JOHN DAY BASIN BEAVER RESTORATION ASSESSMENT TOOL

BUILDING REALISTIC EXPECTATIONS FOR PARTNERING WITH BEAVER IN RESTORATION & CONSERVATION

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EXECUTIVE SUMMARY

This report presents an application of the Beaver Restoration Assessment Tool 3.0.20 (BRAT; http://brat.riverscapes.xyz/) a tool for building realistic expectations for partnering with beaver in conservation and restoration (Macfarlane et al., 2017). In this application, we analyzed all the perennial rivers and streams within the John Day basin (6-digit USGS Hydrologic Unit Code (HUC 6)). The John Day basin was subset into four smaller watersheds for running the BRAT model: Lower John Day, Middle Fork John Day, North Fork John Day, and Upper John Day watersheds (8-digit USGS Hydrologic Unit Code (HUC 8)).

The backbone to BRAT is a capacity model developed to assess the upper limits of riverscapes to support beaver dam-building activities. It outputs an estimated density of dams (i.e. dams per length of stream) and a rough count of an upper limit (i.e. capacity) of how many dams the conditions in and surrounding a reach could support. Both existing and historic capacity were estimated using readily available spatial datasets to evaluate seven lines of evidence: (1) a reliable water source; (2) stream bank vegetation conducive to foraging and dam building; (3) vegetation within 100 m of edge of stream to support expansion of dam complexes and maintain large beaver colonies; (4) likelihood that dams could be built across the channel during low flows; (5) the likelihood that a beaver dam on a river or stream is capable of withstanding typical floods; (6) evidence of suitable stream gradient; and (7) evidence that river is too large to allow dams to be built and to persist. Fuzzy inference systems were used to combine these lines of evidence while accounting for categorical ambiguity and uncertainty in the continuous inputs driving the models. The existing model estimate of capacity was driven with LANDFIRE 30 m resolution vegetation data from 2014, whereas the 'historic' estimate represents a pre-European settlement model of vegetation, also from LANDFIRE.

The estimated existing John Day basin (HUC 6) capacity is 120,945 dams or roughly 11 dams/km. By contrast, the same model driven with estimates of historic vegetation types estimated the John Day basin -wide capacity at 169,781 dams or roughly 15 dams/km reflecting a 29% loss compared to historic capacity. Comparison of the individual HUC 8 within the John Day basin are illustrated in Table 1.

Nearly all of the capacity loss from historic conditions can be explained in terms of riparian vegetation loss, vegetation conversion and degradation associated with high intensity land use including: 1) conversion of valley bottoms to urban and agricultural land uses, 2) overgrazing in riparian and upland areas, 3) conifer encroachment of wet meadow areas. Despite the losses in beaver dam capacity, John Day basin's waterways are still capable of supporting and sustaining a substantial amount of beaver dam-building activity (120,945 dams).

Table 1: Estimated existing and historic capacity for the Lower John Day, Middle Fork John Day, North Fork John Day, Upper John Day (HUC 8 watersheds), and the John Day basin (HUC 6

	Existing Capacity			Historic Capacity		
Category	**Estimated Dam Capacity**	**Estimated Dams/km total**		**Estimated Existing Dams/km total**	**Estimated Historic Dams/km total**	**% Loss**
Lower John Day	19,781	7		28,540	10	31%
Middle Fork John Day	16,929	11		22,661	15	25%
North Fork John Day	51,241	14		69,097	20	26%
Upper John Day	32,994	10		49,483	15	33%
John Day	120,945	11		169,781	15	29%

Identifying these losses in beaver dam capacity incentivizes plans for restoration and conservation opportunities to be considered. To aid groups in their decisions and what possible risks may arise the BRAT model supplies the following management outputs: 1) potential risk areas, 2) unsuitable or limited dam building opportunities, and 3) conservation and restoration opportunities. As such, the BRAT model identifies where streams are relative to human infrastructure and high intensity land use, and conservatively shows how that aligns with where beaver could build dams.

The existing capacity model was verified in the Middle Fork John Day using only one beaver dam, North Fork John Day using only two dams, and the Upper John Day using 9 dams. In these watersheds we found that model performance was good, with electivity indices that effectively segregated out amongst the capacity categories. The existing capacity model was also verified in the Lower John Day watershed using 281 actual dam locations, concentrated in Bridge Creek. These dams helped identify a known limitation of 30 m vegetation data – that it struggles to capture narrow riparian vegetation corridors especially in deeply incised streams such as Bridge Creek (Macfarlane et al., 2017a). In this setting, higher resolution vegetation data or on-the-ground data collection will be required to effectively capture the riparian vegetation present and thus effectively capture beaver dam capacity. The extensive and on-going (as of February 2019) field-based dam collection campaign by North Fork John Day Watershed Council staff and others will further validate the existing capacity model.

The spatially explicit outputs from this application of BRAT provides stakeholders with the information needed to understand patterns of beaver dam capacity, potential risks to human infrastructure, as well as constraints and opportunities for using beaver in restoration and conservation. Not only does this information help with broad-scale planning efforts, but the resolution is sufficient to support design and on- the-ground implementation of conservation and restoration activities.

INTRODUCTION

The current scope of stream and riparian degradation in the western U.S. is enormous (Paulsen et al., 2006). Even with more than $10 billion spent annually, these traditional restoration efforts are barely scratching the surface of what could be restored. Moreover, a disproportionate amount of money is spent on too few miles of streams and rivers leaving millions of miles of degraded streams neglected. To fill this gap, restoration practitioners are increasingly trying restoration techniques that are more cost-effective, less intensive, and can more practically scale up to the scope of degradation (Silverman et al., 2018).

Conservation and restoration involving beaver is not new. For example, in fall 1948, 76 live nuisance beaver were parachuted into the Frank Church Wilderness of Idaho with only one fatality (Heter, 1950). Partnering with beaver, without parachutes, is now broadly appreciated as an effective low-tech riparian and wet meadow restoration technique. This appreciation stems from beavers long recognized status as ‘ecosystem engineers’ (Wright et al., 2002) with the capability of restoring streams, rivers and wetlands to the benefit of numerous upland, riparian and aquatic flora and fauna (Naiman et al., 1986). Beaver dam-building activities lead to a cascade of hydrologic, geomorphic, and ecological feedbacks that increase stream complexity and benefit aquatic and terrestrial biota (Rosell et al., 2005). Dam complexes increase system roughness and resilience, increase groundwater recharge and elevate water tables, create ponds, wetlands and critical habitat for fish, amphibians, small mammals, and vegetation. Beaver dams expand riparian areas, change timing, delivery and storage or water, sediment and nutrients (Bird et al., 2011). As a result, beaver are increasingly being used as a key component of stream restoration strategies (e.g. Curran and Cannatelli, 2014). Using beaver dam building as a restoration agent actually produced a population level increase in density, survival and production of ESA listed salmon (Bouwes et al., 2016); (Pollock et al., 2014).

Nevertheless, until the development of the Beaver Restoration Assessment Tool (BRAT) (Macfarlane et al., 2017), predictive spatial models resolving where beaver dams within a drainage network can be built and sustained have been lacking. In summary, dam building beaver need water and wood. The type and extent of wood/vegetation matters most to predict dam building capacity. While the flow regime acts to potentially limit dam capacity. Existing dam capacity estimates where and to what extent beaver can build dams now. Or in other words, how many beaver dams could a particular stream reach support? Dam building capacity is reported as number of dams per mile (or km). Historic capacity estimates where and to what extent beaver could build dams historically. Also, lacking until the development of BRAT was a model that identifies places where beaver might build dams that could be in direct conflict with land uses and management priorities (e.g., damming of culverts or irrigation canals and flooding of roads or railroads).

Currently there is massive enthusiasm to use beaver as a restoration strategy as well as a growing need to constructively temper this enthusiasm. As such, BRAT was developed to provide more realistic expectation management for using beaver as a restoration agent and serves as a planning tool intended to help resource managers, restoration practitioners, wildlife biologists and researchers better manage expectations about where beaver might be useful. Specifically, BRAT is a spatially explicit network tool that predicts where along streams and rivers beaver may be useful as a restoration tool and where they may be a nuisance, in which case their impacts can be mitigated or the nuisance beaver can serve as a source population for live-trapping and relocation to areas where they can help achieve other management objectives. The model has been run for the entire state of Utah (Macfarlane et al., 2017) and is currently used by the Utah Division of Wildlife Resources to help manage their beaver populations, carry out habitat restoration and implement their beaver management plan. We are currently (FY19) running BRAT for the entire state of Idaho and large portions of Wyoming, Oregon and California.

BRAT is a tool for imaging what is possible. As (Goldfarb, 2018; page 237) elegantly states, “Although BRAT’s primary value is technical, it is, too, an achievement of the imagination, a method for visualizing the magnificently ponded world that predated European trapping — a time machine to the Castorocene”. The BRAT capacity model outputs ‘paint’ a vision of what watersheds once were, and what they could be if beaver were allowed to return. BRAT provides a vision for what's possible and how partnering with beaver can help increase the resilience of watersheds to drought, fire, and climate change (Silverman et al., 2018). BRAT can be used for planning and outreach, expectation management, and conservation and restoration prioritization.

This project focused geographically on the John Day basin (HUC 6) and project deliverables will be used as a tool for managing dam-building beaver. The three main objectives of the project were to:

1. Run BRAT for the John Day basin (HUC 6);
2. Validate BRAT using field and Google Earth reconnaissance; and
3. Synthesize findings from BRAT into recommendations for beaver management.

This report's **primary purpose is to document the fulfillment of these three objectives** and explain how the analyses and tools presented can assist in the management of dam-building beaver populations across the John Day basin.

METHODS

BRAT - Beaver dam capacity model

Beaver dams, not beaver themselves, provide the impacts to the geomorphology of the streams that we seek. As such, the BRAT model estimates beaver dam capacity not beaver habitat. While beaver can survive in wide range of conditions, where they build dams is more limited. Dam building activity varies dramatically according to flow regime and availability of dam building materials. Thus, BRAT's backbone is a capacity model developed to assess the upper limits of riverscapes to support beaver dam-building activities. Our estimates of beaver dam capacity come from seven lines of evidence: (1) a reliable water source; (2) stream bank vegetation conducive to foraging and dam building; (3) vegetation within 100 m of edge of stream to support expansion of dam complexes and maintain large beaver colonies; (4) likelihood that dams could be built across the channel during low flows; (5) the likelihood that a beaver dam on a river or stream is capable of withstanding typical floods; (6) evidence of suitable stream gradient; and (7) evidence that river is too large to allow dams to be built and to persist.

The four primary questions that the BRAT capacity model asks:

1. Is their enough water present to maintain a pond?
2. Are enough and the right types of woody resources present to support dam building?
3. Can beaver build a dam at base flows?
4. Are dams likely to withstand typical floods?

With the BRAT model, we approximate quantitative answers to these questions with GIS data. For this application, we used the following publicly available datasets of national extent (Table 1) that provide direct approximations for these lines of evidence based largely on remotely-sensed imagery and regionally-derived empirical relationships. While we fully recognize that higher resolution inputs with greater accuracy and fidelity could result in more precise model outputs, such higher resolution data are not freely available and as such we use freely and broadly available datasets of coarser resolution with the belief that these datasets will provide useful estimates.

Table 2: Input data used to represent the lines of evidence of the John Day basin BRAT beaver dam capacity model.

Input Data	Criteria	Source
Streams and rivers	Perennial water	USGS National Hydrography Dataset http://nhd.usgs.gov/
LANDFIRE 2014 (EVT and BPS)	Riparian vegetation	LANDFIRE land cover data http://www.landfire.gov/
USGS baseflow equations	Dam could be built	http://pubs.usgs.gov/sir/2012/5078/
USGS 2-year peak flow equations	Dam could withstand floods	https://pubs.usgs.gov/sir/2008/5126/index.html
10 m DEM	Evidence of stream gradient	USDA NRCS Geospatial Data Gateway http://datagateway.nrcs.usda.gov/

The beaver dam capacity model is described thoroughly in Macfarlane et al. (2017), and online documentation describing how to run the model is available at http://brat.riverscapes.xyz/. Therefore, in this report, we only briefly describe the capacity model. Our capacity model estimates the capacity of riverscapes to support dam-building activity by approximating the maximum number of dams that can be sustained, based on vegetation resources and typical stream flows. Model outputs are calibrated to a range of dam densities found in nature and reported in the literature, which locally can be as high as 40 dams per km, or roughly one dam every 25 m. These high densities are only found where multiple colonies maintain large dam complexes, which vary from 3 to 15 dams each (Gurnell, 1998). We express the model output in dams per kilometer because a) it is directly comparable to densities that can be calculated in GIS from field GPS measurements, b) densities can also be approximated with aerial imagery and/or overflights, and c) linear dam density is commonly reported in the literature so there are valid estimates for direct comparison. The output categories are as follows:

- None – 0 dams: *segments deemed not capable of supporting dam building activity*
- Rare – > 0-1 dam/km: *segments barely capable of supporting dam building activity; likely used by dispersing beaver*
- Occasional – > 1-5 dams/km: *segments that are not ideal, but can support an occasional dam or small colony*
- Frequent – > 5-15 dams/km: *segments that can support multiple colonies and dam complexes, but may be slightly resource limited*
- Pervasive – > 15-40 dams/km: *segments that can support extensive dam complexes and many colonies.*

To assess evidence of a stream within a network being a reliable water source for dam-building beaver we use the National Hydrography Dataset (NHD) cartographically derived 1:24 000 drainage network. The NHD network differentiates between perennial, intermittent, and ephemeral watercourses. We use the perennial designation segmented into 300 m long segments because a) this is a reasonable length over which to approximate reach-averaged slope from a 10 m DEM, and b) 300 m segments produce a reasonable length along which to sample 30 m LANDFIRE vegetation data within buffers and get a representative sample.

To assess beaver forage and building material preferences, we classify LANDFIRE EVT 2014 (first made available in 2016), a nationwide 30 m Landsat satellite imagery-based landcover classification (LANDFIRE, 2014), into beaver dam-building material preference categories. Based on these preferences, we assign a single numeric suitability value from 0-4 to each of the land cover classes, with zero representing unsuitable food/building material and four representing preferred food and building material. The result is a look-up table of LANDFIRE land cover classes and associated beaver preference values that is applied to raster data on a cell-by-cell basis.

Riverscapes with narrow riparian corridors limit beaver dam construction opportunities relative to those with expansive riparian areas and/or adjacent deciduous forests with preferred woody browse (e.g. aspen). To represent this important distinction, we generate two buffers along the drainage network in which we assessed beaver dam-building preference values:

- A 30 m buffer representing the streamside vegetation; and
- A 100 m buffer representing the maximum harvest distance (Figure 1).

We based these buffer distances on documented distances from water that beaver typically travel to harvest woody stems for dam and lodge construction, and winter food caches. Many studies indicate that most of the woody species utilized by beaver occur within 30 m of the edge of water and that a majority of foraging occurs within 100 m.

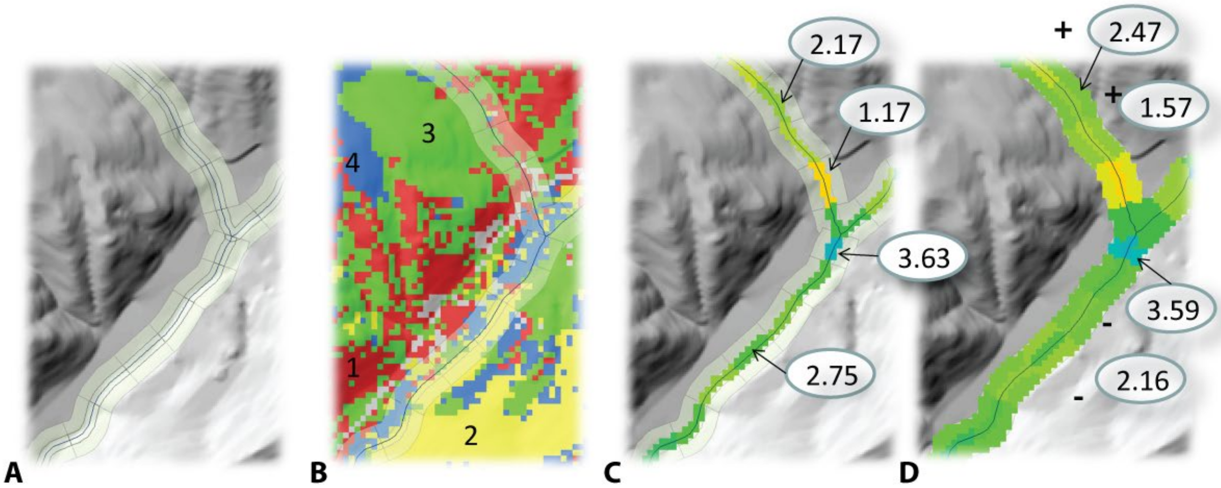

Figure 1: Reach scale illustration of derivation of streamside vs. riparian vegetation scores from 30 vs. 100 m stream network buffers. A shows the 30 m and 100 m buffers, which we used to summarize intersecting pixels from 30 m resolution classified LANDFIRE raster in B. Dam building suitability are shown in B and range from 0 (unsuitable; grey) to 4 (optimal; blue) with red for 1, yellow for 2, and green for 3. C & D contrast the buffer averaged values for the 30 m buffer (C) and the 100 m buffer (D).

To infer whether it is likely that beaver could physically build a dam during low-flow conditions, we calculate stream power ($\Omega = \rho g Q S$) at baseflow.

Where Ω is the stream power (in Watts), ρ is the density of water (1000 kg/m3), g is acceleration due to gravity (9.8 m/s2), Q is discharge (m3/s), and S is the channel slope.

To infer the likelihood that a beaver dam will persist once built, the two-year recurrence interval peak flood (Q_2) stream power is calculated for each reach based on drainage area and USGS regional curves. To calculate reach slope we use the NHD network segmented into 300 m long reaches and extract elevations at top and bottom of each reach based on the DEM and divide by reach length. The two slope values that matter for the BRAT capacity model are < 0.5 percent slope because dam density goes down in very flat areas and > 23% slope because dams cannot be built and sustained in very steep reaches. All seven lines of evidence (described above) are combined within a fuzzy inference system (FIS) to estimate the maximum beaver dam density (dams/km) of riverscapes (Figure 2 and Figure 3).

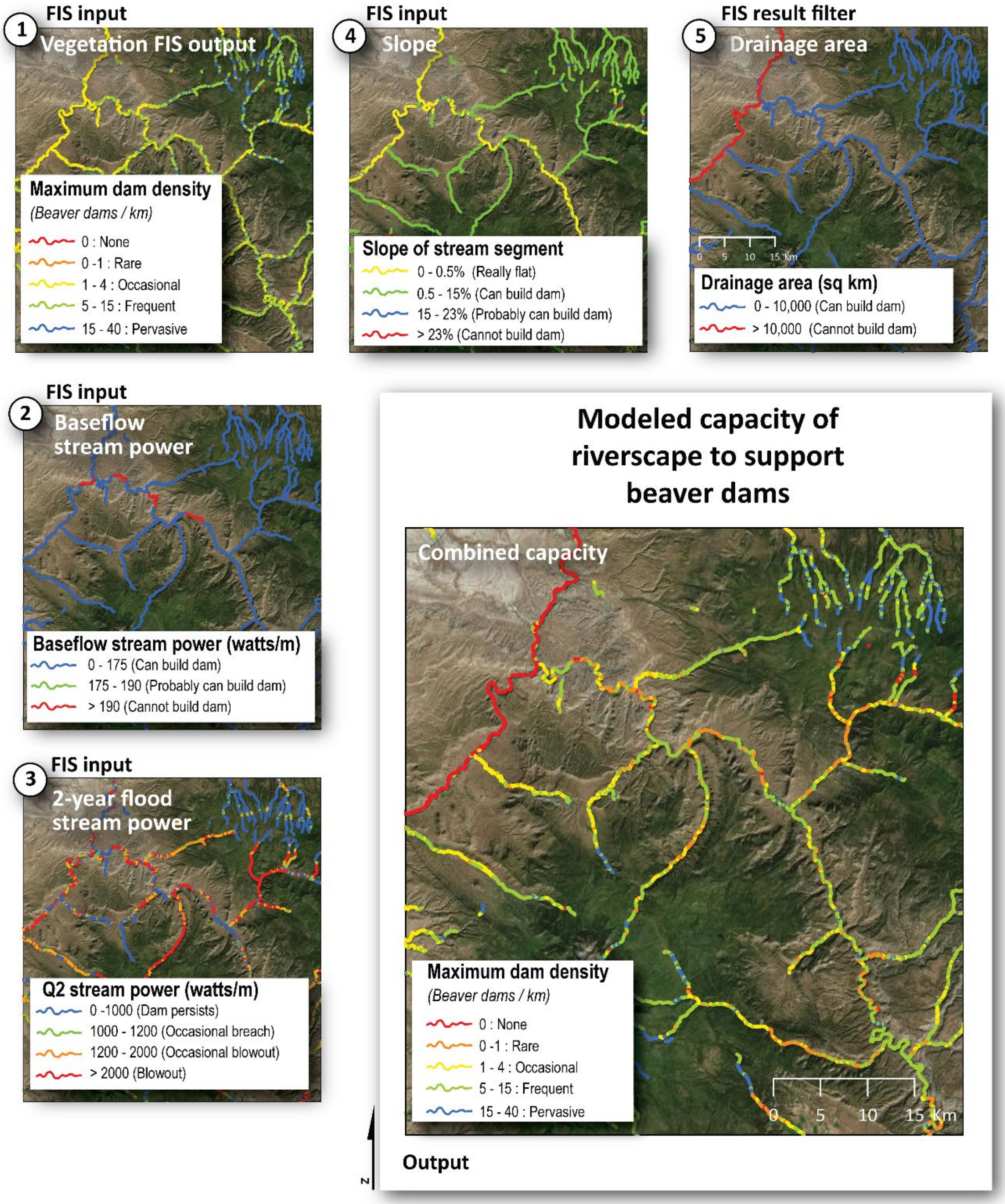

Figure 2: Methodological illustration of inputs (1-5) and output for the combined capacity model of riverscapes capacity to support beaver dam-building activity. Model output is expressed as dam density (dams/km).

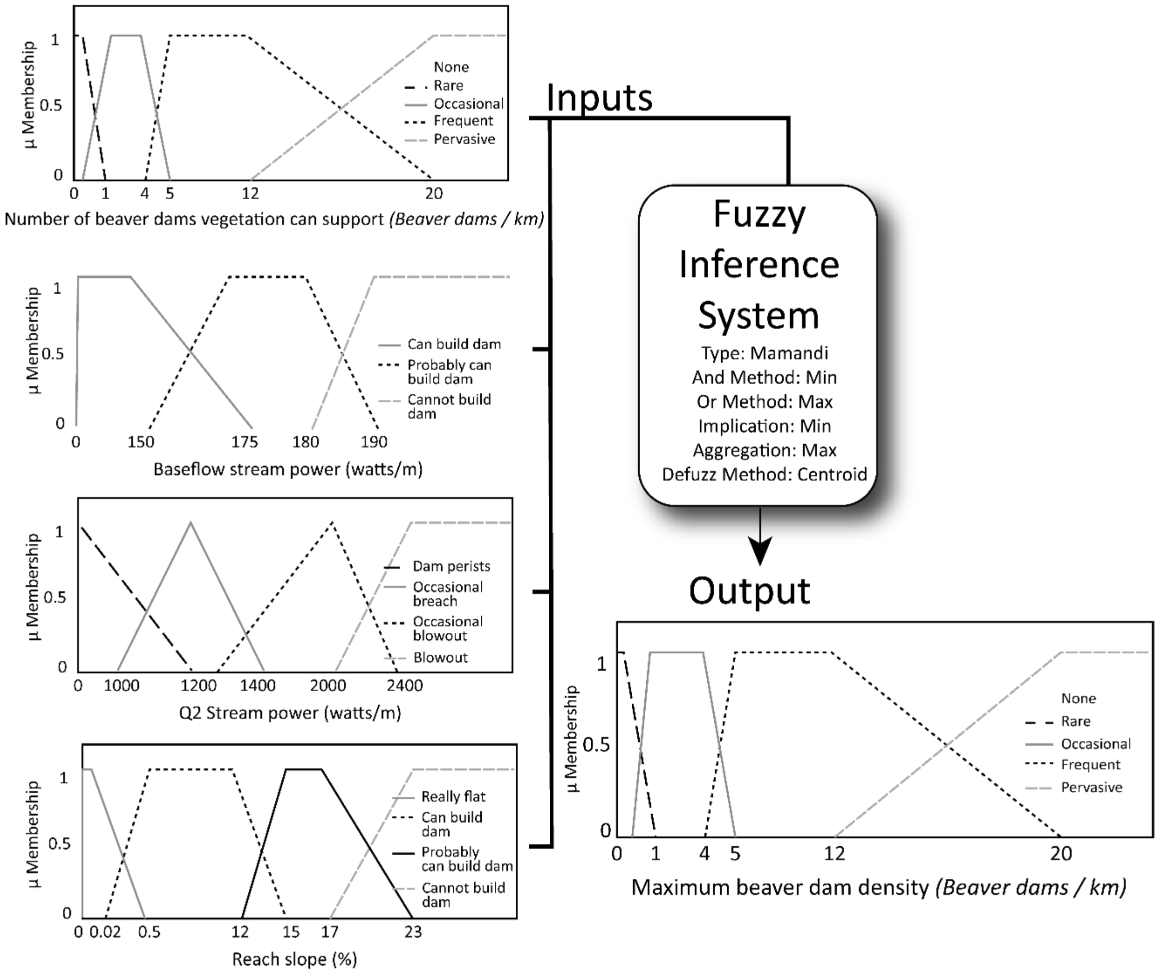

Figure 3: Combined capacity Fuzzy Inference System for capacity of riverscapes to support dam building beaver activity. This shows the specification of fuzzy membership functions with overlapping values for categorical descriptors in inputs and the output.

BRAT is more than a capacity model

The BRAT capacity model can help explain dam density patterns and to explore appropriate locations for Beaver Dam Analogs (BDA) and restoration using beaver. However, a beaver dam capacity model alone is not enough to effectively plan for large scale management and restoration of dam-building beaver. In this section, we describe how the BRAT model assess risk and opportunity for using beaver in conservation and restoration and we argue that suitable dam-building habitat for beaver can be planned for at the watershed-wide level using the outputs of the capacity model and a management model assessing risk based on where streams with beaver dam capacity are relative to human infrastructure and high intensity land use.

Risk assessment using proximity to human infrastructure

There is no doubt that beaver can be a destructive nuisance in the built environment and anywhere human infrastructure exists (Bhat et al., 1993, Hill, 1976, McKinstry and Anderson, 1999). Beaver can clog culverts, interfere with diversions, flood public and private infrastructure, and harvest trees in undesirable locations. In an attempt to identify potential conflicts in the built environment, the BRAT model identifies where streams are relative to infrastructure and high intensity land use, and conservatively shows where that aligns with streams where beavers could potentially build dams.

For example, beaver are not generally welcome or useful additions to irrigation canals. Thus, distance from canals are cast in terms of ‘beaver distances’ (immediately adjacent, within normal forage range, within plausible forage range, or far enough to be outside the range of concern). The model casts the following human infrastructure in terms of ‘beaver distances’:

1. distance to roads;
2. distance to road crossings;
3. distance to railroads;
4. distance to canals;
5. average land use intensity and;
6. distance to nearest infrastructure

However, these calculations are unrealistically restrictive because the analysis only shows how close streams are to the listed infrastructure, regardless of whether the infrastructure is ‘cloggable’ or ‘floodable’. To account for ‘cloggable’ or ‘floodable’ infrastructure the model defines the areas beaver dams could flood – the valley bottoms. For example, while roads can be examined in terms of distance from the channel (as described above), we should only be interested in roads within the valley bottom if we are concerned about road flooding problems. Thus, we calculate proximity to the following ‘floodable’ or ‘cloggable’ infrastructure:

1. roads within valley bottoms;
2. road crossings;
3. canals and;
4. railroads within valley bottoms

Once again calculating proximity to ‘floodable’ or ‘cloggable’ infrastructure is limited because for example, a ‘road crossing’ could be a large bridge with plenty of clearance which is not necessarily a problem, or it could be a small culvert which is much more likely to have a clogging issue. Also, this ‘floodable’ or ‘cloggable’ infrastructure analysis is unrealistically restrictive because this analysis only shows how close the stream is to these ‘floodable’ or ‘cloggable’ infrastructure not how close the beaver might build a dam to that infrastructure.

The BRAT model attempts to be more realistic by accounting for where beaver are likely to build dams along each reach. Therefore, the model identifies where ‘floodable’ or ‘cloggable’ infrastructure is in close proximity to the drainage network, where land use intensity is high, and where beaver are likely to build dams along that watercourse. In other words, the model identifies reaches as having some risk of human-beaver conflict given that beaver can build dams on that reach and that those dams could potentially have a negative effect on nearby infrastructure. The quantification of risk for each reach is based on the number of beaver dams that could be built there, how close infrastructure – especially ‘floodable’ or ‘cloggable’ infrastructure – is, and how high land use intensity is along the reach. This assessment is still a conservative over-prediction of potential risk but provides a good starting point at predicting potential risk areas.

Management layers

We have developed management layers and associated maps that combine capacity estimates, and risk analysis (described above) for use in beaver related conservation and restoration. The management output layers identify streams that are: low-risk with restoration and conservation opportunities, moderate or high risk where beavers can build dams and; natural or anthropogenically limited areas where beaver cannot build dams now. Specifically, the three beaver management layers/maps are: 1) ‘unsuitable or limited beaver dam building opportunities’, 2) ‘areas beavers can build dams, but could be undesirable', and 3) 'possible beaver dam conservation or restoration opportunities'. Further documentation and discussion/development of these layers/maps can be found here.

Model validation

A capacity model is difficult to 'validate' because rarely, if ever, would the entire riverscape be at 'capacity'. However, since the BRAT model output is dam density, direct comparison to actual dam densities is a useful form of validation of model performance. We validated our model in three different ways. First, model outputs were ground truthed to confirm whether or not the predictions seemed reasonable (e.g. places with no evidence of beaver dams are modeled with a capacity equal to 0 dams/km). Second, actual beaver dam locations were used to calculate densities and compare actual densities to modeled capacity estimates. Finally, an electivity index was used to show whether higher preference was exhibited for beaver dam construction in reaches that predicted higher capacities.

To facilitate model calibration and verification we conducted two half day field site visits (10/23/18 and 10/25/18) to various stream reaches. At these sites, as well as along the route to these sites, we field calibrated and verified the preliminary runs of the BRAT model.

To facilitate model validation, actual dam counts were collected using virtual reconnaissance in Google Earth. A trained technician used Google Earth to examine the entire stream network within watershed for beaver dams. The technician navigated up and down every stream in the drainage network at an 'eye altitude' of roughly 500-600 m above ground (~scale 1:2000) and when potential dams were identified the technician zoomed in and assessed other lines of visual evidence (e.g. pond shape, evidence of dam, evidence of riparian harvest, evidence of skid trails, etc.). When likely beaver dams were identified, locations were recorded. The resulting dam location data were used for model calibration and validation. We refer to this exercise as 'censusing' because the entire perennial network is sampled. However, it is important to point out that this is not a complete census, it is a sample from a snap shot in time of imagery. Moreover, these methods generally under-sample total dams, especially in forested ecosystems. Due to the limitations of the desktop method, the North Fork Watershed Council is conducting a field-based beaver dam collection campaign planned to extend into the summer of 2019.

Finally, to assess whether or not beaver dam-building was preferentially taking place in reaches with higher capacity estimates, an electivity index (EI) was calculated. This logic, follows conceptually from the 'ideal free distribution' (Fretwell and Lucas, 1970), such that the distribution of beaver dams (in this case) should match the distribution of resources to support such construction and maintenance activities. Following Pasternack (2011) an *EI*, was calculated for each segment type (*i*):

$$\boldsymbol{EI_i} = \frac{(\boldsymbol{n_i}/\sum \boldsymbol{n_i})}{(\boldsymbol{l_i}/\sum \boldsymbol{l_i})}$$

where ni is the number of beaver dams surveyed in segment type *i* and li is the length of that segment type. The *EI* essentially normalizes utilization by availability such that i) an *EI* value of one indicates utilization of available habitat without preference or avoidance, ii) an *EI* value less than one indicates avoidance of a particular habitat, whereas iii) an *EI* value greater than one indicates preference for a habitat. The segment types (*i*) are a classification that corresponds to the linguistic categories used in the FIS. If the capacity model is effectively segregating actual dam densities, we would expect an *EI* close to zero for the *none* and *rare* classes, less than one for the *occasional* class, greater than one for the *frequent* class, and much greater than one for the *pervasive* class.

RESULTS & INTERPRETATIONS

Model outputs

The John Day basin BRAT outputs consist of the following seven stream network classifications: 1) existing beaver dam capacity, 2) historic beaver dam capacity, 3) existing dam complex size, 4) historic dam complex size, 5) unsuitable or limited beaver dam opportunities, 6) areas beavers can build dams, but could be undesirable, and 7) restoration or conservation opportunities. The secondary outputs include maps, summary tables and figures of each of the seven stream network classifications at the John Day basin scale.

Beaver dam capacity models

The beaver dam capacity models were run for existing (based on 2014 imagery) and an estimate of historic conditions based on LANDFIRE BpS data. The estimated existing beaver dam capacity for the John Day basin is 120,945 dams (Figure 4 and Table 3) or roughly 11 dams/km. By contrast, the same model driven with estimates of historic vegetation types estimated John Day basin-wide capacity at 169,781 dams (Figure 5 and Table 3) or roughly 15 dams/km. In this case, the existing capacity is a 29% reduction compared to historic capacity. The estimated existing Lower John Day watershed (HUC 8) capacity is 19,781 dams or roughly 7 dams/km. By contrast, the same model driven with estimates of historic vegetation types estimated the Lower John Day watershed (HUC 8) capacity at 28,540 dams or roughly 10 dams/km reflecting a 31% loss compared to historic capacity. The estimated existing Middle Fork John Day (HUC 8) capacity is 16,929 dams or roughly 11 dams/km. By contrast, the same model driven with estimates of historic vegetation types estimated the Middle Fork John Day capacity at 22,661 dams or roughly 15 dams/km reflecting a 25% loss compared to historic capacity. The estimated existing North Fork John Day (HUC 8) capacity is 51,241 dams or roughly 14 dams/km. By contrast, the same model driven with estimates of historic vegetation types estimated the North Fork John Day capacity at 69,097 dams or roughly 20 dams/km reflecting a 26% loss compared to historic capacity. The estimated existing Upper John Day (HUC 8) capacity is 32,994 dams or roughly 10 dams/km. By contrast, the same model driven with estimates of historic vegetation types estimated the North Fork John Day capacity at 49,483 dams or roughly 15 dams/km reflecting a 33% loss compared to historic capacity (Table 3). Dam building capacity can be re-cast in terms of what size dam complex (single dam, small complex (1-3 dams), medium complex (3-5 dams), or large complex (greater than 5 dams)) can fit in a reach. Existing dam complex size for the John Day basin is mapped in Figure 6. Historic dam complex size for the John Day basin is mapped in Figure 7.

Table 3: Gross summary of contrast between existing and historic beaver dam capacity estimates for the John Day basin.

	Existing Capacity			Historic Capacity		
Category	**Estimated Dam Capacity**	**Estimated Dams/km total**		**Estimated Existing Dams/km total**	**Estimated Historic Dams/km total**	**% Loss**
Lower John Day	19,781	7		28,540	10	31%
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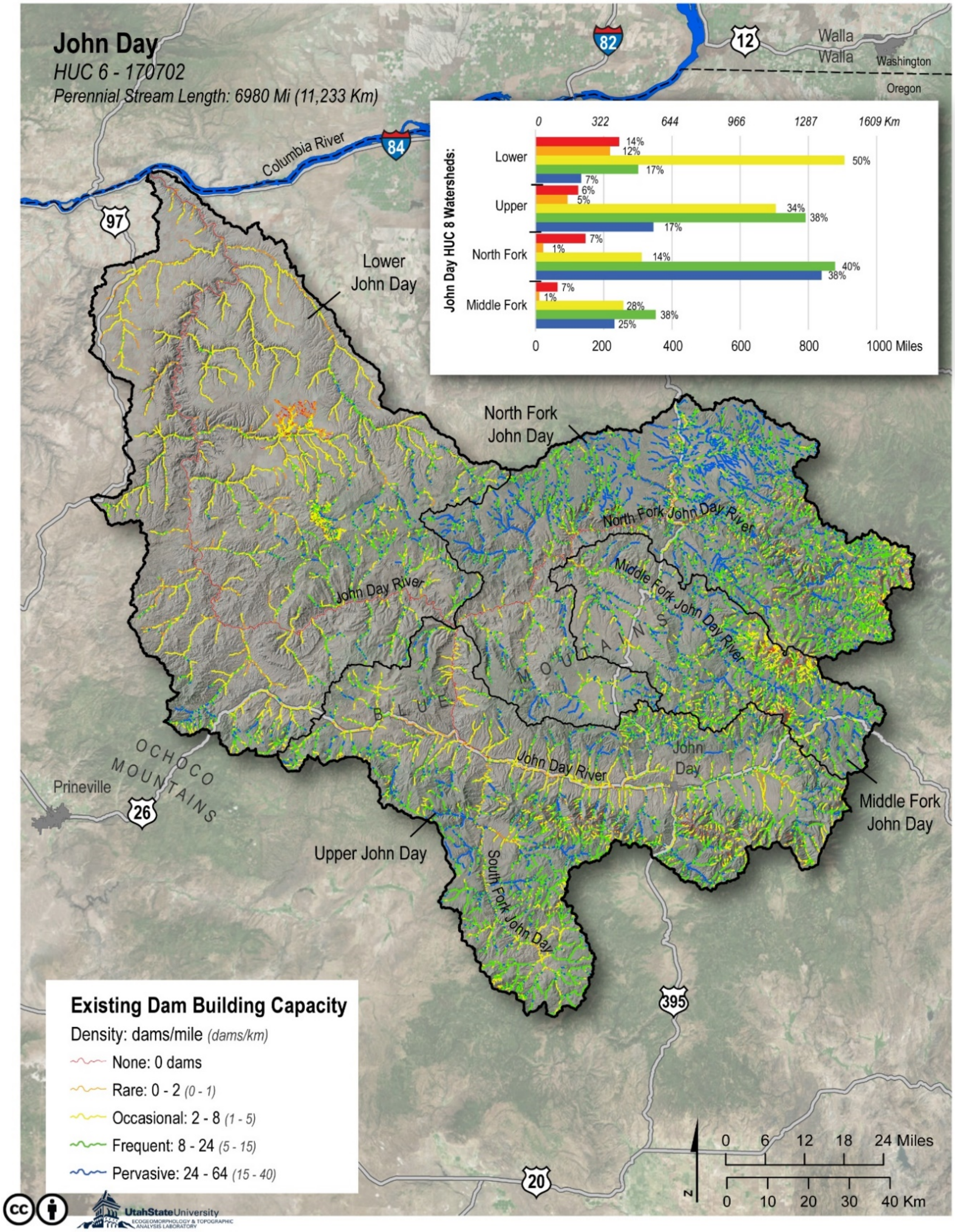


Figure 4: Modeled beaver dam capacity for existing conditions for the John Day basin (HUC 6).

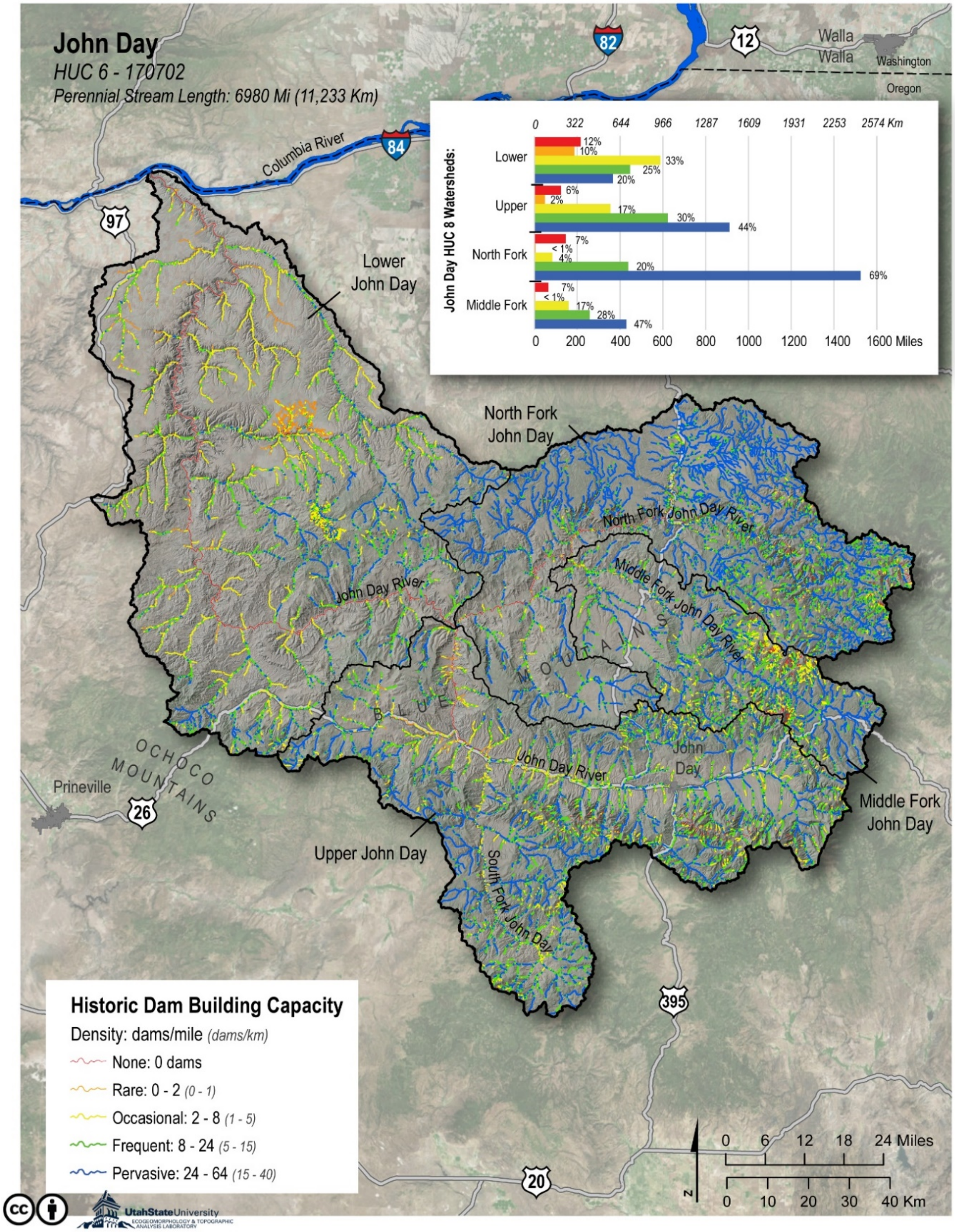


Figure 5: Modeled beaver dam capacity for historic conditions for the John Day basin (HUC 6).

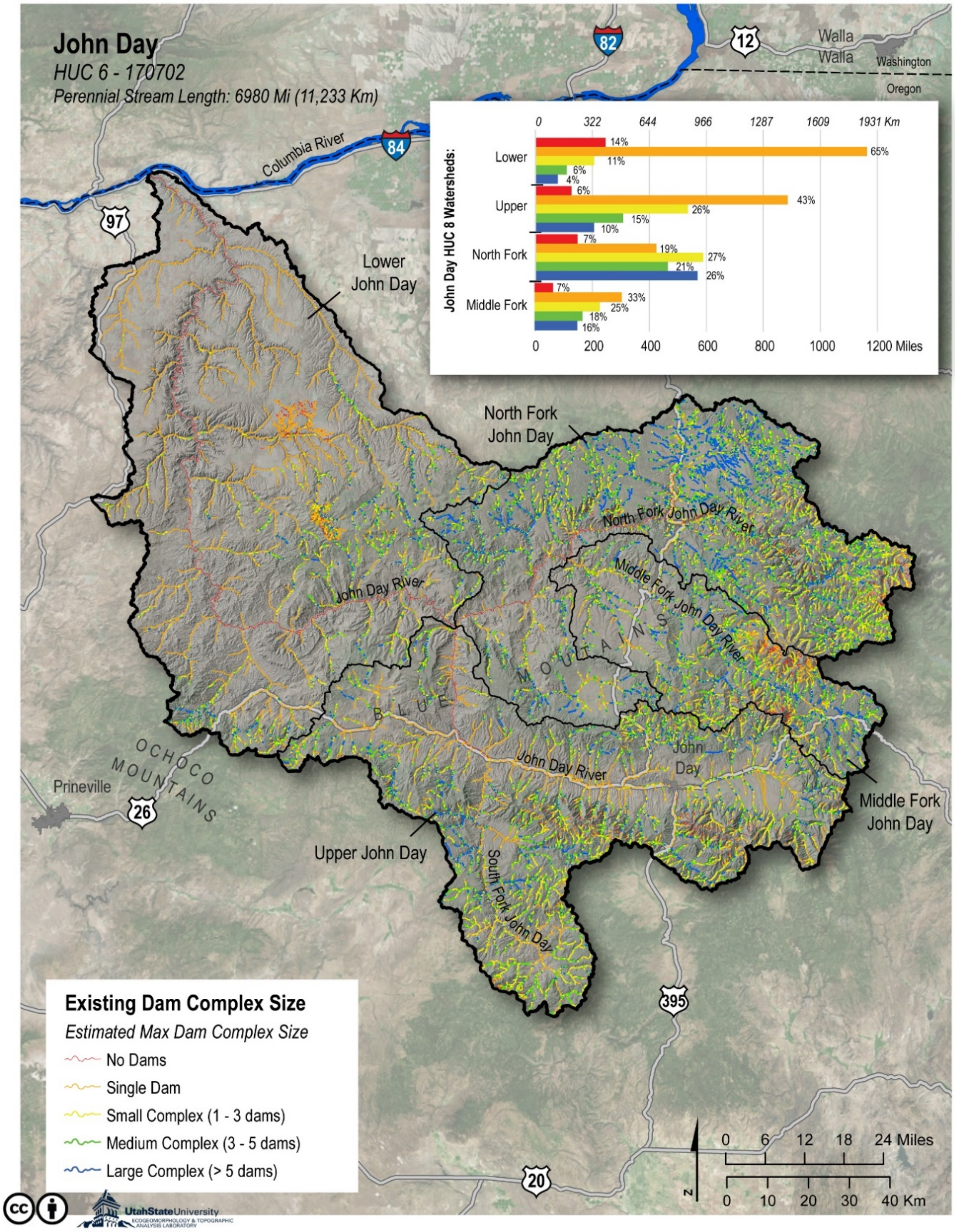


Figure 6: Modeled existing dam complex size for the John Day basin (HUC 6).

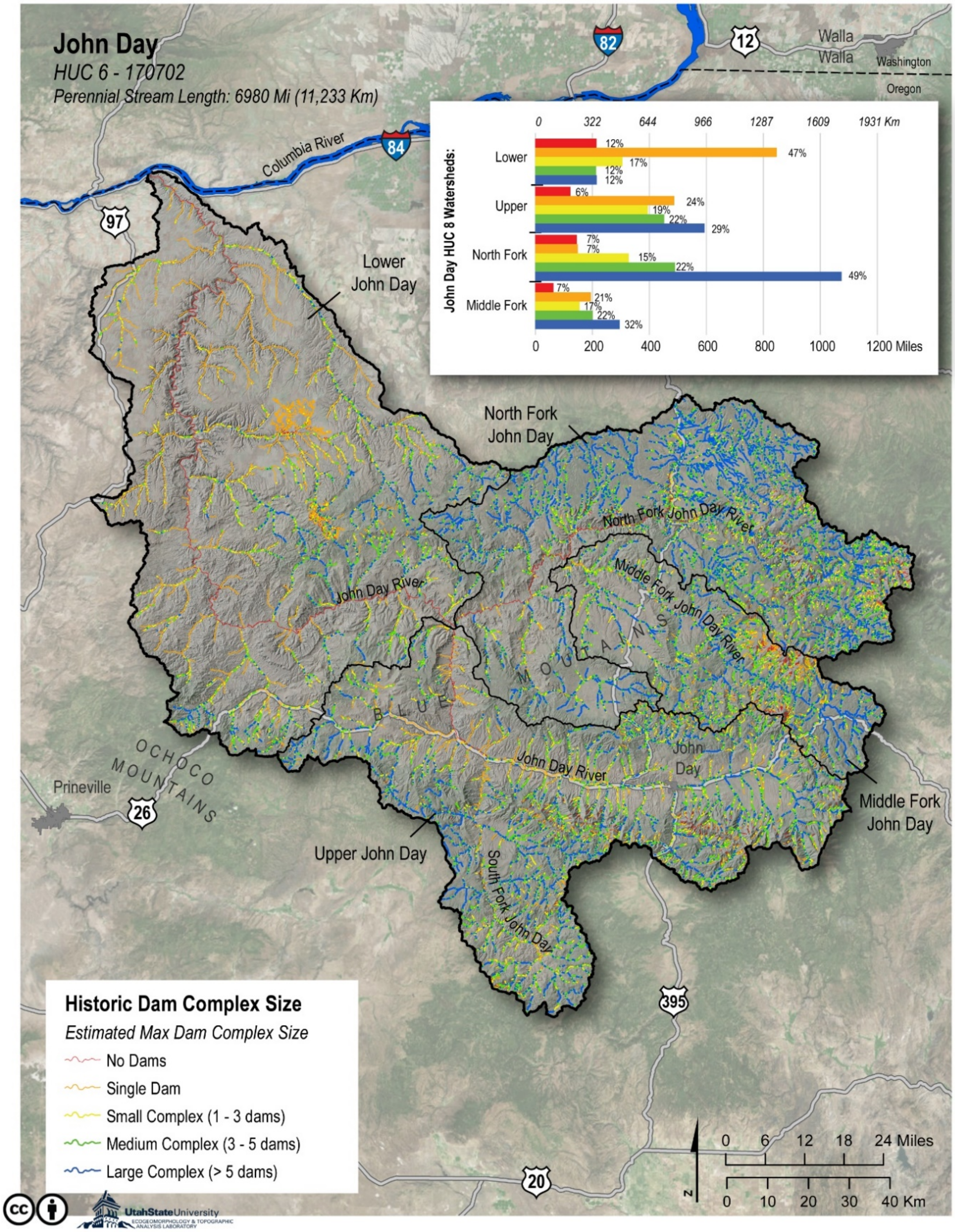


Figure 7: Modeled historic dam complex size for the John Day basin (HUC 6).

Management layers

Conservation and restoration opportunities

The BRAT model identifies opportunities where low-risk restoration and conservation opportunities exist for using beaver in stream conservation and restoration (Figure 8). The layer/map represents areas with limited ‘risk’ of human-beaver conflict and some existing capacity. The map consists of the following categories: i) ‘easiest - low hanging fruit’ has capacity, just needs beaver, ii) ‘straight forward - quick return’ is currently occasional capacity but historically was higher capacity, iii) ‘strategic’ is currently degraded but historically was higher capacity. These areas typically need long-term riparian recovery first (e.g. grazing management), and 4) ‘other’. The ‘other’ category is based on higher ‘risk’ of human-beaver conflict and lower existing dam building capacity (i.e., reaches that are likely not worth beaver dam related conservation and restoration actions). 30% of the John Day basin is categorized as ‘easiest’ conservation and restoration opportunities, suggesting there are many low-hanging fruit beaver-related restoration opportunities available.

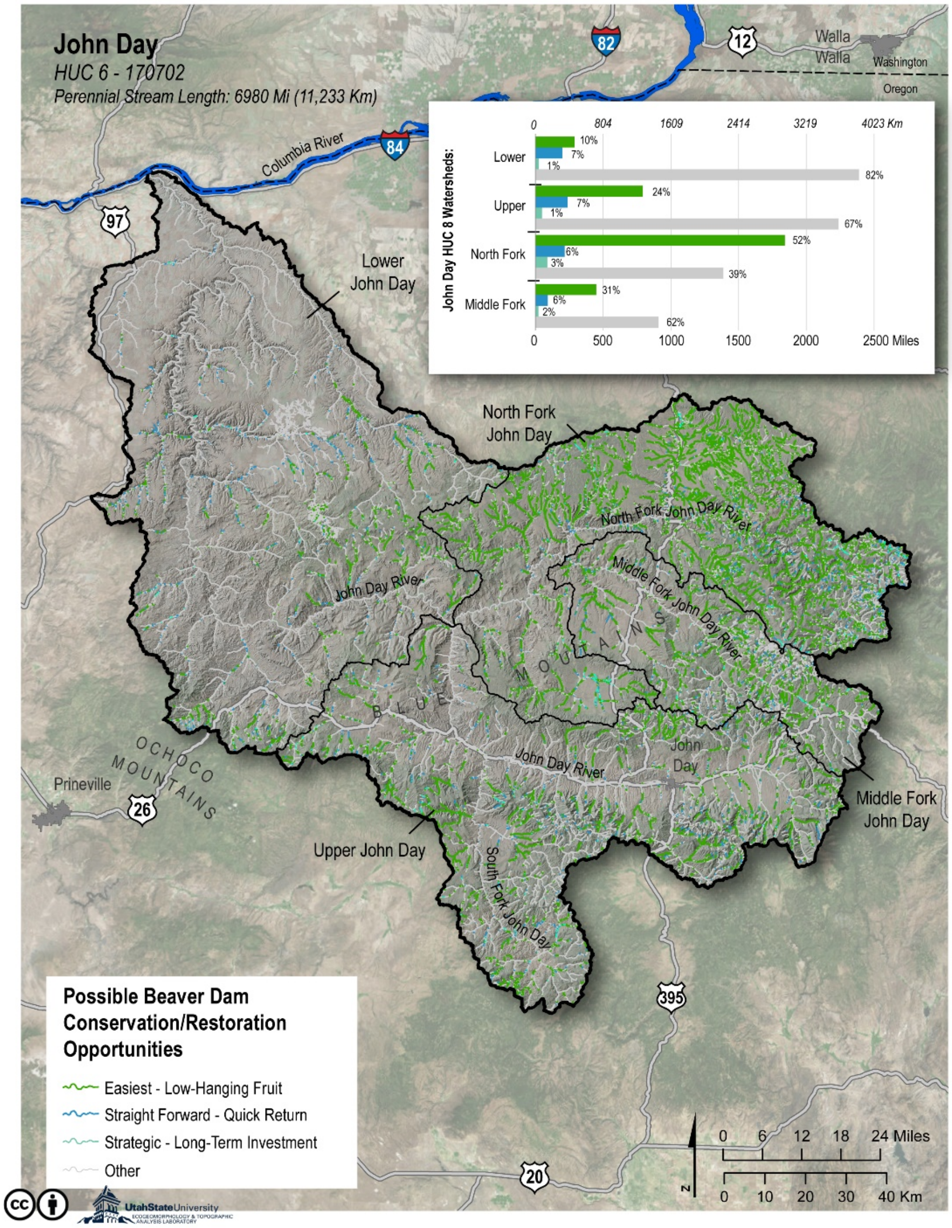


Figure 8: Modeled conservation and restoration opportunities for the John Day basin (HUC 6).

Potential risk areas

The BRAT model identifies potential risks areas -- streams that are close to human infrastructure or high land use intensity and where the capacity model estimates that beavers can build dams. The layer/map is called ‘areas beavers can build dams, but could be undesirable’ (Figure 9). 50% of the John Day basin is categorized as ‘negligible’ risk, suggesting there are many low risk beaver-related restoration opportunities available.

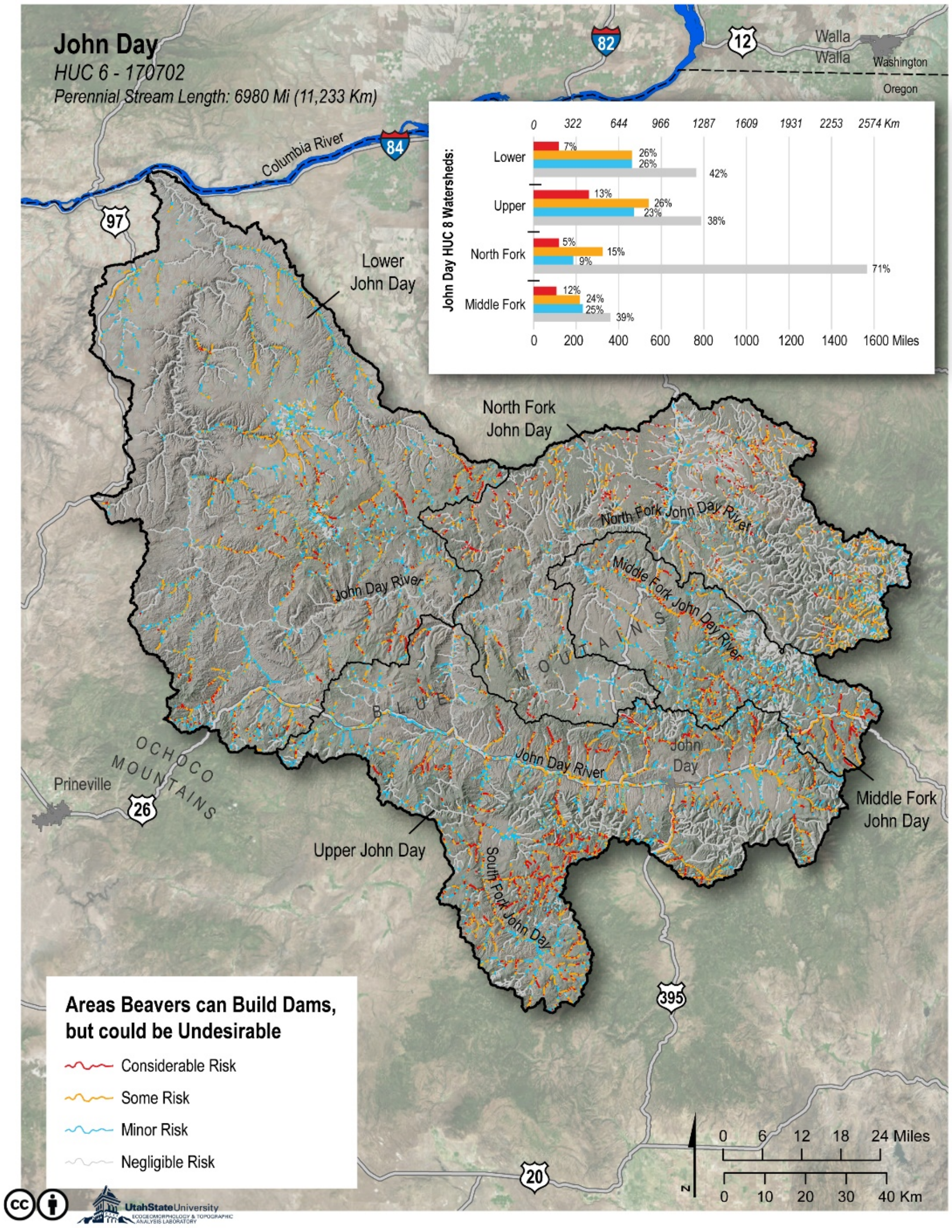


Figure 9: Modeled areas beavers can build dams but could be undesirable for the John Day basin (HUC 6).

Unsuitable or limited dam building opportunities

The BRAT model also identifies areas where beaver cannot build dams now, the model also differentiates into anthropogenically and naturally limiting areas. The layer/map is called ‘unsuitable or limited dam building opportunities’ (Figure 10). Only 8% of all perennial streams in the John Day basin were categorized as unsuitable for beaver dam building.

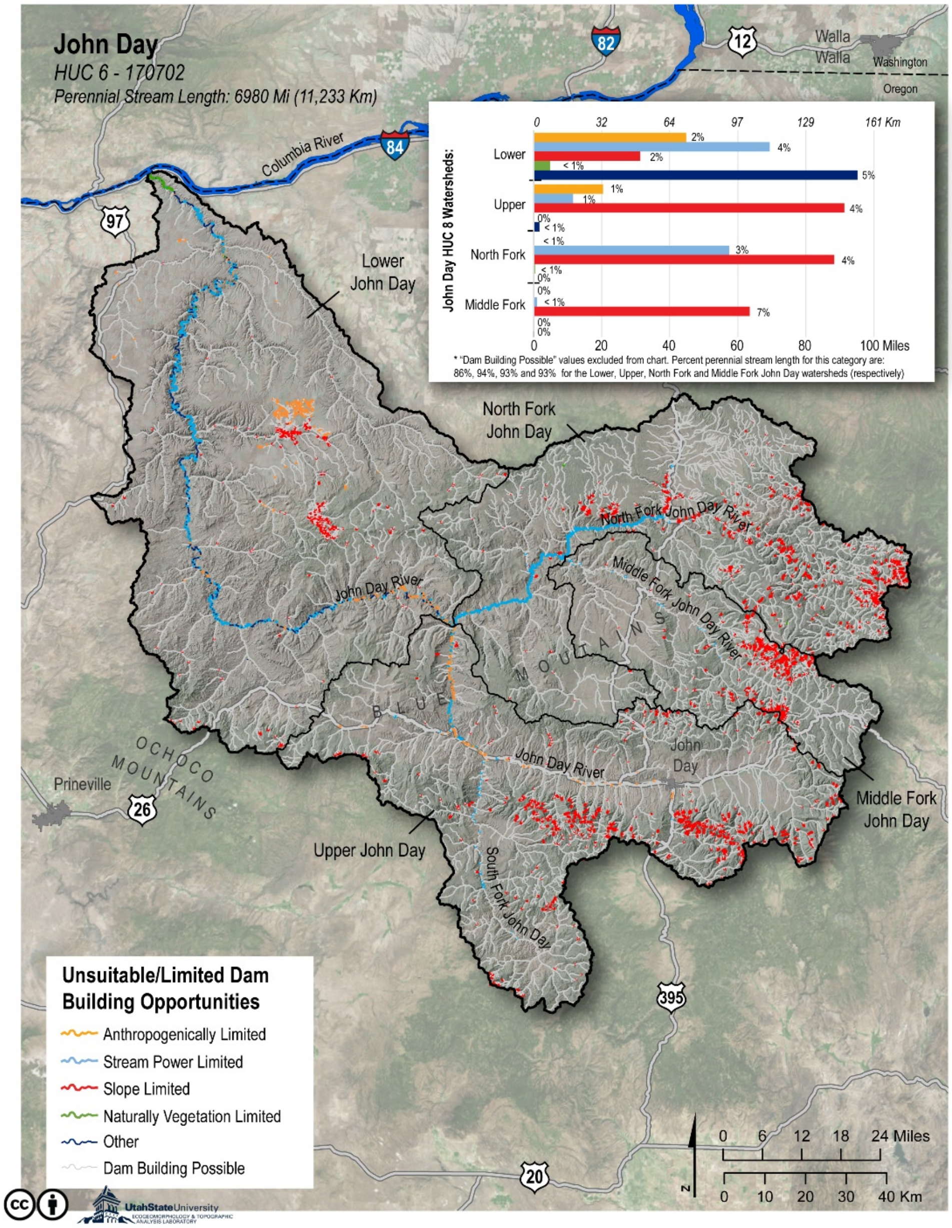


Figure 10: Modeled unsuitable/limited dam building opportunities for the John Day basin (HUC 6).

Model intermediates

Anthropogenic constraints layers

The BRAT model identifies anthropogenic constraints based on proximity to human infrastructure (Figure 11) and include, distance to roads (Figure 12), distance to roads within valley bottoms (Figure 13), distance to road crossings (Figure 14), distance to canals (Figure 15) and distance to nearest infrastructure (Figure 16). The BRAT model identifies also identifies land use intensity (Figure 17). This proximity analysis highlights possible risks (i.e. flooding and clogging) that might occur to this infrastructure.

Context layers

Figure 11 shows the context layers: canals, valley bottoms, roads, and railroads that the model used to calculate overall and individual proximity of streams to human infrastructure.

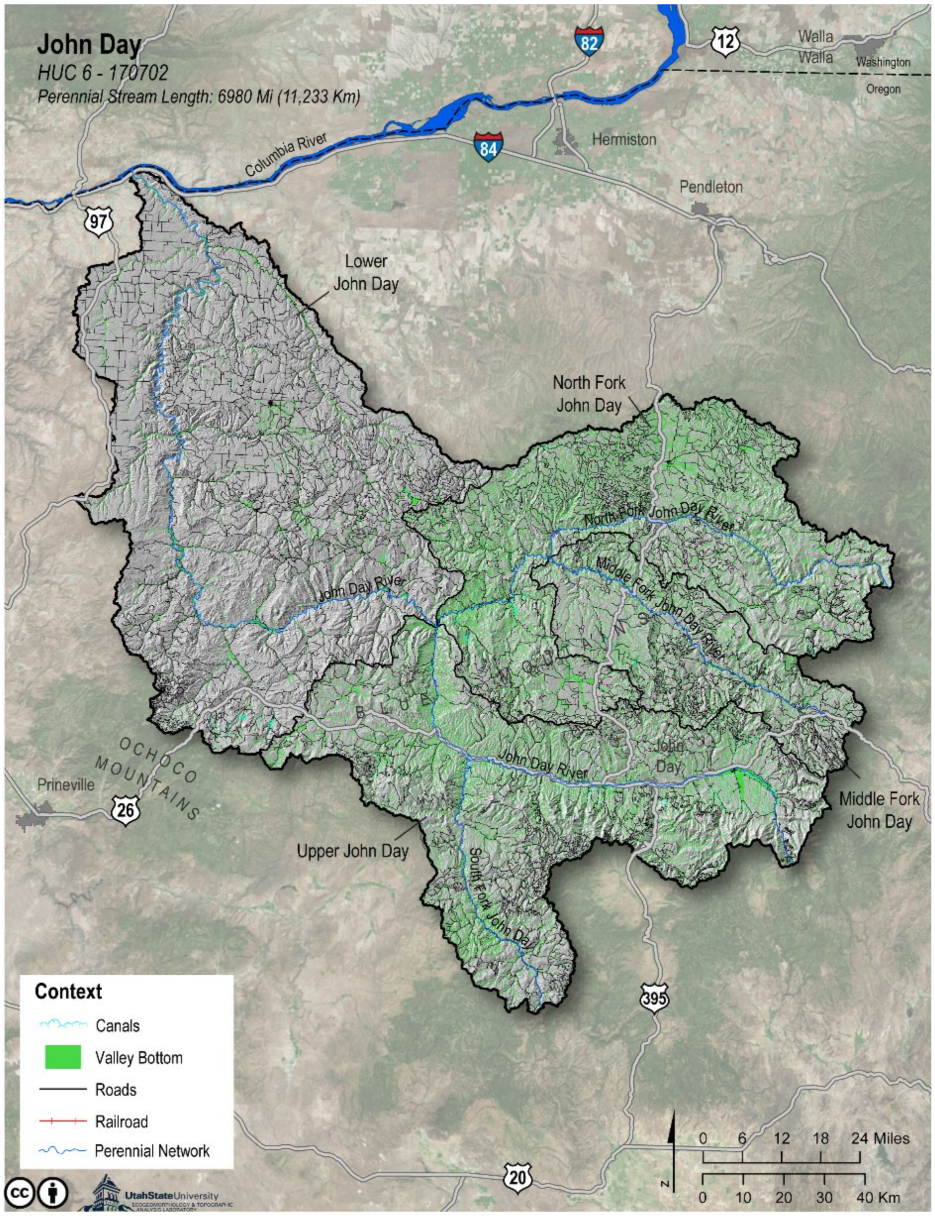


Figure 11: Context layers used in the BRAT model for the John Day basin (HUC 6).

Distance to road

Figure 12 shows the Euclidean distance of roads to the perennial stream network and was calculated because beaver dam building can flood roads. Hence, roads in close proximity to streams where beaver can build dams are considered a potential risk area.

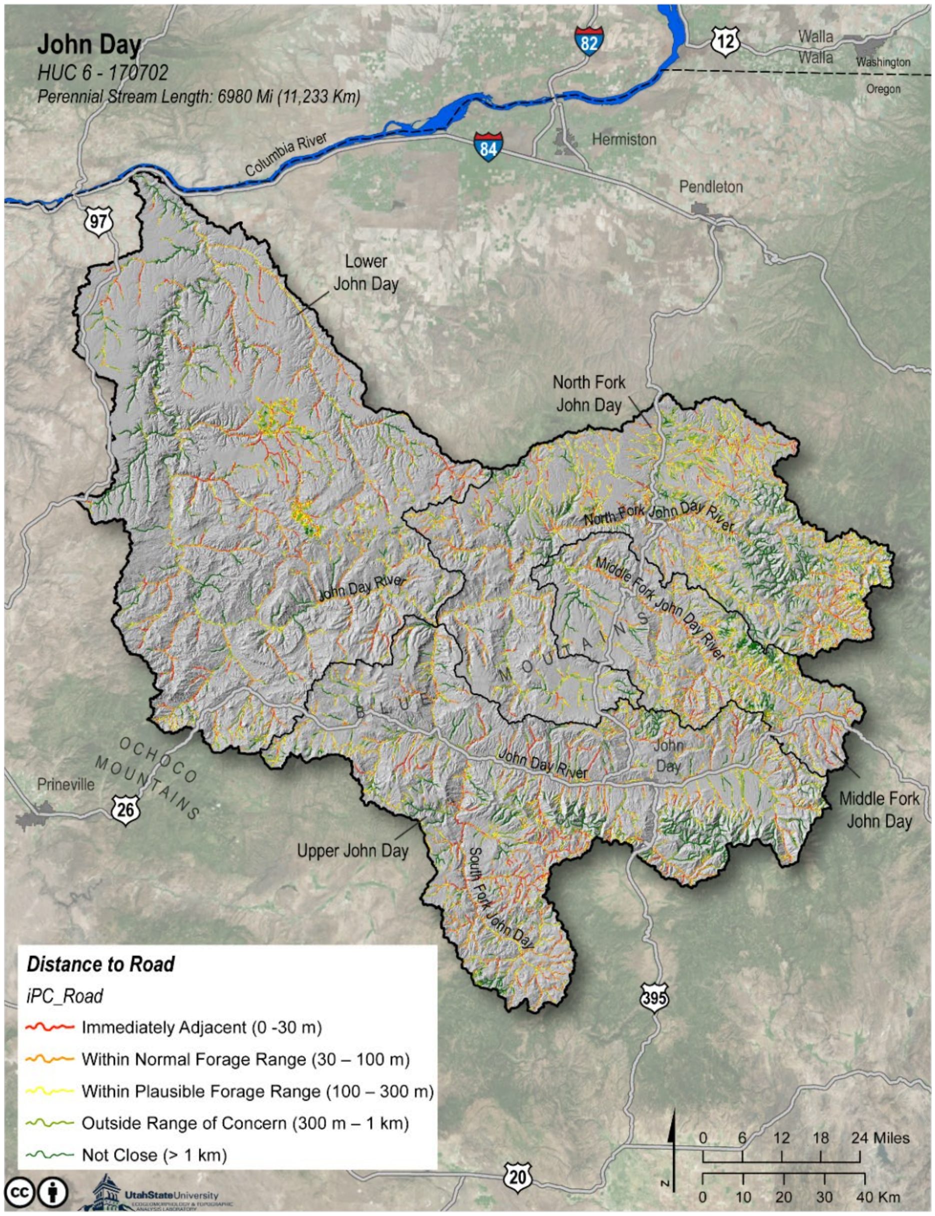


Figure 12: Euclidean distance to roads for the John Day basin (HUC 6).

Distance to roads within valley bottoms

Figure 13 shows the Euclidean distance of roads within valley bottoms to the perennial stream network and was calculated because beaver dam building can flood roads that are in the floodplain (valley bottom). Hence, roads within valley bottoms in close proximity to streams where beaver can build dams are considered a high risk area.

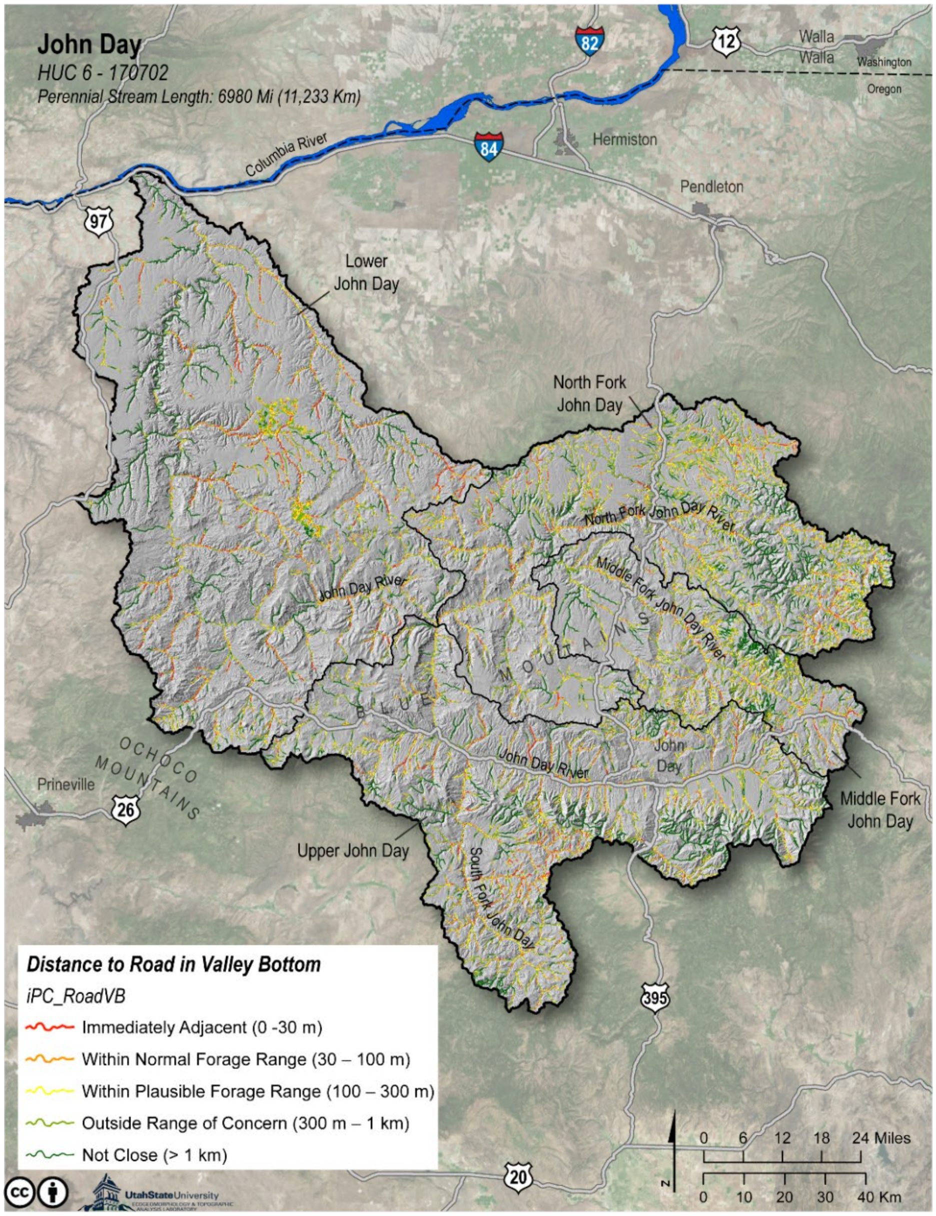


Figure 13: Euclidean distance to roads within the valley bottom for the John Day basin (HUC 6).

Distance to road crossing

Figure 14 shows the Euclidean distance of road crossings to the perennial stream network and was calculated because road crossings can be advantageous locations for beavers to build dams but can cause damage to infrastructure in these areas. For example, beaver dams can be constructed on the upstream end of culverts causing potential clogging of issues and flooding of roadways. Hence, road crossings are considered a high risk area.

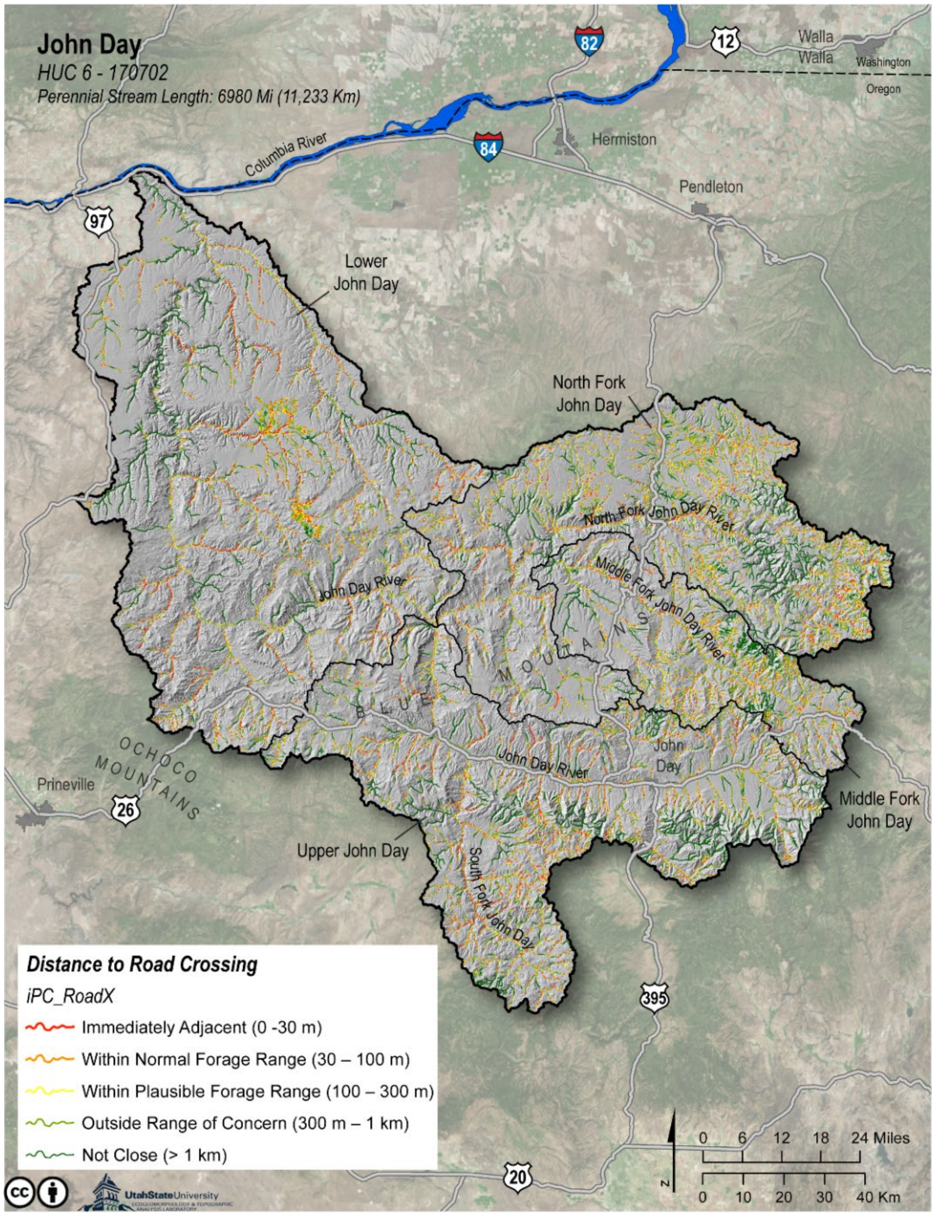


Figure 14: Euclidean distance to road crossings for the John Day basin (HUC 6).

Distance to canal

Figure 15 shows the Euclidean distance of canals to the perennial stream network and was calculated because beaver dams in canals can alter the flow of water in canals designed to provide stable and undisturbed water delivery. As such, canals in close proximity to streams where beaver can build dams are considered a high risk area.

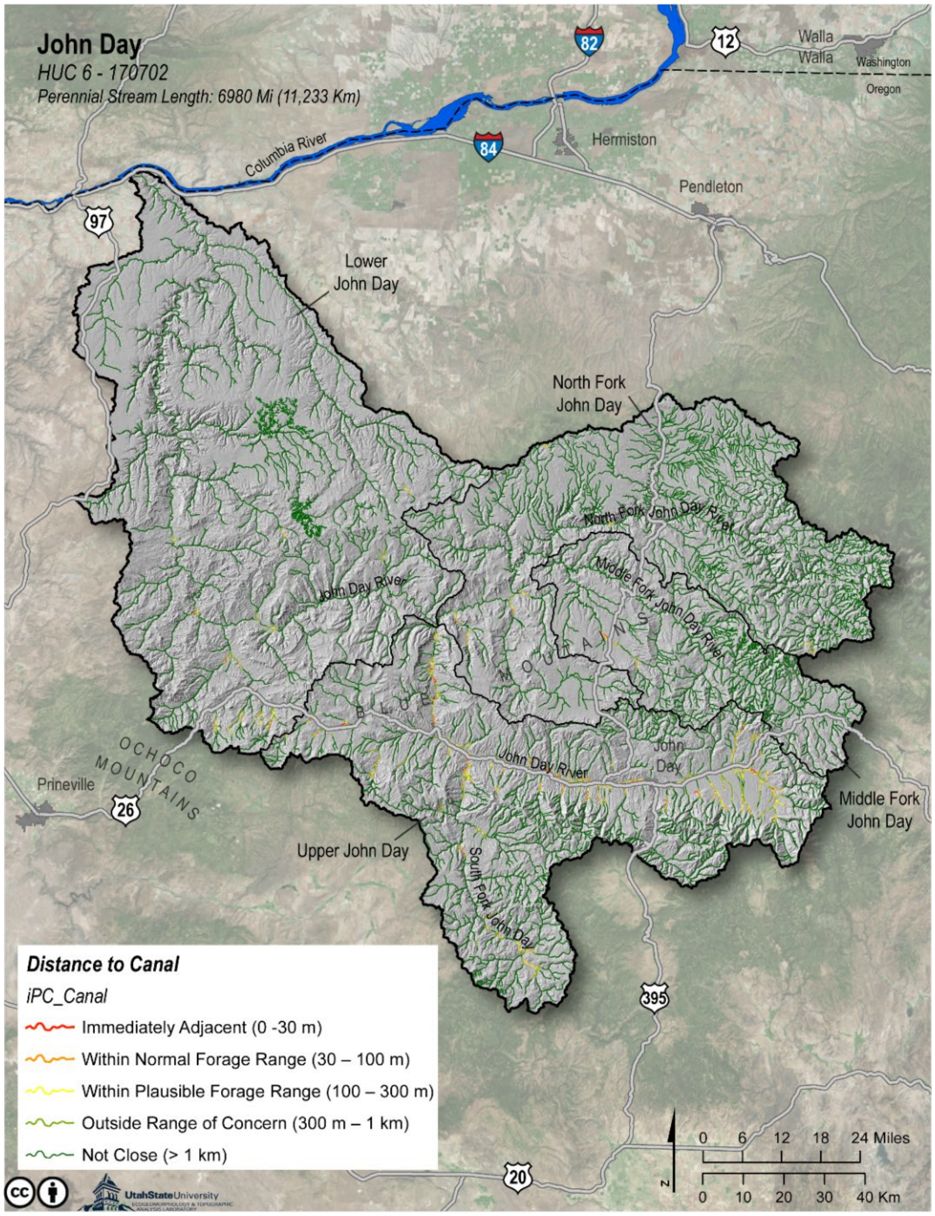


Figure 15: Euclidean distance to canals for the John Day basin (HUC 6).

Distance to infrastructure

Figure 16 shows the minimum distance of streams to human infrastructure, including roads, roads in the valley bottom, road crossings, and canals. This is a simple visualization of overall risk to man-made structures and shows reaches where beaver *may* cause impacts, though risk of an individual reach varies by the susceptibility of infrastructure to flooding and the likelihood of beaver building dams there.

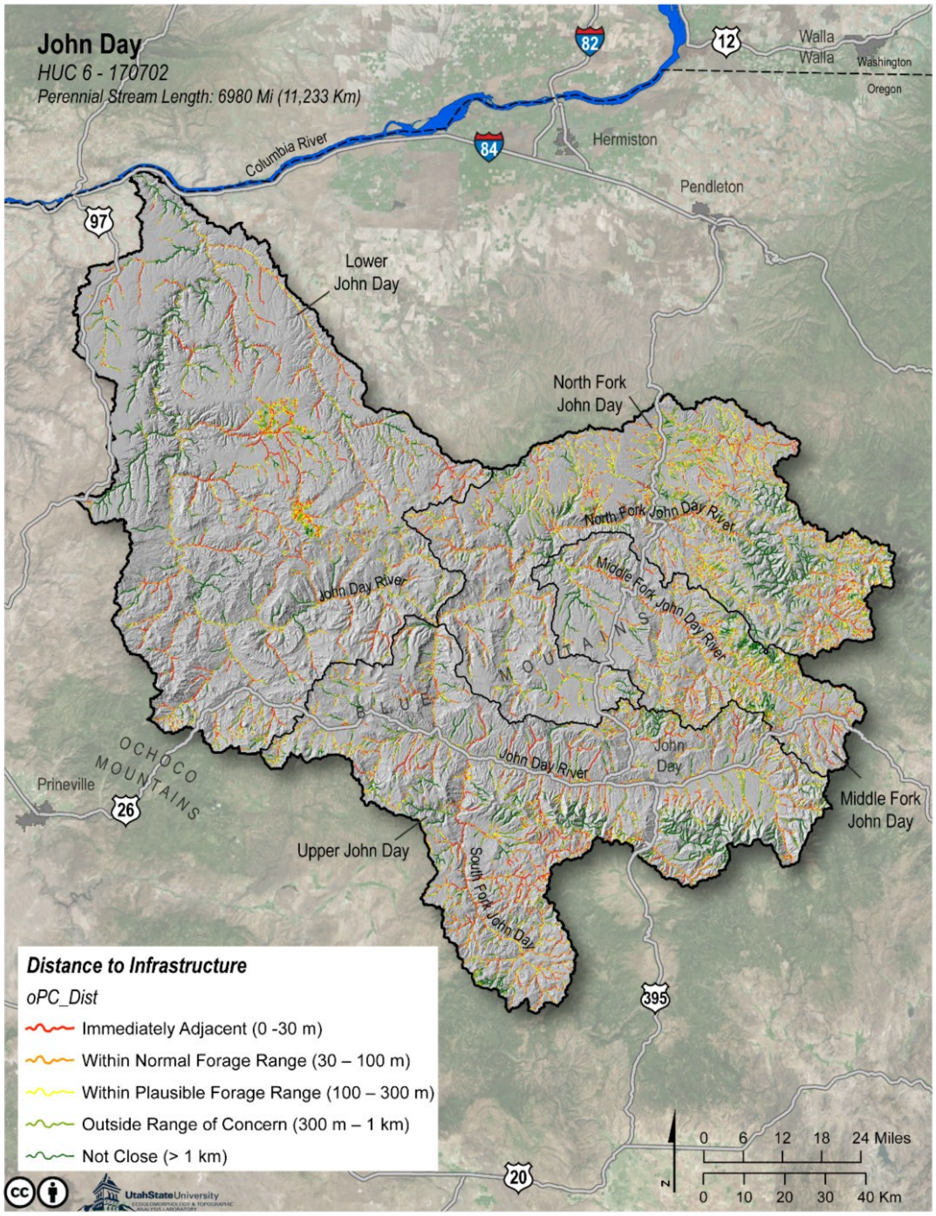


Figure 16: Euclidean distance to human infrastructure for the John Day basin (HUC 6).

Land use intensity

Figure 17 shows land use intensity for the perennial stream network and was modeled with the rational that the higher the land use intensity score the higher the potential human-beaver conflict.

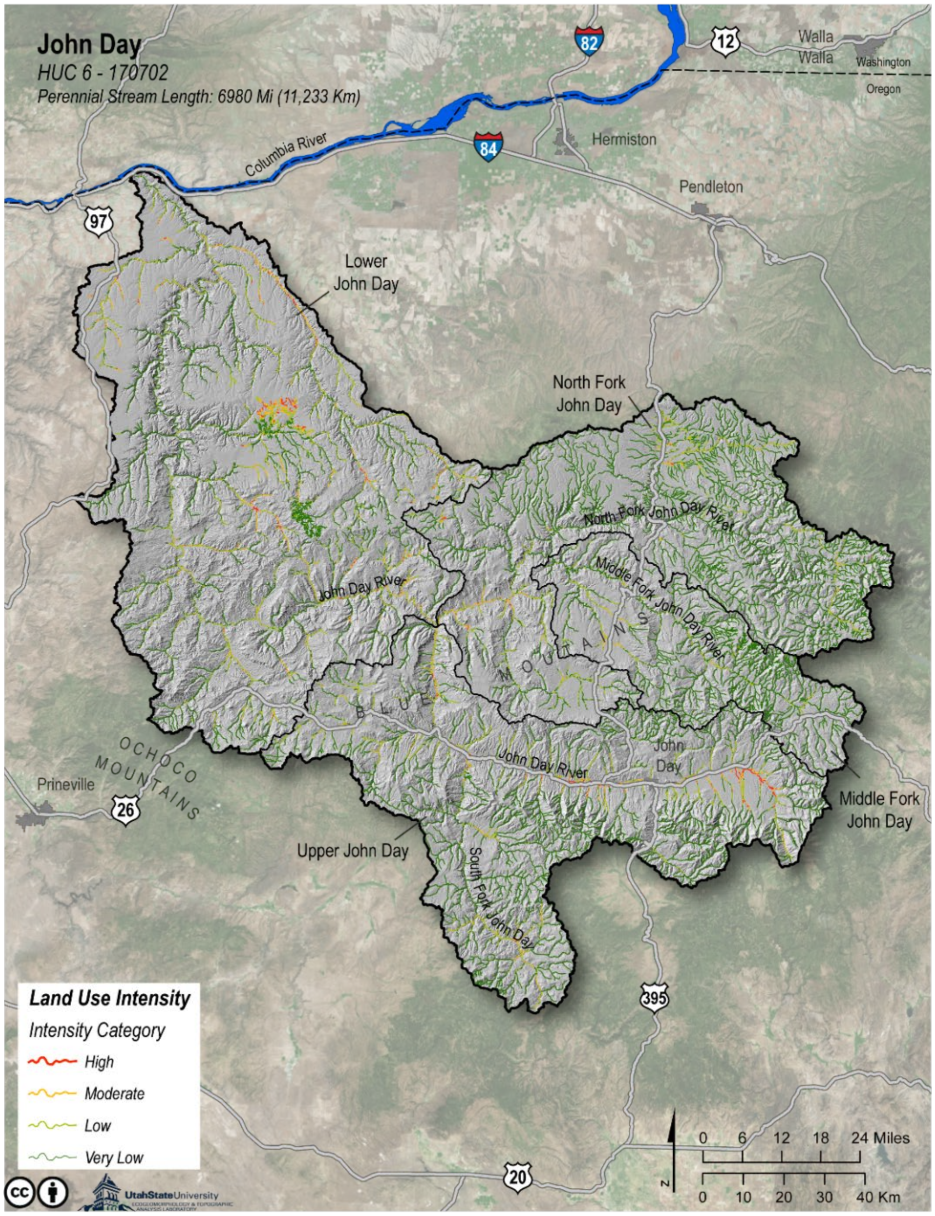


Figure 17: Modeled land use intensity for the John Day basin (HUC 6).

Model calibration

On October 23, and 24 2018 we conducted site tours in the Middle Fork John Day and Upper John Day watersheds. We visited 21 sites over the course of the site tours (Figure 18).

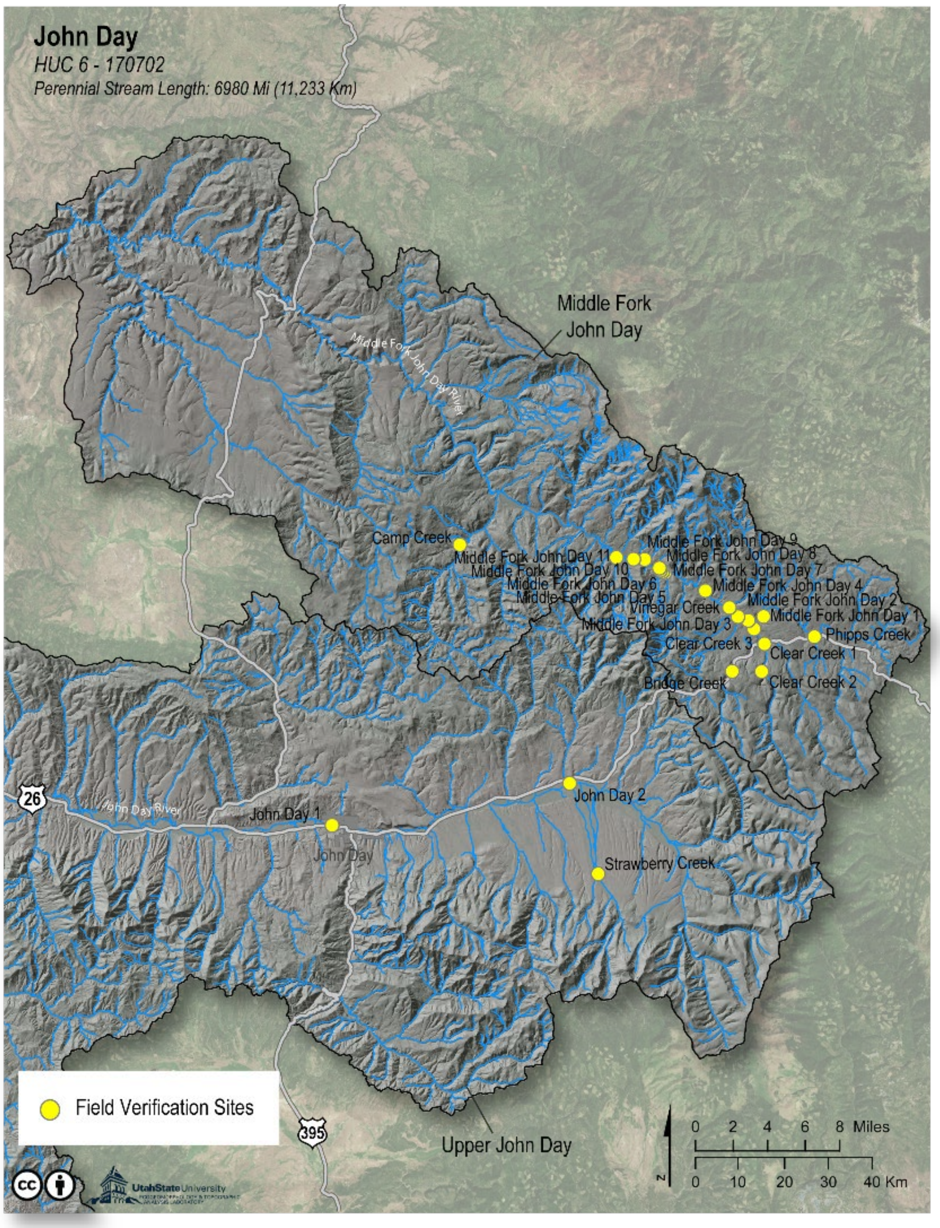


Figure 18: Model calibration and verification site visit locations within the Middle Fork John Day and Upper John Day watersheds.

Throughout the field tour we calibrated and validated the BRAT model outputs focusing primarily on examining four important inputs to the model: NHD stream network, base flow stream power estimates, typical 2-year flood stream power estimates, and existing vegetation conditions. We found that the NHD perennial stream codes exaggerated the actual perennial stream network (i.e. many streams coded as perennial were actually found to be intermittent or ephemeral). However, we concluded that the task of recoding the streams was beyond the scope of this current project but could be pursued in the future with additional funding. While verifying stream power estimates we found that base flow and 2-year flood estimates, used in the model, were of sufficient accuracy and precision to meet our modeling needs.

For the vegetation verification component, we were most interested in verifying three dam building preference classifications: The "Northern Rocky Mountain Ponderosa Pine Woodland and Savanna" coded as a ‘3’ ,"Rocky Mountain Subalpine/Upper Montane Riparian Shrubland" coded as a ‘4’ and "Inter-Mountain Basins Montane Riparian Shrubland" coded as a ‘4’. Based on the lack of desirable deciduous shrubs and trees in these classes, we decided to reduce their beaver dam building material preference scores to 2’s.

The roads input layer was refined and updated using the US Forest Service roads layer to determine the maintenance level (i.e. not maintained, closed, or open for use). The ‘open for use roads’ were selected and this selection of roads was merged with the existing roads layer outside of the forest service boundary.

Based on the site visit model calibration efforts, listed above, we calibrated our model and reran it. The data provided within this report is based on this updated model run.

Model verification

We used three forms of model verification to assess the performance of the capacity model.

1. How do dam densities track between predicted and actual?
2. Do the electivity indices increase appreciably from the *none* to the *pervasive* class?
3. Are spatial predictions coherent and logical?

How do dam densities track between predicted and actual?

Model verification occurred in Lower John Day, Middle Fork John Day, North Fork John Day, and Upper John Day watersheds. Figure 19 shows actual beaver dam locations throughout the study area based on either virtual reconnaissance in Google Earth or spatially limited ground based identification.

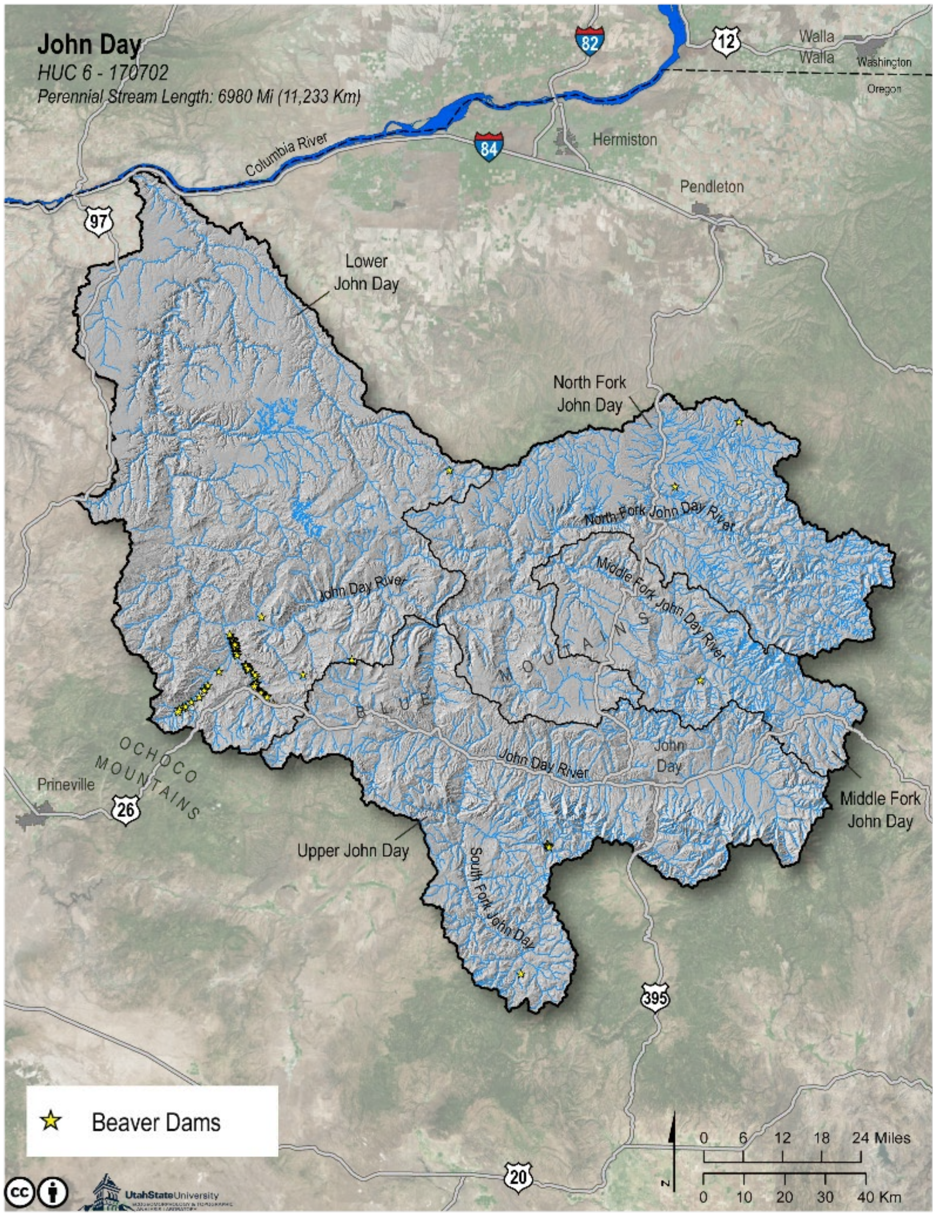


Figure 19: Actual beaver dam locations (n = 293) identified throughout the John Day basin (HUC 6) from a mix of desktop dam censusing and field observations.

Lower John Day Watershed HUC 8

A total of 281 actual beaver dams were identified, heavily concentrated in Bridge Creek, in the Lower John Day watershed (HUC 8). As such, we verified the performance of the existing capacity model using these 281 dams representing 0.46% of the 2,905 kilometers of perennial streams. No beaver dams were found where the model predicted no dams could be supported. Of the total 64 stream segments with validation dam counts 31 exceeded the capacity estimates indicating that the model effectively segregates the factors controlling beaver dam occurrence and density only 52% of the time (Figure 20). Thus, the model run with 30 m LANDFIRE data underestimated capacity 48 % of the time. After interrogating the model inputs, and intermediates we attribute this underestimation of capacity to a known limitation of 30m vegetation data – that it struggles to capture narrow riparian vegetation corridors especially in deeply incised streams such as Bridge Creek (Macfarlane et al., 2017a). This inability of LANDFIRE EVT to adequately capture riparian vegetation in Bridge Creek resulted in an underestimation of the capacity of this riverscape to support beaver dam building. Specifically, instead of high (3 to 4) beaver dam building preference scores the area was miss classified with low and moderate (1-2) preference scores. In this setting, higher resolution vegetation data or on-the-ground data collection will be required to effectively capture the riparian vegetation present and thus effectively capture beaver dam capacity. Validation data can be found here.

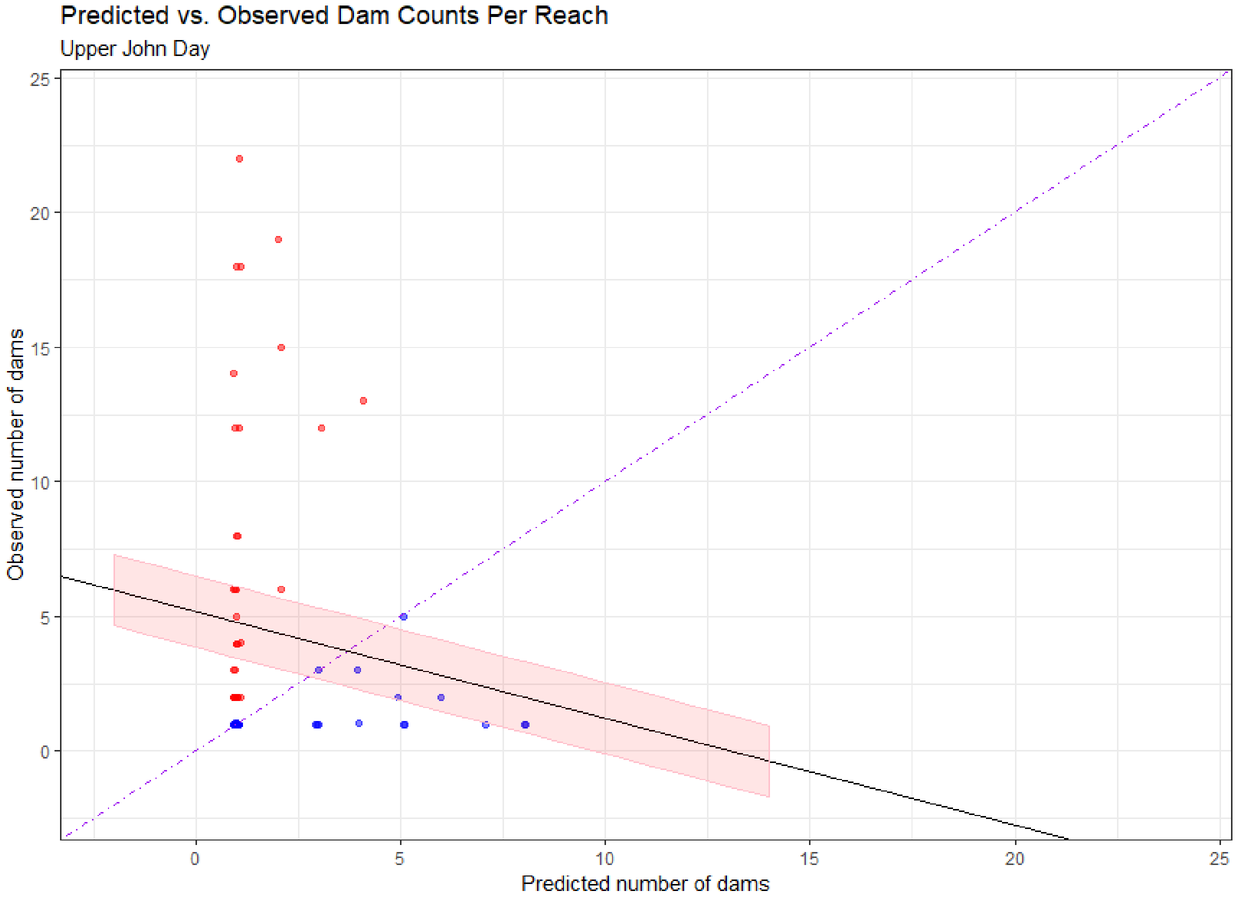


Figure 20: Predicted vs. observed dam counts (per reach) Lower John Day watershed (HUC 8). Red points represent reaches where BRAT underestimates dam capacity; blue points represent reaches where BRAT capacity estimates are equal to or higher than surveyed dam counts and therefore accurate; the dashed purple line represents the line of perfect agreement; the solid black line is the regression between observed and predicted dams with 95% confidence intervals in pink.

Middle Fork John Day Watershed HUC 8

Our Google Earth census only identified a single dam in the Lower John Day watershed (HUC 8) (Table 5). No beaver dams were found where the model predicted no dams could be supported. The stream segment with the validation dam count did not exceed the capacity estimates indicating that the model effectively segregates the factors controlling beaver dam occurrence and density 100% of the time (Figure 21). Validation data can be found here.

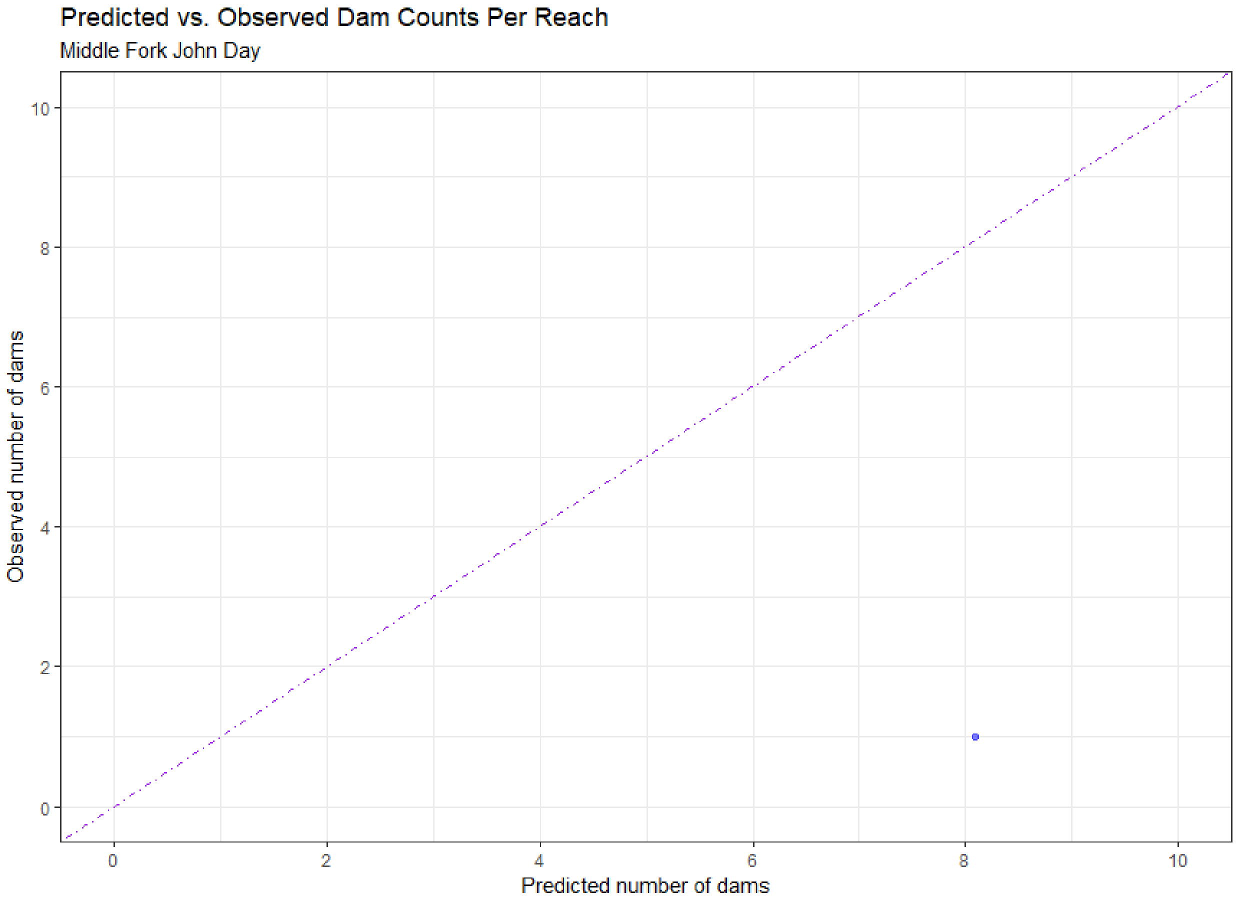


Figure 21: Predicted vs. observed dam counts (per reach) Middle Fork John Day watershed (HUC 8). Red points represent reaches where BRAT underestimates dam capacity; blue points represent reaches where BRAT capacity estimates are equal to or higher than surveyed dam counts and therefore accurate; the dashed purple line represents the line of perfect agreement. No regression was built between predicted and surveyed dams for the North Fork John Day due to low sample size (n=1 reach with observed dams).

North Fork John Day Watershed HUC 8

Our Google Earth census only identified two dams in the North Fork John Day watershed (HUC 8) (Table 6). No beaver dams were found where the model predicted no dams could be supported. No beaver dams were found where the model predicted no dams could be supported. The stream segment with the validation dam count did not exceed the capacity estimates indicating that the model effectively segregates the factors controlling beaver dam occurrence and density 100% of the time (Figure 22). Validation data can be found here.

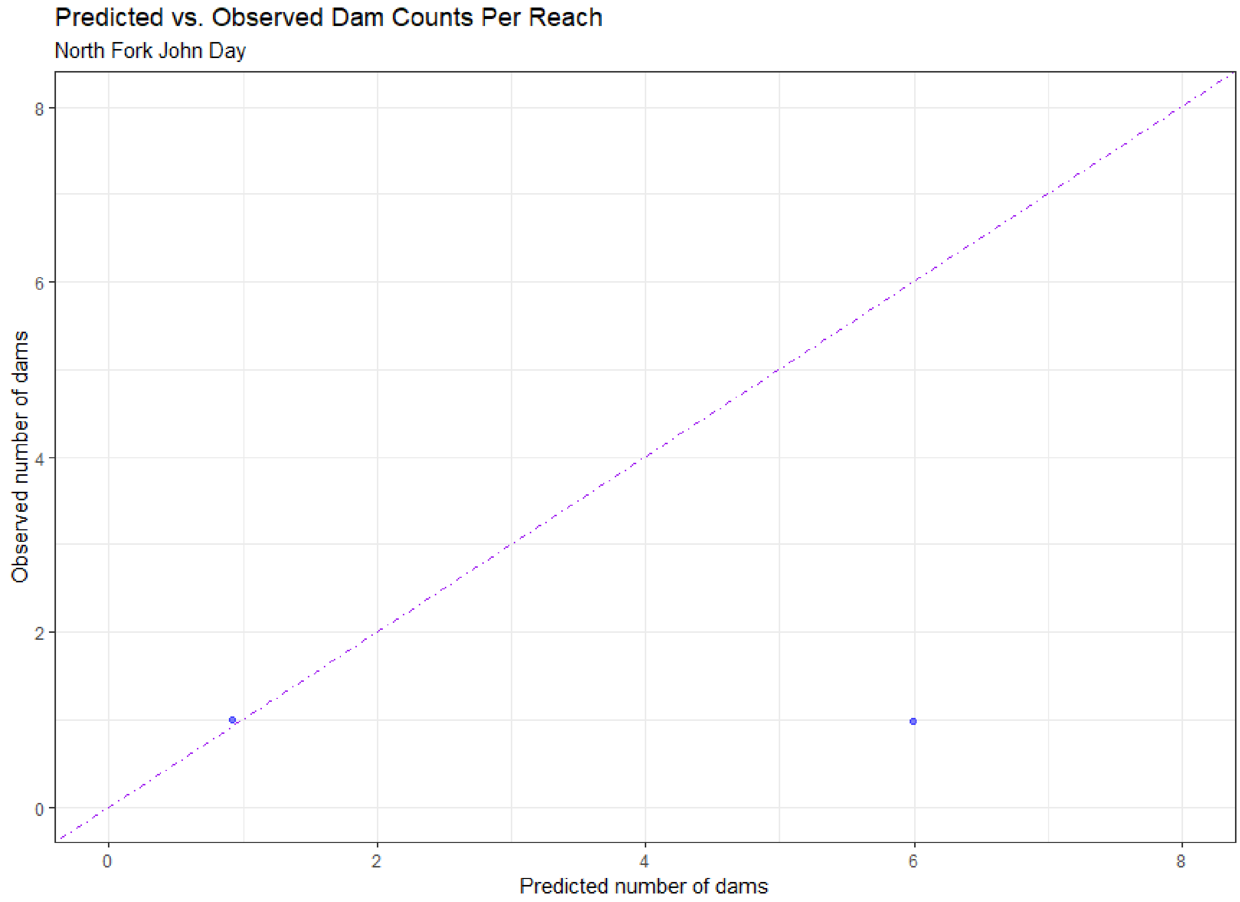


Figure 22: Predicted vs. observed dam counts (per reach) North Fork John Day watershed (HUC 8). Red points represent reaches where BRAT underestimates dam capacity; blue points represent reaches where BRAT capacity estimates are equal to or higher than surveyed dam counts and therefore accurate; the dashed purple line represents the line of perfect agreement. No regression was built between predicted and surveyed dams for the North Fork John Day due to low sample size (n=2 reaches with observed dams).

Upper John Day Watershed HUC 8

A total of 9 dams were identified across the Upper John Day watershed (HUC 8) (Table 7). As such, we verified the performance of the existing capacity model using these 9 dams representing 0.04% of the 3,316 kilometers of perennial streams. No beaver dams were found where the model predicted no dams could be supported. Of the total 5 stream segments with validation dam counts none exceeded the capacity estimates indicating that the model effectively segregates the factors controlling beaver dam occurrence and density 100% of the time (Figure 23). Validation data can be found here.

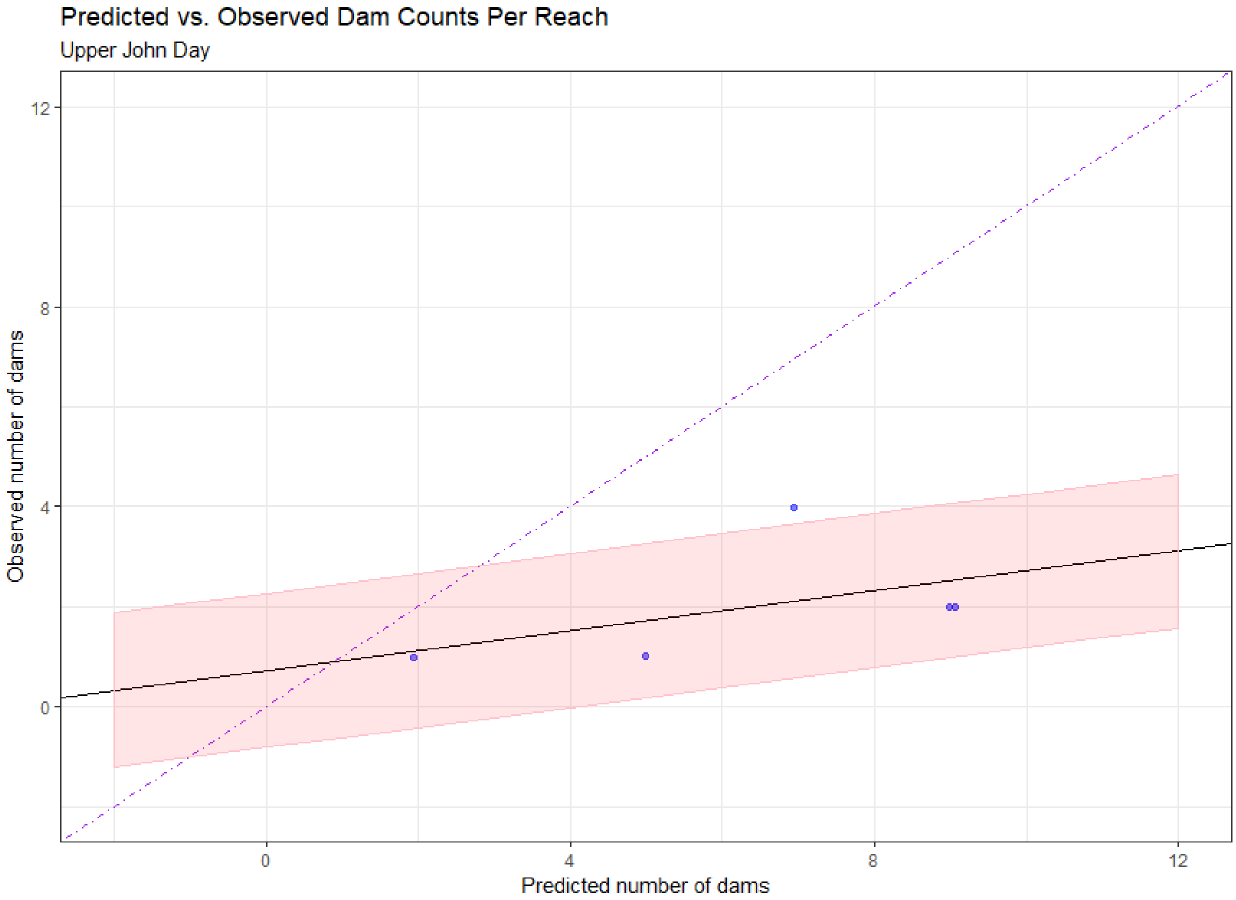


Figure 23: Predicted vs. observed dam counts (per reach) Upper John Day watershed (HUC 8). Red points represent reaches where BRAT underestimates dam capacity; blue points represent reaches where BRAT capacity estimates are equal to or higher than surveyed dam counts and therefore accurate; the dashed purple line represents the line of perfect agreement; the solid black line is the regression between observed and predicted dams with 95% confidence intervals in pink.

Do the electivity indices increase appreciably from the *none* to the *pervasive* class?

The Electivity index show that in the Middle Fork, North Fork, and Upper John Day watersheds that beavers preferentially dam in reaches with higher modelled dam capacity while avoiding those with lower capacity. That is, beaver exhibited avoidance of reaches predicted as supporting none, rare or occasional densities, and beaver exhibited preference for areas predicted as having frequent or pervasive dam densities. However, as mentioned above, we had only a small number of actual dams to verify the model's performance in these watersheds. Based on this limited sample size we found that model performance was good with electivity indices that effectively segregated out amongst the capacity categories.

Table 4, shows that the model run with LANDFIRE data in the Lower John Day watershed underestimated capacity making it appear that beaver are preferring reaches in the rare and occasional capacity categories. Table 5, Table 6 and Table 7 show that in the Middle Fork, North Fork, and Upper John Day watersheds that beavers preferentially dam in reaches with higher modelled dam capacity while avoiding those with lower capacity. That is, beaver exhibited avoidance of reaches predicted as supporting *none*, *rare* or *occasional* densities, and beaver exhibited preference for areas predicted as having *frequent* or *pervasive* dam densities. However, as mentioned above, we had only a small number of actual dams to verify the model's performance in these watersheds. Based on this limited sample size we found that model performance was good with electivity indices that effectively segregated out amongst the capacity categories.

Table 4: Existing number of dams and BRAT modeled capacity estimates for Lower John Day watershed (HUC 8).

Segment Type	Stream Length	Stream Length	% of Drainage Network	Surveyed Dams	BRAT Estimated Capacity	Average Surveyed Dam Density	Average BRAT Predicted Capacity	% of Modeled Capacity	Electivity Index
	m	*km*	*%*	*# of dams*	*# of dams*	*dams/km*	*dams/km*	*%*	
None	395,282.7	395.3	14%	0	0	0	0	0%	0
Rare	351,757.4	351.8	12%	50	1957	0.14	5.563494186	3%	1.47
Occasional	1,457,671.1	1457.7	50%	138	7,606	0.09	5.217912358	2%	0.98
Frequent	484,819.0	484.8	17%	77	5,345	0.16	11.02473225	1%	1.64
Pervasive	215,501.2	215.5	7%	16	4,873	0.07	22.61239873	0%	0.77
Total	**2,905,031.4**	**2,905.0**	**NA**	**281**	**19,781**	**0.10**	**6.81**	**1%**	**NA**

Table 5: Existing number of dams and BRAT modeled capacity estimates for Middle Fork John Day watershed (HUC 8).

Segment Type	Stream Length	Stream Length	% of Drainage Network	Surveyed Dams	BRAT Estimated Capacity	Average Surveyed Dam Density	Average BRAT Predicted Capacity	% of Modeled Capacity	Electivity Index
	m	*km*	*%*	*# of dams*	*# of dams*	*dams/km*	*dams/km*	*%*	
None	103,806.5	103.8	7%	0	0	0	0	0%	0
Rare	17,337.0	17.3	1%	0	98	0.00	5.65265186	0%	0.00
Occasional	413,591.3	413.6	28%	0	1,947	0.00	4.707546076	0%	0.00
Frequent	567,414.8	567.4	38%	0	6,266	0.00	11.04306801	0%	0.00
Pervasive	371,912.8	371.9	25%	1	8,618	0.00	23.17209666	0%	3.96
Total	**1,474,062.3**	**1,474.1**	**NA**	**1**	**16,929**	**0.00**	**11.48**	**0%**	**NA**

Table 6: Existing number of dams and BRAT modeled capacity estimates for North Fork John Day watershed (HUC 8).

Segment Type	Stream Length	Stream Length	% of Drainage Network	Surveyed Dams	BRAT Estimated Capacity	Average Surveyed Dam Density	Average BRAT Predicted Capacity	% of Modeled Capacity	Electivity Index
	m	*km*	*%*	*# of dams*	*# of dams*	*dams/km*	*dams/km*	*%*	
None	235,428.7	235.4	7%	0	0	0	0	0%	0
Rare	37,041.1	37.0	1%	0	200	0	5.399408944	0%	0.00
Occasional	500,938.0	500.9	14%	1	2,389	0.00	4.769053337	0%	3.53
Frequent	1,412,863.7	1,412.9	40%	0	15,803	0	11.18508449	0%	0.00
Pervasive	1,349,097.1	1349.1	38%	1	32,850	0.00	24.34961931	0%	1.31
Total	**3,535,368.6**	**3,535.4**	**NA**	**2**	**51,242**	**0.00**	**14.49**	**0%**	**NA**

Table 7: Existing number of dams and BRAT modeled capacity estimates for Upper John Day watershed (HUC 8).

Segment Type	Stream Length	Stream Length	% of Drainage Network	Surveyed Dams	BRAT Estimated Capacity	Average Surveyed Dam Density	Average BRAT Predicted Capacity	% of Modeled Capacity	Electivity Index
	m	*km*	*%*	*# of dams*	*# of dams*	*dams/km*	*dams/km*	*%*	
None	200,948.3	200.9	6%	0	0	0	0	0%	0
Rare	151,263.2	151.3	5%	0	787	0	5.2028512	0%	0.00
Occasional	1,134,099.8	1134.1	34%	0	5,481	0.00	4.832908002	0%	0.00
Frequent	1,274,251.7	1,274.3	38%	0	13,966	0	10.96015797	0%	0.00
Pervasive	556,075.6	556.1	17%	9	12,761	0.02	22.94832056	0%	5.96
Total	**3,316,638.5**	**3,316.6**	**NA**	**9**	**32,995**	**0.00**	**9.95**	**0%**	**NA**

Are spatial predictions coherent and logical?

Lower John Day

Figure 24 shows how LANDFIRE data failed to capture the riparian vegetation classes along Bridge Creek, resulting in an underestimation of beaver dam capacity. Specifically, the BRAT model estimated ‘Occasional’ dam building capacity (2-8 dams per mile) along Bridge Creek whereas surveyed dam locations showed that these reaches can support ‘Pervasive’ dam building (24-64 dams per mile). Given the high density of dams observed on Bridge Creek and the reliance of beaver dam building activities on streamside vegetation, we can assume that preferred riparian vegetation is present along this reach. Existing vegetation suitability derived from LANDFIRE, however, shows moderately and barely suitable vegetation along Bridge Creek. This is a good example of two downfalls associated with LANDFIRE data: 1) low resolution data that does not capture details below 30-by-30 m pixel, and 2) misidentification of vegetation.

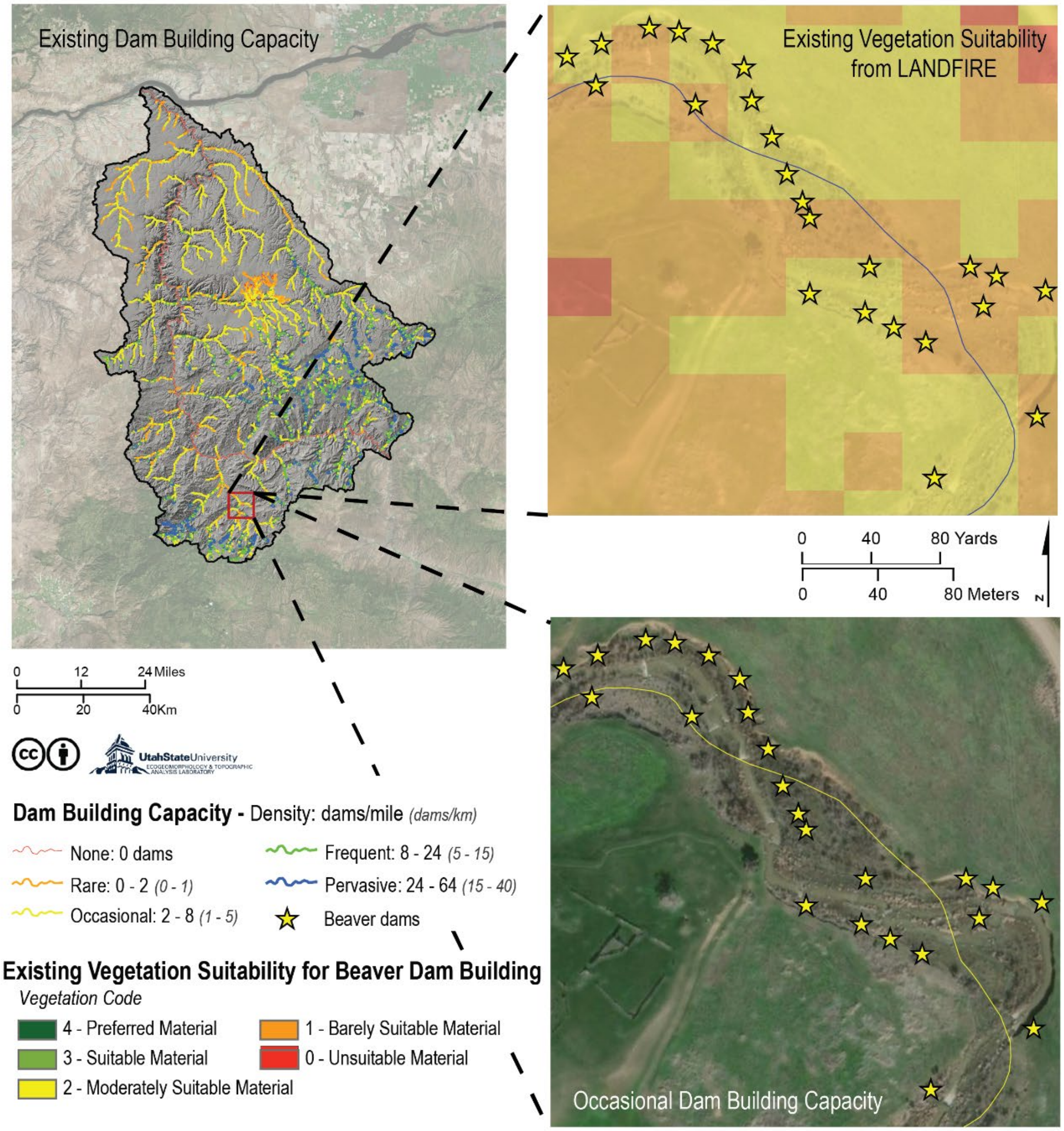


Figure 24: Map showing Bridge Creek in the Lower John Day watershed and how LANDFIRE data failed to capture the narrow riparian corridor in this deeply incised stream.

Middle Fork John Day

With only one actual dam identified in the Middle Fork John Day watershed we were unable to determine if the capacity model predictions were spatially coherent and consistent.

North Fork John Day

With only two actual dams identified in the North Fork John Day watershed we were unable to determine if the capacity model predictions were spatially coherent and consistent.

Upper John Day

We used existing dam location data (*n* =9) from the Upper John Day watershed to ascertain whether the beaver dam capacity model predictions are coherent and logical. In Figure 25 we highlight the contrast between existing and historic capacity predictions, the number and location of existing beaver dams, to show that the capacity model predictions were spatially coherent and consistent. We also illustrate that the highest density of beaver dams identified in Google Earth were located on a reach where the BRAT model estimated pervasive capacity.

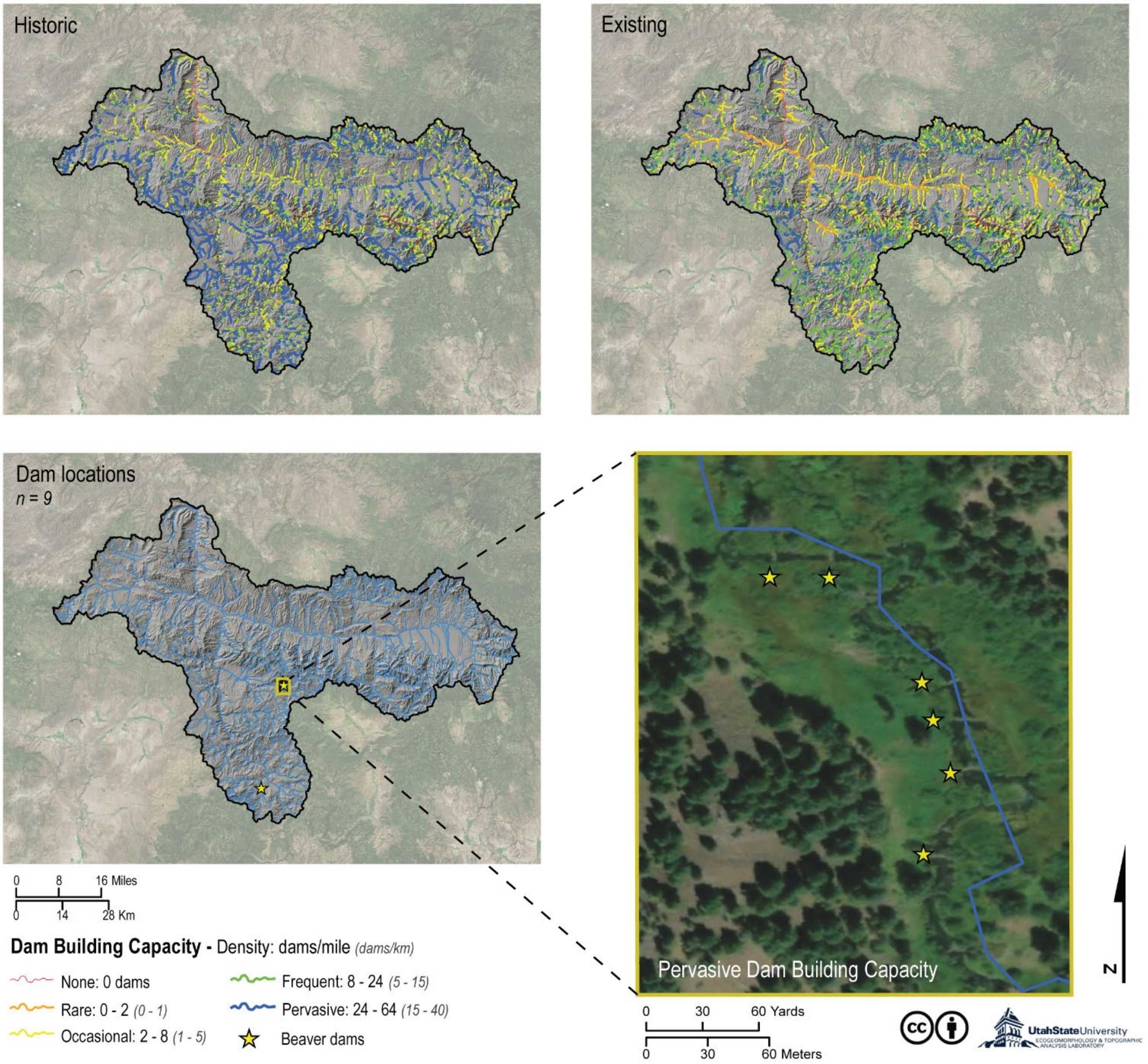


Figure 25: Map of BRAT historic capacity estimates (upper left), existing capacity estimates (upper right), and surveyed beaver dam locations (n=9; lower left) for the Upper John Day watershed (HUC 8). At lower right, an inset where 6 surveyed beaver dam locations correspond with a reach BRAT identified as capable of supporting 'Pervasive' capacity.

Deliverables

The contracted deliverables were:

1. Complete run of standard latest BRAT on the perennial portion of the 1:24K NHD network (11,279 KM of stream) segmented at 300 m including:
    - Existing (based on 2014 LANDFIRE data, the most current data available) beaver dam capacity estimates (dams /km)

        - Refine model using improved vegetation data analysis
        - Refine model using improved stream network
    - Historic beaver dam capacity estimates (based on LANDFIRE BPS data (dams /km)
    - Potential for human beaver conflict (probability)
        - Refine conflict model (include public tolerance to beaver dams).
    - Beaver management, restoration and conservation predictions
        - Refine management model to reflect North Fork John Day Watershed Council management priorities. PI will work with North Fork John Day Watershed Council staff to refine models as appropriate.
2. Calibration and validation of BRAT performance using available ground-truth data and inventory of existing beaver dams.
3. Google Earth-based virtual inventory of existing beaver dams and field based data collection of dam locations.

GIS data layers

The GIS data layers that make up the maps are available in KMZ here, shapefile here and layer package formats here and enable visualization and querying in GIS programs. We encourage the use of the layer packages because this format provides all the inputs, intermediates and outputs symbolized in a standard format which increases their usability. Viewing the KMZ files in Google Earth or ArcGIS Earth is an effective way to visualize and interrogate these *output* datasets because of the 3-D capabilities, image rendering speed and the quality of the base imagery. If you need help using the GIS data we have developed a series of tutorial videos and other instructions found here. For non-GIS users we have generated an Esri Story Map of the project that can be viewed here and a map atlas of BRAT outputs which, can be found here.

DISCUSSION & RECOMMENDATIONS

Caveats

Although BRAT was run with freely-available, national data, and produces reasonable results, some caveats should be kept in mind:

- The capacity models are only as good as the inputs. As shown in the results section the logic of the capacity model and model performance appears robust (i.e. the model gets the right answers for the right reasons and the wrong answers for the right reasons – namely, if the inputs are inaccurate). However, this does not mean that the model will be correct on each and every reach of stream that was modeled.
- The vegetation mapping, digital elevation model and drainage network (stream position) mapping are all relatively coarse, and have inherent inaccuracies when examined at scales at the limits of their precision. This run of BRAT helps sample across reasonable extents at reasonable, reach-scale resolutions to make the significance of those inaccuracies less impactful. As such, model verification shows that the model does a good job at capturing capacity in most cases.
- Small streams with narrow bands of riparian vegetation may not have the spatial extent to be resolved in 30 m datasets, like LANDFIRE. This is particularly true for highly incised streams, such as, Bridge Creek because incised streams are hydrologically disconnected from their channels and as floodplains and channels are decoupled, riparian plant performance declines, eliminating the existence of many riparian species. As such, in such settings, higher resolution vegetation inputs may be more appropriate (e.g., Macfarlane et al., 2016), or an on-the-ground assessment may be necessary. Fortunately, with minor modifications, the BRAT tool can be run with higher resolution input data. Even with this know limitation, we still believe that 30 m resolution LANDFIRE data is an appropriate input for watershed-scale evaluations of beaver dam capacity.

- While investment in higher resolution data could improve the precision of the model outputs in some localities, and pixel-by-pixel accuracy, it could cost a lot more without that great of an increase in accuracy or utility of the outputs. If these high resolution data become freely available in the future, or very affordable, it may make sense to run an updated version of the BRAT model with new inputs. However, we do not recommend undertaking expensive data acquisition campaigns for the sole purpose of improving the model outputs.
- The capacity model and infrastructure layers are all based on a 2014 snapshot of conditions.
- The BRAT model predicts only the maximum number of dams that can be supported, not the expected number of dams across a given area.
- As shown in Figure 19 there are only 293 actual beaver dams within the John Day basin (HUC 6). The apparent lack of dams in the watershed could be the result of: i) not having sufficient ground data and ii) the difficulties of identifying beaver dams in forested areas using the Google Earth approach.
- Figure 8 shows where there are low-risk restoration and conservation opportunities using beaver. However, this map is an under estimation of opportunities (i.e., conservative)
- How does one determine whether a reach should be a conservation or restoration reach? We suggest comparing realized dam counts to existing capacity. 'Low hanging fruit' reaches at or near capacity should be flagged as conservation reaches where, for example, a trapping closure could be implemented. 'Low hanging fruit' reaches with no realized-capacity and/or under-utilized-capacity should be target for restoration and/or translocation. These reaches are good candidates for using BDAs to promote beaver retention. 'Quick-return' reaches are also good candidates for BDAs and better land management to improve conditions for encouraging beaver recovery in the area.
- Figure 9 is a conservative first cut of 'risk' and just because this layer/map shows there to be some risk does not mean that beaver impacts will actually be a problem and if beaver impacts occur, they might easily be mitigated.
- The BRAT model can be manually run as a simple inference system in the field using a data capture form found here. Using the field-based BRAT data form one can override the model outputs that are based on remotely sensed data. The field-based BRAT data collection, that relies on ocular estimates and expert opinion can be done in an opportunistic way as one traverses the watershed or could be a more planned data capture campaign focused on priority restoration areas.
- In this small contract (< $22,000), the expectation management and vision provided by the BRAT model could stand to save millions of dollars. If one considers the cost of current restoration practices, the scope of areas that could use improvement, and the relatively low-cost of beaver-assisted restoration, dramatic gains and improvements could be made.
- As the existing capacity model indicates, the John Day basin is only at 1% of existing capacity indicating there are numerous opportunities throughout the watershed to increase the amount of beaver dam-building activities.

Future versions of BRAT

Since 2014, BRAT has undergone continuous development and is currently undergoing a major overhaul. We are currently working on BRAT 3.1 (this scope of work was run with BRAT 3.0.20) and BRAT 4.x is planned to be released in 2019. While there will be improvements in some of the intermediates and management outputs. The heart of the BRAT model (i.e. the capacity estimates) has not changed and will not change in subsequent versions of BRAT. Moreover, the new BRAT will be fully compatible with RAVE (http://rave.riverscapes.xyz), which allows an ArcGIS user to easily add model outputs to map and view metadata from the project. Unfortunately, BRAT 3.0.20 outputs are not RAVE compliant at this point. Instead, shapefiles and layer packages (to maintain organization and symbology) have been provided here in this report. If significant changes occur in the watershed (e.g. through disturbances like fire, land-use practices and restoration) it may make sense to re-run BRAT capacity model for a future snap-shot in time.

Riverscapes network models to inform management

There are a variety of 'sister' network models in the Riverscapes Consortium (http://riverscapes.xyz). For example, the Riparian Condition Assessment Toolbox (RCAT: http://rcat.riverscapes.xyz), could be quite helpful for examining riparian conditions to contextualize BRAT results as well as exploring recovery potential for riparian improvement to expand beaver dam-building capacity. By contrast, the Geomorphic Network Assessment Tool (GNAT-http://gnat.riverscapes.xyz) could be helpful in terms of building more realistic expectations for defining what is physically and geomorphically possible at a given site.

Beaver management recommendations

Beaver Dam Analogues

From our experience working in locations such as Birch Creek, Idaho (http://beaver.joewheaton.org/logan-workshop-materials.html - See Jay Wilde's story) we have found that building Beaver Dam Analogues (BDAs) at release sites to provide cover from predation can significantly increase the likelihood of successful translocations. As such, we recommend that BDAs be built at release sites where appropriate.

We have also learned that BDAs and PALS (post-assisted log structures) can be an affordable addition to streams and that these structures allow the opportunistic behavior of beaver to be taken advantage of. Specifically, we have seen beaver switch from bank-lodging to dam building where these structural elements are available.

'Living with beaver' strategies

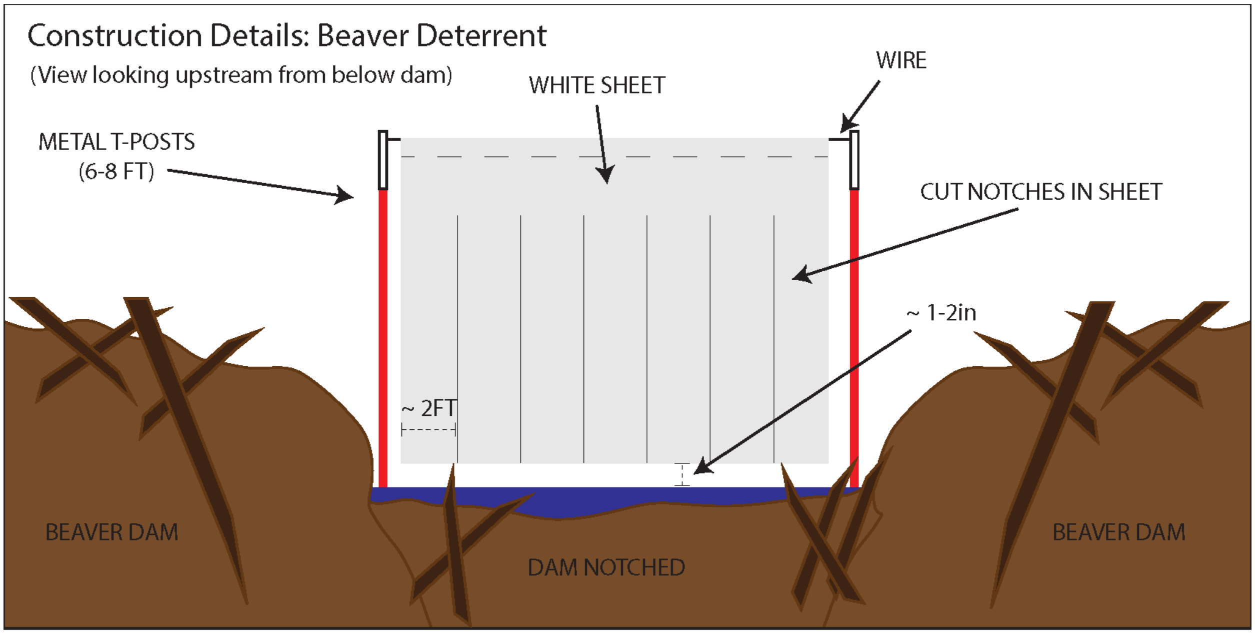
Traditionally, beaver management has relied on lethal trapping to prevent threats to infrastructure posed by beaver dam building activity. The increased awareness of the ecosystem benefits provided by beaver activity and their ability to help achieve a number of restoration goals has spurred the development of approaches capable of mitigating the negative results of beaver activity in order to retain the benefits such activity produces. Here we summarize a number of 'living with beaver' strategies.

Breach dam

Breaching or partial breaching (i.e., notching) a dam is an effective way to mitigate the risk of flooding due to a specific dam, if that dam is no longer being actively maintained by beaver. Breaching, rather than full removal, allows managers to effectively control the water height of the dam while also still retaining the ecosystem services provided by such a dam. Breaching a dam is not an effective strategy if the dam is being actively maintained, given beavers' ability to repair breaches within short periods of time (i.e., hours to days).

Notch dam and install beaver deterrent

In areas where an actively maintained dam is posing a threat of flooding but has not reached a critical level, notching the dam to reduce the pond height and installing a beaver deterrent may reduce the threat of flooding. A beaver deterrent is simply a white sheet that is strung between two fence posts and placed just upstream of the notched dam, such that it can move freely in the wind. The sheet is cut vertically to create strips that can blow in the wind. The movement of the sheet deters beaver from repairing the notched dam (Figure 26). This approach is very inexpensive and an excellent first approach to dealing with potentially threatening pond heights.



Construction Notes

1. Notch dam to desired pond level height.
2. Pound 6-8 ft. metal fenceposts just upstream of dam notch. Fencepost length depends on depth of pond/height of dam)
3. Attach 11-gauge or baling wire between the tops of fenceposts.
4. Affix white sheet or Tyvek house wrap to wire between fenceposts ~1-2 inches above pond water level. Clamps, clothespins, or sewing a sleeve can all be used to attach the sheet to wire.
5. Cut slits into the sheet spaced ~ 2ft.

Figure 26: Schematic of a beaver deterrent used to control pond height.

Install pond leveler to control pond height

Pond levelers are another way managers and land owners can mitigate the risk of flooding due to beaver activity while allowing beaver to remain in a given area. Pond levelers installation typically requires a half-day of labor for 2-3 people and materials cost approximately $600 – 1000 depending on site specific conditions. A pond leveler consists of a flexible, perforated plastic pipe that has an inflow protected by a large metal cage and is anchored to the bottom of the pond, and runs through the dam, and is set at the desired water level height. It may be necessary to notch the dam in order to set the pipe at the desired pond height. Following installation, we recommend placing additional material over the end of the pipe in order to prevent beaver from clogging the outflow. Examples of a pond leveler installation are shown in Figure 27.

Figure 27: Pond leveler installation. From left: securing flexible pipe in cage to protect inflow from being clogged; placing pipe into beaver pond; rebuilding beaver dam after setting pipe into notched dam at desired water height.

Beaver deterrent to prevent culvert/irrigation diversion clogging

As shown above beaver deterrents (Figure 26) can be used pre-emptively in order to prevent beaver from becoming active in areas that are determined to be high risk. We recommend using beaver deterrents where streams are diverted for irrigation.

Removal, live trapping and relocation

If beaver activity is having a negative impact and/or posing unacceptable risks, and 'living with beaver' strategies have proved ineffective, then removal, whether by live trapping and relocation or lethal trapping may be required. We strongly recommend live-trapping and relocation in order to maintain the benefits of beaver activity elsewhere in the watershed, and further recommend that lethal trapping should be treated as a last resort. While we recognize that beaver activity may pose a threat at any time of year, we recommend, when possible that trapping and relocation do not take place during winter months, when their chances of survival are limited. Choosing an appropriate relocation site, with suitable habitat, and limited threats to infrastructure is also critical.

CONCLUSIONS

With the development of the John Day basin BRAT model the scope of what is possible in terms of partnering with beaver for restoration is now clearly defined and mapped. For example, the 'easiest: low-hanging fruit' reaches identified in Figure 8 should be further analyzed for beaver related conservation and restoration. We believe the John Day basin BRAT model helps build realistic expectations about what beaver dam-building may achieve locally on a given stream, and also helps scale-up those expectations at the watershed level. BRAT model outputs can be used to initialize restoration and conservation planning and can also support initial conceptual design and siting of specific restoration actions. BRAT model outputs can also aid with expectation management, and conservation and restoration prioritization.

As we well know, beaver dam building activities can cause conflict where valuable infrastructure and/or land is impacted. Many conflicts can be managed to minimize damage while ensuring animal welfare and delivering ecosystem benefits. Understanding the capacity of streams to support dam building and identifying areas of risk and opportunity is therefore critically important for the effective beaver management. This application of BRAT provides the information needed to understand actual and potential beaver dam capacities, where human infrastructure is present, where nuisance beaver can be relocated, where 'living with beaver' strategies may be needed and where beaver can be employed in watershed conservation and restoration efforts to recover degraded streams, meadows and wetlands.

ACKNOWLEDGMENTS

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APPENDIX A: JOHN DAY BASIN BRAT ATLAS

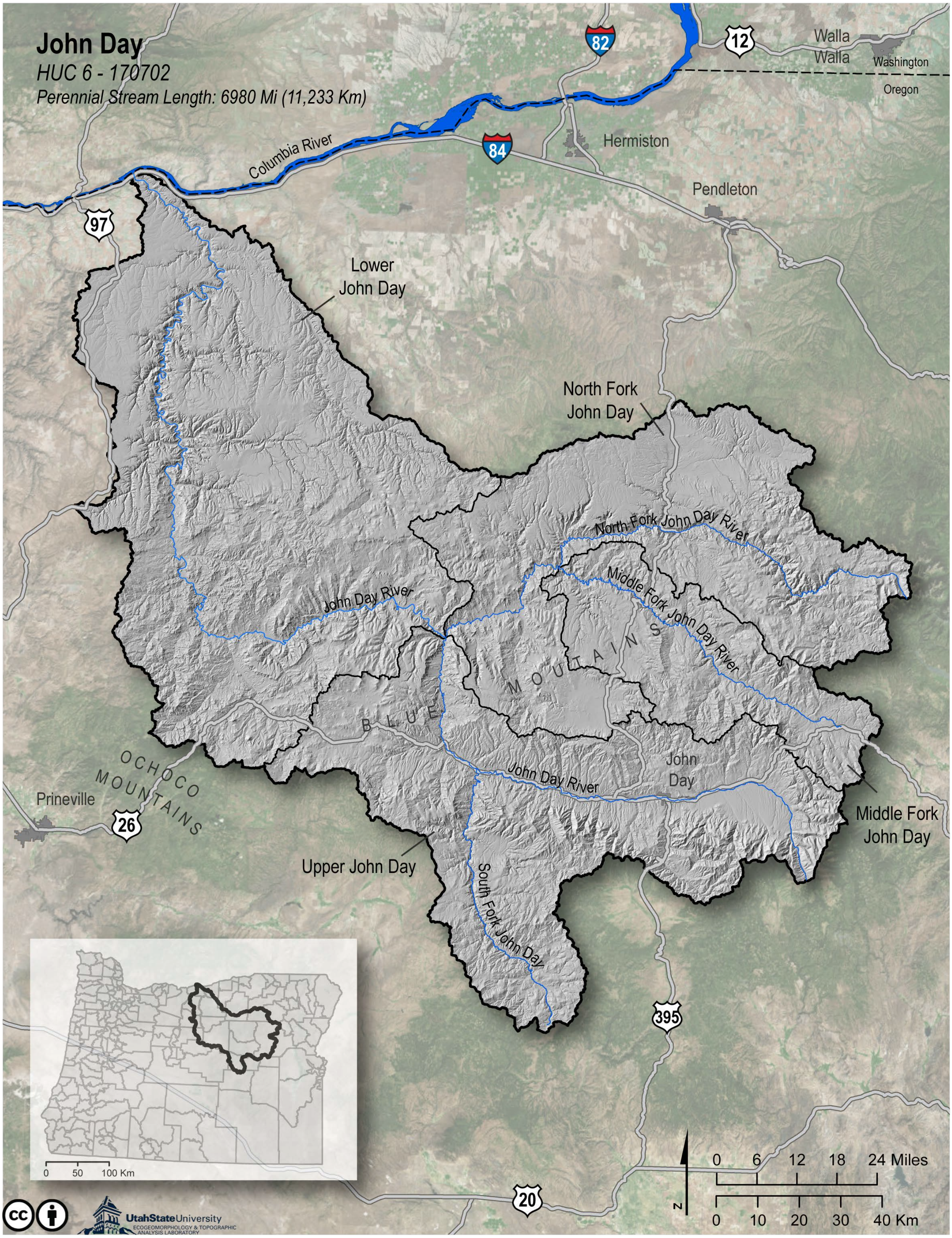
The John Day Basin BRAT Atlas includes maps of existing beaver dam capacity, historic beaver dam capacity, potential risks and conservation and restoration opportunities for the John Day basin and can be downloaded as a separate PDF file here.

Beaver Restoration Assessment Tool (BRAT) Atlas

John Day
Inputs

UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY

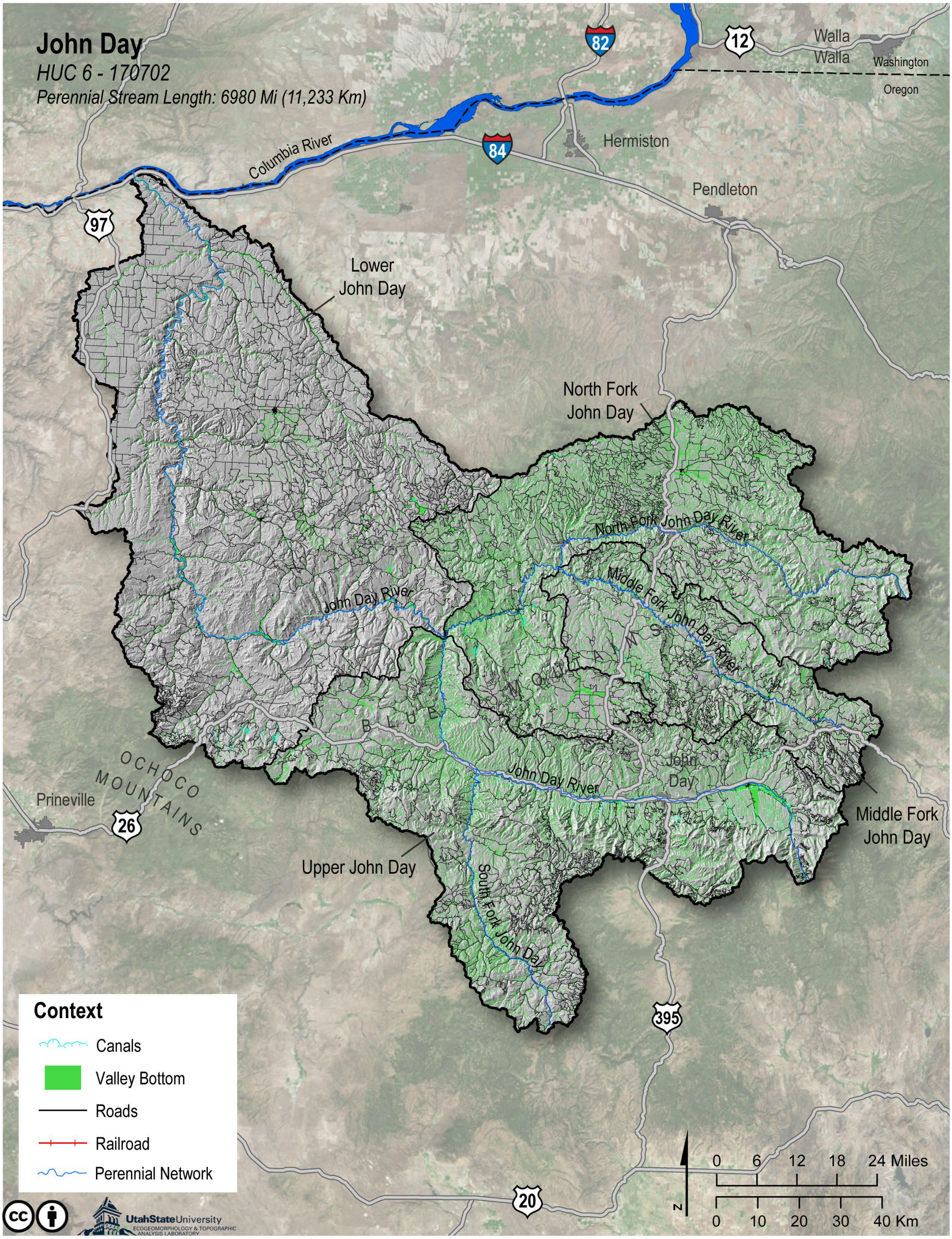
UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY
@FHC THE FLUVIAL HABITATS CENTER



John Day

HUC 6 - 170702

Perennial Stream Length: 6980 Mi (11,233 Km)


John Day
HUC 6 - 170702
Perennial Stream Length: 6980 Mi (11,233 Km)
82
12
Walla Walla
Washington
Oregon
Columbia River
84
Hermiston
Pendleton
97
Lower John Day
North Fork John Day
North Fork John Day River
Middle Fork John Day River
John Day River
BLUE MOUNTAINS
OCHOCO MOUNTAINS
Prineville
26
John Day
Middle Fork John Day
Upper John Day
South Fork John Day
395
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Context
Canals
Valley Bottom
Roads
Railroad
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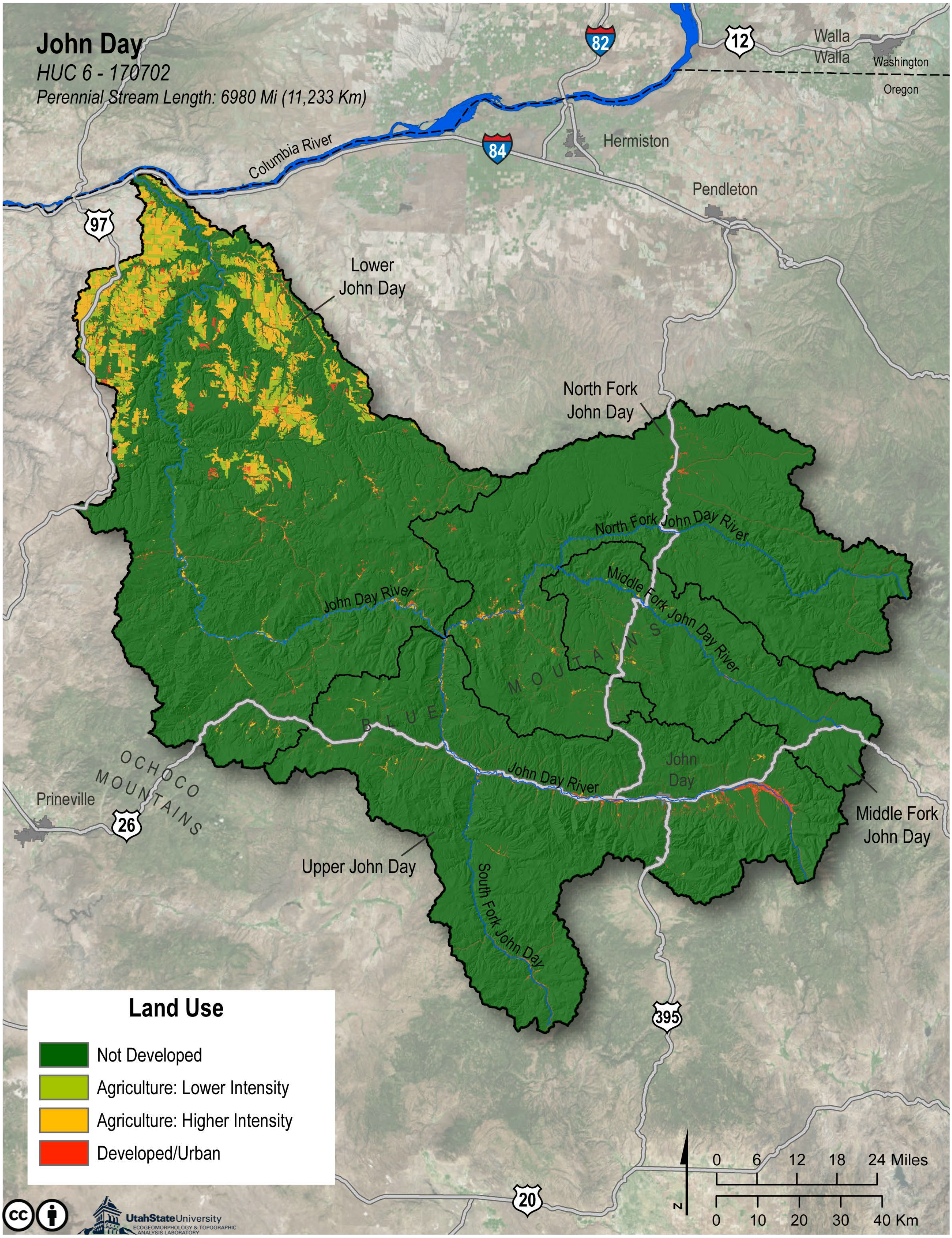
UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY



John Day

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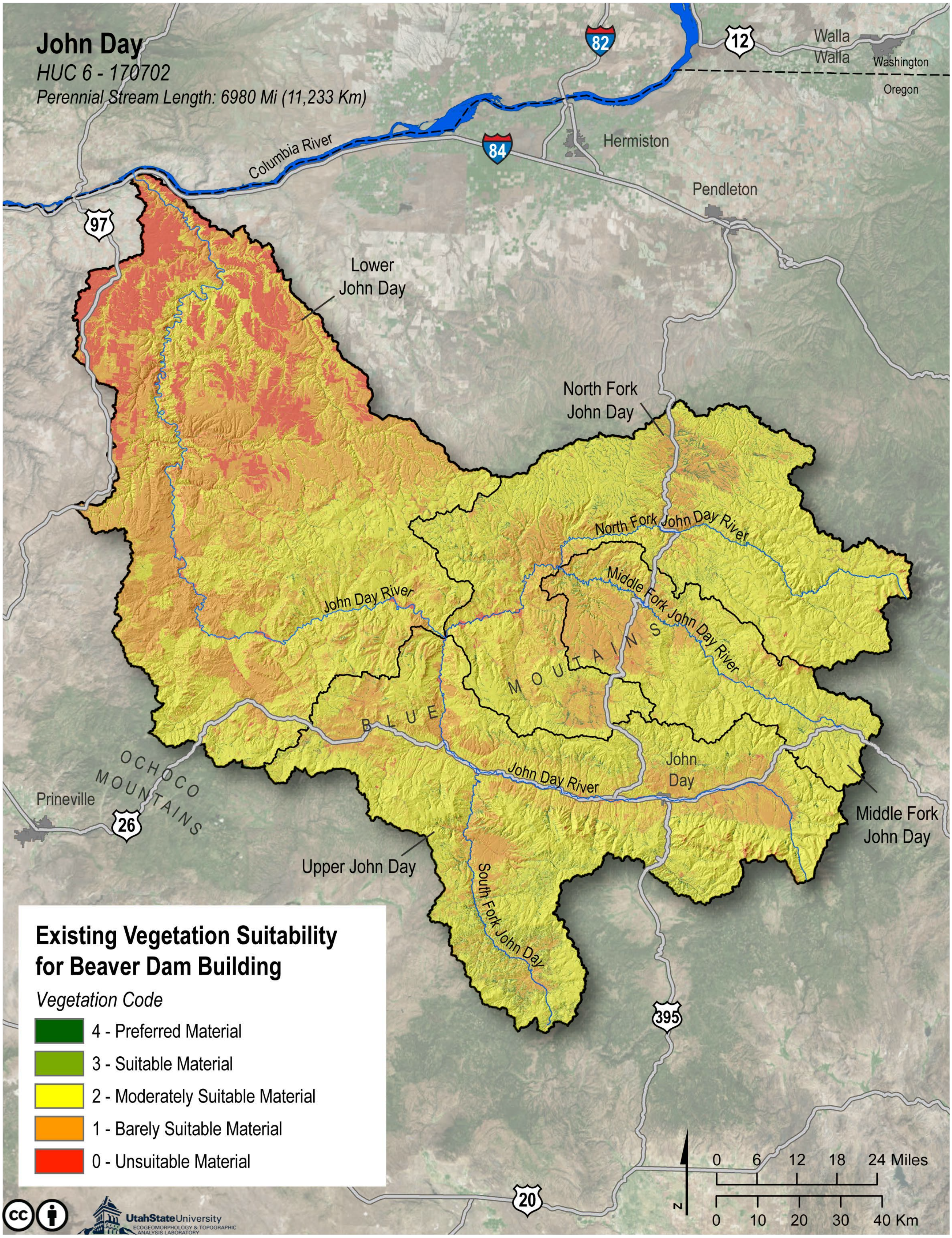
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John Day River
BLUE MOUNTAINS
OCHOCO MOUNTAINS
Prineville
26
John Day River
John Day
Middle Fork John Day
Upper John Day
South Fork John Day
395
20
Existing Vegetation Suitability for Beaver Dam Building
Vegetation Code
4 - Preferred Material
3 - Suitable Material
2 - Moderately Suitable Material
1 - Barely Suitable Material
0 - Unsuitable Material
N
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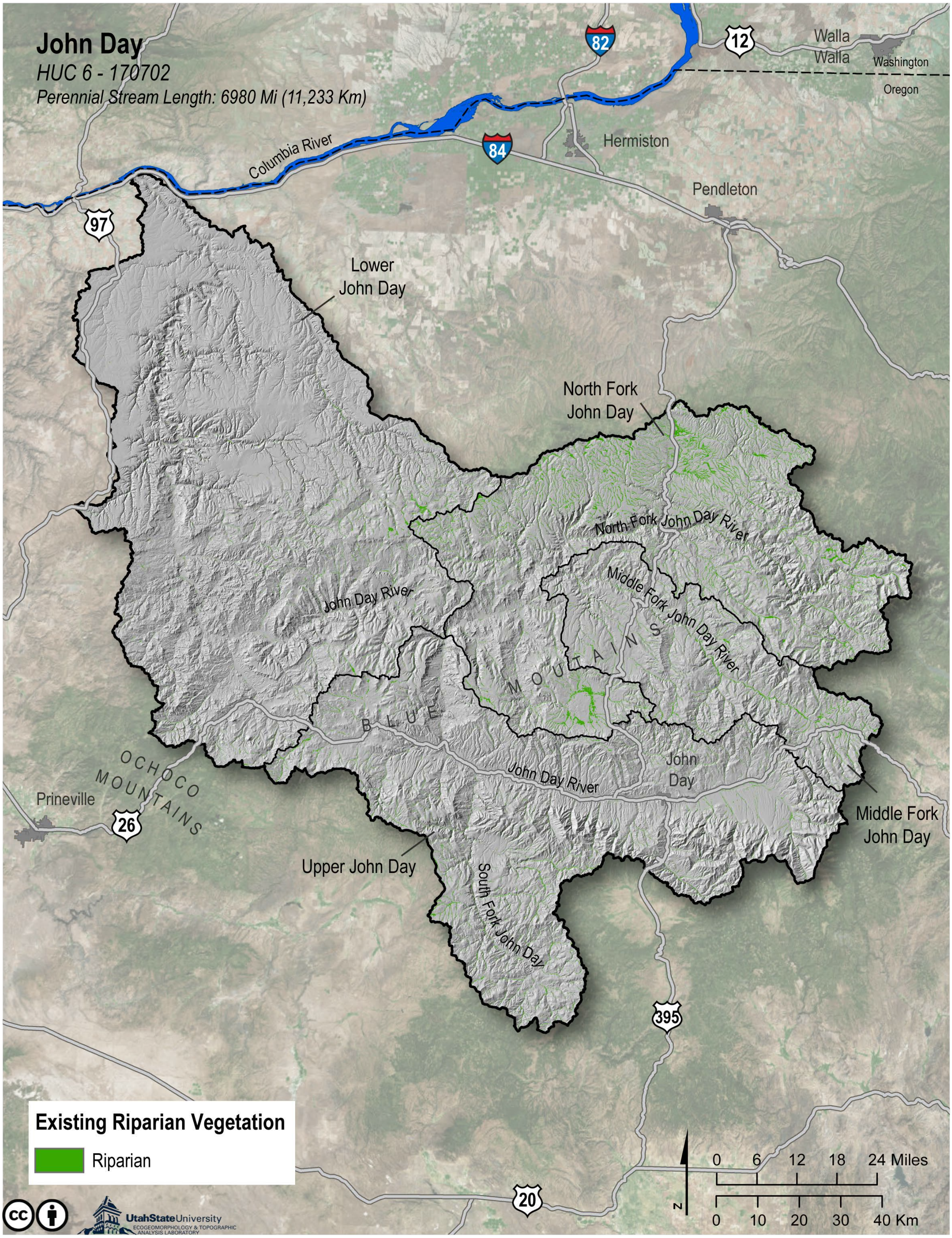
UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY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BLUE MOUNTAINS
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Prineville
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Upper John Day
South Fork John Day
395
Existing Riparian Vegetation
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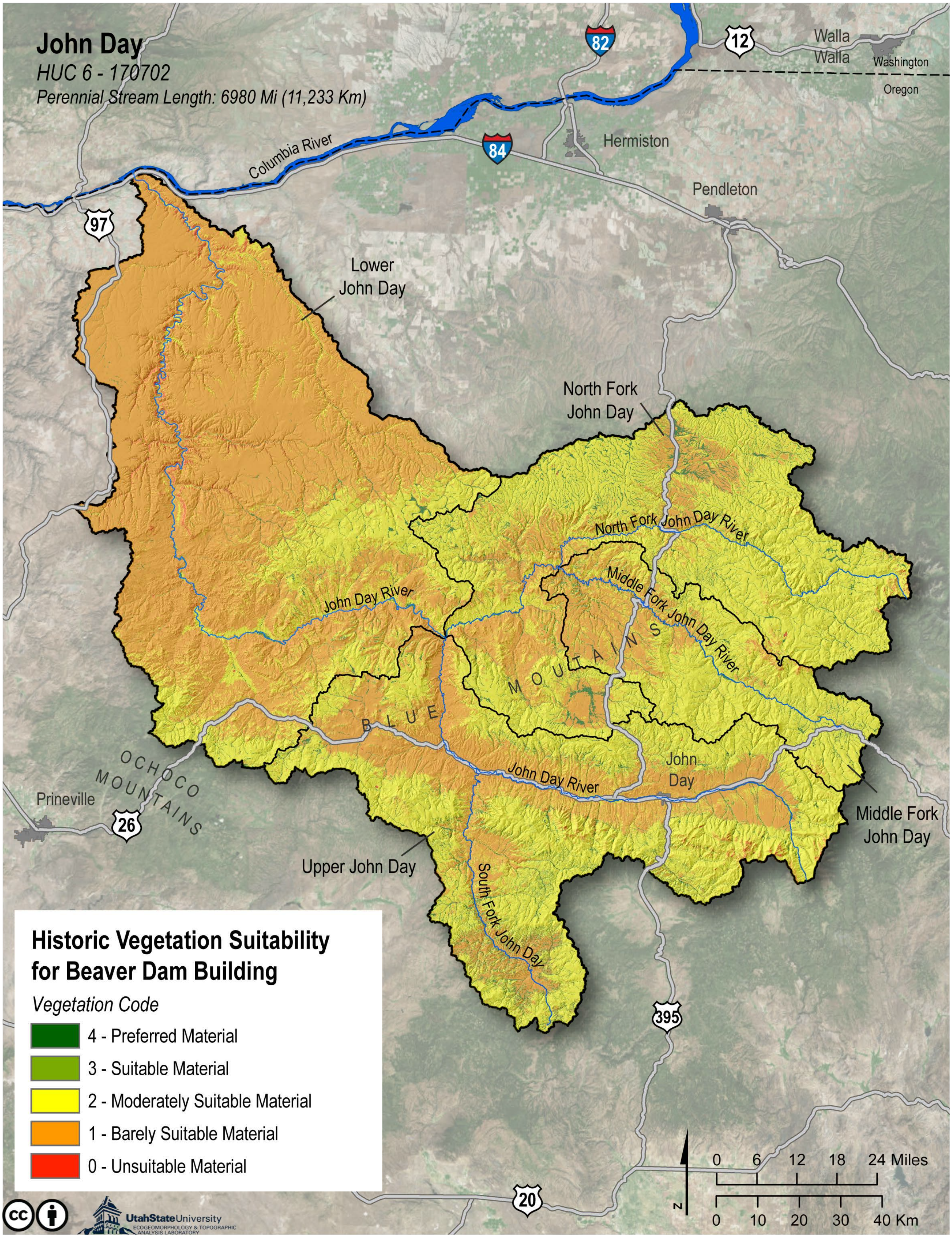
UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY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Middle Fork John Day River
John Day River
BLUE MOUNTAINS
OCHOCO MOUNTAINS
Prineville
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John Day
Middle Fork John Day
Upper John Day
South Fork John Day
395
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Historic Vegetation Suitability for Beaver Dam Building
Vegetation Code
🟩 4 - Preferred Material
🟩 3 - Suitable Material
🟨 2 - Moderately Suitable Material
🟧 1 - Barely Suitable Material
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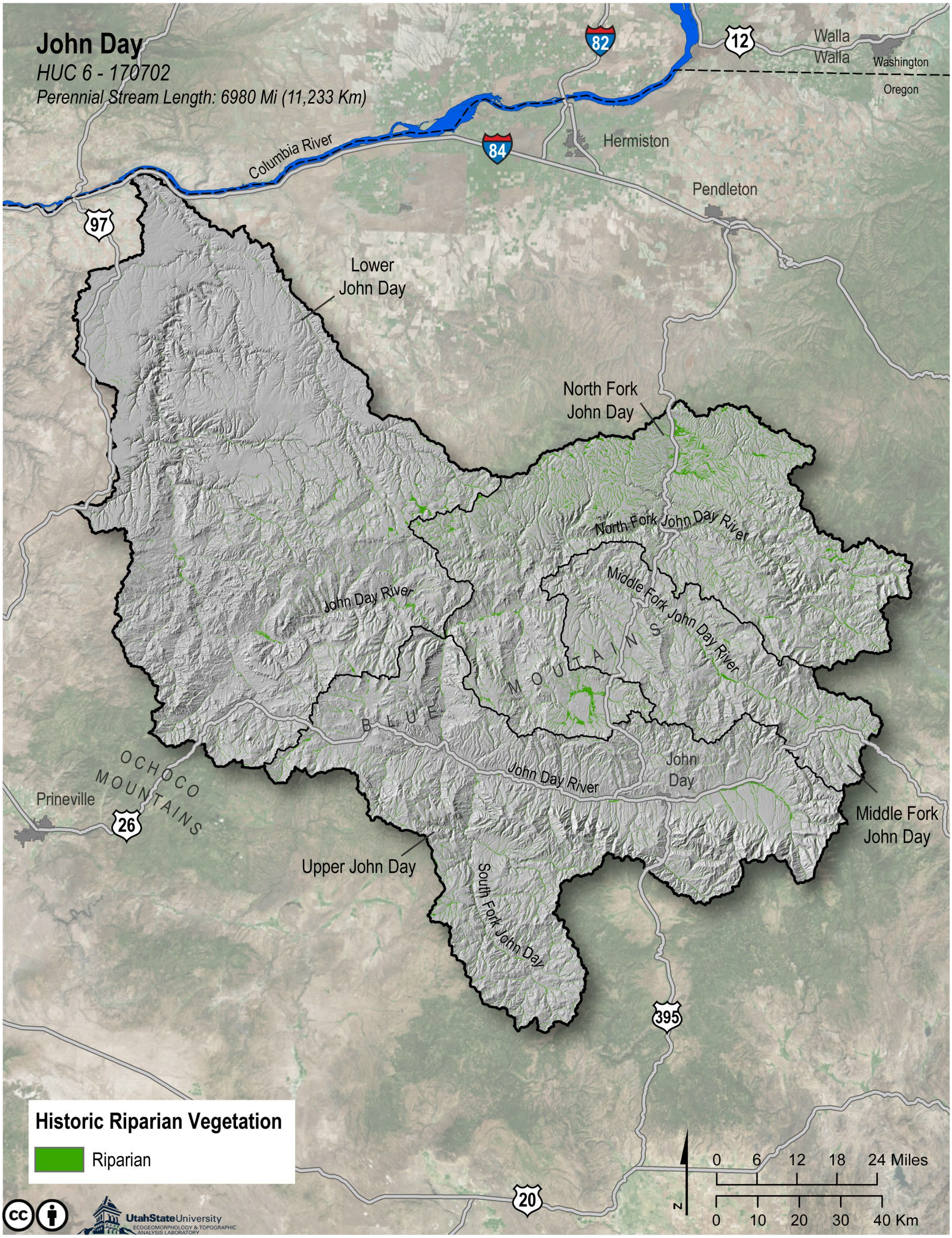
UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY



John Day

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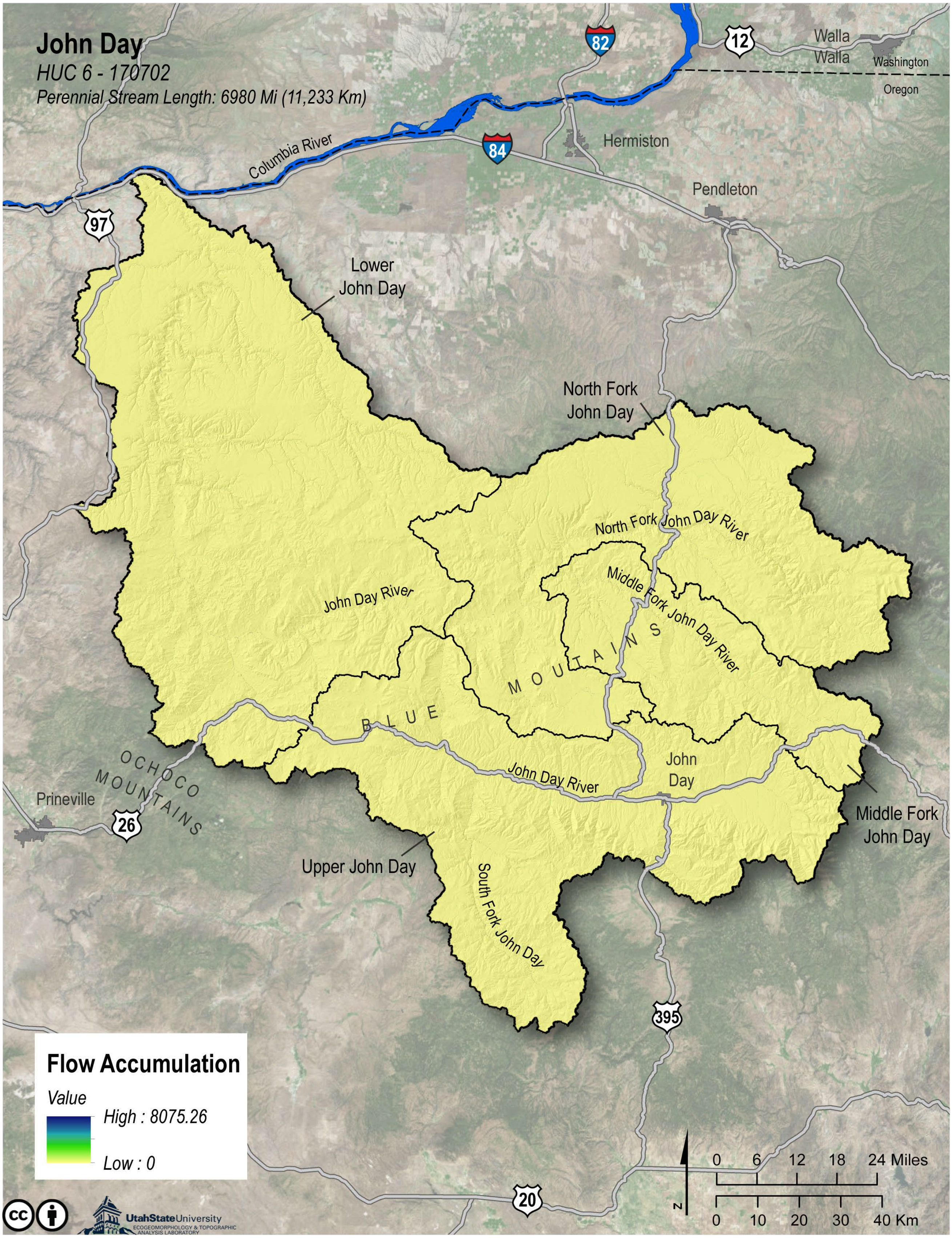
Perennial Stream Length: 6980 Mi (11,233 Km)

Historic Riparian Vegetation

🟩 Riparian



John Day

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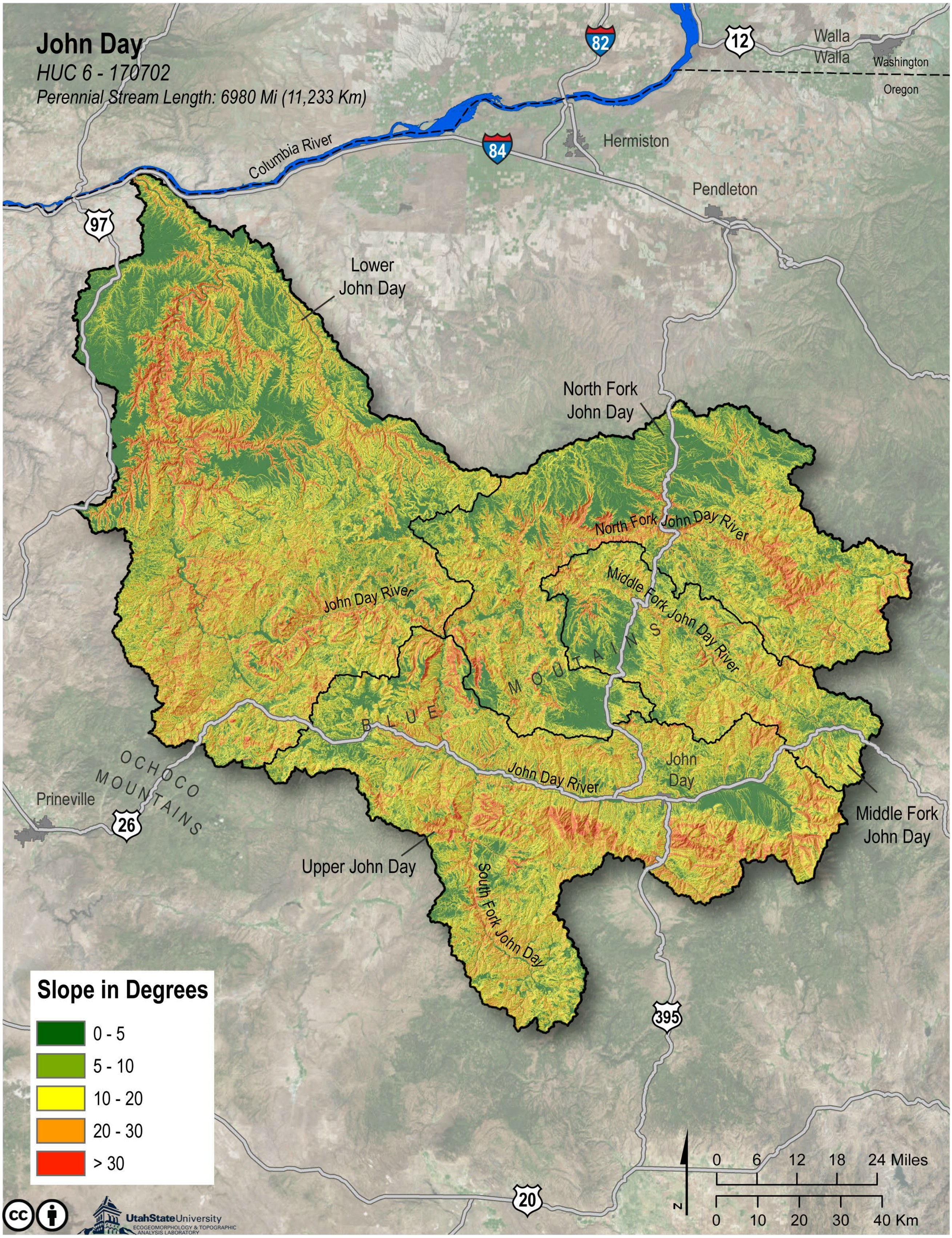
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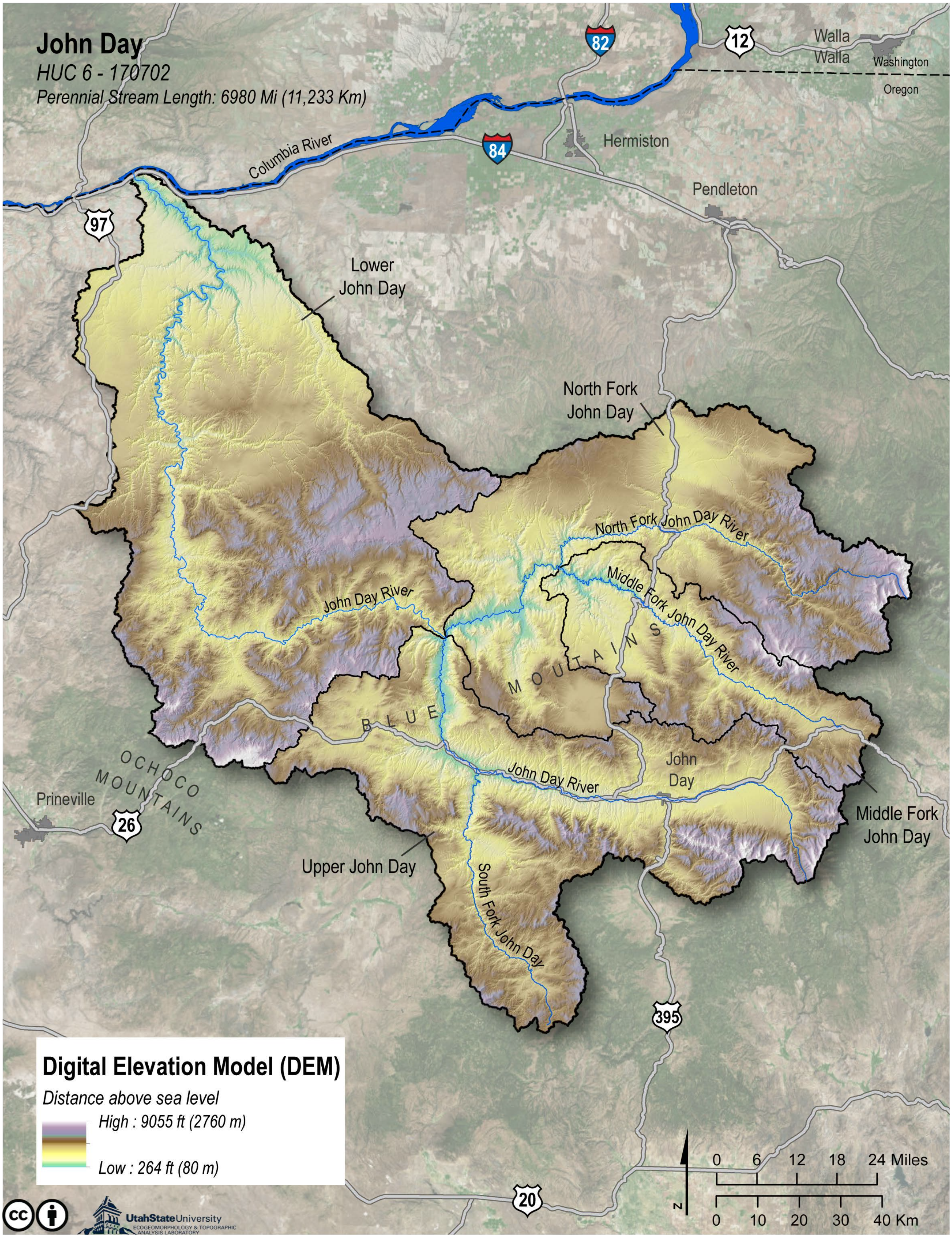
UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY



John Day

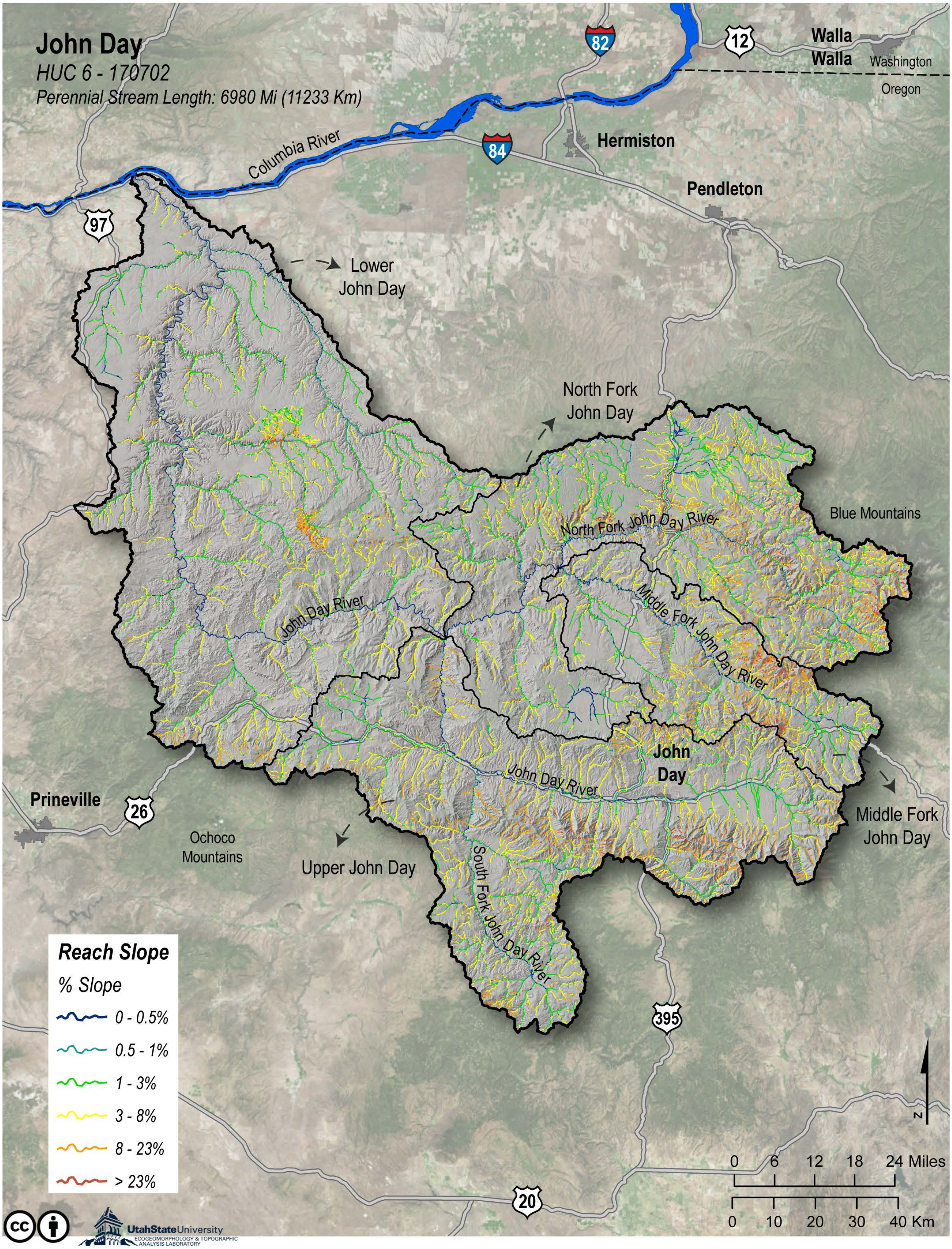
HUC 6 - 170702

Perennial Stream Length: 6980 Mi (11,233 Km)

Beaver Restoration Assessment Tool (BRAT) Atlas

John Day
Intermediates

UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC
ANALYSIS LABORATORY



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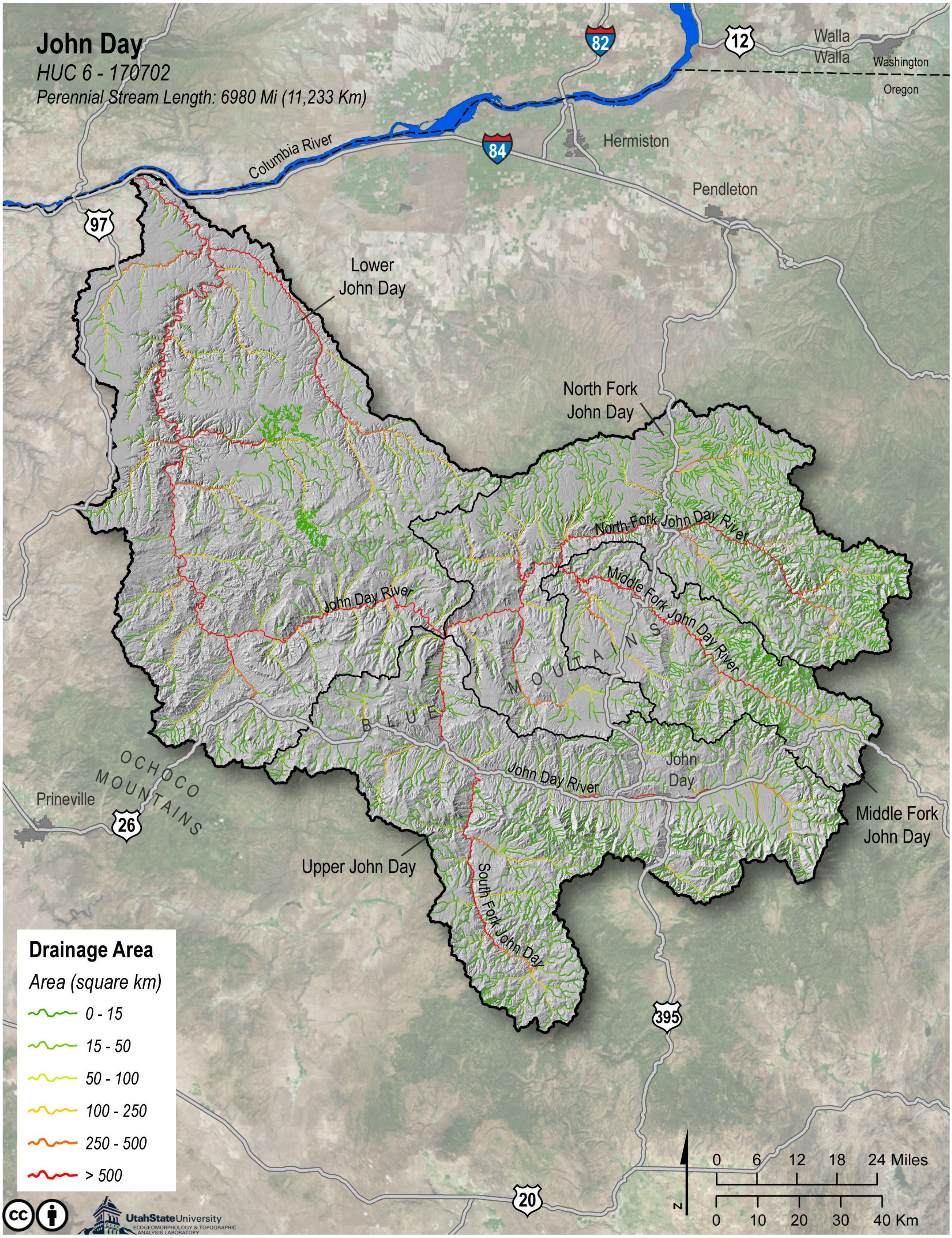
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Drainage Area
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100 - 250
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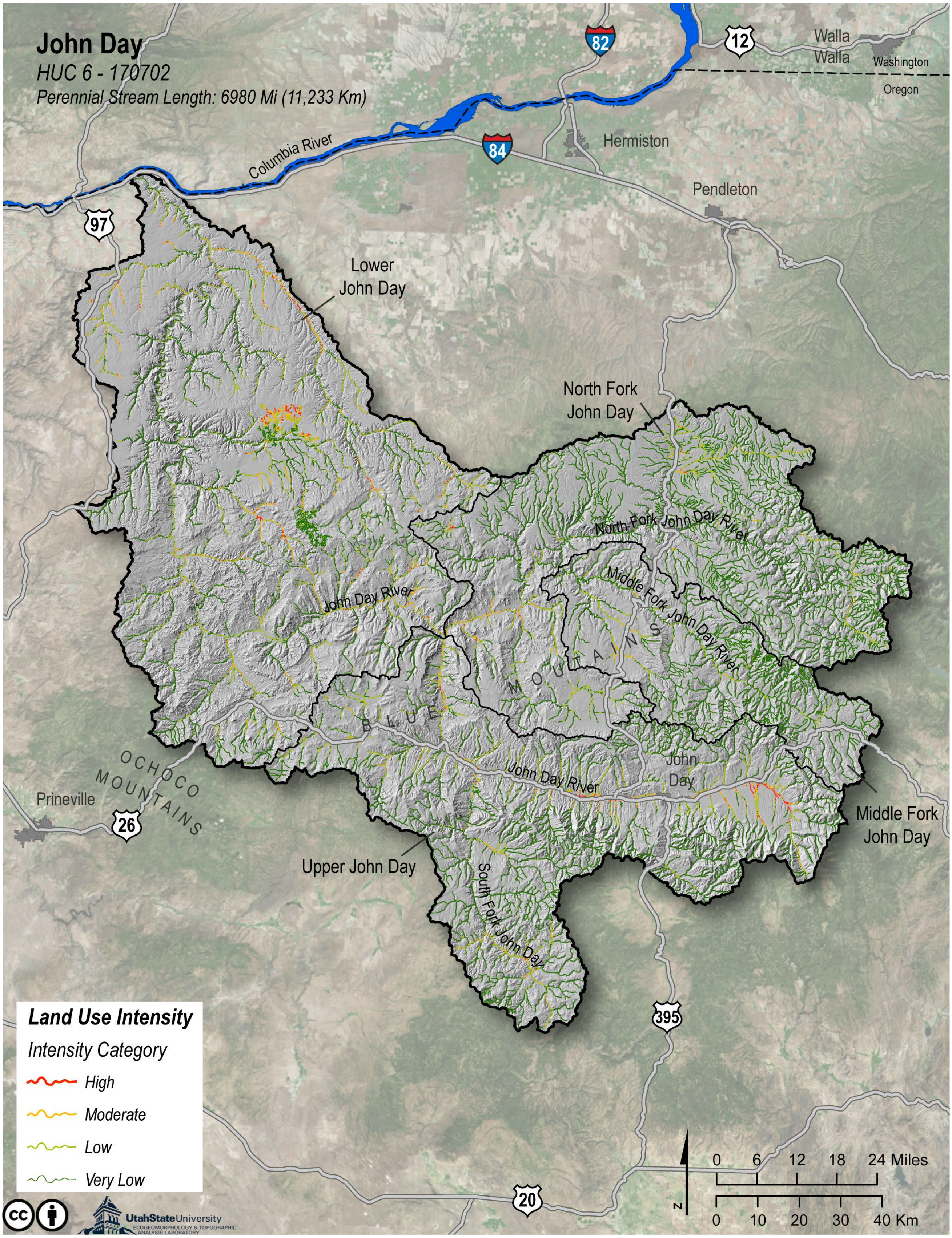
UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY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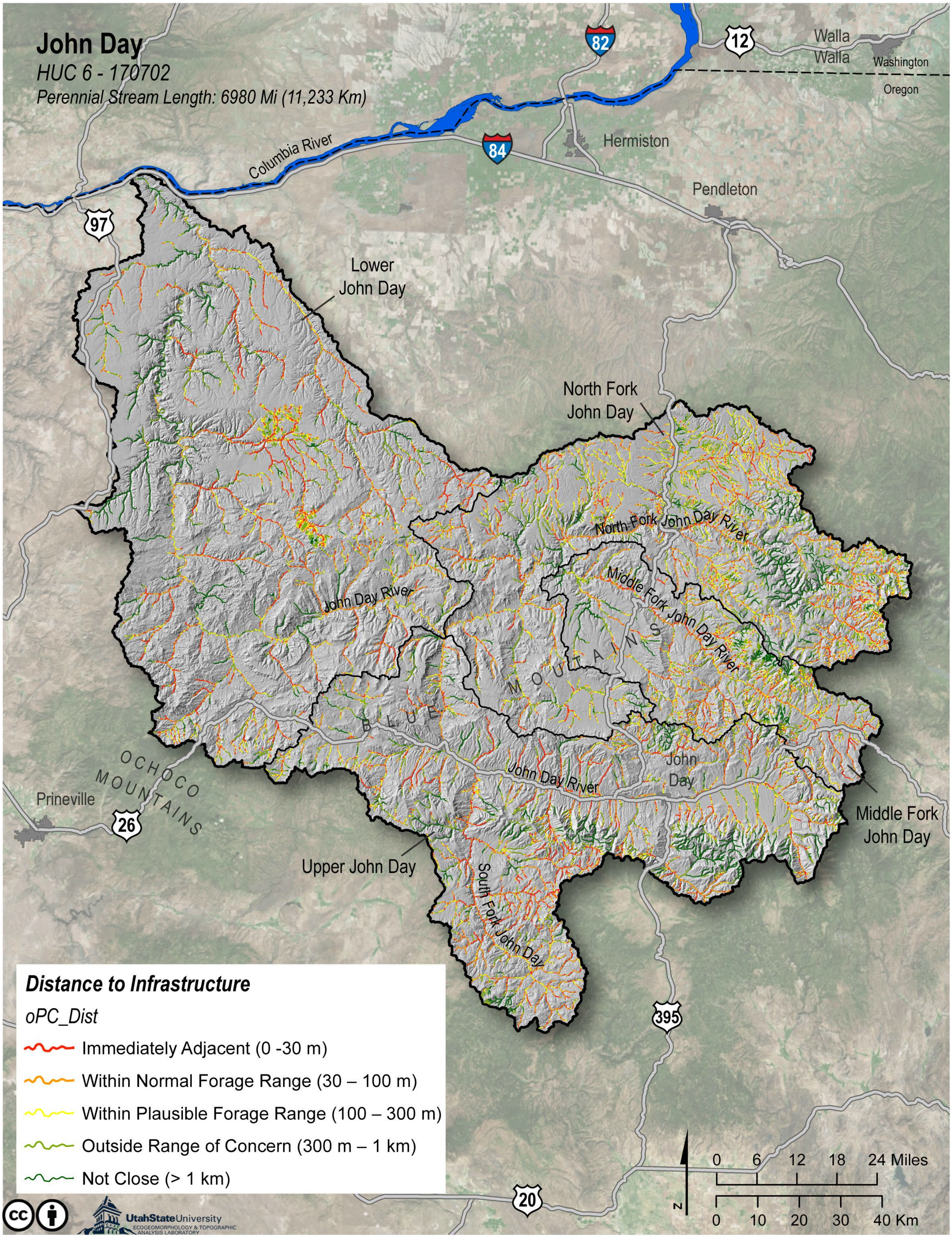
UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY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Distance to Infrastructure
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Immediately Adjacent (0 -30 m)
Within Normal Forage Range (30 – 100 m)
Within Plausible Forage Range (100 – 300 m)
Outside Range of Concern (300 m – 1 km)
Not Close (> 1 km)
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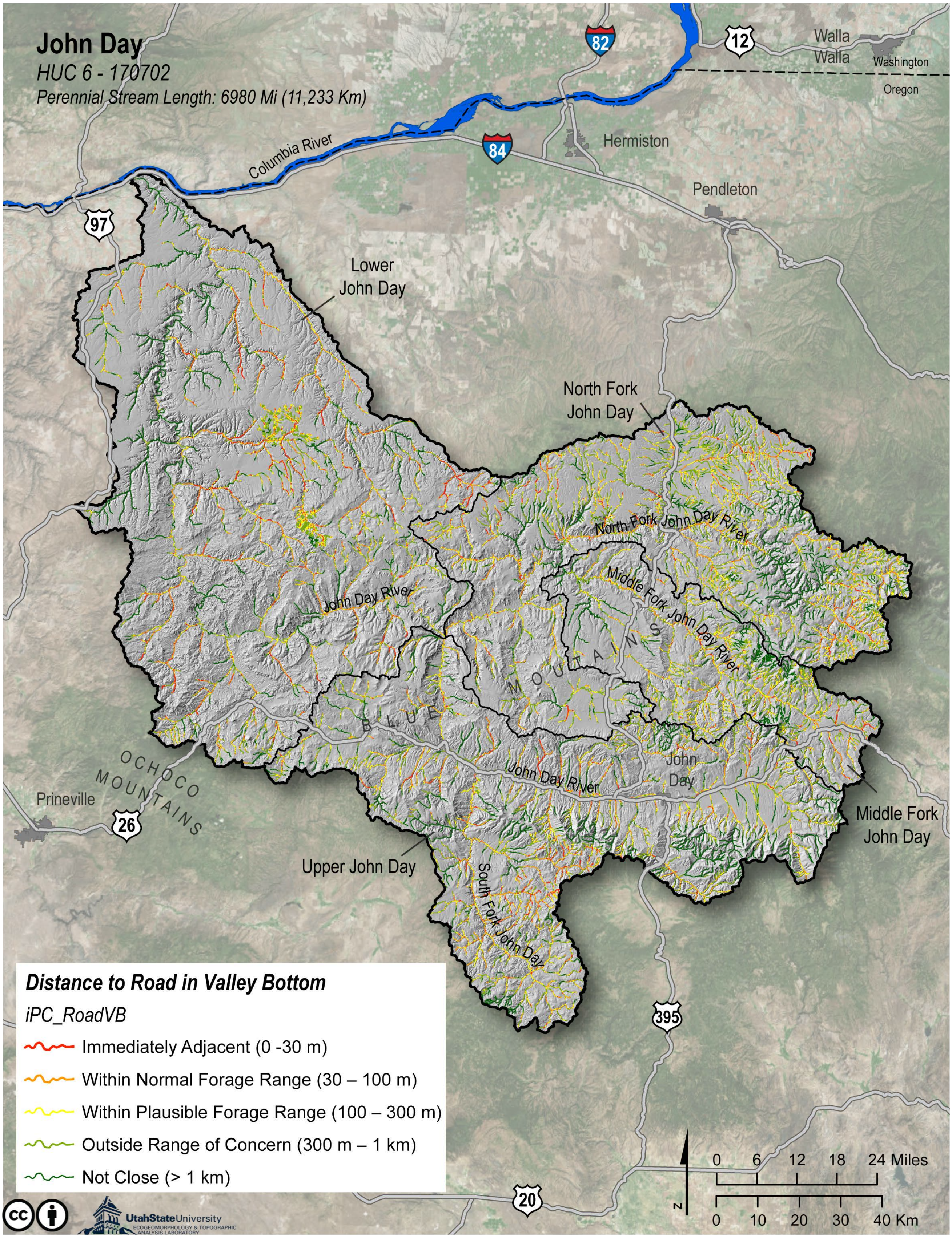
UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY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BLUE MOUNTAINS
John Day River
John Day
Middle Fork John Day
OCHOCO MOUNTAINS
Prineville
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Upper John Day
South Fork John Day
395
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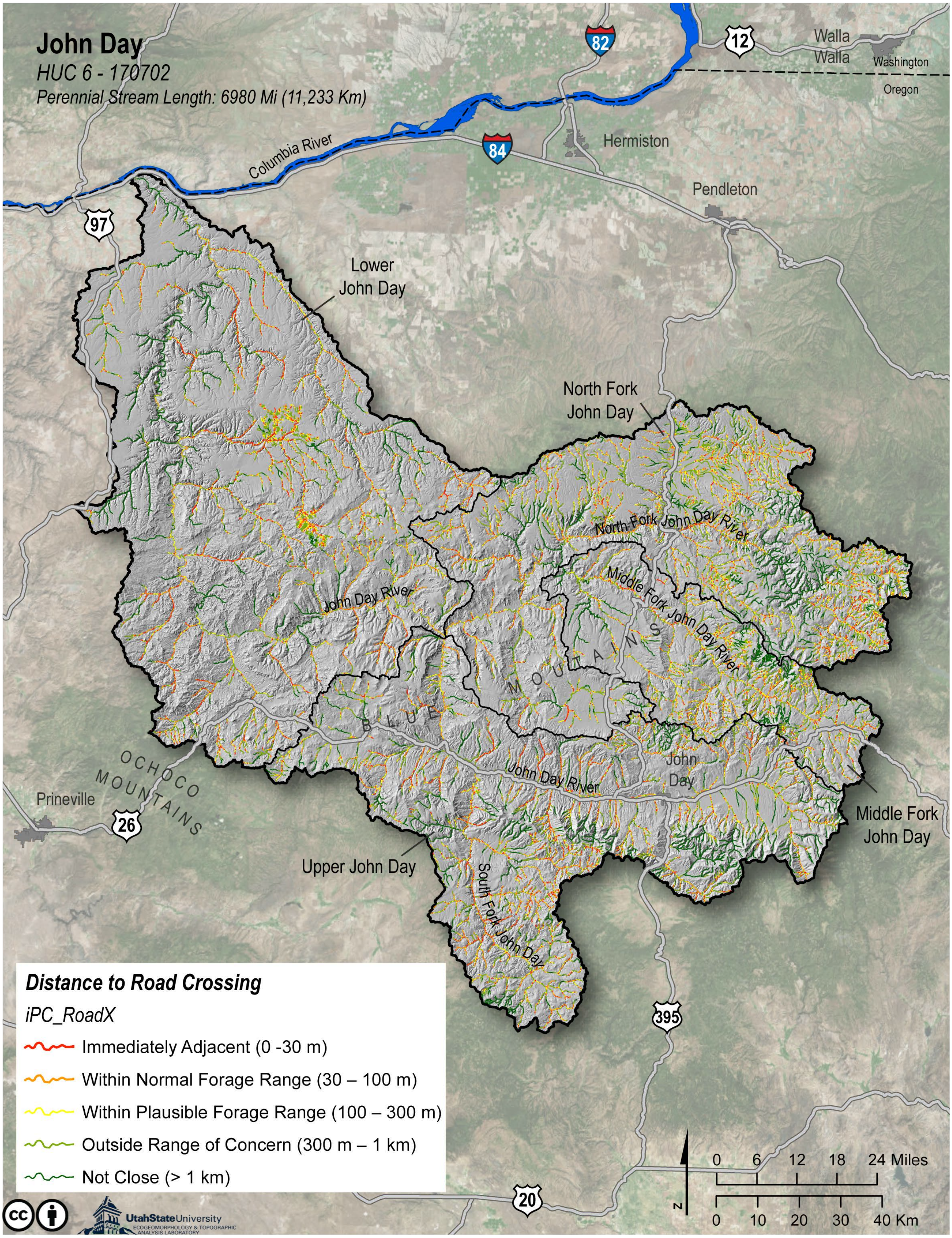
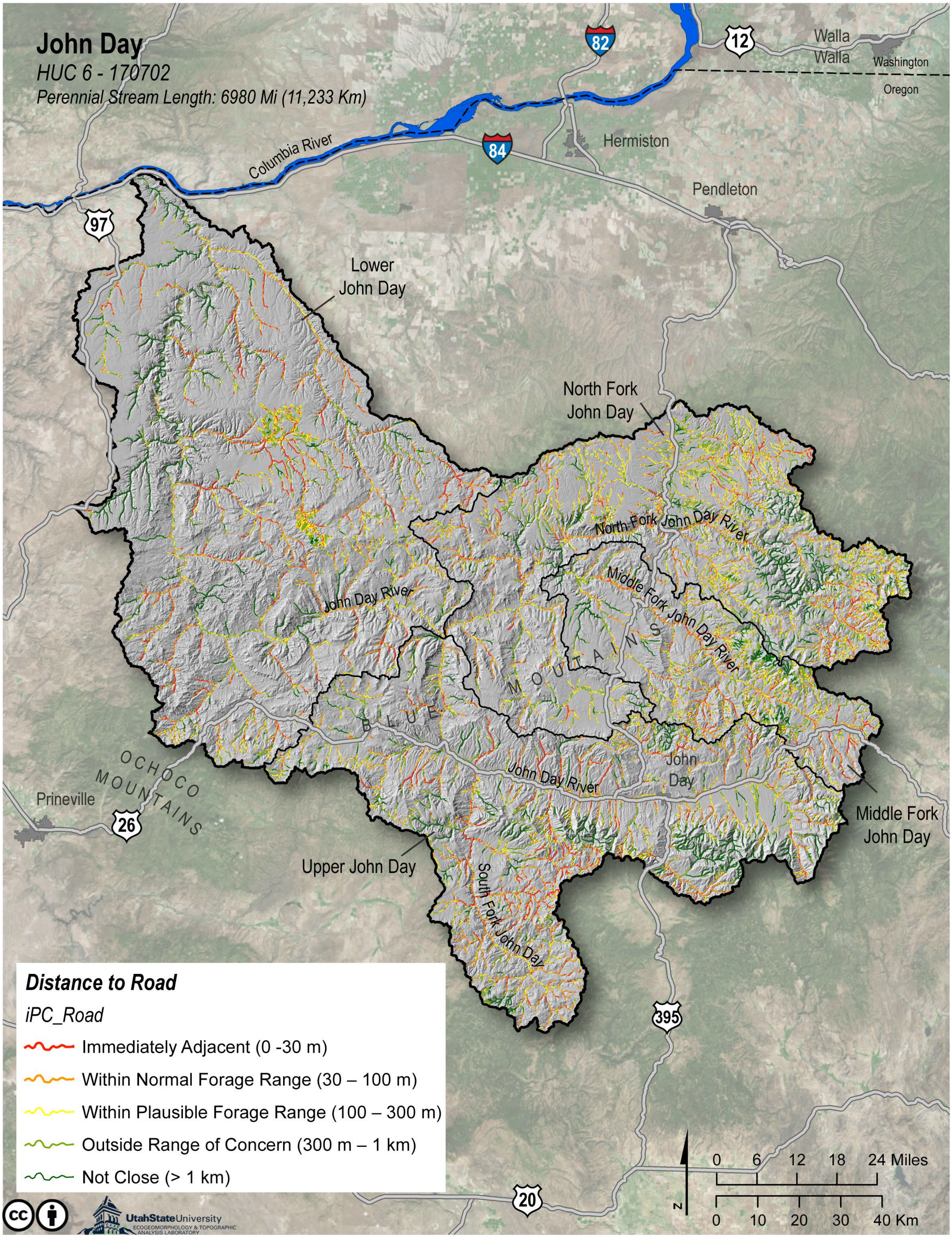
Distance to Road in Valley Bottom
iPC_RoadVB
Immediately Adjacent (0 -30 m)
Within Normal Forage Range (30 – 100 m)
Within Plausible Forage Range (100 – 300 m)
Outside Range of Concern (300 m – 1 km)
Not Close (> 1 km)
N
0 6 12 18 24 Miles
0 10 20 30 40 Km
UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY

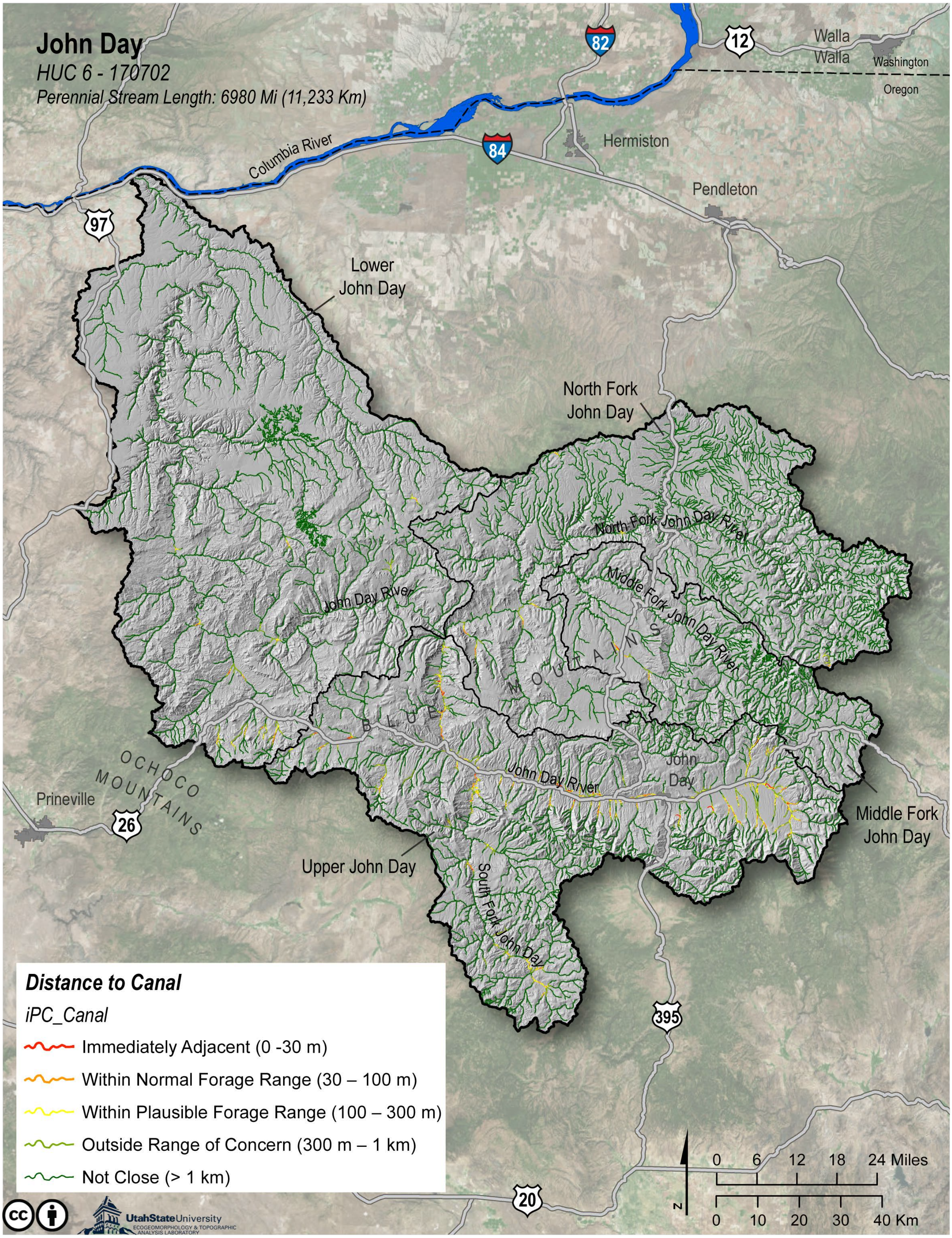


John Day

HUC 6 - 170702

Perennial Stream Length: 6980 Mi (11,233 Km)


John Day
HUC 6 - 170702
Perennial Stream Length: 6980 Mi (11,233 Km)
82
12
Walla
Walla
Washington
Oregon
Columbia River
84
Hermiston
Pendleton
97
Lower
John Day
North Fork
John Day
North Fork John Day River
Middle Fork John Day River
John Day River
BLUE MOUNTAINS
OCHOCO MOUNTAINS
Prineville
26
John Day River
John
Day
Middle Fork
John Day
Upper John Day
South Fork John Day
395
20
Distance to Road
iPC_Road
Immediately Adjacent (0 -30 m)
Within Normal Forage Range (30 – 100 m)
Within Plausible Forage Range (100 – 300 m)
Outside Range of Concern (300 m – 1 km)
Not Close (> 1 km)
N
0
6
12
18
24 Miles
0
10
20
30
40 Km
UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY


John Day
HUC 6 - 170702
Perennial Stream Length: 6980 Mi (11,233 Km)
82
12
Walla Walla
Washington
Oregon
Columbia River
84
Hermiston
Pendleton
97
Lower John Day
North Fork John Day
North Fork John Day River
Middle Fork John Day River
John Day River
BLUE MOUNTAINS
OCHOCO MOUNTAINS
Prineville
26
John Day River
John Day
Middle Fork John Day
Upper John Day
South Fork John Day
395
20
Distance to Canal
iPC_Canal
Immediately Adjacent (0 -30 m)
Within Normal Forage Range (30 – 100 m)
Within Plausible Forage Range (100 – 300 m)
Outside Range of Concern (300 m – 1 km)
Not Close (> 1 km)
N
0 6 12 18 24 Miles
0 10 20 30 40 Km
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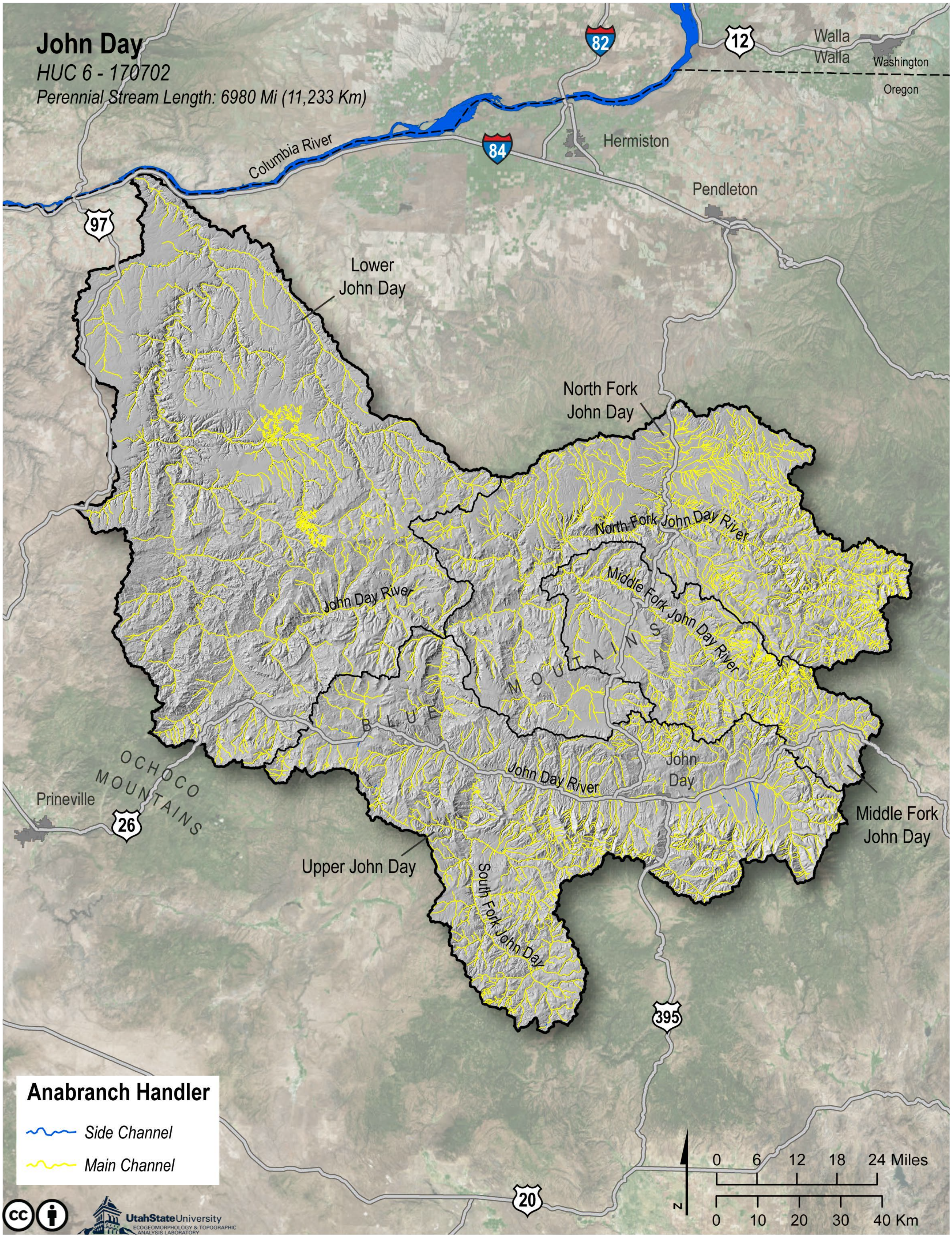
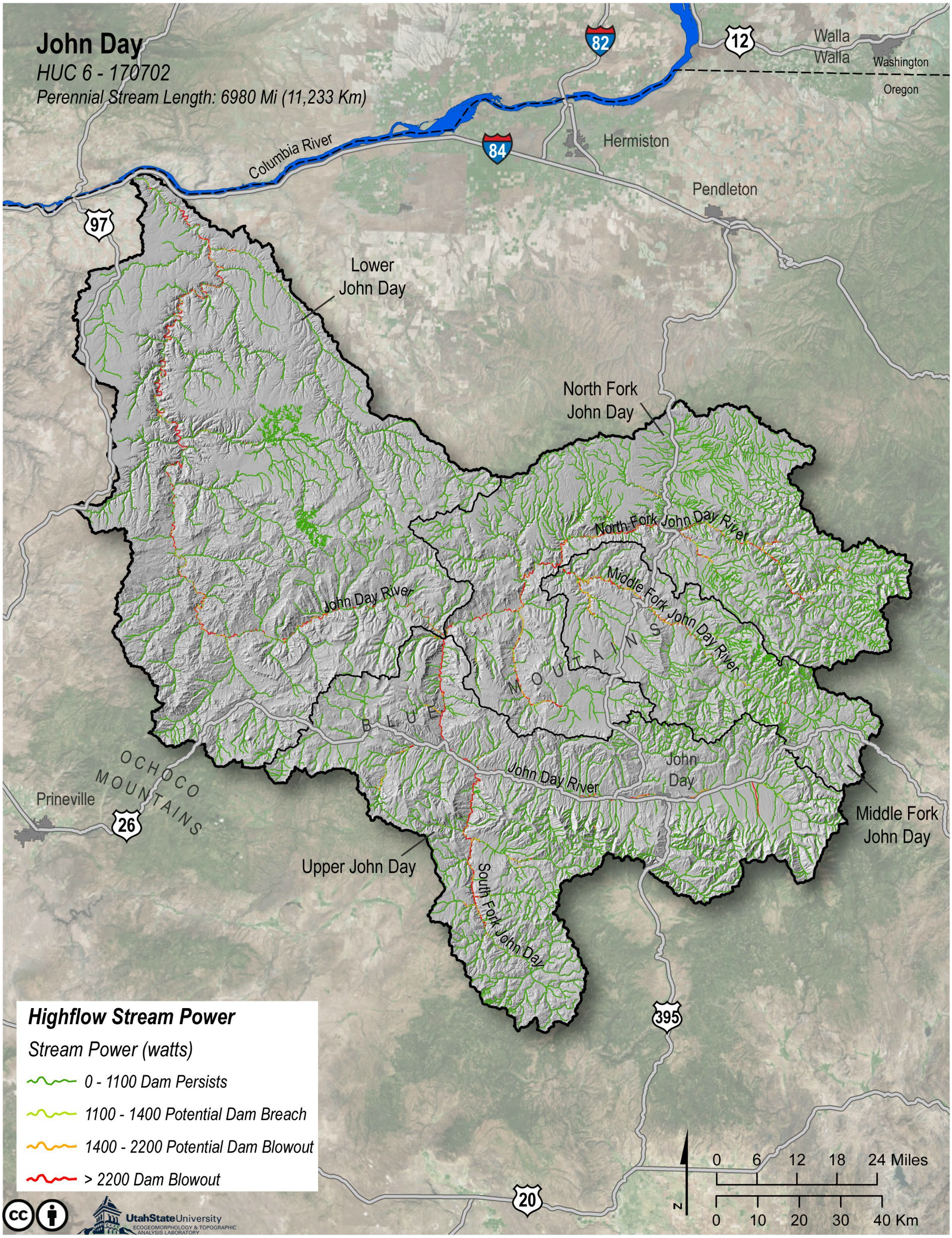
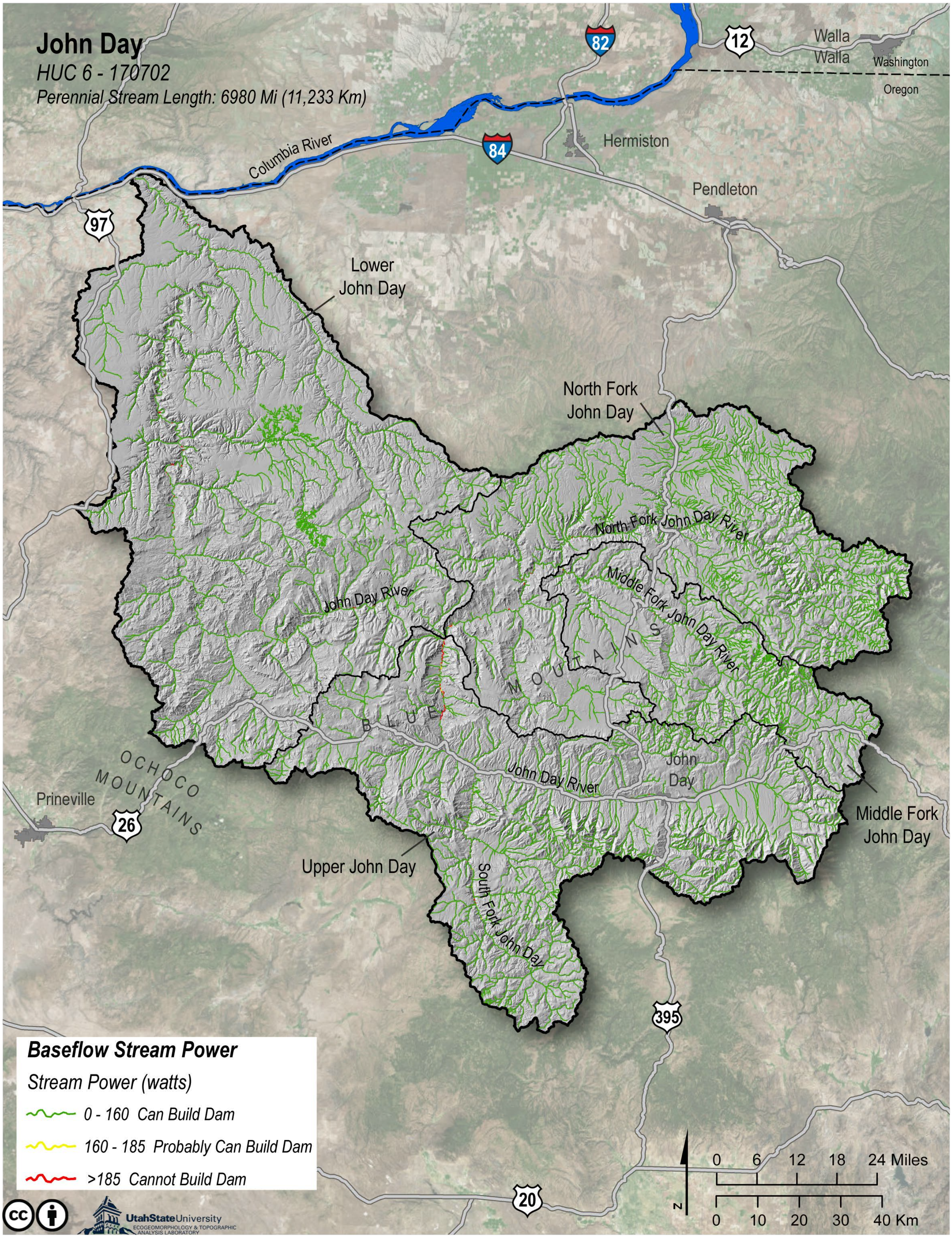
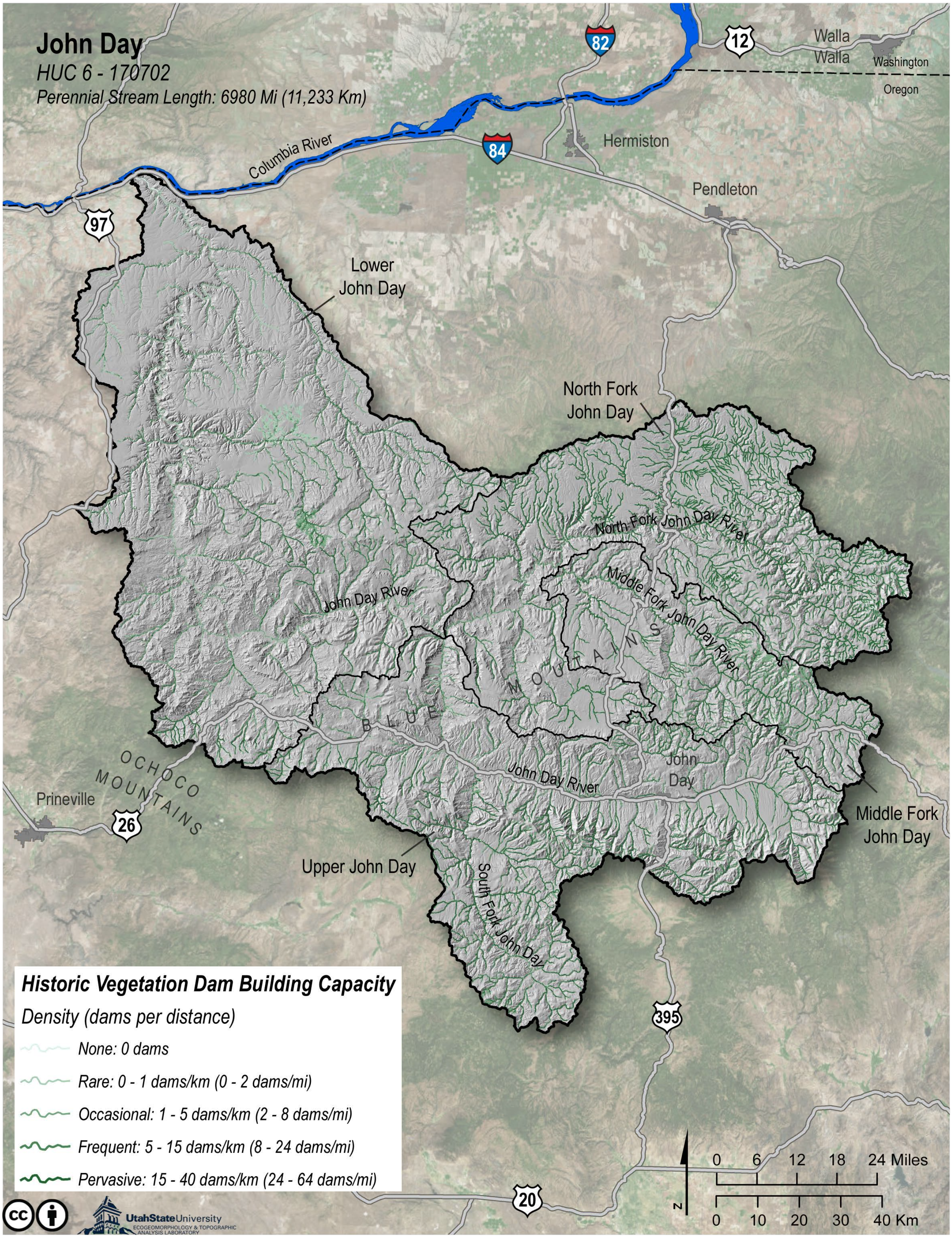
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY


John Day
HUC 6 - 170702
Perennial Stream Length: 6980 Mi (11,233 Km)
Columbia River
Walla Walla
Washington
Oregon
Hermiston
Pendleton
82
12
84
97
Lower John Day
North Fork John Day
North Fork John Day River
Middle Fork John Day River
John Day River
BLUE MOUTAINS
OCHOCO MOUNTAINS
Prineville
26
John Day
Middle Fork John Day
Upper John Day
South Fork John Day
395
20
Anabranch Handler
Side Channel
Main Channel
N
0 6 12 18 24 Miles
0 10 20 30 40 Km
UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY


John Day
HUC 6 - 170702
Perennial Stream Length: 6980 Mi (11,233 Km)
82
12
Walla Walla
Washington
Oregon
Columbia River
84
Hermiston
Pendleton
97
Lower John Day
North Fork John Day
North Fork John Day River
Middle Fork John Day River
John Day River
BLUE MOUTAINS
OCHOCO MOUNTAINS
Prineville
26
John Day
John Day River
Middle Fork John Day
Upper John Day
South Fork John Day
395
20
Highflow Stream Power
Stream Power (watts)
0 - 1100 Dam Persists
1100 - 1400 Potential Dam Breach
1400 - 2200 Potential Dam Blowout
> 2200 Dam Blowout
N
0 6 12 18 24 Miles
0 10 20 30 40 Km
UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY


John Day
HUC 6 - 170702
Perennial Stream Length: 6980 Mi (11,233 Km)
82
12
Walla Walla
Washington
Oregon
Columbia River
84
Hermiston
Pendleton
97
Lower John Day
North Fork John Day
North Fork John Day River
John Day River
Middle Fork John Day River
BLUE MOUTAINS
OCHOCO MOUNTAINS
Prineville
26
John Day River
John Day
Middle Fork John Day
Upper John Day
South Fork John Day
395
20
Baseflow Stream Power
Stream Power (watts)
0 - 160 Can Build Dam
160 - 185 Probably Can Build Dam
>185 Cannot Build Dam
N
0 6 12 18 24 Miles
0 10 20 30 40 Km
UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY


John Day
HUC 6 - 170702
Perennial Stream Length: 6980 Mi (11,233 Km)
82
12
Walla Walla
Washington
Oregon
Columbia River
84
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Lower John Day
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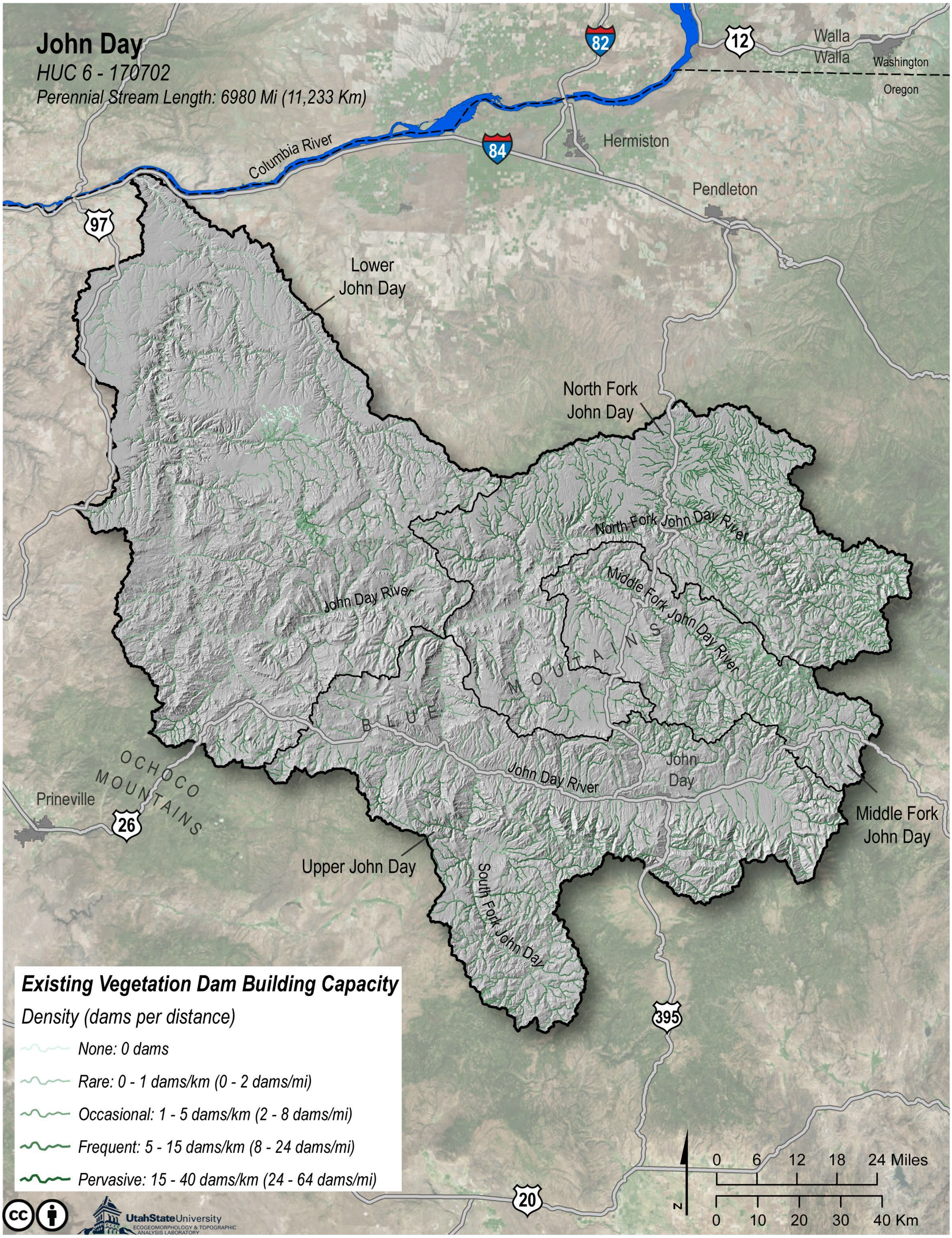
John Day River
BLUE MOUNTAINS
OCHOCO MOUNTAINS
Prineville
26
John Day
John Day River
Middle Fork John Day
Upper John Day
South Fork John Day
395
20
Historic Vegetation Dam Building Capacity
Density (dams per distance)
None: 0 dams
Rare: 0 - 1 dams/km (0 - 2 dams/mi)
Occasional: 1 - 5 dams/km (2 - 8 dams/mi)
Frequent: 5 - 15 dams/km (8 - 24 dams/mi)
Pervasive: 15 - 40 dams/km (24 - 64 dams/mi)
N
0 6 12 18 24 Miles
0 10 20 30 40 Km
UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY



John Day

HUC 6 - 170702

Perennial Stream Length: 6980 Mi (11,233 Km)

Existing Vegetation Dam Building Capacity

Density (dams per distance)

- *None: 0 dams*
- *Rare: 0 - 1 dams/km (0 - 2 dams/mi)*
- *Occasional: 1 - 5 dams/km (2 - 8 dams/mi)*
- *Frequent: 5 - 15 dams/km (8 - 24 dams/mi)*
- *Pervasive: 15 - 40 dams/km (24 - 64 dams/mi)*

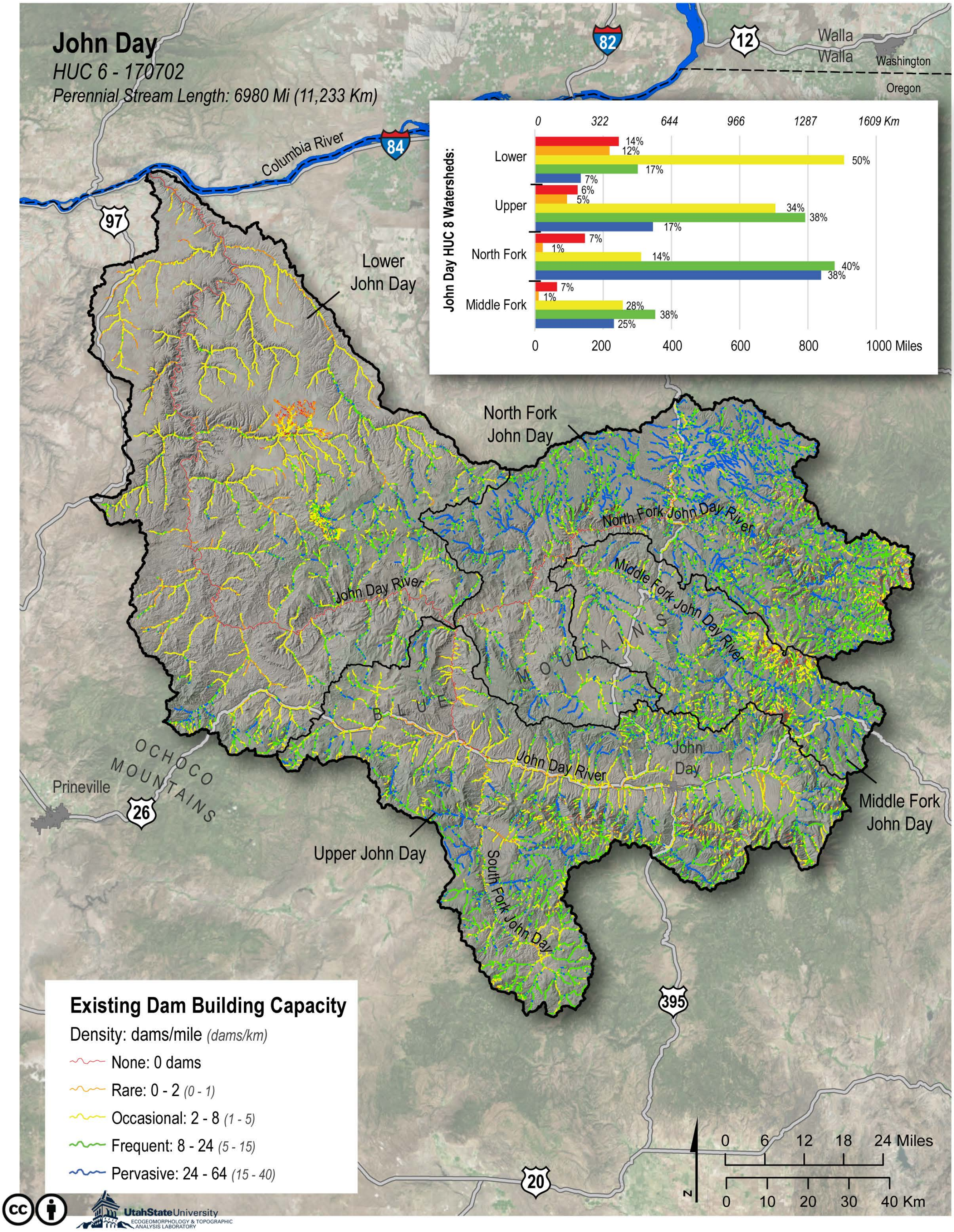
Beaver Restoration Assessment Tool (BRAT) Atlas

John Day
Outputs

John Day

HUC 6 - 170702

Perennial Stream Length: 6980 Mi (11,233 Km)



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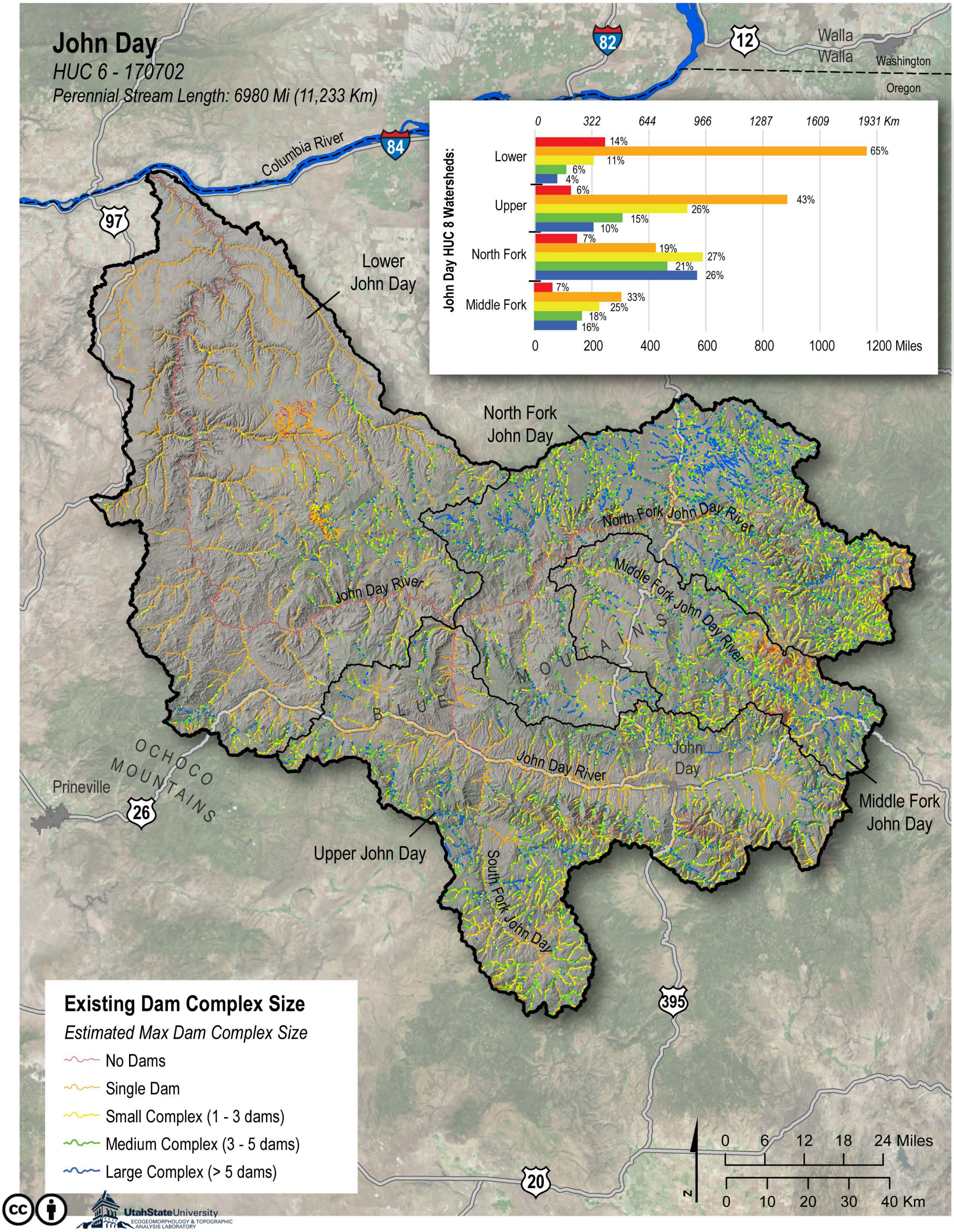
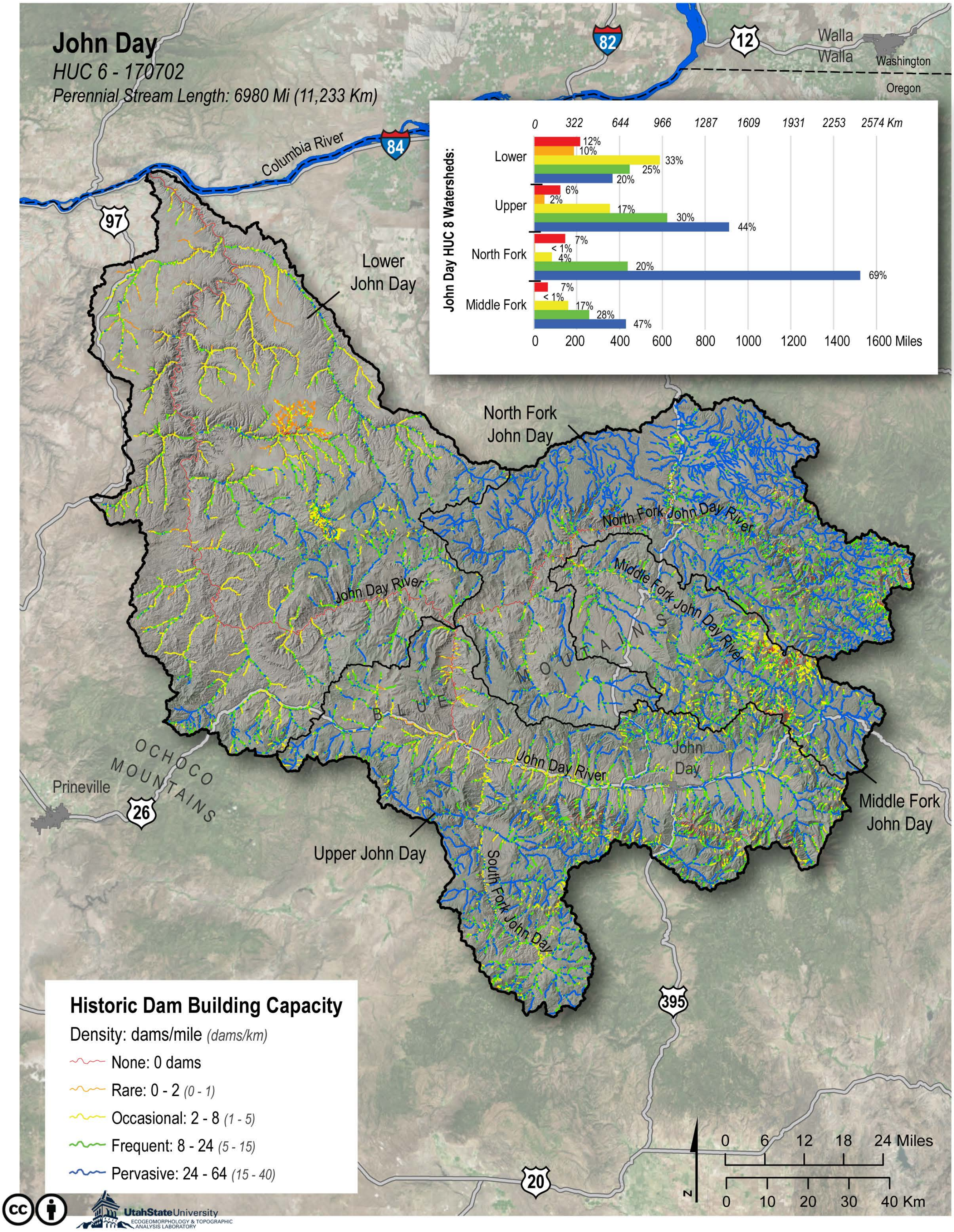


John Day

HUC 6 - 170702

Perennial Stream Length: 6980 Mi (11,233 Km)

UtahStateUniversity
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY



John Day

HUC 6 - 170702

Perennial Stream Length: 6980 Mi (11,233 Km)

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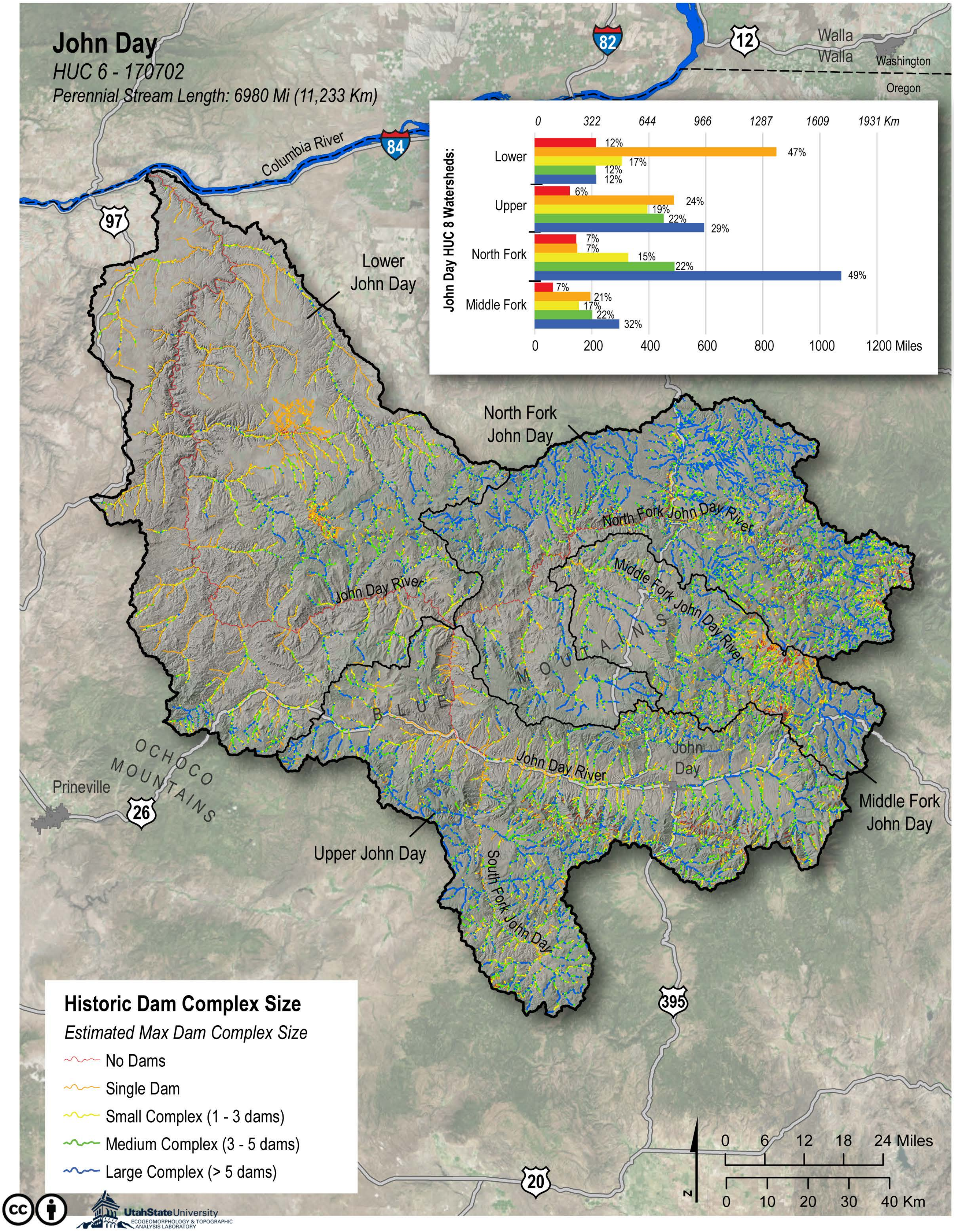
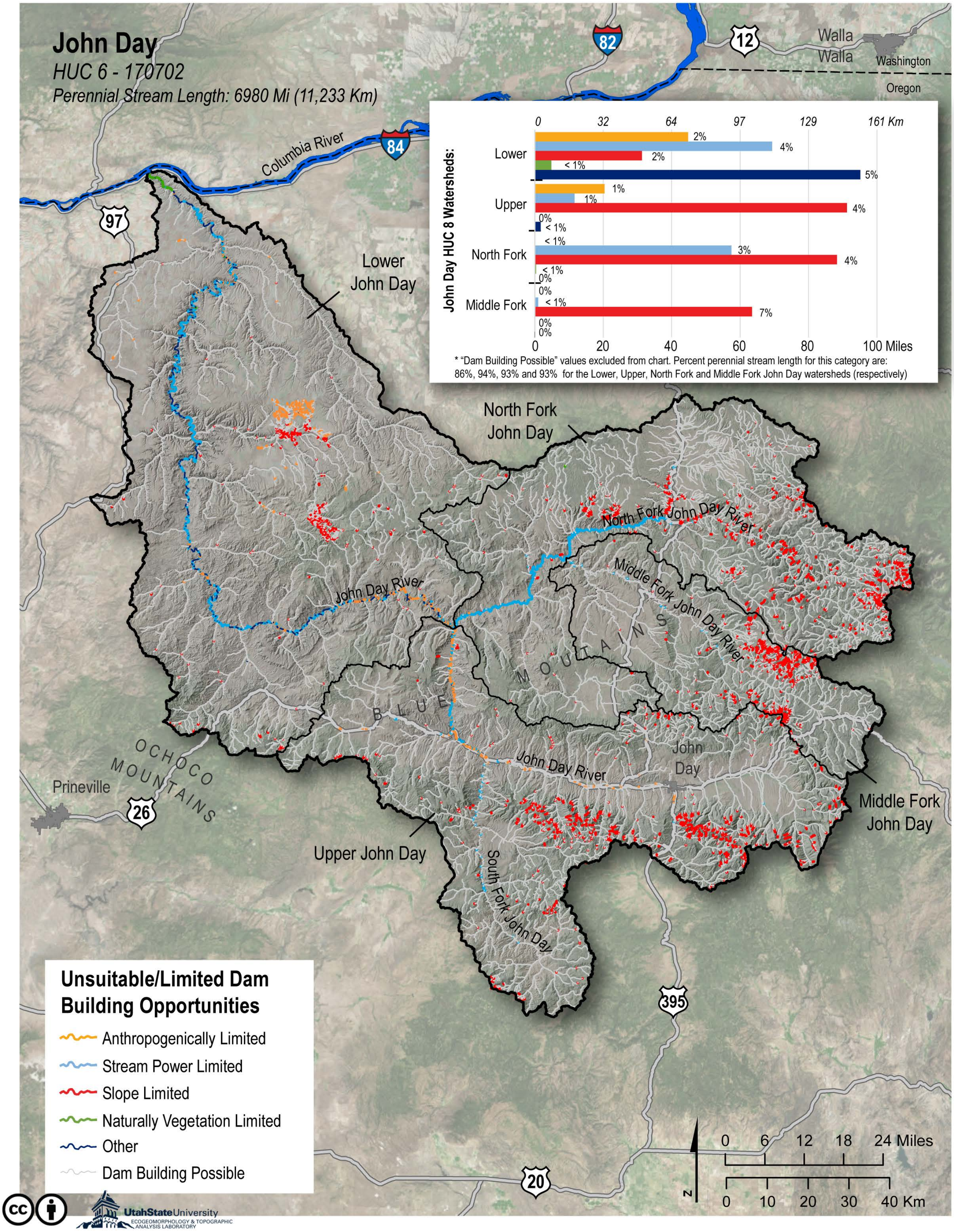
ECOGEOMORPHOLOGY & TOPOGRAPHIC ANALYSIS LABORATORY


John Day
HUC 6 - 170702
Perennial Stream Length: 6980 Mi (11,233 Km)
0
322
644
966
1287
1609
1931 Km
John Day HUC 8 Watersheds:
Lower
12%
47%
17%
12%
12%
Upper
6%
24%
19%
22%
29%
North Fork
7%
7%
15%
22%
49%
Middle Fork
7%
21%
17%
22%
32%
0
200
400
600
800
1000
1200 Miles
82
12
Walla Walla
Washington
Oregon
Columbia River
84
97
Lower John Day
North Fork John Day
North Fork John Day River
Middle Fork John Day River
John Day River
BLUE MOUNTAINS
OCHOCO MOUNTAINS
Prineville
26
John Day
John Day River
Middle Fork John Day
Upper John Day
South Fork John Day
395
20
Historic Dam Complex Size
Estimated Max Dam Complex Size
No Dams
Single Dam
Small Complex (1 - 3 dams)
Medium Complex (3 - 5 dams)
Large Complex (> 5 dams)
N
0
6
12
18
24 Miles
0
10
20
30
40 Km



John Day

HUC 6 - 170702

Perennial Stream Length: 6980 Mi (11,233 Km)

* "Dam Building Possible" values excluded from chart. Percent perennial stream length for this category are: 86%, 94%, 93% and 93% for the Lower, Upper, North Fork and Middle Fork John Day watersheds (respectively)

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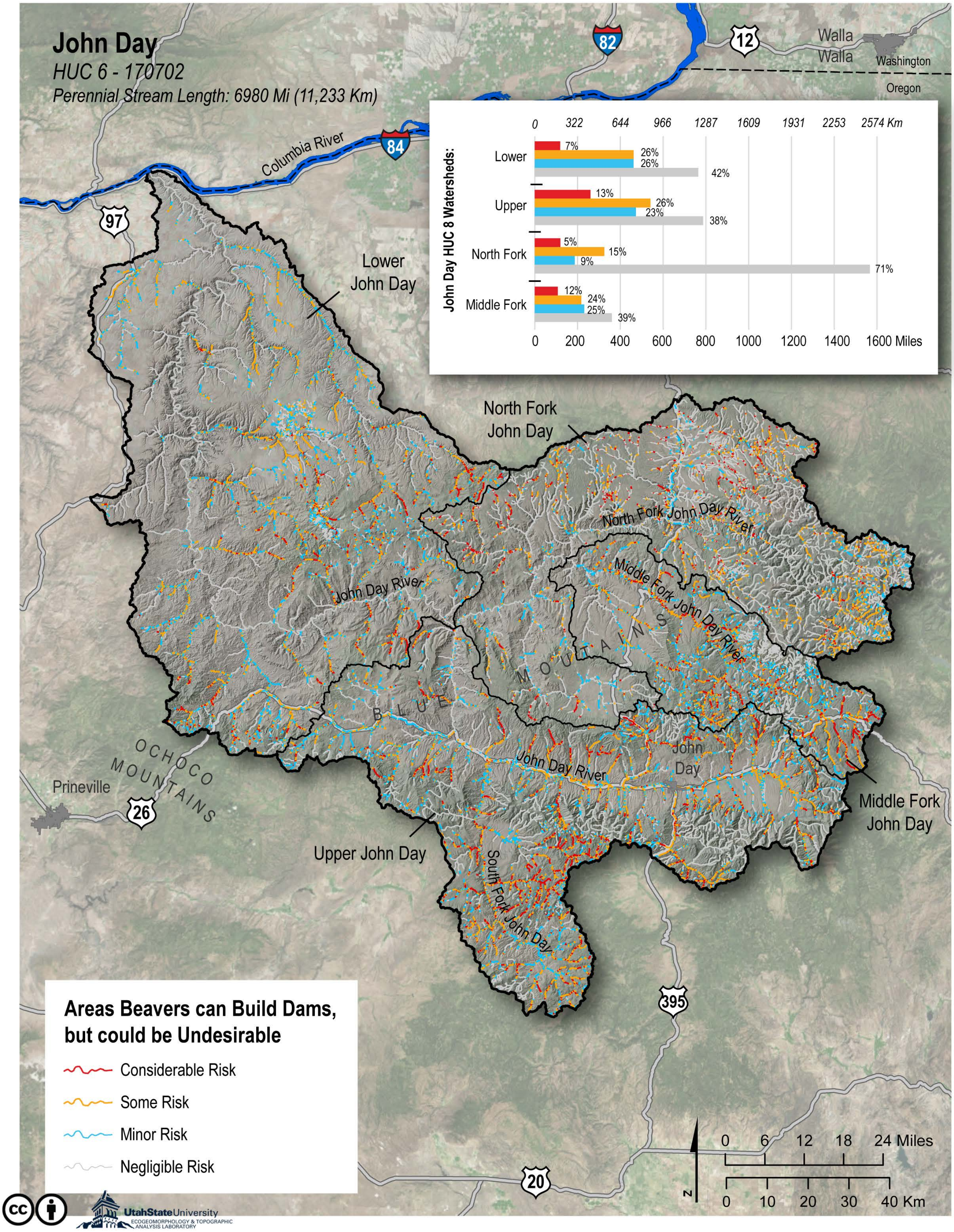

John Day
HUC 6 - 170702
Perennial Stream Length: 6980 Mi (11,233 Km)

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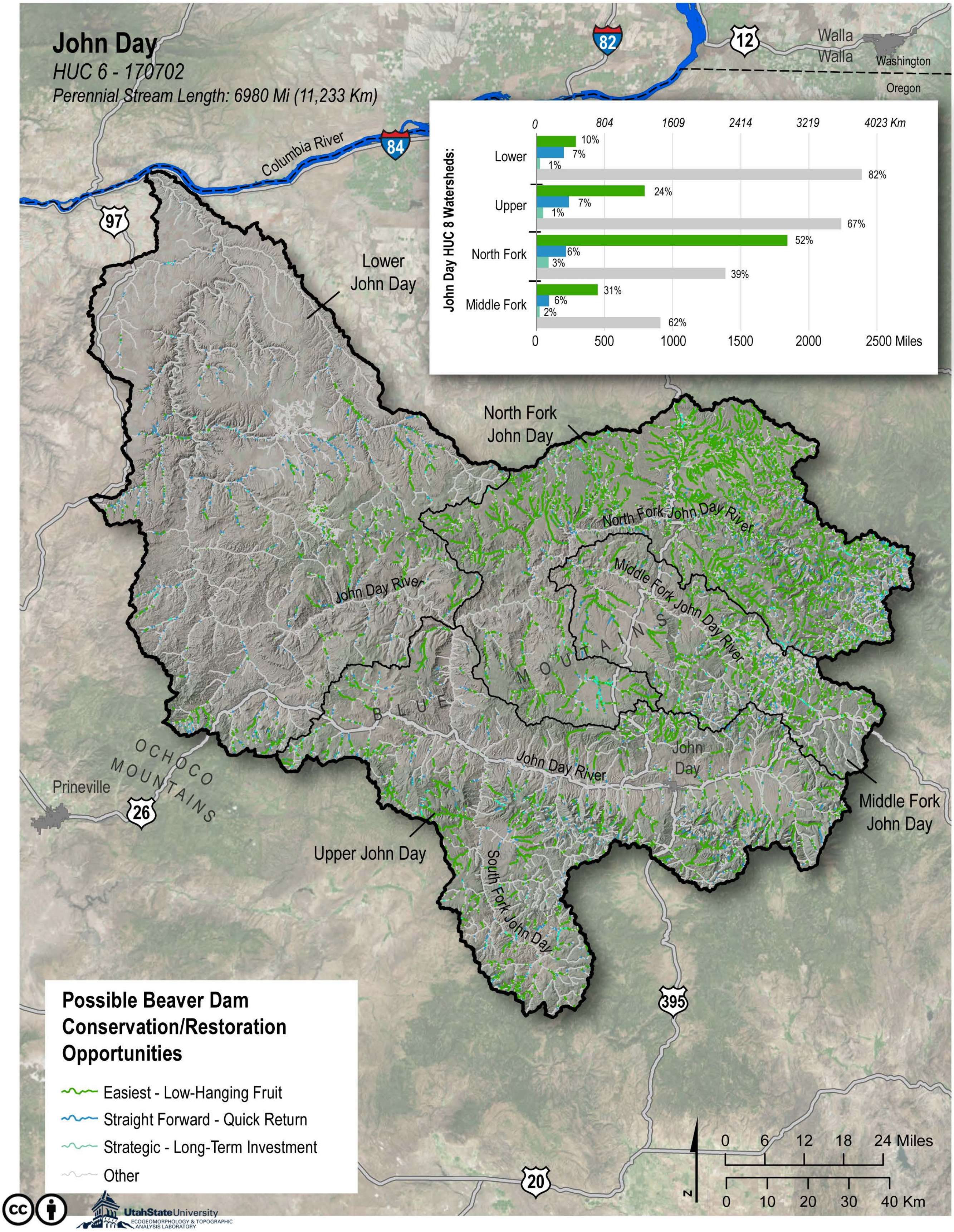

John Day

HUC 6 - 170702

Perennial Stream Length: 6980 Mi (11,233 Km)

Possible Beaver Dam Conservation/Restoration Opportunities

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