DRAFT Technical Memorandum

To: Memo to File
From: Jarvis Caldwell and Michael Barclay, HDR Inc.
Project: City of Bend Surface Water Improvement Project
Date: March 13, 2012
RE: Tumalo Creek Instream Flow Study

Summary

The purpose of this technical memorandum is to present the methods, results and analysis, and discussion of the instream flow study (Study) conducted by City of Bend (City) on Tumalo Creek, Deschutes County, Oregon. The Study was conducted in support of an Environmental Assessment being prepared by the U.S. Forest Service - Deschutes National Forest (USFS) for the City of Bend Surface Water Improvement Project (Project).

The instream flow study was conducted September through December 2011 in the section of Tumalo Creek potentially affected by the Project, referred to herein as the Project-affected area. Studies included the development of fish habitat versus flow relationships, the development of channel versus flow relationships, the development of habitat duration analyses and the development of a geomorphic process analysis.

Flow-habitat relationships (Weighted Useable Area) were developed using the one-dimensional (1D) Physical Habitat Simulation model (PHABSIM). Channel Flow Response (CFR) relationships were developed to provide graphical demonstration of changes in channel flow characteristics as a function of incremental changes in discharge.

Habitat Duration Analyses (HDA), which integrate flow-habitat relationships with hydrology and project operations, were used to provide an examination of flow versus habitat over time. Individual study reach and sub-reach hydrology data sets used in the HDA were constructed using City of Bend diversion flows and downstream TID diversion flows, including senior or equal priority date instream water rights and TID standard operating practices.

Geomorphic processes were analyzed using anecdotal and empirically-collected data from the PHABSIM study with a goal of evaluating the effects of a change in stage and the potential effects on floodplain inundation and channel stability.

Studies were conducted in accordance with the November 2011 Tumalo Creek Instream Flow Study Plan (Study Plan) and in collaboration with the USFS and the Oregon Department of Fish and Wildlife (ODFW).

It is important for those interested in the analysis phase of the instream flow study to recognize that the end result of an instream flow study is not a set instream flow value but models of simulated ranges of instream flow values. These models are used by specialists and decision makers as tools, in concert with other analytical tools and information, to evaluate the effect of alternative stream flows on project operations and fish and aquatic habitat.

This Technical Memorandum describes effects on fish habitat based on water use, diversion water rights, and instream water rights of today. Readers should understand these water rights and

subsequent management conditions are in flux. Tumalo Irrigation District is continuing to complete its Tumalo Feed Project, as well as continuing its successful annual leasing program which will continue to protect an additional amount of water instream in Reach B with senior water rights. The likely outcome of this process will be increased Instream water rights below TID's diversion. See Tumalo Irrigation District's Water Conservation Plan (TID 2005).

1.0 Surface Water Improvement Project Background

To meet current and future municipal water supply demands, the City relies on a dual-source water supply that is comprised of groundwater from the Deschutes Regional Aquifer and surface water from Tumalo and Bridge Creeks. Each of these water sources provides about one-half of the City's annual water supply. The dual-source system is reliable, meets the City's current and future water supply needs, and offers operational flexibility to manage water supply risks and minimize environmental impacts to either resource.

The surface water source from Tumalo and Bridge Creeks has been in use by the City since 1926 and is in need of repair and replacement. Some of the City's goals in repairing / upgrading the surface water supply system include:

- Preserve the City's dual-source supply of municipal water into the future, providing residents continued access to reliable, high-quality drinking water
- Address deteriorating pipelines that carry approximately 50% of the City annual municipal water supply from Bridge Creek to a storage and disinfection facility at the City Outback site
- Relocate the pipeline from an existing location that runs through forest service lands into existing transportation rights of ways

The proposed project (the Build Alternative described below) would repair, replace, or upgrade existing facilities, potentially add new water treatment or hydropower generating facilities, and expand the supply capacity. The supply alternatives are described further below and the in the Environmental Assessment developed by the US Forest Service.

1.1 Existing System

The City's existing surface water system from Tumalo / Bridge Creeks is generally depicted in Figure 1 along with Tumalo Irrigation District (TID) water diversion facilities and the hydrologic system. The City's existing facilities generally include:

1. Facilities on Federal lands managed by the US Forest Service
    a. An upper diversion (spring complex) from Tumalo Creek to Bridge Creek;
    b. An intake on Bridge creek;
    c. Two 12- to 20-inch diameter existing pipelines about 10 miles long;
2. Facilities on City or private lands:
    a. Water treatment and storage facilities at the City's Outback site;
    b. A return flow system that returns unused water back to Tumalo Creek in the vicinity of Shevlin Park; and
    c. Treated water transmission pipelines from the Outback site into the City.

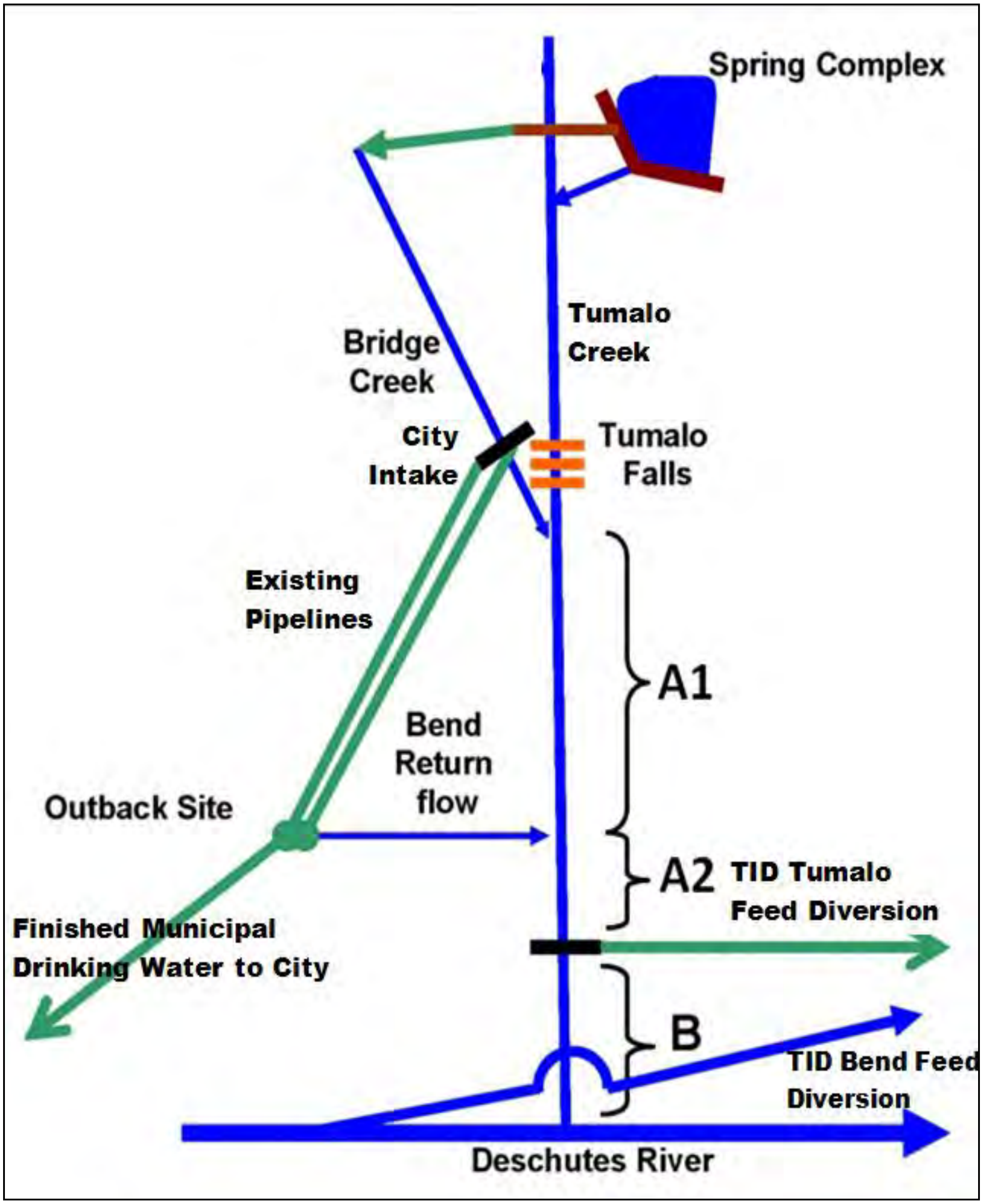


Figure 1. Tumalo Creek flow schematic with diversion locations

1.2 The No-Build Alternative

The No-Build alternative would leave the City's existing facilities on Federal Lands unmodified. The City would continue to maintain its existing facilities under its existing Special Use Permit (SUP) from the Forest Service.

On City lands (the "Outback" site), the City would upgrade treatment facilities to meet drinking water treatment regulations; continue to maintain its existing facilities and replace them as needed, and continue develop the Outback site with new facilities identified in the City's water planning documents.

Under the No-Build Alternative, the City's capacity to divert water from Bridge / Tumalo Creeks is limited to 18.2 cubic feet per second (cfs). There are no water diversion limits in the existing Special Use Permit that the City would continue to operate under with the No Build Alternative.

Under the No-Build alternative, the City diverts 18.2 cfs from Bridge / Tumalo creeks continuously. A return flow would continue to be generated under the No-Build Alternative during periods when the City would be using less than 18.2 cfs. This would occur because the City, due to operational limitations, must divert 18.2 cfs continuously with the existing system (No-Build Alternative).However, the City's actual use could be less due to lower water demand in winter or water rights restrictions. Water that is not taken in to the City's Outback tank facilities is returned to Tumalo Creek in the vicinity of Shevlin Park, about 9.5 miles downstream from the City's Intake. The return flow can sometimes entrain turbidity.

1.3 The Build Alternative

The Build Alternative generally includes:

1. Facilities on Federal Land
    a. Leave the upper diversion (spring complex) from Tumalo Creek to Bridge Creek un-modified;
    b. Upgrade the existing Intake with new fish screens and new building enclosure;
    c. Install a new 30-inch diameter pipeline about 9.5-miles long from the Intake to the Outback site; abandon the existing pipelines;
    d. Install water treatment ponds on Federal lands adjacent to the Outback site;
2. Build facilities on the City-Owned portion of the Outback site including:
    a. New flow control valves that allow City to limit diversion to just what is needed to meet City water demands; elimination of the return flow to Tumalo Creek in the vicinity of Shevlin Park;
    b. A new hydroelectric powerhouse with bypass and hydraulic control structures;
    c. New pre-treatment basins (optional);
    d. A new filtration water treatment system / building;
    e. Miscellaneous piping, tanks, and vaults.

The new pipeline and flow control system installed with the Build alternative would allow the City to limit its water diversion rates to just what is needed to meet City water demands or comply with water right restrictions. This will eliminate the need for return flow and, instead, leave more water in the stream at the point of diversion and for 9.5 miles downstream during times when the City uses less than 18.2 cfs. This benefit is further described below.

2.0 Study Goal

The primary goal of the Study was to quantify or characterize fisheries habitat as a function of flow within the Project-affected area of Tumalo Creek using hydraulic, habitat, and hydrologic modeling methods. The specific objectives of the Study included:

- Estimate the habitat index versus flow relationships using the Physical Habitat Simulation system for fish in the Project-affected area.
- Use habitat index versus flow relationships to develop habitat duration or time series analyses of fish habitat over time under both No-Build and Build Alternative City water diversion scenarios.

A secondary goal of the Study was to evaluate the effects of changes in stream flow on stream geomorphic processes using the empirically collected data and hydraulic modeling results from the PHABSIM study.

3.0 Summary of Tumalo Creek Watershed and Hydrology

3.1 Watershed

Tumalo Creek flows approximately 18 miles through the 48 square mile Tumalo Creek watershed. Tumalo Creek is a perennial stream located in the glaciated eastern Cascade Mountains. Tumalo Creek is fed primarily from snowmelt and spring-water. The highest peaks include Ball Butte at 8,091 feet and Tumalo Mountain at 7,775 feet. Tumalo Creek is formed by five primary headwater tributaries which include North Fork Tumalo Creek, Middle Fork Tumalo Creek, Bridge Creek, South Fork Tumalo Creek, and Tumalo Lake Creek. South Fork Tumalo Creek and Tumalo Lake Creek enter Tumalo Creek within the Project-affected area, whereas the other three join above the Project-affected area. The confluence of Tumalo Creek with the Upper Deschutes River is approximately 3200 feet in elevation (City of Bend 2010).

3.2 Hydrology

Flows in Tumalo Creek fluctuate from extreme lows during winter of approximately 50 cfs to high spring-time flows of approximately 300-400 cfs (City of Bend 2010) as shown in Figure 2. Abundant spring-water in the watershed maintains a relatively high base flow during the winter freeze-up season and during the late summer through early fall dry season.

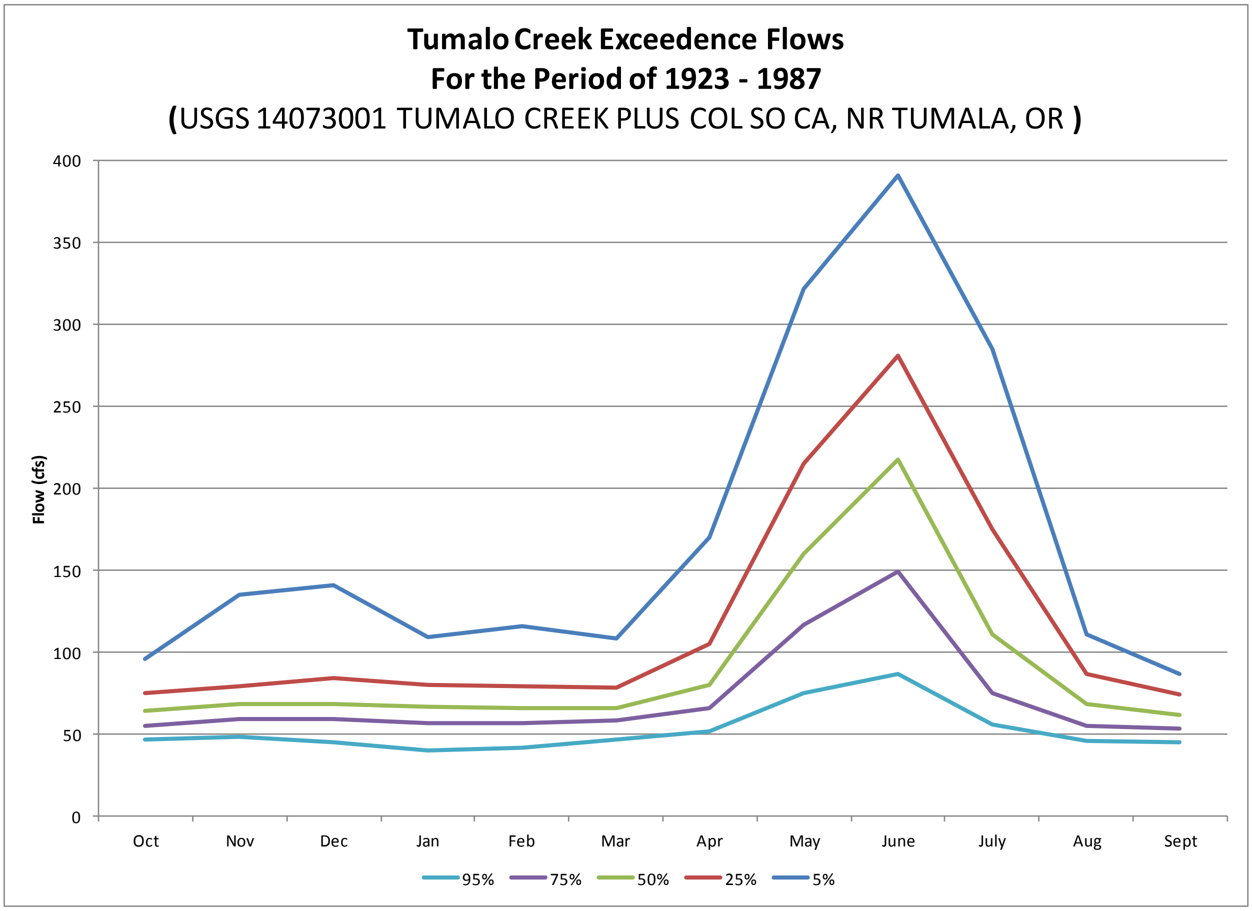


Figure 2. Monthly flow exceedances derived from USGS gauging station on Tumalo Creek just below Shevlin Park from 1923 to 1987.

3.3 City Water Operations

The City relies on its dual-source including groundwater and the Tumalo / Bridge Creeks surface water system to supply municipal drinking water to the City. Due to reliability, mechanical simplicity, energy efficiency, cost-effectiveness, water quality, reduced operations burden, and other factors, Surface Water is the City's primary water source. The City relies on its surface water source year-round as a base flow of water. When water demands increase in summer, the City turns on its wells to meet the additional water demand.

There are many factors that limit or could limit the City's surface water diversion. They are illustrated in Figure 3 and include: 1) available stream flow and water right restrictions; 2) lower City demand for water such as during winter; 4) design of infrastructure such as treatment; and / or 5) City choice to increase water supply from other sources.

Steamflow / Water Rights	Water Demand	Facility Design
During periods of low Streamflow, Oregon Water Resources limits water diversions using the system of prior appropriation. City water rights include a mix of seniority, at times limiting availability.	The City's diversion of water is limited to water that is used beneficially. Currently approximately one-half of the the year, the City's water demand / use is less than 10 cfs	The City's water filtration facility is designed to produce 21 cfs on a sustainable basis

Figure 3. Factors limiting City of Bend surface water diversion.

The City holds surface water rights from Bridge and Tumalo, and their ability to use these rights is limited by the rights' seasons of use and dates of priority, available stream flows, municipal demand, and demands of other Tumalo Creek water users. For example, Tumalo Irrigation District holds senior water rights that authorize the use of water during irrigation season, which can be significantly greater than the City of Bend's. During periods of low stream flow, the State of Oregon watermaster distributes the flow in Tumalo Creek between TID, the City, and other Tumalo Creek water right holders according to a predetermined proportional-share formula based on the rights' priority dates. During these periods, the City receives less than the maximum authorized rate for its water rights. Figure 4 illustrates how the City's water rights are curtailed during periods of low stream flow.

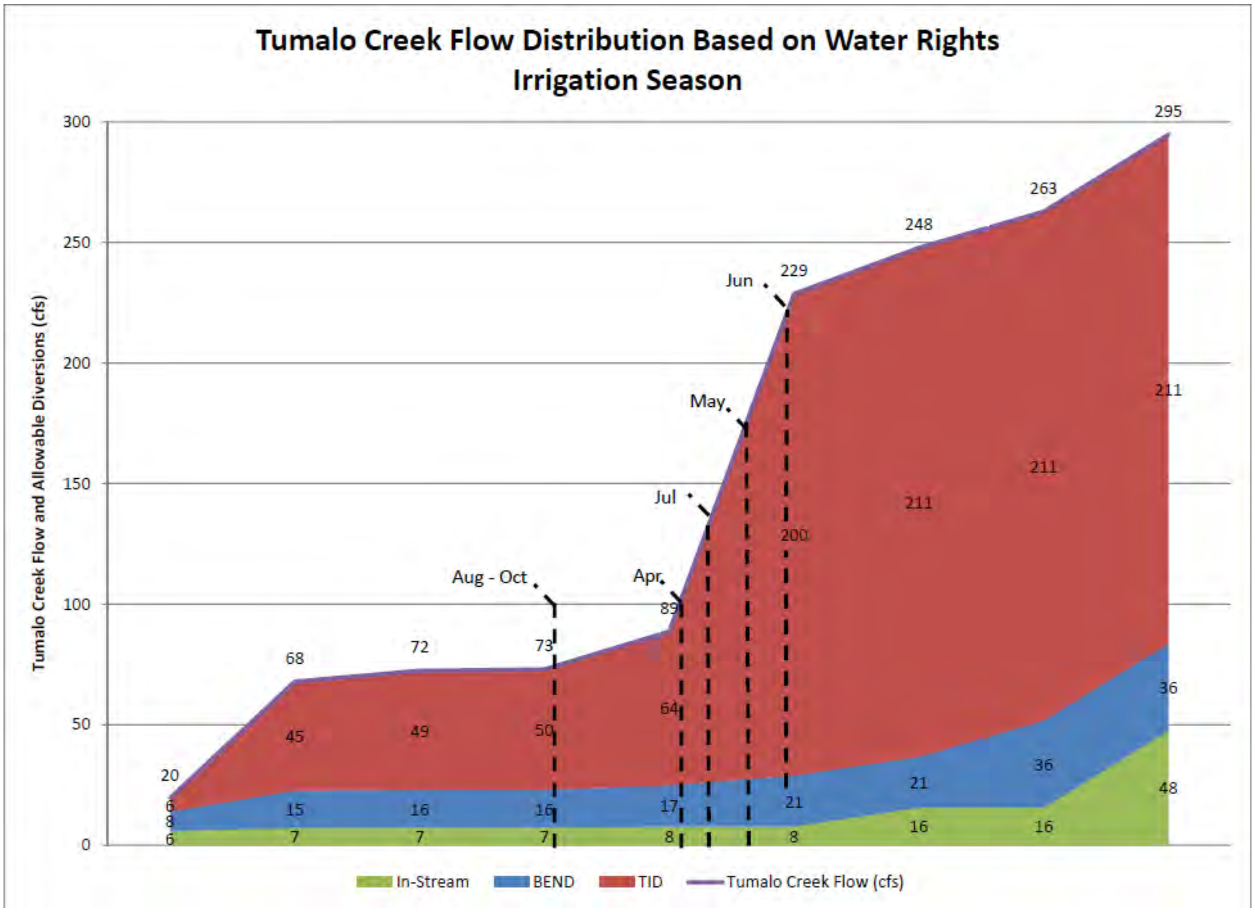


Figure 4. Distribution of Water Rights on Tumalo Creek during periods of low stream flow (vertical dashed lines indicate typical flow values for that month)

Lower water demands also limit the amount of water that would be diverted under the Build alternative. During about one-half of the year, the City's current water demand is 10 cfs or less. In the non-peak season water-use months, it is anticipated that demand will not reach the 21 cfs modeling scenario until approximately 2040. The City is planning for this winter demand to grow over time. However, until it does, lower demand will limit the City's actual diversion during non-peak season water-use months to less than the capacities of the No-Build and Build systems, and to less than what was modeled to assess potential environmental impacts in this memorandum.

The water supply capacity of the system could be limited by the design of facilities. For example, the design of the water filtration facility is for 21 cfs flow rate on a long-term sustainable basis.

3.4 Hydrology Under the No-Build and Build Alternatives

This memorandum provides a description of maximum diversions and a forecast of minimum creek flows under the No-Build and Build alternatives. The purpose of the forecast is to provide a basis for estimation of fish habitat under each alternative. As noted under the "Limitations" section, the diversion scenarios under the Build alternative is simplified and is a maximum. The actual diversions can be expected to be smaller (and the habitat impact smaller) due to limitations not considered that would reduce the City's actual diversion including: stream flow / water rights and actual City demands for water.

The hydrology associated with the No-Build and Build alternatives is integrated with the habitat index of Weighted Useable Area, described below, to analyze Project effects on fish habitat over time. The following paragraphs summarize the development of hydrology data sets used to model the No-Build and Build project alternatives in the habitat analyses.

3.4.1 Native inflow data set

Tumalo Creek flow was gaged from October 1923 through September 1987 and records are available on a daily time step. The gage records are the sum of Tumalo creek flow downstream of the City's return flow from Outback (but upstream of the existing TID diversion) and the diversions at the historic Columbia Southern Canal diversion location that occurred upstream from the City's return flow but is now abandoned. The historical gage record does not reflect natural conditions since the City was diverting water from the Creek upstream during this time. To "naturalize" the gage record, the City's estimated use was added to the gage record to develop a "native" flow record. The native flow record is representative of the conditions just upstream of the existing TID diversion. Figure 1 above illustrates the Tumalo Creek Flow schematic along with existing diversion locations.

Using the native flow record, combined with estimates of accretion discussed below, mean daily flows at the top of the Project-affected area (confluence of Bridge and Tumalo Creeks) were calculated for the period of record.

3.4.2 Individual Reach and Sub-reach Hydrology Data Sets

Hydrology data sets were prepared for the No-Build Alternative (existing system under future conditions) and the Build Alternative (proposed system under future conditions) as described below. For Reach B, typical operating conditions for the Tumalo Irrigation District (TID) were assumed.

The constructed hydrology data sets represent future conditions with maximum theoretical diversion rates for both the City and TID. The resulting habitat duration analysis was therefore designed to include these maximal conditions in the model, even though these maximal conditions are expected to occur infrequently as described above due to water right limitations.

3.4.2.1 Overview of No-Build and Build Alternatives

For each study reach and/or sub-reach, two hydrology data sets were constructed. City of Bend diversion flows, downstream TID diversion flows, including senior or equal priority date instream water rights and TID standard operating practices were all accounted for in the construction of the hydrology data sets.

The following two hydrology data sets were constructed for each reach or sub-reach:

- The No-Build Alternative with a maximum daily diversion of 18.2 cfs with no return flow
- The Build Alternative with current design for diversion of 21 cfs with no return flow.

Return flows were not including in the quantitative hydrologic or habitat modeling since the magnitude of the flow benefits are variable and could change over time, as described below. A return flow would be generated under the No-Build Alternative when the City would be using less than 18.2 cfs. This would occur because the City must divert 18.2 cfs continuously with the existing system (No-Build Alternative), but the City's actual use could be less due to lower water demand in winter or water rights restrictions. With the No-Build Alternative, the return flow would be returned to the creek about 9.5 miles downstream from the City's intake. With the Build Alternative that includes flow control, the City would divert only what is needed for use so more water would be left in-stream at the intake and along the 9.5 miles of creek downstream.

For example, assume the City's use is 10 cfs. The No-Build Alternative would divert 18.2 cfs, and return 8.2 cfs 9.5 miles downstream. The Build Alternative would only divert 10 cfs. The Build Alternative would result in 8.2 cfs more flow in Tumalo creek for 9.5 miles downstream from the City's intake. Further downstream from this, the No-Build and Build Alternatives would result in the same flow in the creek (native creek flow less 10 cfs).

So the Build Alternative will increase creek flows in the 9.5 miles downstream of the City's intake for conditions when the City uses less than 18.2 cfs. This commonly occurs when the City's demand is less than 18.2 cfs (currently all winter), when water rights restrict the amount of water used by the City to less than 18.2 cfs (many time during low flow – late summer conditions), and if the City were to choose to use more water from a different source.

The return flows and the potential for the Build Alternative to provide more water in the 9.5 miles downstream of the City's intake was not modeled quantitatively. The frequency and duration of this benefit with the Build alternative is variable. Also, the City's use will increase over time so it could be argued that the flow benefits of the Build alternative would decrease over time and portions of the benefit may eventually be eliminated entirely (e.g.; when the City's winter demand starts to exceed 18.2 cfs in the winter). However the portions of the flow benefit with the Build Alternative related to water rights restrictions are expected to persist.

For these reasons, the return flow associated with the No-Build alternative and the correlated additional water left in-stream with the Build alternative were not modeled quantitatively. Instead, the alternatives are evaluated under future demand conditions at the system capacities, 18.2 cfs for the No-Build and 21 cfs for the Build Alternative. The evaluation under future higher demand conditions results in the maximum projected flow differential between the two alternatives and the maximum project habitat impact. Evaluation under these future higher demand scenarios also eliminates the need to quantitatively characterize the correlated conditions of return flow with the No-Build alternative and water left in-stream with the Build alternative.

3.4.2.2 Stream Flow Accretion

If stream flow accretion is relatively substantial, the volume and distribution of the accretion within the sub-reach must be accounted for in the habitat model.

Stream flow accretion (tributary and spring flow entering within the Project-affected area) was estimated based on apportioning Tumalo Creek flows by the drainage area and mean annual precipitation. Mean annual precipitation was used due to the variation in precipitation and runoff across the topography of the watershed. The mean annual precipitation used PRISM (Parameter-elevation Regressions on Independent Slopes Model), which incorporates 30 years of data (1971 through 2000) into a Geographic Information Systems (GIS) grid (OCS, 2011). The sub-basins within the Tumalo Creek watershed were delineated using the USGS StreamStats application (USGS, 2011). The sub-basins were overlaid onto the mean annual precipitation (Figure 5).

Principal tributaries (South Fork Tumalo Creek and Tumalo Lake Creek) and sources of spring flow within the Project-affected area are located in Sub-reach A1-RR. Nearly all accretion within the Project-affected area enters upstream of RM 10.4, the downstream terminus of Sub-reach A1-RR. Estimated total median annual accretion within the A1-RR is 16.7 cfs. Median annual accretion is distributed in Sub-reach A1-RR approximately as shown in Table 1. Estimated mean monthly accretion to Sub-reach A1-RR is shown in Table 2.

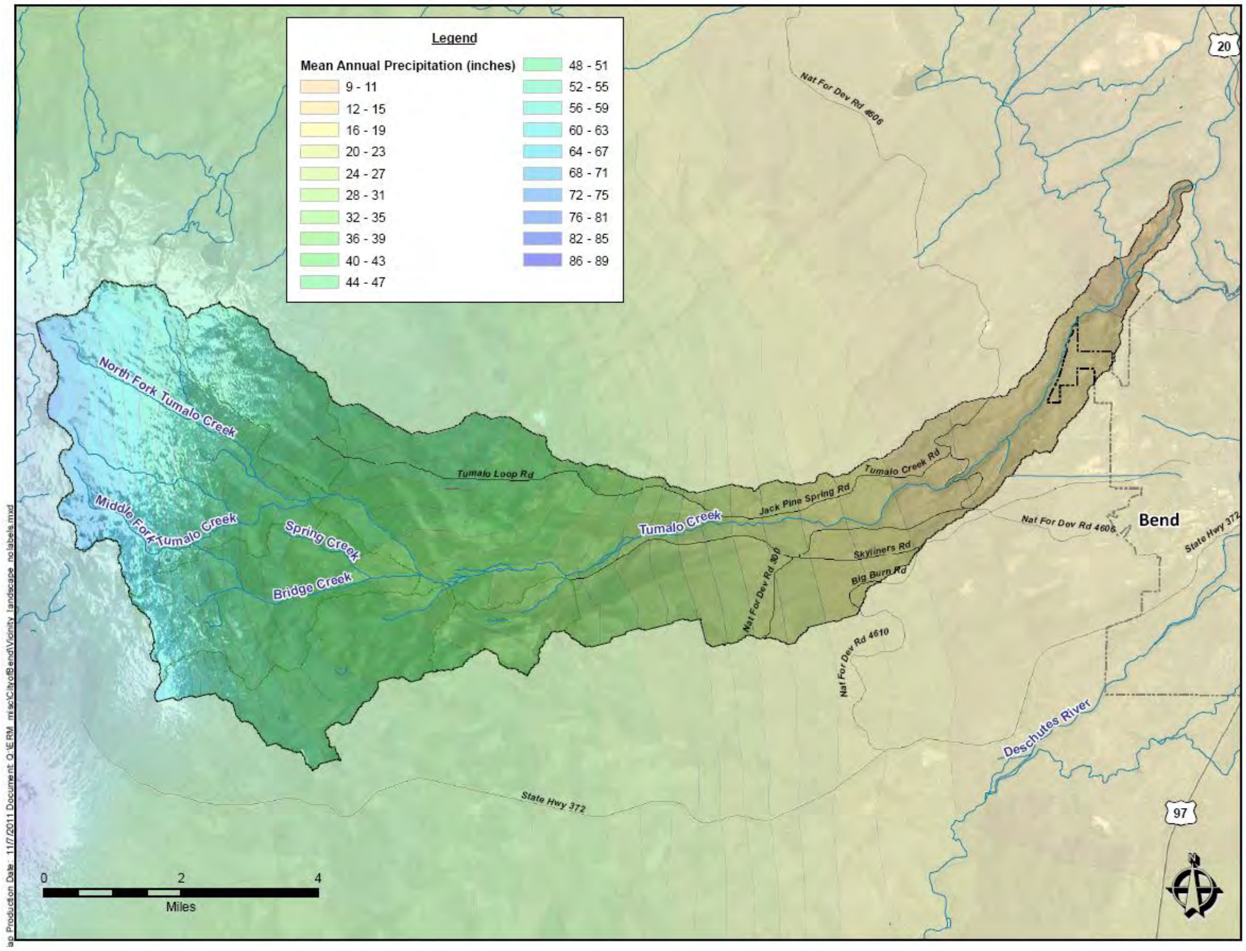


Figure 5. Tumalo Creek Watershed and Sub-basin mean annual precipitation

Table 1. Volume and distribution of stream flow accretion in Sub-reach A1-RR.

	Sub-reach A1-RR Top	Spring A	SF Tumalo	Spring B	Tumalo Lake Creek	Spring C	Sub-reach A1-RR Bottom	Total
River mile:	***16.0***	15.7	15.0	14.3	13.3	12.9	***10.4***	5.6
Median Discharge (cfs):		1.80	8.30	3.67	2.59	0.37		16.7
Percent Contribution		10.8%	49.6%	21.9%	15.5%	2.2%		100%

Table 2. Estimated median monthly accretion flow entering Sub-reach A1-RR.

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Median Accretion (cfs)	14.7	15.3	15.1	15.0	14.9	17.3	18.0	35.2	48.0	25.4	16.2	14.6

3.4.2.3 Summary of Hydrology Data Sets

Ten hydrology data sets were constructed for the habitat analyses; one each for No-build and Build in each of the five reaches/sub-reaches, as shown in Table 3.

Table 3. Calculation logic for the hydrology data sets developed for use in the Tumalo Creek Instream Flow Study

Reach or Sub-reach	No –build	Alternative Build
Sub-reach A1-RR Upper	Available Native Inflow[1] + Sub-reach A1-RR accretion (Spring A only) - Maximum of 18.2 cfs according to the City diversion scenarios as shown below in Table 4.	Available Native inflow + Sub-reach A1-RR accretion (Spring A only) - Maximum of 21cfs City according to the City diversion scenarios as shown below in Table 4
Sub-reach A1-RR Lower	Available Native Inflow[1] + Sub-reach A1-RR accretion (Spring A, SF Tumalo, Spring C) - Maximum of 18.2 cfs according to the City diversion scenarios as shown below in Table 4.	Available Native inflow + Sub-reach A1-RR accretion (Spring A, SF Tumalo, Spring C) - Maximum of 21cfs City according to the City diversion scenarios as shown below in Table 4.
Sub-reach A1-B	Available native inflow + Sub-reach A1-RR accretion - Maximum of 18.2 cfs according to the City diversion scenarios as shown below in Table 4	Available native inflow + Sub-reach A1-RR accretion - Maximum of 21cfs City according to the City diversion scenarios as shown below in Table 4
Sub-reach A2	Available Native inflow + Sub-reach A1-RR accretion - Maximum of 18.2 cfs City according to the City diversion scenarios as shown below in Table 4	Available Native inflow + Sub-reach A1-RR accretion - Maximum of 21cfs City according to the City diversion scenarios as shown below in Table 4
Reach B	Available Native inflow + Sub-reach A1-RR accretion - Maximum of 18.2 cfs City according to the City diversion scenarios as shown below in Table 4 - TID assumed diversion and operating scenarios (Table 5).	Available Native inflow + Sub-reach A1-RR accretion - Maximum of 21cfs according to the City diversion scenarios as shown below in Table 4 - TID assumed diversion and operating scenarios (Table 5).

1. Native inflow is calculated by subtracting daily accretion values from the Native Flow record described above representing reach A2.

The following diversion scenario tables for the City (Table 4) and TID (Table 5) were developed for the purpose of the habitat duration analysis. For native creek flows less than 50 cfs with the Build alternative, the City plans to not exceed the flow capacity of the No-Build alternative (18.2 cfs). For diversions of 18.2 cfs or less, the diversions of the No-Build and Build alternatives would be identical since neither would be capacity limited and would be driven by other operating parameters like water rights and demands. Therefore, for creek native flows of 50 cfs or less and City diversions of 18.2 cfs or less, there is no creek flow impact when comparing the Build and No-Build alternatives.

The City's diversion scenario table shows that for flows up to 50 cfs, there is no difference in diversion rate between the No-Build and the Build Alternative data sets. Only after stream flow reaches 50 cfs would the City's diversion rate potentially be allowed to change between the No-Build and Build alternatives, when the Build alternative diversion could increase from 18.2 cfs to 21 cfs if the demand exists and water rights allow. Although, when native flow exceeds 50 cfs the Build alternative is modeled to divert 21 cfs, demand conditions and water rights restrictions would most likely result in actual diversions being less than 21 cfs.

Table 5 shows the typical operations of TID diversions that occur at the upstream end of Reach B. These values were determined as being typical through discussions with representatives from TID.

For the purpose of modeling, the City's diversion as shown in Table 4 is assumed to be met upstream of Reach A at the City's intake. The amount of water remaining in Tumalo Creek just upstream of the TID diversion is calculated. The TID diversion is modeled to be the lesser of the "TID assumed diversion" or the Tumalo Creek flow minus the "minimum instream pass". This ensures the minimum instream pass is achieved while providing TID the maximum diversion possible up to the amount assumed. This modeling methodology does not correspond precisely to the mechanics of water rights distribution but reasonably accurately models the flow in Reach B, the impact of the City's alternatives on Reach B, and projects the maximum impact to Reach A since the method assumes the City does not get curtailed by water rights.

Table 4. City of Bend diversion scenarios used for hydrology data sets that impact Reach A

Native Flow (cfs)	No-Build	Irrigation Build Proposed 04/01-11/01	Non-irrigation Build Proposed 11/2-03/31
0	0.00	0.00	0.00
20	8.00	8.00	8.00
25	10.04	10.04	10.04
30	12.08	12.08	12.08
35	14.12	14.12	14.12
40	16.16	16.16	16.16
45	18.20	18.20	18.20
50	18.20	21.00	21.00

Table 5. Typical TID diversion scenarios used for hydrology data sets that impact Reach B

Month	Month	TID Assumed Diversion[1] (cfs)	Minimum Instream Pass[2] (cfs)
January	1	0	5
February	2	0	5
March	3	0	5
April	4	70	8
May	5	120	8
June	6	120	8
July	7	80	8
August	8	65	8
September	9	50	8
October	10	50	8
November	11	0	5
December	12	0	5

1. TID assumed diversions represent historical and planned diversions
2. 5 cfs represents typical historical bypass flows during off-season stock runs; 8 cfs represents senior Instream water rights at TID's diversion.

3.5 Limitations of the Hydrologic Modeling

The hydrologic data sets for the No-Build and Build alternatives were developed to demonstrate the maximum impact that could occur from City diversion within the various flow scenarios modeled. In reality, during the peak water demand season the amount of water available to the City under the modeling scenarios is likely significantly less based on the need to share the water with existing water right holders on Tumalo Creek. Moreover, the City currently has a wide range of demands during a typical year with the lowest demand occurring in the winter, typically less that 10 cfs. So the modeling performed herein overstates the impacts of the City's Build alternative since actual diversions will be restricted as described above and under the section titled, "City's Operations".

At the same time Bend's demands are increasing, the other senior water right holder on the stream anticipates continuing to reduce its current annual water losses of over 30,000 acre feet, by continuing to construct conserved water projects. TID plans to protect the conserved water in stream as the conservation projects are completed (Tumalo Irrigation District 2005 Water Management and Conservation Plan).

4.0 Habitat Methods

4.1 Selection of Methodology

In consultation with the USFS and ODFW the City selected the PHABSIM as the primary instream flow method. PHABSIM is the most widely accepted and applied fish habitat model in Oregon and the United States.

The instream flow study methodology described herein is consistent with guidelines originally developed and maintained by the US Fish and Wildlife Service's (USFWS) Instream Flow Group (now USGS, Aquatic Systems and Technology Applications Group, Fort Collins Science Center). Physical and hydraulic parameters were measured using a combination of standard techniques of the USFWS methodology (Milhous 1984, Milhous 1989, Trihey and Wegner 1981, Bovee 1982, Bovee 1997, Bovee et al. 1998), USGS (Rantz 1982)) and specific techniques outlined in the Study Plan.

4.2 Delineation of Study Area, Reach, and Sub-reach

The City used results of habitat mapping previously collected by the USFS (USFS 1999, USFS 2008) and ODFW, 1992) for the Project-affected area. Based on habitat mapping results and other information, the City, USFS, and ODFW collaboratively delineated the Project-affected area into reaches and sub-reaches. Reach and sub-reach delineations and habitat mapping methods and results are presented briefly in the body of this technical memorandum and are described in more detail in the Study Plan.

4.2.1 Study Area

The study area extends 16.0 river miles from the confluence of Tumalo Creek and Bridge Creek at river mile (RM) 16.0 on Tumalo Creek downstream to the confluence of Tumalo Creek and the Deschutes River at RM 0.0.

For the purposes of this study, the 16.0 mile study reach in its entirety is also referred to as the Project-affected area.

4.2.2 Study Reaches

Because stream flows in the study area are independently affected by the City and the Tumalo Irrigation District (TID), the study area was segmented at TID's diversion (RM 2.8) into two Reaches – Reach A, above and Reach B, below (Figure 6).

4.2.3 Study Sub-reaches

In instream flow studies, a study reach is segmented into homogeneous stream segments, where necessary, based on geomorphology, hydrology, and channel metrics. Once delineated a segment is termed a sub-reach. The characteristic feature of a sub-reach is general homogeneity of the channel structure and flow regime. When delineating based on flow regime, a sub-reach may be warranted only where accretion or depletion changes the base flow discharge by more than 10%. Factors affecting channel morphology along a watercourse include slope and sediment supply (Bovee 1982).

Reach A was segmented into three sub-reaches based on the City's point of return flow and differences in channel characteristics. A sub-reach segment boundary was placed at river mile 10.4 based on a change in longitudinal channel slope. The sub-segment boundary based on slope coincided with the boundary based on accretion. Hydrologic analyses indicated that nearly 100% of natural accretion in Reach A had entered the stream by river mile 10.4. A second sub-reach boundary was placed at the City's point of return flow at river mile 5.4. See Section 3.4 of this Technical Memorandum for a more detailed description of the hydrologic analyses.

Because Reach B is generally homogeneous in flow regime and channel morphology it was not segmented into sub-reaches.

Reach delineation based on water project influences and channel characteristics is described in Table 5. Figure 6 provides a map of the sub-reaches in relation to local landmarks.

Table 5. Description and location of Reaches and Sub-reaches.

Reach or Sub-Reach Name	Reach or Sub-Reach Abbreviation	Reach or Sub-Reach Description	Location (approximate begin-end RM)[1]	Length (miles)	Channel Slope[2] (%)
Sub-reach A1-RR	SR A1-RR	Tumalo Creek and Bridge Creek confluence to near the confluence of Jack Pine Spring and Tumalo Creek. This sub-reach is also referred to as the "Restoration Reach".	16.0 – 10.4	5.6	1.2
Sub-reach A1-B	SR A1-B	Near confluence of Jack Pine Spring to City of Bend return flow.	10.4 - 5.4	5.0	3.2
Sub-reach A2	SR A2	City of Bend Return Flow to Tumalo Feeder Canal diversion	5.4 – 2.8	2.7	1.1
Reach B	SR B	Tumalo Feeder Canal diversion to confluence with Deschutes River	2.8 - 0.0	2.8	2.5

[1] River Miles were updated for the Final Technical Memoranda.
[2] Slopes calculated from USGS topographic contour information.

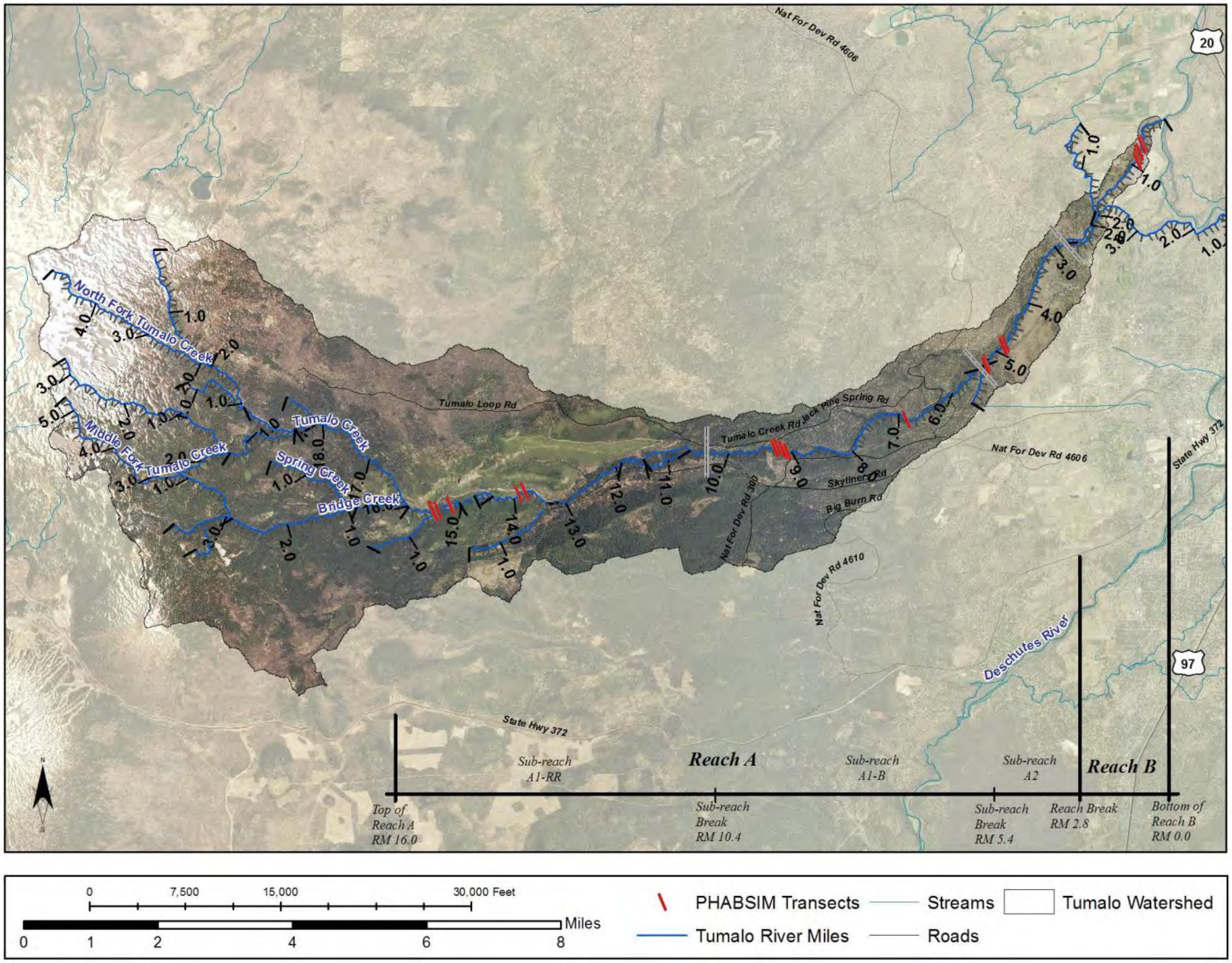


Figure 6. Tumalo Creek Instream flow study area showing reach breaks, sub-reach breaks and transect locations.

4.3 Study Site and Transect Selection

Study sites (transect or transect cluster locations) were selected within a sub-reach to represent the range of channel and habitat types in the sub-reach. Exact transect locations within each sub-reach were selected using professional judgment and in consultation with the USFS. Prior to transect selection in the field with the USFS, the City provided a pre-field package that included a description of the study area and mesohabitat frequencies based on existing USFS and ODFW survey data. The goal of transect selection was to obtain accurate representation of the habitat index versus flow relationship for each PHABSIM reach. This goal was achieved by distributing study sites (i.e., transects and transect clusters) throughout each PHABSIM study reach or sub-reach in such a way that all dominant[1] habitat types were represented by at least two habitat units. Habitat types with a high diversity or complexity in a particular reach, such as pools, were often represented by three or more individual habitat units. A total of 31 transects were selected. Below is a description by sub-reach of mesohabitat types used in habitat mapping and transect selection.

4.3.1 Sub-reach A1-RR (Restoration Reach)

Steam inventory data collected in 2008 by the USFS for the restoration reach did not delineate between fast water habitat types of riffle, rapid, or cascade. All fast habitat was called turbulent. However, based on the generally low gradient of this section of stream and field observations during the implementation of this Study, turbulent habitat types are mostly riffles with few rapids. Habitat frequencies are shown below in Table 6 for Reach A1-RR. Turbulent habitat dominates 84% of the sub-reach, with a variety of pool types comprising the remaining 16%.

Table 6. Habitat frequencies for Sub-reach A1-RR (restoration reach – Near Jack Pine Spring to Tumalo Creek and Bridge Creek confluence) based on stream inventories conducted by USFS 2008.

		A1-RR		
	Habitat	**Length**	**Length Frequency**	**Number of Representative Transects Selected**
Fast	Turbulent (Riffle/Rapid)	23,135	84%	5
Slow (pool)	Dam	610	2%	3
	Plunge	228	1%	
	Scour	1,773	6%	
	Lateral	773	3%	
	Mid Channel	1,128	4%	
Total		**27,647**	**100%**	**8**

4.3.2 Sub-reach A1-B

Steam inventory data collected in 1999 by the USFS for Sub-reach A1-B delineated the fast and slow water habitat types as shown in Table 7. Riffles and rapids dominate at 86% of the sub-reach, with a variety of pool types comprising the remaining 14%.

---

[1] For the purposes of this study a dominant habitat type must have a frequency of 5% or greater.

Table 7. Habitat frequencies for Sub-reach A1-B (From City of Bend's return flow to near Jack Pine Spring) based on stream inventories conducted by USFS 1999.

			A1-B	
Habitat		**Length**	**Adjusted Length Frequency**	**Number of Representative Transects Selected**
Fast	Riffle	7,592	28%	3
	Rapid	15,835	58%	3
	Cascade	1,215	0%	
Slow (pool)	Mid Channel	0	-	3
	Scour	2,408	9%	
	Lateral	134	0%	
	Dam	356	1%	
	Plunge	759	3%	
Total		**28,299**	**100%**	**9**

4.3.3 Sub-reach A2

Steam inventory data collected in 1999 by the USFS for Sub-reach A2 delineated habitat types as shown in Table 8. Of the 2.7 miles in Reach A2, 0.6 miles of river were not inventoried in 1999 (from the Tumalo Irrigation District's Feeder Canal at RM 2.8 to Shevlin Park Market Rd at RM 3.4). The habitat frequencies in Table 8 for Reach A2 show that riffles dominate 80% of the sub-reach, with a variety of pool types comprising the remaining 20%.

Table 8. Habitat frequencies for Sub-reach A2 based on stream inventories conducted by USFS 1999.

			Reach A2	
Habitat		**Length (ft)**	**Length Frequency**	**Number of Representative Transects Selected**
Fast	Riffle	7,626	80%	4
	Rapid	0	0	
	Cascade	0	0	
Slow (pool)	Mid Channel	201	2%	2
	Scour	497	5%	
	Lateral	812	8%	
	Dam	356	4%	
	Plunge	80	1%	
Total		**9,572**	**100%**	**6**

4.3.4 Reach B

Steam inventory data collected in 1992 by ODFW for Reach B delineated habitat types are shown in Table 9.

Table 9. Habitat frequencies for Reach B based on stream inventories conducted by ODFW 1992.

Reach B				
Habitat		**Length (ft)**	**Adjusted Length Frequency**	**Number of Representative Transects Selected**
Fast	Riffle/Run	13,228	81%	5
Slow	Pool	1,302	8%	2
	Glide	1,794	11%	1
Side Channel		403		
Backwater		62		
Total		**16,790**	**100%**	**8**

4.3.5 Final Study Site and Transect Locations

Table 10 below summarizes the study sites and 31 transects that were selected in consultation with the USFS. Included in the table are the UTM coordinates and a brief field based description of each transect.

Table 10. Final transect table for the Tumalo Creek Instream flow study.

Reach	Sub-reach	Transect	Habitat	Easting	Northing	Description and Selection Notes
A	A1-RR	1	Riffle	617837	4876726	Velocity shadows, moderate depth.
	A1-RR	2	Pool	617804	4876737	Lateral scour, bend, deep, large woody debris on right bank
	A1-RR	3	Riffle	617686	4876655	Slow, small substrate, wide
	A1-RR	4	Riffle	616051	4876323	Large woody debris on left bank, apex of bend, deep thalweg, narrow
	A1-RR	5	Pool	616060	4876384	Fast, turbulent, narrow, large substrate, no wood, side channel is ground water through flow
	A1-RR	6	Riffle	615766	4876212	Moderate depth, large woody debris on left bank, low turbulence.
	A1-RR	7	Riffle	615643	4876237	side channel on left bank side, shallow, fast, turbulent, white water
	A1-RR	8	Pool	615606	4876227	Right bank tail pin = 0615680/4876154, South Fork Tumalo just behind left bank head pin
	A1-RR	S.F. Q	Riffle	615677	4876130	Discharge Site on S.F. Tumalo Creek, behind Transect 8 head pin, added head pin, tail pin for tape.
	A1-B	1	Riffle	626929	4878723	Low gradient riffle, shallow, wide
	A1-B	2	Riffle	626911	4878738	Low gradient riffle, deep, wide
	A1-B	3	Pool	624095	4877874	Plunge, short, shallow, overhead vegetation on right bank, bubble curtains
	A1-B	4	Rapid	624088	4877874	Deep, fast, large substrate, small eddy left bank side.
	A1-B	5	Rapid	624004	4877914	Deep, fast, wide, undercut bank on left bank, spawning size gravel on right bank side.
	A1-B	6	Riffle	623963	4877919	High Gradient, Large cobble, shallow, wide, undercut bank on left bank, 4" Trout
	A1-B	7	Pool	623847	4877994	Lateral Scour, Fast, moderate depth.
	A1-B	8	Pool	623800	4877964	Scour, deep, boulder/bedrock, backwater right bank side, velocity chute.
	A1-B	9	Rapid	623784	4877950	Very fast, large woody debris on right bank side, moderate depth, large substrate.
	A2	1	Riffle	629239	4880619	Very fast, large substrate, narrow, moderate depth, fallen tree upstream.\
	A2	2	Pool	629199	4880578	Wide, slow left bank velocities, deep scour mid unit, large woody debris spanner, large woody debris on left bank side.
	A2	3	Riffle	629181	4880542	wide, shallow, small substrate, large woody debris on left bank side
	A2	4	Riffle	628809	4880141	Medium gradient, right bank deeper overhead vegetation, shallow.
	A2	5	Riffle	628791	4880106	Moderate depth, moderate gradient, medium to large substrate.
	A2	6	Pool	628779	4880078	Overhead vegetation, Deep fast velocities in thalweg slow on margins.
B	B	1	Pool	632397	4885502	Mid-channel, boulders with velocity shadows, moderate depth
	B	2	Riffle	632375	4885481	Run, Deep, relatively low disturbance, fast velocities, mixed substrate
	B	3	Riffle	632362	4885471	Rapid, shallow, wide, overhead vegetation left bank, small substrate on right bank, bedrock upstream, very turbulent on left bank side.
	B	4	Riffle	632356	4885456	Moderate depth, fast velocities, turbulence mid channel, wide, slight bend.
	B	5	Riffle	632274	4885280	On slight bend, shallow left bank, deeper thalweg, fast velocities, wider.
	B	6	Glide	632264	4885185	Moderate depth, laminar water, moderate/small substrates, fast (@ ~70 cubic feet per second)
	B	7	Riffle	632271	4885107	Rapid, Fast velocities, mixed substrate, moderate depth, some standing waves, narrow.
	B	8	Pool	632257	4885090	Scour, deep (~2.5-3'), very large boulder right bank, backwater spanner just upstream.

4.4 Target Calibration Flows

The goal of selecting target calibration flows is to obtain water surface elevation (stage) versus discharge measurements at two to three different discharges at each transect. The flow levels are referred to generically as a low flow, middle flow, and high flow or a low flow and high flow when just two measurements are taken. The terms low, middle, and high are only relative to each other. The terms are not necessarily relative to a point on the stream hydrograph. Each of these measurements is referred to as a calibration flow. The stage versus discharge relationship at each calibration flow is used by the hydraulic model to predict channel hydraulics over a range of discharges. In addition to stage versus discharge, velocities at 1- 2 foot intervals across each transect were measured at the high calibration flow.

Because of Tumalo Creek's typically low discharge variability during September through March (Figure 1) the City was uncertain if three sufficiently different flow levels would occur during the study period of September through December, 2011. For this reason, the City proposed in the Study Plan to install miniature continuous recording water level instrument at each transect in anticipation of a possible fall rain-on-snow event that would provide a higher stage versus discharge point. A rain-on-snow event did not occur so the transducer data were not useable as a calibration flow.

The City was able to collect two stage discharge measurements in Reach A and three in Reach B. Table 11 provides the calibration flow levels measured.

Table 11. Calibration flow measurements in Tumalo Creek.

Reach or Sub-reach	Low Flow	Middle Flow	High Flow
A1-RR	67[1]		78[3]
A1-B	66[1]		80[3]
A2	72[1]		78[3]
B	24[1,2]	64[1]	78[3]

1 City intake operating.
2 TID Feeder Canal Intake open for stock run diversion.
3 City intake shut.

4.5 Target Species/Lifestage Selection and Habitat Suitability Criteria

4.5.1 Target Species/Lifestage Selection

The City consulted with the USFS and ODFW to identify the primary target species/lifestages for the Tumalo Creek the Study. Redband trout (*Oncorhynchus mykiss gairdneri*) was identified as the target species with three lifestages to be modeled; adult, juvenile, and spawning.

4.5.2 Habitat Suitability Criteria

The following is a summary of Redband trout habitat suitability criteria (HSC) development for use in the Study model.

Category III[2] HSC for Redband trout do not exist for Tumalo Creek. Therefore, in collaboration with the USFS and based on data provided by ODFW, Category I HSC specific to Tumalo Creek were developed. Two category II/III and one Category I data sets were used as a basis for the Tumalo creek HSC

---

[2] Curve type: Category I - hand-drawn or a composite of various curves based on professional judgment, Category II - based on habitat use data, Category III - based on habitat use data adjusted by habitat availability data

development. The category II/III data sets came from the Upper North Fork American River (UNFA), CA and the Upper Klamath River (UKR), Oregon. The UKR data set was developed for Redband trout specifically while the UNFA was developed for rainbow trout (*Oncorhynchus mykiss*). The category I data came from an Instream flow study on Rock Creek, Powder River Basin, Oregon which were modified HSC from an Instream flow study on the Crooked River, Oregon.

An HSC development table (Table 12) has been included below as well as the tabular and curves for each Redband trout lifestage.

Table 12. Habitat suitability development table

Attribute	Curve(s) Selected	Rational
Spawning		
Velocity	Used a combination of data from the Upper Klamath River Redband trout curve and the Crooked River/Rock Creek Redband trout curve	Curve is generally broad. It envelopes field developed HSC curves for Redband from the Upper Klamath River, OR for lower velocities and recent consensus derived Redband curves from Rock Creek, OR. It envelopes literature findings from Muhlfeld, 2002 and the Columbia River Redband Trout Species Account, 2005.
Depth	Used a combination of data from the Upper Klamath River Redband trout curve and the Crooked River/Rock Creek Redband trout curve	Curve is generally broad. It envelopes field developed HSC curves for Redband from the Klamath River, OR and recent consensus derived Redband curves from Rock Creek, OR. It captures literature findings from Muhlfeld, 2002 and the Columbia River Redband Trout Species Account, 2005.
Substrate	Developed Category I HSC	Used a dominant substrate coding system. Preferences are based on literature describing substrate sizes used in nest development by Redband trout, comparisons to other Redband trout HSC curves, and professional judgment.
Juvenile		
Velocity	Upper North Fork Feather River rainbow trout	The Upper North Fork Feather River data set was developed based on 437 observations of juvenile rainbow trout at flows between 40 and 140 cfs. These flows are consistent with flows observed in Tumalo Creek. The proposed curve favors slightly lower velocities than the Rock Creek, OR curve and is generally consistent with Muhlfeld, 2002.
Depth	Modified Upper Klamath River Redband trout	The curve uses juvenile Redband trout data from the Upper Klamath River to define the left side of the curve. It is generally believed that juvenile trout will use deeper water if available; therefore, the right side of the Klamath curve was modified to include all depths greater than 1.3 ft as preferable. The proposed curve is generally consistent with Muhlfeld, 2002 and the Rock Creek, OR consensus curve.
Adult		
Velocity	Upper Klamath River Redband trout curve	The upper North Fork Feather River data set was developed from 179 observations. The stream flows in the U.N.F Feather River when data were collected are similar to the base flows found in Tumalo Creek for much of the year. The curve is supported by findings in Muhlfeld, 2001.
Depth	Upper Klamath River Redband trout curve	The curve is based on the S.F. Stanislaus Use curve. It is identical except that depths greater than 2.3 ft are not limited. The S.F. Stanislaus Use curve is shifted left from the Rock Creek, Upper Klamath and Upper North Fork Feather River curves but consistent with the findings from Muhlfeld, 2002. Stream characteristics for the S.F. Stanislaus are similar in average width, slope and elevation to that of Tumalo Cr. Discharges at the time of data collection were at or lower than base flows on Tumalo Cr. for much of the year.

Tables 13 – 19 and Figures 7 - 13 present the habitat suitability curves used in the Tumalo Creek PHABSIM.

4.5.2.1 Redband Trout Spawning Habitat Suitability Curves

Table 13. Redband trout spawning velocity HSC.

Velocity	Suitability Index
0.0	0.00
0.15	0.15
0.45	1.00
1.90	1.00
2.20	0.89
2.60	0.58
3.00	0.32
3.40	0.11
3.80	0.03
4.20	0.00
5.00	0.00

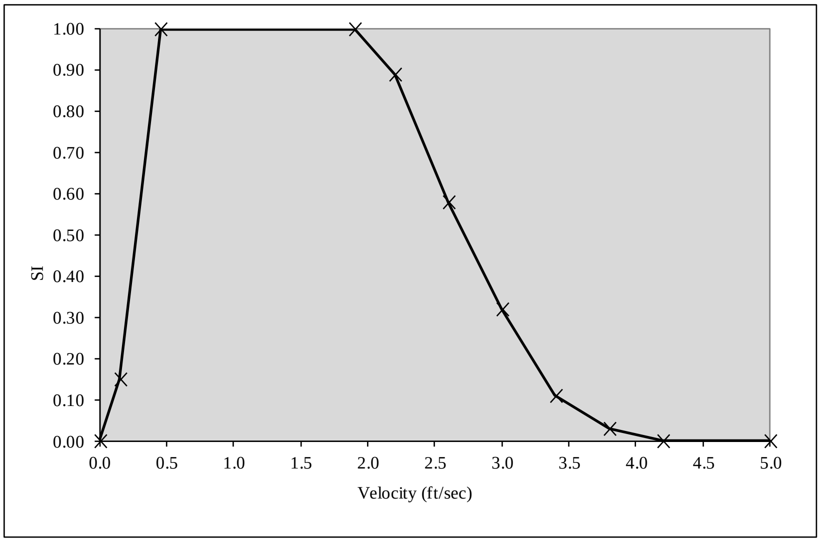


Figure 7. Redband trout spawning velocity HSC.

Table 14. Redband trout spawning depth HSC

Depth	Suitability Index
0.0	0.00
0.25	0.41
0.75	1.00
1.5	1
2.0	0.40
2.5	0.15
3.5	0.10
6	0.05

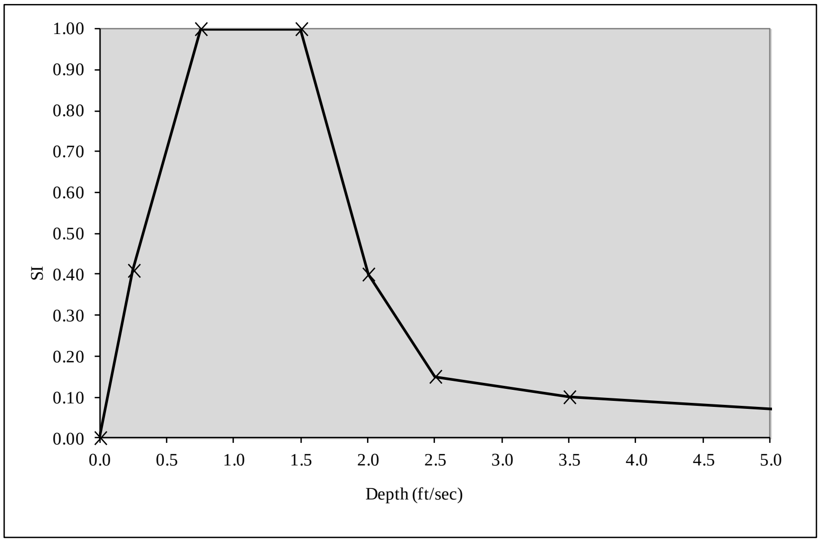


Figure 8. Redband trout spawning depth HSC

Table 15. Redband trout spawning substrate HSC

Substrate	Suitability Index	Size (in)
1.0	0.00	0.0-0.2
2	1.00	0.2-0.8
3	1.00	0.8-2
4	0.5	>2.0-3.0
5.0	0.00	3-4.5
6	0.00	4.5-6
7	0.00	>6.0-9.0
8	0	>9

Figure 9. Redband trout spawning substrate HSC

4.5.2.2 Redband Trout Juvenile Habitat Suitability Curves

Table 16. Redband trout juvenile velocity HSC

Velocity	Suitability Index
0.0	0.75
0.05	0.80
0.15	0.88
0.25	0.95
0.35	0.98
0.45	1.00
0.55	0.99
0.65	0.97
0.75	0.92
0.85	0.86
0.95	0.79
1.05	0.72
1.2	0.64
1.25	0.58
1.35	0.52
1.45	0.47
1.55	0.43
1.65	0.39
1.75	0.35
1.85	0.32
1.95	0.30
2.05	0.28
2.65	0.24
2.75	0.24
2.9	0.22
2.95	0.21
3.05	0.19
3.15	0.16
3.25	0.13
3.35	0.11
3.45	0.09
3.55	0.07
3.65	0.05
3.75	0.04
3.85	0.03
3.95	0.02
4.1	0.01
4.15	0.01
4.25	0.00

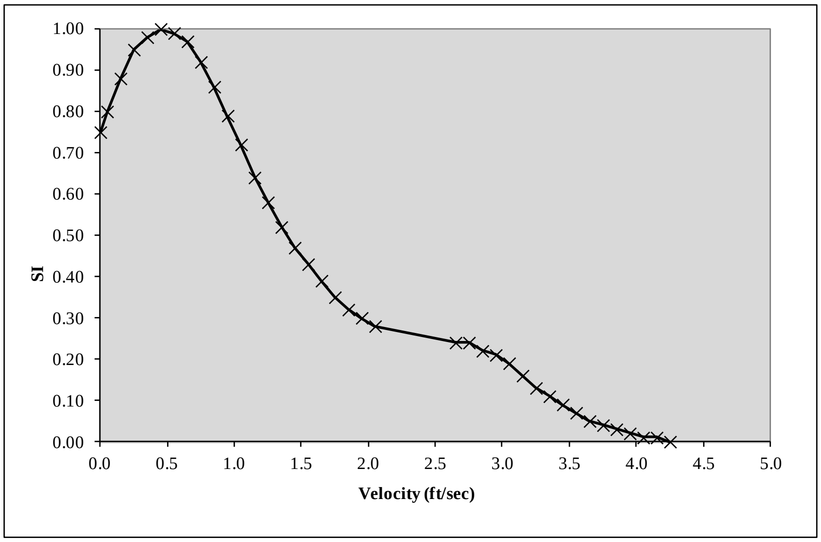


Figure 10. Redband trout juvenile velocity HSC

Table 17. Redband trout juvenile depth HSC

Depth	Suitability Index
0	0.00
0.1	0.13
0.30	0.29
0.50	0.50
0.70	0.68
0.9	0.84
1.1	0.97
1.3	1.00
10.00	1.00

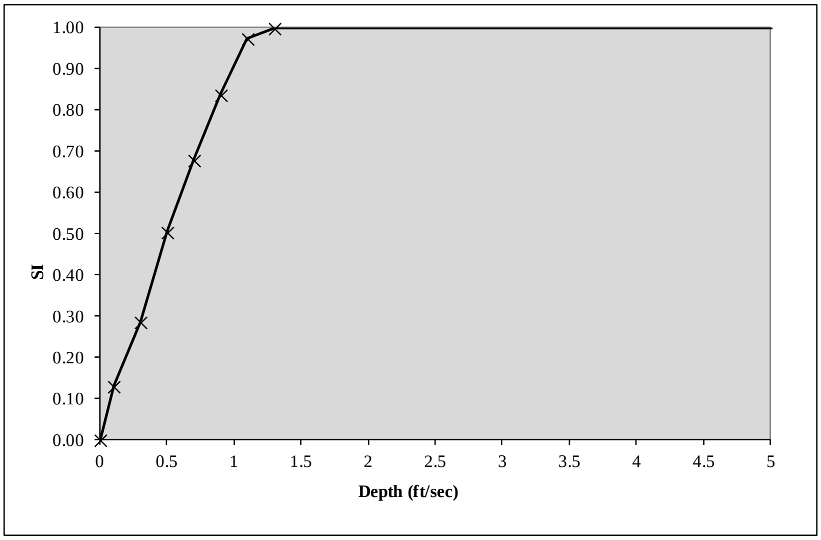


Figure 11. Redband trout juvenile depth HSC

4.5.2.3 Redband Trout Adult Habitat Suitability Curves

Table 18. Redband trout adult velocity HSC

Velocity	Suitability Index
0.0	0.18
0.05	0.23
0.15	0.37
0.25	0.52
0.4	0.65
0.45	0.78
0.55	0.88
0.65	0.95
0.8	1.00
0.85	0.99
0.95	0.96
1.05	0.92
1.2	0.87
1.25	0.81
1.35	0.75
1.45	0.69
1.6	0.63
1.65	0.57
1.75	0.52
1.85	0.48
2.0	0.45
2.05	0.43
2.15	0.41
2.25	0.4
2.4	0.38
2.95	0.33
3.05	0.31
3.15	0.29
3.3	0.26
3.35	0.22
3.45	0.19
3.55	0.15
3.7	0.11
3.75	0.07
3.85	0.06
3.95	0.04
4.1	0.03
4.15	0.02
4.25	0.00

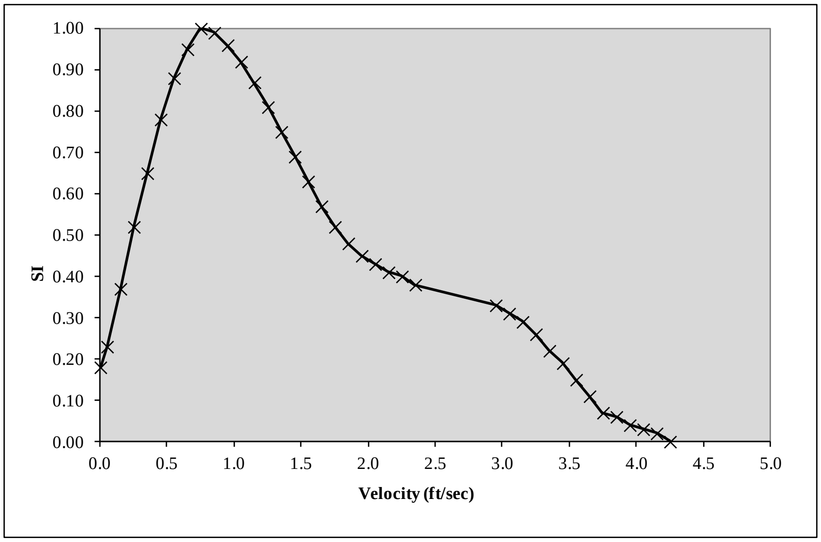


Figure 12. Redband trout adult velocity HSC

Table 19. Redband trout adult depth HSC

Depth	Suitability Index
0.4	0.00
0.5	0.13
0.7	0.29
0.9	0.47
1.1	0.62
1.3	0.73
1.5	0.82
1.7	0.89
1.9	0.93
2.1	0.98
2.3	1.00
10	1.00

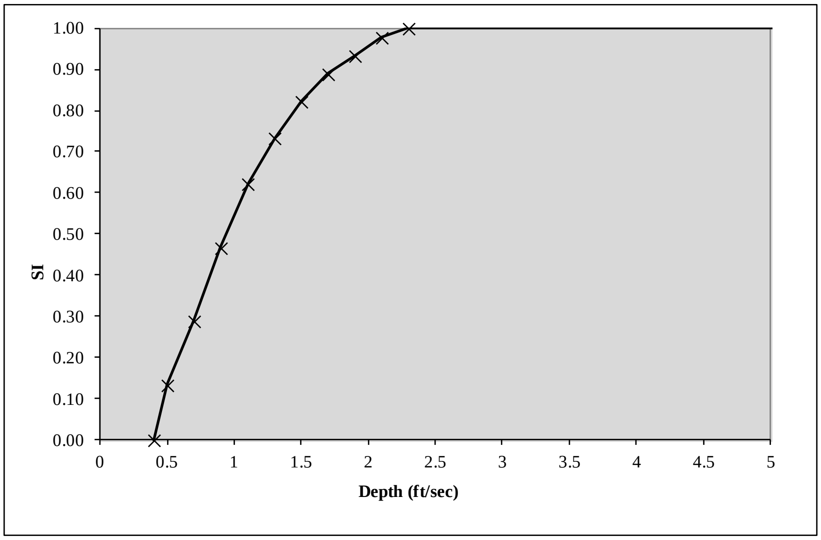


Figure 13. Redband trout adult depth HSC

4.6 Field Data Collection

4.6.1 General Method

Physical and hydraulic parameters were measured using a combination of standard techniques of the USFWS methodology (Trihey and Wegner 1981, Bovee 1982, Bovee et al. 1998, USGS (Rantz 1982), and techniques outlined in the Study Plan.

4.6.2 Surveying and Controls

All elevations were surveyed by standard differential survey techniques using an auto-level instrument. Headpin and tailpin elevations, water surface elevations (WSE), hydraulic controls, and above-water bed and bank elevations were referenced to a temporary benchmark serving a single transect or transect cluster. Where reasonable (line of sight or one turning point), benchmarks were tied together. At a minimum, all transects in a single mesohabitat unit were surveyed to a common datum. Transect locations were fixed, to the accuracy level possible, using a handheld GPS instrument.

4.6.3 Water Surface Elevation/Discharge

Water surface elevations were obtained at all transects during each field visit at the calibration flow levels (Table 7). Discharge measurements were made at appropriate transects in each transect cluster or study site during each field visit.

The City had anticipated collection of a high calibration flow greater than 100 cfs during a rain-on-snow event using continuous water level recorders (pressure transducers) installed at each transect. Pressure transducers were used because the unpredictable timing and very short duration of a possible rain-on-snow event would have likely precluded the deployment of a field crew. The pressure transducers were installed as described in the Study Plan. However, stream flow did not exceed approximately 80 cfs during the study period.

4.6.4 Calibration Velocity

One velocity calibration set was collected at the high flow at each transect. Velocities were collected using standard USGS protocol where velocity is measured at 60% of depth up to depths of 2.4 ft, and at 20% and 80% of depth for depths equal to or greater than 2.5 ft. If there was a significant upstream flow obstruction, velocities were measured at 20% and 80% of depth. During measurement, velocity meters were oriented to measure the full velocity magnitude at each station with any flow angle noted.

Temporary staff gage levels and the time of day were recorded at the beginning and end of each transect measurement to note potential changes in stage.

4.6.5 Substrate and Cover

Substrate and cover was visually classified during low flow conditions according to standard instream flow procedures.

Percent occurrence of all substrate size classes within the immediate vicinity of the transect (1-2 ft radius from vertical) was recorded. Substrate categories and particle size are shown in Table 20 while cover types and coding are shown in Table 21.

Table 20. Substrate sizes classes.

Substrate Type	Size (inches)
Organics, Silt, Sand	0.0-0.2
Small gravel	0.2-0.8
Medium gravel[1]	0.8-2
Large gravel	2-3
Very Small cobble	3-4.5
Small Cobble	4.5-6
Medium cobble	6-9
Large cobble. Boulder, Bedrock	>9

1. Medium gravel size class based on Redband Trout substrate preference needs identified in Muhlfeld, C.C. 2002.

Table 21. Cover classifications.

Code	Cover Type
0.1	none
1.0	cobble (3-12")
2.0	boulder
3.0	fine woody vegetation (<1")
4.0	branches
5.0	log (>1' diameter)
7.0	Over hanging vegetation (>2' above substrate)
8.0	under cut bank
9.0	aquatic vegetation
10.0	rip-rap
combos: 3.7, 4.7, 5.7, 9.7[1]	--

1. Combo codes e.g. 4.7 = branches with over hanging vegetation

4.6.6 Miscellaneous Data Collection

Photographs were taken of all transects from downstream and other points, as necessary, at each measured flow. To the extent possible, each photograph was taken from the same location at each of the three calibration flows.

Data sheets for each study site were completed as follows:

- Photo Log – for each flow/visit (Provided in Attachment A – Transect Photos)
- Site Documentation – map showing location, type, and numbering of transects – completed once
- GPS Universal Transverse Mercator (UTM) coordinates for each headpin (or mid-channel if headpin reading could not be obtained) and benchmark – completed once
- Water Surface Elevation (WSE) and Level Loop – WSE completed at each calibration flow, level loop completed once, pin heights validated at each visit
- Discharge – for each flow; at one, two, or more transects
- Depth and Velocity – at each transect for one calibration flow
- Stage of Zero Flow – collected once for each transect
- Cross-Section Profile and Substrate – completed once for each transect
- Task Completion Checklist – in field for every visit

4.7 Hydraulic Modeling and Calibration

An overview of the methods used in the PHABSIM calibration process is provided below. Detailed PHABSIM hydraulic modeling calibration methods, parameters and statistics for each sub-reach have been included in Attachment B – Tumalo Creek - PHABSIM Hydraulic Calibration Report.

4.7.1 Discharge and Water Surface Elevation

Hydraulic models were calibrated in the HYDSIM routine of RHABSIM 3.0. Hydraulic modeling procedures appropriate to the study site and level of data collection were used for modeling water surface elevations and velocities across each transect.

For transects where three water surface elevations were collected (Reach B), these procedures included the development of stage/discharge rating curves using log-log regression (IFG4) and Manning's formula (MANSQ). The most appropriate and accurate method was selected based on a direct comparison of results from each model with MANSQ set as the default modeling method. If individual transects did not calibrate sufficiently well using MANSQ, based on general guidelines of maximum Beta (0.5), and/or professional judgment, then log/log was chosen.

For transects where only two water surface elevations were collected (Sub-reaches A1RR, A1B, and A2), stage/discharge rating curves were developed and calibrated using MANSQ. While MANSQ was the primary modeling method, transects were also evaluated in IFG4 to ensure that the β coefficients for each transect were similar. The MANSQ modeling procedure uses a power function of the ratio of simulated discharge to observed discharge for adjusting channel conveyance at different discharges at each transect. When more than one discharge measurement was available for calibration, the exponent (β) was adjusted until good agreement of simulated versus observed water surface elevations was achieved for all discharges (T. Waddle et al 2000).

4.7.2 Velocities

The hydraulic model utilized the “one-velocity set” method, which uses measured velocities across a given transect and estimates a Manning’s N value for each cell to achieve the given discharge. Calibration techniques include adjustments to the Manning’s N to obtain accurate predictions of measured velocities, as well as reasonable predictions of velocities at simulated flows.

The purpose of the velocity calibration is to accurately simulate the measured velocities and water surface elevations at the observed flows while at the same time providing reasonable velocities and water surface elevations at the range of simulated flows. Changes to velocities were kept to a minimum and revised only when specific changes improved model performance.

4.7.3 Model Extrapolation

Extrapolation of flows beyond the lowest and highest calibration measurements was necessary to achieve as much of the range of the hydrograph as possible. The limits of extrapolation beyond field measured calibration stage/discharge pairs were evaluated based on model performance, channel shape, and modeling method, all of which contribute to establishing reasonable extrapolation limits within the hydraulic model. Based on these factors, the extrapolation limits used in the Tumalo Creek PHABSIM hydraulic models extended from 0.4 times (or 40% of the lowest stage/discharge pair) to 2.5 times (or 250% of the highest stage/discharge pair). This range is consistent with standard PHABSIM extrapolation allowances. Table 22 below shows the simulated flows used in the development of rating curves for each hydraulic model.

Table 22. Simulation flows used in each PHABSIM hydraulic model.

Sub-reach A1-RR (cfs)	Sub-reach A1-B (cfs)	Sub-reach A2 (cfs)	Reach B (cfs)
22	26	28	9.5
25	28	30	12
28	31	32	15
31	34	34	18
34	37	36	21
37	40	38	24
40	45	40	27
45	50	45	30
50	55	50	35
55	60	55	40
60	65	60	45
65	70	65	50
70	75	70	55
75	80	75	60
80	85	80	65
85	90	85	70
90	95	90	75
95	100	95	80
100	105	100	90
105	110	105	100
110	115	110	110
120	120	120	120
130	130	130	130
140	140	140	140
150	150	150	150
160	160	160	160
170	170	170	170

Sub-reach A1-RR (cfs)	Sub-reach A1-B (cfs)	Sub-reach A2 (cfs)	Reach B (cfs)
180	180	180	180
190	190	190	190
202	200	195	195

4.8 Habitat Modeling

Habitat models for Tumalo Creek were generated in the HABSIM routine of RHABSIM 3.0. In the habitat modeling process, HSC for each lifestage of Redband trout (Section 4.5) are integrated with the hydraulic models for each reach or sub-reach resulting in an index of available habitat. This index is called Weighted Useable Habitat (WUA).

4.8.1 Habitat Calculation

WUA was calculated using the standard multiplication calculation. This calculation is performed on each data point or “cell” across each transect at every simulation flow in the model. The equation is:

$$(CI) = V_i * D_i * S_i$$

Where: CI is the composite suitability of cell i, V_i is the suitability associated with velocity in cell i, D_i is the suitability associated with depth in cell i, and S_i is the suitability associated with channel index (substrate) in cell i (only applicable to spawning).

4.8.2 Transect Weighting

Within each sub-reach, transects were weighted relative to the abundance of the mesohabitat they represented. Table 23 summarizes the transect weighting for each reach or sub-reach.

Table 23. Transect weighting factors for use in the derivation of WUA for each sub-reach.

Reach	Sub-Reach	Number of Transects	Transect Number	Mesohabitat Type	Transect Weighting Factor (%)
A	A1-RR	8	1	Riffle	16.80
			2	Pool	5.34
			3	Riffle	16.80
			4	Riffle	16.80
			5	Pool	5.33
			6	Riffle	16.80
			7	Riffle	16.80
			8	Pool	5.34
					100.00%
	A1-B	9	1	Riffle	9.33
			2	Riffle	9.33
			3	Pool	4.67
			4	Rapid	19.33
			5	Rapid	19.33
			6	Riffle	9.34
			7	Pool	4.67
			8	Pool	4.68
			9	Rapid	19.33
					100.00%
	A2	6	1	Riffle	20.00
			2	Pool	10.00
			3	Riffle	20.00
			4	Riffle	20.00
			5	Riffle	20.00
			6	Pool	10.00
					100.00%
B	B	8	1	Pool	4.00
			2	Riffle	16.20
			3	Riffle	16.20
			4	Riffle	16.20
			5	Riffle	16.20
			6	Glide	11.00
			7	Riffle	16.20
			8	Pool	4.00
					100.00%

4.9 Habitat Duration Analysis

4.9.1 Construction of the Habitat Duration Curve

WUA is a static relationship that does not represent how often a specific flow/habitat relationship occurs. For this reason, in many cases WUA is not considered the final result of a PHABSIM instream flow study. A more complete analysis is the habitat duration analysis (HDA), sometimes referred to as a time series analysis. An HDA integrates WUA with hydrology and project operations to provide a dynamic analysis of flow versus total habitat over time under different operational scenarios. According to Bovee (1998) the habitat duration curve is valuable for quantifying differences in habitat availability between baseline and alternative conditions.

A habitat duration curve (Figure 14) is constructed in exactly the same way as a flow duration curve, but uses mean daily habitat instead of mean daily discharge on the Y axis. For each record of mean daily flow in the hydrology data set(s), the program "looks up" the corresponding WUA from the WUA table (Figure 15). The WUA index (square feet of habitat per 1,000 linear feet of stream) is then multiplied by the sub-reach length to derive mean daily total habitat in the sub-reach for that day of record. Sub-reach habitat is summed in reaches that have sub-reaches. The program then generates a habitat duration curve for the period of record for both the selected baseline and alternative flow hydrology sets.

Although habitat duration curves look like flow duration curves, there is no direct correspondence between the two. For example, the habitat that is exceeded 90% of the time usually does not correspond to the discharge that has the same exceedance probability. This discordance occurs because of the bell-shaped relationship between total habitat and discharge. The same amount of habitat can occur at different discharges (Bovee 1998).

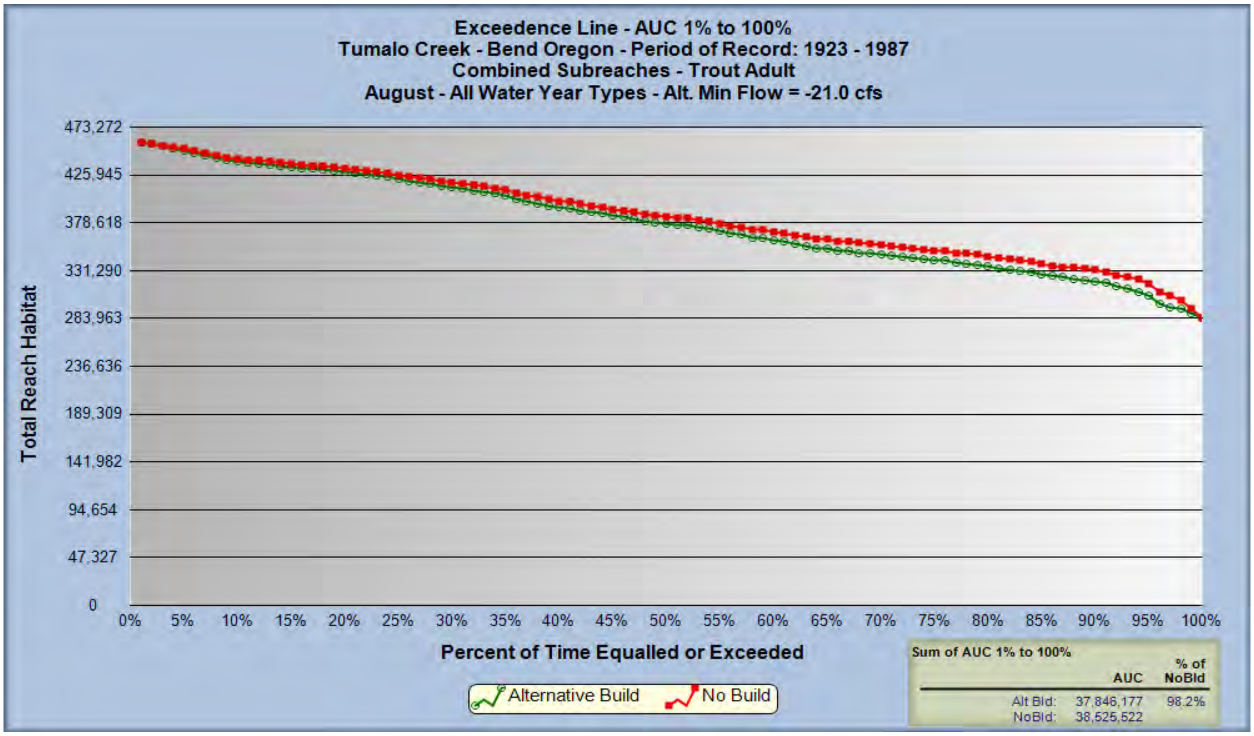


Figure 14. Example habitat duration chart.

Period of Record Mean Daily Flow	
Date in Hydrology period of Record	Mean Daily Discharge (cfs)
01/01/1980	80
01/02/1980	40
01/03/1980	30
01/04/1980	90
01/05/1980	100
01/06/1980	120
01/07/1980	130
01/08/1980	150
01/09/1980	200
01/10/1980	250
01/11/1980	250
01/12/1980	250
01/13/1980	120
01/14/1980	60
01/15/1980	45
01/16/1980	20
01/17/1980	15

WUA Function	
Discharge (cfs)	WUA
4	5,854
6	6,388
8	7,331
10	8,105
15	9,351
20	9,621
25	9,808
30	10,102
35	10,300
40	10,450
45	10,890
50	11,090
60	11,321
70	11,549
80	12,154
90	13,024
100	12,955

Period of Record Mean Daily Habitat	
Date in Hydrology period of Record	Mean Daily WUA
01/01/1980	12,154
01/02/1980	10,450
01/03/1980	10,102
01/04/1980	13,024
01/05/1980	12,955
01/06/1980	12,100
01/07/1980	12,025
01/08/1980	11,825
01/09/1980	11,250
01/10/1980	10,830
01/11/1980	10,830
01/12/1980	10,830
01/13/1980	11,321
01/14/1980	9,921
01/15/1980	10,890
01/16/1980	9,921
01/17/1980	9,351

Figure 15. Conversion from mean daily flow to mean daily habitat.

Habitat duration calculations were made using a program written in the Microsoft programming language Visual Basic.

While visually comparing two habitat duration curves may be informative, knowing the quantitative difference between the two is necessary. The quantitative difference is determined first by calculating the area under the curve (AUC). AUC is calculated by summing the Total Reach Habitat values at one percent increments of the habitat duration curve (Figure 16).

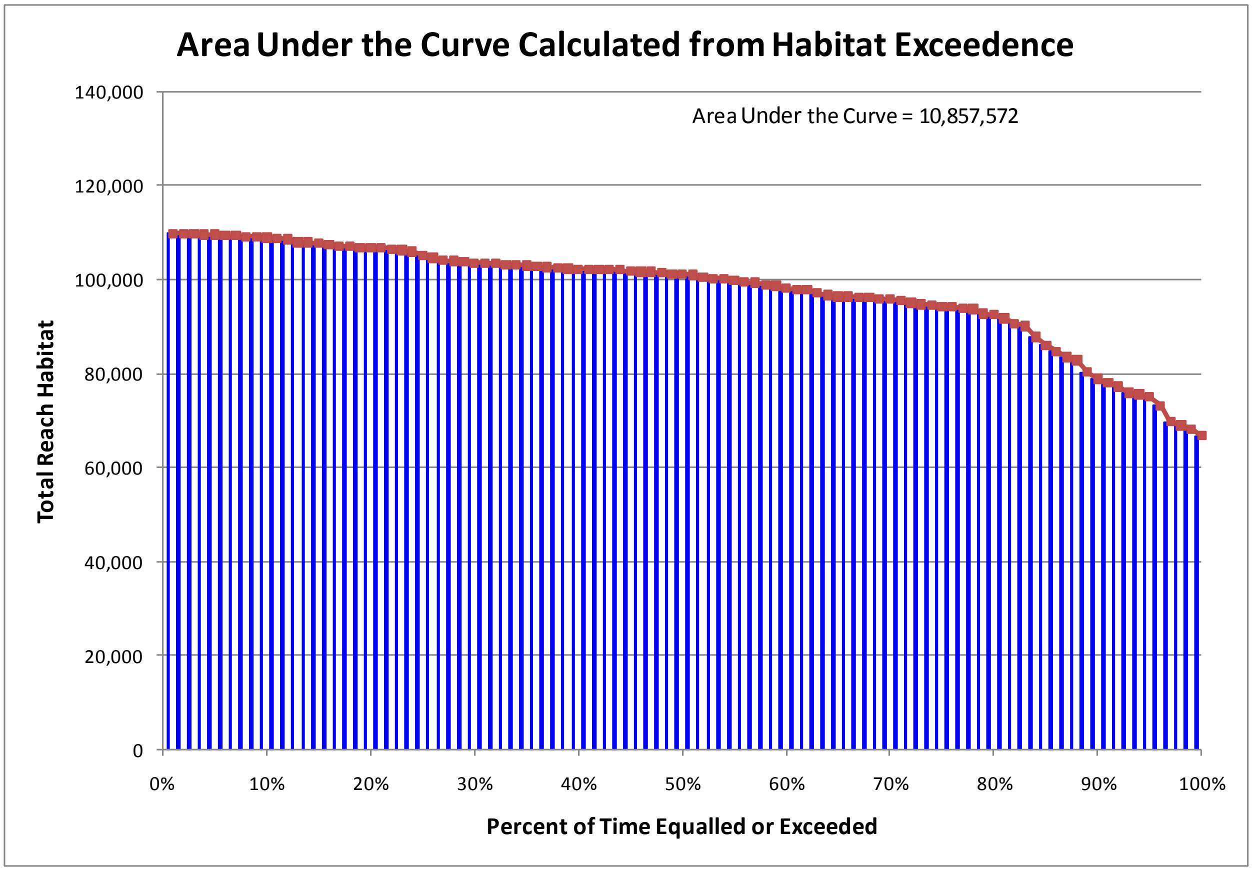


Figure 16. Example monthly habitat duration curve showing exceedance values at 1 percent increments.

The AUC index of one curve, such as an alternative flow scenario, can then be compared to the AUC index of another, such as the baseline flow scenario. How one curve compares to another is generally expressed as "percent difference".

4.9.2 Periodicity

The habitat duration analysis was run for seasonal periods when the lifestage was present (Table 24).

Table 24. Redband trout periodicity table for input into the habitat duration analysis

Species	Lifestage	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Redband Trout	Spawning					X	X	X	X	X	X	X	X	X	X										
	Juvenile	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Adult	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

4.9.3 Summary of HDA Program Inputs and Runs

Input parameters to the HDA included the following:

- Build and No-build hydrologic record calculated for each reach/sub-reach
    - Mean daily flow for the period of record October 1923 to October 1987;
    - Accretion in the study area, on a mean daily basis, is accounted for in Sub-reach A-1 RR;
    - No water year types - all water year types combined;
- WUA by reach/sub-reach for all species/life stages; and
- Periodicity for each species/life stage.

Comparison options include:

- Alternative Build to No-build;

5.0 Geomorphic Process Methods

Three transects were selected from each of the four sub-reaches to use in the analysis. Transects were chosen based on uniformity (e.g., little converging or diverging flow, uniform substrate). Riffle transects were predominantly chosen, with one rapid transect selected in sub-reach A1-B and one glide transect selected in Reach B. Table 25 identifies the transects selected for analysis.

Table 25. Sites and habitat types of transects selected for additional analysis.

Site	Transect	Habitat Type
A1 RR	3	Riffle
	4	Riffle
	6	Riffle
A1 B	1	Riffle
	2	Riffle
	4	Rapid
A2	3	Riffle
	4	Riffle
	5	Riffle
B	2	Riffle
	4	Riffle
	6	Glide

5.1 Establish Bankfull Stage

Bankfull stage for each transect was estimated using an existing estimate of the USFS in *Tumalo Creek Bankfull Discharge Calculations* (Wasniewski 2004), because the location of bankfull stage was not recorded during PHABSIM field data collection. The stage/discharge relationship established during PHABSIM modeling were used to estimate a bankfull stage at each cross section given the USFS estimate of bankfull discharge.

5.2 Particle Size

Substrate data were collected as part of the PHABSIM analysis as described in Section 4.6.5. Substrate data were analyzed by particle size and estimates of the average particle size for each transect were developed. The field data were converted to an average particle size by taking the mid-point of the range (converting inches to millimeters), calculating the percentage of the cross section that that particle size constituted in the bed (partial size fraction), then summing the partial size fractions for cross section. For example, if small gravel (10.2 mm) was located from station 12 to 20 in a bankfull channel of 50 ft, the partial size fraction is ((20-12)/50)*10.2. This analysis was done for each "bin" along the cross section. The values for each bin were then totaled resulting in a cross-section-averaged particle size. These data were used to provide a rough estimate of the median (D_{50}) particle size within the cross section to qualitatively discuss potential for movement given the slight change in stage proposed by the City.

5.3 Channel Shear Stress

Cross section data from the twelve transects and slopes derived from 1:24k maps and field data to estimate channel shear. Field data were used for slope in Reaches A1-RR and B, while 1:24k map data were used for Reaches A1-B and A2. Channel shear is the force on the bed that generates particle movement. Channel shear stress for each cross section was estimated by WinXSPro (Hardy et al. 2005). Channel shear is a function of the depth/slope product: ρRS, where ρ = density, R = hydraulic radius, and S = slope. Reach or sub-reach slopes were not collected as part of the PHABSIM study so map-based slopes were used in the model, except for Reach B, where transects had been linked together and a more accurate slope was possible, and in Reach A1-RR where USFS had collected slope data.

6.0 Results

6.1 Channel/Flow Response

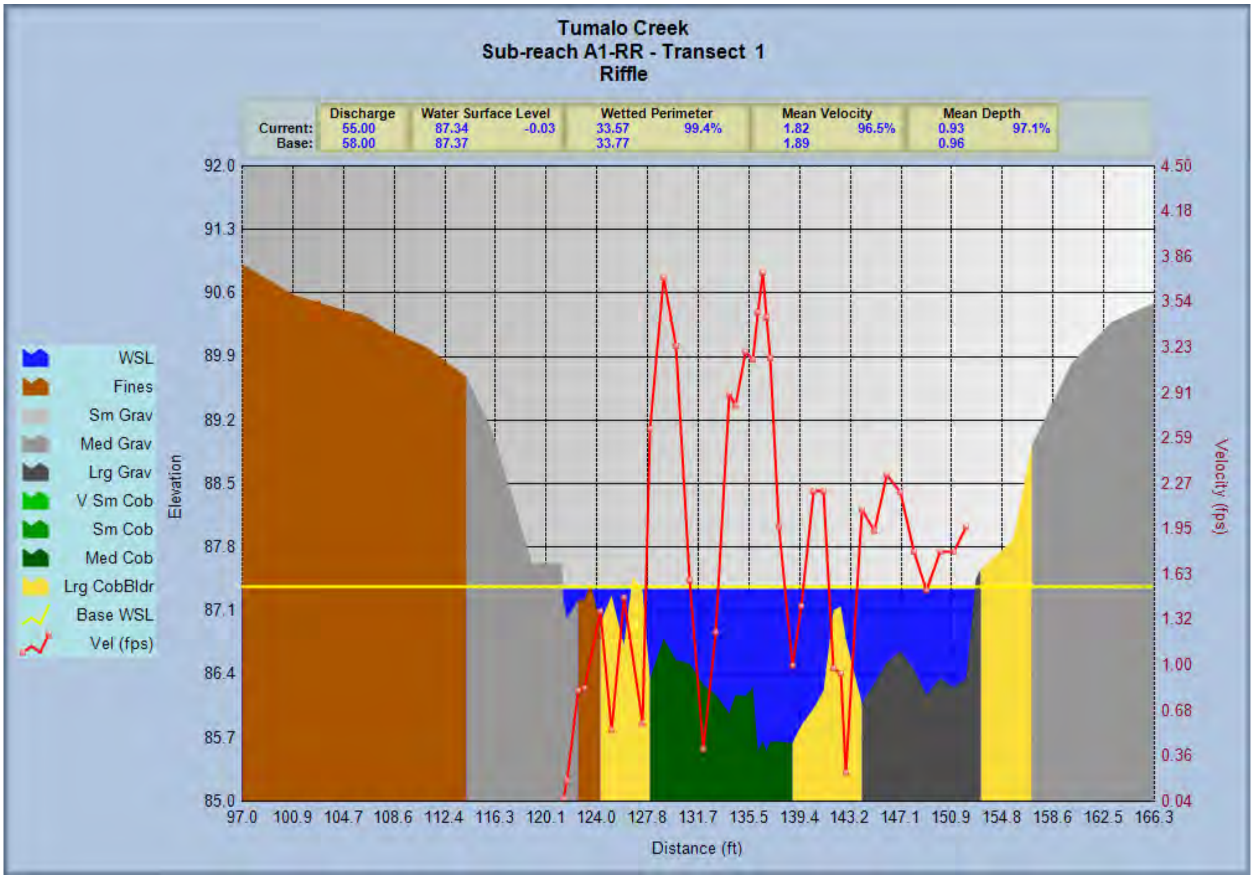
Graphical and tabular results were developed from the Tumalo Creek hydraulic models. A dynamic plot of the cross sectional profile of each transect was developed from the survey measurements and hydraulic model results. The dynamic plot enables the user to input a discharge of choice and the water surface and velocity pattern, wetted perimeter, average velocity, and average depth for that discharge are displayed in comparison to the same parameters for a chosen baseline flow. The dominant substrate types across the transect are also displayed.

An example of the graphic for one of the 31 transects is shown below in Figure 17. All 31 transects are presented in Attachment C.

For presentation purposes "Base" discharge is set for all 31 transects at the median annual flow under the No-build scenario for Tumalo creek while the "Current" discharge is set to 3 cfs less. This example emulates a comparison of an 18.2 cfs withdrawal under the No-Build versus a 21 cfs withdrawal under the Alternative Build scenario.

Colors along the stream bottom profile represent substrate sizes. The solid blue represents the water in the channel under the Current discharge scenario. The yellow horizontal line represents the water surface under the Base discharge condition. The red jagged line represents the velocity pattern across the stream under the Base discharge. Hydraulic statistics such as percent change in wetted perimeter, average depth, and average velocity from the Base discharge are shown across the top of the chart.

Tabular results are presented in Table 26 for the comparison between the 18.2 cfs withdrawal under the No-Build versus a 21 cfs withdrawal under the Alternative Build scenario.



	Discharge	Water Surface Level		Wetted Perimeter		Mean Velocity		Mean Depth	
Current:	55.00	87.34	-0.03	33.57	99.4%	1.82	96.5%	0.93	97.1%
Base:	58.00	87.37		33.77		1.89		0.96	

Figure 17. Example of the Channel/Flow Response cross sectional profile interactive tool.

Table 26. Summary of channel response to change in discharge for all transects

							Starting Discharge (Base) = 58 cfs			Comparison Discharge (Current) = 55 cfs					
				Water Surface Elevation (ft)			Wetted Perimeter (ft)			Mean Velocity (fps)			Mean Depth (ft)		
Reach	Sub-reach	Transect	Habitat	58 cfs	55 cfs	Change	58 cfs	55 cfs	% Change	58 cfs	55 cfs	% Change	58 cfs	55 cfs	% Change
A	A1-RR	1	Riffle	87.37	87.34	-0.03	33.77	33.57	-0.6%	1.89	1.82	-3.7%	0.96	0.93	-3.1%
	A1-RR	2	Pool	88.40	88.36	-0.04	26.84	25.84	-3.7%	1.35	1.38	2.2%	1.73	1.83	5.8%
	A1-RR	3	Riffle	95.95	95.93	-0.02	42.28	41.78	-1.2%	1.71	1.68	-1.8%	0.64	0.64	0.0%
	A1-RR	4	Riffle	88.20	88.17	-0.03	27.74	27.54	-0.7%	2.62	2.55	-2.7%	0.66	0.63	-4.5%
	A1-RR	5	Pool	94.47	94.44	-0.03	23.99	23.99	0.0%	1.57	1.50	-4.5%	1.74	1.71	-1.7%
	A1-RR	6	Riffle	96.21	96.18	-0.03	28.96	28.96	0.0%	1.93	1.93	0.0%	0.79	0.76	-3.8%
	A1-RR	7	Riffle	95.52	95.49	-0.03	35.20	33.68	-4.3%	1.78	1.88	5.6%	0.62	0.62	0.0%
	A1-RR	8	Pool	93.88	93.85	-0.03	26.63	26.20	-1.6%	1.47	1.39	-5.4%	1.00	1.00	0.0%
	A1-B	1	Riffle	96.73	96.70	-0.03	37.40	37.40	0.0%	1.89	1.85	-2.1%	0.79	0.76	-3.8%
	A1-B	2	Riffle	96.03	96.00	-0.03	33.63	33.52	-0.3%	1.77	1.73	-2.3%	0.99	0.96	-3.0%
	A1-B	3	Pool	92.81	92.78	-0.03	37.44	37.44	0.0%	1.61	1.56	-3.1%	1.18	1.15	-2.5%
	A1-B	4	Rapid	93.69	93.66	-0.03	28.03	28.03	0.0%	1.82	1.78	-2.2%	1.09	1.05	-3.7%
	A1-B	5	Rapid	91.28	91.25	-0.03	30.35	30.35	0.0%	1.73	1.68	-2.9%	0.96	0.92	-4.2%
	A1-B	6	Riffle	91.01	90.99	-0.02	46.03	46.03	0.0%	2.07	2.02	-2.4%	0.70	0.68	-2.9%
	A1-B	7	Pool	94.81	94.79	-0.02	34.87	34.10	-2.2%	1.08	1.08	0.0%	1.01	1.04	3.0%
	A1-B	8	Pool	91.65	91.62	-0.03	33.36	33.36	0.0%	1.03	1.01	-1.9%	1.88	1.84	-2.1%
	A1-B	9	Rapid	93.67	93.64	-0.03	31.29	31.29	0.0%	1.90	1.86	-2.1%	0.90	0.87	-3.3%
	A2	1	Riffle	96.19	96.17	-0.02	24.11	24.11	0.0%	2.4	2.46	2.5%	0.84	0.81	-3.6%
	A2	2	Pool	93.45	93.42	-0.03	42.77	42.23	-1.3%	0.74	0.71	-4.1%	1.54	1.52	-1.3%
	A2	3	Riffle	94.53	94.5	-0.03	38.51	38.51	0.0%	2.36	2.31	-2.1%	0.64	0.61	-4.7%
	A2	4	Riffle	94.47	94.45	-0.02	33.14	33.14	0.0%	2.16	2.11	-2.3%	0.71	0.69	-2.8%
	A2	5	Riffle	95.8	95.77	-0.03	39.79	38.84	-2.4%	2.05	2.01	-2.0%	0.7	0.68	-2.9%
	A2	6	Pool	94.9	94.86	-0.04	31.5	31.5	0.0%	0.68	0.66	-2.9%	1.8	1.77	-1.7%
B	B	1	Pool	92.48	92.45	-0.03	22.13	22.13	0.0%	1.84	1.83	-0.5%	1.53	1.50	-2.0%
	B	2	Riffle	94.09	94.05	-0.04	19.58	19.58	0.0%	1.91	1.85	-3.1%	1.43	1.40	-2.1%
	B	3	Riffle	95.28	95.26	-0.02	28.21	28.21	0.0%	1.72	1.66	-3.5%	1.02	0.99	-2.9%
	B	4	Riffle	96.62	96.59	-0.03	20.00	20.00	0.0%	2.21	2.14	-3.2%	1.38	1.35	-2.2%
	B	5	Riffle	95.19	95.17	-0.02	26.53	26.53	0.0%	2.13	2.06	-3.3%	0.86	0.84	-2.3%
	B	6	Glide	94.28	94.25	-0.03	25.47	25.47	0.0%	1.67	1.62	-3.0%	1.23	1.20	-2.4%
	B	7	Riffle	91.76	91.73	-0.03	22.15	22.15	0.0%	2.06	1.99	-3.4%	1.07	1.04	-2.8%
	B	8	Pool	93.59	93.56	-0.03	28.07	27.84	-0.8%	1.25	1.21	-3.2%	1.11	1.08	-2.7%

6.2 Weighted Useable Area

Weighted useable area, the primary product of PHABSIM, is an index of available habitat for each species/lifestage at a given discharge.

Sub-reach A1-RR has five major sources of accretion, including two tributaries and 3 springs. During transect placement, five of the eight transects in sub-reach A1-RR were located above South Fork Tumalo Creek and Spring B and Spring C. For this reason, sub-reach A1-RR was further separated into two separate habitat models. Model A1-RR – Upper, includes transects 8 through 4 and the model A1-RR- Lower, includes transects 3 through 1.

WUA results for each sub-reach are presented in both table and plot form below in Tables 27 through 31 and Figures 18 through 22.

Table 27. Tabular WUA results for sub-reach A1-RR - Upper for three lifestages of Redband trout.

Sub-reach A1-RR Redband Trout WUA			
Discharge (cfs)	**Spawning**	**Juvenile**	**Adult**
22.0	1,121	3,280	1,627
25.0	1,208	3,293	1,702
28.0	1,278	3,302	1,764
31.0	1,333	3,309	1,830
34.0	1,372	3,330	1,908
37.0	1,399	3,347	1,978
40.0	1,407	3,366	2,035
45.0	1,406	3,409	2,115
50.0	1,402	3,462	2,177
55.0	1,395	3,486	2,232
60.0	1,385	3,510	2,274
65.0	1,363	3,525	2,312
70.0	1,333	3,528	2,332
75.0	1,305	3,505	2,327
80.0	1,281	3,486	2,322
85.0	1,268	3,467	2,315
90.0	1,266	3,456	2,315
95.0	1,266	3,440	2,311
100.0	1,268	3,432	2,306
105.0	1,273	3,428	2,294
110.0	1,280	3,436	2,280
120.0	1,301	3,456	2,258
130.0	1,324	3,487	2,241
140.0	1,349	3,527	2,253
150.0	1,374	3,577	2,275
160.0	1,398	3,636	2,303
170.0	1,426	3,693	2,339
180.0	1,468	3,758	2,377
190.0	1,530	3,818	2,413
202.0	1,619	3,905	2,456

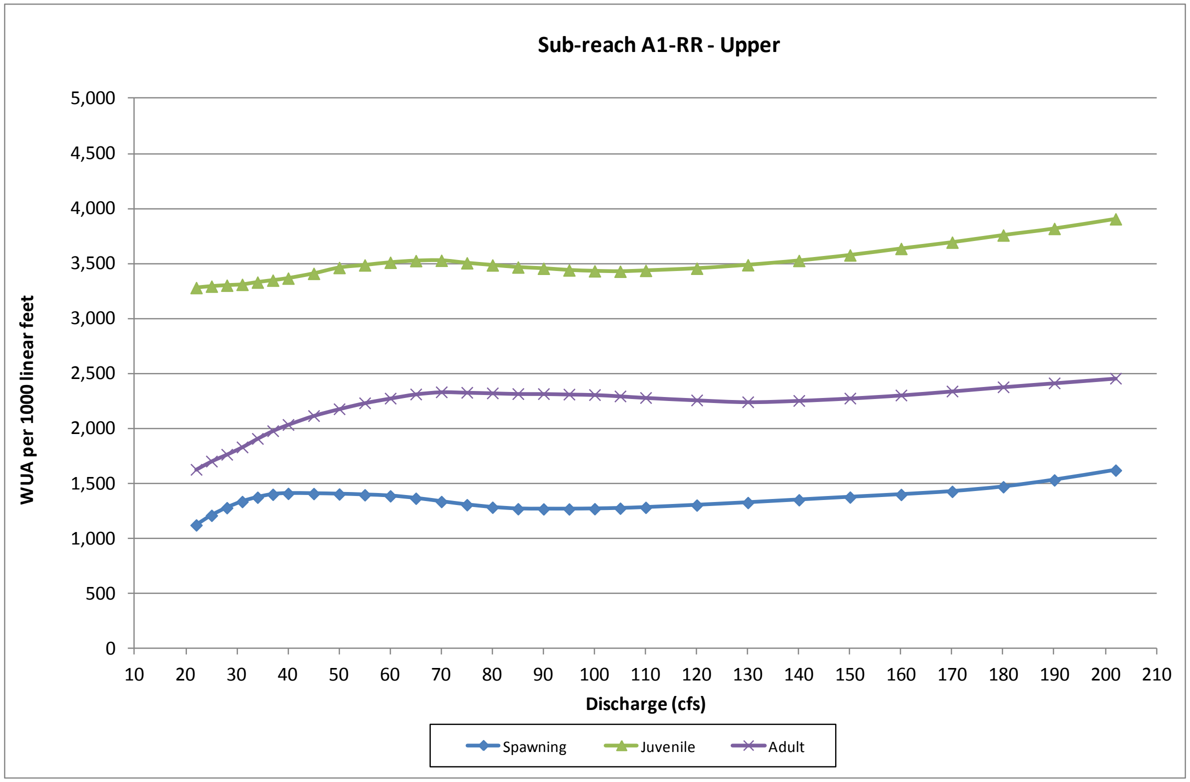


Figure 18. Graphical WUA results for sub-reach A1-RR for three lifestages of Redband trout.

Table 28. Tabular WUA results for sub-reach A1-RR - Lower for three lifestages of Redband trout.

Sub-reach A1-RR Redband Trout WUA			
Discharge (cfs)	Spawning	Juvenile	Adult
22.0	4,962	3,939	1,948
25.0	5,202	3,881	2,057
28.0	5,397	3,808	2,131
31.0	5,564	3,735	2,187
34.0	5,703	3,678	2,230
37.0	5,803	3,636	2,261
40.0	5,865	3,590	2,285
45.0	5,916	3,535	2,318
50.0	5,865	3,497	2,342
55.0	5,733	3,466	2,369
60.0	5,540	3,436	2,391
65.0	5,308	3,409	2,412
70.0	5,074	3,388	2,437
75.0	4,823	3,361	2,455
80.0	4,547	3,323	2,465
85.0	4,274	3,279	2,471
90.0	4,023	3,238	2,474
95.0	3,759	3,194	2,461
100.0	3,518	3,148	2,444
105.0	3,280	3,092	2,416
110.0	3,049	3,034	2,376
120.0	2,644	2,924	2,284
130.0	2,281	2,820	2,197
140.0	1,985	2,720	2,103
150.0	1,753	2,617	2,020
160.0	1,546	2,515	1,939
170.0	1,401	2,424	1,869
180.0	1,287	2,340	1,809
190.0	1,189	2,271	1,747
202.0	1,111	2,201	1,686

Figure 19. Graphical WUA results for sub-reach A1-RR for three lifestages of Redband trout.

Table 29. Tabular WUA results for sub-reach A1-B for three lifestages of Redband trout.

Sub-reach A1-B Redband Trout WUA			
Discharge (cfs)	Spawning	Juvenile	Adult
26.0	2,553	8,141	4,201
28.0	2,663	8,306	4,414
31.0	2,820	8,548	4,708
34.0	2,956	8,781	4,981
37.0	3,106	9,013	5,244
40.0	3,251	9,234	5,494
45.0	3,519	9,568	5,866
50.0	3,763	9,793	6,212
55.0	3,951	9,962	6,512
60.0	4,044	10,082	6,766
65.0	4,115	10,193	7,025
70.0	4,148	10,266	7,254
75.0	4,177	10,317	7,479
80.0	4,202	10,347	7,682
85.0	4,214	10,356	7,848
90.0	4,219	10,360	7,988
95.0	4,214	10,348	8,110
100.0	4,184	10,336	8,227
105.0	4,142	10,313	8,326
110.0	4,089	10,290	8,419
115.0	4,019	10,259	8,493
120.0	3,941	10,228	8,564
130.0	3,774	10,162	8,687
140.0	3,617	10,072	8,790
150.0	3,450	9,966	8,845
160.0	3,274	9,904	8,869
170.0	3,104	9,864	8,869
180.0	2,945	9,815	8,849
190.0	2,794	9,783	8,820
200.0	2,653	9,756	8,819

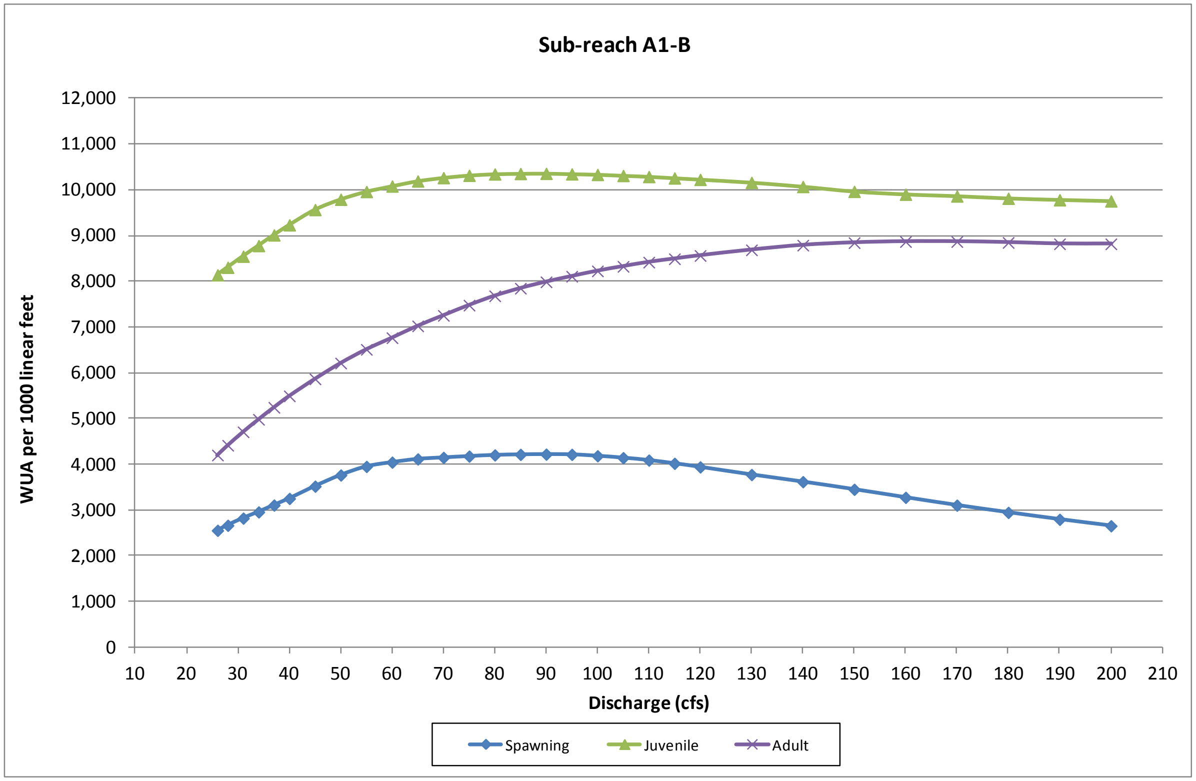


Figure 20. Graphical WUA results for sub-reach A1-B for three lifestages of Redband trout.

Table 30. Tabular WUA results for sub-reach A2 for three lifestages of Redband trout.

Sub-reach A2 Redband Trout WUA			
Discharge (cfs)	Spawning	Juvenile	Adult
28.0	4,698	8,085	3,741
30.0	4,871	8,175	3,850
32.0	5,030	8,253	3,956
34.0	5,170	8,330	4,063
36.0	5,283	8,398	4,169
38.0	5,404	8,466	4,280
40.0	5,504	8,527	4,382
45.0	5,714	8,698	4,690
50.0	5,879	8,829	4,993
55.0	6,049	8,925	5,257
60.0	6,141	9,000	5,487
65.0	6,171	9,057	5,694
70.0	6,160	9,105	5,880
75.0	6,128	9,137	6,034
80.0	6,080	9,162	6,160
85.0	5,971	9,194	6,269
90.0	5,851	9,215	6,367
95.0	5,718	9,217	6,445
100.0	5,587	9,207	6,529
105.0	5,459	9,195	6,610
110.0	5,320	9,169	6,669
120.0	5,112	9,137	6,773
130.0	4,926	9,103	6,871
140.0	4,777	9,052	6,942
150.0	4,683	9,035	7,006
160.0	4,570	8,990	7,071
170.0	4,462	8,914	7,121
180.0	4,354	8,841	7,143
190.0	4,223	8,766	7,171
195.0	4,138	8,727	7,186

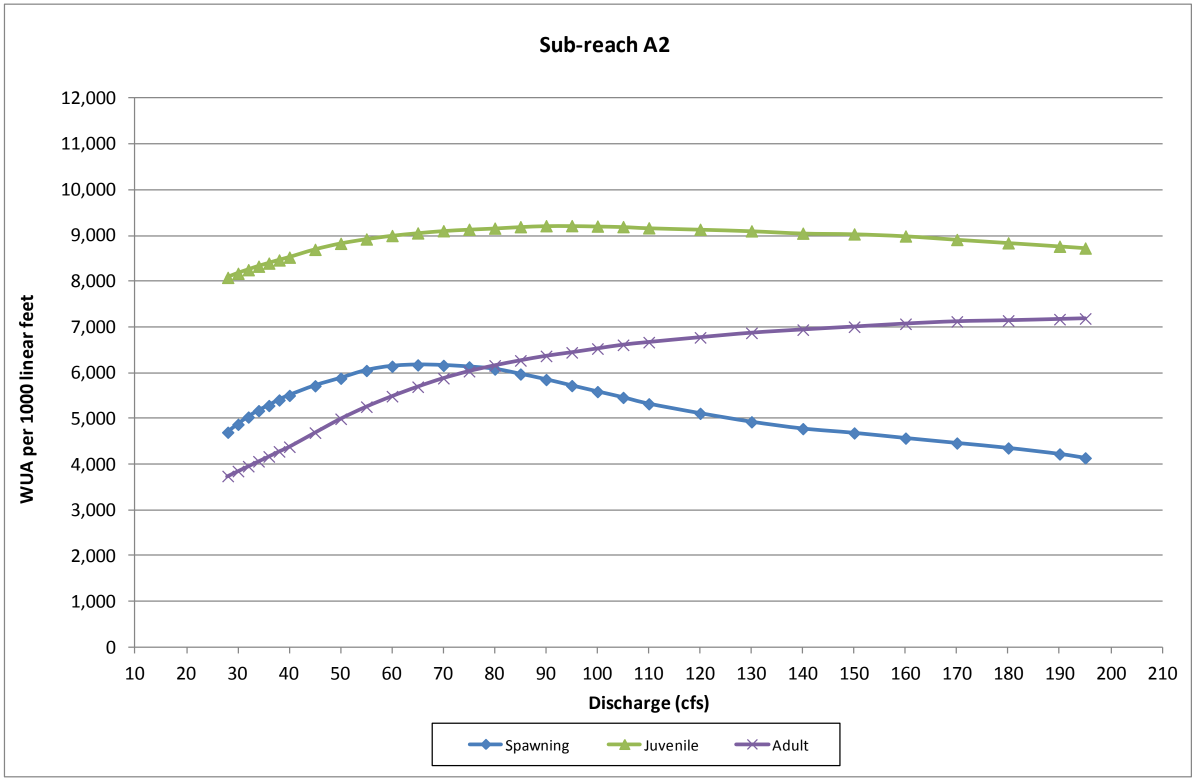


Figure 21. Graphical WUA results for sub-reach A2 for three lifestages of Redband trout.

Table 31. Tabular WUA results for Reach B for three lifestages of Redband trout.

	Reach B Redband Trout WUA		
Discharge (cfs)	Spawning	Juvenile	Adult
9.5	4,244	7,808	3,170
12.0	4,826	8,144	3,788
15.0	5,372	8,312	4,320
18.0	5,815	8,345	4,733
21.0	6,174	8,303	5,043
24.0	6,435	8,225	5,283
27.0	6,619	8,131	5,454
30.0	6,744	8,039	5,587
35.0	6,817	7,888	5,744
40.0	6,742	7,733	5,827
45.0	6,566	7,578	5,873
50.0	6,311	7,426	5,893
55.0	6,004	7,251	5,888
60.0	5,686	7,057	5,861
65.0	5,362	6,845	5,806
70.0	5,060	6,639	5,704
75.0	4,782	6,431	5,577
80.0	4,526	6,222	5,424
90.0	4,102	5,845	5,106
100.0	3,787	5,518	4,799
110.0	3,529	5,256	4,504
120.0	3,306	5,062	4,270
130.0	3,110	4,933	4,072
140.0	2,929	4,860	3,914
150.0	2,767	4,818	3,791
160.0	2,617	4,787	3,700
170.0	2,484	4,782	3,618
180.0	2,367	4,806	3,554
190.0	2,266	4,846	3,505
195.0	2,218	4,870	3,487

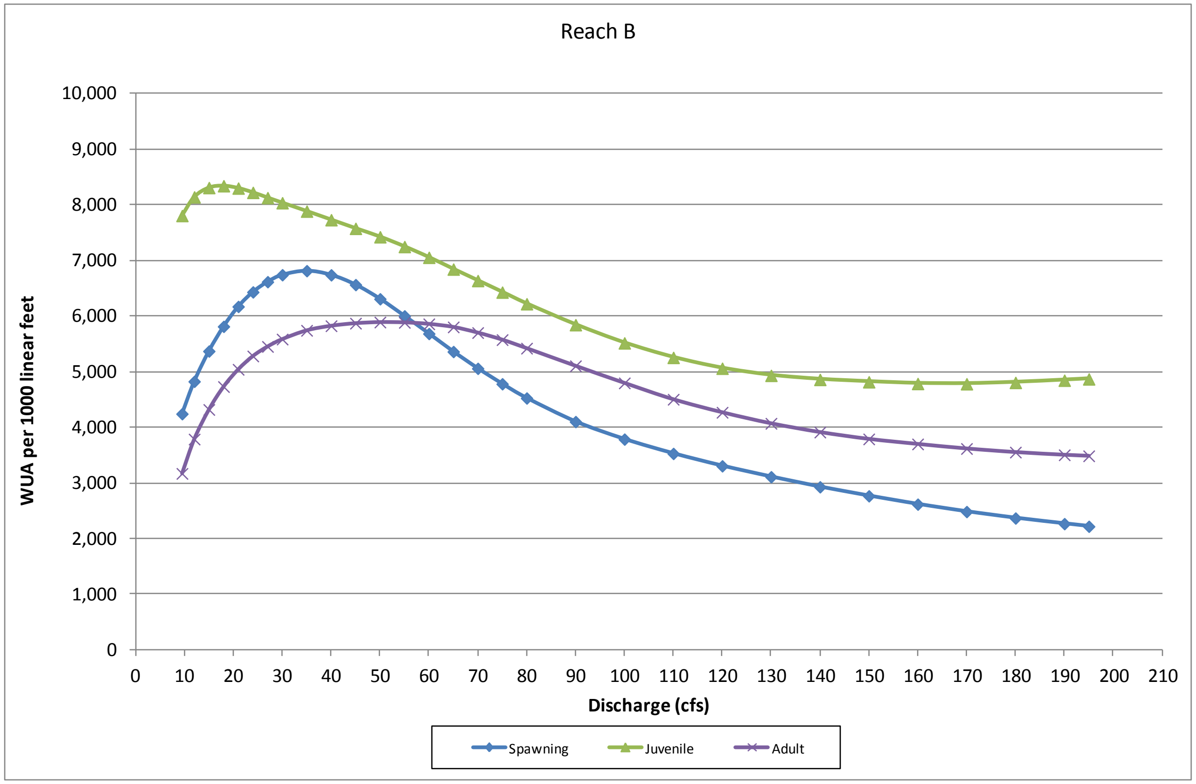


Figure 22. WUA for Reach B for three lifestages of Redband trout.

6.3 Habitat Duration Analysis

6.3.1 HDA Output

Results of the HDA are shown in the bar charts and tables below. Habitat duration curves as shown in Figure 14 were developed for each Redband trout lifestage, for each month, and for each reach and sub-reach, resulting in a total of over 180 charts. To summarize the large number of charts, bar graphs were developed to compare AUC of the No-Build (-18.2 cfs) against the Build Alternative (-21 cfs) scenario by lifestage for each month. Further, summary tables were developed that show percent difference in AUC values of the No-Build to the Build Alternative scenarios by lifestage and by month.

Results for sub-reaches in Reach A are shown as combined (all sub-reaches merged) and individually. The combined sub-reach results best represent the change in Redband trout habitat expected on Tumalo Creek as all Reach A sub-reaches are equally effected by the City's upstream diversion and because the return flow from the Outback facility was not included in the model.

As described above in section 6.2, sub-reach A1-RR was separated into two habitat models due to the location PHABSIM transects in relation to major accretion nodes (South Fork Tumalo Creek and various springs). Habitat duration results are shown below for the combined sub-reach A1-RR model as well as the A1-RR – Upper model and the A1-RR – Lower model. Reach B does not have sub-reaches.

6.3.2 Reach A

Combined Reach A results are a product of combining sub-reaches A1-RR[3], A1-B and A2.

---

[3] As discussed, Sub-reach A1-RR was separated into two distinct models due to accretion concerns. The results of this analysis were not incorporated into the Combined Sub-reaches for Reach A results as there was a 1% or less change between A1-RR when combined versus when split in to two separate models.

6.3.2.1 Combined Reach A

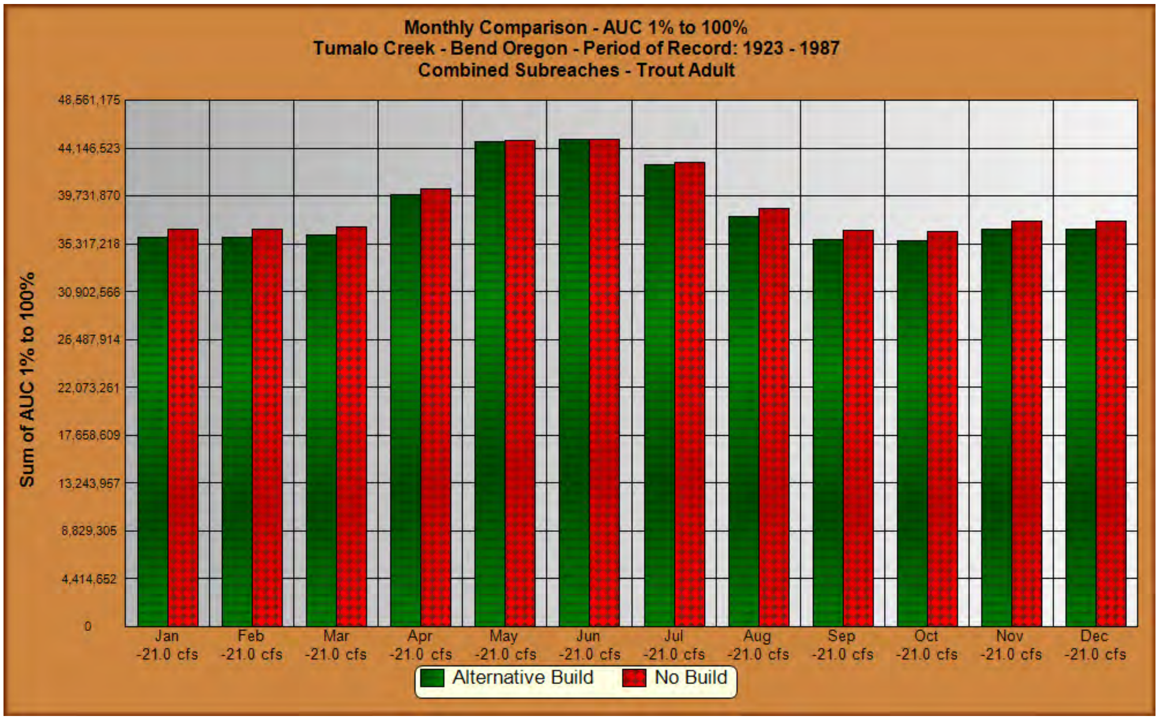


Figure 23. Combined Reach A monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout adult lifestage.

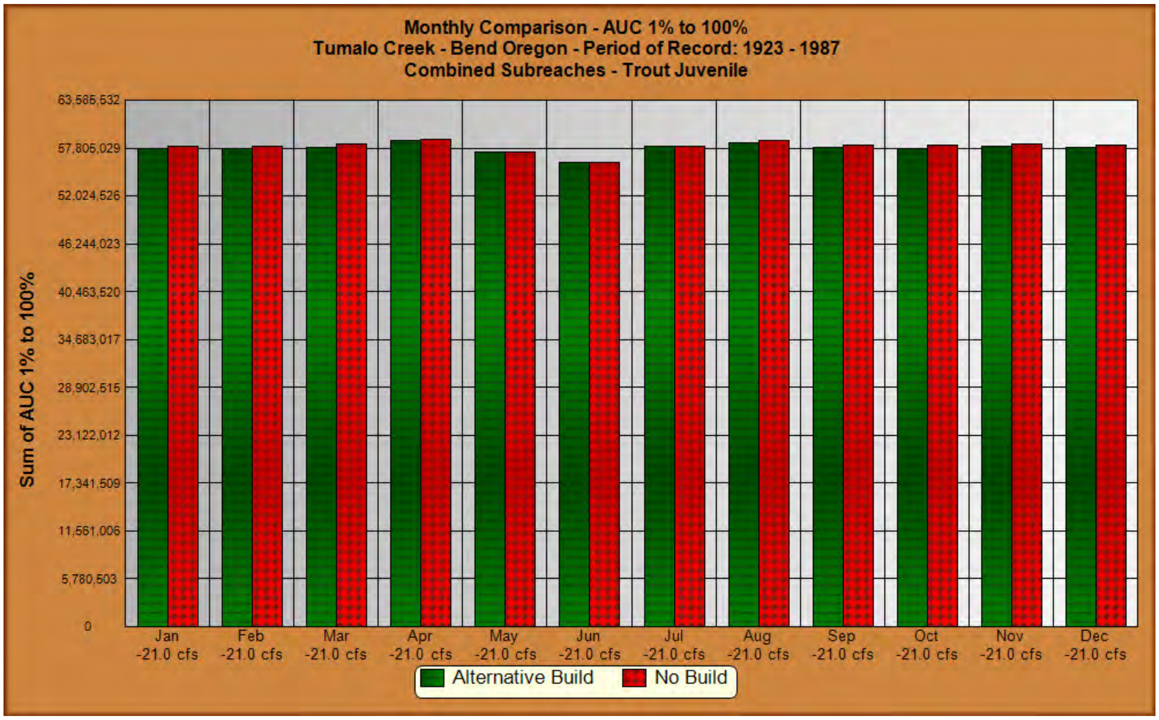


Figure 24. Combined Reach A monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout juvenile lifestage.

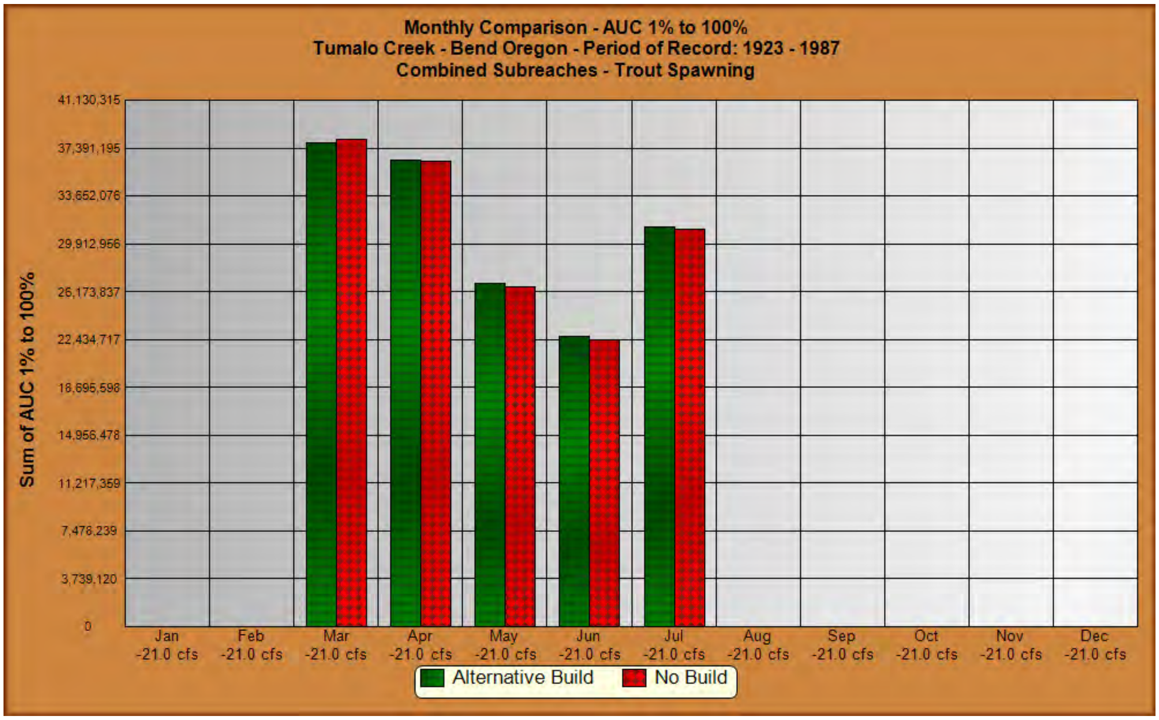


Figure 25. Combined Reach A monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout spawning lifestage.

Table 32. Combined Reach A monthly percent difference in AUC between the Build and No-Build scenarios for Redband trout.

Tumalo Creek - Bend Oregon - Reach A (Combined Sub-reaches)
All Water Year Types - Sum of AUC 1% to 100%

	Alternative Build As % of No-Build											
Alternative Build Withdrawal (cfs)>	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**
Species/Lifestage	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Trout Spawning			99	100	101	101	101					
Trout Juvenile	99	99	99	100	100	100	100	100	99	99	99	100
Trout Adult	98	98	98	99	100	100	99	98	98	98	98	98

=>100% =>90% <90%

6.3.2.2 Combined Sub-reach A1-RR

Combined Sub-reach A1-RR results are a product of combining the A1-RR – Upper and A1-RR – Lower habitat models.

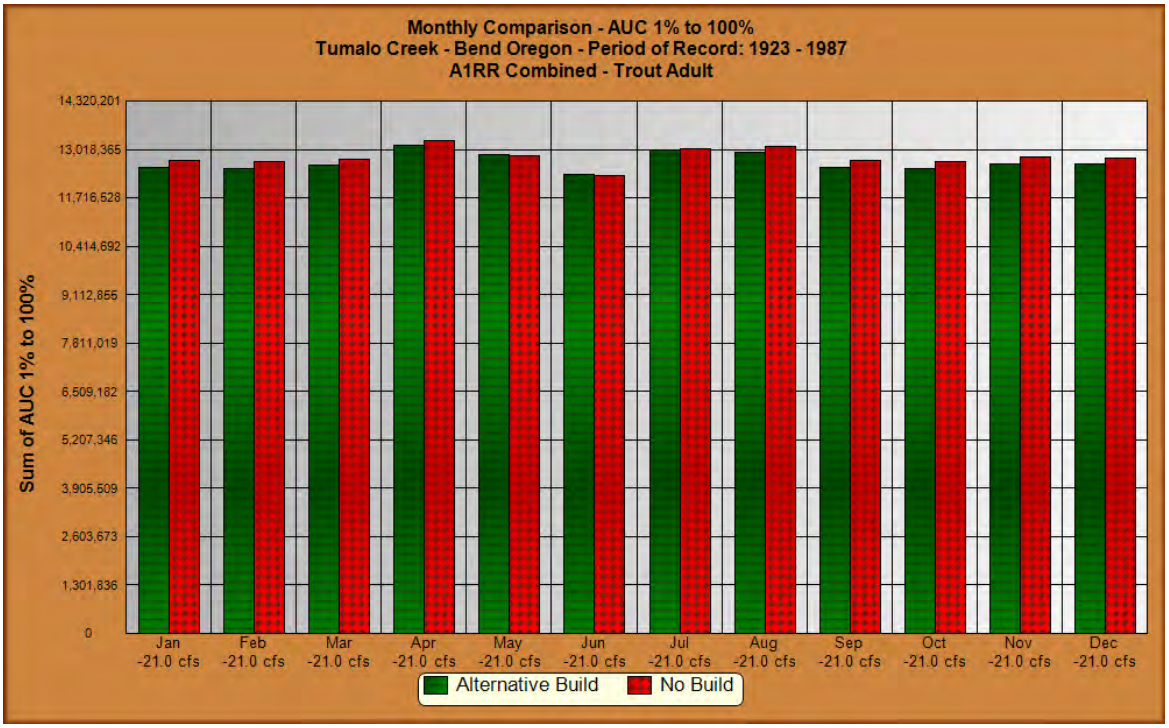


Figure 26. Combined sub-reach A1-RR monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout adult lifestage.

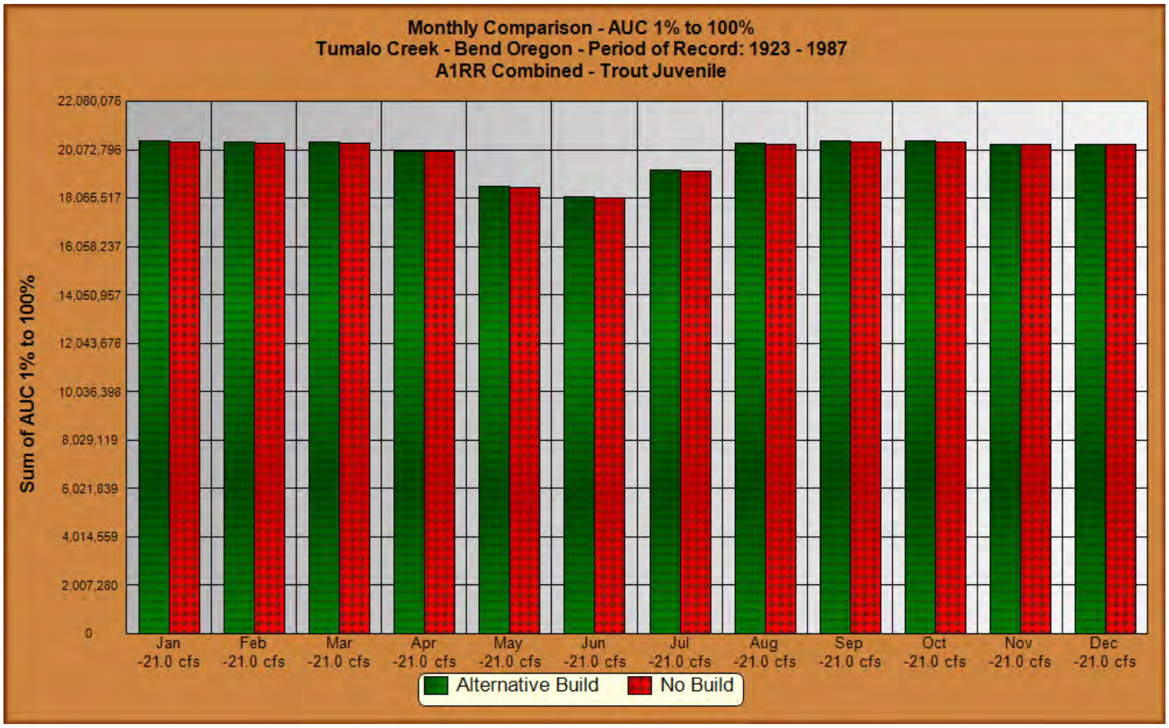


Figure 27. Combined sub-reach A1-RR monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout juvenile lifestage.

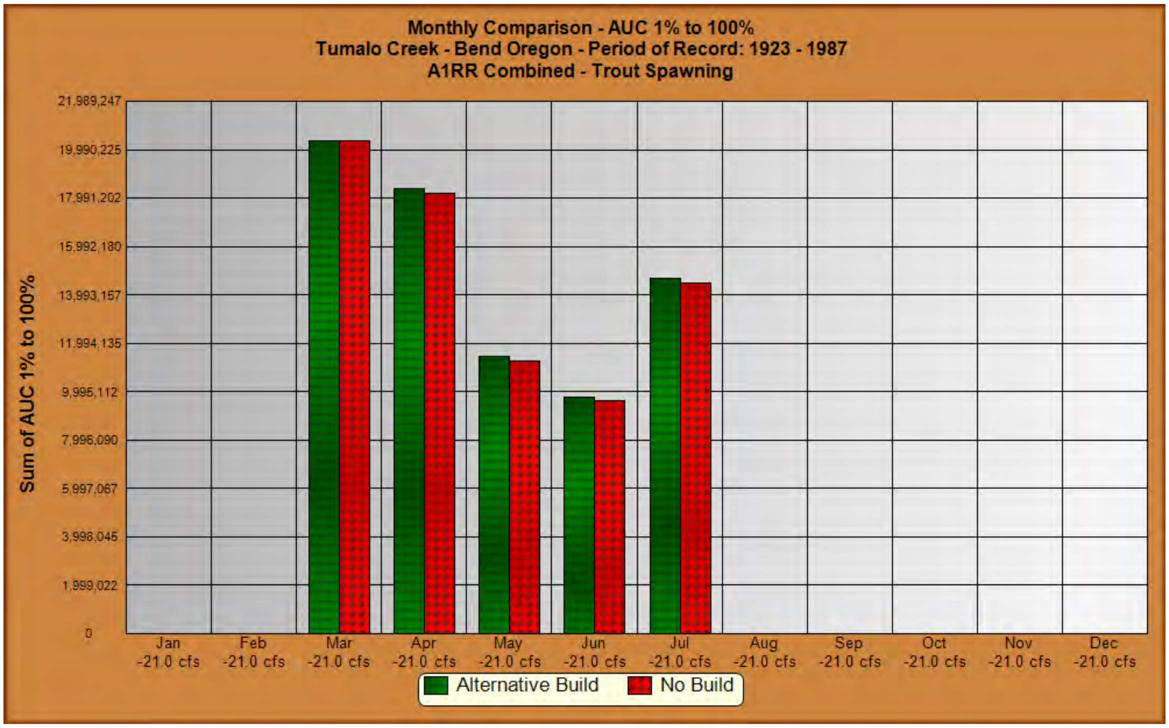


Figure 28. Combined sub-reach A1-RR monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout spawning lifestage.

Table 33. Combined sub-reach A1-RR monthly percent difference in AUC between the Build and No-Build scenarios for Redband trout.

Tumalo Creek - Bend Oregon - Sub-reach A1-RR Upper and Lower Models Combined

All Water Year Types - Sum of AUC 1% to 100%

	Alternative Build As % of No-Build											
Alternative Build Withdrawal (cfs)>	-21	-21	-21	-21	-21	-21	-21	-21	-21	-21	-21	-21
Species/Lifestage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Trout Spawning			100	101	102	101	101					
Trout Juvenile	100	100	100	100	100	100	100	100	100	100	100	100
Trout Adult	99	99	99	99	100	100	100	99	98	98	99	99

=>100% =>90% <90%

6.3.2.3 Sub-reach A1-RR – Upper

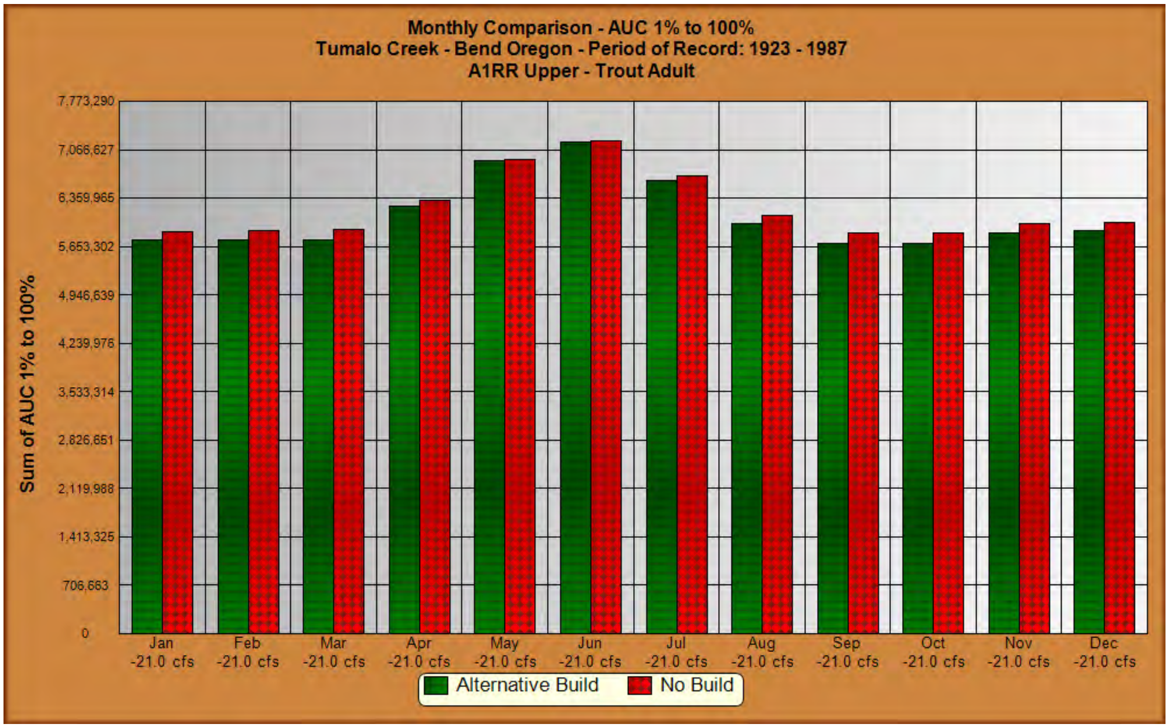


Figure 29. Sub-reach A1-RR – Upper monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout adult lifestage.

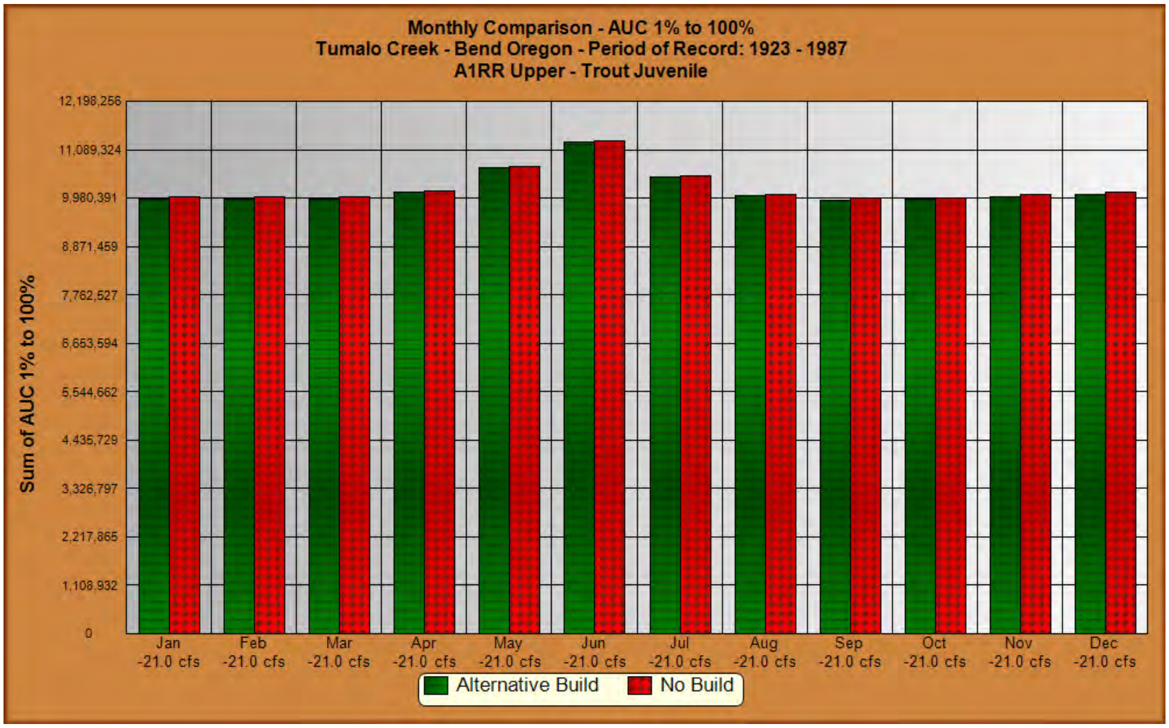


Figure 30. Sub-reach A1-RR – Upper monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout juvenile lifestage.

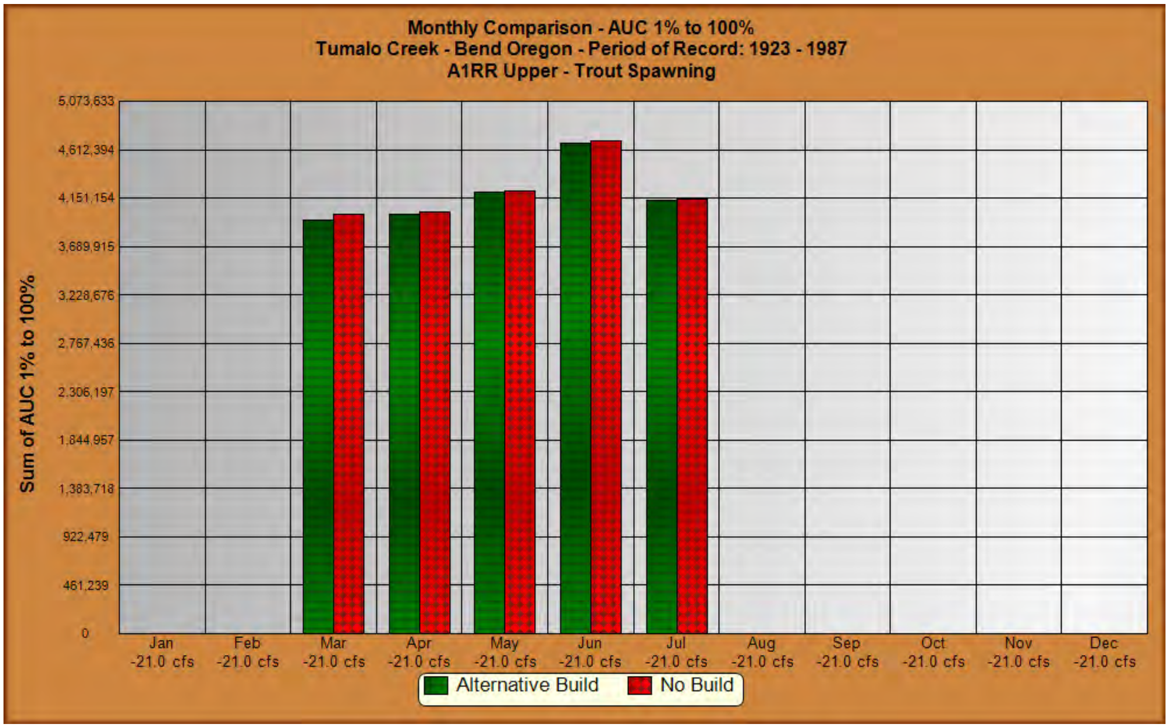


Figure 31. Sub-reach A1-RR – Upper monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout spawning lifestage.

Table 34. Sub-reach A1-RR - Upper monthly percent difference in AUC between the No-Build and Build Alternative scenario for Redband trout.

Tumalo Creek - Bend Oregon - Sub-reach A1-RR Upper

All Water Year Types - Sum of AUC 1% to 100%

	Alternative Build As % of No-Build											
Alternative Build Withdrawal (cfs)>	-21	-21	-21	-21	-21	-21	-21	-21	-21	-21	-21	-21
Species/Lifestage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Trout Spawning			98	99	100	99	100					
Trout Juvenile	100	100	100	100	100	100	100	100	100	100	100	100
Trout Adult	98	98	98	99	100	100	99	98	98	98	98	98

=>100% =>90% <90%

6.3.2.4 Sub-reach A1-RR – Lower

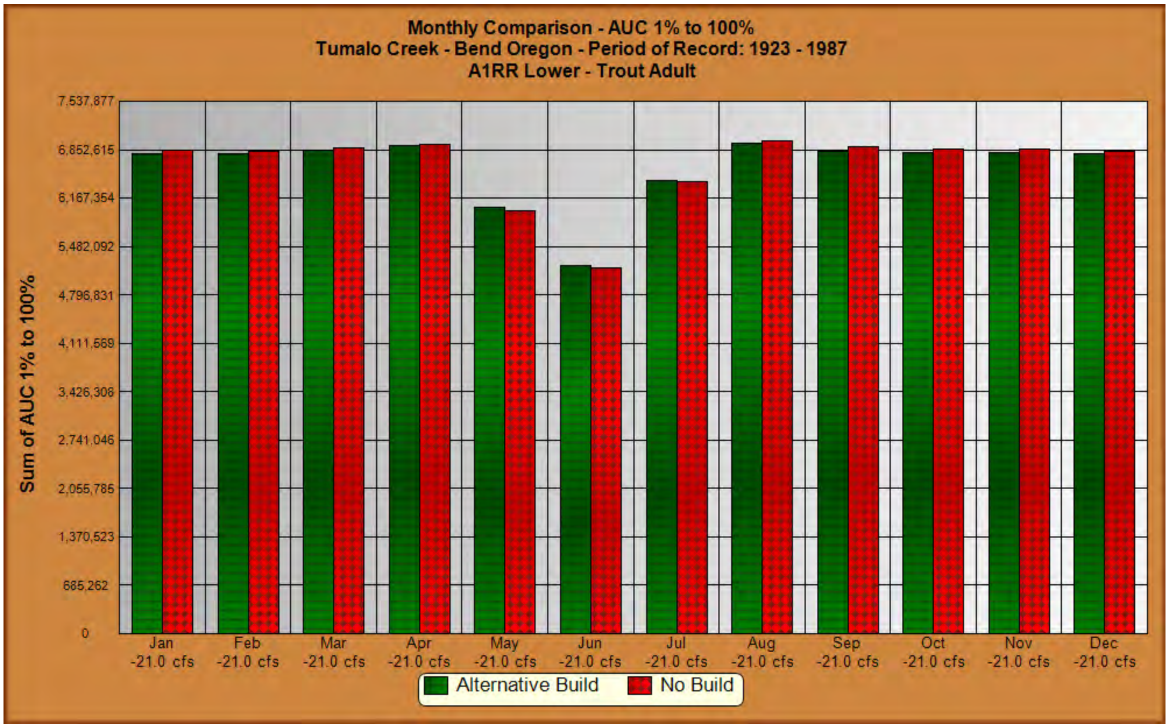


Figure 32. Sub-reach A1-RR – Lower monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout adult lifestage.

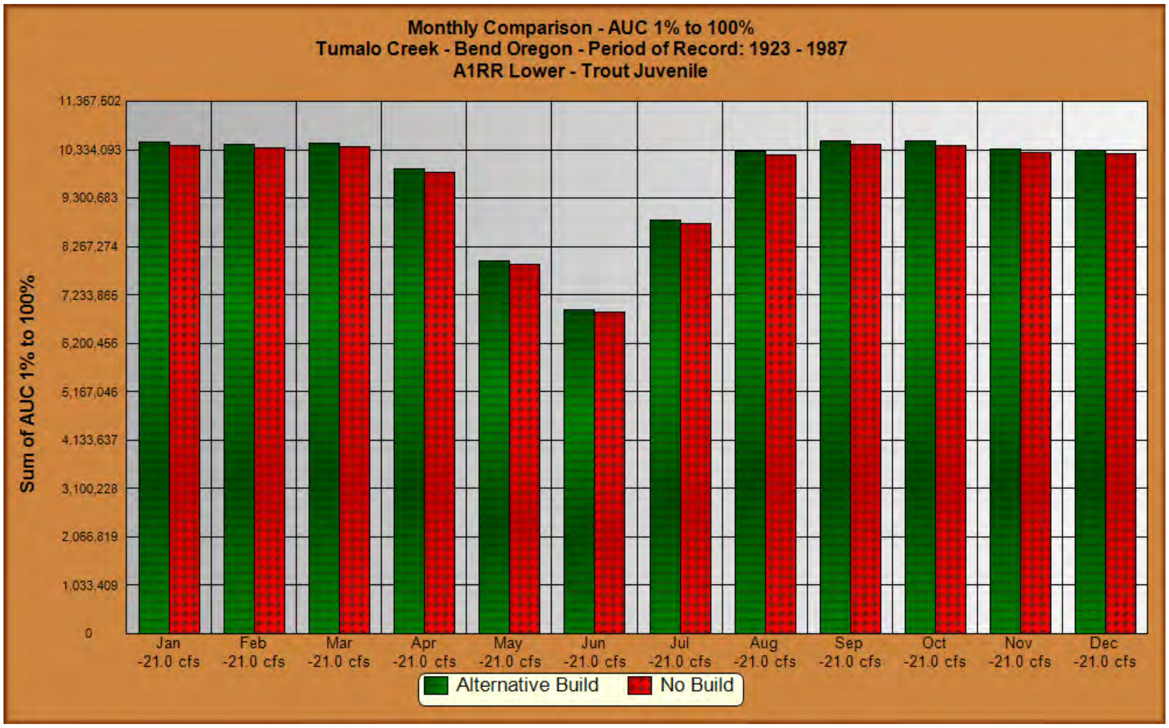


Figure 33. Sub-reach A1-RR – Lower monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout juvenile lifestage.

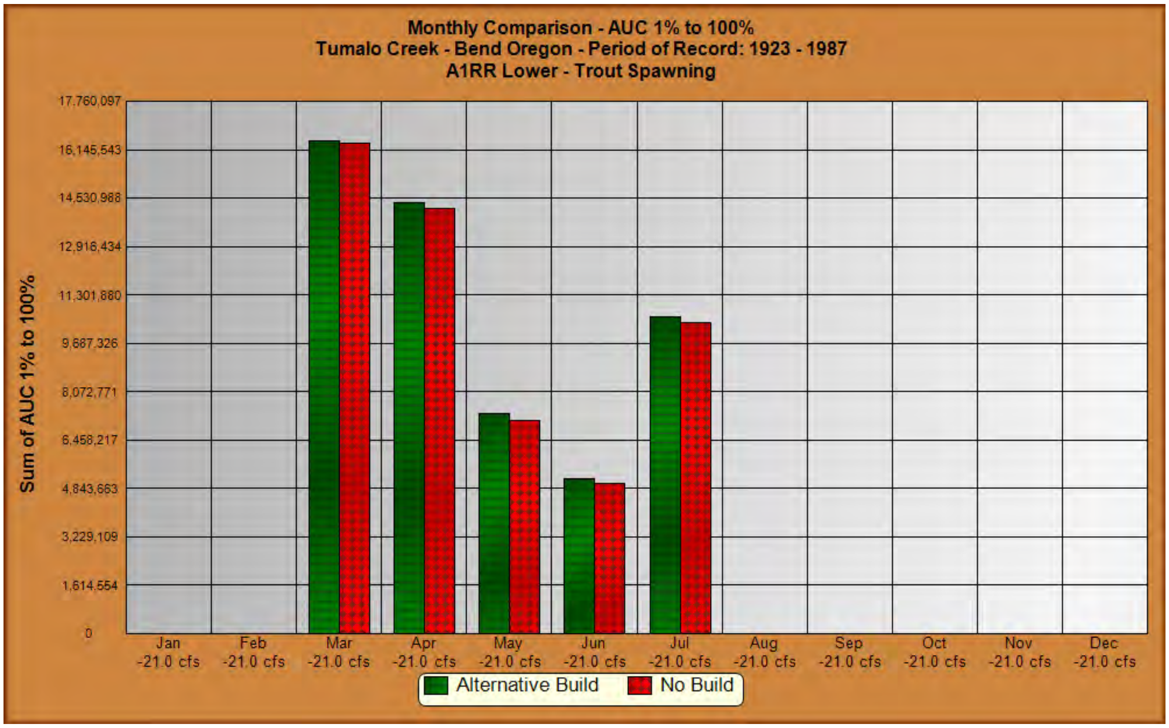


Figure 34. Sub-reach A1-RR – Lower monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout spawning lifestage.

Table 35. Sub-reach A1-RR – Lower monthly percent difference in AUC between the No-Build and Build Alternative scenario for Redband trout.

Tumalo Creek - Bend Oregon - Sub-reach A1-RR Lower
All Water Year Types - Sum of AUC 1% to 100%

	Alternative Build As % of No-Build											
Alternative Build Withdrawal (cfs)>	-21	-21	-21	-21	-21	-21	-21	-21	-21	-21	-21	-21
Species/Lifestage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Trout Spawning			100	102	103	103	102					
Trout Juvenile	101	101	101	101	101	101	101	101	101	101	101	101
Trout Adult	99	99	99	100	101	101	100	99	99	99	99	99

=>100% =>90% <90%

6.3.2.5 Sub-reach A1-B

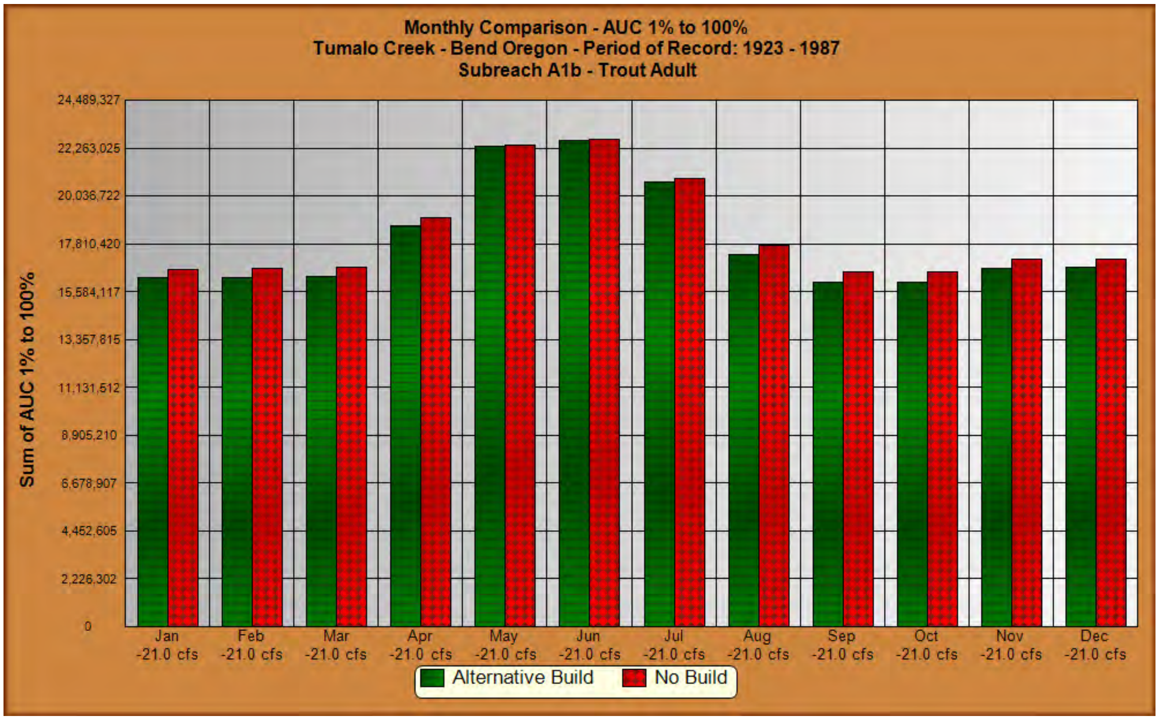


Figure 35. Sub-reach A1-B monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout adult lifestage.

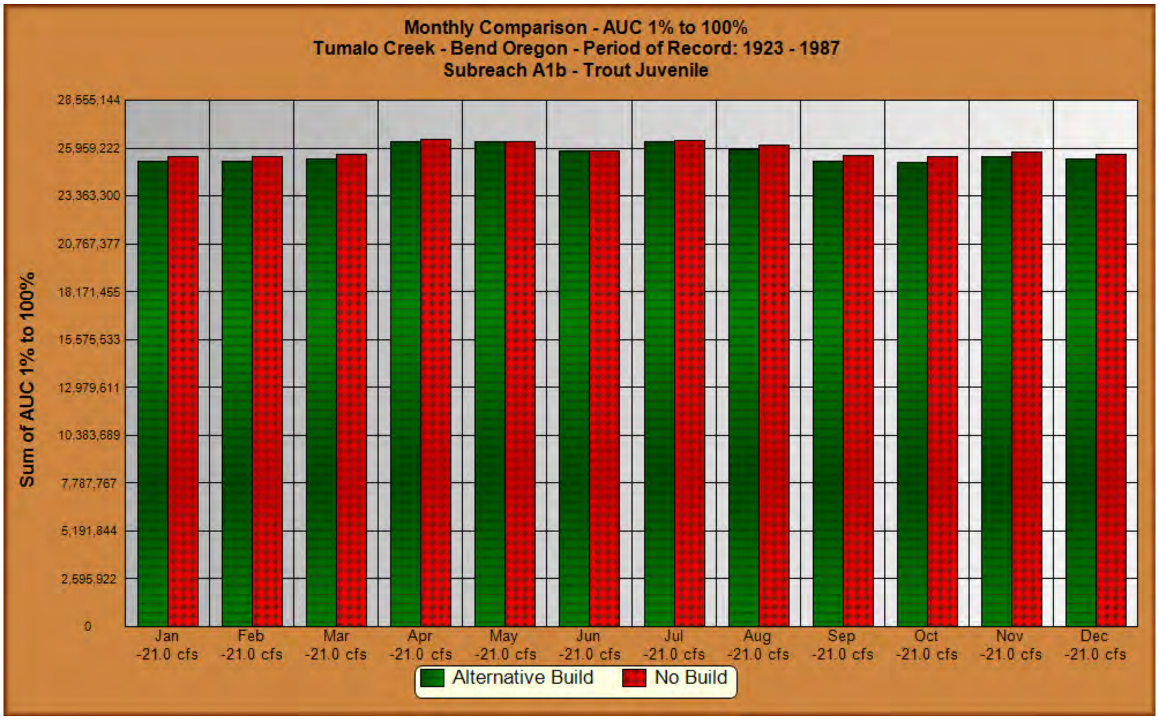


Figure 36. Sub-reach A1-B monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout juvenile lifestage.

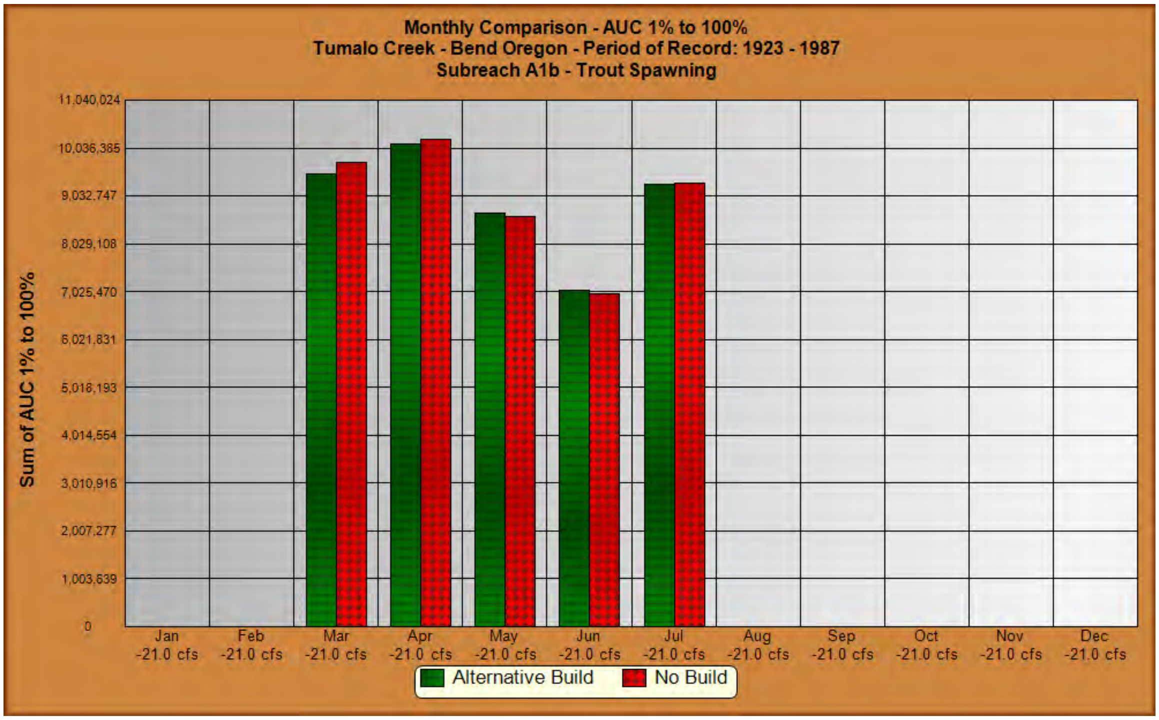


Figure 37. Sub-reach A1-B monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout spawning lifestage.

Table 36. Sub-reach A1-B monthly percent difference in AUC between the No-Build and Build Alternative scenario for Redband trout.

Tumalo Creek - Bend Oregon - Sub-reach A1-B
All Water Year Types - Sum of AUC 1% to 100%

	Alternative Build As % of No-Build											
Alternative Build Withdrawal (cfs)>	-21	-21	-21	-21	-21	-21	-21	-21	-21	-21	-21	-21
Species/Lifestage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Trout Spawning			98	99	101	101	100					
Trout Juvenile	99	99	99	99	100	100	100	99	99	99	99	99
Trout Adult	98	98	97	98	100	100	99	98	97	97	98	98

=>100% =>90% <90%

6.3.2.6 Sub-reach A2

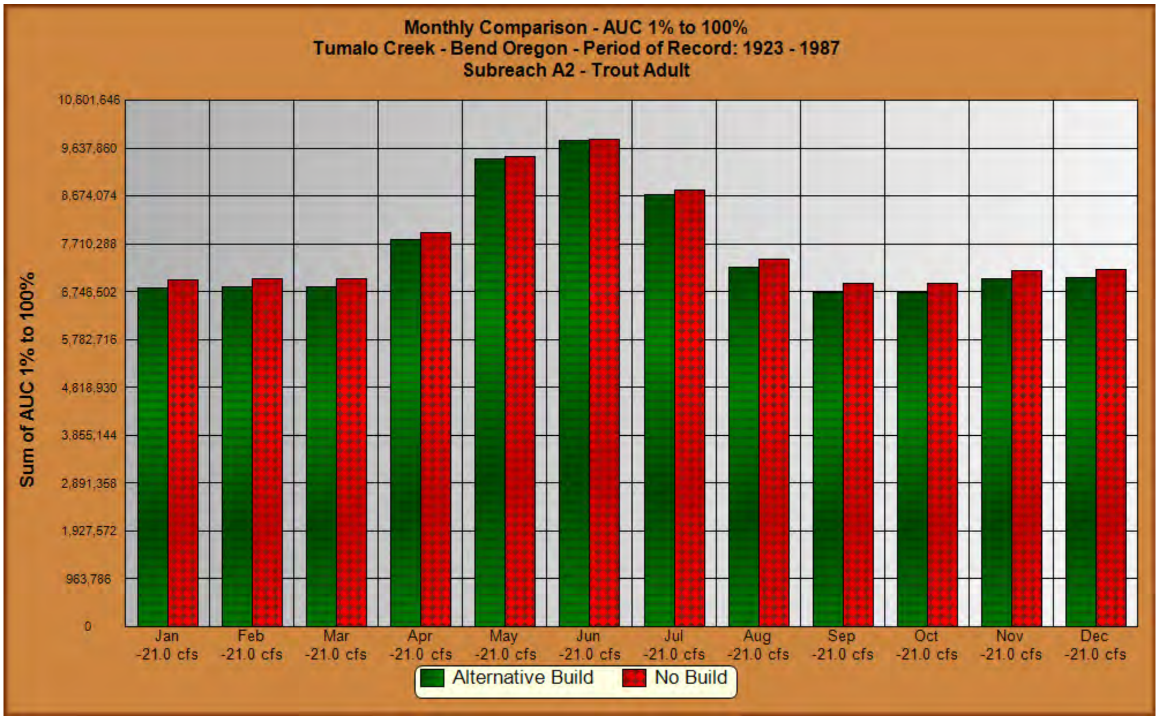


Figure 38. Sub-reach A2 monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout adult lifestage.

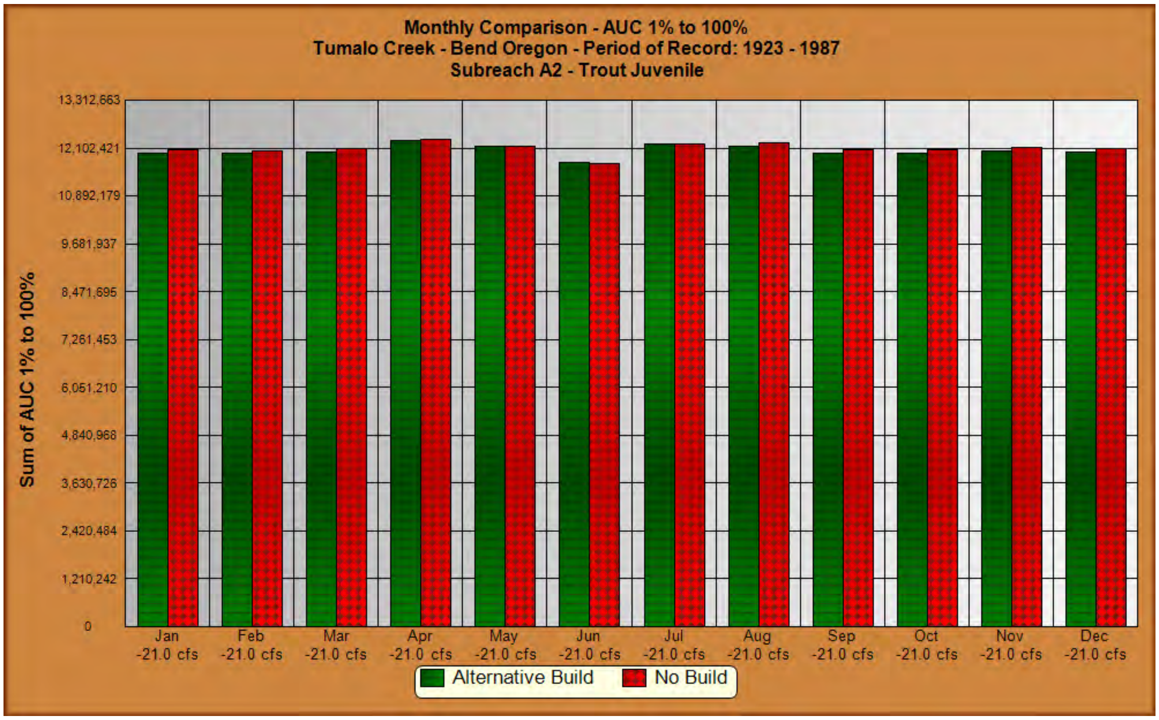


Figure 39. Sub-reach A2 monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout juvenile lifestage.

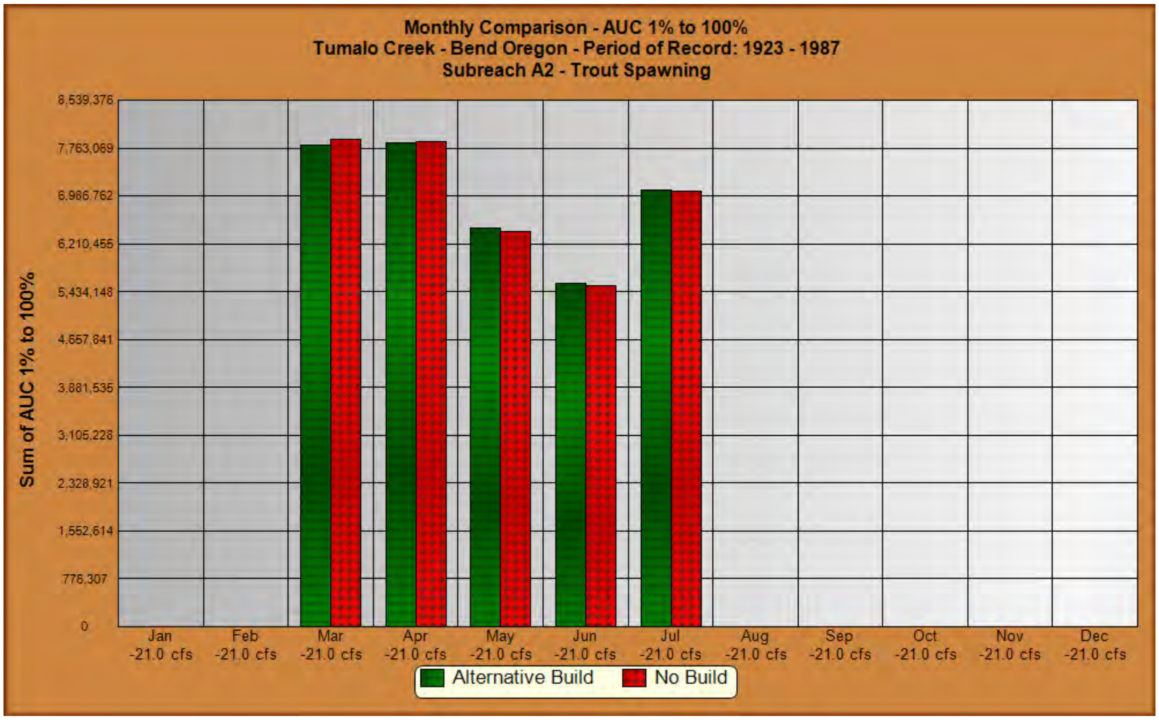


Figure 40. Sub-reach A2 monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout spawning lifestage.

Table 37. Sub-reach A2 monthly percent difference in AUC between the No-Build and Build Alternative scenario for Redband trout.

Tumalo Creek - Bend Oregon - Sub-reach A2
All Water Year Types - Sum of AUC 1% to 100%

	Alternative Build As % of No-Build											
Alternative Build Withdrawal (cfs)>	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**
Species/Lifestage	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Trout Spawning			99	100	101	101	100					
Trout Juvenile	99	99	99	100	100	100	100	99	99	99	99	99
Trout Adult	98	98	98	98	100	100	99	98	97	97	98	98

=>100% =>90% <90%

As an extension of the habitat duration analysis provided above, a supplemental analysis was conducted for sub-reach A2. The goal was to compare "Current Conditions" against the "No Build" alternative. The City's "Current Conditions" water use was derived from the year 2011 use record. Results are provided in Appendix A.

6.3.3 Reach B

Monthly habitat duration results for Reach B are shown below. The distinct notched patterns, exhibited on the bar charts below, are a direct result of TID's irrigation deliveries which were modeled during the months of April through October. The non irrigation season was modeled November through March.

As discussed above in Section 3.4, Reach B model runs included TID's assumed irrigation deliveries as well as the City's maximum diversions. Results indicate that the largest potential change in habitat would occur during peak flow months (May - July) corresponding to TID's largest irrigation deliveries.

During non-irrigation season, TID provides irrigation water to agricultural consumers through deliveries called Stock Runs. During the winter, stock run deliveries typically occur approximately every six weeks, for one week. Because of the discontinuous diversion condition and the generally unpredictable flow rate of the Stock Run deliveries, they were not included in the model runs and are therefore not reflected in the results.

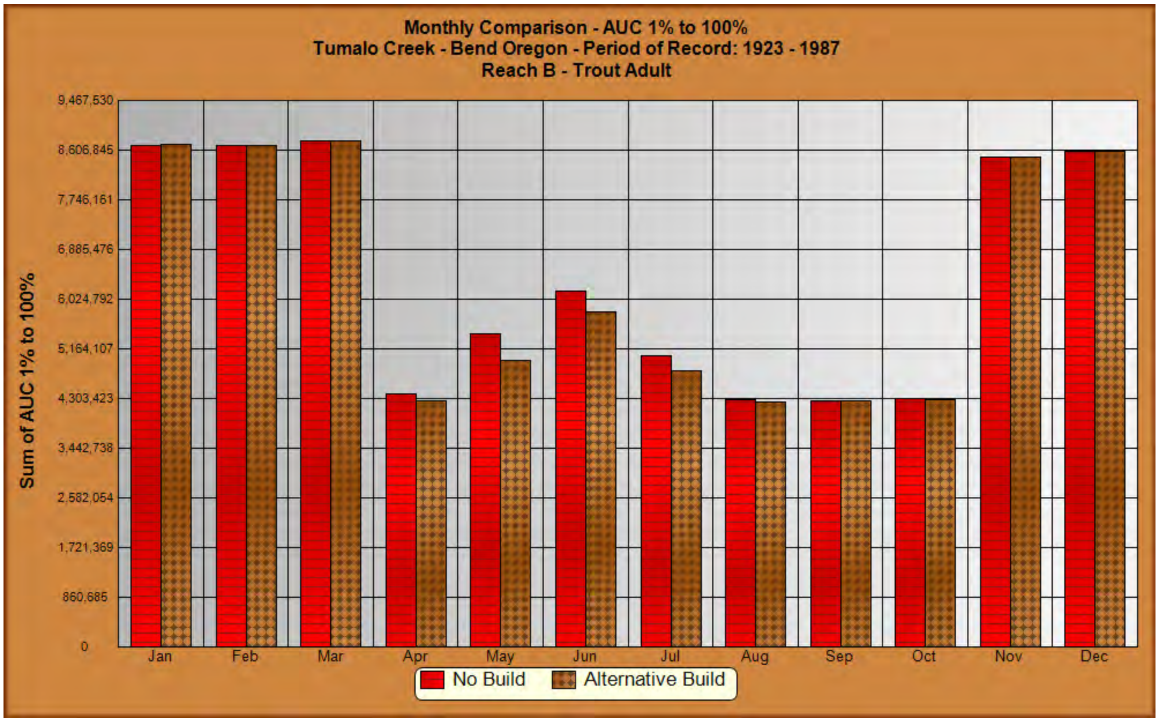


Figure 41. Reach B monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout adult lifestage.

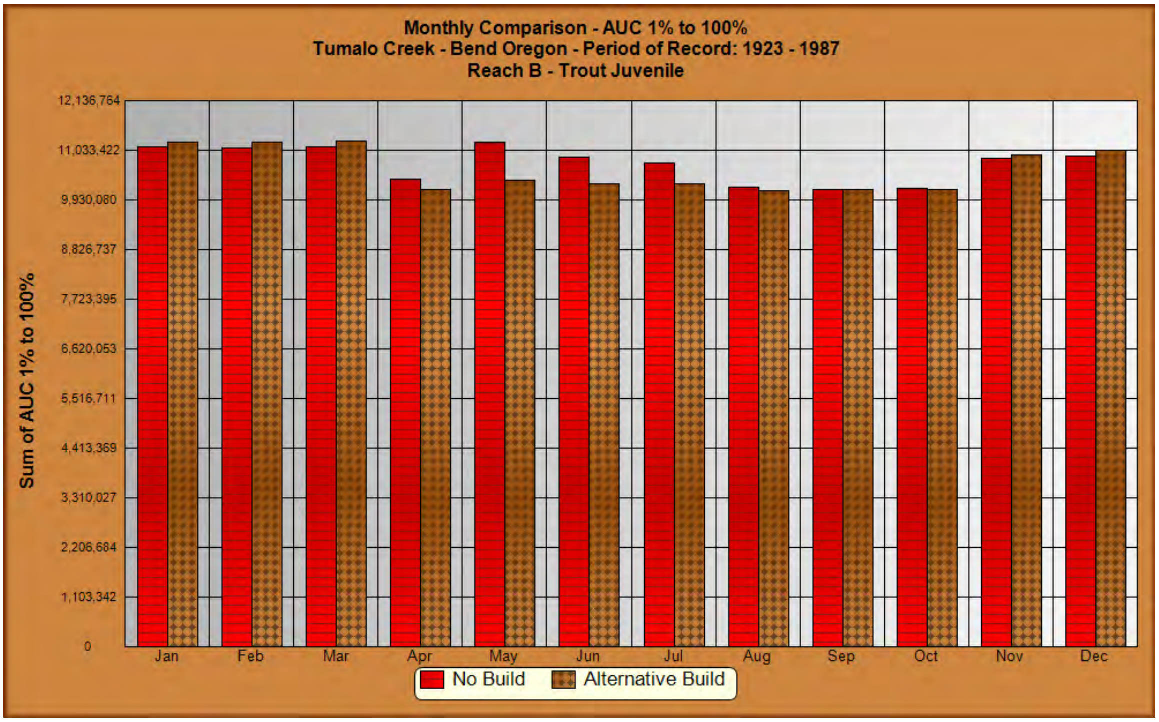


Figure 42. Reach B monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout juvenile lifestage.

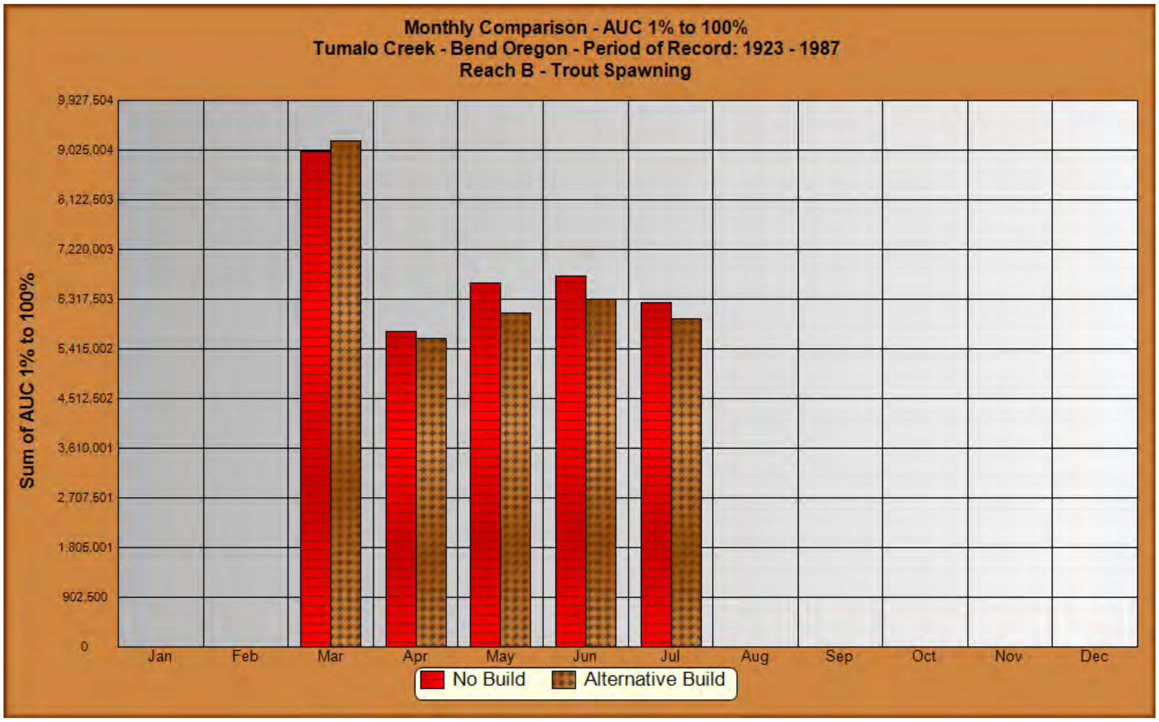


Figure 43. Reach B monthly comparison of AUC for the No-Build and Build Alternative scenario for Redband trout spawning lifestage.

Table 38. Reach B monthly percent difference in AUC between the No-Build and Build Alternative scenario for Redband trout.

Tumalo Creek - Bend Oregon - Reach B
All Water Year Types - Sum of AUC 1% to 100%

	Alternative Build As % of No-Build											
Alternative Build Withdrawal (cfs)>	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**	**-21**
Species/Lifestage	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Trout Spawning			102	98	92	94	95					
Trout Juvenile	101	101	101	98	92	95	96	99	100	100	101	101
Trout Adult	100	100	100	97	91	94	95	99	100	100	100	100

=>100%	=>90%	<90%

7.0 Geomorphic Processes Results

7.1 Bankfull

Bankfull discharge was estimated by the U.S. Forest Service in 2004 in Reach A1-RR using three techniques: flood frequency, Mannings equation using field indicators, and a gage adjustment method (Wasniewski 2004). Because there are no appreciable withdrawals or accretion between A1-RR and the top of Reach B, the same bankfull estimate was used for these three reaches. In sub-reach A1-RR, near the confluence of Tumalo Creek and Bridge Creek bankfull estimates were between 280-300 cfs and near Skyliners bridge (RM 13.2) bankfull estimates ranged from 300-345 cfs. For the purposes of this analysis, bankfull discharge was estimated at 300 cfs for Reaches A1-RR, A1-B, and A2, and 180 cfs for Reach B. Because the typical maximum withdrawal in Reach B can reach 120 cfs during May and June, the estimated bankfull discharge was reduced by this amount to an assumed bankfull discharge of 180 cfs.

7.2 Particle Size

As described above, the most uniform cross sections in each study site were selected. The estimated D_{50} (based on cross-section averaged particle size) ranged from small gravel to small boulder (Table 39). Of the twelve transects, six were cobble dominated and five were gravel dominated. The coarsest substrate was found on Transect 4 of A1B, and the finest was found on A1 RR T3.

Table 39. Cross-section-averaged particle sizes established for each cross section.

Site	Transect	Cross-section-averaged particle size		
		mm	inches	classification
A1 RR	3	13	0.5	Small gravel
	4	91	3.6	Very small cobble
	6	54	2.1	Large gravel
A1 B	1	148	5.8	Medium cobble
	2	167	6.6	Medium cobble
	4	281	11.1	Small boulder
A2	3	60	2.4	Large gravel
	4	101	4.0	Very small cobble
	5	148	5.8	Medium cobble
B	2	87	3.4	Very small cobble
	4	73	2.9	Large gravel
	6	46	1.8	Medium gravel

7.3 Channel Shear Stress

Results from the WinXSPro channel shear are presented in Table 40. Channel shear ranges from a low of about 44 N/m^2 in Reach A1-RR to a maximum of 205 N/m^2 in the steepest reach A1-B.

Table 40. Estimates of channel shear at bankfull stage.

Site	Transect	Slope (ft/ft)	Bankfull Stage (300 cfs) (ft)	Bankfull Channel Shear (N/m^2)
A1-RR	3	0.012**	1.74	44
	4	0.014**	2.36	60
	6	0.016**	2.44	75
A1-B	1	0.032	2.60	171
	2		3.16	166
	4		3.43	205
A2	3	0.011	2.82	58
	4		2.20	53
	5		2.73	60
B	2	0.018**	2.85	96
	4		2.61	83
	6		2.57	95

*From thalweg to water surface; from low flow measured water surface to maximum modeled discharge or to estimated bankfull, whichever was greater.
**Slope based on field data

7.4 Field Observations

Several field indicators of channel and bank stability were observed during PHABSIM field data collection. The observations included the resistance of substrate to movement, boulders, bank material (i.e., brush, trees, dense root mats, undercut banks, cohesion), and moss on rocks. These observations are useful in the interpretation of the quantitative data, and provide indicators of potential for lateral or vertical movement of the channel due to changes in hydrology.

8.0 Discussion

The primary goal of the Tumalo Creek Instream flow study was to examine the relationship between flow and habitat for three lifestages of Redband trout under two different proposed project operations, the No-Build and Build Alternatives. The study integrated WUA results with proposed project hydrology in a habitat duration analysis to determine the effect of proposed changes in water withdrawals on available Redband trout habitat.

One dimensional hydraulic models were developed for each sub-reach in the study area resulting in the development of stage/discharge relationships for a range of flows from as low as 9 cfs in Reach B to as high as 202 cfs in Reach A. Habitat models were then constructed for the range of flows using the hydraulic models and habitat suitability criteria for adult, juvenile and spawning lifestages of Redband trout. The response of each lifestage to changes in discharge as described by the WUA functions are discussed below as are the results of the habitat duration analysis which compared the No-Build scenario to the Alternative Build scenario.

8.1 Channel Flow Response

The results of the Channel Flow Response analysis show that a Project withdrawal of 2.8 cfs would result in very small changes in hydraulic conditions. At the median flow range of 50 to 60 cfs, a withdrawal of 2.8 cfs would reduce Tumalo Creek water surface elevation by approximately 0.03 feet (averaged across all transects). Wetted perimeter would be reduced by 0.6%, mean channel velocity would be reduced by 2.0%, and mean channel depth would be reduced by 2.0%. Across all transects there was not a strong trend of any particular mesohabitat type changing more than others for any of the metrics. At the bankfull flow estimate near 300 cfs, a withdrawal of 2.8 cfs would reduce Tumalo Creek water surface elevation by an average of 0.01 feet (Table 41). Just using the change in stage, channel shear (which is a function of cross sectional area and slope) would potentially be reduced a maximum of 0.5 N/m^2, which is a very small amount. Natural channels have so many variables that dictate sediment transport, this small change in channel shear would not result in a quantifiable or measurable change in sediment transport.

Table 41. Stage and channel shear change resulting from a reduction of 2.8 cfs from bankfull stream flow.

Site	Transect	Reduction in stage from 2.8 cfs reduction (ft)	Reduction in channel shear from 2.8 cfs reduction (N/m^2)
A1RR	3	0.001	nil
	4	0.001	0.5
	6	0.008	nil
A1B	1	0.010	0.5
	2	0.012	0.4
	4	0.014	0.5
A2	3	0.013	nil
	4	0.010	0.4
	5	0.013	nil
B	2	0.008	nil
	4	0.011	nil
	6	0.013	nil

8.2 WUA

8.2.1 Reach A

WUA functions for adult and juvenile lifestages indicate that habitat is generally suitable over a wide range of stream flows. A more detailed investigation of the WUA results indicated that as discharge increases, velocity preferences are increasingly exceeded, driving suitability down. At the same time, habitat suitability based on depth alone, increases with increasing stream flow. The resulting functions are therefore relatively flat, suggesting that preferred habitat is lost due to increased velocities at a rate that is slightly higher than habitat is gained due to increasing depths.

The spawning WUA functions for each sub-reach show a narrower band of flows that provide optimal habitat availability, compared to that of the juvenile and adult lifestages. For spawning Redband trout optimal combinations of depth, velocity and substrate are generally confined to flows of less than 90 cfs and greater than 45 cfs depending on the sub-reach. Both sub-reach A1-RR and sub-reach A2 show a similar amount of suitable habitat as compared to sub-reach A1-B, owing to the greater availability of suitable spawning gravels observed. Suitable spawning gravels observed in sub-reach A1-B were limited and found mostly along channel margins and in depositional areas behind boulders and upstream obstructions.

8.2.2 Reach B

WUA functions for all three Redband trout lifestages indicate that habitat is generally suitable when stream discharge is less than 100 cfs. Channel morphology and gradient play an important factor in the observed habitat functions in this reach. The channel is generally narrower and higher gradient than found in Reach A, thereby resulting in higher velocities per unit discharge. As a result, the WUA functions slope downward at a higher rate than found in Reach A.

WUA results indicate that suitable combinations of depth, velocity and substrate for the spawning lifestage occur when creek flows are between 30 cfs and 80 cfs. Suitable spawning substrate was fairly well distributed among the transects and along the transect cross sections, though patch size was variable. The total amount of available spawning habitat in Reach B was similar to that found in sub-reach A1-RR and sub-reach A2.

8.3 Habitat Duration

The percent difference in area-under-the- curve between the No-Build and the Build Alternative varies depending on lifestage, month, and the reach or sub-reach. Overall, the percent difference in AUC was small. This small change in habitat between the No-Build and Build Alternative is consistent with the small changes in hydraulics as described in Section 8.1, above.

Just as there were small reductions in AUC, increases in AUC were also observed in numerous months throughout the results presented above. Increases in AUC due to a reduction of stream flow can occur when stream flow is greater than the discharge that represents the peak of the WUA habitat index. An example from Reach B will be used to demonstrate. If stream flow in Tumalo Creek one day in March during the period of record is 100 cfs, it is 65 cfs greater than the discharge that represents the maximum habitat suitability predicted in Reach B (35 cfs) for Redband trout spawning. If stream flow is reduced by 2.8 cfs on that day in March, habitat suitability according to the WUA index function will increase slightly. As described in the habitat duration methods above, each day for the period of record is analyzed in this way thereby contributing to the overall AUC result for each lifestage and reach. A two percent increase in AUC can be described as a 2 % increase in habitat over time.

8.3.1 Reach A

Despite the City’s conservative model parameters, including the use of maximum daily diversion rates and not accounting for increased flows in Sub-reaches A1-RR and A-1B due to the elimination of the return flow at RM 5.4, changes in Redband trout habitat for all lifestages were very small. The greatest reduction in AUC occurs in sub-reaches A1-B and A2 at approximately 3% for the adult lifestage in the months of September and October. For the combined Reach A model, the greatest reduction in AUC is for adult at 2%, while AUC for spawning and juvenile showed changes of +/- 1%.

The relatively small change in AUC is primarily due to two factors: a) the relatively small difference in discharge between the No-Build and Build Alternative and b) because the peaks of the WUA curves are relatively broad for all lifestages a small change in discharge results in only a small change in WUA.

The reason the adult lifestage is more sensitive during low flow months than the other lifestages is because the WUA curve drops off more steeply at lower flows.

8.3.2 Reach B

As in Reach A, the City modeled Reach B with the intention of including the conditions that would result in a maximum potential change in habitat for Redband trout. Reach B model runs included the City's diversion scenarios as shown in Table 23 above and TID's assumed irrigation deliveries and minimum bypass flows as shown in Table 24. Results indicate that the largest potential change in habitat would occur during peak stream flow months (May and June) corresponding to TID's largest irrigation deliveries from Tumalo Creek.

Habitat changes in Reach B for all lifestages were most sensitive to the combined diversions of the City (21 cfs) and TID (120 cfs) in May and June. Spawning and juvenile AUC were reduced by 8% and the adult AUC was reduced by 9%. These higher percent differences in AUC between the No-Build and Alternative Build, compared to Reach A, are primarily due to the theoretical combination of both the City's and TID's withdrawals. When withdrawals are combined, the residual flow in the stream is "pushed to the left of the WUA curve"; meaning that small changes in discharge can have a greater effect on WUA.

It should be noted that the City's diversion rates or TID's assumed irrigation delivery rates are variable and may not equal the maximum diversion withdrawals used in the habitat model. In addition, stream flows in Reach B are rarely reduced to 8 cfs (April-Oct) or 5 cfs (Nov to March) and these minimum instream flow requirements or agreements are likely to increase as stated in the Executive Summary.

8.4 Geomorphic Processes

Three out of the four reaches investigated are resistant to lateral or vertical movement. In sub-reach A2, sub-reach A1-B and sub-reach B, the stream bed is composed of coarse and relatively immobile material as seen by imbricated and occasionally mossy particles, and stable banks. These reaches generally meet the criteria for Rosgen B-type channels (Rosgen 1996), so it is typical of these reaches to be resistant to lateral or vertical movement.

Sub-reach A1-RR also known as the restoration reach, travels through a meadow. There is lateral shifting as evidenced by some bank failures and numerous side channels. Surveys have been done documenting the lateral and vertical shifts (USFS 2010). Aerial photos clearly show the dynamic nature of Tumalo Creek in this reach. Sub-reach A1-RR meets the criteria for a Rosgen C-type channel, and as such, shifting through the valley is expected. There is meadow vegetation, shrubs, and large woody debris that act as both protection from bank erosion and act as forcing elements that provide some three-dimensional heterogeneity. There is deformable and mobile substrate as documented by the changes in the data collected by the USFS (2010).

A 2.8 cfs change at bankfull discharge constitutes a very small percentage of the predicted channel forming/changing stream flows. Yet, given the responsiveness of this reach, this is where a change might manifest. A change of 2.8 cfs at bankfull discharge results in an average of 0.01' change in stage, which is generally about a 0.5 N/m^2 change in average channel shear stress. If channel shear is at or near the critical shear (the point at which movement begins) for an individual particle, a decrease in stream flow could result in a slight decrease in sediment transport though these changes would largely be immeasurable. The stage change of usually less than 0.01 feet is unlikely to affect inundation of the floodplains.

9.0 Variances to the Study Plan

The study was conducted in accordance to the November, 2011 study plan. There were no variances.

10.0 List of Appendices and Attachments

This study proposal includes one appendix:

- Appendix A: Habitat Duration Supplement – Current Conditions for Sub-reach A2

This study proposal includes three attachments:

- Attachment A: Transect Photo Log
- Attachment B: PHABSIM Calibration Report
- Attachment C: Channel Flow response Charts

11.0 References Cited

Bovee, K. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream Flow Information Paper No. 12. FWS/OBS-82/26. U.S. Fish and Wildlife Service, Office of Biological Services, Fort Collins, Colorado.

______ 1997. Data collection procedures for the Physical Habitat Simulation System. U.S. Geological Survey, Biological Resources Division, Fort Collins, Colorado.

______., B.L. Lamb, J.M. Bartholow, C.B. Stalnaker, J. Taylor and J. Henriksen. 1998. Stream habitat analysis using the instream flow incremental methodology. U.S. Geological Survey, Biological Resources Division Information and Technology Report USGS/BRD-1998-0004.

City of Bend 2010. City of Bend Ambient Water Quality Monitoring: Deschutes River and Tumalo Creek 2005-2008 (Bend, Oregon). 86pp.

Guo, Junke. 2002. Hunter Rouse and the Shields diagram. Advance in Hydraulics and Water Engineering, Proc. 13th IAHR-APD Congress, Vol. 2, World Scientific, Singapore. http://myweb.unomaha.edu/~junkeguo/rouse.pdf

Hardy, T., Panja, P. and Mathias D. 2005. WinXSPRO, a channel cross section analyzer, Ver 3.0. General Technical Report RMRS-GTR-147 (Users Manual). USDA Forest Service. Rocky Mountain Research Station. Program can be downloaded: http://www.stream.fs.fed.us/publications/winxspro.html

Milhous, R.T., M.A. Updike, and D.M. Schneider. 1989. Physical habitat simulation system reference manual -- version II. Washington, DC: U.S. Fish and Wildlife Service Biological Report 89(16). 1-403 p.

Milhous, R.T., D.L. Wegner, and T. Waddle 1984. User's Guide to the Physical Habitat Simulation System (PHABSIM). Instream Flow Information Paper No. 11. U. S. Fish Wildl. Serv. FWS/OBS-81/43 (revised). 475 pp.

Muhlfeld, C. C., 2002. Spawning Characteristics of Redband Trout in a Headwater Stream in Montana. North American Journal of Fisheries Management 22: 1314-1320.

OCS, 2011. The NRCS PRISM Climate Mapping Project. 4

ODFW, 1992. Tumalo Creek Fish Habitat Summary. 14p.

Pitlick, J., Y.Cui, and P.Wilcock Manual for computing bed load transport using BAGS (Bedload Assessment for Gravel-bed Streams) software. USDA Forest Service. Rocky Mountain Research Station. General Technical Report RMRS-GTR-223. Manual and software can be downloaded: http://www.stream.fs.fed.us/publications/bags.html

Rantz, S.E. 1982. Measurement and computation of stream flow: Volume 1. Measurements of stage and discharge. United States Geological Survey Water Supply Paper 2175. 284p.

Rosgen, D. 1996. Applied River Morphology. Wildland Hydrology. Pagosa Springs, Colorado. International Standard Book Number 0-9653289-0-2.

Stuart, A. M, Grover, D., Nelson, T.K., and S.L. Thesfeld. 2007. Redband Trout Investigations in the Crooked River Basin - In Schroeder, R.K., and J.D. Hall, editors. 2007. Redband Trout: resilience and challenge in a changing landscape. Oregon Chapter, American Fisheries Society, Corvallis.

Trihey, E.W., and D. Wegner. 1981. Field data collection procedures for use with the Habitat Simulation System of the Instream Flow Group, USFWS, Fort Collins, Colorado.

TID, 2005. Tumalo Irrigation District Water Management and Conservation Plan Update, November 22, 2005. Prepared by: David Evans & Associates, Bend, Oregon. 78p.

USFS 1999. Tumalo Creek Level II Stream Inventories. Deschutes National Forest. Bend/Ft Rock Ranger District.

USFS 2010. Tumalo Creek Restoration Reach Survey Data. Deschutes National Forest. Bend/Ft Rock Ranger District.

_____ 2008. Upper Tumalo Creek Level II Stream Inventories. Post Restoration. Deschutes National Forest. Bend/Ft Rock Ranger District.

USGS, 2011. Oregon StreamStats. http://water.usgs.gov/osw/streamstats/oregon.html

Waddle, T.J., Steffler, P., Ghanem, A., Katopodis, C. & Locke, A. (2000) Comparison of one and two-dimensional open channel flow models for a small habitat stream. Rivers 7, 205-220.

Waddle, T.J., 2001, PHABSIM for Windows—user's manual and exercises: U.S. Geological Survey Open-File Report 01-340, 288 p.

Wasniewski, L. Tumalo Creek bankfull discharge calculations. Unpublished report. Prepared for USDA Forest Service, Deschutes National Forest, February 20, 2004. Provided by Jason Gritzner (jgritzner@fs.fed.us), USFS, 1/30/2012, to J.Caldwell, HDR Inc.

Wilcock, P., J.Pitlick, and Y.Cui. Sediment transport primer estimating bed-material transport in gravel-bed rivers. USDA Forest Service. Rocky Mountain Research Station. General Technical Report RMRS-GTR-226. Primer and software can be downloaded: http://www.stream.fs.fed.us/publications/bags.html

Appendix A

Habitat Duration Supplement – Current Conditions for Sub-reach A2

A supplemental habitat duration analysis was conducted to support the Instream Flow Study Technical Memorandum prepared for Tumalo Creek and the City of Bend Surface Water Improvement Project.

The primary objective of the supplemental analysis was to compare "Current Conditions" against the "No Build" alternative for sub-reach A2 of Tumalo Creek, from the point of City's return flow to the point of diversion by TID. The City's "Current Conditions" water use rates were derived from the year 2011 use record, as shown in Table 1.

Table 1. City of Bend Surface Water Use in cfs (Maximum day based on 2011)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10.2	8.2	8.1	11.1	16.5	16.5	17.1	17.2	17.2	16.5	8.1	8.3

In the figures below, "Current Conditions" assumed monthly diversion rates which are listed along the x-axis and "Max Div Rate" represents a monthly 18 cfs withdrawal. The analysis was conducted for the period of record, from 1923 – 1987.

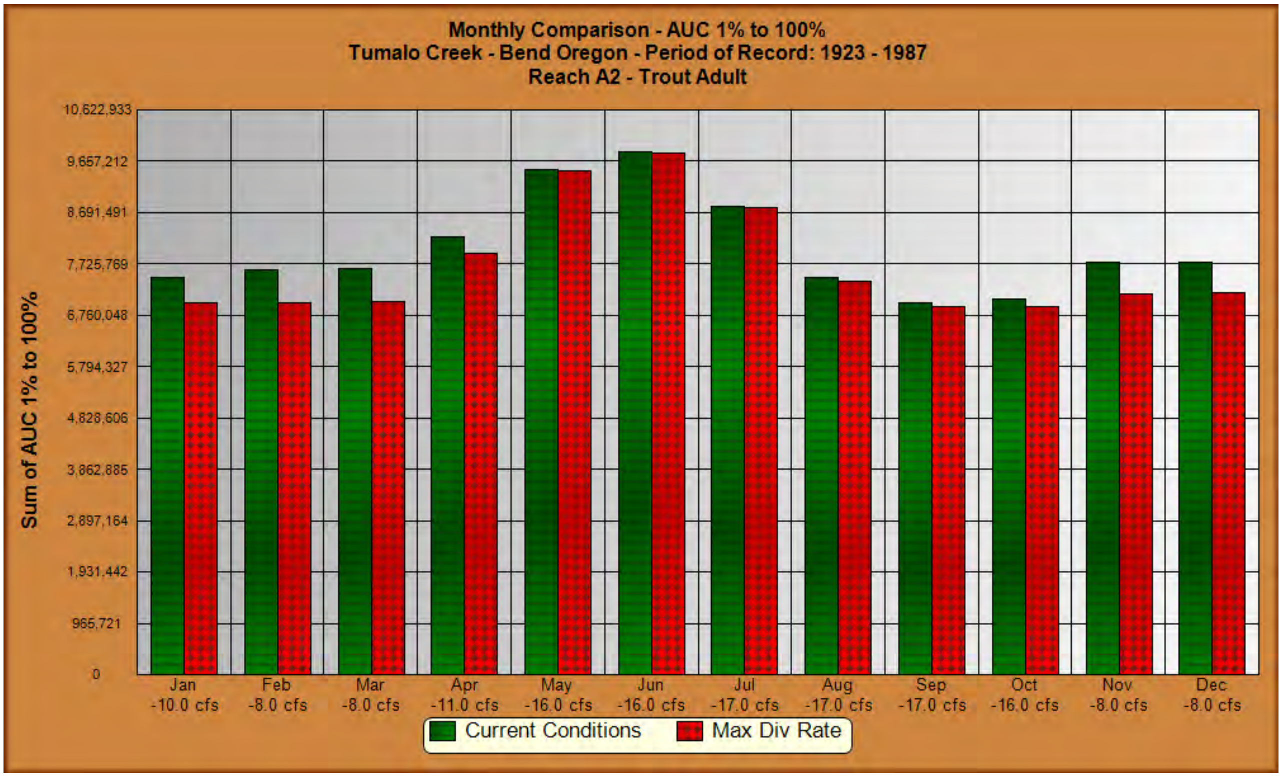


Figure 1. **Sub-reach A2 monthly comparison of AUC for “Current Conditions” to the Maximum Diversion Rate (No Build -18 cfs) scenario for Redband trout adult lifestage**

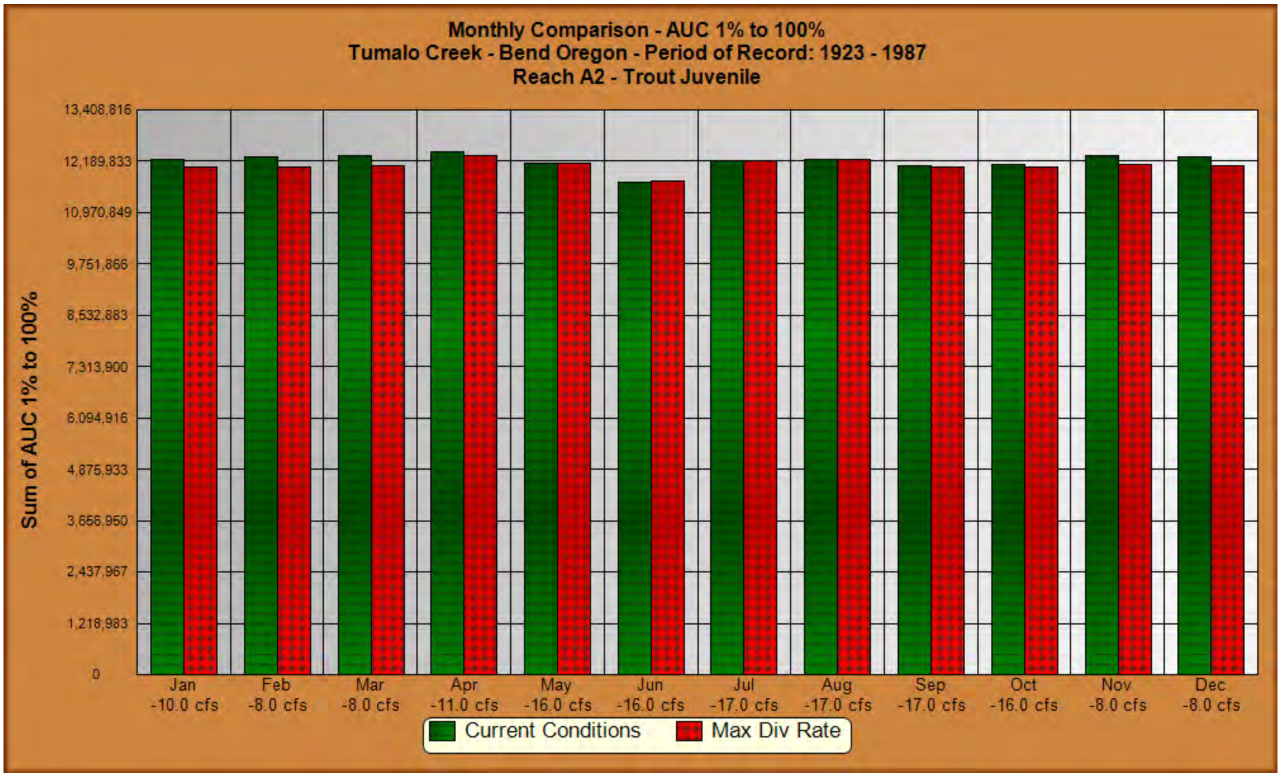


Figure 2. Sub-reach A2 monthly comparison of AUC for "Current Conditions" to the Maximum Diversion Rate (No Build -18 cfs) scenario for Redband trout juvenile lifestage

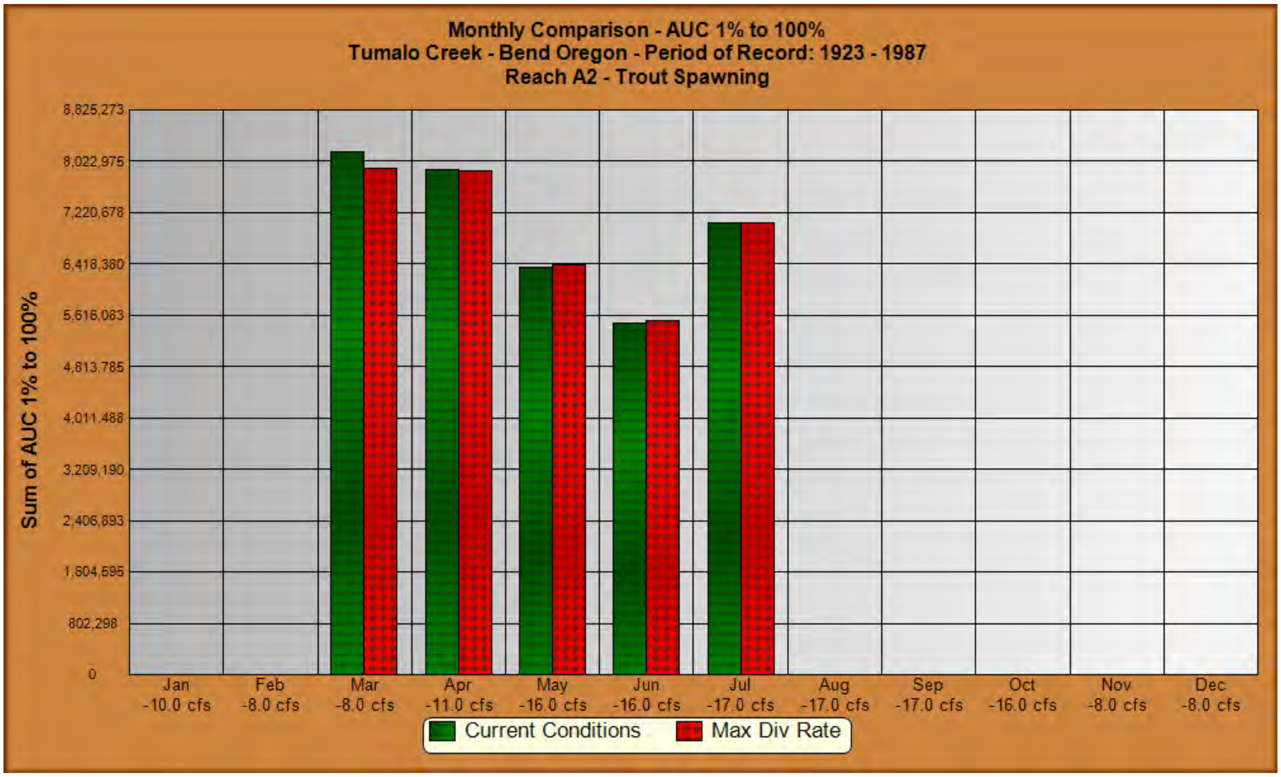


Figure 3. Sub-reach A2 monthly comparison of AUC for “Current Conditions” to the Maximum Diversion Rate (No Build -18 cfs) scenario for Redband trout spawning lifestage

Table 2. Sub-reach A2 monthly percent difference in AUC between “Current Conditions” and the Maximum Diversion Rate (No-Build -18 cfs) for Redband trout.

Tumalo Creek - Bend Oregon - Sub-reach A2

All Water Year Types - Sum of AUC 1% to 100%

	Current Conditions As % of Max Div Rate											
Current Conditions Withdrawal (cfs)>	**-10**	**-8**	**-8**	**-11**	**-16**	**-16**	**-17**	**-17**	**-17**	**-16**	**-8**	**-8**
Species/Lifestage	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Trout Spawning			103%	100%	99%	99%	100%					
Trout Juvenile	102%	102%	102%	101%	100%	100%	100%	100%	100%	101%	102%	102%
Trout Adult	107%	109%	109%	104%	100%	100%	100%	101%	101%	102%	108%	108%

=>100%	=>90%	<90%