Modeling intrinsic potential for beaver (*Castor canadensis*) habitat to identify and prioritize suitable release sites in the Rogue River Basin

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Background

Beaver (*Castor canadensis*) are credited as ecosystem engineers because they can create dams, which change the timing, delivery, and storage of water, sediment, nutrients, and organic matter within a stream network (Macfarlane et al, 2017). This capability to affect streamflow has attracted riparian restoration practitioners to find ways to mimic, restore, or relocate beaver on the landscape, especially as climate-change threatens the predictability of stream flow patterns (Dittbrenner et al, 2018). It has been suggested that restoring beaver, and their dams to the landscape can help to enhance lateral and vertical connectivity of the stream channel to groundwater, floodplains, and adjacent uplands. These hydrological enhancements may benefit cold-water fisheries (Snodgrass & Meffe, 1998), like trout and salmon, which depend on cold water inputs to stream networks for cold-water refugia (Issak et al, 2015). Current restoration efforts with beaver focus on population recovery and beaver relocation from nuisance locations to areas where they can be used as a passive restoration tool on the landscape (Macfarlane et al, 2017) The question becomes, ***where should beaver be relocated as a restoration tool***?

To successfully relocate problem beaver in the Rogue Basin under the ODFW Beaver Relocation Requirements (ODFW, 2017), a list of suitable release sites should be compiled to lay the groundwork for a potential relocation *before* a problem-beaver relocation is needed. Locating suitable relocation sites may help restore beaver populations away from human conflict and restore hydrologic connectivity to benefit fish assemblages (Snodgrass & Meffe, 1998), including federally listed threatened Southern Oregon Northern California Coast (SONCC) coho salmon. Developing an assessment tool to model Beaver Intrinsic Potential (BIP) (Dittbrenner et al, 2018; Smith & Ory, 2016) can narrow down potential release sites in the basin based on intrinsic (i.e. difficult to change) topological factors like stream gradient, bankfull channel width, and valley width. These sites can then be narrowed by land ownership status, and ground-truthed for suitability, so surveyors can investigate and document site-specific characteristics like beaver presence, suitable instream habitat, and suitable forage availability (Halsey & Keasberry, 2018).

Introduction

Dittbrenner (2018) performed a review of studies that developed a variety of criteria to identify suitable areas for beaver needs, and outlined a BIP model workflow. Workflows to populated vector stream networks with topographic attributes derived from hydrologic raster information were adopted for developing data (Davies et al, 2007; Hall et al, 2007; Beechie & Imaki, 2014). The model criteria have been adapted based on currently available national data sources and other beaver suitability modeling efforts (Dittbrenner, 2018; Halsey and Keasberry, 2018).

The Rogue Basin Beaver Intrinsic Potential (BIP) model filters down potential release sites in the basin based on intrinsic (i.e. difficult to change) topological factors including stream gradient, bankfull channel width, and valley width. These sites can then be narrowed by land ownership status, and ground-truthed for suitability. This approach assumes that stream gradient is a predictor of stream channel morphology, and that all precipitation falling in the catchment flows through natural streams. The model does not consider land cover; therefore, it assumes that vegetation at all sites is equal and suitable to support beaver. The model is constrained by the quality and scale of input data sets.

The hypothesis of this model is that low gradient, narrower streams will have lower velocity flow that have potential to support beaver dams. Lower velocity stream flows reduce the possibility of dam blow out. Restoring beaver to low gradient streams are more likely to enhance lateral and vertical connectivity of the stream channel to groundwater, floodplains, and adjacent uplands, and may benefit fish assemblages.

Project Requirements

Data Requirements

Data from readily available, region-wide, open data sources are utilized. Since the Rogue Basin contains Oregon and portions of California, data must span the entire basin.

Table 1: Source data feeding intrinsic potential model.

Input Data	Description	Source
NHD Plus HD Hydrography & Rasters	10-meter 3D Elevation Program Digital Elevation Model (3DEP DEM), derivative products, waterbodies, watershed boundaries, and streams.	USGS National Hydrography Dataset Plus High Resolution (NHDPlus HR) for 4-digit Hydrologic Unit - 1710 (published 20181030), 10 m grid rasters, 1:24,000 scale vectors https://www.usgs.gov/core-science-systems/ngp/national-hydrography/nhdplus-high-resolution
Simplified Hydrography	Flowline without intermittent streams, disconnected segments, braids, and diverging flow. Used to validate drainage area calculation.	USDA & USFS Rocky Mountain Research Station, National Stream Internet (NSI). https://www.fs.fed.us/rm/boise/AWAE/projects/NationalStreamInternet.html
Precipitation	Mean annual precipitation in mm (intermediate variable) to derive bankfull width.	800 m gridded precipitation (mm) cells from PRISM http://prism.oregonstate.edu/normals/
Land Ownership	The USGS Protected Areas Database of the United States (PAD-US) is the nation's inventory of protected areas, including geographic boundaries of public land ownership (primarily Federal and State, local government data is incorporated with increasing frequency) and voluntarily provided private conservation lands (e.g., Nature Conservancy Preserves or land trust easements) from authoritative data sources.	U.S. Geological Survey, Gap Analysis Program (GAP). Published May 2016. Protected Areas Database of the United States (PAD-US), version 1.4 Combined Feature Class. https://gapanalysis.usgs.gov/padus/data/download/
Valley Confinement Algorithm	The Valley Confinement Algorithm (VCA) is a GIS based program that uses NHDPlus data to delineate unconfined valley bottoms. Valley confinement describes the degree to which bounding topographic features (such as hillslopes, alluvial fans, glacial moraines, and river terraces) limit the lateral extent of the valley floor and the floodplain along a river.	The algorithm uses nationally available digital elevation models (DEMs) at 10-30 m resolution to generate results at subbasin scales (8-digit hydrologic unit). User-defined parameters allow results to be tailored to specific applications and landscapes. https://www.fs.usda.gov/rmrs/projects/valley-confinement-algorithm-vca

	Valleys can be broadly classified as confined or unconfined, with corresponding differences.	

Geographic Coordinate System: GCS North American 1983
Projected Coordinate System: NAD 1983 UTM Zone 11N
Projection: Transverse Mercator

Metadata is updated and available for all source data sets.

Database Schema

The database structure of this model stems from the Arc Hydro data framework, which stored and managed all the National Hydrography Dataset (NHD) source datasets. Outputs for each Rogue Basin watershed are stored in a file geodatabase.

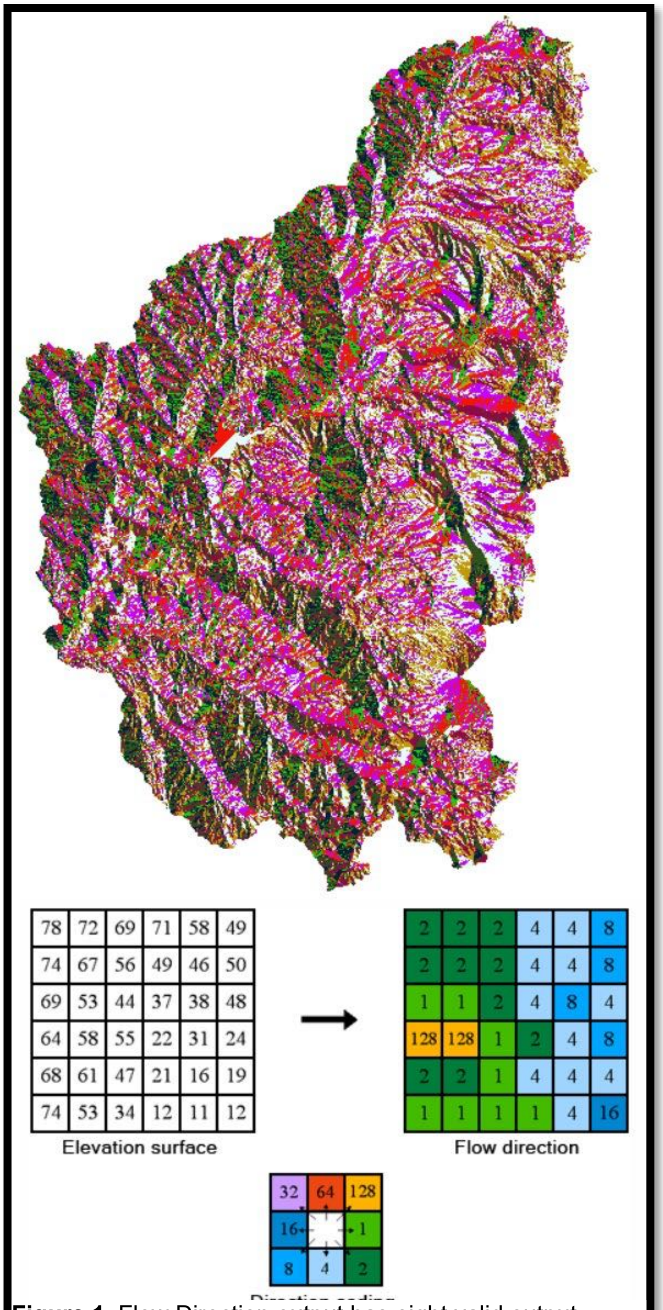
Methods

Tools

Arc Hydro toolbox 2.0.10 for ArcGIS Pro (http://downloads.esri.com/archydro/archydro/Setup/Pro) was utilized for the bulk of geoprocessing steps in the model. The purpose of Arc Hydro GIS for Water Resources is to “define a simple model that would simultaneously serve as the basic hydrology layer on a GIS and also serve water resource applications” (ESRI, 2002). The Arc Hydro toolbox was built jointly by ESRI and Center for Research in Water Resources of the University of Texas at Austin. The tools are intended to populate feature attributes in the data framework, relate features across data layers, and support hydrological analysis.

Hydrologic Modeling

1. Execute Flow Direction from the drainage-enforced DEM, which generates the flow direction grid where each cell indicates the direction of the steepest descent from that cell, 10m x 10m (Figure 1).
2. Execute Flow Accumulation, which computes the flow accumulation grid that contains the accumulated number of cells upstream of a cell, for each cell in the input flow direction grid (Figure



78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

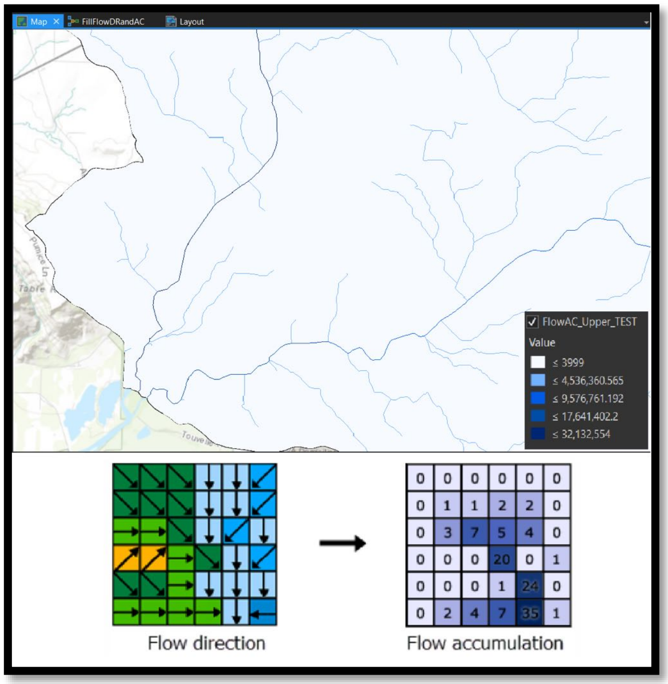
2	2	2	4	4	8
2	2	2	4	4	8
1	1	2	4	8	4
128	128	1	2	4	8
2	2	1	4	4	4
1	1	1	1	4	16

32	64	128
16		1
8	4	2

Figure 1: Flow Direction output has eight valid output directions relating to the eight adjacent cells into which flow could travel. This approach is commonly referred to as an eight-direction (D8) flow model. http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-flow-direction-works.htm

2). Davies et al (2007) states that this output represents the total number of cells that contribute runoff to any given cell in the grid. The input is the flow direction raster.

3. Execute Raster Calculator to determine drainage area (A, km^2) from flow accumulation output. Validate Drainage Area workflow with calculated dataset by comparing to the Simplified Hydrology Total Drainage Area (km^2) attributes.
4. Determine Average Annual Upstream Precipitation (P, cm) with Raster Calculator (Figure 3). Precipitation data was resampled from original 800 x 800 m grid to 10 x 10 m and then converted to centimeters to support the next calculation.
5. Calculate average annual upstream precipitation with Raster Calculator by dividing annual cumulative precipitation value (cm) by drainage area in each cell.



0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	1

Flow accumulation

Figure 2: Flow Accumulation tool "calculates accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster". http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-flow-accumulation-works.htm

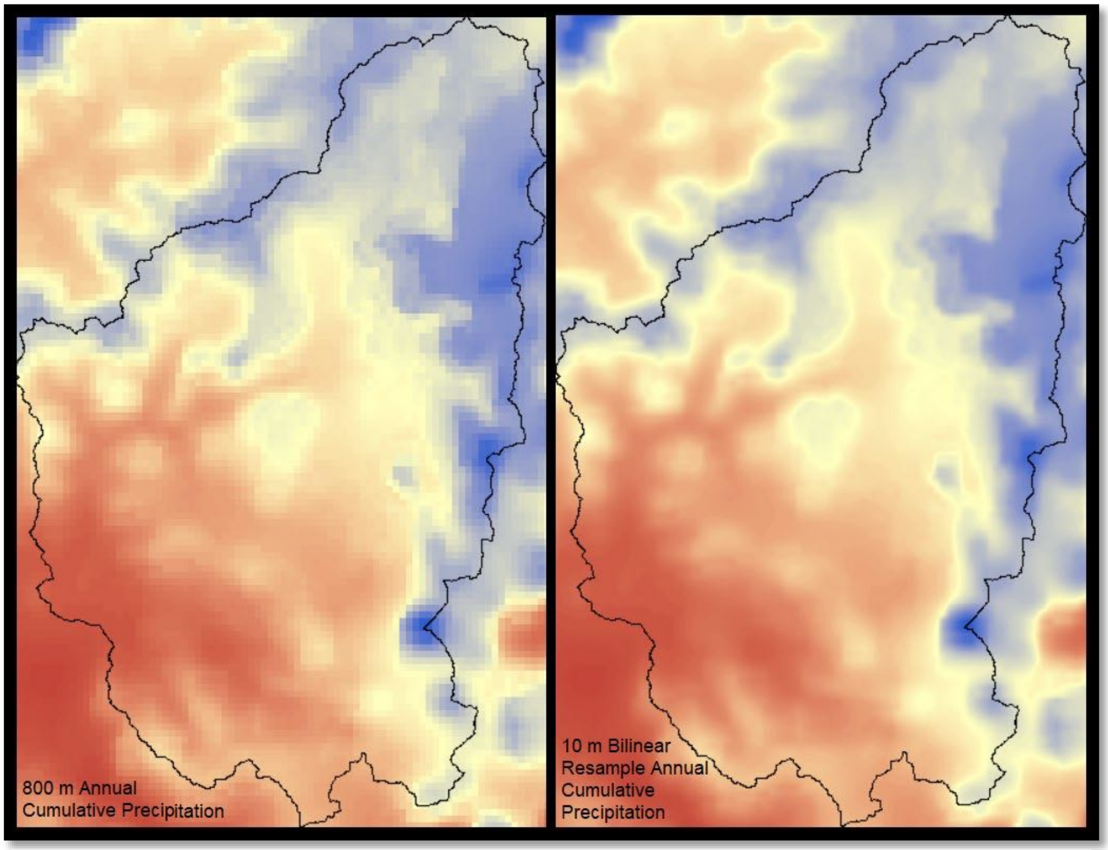


Figure 3: Bilinear resampling is useful for continuous data, like precipitation across the landscape, and will cause some smoothing of the data (http://pro.arcgis.com/en/pro-app/tool-reference/environment-settings/resampling-method.htm).

Model Development

6. Bankfull channel width (*w*, m) was estimated for each reach after Davies et al. (2007), Hall et al. (2007), and Beechie & Imake (2014), based on drainage area (A, km^2) and average upstream annual precipitation (P, cm) calculated during hydrologic modeling processes.

$$bankfull\ channel\ width\ (w) = 0.042(A^{0.48})(P^{0.74})$$

7. Valley Confinement Algorithm (VCA) by Nagel et al. (2014) was applied to NHD Plus HD HUC8 watersheds of Rogue Basin to serve as a surrogate measure for valley width (Figure 4). Value added attributes from the NHD Plus dataset were used to satisfy the tool's requirement for a cumulative drainage area attribute. Precipitation (cm) was calculated from PRISM 30-year data according the Nagel (2014).

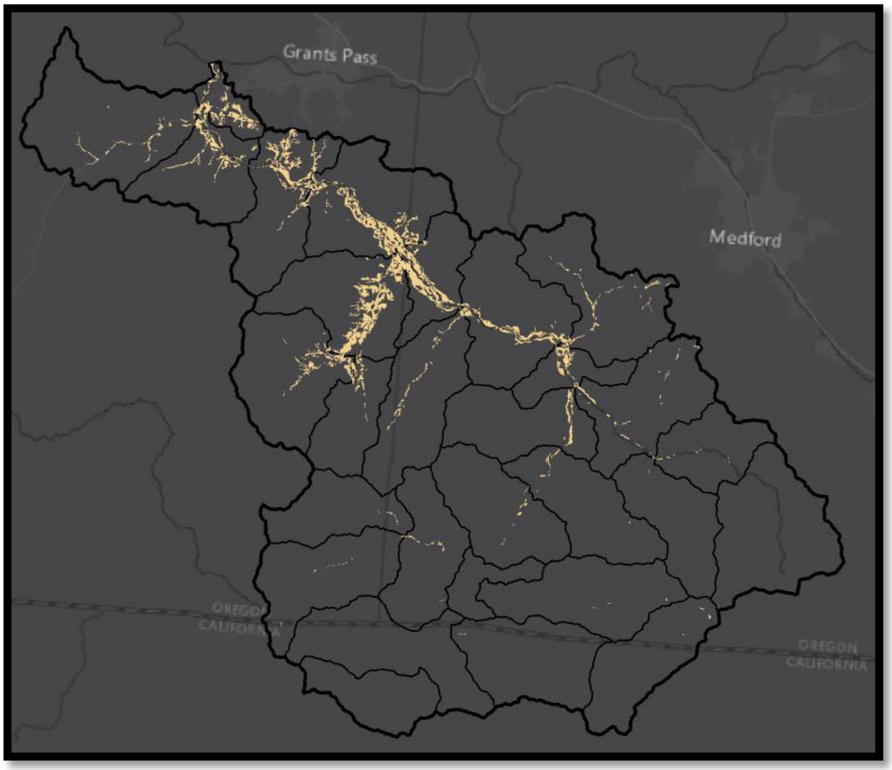


Figure 4: Unconfined valley delineated for the Applegate Watershed.

Attribute Transfer/Calculation

8. Stream vectors were split based on distance at 200 meters to facilitate topographic value extraction.
9. Values were extracted to the stream feature.
    i. Bankfull Width (w)
    ii. Gradient (g)
    iii. Unconfined Valley
10. Rankings were calculated using the criteria in Table 2.
11. Ditches, ephemeral streams, and piping classed hydrology features were ranked as zero, as requested by the project review team.

Table 2: Beaver Intrinsic Potential (BIP) model ranking criteria.

Appendix A

Stream Gradient	Rank
< 1%	4
< 2%	3
< 4%	2
< 6%	1
< 10%	0.5
> 10%	0

+

Bankfull Width	Rank
< 7 m	4
< 10 m	3
< 18 m	2
< 24 m	1
> 24 m	0

+

Unconfined Valley
2

=

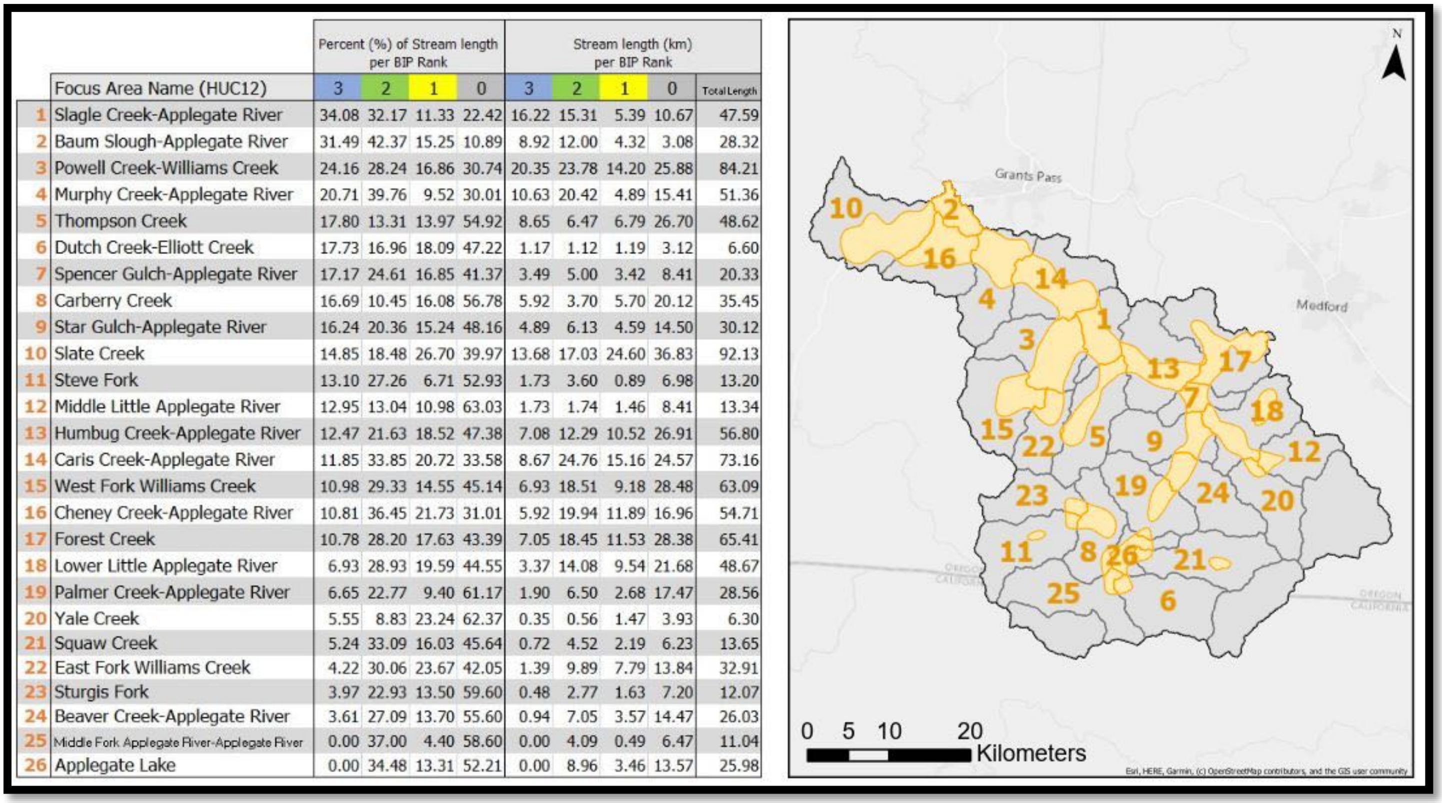
Cumulative rank	Intrinsic Potential (IP) Rank
9 - 10	3
7 - 8	2
5 - 6.5	1
> 5	0

=

Beaver IP Rank	
3	**High**
2	**Medium**
1	**Low**
0	**No**

Density Analysis

During the model review process, project reviewers identified a need to develop focus areas to help guide field validation and clusters of highly ranked steam segments. A density analysis was developed by performing kernel density analysis with weighted stream BIP ranking for each watershed in the Rogue Basin. The output was transformed and converted to a polygon divided into focus areas by sub-watershed(Figure 5).



		Percent (%) of Stream length per BIP Rank				Stream length (km) per BIP Rank				
	Focus Area Name (HUC12)	3	2	1	0	3	2	1	0	Total Length
1	Slagle Creek-Applegate River	34.08	32.17	11.33	22.42	16.22	15.31	5.39	10.67	47.59
2	Baum Slough-Applegate River	31.49	42.37	15.25	10.89	8.92	12.00	4.32	3.08	28.32
3	Powell Creek-Williams Creek	24.16	28.24	16.86	30.74	20.35	23.78	14.20	25.88	84.21
4	Murphy Creek-Applegate River	20.71	39.76	9.52	30.01	10.63	20.42	4.89	15.41	51.36
5	Thompson Creek	17.80	13.31	13.97	54.92	8.65	6.47	6.79	26.70	48.62
6	Dutch Creek-Elliott Creek	17.73	16.96	18.09	47.22	1.17	1.12	1.19	3.12	6.60
7	Spencer Gulch-Applegate River	17.17	24.61	16.85	41.37	3.49	5.00	3.42	8.41	20.33
8	Carberry Creek	16.69	10.45	16.08	56.78	5.92	3.70	5.70	20.12	35.45
9	Star Gulch-Applegate River	16.24	20.36	15.24	48.16	4.89	6.13	4.59	14.50	30.12
10	Slate Creek	14.85	18.48	26.70	39.97	13.68	17.03	24.60	36.83	92.13
11	Steve Fork	13.10	27.26	6.71	52.93	1.73	3.60	0.89	6.98	13.20
12	Middle Little Applegate River	12.95	13.04	10.98	63.03	1.73	1.74	1.46	8.41	13.34
13	Humbug Creek-Applegate River	12.47	21.63	18.52	47.38	7.08	12.29	10.52	26.91	56.80
14	Caris Creek-Applegate River	11.85	33.85	20.72	33.58	8.67	24.76	15.16	24.57	73.16
15	West Fork Williams Creek	10.98	29.33	14.55	45.14	6.93	18.51	9.18	28.48	63.09
16	Cheney Creek-Applegate River	10.81	36.45	21.73	31.01	5.92	19.94	11.89	16.96	54.71
17	Forest Creek	10.78	28.20	17.63	43.39	7.05	18.45	11.53	28.38	65.41
18	Lower Little Applegate River	6.93	28.93	19.59	44.55	3.37	14.08	9.54	21.68	48.67
19	Palmer Creek-Applegate River	6.65	22.77	9.40	61.17	1.90	6.50	2.68	17.47	28.56
20	Yale Creek	5.55	8.83	23.24	62.37	0.35	0.56	1.47	3.93	6.30
21	Squaw Creek	5.24	33.09	16.03	45.64	0.72	4.52	2.19	6.23	13.65
22	East Fork Williams Creek	4.22	30.06	23.67	42.05	1.39	9.89	7.79	13.84	32.91
23	Sturgis Fork	3.97	22.93	13.50	59.60	0.48	2.77	1.63	7.20	12.07
24	Beaver Creek-Applegate River	3.61	27.09	13.70	55.60	0.94	7.05	3.57	14.47	26.03
25	Middle Fork Applegate River-Applegate River	0.00	37.00	4.40	58.60	0.00	4.09	0.49	6.47	11.04
26	Applegate Lake	0.00	34.48	13.31	52.21	0.00	8.96	3.46	13.57	25.98

Figure 5: BIP focus areas are highlighted in orange and are ranked according to the percent (%) of stream length within the focus area categorized as having high beaver intrinsic potential (BIP = 3).

Data Output

The results are 200-meter segments of high-resolution NHD Flowline streams and associated attributes. Figure 6 shows that higher ranked stream segments are more likely to be in the valley or already near a body of water. The results provide restoration practitioners with landscape-scale analyses to support suitable locations to restore beaver. Ranked stream segments can be field validated, beaver presence or other habitat suitability factors assessed, and discussed further among stakeholders with intimate knowledge of ranked local streams.

Appendix A

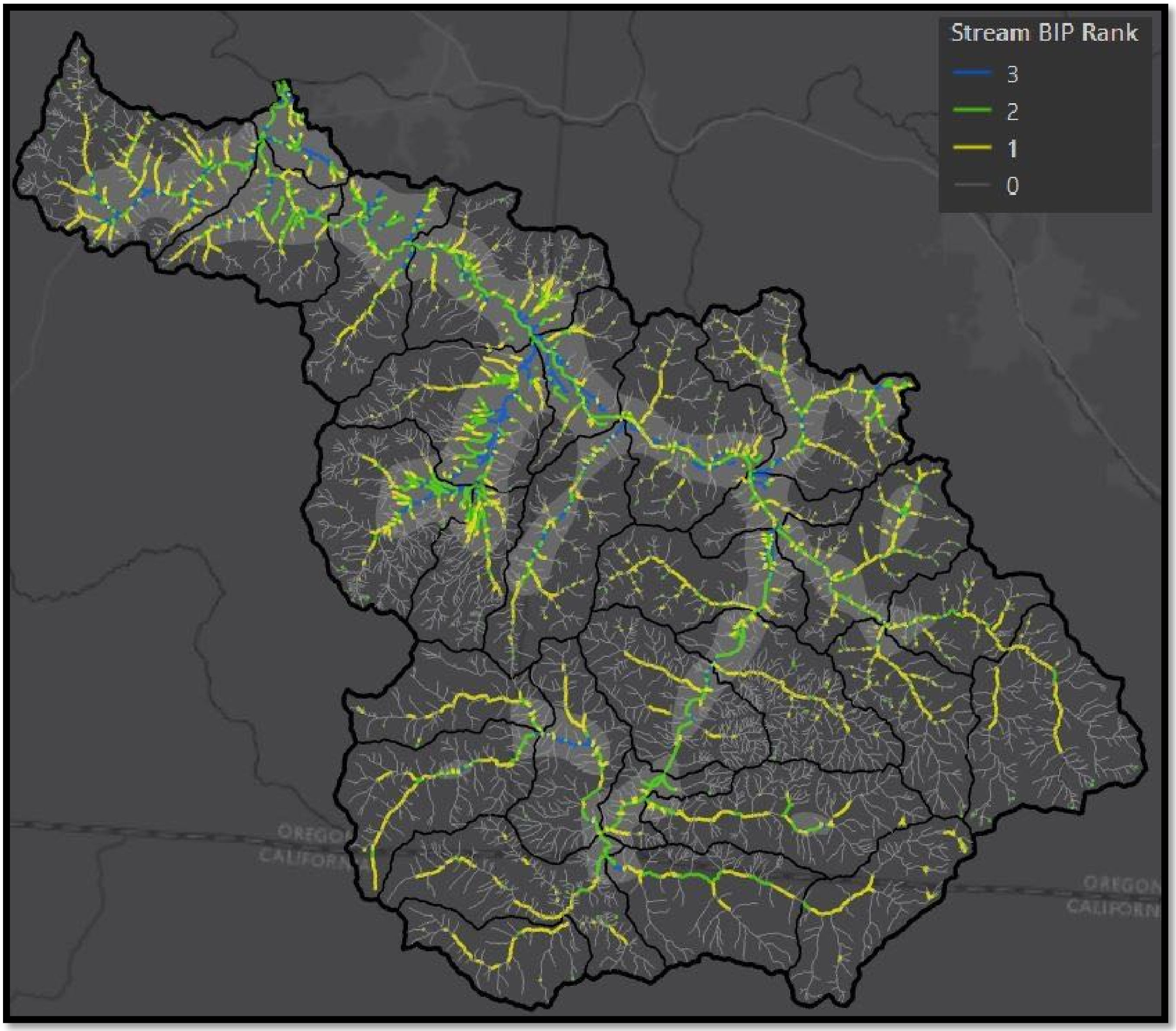


Figure 6: BIP cumulative ranking results reveal, as expected, that low gradient, wider streams tend to be located in valleys or near existing ponds and lakes.

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Appendix A

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