Appendix G
Channel Complexity Analysis

Channel and floodplain complexity have been identified as major objectives for the Tucannon River, and complexity has increasingly been associated with juvenile salmonid rearing and overwintering, as well as benefits for many other aquatic species in the main report. Because of this multi-species and multi-lifestage benefit, it is important to examine a reach's complexity at several different flow levels—typically at lower, sustained flows (see Table G-1). For this assessment, river complexity refers to the geomorphic condition of multi-threaded or anastomosing channels, side channels, and split flow. Floodplain complexity is often characterized by small, dynamic channels that interact freely with the surrounding floodplain. While greater floodplain complexity typically results in a larger total water surface area, it is distinct from floodplain connectivity in that it examines individual flow paths separated by floodplain.

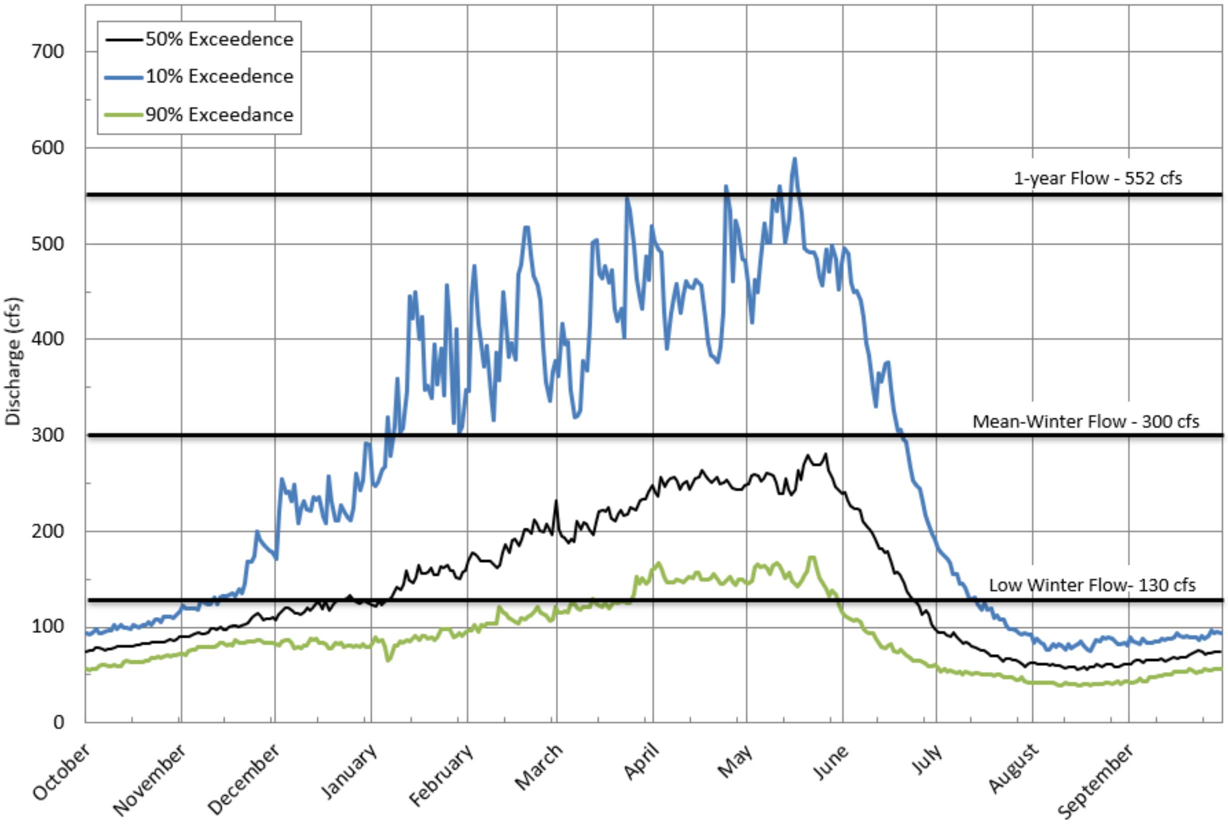
Table G-1
Flow Used for Examining Complexity

Flow Description	Data Source	Flow Rate at Starbuck
Low-Winter Flow	Water Surface DEM	130 cfs
Mean-Winter Flow	2D Hydraulic Model	300 cfs
1-year Flood Event	2D Hydraulic Model	552 cfs

cfs: cubic foot per second
DEM: Digital Elevation Model

Low-winter and mean-winter flows are sustained for longer periods of time and will therefore provide benefits to juvenile salmonid rearing habitat. The 1-year flow is episodic in nature, and complexity will most likely provide benefit in the form of high-velocity refugia. These three flows should represent a broad range of river conditions where habitat benefits from complexity are most relevant for juvenile salmonids as shown in Figure G-1.

Figure G-1
Complexity Flows and Hydrograph at the Starbuck Gage: 10%, 50%, and 90% Flows from 1971 to 2019



Analysis Overview

The concept for the Standardized Complexity Evaluation (SCE) discussed in this section was largely influenced by the River Complexity Index (RCI) shown in Equation G-1. RCI is a method of measuring complexity at bankfull flow proposed by (Brown 2002; Beechie et al. 2017; USFS 2012). The method takes the product of reach sinuosity and node density, a measure of channel connections in a reach. A more complete explanation of the RCI method can be found in “River Complexity Index (RCI): A Standard Method” (Buelow et al. 2017).

Equation G-1

$$RCI = S * (1 + D) = \left(\frac{Main\ Channel\ Length}{Valley\ Centerline\ Length}\right) * \left(1 + \frac{Number\ of\ Stream\ Nodes}{Valley\ Centerline\ Length}\right)$$

where:

RCI = River Complexity Index for a reach

S = sinuosity of the reach

D = node density of the reach

Note: RCI equation from "River Complexity Index (RCI): A Standard Method" (Buelow et al. 2017). Originally developed by Brown 2002.

The SCE developed in this analysis draws from the basic parameters of RCI by using the sinuosity of the reach and the number of islands in the reach, as shown in Figure G-2. For this assessment, RCI presents three problems that led to the development and use of the new method, SCE. First, the nodes described in the RCI method are difficult to capture and define using Light Detection and Ranging (LiDAR)-produced Digital Elevation Model (DEM) and Geographic Information Systems (GIS) data processing techniques. Second, RCI does not sufficiently capture the complexity gained through a single long side channel, as explained in more detail below. Finally, the RCI method presents no way to weight different complexity factors (sinuosity and node density).

In order to address the first problem, islands were counted instead of nodes. Because every pair of nodes represents an island, counting the number of islands per reach can be used as a scalable representation for node density, as shown in Figure G-2. Islands can be easily recognizable as distinct polygons in GIS applications, and statistics can be quickly generated on where and how big these islands are. Water surface polygons for the low-winter flow, mean-winter flow, and 1-year flow were generated using a two-dimensional (2D) HEC-RAS model and the direct outputs from the LiDAR water surface data. For a complete discussion on the modeling, see Appendix D of this report.

For this assessment, only islands that were greater than 12 meters in length were counted towards this metric to remove any short side channels or areas that form small mid-channel bars. The RCI method recommends choosing the bankfull width as the threshold for island length, and the SCE method used in this analysis follows that recommendation. The island length threshold of 12 meters was chosen based on an average wetted flow width at the 1-year flow event. It should be noted that, because islands were used instead of nodes, the complexity values produced by this analysis are not directly comparable to the RCI method. For more details on how island data are extracted from the dataset, see the Detailed Instructions for Performing this Analysis section below.

In order to more accurately represent a single long side channel in the SCE method, a third parameter was used to characterize complexity in addition to sinuosity and island density: island perimeter length. Through the analysis, it was observed that several reaches with long side channels were scoring more poorly in the Complexity analysis than expected from field observations when using only sinuosity and island density. While a single long side channel may not represent as much complexity as many smaller side channels and split flows, it does represent significantly more complexity than a confined single thread channel, as shown in Figure G-3. Therefore, the island perimeter length parameter was added into the calculation of complexity to account for these situations, as well as to provide a more complete and accurate view of complexity within the project area.

Figure G-2
Islands (using Standardized Complexity Evaluation) vs. Nodes (using River Complexity Index)

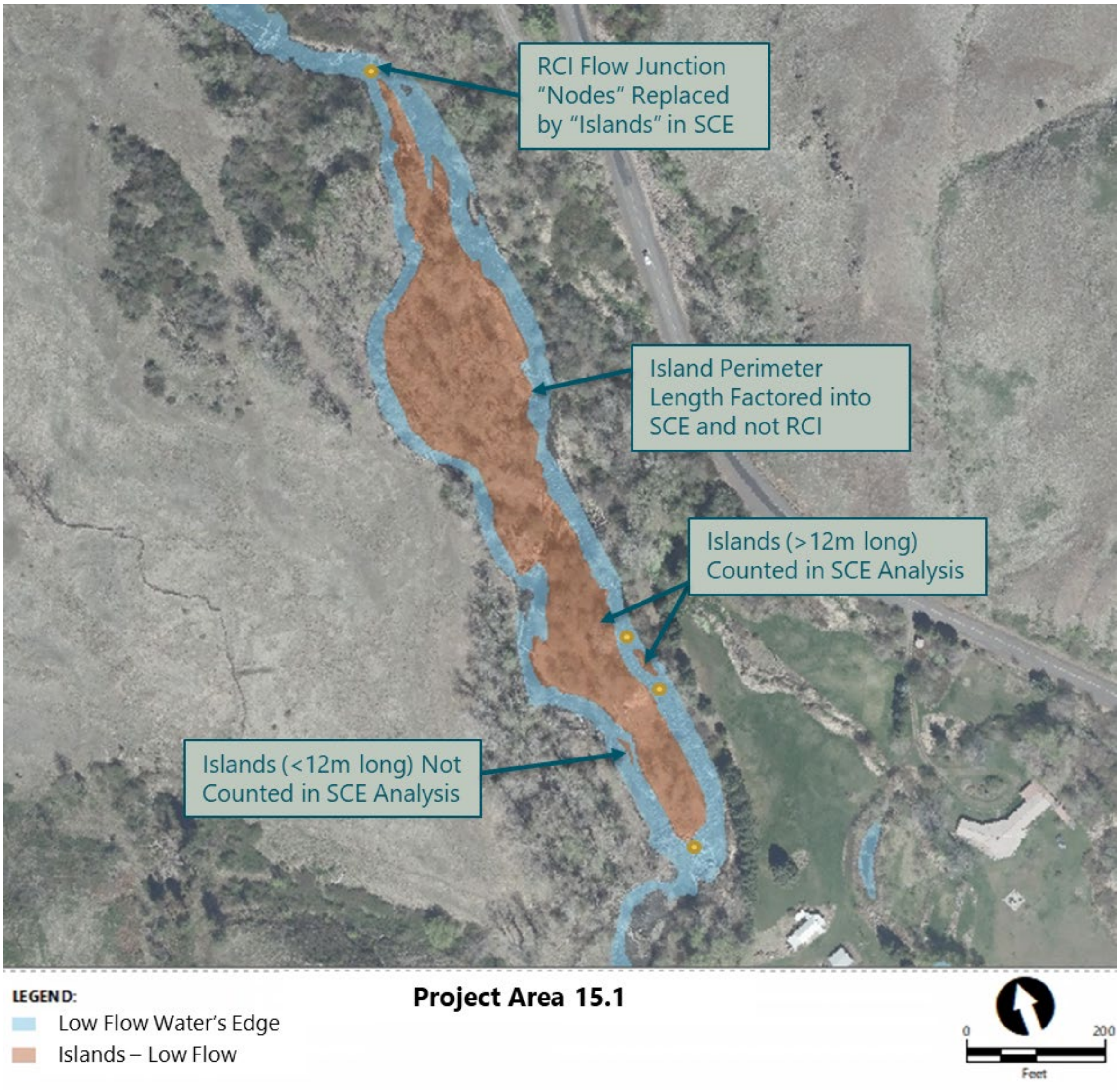
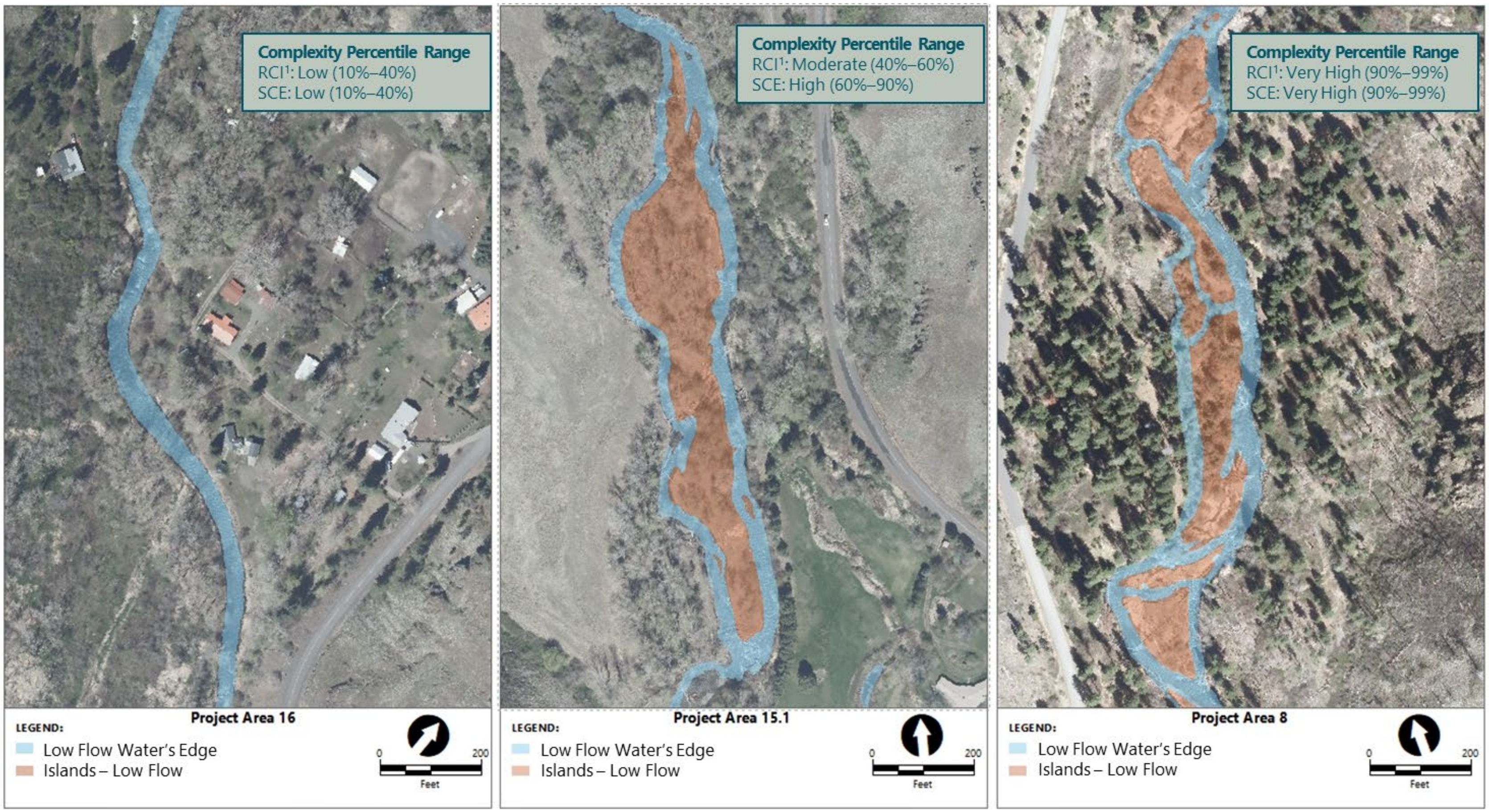


Figure G-3
Complexity Comparison



Note:

1. RCI values were standardized based on the same standardization techniques in SCE to obtain comparable values.

The complexity evaluation used in this analysis sums these three parameters, as shown in Equation G-2. In order to account for differing reach lengths, each parameter was divided by the length of the valley (already included in the calculation of sinuosity) and standardized such that the maximum value across all three flows examined was 1. The benefit of standardizing all three parameters allows for each parameter to be examined initially on an equal footing, without weighting any parameter without purpose. After the standardization, with the SCE it is then possible to choose weighting factors based on the perceived importance towards complexity.

Equation G-2

$$W_s(\mathrm{S}) + W_i(\mathrm{I}) + W_p(\mathrm{P}) = \text{Standardized Complexity Evaluation (SCE)}$$

where:

W_x = weighting factor for the given parameter

S = standardized sinuosity per project area

I = island count per valley length per project area, standardized across all three flows

P = island perimeter per valley length per project area, standardized across all three flows

The utility of this tool is that these factors can be weighted differently, and the amount of influence a specific factor has on the complexity evaluation can be changed based on a specific need. As shown in Equation G-2, each of these parameters was weighted based on perceived importance to the Tucannon River: 0.5 for island count, 0.4 for island perimeter, and 0.1 for sinuosity. Sinuosity in the Tucannon River basin has very little variation; even the river's most complex sections do not form large meander bends due to its tendency to quickly form side channels and cut off the meander bends. For this reason, the complexity in the Tucannon River basin is much more dependent on the number of flow paths and the size of side channels than the overall sinuosity, as demonstrated in Figure G-3.

It should be noted that, because of the way the complexity index is calculated, the resulting values are comparable only to other reaches in this analysis. Should this method be applied to other river systems, the resulting values would only be relative to that system. This method is not meant to compare complexity between river systems but rather to examine the complexity of a reach compared to other reaches within the system. Furthermore, the selection of these specific parameters and weighting factors is tailored to the Tucannon River system, its geomorphic processes, and unique history, and may need modification before applying to other systems.

Complexity Trends and Patterns

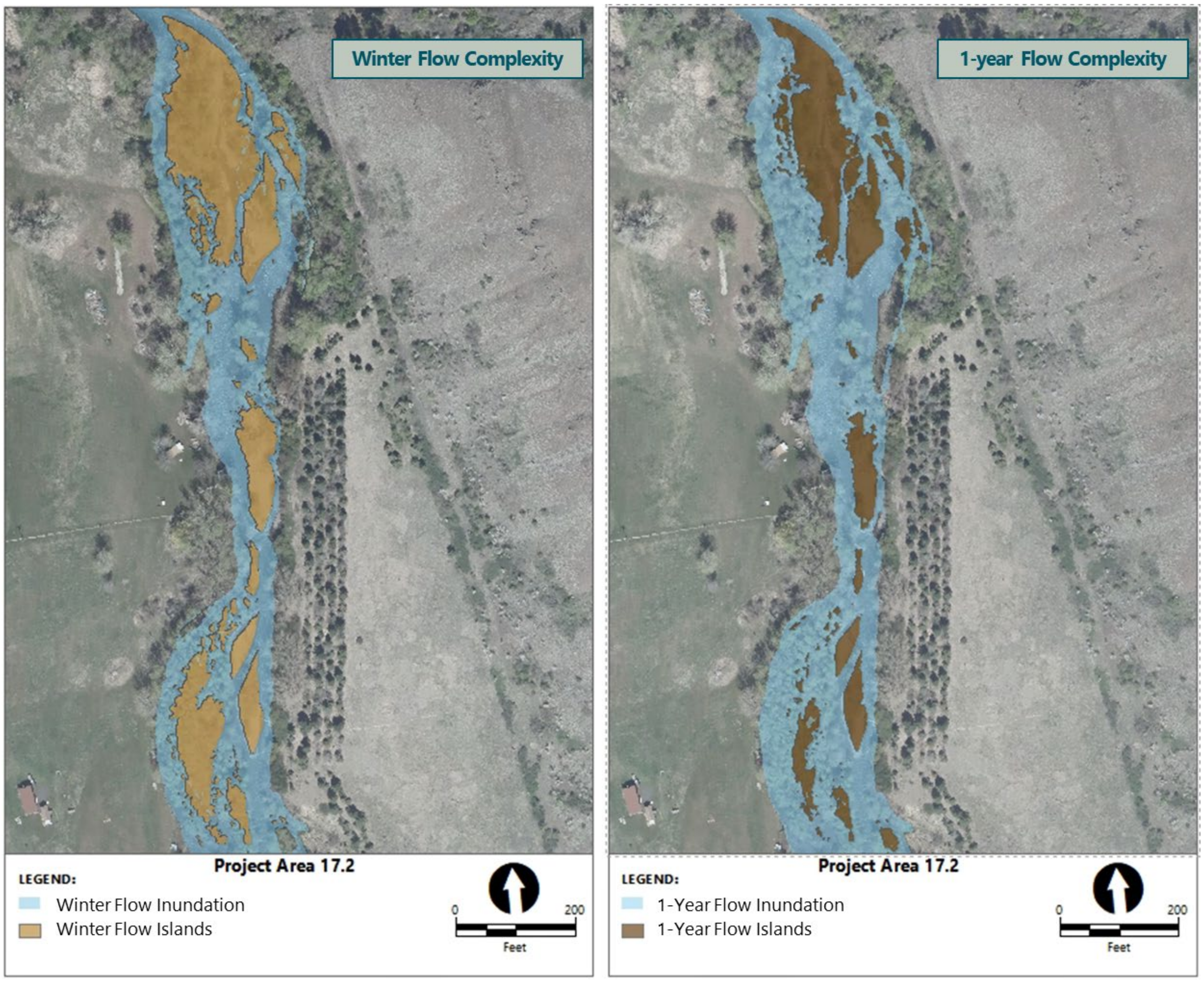
This section briefly describes some of the basin-wide trends and findings from the Complexity analysis. A more detailed breakdown of how this analysis applies to individual project areas is discussed in the Project Area Cut Sheets in Appendix J. This section references figures that are provided at the end of this appendix.

Unlike the floodplain connectivity analysis, river complexity shows few basin-wide trends and is more useful when examined on an individual basis in the assessment. Complexity at any of the three flows (low-winter flow, mean-winter flow, and 1-year flow), shown in Figure G-5, shows very little correlation with valley position, which is likely due to the fact that complexity is more dependent on localized geomorphic features such as instream wood and sediment size and availability.

As expected, most project areas show an increase in complexity as flows increase, likely due to more of the floodplain, and therefore higher flow side channels, becoming activated. However, there are a few exceptions that show a decreasing trend of complexity across flows. These exceptions are likely due to island size decreasing as flows rise, which decreases the total island perimeter length and possibly puts the island below the size class as shown in Figure G-4. The individual characteristics that make up the complexity score for each project area are shown in Figures G-6, G-7, and G-8.

Complexity does not show any strong correlations to the other metrics, although the low-winter flow complexity shows the most correlation (although a low r^2 of 0.2 to 0.3) with the 2-year connected area per valley mile (positive) and channel stream power and total stream power (negative). As described in Appendix H, stream power plays a large role in sediment transport dynamics, suggesting that complexity may be tied to the availability of sediments transported at the 2-year flow.

Figure G-4
Decreasing Complexity at Higher Flows



Scoring for Prioritization

In order to combine the SCE analysis results for the three flow levels into one complexity value to be used as a metric in the prioritization, weights were assigned to each SCE analysis result, which were then summed to produce the final metric value. Table G-2 provides the weights chosen to combine these results. The complexity weighting in Table G-2 favors the low-winter flow and mean-winter flow complexity values over the 1-year flow complexity results due primarily to the fact that the mean-winter and low-winter flows represent a significant portion of the hydrograph compared to the 1-year flow. While the high-flow refugia provided by the complexity at the 1-year flow is important, the mean-winter and low-winter flows better indicate habitat conditions as well as overall geomorphic processes.

Table G-2
Weighting SCE Analysis Results for Prioritization Metric

Complexity Metric Weighting	
SCE Analysis Result	**Percent Weight**
Low-Winter Flow Complexity	40%
Mean-Winter Flow Complexity	40%
1-year Flow Complexity	20%

The next step in the prioritization process is to rank, classify, and score each project area in each of the three metrics (Complexity, Connectivity, and Excess Transport Capacity). Project areas are ranked in the Complexity metric from best to worst by the scores determined using the weightings described in Table G-2. Each project area then has a rank for the Complexity metric and can be classified and scored according to the classification and scoring systems outlined in Table G-3.

This step is needed because the most benefit from restoration actions does not necessarily come from the projects that rank the highest. Because restoration work has been performed in this watershed for several years, some areas already have excellent complexity and rank the highest in that metric. But performing additional complexity-targeted restoration work on these areas would provide very little benefit. Therefore, through discussion with the basin stakeholders, it was decided that the classification and scoring system for complexity would not target the best or the worst ranked project areas in complexity but rather those with moderate complexity scores, as shown in Table G-3. This approach takes into account that the moderately complex reaches still have the opportunity to improve in complexity, but they are also not so homogenous that a great deal of restoration work would be required to raise the complexity. Table G-3 describes the concepts behind the classifications and scoring for complexity.

Table G-3
Complexity Classifications and Scoring

Percentile Rank	Class	Class Score	Metric Score Threshold[1]	Class Conceptualization
90th to Top	1	0	0.471	Project areas in this class are the most complex in the assessment area and therefore have very little additional complexity potential to be gained. Restoration efforts targeting complexity should focus instead on raising other project areas towards this level.
60th to 90th	2	3	0.206	Project areas in this class have moderately high complexity scores, such that restoration efforts should quickly achieve gains in the complexity of the reach pushing it towards the upper 10% of project areas. These project areas should be a secondary target for complexity-focused restoration efforts.
40th to 60th	3	5	0.177	Project areas in this class have the most potential for complexity gains and may currently be subpar for geomorphic processes and habitat conditions. The high potential in these areas means any effort will provide excellent benefit. These areas should be the primary target of complexity-focused restoration efforts in order to maximize benefit for effort.
10th to 40th	4	1	0.095	Complexity in project areas of this class falls below average for the assessment area, and complexity-focused restoration in these reaches should only be targeted after areas where it will be easier to maximize the benefit gained for the effort. These areas should be the last targeted for restoration focused on complexity.
Bottom to 10th	5	0	0	Project areas in this class are the least complex in the assessment area and would likely require a large amount of restoration effort to make only marginal gains in complexity. Restoration efforts for complexity should focus on areas with more easily achievable complexity.

Notes:

1. This is the score that defines the lower limit for the corresponding classification for this metric. These data can be used to track progression of project areas and compare to how they would rank according to the levels of this assessment, as new restoration projects are complete and new data become available.

Detailed Instructions for Performing this Analysis

Part of the purpose of this assessment is to define repeatable and data driven methods for assessing project areas and how they have progressed in relation to their goals. This section provides the detailed steps taken to perform the Complexity analysis of the Tucannon River so that these analyses can be repeated in the future for additional analyses and evaluation of progress. Table G-4 provides the data that will need to be collected to reassess the project areas for complexity.

Table G-4
Raw Data Needed to Perform SCE Analysis

Data Needed	Used For	Source
Topography Digital Elevation Model	2D hydraulic modeling	LiDAR, preferably blue-green and 0.5-meter horizontal accuracy or greater
Hydrology	Flows used in hydraulic modeling	Hydrologic gage data[3]
Water surface inundation boundaries[1]	Calculation of island count and island perimeters	2D hydraulic modeling results, or as a product of LiDAR flown at the desired flow[4]
River centerline	Calculation of sinuosity	Aerials or LiDAR
Valley centerline	Calculation of sinuosity, ICPVL[2], and PPVL[2]	Aerials or LiDAR
Project area delineations	Calculation of all metrics per project area	Project area shapefiles from this assessment

Notes:

1. Water surface boundaries should be for the flows desired for the analysis: in this assessment, 130 cfs, 300 cfs, and 552 cfs.
2. Island count per project area valley length (ICPVL) and perimeter per project area valley length (PPVL), as described below.
3. See Appendix C for a description of gage locations on the Tucannon River and methods used to interpret those data.
4. With blue-green LiDAR now commonly available, water surface shapefiles are easily produced with LiDAR flights. This has the effect of providing the necessary inundation information for whatever flow the LiDAR is collected. Ideally, in the future, LiDAR flights would be timed to approximately match one of the low-flow conditions described for complexity in this assessment (low-winter 130 cfs).

The following steps will assume the user has adequate GIS knowledge and access to the same data sources as those produced in this report.

1. This analysis uses three flow water surface inundation boundaries: the low-winter flow (130 cubic feet per second [cfs]), mean-winter flow (300 cfs), and 1-year flow (552 cfs). The low-winter flow water surface elevation raster was obtained directly from LiDAR survey information. The mean-winter flow and 1-year flows were obtained as a HEC-RAS 2D model output. See the main report and Appendices C and E for details on the hydrologic analysis and hydraulic modeling methods.
2. The water surface elevation rasters were imported into GIS as simple polygon shapefiles. These were manually reviewed and corrected for inconsistencies and differences from the conditions noted during field observations.

3. GIS was used to separate the void spaces of each flow polygon into their own polygon shapefile. These areas represent the islands for analysis.
4. The minimum bounding geometry was then calculated for each island. The island shapefiles were then filtered to include only islands with a minimum dimension of the minimum bounding geometry greater than 12 meters.
5. GIS was used to calculate the perimeter of each island as well as which project area each island occurs in. These figures are summed together for each project area, and from this the "island count per project area" and "perimeter sum per project area" seen in Table G-5 were calculated. Islands that span two project areas were counted as 0.5 island in each for the island count, and only the length of the perimeter that occurred in each project area was counted in the perimeter sum.
6. Both the river centerline and the valley center line were manually digitized from the aerial photographs and relative elevation maps. These were used to calculate the valley length and river length for each project area shown in Tables G-5 and G-6. Sinuosity was also calculated by dividing the river length by the valley length.
7. These three statistics form the basis for this analysis: island count per project area, island perimeter per project area, and sinuosity.
8. As shown in Tables G-5 and G-6, island count per project area and island perimeter per project area were divided by the valley length to standardize and obtain the island count per project area valley length (ICPVL) and perimeter per project area valley length (PPVL).
9. The ICPVL and PPVL were each standardized across all three flows by dividing by the largest value of the respective statistic (see Equation G-3). Sinuosity was also standardized to the largest value but is the same across all three flows. These three standardized statistics are shown for each project area in Tables G-5 and G-6.

Equation G-3

$$\text{Standarized CS } = \frac{CS_i}{CS_{\text{max}\,all\;flows}}$$

where:

CS = complexity statistic (either ICPVL or PPVL)

10. Finally, these three statistics were summed with weighting factors shown in Equation G-4. These provide the final SCE values shown in Tables G-5 and G-6. These SCE values are used in the final prioritization.

Equation G-4

$$W_s(\mathrm{S}) + W_i(\mathrm{I}) + W_p(\mathrm{P}) = \text{Standardized Complexity Evaluation (SCE)}$$

where:

W_s = 0.1: weighting factor chosen for the standardized sinuosity

W_i = 0.5: weighting factor for standardized ICPVL

W_p = 0.4: weighting factor for standardized PPVL

S = standardized sinuosity per project area

I = island count per valley length per project area, standardized across all three flows

P = island perimeter per valley length per project area, standardized across all three flows

References

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Tables

Figures