specific human features include bridges, roads, culverts, diversions, levees, drains, pumps, and bank protection (riprap, etc.). A complete set of photographs with brief descriptive captions are in Attachment A.

Channel bed and bank sediments were sampled at 11 locations along Catherine Creek. Samples were logged visually and submitted for physical properties and gradation analysis. Samples were classified using methods described in Reclamation's 5005 [Earth Manual, Part 2, Third Edition, and the Unified Soil Classification System (USCS)]. The results of the laboratory testing are shown on the summary and gradation analysis sheets in Attachment B.

Channel bed and bar sediments were sampled using pebble counts at 17 locations. Pebble counts were performed using systematic sampling at evenly spaced intervals along a measuring tape. In most areas, the spacing was 0.5 feet. Sediment bars that were relatively small in length often required multiple transects to complete a minimum of 100 counts. A gravelometer was used in the measurement of each particle size. Pebble count data sheets and graphic plots are in Attachment C of this appendix.

Channel profiles were surveyed using an electronic distance finder and a standard fiberglass survey rod. Channel profiles and cross sections were prepared and used to identify significant natural and human-placed vertical grade controls, determine wetted width, and calculate the active channel width-to-depth ratios. Channel cross-sectional profiles are in Attachment D.

Channel geometry and flow characteristics were measured and calculated from GIS data and survey profiles. A compilation of the measured attributes in provided in Appendix D.

3. Regional Geology

The Grande Ronde Valley and Catherine Creek are within the Blue Mountain physiographic province in northeast Oregon (Figure 2). The modern Grande Ronde Valley is a large structural basin situated along the east flank of the Blue Mountain uplift, bordered by the Blue Mountains to the northwest, the Wallowa Mountains to the east, and the Elkhorn Mountains to the south (Carson 2001).

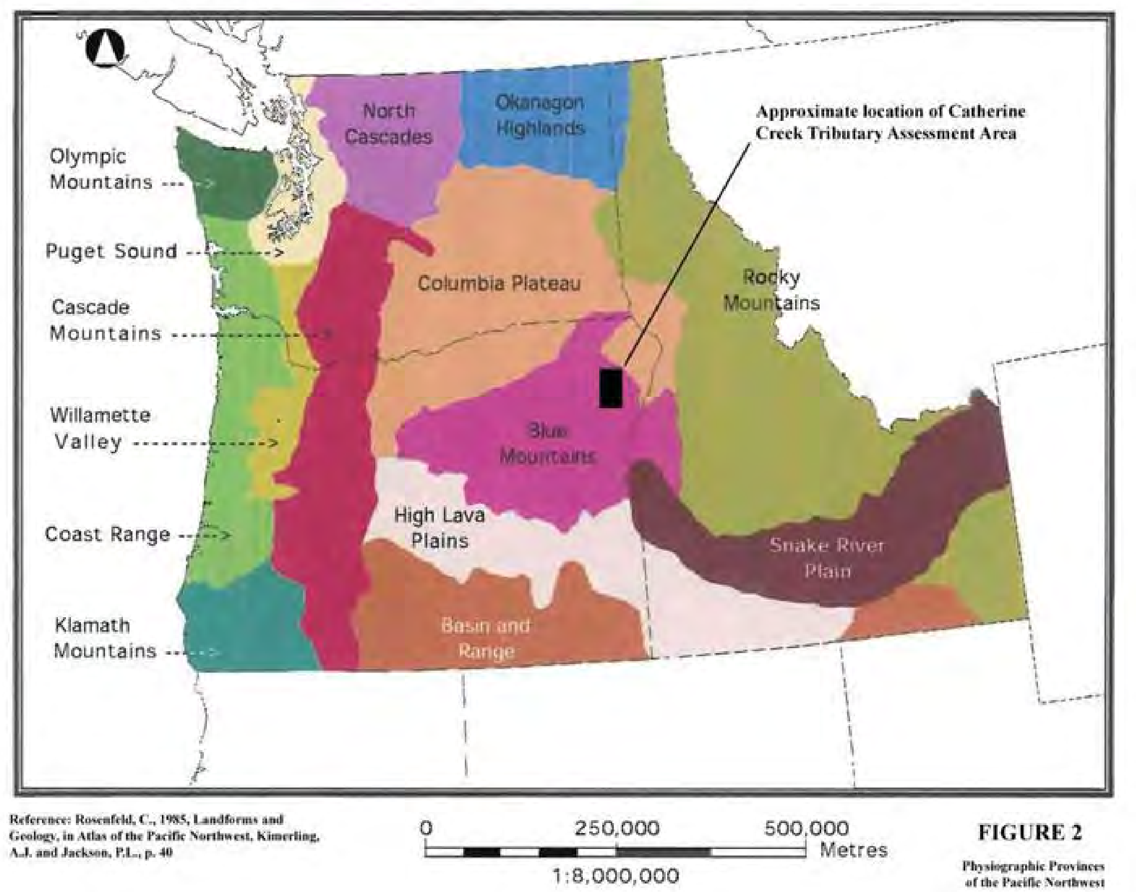

Figure 2. Physiographic provinces of the Pacific Northwest.

Radiometric dating of ash samples from deep wells have been used to determine sediment accumulation and subsidence rates of the Grande Ronde basin. Ash layer dating suggest sediment accumulation began during the Miocene, and that over the last 2.6-millon years the southwest margin of the basin has subsided faster than the northeast side of the basin (Carson 2001). Subsidence of the basin opposite the direction of flows has resulted in a low gradient across the basin and infilling by alternating lacustrine and fluvial depositional conditions along the southern portion of the valley creating what is now a broad, flat plain that Catherine Creek meanders through.

The western most out crops of the Wallowa batholith (Cretaceous) are exposed along the upper reaches of Catherine Creek. The unit is composed of medium-grained granodiorite and tonolite, and fine- to medium-grained diorite. Aside from the granitic rocks of the Wallowa Mountains, the mountains surrounding the Grande Ronde Valley are mostly Miocene Columbia River Basalt Group, Grande Ronde Formation, and younger volcanic rocks of the Powder River Volcanic Field.

A thick sedimentary valley-fill sequence overlies the bedrock in the Grande Ronde basin. The most detailed information on the sediments comes from water wells. In one deep well the valley-fill sediments coarsen upward from a thin section of organic clays and silts, into a 1550-foot-thick section of sandy silt interbedded with thin seams of gravel and sand (Van Tassell 2001). Samples from deep water wells in the valley show mostly river channel, floodplain, marsh, and shallow lake sediments, indicating the basin was never a deep water environment (Carson 2001).

Sequences of laterally discontinuous gravel, sandy gravels, and sandy silts, interfingered with valley margin deposits of poorly sorted bouldery conglomerate and alluvial fan debris suggest the basin fill was largely alluvial and fluvial, and the presence of lacustrine sediments indicates intermittent/temporary damming of the outflow and deposition related to tectonic tilting of the basin (Van Tassell 2001). It has been suggested that ephemeral lakes and marshes developed in part due to periodic damming of the Grande Ronde River by landslides from the western flank of Mount Harris, and landslides at Rhinehart Gap at the northern end of the basin (Ferns et al. 2010).

Glaciation in the Wallowa Mountains contributed many depositional and geomorphic changes in the surrounding river basins (Figure 3). The depositional history of the Grande Ronde Valley during the Pleistocene was dominated by three episodes of alpine glaciations in the adjacent highlands of the Elkhorn and Wallowa Mountains (Ferns et al. 2002). Both the Grande Ronde River and Catherine Creek carried glacial outwash into the Grand Ronde Valley, producing terrace and alluvial fan-delta deposits as sedimentation rates fluctuated during glacial advances and retreats (Ferns et al. 2010). Pleistocene deposits also include air-fall ash from Cascades volcanic eruptions, and loess from outburst glacial flood deposits near Pendleton, which were blown into the basin (Fern 2010).

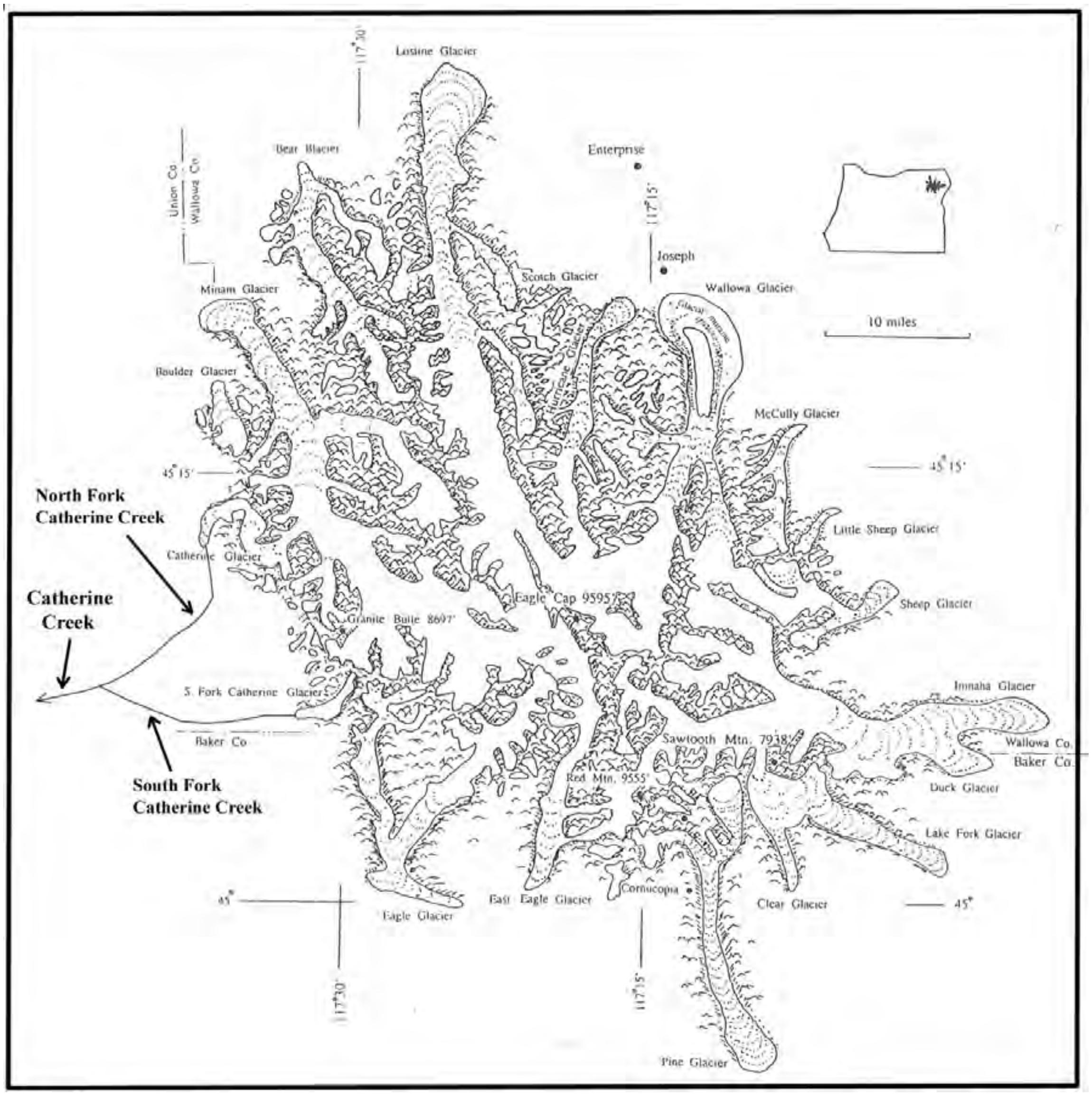

Figure 3. Extent of Pleistocene glaciers in the Wallowa Mountains (Orr 1992).

The modern day floor of the Grande Ronde Valley where lower Catherine Creek runs north to the Rhinehart Gap is a broad, flat alluvial plain, ringed by terraces, alluvial fans, and debris flow and landslide deposits (Van Tassell 2001). Large alluvial fan-deltas have formed where major streams, such as Catherine Creek and the Grande Ronde River, have entered the valley. The valley's alluvial plain is traversed by meandering streams and is marked by marshes and shallow lakes in the south, and low-relief, windswept ridges of aeolian sand and silt in the north (Van Tassell 2001).

Agricultural activity has altered the natural drainage patterns of the Grande Ronde River and Catherine Creek in the last hundred years. Numerous irrigation ditches, drainage canals, and levees have been constructed to control the flow of water. The State Ditch, an 8-mile bypass, was dug around 1870 to aid in the conveyance of flood flows. The ditch evolved to eventually capture all of the Grande Ronde River. As a result, flows in the old Grande Ronde River channel have been significantly reduced and only Catherine Creek now flows through the downstream 22.5 miles. Ladd Marsh and Hot Lake are remnants of a larger lake that occupied the southern end of the Grande Ronde Valley prior to alterations beginning in the 1870s with redirecting of the Grande Ronde by construction of the State Ditch and rerouting of Catherine Creek.

4. Site Geology

The bedrock stratigraphy of the Grande Ronde Valley consists of Tertiary Powder River Volcanic Field and Columbia River Basalt Group (Tb) basalt, andesite and dacite lava flows; Pre-Tertiary meta-sedimentary and intrusive volcanic rocks (Trsv) composed of marine sedimentary rocks (metamorphic limestone); and intrusive volcanic rocks (altered diorite) of the Wallowa Batholith to the east. Surface units consist of a thick valley-fill sequence of alluvium (QTal); valley floor sediments consisting of fine-grained fluviolacustrine sediments (Qal1); alluvial fan-delta (Qfd) and coarse-grained fluvial sediments (glacial outwash) (Qal2); valley margin sediments consisting of landslide deposits (Qls) and colluviums (Qc); and active sediment deposits consisting of loess (L) and active channel alluvium (Qa). The main geologic units are described in general from youngest to oldest in the following sections; on the Geologic Explanation, and shown on cross-sectional profiles in this appendix.

4.1 Active Sediments

Active sediments present in the assessment area include loess (L) and active alluvium (Qa).

Loess (L) consists of homogeneous, non-stratified, slightly indurated deposits consisting primarily of windblown silt with lesser amounts of fine sand, sandy silt and silty sand with some lean clay, including Mazama and older ash-fall deposits. The loess is generally firm, with occasional continuous moderately open vertical parting planes (cracks) forming along the banks of the creek, the loess in these areas tends to become over-steepened, resulting in occasional slab failures when subjected to high stream flows and saturated conditions (Figure 4).

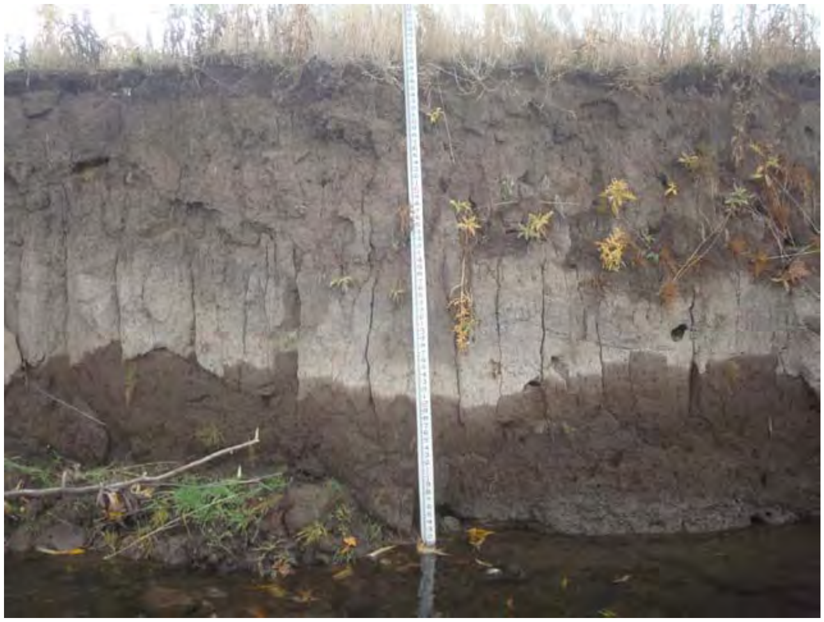

Figure 4. View of loess (L) exposure on the outside bank of a meander bend along Catherine Creek at river mile (RM) 37.25. Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation – November 10, 2010.

Active Alluvium (Qa)

The active alluvium (Qa) is surficial sediment subjected to seasonal transport and deposition cycles within the bed of Catherine Creek, side channels, and floodplain. Two general types of active alluvium material; fine-grained sediment (silt and sand bars) that occupy the lower gradient sections of Catherine Creek; and coarse-grained sediment (gravel, cobble, and boulder bars and riffles) within the upper reaches.

The active alluvium (Qa) in the artificial backwater sections of Catherine Creek (behind Elmer and Davis dams) is submerged (Figure 5) and difficult to observe. However, based on samples from the lower banks, the overall soft texture of the submerged bed, and low gradient of the reach, it is likely the active alluvium consists primarily of fines, including silt, elastic silt, fine sand and clay, derived from sorted upland sediments, and reworked and redeposited valley plain fluviolacustrine and loess sediments (Qal1) eroded from the banks.

Figure 5. View looking upstream at typical section of Catherine Creek, upstream of Elmer Dam at RM 13.60. Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation – July 10, 2010.

The active alluvium grades in an upstream direction from silt and sand, to sand and fine gravel (Figures 6 and 7).

Figure 6. **View looking downstream at active alluvium (Qa) deposits in a sand bar along Catherine Creek at RM 30.89. Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation- July 28, 2010.**

Figure 7. **Close up view of active alluvium (Qa) deposit consisting of medium sand (2 mm) sized fragments, Catherine Creek at RM 31.40. Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation - July 28, 2010.**

The active alluvium (Qa) in the upper reaches of Catherine Creek consists predominantly of poorly sorted gravel with sand, silt and scattered cobbles, derived from reworked and re-deposited alluvial fan-delta (Qfd), and coarse-grained alluvium deposits (reworked glacial outwash (Qal2) (Figures 8 and 9).

Figure 8. View looking downstream at active alluvium (Qa) deposit forming riffles along the bed of Catherine Creek at RM 39.10. Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation – August 2, 2010.

Figure 9. View looking downstream at active alluvium (Qa) deposit forming a gravel and cobble bar along the bed of Catherine Creek at RM 41.65. Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation – August 16, 2010.

About 6 miles east of Union the creek is confined to a canyon formed by bedrock and Oregon State Highway (S.H.) 203 to the north, and a large pre-historic landslide to the south (Figure 10). Here the active alluvium is composed primarily of gravel with sand, cobbles, and boulders. The channel in the vicinity of Catherine Creek State Park, in the area of RM 49.0, is less confined, but the active alluvium (Qa) also consists of gravel, sand and cobbles with boulders and occasional blocks (Figure 11).

Figure 10. View looking upstream at active alluvium (Qa) deposits along the bed of Catherine Creek at RM 46.20. Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation – August 18, 2010.

Figure 11. View looking downstream at active alluvium (Qa) deposits along the bed of Catherine Creek at RM 48.45 (near Catherine Creek State Park). Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation – August 17, 2010.

Catherine Creek upstream of the state park flows through a broad flat valley, referred to locally as Hall Ranch, which is underlain by a thick accumulation of glacial outwash deposited by Catherine and Little Creeks (Carson 2001). The channel is braided and the active alluvium (Qa) is composed of primarily of rounded cobbles with well-sorted (mostly coarse) gravel and sand (Figure 12). The alluvium is derived primarily from reworked glacial outwash (Qg) deposits, and to a lesser extent slopewash and colluvium from the slope on the north side of the valley.

Figure 12. View looking downstream at active alluvium (Qa) deposits along the bed of Catherine Creek RM 51.40. Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation – August 19, 2010.

The upper most section of Catherine Creek again flows through a narrow canyon, from the confluence of the North and South Forks of Catherine Creek downstream to the head of the broad Hall Ranch valley. The valley side slopes are rather steep with shallow bedrock surfaces, the active alluvium is composed of cobbles and gravel with sand and occasional boulder size material (Figures 13 and 14). The active alluvium is derived from slopewash and colluvium from the step side slopes, and reworked glacial till and outwash materials from the upper reaches of the North and South Forks of Catherine Creek.

Figure 13. View looking from right to left at the active alluvium (Qa) forming the bed of Catherine Creek at RM 52.30. Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation - November 10, 2010.

Figure 14. Close up view of active alluvium (Qa) deposit consisting of cobble (3- to 12-inch) size rocks, Catherine Creek at RM 54.86. Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation – November 10, 2010.

Valley Floor Sediments

Valley Floor sediments present in the assessment area includes Fluviolacustrine Sediments (Qal1), Alluvial Fan-delta Sediments (Qfd), and Fluvial Sediments (Qal2).

Fluviolacustrine Sediments (Qal1).

Alluvial plain lacustrine sediments (Qal1) form the banks (Figure 15) and bed (Figure 16) of Catherine Creek throughout most of lower reaches within the agricultural plain of the Grande Ronde Valley. The deposits are stratified (1 to 3 foot layers) and composed predominantly of soft to hard, silt and silty sand (Figure 17). There are also lenses and layers of diatomaceous silts and clays. These sediments are indicative of marsh, low energy fluvial, and shallow lake conditions at the time of deposition (Ferns et al. 2002). Shallow lake and marsh deposits extending north from Hot Lake dominate the southwest end of the valley. Ladd Marsh is the remnant of an extensive shallow lake that covered more than 30 square miles of the Valley Floor prior to construction of the State Ditch and rerouting of Catherine Creek (Ferns et al. 2002). Water well logs indicate the alluvial plain fluviolacustrine sediments are up to about 50 feet thick.

Figure 15. View looking upstream at fine-grained fluviolacustrine sediments (Qal1) exposed along the left bank of Catherine Creek at RM 21.28. Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation – July 11, 2010.

Figure 16. View looking downstream at fine-grained fluviolacustrine sediments (Qal1) forming the bed of Catherine Creek at RM 32.85. Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation – August 1, 2010.

Figure 17. Close up of stratified fine-grained fluviolacustrine sediments (Qal1) exposed on the bank of Catherine Creek at RM 22.70, material consists of brown silty sand (SM) overlain by firm to hard light colored sandy silt and diatomaceous silt. Catherine Creek TA-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation – July 30, 2010.

Alluvial Fan-delta Sediments (Qfd)

The alluvial fan-delta formed where Catherine Creek enters the Grande Ronde Valley near Union. The deposits grade from coarse grained near the mouth of the interfingering with finer grained sediments where the fan merges with the alluvial plain (Ferns et al. 2002). The deposits are composed predominantly of poorly graded gravel with sand, silt, and cobbles, well-graded gravel with sand, silt, and cobbles, and occasional beds of red iron-oxidized silty sand (Figure 18).

Figure 18. View of alluvial fan-delta deposits (Qfd) exposed along the left bank of Catherine Creek river mile 40.33 (union). Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation - August 2, 2010.

Based on well logs, the Catherine Creek fan-delta has a greater percentage of fines than the Grande Ronde River fan-delta, the fines are derived from the heavily glaciated highlands upstream of Union, and a large amount of fine glacial flour was washed down onto the fan-delta by high-flow glacial melt water (Ferns et al. 2002). Gravel that underlies the fan-delta has a maximum thickness of approximately 500 feet, and is about 300 feet thick at Union (Carson 2001). Fan-delta deposits are locally overlain by overbank silt and fine sand deposits and cut by active alluvial channels (Ferns et al. 2002).

Trends of modern and abandoned channels on the fan surface indicate progressive northwestward tilting along the southeast section of the Grande Ronde Valley near Union over time (Ferns et al. 2002). The uphill part of the Catherine Creek fan-delta is likely to be more poorly sorted and contain greater amounts of debris flow deposits, while the distal (downslope) margins become finer where the delta merges with the alluvial plain (Ferns et al. 2002).

Fluvial Sediments (Qal2)

Upstream of Union, Catherine Creek flows northwestward along flat-floored, northwest trending valleys which are underlain by thick accumulations of fluvial sediments (glacial outwash) deposited by Catherine Creek (Ferns et al. 2002). The deposits are derived from glacial till, which are unconsolidated, poorly stratified deposits of silt, coarse gravel, sand and loess, eroded from rocks of the Wallow Batholith, exposed mainly in lateral moraines along the upper reaches of Catherine Creek (Ferns et al. 2010). Glacial outwash, reworked and mixed with fluvial deposits, forms much of the bed and banks of the upper reaches of Catherine Creek. The deposits are composed predominantly of well- to poorly-sorted gravel with sand, silt, and cobbles, with scattered boulders and interbeds of silty sand (Figure 19). The fluvial sediment (glacial outwash) deposits likely interfingered with fan-delta deposits in the middle reaches near Union at the apex of the Catherine Creek fan-delta.

Figure 19. View of fluvial sediments interbedded with silty sand (Qal2) exposed along the right bank of Catherine Creek at river mile 51.02. Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation - August 19, 2010.

Valley Margin Sediments

Valley margin sediments present in the assessment area include landslide deposits (Qls) and colluvium (Qc).

Landslide Deposits (Qls).

Landslide deposits form the south bank of Catherine Creek throughout the canyon section near Catherine Creek State Park (Figure 20). The deposits are composed of unconsolidated, chaotically mixed masses of rock and soil (Gehrels 1981). Landforms are typically hummocky surfaces marked by closed depressions, springs and wet seeps, scarps, cracks and crevices, the landslides deposits are often traceable upslope to scarps or slip surfaces. In the assessment area, the landslides generally originate along contacts between competent lava flows and underlying tuffaceous units (Ferns et al. 2002). The landslide appears to be inactive now with the exception of small-scale erosion at the toe and soil creep along the relatively steep hillsides above Catherine Creek.

Figure 20. View looking downstream along a section where the left bank of Catherine Creek is comprised of landslide debris (Qls) near river mile 46.21. Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation - August 18, 2010.

Colluvium (Qc)

Colluvium deposits at the mouths of small side canyons, exposed primarily along the south side of the valley and along the south bank of Catherine Creek throughout much of reach 4 (Figure 21). The deposits grade down slope from coarse grained boulder to gravel to fine to medium-grained gravel, sand and silt deposits near the Valley Floor (Figure 22).

Figure 21. View looking downstream at colluvium (Qc) forming the left (south) bank of Catherine Creek near river mile 44.00. Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation – September 9, 2011.

Figure 22. Close-up view colluvium (Qc) deposits along the left (south) bank of Catherine Creek near RM 44.00. Catherine Creek Tributary Assessment-Grande Ronde River Basin-Tributary Habitat Program, Oregon – Bureau of Reclamation – September 9, 2011.

Quaternary-Tertiary Valley-fill Sediments (QTal)

The valley-fill is the thickest sedimentary unit in the area, the sediments overly the bedrock and forms the deep valley deposits in the Grand Ronde basin. The sediments are not well exposed in the study area, but detailed information from water wells indicate the valley-fill sediments coarsen upward from a thin section of organic clays and silts, into a 1,550-foot thick section of sandy silt interbedded with thin seams of gravel and sand (Van Tassell 2001). Samples from deep water wells in the valley show mostly river channel, floodplain, marsh and shallow lake sediments, indicating the basin was never a deep water environment (Carson 2001).

4.2 Bedrock Units

Bedrock is exposed along the banks of the upper reaches of Catherine Creek upstream of Union. The bedrock consists of undifferentiated volcanic rocks of the Tertiary Powder River Volcanic Field and Columbia River Basalt Group (Tb) composed of basaltic, basaltic andesite, andesite and dacite lava flows; Pre-Tertiary meta-sedimentary and intrusive volcanic rocks (Trsv) composed of marine sedimentary rocks (metamorphic limestone), and intrusive volcanic rocks of the Wallowa Batholith to the east (Gehrels 1981).

5. Geomorphology

5.1 Introduction

Various geomorphic (physical) processes are responsible for creating and maintaining riverine habitat for multiple aquatic species. The manipulations to Catherine Creek and its floodplain within the TA area have a cumulative impact on the physical processes and instream functions that sustain salmonid habitat. These impacts, to varying levels, collectively contribute to the known limiting factors that include water quantity (low summer flows), water quality (elevated summer temperatures, low dissolved oxygen levels), poor habitat quantity/diversity (low abundance of pool habitat and lack of habitat diversity), returning adult passage, excess fine sediment and degraded riparian conditions (NOAA Fisheries 2008). Below is a general discussion on causes and interrelations between the known limiting factors.

The limiting factor of water quantity is primarily a result of the combination of water withdrawal combined with seasonal low flow. Water quantity is compromised due to mid-July through the end of September withdrawals that can reduce instream flows by 90 to 95 percent (NOAA Fisheries 2008). Additionally, decreed water rights and permitted withdrawals may exceed the actual flow of Catherine Creek (NOAA Fisheries 2008). Reduction of groundwater recharge is due to multiple factors including reduced floodplain interaction during high flow events and reduction of total floodplain area associated with construction of roads and levees and other impervious surfaces, and the development of the floodplain into agricultural use. Low flow conditions can also contribute to other limiting factor conditions. The water quality parameter of elevated summer water temperatures can be exacerbated by low flow conditions. The reduction in water depth in the main channel can increase the effect of the surface warming due to solar radiation. Low flow conditions can lend to the limiting factor of reduced habitat by reducing the overall depth and wetted width (NOAA Fisheries 2008). This would presumably reduce the depth of pools for holding and resting as well as reducing the near bank-rearing habitat. Low flow conditions can also promote the limiting factor of passage by creating upstream and downstream passage barriers in the main channel as well as cut-off passage into tributaries or off-channel habitat.

The limiting factor of water quality has two parameters: elevated summer water temperature and low dissolved oxygen (DO). DO is not addressed in this report. Elevated water temperature is directly related to multiple factors, including degraded riparian conditions, water diversion and return, and reduced river and floodplain interaction. When the riparian vegetation that shades the stream has been altered, or is not present, more solar radiation is absorbed by the stream causing the water temperature to rise. Surface water withdrawals can also contribute to increased temperatures in the main channel by reducing the depth of water in the channel as described above. In addition, the water that is diverted off the main channel may absorb greater amounts of solar radiation given the shallow depth and lack of vegetation along most ditches or ponds before returning to the main channel via surface flow. Another contributor to the elevated summer temperatures in the very low stream gradient on the valley floor. The low gradient leads to very low water velocities that can in turn lead to the thermal stratification of the water column. With thermal stratification, the warmest water is at the surface and essentially warms the water that flows through the fish ladders at diversion dams, and may create a thermal barrier. Reduction of groundwater recharge as described above can also promote elevated summer water temperatures. Floodplain interaction at high flow allows water to enter the hyporheic zone via infiltration. This water is “stored” in the ground to return to the main channel as cooler recharge water during times of low flow.

Fish passage is listed as a limiting factor, and is related to or a product of one or more other conditions or manipulations. One of the causal conditions for reduced fish passage is low flow, which is described above. Extreme in-channel low flow can cause a migration barrier to both returning adults as well as smolts attempting to migrate within Catherine Creek (NOAA Fisheries 2008). Elevated summer water temperatures and thermal stratification can also impede passage, as described above. Increased amounts of absorbed solar radiation combined with low flow can elevate summer water temperatures to limit access of returning adults as well as summer rearing (NOAA Fisheries 2008). During high flows, loss of instream habitat complexity from bank hardening, channelization, and reduced large wood in the channel can also result in velocity barriers to certain life stages of Chinook and salmon.

Habitat quantity and diversity is also a limiting factor. The reduction of habitat quantity and diversity likely began with modifications that took place beginning soon after the settlement of the valley by Anglo-European settlers in the mid to late 1800s and continued until as recently as the mid-1970s. Past logging practices have reduced the amount of large wood available from the upland areas. The implementation of agricultural land use practices including the conversion of wetlands, meadows, and multiple channel systems to grazing and crop production has decreased areal extent of off-channel habitat and reduced diversity of instream habitat. Vegetation removal or conversion from riparian species to agricultural or upland species decreases large wood recruitment for instream complexity and cover, and reduces nutrients and food for aquatic macro-invertebrates that fish feed on. Bank armoring and or channelization reduce the natural rates of channel migration. Channel migration is a product of bank erosion accompanied by bar building on the opposite bank. Erosion of the bank supplies needed sediment and potentially some woody debris to the system. Concurrent bar building through deposition provides low floodplain surfaces for colonizing vegetation (such as cottonwoods) and high-flow refuge for fish. Disturbances to the balance between erosion and deposition often result in a depletion of one or the other. When that occurs, processes that create and maintain diverse habitat types are not able to do so. The result is a decrease of in-channel complexity and habitat diversity. Reduced habitat quantity is further attributed to low flow conditions including velocity barriers, described above.

The limiting factor of excess fine sediment has been well documented (GRWQC 2000; NOAA Fisheries 2008; Nowak 2004). Fine sediment can come from multiple sources. Sections of bank throughout the assessment area that have altered or removed vegetation are more susceptible to localized erosion. Fine sediment can also be incorporated into the system by scour of the floodplain surface during high flow. Another source of fine sediment input can be from upstream/upland sources where logging and subsequent fires have altered the surface runoff characteristics and increased fine sediment input. Increased levels of fine sediment can degrade potential spawning habitat by increasing the level embeddedness of spawning gravels, as well as reduce the survival during the incubation period (NOAA Fisheries 2008). In areas where floodplain interaction has been reduced through levees or channelization, the fine sediment remains in the system rather than being allowed to deposit on the floodplain (NOAA Fisheries 2008).

5.2 Purpose and Scope

The primary objectives of the geomorphic assessment are to:

- Delineate and describe geomorphic reaches based on differing geomorphology that includes:
    - Natural controls on morphology including geology, valley confinement, and valley and channel gradient.
    - Historic conditions
    - Current channel form and process.

Additional objectives include:

- Discuss the conditions and processes noted above as they relate to or contribute to the identified limiting factors that affect the reproduction and/or survival of salmonid species.
- Discuss initial rehabilitation strategies that address the current conditions/limiting factors that are affecting the reproduction and/or survival of salmonid species.

5.3 Geomorphic Reach Delineation

Geomorphic reaches along Catherine Creek were identified based on differences in physical parameters that include channel gradient, surficial geology, physical processes, and valley confinement, and grouped by area (Figure 23). Individual reach boundaries are determined by physically significant differences in these parameters. Seven geomorphic reaches were identified within the TA area on Catherine Creek. These reaches are combined into three groups as noted in Table 1 to facilitate discussion of general physical characteristics.

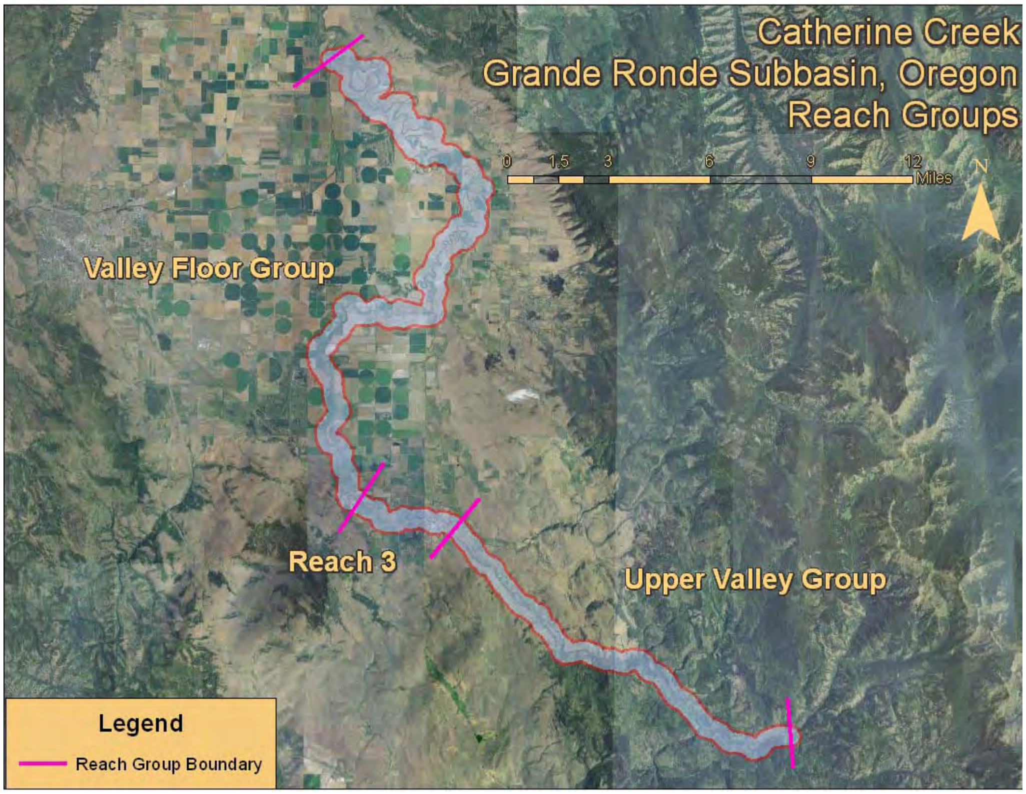

Figure 23. A plan view showing the geomorphic reach groups on Catherine Creek.

Table 1. Locations, surficial geology, confinement classification, and grouping of geomorphic reaches along Catherine Creek.

Geomorphic Reach	Location by RM	Surficial Geology	Confinement Classification	Group
7	52.0 – 54.9	Alluvium/bedrock	Confined	Upper Valley Group
6	50.11 – 52.0	Alluvium	Unconfined	Upper Valley Group
5	45.8 – 50.11	Alluvium/Landslide	Confined	Upper Valley Group
4	40.78 – 45.8	Alluvium/Bedrock	Unconfined	Upper Valley Group
3	37.2 – 40.78	Alluvium (Fan-delta)	Unconfined	Alluvial Fan
2	22.5 – 37.2	Fluvial-Lacustrine	Unconfined	Valley Floor Group
1	0.0 – 22.5	Fluvial-Lacustrine	Unconfined	Valley Floor Group

5.3.1 Upper Valley Group, Reaches 7 through 4

Geomorphic reaches 7 through 4 comprise the Upper Valley Group on Catherine Creek. The group includes the area from the confluence of the North and South Fork of Catherine Creek near RM 54.9 downstream to the valley mouth, just upstream of the town of Union at RM 40.78 (Figure 24). Within the Upper Valley Group, the reaches range from confined to unconfined by bedrock hillslopes that form the valley walls, with the valley floor being comprised of alluvium. The valley walls within the Upper Valley Group are comprised of bedrock that includes dacite and basalt in the lower and mid-sections of the valley segment, and andesite, basalt, and argillite in the top section (Ferns et al. 2010). Other units mapped by Ferns et al. (2010) include local landslides and a large debris flow/debris avalanche. Channel bed and bank materials were observed to range from boulders to silt-sized material. Natural lateral and vertical control in the Upper Valley Group comes from bedrock and the coarser fraction of alluvium and landslide material that includes boulders, and cobble. The overall channel gradient averages about 1.1 percent within the Upper Valley Group. Banks range from gently sloping with grass, willow, small tree and a few large trees (Figure 25). Large and small trees are defined as 21 to 31.9 inches diameter-at-breast-height (dbh) and 9 to 20.9 inches dbh, respectively (USFS 2008). In reaches 4 and 6, the majority of the floodplain has been altered to agriculture or pasture land. Vegetation along the banks includes willow, aspen, and small cottonwood trees. Small stands of relic cottonwood galleries are present along the banks and in the floodplain. In reach 6, floodplain that had been converted to grass and pasture land is now returning to native floodplain and streambank species. Current use by Chinook salmon and steelhead includes migration, spawning, and rearing (NOAA Fisheries 2008).

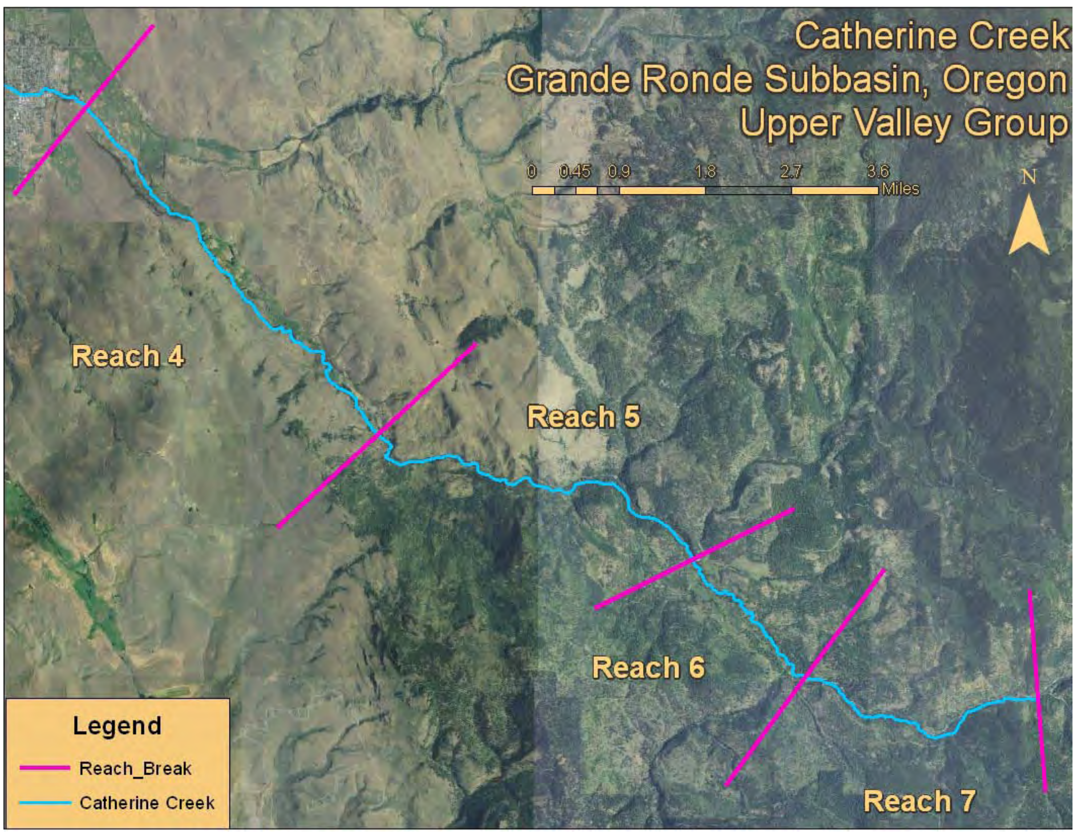

Figure 24. Location map of the Upper Valley Group on Catherine Creek, with reaches sequentially numbered from upstream to downstream.

Figure 25. Various bank conditions, vegetation, and substrate in the Upper Valley Group.

Historic Conditions.

Historically, within the Upper Valley Group, Catherine Creek likely looked similar to the way it looks today. The stream would have alternated between higher energy, confined reaches with lower sinuosity, and unconfined reaches with greater sinuosity and lower stream energy. The general vegetation composition within the Upper Valley Group reaches would have likely consisted of riparian galleries that included cottonwood, aspen, and willow in the unconfined reaches (NOAA Fisheries 2008). Floodplain vegetation likely consisted of grasses and shrubs with wetland vegetation in areas inundated by or connected to beaver complexes. Extensive beaver activity would have created diverse instream and floodplain habitats, with deep pools and strong connections to floodplains in the unconfined reaches (NOAA Fisheries 2008). Large woody debris (LWD) would have been present on the floodplain and instream where it would have added to channel complexity. Catherine Creek likely migrated within its floodplain in unconfined areas, which would have supplied some woody debris to the channel; however, the rate of migration into and through mature stands would have been slow enough that this would not have provided the majority of LWD to the stream.

Instream LWD was likely supplied primarily from upland coniferous forests via debris flows or mass wasting events from excessive rain and/or rain-on-snow events (NOAA Fisheries 2008). Once incorporated, the large wood may have only migrated a short distance downstream during large run-off events due to flatter gradients and depositional processes in the unconfined reaches. In-channel substrate would have been coarser in the confined reaches and finer in the unconfined reaches, similar to present day conditions.

Current Conditions

Conditions including sinuosity, width-to-depth ratios and valley and stream gradient have likely changed as a result of the manipulations that have been applied by humans to the channel, banks, and floodplain of Catherine Creek in the Upper Valley Group. Observed shortening of the channel would have increased the stream gradient by decreasing sinuosity over the same valley length potentially resulting in local changes to the width-to-depth ratio access to the floodplain or the floodplain width. Essentially all of the observed manipulations to the channel and floodplain were completed by the earliest set of complete aerial photographs (1956). However, some change is still detectable through remote analysis of the later aerial photographs. The results of the remote analysis showed that channel sinuosity has slightly increased in reach 4 from 1.05 in 1956 to 1.07 in 2008. In reach 6, there was a slight increase from 1.11 in 1964 to 1.19 in 2008, likely due to the river readjusting to decreased levels of ‘management’. In reach 5, the sinuosity decreased from 1.08 in 1964 to 1.06 in 2008. In reach 7, the sinuosity remained relatively constant from 1956 to 2008. In both cases, where amounts of increase and decrease in sinuosity were noted the amount of change is small and could partially be contributed to parallax, where the edges of the areal image are distorted. In addition, the image quality of the earlier aerial photos made precise mapping and analysis difficult.

Results from field measurements, observations, and remote analysis using GIS software show that the geomorphic conditions differ from reach to reach in the Upper Valley Group (see Attachment A – Photographic Documentation, of reaches 7 through 4). Stream gradients range from 1.57 percent to 0.83 percent, and valley gradients range from 1.64 percent to 0.89 percent. Both steadily decrease in the downstream direction. The average width to depth ratio is 27:1. Reach 5 has the lowest width to depth ratio at 20:1, and reach 6 has the highest at 34:1 (Table 2) (see Attachment D for drawings of cross sections in reaches 7 through 4).

Table 2. Valley and channel gradients, sinuosity, and width-to-depth ratios of the Upper Valley Group of reaches on Catherine Creek.

Geomorphic Reach	Valley Gradient (percent)	Stream Gradient (percent)	Sinuosity	Average Width:Depth
7	1.64	1.57	1.04	28:1
6	1.50	1.25	1.19	34:1
5	1.10	1.00	1.06	20:1
4	0.89	0.83	1.07	25:1

Calculated sinuosity values for each reach within the Upper Valley Group are similar, with the exception of reach 6, an unconfined reach. Within reach 6, the sinuosity has increased, and therefore the channel gradient has decreased. This is due to the stream readjusting to the impacts to the stream that occurred in association with the construction of Highway 203/Medical Springs Highway sometime prior to 1937. Reach 4, the other unconfined reach, has a low sinuosity. Reasons for the lower sinuosity in the reach include sections of more coarse substrate and reduced sediment supply, as well as lateral and vertical control of bedrock. Reaches 7 and 5 are naturally confined; therefore, a low sinuosity value in those reaches is considered normal, and has not likely changed compared with historic conditions.

Pebble counts were conducted in each reach in order to develop grain size distribution curves for substrate in the active channel bottom including the thalweg and bars (see Attachment B for complete set of grain size distribution curves). The dominant substrate of the Upper Valley Group is cobble and gravel; however, boulders, sands, and fine material were also observed. The D_{50}, (meaning that 50 percent of the material is smaller than that size) measurements for the Upper Valley Group range from 33.5 mm in reach 6 to 70.9 mm in reach 7, with the average D_{50} for the Upper Valley Group being 56.2 mm (see Table 3 for complete gradation averages).

Table 3. Average gradation analysis of in-channel substrate within the Upper Valley Group on Catherine Creek.

Reach	Average Diameter of Substrate (mm)				
	D_{15}	D_{35}	D_{50}	D_{84}	D_{95}
7	37.7	57.1	70.9	119.8	191.2
6	4.3	18.9	33.5	93.5	142.3
5	21.7	48.1	63.2	120.4	166.6
4	29.2	44.8	57.2	111.2	157.1

Physical Processes

Channel migration, sediment transport, and large wood recruitment are the primary physical processes that create and maintain instream salmonid habitat in Catherine Creek. Each is discussed individually below.

Migration

Observed evidence of vertical and lateral migration within the Upper Valley Group area varied from reach to reach as well as within each reach with sections of bank showing signs of local scour and/or undercutting commonly observed in all reaches (see Attachment A – Photographic Documentation). In reaches 7 and 5, overall migration rates are low due to natural conditions/controls such as non-erosive bedrock and coarse-grained bed and bank material, increased confinement, and steeper gradient. In reach 6, observed indications of active lateral migration included vertical bare banks, with associated meander/lateral sediment bar deposition, bifurcation and avulsion of the channel as a result of the high spring flow from 2010. These observations as well as bar formation and growth in reach 6 indicate that the vertical and lateral migration rates are somewhat representative of a stream that is in dynamic equilibrium. In reach 4, areas with low migration rates exist at the bottom and top of the reach, although some local bank erosion is noted to be occurring in the top section. The overall low migration rate in these sections can be attributed to bedrock and coarse alluvial material that act as natural vertical and lateral migration controls. In the mid-section of reach 4 from approximately RM 44.0 upstream to RM 44.95, accelerated rates of migration are noted to be occurring, with rapid migration occurring multiple times, the most recent occurring during the spring high low of June 2010 being the most recent (Dyke 2010; 2011). The accelerated rate is due to a combination of erodible bank materials and altered riparian vegetation.

Sediment Transport

Initial sediment transport calculations utilizing data collected at cross-sections that includes particle sizes of D_{50} (meaning 50 percent of the material is smaller than) and D_{84} (meaning 84 percent is smaller than) and general channel geometry (bankfull width and depth) and average channel slope were used to calculate hydraulic radius, shear stress and critical shear stress. The HEC-RAS model was not built for reaches 5, 6 and 7. Shear stresses calculated from cross-sections range from about 1.6 lb/ft^2 in reach 7 to 1.2 lb/ft^2 in reach 5. HEC-RAS model results show a reach average shear stress of around 1.1 lb/ft^2 at a 1.5 year recurrence interval in reach 4 (Appendix D). However, there is a wide range of conditions throughout each reach including slope, estimated bankfull area, wetted perimeter, and sediment size in reach 4. Overall, reach 7 is a sediment transport reach with s steep slope and coarser substrate. Reach 6 is a sediment storage reach as noted by large point bars and local channel evulsions due to sediment build up. Reach 5 is predominantly a sediment transport reach as it is confined with a narrow floodplain. The top and bottom sections of reach 4 are primarily sediment transport sections. In both sections the channel is somewhat confined with coarser substrate. The mid-section is a sediment storage sections with smaller substrate, numerous point bars, increased lateral migration rates, as well as noted channel evulsion sites.

Large Wood

Observed occurrences of large wood within the active channel were low. Small sections of live large trees were observed growing along the banks and within the floodplain throughout the Upper Valley Group area. Although some wood (cottonwood and Alder) was likely supplied to the stream from the banks on the valley floor by beaver activity, blow down, and mortality, the main source of large wood is likely from mass wasting in upland forests resulting rain-on-snow events or intense rainstorms.

Anthropogenic Manipulations

Although beyond the scope of this effort, impacts to the headwater areas of the subbasin should be noted. Over 11,000 acres of the upland vegetation has been altered by logging practices. Additionally, over 4,000 acres have been burned in forest fires since 1985. The channel, banks, and adjacent floodplain areas within the Upper Valley Group on Catherine Creek have all experienced anthropogenic manipulations to some degree. Manipulations generally include road construction and bridges, bank protection measures, alteration of floodplain and bank vegetation, surface water withdrawal sites, and in some cases, possible channel relocation. The individual reaches exhibit increasing degrees of impacts from past and ongoing manipulation as one moves from the upper most reach (7) downstream.

Manipulations to the channel or within the floodplain in reach 7 appear to be minimal, aside from possible alteration to the vegetation from land clearing and grazing. Human features along the banks in reach 7 are limited to a single bridge at the downstream end. A road that traces along the north side of the valley along the transition from the floodplain of Catherine Creek to the adjacent upland slopes for the entire length of the reach (Table 4). The road may slightly alter the timing of runoff and the sediment input to the system, but the impact to channel processes is likely minimal. It should be noted that the entire length of reach 7 was not surveyed due to access issues. If further assessment or project identification and development occur in reach 7, the entire reach should be evaluated.

Table 4. List of anthropogenic features in reach 7 on Catherine Creek.

Reach 7 Anthropogenic Features		
Anthropogenic Feature	**Quantity**	**Length (ft)**
Bridge	1	

Reach 6 has undergone manipulations to the channel and floodplain. The 2009 LiDAR imagery indicates that 26 acres has been disconnected from the main channel by Highway 203/Medical Springs. In addition, vegetation has been cleared or altered and land use includes historical grazing. The area is now the Eastern Oregon Agricultural Research Center. Grazing does take place within the riparian area on an annual basis; however, the amount of time that the grazing is allowed is limited (DelCurto 2011). Human features noted along the stream in reach 6 are small sections of bank protection associated with Highway 203/Medical Springs Highway and a small section of gravel road, both of which are located at the upstream end of the reach. In addition, Highway 203/Medical Springs highway bisects the left floodplain for the entire length of the reach (Table 5).

Table 5. List of anthropogenic features in reach 6 on Catherine Creek.

Reach 6 Anthropogenic Features		
Anthropogenic Feature	**Quantity**	**Length (ft)**
Road (paved/Unpaved)		9,697
Bank Protection		334

Within reach 5, Catherine Creek runs adjacent to Medical Springs Highway/203 along the right bank for about a quarter of the reach length. Subangular to angular riprap protects the road prism in essentially all instances where the road prism forms the right bank of the stream. Another method of bank protection that was observed within the reach was cabled log bank protection along the left bank, downstream of the bridge near RM 47.6 (Table 6).

Table 6. List of anthropogenic features in reach 5 on Catherine Creek.

Reach 5 Anthropogenic Features		
Anthropogenic Feature	Quantity	Length (ft)
Road (paved/Unpaved)		6,640
Bank Protection		5,693
Bridge	5	
Historic Abutment	3	
Push-up Diversion	1	
Well	1	
Submersible Pump	1	
Gauge	1	

Reach 4 has potentially been manipulated to the largest degree of all the reaches in the Upper Valley Group. In the downstream end of the reach, the general location of Catherine Creek along the left valley wall is likely controlled by cross-valley sloping caused by the Catherine Creek Fault, which shows displacement down and to the east (Ferns et al. 2010). However, in the areas of RM 41.1 and 41.5 the 2009 LiDAR imagery show evidence of past migration in the form of channel scars. The 1937 aerial imagery shows differences in vegetation that also suggest that the stream could have meandered away from the left valley wall in these two areas prior to the original construction of Highway 203/Medical Springs Highway. Additional sections of channel scars are visible in the LiDAR in the upstream section of the reach. Migration in these locations was likely the result of the channels response to large flow events that delivered significant amounts of bedload and debris from upstream, choked the channel causing some avulsion, and then over time the channel eventually returned to its "original" position controlled by slope/topography and structural geology. Other human features along the banks include multiple bridges, head gates, and both channel spanning concrete as well as pushup type diversions associated with surface water withdrawals, multiple sites of surface water return, and four round concrete vaults of unknown use or purpose (Table 7).

Table 7. List of anthropogenic features in reach 4 on Catherine Creek.

Reach 4 Anthropogenic Features		
Anthropogenic Feature	**Quantity**	**Length (ft)**
Road (paved/Unpaved)		5,766
Levee		866
Bank Protection		2,989
Bridge	3	
Headgate	2	
Channel-spanning Diversion	2	
Push-up Diversion	3	
Concrete Vault	4	
Surface Water Return	5	

Impacts

The impacts of past logging practices and fire history in the headwater area of the Catherine Creek subbasin have impacts over the entire length of Catherine Creek. The two collectively can alter the volume and timing of surface run off and sediment input characteristics to the main channel as well as large wood input. Within the assessment area, manipulations to the floodplain, channel cross-section, banks, and planform of the channel within the Upper Valley Group area also collectively have an impact to the physical function of Catherine Creek. These impacts, both directly and indirectly, contribute to the known limiting factors. Cumulatively, this list of impacts and associated limiting factors affects all life stages of Chinook salmon and steelhead (NOAA Fisheries 2008). The limiting factors and the relationships to each other were previously discussed in the Introduction section of this appendix. Below, each of the limiting factors is discussed as it pertains to the manipulations observed in the Upper Valley Group area.

Water Quantity

In the Upper Valley Group, the limiting factor of water quantity is likely a culmination of multiple factors. Reduced floodplain interaction during high flow events as a result of levees, channelization, and development of the floodplain into agricultural use predominantly in reach 4 and 6, may contribute slightly to the water quantity limiting factor by reducing the levels of low flow recharge. There are a total of nine surface diversions or pumps in reaches 5 and 6 that take water from the main channel. However, the combination of seasonal low flow and surface water withdrawals likely do not create adverse low flow conditions in the Upper Valley Group. The limiting factor of water quantity is likely a cumulative effect that is more pronounced in the downstream reaches.

Elevated Summer Water Temperature

In addition to the nine water removal sites discussed above, there are five surface return sites that were observed in reach 4 that likely return warm water to the main channel. Vegetation along the channel and in the floodplain has been altered or removed to the greatest extent in reach 4, followed by reach 6. The alteration or removal of the vegetation allows for an increase in the amount of solar radiation that is absorbed by the water in the main channel. Reaches 5 and 7 also have altered vegetation along the banks and within the floodplain, although to a lesser degree. Reduced floodplain interaction during high flow events as a result of levees, and channelization, and development of the floodplain into agricultural use predominantly in reach 4 and 6 reduces the amount of cool water input during low flow conditions (see Tables 5-7). A flight that recorded water surface temperatures with forward looking infared (FLIR) was conducted in 2000 by Watershed Sciences, LLC. The results show a steady warming from the confluence of the North and South Forks at the top of reach 7 downstream to the confluence with Little Catherine Creek at the bottom of reach 6. Another section of warming was noted from RM 44.7 near the top of reach 4, downstream to RM 41.6, near the bottom of reach 4.

Habitat Quantity and Diversity

In unconfined alluvial systems such as reaches 4 and 6, beaver activity is one mechanism that promotes physical processes such as river and floodplain interaction and channel migration that produces and maintains different habitat types within the main channel and floodplain. Conversion of wetlands, meadows, and multiple channel systems to pasture and cropland in these unconfined reaches also results in decreased areal extent of habitat and reduced diversity of instream habitat. Reduced habitat quantity is also attributed to surface water withdrawals by reducing first the depth and then the wetted width of the channel (NOAA Fisheries 2008). Less water can also contribute to a reduced amount of low energy habitat found along the margins of the stream, as well as overall number and or depth of pools. Another contributing factor to the reduction in quality and diversity of habitat may be a result of channel-spanning diversion dams in reaches 4 and 5. Dams have multiple effects on the stream and physical processes. The dams act as artificial grade control structures that alter sediment transport characteristics and reduce dynamic adjustment to changes in sediment load and hydrology. The backwater area upstream of the dams becomes an artificial depositional zone, filling existing pools with sediment. Pools may not be re-established in the low energy environment that exists upstream of the dam during high-water events that normally would mobilize sediment (during channel forming or greater flow recurrences).

Fish Passage

Those conditions and contributors that contribute to the overall limiting factor of fish passage include the nine surface withdrawal sites in reaches 4 and 5 and the noted warming trends in the downstream direction within the valley segment. In addition, there are channel-spanning diversion dams; both concrete and push-up type within reach 4. Although all of the concrete dams have fish ladders, fish passage effectiveness at low flow remains unclear, as communicated by local biologists in a 2011 habitat work session. The push-up type diversions may also be migration barriers from a height as well as a velocity standpoint.

Fine Sediment

The limiting factor of fine sediment has been well documented (GRWQC 2000; NOAA Fisheries 2008; Nowak 2004). Fine sediment can come from also has multiple sources. Banks throughout the Upper Valley Group are comprised of 4 to 12 inches of silt sand and clay overlying gravel and sand with cobble. Sections of bank in all four reaches that have altered or removed vegetation are more susceptible to localized erosion. Fine sediment can also be incorporated into the system by scour of the floodplain surface during high flow. Another source of fine sediment input can be from upstream sources where logging and fires have altered the surface runoff characteristics and increased fine sediment input. As with temperature and water quantity, the effects of fine sediment are likely a cumulative result that increases in the downstream direction. Increased levels of fine sediment can degrade potential spawning habitat by increasing the level embeddedness of spawning gravels, as well as reduce the survival during the incubation period (NOAA Fisheries 2008). In areas where floodplain interaction has been reduced through levees or channelization, the fine sediment remains in the system rather than being allowed to deposit on the floodplain (NOAA Fisheries 2008). Fine sediment that is deposited in the artificial backwater areas upstream of channel spanning diversion dams is likely flushed during bankfull or channel forming flow, but only after the initial aggradation that would occur as a result of the channel adjusting to the artificial grade control that the structures impose.

Riparian Condition

Within the Upper Valley Group, riparian vegetation along the banks and within the floodplain has been altered to varying degrees. The alterations contribute to multiple limiting factors including elevated water temperatures, excess fine sediment, and reduced habitat quality and quantity. Effects from habitat modification, increased fine sediment, and increased water temperature could all be improved with the enhancement of vegetation condition (GRWQC 2000). While not the only problem, riparian habitat degradation is a serious problem and addressing this issue will also indirectly address temperature, stability, sediment, other water quality factors and habitat (GRWQC 2000).

Conclusions

Anthropogenic impacts within all four reaches in the Upper Valley Group on Catherine Creek contribute to the identified limiting factors for salmonids. These impacts result from human alterations including channelization, hardened banks, levees, instream diversion dams, water withdrawals, altered riparian and floodplain vegetation, reduced large wood recruitment to the stream, and reduced and hardened floodplain areas.

Recommendations

In order to address the causes of the limiting factors within the Upper Valley Group, an approach that uses a strategy of prioritizing rehabilitation activities based on potential long-term benefit as described by Roni et al. (2002) should be considered. Components of the strategy could address the immediate need to increase habitat quality and quantity by adding complexity and cover in the main channel within the reach group. The addition of wood or other structures in the main channel would increase channel roughness and hydraulic complexity, which would increase habitat quality by adding channel complexity and instream cover for rearing and migrating Chinook salmon and steelhead. Habitat quantity would be improved due to the increased number of scour pools that would potentially form as a result of the stream adjusting to the new hydraulic feature and channel roughness.

The focus of rehabilitation efforts in the Upper Valley Group reaches should include multiple strategies that;

1. Restore long-term processes.
2. Restore short-term habitat.

Restoration of long-term processes include: re-initiating floodplain processes, including floodplain access through increased overbank flow which may alter the energy regime within the channel, allow more diverse bedform development and increased variability of hydraulic conditions within the channel, and provide groundwater recharge to floodplain areas that provide long-term flows to the channel; and increasing channel migration will increase habitat quality and quantity by redistributing sediment and debris, adding woody materials to the channel, and increase length and area of active channel and associated habitat. In addition, when components of the strategy of restoring short-term habitat, such as instream large wood are combined with re-initiation of long-term processes, additional habitat quality is gained. Identifying appropriate strategies and individual projects that would allow floodplain access and channel migration to re-establish in areas of willing landowners should be completed at the reach scale.

5.3.2 Alluvial Fan Reach; Reach 3

Reach 3 extends through the Catherine Creek alluvial fan from the downstream end of reach 4 at RM 40.78 downstream to the toe of the alluvial fan at RM 37.2 (Figure 26). The town of Union is located in the upstream half of the reach.

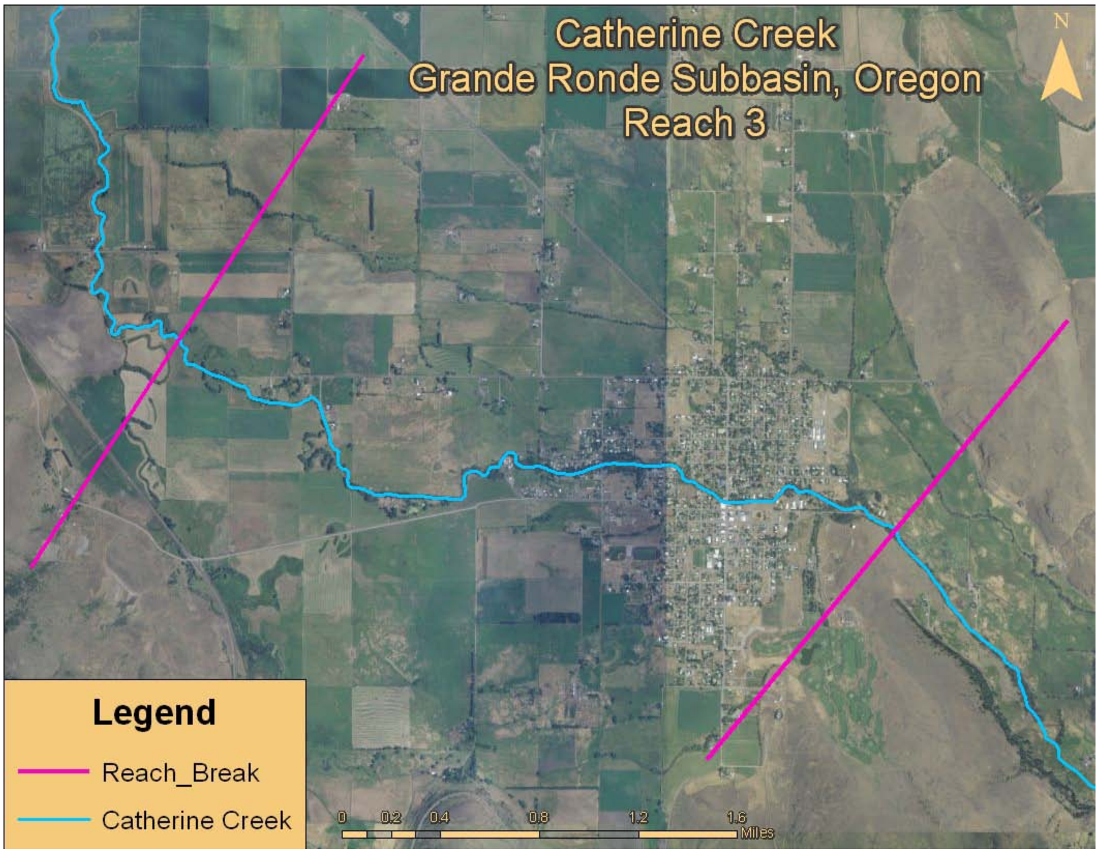

Figure 26. Location map of reach 3, which covers the Catherine Creek alluvial fan.

Reach 3 is developed on an alluvial fan deposit from the Pleistocene and early Holocene (between 25 million and 12,000 years ago) which extends upstream and downstream from Union, Oregon. This reach is naturally a gently sloping fluvial fan-delta that developed through alluvial processes (Ferns et al. 2010). The floodplain functions differently than a typical fluvial floodplain. Being on an alluvial fan, this reach was pre-historically dynamic with multiple high-flow channels. Flooding would have spread out across the sloping fan surface as sheet and distributary flow rather than in a discreet floodplain, and fine sediment would have been dispersed without building a typical depositional floodplain surface. The channel would have been single-threaded following seasonal high flows or sediment transport events, but the channel location may have switched back and forth between multiple channels across the fan surface. The lower third of the reach would have had a more developed floodplain due to lower gradient and finer grained sediment than the upstream two-thirds of the reach. This fan structure and the processes that formed it are remnant from the post-Pleistocene runoff and wetter climates. Present day Catherine Creek is "underfit" in that it is superimposed on the old fan surface and channels without having the sediment load, competency, or capacity to continue the physical processes that built the fan. The stream has adjusted to a different type of system in this reach. The lower third has developed into an unconfined alluvial channel with fine-grained banks that can be eroded, allowing the channel to develop a meandering planform. The upper third to two-thirds is likely developed within the most recent channel from the alluvial fan processes, without enough flow volume and competency to significantly interact with the banks. Thus, today's "channel forming flow" likely does not do much in the way of channel cross-section development and maintenance and the channel would not be expected to migrate.

Material directly adjacent to the stream has been mapped as alluvium and described as channels locally choked with overbank silt by Ferns et al. (2010). Material in the floodplain has been mapped as fluvial fan-delta deposits (Ferns et al. 2010). Channel bed materials were observed to be predominantly cobble and gravel with boulders present in the upstream section. Bank materials were observed to be inter-bedded sands, gravel and cobbles, indurated fine sand and iron oxidized, moderately cemented gravel and cobble. Natural lateral and vertical control in reach 3 appears to come from a combination of the substrate size and cohesive and/or cemented condition observed. In addition, there is an anthropogenic component to the lateral and vertical control provided by various anthropogenic features including multiple grade control structures, channel spanning concrete diversion dams, and bank protection, including riprap and concrete walls along the edge of the channel. There is also apparent channel straightening with remnant oxbows cut-off from the main channel. Banks range from gently sloping with grass, shrubs, and some mature trees; to banks that are vertical and artificially constructed (Figure 27). Some instances of bank trampling were observed, particularly in the downstream end of the reach. Within the town of Union in the upper section of reach 3, the majority of the current land use practice is commercial and residential. Land use practices include agricultural land beyond the town limits. Results from a cursory channel profile generated in GIS show that the channel gradient ranges from 0.50 to 1 percent at the upstream end of the reach, flattening to 0.01 to 0.05 percent at the downstream end (Table 8). Current use by Chinook salmon includes migration, rearing, and some spawning.

Figure 27. Various bank conditions, vegetation, and substrate in reach 3.

Table 8. Location, surficial geology, and confinement of reach 3 on Catherine Creek.

Geomorphic Reach	Location by RM	Surficial Geology	Confinement Classification
3	37.2 – 40.78	Alluvium/Fan-delta	Unconfined

Historic Conditions

Traveler's accounts of historic conditions in the Catherine Creek area collected by Beckham (1995) include descriptions of vegetation describing various grasses in the floodplain, and willows and cottonwoods along the banks of Catherine Creek and the Grande Ronde.

Based on the typical behavior of a stream channel on an alluvial fan and evidence in historic aerial photographs and LiDAR imagery, it can be hypothesized that Catherine Creek had multiple overflow channels running down the remnant alluvial fan that were likely activated during the spring freshet, or during rain on snow events. There may have been multiple main channel paths as well, with activation governed by sediment load and deposition, woody debris from upstream or beaver activity. Flows may have shifted from one channel to another every few years as sediment and debris deposited at the apex or upstream area of the alluvial fan.

Current Conditions

Conditions including sinuosity, width-to-depth ratios and valley and stream gradient have likely changed as a result of manipulations that have been applied to the channel, banks and floodplain of reach 3. Shortening of the channel by the disconnection of meanders would increase the stream gradient by decreasing the length of active stream over the same valley length.

Conditions of sinuosity and width-to-depth ratios have likely changed as a result of the manipulations that have been applied by humans to the channel, banks, and floodplain of Catherine Creek in the reach 3. Observed shortening of the channel would have increased the stream gradient by decreasing sinuosity over the same valley length potentially resulting in local changes to the width-to-depth ratio and access to the floodplain or the floodplain width. Although a considerable amount of development along the banks of Catherine Creek and within the floodplain had occurred by the earliest set of aerial photos (1937) within reach 3, significant changes to the channel planform can be observed to be occurring in the 1937 aerial photos and completed in the 1964 aerial photos. A comparison of the 1937 aerial photographs and the 2009 NAIP imagery shows local areas of both improvement and degradation in vegetation in reach 3. Overall, the vegetation appears to have successively decreased in reach 3 in the aerial 1937, 1965, 1964, and 1971. A comparison of the 1971 and the 2008 aerial photographs show an overall improvement the riparian vegetation; however, it is believed that there is a considerable departure from natural historic riparian and floodplain vegetation conditions. The results of the remote analysis also indicate that channel sinuosity decreased from 1.45 in 1937 to 1.14 in 2008. In addition, approximately 3,637 linear feet of channel was observed to be partially disconnected in the 1937 aerial photographs. Additional manipulations are further discussed below (see Attachment A for photographic documentation of reach 3).

Results from field measurements, observations, and remote analysis using GIS software show that within reach 3, the stream and valley gradients is less than 1 percent. The channel has relatively low sinuosity, and appears to be slightly entrenched as a result of channelization efforts that include bank hardening and the cutting off of historic meander section, particularly in the downstream end. The average width to depth ratio is 20:1 (Table 9) (see Attachment D for drawings of cross sections in reach 3).

Table 9. Valley and channel gradients, sinuosity, and width-to-depth rations of reach 3 on Catherine Creek.

Geomorphic Reach	Valley Gradient (percent)	Stream Gradient (percent)	Sinuosity	Average Width:Depth
3	0.65	0.57	1.14	20:1

Pebble counts were conducted in reach 3 in order to develop grain size distribution curves for substrate in the active channel bottom including thalweg and bars (see Attachment B for complete set of grain size distribution curves). The dominant substrate is cobble and gravel; however, sands and fine material were observed. The D_{50}, (meaning that 50 percent of the material is smaller than that size) measurements for reach 3 range from 42.6 mm to 50.5 mm, with the average D_{50} for reach 3 being 46.85 mm (Table 10).

Table 10. Average gradiation analysis of in-channel substrate within reach 3 on Catherine Creek.

Reach	Average Diameter of Substrate (mm)				
	D_{15}	D_{35}	D_{50}	D_{84}	D_{95}
7	27.9	38.15	46.85	86.63	127.7

Physical Processes

Channel migration, sediment transport and large wood recruitment are the primary physical processes that create and maintain instream salmonids habitat in Catherine Creek. Each is discussed individually below.

Migration

Although local sections of vertical bare banks and some undercutting were observed throughout the reach, overall rates of lateral and vertical migration appear to be low. Channelization by the construction of levees, as well the reported 'raising and revetting' of banks in 1949 by the U.S. Army Corps of Engineers (USACE) has resulted in conditions that require a flow of greater than the 500 year recurrence interval to overtop the banks at 70 percent of cross-section locations within the reach. In addition to the human manipulations, the natural processes responsible for the construction of the fan have changed. Lower flow volumes and sediment load than those that were active when the fane was actively building exist in the system in the present day. The combination of the two factors, anthropogenic manipulation and a change to the fluvial and geomorphic processes, result in a stream that is underfit for the channel that it resides in anthropogenic causes of the reduction of lateral migration and apparent incision are discussed below in the manipulations sections.

Sediment Transport

Initial sediment transport calculations utilizing data collected at cross sections that includes particle sizes of D_{50} (meaning 50 percent of the material is smaller than) and D_{84} (meaning 84 percent is smaller than) and general channel geometry (bankfull width and depth) and average channel slope were used to calculate hydraulic radius, shear stress and critical shear stress. HEC-RAS model results show a reach average shear stress of around 1 lb/ft2 at a 1.5-year recurrence interval (Appendix D). However, there is a wide range of conditions throughout the reach including slope, estimated bank-full area, substrate size, and wetted perimeter. Overall, the upstream half of reach 3 is a sediment transport section, as indicated by a steeper slope and an in-channel substrate that is slightly coarser. The lower half is a sediment storage section, which is evident by the observed increase in developed point bars and finer sediment.

Large Wood

Observed and documented occurrences of large wood within the active channel were low in reach 3 (Kavanagh, Jones, and Stein 2010). Although some wood (cottonwood and alder) were likely supplied to the stream from the banks of the alluvial fan from beaver activity, blow down or simply dying and falling in, the main source of large wood was likely from upland forests upstream. Large wood that was incorporated upstream would have be transported into reach 3 during high water events, such as rain on snow or intense local rainstorms, but likely did not transport much farther than the distal end of the alluvial fan near the bottom of the reach as the stream transitions to a very low-gradient, low energy environment in downstream reaches. The lack of large wood is likely exacerbated by past channel-clearing efforts as well.

Manipulations

In addition to the manipulation of the channel planform and floodplain described above, the active channel and banks within reach 3 on Catherine Creek have experienced a number of significant anthropogenic manipulations. Manipulations generally include road construction and bridges, bank protection measures, alteration to floodplain and bank vegetation, surface water withdrawal sites and sometimes channelization (Table 11). One online document from the USACE indicate that in addition to woody debris removal performed in the mid 1980s, emergency work was performed in 1949 that is described as raising and revetting the banks of Catherine Creek at critical sections through and in the vicinity of Union, Oregon (USACE 2011a). Another document states that emergency work was also accomplished in 1950 and 1951, and describes a project that would provide local flood protection through the construction of levees, channel clearing, straightening, enlargement, and realignment along 27.2 miles of Catherine Creek. The document does state that funds were expended on the project but does not state specific type of work or the location (USACE 2011b). A third document notes that local farmers have in several cases excavated channel cut-offs across narrow reaches of stream meanders, and constructed low earth levees (Appendix D). Several instances of this can be noted in the downstream end of the reach in the 1937 and 1956 aerial photographs.

Human features along the banks in reach 3 include bridges, historic abutments, roads, levees, bank protection, diversions, pumps, wells, and a stream gage. Observed levees are concentrated in the downstream third of the reach from RM 37.86 to the bottom of the reach at RM 37.2, and are small constructed or push-up type. Although bank protection/manipulations were observed throughout the reach, there is a higher concentration along the banks within the town of Union. Due to the high density of roads in the town of Union, total road lengths were not calculated for the floodplain and along the banks in this reach.

Table 11. List of anthropogenic features along the bank and within the floodplain in reach 3 on Catherine Creek.

Reach 3 Anthropogenic Features		
Anthropogenic Feature	**Quantity**	**Length (ft)**
Bridge	5	
Concrete/rock spur	13	
Diversions	4	
Surface water return	7	
Pump	2	
Grade control structures	8	
Plug	8	
levee		1,903
Bank protection		335
Water wells	Unknown	
Channel Straightening?		

Impacts

Manipulations to the floodplain, channel cross section, banks, and planform within reach 3 collectively have an impact to the physical function of Catherine Creek. These impacts, both directly and indirectly, contribute to the limiting factors affect all life stages of Chinook salmon and steelhead (NOAA Fisheries 2008). The limiting factors and the relationships to each other were previously discussed in the Introduction section of this appendix. Below, each of the limiting factors will be discussed as it pertains to the manipulations observed in reach 3.

The limiting factor of water quantity is primarily a combination of multiple factors. Within reach 3, there are four surface diversions. In addition, there are the surface diversions upstream in reaches 4 and 5 that were previously noted. The cumulative effect of the surface withdrawals in this reach and those upstream, combined with seasonal low flow can create a water quantity limiting factor. The low condition in the reach also contributes to additional limiting factors such as water quality, reduced habitat quantity and quality and fish passage. All of those will be discussed below.

The limiting factor of elevated summer water temperatures is directly related to multiple factors, including water diversion and return, and reduced river and floodplain interaction, and translocation of existing conditions from upstream. The effects of surface water withdrawals in reach 3 and upstream in reach 4 and 5 combined with seasonal low flow has been described in the water quantity section. The effects of the absorption of solar radiation during low flow have also been previously described. Water that enters the reach from upstream is noted to warm on arrival (Watershed Sciences, LLC. 2000). That condition combined with low flow conditions are the biggest contributors to elevated summer water temperatures. In the downstream third of the reach, reduction of groundwater recharge due to reduced floodplain interaction during high flow events due to levees and the conversion of floodplain to agricultural use also contribute to the higher water temperatures. Floodplain interaction at high flow allows water to enter the hyporheic zone via infiltration. This water is "stored" in the ground to return to the main channel as cooler recharge water during times of low flow.

A reduction in habitat quantity and diversity is a result of the manipulations described above. Channelization by the "revetting" and hardening of bank in the mid and upstream sections increases and levees in the downstream section have the physical structure of the stream channel and floodplain. Hardened banks may alter sediment and streamflow interactions and result in reduction of instream habitat quality in the mid and upstream sections. In the lower third of reach 3, the channelization has reduced channel migration and deposition. Migration is a product of bank erosion accompanied by bar building on the opposite bank. Erosion of the bank supplies needed sediment and potentially some woody debris to the system. Concurrent bar building through deposition provides low floodplain surfaces for colonizing vegetation (such as cottonwoods) and high-flow refuge for fish. Disturbances to the balance between erosion and deposition often result in a depletion of one or the other. When that occurs, processes that create and maintain diverse habitat types are not able to do so. The effects of channelization, and the reduction of channel length that has occurred in the downstream end of reach 3 lends to the diminished habitat quantity and diversity by slowing rates of lateral migration and subsequent deposition. Floodplain access by the river is also reduced, leading to the reduction of high flow, and/or off channel habitat. Reduced habitat quantity is also attributed to low-flow conditions due to the combination of seasonal low flow and surface water withdrawals by reducing first the depth and then the wetted width of the channel (NOAA Fisheries 2008). Another contributing factor to the reduction in quality and diversity of habitat may be a result of the channel-spanning diversion dams. The dams act as artificial grade control structures, limiting the amount of vertical migration, so the process of self adjustment of the stream may be interrupted. The backwater area upstream of the dam becomes an artificial depositional zone, filling existing pools with sediment.

The limiting factor of fish passage is again the product of one or more conditions. One of the related conditions is low flow, which is described above. The low-flow condition can cause a low-flow migration barrier to both returning adults as well as smolts attempting to migrate out of or within Catherine Creek (NOAA Fisheries 2008).

Additional manipulations that may contribute to fish passage issues within reach 3 are the channel spanning diversion dams. Although all of the channel spanning diversions are equipped with fish ladders, the low-flow effectiveness remains unclear, as communicated by local biologists in a 2011 habitat work session. During high flows, loss of complexity within the channel can result in velocity barriers to certain life stages. This loss of complexity is a result of bank hardening, channelization, levees, and clearing of instream woody debris.

The limiting factor of excess fine sediment can have multiple sources as previously described in the Upper Valley Group section. Within the mid and upstream sections of reach 3, fine sediment input is likely low given the overall low rate of migrations. Fine sediment is likely transported into and through the upper two-thirds of the reach during high runoff events. The lower one-third of reach 3 has occurrences of localized fine sediment input from bank erosion noted at RM 37.25 in 2010 and 38.85 in 2011.

The limiting factor of riparian condition within reach 3 is primarily due to altered vegetation within the floodplain in the lower third of the reach where floodplain and wetland areas have been converted to agricultural use. Vegetation is present along the streambank throughout most of the reach. However, the successional stage and composition of the vegetation community itself are impaired with mostly decadent trees and grasses observed.

Conclusion

Anthropogenic impacts within reach 3 on Catherine Creek contribute to the identified limiting factors for salmonids. These impacts result from human alterations including hardened banks, levees, instream diversion dams and water withdrawals, altered riparian and floodplain vegetation, reduced large wood recruitment to the stream, and reduced and hardened floodplain areas.

Recommendations

In order to address the causes of the limiting factors within reach 3, both short-term and long-term approaches that use a strategy of prioritizing rehabilitation activities based on potential long-term benefit as described by Roni et al. (2002) should be considered.

The rehabilitation strategy for reach 3 should address the need to increase habitat quality and quantity by increasing in the main channel in appropriate sections of reach 3. The addition of wood or other structures to the main channel would increase channel roughness and hydraulic complexity, which would increase habitat quality by adding channel complexity and instream cover for rearing and migrating Chinook salmon and steelhead. Habitat quantity would be improved with increased in-channel diversity by increasing the number of scour pools that would form as a result of the stream adjusting to the new hydraulic features.

The focus of rehabilitation efforts in reach 3 should include multiple strategies that:

1. Reconnect isolated habitat.

2. Restore long-term processes.

3. Restore short-term habitat.

Reconnection of isolated habitats could involve reconnection of some of the oxbows that have been disconnected since 1937. Reconnection would include reconnecting the main channel and oxbows by appropriate means to allow access while not creating a stranding issue. This action would increase habitat quantity by adding access to remnant existing habitat that is currently not accessible as well as adding additional habitat beyond that which currently exists. Restoring long-term processes by re-initiating floodplain processes, including floodplain interaction through more frequent overbank flows and restoration of appropriate riparian and floodplain vegetation would increase habitat quantity and quality. When components of the strategy of restoring short-term habitat, such as instream large wood are combined with re-initiation of long-term processes, additional habitat quality is gained. Identifying appropriate strategies and individual projects that would allow floodplain interaction and channel migration to re-establish in areas with willing landowners should be completed at the reach scale.

5.3.3 Valley Floor Group: Reaches 2 and 1

Reaches 2 and 1 comprise the Valley Floor Group on Catherine Creek. This group extends from the toe of the Catherine Creek alluvial fan, near RM 37.2 downstream to the confluence of Catherine Creek and the State Ditch at RM 0.0 (Figure 28).

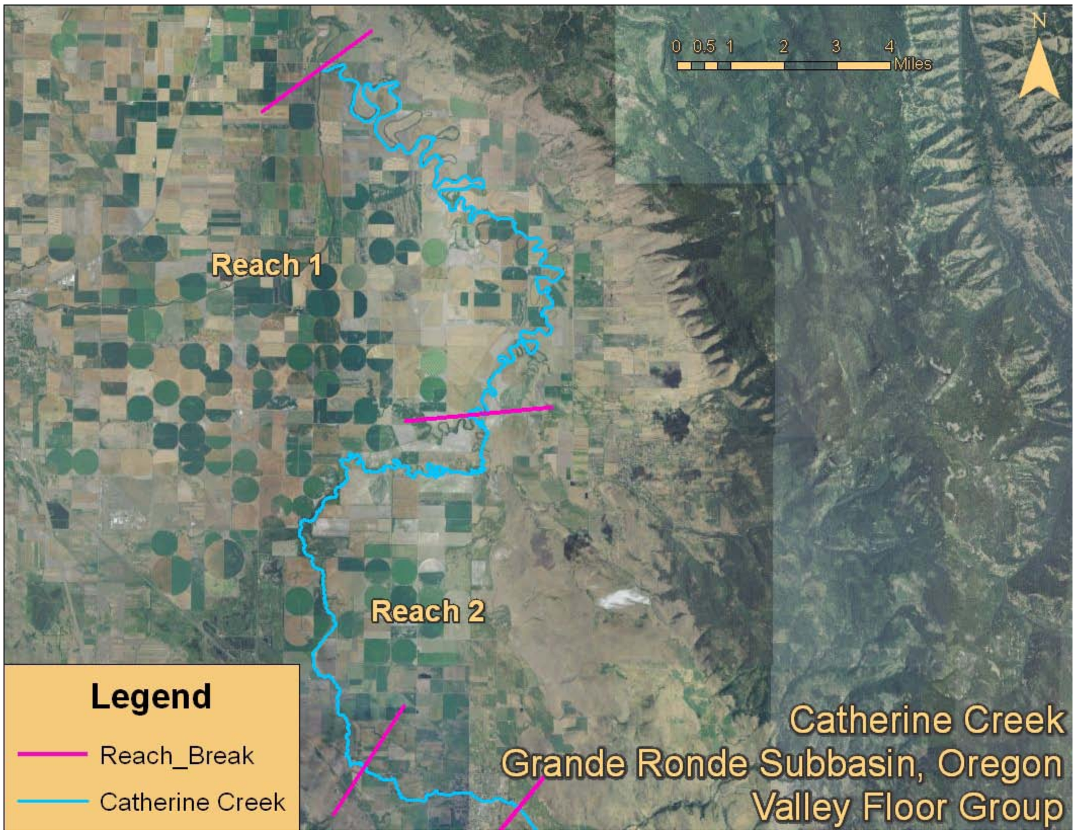

Figure 28. Location map of the Valley Floor Group on Catherine Creek.

Within the Valley Floor Group the reaches are unconfined, with very broad, flat floodplains that have developed through vertical accretion processes where sediment is accumulated on the floodplain when water is out of bank. The floodplain materials have previously been mapped as alluvium by Ferns (2010), and described as stream gravels with channels locally choked with over bank silt bound by fluvial lacustrine and alluvial plain materials that include clay and sand (Table 12). The processes of lateral accretion where bars build in response to channel migration within the active channel are occurring at overall low rates in reach 1. However, bar development was observed during low flow conditions due to surface diversions in sections of reach 2 upstream of the Elmer Dam backwater pool (see Attachment A). Within the Valley Floor Group, the channel gradient is very low and the channels are very sinuous. In addition, some sections of the channel in the Valley Floor Group appear to be locally entrenched. Channel bed materials were observed to be loose fine sands and silts, and dense cohesive clayey silts. Bank materials were observed to be inter-bedded cohesive silts, clays, clayey silts and indurated fine sands, and range from gently sloped to vertical (Figure 29). Natural lateral and vertical control appears to be provided by the cohesive material observed in the banks and on the channel bottom where present. There is an anthropogenic component to the vertical control as well in the form of multiple channel spanning concrete diversion dams. Current use by Chinook salmon and steelhead includes migration in reach 1 and migration and rearing in reach 2 (NOAA Fisheries 2008). The mainstem of Catherine Creek up to the town of Union supports rearing and migration for steelhead as well (NOAA Fisheries 2008).

Table 12. Location, surficial geology, and confinement classification of the Valley Floor Group on Catherine Creek.

Geomorphic Reach	Location by RM	Surficial Geology	Confinement Classification	Grouping
2	22.5 – 37.2	Alluvium/Fluvial-Lacustrine	Unconfined	Valley Floor Group
1	0.0 – 22.5	Alluvium/Fluvial-Lacustrine	Unconfined	Valley Floor Group

Figure 29. Various bank conditions, vegetation, and substrate in the Valley Floor Group.

Historic Conditions

Historically, the Valley Floor Group area was likely a low energy environment that contained wet meadows, emergent wetlands, and open water complexes (NOAA Fisheries 2008). Historical descriptions compiled from the journals of pioneers describe the valley floor as having numerous small creeks and rivulets running through all parts. Tule Lake existed in the south-central valley floor, and was fed by runoff and overflow from Catherine Creek and the Grande Ronde River, and drained back into both (Duncan 1998) (Figure 30**Error! Reference source not found.**). Catherine Creek historically flowed into the lake at its southeastern end and flowed out on its northeastern side.

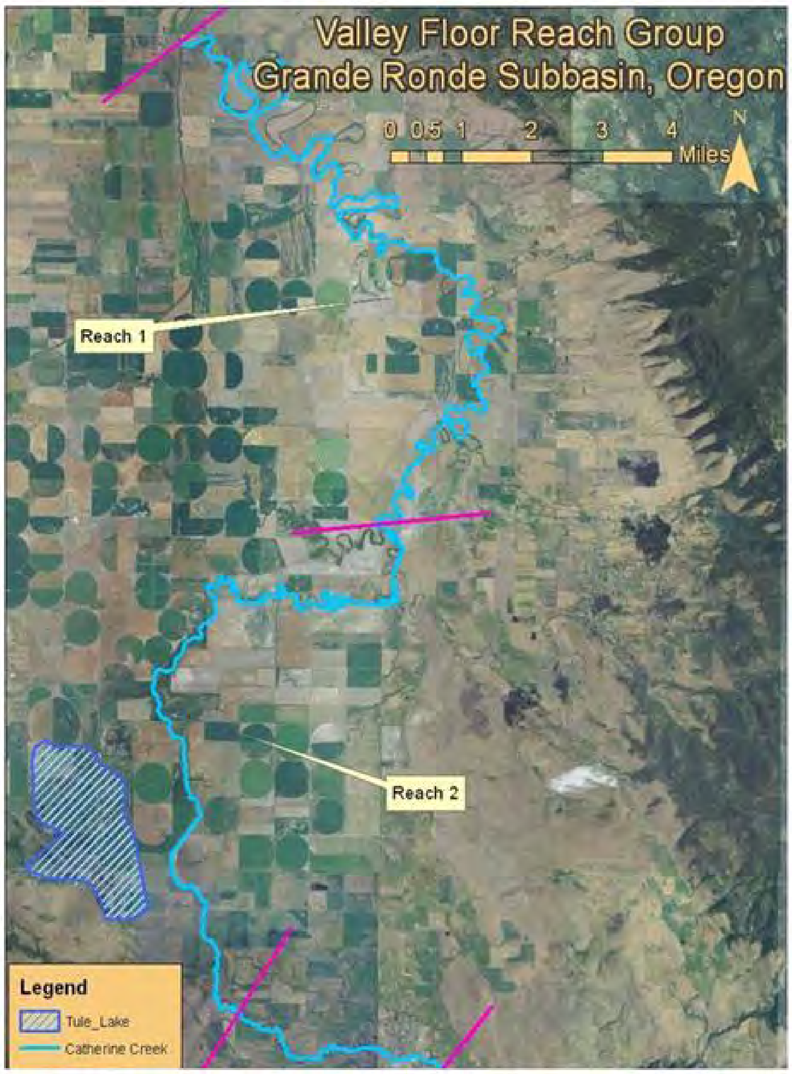

Figure 30. Showing the location of Tule Lake based of General Land Office (GLO) maps. Note the size is significantly smaller than described in historical accounts.

The reported size of the lake varies from 2,300 acres (Beckham 1995) up to 20,000 acres (Duncan 1998). In addition, Hot Lake was a spring-fed lake in the same area. Historical accounts describe the valley floor conditions as wet and marshy. Duncan (1998) reports that an estimated 72,000 acres in the middle valley were subject to flooding, and that up to 60 percent of the valley floor might be inundated for as long as 5 months. Another historical account described the area from La Grande, across the valley to Union and Cove as big cattail swamps (Duncan 1998). Vegetation on the floodplain was noted to be camas root, red clover, rye grass, and other grasses (Beckham 1995; Duncan 1998). The banks of Catherine Creek (and the Grande Ronde) were noted to be high and muddy, covered with Cottonwoods, willows and other underbrush (Beckham 1995; Duncan 1998). Duncan (1998) noted that the Umatilla Tribe named the Grande Ronde and Catherine Creek valley “cop-copi” for the large, dense black cottonwood trees that lined the riverbanks. Noted wildlife included numerous inhabitants from the otter family, along with deer, raccoon, elk, and beaver (Beckham 1995).

Based on the historical accounts from Beckham (1995) and Duncan (1998), it appears the Valley Floor Group area contained vast wetlands that were inundated for long periods of time beginning during the spring freshet. The channel was likely a single-thread channel with numerous side, overflow channels, and interconnected wetlands that would have been inundated because of high flows and beaver activity.

Current Conditions

Results from field measurements, observations, and remote analysis using GIS software indicate that the two reaches exhibit similar physical characteristics of width-to-depth ratios and gradient. The largest difference in the two reaches being in the sinuosity (Table 13) (see Attachment A – Photographic Documentation of reaches 2 and 1).

Table 13. Valley and channel gradients, sinuosity, and average width-to-depth ratios of the Upper Valley Group on Catherine Creek.

Reach	Valley Gradient (percent)	Stream Gradient (percent)	Sinuosity	Average Width:Depth
1	0.03	0.01	2.4	10:1
2	0.04	0.03	1.4	10:1

In the Valley Floor Group, characteristics of valley and stream gradient and width-to-depth ratios likely remain relatively stable given the anthropogenic manipulations. However, sinuosity has changed as a result of the shortening within both reaches in the Valley Floor Group. In reach 2, the channel has been shortened by nearly 12,500 feet, with a resulting decrease in sinuosity from 1.61 in 1937 to 1.40 in 2009. Similarly, the channel length in reach 1 was shortened by approximately 28,800 feet resulting in a decrease in sinuosity from 3.00 in 1937 to 2.40 in 2009. Due to the naturally low gradient in both reaches, the overall channel gradient in the Valley Floor Group was not impacted a great deal by the reduced channel length.

No pebble counts were conducted in reaches 2 and 1 due to high water depths at the time of data collection, but the observed dominant mobile bed material consisted of medium sand sized material (2 mm or less) silts, clays, and ash.

Bank material was observed to be inter-bedded indurated fine sands, and dense, cohesive silts, clays, and ash. The denser materials may act as an aquatard to some degree and promote lateral movement of the perched water table, rather than allowing continued downward infiltration. The banks range from gently sloping to vertical. In the Valley Floor Group, the channel of Catherine Creek is primarily located within fine-grained alluvial and fluvial lacustrine sediments. However, Catherine Creek does meander into a higher terrace along the left bank from about RM 5.2 to 5.8, along the right bank at RM 13.0 and again at RM 2.9 to 3. At RM 3.7 the creek meanders against the toe of a bajada (geologic feature formed by coalescing or overlapping alluvial fans) that forms the base of the Wallowa Mountains along the right bank. Materials in the banks developed in higher terraces and the bajada consisted of indurated fine sands and cohesive silts and clays similar to the alluvial and fluvio-lacustrine valley fill previously described.

Vegetation, when present on the face of the bank is comprised of grasses, shrubs, and willows, with occasional small dbh trees. Vegetation along the tops of the banks is predominantly grasses and shrubs with willows and sapling trees; however, some mature deciduous trees are present.

The floodplain is generally very wide, with subtle terrace rises. The morphology of the Valley Floor Group is generally indicative of a low energy environment, with surface water ponding within historic oxbows and topographic lows on the floodplain and very low gradient channels. Extensive sections of one or both sides of Catherine Creek in both reaches have been altered with levee construction. There are typically two types of levees; large constructed levees that may be up to 30 feet tall, and smaller levees that may actually be the natural result of out of bank flood processes. Areas behind levees can be marshy. In instances where the levees are set back from the top of the bank, the floodplain area between the bank and the levee toe is typically a flat elongate bench where woody debris and flood deposits accumulate. Materials include flood deposits of silts and fine sands inter-bedded with clay. Within the floodplain area, there are relict channel scars visible in the LiDAR. These relict scars may contain slightly coarser material with higher porosity that interacts with the less permeable layers described above and may provide a conduit to return shallow groundwater back to the current active channel.

Physical Processes

Hydraulics

It should be noted that the hydraulics within reach 1 are not typical of a mountain stream, which many common geomorphic descriptions are based upon. The hydraulics of the Valley Floor Group are more indicative of an emphemeral lake or estuary. Therefore, typical values of geomorphic properties such as the width-to-depth ratio and bankfull flow values do not apply in reach 1. The physical characteristics of this reach are dominated by backwater effects from the Grande Ronde River that are controlled by Rhinehart Gap and the timing of runoff in the Grande Ronde. This means that processes of sediment and water movement through this reach are dominated by hydrograph timing and magnitude of both Catherine Creek and the Grande Ronde River, not Catherine Creek alone. The steady state HEC-RAS hydraulic model indicated that average in-channel velocities are very low and are typically around 1.3 feet per second at discharges with recurrence intervals between 1.5 and 100 years. Similarly, shear stresses are very low, indicating the potential to only transport fine-grained sediment and little potential to erode the channel or banks 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 5-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 (Appendix D).

Channel migration, sediment transport, and large wood recruitment are the primary physical processes that create and maintain instream habitat in Catherine Creek. Each is discussed below.

Migration

In the Valley Floor Group, banks ranged from gently sloping and vegetated to high, near vertical and often void of vegetation. In reach 2, there were small local sections of bank that showed slumping that was usually associated with removed riparian vegetation, slight erosion of the bank on the outside of meander bends and corresponding lateral accretion in the inside of meander bends was also observed at low flow. In reach 1, bank slumps and bars were also noted although less frequently. In some instances where tall banks were noted, anecdotal evidence in the form of casual discussions noted dozer tracks that still exist in the bottom of the channel suggest in addition to the straightening, the channel may have been artificially deepened to convey more flow, and provide material to construct plugs across oxbow entrances and exists at some locations (Kuchenbecker 2010). Results of a 1937 analysis and 2008 and 2009 aerial photographs showed little or no natural change in channel planform. Given multiple natural factors, including the overall low gradient and base level provided by the Rhinehart Gap, the lacustrine nature of the valley floor as noted by the dense, consolidated fine grained bank material that includes interbedded sands, silts and clays, lateral and vertical migration rates would be expected to be low. In addition, the stream energy is further reduced in both reaches by the backwater effects of diversion dams in both reaches.

Sediment Transport

Calculations to determine if the D_{50} sized material mobilized during channel forming flow discharge were not performed in the Valley Floor Group. In non-backwatered sections, the in-channel substrate was observed to be medium sand (2 mm or less) using the unified soil classification system (USCS). This sand appears to move via saltation at low flows, forming dune-ripple and delta-type bedforms in the wetted channel. Given those observations, it is assumed that the medium sand in-channel substrate is mobilized and transported during channel forming flow. Finer particles (silt and clay) are likely transported as suspended sediment at a wide range of flows.

Large Wood

Large wood recruitment potential is assumed to be low in the Valley Floor Group area based on the very low gradient and lack of large trees in and adjacent to the riparian area along the stream. Oregon Department of Fish and Wildlife (ODFW) staff (2010) observed and documented a low number of pieces of large wood in the channel. Historically, large wood (predominantly cottonwood and alder) was likely supplied to the stream from the banks of the valley floor by beaver activity, blow down, or simply dying and falling in. It is unlikely that large wood was transported into these reaches from upland forests upslope or from upstream reaches. The flat gradient of both the valley and the river channel downstream from the toe of the alluvial fan near the break between geomorphic reaches 2 and 3 combined with the Tule Lake flow-through likely precluded any large wood moving into these reaches from upstream.

Manipulations

Within the Valley Floor Group, alterations to the channel, banks and adjacent floodplain began soon after the arrival of Anglo-European settlers. The extirpation of beaver (Duncan 1998), the initiation of surface water withdrawals, and the conversion of floodplain and wetlands to crop production and pasture followed settlement. Within both reaches of the Valley Floor Group, the channel bed, banks, and adjacent floodplain areas have experienced significant anthropogenic manipulations. Manipulations generally include road construction and bridges, construction of levees along the channel and within the floodplain, alteration to floodplain and bank vegetation, surface water withdrawal and channel relocation. Below is a description of the anthropogenic features in reaches 2 and 1 of the Valley Floor Group.

In reach 2, one of the earliest modifications to the channel planform of Catherine Creek was the draining of Tule Lake in 1870 (Beckham 1995). This action entailed the re-routing and channelization of Catherine Creek around the lake on the east side in a constructed channel. The comparison of the GLO maps (circa 1864-1876) to the current channel alignment in ortho-rectified aerial photographs suggests that the location of the main channel was altered beginning around RM 34.4 and continuing downstream to about RM 31.4. Other stream channel manipulations include the reduction of overall channel length by nearly 3 miles since 1937. This has been accomplished by cutting off individual sections of channel meanders. Some of the meanders that have been disconnected since 1937 now function as off channel storage ponds that are filled by spring melt of valley floor snow as well as overbank inundation from Catherine Creek during high flows. Other historic oxbows have been filled in with soil and converted to agricultural use. The cut off sections are concentrated in the downstream half of reach 2 between RM 23.5 to 30.0 and within a short upstream section from RM 35.8 to 37.8.

Additional manipulations to Catherine Creek in reach 2 include levees, roads, and bridges (Table 14). Levees have been constructed essentially through the entire reach. The levees are generally located along the edges of the meander belt-width. This means that the majority of the reach is enclosed in levees even though the total length in feet of levees in reach 2 is a much lower figure than the total length of channel and banks. Catherine Creek exhibits a high degree of sinuosity within a wide band of area between two relatively straight levees. A numerical analysis that compares the total length of levees to the channel length and total bank length (two times the channel length) indicates that the total length of levee is about 55 percent of the total length of banks.

Included in the levees are nine sections that act as plugs across the entrance and/or exit of historic main and/or side channels. In addition to the levees, 39,262 linear feet of paved highway, gravel, and private (field access) roads that may also act as levees either directly adjacent to Catherine Creek or within the floodplain are present. Bank protection in the form of riprap comprised of concrete blocks, rock cobbles and boulders, and car bodies was noted, but overall covers less than 1 percent of both banks (Table 14). Bank and floodplain vegetation has also been highly modified from those historic conditions described by Beckham (1995) and Duncan (1998). Although some willow and large dbh cottonwood trees exist along the immediate bank, there are likely fewer today than recent historic condition. In the floodplain areas away from the channel bank, multi-story, multi-species, and varied age-class native vegetation has been almost completely replaced by commercial crops and pasture grass.

Table 14. List of anthropogenic features in reach 2 on Catherine Creek.

Reach 2 Anthropogenic Features		
Anthropogenic Feature	**Quantity**	**Length (ft)**
Bridge	6	
concrete/rock spur	1	
Head gate	2	
Diversion	2	
Pump	6	
Plug	9	
Road (paved/unpaved/private)		23,027
Levee		91,020
Bank Protection		468

Within reach 1 one of the earliest known modifications was an indirect action in that it was not implemented on Catherine Creek itself, but certainly resulted in significant impact to Catherine Creek. That action was the original excavation during the 1860s of what would become the State Ditch section on the Grand Ronde River. The original excavation was 6 feet wide and 3 feet deep (Duncan 1998), but eventually captured the entire Grande Ronde River and now re-routes the entire discharge of the Grande Ronde River. When this capture occurred, the confluence of Catherine Creek and the Grande Ronde was shifted several miles downstream and the section of present-day Catherine Creek from RM 22.5 to RM 37.2 now flows in the old Grande Ronde River channel without the input and influence of the main Grande Ronde River. Other manipulations to Catherine Creek within reach 1 include the reduction in channel length of nearly 5.5 miles that has occurred since 1937 through channel straightening accomplished by cutting off large meanders. Most of the meanders disconnected since 1937 now act as irrigation storage areas that are filled during the spring freshet either by the opening of valves or gates or by inundation from overbank flows from Catherine Creek and/or spring melt of valley floor snowpack. The cut-off sections are concentrated in the downstream half of the reach between RM 5.6 and 14.0.

Similar to reach 2, levees have been constructed throughout essentially the entire length of reach1. The same numerical analysis method described above indicates the total length of levee is about 48 percent of the total length of the banks. Again, this percentage number is deceiving due to the levees generally being located along the edges of the meander belt-width, and the stream having a high sinuosity. The levees types are the same as those observed in reach 2 and previously described. Included in the levees are 19 sections that act as plugs across the entrance and exit of historic main and side channels. In addition to the levees along the banks and within the floodplains, 47,309 linear feet of paved highway, gravel and private (field access) roads may also act as levees either along Catherine Creek or within the floodplain within reach 1. Bank protection in the form of riprap comprised of concrete blocks and rock cobbles and boulders was noted, but overall covers less than 1 percent of both banks (Table 15). Vegetation has also been highly altered. Although some willow and large dbh cottonwood trees exist along the immediate bank, there are likely fewer today than recent historic conditions. In the floodplain areas away from the channel bank, native vegetation has been almost completely replaced by commercial crops and pasture grass.

Table 15. List of anthropogenic features in reach 1 on Catherine Creek.

Reach 1 Anthropogenic Features		
Anthropogenic Feature	**Quantity**	**Length (ft)**
Bridge	6	
Historic abutments/piers	8	
water return/drains	11	
Diversion dam	1	
Earthen Dam	1	
Dock	1	
Pump	10	
Head gate	1	
In channel pilings	1	
Suspended pipe	2	
Levee		112,126
Roads (paved/gravel/private)		47,309
Bank protection		725

Impacts

Manipulations to the floodplain, channel cross section, banks, and planform within the Valley Floor Group collectively have an impact to the physical function of Catherine Creek. These impacts, both directly and indirectly, contribute to the identified limiting factors that affect all life stages of Chinook salmon and steelhead (NOAA Fisheries 2008). The limiting factors and the relationships to each other have been previously discussed in the Introduction section of this appendix. Below, each of the limiting factors will be discussed as it pertains to the manipulations observed in the Valley Floor Group.

The limiting factor of water quantity and its relationship to other limiting factors or conditions has been previously discussed. In the Valley Floor Group, there are 3 head gates, 3 channel spanning diversion dams, and at least 16 pumps. The amount of water withdrawal within the reach group, combined with the withdrawals upstream of the Valley Floor Group can lead to a low-flow condition in the areas beyond the backwater pools of the Davis and Elmer dams, particularly when seasonal low flow is an issue.

The limiting factor of elevated summer water temperatures is likely the product of warm water from upstream as well as conditions within both reaches in the Valley Floor

Group. In the Upper Valley Group, 11 sites of water return and shallow drain sites were observed. In one case, ponded water was being pumped from a historic oxbow back into the main channel. Water returning to the main channel via surface run off, gravity or pumping could have warmed in the historic oxbows or shallow ponds, which could contribute to elevated water temperatures, as well as high nutrients in the main channel. The natural condition of low-stream gradient can also lead to warmer water temperatures, given that low velocity water can thermally stratify. Thermal stratification was observed just below the Davis dams with a maximum temperature of 26.9^{o}C being recorded at RM 9.0, downstream of Elmer Dam (Watershed Sciences, LLC. 2000). Potential implications of the thermal stratification will be discussed below in the fish passage discussion.

The limiting factor of reduced habitat quantity and diversity in the Valley Floor Group is a result of the previously described manipulations to the channel and floodplain. The draining of the original wet meadow, emergent wetlands and open water complexes on the valley floor for the implementation of agricultural land use practices including grazing, combined with extirpation of beaver have resulted in reduced habitat quantity and diversity by simplifying the physical structure of the stream channel and floodplain (NOAA Fisheries 2008). In unconfined wetland systems such as reaches 1 and 2, beaver activity is one mechanism that promotes physical processes such as river and floodplain interaction and in-channel complexity that produce and maintain different habitat types within the main channel and floodplain (NOAA Fisheries 2008). The result is a reduction in the aerial extent of off-channel habitat and diversity of instream habitat. Reduced habitat quantity is also attributed to surface water withdrawals by reducing the depth and wetted width of the channel (NOAA Fisheries 2008). This would presumably reduce the amount of rearing habitat found along the margins of the stream, as well as the depth and overall number of pools in those areas not submerged in the backwater pools of the Upper and Lower Davis dams and Elmer Dam. The diversion dams can act as artificial grade control structures, altering sediment transport processes so the process of self-adjustment of the stream may be interrupted. The backwater area upstream of the diversion dams becomes an artificial depositional zone, filling any previously existing pools with sediment. Pools may not be re-established when the sediment is mobilized and transported during periods of channel forming flow due to lack of instream complexity. Some of the sediment deposited in the backwater pools is likely flushed out during channel forming flow, but only to the elevation imposed by the artificial grade control. Construction of levees along the channel bank or in the floodplain can also reduce habitat quantity and quality by altering hydraulic conditions within the channel.

Fish passage is listed as a limiting factor, and was previously discussed. In the Valley Floor Group, fish stranding in historic oxbows may contribute to the limiting factor of fish passage. The oxbows are filled either by bank overtopping or by the opening of gates during spring runoff. Any fish that enters would be trapped, as there is no fish return mechanism on the oxbows. In addition to low-flow conditions, the thermal stratification of the water column in low water velocity areas recorded in 2000 during FLIR data collection may form a thermal migration barrier when the heated water at the surface flows through the fish ladders. Fish passage effectiveness at low flow remains unclear, as communicated by local biologists in a 2011 habitat work session. However, both Davis dams were completely reconstructed in 2011 and included new fish ladders for passage.

Within the Valley Floor Group, the limiting factor of excess fine sediment likely has multiple causes. The previously described occasional bank slumping and slight erosion contributes some fine sediment to the system, in addition to fine sediment transported from into the Valley Floor Group from upstream. Given the composition of the banks, that includes silts, fine sands, and clay. Once fine sediment is incorporated into the system, it likely stays suspended in the water column. Uniform channels with little variability and reduced floodplain interaction do not provide adequate sediment storage areas such as near channel wetlands and side channels and instream pools.

The limiting factor of riparian vegetation in the Valley Floor Group is due to the multiple impacts of vegetation alteration and/or removal that were discussed previously. In the Valley Floor Group, a high percentage of the vegetation along the banks has been removed or altered. In much of the Valley Floor Group, floodplain vegetation has almost completely been removed to allow for agricultural development. The effects from habitat modification, increased fine sediment, and increased water temperature could all be improved with the improvement of vegetation condition (GRWQC 2000). While not the only concern, riparian habitat degradation is a serious problem and addressing this issue also indirectly addresses water quality factors such as temperature, stability, sediment, and habitat (GRWQC 2000)

Conclusion

Anthropogenic impacts within the Valley Floor Group on Catherine Creek contribute to the identified limiting factors for salmonids. These impacts result from human alterations including hardened banks, levees, instream diversion dams and water withdrawals, and altered riparian and floodplain vegetation.

Recommendations

In order to address the causes of the limiting factors in a systematic way within the Valley Floor Group, both short-term and long-term approaches that use a strategy of prioritizing rehabilitation activities based on potential benefits as described by Roni et al. (2002) should be considered. The short-term strategy could employee pilot projects to address the immediate need to increase habitat quality and quantity by adding complexity in the main channel in reaches 1 and 2. The addition of wood or other structures in the main channel would increase channel roughness and hydraulic complexity, which would in turn increase habitat quality by adding in-channel complexity and instream cover for rearing and migrating Chinook salmon and steelhead. Habitat quantity would be provided with increased in channel structure roughness by increasing the number of scour pools that would form as a result of the stream adjusting to the new hydraulic feature.

The long-term focus of rehabilitation efforts in the Valley Floor Group reaches should include multiple strategies that;

1. Reconnect isolated habitats.
2. Restore long-term processes.
3. Restore short-term habitat.

Reconnection of isolated habitats could involve reconnection of some of the oxbows that have been disconnected since 1937 and include reconnecting the main channel and oxbows by appropriate means to allow access but avoid a stranding issue. This action would increase habitat quantity by adding access to remnant existing habitat that is currently not accessible as well as adding additional habitat beyond that which currently exists. Restoring long-term processes by re-initiating floodplain processes, including floodplain interaction through more frequent overbank flows and restoration of appropriate riparian and floodplain vegetation would increase habitat quantity and quality. When components of the strategy of restoring short-term habitat, such as instream large wood are combined with re-initiation of long-term processes, cumulative benefits to habitat quality occur. Identifying appropriate strategies and individual projects that would allow floodplain access and channel migration to re-establish in areas with willing landowners should be completed at the reach scale.

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