# IDAHO BEAVER RESTORATION ASSESSMENT TOOL Building Realistic Expectations for Partnering with Beaver in Conservation and Restoration

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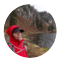

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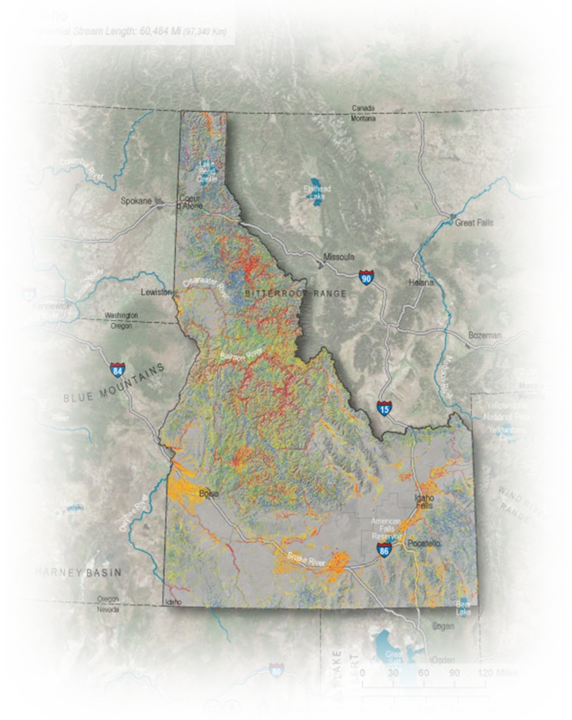
# IDAHO
# BEAVER RESTORATION ASSESSMENT TOOL

## Building Realistic Expectations for Partnering with Beaver in Conservation and Restoration



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# EXECUTIVE SUMMARY

This report presents an application of the Beaver Restoration Assessment Tool [3.0.20](3.0.20) (BRAT; [http://brat.riverscapes.xyz/](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 state of Idaho.

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 2016, whereas the 'historic' estimate represents a pre-European settlement model of vegetation, also from LANDFIRE.

The estimated existing Idaho statewide capacity is 994,299 dams or roughly 8 dams/km. By contrast, the same model driven with estimates of historic vegetation types estimated the statewide capacity at 1,743,459 dams or roughly 15 dams/km reflecting a 43% loss compared to historic capacity. Comparison of the Idaho Fish and Game administrative boundaries of Idaho 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, Idaho's waterways are still capable of supporting and sustaining a substantial amount of beaver dam-building activity (994,299 dams).

*Table 1: Estimated existing and historic capacity by the administrative region of Idaho*

| Category | Existing Capacity | | Historic Capacity | | % Loss |
|---|---|---|---|---|---|
| | **Estimated Dam Capacity** | **Estimated Dams/km total** | **Estimated Dam Capacity** | **Estimated Dams/km total** | |
| Clearwater | 193,666 | 8 | 302,764 | 13 | 36% |
| Magic Valley | 111,959 | 7 | 230,656 | 15 | 51% |
| Panhandle | 136,755 | 11 | 214,606 | 18 | 36% |
| Salmon | 100,675 | 7 | 189,739 | 14 | 47% |
| Southeast | 103,387 | 10 | 184,839 | 18 | 44% |
| Southwest | 225,548 | 7 | 423,640 | 14 | 47% |
| Upper Snake | 122,566 | 10 | 197,946 | 16 | 38% |
| **Idaho** | **994,299** | **8** | **1,743,459** | **15** | **43%** |

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 statewide, using 8,060 actual dam locations. Results indicate that the model effectively segregates the factors controlling beaver dam occurrence and density 89.97% of the time. The model verification results also indicate that beavers preferentially dam in reaches with higher modeled dam capacity while avoiding those with lower capacity.

The spatially explicit outputs from this application of BRAT provides Idaho Fish and Game (IDF&G) staff with the information needed to understand patterns of beaver dam capacity, potential risks to human infrastructure, as well as constraints and opportunities for using dam building beaver in restoration and conservation. This information helps with both statewide planning efforts and individual watershed scale planning as well as 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 funds are 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 enormous scope of degradation (Silverman et al., 2018).

Watershed 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). Beaver assisted restoration, without the use of parachutes, is now broadly appreciated as an effective low-tech stream, riparian and wet meadow restoration technique.

This appreciation of beaver as a restoration agent 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, whereas 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 use 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 beaver assisted restoration 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 restoration and conservation 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. BRAT has also been run for large portions of Wyoming, Oregon and California along with smaller portions of New York, Washington and the United Kingdom.

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 entire state of Idaho 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 Idaho;
2. Validate BRAT statewide 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 Idaho.

# 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. 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 there 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. Can dams withstand typical floods?

With the BRAT model, we approximate quantitative answers to these four 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 on remotely sensed imagery and regionally derived empirical relationships. While we recognize that higher resolution inputs with greater accuracy and exactness 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 Idaho BRAT beaver dam capacity model.*

| **Input Data** | **Criteria** | **Source** |
|---|---|---|
| Streams and rivers | Perennial water | USGS National Hydrography Dataset<br>http://nhd.usgs.gov/ |
| LANDFIRE 2016 & LANDFIRE 2014 (EVT and BPS) | Riparian vegetation | LANDFIRE land cover data<br>http://www.landfire.gov/ |
| USGS baseflow equations | Dam could be built | Wood et al. 2009<br>Hortness and Berenbrock 2001<br>Wilkowske et al. 2008 |
| USGS 2-year peak flow equations | Dam could withstand floods | Wood et al. 2016<br>Berenbrock 2002 |
| 10 m DEM | Evidence of stream gradient | USDA NRCS Geospatial Data Gateway<br>http://datagateway.nrcs.usda.gov/ |

The beaver dam capacity model is described thoroughly in Macfarlane et al. (2017), and detailed 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 length (miles) 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 2016 (first made available in 2019), a nationwide 30 m Landsat satellite imagery-based landcover classification (LANDFIRE, 2016), into beaver dam-building material preference categories. Where 2016 LANDFIRE data was not available during modeling, LANDFIRE EVT 2014 data was used. 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.

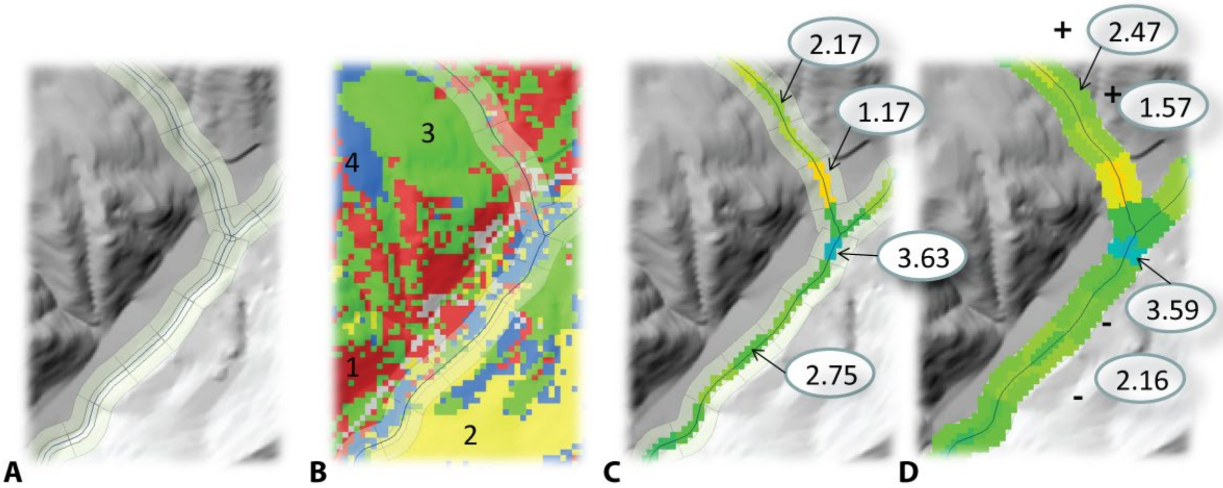

*Figure 1: Reach scale illustration of derivation of streamside vs. riparian vegetation scores from 30 vs. 100 m stream network buffers. A shows the 30 m and 100 m buffers, which we used to summarize intersecting pixels from 30 m resolution classified LANDFIRE raster in B. Dam building suitability are 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 ($\Omega = \rho gQS$) 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).

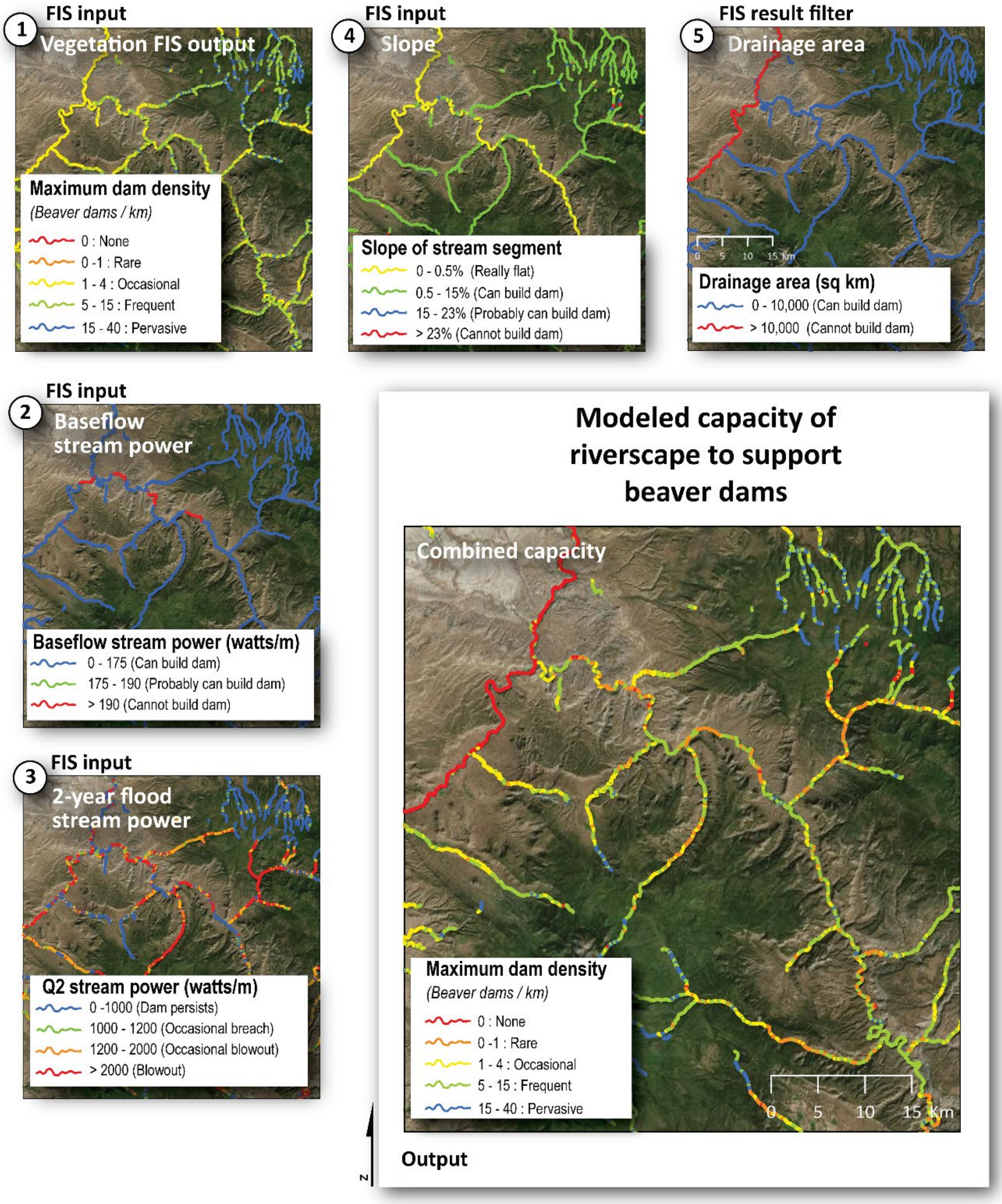

*Figure 2: Methodological illustration of inputs (1-5) and output for the combined capacity model of riverscapes capacity to support beaver dam-building activity. Model output is expressed as dam density (dams/km).*

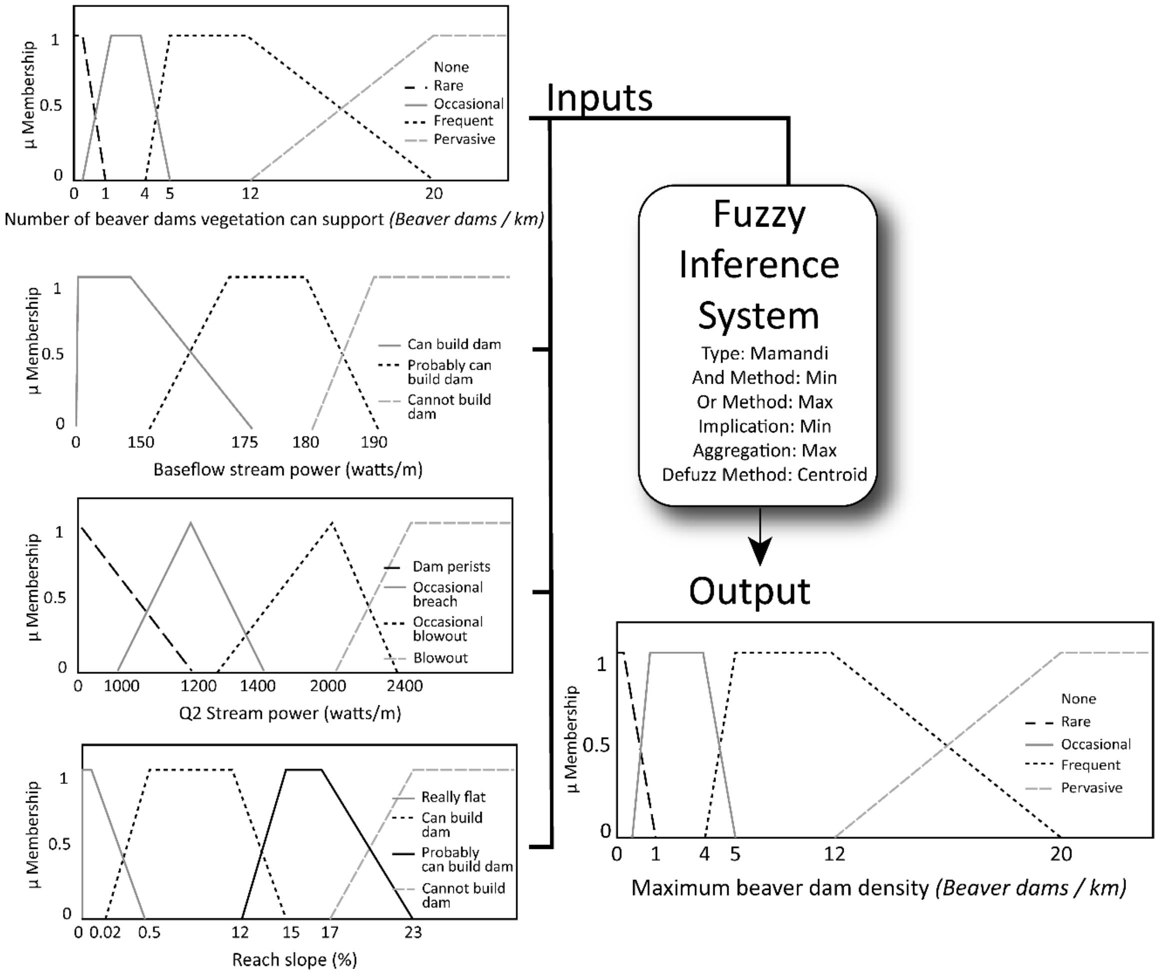

*Figure 3: Combined capacity Fuzzy Inference System for capacity of riverscapes to support dam building beaver activity. This shows the specification of fuzzy membership functions with overlapping values for categorical descriptors in inputs and the output.*

## BRAT dam building beaver conservation and restoration 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 statewide and watershed levels using the outputs of the capacity and management models. The different components of the conservation and restoration model are described below and together makeup a robust model for 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 welcome or useful additions to diversion structures or irrigation canals. Thus, distance from canals and points of diversion 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. distance to points of diversion;
6. average land use intensity and;
7. distance to nearest infrastructure

However, these calculations are unrealistically restrictive because the analysis only shows how close streams are to the above 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 (stream channels and active floodplain) 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. railroads within valley bottoms;
3. road crossings;
4. canals and;
5. points of diversion

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 dam building conservation and restoration model accounts for risk by identifying 'floodable' or 'cloggable' infrastructure that 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 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, how close infrastructure – especially 'floodable' or 'cloggable' infrastructure – is, and how high land use intensity is. This assessment is an over-prediction of potential risk and provides a conservative prediction of potential risk areas.

### Dam building beaver management layers

We have developed dam building beaver management layers and associated maps that combine capacity estimates and risk analysis (described above) for use in beaver related conservation and restoration. The management outputs 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’. An additional layer based on the surveyed dams throughout Idaho was produced representing ‘current beaver dam management strategies’. Further documentation and discussion/development of these layers/maps can be found here.

## Model calibration

IDF&G staff selected three watersheds, Lower Henry’s Fork, Little Wood, and Jordan for BRAT model calibration. These watersheds were selected because either ongoing beaver related conservation and restoration efforts were taking place and/or future BDA and or translocation efforts were planned. Provisional BRAT model runs including inputs, intermediates and outputs were provided to IDF&G staff familiar with these watersheds. Instructions on how to effectively interrogate these datasets along with a standard list of questions to evaluate the accuracy and utility of the model was also provided to the staff members.

## 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 model validation. 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 surveyed dam densities to modeled dam 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 validation, actual dam counts were collected using virtual reconnaissance in a web map with 2013 0.5-meter NAIP Imagery. A trained technician used the web map 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 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 where shadows obstruct ground imagery.

Dam counts were plotted against predicted existing capacity counts and a quantile regression was performed on the 50th, 75th, and 90th percentiles of these data. Quantile regression using upper percentiles (i.e., 75th, 90th) is used to evaluate habitat models because many of these systems have low surveyed dam densities. Upper percentiles represent the highest levels of surveyed dam density which correspond most closely with true capacity (Cade and Noon, 2003), which is what we are modeling. Dam counts were also compared to predicted capacity counts spatially in the “predicted dam density vs. surveyed dam density” layer.

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*):

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

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 Idaho BRAT outputs consist of seven stream network classifications: 1) existing beaver dam capacity (Figure 4), 2) historic beaver dam capacity (Figure 5), 3) existing dam complex size (Figure 6), 4) historic dam complex size (Figure 7), 5) restoration or conservation opportunities (Figure 8), 6) areas beavers can build dams, but could be undesirable (Figure 9), and 7) unsuitable or limited beaver dam opportunities areas beavers can build dams (Figure 10). These figures represent results from the Southwest Region. Additional statewide, regional and watershed level data and summary products can be found here.

## Beaver dam capacity model

### Idaho statewide & by administrative regions

The BRAT beaver dam capacity model was run for existing (based primarily on 2016 imagery) and an estimate of historic conditions based on LANDFIRE BPS data. The estimated existing Idaho statewide capacity is 994,299 dams or 8 dams/km (Table 3). By contrast, the same model driven with estimates of historic vegetation types estimated the statewide capacity at 1,743,459 dams or 15 dams/km reflecting a 43% loss compared to historic capacity (Table 3). Comparison of the IDF&G administrative regions of Idaho are also illustrated in (Table 3).

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, Idaho's waterways are still capable of supporting and sustaining a substantial amount of beaver dam-building activity (994,299 dams).

*Table 3: Gross summary of contrast between existing and historic beaver dam capacity estimates for Idaho by administrative region.*

|  | Existing Capacity |  | Historic Capacity |  |  |
|---|---|---|---|---|---|
| **Category** | **Estimated Dam Capacity** | **Estimated Dams/km total** | **Estimated Dam Capacity** | **Estimated Dams/km total** | **% Loss** |
| Clearwater | 193,666 | 8 | 302,764 | 13 | 36% |
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| Panhandle | 136,755 | 11 | 214,606 | 18 | 36% |
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| Upper Snake | 122,566 | 10 | 197,946 | 16 | 38% |
| **Idaho** | **994,299** | **8** | **1,743,459** | **15** | **43%** |

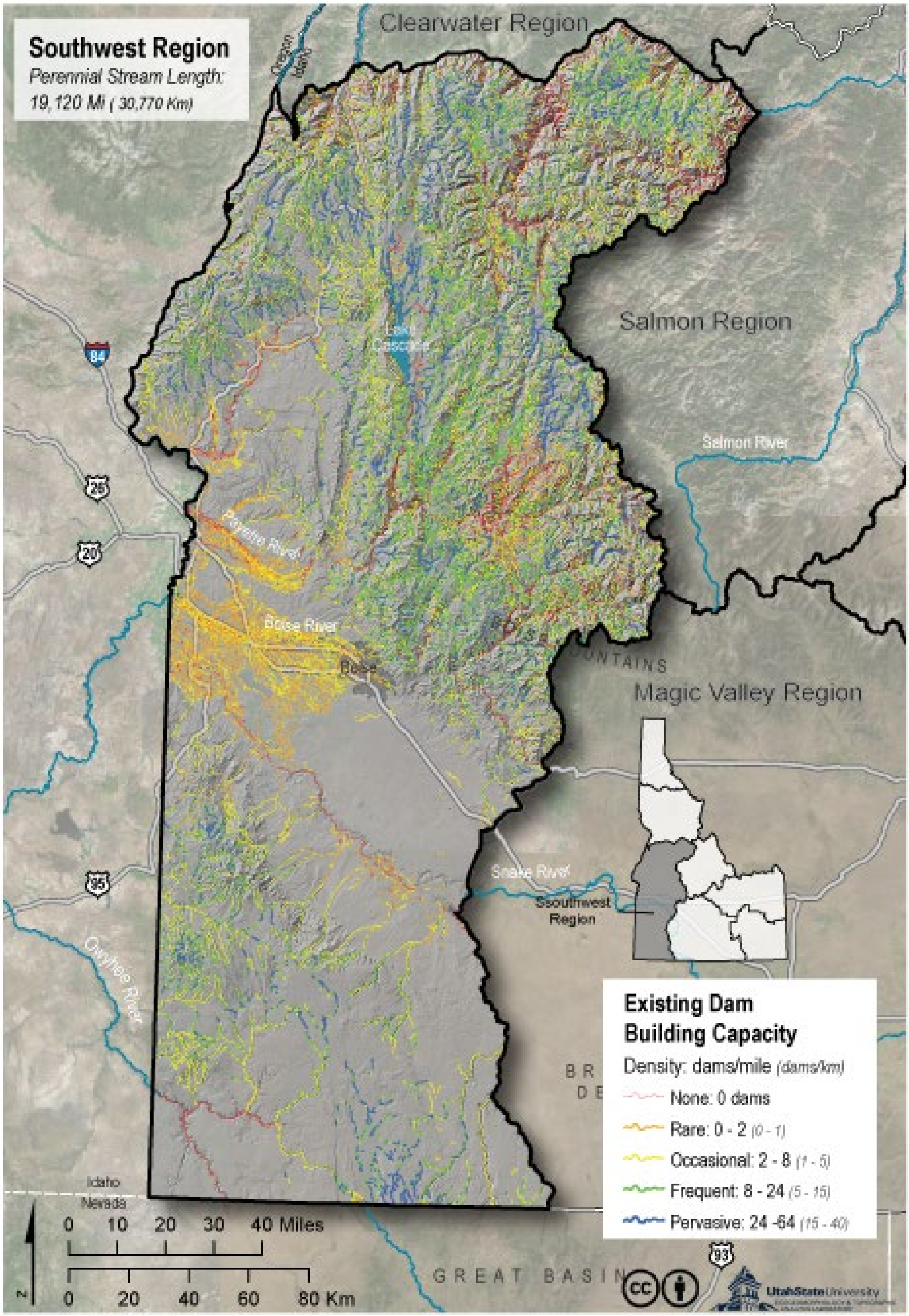

*Figure 4: Modeled beaver dam capacity for existing conditions for the Southwest Region of Idaho.*

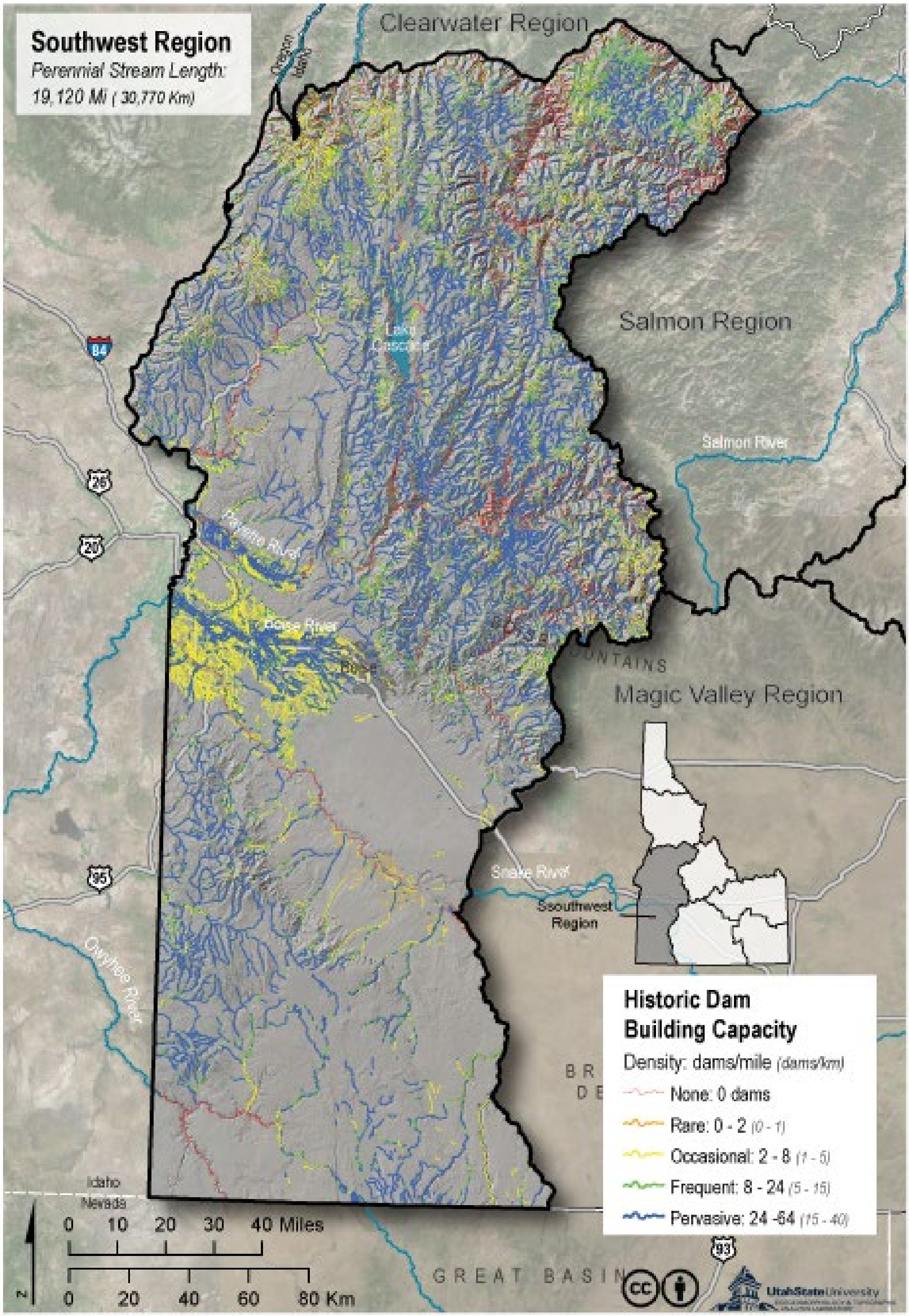

*Figure 5: Modeled beaver dam capacity for historic conditions for the Southwest Region of Idaho.*

Figure 6 shows the comparison between existing and historic capacity for the Southwest Region of Idaho.

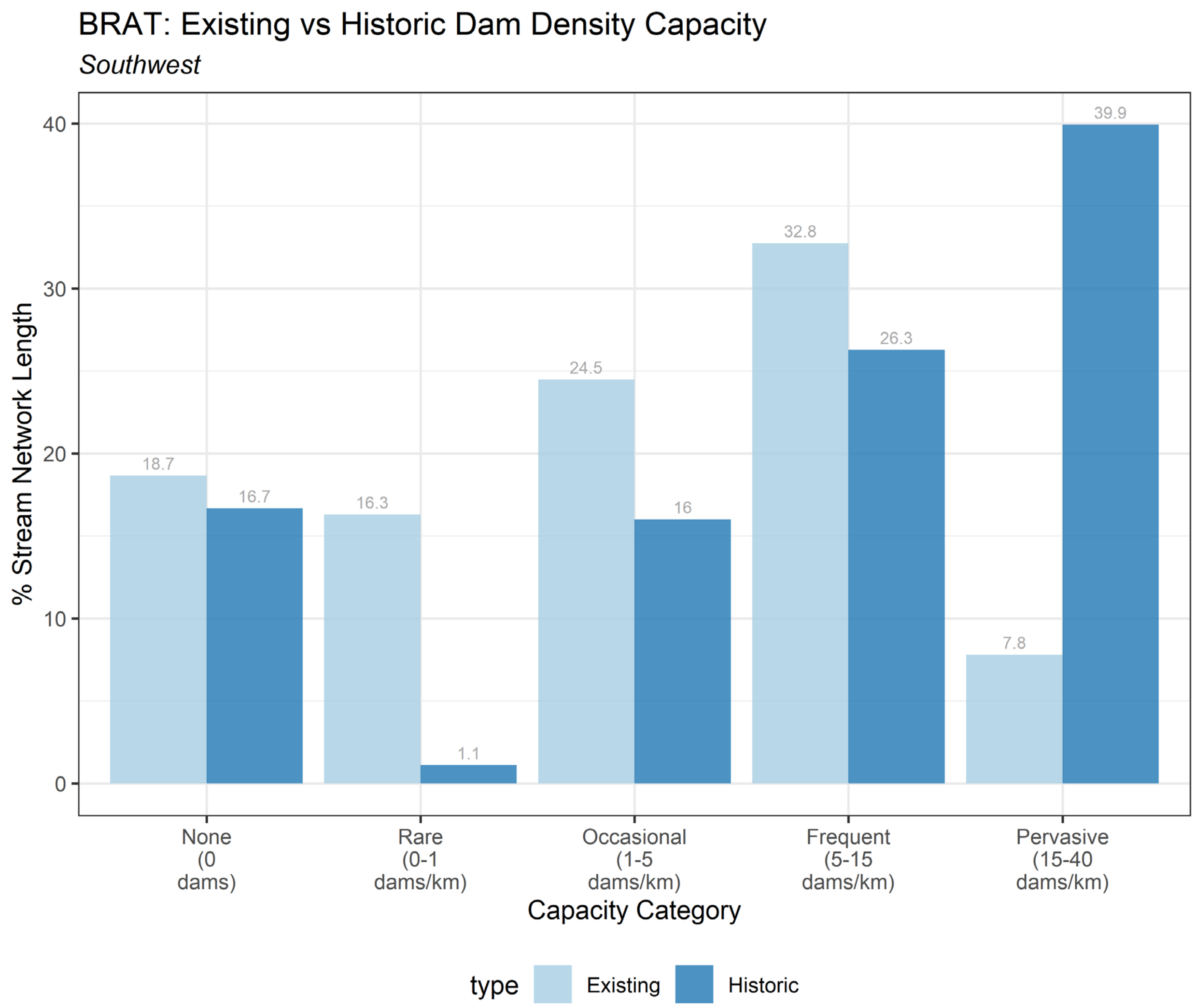

*Figure 6. Existing vs. historic dam capacity by category for Southwest Region of Idaho.*

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 southwest region of Idaho is mapped in Figure 7. Historic dam complex size for southwest region of Idaho is mapped in Figure 8.

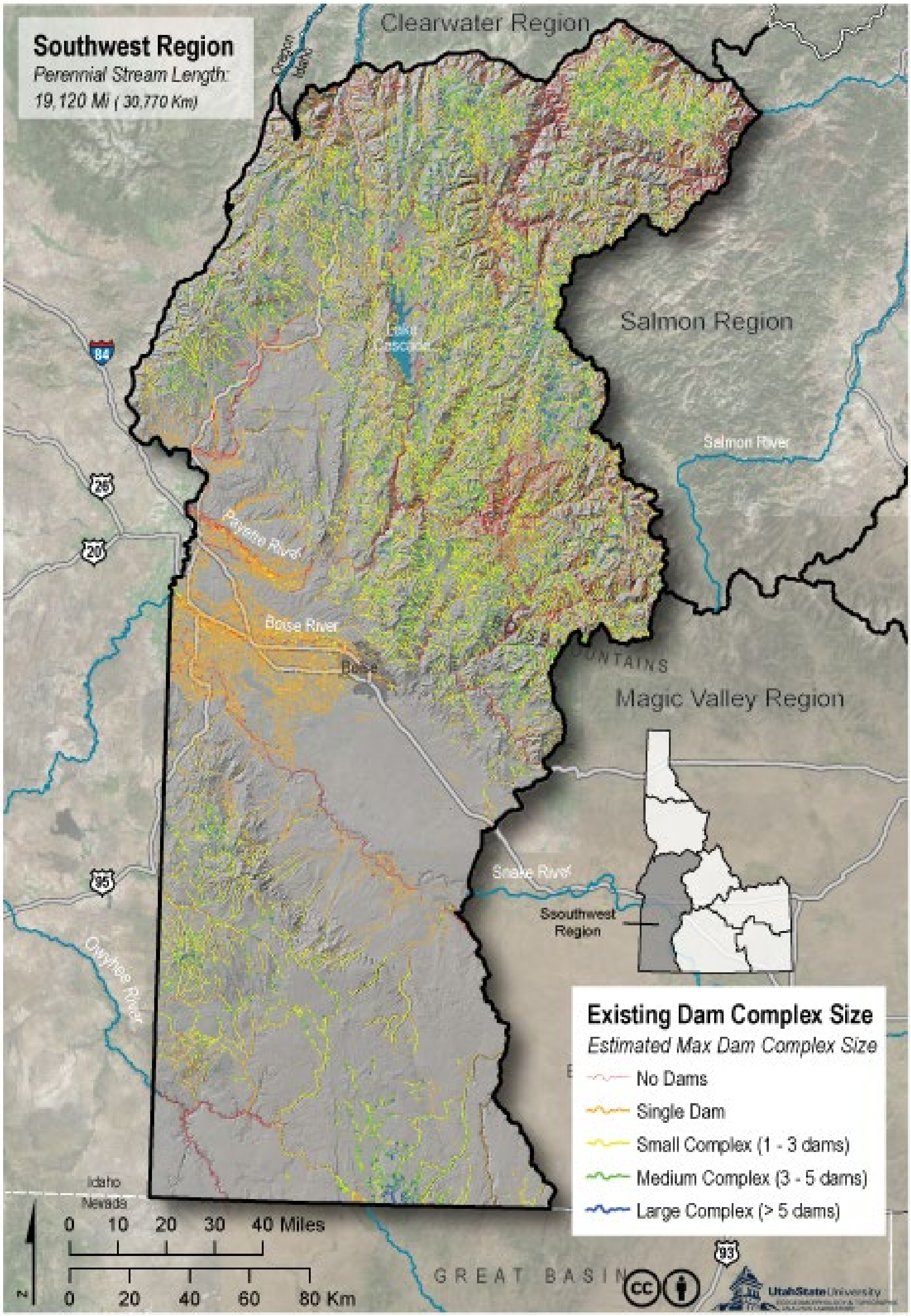

*Figure 7: Modeled existing dam complex size for the Southwest Region of Idaho.*

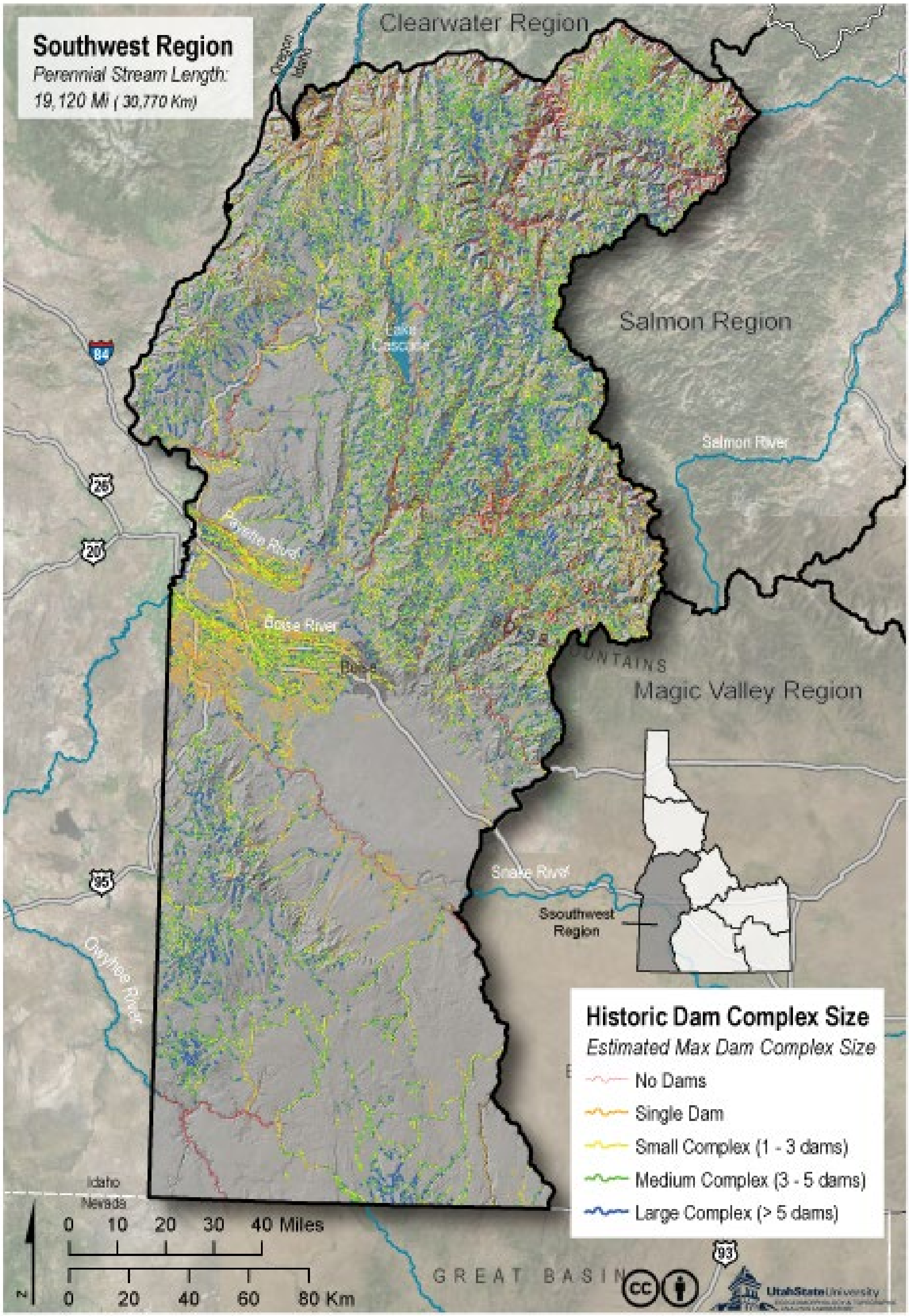

*Figure 8: Modeled historic dam complex size for the Southwest Region of Idaho.*

## 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 9). The layer/map represents areas with limited 'risk' of human-beaver conflict and some level of 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). 27% of Idaho is categorized as 'easiest' conservation and restoration opportunities, suggesting there are many low-hanging fruit beaver-related restoration opportunities available.

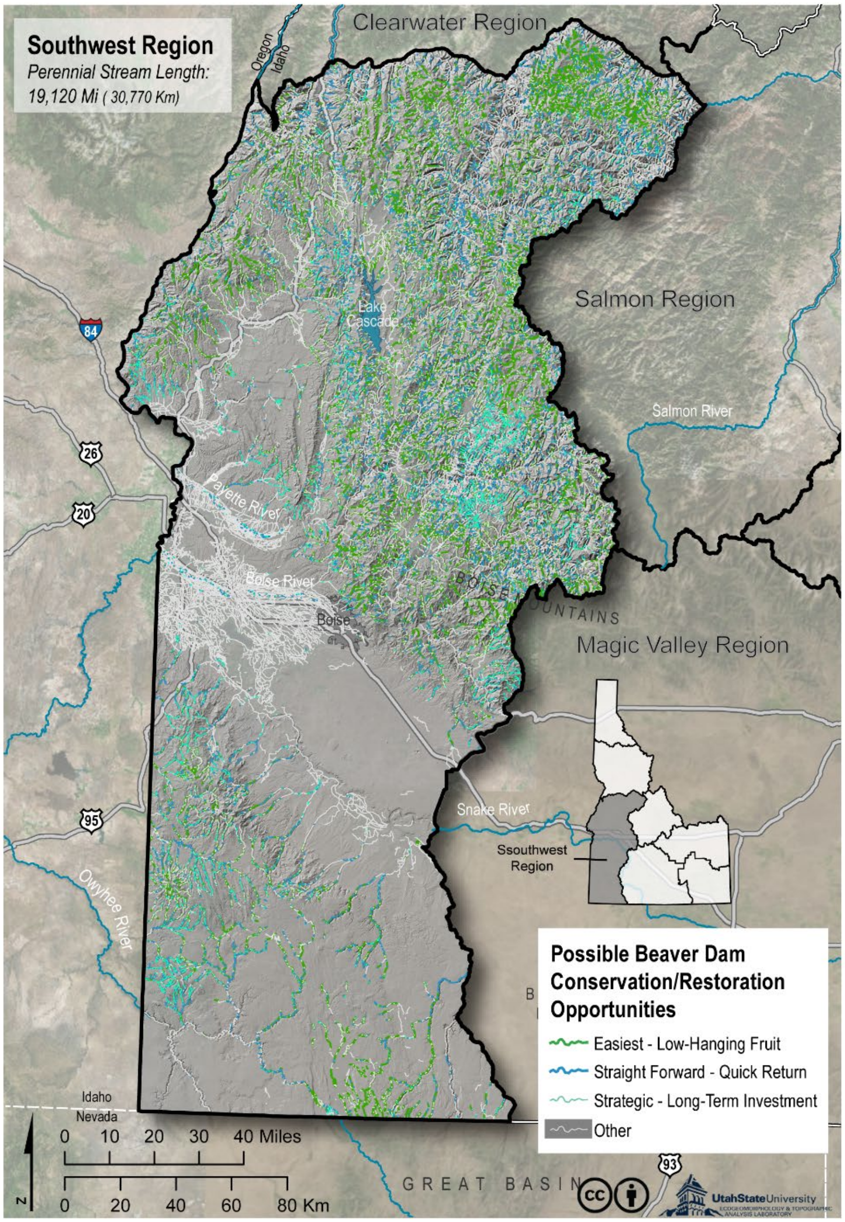

*Figure 9: Modeled conservation and restoration opportunities for the Southwest Region of Idaho.*

## 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 10). 59% of Idaho is categorized as 'negligible' risk, suggesting there are many low risk beaver-related restoration opportunities available.

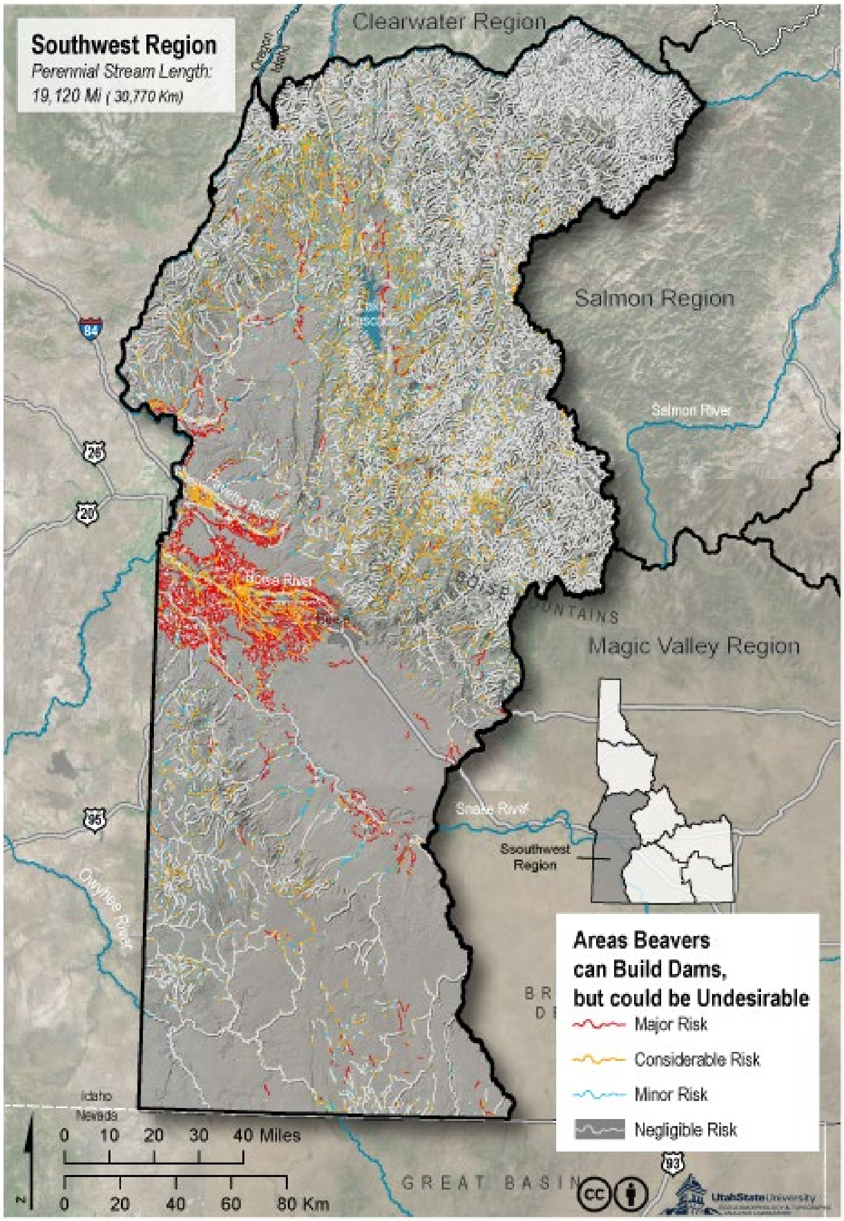

*Figure 10: Modeled areas beavers can build dams but could be undesirable for the Southwest Region of Idaho.*

## Unsuitable or limited dam building opportunities

The BRAT model also identifies areas where beaver cannot build dams now, and differentiates these into anthropogenically and naturally limiting areas. The layer/map is called ‘unsuitable or limited dam building opportunities’ (Figure 11). Only 18% of all perennial streams in Idaho were categorized as unsuitable for beaver dam building.

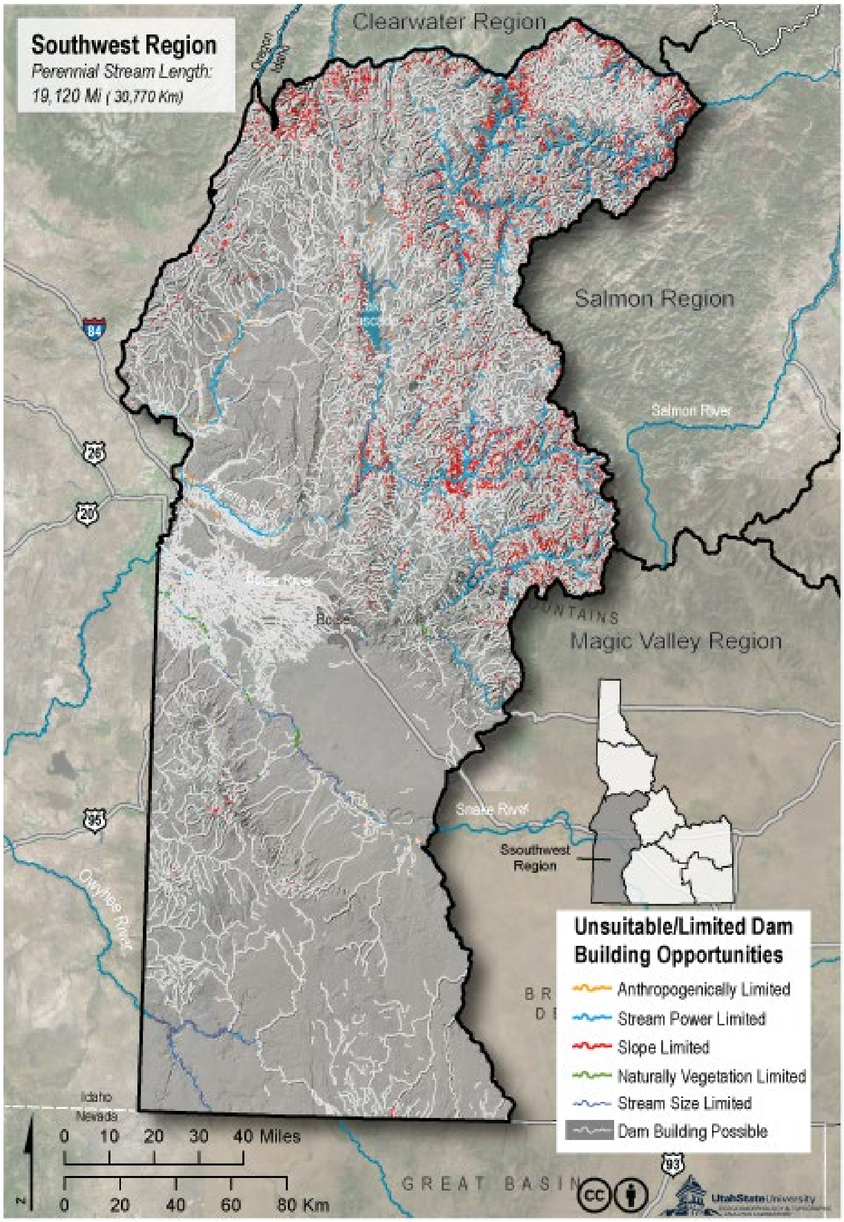

*Figure 11: Modeled unsuitable/limited dam building opportunities for the Southwest Region of Idaho.*

## Model intermediates

### Anthropogenic constraints layers

The BRAT model identifies anthropogenic constraints based on proximity to human infrastructure (Figure 12) and includes distance to roads (Figure 13), distance to roads within valley bottoms (Figure 14), distance to road crossings (Figure 15), distance to railroads, distance to railroads within valley bottoms, distance to canals (Figure 16), distance to points of diversion, and distance to nearest infrastructure (Figure 17). The BRAT model identifies also identifies land use intensity (Figure 18). This proximity analysis highlights possible risks (i.e. flooding and clogging) that might occur to this infrastructure. These figures are results from the Little Wood watershed. Additional watershed level intermediate data can be found here.

#### *Context layers*

Figure 12 shows the Little Wood watershed as an example of the context layers: canals, valley bottoms, roads, and railroads that the model used to calculate overall and individual proximity of streams to human infrastructure.

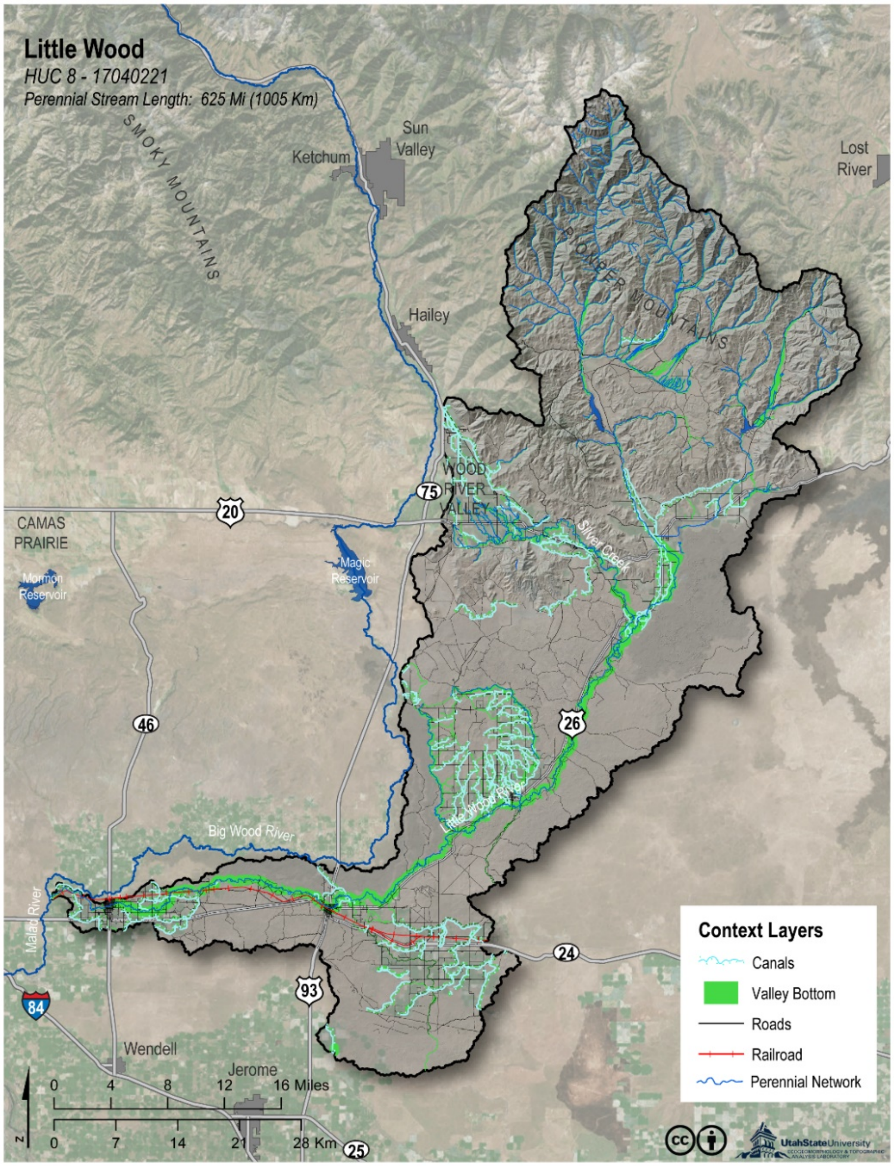

*Figure 12: Little Wood watershed context layers used in the Idaho BRAT model.*

### *Distance to road*

Figure 13 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.

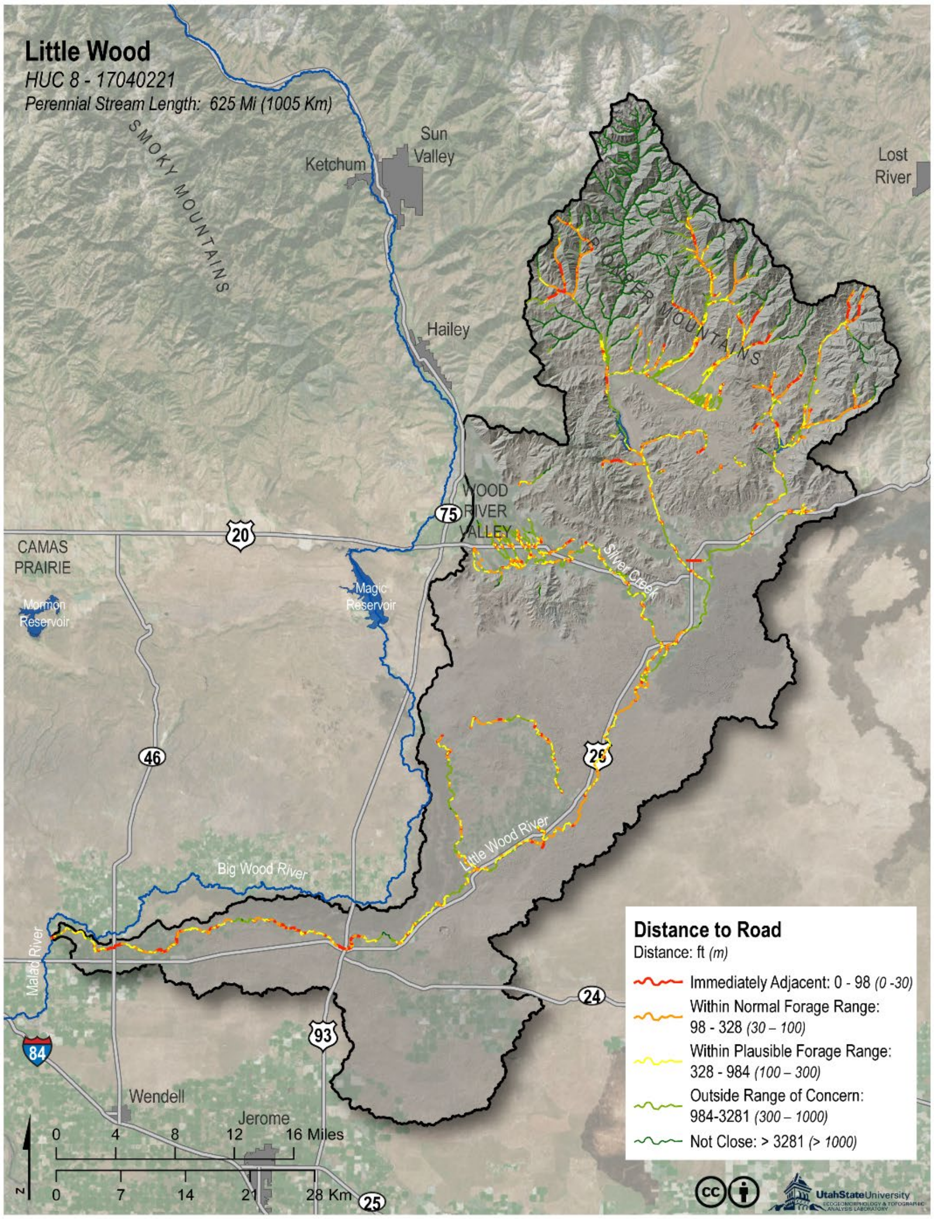

*Figure 13: Little Wood watershed Euclidean distance to roads layer used in the Idaho BRAT model.*

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### *Distance to roads within valley bottoms*

Figure 14 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.

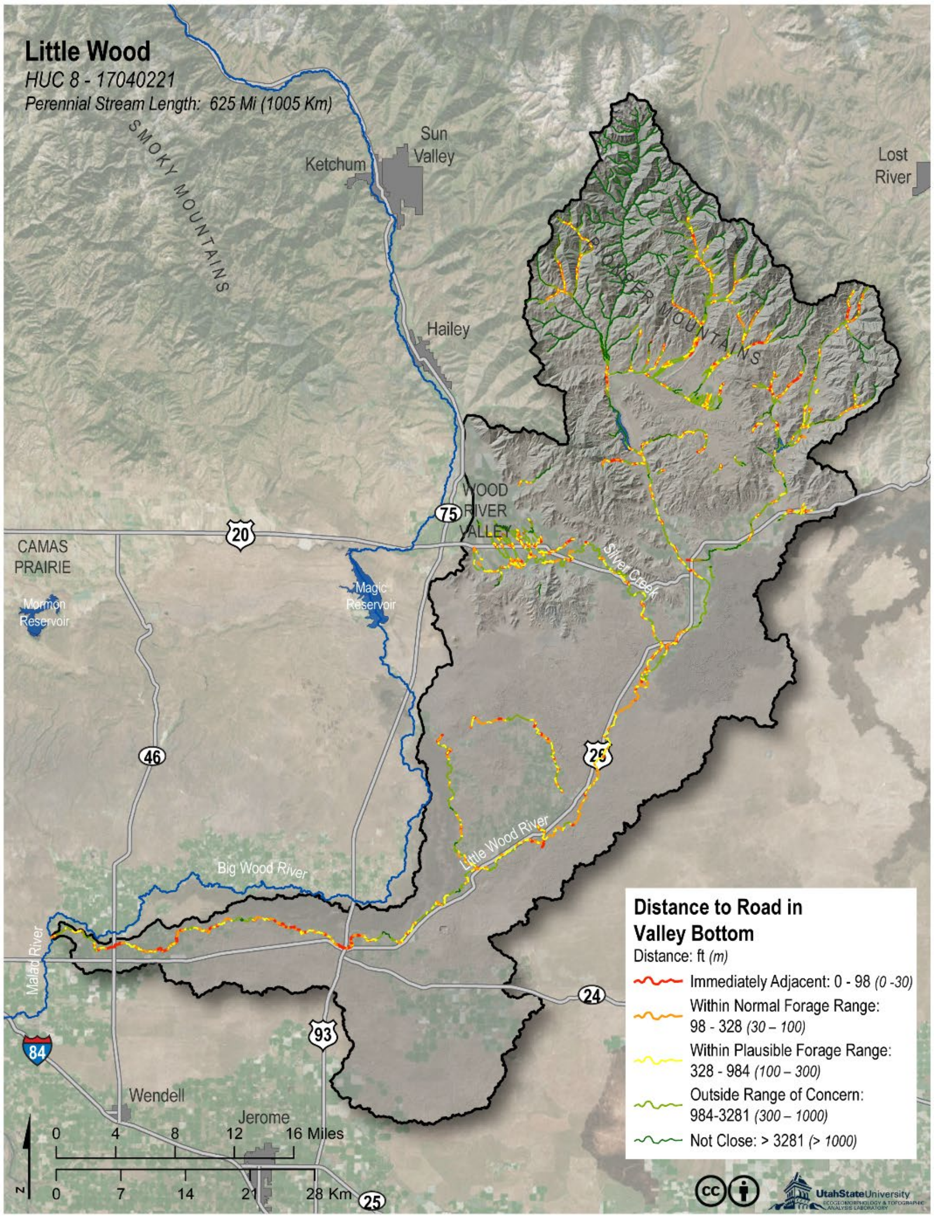


*Figure 14: Little Wood watershed Euclidean distance to roads within the valley bottom layer used in the Idaho BRAT model.*

### *Distance to road crossing*

Figure 15 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.

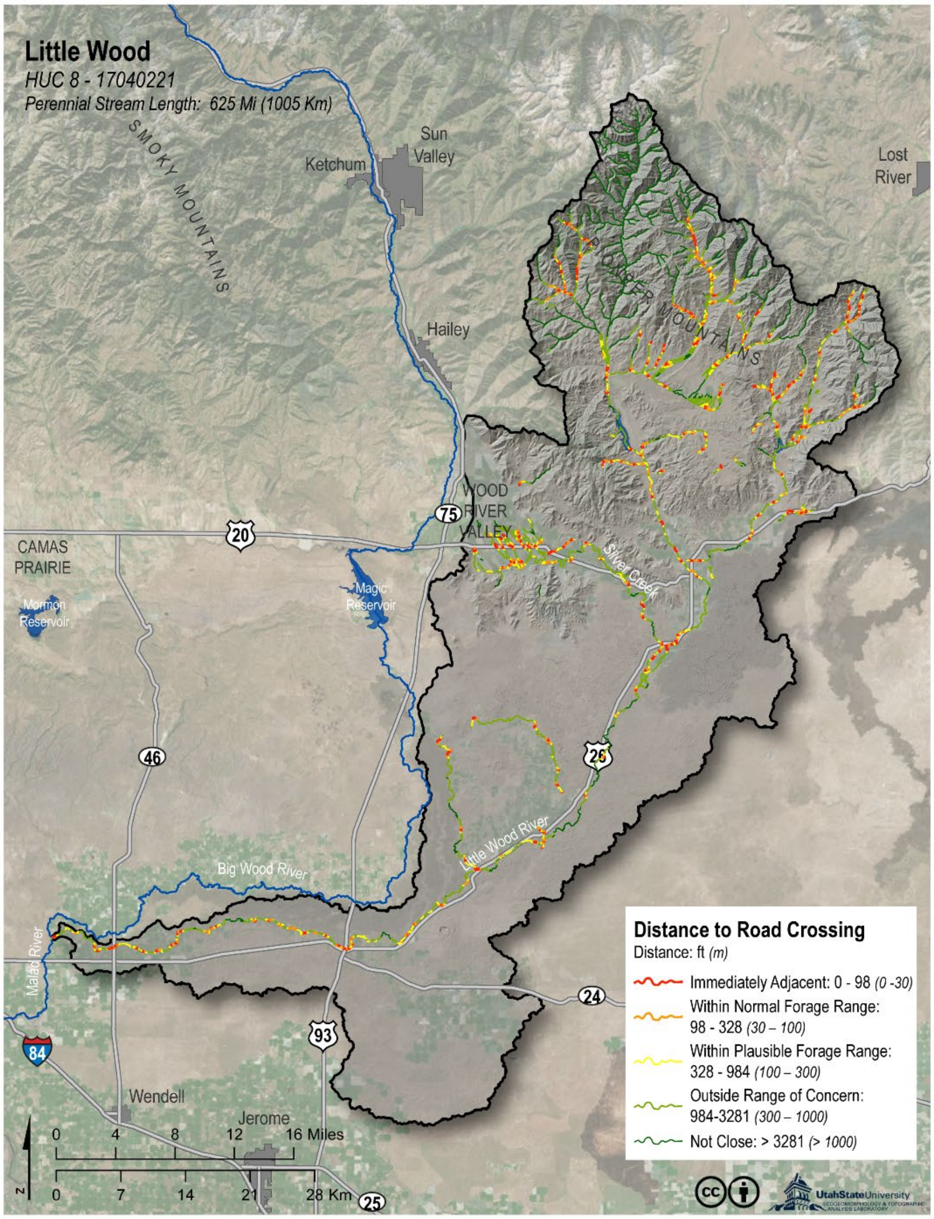


*Figure 15: Little Wood watershed Euclidean distance to road crossings layer used in the Idaho BRAT model.*

### *Distance to canal*

Figure 16 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.

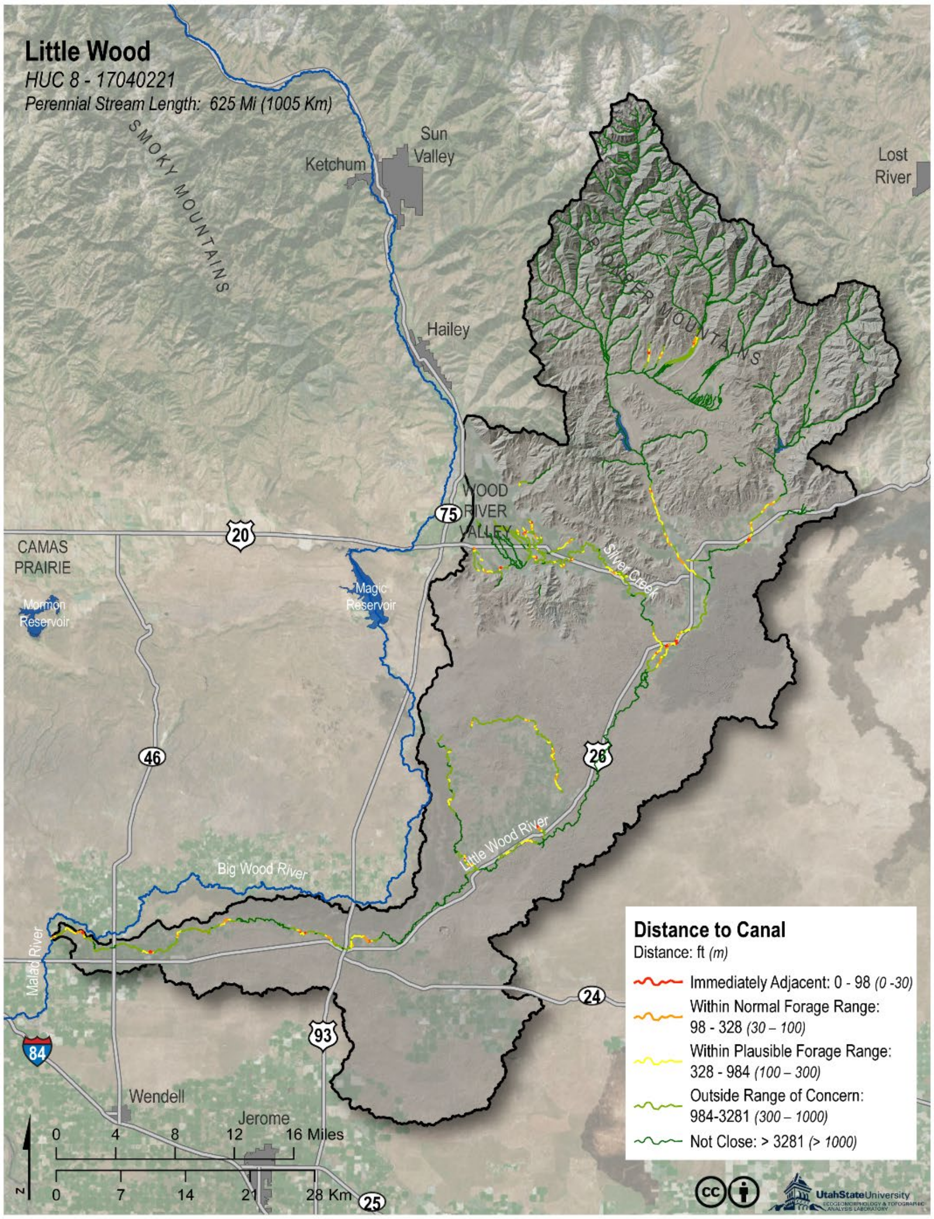


*Figure 16: Little Wood watershed Euclidean distance to canals layer used in the Idaho BRAT model.*

### *Distance to infrastructure*

Figure 17 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.

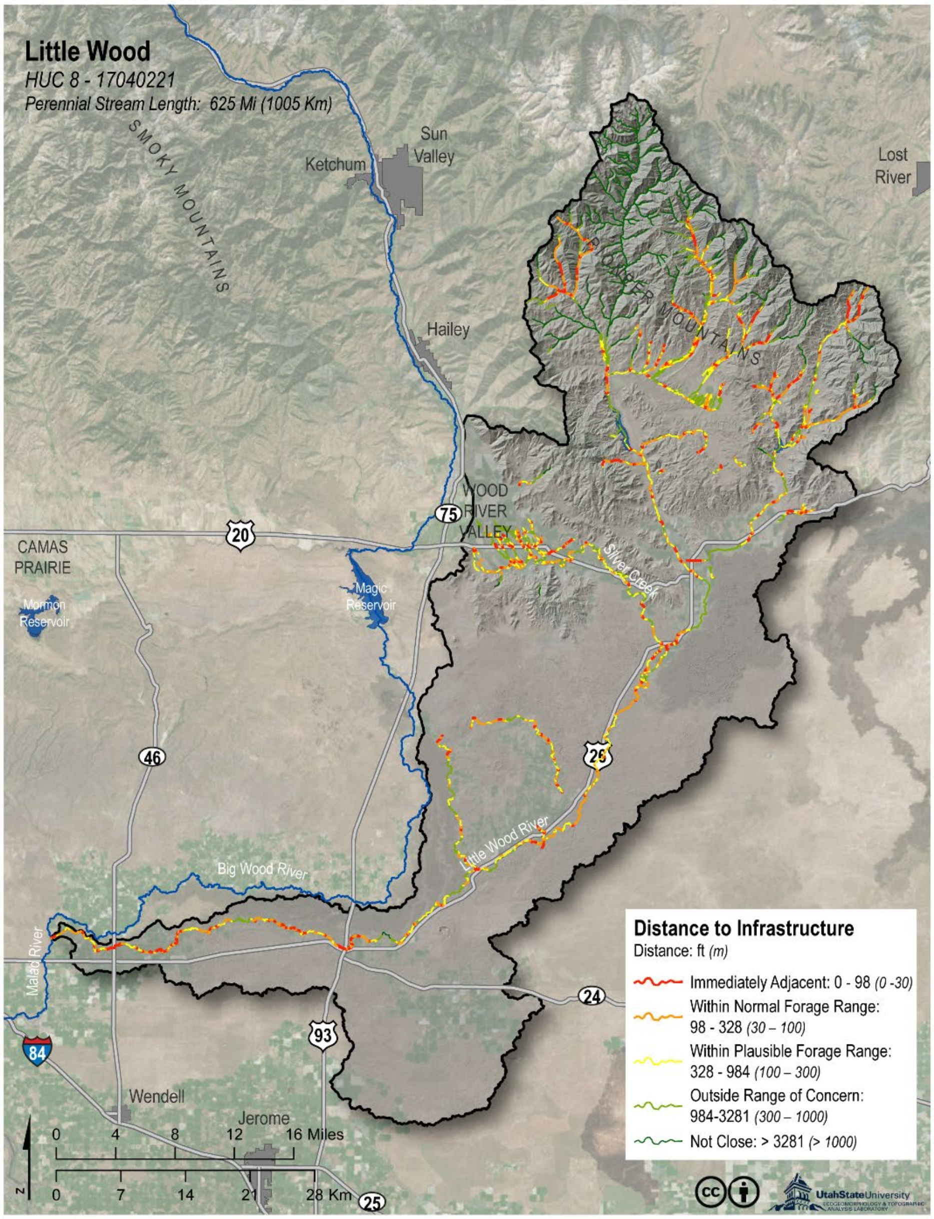


*Figure 17: Little Wood watershed Euclidean distance to human infrastructure layer used in the Idaho BRAT model.*

### *Land use intensity*

Figure 18 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.

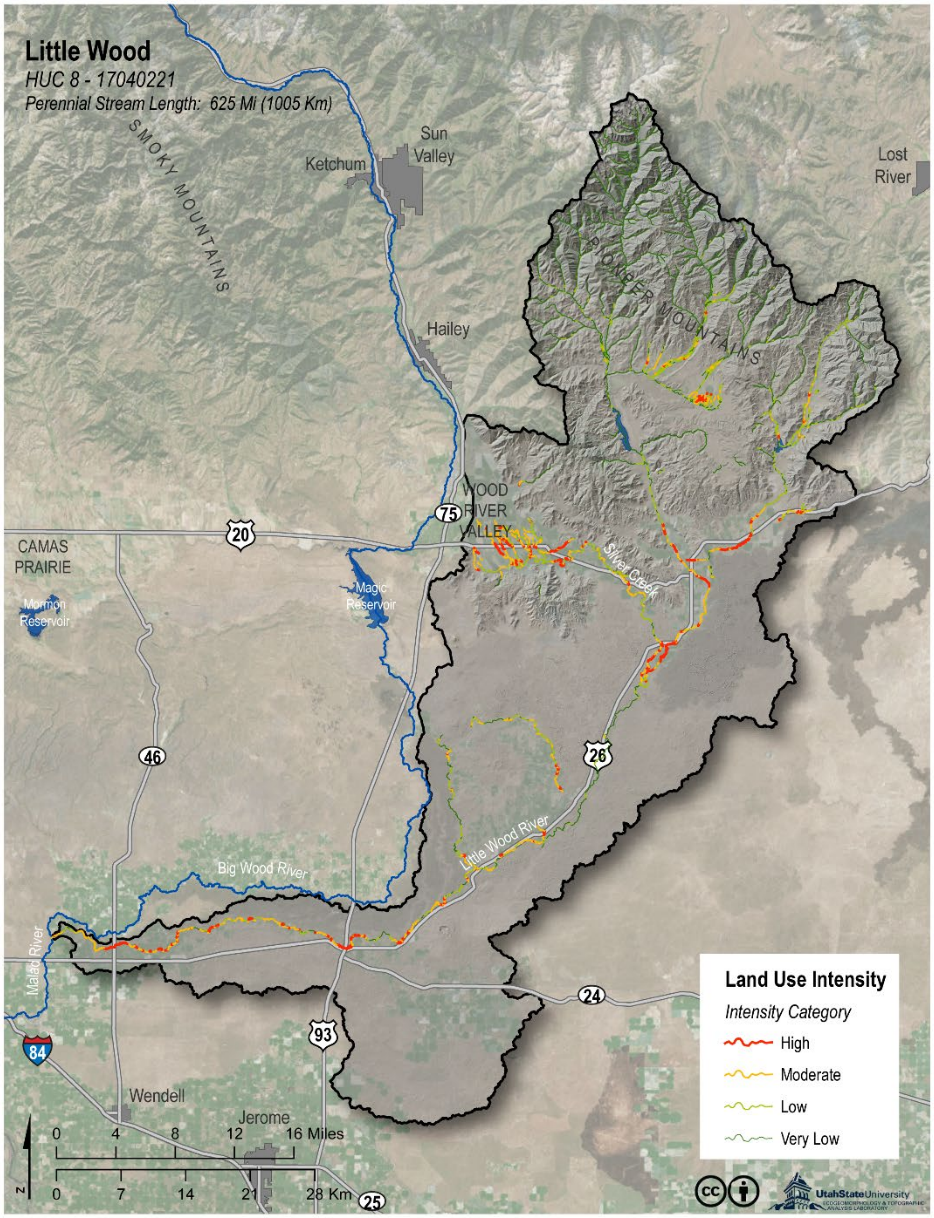


*Figure 18: Little Wood watershed land use intensity layer used in the Idaho BRAT model.*

## Model calibration

IDF&G staff provided concrete and detailed written feedback regarding the accuracy, and usability of the BRAT model in the calibration watersheds. The vast majority of the feedback can be assigned to the following four categories:

1. **Low resolution input data:** As anticipated, IDF&G staff provided examples of where input vegetation and land use data was lacking in detail and correctness. The input data for our provisional run for both landcover and land use was 2014 LANDFIRE EVT data. It was fortuitous that in May 2019, during this review process, LANDFIRE made the 2016 existing landcover/land use data available and we were able to rerun the BRAT model primarily using this updated dataset, though LANDFIRE 2014 had to be used for small portions of southern Idaho.
2. **Inadequate canal and irrigation infrastructure:** We resolved this issue by identifying points of diversion data, adding ditches to the dataset, and modifying the conservation and restoration model to identify any canals or ditches as high risk areas.
3. **Lack of land ownership information**: We improved the model to include land ownership and created a script that calculated distance from private land as a way to help identify areas suitable for beaver translocation.
4. **Risk model parameters are too restrictive**: As directed we adjusted the risk model parameters to make the model less restrictive.

## Model validation

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

1. Are there surveyed dams where the model predicted existing dam capacity as *none*?
2. How do dam densities track between predicted and actual?
3. Do the electivity indices increase appreciably from the *none* to the *pervasive* class?

### How do dam densities track between predicted and actual?

Figure 19 shows a total of 9,048 actual beaver dams were identified throughout Idaho based on virtual reconnaissance using a webmap. Dams were concentrated in reaches where the BRAT capacity model estimated frequent and pervasive dam densities

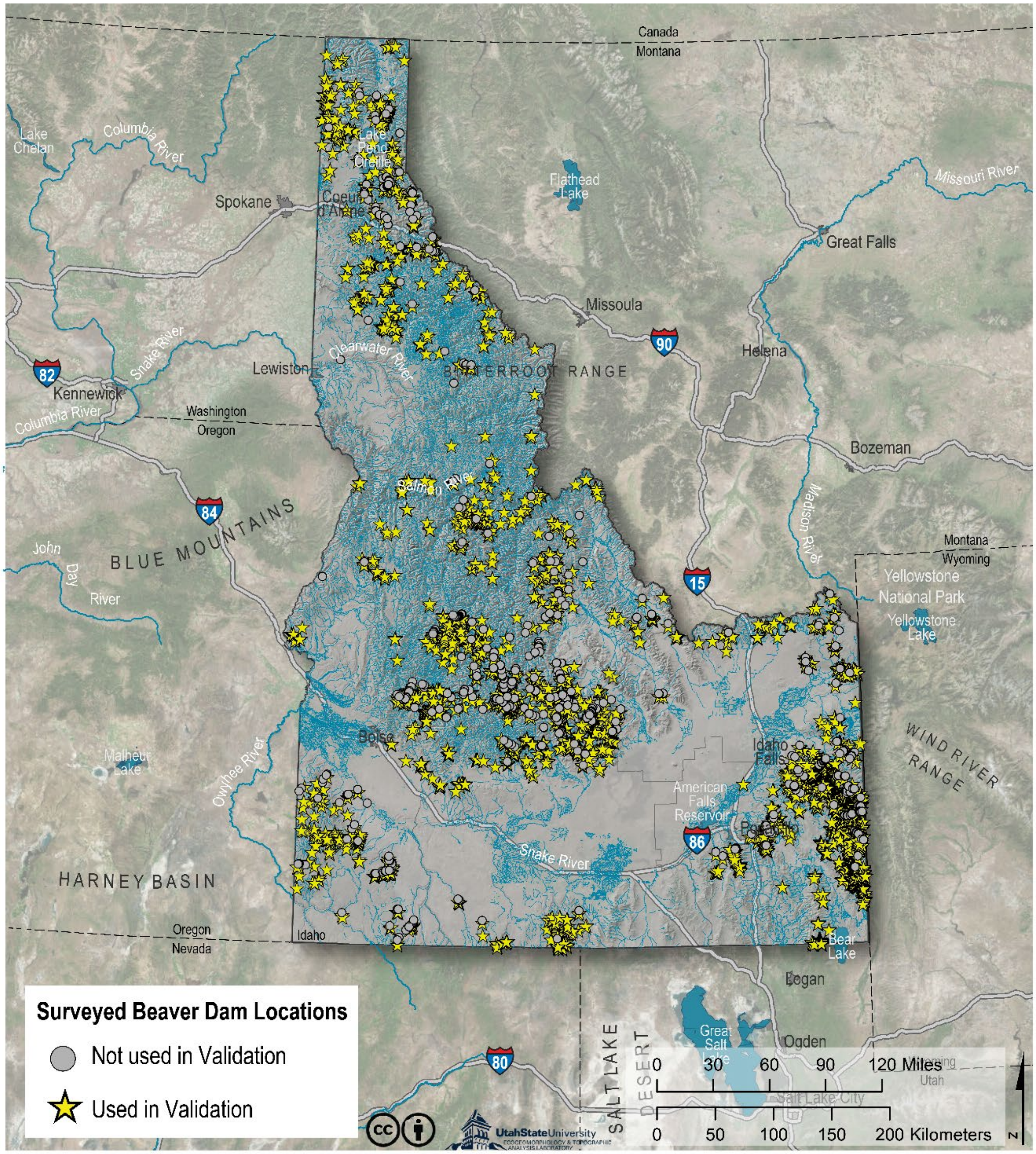


*Figure 19: Actual beaver dam (based on 2013 0.5 meter NAIP imagery) identified throughout Idaho from desktop dam censusing. Of the 9,048 dams 8,060 were within 60 m of the NHD stream lines and therefore, were used in the model validation.*

## Idaho Statewide

We verified the performance of the existing capacity model using a total of 8,060 actual beaver dams representing 0.8% of the 118,319 km of perennial streams across the state of Idaho. 70 beaver dams were found where the model predicted no dams could be supported. Of the total 3,723 stream segments with validation dam counts 382 exceeded the capacity estimates indicating that the model effectively segregates the factors controlling beaver dam occurrence and density 89.74% of the time (Figure 20). Thus, the model run with 30 m LANDFIRE data only underestimated capacity 10.26% of the time (Figure 20). Validation data can be found here.

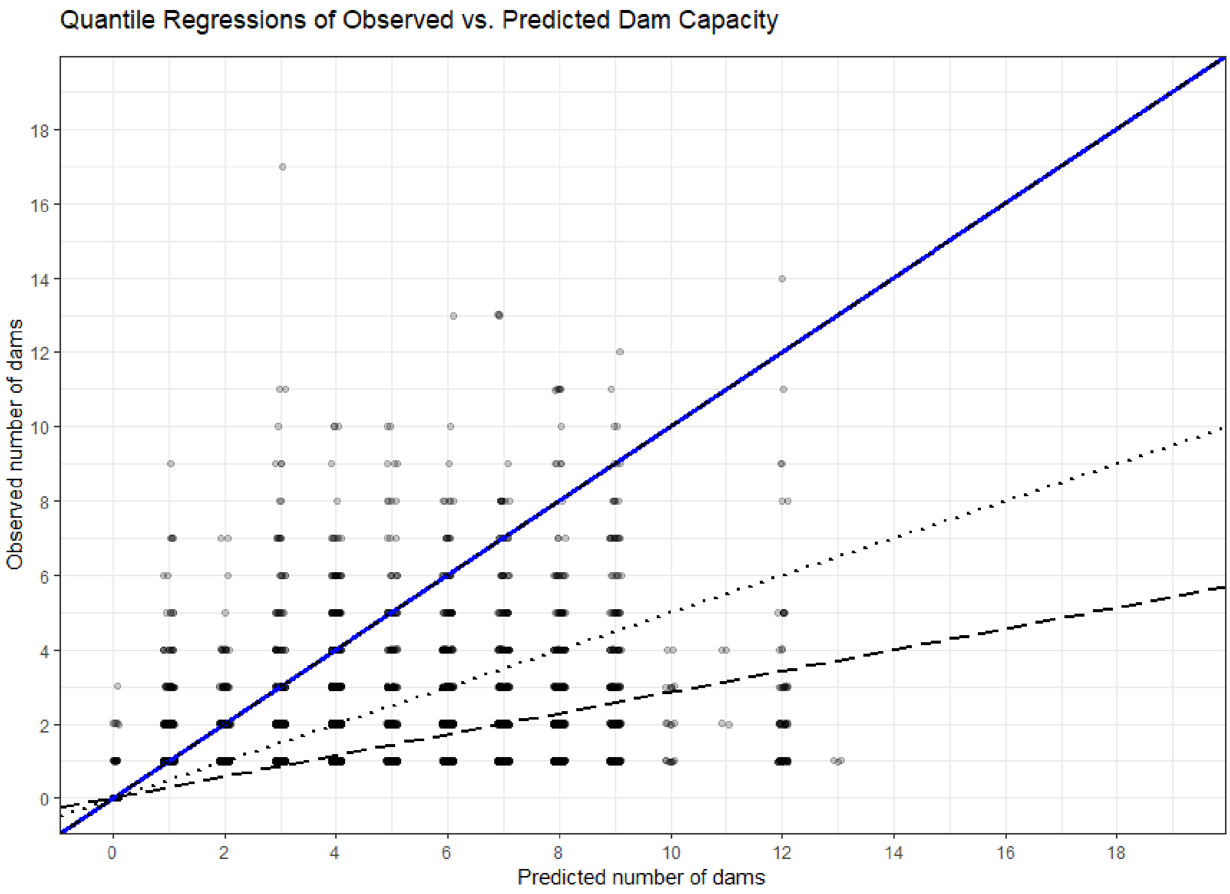


*Figure 20: Predicted vs. observed dam counts (per reach) for Idaho. The blue line is line of perfect agreement (1:1 relationship), dashed line is the 50th percentile (median) regression, dotted line is the 75th percentile regression, and dot-dashed line is the 90th percentile regression (not visible due to direct correspondence with line of perfect agreement in this graphic). The nearer the higher percentile regression is to the 1:1 ratio, the better the model is performing.*

### Clearwater Region

For the Clearwater Region we verified the performance of the existing capacity model using 274 dams representing 0.2% of the 22,901km of perennial streams across the region. 8 beaver dams were found where the model predicted no dams could be supported. Of the total 149 stream segments with validation dam counts 19 exceeded the capacity estimates indicating that the model effectively segregates the factors controlling beaver dam occurrence and density 87.25% of the time (Figure 21). Thus, the model run with 30 m LANDFIRE data underestimated capacity 12.75% of the time (Figure 21). Validation data can be found here.

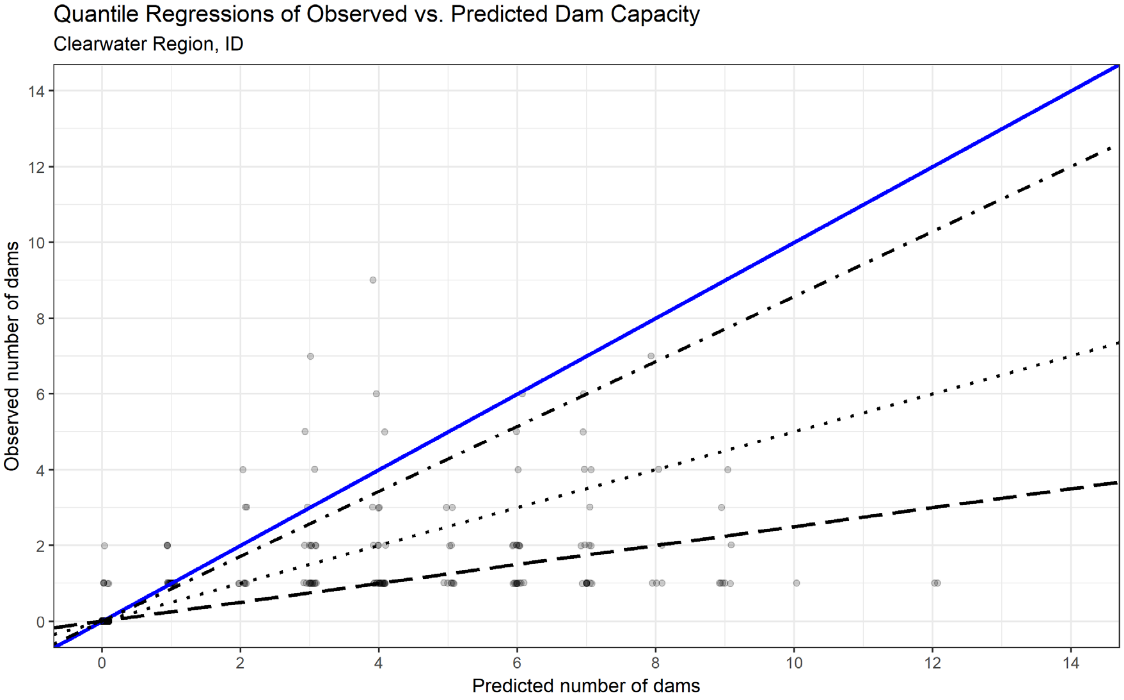


*Figure 21: Predicted vs. observed dam counts (per reach) for Clearwater Region. The blue line is line of perfect agreement (1:1 relationship), dashed line is the 50th percentile (median) regression, dotted line is the 75th percentile regression, and dot-dashed line is the 90th percentile regression. The nearer the higher percentile regression is to the 1:1 ratio, the better the model is performing.*

## Magic Valley Region

For the Magic Valley Region we verified the performance of the existing capacity model using 864 dams representing 0.7% of the 15,690 km of perennial streams across the region. 11 beaver dams were found where the model predicted no dams could be supported. Of the total 406 stream segments with validation dam counts 60 exceeded the capacity estimates indicating that the model effectively segregates the factors controlling beaver dam occurrence and density 85.22% of the time (Figure 22). Thus, the model run with 30 m LANDFIRE data underestimated capacity 14.78% of the time (Figure 22).

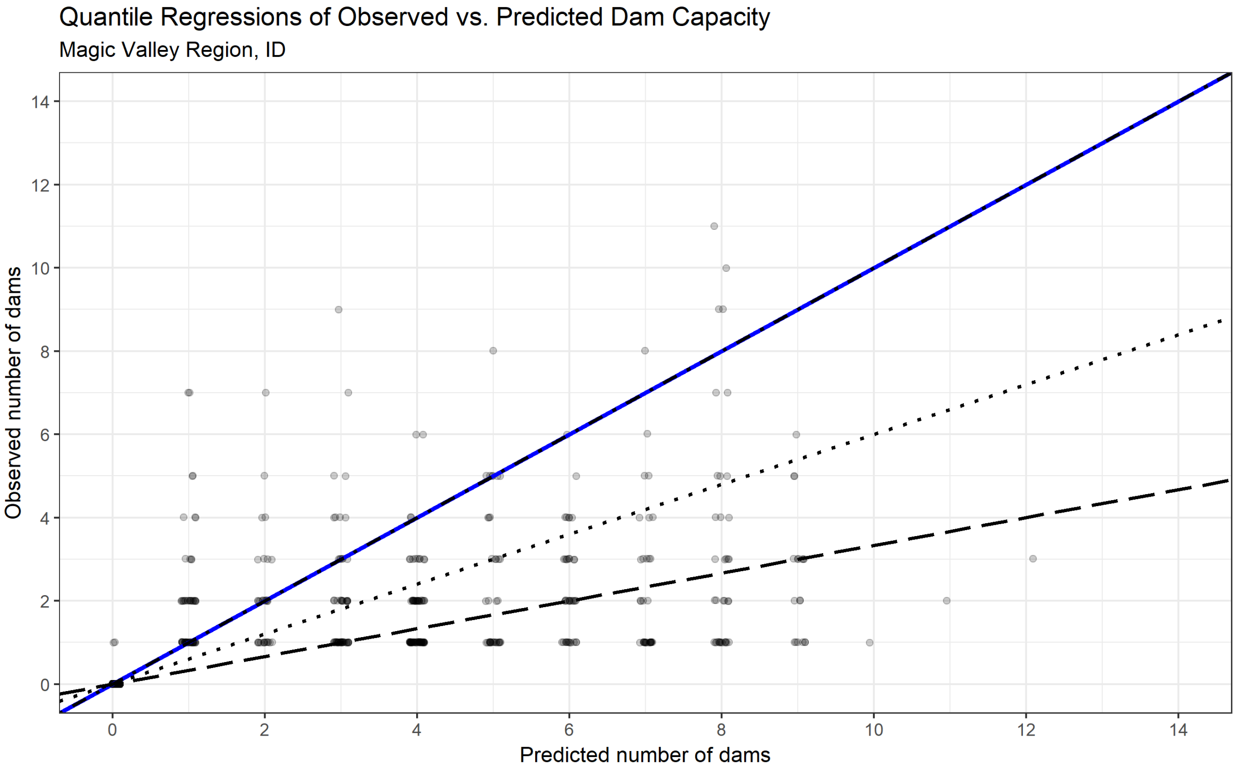


*Figure 22: Predicted vs. observed dam counts (per reach) for the Magic Valley Region. The blue line is line of perfect agreement (1:1 relationship), dashed line is the 50th percentile (median) regression, dotted line is the 75th percentile regression, and dot-dashed line is the 90th percentile regression. The nearer the higher percentile regression is to the 1:1 ratio, the better the model is performing.*

## Panhandle Region

For the Panhandle Region we verified the performance of the existing capacity model using 684 dams representing 0.8% of the 11,962 km of perennial streams across the region. 4 beaver dams were found where the model predicted no dams could be supported. Of the total 357 stream segments with validation dam counts 20 exceeded the capacity estimates indicating that the model effectively segregates the factors controlling beaver dam occurrence and density 94.40% of the time (Figure 23). Thus, the model run with 30 m LANDFIRE data underestimated capacity 5.60% of the time (Figure 23).

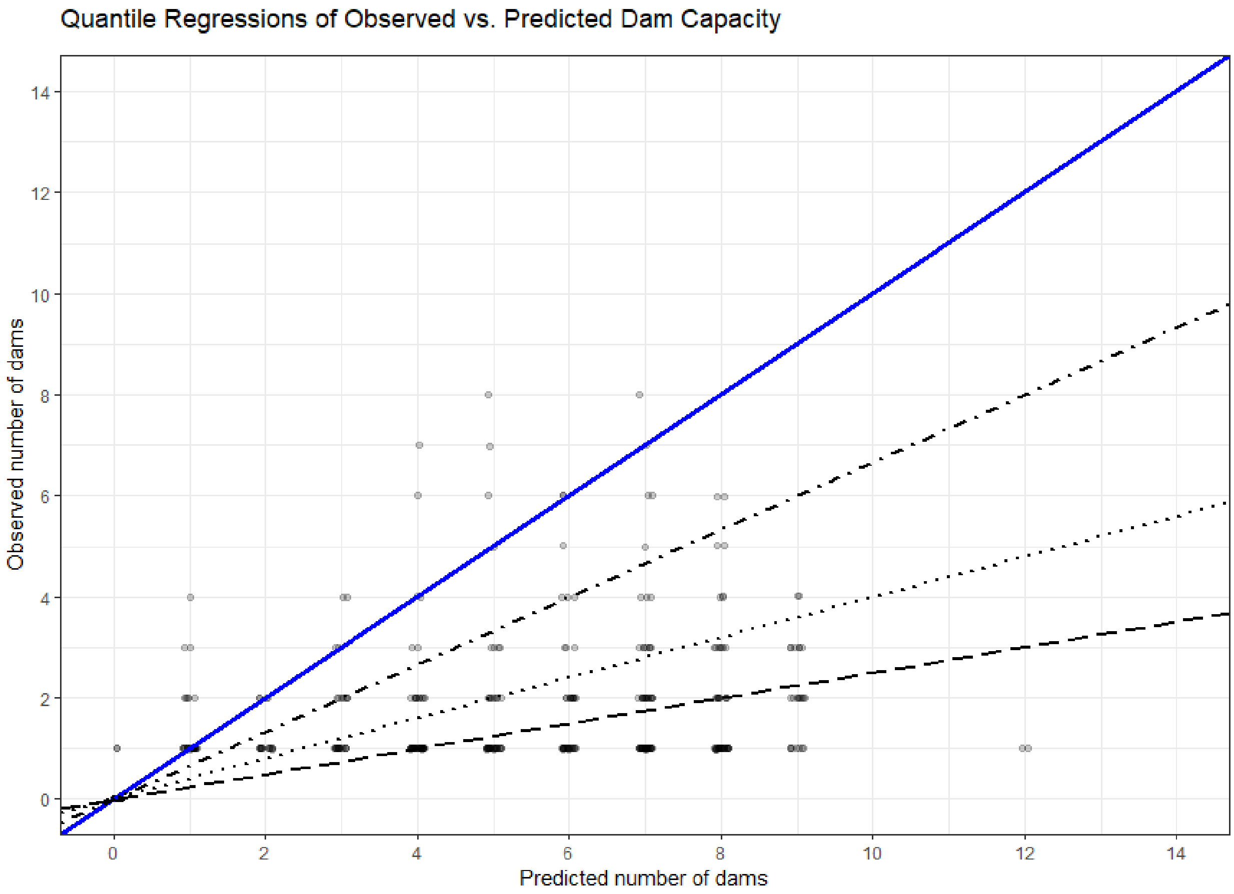


*Figure 23: Predicted vs. observed dam counts (per reach) for the Panhandle Region. The blue line is line of perfect agreement (1:1 relationship), dashed line is the 50th percentile (median) regression, dotted line is the 75th percentile regression, and dot-dashed line is the 90th percentile regression. The nearer the higher percentile regression is to the 1:1 ratio, the better the model is performing.*

### Salmon Region

For the Salmon Region we verified the performance of the existing capacity model using 696 dams representing 0.7% of the 13,867 km of perennial streams across the region. 18 beaver dams were found where the model predicted no dams could be supported. Of the total 379 stream segments with validation dam counts 38 exceeded the capacity estimates indicating that the model effectively segregates the factors controlling beaver dam occurrence and density 89.97% of the time (Figure 24). Thus, the model run with 30 m LANDFIRE data underestimated capacity 10.03% of the time (Figure 24).

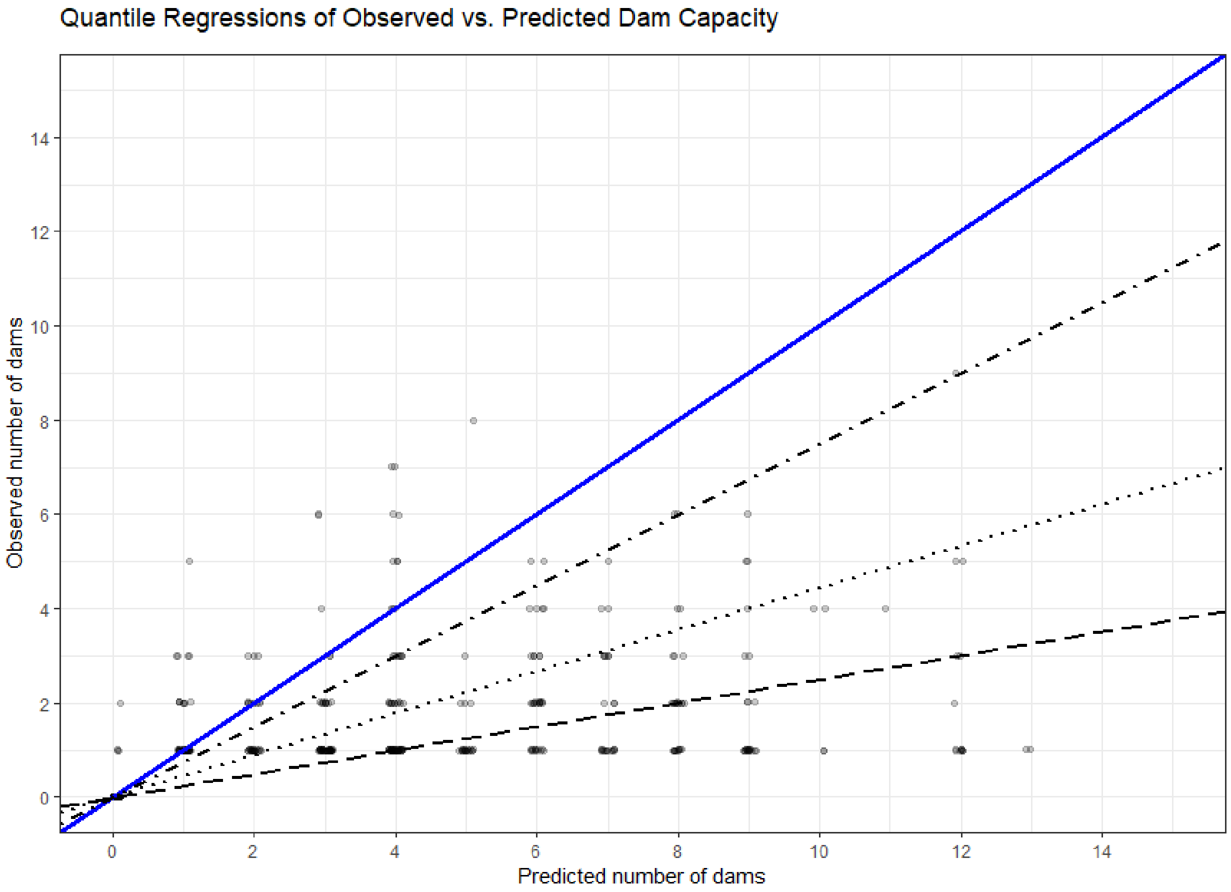


*Figure 24: Predicted vs. observed dam counts (per reach) for the Salmon Region. The blue line is line of perfect agreement (1:1 relationship), dashed line is the 50th percentile (median) regression, dotted line is the 75th percentile regression, and dot-dashed line is the 90th percentile regression. The nearer the higher percentile regression is to the 1:1 ratio, the better the model is performing.*

## Southeast Region

For the Southeast Region we verified the performance of the existing capacity model using 2,248 dams representing 2.1% of the 10,469 km of perennial streams across the region. 2 beaver dams were found where the model predicted no dams could be supported. Of the total 843 stream segments with validation dam counts 102 exceeded the capacity estimates indicating that the model effectively segregates the factors controlling beaver dam occurrence and density 87.90% of the time (Figure 25). Thus, the model run with 30 m LANDFIRE data underestimated capacity 12.10% of the time (Figure 25).

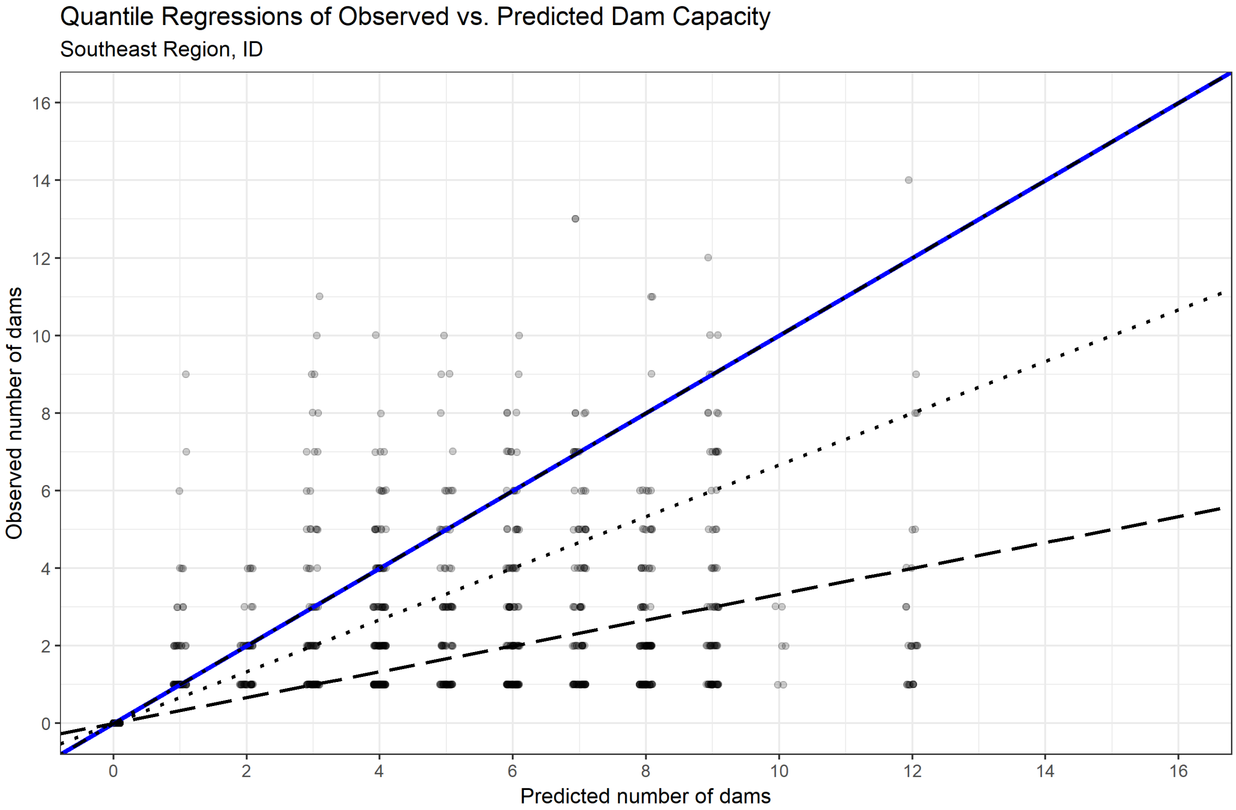


*Figure 25: Predicted vs. observed dam counts (per reach) for the Southeast Region. The blue line is line of perfect agreement (1:1 relationship), dashed line is the 50th percentile (median) regression, dotted line is the 75th percentile regression, and dot-dashed line is the 90th percentile regression. The nearer the higher percentile regression is to the 1:1 ratio, the better the model is performing.*

## Southwest Region

For the Southwest Region we verified the performance of the existing capacity model using 1,002 dams representing 0.5% of the 30,770 km of perennial streams across the region. 23 beaver dams were found where the model predicted no dams could be supported. Of the total 614 stream segments with validation dam counts 66 exceeded the capacity estimates indicating that the model effectively segregates the factors controlling beaver dam occurrence and density 89.25% of the time (Figure 26). Thus, the model run with 30 m LANDFIRE data underestimated capacity 10.75% of the time (Figure 26).

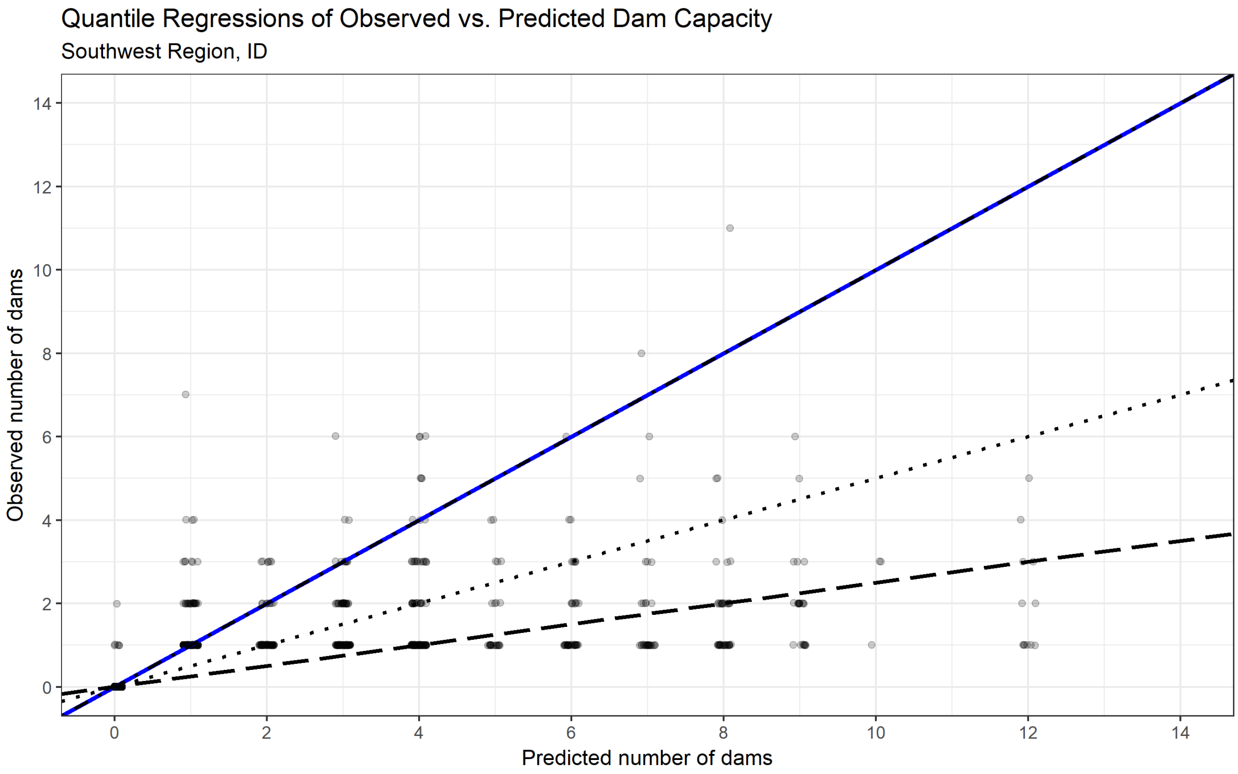


*Figure 26: Predicted vs. observed dam counts (per reach) for the Southwest Region. The blue line is line of perfect agreement (1:1 relationship), dashed line is the 50th percentile (median) regression, dotted line is the 75th percentile regression, and dot-dashed line is the 90th percentile regression. The nearer the higher percentile regression is to the 1:1 ratio, the better the model is performing.*

## Upper Snake Region

For the Upper Snake Region we verified the performance of the existing capacity model using 2,292 dams representing 2.0% of the 12,492 km of perennial streams across the region. 4 beaver dams were found where the model predicted no dams could be supported. Of the total 980 stream segments with validation dam counts 78 exceeded the capacity estimates indicating that the model effectively segregates the factors controlling beaver dam occurrence and density 92.04% of the time (Figure 27). Thus, the model run with 30 m LANDFIRE data underestimated capacity 7.96% of the time (Figure 27).

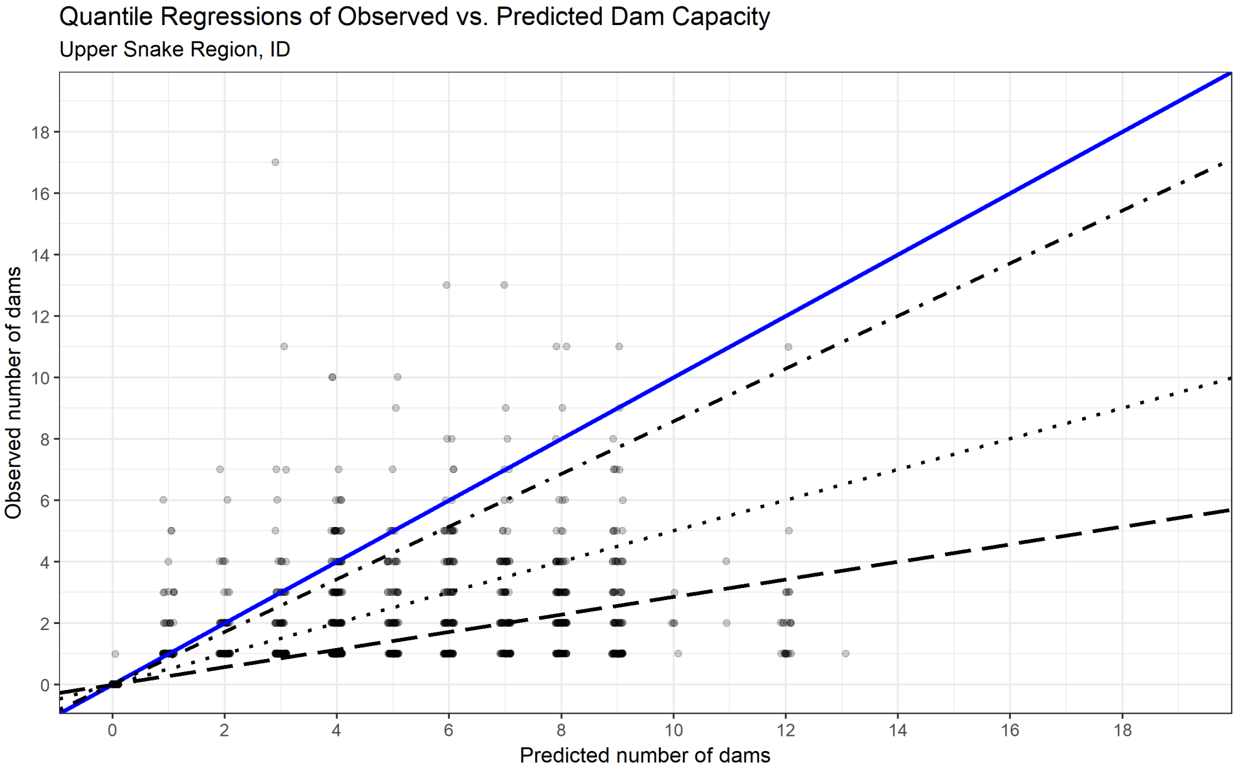


*Figure 27: Predicted vs. observed dam counts (per reach) for the Upper Snake Region. The blue line is line of perfect agreement (1:1 relationship), dashed line is the 50th percentile (median) regression, dotted line is the 75th percentile regression, and dot-dashed line is the 90th percentile regression. The nearer the higher percentile regression is to the 1:1 ratio, the better the model is performing.*

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

The Electivity indices results in Table 4, Table 5, Table 6, Table 7, Table 8, Table 9, Table 10 and Table 11 show that throughout the perennial streams of Idaho 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.

*Table 4: Existing number of dams and BRAT modeled capacity estimates Idaho statewide.*

| Segment Type | Stream Length | % of Drainage Network | Surveyed Dams | BRAT Estimated Capacity | Average Surveyed Dam Density | Average BRAT Predicted Capacity | % of Modeled Capacity | Electivity Index |
|---|---|---|---|---|---|---|---|---|
| | *km* | *%* | *# of dams* | *# of dams* | *dams/km* | *dams/km* | *%* | |
| None | 21,820.5 | 18% | 70 | 0 | 0.003 | 0.00 | 0.00% | 0.05 |
| Rare | 16,593.0 | 14% | 37 | 81,486 | 0.002 | 4.91 | 0.05% | 0.03 |
| Occasional | 24,087.0 | 20% | 371 | 110,608 | 0.015 | 4.59 | 0.34% | 0.23 |
| Frequent | 40,270.6 | 34% | 2,289 | 448,010 | 0.057 | 11.12 | 0.51% | 0.85 |
| Pervasive | 15,548.0 | 13% | 5,112 | 354,195 | 0.329 | 22.78 | 1.44% | 4.94 |
| **Total** | **118,319.0** | **N/A** | **7,879** | **994,299** | **0.067** | **8.40** | **0.79%** | **N/A** |

*Table 5: Existing number of dams and BRAT modeled capacity estimates for the Clearwater Region.*

| Segment Type | Stream Length | % of Drainage Network | Surveyed Dams | BRAT Estimated Capacity | Average Surveyed Dam Density | Average BRAT Predicted Capacity | % of Modeled Capacity | Electivity Index |
|---|---|---|---|---|---|---|---|---|
| | *km* | *%* | *# of dams* | *# of dams* | *dams/km* | *dams/km* | *%* | |
| None | 5,152.5 | 22% | 8 | 0 | 0.002 | 0.00 | 0.00% | 0.13 |
| Rare | 1,303.0 | 6% | 2 | 5,947 | 0.002 | 4.56 | 0.03% | 0.13 |
| Occasional | 3,924.2 | 17% | 17 | 17,059 | 0.004 | 4.35 | 0.10% | 0.37 |
| Frequent | 9,464.9 | 41% | 96 | 104,814 | 0.010 | 11.07 | 0.09% | 0.86 |
| Pervasive | 3,056.7 | 13% | 147 | 65,846 | 0.048 | 21.54 | 0.22% | 4.08 |
| **Total** | **22,901.3** | **N/A** | **270** | **193,666** | **0.012** | **8.46** | **0.14%** | **N/A** |

*Table 6: Existing number of dams and BRAT modeled capacity estimates for the Magic Valley Region.*

| Segment Type | Stream Length | % of Drainage Network | Surveyed Dams | BRAT Estimated Capacity | Average Surveyed Dam Density | Average BRAT Predicted Capacity | % of Modeled Capacity | Electivity Index |
|---|---|---|---|---|---|---|---|---|
| | *km* | *%* | *# of dams* | *# of dams* | *dams/km* | *dams/km* | *%* | |
| None | 2,793.8 | 18% | 11 | 0 | 0.004 | 0.00 | 0.00% | 0.07 |
| Rare | 4,770.9 | 30% | 1 | 23,885 | 0.000 | 5.01 | 0.00% | 0.00 |
| Occasional | 3,091.3 | 20% | 89 | 14,651 | 0.029 | 4.74 | 0.61% | 0.51 |
| Frequent | 3,605.7 | 23% | 274 | 40,825 | 0.076 | 11.32 | 0.67% | 1.36 |
| Pervasive | 1,427.9 | 9% | 504 | 32,598 | 0.353 | 22.83 | 1.55% | 6.30 |
| **Total** | **15,689.6** | **N/A** | **879** | **111,959** | **0.056** | **7.14** | **0.79%** | **N/A** |

*Table 7: Existing number of dams and BRAT modeled capacity estimates for the Panhandle Region.*

| Segment Type | Stream Length | % of Drainage Network | Surveyed Dams | BRAT Estimated Capacity | Average Surveyed Dam Density | Average BRAT Predicted Capacity | % of Modeled Capacity | Electivity Index |
|---|---|---|---|---|---|---|---|---|
| | *km* | *%* | *# of dams* | *# of dams* | *dams/km* | *dams/km* | *%* | |
| None | 2,048.0 | 17% | 4 | 0 | 0.002 | 0.00 | 0.00% | 0.04 |
| Rare | 406.5 | 3% | 5 | 2,126 | 0.012 | 5.23 | 0.24% | 0.23 |
| Occasional | 1,119.9 | 9% | 21 | 5,545 | 0.019 | 4.95 | 0.38% | 0.35 |
| Frequent | 5,205.5 | 44% | 97 | 61,354 | 0.019 | 11.79 | 0.16% | 0.35 |
| Pervasive | 3,182.3 | 27% | 515 | 67,730 | 0.162 | 21.28 | 0.76% | 3.02 |
| **Total** | **11,962.3** | **N/A** | **642** | **136,755** | **0.054** | **11.43** | **0.47%** | **N/A** |

*Table 8: Existing number of dams and BRAT modeled capacity estimates for the Salmon Region.*

| Segment Type | Stream Length | % of Drainage Network | Surveyed Dams | BRAT Estimated Capacity | Average Surveyed Dam Density | Average BRAT Predicted Capacity | % of Modeled Capacity | Electivity Index |
|---|---|---|---|---|---|---|---|---|
| | *km* | *%* | *# of dams* | *# of dams* | *dams/km* | *dams/km* | *%* | |
| None | 2,939.7 | 21% | 18 | 0 | 0.006 | 0.00 | 0.00% | 0.13 |
| Rare | 680.6 | 5% | 3 | 3,277 | 0.004 | 4.81 | 0.09% | 0.09 |
| Occasional | 3,937.8 | 28% | 20 | 16,799 | 0.005 | 4.27 | 0.12% | 0.10 |
| Frequent | 5,229.1 | 38% | 268 | 54,580 | 0.051 | 10.44 | 0.49% | 1.05 |
| Pervasive | 1,080.2 | 8% | 368 | 26,019 | 0.341 | 24.09 | 1.41% | 6.98 |
| **Total** | **13,867.5** | **N/A** | **677** | **100,675** | **0.049** | **7.26** | **0.67%** | **N/A** |

*Table 9: Existing number of dams and BRAT modeled capacity estimates for the Southeast Region.*

| Segment Type | Stream Length | % of Drainage Network | Surveyed Dams | BRAT Estimated Capacity | Average Surveyed Dam Density | Average BRAT Predicted Capacity | % of Modeled Capacity | Electivity Index |
|---|---|---|---|---|---|---|---|---|
| | *km* | *%* | *# of dams* | *# of dams* | *dams/km* | *dams/km* | *%* | |
| None | 1,187.9 | 11% | 2 | 0 | 0.002 | 0.00 | 0.00% | 0.01 |
| Rare | 2,355.5 | 22% | 8 | 11,140 | 0.003 | 4.73 | 0.07% | 0.02 |
| Occasional | 1,999.8 | 19% | 53 | 9,695 | 0.027 | 4.85 | 0.55% | 0.12 |
| Frequent | 2,899.0 | 28% | 538 | 34,115 | 0.186 | 11.77 | 1.58% | 0.87 |
| Pervasive | 2,027.1 | 19% | 1,636 | 48,437 | 0.807 | 23.89 | 3.38% | 3.78 |
| **Total** | **10,469.2** | **N/A** | **2,237** | **103,387** | **0.214** | **9.88** | **2.16%** | **N/A** |

Table 10: Existing number of dams and BRAT modeled capacity estimates for the Southwest Region.

| Segment Type | Stream Length | % of Drainage Network | Surveyed Dams | BRAT Estimated Capacity | Average Surveyed Dam Density | Average BRAT Predicted Capacity | % of Modeled Capacity | Electivity Index |
|---|---|---|---|---|---|---|---|---|
| | *km* | *%* | *# of dams* | *# of dams* | *dams/km* | *dams/km* | *%* | |
| None | 5,740.9 | 19% | 23 | 0 | 0.004 | 0.00 | 0.00% | 0.13 |
| Rare | 5,014.8 | 16% | 10 | 24,781 | 0.002 | 4.94 | 0.04% | 0.06 |
| Occasional | 7,532.9 | 24% | 124 | 34,872 | 0.016 | 4.63 | 0.36% | 0.52 |
| Frequent | 10,078.6 | 33% | 406 | 109,503 | 0.040 | 10.86 | 0.37% | 1.28 |
| Pervasive | 2,403.0 | 8% | 408 | 56,392 | 0.170 | 23.47 | 0.72% | 5.38 |
| **Total** | **30,770.2** | **N/A** | **971** | **225,548** | **0.032** | **7.33** | **0.43%** | **N/A** |

Table 11: Existing number of dams and BRAT modeled capacity estimates for the Upper Snake Region.

| Segment Type | Stream Length | % of Drainage Network | Surveyed Dams | BRAT Estimated Capacity | Average Surveyed Dam Density | Average BRAT Predicted Capacity | % of Modeled Capacity | Electivity Index |
|---|---|---|---|---|---|---|---|---|
| | *km* | *%* | *# of dams* | *# of dams* | *dams/km* | *dams/km* | *%* | |
| None | 1,810.9 | 14% | 4 | 0 | 0.002 | 0.00 | 0.00% | 0.01 |
| Rare | 2,044.6 | 16% | 8 | 10,040 | 0.004 | 4.91 | 0.08% | 0.02 |
| Occasional | 2,475.3 | 20% | 47 | 12,034 | 0.019 | 4.86 | 0.39% | 0.11 |
| Frequent | 3,788.0 | 30% | 612 | 43,022 | 0.162 | 11.36 | 1.42% | 0.91 |
| Pervasive | 2,372.9 | 19% | 1,542 | 57,470 | 0.650 | 24.22 | 2.68% | 3.67 |
| **Total** | **12,491.7** | **N/A** | **2,213** | **122,566** | **0.177** | **9.81** | **1.81%** | **N/A** |

# DELIVERABLES

This project will consist of implementing BRAT for the entire state of Idaho. This included calibration, validation and refinement of the BRAT models based on feedback for IDF&G staff.

1. Develop and run BRAT on the perennial portion of the 1:24K NHD network (60,484 miles) segmented at 300 m including:
    - Existing (based on 2016 LANDFIRE data, the most current data available) beaver dam capacity estimates (dams /km)
    - Historic beaver dam capacity estimates (based on LANDFIRE BPS data (dams /km)
    - Potential for human beaver conflict (probability)
        - Refine conflict model. This resulted in a model that asses risk and opportunity for using beaver in conservation and restoration.
    - Beaver management, restoration and conservation predictions reflecting management priorities
2. Calibration and validation of BRAT performance using harvest and nuisance trapping data.
3. Google Earth-based virtual inventory of existing beaver dams and field based data collection of dam locations.

Deliverable data products include:

1. KMZ of each of four primary BRAT outputs (existing capacity, historic capacity, risk, limiting factors, and conservation and restoration opportunities)
2. Shapefiles and layer packages of each of four primary outputs (existing capacity, historic capacity, risk, limiting factors, and conservation and restoration opportunities)
3. Posting of existing and historic beaver dam capacity output layers to public website
4. Full interpretive report with management recommendations
5. Idaho-wide virtual inventory of existing beaver dams as KMZ
6. Atlas of BRAT outputs

## GIS data layers

The GIS data layers that make up the maps are available in KMZ for the perennial network of each HUC 8 watershed, as an example American Falls data is found 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 very accurate 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 is 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. The BRAT samples 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 excellent 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 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 find 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 2016 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.
- Figure 9 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? The BRAT model does this by comparing realized dam counts to existing capacity. ‘Low hanging fruit’ reaches with >25% of existing capacity already occupied by dams are flagged as ‘Immediate - Beaver 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 10 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 medium-sized contract ($74,694), 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 and statewide dam census indicates, Idaho is only at .8% 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 during the scope of this work has undergone a major overhaul and is now BRAT 3.0.20. However, the heart of the BRAT model  the capacity estimates has not changed and will not change in subsequent versions of BRAT. BRAT 4 is planned to be released in 2020. BRAT 4 will be open source and web-based without any Esri dependences. BRAT 4 will also be fully compatible with RAVE (http://rave.riverscapes.xyz), which allows users 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 (Wheaton et al., 2019). Specifically, we have seen beaver switch from bank-lodging to dam building where these structural elements are available.

### 'Living with beaver' strategies

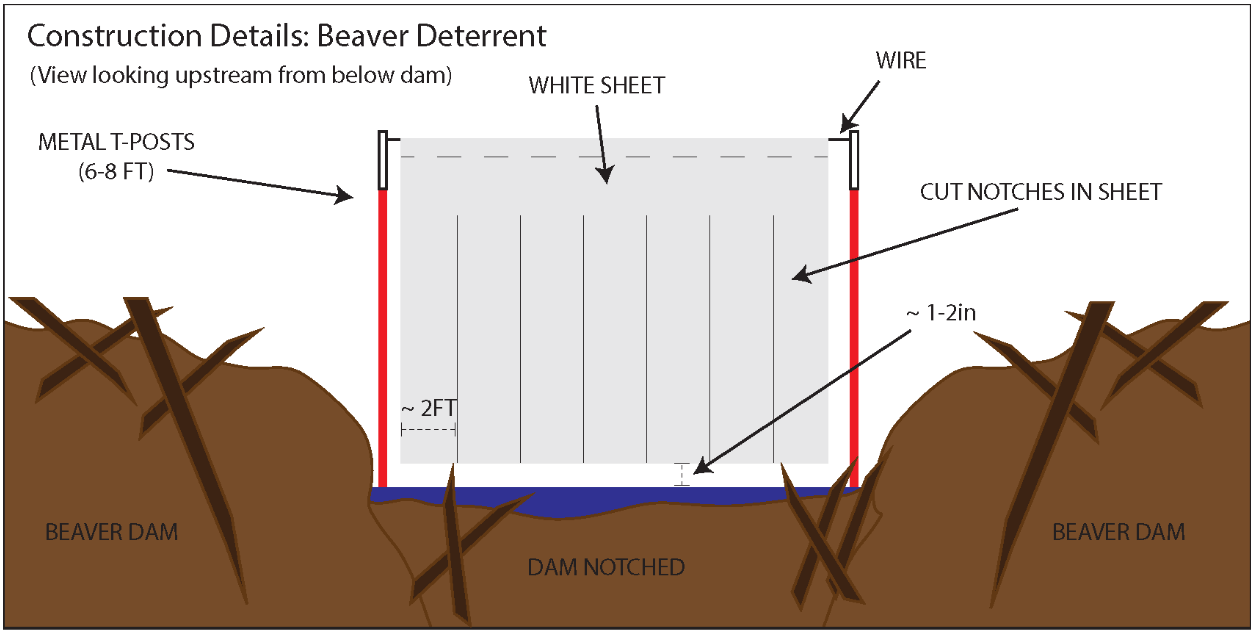
Traditionally, beaver management has relied on lethal trapping to prevent threats to infrastructure posed by beaver dam building activity. The increased awareness of the ecosystem benefits provided by beaver activity and their ability to help achieve a number of restoration goals has spurred the development 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 28). 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 28: 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 29.

*Figure 29: 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 28) 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 Idaho 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 9 should be further analyzed for beaver related conservation and restoration. We believe the Idaho 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.

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