Appendix C
Hydrologic Analysis Methods and Results

The methods of hydrologic analysis described in the following sections closely mimic the processes used for the 2010 Geomorphic Assessments and Habitat Prioritizations hydrologic analyses. The last 8 years of flow data from the following described sources were updated in the existing analyses and, apart from the updated results, all other methodologies remained the same. Because hydrology analyses can be subjective depending on the methods used and data sources drawn from, it is recommended that this method be repeated for any future analyses unless new sources of information become available and allow for a more accurate approach.

It should be noted that the "Low-Winter Flow" seen in this assessment was not determined using a hydrologic analysis. Instead, this is the flow that occurred during periods of key data collection, the low-winter flow during the Light Detection and Ranging (LiDAR) collection in November 2017, and the mean-winter flow during the aerial collection in April 2018. While these flows do not correspond directly to a statistically recognized flow event, they are representative of typical lower flows that occur during that time of year.

Hydrologic Information

Information on hydrology in the Tucannon River basin was available from multiple stream gages (both on the Tucannon River and its tributaries) and spatially distributed rainfall data. Subbasin delineations were also available for use in estimating discharge contributions from tributaries that are not gaged.

Stream Discharge Data

Stream discharge data were available from three gages on the Tucannon River and its major tributaries. See Figure 2-5 of the main report for a basin map including stream gage locations. The following sections provide a brief description of the gages used to help evaluate basin hydrology.

U.S. Geological Survey Gage near Starbuck, Washington

Discharge data in the Tucannon River near Starbuck were available from the U.S. Geological Survey (USGS) gage No. 13344500 (USGS 2018a). The gage is located at approximately river mile (RM) 8.2, just downstream of the Smith Hollow Road crossing and the confluence of the Smith Hollow tributary. The drainage basin upstream of the gage is approximately 431 square miles. The available period of record for the gage is from October 1, 1914, through August 5, 2018. Three significant data gaps exist in the period of record: one from water years 1918 to 1928, a second from water years 1932 to 1958, and a third from water years 1991 to 1994. A total of 62 water years are available in the gage data. Approved peak streamflow data were available for 61 of the water years (water year 2018 peak streamflow was not approved for publication at the time of this analysis).

Department of Ecology Gage near Marengo, Washington

Discharge data in the Tucannon River near Marengo were available from the Washington State Department of Ecology (Ecology) gage 35B150. The gage is located at approximately RM 26.9, just downstream of Marengo and the Turner Road crossing. The drainage basin upstream of the gage is approximately 160 square miles. The available period of record for the gage is from June 2003 to the present. This location was also the site of a former USGS gage (No. 13344000). The available period of record for the former USGS gage is from water years 1913 to 1930. The data from the former USGS gage were not used in the analysis.

Department of Ecology Gage on Pataha Creek near the Mouth

Discharge data in Pataha Creek near the confluence with the Tucannon River were available from Ecology gage 35F050. The gage is located on Pataha Creek at approximately RM 1.2, just downstream of the State Route 261 crossing. Pataha Creek enters the Tucannon River at approximately RM 12.5. The drainage basin upstream of the gage is approximately 184 square miles.

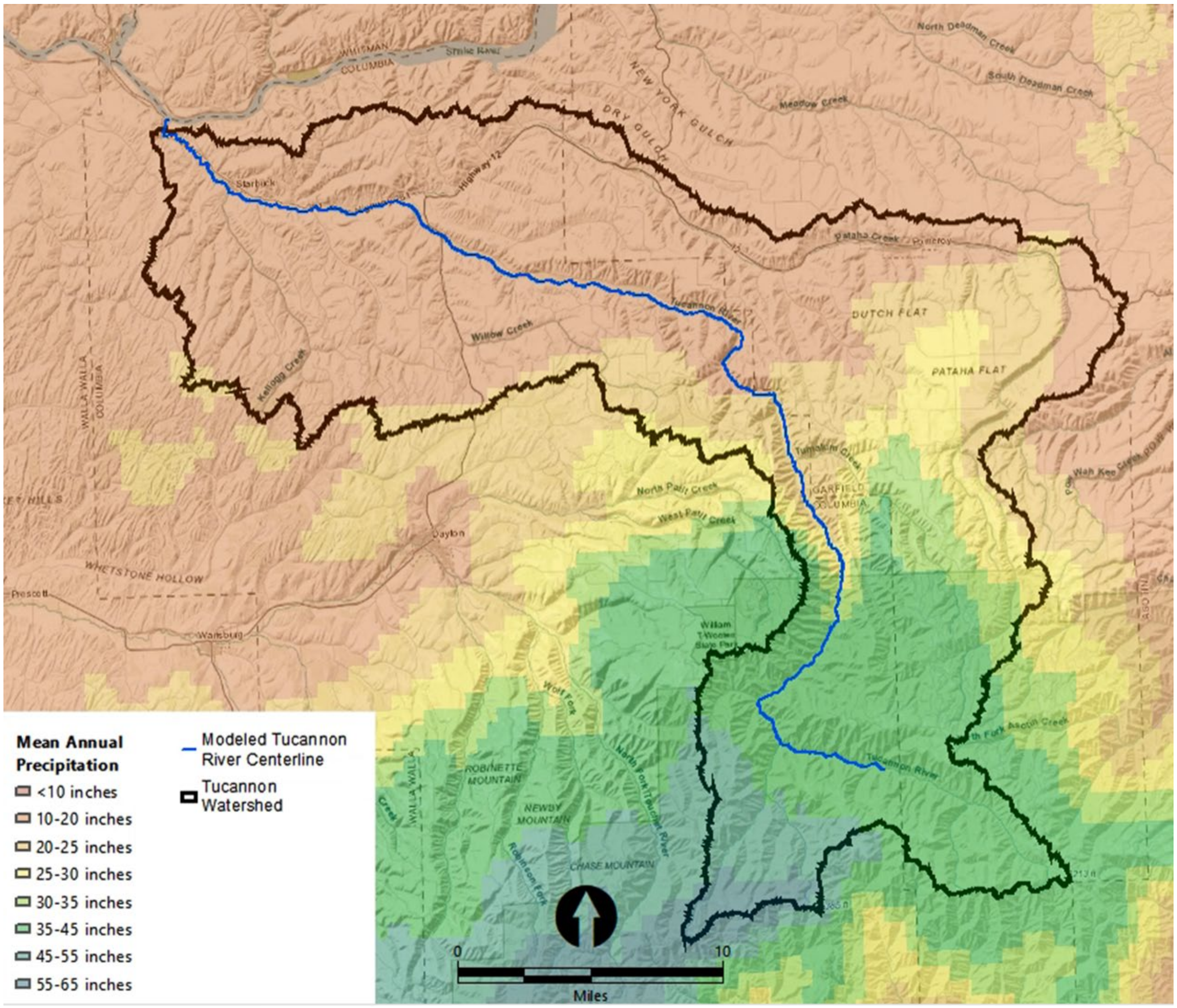
Precipitation Data

Precipitation data for the basin were summarized in the Tucannon Subbasin Plan and were available geospatially from Oregon State University through the PRISM climate model (OSU 2019). The distribution of precipitation in the basin is highly dependent on elevation. Mean annual precipitation ranges from 10 inches at lower elevations to more than 40 inches at higher elevations. Figure C-1 shows the distribution of mean annual precipitation over the Tucannon River basin (CCD 2004).

Basin Delineations

Basin and subbasin delineations are available as geospatial data through USGS stream stats (BLM 2009; USGS 2018b) for the Tucannon River. These delineations provided information on contributing area, basin shape, slope, and elevation. The major subbasins and gage locations in the Tucannon River basin are listed in Table C-1.

Figure C-1
Mean Annual Precipitation Distribution – Tucannon River Basin



Note: Precipitation data were drawn from the Oregon State University PRISM climate model (OSU 2019) and represent the 30-year (1981 to 2010) annual average.

Table C-1
Tucannon Tributaries and Basin Areas

Major Tributary/ Location on River	Location (RM)	Tributary Area (square miles)	Basin Area Above Confluence (square miles)	Basin Area Below Confluence (square miles)	Basin Area Increase (square miles)
Mouth	0	-	504	504.0	14.0
Kellogg Creek	4.9	34.5	455.5	490.0	58.5
Starbuck Gage	8.8	-	431.5	431.5	0.77
Smith Hollow	8.8	20.6	410.1	430.7	25.8
Pataha Creek *(Gaged)*	12.4	184.8	220.1	404.9	189
Willow Creek	14.9	29.9	186.4	216.3	56.3
Marengo Gage	27.2	-	160	160.0	22.2
Tumalum Creek	35.8	16.0	121.8	137.8	19.7
Cummings Creek	38.1	19.9	98.3	118.2	42.1
Little Tucannon River	48.3	8.4	67.7	76.1	12.4
Panjab Creek	50.4	25.4	38.3	63.7	25.4

Hydrologic Analysis

Flood Magnitude and Frequency Analysis

A flood magnitude and frequency analysis for the Tucannon River was conducted using peak discharge data from the gage at Starbuck. Two methods were used in the selection of the peak discharge event series for the flood magnitude and frequency analysis:

1. The series of annual peak discharges for the period of record.
2. All independent discharge peaks above a threshold of 720 cubic feet per second (cfs). This threshold provided a series of 63 independent flood events (equivalent to the number of years of record). This selection method is also known as a partial duration series (PDS) analysis (Madsen et al. 1997).

The two peak discharge series selection methods were justified given the nature of the basin hydrology (i.e., the occurrence of drought years with no appreciable flood event) and the goals of the analysis. The drought year peak discharges can be seen below the PDS threshold of 720 cfs. Each peak discharge series was used to develop a Log-Pearson Type III (LP3) exceedance probability curve. Overall, the PDS method typically provides larger peak discharges for the more frequent events (i.e., 1- and 2-year return periods) while only providing slightly smaller peak discharges for the less frequent flood events when compared to using the annual peak discharge series method. The results of the LP3 analysis using both data sets are shown in Table C-2.

Table C-2
Flood Magnitude and Frequency at the Starbuck Gage

Return Period (year)	Annual Exceedance Probability	Peak Discharge (cfs): LP3	Peak Discharge (cfs): LP3 over Threshold	Percent Difference
1	100%	164	552	237%
2	50%	1,108	1,436	30%
5	20%	2,420	2,530	5%
10	10%	3,713	3,589	-3%
25	4%	5,948	5,437	-9%

It is important to note the large difference in the peak discharge between the LP3 analysis using the annual peaks series and the PDS for the 1-year return period. Using the annual peak discharges series for the LP3 analysis yields a 1-year return period discharge less than the mean annual discharge. However, using the PDS method for the LP3 analysis yields a 1-year return period discharge roughly 3 times the magnitude of the mean annual discharge. This difference is the result of drought years in the annual peak discharge series and the absence of small peak discharges from drought years in the PDS method. As the exceedance probability decreases, the results of the two methods become more similar, with the PDS method providing a slightly smaller discharge for return periods longer than 5 years.

For the 1-year return period, the peak discharge from the LP3 analysis using the PDS was used for subsequent analysis. For the 2-, 5-, 10-, 25-, and 100-year return periods, the peak discharges from the LP3 analysis using the annual peak discharge series were used for subsequent analysis.

Basin Area Discharge Scaling

To calculate the discharge contributions for ungaged flow change locations on the Tucannon River, the basin area scaling method developed by Thomas et al. (1994) and referenced in the USGS Fact Sheet *Methods for Estimating Flood Magnitude and Frequency in Washington* (USGS 2001) was used. Thomas's basin area scaling method (Equation C-1) uses the basin area proportions and a regional exponent to scale discharges from a gaged location to an ungaged location. The method is suitable for ungaged basins with a basin area between 50% and 150% of the gaged location basin area.

The regional exponent (x) for the Tucannon River basin is 0.59 (Table 3, USGS 2001). The results of this method applied to the major tributary basin areas are shown in Table C-3 as flow proportion percentages. It should be noted that several ungaged flow change locations in the upper basin are less than 50% of the gage location's basin area. These estimates are beyond the recommended limitations of the method and should therefore be compared with other methods for determining basin contributions including stream gage data correlations.

Equation C-1[1]

$$Q_u = Q_g \left(\frac{A_u}{A_g}\right)^x$$

where:

Q_u	=	peak discharge, in cfs, at the ungaged site for a specific recurrence interval
Q_g	=	peak discharge, in cfs, at the gaged site for a specific recurrence interval
A_u	=	contributing drainage area, in square miles, at the ungaged site
A_g	=	contributing drainage area, in square miles, at the gaged site
x	=	exponent for the region in which both sites are located

Note:

1. USGS Fact Sheet Methods for Estimating Flood Magnitude and Frequency in Washington (USGS 2001) developed by Thomas et al. 1994.

Table C-3
Flow Change Locations and Discharge Contributions

Major Tributary/ Location on River	Thomas (1994) Flow Proportion as % of Starbuck	Flow as % of Marengo[5]	Flow as % of Starbuck, with Gage Corrections	Difference in Proportion
Kellogg Creek	109.6%	-	109.6%	0.0%
Starbuck Gage	107.8%	-	107.8%	0.0%
Smith Hollow[1,3]	100.0%	-	100.0%	0.0%
Pataha Creek[2]	99.9%	-	100.0%	0.1%
Willow Creek[3]	96.3%	-	97.0%	0.7%
Marengo Gage[4,5]	66.5%	100%	86.0%	19.5%
Tumalum Creek	55.7%	92%	82.0%	26.3%
Cummings Creek	51.0%	84%	75.1%	24.1%
Little Tucannon River	46.6%	64%	68.6%	22.0%
Panjab Creek	35.9%	58%	52.9%	17.0%
Above Panjab Creek	32.3%	43%	47.6%	15.3%

Notes:

1. For the purposes of modeling, the discharge downstream of Smith Hollow was assumed to be equivalent to the discharge at the Starbuck gage.
2. The gage correlation correction for Pataha Creek is 9% of the discharge at Starbuck.
3. The remainder of the discharge proportion for the gage correction method was split evenly between Smith Hollow and Willow Creek, with both tributaries accounting for 1% of the discharge at the Starbuck gage.
4. The gage correlation correction for the Marengo gage is 86% of the discharge at Starbuck.
5. Proportioning of the discharge at Marengo to tributaries used Thomas's basin area scaling method with Marengo as the gaged location.

Stream Gage Correlations

To improve the flow estimates provided by the basin area scaling method, correlations between discharge at the Starbuck gage and two other gages (Marengo and Pataha) were made. Although the period of record at these gages is not sufficiently long to conduct a flood frequency analysis using the LP3 method, the gage data were sufficient to develop reasonable discharge correlations to the gage at Starbuck. To develop the correlation, mean daily discharges at the Marengo and Pataha Creek gages were plotted against mean daily discharges greater than or equal to 400 cfs at the Starbuck gage and a linear trend line with an origin of (0,0) was fit to the data. These correlations showed the following:

- Discharge at the Marengo gage was typically 86% of the discharge at the Starbuck gage (Figure C-2).
- Discharge at the Pataha Creek gage was typically 9% of the discharge at the Starbuck gage (Figure C-3).

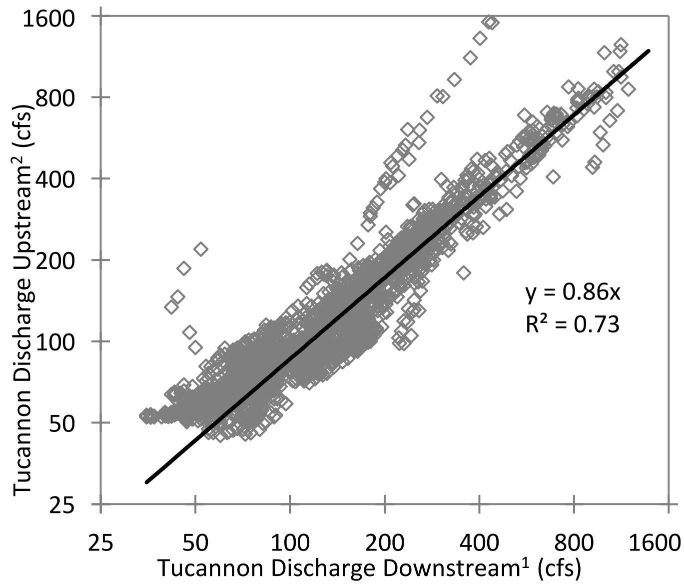
The results of applying these gage correlation corrections to the basin area scaling method are shown in the column titled “Flow as % of Starbuck, with Gage Corrections” in Table C-3 as flow proportion percentages. The table also shows the difference in flow proportions between the basin area scaling method and the gage correlation corrections to the basin area scaling method. The flow change locations and discharge contributions are also shown in Figures C-2 and C-3.

Table C-3 shows the basin area scaling method’s underestimation of the discharge at Marengo and overestimation of discharge from Pataha Creek. The differences can be attributed to differences in the shape of the contributing areas and the distribution of mean annual precipitation in the basins. Although the Pataha Creek subbasin comprises approximately 43% of the contributing area to the Tucannon River at the Starbuck gage, it produces a significantly smaller percentage of the discharge as shown by the gage data correlation. Two primary factors reduce the relative discharge contribution of Pataha Creek:

- The long and narrow shape of the Pataha Creek basin is not conducive to producing large peak discharges.
- The Pataha Creek basin receives less precipitation per area compared to the upper portion of the Tucannon River. For example, only 8.8% of the Pataha Creek subbasin receives more than 30 inches of precipitation per year, compared to nearly 59% of the Tucannon River basin above Pataha Creek.

The stream gage correlation results are consistent with previously published hydrologic analysis results (Hecht et al. 1982). Hecht et al. focused on a single water year (1980) and found that, relative to total average annual flow at the Starbuck gage, Pataha Creek contributed approximately 11% of the average annual flow while the Tucannon basin upstream of Pataha Creek contributed approximately 85% of the flow.

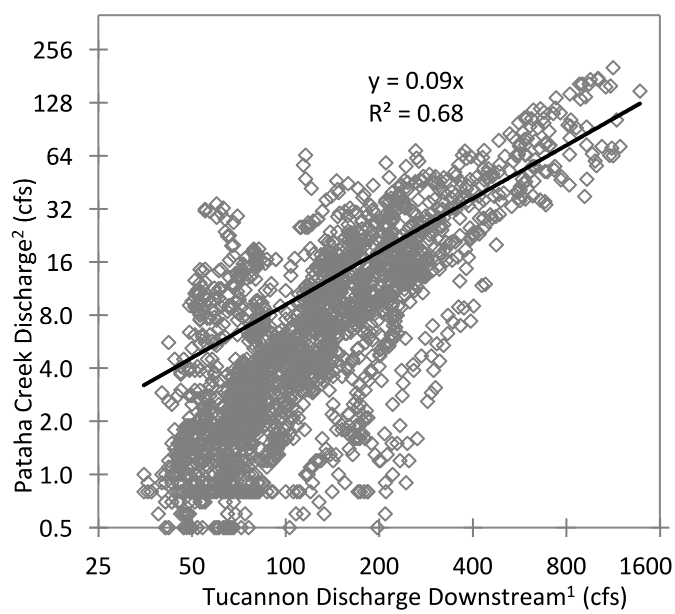
Figure C-2
Discharge Correlation Between Marengo and Starbuck Gages



Notes:

1. Discharge at the USGS Starbuck gage (13344500, RM 8.8, drainage area 431.5 square miles
2. Discharge at the Ecology Marengo gage (35B150), RM 27.2, drainage area 160 square miles

Figure C-3
Discharge Correlation Between Pataha Creek and Starbuck Gages



Notes:

1. Discharge at the USGS Starbuck gage (13344500, RM 8.8, drainage area 431.5 square miles
2. Discharge at the Pataha Creek gage, drainage area 184.8 square miles

Final Flows used for Modeling

Final reporting of the basin and tributary hydrology is provided in Table C-4. These flows were used in the final modeling effort, in addition to the standard return period statistics. The maximum monthly average flow for the months of January to May was used to represent higher winter flows. This metric is based on the average monthly statistics at the Starbuck gage, and scaled using the same final equation as the yearly return periods.

Table C-4
Model Hydrology

Flow Change (RM)	Tributary/ Location Name	Return Period (years)							Maximum Average Winter Flow[2] (cfs)
		1	2	5	10	25	50	100	
4.9	Kellogg Creek	595	1,548	2,728	3,869	5,861	7,850	10,379	323
8.8	Smith Hollow[1]	552	1,435	2,528	3,585	5,431	7,275	9,619	300
12.4	Pataha Creek	532	1,383	2,437	3,457	5,237	7,014	9,275	289
14.9	Willow Creek	367	956	1,683	2,388	3,617	4,845	6,406	200
35.8	Tumalum Creek	367	954	1,573	2,231	3,327	4,418	5,799	199
38.1	Cummings Creek	348	906	1,474	2,090	3,106	4,117	5,411	189
48.3	Little Tucannon River	284	738	1,192	1,691	2,512	3332	4,367	154
50.4	Panjab Creek	267	694	1,109	1,574	2,334	3,094	4,058	152
55.14	Above Panjab	168	436	723	1,026	1,545	2,072	2,745	145

Notes:

1. For the purposes of modeling, the discharge downstream of Smith Hollow was assumed to be equivalent to the discharge at the Starbuck gage.
2. The highest monthly average flow during the months of January to May at the Starbuck gage.

One additional flow was used in the analyses, termed the “Low-Winter Flow” as shown in Table C-5. This flow was not based on a statistical analysis but rather is the flow that occurred during the LiDAR flight. The topobathymetric LiDAR was able to produce a water surface elevation raster that made modeling this flow unnecessary. This flow does not have an exact statistical relevance but is approximately the average flow for the late summer and early fall months.

Table C-5
Low Flow Information

Flow Designation	Data Source	Data Dates	Average Flow During Dates at Starbuck Gage	Approximate Statistical Flow[1]
Low-Winter Flow	2017 LiDAR Water Surface Raster	November 17–19, 2017	120 cfs	20% Exceedance Flow for November

References

BLM (Oregon Bureau of Land Management), 2009. Watershed Boundaries Oregon and Washington. GIS Shapefile.

CCD (Columbia Conservation District), 2004. *Tucannon Subbasin Plan.* Prepared for Northwest Power and Conservation Council. May 2004.

Hecht, B., R. Enkelboll, C. Ivor, and P. Baldwin, 1982. *Sediment transport, water quality, and changing bed conditions, Tucannon River, southeastern Washington*. Report prepared for the USDA Soil Conservation Service, Spokane, Washington, April 1982.

Madsen, H., P.F. Rasmussen, and D. Rosbjerg, 1997. "Comparison of annual maximum series and partial duration series methods for modeling extreme hydrologic events: 1. At-site modeling." *Water Resources Research* 33(4):747–757.

OSU (Oregon State University Climate Service), 2019. PRISM Climate Group. Available at: http://prism.oregonstate.edu. Map Created July 2019.

Thomas, B.E., H.W. Hjalmarson, and S.D. Waltemeyer, 1994. *Methods for estimating magnitude and frequency of floods in southwestern United States*. U.S. Geological Survey Open-File Report 93-419.

USGS (U.S. Geological Survey), 2001. Fact Sheet on Methods for Estimating Flood Magnitude and Frequency in Washington.

USGS, 2018a. Monitoring Location 13344500, Tucannon River Near Starbuck, Washington. Accessed November 2018. Available at: https://waterdata.usgs.gov/monitoring-location/13344500/.

USGS (U.S. Geological Survey), 2018b. Streamstats in Washington. Available at: http://water.usgs.gov/osw/streamstats/Washington.html.