THE UTAH BEAVER RESTORATION ASSESSMENT TOOL:

A DECISION SUPPORT & PLANNING TOOL
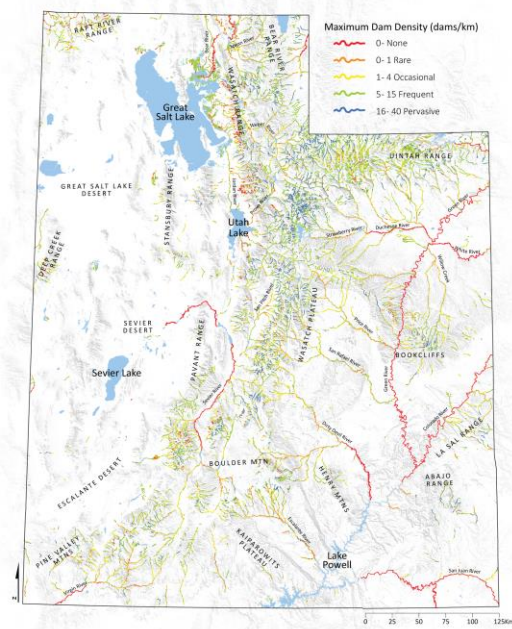
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EXECUTIVE SUMMARY

This report presents the development and application of the Beaver Restoration Assessment Tool (BRAT), a decision support and planning tool for beaver management, to analyze all perennial rivers and streams in Utah. The backbone to BRAT is a capacity model developed to assess the upper limits of riverscapes to support beaver dam-building activities. Both existing and historic capacity were estimated with readily available spatial datasets to evaluate five key lines of evidence: 1) a perennial water source, 2) availability of dam building materials, 3) ability to build a dam at baseflow, 4) likelihood of dams to withstand a typical flood, and 5) likelihood that stream gradient would limit or completely eliminate dam building by beaver. Fuzzy inference systems were used to combine these lines of evidence while accounting for uncertainty.

The capacity model estimated existing statewide capacity at 226,989 beaver dams (8.3 dams/km) and the historic capacity at 320,658 dams (11.7 dams/km), reflecting a 29% loss of historic capacity. Nearly all of this capacity loss can be explained in terms of vegetation loss and degradation associated with land use: i) urbanization along the Wasatch Front and Cache Valley, ii) conversion of other valley bottoms to agricultural land uses, and iii) overgrazing in upland areas. Despite the losses, the relatively high proportion of publicly owned lands in the state and reasonable condition of many streams in the state mean Utah's watersheds are still capable of supporting and sustaining a substantial amount of beaver dam building activity. Dam capacity was found to be well distributed throughout each of the five UDWR regions in the state with slightly higher proportional capacity in the Northern and Central regions.

We verified the performance of the existing capacity model using 2852 existing dams at four watersheds scattered throughout the state and representing 12.5% of the 27,345 kilometers of perennial streams in the state analyzed. In all four watersheds, model performance was spatially coherent and logical, with electivity indices that effectively segregated out amongst the capacity categories. That is, beaver dams were not found where the model predicted no dams could be supported, beaver exhibited avoidance of reaches predicted as supporting rare or occasional densities, and beaver exhibited preference for areas predicted as having pervasive dam densities. Of the total 1143 stream segments with validation dam counts only 15 exceeded the capacity estimates indicating that the model effectively segregates the factors controlling beaver dam occurrence and density 99% of the time. These watersheds had average dam densities ranging from 0.1 dams/km to 1.6 dams/km with an average of 0.83 dams/km and roughly 9% of modeled capacity. We found that validation watersheds in the northern portion of the state were currently at a higher percentage of capacity than watersheds in the southern portion. The Logan/Little Bear watershed (Northern Region) is currently 16% of capacity and Strawberry watershed (Northeastern Region) is 13% whereas the Fremont watershed (Southern

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and Southeastern Regions) and Price watershed (Central and Southeastern Regions) are currently both only 1% of existing capacity. If these validation watersheds are in fact representative of statewide trends then dam building beaver populations across the state are only at a small fraction of the actual capacity and are much lower in the southern portion of the state than in the northern.

To make some rough estimates of beaver dam numbers for the state, we extrapolated our findings from the verification watersheds using the capacity model. We determined the full range of percent of capacity estimates realized by capacity prediction categories, which ranged from 1 to 38% with an average of 8%. Using a variety of estimates, we estimate there are somewhere around 20,000 beaver dams currently in the state, but it is plausible the number is as high as 40,000. Either way, the state of Utah's rivers and streams are well below the capacity of those streams to support beaver dams (8% to 17% of capacity). Given that beaver have not been actively promoted or encouraged in most parts of the state, and in many parts they are actively removed, it is likely that historically (pre-European settlement) the realized percent of capacity was much higher (likely 30% to 50%).
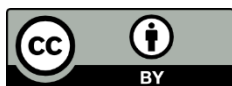
The decision support and planning tool side of BRAT uses simple geospatial analysis and rule systems to account for the recovery potential of riparian habitat and human conflict with beaver dam building to segregate the stream network into various conservation and restoration zones. BRAT categorized 35% of the state as 'Low-hanging Fruit' streams signifying habitats that are either currently inhabited by beaver or are in relatively good condition for beaver re-colonization and/or reintroduction. Another 29% of the state was identified as 'Living with Beaver' signifying areas that could benefit from 'Living with Beaver' strategies.

The model would benefit from additional actual dam count data. These data could be used to further validate the model and could also be used to identify source and sink zones throughout the state. Accurate identification of source and sink zones will help UDWR biologist manage beaver populations, especially nuisance beaver.

We believe the spatially explicit outputs from BRAT provides UDWR biologists with the information needed to effectively identify where nuisance beaver can be relocated, where 'Living with Beaver' strategies may be needed and where beaver can be used for watershed restoration efforts to have the greatest potential to yield increases in biodiversity and ecosystem services.

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INTRODUCTION

Beaver dam-building activities lead to a cascade of hydrologic, geomorphic, and ecologic feedbacks that increase stream complexity and benefit aquatic and terrestrial biota. As a result, beaver are increasingly being used as a key component of stream restoration strategies. However, predictive spatial models resolving where within a drainage network beaver dams can be built and sustained are lacking. Moreover, a capacity model approach alone is not enough because many places that beaver might build a dam are in direct conflict with humans (e.g., damming of culverts or irrigation canals and flooding of roads or railroads).

The Beaver Restoration Assessment Tool (BRAT) was developed to fill this void and serves as a decision support and planning tool intended to help resource managers, restoration practitioners, wildlife biologists and researchers assess the potential for beaver as a stream conservation and restoration agent over large regions. In 2012-2013 we developed the beaver dam building capacity model portion of the tool and tested it in a pilot project in the Escalante and Logan watersheds (Macfarlane and Wheaton 2013). Results from the pilot study indicated that the model was effective at predicting beaver dam capacity across diverse physiographic settings (Wheaton et al. 2014).

The project described herein improves upon the pilot beaver dam building capacity model, extends the coverage to the entire state of Utah, and develops and tests the decision support and planning components of the tool. The decision support tool accounts for where beaver may pose potential nuisance problems, where 'Living with Beaver' strategies may be needed, where re-colonization and/or reintroduction is most appropriate and identifies potential conservation and restoration areas for beaver. By combining the capacity and decision support approaches, resource managers have the necessary planning information to estimate where and at what level re-introduction of beaver and/or conservation is appropriate.

The four main objectives of the project were to:

1. Complete the development of the BRAT Decision Support and Planning Tool
2. Run BRAT for entire state of Utah
3. Validate BRAT at select target watersheds
4. Synthesize findings from BRAT into recommended adjustments to Utah Beaver Management Plan 2010-2020

This report's primary purpose is to report on the fulfillment of these four objectives and explain how the analyses and tools presented can assist UDWR staff in the management of dam-building beaver populations across the state in accordance with the Utah Beaver Management Plan 2010-2020 (2010).

METHODS

STUDY AREA

While this study is for UDWR and its primary focus is the entire state of Utah, six of the eight USGS geohydrologic regions that make up Utah extended into neighboring states. The BRAT analysis is a watershed-based network analysis that requires information based on the entire watershed upstream of any stream segment/reach of analysis. As such, our analysis necessarily covered the entirety of watersheds within Utah and their upstream extents in neighboring states. Figure 1 shows the mapping extent of the project which extends well beyond the boundary of Utah to include portions of all adjacent states including Nevada, Idaho, Wyoming, Colorado, New Mexico and Arizona. This added extent includes all Hydrologic Unit Code (HUC) 8 watersheds that intersected the Utah border and amounts to an additional 13,216 km of streams or 48% more streams outside the state of Utah (Table 1; Figure 2). We processed these additional HUC 8 watersheds that intersected the Utah border for two reasons: i) flow accumulation rasters must be computed on a watershed by watershed basis. If watersheds were 'split' at the state line, rivers on the periphery of the state line would have incorrect flow accumulation and stream power values; & ii) the relative ease of computing BRAT made it worth processing the additional areas just in case these data were desired by resource managers that work in watersheds that extend outside of the state.

The three notable exceptions to this were the upper Green River, Upper Yampa River and Upper Colorado River, which collectively include sizeable portions of Wyoming and Colorado and have different HUC 8 watersheds for their upper portions. For these basins, we added the additional flow accumulation areas to the corresponding downstream HUCs.

Table 1 – Length of streams and rivers analyzed as part of this project within and outside Utah.

Streams & Rivers Analyzed		
	Kilometers	Miles
Utah	27,345	16,991
Additional	13,216	8,212
Total	40,561	25,203

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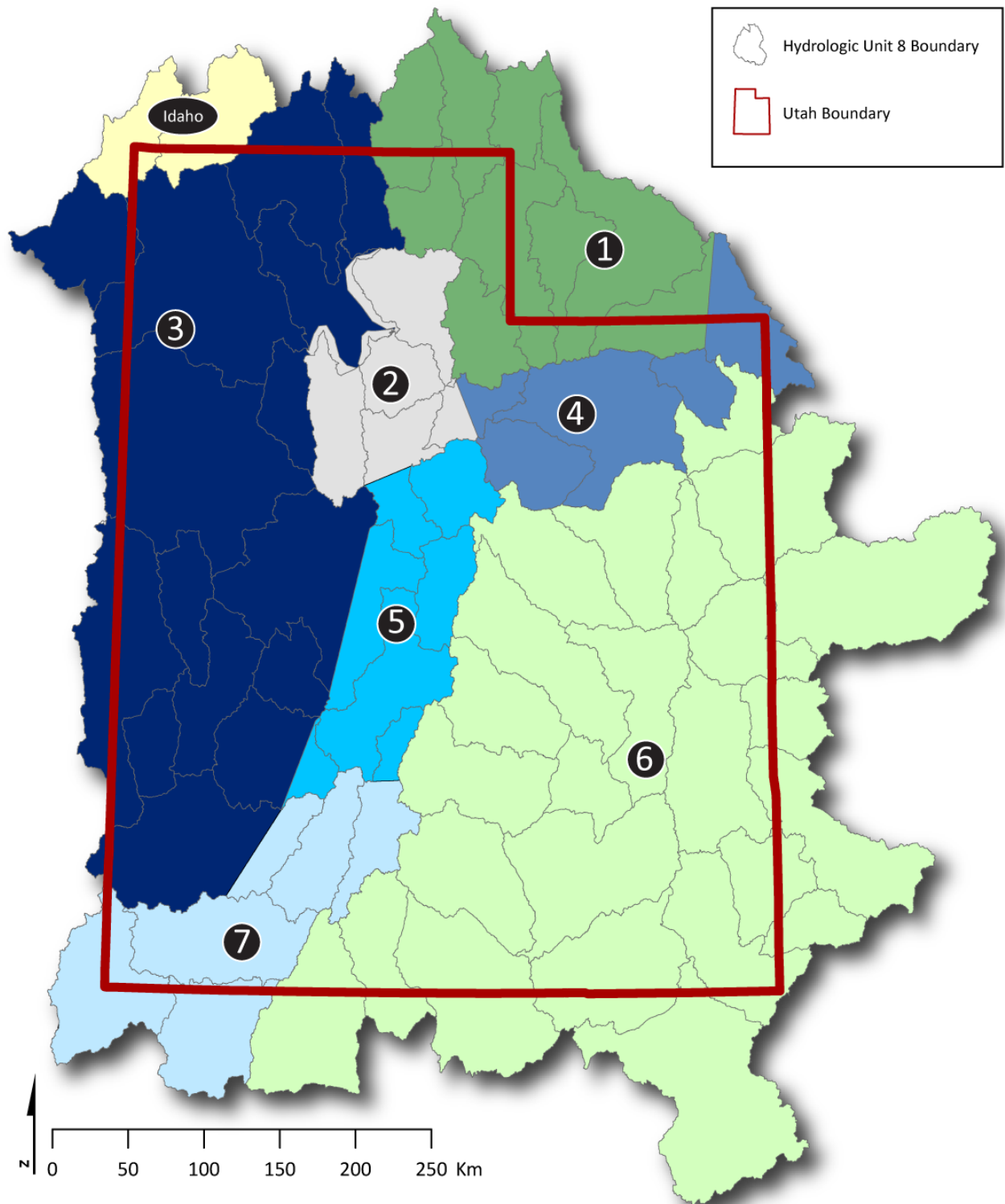
Figure 1 – Map showing all HUC 8 watersheds within the USGS Geohydrologic regions that were assessed in the statewide BRAT.
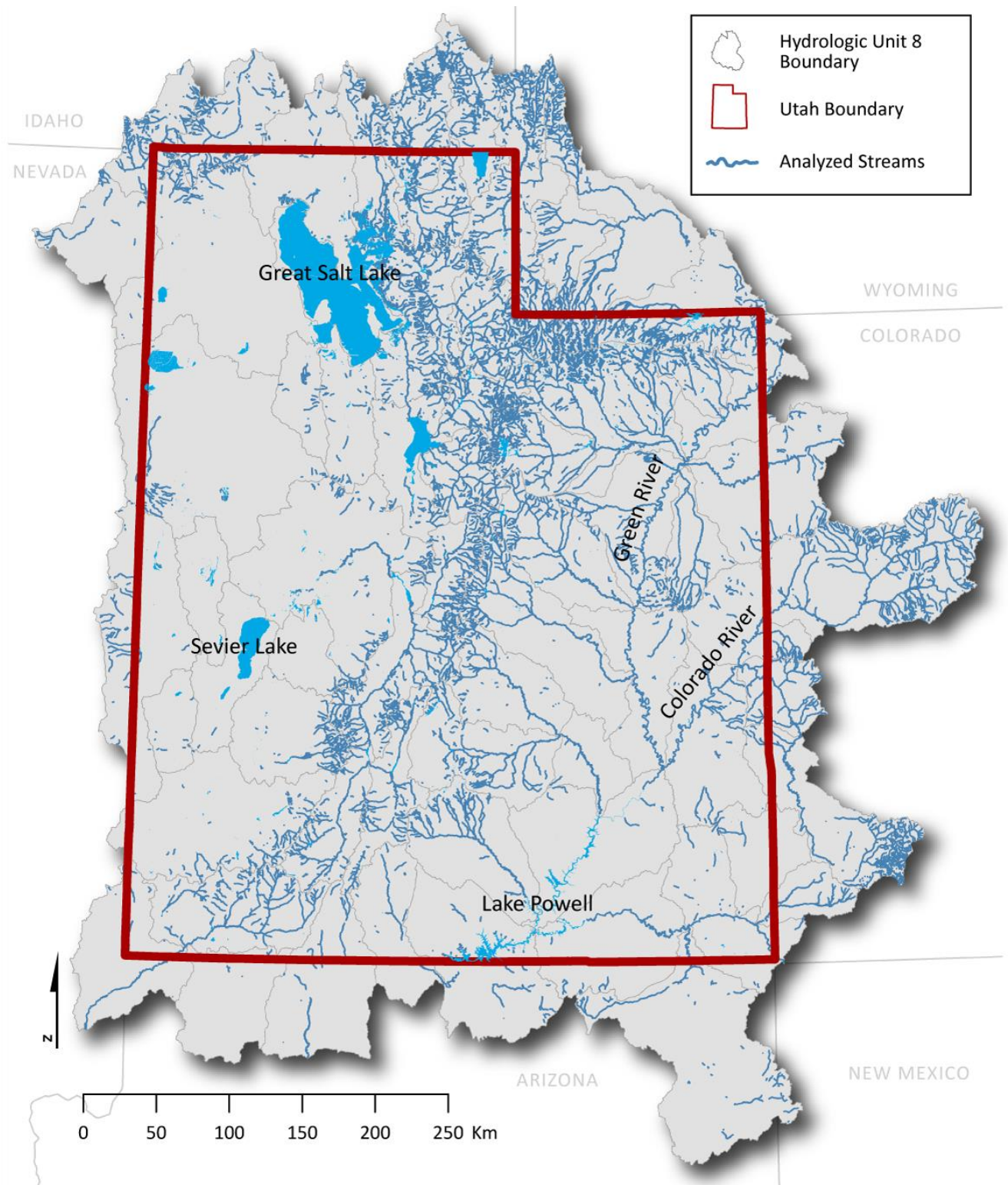
Figure 2 – Extent of 40,561 kilometers of streams included in this project analysis, showing the 27,345 kilometers in Utah, and 13,216 kilometers in neighboring states of Nevada, Idaho, Wyoming, Colorado, New Mexico and Arizona, which flow through common HUCs.

BEAVER DAM CAPACITY MODEL

The beaver dam capacity model is described thoroughly in Macfarlane and Wheaton (2013), Wheaton et al. (2014) and online documentation describing how to run the model is available at http://brat.joewheaton.org. Therefore, in this report, we only briefly describe the capacity model, instead focusing on the model modifications since the pilot project. Many of these refinements are associated with calibration to actual dam counts from Google Earth-based beaver dam census data. This census data was collected across a physiographically diverse group of four watersheds throughout Utah - including the Logan/Little Bear, Strawberry, Price and Fremont basins. Additional dam complexes throughout the state were also identified 'on-the-fly' in Google Earth and were used to verify how well the model was preforming across a huge diversity of conditions.

Modeling efforts were specifically focused on north American beaver (*Castor canadensis*) dam-building activity because dam construction provides the positive hydrologic, geomorphic, and ecologic feedbacks that create diverse aquatic habitats that process-based stream restoration efforts attempt to exploit (Bird et al., 2011). While UDWR is responsible for managing beaver populations not only where they build dams, the range of beaver and suitable habitats to sustain their basic survival extend to virtually every corner of the state's 27,345 kilometers of perennial rivers and streams. Their woody vegetation harvesting activities may be of interest from a nuisance and human-beaver conflict perspectives, but it is really their dam building activities that have the biggest impact and are of most interest from a management perspective. These impacts can be both negative (e.g. undesirable flooding of infrastructure, clogging of culverts, impeding water diversions, etc.) and positive (e.g. ecosystem services from flooding, raised water tables, flow attenuation, expanded riparian, subirrigation of valleys, improved habitat complexity, etc.).

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.

Our statewide estimates of beaver dam densities at full capacity came from the following five lines of evidence:

1. Evidence of a perennial water source.
2. Evidence of stream bank vegetation to support dam-building activity and riparian/upland fringe vegetation to support expansion of dam complexes.
3. Evidence that a beaver dam could physically be built across the channel during low flows.
4. Evidence that a beaver dam is likely to withstand typical floods.
5. Evidence of high stream gradient that limits or eliminates dam building by beaver. This line of evidence was added with the statewide run.

These lines of evidence can be directly measured with a high degree of accuracy (and expense) for any reach of stream or river and analyzed directly. In the planning of specific management, mitigation or restoration actions, such a detailed local analysis might be warranted. However, with over 27,000 kilometers of streams and rivers to manage, such an analysis based on locally collected field data is not realistic. As such, we turn here to widely available, free, national datasets that provide direct approximations for all these lines of evidence based largely on remotely sensed imagery and regionally-derived empirical relationships (Table 2).

Table 2 – Shows the input data used to represent each of the five lines of evidence of the capacity model.

Input Data	Line of Evidence	Source
Streams, Waterbodies, Watersheds	Evidence of Perennial Water Source	USGS National Hydrography Dataset http://nhd.usgs.gov/
Landfire 2011 (EVT and BPS)	Evidence of stream bank and upland vegetation	Landfire http://www.landfire.gov/
USGS base flow regression equations	Evidence that a dam could be built	Wilkowske et al. http://pubs.usgs.gov/sir/2008/5230/
USGS 2 year peak flow regression equations	Evidence that a dam could withstand typical floods	Kenney et al. http://pubs.usgs.gov/sir/2007/5158/
10 m Digital Elevation Model	Evidence of stream gradient	USDA NRCS Geospatial Data Gateway http://datagateway.nrcs.usda.gov/

In traditional Habitat Suitability Index models, different pieces of empirical evidence are combined to score the relative quality of physical habitat. However, it is challenging to translate species' habitat utilization patterns into inference on preferences (Leclerc, 2005a, b) as both complete availability and utilization data are needed. Furthermore, such models are often quite sensitive to the accuracy and quality of the input data used. The habitat suitability curves that relate each physical variable to 'habitat suitability' are also empirically derived and can require significant investment in field data collection to build robust and regionally appropriate curves. Since in this statewide analysis we are relying on fairly coarse spatial data (e.g. 30 meter resolution pixel vegetation predictions) that can sometimes locally inaccurate, we decided

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against a traditional habitat suitability modelling approach. We used an alternative approach relying on fuzzy inference systems (FIS) that allow 'computing with words,' whereby multiple lines of evidence are combined mathematically with simple rule tables, explicitly accounting for the uncertainty that arises from ambiguity in categorical data (Openshaw, 1996; Zadeh, 1996). Fuzzy habitat models are more flexible and more easily applied without invalidating necessary assumptions of traditional habitat models (Mocq et al., 2013; Schneider and Jorde, 2003). Fuzzy inference systems also allow the building of very mechanistic, process-based models that can be informed by empirical data, but don't require as much of it to produce a robust model.

The rest of the sub-sections primarily describe the changes and improvements made to the capacity model in this project as compared with the BRAT pilot study. The first and primary element beaver need is water. After that, vegetation is the primary control on the distribution of beaver dams. Then we use other lines of evidence to assess how stream power and slope can limit beaver dam building activity.

EVIDENCE OF PERENNIAL WATER SOURCE

Beavers need a perennial, year-round source of water to survive. Although they can sometimes make due from springs, ponds and lakes, in an arid state like Utah, the vast majority of their habitat is on perennial streams and rivers. Beavers can sometimes turn intermittent streams into perennial streams (Hood, 2011). However, for a statewide model, this is likely to be of negligible significance.

For the statewide model, we used the nationally available National Hydrologic Dataset (NHD) as a drainage network on which to base our model. The NHD differentiates between perennial (year round), intermittent (seasonal) and ephemeral (episodic) watercourses. The NHD 'FCODE' attribute was used to identify ephemeral and intermittent streams and these stream types were eliminated as model inputs. We used high-resolution satellite imagery (e.g. sub-meter) to confirm this classification throughout the State of Utah. Based on virtual reconnaissance in Google Earth of the contrast between late spring and autumn imagery, we found the perennial designation to be highly reliable at capturing streams with perennial flow, but it also includes many intermittent streams. We found the NHD ephemeral and intermittent designations to be much less reliable and in particular the intermittent streams were grossly over estimated (primarily misclassifying ephemeral water courses as intermittent), while ephemeral water courses were largely under estimated. We found virtually no evidence of perennial streams misclassified as intermittent or ephemeral, and we interpreted the intermittent streams misclassified as perennial as primarily those which beaver could potentially expand into and convert to perennial. Thus, for our purposes, the perennial NHD designation was adequate and comprised roughly 27,000 km of an 85,000 km network.

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We used the older NHD 1:24,000 network rather than the newer NHDPlus 1:100,000 network model. The cartographically-derived 1:24,000 network provided better resolution then the DEM-derived 1:100,000 network (i.e. stream lines follow the actual streams more precisely and overlay more consistently on aerial imagery). The 1:24,000 network is also more extensive spatially (higher drainage density) and includes 30% more length of streams. The 1:24,000 NHD network geometry is largely consistent with the blueline stream network found on 1:24,000 USGS Quadrangle maps.

NHD networks flow virtually through lakes, ponds and reservoirs with connecting linework known as 'artificial paths'. In the statewide model we included artificial paths outside of large water bodies (e.g. lakes and reservoirs) because virtual reconnaissance in Google Earth revealed that beaver do not generally build dams on such large water bodies. By contrast, artificial paths through small water bodies they do use and in some cases NHD actually picks up natural beaver ponds as 'artificial paths'. For example, we identified a discontinuous streamline in the Temple Fork drainage attributed as an artificial path with the centerline running through a beaver dam (Figure 3). Using the NHD water body data we established a water body threshold size of 500 square meters (a conceivably large beaver pond) at which any stream segment running through a water body larger than this threshold was removed from the analysis. Using manual editing in Google Earth all stream segments in ponds not considered to be beaver ponds were also removed (e.g. the thousands of stock ponds and small reservoirs throughout the state). Thus, the only artificial paths that remained were those associated with beaver ponds. In the statewide model we included stream segments attributed as 'connectors'. Connectors are defined as a known connection between two NHD flowlines that are spatially represented when data is not available; inclusion of connectors allowed for a more continuous stream network. Finally in the statewide model we included side channels of large rivers to capture these important dam-building beaver habitats. Some of these already existed on the 1:24,000 NHD network, and others we manually digitized tracing off the most recent National Agriculture Imagery Program (NAIP) aerial imagery.

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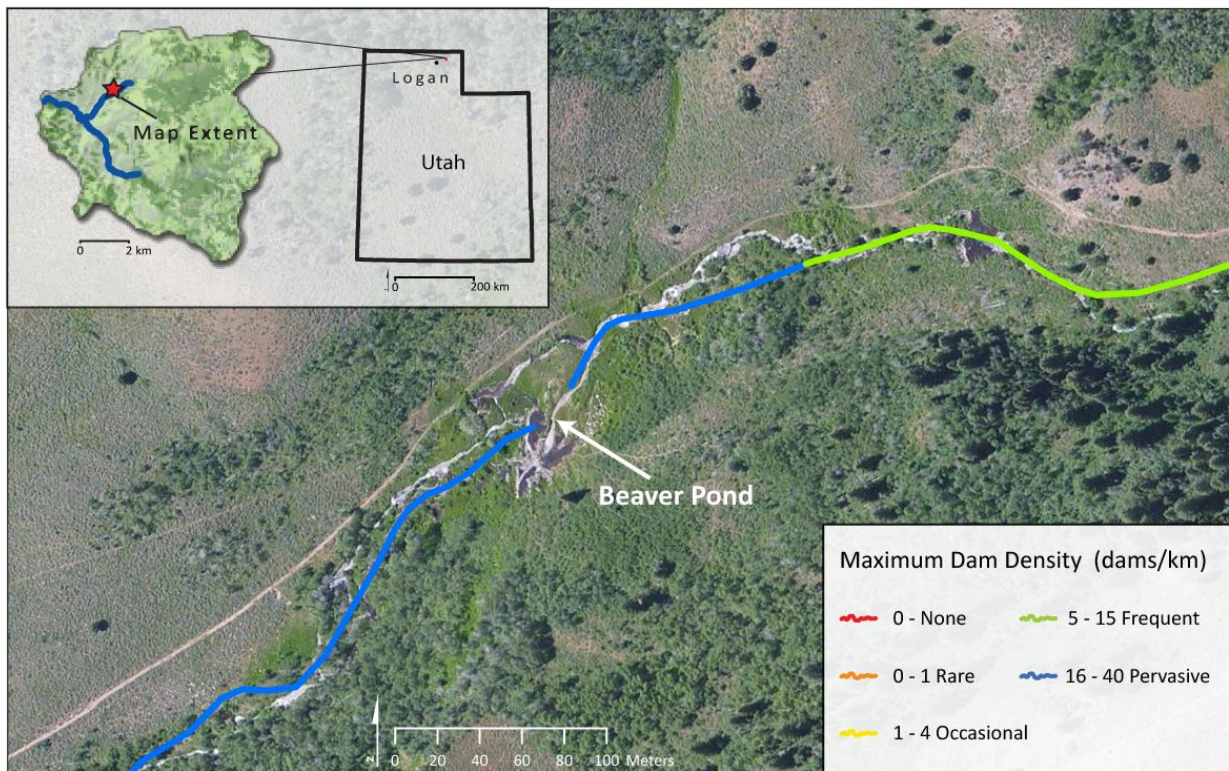
Figure 3 – Pilot study validation data in the Logan/Little Bear watershed is depicted. Artificial paths were excluded in the pilot study. During virtual reconnaissance in Google Earth, we found artificial paths that were the flow path through large beaver ponds. Therefore, artificial paths were included in the BRAT statewide model.

EVIDENCE OF WOODY VEGETATION FOR BUILDING MATERIAL

To assess the evidence of available woody vegetation for dam construction in the statewide run we used the 2011 LANDFIRE vegetation dataset, (made available in 2013) instead of the 2008 data that was used in the pilot project. Like the 2008 data, the 2011 dataset is a nationally available classification of 30 m LANDSAT satellite imagery (LANDFIRE 2014). Like in the Macfarlane and Wheaton (2013) pilot project, we classified the LANDFIRE cover types according to beaver preferences established in the literature by assigning a single numeric suitability value from 0-4, with zero representing unsuitable food/building material and four representing preferred food/building material to each of the land cover classes. However, for the state-wide run we 'relaxed' some of our categories based on Google Earth and on-the-ground validation that suggested that dam-building beaver were not as discriminating and selective as we first thought. For example, in the field we documented beaver utilizing sagebrush for dam building and showed that areas dominated by sagebrush steppe could support 'occasional' and in some cases 'frequent' dam densities. As a result the categorical preference value for the sagebrush class was increased from 1 to 2. The preference values of the 'developed' categories were also increased in the statewide run based on validation data showing beaver dam densities were

higher than initially realized in the pilot project in the developed land cover classes. LANDFIRE vegetation classifies some areas of the riparian corridor as open water which tends to include active stream channel and areas immediately adjacent. In the pilot study these pixels were classified as a 0 but this classification value resulted in an underestimate of capacity. For the statewide run we reclassified the open water pixels to more accurately represent the riparian vegetation that likely exists in these locations. In the north, open water is now classified as a 3 and in the south, open water is now classified as a 2. The logic being that the majority of the southern regions have a riparian corridor that is dominated by invasive riparian (preference value 2) and that in the north it is likely that what is categorized as open water is actually willow or another deciduous riparian vegetation (preference value 3). These classifications are stored as simple look-up tables that can be viewed to compare the pilot and statewide beaver preference values (see http://brat.joewheaton.org for these tables).

Riverscapes with suitable vegetation in a narrow band within or along their banks, contrast sharply with those that have expansive riparian or adjacent upland forests with desirable woody browse and building materials (e.g. aspens). To represent this important distinction, we sampled vegetation classes from two derived buffers along our perennial drainage network:

- A 30 m buffer representing vegetation available along the stream bank (Figure 5 see step 3a); and
- A 100 m buffer representing vegetation within a broader riparian/upland fringe area (Figure 5- see step 3b).

The buffer distances were based on our own field observations and corroborated with data in the literature that indicate that harvesting can extend up to 100 m away from the channel. The 30 m buffer is partly based on the pixel size of the imagery and is meant to represent most of the woody species available to beaver within close proximity to the channel (Figure 4). These buffer distances remained the same in the statewide run. All of the riparian vegetation scores (between 0 and 4) within the buffer along every reach segment (generally 250 m long) were averaged to get a mean score between 0 and 4 for each segment (done separately for 30 m and 100 m buffers.
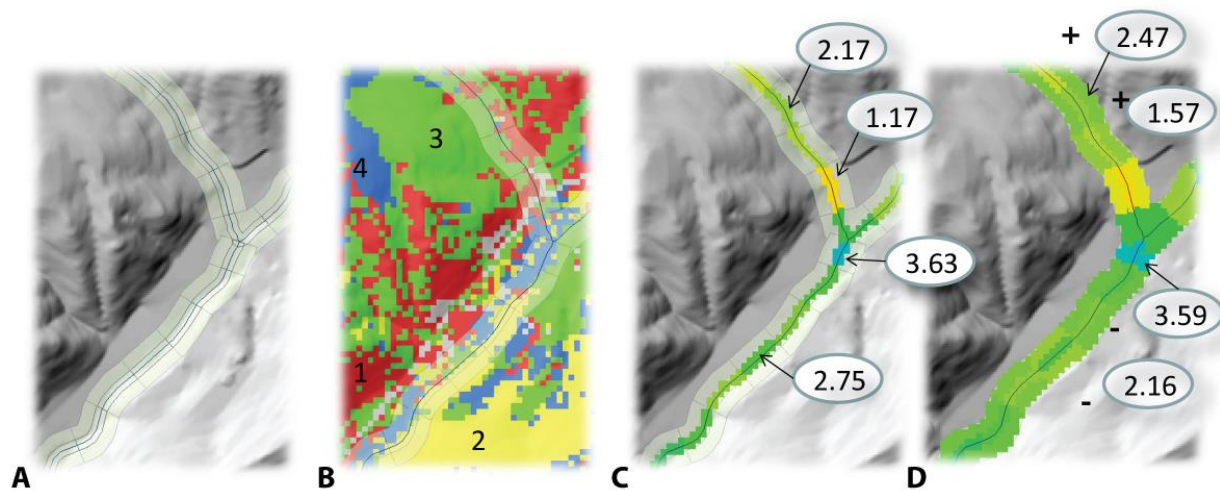
Figure 4 – Reach scale illustration of 30 vs. 100 meter stream network buffer A, the 30 m pixel resolution classified LANDFIRE raster B, the buffer averaged values for the 30 m buffer C, versus the 100 meter buffer D. Dam building suitability range from 0 (unsuitable) to 4 (optimal) and in B are shown with red for 1, yellow for 2, green for 3 and blue for 4.

These two lines of evidence were combined using an FIS to estimate collectively the dam building density the riverscape can support. Accordingly, the buffered polygon segments with their associated distribution of building material categorical preference values (0-4; unusable to preferred) were converted to continuous values using a zonal statistics geoprocessing operation. These values were then extracted from the polygon buffers and mapped onto the polyline drainage network for each segment. Two fields resulted from this operation and were added to the NHD drainage network's attribute table: a stream bank vegetation score and a riparian/upland fringe vegetation score. The FIS output values were calibrated to values typically reported in the literature and that we have field-documented throughout the western US: none (0), rare (1), occasional (2-4 dams/km), frequent (5-15 dams/km) and pervasive (16-40 dams/km). The rare category was added in the statewide run to represent the dams of dispersing beaver that built in marginal areas at very low densities. These dams tend to be blown out each year at high flows.

The vegetation based output is an intermediate output, based solely on the availability of dam building materials (Step 4 in Figure 5). It does not consider the extent to which river flows may limit beaver from achieving this capacity.
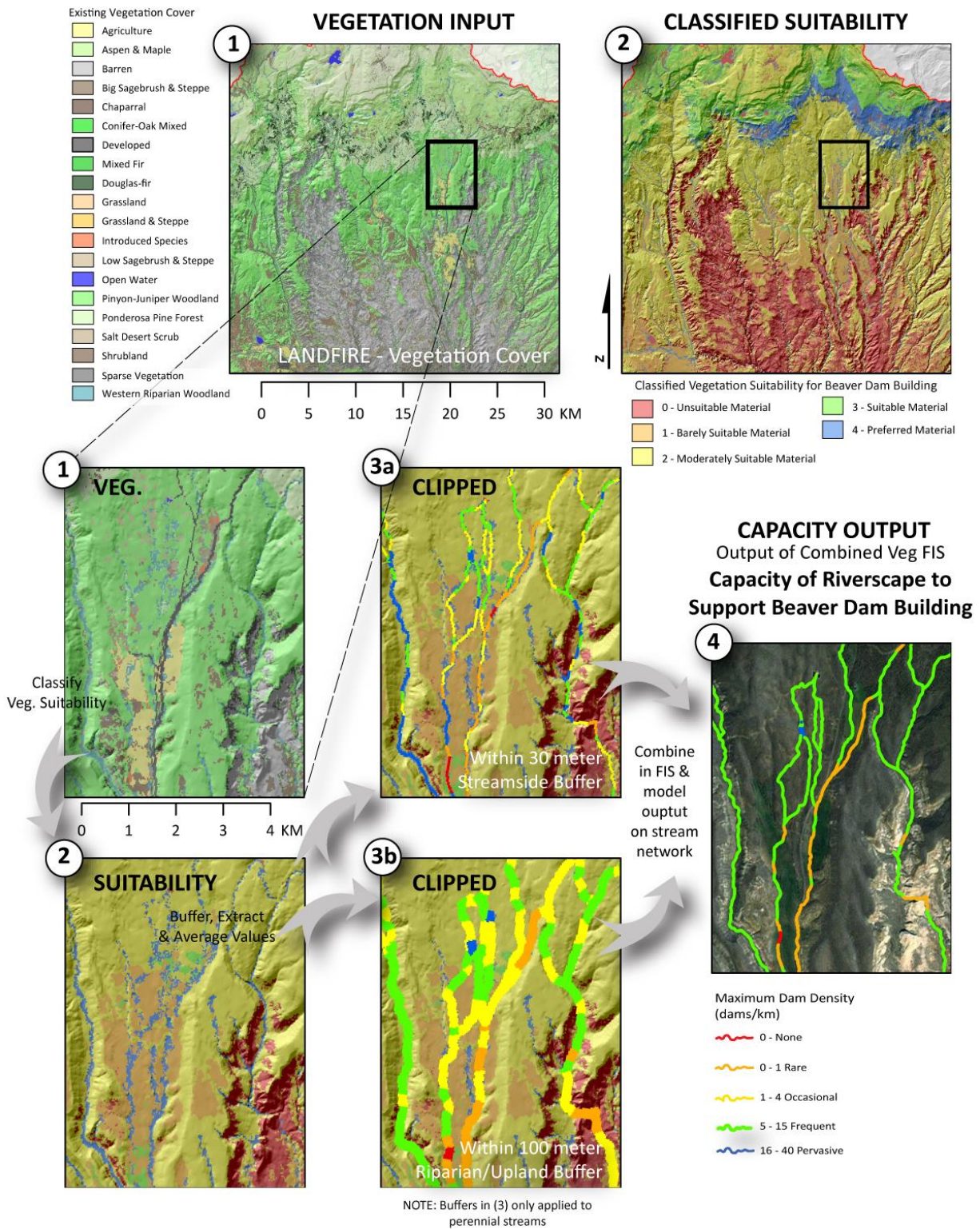
Figure 5 – Network scale illustration of the workflow for determining the capacity of riverscapes to support beaver dam-building activity, based solely on the availability of suitable building material. Vegetation data (1), is classified based on beaver preferences (2). These suitability classes are then averaged within two buffers: a streamside buffer (30 m) in 3a and a riparian/upland buffer (100 m) in 3b. They are then combined using a FIS to estimate the maximum dam density (4).

EVIDENCE THAT A BEAVER DAM CAN BE BUILT

As with the Macfarlane and Wheaton (2013) BRAT pilot, both the evidence that a beaver dam can be built and that it is likely to withstand floods come from estimates of stream power. To infer whether or not it was likely that a beaver dam could be built, we calculated stream power at a representative baseflow. Using Wilkowske et al. (2008), for each USGS Geohydrologic Region in Utah, we approximated baseflow with the discharge exceeded 80% of the time for the month with the lowest runoff (Q_{p80}). We determined the month with the lowest runoff per region based on USGS gauge data. For an explanation of stream power and a description of its role in the capacity model see the Appendix on the Role of Stream Power.

Since the 1:24,000 NHD network dataset does not include associated flow accumulation rasters like the NHDPlus 1:100,000 network does, we derived our own flow accumulation rasters from 10 m USGS DEMs from the national elevation dataset. This allowed for better quality control over these data. As with the Macfarlane and Wheaton (2013) pilot project, the stream network was divided into 250 m long segments. At each segment a Q_{p80} estimate was made as described in Macfarlane and Wheaton (2013). This Q_{p80} estimate was then substituted into the stream power equation and used to infer the following simple linguistic categories:

- Can build dam
- Can probably build dam
- Cannot build dam

The 'cannot build dam' category was based on distributions of Q_{p80} stream power derived for parts of the drainage network that had vegetation suitable to support beaver, may even have evidence of beaver activity, but had no evidence that beaver dams ever existed. Such reaches were typically higher gradient, larger stream order (i.e. > 3-4) and high baseflow stream powers. By contrast, the 'can build dam' category was based on stream power distributions derived for areas where beaver have frequently constructed persistent dams. Those segments with only occasional dam activity were used to calibrate the 'can probably build dam' category. The overlap in the stream power distributions were used to represent the overlap in the fuzzy membership functions in the baseflow stream power input (Figure 8; see step 2).

For the statewide run, we calibrated the baseflow stream power thresholds based on the derived baseflow stream powers at over 2852 dam locations. This resulted in a general reduction to stream power values in the fuzzy membership functions - (See Appendix A – Changes to Stream Power Thresholds).

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STATEWIDE RUN IMPROVEMENTS TO FLOW ACCUMULATION VALUES

In the Macfarlane and Wheaton (2013) pilot study, we found that the 1:100,000 scale NHD stream network did not always precisely overlay the maximum flow accumulation value due to the coarseness of the input data. This was especially noticeable in unconfined valley settings where the maximum flow accumulation value could be offset as much as 100 meters from the stream centerline. Although we used a higher resolution stream network (1:24,000 scale) with better geometry, this does not ensure that the stream always lines up in the low point in the valley where flow accumulation values derived from a 10 m DEM are highest. To resolve this issue in the statewide run, we sampled all flow accumulation values in a 100 m buffer, and used zonal statistics to capture the maximum flow accumulation values for each buffered segment. This greatly improved the consistency and progression downstream of increasing flow accumulation values. At some tributary junctions the above algorithm artificially elevated flow accumulation value for the downstream most tributary segment, and these were manually adjusted to match their next upstream segment.

EVIDENCE THAT A BEAVER DAM WILL LIKELY PERSIST

To infer whether or not it was likely that a beaver dam would persist once built; the two-year recurrence interval peak flood (Q_2) stream power was calculated using regional curve approximations from the USGS (Kenney 2008). As described in the Macfarlane and Wheaton (2013) pilot, fuzzy membership functions for the following categories were developed:

- Dam persists – *regardless of peak flow, the dam remains in-tact*
- Occasional breach of dam – *peak flows may cause a partial breach of a dam, that is easily repaired by beaver*
- Occasional blowout of dam – *peak flows may occasionally cause a dam to completely washout, and be abandoned, but the frequency of this occurrence is low*
- Blowout – *peak flows will certainly lead to a blowout*

Distributions of stream power were derived using the Q_2 estimates and reach-averaged slope to develop empirical relationships for each of the fuzzy categories based on where specific dams experiencing roughly Q_2 flows exhibited each of the above categories. The ambiguous overlap between the categories was explicitly accounted for with overlapping fuzzy membership functions.

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MODIFICATIONS TO Q_2 STREAM POWER THRESHOLDS AND EQUATIONS

The Q_2 thresholds established in the pilot study were reduced for the statewide run of the capacity model. These changes were based on identifying the stream power at which dams tended to breach and blow out. Figure 4 shows a dam on the upper Logan River that breached at around 1200 to 1400 watts and later sustained a blow out at around 2000 to 2400 watts in the spring runoff of 2014. (See Appendix A – Changes to Stream Power Thresholds). In the statewide run, stream power values were frequently increased across the stream network compared with the pilot. The pilot was often underestimating stream power because of erroneously low flow accumulation values. With the addition of 100 m maximum flow accumulation buffer, more realistic estimates of stream power were estimated. We used these to update the relationships between Q_2 and the fate of dams (i.e. blown out, breached, intact) with a broader dataset of dams subjected to a recent Q_2 flood and how well they held up to typical Q_2 floods. In particular, Q_2 threshold ranges for each of the fuzzy membership functions were updated based on empirical data from the Logan River that showed the stream power at which dams were being breached and blown out (see Figure 6).

For the statewide run the Q_2 regression equation for USGS Geohydrologic Region 2 and 6 were modified. The Region 2 regression equation variable, precipitation, was modified to increase the discharge values to better reflect typical high flows based on USGS gauge data. Whereas for Region 6 the equation was modified to decrease discharge values to also better reflect typical high flows based on USGS gauge data. In addition, we revisited the accuracy of the annual average precipitation estimates and average elevation estimates used in the regional curves for region 2 and 6. The annual average precipitation value in the Q_2 regional regression equation for region 2 was revised from 23.23 to 40 inches and for region 6 the average elevation value in the Q_2 regional regression equation was increased from 6182.81 to 8000 feet to decrease the Q_2 values to match typical high flow values.

Figure 6 – Late June 2014 photo showing a blown out beaver dam on the upper Logan River. This dam was blown out in late May 2014 by a typical flood. The Q$_2$ stream power of this reach was calculated at 2400 watts. We used this information to help develop the Q$_2$ streampower thresholds.

OTHER MINOR REFINEMENTS TO THE CAPACITY MODEL

The two FIS models described above and incorporated together in the combined model (see § Combined Model) produce largely accurate estimates for the vast majority of streams and rivers. However, in virtual reconnaissance of model results over 1000's of kilometers of stream, we found three basic scenarios where the model was producing unreliable predictions:

1. Situations where stream slope was limiting (either too steep or too flat), beaver dam predictions were off (too high in steep areas where there were none, too high in really flat areas where higher dam densities were not needed).
2. Big main-stem rivers that cannot support dams on the mainstem.
3. Montane meadows that were consistently under predicting capacity.

The next three subsections describe minor refinements that were made to the model to address these limitations. Some of these minor modifications are incorporated into the 'combined FIS' (described in the § Combined Model section), whereas others are written in as conditional logic applied on a reach-by-reach basis over-riding or modifying the FIS predictions if specific conditions are met.

EVIDENCE THAT CHANNEL SLOPE IS LIMITING

We found two situations where preliminary capacity model estimates where just stream power was used to limit their range was inadequate. The first was situations in which very steep (> 10% slope) segments of primarily first order streams in headwaters were not limiting capacity based on stream power (owing primarily to small flow accumulation drainage area). In these situations, vegetation was optimal, and drainage area was small so high capacities were predicted, but empirically we never find any beaver dams in these locations. This was very prominent in the steep mountain headwater streams along the Wasatch Range for example. Moreover, many investigators (Allen, 1983; Gurnell, 1998) have noted upper slope thresholds as a limitation for beaver dam construction. For example, in Colorado Retzer (1956) reported never finding beaver colonies on streams with greater than 15% slope. For the statewide run a slope threshold was added to the capacity model. Under this threshold if a stream segment had a slope greater than 23% the segment was classified as 'beaver can't build a dam' and if a stream segment has a slope greater than 17% the segment's beaver dam capacity was reduced to the next lowest category. Instead of basing these thresholds on literature reported values, we based them on querying slope at 2852 locations we had beaver dams identified and looking at outliers. No beaver dams existed on greater than 23% stream slopes but some sparse dams were found between 17% and 23%.

The second situation where the preliminary capacity model estimates were over predicting dam densities was in exceptionally low slope reaches (i.e. slopes < 0.0002). Most primary beaver dams (i.e. ones that supports a lodge) are roughly a meter in height and can reach heights well above three meters (Gurnell, 1998), with secondary dams typically at least 30 – 50 cm in height. As dam backwater distance upstream is a function of both channel slope and dam height, even a 50 cm high dam in a 0.0002 slope channel has a 250 meter backwater (hence you can only have four dams per kilometer in this example). Beaver build secondary dams to extend their foraging and building material harvesting range upstream and/or downstream of a primary dam. Thus, in lower slope areas, they simply do not need as many dams to accomplish this. To accommodate this, we lowered dam capacities by one category (e.g. from 'frequent' to 'occasional') in reaches with 'really flat' slopes (< 0.0002) to produce more realistic dam densities in such reaches (See §Appendix A – Changes to Stream Power Thresholds).

MAXIMUM UPSTREAM FLOW ACCUMULATION THRESHOLD

For the statewide run a maximum upstream drainage threshold value was added at which a beaver could not build a dam. This threshold was added because we found that stream power by itself was not always adequate at determining when a river was too large to allow dams to be built and to persist. From validation data we determined that for USGS Geohydrologic Region 6 the drainage threshold should be 3860 square miles because large scale water

withdrawal in these streams greatly reduces discharge (e.g., Escalante, San Rafael, Virgin and Price rivers). For all other USGS Geohydrologic Regions in the state a drainage threshold of 1800 square miles was assigned. Additionally, for the statewide run the flow accumulations of rivers that originated outside of the state as well as drainage area of rivers that flowed from one Geohydrologic region to another were cumulatively assessed to capture accurate and complete upstream drainage area values.

MONTANE MEADOW ADJUSTMENTS

During the statewide run we identified montane streams with very low stream power (Q_2 of less than 250 watts) and LANDFIRE vegetation that scored the reaches as 'occasional' but in which actual dam densities from the Google Earth census showed 'frequent' dam densities. These reaches tended to be high montane meadows on streams of low stream order (generally 1st or 2nd), and less optimal vegetation because of the hard winters, short growing season and high altitude. Figure 7 shows Saddle Creek in the Upper Blacksmith Fork drainage of the Northern region and is a good example of this situation where our model initially underestimated capacity. A site visit to the area confirmed, as was classified by LANDFIRE, that the vegetation within the 100 m buffer consists mostly of sagebrush, forbs and grasses with an aspen community on the very fringe, thus the area was correctly given a vegetation score of 'occasional'. The site visit also confirmed that the area had low stream power and 'frequent' dam densities as indicted by the Google Earth dam count data. Rather surprisingly, we found that beaver are utilizing sagebrush, mud, and rocks to build dams in the area.

To resolve the model's underestimation of dam density in these low-order, montane meadow streams we added conditional logic to the model that increased the capacity of segments that met the criteria: 'occasional' vegetation score and Q_2 less than 250 watts. For the final output these segments were elevated from the 'occasional' to 'frequent' category. The logic being that in these headwater reaches with low stream power beaver can "get away with" building high density dams with less than ideal material.
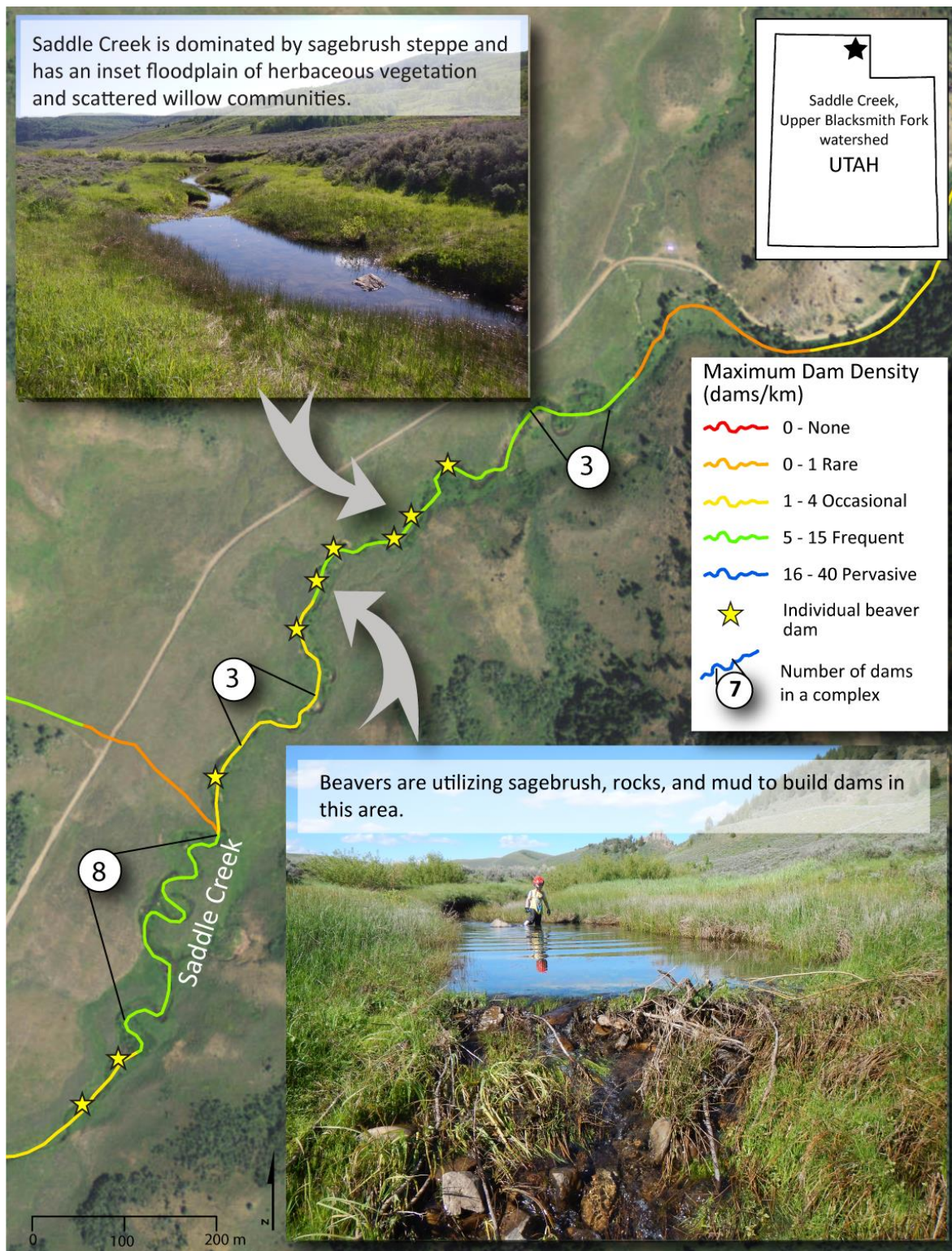
Figure 7 – Map showing Saddle Creek, a headwater stream of the Blacksmith Fork drainage. Ground verification data collected along these reaches was used to produce the 'Montane Meadow Adjustments', which resolved the models initial tendency to underestimate capacity.

COMBINED MODEL

The five lines of evidence – perennial water source, woody vegetation for building materials, evidence that a dam can be built, evidence of dam persistence, and evidence that stream slope was not too steep – were combined within a final FIS to estimate the maximum beaver dam density (dams/km) of riverscapes. In addition, the minor refinements were incorporated as conditional logic. Figure 8 shows an example of how when applied spatially, these inputs are combined to produce the maximum potential of a riverscape to support beaver dams. Each ~250 m reach segment has a predicted capacity (in terms of maximum number of dams). Thus, the capacity density estimates can be multiplied by the segment length to calculate a total maximum number of dams for each segment. These capacity numbers are summed to estimate the total capacity of the system. In some systems, the vegetation model drives the primary output (e.g. Figure 8).

We used the four output categories (none, occasional, frequent and pervasive) from Macfarlane and Wheaton (2013) pilot, but also added a 'rare' category and adjusted the occasional class accordingly:

- None – 0 dams: *segments deemed not capable of supporting dam building activity*
- Rare – 1 dam/km: *segments barely capable of supporting dam building activity; likely used by dispersing beaver*
- Occasional – 2-4 dams/km: *segments that are not ideal, but can support an occasional dam or even a small colony*
- Frequent – 5-15 dams/km: *segments that can support multiple colonies and dam complexes, but may be slightly resource limited*
- Pervasive – 16-40 dams/km: *segments that can support extensive dam complexes and many colonies*
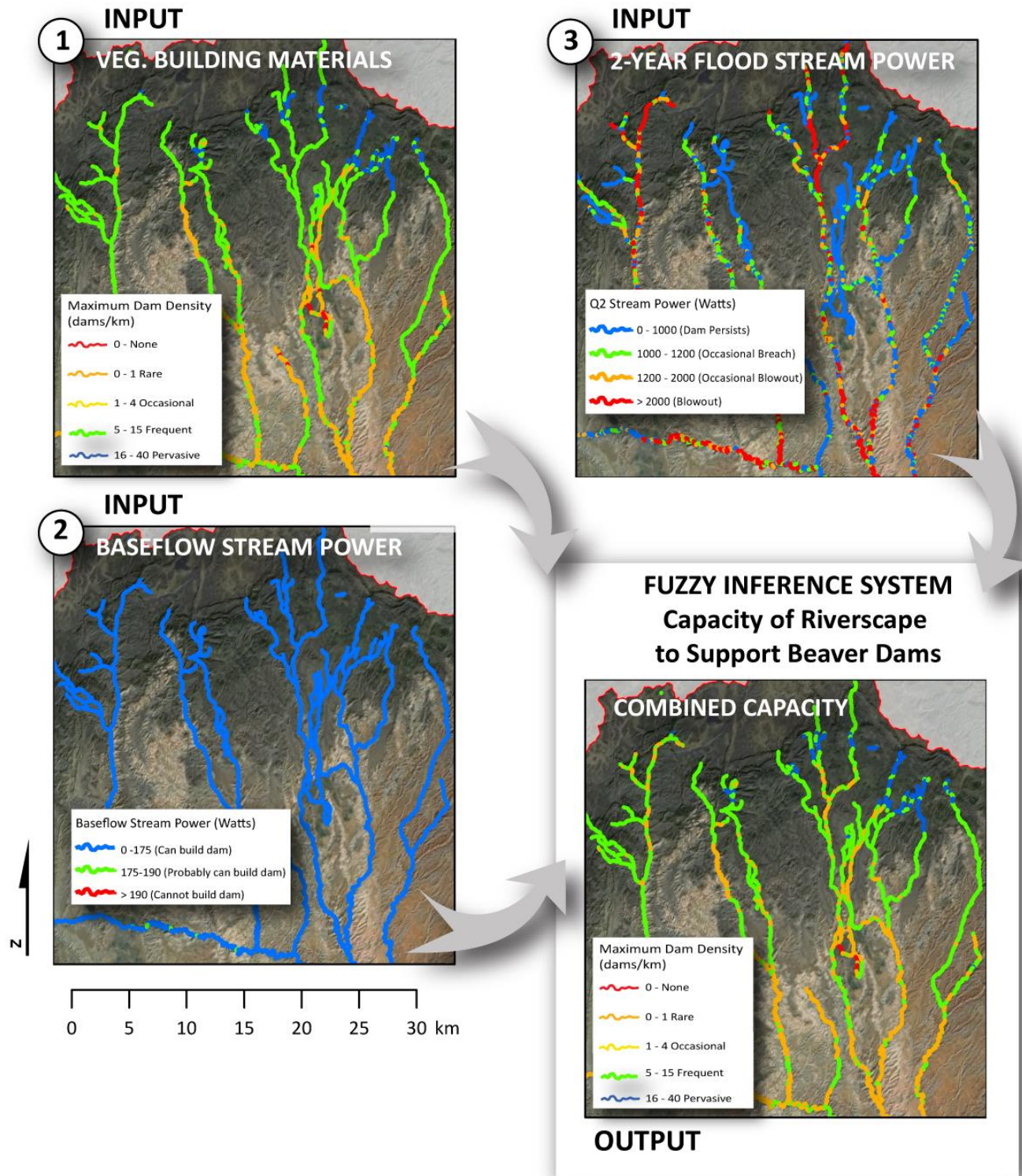
Figure 8 – Methodological illustration of inputs (1-3) and output for the combined model of riverscape capacity to support beaver dam-building activity. Model output is expressed as dam density (dams/km).

EXISTING AND HISTORIC CAPACITY

The statewide capacity model was run using both existing and historic vegetation. The existing vegetation was acquired from the 2011 LANDFIRE Existing Vegetation Type (EVT) data and the historic was acquired from the LANDFIRE Biophysical Setting (BpS) layer (Schmidt et al., 2002). The BpS layer represents the vegetation that may have been dominant on the landscape prior to Euro-American settlement based on both the current biophysical environment and an approximation of the historical disturbance regime (LANDFIRE 2014). Running existing and historic vegetation is an important component of BRAT because the ratio of existing to historic capacity is used to calculate riparian condition and recovery potential. Riparian condition and recovery potential are important inputs into the Beaver Conservation Zone Inference System and helps to determine the level of conservation or restoration status a given stream segment receives.

MODEL VERIFICATION

A capacity model is difficult to 'validate' because rarely, if ever, would the entire riverscape be at 'capacity'. However, since the model output was dam density, direct comparison to actual dam densities is a useful form of verification of model performance. We verified our model in three different ways. First, model outputs were ground truthed to confirm whether or not the predictions seemed reasonable (e.g. places we've never seen evidence of beaver dams show up as having 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 verification, actual dam counts were collected for the Logan/Little Bear, Strawberry, Price and Fremont HUC 8 watersheds using virtual reconnaissance in Google Earth. A trained technician used Google Earth to examine the entire stream network within the four validation watersheds 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 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. Each point was given an accuracy estimate of very high, high, medium and low based on the likelihood that the identified dam was actually a beaver dam. To corroborate these observations, dam locations with medium and low status were independently reexamined in Google Earth by a supervisor to determine if the dam should remain in the dataset or not. For the Logan/Little Bear, and Strawberry very high quality 2013 imagery was available in Google Earth and was the basis of

the mapping. However, the Fremont and the Price had lower quality 2011 and 2012 imagery which made it more difficult to reliably discern beaver dams resulting in an underestimation of actual dams for these watersheds. The resulting dam location data was used for model calibration and validation.

Finally, to assess whether or not beaver dam building was preferentially taking place in reaches with higher capacity estimates, an electivity index 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 electivity index EI, was calculated for each segment type (i):

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

where n_i is the number of beaver dams surveyed in segment type i and l_i 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 fuzzy inference system. 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.

DECISION SUPPORT AND PLANNING TOOL

The capacity model can help explain dam density patterns and to explore appropriate locations for beaver introductions and relocations. However, the capacity model alone is not enough to effectively plan for large scale management and restoration of dam-building beaver. Potential human conflicts (e.g., proximity to road/culvert crossings, and irrigation diversions) also need to be explored for context and to highlight potential constraints. In this section we describe the development of two preliminary, logical spatial models that help build out the BRAT: a i) Human-Beaver Potential Conflict Model, and ii) the Beaver Management, Conservation and Restoration Potential Model. These spatial models with the capacity model outputs collectively comprise the first generation of the Utah BRAT Decision Support and Planning Tool for management, conservation and restoration of beaver throughout the state of Utah.

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HUMAN-BEAVER CONFLICT POTENTIAL MODEL

There is no doubt that beaver can be a destructive nuisance in the built environment and anywhere where 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 address potential conflicts in the built environment, we developed the Human-Beaver Potential Conflict Model. This inference system utilizes GIS data characterizing potential points of conflict and includes: canals, roads, culverts, railroads, stream crossings by roads, water related land use and land ownership to determine at the reach scale (~250 m segments) the probability of potential conflict. Each of these layers exist as vector GIS layers (typically polylines or points). For each model, we derived a Euclidian distance raster for each of the inputs for which a potential conflict might exist. We then developed simple transform functions (see small print in Figure 9), to translate these distances to a probability of human-beaver conflict based on the simple logic that if a dam-building beaver was present, the closer a water-course is to said infrastructure, the higher the probability of conflict is. We then perform a simple zonal statistic operation in a 30 m buffer along each 250 m segment to use the maximum probability of conflict calculated.

Figure 9 is a flow chart diagramming the conditional logic. The formula and set probabilities (in red) in Figure 9 highlight the logic and calculations used for this initial version of the conflict potential model. All the probability transform functions and inflection points are adjustable and were chosen here to highlight relative differences. As the conditional logic suggests, the model essentially independently calculates a probability of conflict for each input (e.g. roads, culverts, railroads, etc.) and then uses the most restrictive output (i.e. highest probability) amongst them. The values in the 'diamonds' can easily be adjusted to make the model more or less restrictive. These initial values are purposely very restrictive. We envision adjusting these values based on specific recommendation from UDWR staff based on interactions with and feedback from stakeholders. For example, in regions or areas where managers and stakeholders are more willing to use 'living with beaver strategies', such conflict probabilities might be lowered, whereas in areas where there is less tolerance for potential nuisance beavers, these could be increased. It is important to emphasize that the logic here is transparent, the distances to human infrastructure are calculated robustly, and the probabilities are subjectively determined according to management priorities. We consider this output as a preliminary first-cut, which can be calibrated and adjusted with feedback from managers.
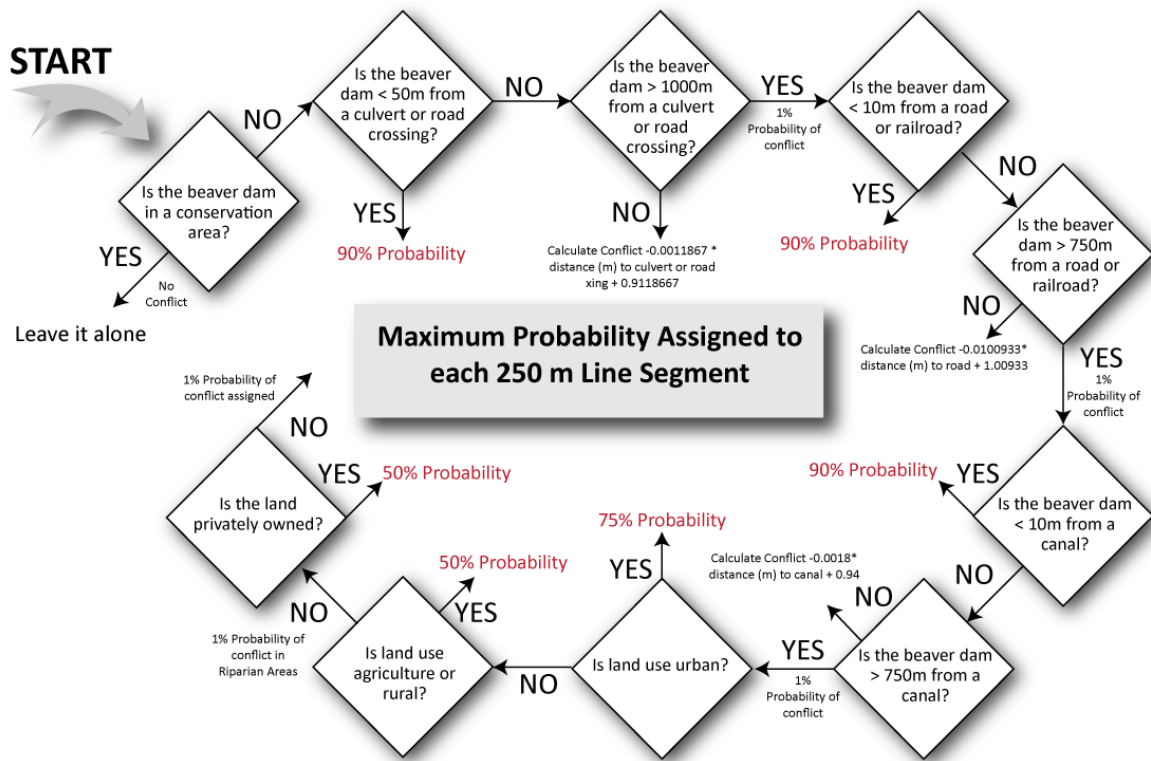
Figure 9 – Flowchart diagramming the human-beaver conflict potential probability model. The initial probability values are very restrictive, resulting in many areas with high probability of conflict values. These probabilities can be adjusted to reflect stakeholder desires.

BEAVER MANAGEMENT, CONSERVATION AND RESTORATION POTENTIAL MODEL

Under the UDWR Beaver Management Plan (UDWR, 2010), watershed restoration using beaver to improve riparian habitats, associated streams and wetlands is proposed as a management objective. Although the plan includes a 'transplant priority table', those priorities do not consider how realistic it is that the target transplant streams will be able to support transplanted nuisance beaver successfully. As a strategy under this restoration objective, the plan suggests:

> 'Conduct site specific evaluations prior to introducing beaver to include consideration for the presence of suitable habitat, low risk of creating damage conflicts and the possibility of establishing barriers that may impede fish migrations.'

While site specific evaluations are always important, we suggest that suitable dam-building habitat for beaver can be better planned for at Statewide and Regional levels using the outputs of BRAT. To organize the capacity estimates and conflict potential outputs into a more useful output to support planning and decision making, we developed the Beaver Management,

Conservation and Restoration Potential Model (Figure 10). It is important to note that this model is initially being run without any data on actual beaver dam locations, but that a more refined output could be provided with such empirical information.

The model leverages the BRAT capacity model to calculate both existing and historic capacity based on the derived current and modeled historic condition of the LANDFIRE riparian vegetation. These data are leveraged to estimate riparian condition and recovery potential based on the contrast of existing and historic capacity. This information is combined with the outputs of the Human-Beaver Potential Conflict Model to differentiate streams segments into seven different management categories. Figure 9 is a flow chart diagramming the conditional logic of the Beaver Management Conservation and Restoration Potential model. The seven stream categories that the inference system uses are: 1) Low-hanging Fruit, 2) Quick Return, 3) Long-term Possibility, 4) Naturally Limiting, 5) Anthropogenically Limiting, 6) Living with Beaver (high source), and 7) Living with Beaver (low source). Their definitions are described below:

1. **Low-hanging Fruit** – Streams that are either currently inhabited by beaver or are in relatively good condition for beaver recolonization. The focus of management in these streams should be conservation of these biodiversity hotpots and the hydrologic, geomorphic and ecosystem processes that maintain them, as well as pursuing expansion or reintroduction of beaver (e.g., trapping and relocation of 'nuisance' beaver colonies from areas where they are in direct conflict with human activity). If empirical mapping of beaver dam locations are available, this category can be subdivided into:
    o Low-hanging Fruit Conservation Zone – Areas with existing beaver populations to be conserved and promoted through trapping protection/regulations, and promoting compatible land use practices.
    o Low-hanging Fruit Restoration Zone – Areas without existing beaver populations or significantly under seeded densities (i.e. < 5 to 10 % of capacity), which have conditions to support frequent to pervasive densities and could easily be transplant sites.
2. **Quick Return** – Streams that currently lack riparian conditions necessary to support beaver dam building activity (e.g., incised or heavily grazed streams) at anything other than rare or occasional densities, but can, with minimal intervention and changes in management practices (e.g., cattle grazing exclosures), exhibit relatively rapid ecological and fluvial responses that allow for beaver recovery and subsequent maintenance of such conditions. For example, in Eastern Oregon using cheap and biodegradable fence posts as beaver dam support structures, we have been able to increase dam life and beaver damming activity, resulting in dramatic streambed aggradation, which promotes reconnection with former floodplain surfaces and increases complexity of in-channel and floodplain habitats (e.g., Pollock et al. 2012). In some instances, quick return

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streams may require structural interventions or riparian restoration prior to translocating beaver, but these streams are expected to be able to recover such conditions relatively quickly (e.g. < 5 years). The primary line of evidence to infer this in the model is a minor departure from historic conditions (e.g. a stream with currently 'occasional' capacity that historically supported 'frequent').

3. **Long-Term Possibility** – Other streams may show potential in terms of colonization by beaver, either because they historically supported beaver populations or could provide the right habitat conditions. However, these systems are not immediately obvious candidates for promoting active dam building beaver populations due to land-use commitments or expense of recovering habitat conditions. Land managers may strategically decide to pursue conservation efforts in these streams because of their position in the drainage network and/or their value. Such locations will often require significant investment and time to recover riparian conditions capable of supporting frequent or greater dam densities.

4. **Unsuitable, Naturally Limited** – Prior to European settlement and trapping of beaver in North America, there would always have been some streams and rivers that were unsuitable for colonization by dam-building beaver. These included streams that were too small, ephemeral, or steep; lacked adequate wood resources for foraging and building; and/or were too large to dam (although floodplain and side-channel habitat may be potentially colonized).

5. **Unsuitable, Anthropogenically Limited** – Streams that are unsuitable for beaver because humans constrain their habitat conditions (e.g., water quantity, water quality, and/or wood availability), and there is high potential for human-beaver conflicts (e.g., beaver blocking irrigation canals). From a beaver dam capacity perspective, these are areas that currently cannot support beaver dam building activity, but historically could. If rare beaver dams are found in such situations, they are prime candidates for transplanting. However, these are not expected to be significant sources of beaver.

6. **Living with Beaver (high source)** – These streams are in areas where beaver activity has some potential to cause damage to infrastructure, but the impacts are minimal and/or easily mitigated with 'Living with Beaver' strategies (Wheaton, 2013). These areas are generally in areas that the capacity model predicted to support *frequent* to *pervasive* dams and are inferred to be capable of providing high source population of beaver. Due to their close enough proximity to sensitive infrastructure and subsequently relatively high probability of human-beaver conflict potential, these areas are slated for 'living with beaver' strategies, which start with mitigation and can culminate in live trapping and transplanting to quick return and/or low-hanging fruit areas.

7. **Living with Beaver (low source)** – These streams are in areas where beaver activity has some potential to cause damage to infrastructure, but the impacts are minimal and/or

easily mitigated with 'Living with Beaver' strategies (Wheaton, 2013). These areas are generally in areas that the capacity model predicted to support *rare* to *occasional* dams and are inferred to be capable of providing only a low source population of beaver. Due to their close enough proximity to sensitive infrastructure and subsequently relatively high probability of human-beaver conflict potential, these areas are slated for 'living with beaver' strategies, which start with mitigation and can culminate in live trapping and transplanting to quick return and/or low-hanging fruit areas.

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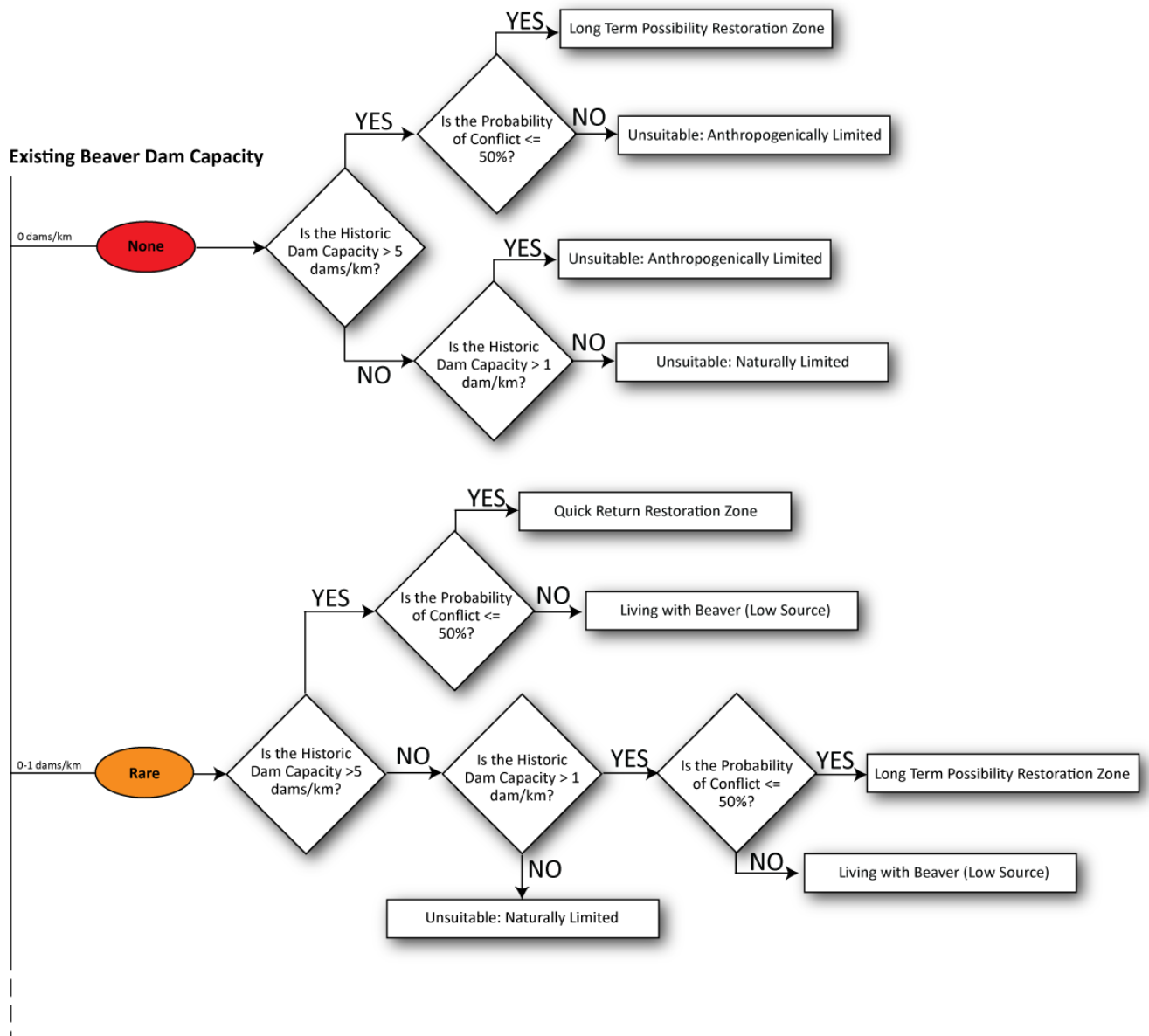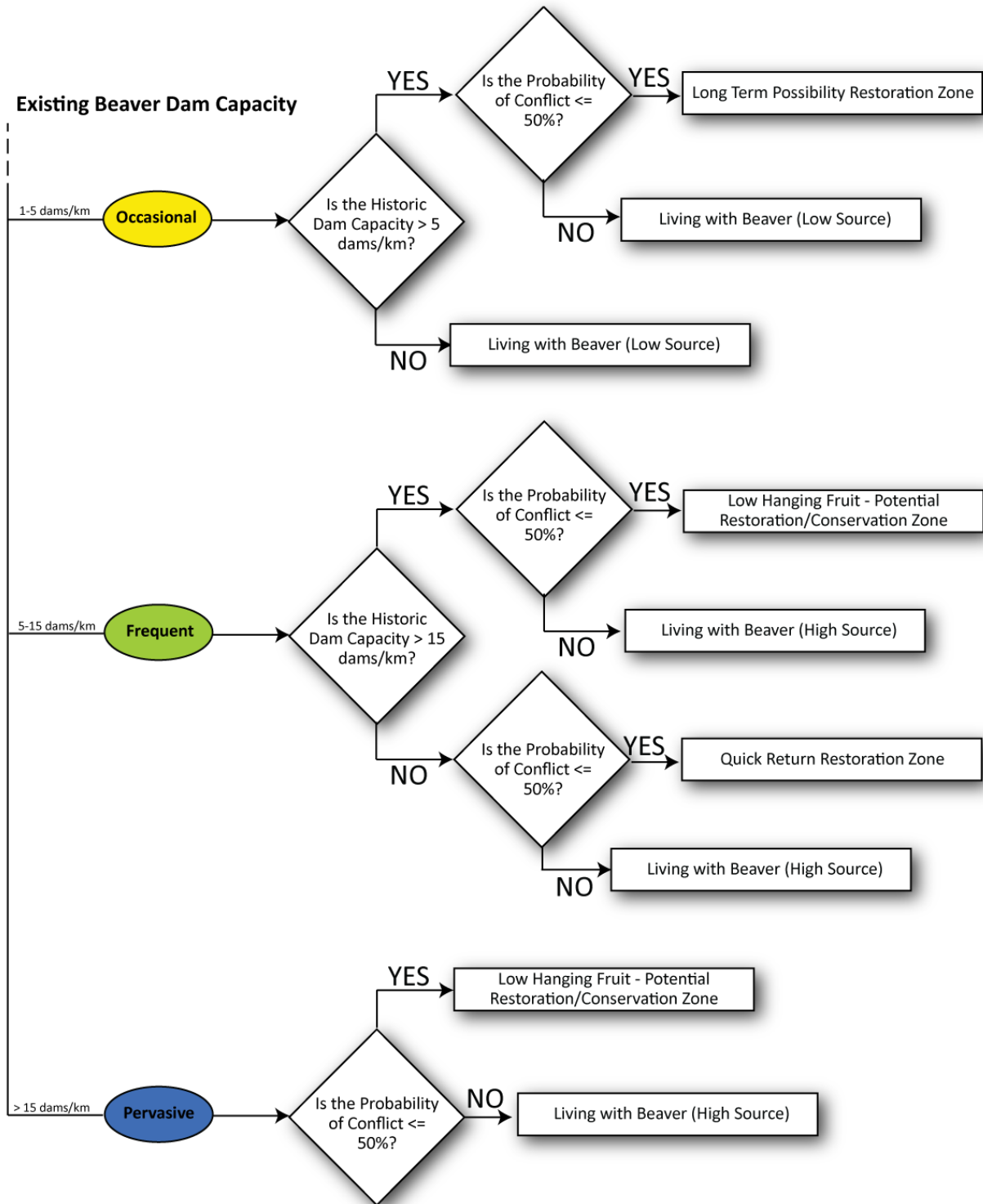
Figure 10 – Flowchart diagramming the Beaver Conservation and Restoration Zone inference system.

EXTRAPOLATIONS TO ESTIMATE NUMBER OF BEAVER DAMS, COLONIES AND POPULATIONS

Using a mix of empirical numbers on beaver dam locations, which were collected primarily for verification of the capacity model outputs, we developed preliminary extrapolations to estimate the plausible range of beaver dam numbers statewide. We then used the dam count estimates to establish ranges for number of colonies and population sizes. Although these estimates are coarse, they still provide baseline numbers to set plausible bounds and provide direct comparison with other estimates.

To estimate the number of dams statewide, we used the dam census data we acquired in four validation watersheds in Utah (total of 2852 dams) to develop simple empirical percent of capacity scaling relationships between the capacity model output categories (e.g. *none*, *rare*, *occasional*, *frequent* and *pervasive*) and actual realized dam densities. Using this simple method, we established a minimum, average and maximum scaling, which were then multiplied on a segment-by-segment basis by the actual dam capacity estimate. We did this for both current and historic beaver dam capacity model estimates and summed them across the entire state.

To estimate the number of colonies statewide, we used estimates reported in the literature (e.g. Gurnell, 1998) on typical number of dams per colony to convert the above dam estimate to a colony estimate. For a minimum estimate of number of colonies, we assumed the higher end of number of dams per colony that we have observed at ten dams per colony and divided this into the minimum estimate of beaver dams. For an upper estimate on number of colonies, we more liberally assumed that four dams per colony were needed and multiplied this by the maximum number of dam estimate. For our best guess, average estimate, we assumed six dams per colony and divided this into our average estimate of number of beaver dams.

Finally, to estimate the population size range, we took the above estimates of number of colonies and multiplied these by a range of literature reported estimates of typical colony size. For a very conservative lower estimate, we multiplied the minimum estimate of number of colonies by two beaver (i.e. just a mating pair). For an upper estimate to round out a plausible maximum, we multiplied our upper estimate of number of colonies by six beaver (i.e. a mating pair and two generations of kits). For our best guess, we assumed four beaver per colony and multiplied this by the average estimate of number of colonies.

RESULTS, ANALYSIS & INTERPRETATION

The primary Utah BRAT outputs consist of the following four stream network classifications: i) Existing Beaver Dam Capacity, ii) Historic Beaver Dam Capacity, iii) Probability of Potential Beaver – Human Conflict, and iv) Preliminary Beaver Conservation and Restoration Zones.

Maps, summary tables and graphics of each of the four stream network classifications are provided at the statewide and UDWR Region scale. Poster sized maps are available at http://etal.usu.edu/Downloads/BRAT/Posters/Statewide/. See the §Appendix C: Utah BRAT for full page maps of each output and maps by UDWR region.

GIS DATA LAYERS

The GIS data layers that make up the maps are available in KML, shapefile and file geodatabase formats which enable visualization and querying in any GIS program. Viewing the KML files (http://etal.usu.edu/Downloads/BRAT/Data/KMZ/) in Google Earth is perhaps the best way to visualize and interrogate these data because of the 3-D capabilities, image rendering speed and the quality of the base imagery. We encourage the use of the BRAT spatial data layers available at (http://etal.usu.edu/Downloads/BRAT/Data/). Additionally, we are working with the Utah Automated Geographic Reference Center (http://gis.utah.gov) to post these same layers to their data resources pages.

BEAVER DAM CAPACITY MODELS

The beaver dam capacity models were run for existing (based on 2011 imagery) and historic conditions. The estimated existing statewide capacity is a maximum of 226,989 dams (Figure 11; Table 3), or roughly 8.3 dams/km. By contrast, the same model driven with estimates of historic vegetation types estimated a statewide historic (i.e. pre European settlement) capacity at 320,658 beaver dams (Figure 12; Table 3), or roughly 11.7 dams/km. Thus, statewide, roughly 71% of historic capacity to support beaver dam building activity has been maintained. The most striking contrasts on the map are found in valley bottoms, which have been converted to urban or agricultural land uses, and to a lesser extent in rangelands and forests where riparian vegetation changes have led to a net loss.

Table 3 – Gross summary of contrast between existing and historic beaver dam capacity estimates for Utah statewide by capacity categories.

Category	Existing Capacity			Historic Capacity			% Capacity of Historic
	Stream Length (km)	% of Stream Network	Estimated Dam Capacity	Stream Length (km)	% of Stream Network	Estimated Dam Capacity	
Pervasive	3,502	13%	81,811	7,830	29%	184,890	44%
Frequent	12,584	46%	129,224	12,377	45%	127,705	101%
Occasional	5,799	21%	15,256	2,939	11%	7,721	198%
Rare	2,323	8%	648	1,158	4%	342	189%
None	3,137	11%	-	3,040	11%	-	0%
Total	**27,345**		**226,939**	**27,344**		**320,658**	**71%**

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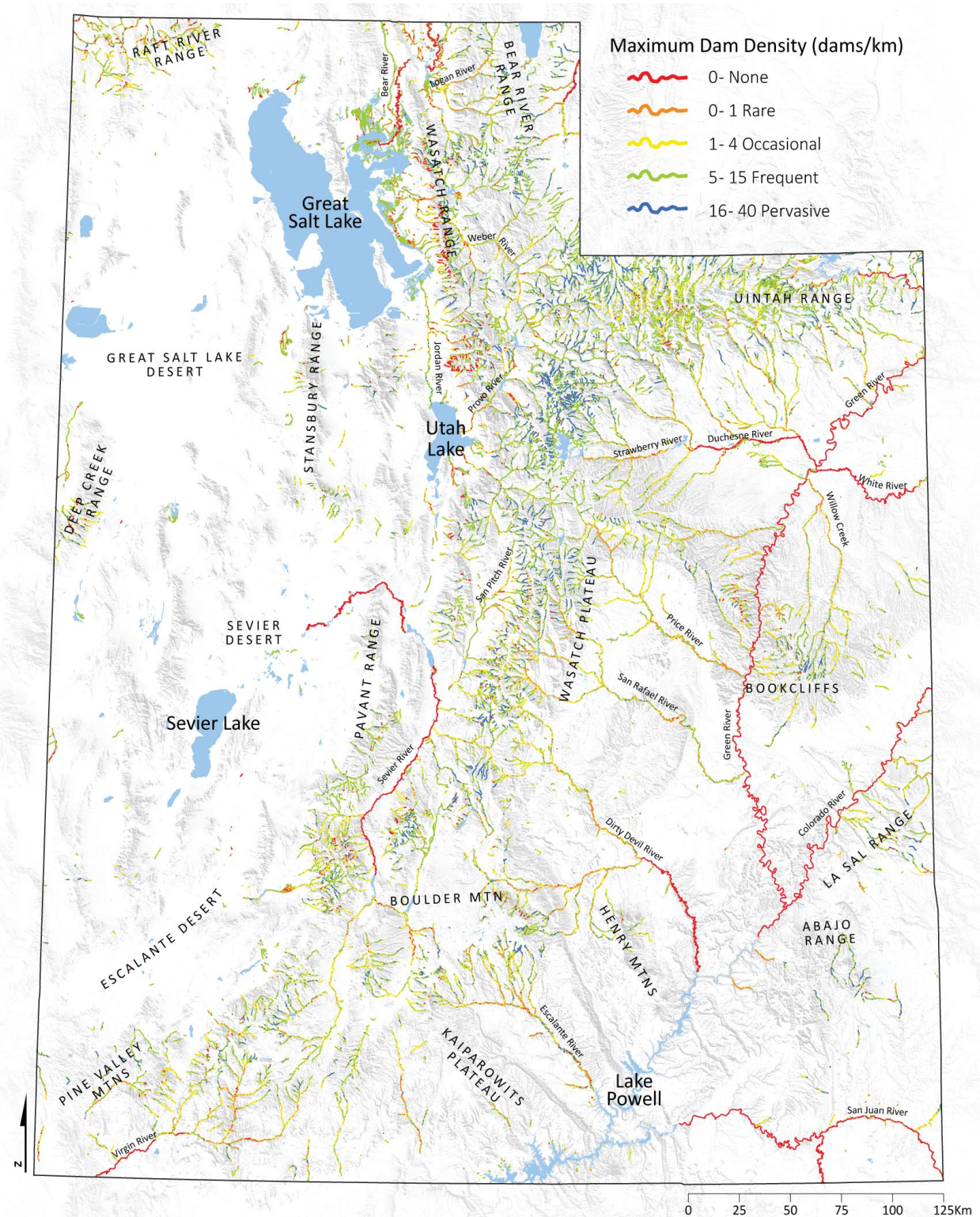
Figure 11 – Modeled beaver dam capacity for existing conditions for State of Utah.
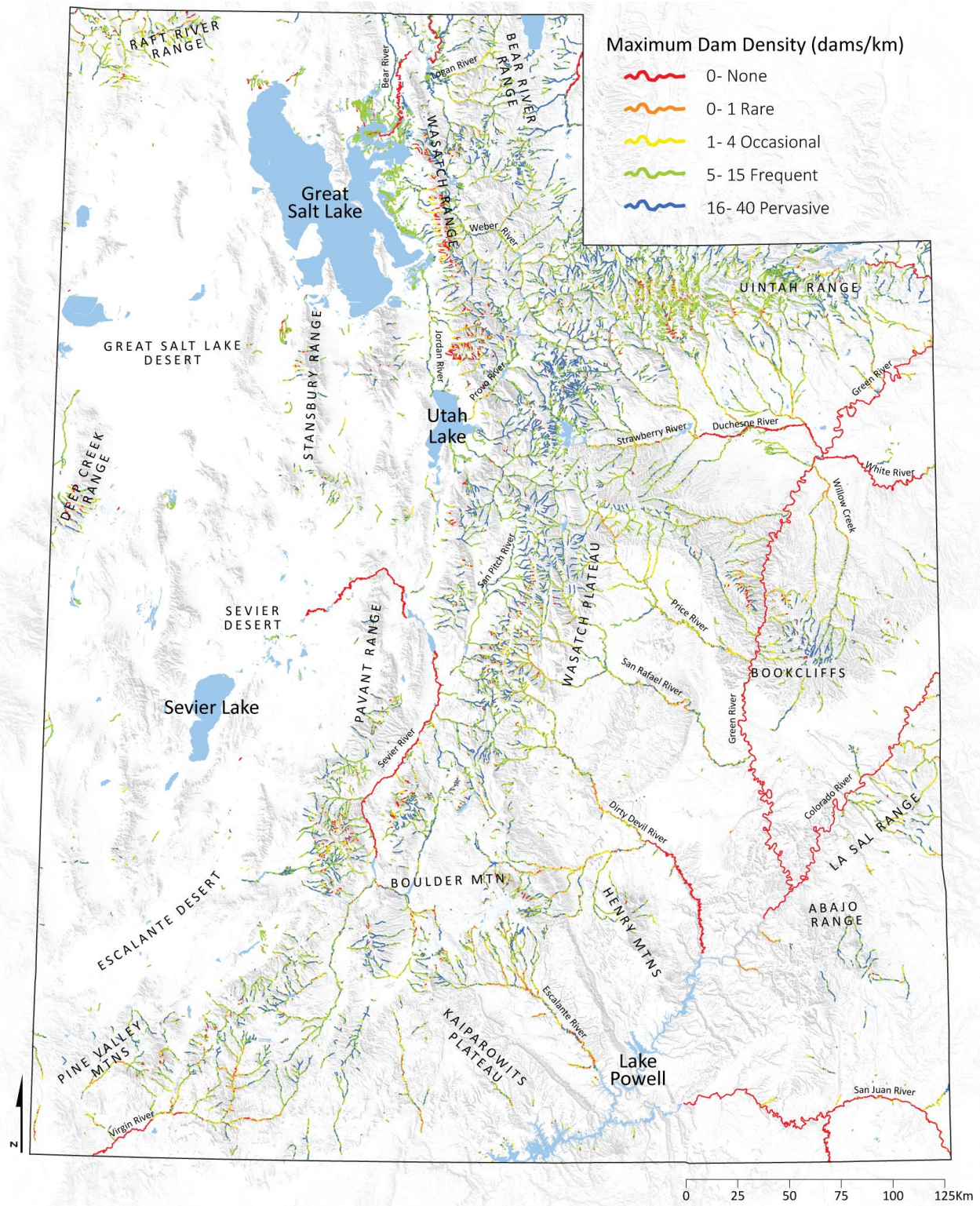
Figure 12 – Modeled beaver dam capacity for historic conditions for State of Utah.

Overall, there is negligible change in the proportion of streams in the *none* and *frequent* categories (<1% and <2% respectively). The roughly 3000 km of *none* category primarily reflects the biggest mainstem rivers in the state (e.g. Colorado River, Green River, Bear River, etc.) that are simply too big for beavers to build dams across the main channels (note that dams can be found on some of the smaller side channels to these rivers where active floodplains still exist). In addition, there are a few steep headwater streams and gorges where slopes and/or stream powers are too high for beaver dams to be built. At 46% of the existing stream network (Table 3), the *frequent* dam density represents the largest single category in both the existing and historic model. With a 1% increase in the number of streams supporting *frequent* beaver dam densities, it is tempting to conclude that conditions on these streams stayed roughly the same when compared to historic estimates. However, if the fate of every individual reach is compared to see whether its capacity stayed the same, increased or decreased, a slightly different picture emerges (Table 4). For example, nearly 11% of reaches throughout the state that could support *frequent* densities historically have degraded and now support lower densities; whereas 32.5% of reaches actually stayed the same and less than 1% improved. Over 12% of reaches that were historically able to support *pervasive* beaver dam densities now only support *frequent* dam densities.

Table 3 indicates that the biggest losses have been in stream reaches that historically supported *pervasive* dam densities and that only 44% of the original 7830 km of these category streams still exist. As Table 4 shows, over half of these reaches have degraded to only supporting *frequent* dam densities. We see many of the historically *pervasive* streams in Figure 12 throughout the Wasatch Plateau, Boulder Mountain and the Bear River Range are amongst those that have declined in Figure 11 and these largely reflect degradation of riparian vegetation conditions. Overall, 0.6% of Utah's perennial streams showed improvements in capacity locally, 29.6% exhibit degraded capacities from historic, and 68.6% have maintained similar capacities (Table 4). The roughly 30% that have lost capacity, are reflected in Table 3, which shows big increases in the *occasional* and *rare* dam capacity categories (representing 29% of all perennial streams now, whereas historically they were only 15%). These are primarily found in the agricultural valleys of the state and along the Wasatch Front.

Table 4 – Confusion Matrix based on a reach segment-by-segment comparison of existing and historic conditions showing what percentage of reaches stayed the same (bold – white), what percentage improved compared to historic estimates (green), and what percentage degraded compared to historic estimates (pink).

Existing	Historic				
	None	Rare	Occasional	Frequent	Pervasive
None	12.7%	0.1%	0.1%	0.5%	0.2%
Rare	0.1%	4.1%	2.7%	1.2%	0.6%
Occasional	0.3%	0.1%	7.4%	9.1%	2.6%
Frequent	0.1%	0.0%	0.4%	32.5%	12.3%
Pervasive	0.0%	0.0%	0.0%	0.7%	12.0%
Capacity Improved from Historic	0.6%				
Capacity Degraded from Historic	29.6%				
Capacity same as Historic	68.6%				

DECISION SUPPORT AND PLANNING RESULTS

STATEWIDE HUMAN-BEAVER CONFLICT POTENTIAL MODEL

The human-beaver conflict potential model is a simplified, probabilistic spatial model that estimates every reach's probability for conflict between humans and beavers irrespective of whether beaver are present, and without regard to what sort of densities of beaver dams could be supported. Figure 13 nevertheless highlights the model results and shows a useful relative score or where the highest number of conflicts may be. The 'blue' (< 10% probability of conflict) stream reaches reflect the most remote, undeveloped parts of the state that are most inaccessible to humans. Collectively, they comprise over 37% of Utah's rivers and streams. For example the high Uintah's represent a large wilderness area that encompasses 185,000 hectares in Northeastern Utah and is free of roads, railroads, culverts and canals. Areas with the lowest probability of conflict also include the large rivers of Eastern and Southeastern Utah; however no beaver dam building capacity is present in these areas because of high stream power (though bank-dwelling beaver may still be present). By contrast the 'red' (>75% of probability) areas reflect streams that are closest to roads, railroads, canals and/or dissected by diversions, culverts, bridges and the like. The probability of potential conflict is, as expected, concentrated in the heavily developed urban portions of the state and some of the most heavily used lands (e.g. agricultural, rangeland, forestry, and mining). Statewide, roughly 24% of the perennial rivers and streams have a > 75% probability of human-beaver potential conflict, and over 37% have a > 50% probability of conflict. As Figure 14 suggests, the most heavily populated UDWR Central and Northern regions have both the lowest percentage and length of streams in the 'blue' (<10% probability of conflict). Interestingly, the Southern, Central and Northern all show relatively high proportions of >75% probability of conflict (27%, 35% and 27% respectively).

The conflict probability model needs to be carefully interpreted. By itself, it is potentially useful for identifying where conflicts could be if and only if two things take place. First, beaver are present, and secondly that humans choose to interpret the actions of beaver as a problem. If a heavily urbanized area has a high probability of conflict, and a large number of beaver, it is not necessarily a problem if 'living with beaver' strategies are adopted. For example, in Park City much of the streams that flow through the city limits are capable of supporting beaver and all have a high probability of conflict. However, there are some areas that the City has identified where beaver can exist without causing harm to public infrastructure and they are allowed to remain, whereas other areas they can indeed be a nuisance and may plug culverts and diversions, and/or cause flooding of roads and basements. In some of these areas the city is installing 'living with beaver' mitigation strategies like 'pond-levelers' and 'beaver deceivers' to keep ponds from reaching a level where they cause flooding (Wheaton, 2013). In other areas, the city has identified that infrastructure is so critical that beaver cannot be allowed, but those areas are good 'source zones' for live trapping of nuisance beaver that may be relocated elsewhere in the area or state for restoration and conservation purposes as per the Utah Beaver Management Plan (UDWR, 2010). It has been shown elsewhere that 'living with beaver' strategies are often cheaper and more effective then lethal control strategies.
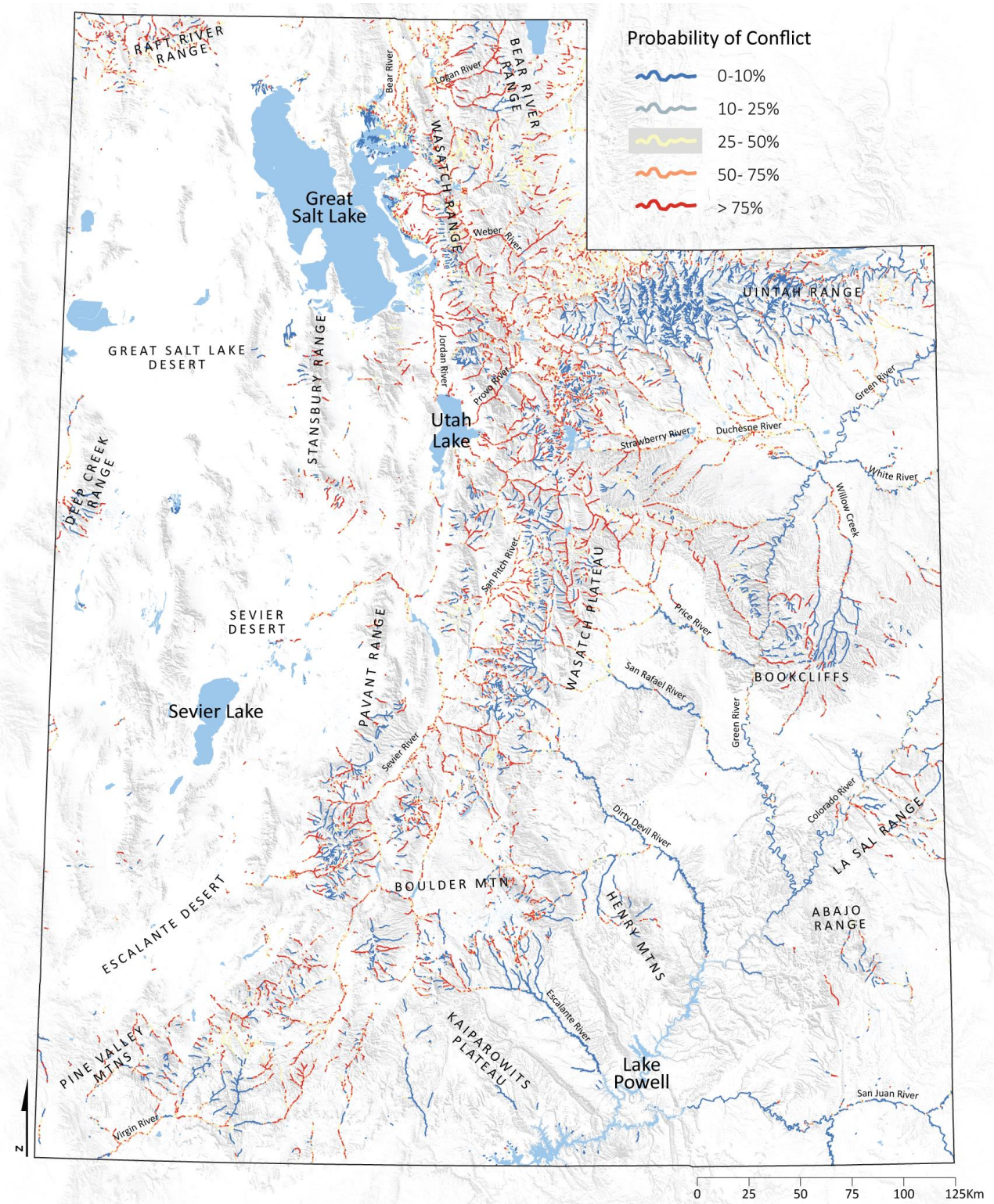
Figure 13 – Utah statewide probability of human-beaver conflict potential estimate.
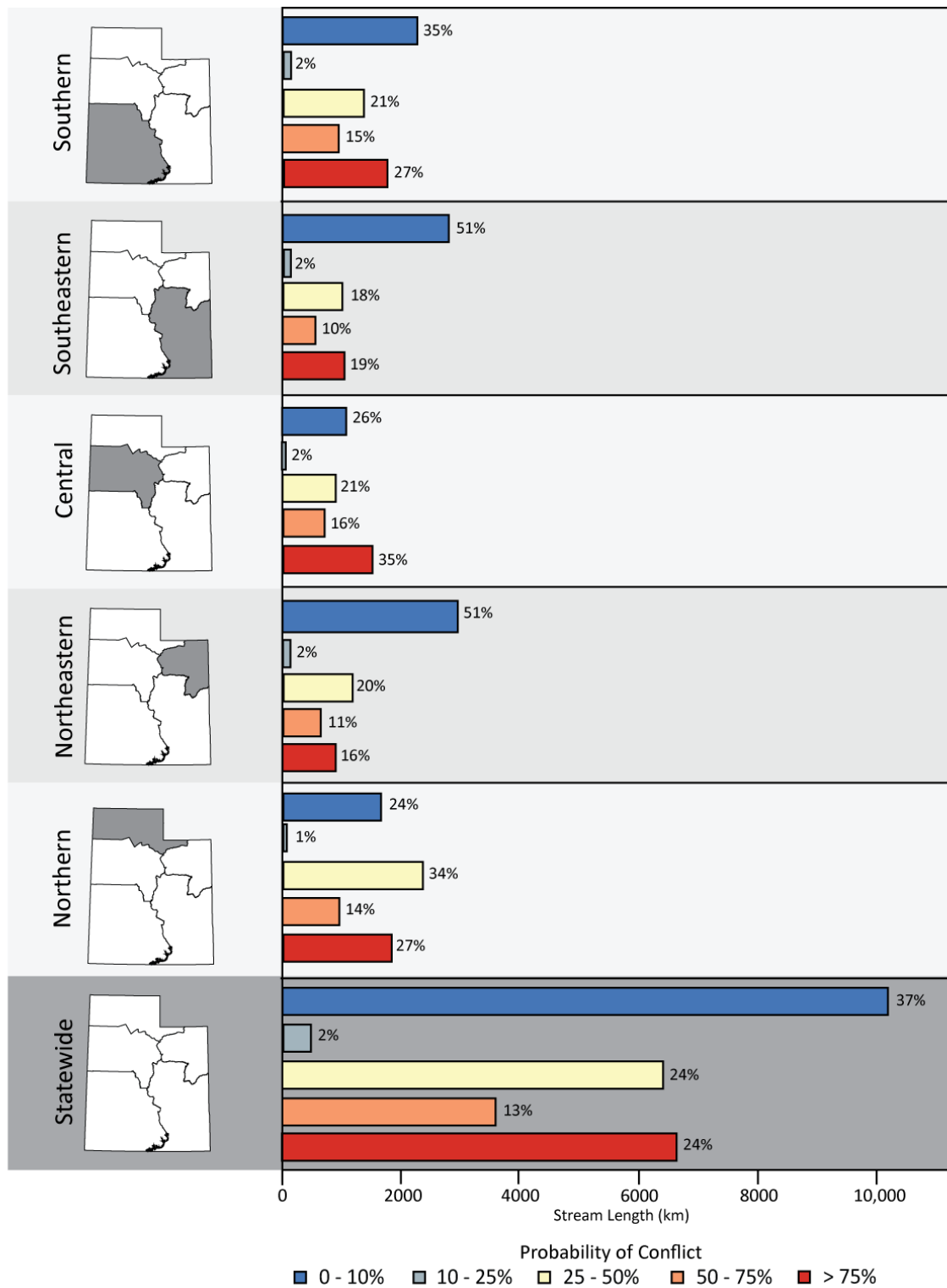
Figure 14 – Utah statewide & UDWR region summary distributions of probability of human-beaver conflict potential.

PRELIMINARY STATEWIDE BEAVER MANAGEMENT, CONSERVATION AND RESTORATION POTENTIAL MODEL

The Beaver Management, Conservation and Restoration Potential Model categorized 35% of Utah as 'Low-hanging Fruit' signifying habitats that are either currently inhabited by beaver or are in relatively good condition for beaver recolonization and/or reintroduction (Figure 15 and Figure 16). We recommend that these areas be used to relocate 'nuisance' beaver colonies from areas where they are in direct conflict with human activity. Another nearly 1/3 (28%) of the state was identified as 'Unsuitable' (12% 'Unsuitable – Naturally Limiting' and 16% 'Unsuitable – Anthropogenically Limiting') indicating areas that are likely out of reach for restoration due to natural or human induced limitations. About 1/3 (29%) of the state was also identified as 'Living with Beaver' (13% low source and 16% high source) indicating that beaver activity has some potential to cause damage to infrastructure, but the impacts are minimal and/or easily mitigated with 'Living with Beaver' strategies. Finally, about 8% of the state was equally divided between 'Quick Return' (4%) representing areas that with minimal intervention and changes in management practices could be suitable for dam-building beaver and 'Long-Term Possibility' (4%) representing streams that could provide the right habitat conditions if significant changes in land-use and major stream and riparian restoration efforts were undertaken. We recommend focusing restoration efforts on the 'Quick Return' streams unless there is a specific reason to tackle a 'Long-Term Possibility' stream.
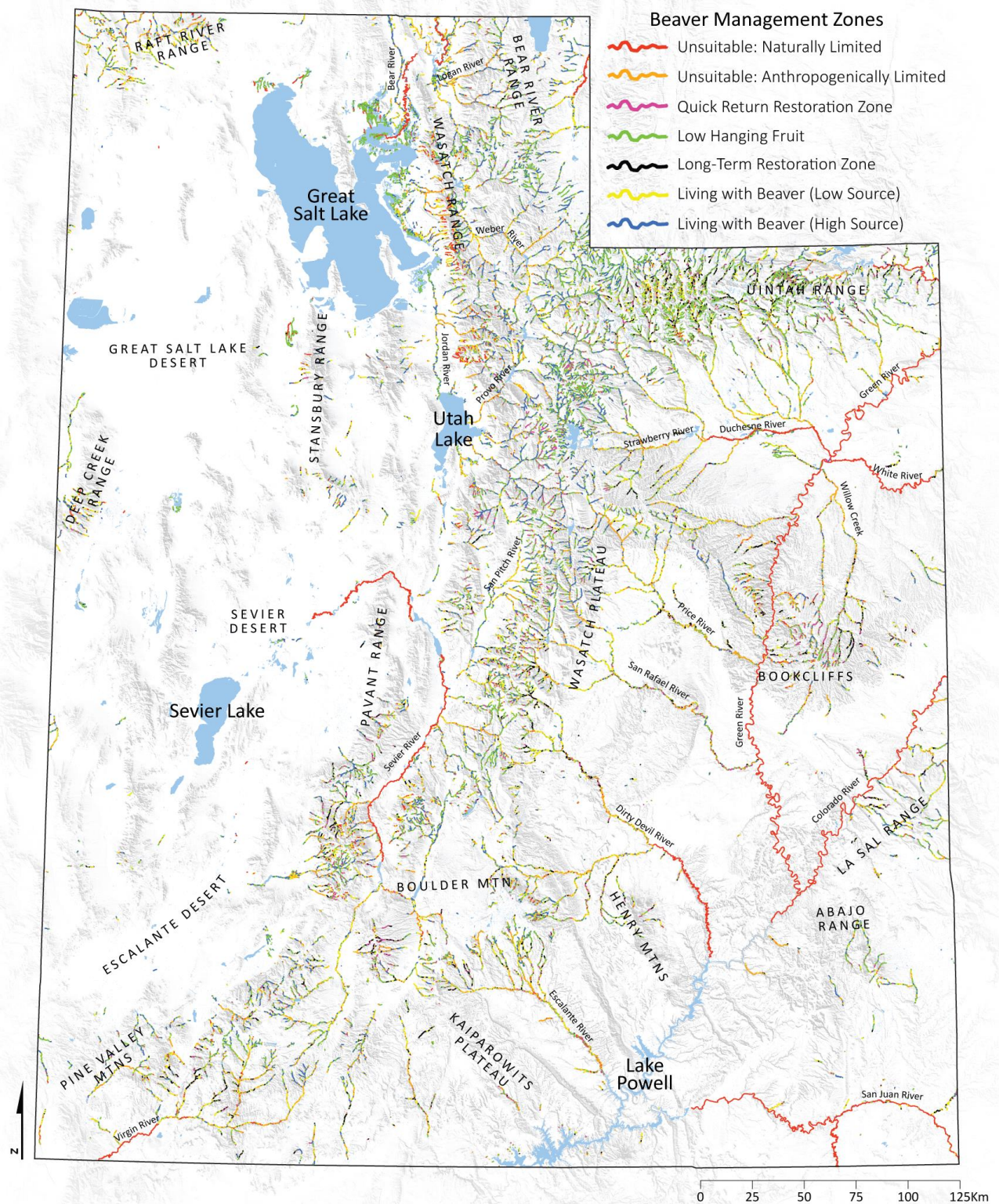
Figure 15 – Preliminary Utah statewide example output of first-cut beaver management zones.
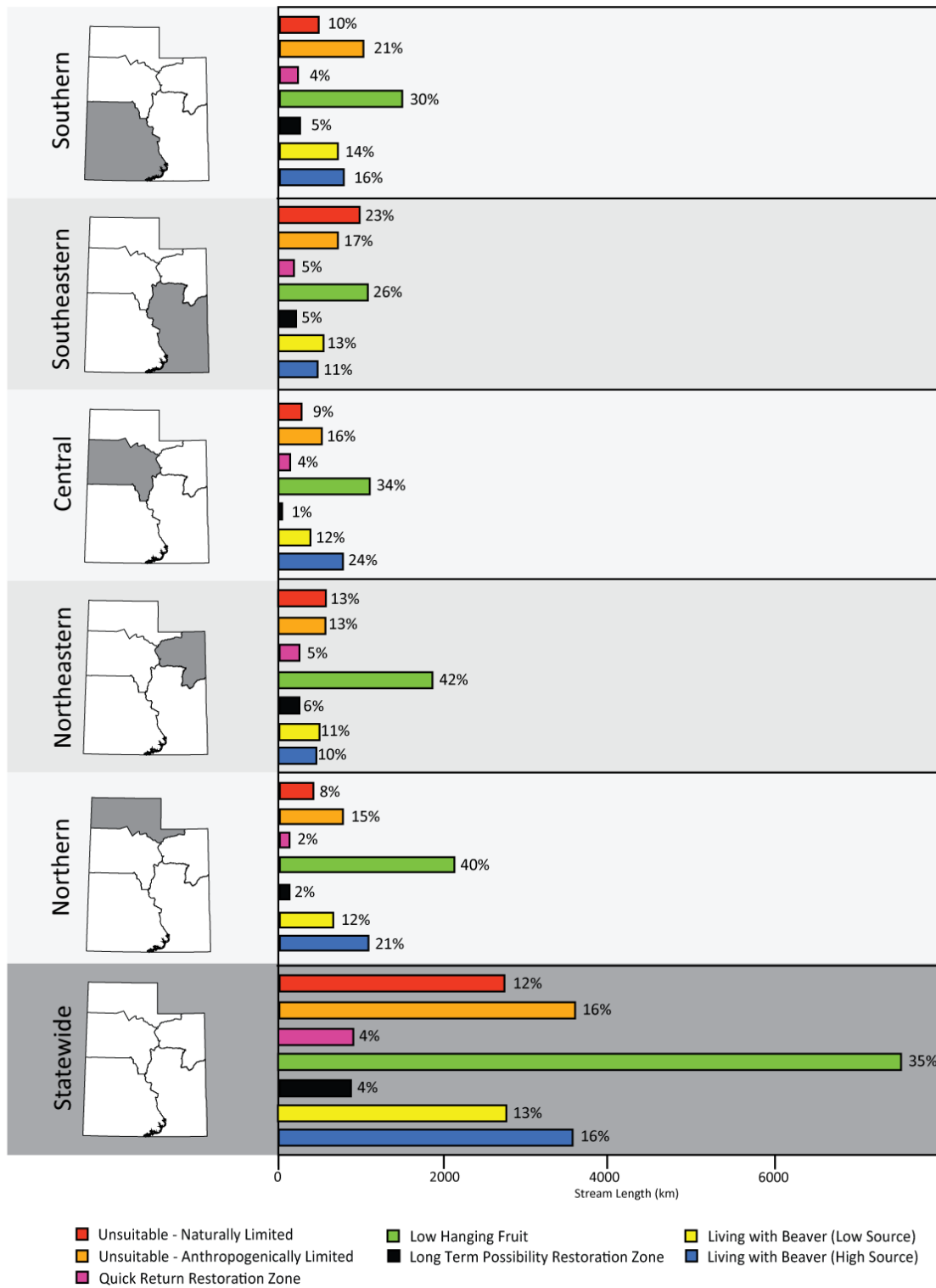
Figure 16 – Preliminary Utah statewide summary distributions of example output of beaver management zones.

STATEWIDE SUMMARY COMPARISON

Figure 17 shows a map of the four statewide river classifications that make up the BRAT outputs. Most of the differences in capacity estimates from existing to historic are a result of an increase in the 'pervasive' category from 13% to 29% and a corresponding decrease in the 'occasional' category from 21% to 11% (Table 3).

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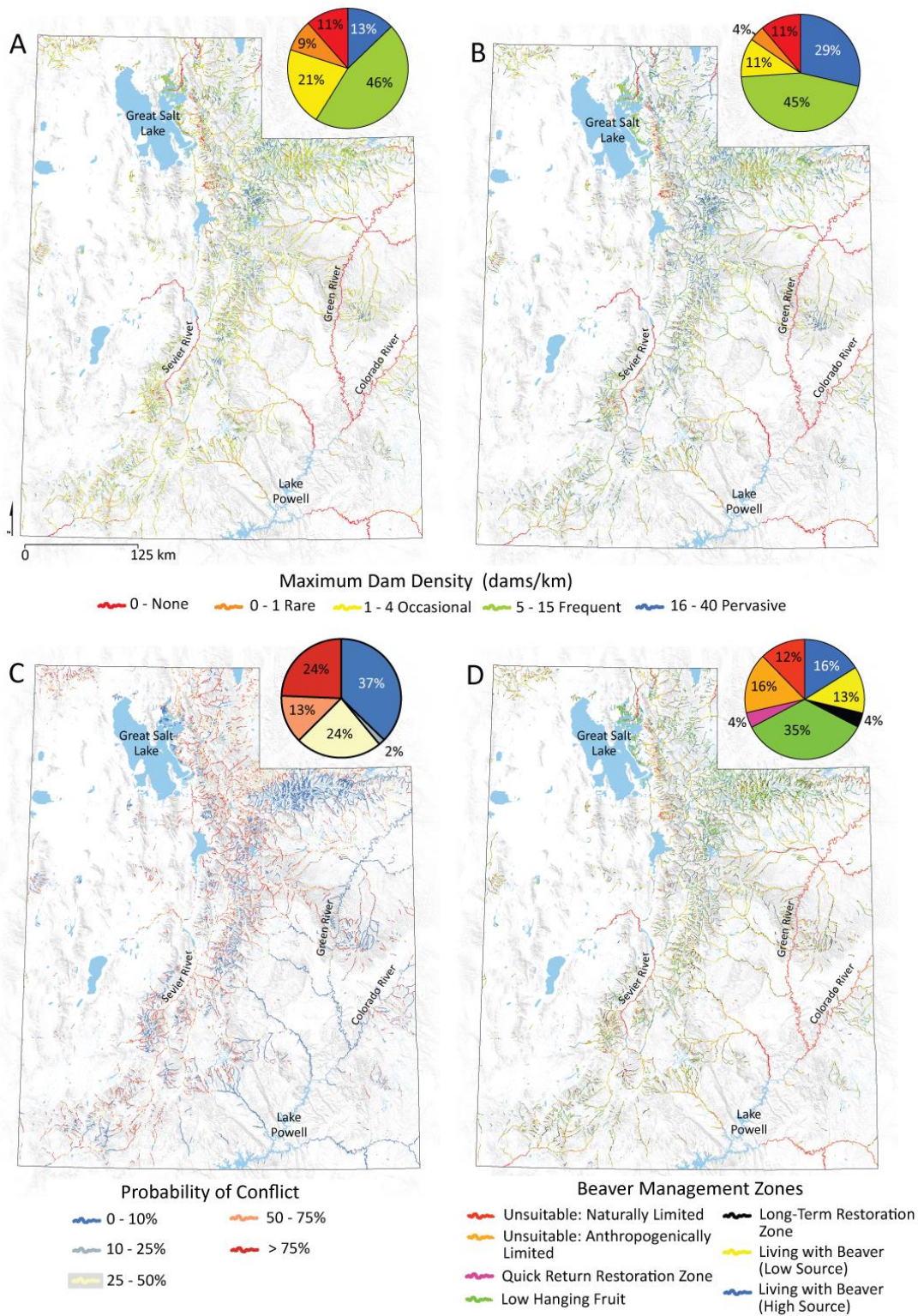
Figure 17 – Map of statewide BRAT outputs that includes A. existing beaver dam capacity, B. historic beaver dam capacity, C. probability of potential conflict, and D. beaver conservation and restoration zones (i.e., Beaver Management Zones).

SUMMARY BY UDWR REGIONS

Figure 14 and Figure 16 summarizes the conflict potential and first-cut of beaver management recommendations by UDWR region whereas Figure 18 and Figure 19 summarizes overall capacity estimates between existing and historic for each region.

The regional data illustrates that existing dam density is well distributed throughout the state with slightly higher proportional capacity in the Central and Northern regions (Figure 18). The Southern Region contains 22% percent of the stream network and provides 21% of the total statewide capacity. If the existing estimated capacity was obtained, this region could support 46,954 dams. The Southeastern region has the lowest proportional capacity providing only 14% of the total existing dam capacity while containing 19% of the stream network with an estimated capacity to support 31,716 dams. In contrast, the Central region is 15% of the network, but provides 18% of the total existing capacity at 40,189 dams. The Northeastern region is 20% of the total stream network and provides 20% of the total existing dam capacity or 45,655 dams. The Northern region has the most existing dam capacity of any region, as well as the highest proportional capacity. It contains 24% of the total stream network yet provides 28% of the total existing capacity for the state at 62,425 dams. One might argue that due to the higher proportional capacities in the Central and Northern regions that these regions should be beaver conservation and restoration focal areas. However, one might also argue that the southern regions should be the focal regions because they are currently at only about 1% of capacity compared to the Northern and Central regions that are at 13% and 16% of capacity respectively (see Figure 21). In reality, it appears that all regions of the state are ripe for beaver conservation and restoration.

The regional data illustrates that each region has the potential capacity to support significantly more pervasive beaver dam reaches than current vegetation can support (Figure 18). The Southern region has the most potential for riparian vegetation recovery. If the riparian vegetation in this region was fully restored to pre-European settlement conditions, the dam capacity could increase from 46,954 dams to 71,115 dams, a 51% increase. Such complete recovery is highly unlikely, due in part to, urbanization. Nevertheless, such recovery potential information can be useful to gauge how various riparian vegetation restoration might impact dam building capacity. The Southeastern, Central and Northern regions have the potential to increase dam capacity by approximately 45%, 38%, and 41% respectively. Whereas the riparian vegetation in the Northeastern region is least impacted and the potential increase if pre-settlement conditions were restored is only 30%. In summary, our data suggests that pre-European settlement riparian vegetation supported significantly more pervasive dam building and currently many of the historically pervasive reaches can only support rare or occasional

dam densities. Some of these streams likely have restoration potential while others are far less likely to recover due to land use pressures and other human induced limitations.
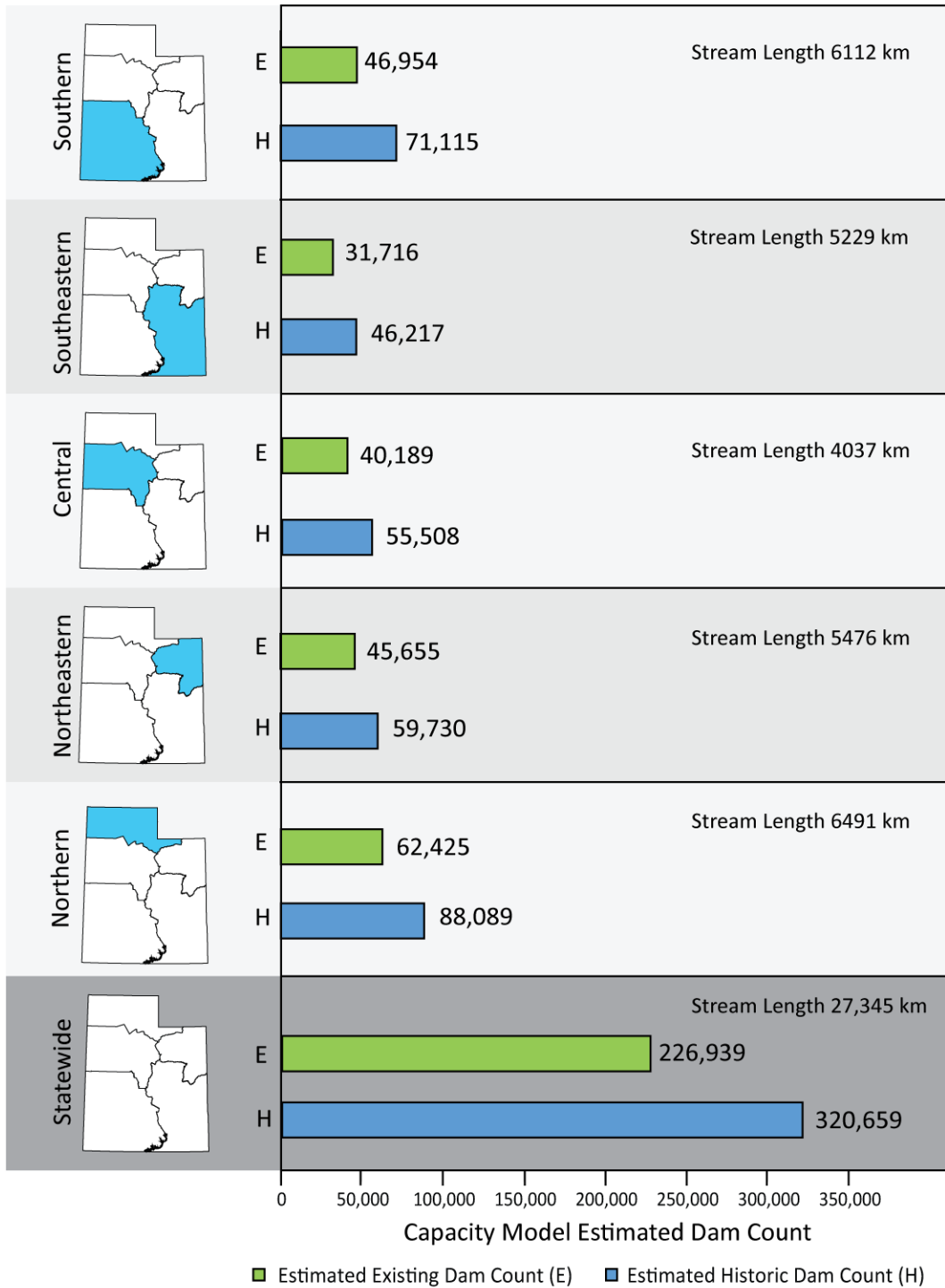
Figure 18 – Summary bar graphs showing the predicted existing and historic beaver dam capacity estimates at the UDWR Region and statewide level.
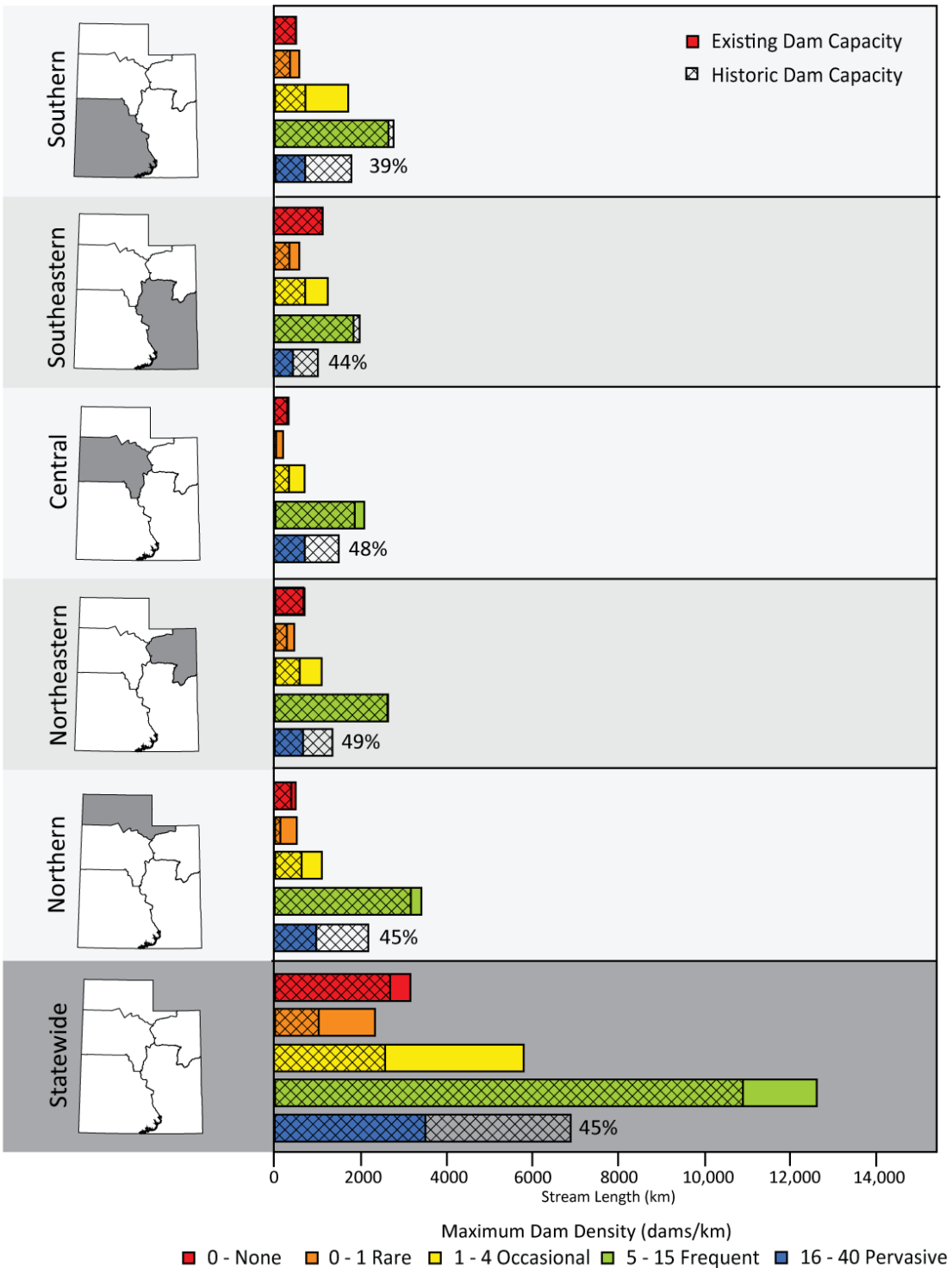
Figure 19 – Bar graph showing statewide and regional existing and historic dam density by category.

CENTRAL REGION

The Central Region (Figure 20), south and west of the Great Salt Lake, is dominated by high desert with the majority of the drainage network located in the eastern portion of the region. In this area, most of the predicted pervasive segments are also in high potential conflict areas (35%) corresponding with the urban communities located in the southern Wasatch Front. However, 34% of the region is characterized as 'Low-hanging Fruit' and 24% is identified as 'Living with Beaver' (High Source) zones. We suggest that these 'Low-hanging Fruit' and 'Living with Beaver' (High Source) reaches should be the focus of beaver conservation and management for this region.
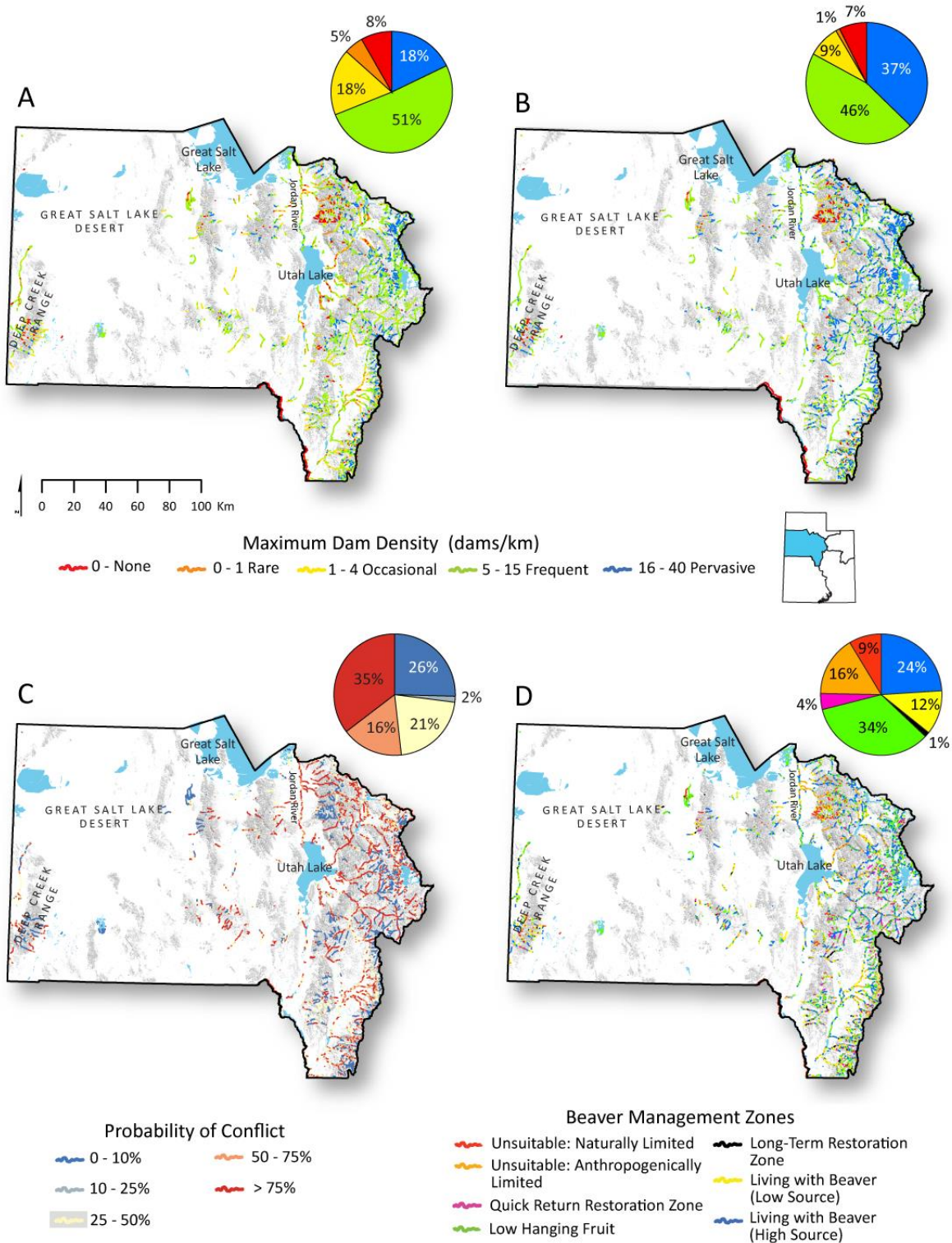
Figure 20 – Map showing BRAT output for the Central Region. A. is the existing capacity B. is historic capacity C. is probability of conflict and D. beaver conservation and restoration zones (i.e., Beaver Management Zones).

NORTHERN REGION

The Northern Region (Figure 21) contains the majority of the urban population yet is identified as having over 40% 'Low-hanging Fruit' and 33% 'Living with Beaver'. This region also has high historic pervasive dam capacity, with existing capacity estimated at 15% and historic capacity at 34%. The 'Living with Beaver' reaches should be managed with nuisance beaver strategies, the 'Low-hanging Fruit' reaches should be utilized as sink areas for nuisance beaver and the reaches with the potential for pervasive dam building should be restored in this region.
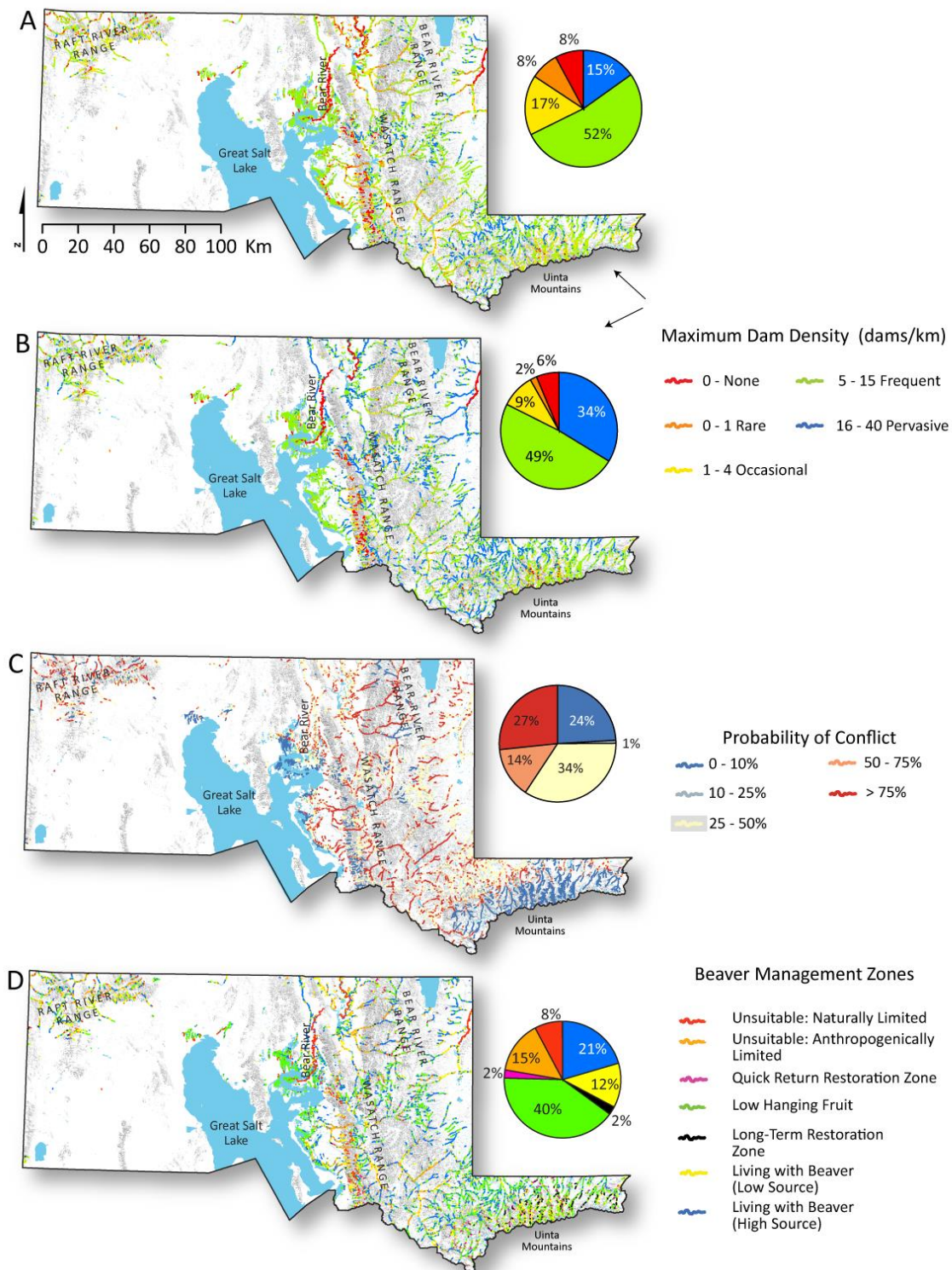
Figure 21 – Map showing BRAT output for the Northern Region. A. is the existing capacity B. is historic capacity C. is probability of conflict and D. beaver conservation and restoration zones (i.e., Beaver Management Zones).

NORTHEASTERN REGION

The Northeastern Region (Figure 22) contains the High Uinta Wilderness and has over 51% very low conflict, suggesting this area may be ideal to promote pervasive beaver dam building activities. The region is the least anthropogenically limited with over 42% characterized as 'Low-hanging Fruit'. Besides potential conflicts associated with Uinta Basin communities, dam building beaver are only limited by the stream power of the Duchesne and Green river.
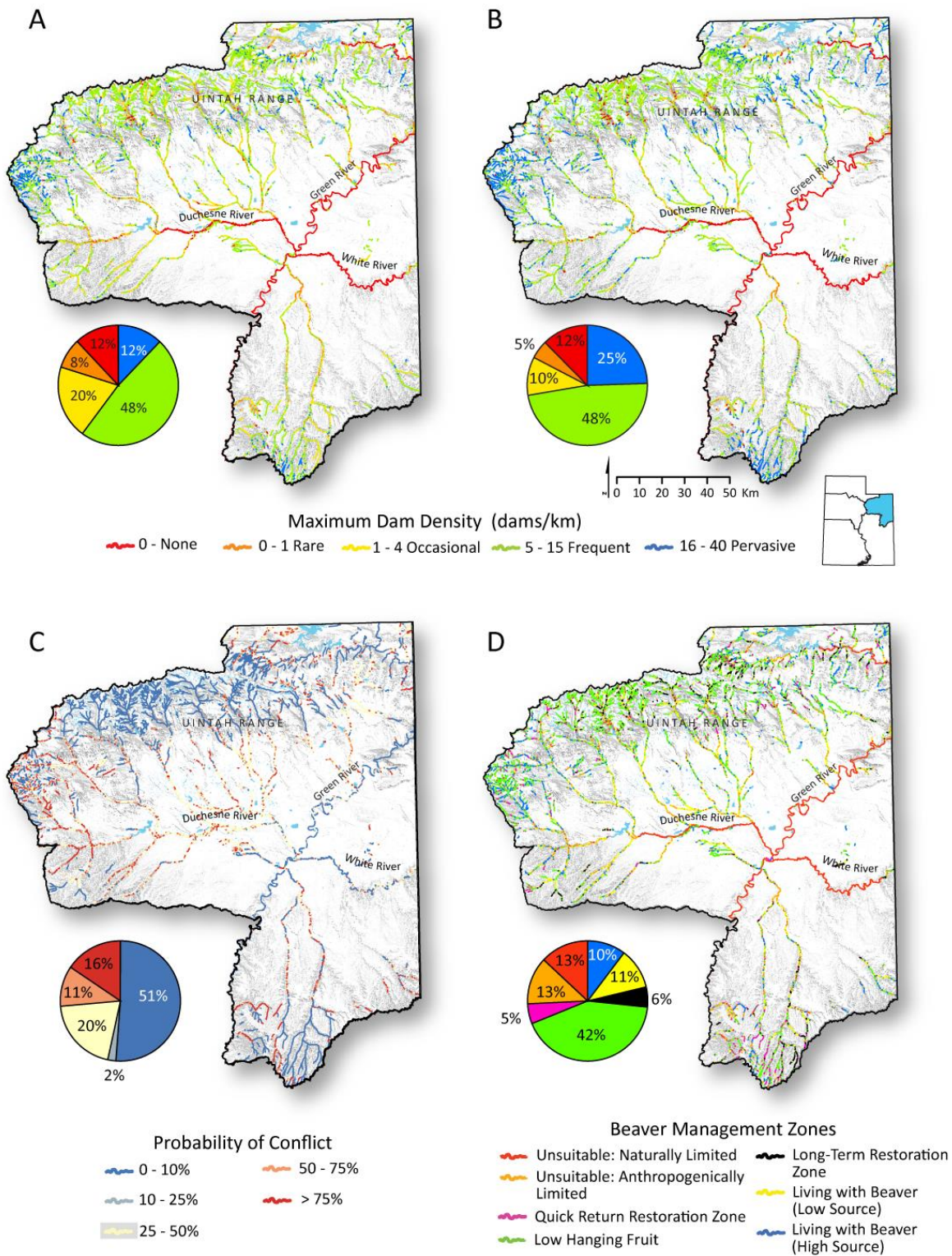
Figure 22 – Map showing BRAT output for the Northeastern Region. A. is the existing capacity B. is historic capacity C. is probability of conflict and D. beaver conservation and restoration zones (i.e., Beaver Management Zones).

SOUTHERN REGION

The Southern Region (Figure 23) is characterized by over 35% very low conflict (0 – 10%) and 30% 'Low-hanging Fruit' streams. The model also suggests that 'historic' beaver dam building capacity in this region could increase from 11% to 29% in the pervasive category. These data suggests that, with innovative resource management strategies and native riparian vegetation restoration projects, there is a high potential for beaver reintroduction in key areas.
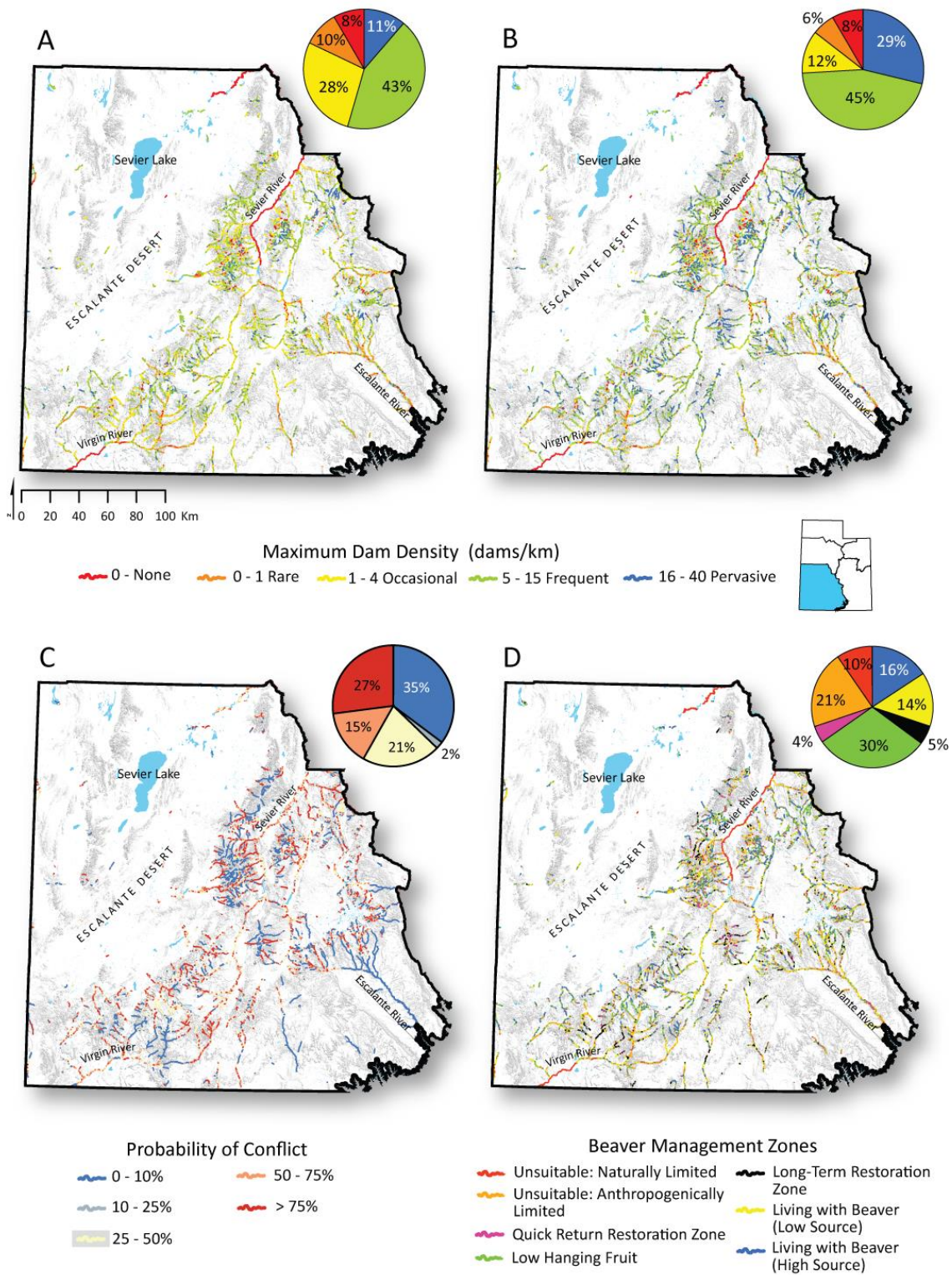
Figure 23 – Map showing BRAT output for the Southern Region. A. is the existing capacity B. is historic capacity C. is probability of conflict and D. beaver conservation and restoration zones (i.e., Beaver Management Zones).

SOUHEASTERN REGION

The Southeastern Region (Figure 24) is characterized by large rivers with high enough stream powers to have over 22% 'no' capacity, with 23% of the region being categorized as 'Naturally limited'. However, over 51% of the region is predicted as having very low conflict allowing for dam building beaver to likely exist without human interference. The model shows that most of the pervasive stream segments are located in the upper San Rafael and Price watersheds with these areas also being predicted as low probability of potential conflict suggesting that the streams in these areas should be investigated further for potential beaver conservation and/or reintroduction.

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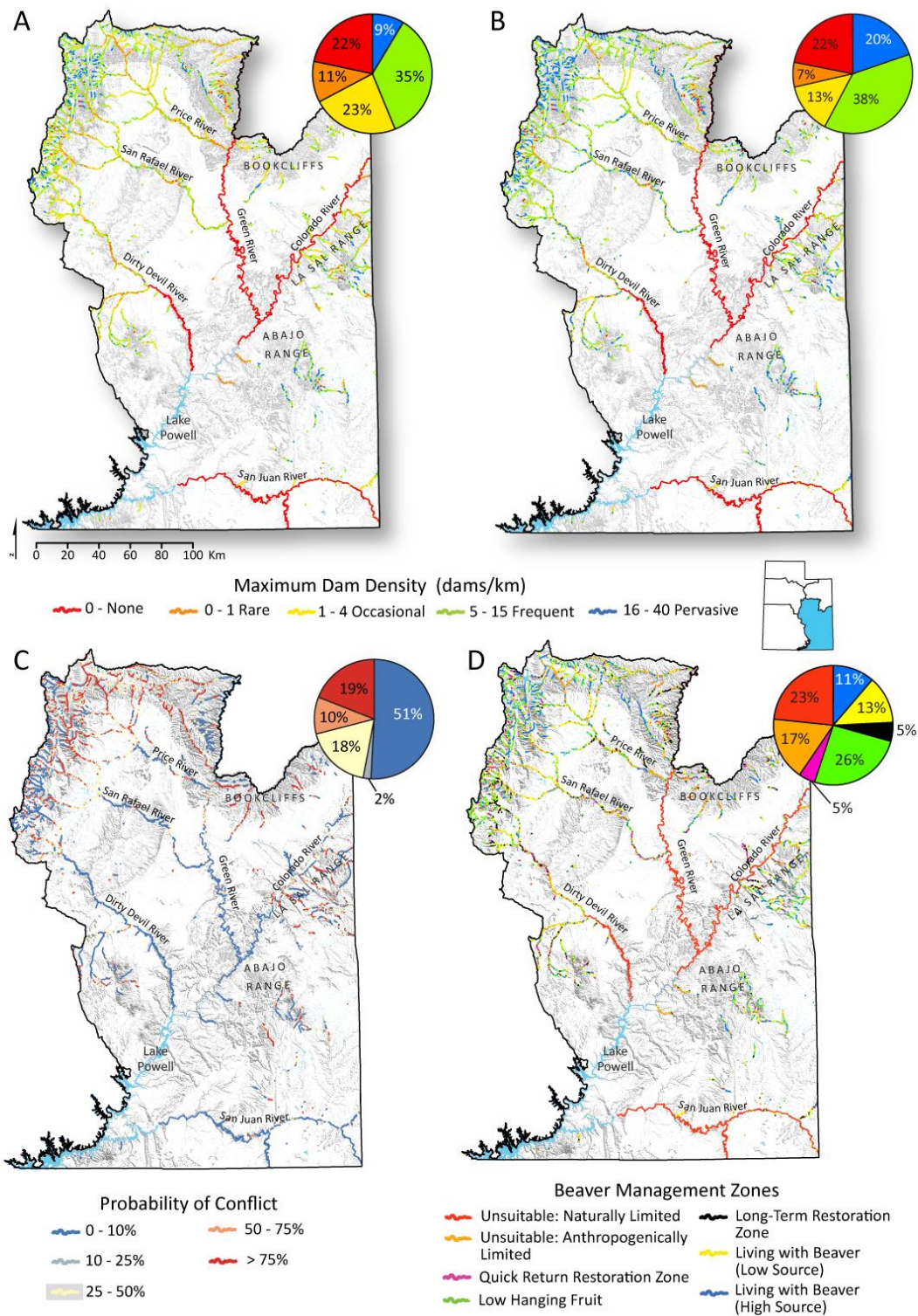
Figure 24 – Map showing BRAT output for the Southeastern Region. A. is the existing capacity B. is historic capacity C. is probability of conflict and D. beaver conservation and restoration zones (i.e., Beaver Management Zones).

MODEL VERIFICATION

Three forms of model verification were used to assess the performance of the capacity model.

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

ARE SPATIAL PREDICTIONS COHERENT AND LOGICAL?

We use examples from each of the four diverse validation watersheds to ascertain whether the model predictions are coherent and logical. The watersheds represent 3425 kilometers of the 27,345 kilometers of rivers and streams analyzed (i.e. 12.5%) and we identified 2852 dams within them. For each watershed, we highlight the contrast between existing and historic capacity predictions, the number and location of existing beaver dams, and we then highlight what the patterns look like in some specific representative reaches.

LOGAN/LITTLE BEAR WATERSHED

The Logan/Little bear watershed is located in north central Utah and drains the *Wasatch Montane Zone* ecoregion of the Bear River Range into the *Cache Valley* ecoregion (Woods et al., 2001). Figure 25 shows existing capacity, historic capacity, and actual dam counts for the Logan/Little Bear watershed in the Northern region. In the Utah portion of the watershed, a total of 1141 dams were counted. These dams are concentrated in the mountainous region of the watershed, only a few dams were identified in Cache Valley. The existing capacity estimates 6919 dams watershed-wide; therefore, the Logan/Little Bear watershed is currently at 16% of total existing capacity. In Franklin Basin (Figure 25– part a), the existing capacity estimate is underlying the actual dam counts for the segment. This shows that the capacity model is effectively identifying all categories of dam densities (none, rare, occasional, frequent and pervasive). Table 5 shows Logan/Little Bear watershed beaver dam summary statistics.

Figure 26 shows Temple Fork a tributary to the Logan River. This figure illustrates that the spatial patterns the model produces make sense and resemble what we see on-the-ground. Using surveys from Lokteff et al. (2013), areas predicted as not able to support beaver on the Logan and Temple Fork are areas where we do not see active dams nor historic evidence of dams (either too steep and too much stream power, or devoid of suitable vegetation). Most of Temple Fork and Spawn Creek supports 'occasional' to 'frequent' dams, and we see precisely this - occasional to frequent dam densities. This pattern is limited primarily by the lack of extensive riparian vegetation or aspen owing to a long history and continuing practice of heavy cattle grazing on Temple Fork. A cattle exclosure fence was installed in 2005 around the Spawn

Creek tributary as part of a passive restoration strategy, and riparian vegetation is slowly recovering (Hough-Snee et al., 2013). Several new dams have been constructed in the 'frequent' dam density lower portion of Spawn Creek over the past three years, most likely by beaver dispersing downstream from a larger colony upstream. In the middle of Spawn Creek is an area flanked by extensive abundant aspen forests that has supported multiple stable colonies and between 8 and 20 (currently 14) active dams in an area less than 0.5 kilometer in length since at least the 1950s. These exact reach segments were predicted as being able to support 'pervasive' dam densities. On Temple Fork, where grazing is still permitted, there are currently roughly 14 beaver dams in the three km upstream from the Spawn Creek confluence (4.6 dams/km). Along this three km reach our model predicted a mixture of 'occasional', 'frequent' and 'pervasive' beaver dams densities and this is precisely what is found on the ground illustrating that the model sufficiently identified these various supplies of preferred food and building material, and changes in stream power that allow various levels of dam building to exist.

Table 5 – Existing number of dams and BRAT modeled capacity estimates for Logan/Little Bear Watershed.

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	17.8	3%	0	0	0.00	0.0	0%	0.00
Rare	76.4	11%	8	21	0.30	0.3	38%	0.06
Occasional	105.3	15%	103	270	1.30	2.5	38%	0.60
Frequent	389.4	56%	675	4002	1.90	10.3	17%	1.06
Pervasive	112.1	16%	355	2626	3.30	23.8	14%	1.95
Total	**701.0**	**NA**	**1141**	**6919**	**1.63**	**9.9**	**16%**	**NA**
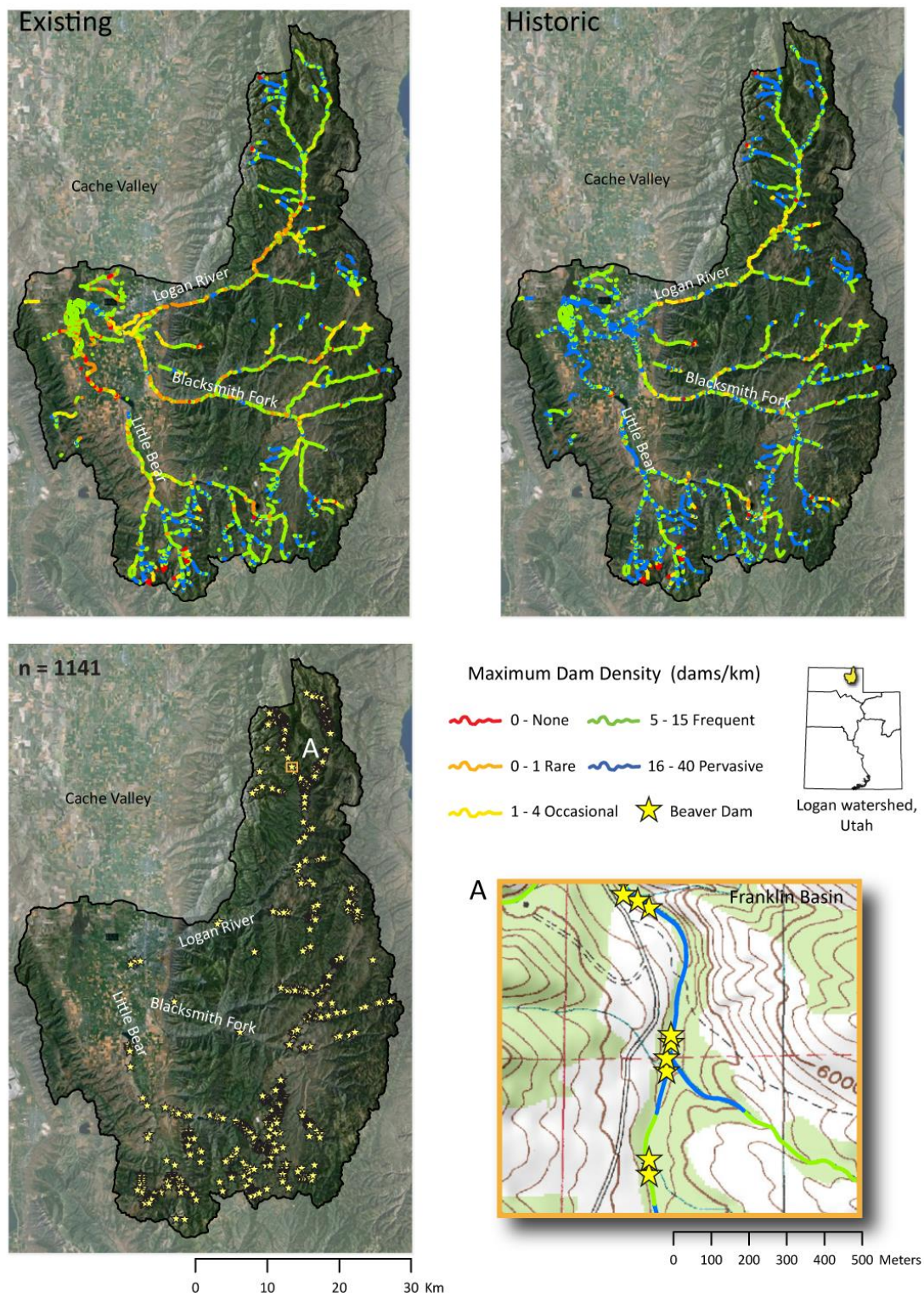
Figure 25 – Map showing the Logan/Little Bear watershed with existing capacity estimates, historic capacity estimates, and actual beaver dam counts.

Figure 26 – Example of verification of capacity model peformance in the Temple Fork wateshed (tributary to Logan River). Individual beaver dams are denoted with yellow stars, whereas dam complexes are shown in circles (number in circle is count of dams) in discrete segments.

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FREMONT WATERSHED

The Fremont watershed is located in south central Utah and drains the *High Plateaus* ecoregion of the Wasatch Plateau and then carves through the *Shale Deserts* and *Semiarid Benchalnds and Canyonlands* ecoregions (Woods et al., 2001). Figure 27 shows the contrast between existing and historic capacity, and actual dam counts for the Fremont watershed which stretches between the Southern and Southeastern UDWR regions. Only 52 dams were identified and were limited to the northwestern corner of the watershed (near Fish Lake) in the *High Plateaus* (Table 6)., whereas the existing capacity estimate for the watershed was 5,945, revealing that less than 1% of the existing capacity is being utilized by dam building beaver. It appears that beavers have been 'eliminated' from the remaining watercourses of the watershed. We predict that, with improved social attitudes towards beaver along with additional pro-beaver resource management, dam-building beaver could thrive in this watershed. Figure 27a shows that the existing capacity model correctly identified areas where an occasional beaver dam exists among many segments identified as rare, where no beaver dams currently exist in the stream segment. Figure 27b shows the capacity model worked well to identify frequent and pervasive beaver dams in the watershed. Table 6 shows Fremont watershed beaver dam summary statistics.

Figure 28 is an example from U M Creek in the Fremont watershed confirming that the spatial dam density patterns from the capacity model accurately depict dam densities and resemble what we see on-the-ground. The model accurately differentiated the reach where 10 actual dams exist as a 'pervasive' density reach. Compared to the surrounding upstream and downstream reaches, these reaches boast a supply of willow within the 30 m buffer and aspen extends throughout the 100 m buffer. This illustrates that the model correctly identified this abundant supply of preferred food and building material, and predicted what is actually found within the reach—pervasive dam densities.

Table 6 – Existing number of dams and BRAT modeled capacity estimates for Fremont watershed.

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	19.4	3%	0	0	0.00	0.0	0%	0.00
Rare	141.1	18%	0	41	0.00	0.3	0%	0.00
Occasional	205.6	26%	5	531	0.03	2.6	1%	0.36
Frequent	313.6	40%	14	3129	0.04	10.0	0%	0.67
Pervasive	97.2	13%	33	2246	0.30	23.3	1%	5.07
Total	**777.0**	**NA**	**52**	**5947**	**0.07**	**7.7**	**1%**	**NA**

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Figure 27 – Map showing the Fremont watershed with existing capacity estimates, historic capacity estimates, and actual beaver dam counts.

Figure 28 – Example of verification of capacity model peformance on U M Creek in the Fremont watershed. Individual beaver dams are denoted with yellow stars. The figure illustrates how the capacity model has effectively captured a high dam density reach.

PRICE WATERSHED

The Price watershed is located in eastern Utah with headwaters in the *Escarpment* ecoregion and trunk streams that carves through the *Shale Deserts* and *Semiarid Benchlands and Canyonlands* ecoregions (Woods et al., 2001). Figure 29 shows existing capacity, historic capacity, and actual dam counts for the Price watershed. The Price watershed includes a small portion of the Central region but is mostly contained in the Southeastern region. Only 89 dams were identified and were limited to a few isolated streams (Table 7). Like in the Fremont, it appears that beavers have been 'eliminated' from the remaining portions of the watershed. The existing capacity estimate for the watershed was 7,688, revealing that only 1% of the existing capacity is being utilized by dam building beaver. As previously stated for the Fremont we believe as social attitudes towards beaver improve along with more pro-beaver resource management, dam-building beaver populations will also significantly increase in this watershed. Figure 29a shows that the existing capacity model appears to have correctly identified on-the-ground dam density patterns and highlights that the model effectively identified an area where beaver are colonizing the 'pervasive' stream segment. Table 7 shows Price watershed beaver dam summary statistics.

Figure 30 depicts Grassy Trail Creek in the Price watershed. This creek also confirmed that the spatial dam density patterns are coherent and logical and match what is found on-the-ground. This example shows a desert riverscape with marginally suitable vegetation in a narrow band along the banks of the creek; the model identifies this area as being able to support 'occasional' dam densities (2-4 dams/km). This illustrates that the model sufficiently identified a limited supply of food and building material, and accurately modeled the 'occasional' dam densities along this creek. This example contrasts sharply with the reaches that have expansive riparian and adjacent upland forests with desirable woody browse and building materials (e.g. aspens) which allow for 'pervasive' dam densities (see Figure 28).

Table 7 – Existing number of dams and BRAT modeled capacity estimates for Price watershed.

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	2.5	0%	0	0	0.00	0.0	0%	0.00
Rare	49.8	5%	2	37	0.01	0.3	5%	0.17
Occasional	154.1	16%	19	733	0.06	2.7	3%	0.77
Frequent	499.6	52%	41	4458	0.08	9.6	1%	0.96
Pervasive	259.2	27%	27	2641	0.20	22.8	1%	2.71
Total	**965.2**	**NA**	**89**	**7869**	**0.09**	**8.2**	**1%**	**NA**

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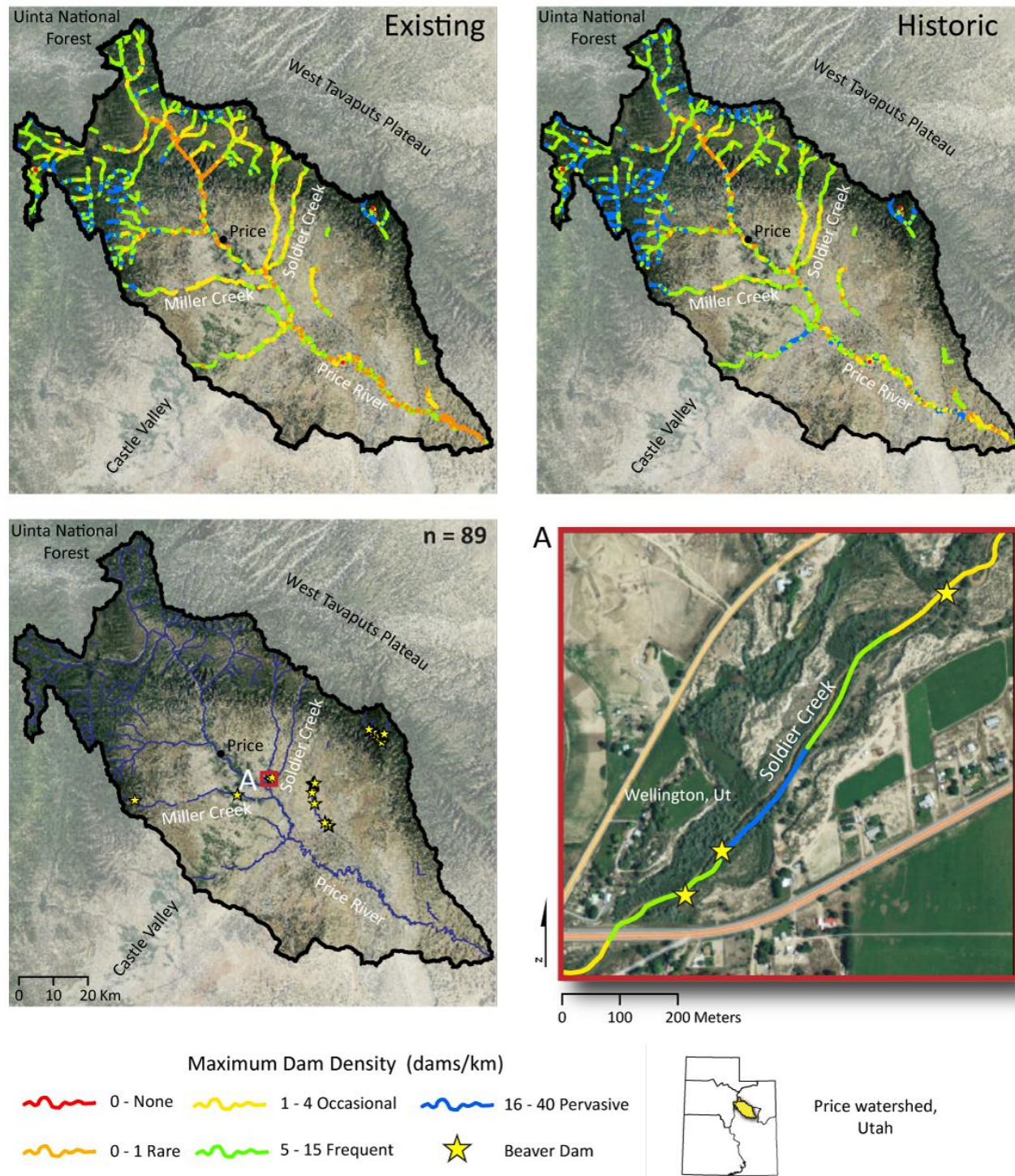
Figure 29 – Map showing the Price watershed with existing capacity estimates, historic capacity estimates, and actual beaver dam counts.
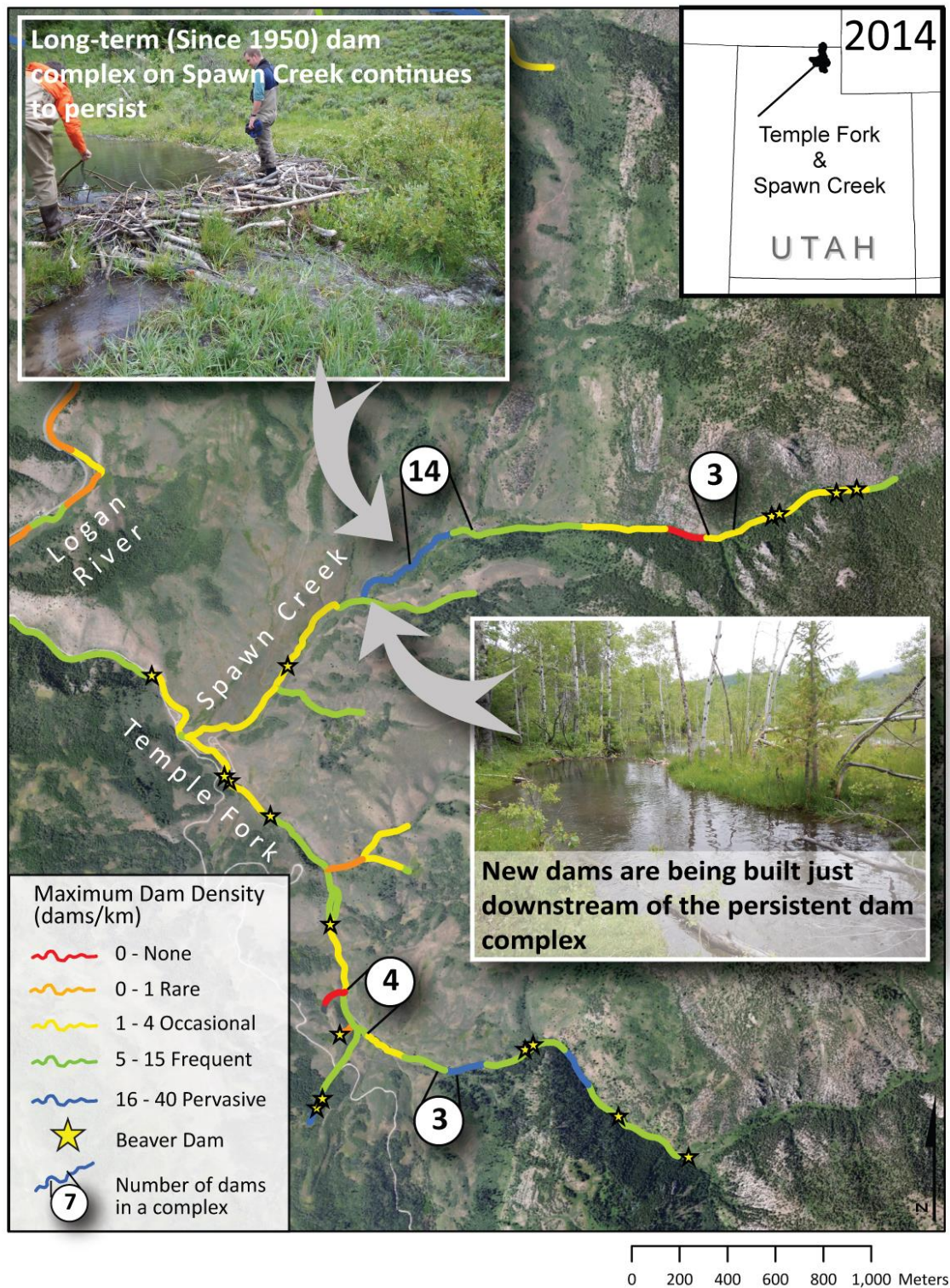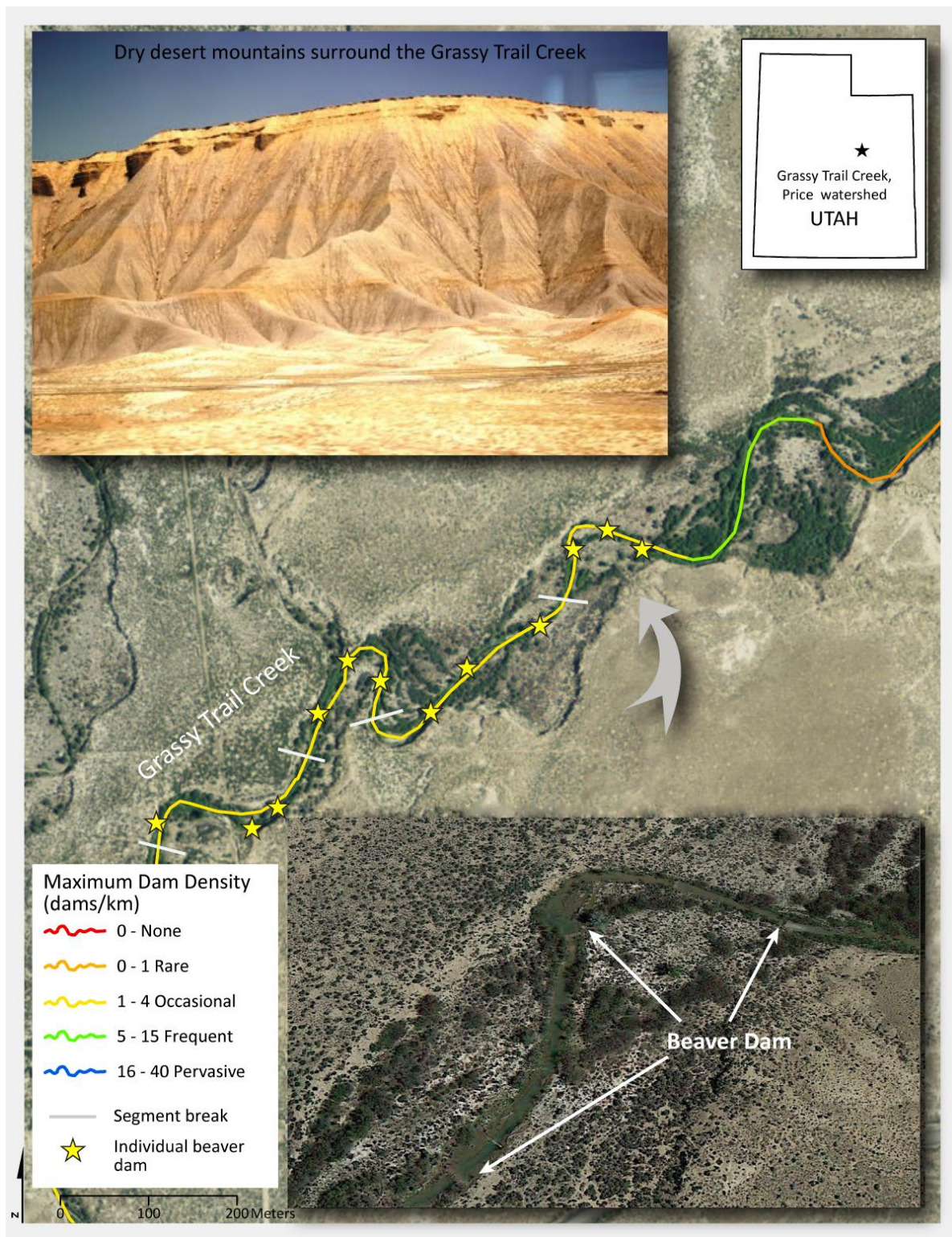
Figure 30 – Example of verification of capacity model peformance on Grassy Trail Creek in the Price watershed. Individual beaver dams are denoted with yellow stars. This figure illustrates how the capacity model has effectively captured occasional dam densities.

STRAWBERRY WATERSHED

The Strawberry Watershed is located in central Utah and drains the *Wasatch Montane Zone* and *Semiarid Foothills* ecoregions before flowing through the *Semiarid Benchalnds and Canyonlands* ecoregions (Woods et al., 2001). Figure 31 shows existing capacity, historic capacity, and actual dam counts for the Strawberry watershed. The Strawberry Watershed is in the Northeastern region. A total of 1,570 dams were identified in the Google Earth-based census, the highest amount recorded of the four watersheds (Table 8). These dams are distributed fairly evenly across the watershed. The existing capacity is 11,804 dams therefore; the watershed is currently at 13% of existing capacity. This watershed has the potential to support a high number of 'pervasive' dams. Figure 31a shows that the capacity model is effectively identifying, frequent and pervasive dam density reaches. Table 6 shows Strawberry watershed beaver dam summary statistics.

Figure 32 is of Mud Creek in the Strawberry Watershed. This example shows that the model differentiated the reach in the center of the photo from neighboring reaches as being able to support 'pervasive' dam densities (16-30 dams/km). Compared to the surrounding upstream and downstream reaches predicted to support 'frequent' dam densities (5-15 dams/km). The center 'pervasive' reach boasts a supply of willow and aspen within the 30 m buffer which extends throughout the 100 m buffer whereas the upstream and downstream reach have a narrower riparian corridor and a less extensive supply of preferred building material. This illustrates that the model sufficiently identified this abundant supply of preferred food and building material, and predicted what is found on-the-ground—very high dam densities where preferred material is extensive and lower dam densities where preferred material is less extensive.

Table 8 – Existing number of dams and BRAT modeled capacity estimates for Strawberry watershed.

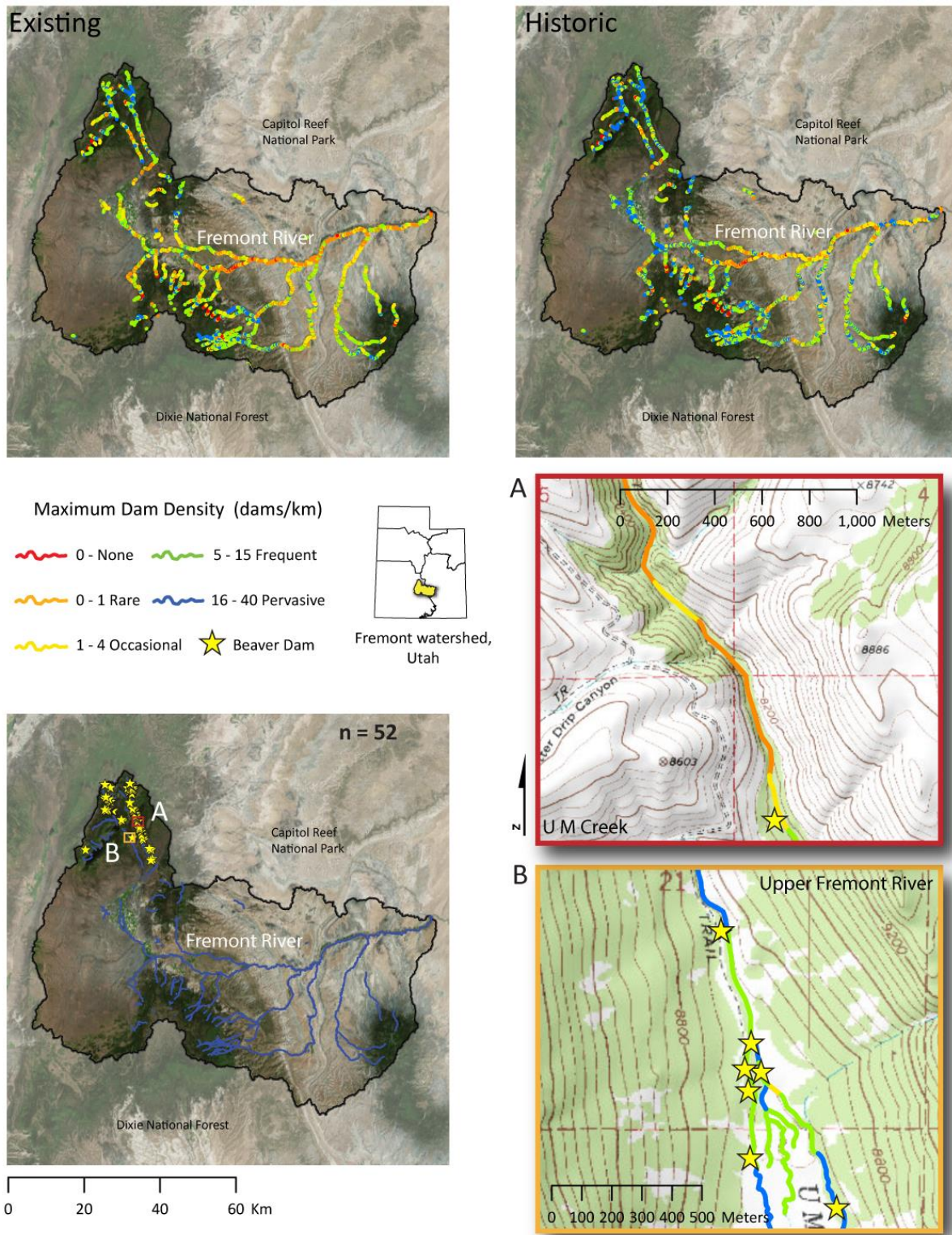| Segment Type	Stream Length	% of Drainage Network	Surveyed Dams	BRAT Estimated Capacity	Average Surveyed Dam Density	Average BRAT Predicted Capacity	% of Modeled Capacity	Electivity Index
	km	%	# of dams	# of dams	dams/km	dams/km	%	
None	9.5	1%	0	0	0.00	0.0	0%	0.00
Rare	127	13%	8	15	0.10	0.3	53%	0.10
Occasional	271	28%	110	412	0.70	2.7	27%	0.44
Frequent	466	47%	867	5117	1.60	10.3	17%	1.07
Pervasive	109	11%	585	6260	2.30	24.3	9%	1.40
Total	**982**	**NA**	**1570**	**11804**	**1.60**	**12.02**	**13%**	**NA**
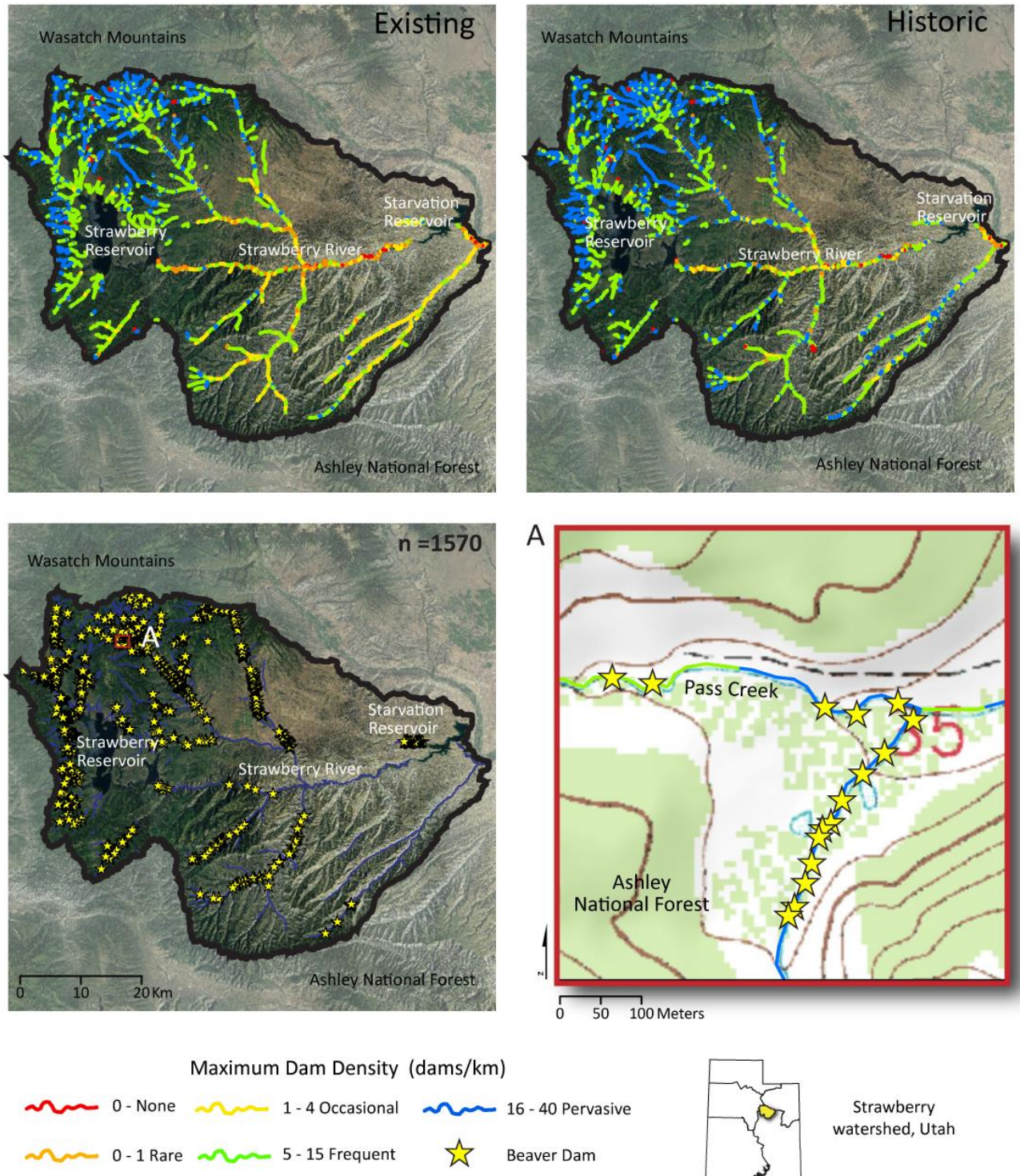
Figure 31 – Map showing the Strawberry watershed with existing capacity estimates, historic capacity estimates, and actual beaver dam counts.
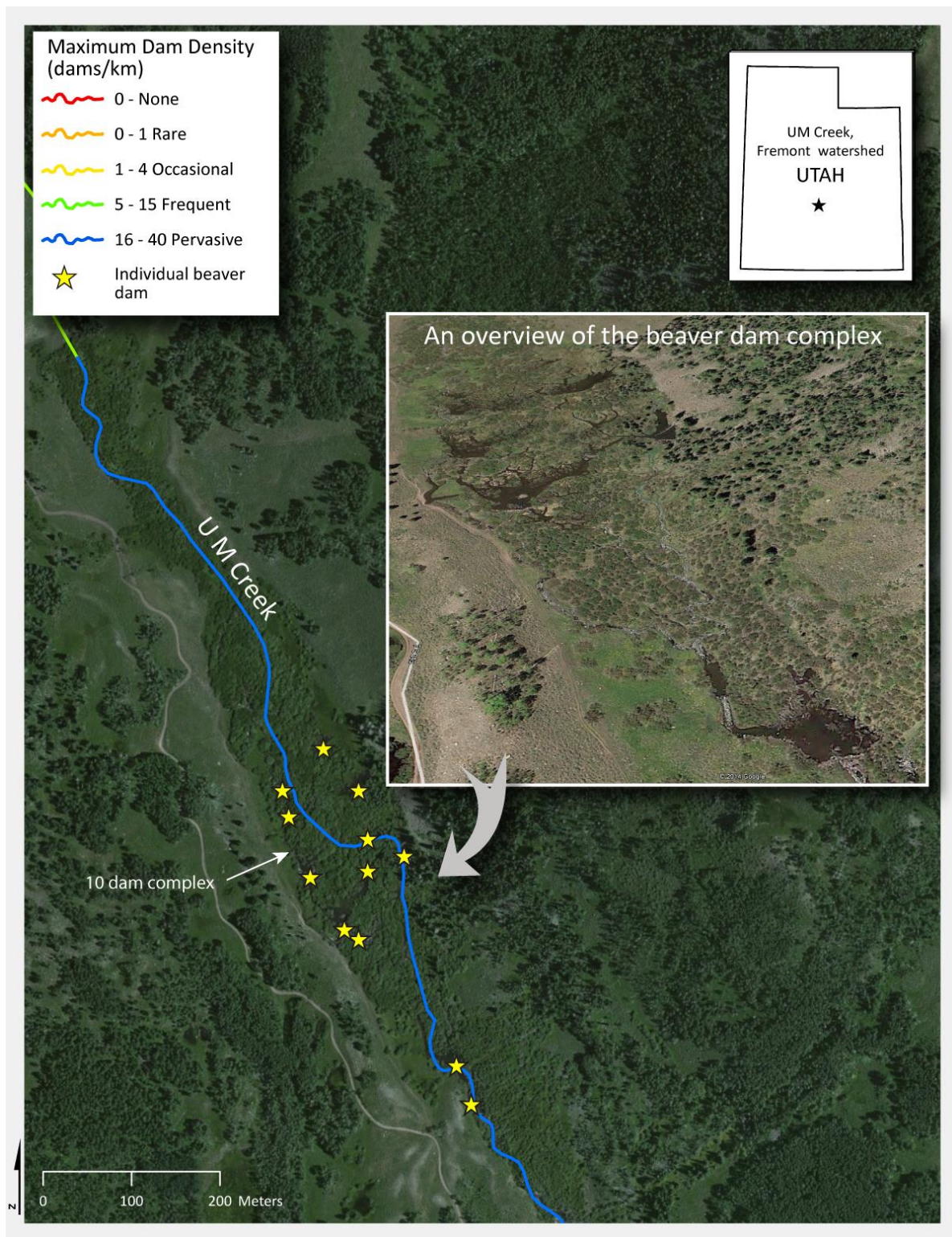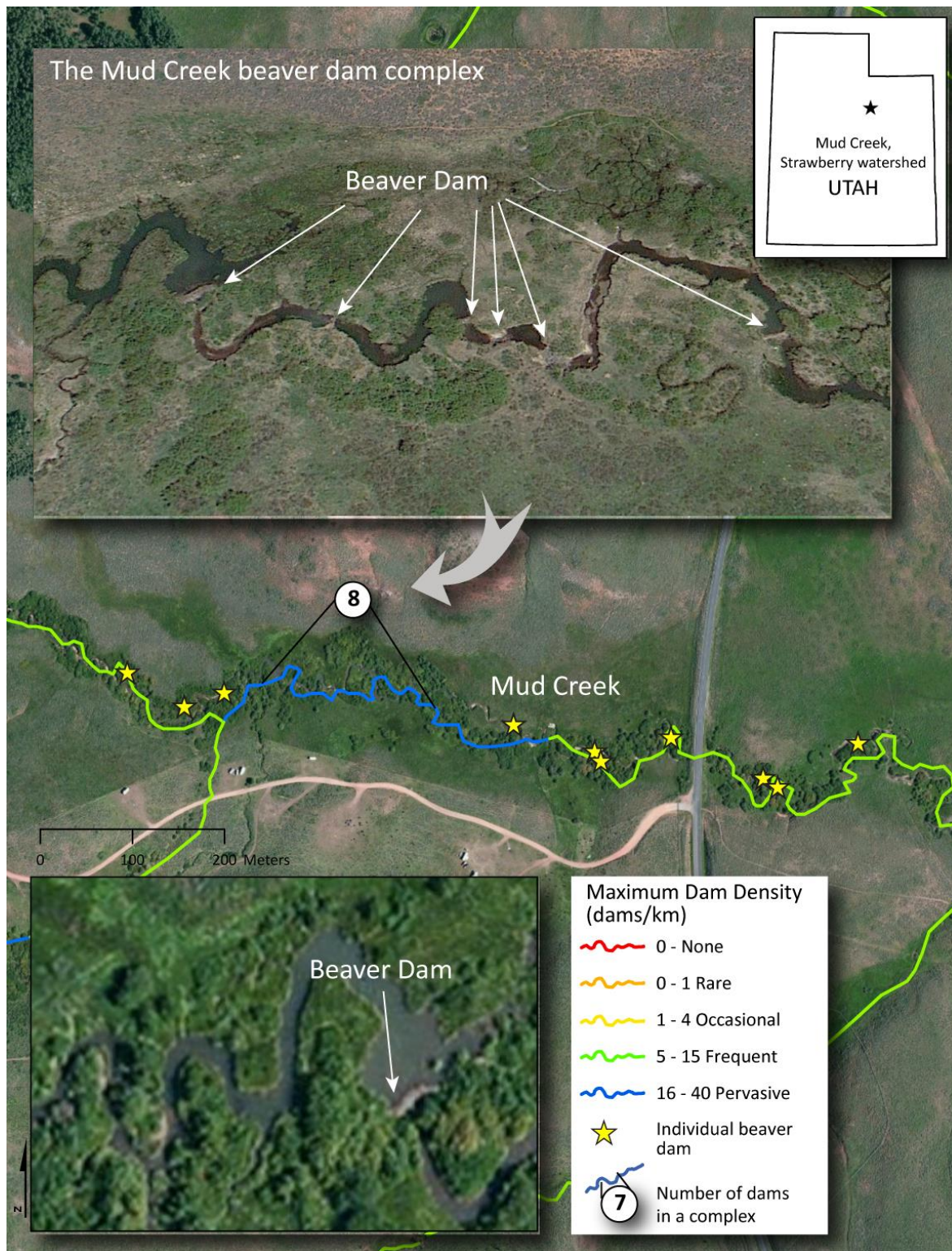
Figure 32 – Example of verification of capacity model peformance on Mud Creek in the Strawberry watershed. Individual beaver dams are denoted with yellow stars, whereas dam complexes are shown in circles (number in circle is count of dams) in discrete segments. The figure illustrates how the model has effectively differentiated pervasive and frequent dam densities reaches.

HOW DO DAM DENSITIES TRACK BETWEEN PREDICTED AND ACTUAL?

To help place the capacity model estimates and validation exercises in context, it is useful to contrast the actual and BRAT capacity predicted dam densities and look at what percent of capacity is actually achieved. The highest percent of model capacity is found in the Logan at 16%, with the Strawberry close behind at 13% (Table 9). By contrast, the Price and Fremont watersheds only have 1% of the dams their modeled capacity would suggest. Thus the average across the four verification watersheds is 9% of capacity. Actual surveyed dam densities in the Price and Fremont over their entire perennial networks are both 0.1 dams/km (clearly in *rare* category) and their predicted capacities are frequent at 8.2 and 7.7 dams/km respectively. Both the Strawberry and Logan have average surveyed dam densities of 1.6 dams/km (in the *occasional* category) and have BRAT predicted capacities of 9.9 and 12.0 dams/km respectively.

Table 9 – Summary of observed number of dams versus predicted capacity estimates for the four verification watersheds.

| Segment Type	Stream Length	Surveyed Dams	BRAT Estimated Capacity	Average Surveyed Dam Density	Average BRAT Predicted Capacity	% of Modeled Capacity
	km	# of dams	# of dams	dams/km	dams/km	%
Price	965.2	89.0	7,869	0.1	8.2	1%
Fremont	777.0	52.0	5,947	0.1	7.7	1%
Strawberry	981.9	1,570.0	11,804	1.6	12.0	13%
Logan	701.0	1,141.0	6,919.0	1.6	9.9	16%
Total	3,425.1	2852	32,539	0.83	9.5	9%

Figure 33 graphically conveys some of the same summary information as Table 9, but also provides the historic estimates and contrasts the reach-averaged dam density (i.e. dam density in reaches with beaver dams) to the network averaged dam density reported in Table 9. Figure 33 shows that reach averaged dam densities are fairly consistent between 9 and 14 dams/km across all four watersheds, whereas network averaged dam density is quite high (1.4 dams/ km) in two watersheds and quite low in the other two (0.1 dams/km). This suggests that beaver are locally building dams and establishing dam complexes and colonies regardless of how high or low the overall dam numbers are in a watershed.
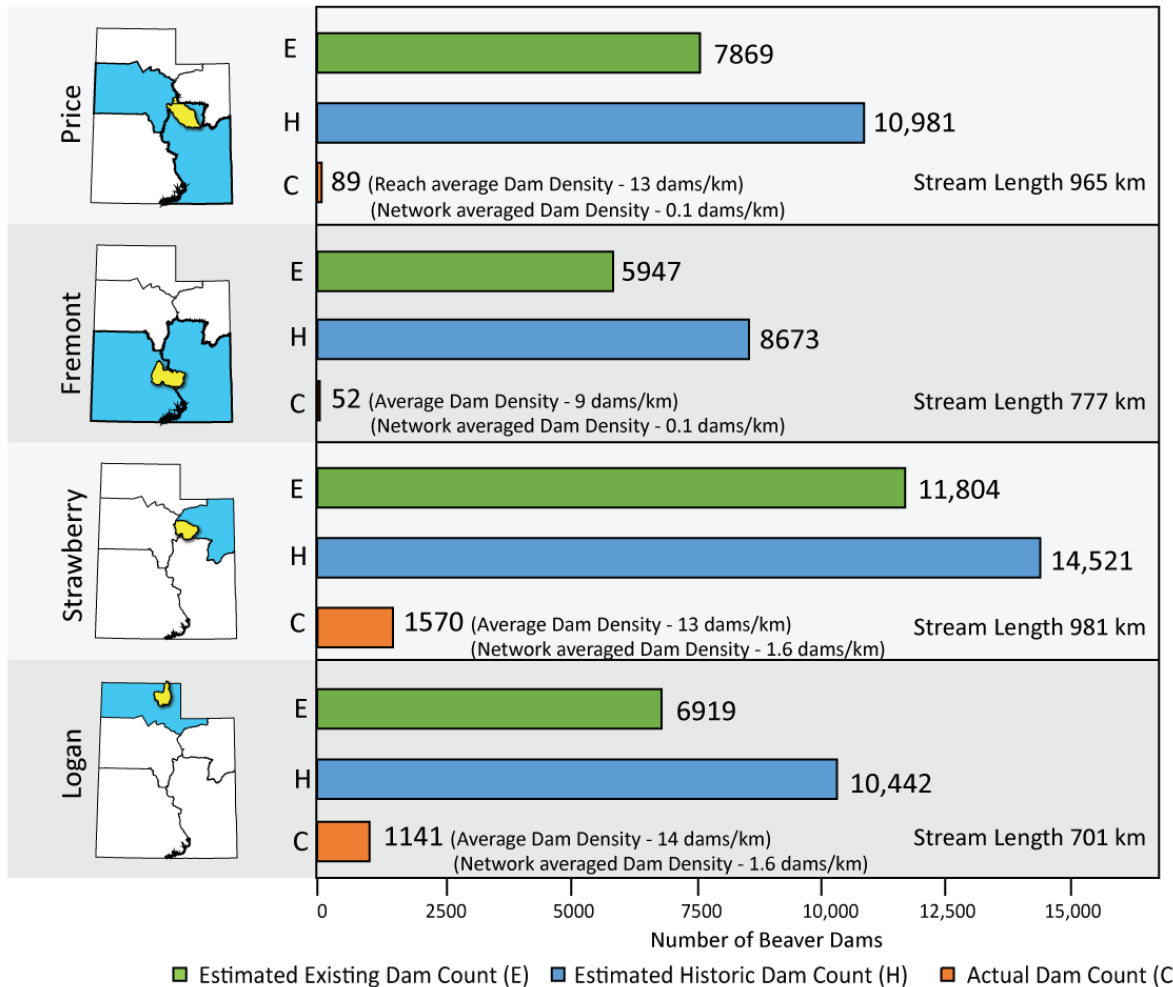
Figure 33 – Bar graph depicting actual dam counts compared to the predicted existing and historic dam counts for the four validation watersheds.

Error! Reference source not found. compares actual dam counts to capacity estimates for each stream segment containing an actual dam count from the Google Earth-based dam census. Of the total 1143 segments with validation dam counts only 15 (< 0.01%) exceeded the capacity estimates suggesting that the capacity model rarely over-predicts capacity relative to actual utilization. In the Logan and Strawberry the watersheds with the highest level of actual dam densities; our model underestimated only 1% of the segments and effectively captured on-the-ground beaver dam occurrences 99% of the time.
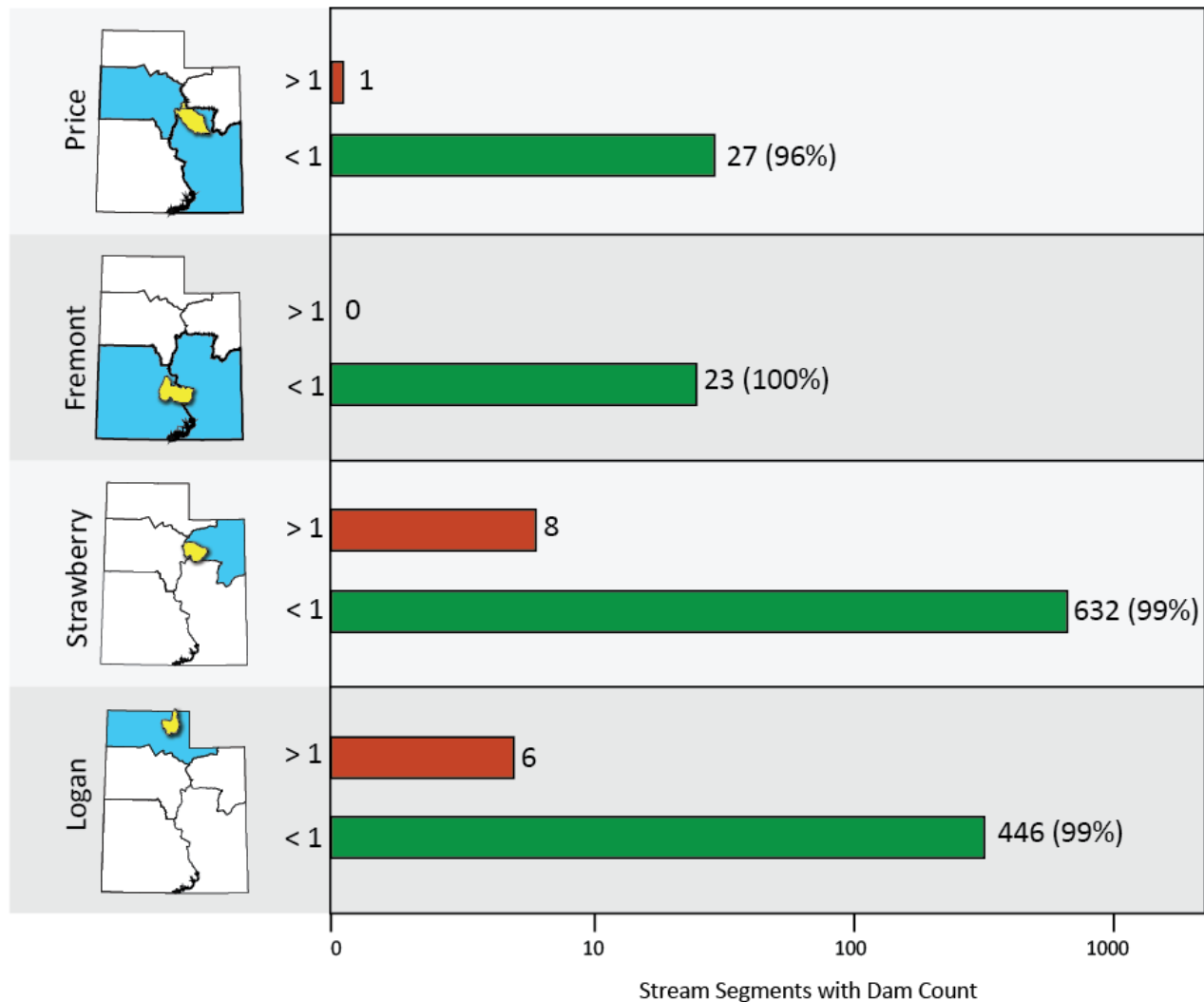
Figure – 34 Summary of how many stream segments with beaver dams and what percent (in parentheses) exceeded the capacity model prediction (red) versus those in which the capacity model was higher than observed (green).

PERCENT CAPACITIES AND ELECTIVITY INDEX

The left axes in Figure 35 show a log scale of number beaver dams, the light bars indicate the observed number of dams, and the dark bars indicate the predicted capacities by dam density categories. Although the same summary information is found in Figure 33, showing it broken out here by category on a log scale here highlights that in the Strawberry and Logan watersheds, all classes have about an order of magnitude discrepancy between actual dams

and capacity, whereas in the Price and Freemont the across all classes are nearly two to three orders of magnitude difference between actual dam counts and capacity.

As the electivity index (*EI*) normalizes beaver dam stream segment utilization, by availability of that segment type, it provides perhaps the most robust form of capacity model verification. The black dashes in Figure 35 shows a consistent, step-wise increase in electivity indices from rare through pervasive classes in all assessed watersheds. An *EI* above 1 indicates a preference for a segment type, an *EI* below 1 indicates avoidance of a habitat, and an *EI* close to 1 (i.e. 0.9 to 1.1) indicates utilization patterns that simply match availability of habitat. Importantly, the *rare* class always has an EI from 0 for the 'none' class in both, up to 5.2 respectively for the 'pervasive' class. There are so few beaver dams in the Price and Fremont relative to the provision of good habitat (i.e. 'frequent'), that the few beaver that are there tend to stick to the 'frequent' and 'pervasive' segments. By contrast in the Logan, there are higher dam numbers and an abundance of 'occasional' segments (62% of drainage network), suggesting that beaver are not actively seeking out this habitat, but simply using what is available to them.
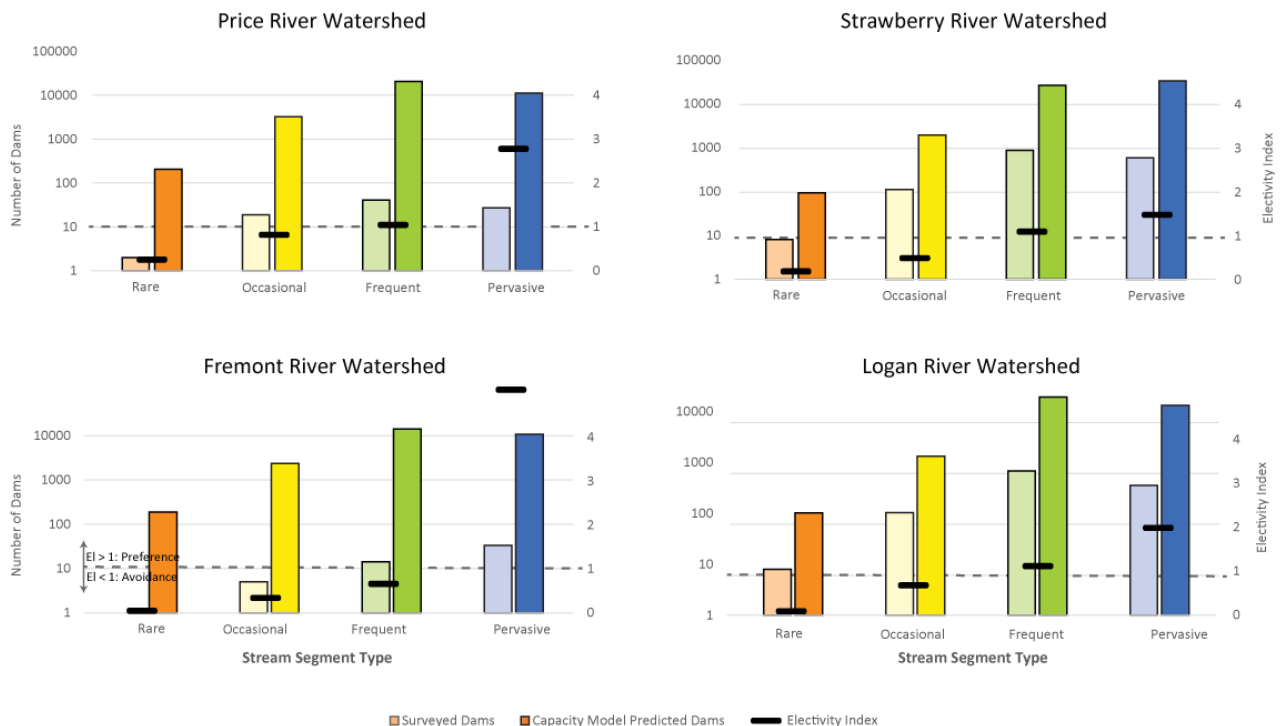
Figure 35 – Electivity Index for each of the four validated watersheds.

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BEAVER DAM AND POPULATION ESTIMATES

Using the beaver dam capacity model predictions, and empirical percent of capacity scaling ratios in four watersheds from over 2852 dams (Table 10), we attempted to provide some plausible bounds on estimated dam counts, colonies and dam-building beaver population throughout the State. When averaged across all reaches with beaver dams by segment type, average percent capacity estimates range from 6% to 24% (Table 10). We know that current densities and percent capacities are well below historic levels (Pollock et al., 2003). However, we should never expect any of these systems to be anywhere near their full capacities across the entire watershed or state. To provide some bounds on historic estimates, we use the upper percent capacity estimate from today as minimum scaling ratio (16%), 50% as an upper estimate and 40% as our 'average' best guess.

Table 10 – Empirical percent of beaver dam capacity scaling ratios for each category summarized across verification watersheds.

Segment Type	Average Surveyed Dam Density	Max Surveyed Dam Density	Min Surveyed Dam Density	Average % of Modeled Capacity	Max % of Modeled Capacity	Min % of Modeled Capacity
	dams/km	dams/km	dams/km	%	%	%
None	0.00	0.00	0.00	0%	0%	0%
Rare	0.10	0.30	0.00	24%	53%	0%
Occasional	0.52	1.30	0.03	17%	38%	1%
Frequent	0.91	1.90	0.04	9%	17%	0%
Pervasive	1.53	3.30	0.20	6%	14%	1%
Average	**0.85**	**1.63**	**0.07**	**8%**	**16%**	**1%**

Using our scaling relationships, we would estimate that there are somewhere between 1558 and 39,315 beaver dams in the state (Table 11). As we counted 2852 dams in little over 12% of the State's perennial rivers and streams, we know that our lower estimate is entirely too conservative. Using our average percent of model capacity estimates by category, we estimate that there are roughly 19,315 dams. Simply scaling up our partial dam census, we would estimate roughly 22,800 dams. Thus, based on current conditions, we would estimate that there are roughly 20,000 beaver dams in the state, but the number could be as high as 40,000. This would correspond to a population estimate of roughly 13,000 beaver, but there could be as many as 58,000. However, population estimates based only dam counts are notoriously unreliable. Blackwell and Pederson (1993) report a UDWR estimate from 1981 of 29,445 beaver. Between 990 and 5010 beaver have been harvested annually in Utah (Table 12), with an average over the last decade of 1589 (Bernales et al., 2012). The same Blackwell and Pederson (1993) report reported a 1971-1982 estimate of only 6471 kilometers of streams in the state with suitable beaver habitat (Table 12), whereas we show almost 22,000 kilometers being able to support beaver dam building activities with *occasional* or higher beaver dam densities (Table 3).

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Table 11 – Extrapolation for Utah statewide estimates of beaver dam counts, colony numbers and beaver population based on beaver dam capacity model for *existing* conditions.

Category	Stream Length (km)	Estimated Dam Capacity	Extrapolated Dam Counts			Estimated Colonies			Population Estimate		
			Average	High	Low	Average (Assuming 6 dams/ colony)	High (Assuming 4 dams/ colony)	Low (Assuming 10 dams/ colony)	Average (Assuming 4 beaver/ colony)	High (Assuming 6 beaver/ colony)	Low (Assuming 2 beaver/ colony)
Pervasive	3,502	81,811	5,186	11,060	836	864	2,765	83.64	3,457	16,590	167
Frequent	12,584	129,224	11,364	21,895	578	1,894	5,474	58	7,576	32,843	116
Occasional	5,799	15,256	2,608	5,820	144	435	1,455	14	1,739	8,730	29
Rare	2,323	648	157	346	-	26	86	-	105	518	-
None	3,137	-	-	-	-	-	-	-	-	-	-
Total	27,345	226,939	19,315	39,120	1,558	3,219	9,780	156	12,877	58,680	312
Per Kilometer	NA	8.3	0.7	1.4	0.1	0.1	0.4	0.0	0.5	2.1	0.0

Table 12 – Some previous estimates of Utah beaver populations, trapping, colony as well as colony sizes, colony densities and dam densities across North America.

Type	Geographic Region	Estimate	Units	Date of Estimate	Source
Population Estimate	State of Utah	29,445	Beaver	1981	Blackwell & Pederson (1993)
Carying Capacity Estimate	State of Utah	25,492	Beaver	1971-1982	Blackwell & Pederson (1993)
Length of streams with suitable baever habitat	State of Utah	6,471	km	1971-1982	Blackwell & Pederson (1993)
Average Beaver trapped per year	State of Utah	1,589	Beaver harvested	2002-2012	Bernales et al. (2012; Table 2)
Average Beaver trapped per year	State of Utah	2,105	Beaver harvested	1982-2012	Bernales et al. (2012; Table 2)
Range of Beaver trapped per year	State of Utah	990-5010	Beaver harvested	1958-2006	UDWR (2010; Figure 2)
Range of Beaver Colony Sizes	North America	2.7 - 7.6	Beaver per Colony	NA	Gurnell (1998)
Beaver Colony Density	North America	0.08 to 1.4	Colonies/km	NA	Gurnell (1998)
Beaver Dam Density	North America	0.14 to 19	Beaver Dams/ km	NA	Gurnell (1998)

Using our range of historic scaling relationships described above, we estimated that pre-European settlement there might have been somewhere between 51,305 and 160,329 beaver dams in the state (Table 13). Using an assumption of 40% of capacity, we estimate that there would have been roughly 130,000 dams at 40% capacity. This guess translates to rough population estimates of somewhere between 10,000 and 250,000 beaver, with our best guess at somewhere around 85,000 beaver. Taking these crude 'average' extrapolations at face value, the 29% loss in historic dam capacity might have corresponded to a current population that is only 15% of its former size (i.e. an 85% loss). Throughout North America the estimated pre-European beaver populations at somewhere between 60 and 400 million and Pollock et al. (2003) reported that modern day beaver populations are thought to be at somewhere around 10 million and rebounding.

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Table 13 – Extrapolation for Utah statewide estimates of beaver dam counts, colony numbers and beaver population based on beaver dam capacity model for *historic* conditions using 40% capacity estimates for average, 50% for high and 16% for low.

Category	Stream Length (km)	Estimated Dam Capacity	Extrapolated Dam Estimate			Estimated Colonies			Population Estimate		
			Average	High	Low	Average (Assuming 6 dams/ colony)	High (Assuming 4 dams/ colony)	Low (Assuming 10 dams/ colony)	Average (Assuming 4 beaver/ colony)	High (Assuming 6 beaver/ colony)	Low (Assuming 2 beaver/ colony)
Pervasive	7,830	184,890	73,956	92,445	29,582	12,326	23,111	2,958.24	49,304	138,668	5,916
Frequent	12,377	127,705	51,082	63,853	20,433	8,514	15,963	2,043	34,055	95,779	4,087
Occasional	2,939	7,721	3,088	3,861	1,235	515	965	124	2,059	5,791	247
Rare	1,158	342	137	171	55	23	43	5	91	257	11
None	3,040	-	-	-	-	-	-	-	-	-	-
Total	27,344	320,658	128,263	160,329	51,305	21,377	40,082	5,131	85,509	240,494	10,261
Per Kilometer	NA	11.7	4.7	5.9	1.9	0.8	1.5	0.2	3.1	8.8	0.4

RECOMMENDATIONS FOR THE UTAH BEAVER MANAGEMENT PLAN

The UDWR has one of the most progressive statewide beaver management plans in the country. This plan paves the way for a more holistic and sustainable approach to beaver management. However, to date, too few examples exist of the plan being implemented on the ground by UDWR personnel and partners as intended, despite large interest amongst a diverse group of organizations and individuals. We believe this is the case in part because although the plan lays out clear policies, goals and strategies; the specifics of how to implement specific strategies on the on the ground are lacking. Actively relocating nuisance beaver to parts of watersheds and the state in which they could be restoration agents is relatively new territory for UDWR staff. Demonstration projects are underway to help provide such guidance (e.g. Watershed Restoration Initiative & Sage Grouse Initiative Funding in Raft River Basin; translocation in Uintah Basin). However, we have tailored the BRAT to specifically help UDWR implement the plan. In other instances below, we make specific recommendations to update the plan.

POPULATION MANAGEMENT

The Utah Beaver Management Plan identified five beaver population management strategies (see italicized text) that could benefit from BRAT data collection techniques and results (UDWR, 2010, p. 13-14). Our primary recommendations are in bold:

- *'Develop a statewide baseline beaver distribution map to document current status'* - *(§Population Management – Objective 1 – Strategy 1)*

    - **Extending** the Google Earth-based **beaver dam census statewide** used here to verify model performance (§Model Verification) could provide a cost effective means to obtain current dam count estimates. A technician was able to reliably identify dams in 12.5% of the State's rivers in less than a month. These dam counts in conjunction with BRAT capacity estimates could be used to estimate current statewide status.

- *'Identify zones on the map to illustrate appropriate beaver management strategies for given geographic areas, i.e. existing populations (including source populations), unoccupied historical range and areas where the potential for conflict is high.'* - *(§Population Management – Objective 1 – Strategy 2)*

- o **Update the Beaver Management Plan with new maps from the outputs of BRAT.** Strategy 2 has essentially been completed with the completion of this report and could be removed. The Beaver Management Zones output of BRAT, effectively differentiates stream segments into seven different management categories. 1) Low-hanging Fruit, 2) Quick Return, 3) Long-term Possibility, 4) Naturally Limiting, 5) Anthropogenically Limiting, 6) Living with Beaver (high source), and 7) Living with Beaver (low source). Each of these categories has a unique set of associated beaver management strategies and therefore serves as a statewide reach level beaver management guide. UDWR may want to work with USU to refine and tweak the logic in the Beaver Management model and the conflict potential inputs. However, a preliminary map is better then no map.

- *'Actively pursue funding and partnerships to conduct ground and possibly aerial beaver population and habitat suitability surveys to obtain 1) detailed distribution information: and, when possible, density estimates..' - (§Population Management – Objective 1 – Strategy 3)*

  - o **Use 'Beaver Monitoring App' to track dams and infer population numbers**. In partnership with Utah State University's Water Quality Extension's 'Utah Water Watch' program, we developed an app for citizen science monitoring of beaver, beaver dams and beaver activity (http://extension.usu.edu/utahwaterwatch/htm/beaver-monitoring-app). The program could coordinate volunteer efforts to target 'missing' parts of the state where we need to know more. The app could also be deployed with UDWR personnel so they could track their observations. We could extend the app to meet UDWR's specific needs and share the database with UDWR.

- *'Obtain methodologies and results from other agencies currently conducting beaver surveys. Consider the methodology developed by UDWR in the statewide 1971-1981 study to allow for comparison of current and historical population data..' - (§Population Management – Objective 1 – Strategy 4)*

  - o **Leverage data collection on beaver from other agencies**. The US Forest Service is actively monitoring beaver dams and estimating populations on some Forests. Similarly, some of the Utah branches of the Natural Resources Conservation Service are actively assessing beaver activity and suitability of streams to support dam building beaver on some private lands. The Bureau of Land Management has no active program but has interst. UDWR could partner with the USFS, NRCS

and BLM to coordinate such activities and leverage these other data collection efforts.

- *'Update the baseline map in the final two years (2018-2020) of the plan.' - (§Population Management – Objective 1 – Strategy 5)*
  - o **Replace the 'baseline map' with BRAT outputs**. It is still an important goal to update the 'baseline map' (not well defined in plan) in 2018-2020, but BRAT provides a far more detailed, accurate and useful and interactive baseline map then the GAP Analysis map in the current plan.

HARVEST MANAGEMENT

In the Utah Beaver Management Plan (UDWR, 2010, p. 14), a harvest management objective of maintaining a 'recreational opportunity of a minimum of 350 trappers and a sustainable harvest of 3,500 beavers annually' is specified. Using the low estimates of roughly 16,000 beaver from roughly 8,000 colonies this may represent an unsustainable harvest level. Since 1958, annual trapping has varied between 990 and 5010 beaver annually, with recent averages around 2105 beaver. Statewide, beaver populations have apparently not collapsed in response to this, but a more region-specific and localized look at what represents sustainable harvest levels is certainly warranted. Although four strategies are provided for managing the harvest, we suggest some additional strategies should be considered.

- o Using BRAT and **encouraging the growth of beaver populations in areas with low conflict potential and high capacity to support beaver could potentially increase this important recreational fur-trapping resource**. We could extend BRAT to explicitly include beaver numbers and identify portions of streams and rivers that could be managed for sustainable harvest.
- o Through time, we recommend that **UDWR work with groups using beaver to restore streams and rivers to limit trapping in areas where beaver are translocated** until such time the restoration benefits have been realized and beaver populations are at a level they can support a sustainable harvest. These concerns are specifically in areas BRAT identified as 'Quick Return Restoration Zones', 'Low Hanging Fruit Restoration Zones' and 'Long-Term Restoration Zones'.
- o **More research is needed to ascertain what a 'sustainable' harvest is.** This should be done in close consultation with current fur trappers to balance their needs and concerns with those of restoration and conservation practitioners. In the meantime, we recommend that UDWR could work with fur trappers to

manage the fur harvest to promote trapping of nuisance beaver in BRAT-identified 'Living with Beaver' portions of streams during the trapping season.

DAMAGE MANAGEMENT

The Beaver Management Plan includes a 'Damage Management' section with the objective of increasing the consistency in response options (lethal and non-lethal) currently in use and increase the frequency of use of non-traditional options (e.g. beaver deceivers and live trapping_ in use (UDWR, 2010, p. 20-25). These so-called 'living with beaver' strategies are one of the key progressive elements that set the plan apart from other states and we applaud UDWR for its forward thinking in this regard. We highly **recommend that UDWR develop an 'Adaptive Beaver Management Plan' that spells out specific 'standard' responses and workflows to nuisance damage situations** and give UDWR staff a workflow to fall back on. We developed such a plan for Park City Municipal Corporation (Wheaton, 2013). The key workflows of the adaptive management plan are highlighted in two flowcharts (Figure 36 and Figure 37), which could be easily adapted by UDWR to represent their circumstances. The core of the adaptive management plan is an adaptive management loop that starts with planning, proceeds through actions ('do'), and evaluation and learning, that either feedback periodically on planning or can be used to adjust actions. The importance of casting the damage management through the lens of an adaptive management plan is it transparently articulates a course of action to follow based on the best available information, but affords UDWR the flexibility to adapt that plan through time as more is learned and situations arise that may not have been anticipated.

Figure 36 – Example of key component of an 'adaptive beaver management' plan for evaluating potential 'nuisance beaver activity' on water courses mapped as 'Living with Beaver' zones. Figure from Wheaton (2013) developed for Park City Municipal Corporation (PCMC), but could be adapted for UDWR purposes.
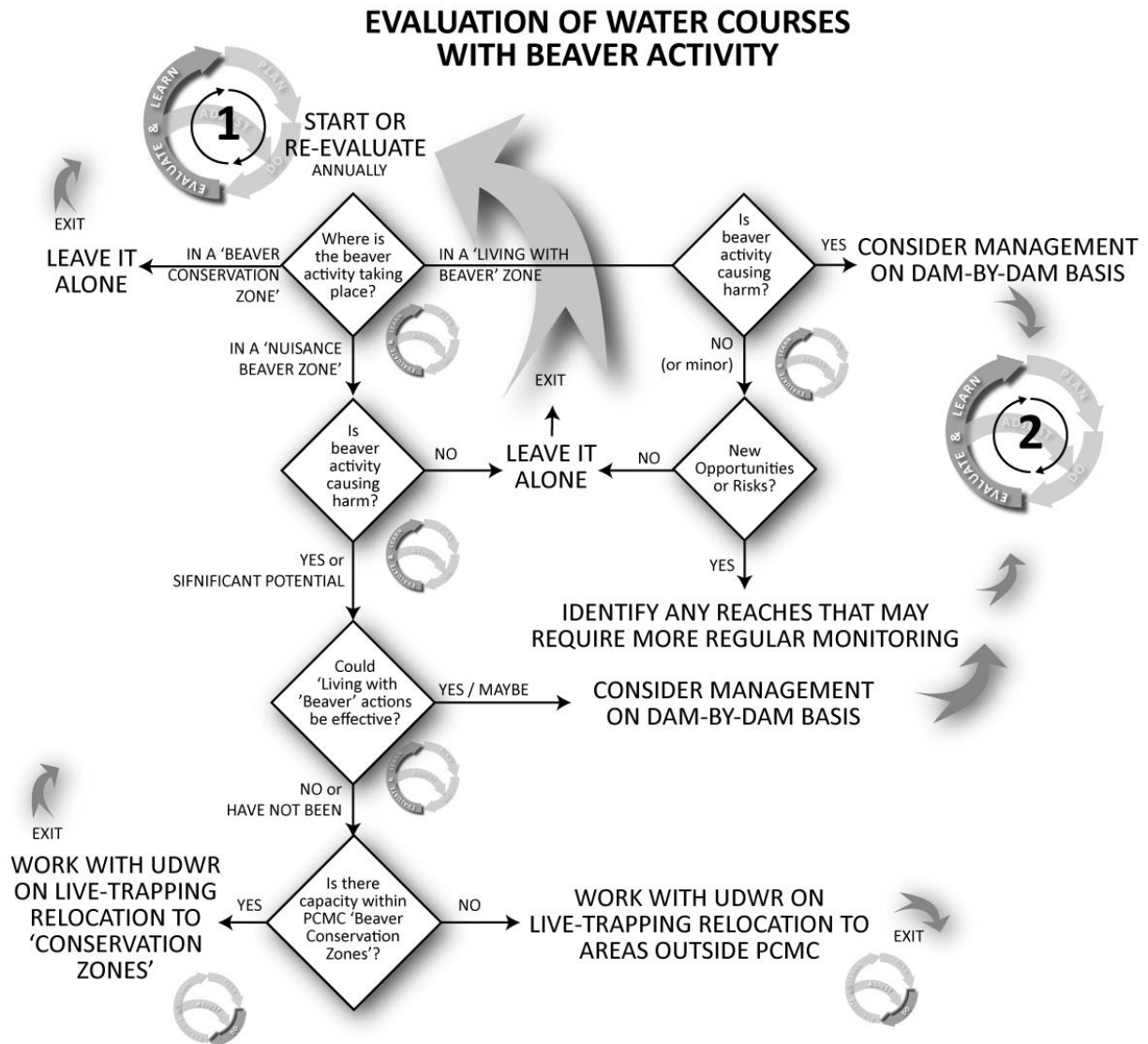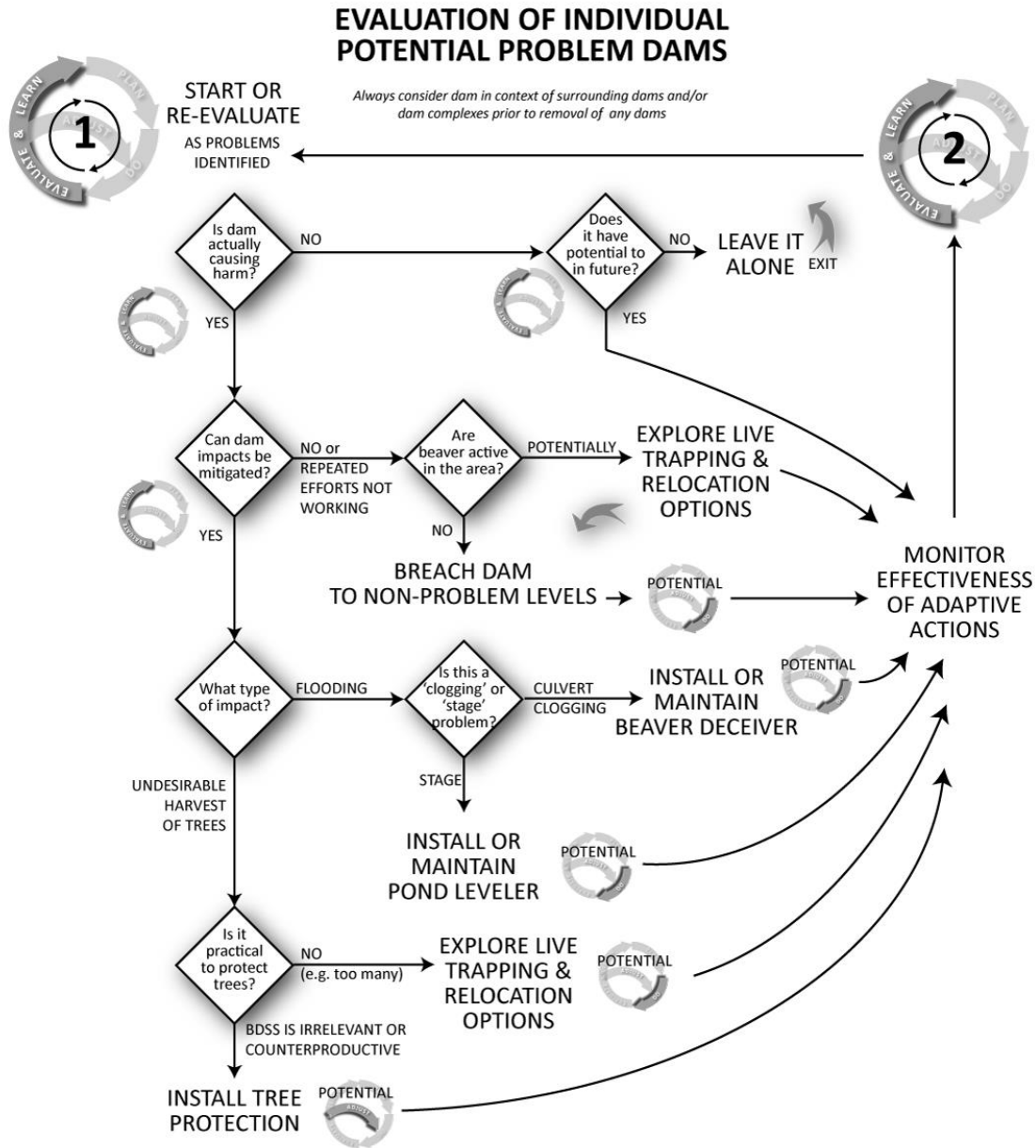
Figure 37 - Example of key component of an 'adaptive beaver management' plan for evaluating potential 'nuisance beaver activity' on water courses mapped as 'Living with Beaver' zones. Figure from Wheaton (2013) developed for Park City Municipal Corporation (PCMC), but could be adapted for UDWR purposes.

STATEWIDE BEAVER TRANSPLANT LIST

The Beaver Management Plan identified a list of streams in Appendix 1 suitable for transplant and ranked these streams by priorities (UDWR, 2010, p. 20-25). This list was simply a brainstorm of individuals involved in creation of the Beaver Management Plan and is a huge under-estimate of potential transplant locations. Moreover, the 'Regional Priority' ranking is not transparent nor is it clear where the ranking comes from. Currently, it is not obvious whether streams not included on this list can receive transplanted, nuisance beaver.

- We recommend that the **transplant list is either replaced or updated to include streams designated by BRAT as 'Low-hanging Fruit Restoration Zone' and 'Quick Return Restoration Zone'**. If desired, these could be differentiated between publicly owned portions of those streams and privately owned. Stakeholder involvement is encouraged to identify the actual stream segments where translocations of beaver occur.
- We recommend that **the Regional Prioritization/Ranking is removed or made more transparent**. BRAT could serve as a better, more objective first cut at this ranking, highlight where such transplant priorities may be more realistic. This is not to suggest that UDWR does not or should not prioritize translocation projects on the basis of a variety of political, logistical and financial realities in addition to the scientific evidence in BRAT. Rather, if such a ranking/prioritization is deemed necessary to include in the plan, its rationale should be more transparent and it should leverage the best available information to support management (e.g. BRAT).

WATERSHED RESTORATION

The plan identifies several data gaps related to watershed restoration (UDWR, 2010, p 17-18) and strategies to fill these (see italic text). We specifically targeted the outputs of BRAT to address these data gaps and help UDWR fulfill the strategies in the plan (see bold text for primary recommendation):

- *'Conduct site specific evaluations prior to introducing beaver to include consideration for the presence of suitable habitat, low risk of creating damage conflicts and the possibility of establishing barriers that may impede fish migration.' – (§Watershed Restoration; Objective 1; Strategy 2)*

  - We recommend that **the BRAT capacity model is used to identify 'suitable habitat' and that the human-beaver conflict potential model identifies areas of low risk of creating damage conflicts**. The 'Beaver Management, Conservation, and Restoration Potential' model makes an attempt to explicitly integrate these

two lines of evidence. BRAT-based dam building capacity estimates could prove useful for identifying areas suitable for beaver establishment as long as one accounts for the reality that beaver can also live in settings without building dams. However, from a restoration perspective, we are typically more interested in promoting beaver, because of their dam building activity (Pollock et al., 2014).

LIVE TRAPPING PROTOCOL

Appendix II of the Beaver Management Plan outlines a 'Protocol for Live Trapping and Transplanting Beaver'. It is an excellent start, but should be updated. There are currently a shortage of UDWR personnel and non-UDWR individuals who have received the training (§1.A of Protocol) and are capable of successfully live trapping whole colonies of nuisance beavers and relocating them to restoration areas. There are many individual organizations, municipalities, agencies and landowners that would like to either a) have nuisance beaver live-trapped and removed from their streams and rivers, or b) have those same nuisance beaver relocated or re-introduced to their streams and rivers. Notwithstanding the enthusiasm of these groups, there is currently little capacity within UDWR to keep up with this demand.

- We recommend that **the COR program and training mentioned** in §1.a.i of the Protocol **is desperately needed to certify trappers** (private or with other agencies) to allow them to implement the intent of the Beaver Management Plan. There is confusion within the agency and certainly outside how people get trained and certified and who to contact. UDWR should more clearly publicize and administer this training.

- We recommend **developing a simple app and web-reporting system to allow UDWR to track and monitor all translocation activities** to help inform population management decisions and future policy. We recommend adding a §1.i section on 'Reporting' and require that all translocation activities are reported and tracked in a central database. That database need not necessarily be made public, but should be made available for UDWR staff and non-UDWR researchers.

- We recommend that the **habitat assessment section (§ 2.a) is inadequate and should be updated based on BRAT**. Specifically, we recommend that an initial, preliminary habitat assessment can be provided by simply referring to the preliminary beaver management zones in BRAT (this can be done easily in Google Earth with layers delivered in this report). Beaver should only be translocated to 'Quick Return Restoration Zones', 'Low Hanging Fruit Zones', and 'Long-Term Restoration Zones'. Before beaver are translocated, an on-the-ground assessment should confirm that the area is not 'unsuitable' (i.e. does not have woody vegetation resources that can support and sustain beaver') and is not in a zone with high potential for nuisance problems. In particular, care should be taken with 'Long-Term Restoration Zones', which may require

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riparian restoration and or recovery before relocating beaver. An example is incised streams, where beaver dams may not last on their own and a structural intervention with beaver dam analogues (Figure 38) may be necessary (Pollock et al., 2014; Pollock et al., 2012).

- **The language surrounding 'source population considerations' is unnecessarily restrictive**. We suggest that there is not clear science to support the rationale behind §2.c.i ('Source Population Considerations', which says 'beaver will only be translocated within the same 2 digit Hydrologic Unit Code'. As an interim fix, we suggest the wording should be relaxed (similar to §2.c.ii) to allow flexibility: e.g. "Translocated beaver should generally be targeted within the same 2 digit Hydrologic Unit Code (in or outside State of Utah) to account for unique characteristics. However, in watersheds with no current beaver population, nuisance beaver from nearby watersheds (even if they do not have the same 2 digit Hydrologic Unit Code) may be considered." A situation in the Raft River Range recently came up, where the existing language was unnecessarily restrictive. If the intent is not to mix populations of beavers, further research could be done on beaver genetics within different populations. However, relaxing the language in the meantime may suffice.
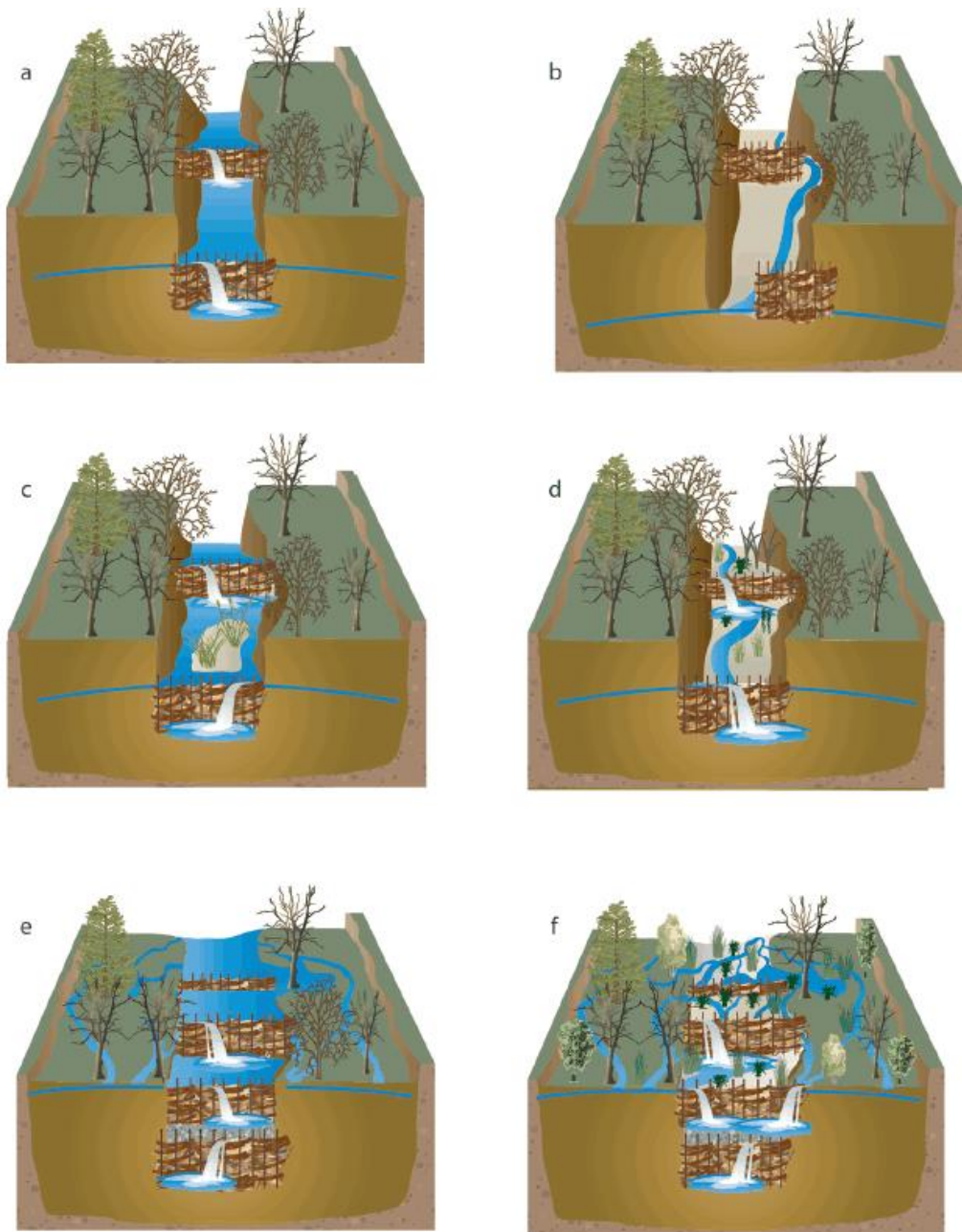
Figure 38 – Conceptual example of how artificial beaver dam analogues can be used in incised channels to promote habitat restoration and floodplain reconnection. Wooden fence posts can be used to anchor constructed beaver dam analogues to make them more stable in settings where they are prone to blowouts. Note that where blow-outs occur (B & D), they can lead to widening of the incision trench (via erosion), which creates a local supply of material, that helps build inset floodplains and create more complex habitat (C, E & F). Figure from Pollock et al. (2014).

FUTURE WORK

With the completion of the statewide run of BRAT the decision support and planning tool is now complete. The next steps are to i) continue to verify and refine the performance of BRAT ii) make BRAT more useful to managers, practitioners and researchers through the development of an ArcGIS Plugin or Add-In, iii) run BRAT in other western states.

MODEL REFINEMENT

CAPACITY MODELS

For Utah and other Western States, we do not foresee major refinement needed for the capacity models, but instead subtle tweaking and calibration. It would be useful and interesting to run the capacity model with higher resolution, higher accuracy in put (e.g. 25 cm resolution classified vegetation instead of 30 M LANDSAT classified imagery; and 1 m LiDAR instead of 10 M National Elevation Dataset DEMs). We imagine more accurate local predictions may be realized, but speculate that the overall picture at regional scales will not change significantly.

It may also be useful to run the model dynamically. Right now, the model is run at a snapshot in time based on a snapshot of vegetation conditions from satellite imagery at one point in time, and flow summary statistics. The model could be run as a time varying simulation where vegetation and flows changed through time. Similarly, the model could be usefully combined with an agent-based beaver model to instead of estimating capacities over time, modeling the dynamics and actual realized number of dams. The model could illustrate how long it takes for beaver to exhaust local wood resources, how long they are abandoned by those colonies and how long those resources take to recover. While such dynamic modelling efforts would be of great scientific value and interest and have findings with relevance to management, they are likely overkill for most day-to-day management needs.

HYDROLOGIC IMPACTS

Ultimately the capacity models could and should be used to support scenario development of different densities and combined with hydrologic modeling efforts that attempt to quantify and explore the impact of beaver dam building on water resources. It is highly likely that if many of Utah's 1st, 2nd and 3rd order streams realized even 15% to 25% of their current capacities, there would be major impacts on water resources. Since beaver dams slow the runoff of water, they promote significant contributions to local ground-water tables and expansion of riparian growth. It is possible that this slowing of water delivery could result in a minor net loss of water

from the system over the season through direct evaporation and evapotranspiration from expanded riparian vegetation areas associated with beaver dams. However, normally, a similar or greater volume of water would leave the system as spring runoff at a time it cannot be fully utilized downstream (e.g. storage capacity of many man-made reservoirs is only so much, and irrigation demands in late spring are generally small) and is therefore 'lost' anyway. We hypothesize that the total seasonal runoff volume impacts will be inconsistent (some gains, some losses) and insignificant compared to the timing impacts. Specifically, since many beaver dams in a system act to create a sponge (inclusive of small storage capacity in beaver dams, and larger storage capacity in alluvial fills of small valley bottoms), we expect beaver dams to slowly release the water out over the summer and early fall months at a time when downstream riparian areas and water users need it most. We speculate that in many watersheds, these gains may be enough to compete with lost storage capacity from a declining snow pack. We recommend more research is done to better establish the empirical relationships between beaver dams and their local hydrologic impacts, and build the hydrologic modeling framework to represent those changes in runoff and delivery as impacted by beaver dams.

CONFLICT POTENTIAL MODEL REFINEMENTS

We are confident we have captured appropriate input data to adequately reflect potential conflict with humans. However, the actually probabilities likely need to be adjusted to more accurately reflect stakeholder desires and concerns. Some places, landowners and managers may have higher tolerances and appetite for 'living with beaver' strategies; whereas others may simply want beaver removed. In general, there is no permanent solution to 'nuisance' beaver problems and all lethal and non-lethal means represent short term mitigations best viewed as maintenance. All the same, the conflict potential model could be adjusted based on recommendations from UDWR staff based on interactions and feedback from various stakeholders. We foresee BRAT being modified to support and reflect a wide spectrum of stakeholder attitudes towards beaver. For instance, urban land is currently given a probability of potential conflict rating of 75%, however some municipalities with concerned pro-beaver citizens may find this probability too restrictive and want it reduced (e.g. Park City, see: Wheaton, 2013). These urban areas may currently be coded as 'Unsuitable – Anthropogenically Limited' but could transition to 'Living with Beaver' zones at the discretion of these stakeholders. In contract, some counties in the state may find that the restrictive default probabilities of potential conflict we used in this version of the model are in line with the desires of their stakeholders and do not need to be adjusted.

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BEAVER MANAGEMENT, RESTORATION AND CONSERVATION MODEL REFINEMENTS

1. The next round of BRAT development should focus on partnering with UDWR staff and other land and resource managers to improve the outputs of the 'Preliminary Statewide Beaver Management, Restoration and Conservation' model output (Figure 15). This would be done by tweaking the underlying inputs and logic of the management model (Figure 9). Combining the actual dam counts with the existing models, we could identify source and sink zones throughout the state where beaver could be relocated or vegetation restoration projects could be implemented based on where they are and are not instead of just where they could be. Specifically,
   a. areas with high existing capacity, low conflict potential, and dam densities approaching greater than 50% of that local capacity should be differentiated as 'Conservation Zones' (a new output);
   b. areas with high potential capacity, reasonable recovery potential, low or moderate existing capacity, low conflict potential and low current dam densities should be promoted as 'Quick Return Restoration Zones';
   c. areas with high existing capacity, low conflict potential, and low existing dam densities should be promoted as 'Low-Hanging Fruit Restoration Zones' and the target of translocation of nuisance beaver.

ADDITIONAL MODEL VERIFICATION

STATEWIDE GOOGLE EARTH DAM CENSUS

We think extending our Google Earth-based dam census statewide could prove to be very useful for more refined Beaver Management, Conservation and Restoration model ouputs and help UDWR make more informed management decisions regarding beaver. We foresee it being a cost effective means to:

1. Obtain current statewide dam count estimates. These dam counts in conjunction with BRAT capacity estimates could be used to refine current percent of capacity estimates and improve population estimates.
2. Further validate the capacity model and provide a rigorous accuracy assessment.

CITIZEN SCIENCE

We partnered with the Utah State University Water Quality Extension and Reid Camp to develop a statewide beaver monitoring program (https://extension.usu.edu/utahwaterwatch/htm/beaver-monitoring-app/) and Beaver Monitoring App. Reid Camp (Eco Tech Solutions) developed the App to run on any iOS device (e.g. iPhone or iPad) to collect spatially explicit beaver dam information. We hope the beaver monitoring program will become a popular activity of citizen scientists across the state and that the resulting data will provide important information on the status and trend of dam-building beaver populations. In the future, we hope to use the citizen science data to validate and improve the BRAT models.

FUTURE BRAT TOOLS

We think we could make BRAT more useful to managers, practitioners and researchers if we could deploy it as:

- A WebGIS application that would allow users to:
    - Explore and visualize a Base-Version of BRAT run for the Western US in a Google Maps interface
    - Run and produce simple BRAT scenarios where user can control parameters:
        - Toggle thresholds and transform functions for the probabilistic Human-Beaver Conflict Potential output
        - Toggle thresholds and adjust logic
    - Export their own BRAT outputs as KML or shapefiles
- An ArcGIS Plugin or Add-In that would allow users to:
    - Download and modify Base-Version of BRAT for area of interest
    - Run and produce BRAT scenarios based on customized user inputs (e.g. higher resolution maps)

RUN BRAT FOR WESTERN STATES

We hope to run BRAT for the entirety of all adjacent states including Nevada, Idaho, Wyoming, Colorado, New Mexico and Arizona. As Figure 1 shows we have already processed a portion of each of these states and we plan on seeking funding to finish the remainder of these states and expand the effort for all Western states. If neighboring states were using a similar system for

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managing beaver, it could make transboundary cooperation on watersheds that straddle multiple states simpler.

CONCLUSIONS

CAPACITY MODEL

During the statewide implementation of BRAT the capacity model underwent significant modifications that greatly improved its predictive performance. In general these modifications made the model less restrictive resulting in increased capacity. However, steep streams and large rivers have lower, more appropriate capacities under the modified model. The resulting spatial dam density patterns across the landscape accurately depict the on-the-ground full capacity patterns. Likewise, based on our validation data in the four validation watersheds (Logan/Little Bear, Strawberry, Price and Fremont) distributed across each of the five UDWR Regions only in rare cases (1% of the time) did actual dam counts exceed our capacity estimates. Similarly, the Electivity Index (*EL*) revealed a progressive increase in all assessed watersheds with an *EI* of 0 for the 'none' class and up to 5.2 for the 'pervasive' class. This indicates that beaver preferred the segments that the capacity model effectively predicted as stream segments able to support higher density dams.

The capacity model shows that Utah has the capacity to support a tremendous amount of beaver dams with an estimated existing capacity of 226,989 dams. The existing dam density is well distributed throughout the state, with slightly more proportional existing capacity in the northern half. The actual dam densities in the watersheds where we collected census data are only a small fraction of capacity (from 1% to 16%)' suggesting that there are many streams and rivers capable of supporting more dam-building beaver. Moreover, the model shows the pre-European settlement capacity (based on LANDFIRE historic capacity) was 320,659 dams. Each UDWR Region has the potential to support more pervasive beaver dam colonies than is being realized with the existing vegetation on the landscape. This suggests that riparian restoration projects that encourage regeneration and expansion of native vegetation could result in significant increases in dam building capacities.

We conclude that the spatially explicit capacity data associated with this project will provide UDWR biologists with invaluable reach-level resolution (250 m stream segments) information that will help answer questions relating to where in the landscape dam-building activity by beaver might be sustainable and at what sort of dam densities. When actual dam count data is available, the BRAT model can effectively identify; source (areas where actual dam counts are close to capacity) and sink areas (areas where actual dam counts are far below capacity). By

effectively delineating source and sink zones UDWR managers have valuable information regarding how to best manage beaver populations especially nuisance beaver.

BRAT DECISION SUPPORT AND PLANNING TOOL

This project represents the first time the entire BRAT Decision Support and Planning Tool has been run. What transforms BRAT from a simple capacity model to an assessment tool is its ability to combine: A) existing and historic capacity, B) riparian habitat condition and recovery potential and C) probabilities of potential conflict with humans (i.e. damage management) into information that assigns stream segments to seven different beaver management, conservation and restoration categories. Results from this initial run indicate that slightly more than 1/3 (35%) of the state's rivers and streams were identified as 'Low-hanging Fruit' signifying habitats that are either currently inhabited by beaver or are in relatively good condition for beaver re-colonization and/or reintroduction. About 1/3 (29%) of the state's rivers and streams were identified as 'Living with Beaver' (13% low source and 16% high source) indicating that beaver activity has some potential to cause damage to infrastructure, but the impacts are minimal and/or easily mitigated with 'Living with Beaver' strategies. Nearly 1/3 (28%) of the state was identified as 'Unsuitable' (12% 'Unsuitable – Naturally Limiting' and 16% 'Unsuitable – Anthropogenically Limiting') signifying streams that are likely not appropriate for restoration with beaver due to natural or human induced limitations. The remaining 8% of the state are equally divided between 'Quick Return' (4%) representing areas that with minimal intervention and changes in management practices (e.g. better grazing management and riparian recovery) could be suitable for dam-building beaver and 'Long-Term Possibility' representing streams that could provide the right habitat conditions if land-use management changed and/or other restoration/recovery was invested in. These 'Long Term Possibility' streams may make sense to be the target of restoration activities for strategic reasons (e.g. ancillary benefits to other target management species – e.g. cutthroat trout or sage grouse). However, such zones are higher risk and are likely more expensive restoration options.

We conclude that the Utah-wide Beaver Restoration Assessment Tool is a powerful decision support and planning tool for dam-building beaver conservation and management. We have developed the model to help UDWR specifically address and implement some of the policies and strategies in the Utah Beaver Management Plan. Moreover, we have provided specific recommendations for adjustments to the Plan. The spatially explicit data from BRAT will help UDWR resource managers more effectively manage dam-building beaver populations by identifying areas suitable for establishment with the least probability of potential conflict. This information can easily be used to establish a list of additional beaver conservation and relocation sites beyond those streams identified in the Utah Beaver Management Plan 2010-

2020 (2010). In addition, with input from UDWR staff, the decision support tool can be refined to support specific resource management strategies.

ACKNOWLEDGEMENTS

DELIVERABLES

There were five specified deliverables for this project:

1. Complete development of BRAT Decision Support System
2. Validate BRAT at select target watersheds
3. Synthesize findings from BRAT into recommended adjustments to State Beaver Management Plan
4. Run BRAT for entire state of Utah and provide deliverables as ArcGIS File Geodatabase, KMZ and via webGIS portal
5. Analyze and publish data and reports when possible

Deliverables one, two and three have been completed with the submission of the report and the associated GIS data. For deliverable four we have posted all the GIS data at: http://etal.usu.edu/Downloads/BRAT/Data/. We also have an agreement with Utah AGRC to host our data on the Utah GIS Portal for public access. For deliverable five we are working on two publications one focuses on the capacity model and the other on decision support and planning tool, plus this report suffices as the primary output.

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APPENDIX A: STREAM POWER IN THE CAPACITY MODEL

ROLE OF STREAM POWER

Stream power provides a simple and well understood proxy for the strength of flows within any given stream segment (Worthy, 2005). Stream power is the product of slope (S) and discharge (Q):

$$\Omega = \rho \cdot g \cdot Q \cdot S$$

Where Ω is stream power (in watts), ρ is the density of water (1000 kg/m^3), g is acceleration due to gravity (9.8 m/s^2), Q is discharge (m^3/s), and S is the channel slope. Stream power (Ω) is readily calculable for any segment of stream if Q is known, because S can be derived from a DEM and drainage network and the density of water (ρ) and gravity (g) are constants.

Discharge for specific recurrence interval flows can be estimated by using or deriving regional curve regression equations that relate Q to upstream drainage area and elevation values at a given site. In this study, we used USGS regional curves developed for the state of Utah (Kenney, 2008; Wilkowske et al., 2008) to produce a time-integrated estimate of the average impact of stream power. Upslope drainage areas were derived for each stream segment from 10 m USGS DEMs using a cumulative drainage area geoprocessing algorithm.

CHANGES TO STREAM POWER THRESHOLDS

The updated BRAT Maltab code and fuzzy inference systems and documentation can be found at http://brat.joewheaton.org and is also hosted at https://bitbucket.org/etal_brat/brat_matlab. Below are the changes to the FIS that were made.

MEMBERSHIP FUNCTIONS: BASEFLOW PILOT STUDY VALUES (WATTS)

- MF1='Can Build Dam': [0 0 150 300]
- MF2= 'Probably Can Build Dam': [150 300 600 1000]
- MF3='Can Not Build Dam': [600 1000 100000 100000]

MEMBERSHIP FUNCTIONS: BASEFLOW UPDATED STATEWIDE VALUES (WATTS)

- MF1='Can Build Dam': [0 0 150 175]
- MF2='Probably Can Build Dam': [150 175 180 190]
- MF3='Can Not Build Dam': [180 190 1000000 1000000]

MEMBERSHIP FUNCTIONS: Q$_2$ PILOT STUDY VALUES (WATTS)

- MF1= 'Dam Persists': [0 1000 2000]
- MF2='Occasional Breach': [1000 2000 5000]
- MF3='Occasional Blowout': [2000 5000 10000]
- MF4='Blowout': [5000 10000 100000 100000]

MEMBERSHIP FUNCTIONS: Q_2 UPDATED STATEWIDE VALUES (WATTS)

- MF1= 'Dam Persists': [0 1000 1200]
- MF2= 'Occasional Breach': [1000 1200 1400]
- MF3= 'Occasional Blowout': [1400 2000 2400]
- MF4= 'Blowout': [2000 2400 1000000 1000000]

STREAM GRADIENT THRESHOLDS

In this study, stream gradient was added as a direct input in the fuzzy inference system for the capacity model.

MEMBERSHIP FUNCTIONS: NEW STREAM GRADIENT VALUES

- MF1= 'Really Flat':[0 0 0.0002 .005]
- MF2= 'Can Build Dam':[0.0002 .005 0.12 0.15]
- MF3= 'Probably Can Build Dam':[0.12 0.15 0.17 0.23]
- MF4= 'Can Not Build Dam':[0.17 0.23 1 1]

APPENDIX B: OUTPUT LOOKUP TABLE

Table 14 – BRAT output attribute lookup table page 1.

Attribute Name	Abstract	Description
iGeo_ElMin	Minimum Segment Elevation	Extracted from a 10 m NED DEM [meters ABMS]
iGeo_ElMax	Maximum Segment Elevation	Extracted from a 10 m NED DEM [meters ABMS]
iGeo_ElBeg	Elevation at Segment Beginning	Extracted from a 10 m NED DEM [meters ABMS]
iGeo_ElEnd	Elevation at Segment End	Extracted from a 10 m NED DEM [meters ABMS]
iGeo_Length	Segment Length	Derived from NHD 24k geometry; typically 250 meters
iGeo_Slope	Segment Slope	Derived from elevation and segment length [percent]
iveg_VT100EX	Vegetation in 100 m buffer - Existing	The existing vegetation type beaver suitability within the 100 m upland foraging zone [value 0-4]
iveg_VT30EX	Vegetation in 30 m buffer - Existing	The existing vegetation type beaver suitability within the 30 m riparian zone [value 0-4]
iveg_VT100PT	Vegetation in 100 m buffer - Potential	The potential vegetation type beaver suitability within the 100 m upland foraging zone [value 0-4]
iveg_VT30EX	Vegetation in 30 m buffer - Potential	The potential vegetation type beaver suitability within the 30 m riparian zone [value 0-4]
iGeo_DA	Up-Slope Drainage Area	Derived from the flow accumulation calculated on 10m NED DEM [square miles]
iHyd_Qlow	Low Flow	Estimated by USGS Regional Curves [CFS]
iHyd_Q2	2 Year RI Flow	Estimated by USGS Regional Curves [CFS]
iHyd_Q25	25 Year RI Flow	Estimated by USGS Regional Curves [CFS]
iHyd_SPlow	Low Flow Streampower	Calculated by Slope & Q Estimate [Watts]
iHyd_SP2	2 Year RI Streampower	Calculated by Slope & Q Estimate [Watts]
iHyd_SP25	25 Year RI Streampower	Calculated by Slope & Q Estimate [Watts]
oVC_EX	Modeled Vegetation Existing Beaver Dam Capacity Density	FIS modelled output of beaver dam density based only on existing vegetation [dams/km]
oVC_PT	Modeled Vegetation Potential Beaver Dam Capacity Density	FIS modelled output of beaver dam density based only on potential vegetation [dams/km]
oCC_EX	Modeled Combined Existing Beaver Dam Capacity Density	Final FIS modelled output of existing beaver dam density based on all combined inputs [dams/km]
oCC_PT	Modeled Combined Potential Beaver Dam Capacity Density	Final FIS modelled output of potential beaver dam density based on all combined inputs [dams/km]

Table 15 – BRAT output attribute lookup table page 2.

Attribute Name	Abstract	Description
mCC_EX_Ct	Existing Capacity Dam Count	Product of oCC_EX and Segment length [dams]
mCC_PT_Ct	Potential Capacity Dam Count	Product of oCC_PT and Segment length [dams]
mCC_EX-PT	Existing to Potential Capacity Ratio	Ratio of actual to potential dam densities [dimensionless ratio between 0 and 1]
iPC_UDotX	Distance to UDoT Culvert	Euclidean distance to nearest UDoT road crossing [meters]
iPC_RoadX	Distance to Road Crossing	Euclidean distance to nearest road crossing [meters]
iPC_RoadAdj	Distance to Road	Euclidean distance to nearest road [meters]
iPC_RR	Distance to Railroad	Euclidean distance to nearest railroad [meters]
iPC_Canal	Distance to Canal	Euclidean distance to nearest canal [meters]
iPC_LU	Water Related Land Use	These are the adjusted flow types by FHC [Urban, Agriculture, Riparian, No Land Use]
iPC_Own	Ownership	These are the adjusted flow types by FHC [Private, STATE, UDWR, BLM, USFS, NPS, Conservation Lands, DOD]
oPC_Prob	Potential for Beaver Conflict Probability	These are the adjusted flow types by FHC [Probability]
oPBRC	Potential Beaver Restoration/Conservation	These are the adjusted flow types by FHC [Management Zones]
e_DamCt	Empirical: Actual Dam Count	These are the adjusted flow types by FHC [dams: optionally NA]
e_DamDens	Empirical: Actual Dam Density	These are the adjusted flow types by FHC [dams/km; Optionally NA]
e_DamPcC	Empirical: Actual Percent of Existing Capacity Ratio	A ratio comparing actual dam count to capacity estimate for segment [ratio between 0 & 1; Optionally NA]
NHDStreamName	NHD Stream Name	The NHD (1:24k) stream name was spatially joined to the BRAT dataset
NHD_FlowType	NHD Fcode	The NHD Fcode for stream type [46006-Perennial; 46003-Intermittent; 55800-Artificial Path; 33400 - Connector
NHD_HUC_8	Hydrologic Unit Code 8	The NHD watershed HUC 8 code for each stream segment
DWR_Region	Utah Division of Wildlife Resources Regions	The UDWR management region for each stream segment
Geohydrologic	USGS Geohydrologic Region	The USGS GeoHydrologic Region used to determine stream power for each stream segment
Ex_Category	Existing Category	The existing vegetation derived BRAT category for each stream segment
Pt_Category	Potential Category	The potential vegetation derived BRAT category for each stream segment

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Table 16 – BRAT output lookup table prefixes and suffixes.

Output Lookup Table Prefixes and Suffixes	
Prefix	
i	input
e	empirical
o	output
m	metric
NHD	Data from the NHD 24K Network
Geo	Data related to the geometry of the segment
Hyd	Data related to hydrologic or hydraulic estimates
Veg	Data related to the vegetation inputs
VC	Vegetation Capacity Model
CC	Combined Capacity Model
PC	Potential Conflict Model
Suffix	
_EX	Existing
_PT	Potential

APPENDIX C: UTAH BRAT ATLAS

This Atlas shows the map outputs of the Utah BRAT model for the entire state as well as by UDWR management regions. Some of the maps shown in this Atlas are also found in the main body of the report, and some are included as sub-figures in a smaller format. Full page versions are provided here.

STATEWIDE MAPS

BEAVER DAM CAPACITY MODELS

EXISTING BEAVER DAM CAPACITY
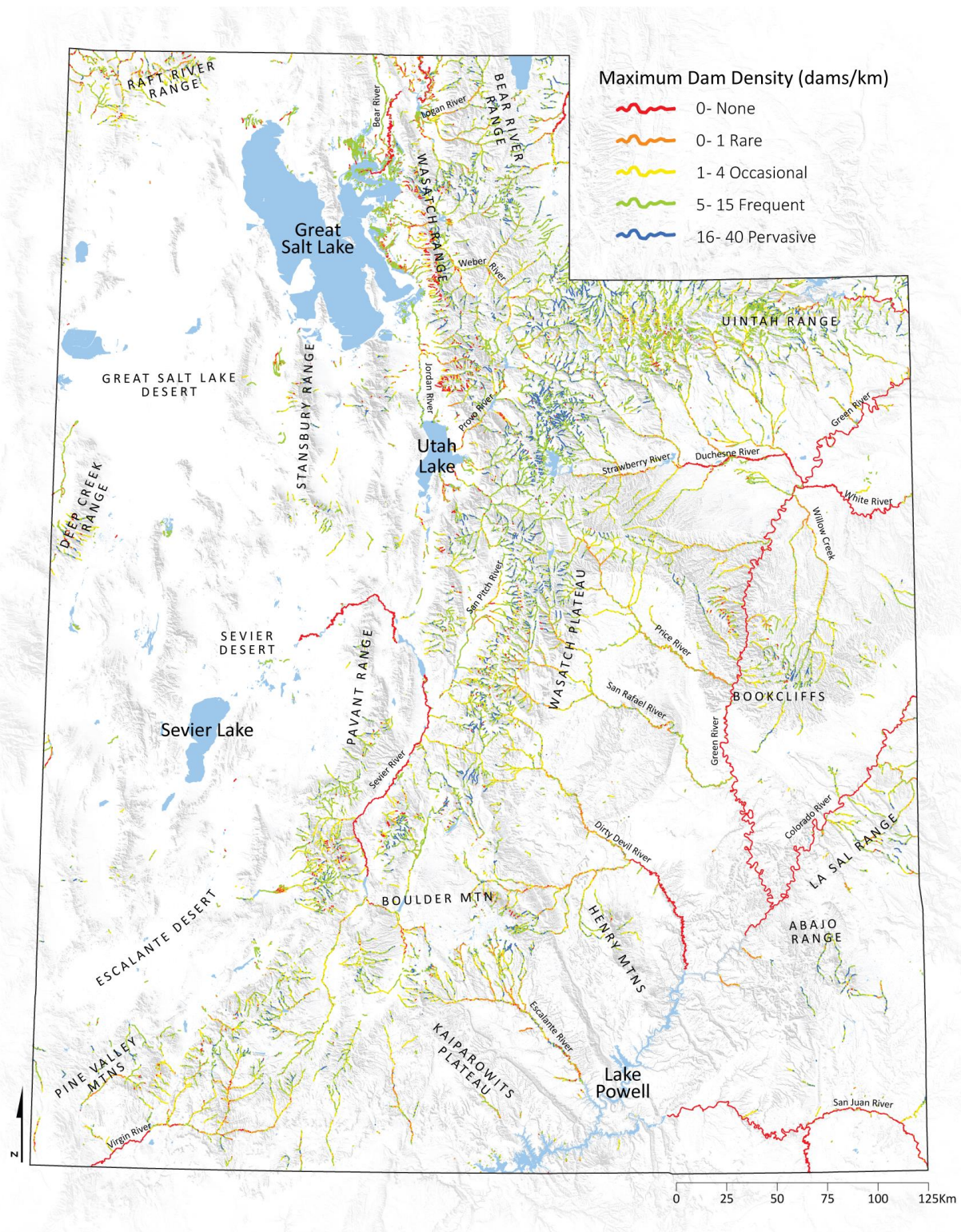
Figure 39 – Existing beaver dam capacity for State of Utah (based on 2011 satellite imagery).

POTENTIAL BEAVER DAM CAPACITY
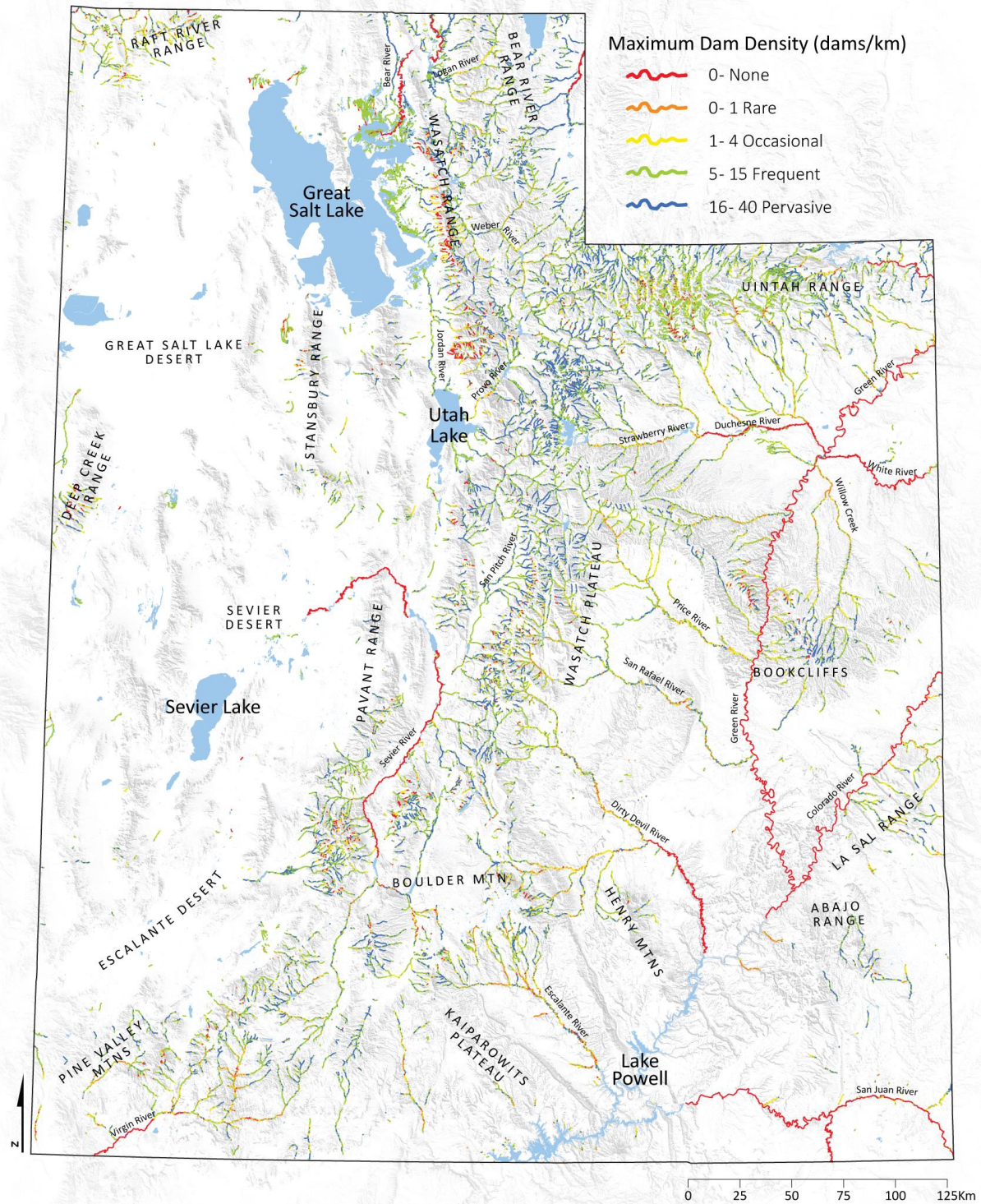
Figure 40 – Historic estimated beaver dam capacity for State of Utah (based on 'potential' LANDFIRE estimates).

DECISION SUPPORT MODELS
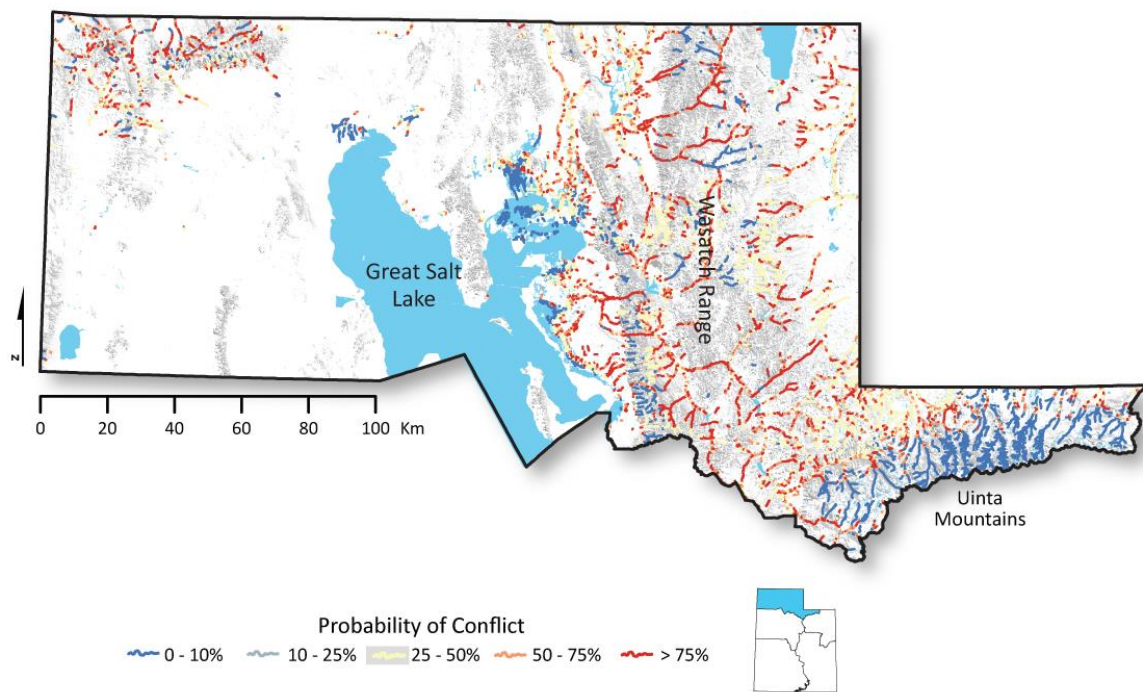
PROBABILITY FOR HUMAN-BEAVER CONFLICT
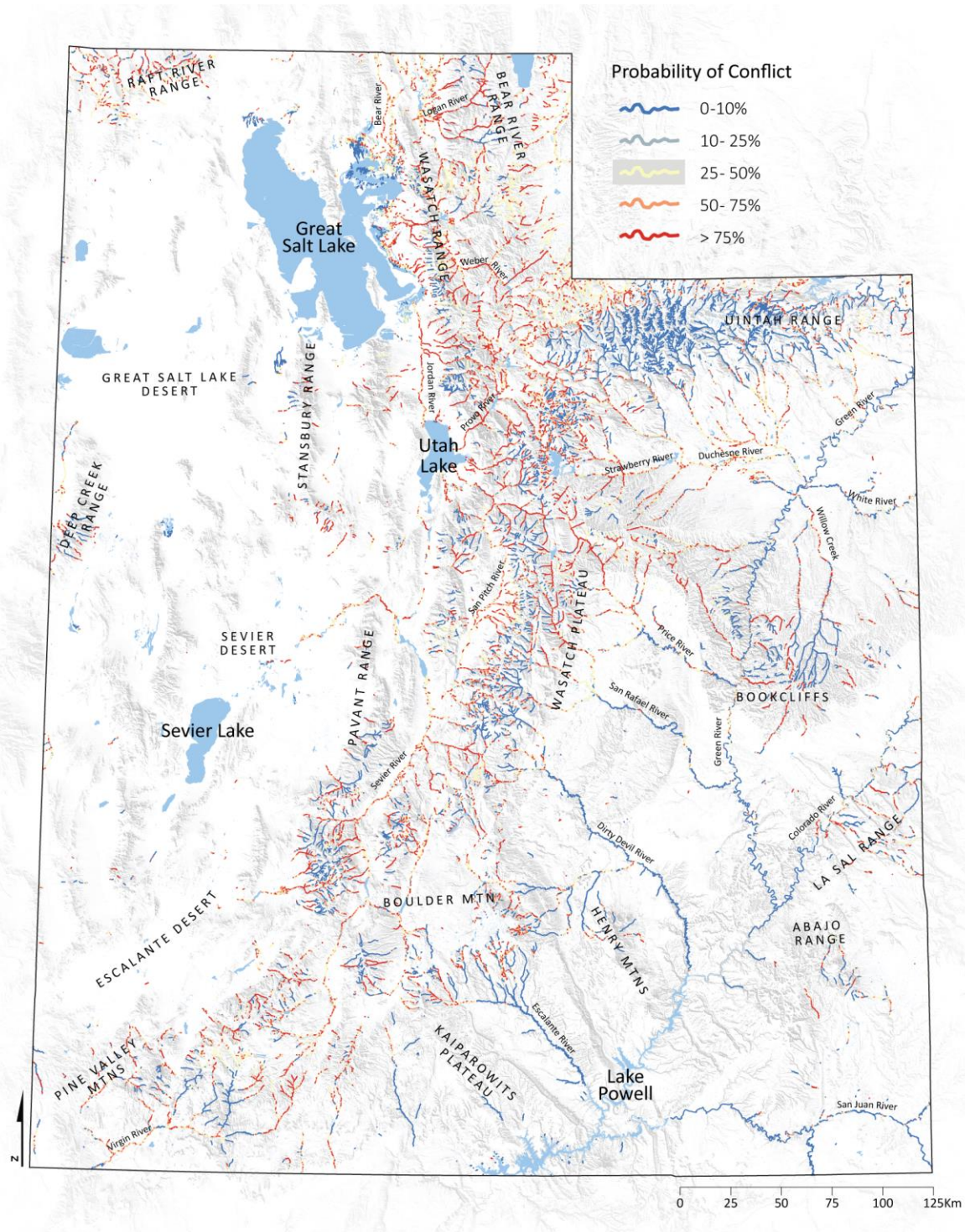
Figure 41 – Existing estimate of probability for human-beaver conflict for State of Utah.

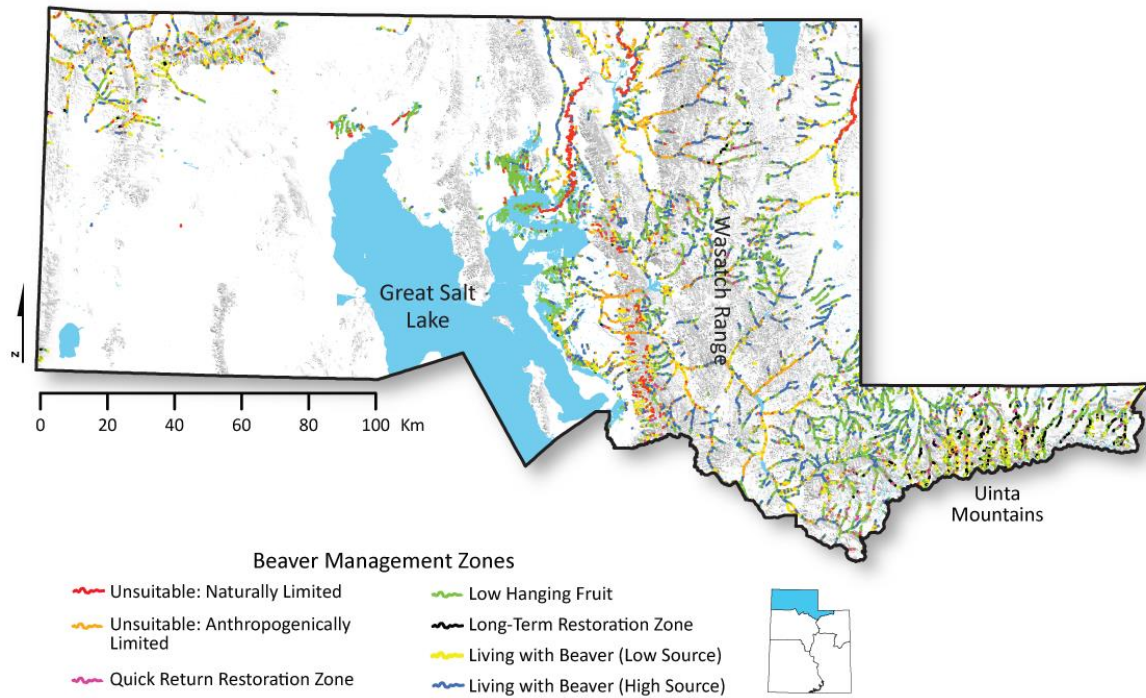## PRELIMINARY BEAVER RESTORATION / CONSERVATION MANAGEMENT MODEL
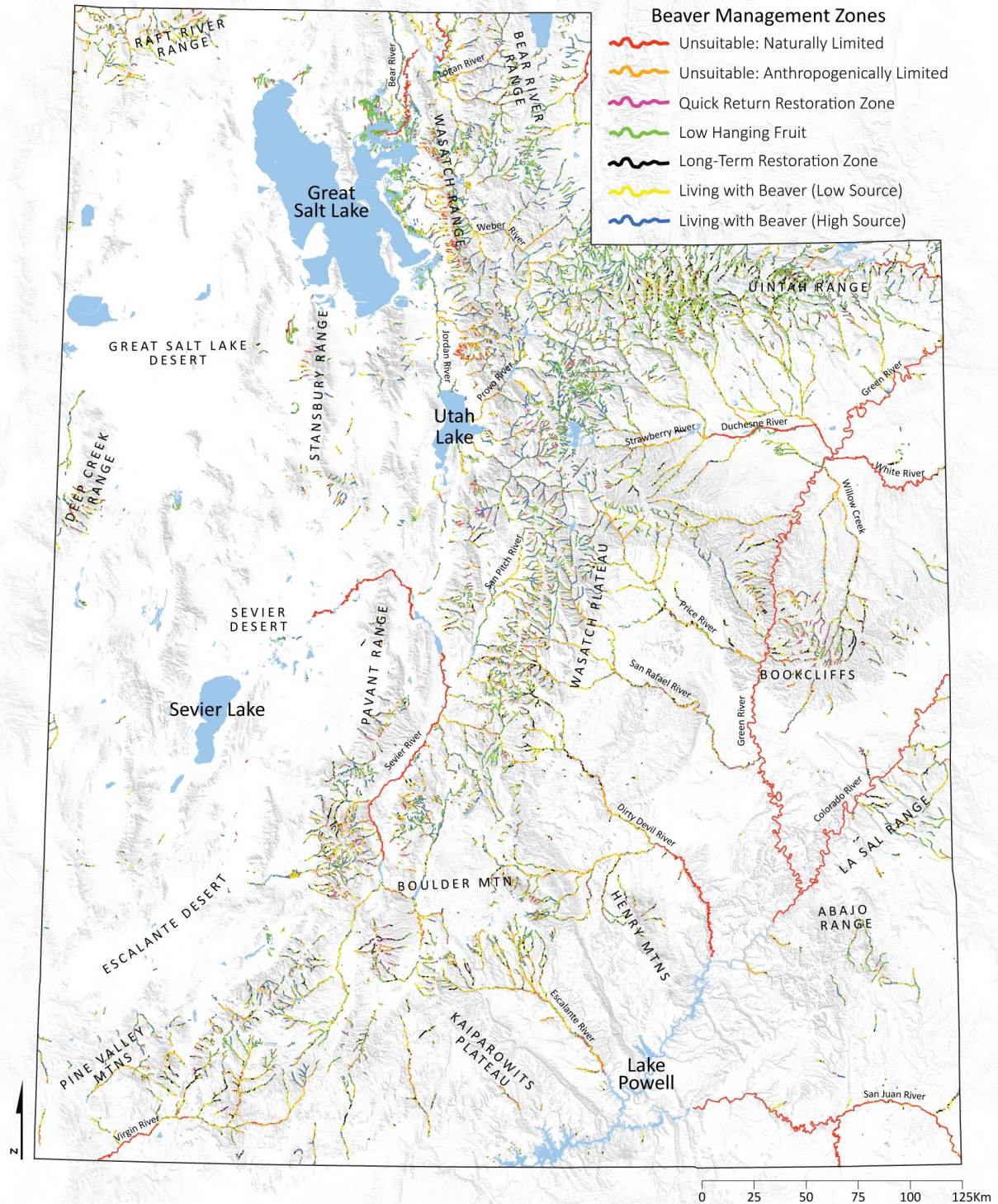
Figure 42 – First cut model of suggested beaver management zones for State of Utah.

MAPS BY REGION

CENTRAL

BEAVER DAM CAPACITY MODELS

EXISTING BEAVER DAM CAPACITY
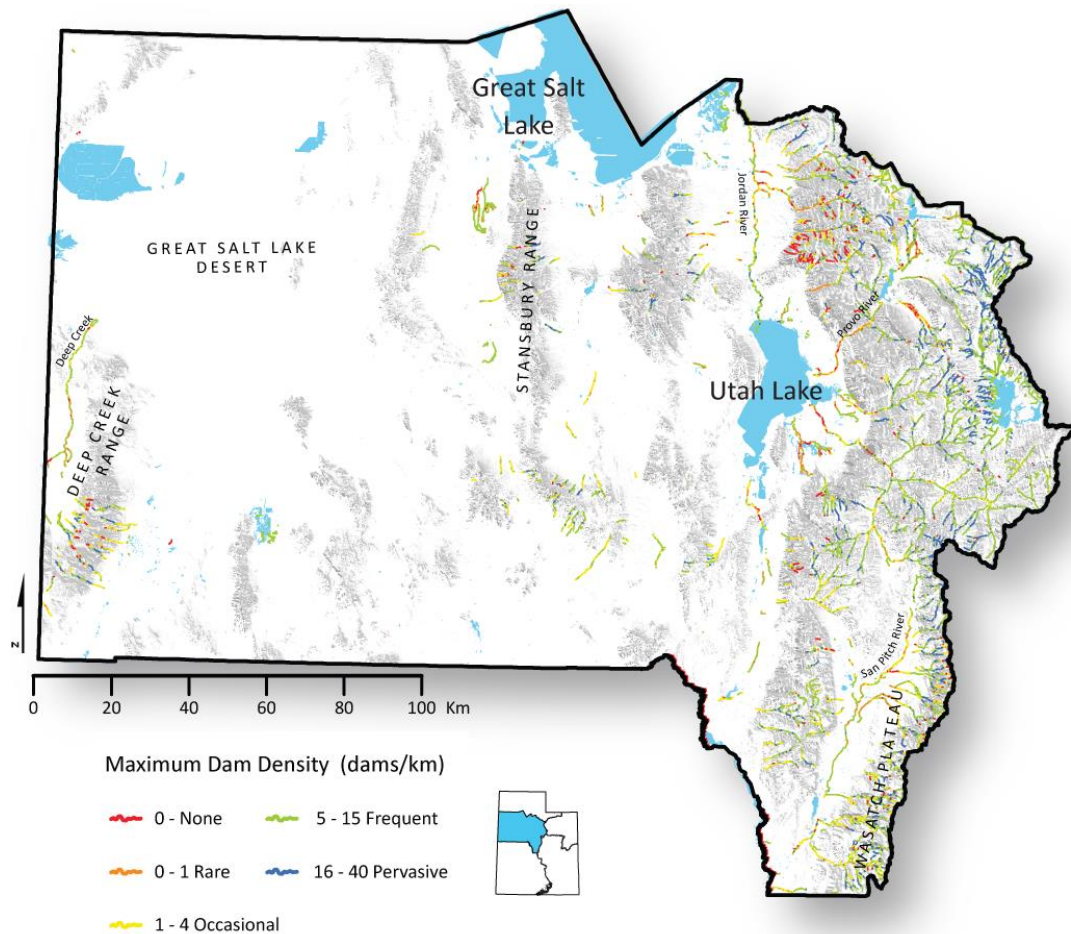
Figure 43 – Existing beaver dam capacity for Central UDWR Region (based on 2011 satellite imagery).

HISTORIC BEAVER DAM CAPACITY
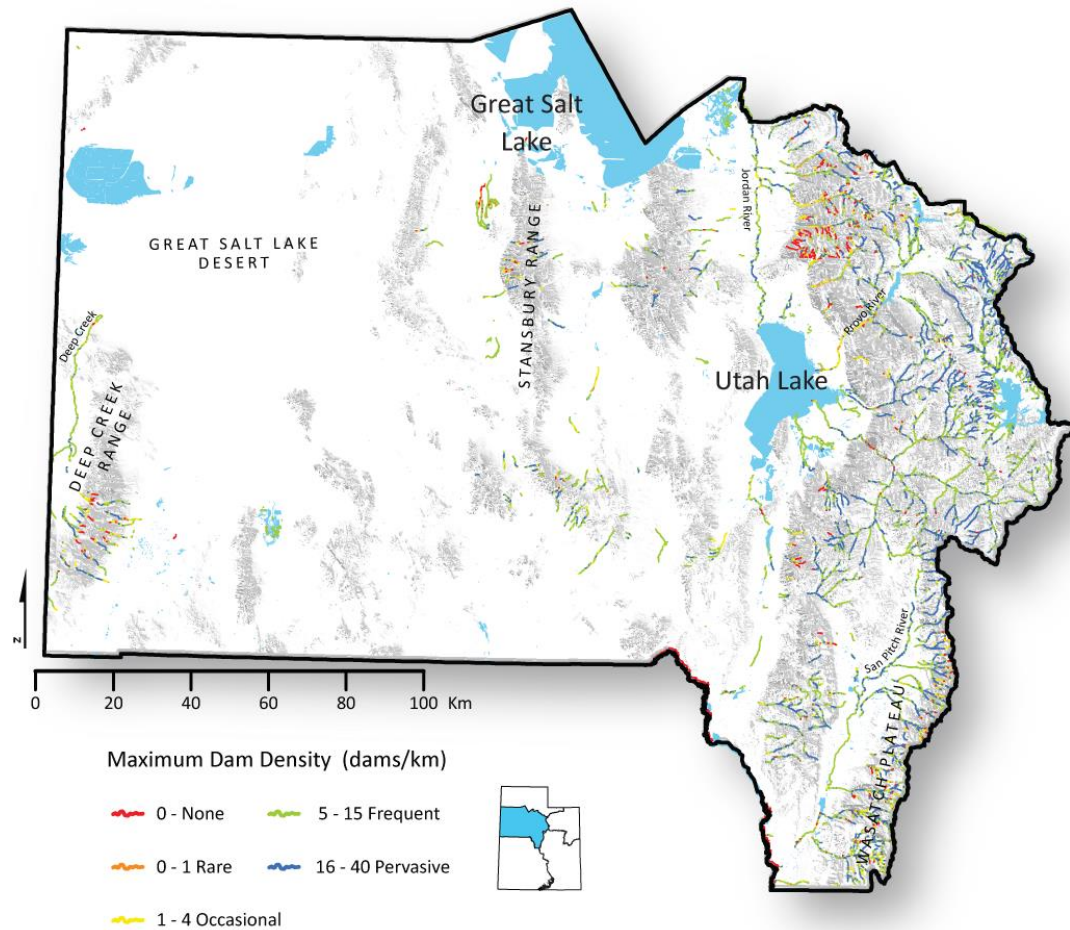
Figure 44 – Historic estimate of beaver dam capacity for Central UDWR Region (based on 'potential' LANDFIRE).

DECISION SUPPORT MODELS

PROBABILITY FOR HUMAN-BEAVER CONFLICT
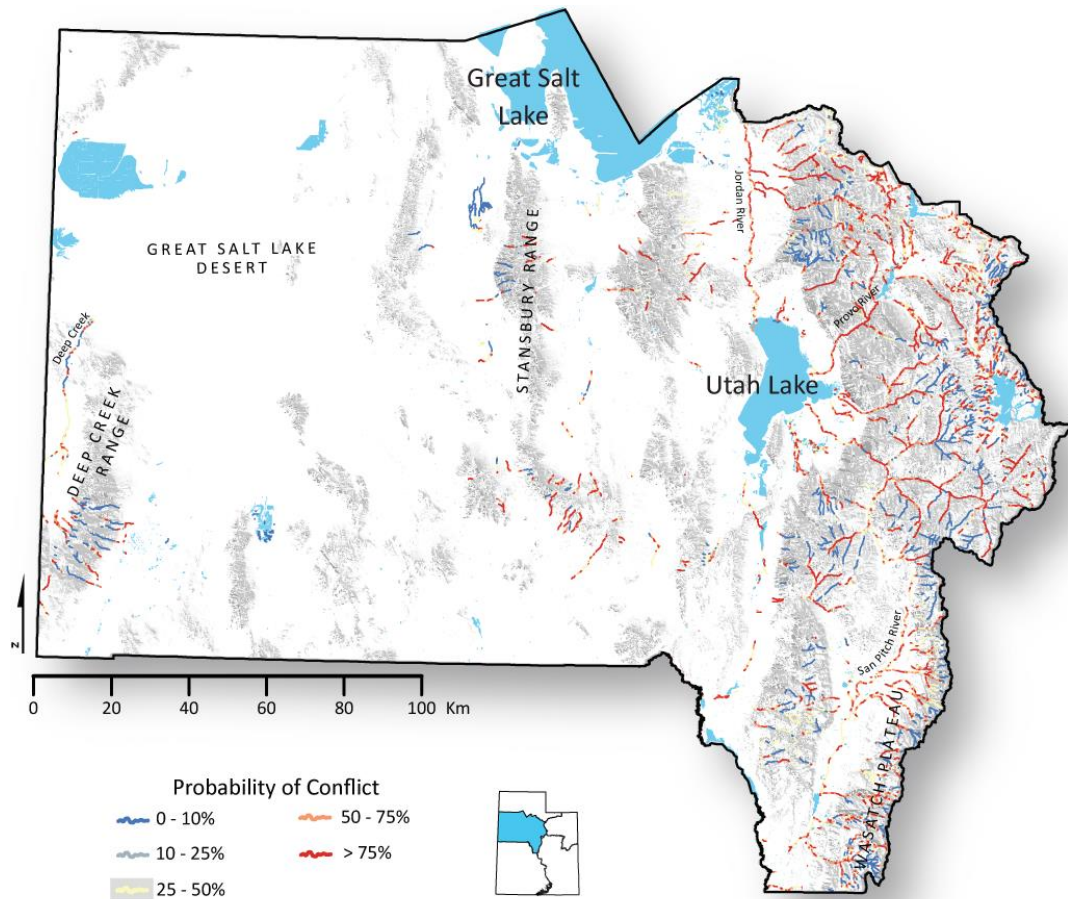
Figure 45 – Existing estimate of probability for human-beaver conflict for UDWR Central Region.

PRELIMINARY BEAVER RESTORATION / CONSERVATION MANAGEMENT MODEL
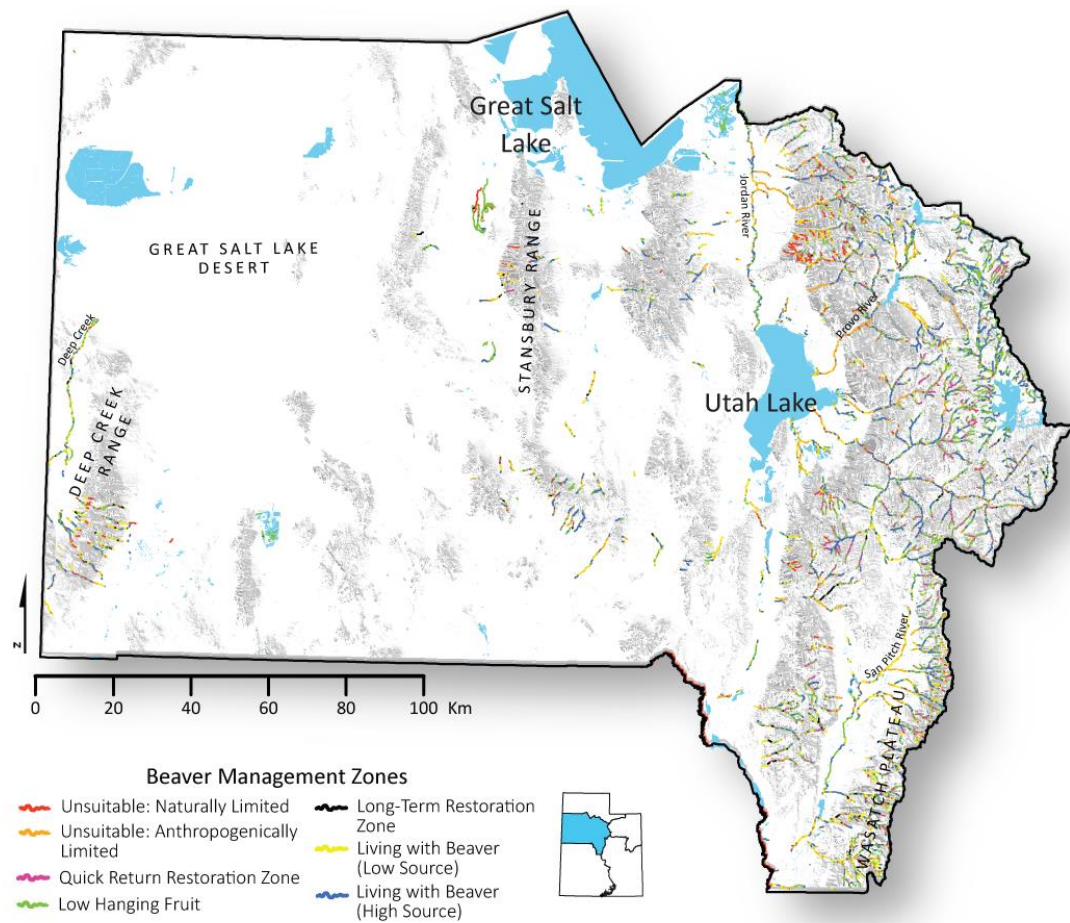
Figure 46 – First cut model of suggested beaver management zones for UDWR Central Region.

NORTHERN

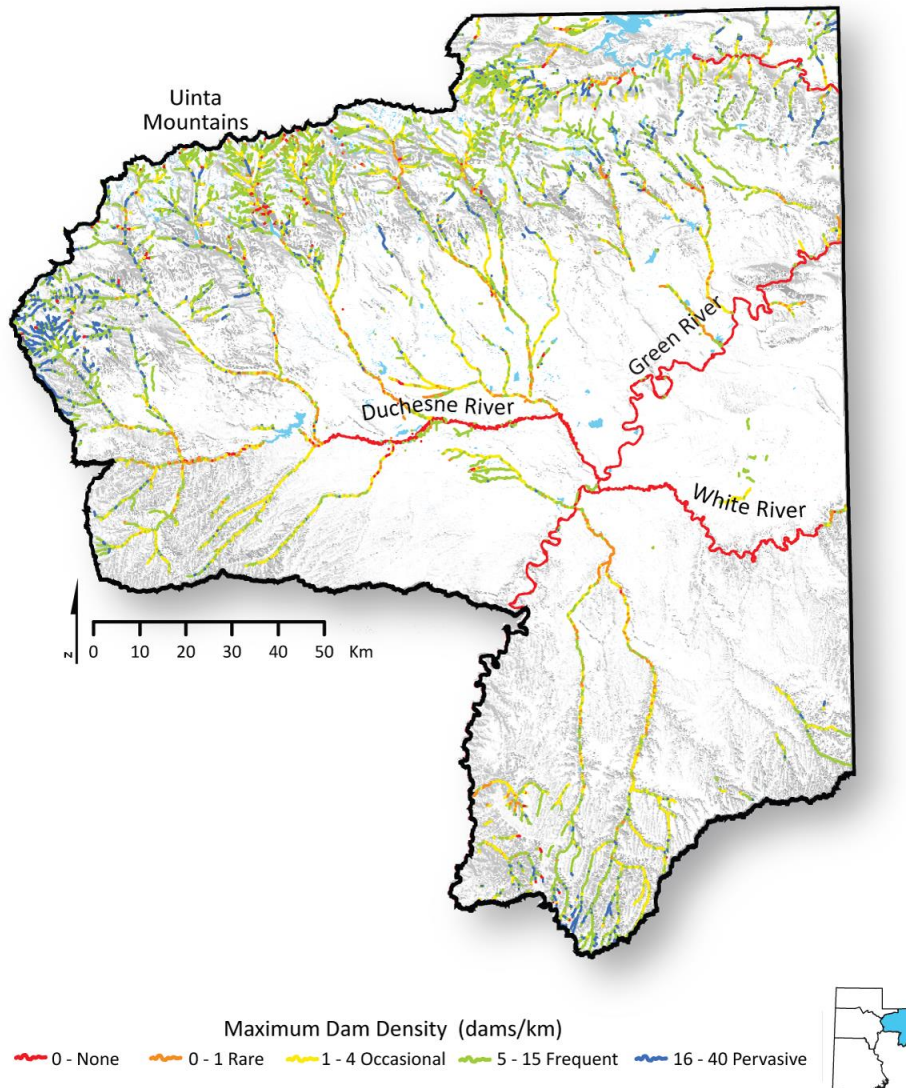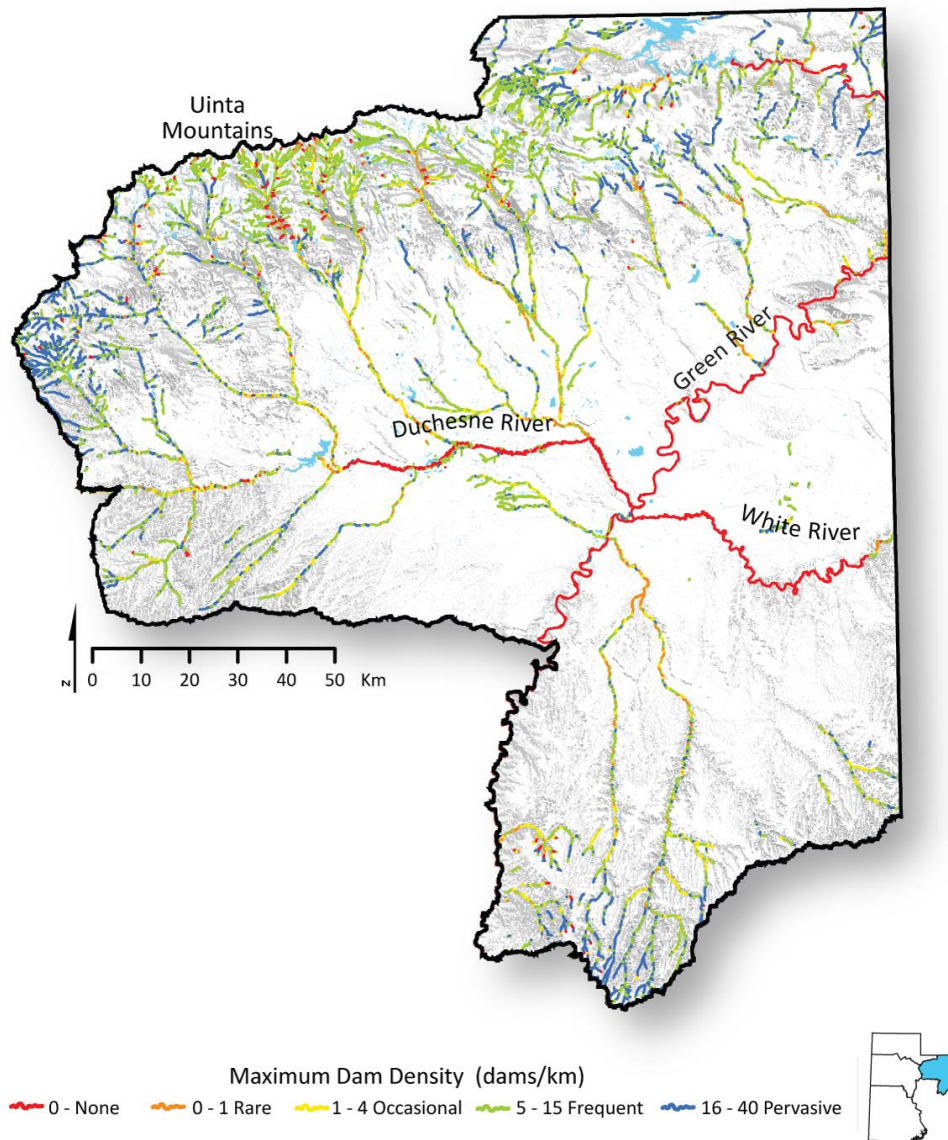## BEAVER DAM CAPACITY MODELS

EXISTING BEAVER DAM CAPACITY
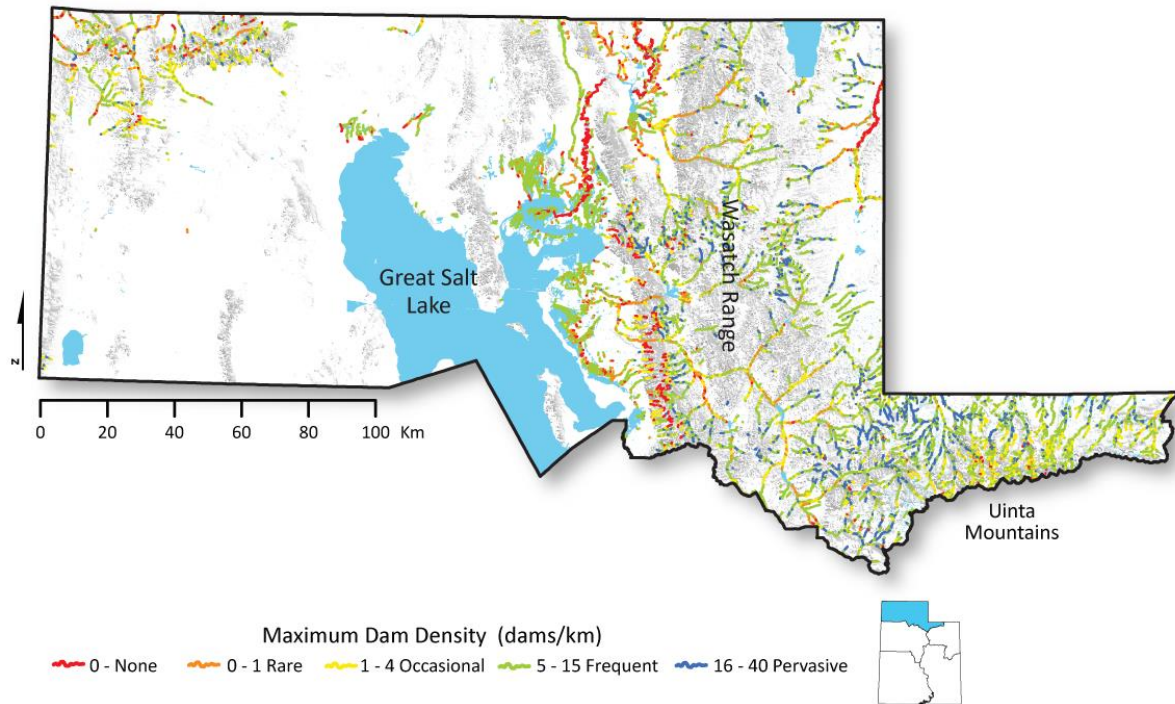
Figure 47 – Existing beaver dam capacity for Northern UDWR Region (based on 2011 satellite imagery).

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HISTORIC BEAVER DAM CAPACITY
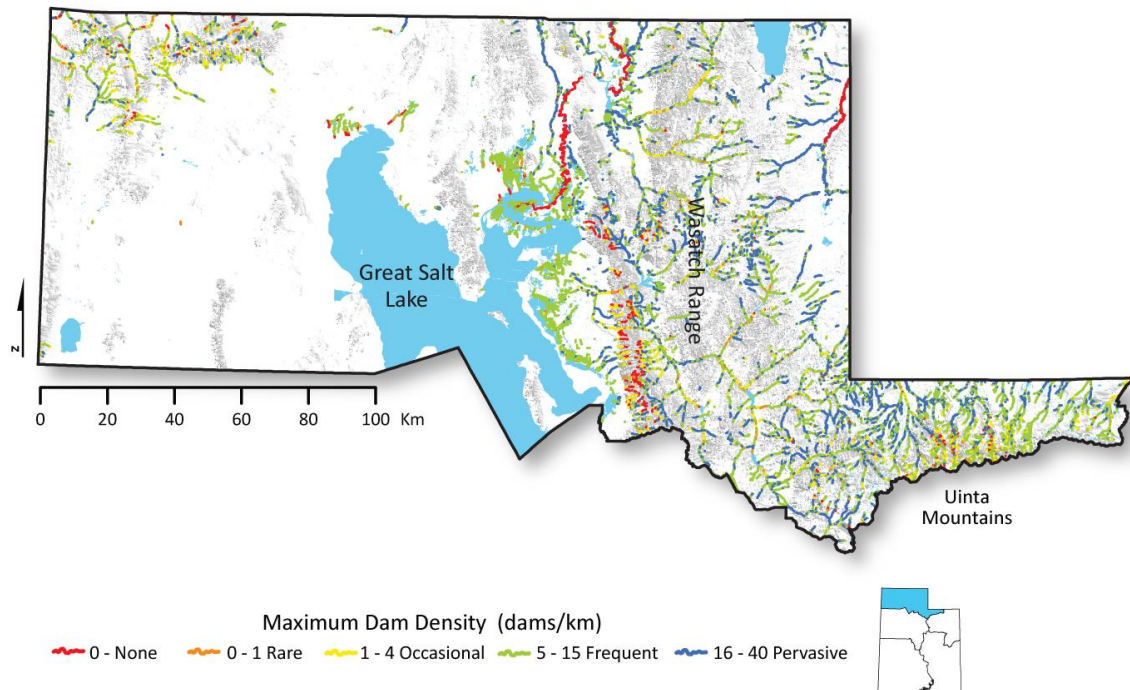
Figure 48 – Historic estimate of beaver dam capacity for Northern UDWR Region (based on 'potential' LANDFIRE).

DECISION SUPPORT MODELS

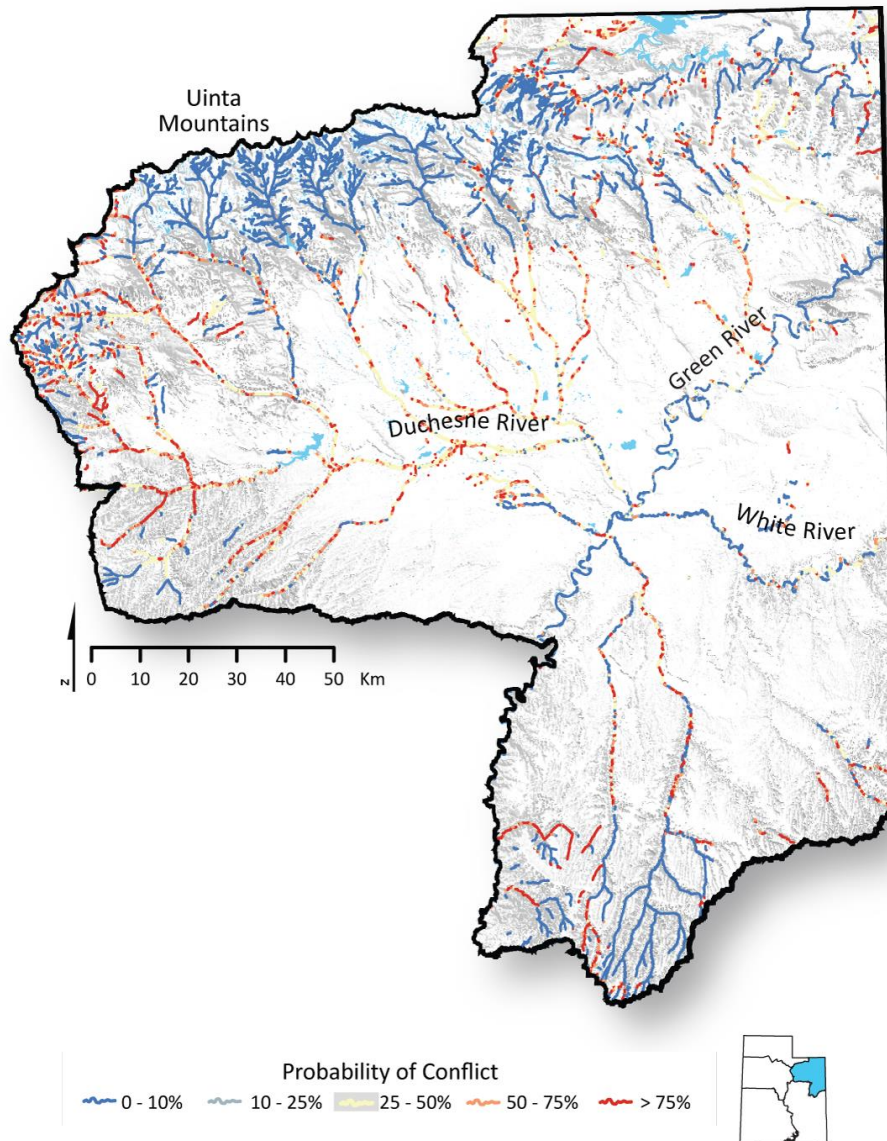## PROBABILITY FOR HUMAN-BEAVER CONFLICT

Figure 49 – Existing estimate of probability for human-beaver conflict for UDWR Northern Region.

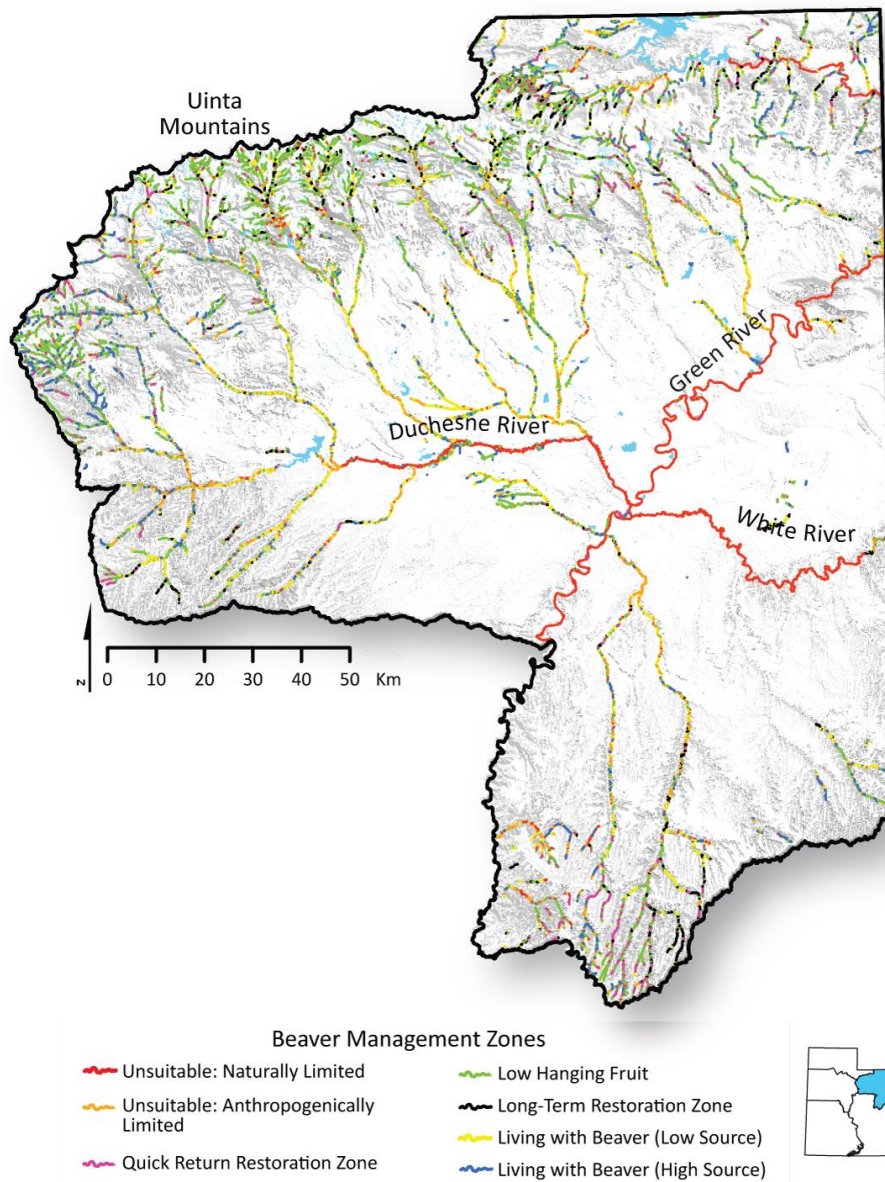## PRELIMINARY BEAVER RESTORATION / CONSERVATION MANAGEMENT MODEL

Figure 50 – First cut model of suggested beaver management zones for UDWR Northern Region.

NORTHEASTERN

BEAVER DAM CAPACITY MODELS
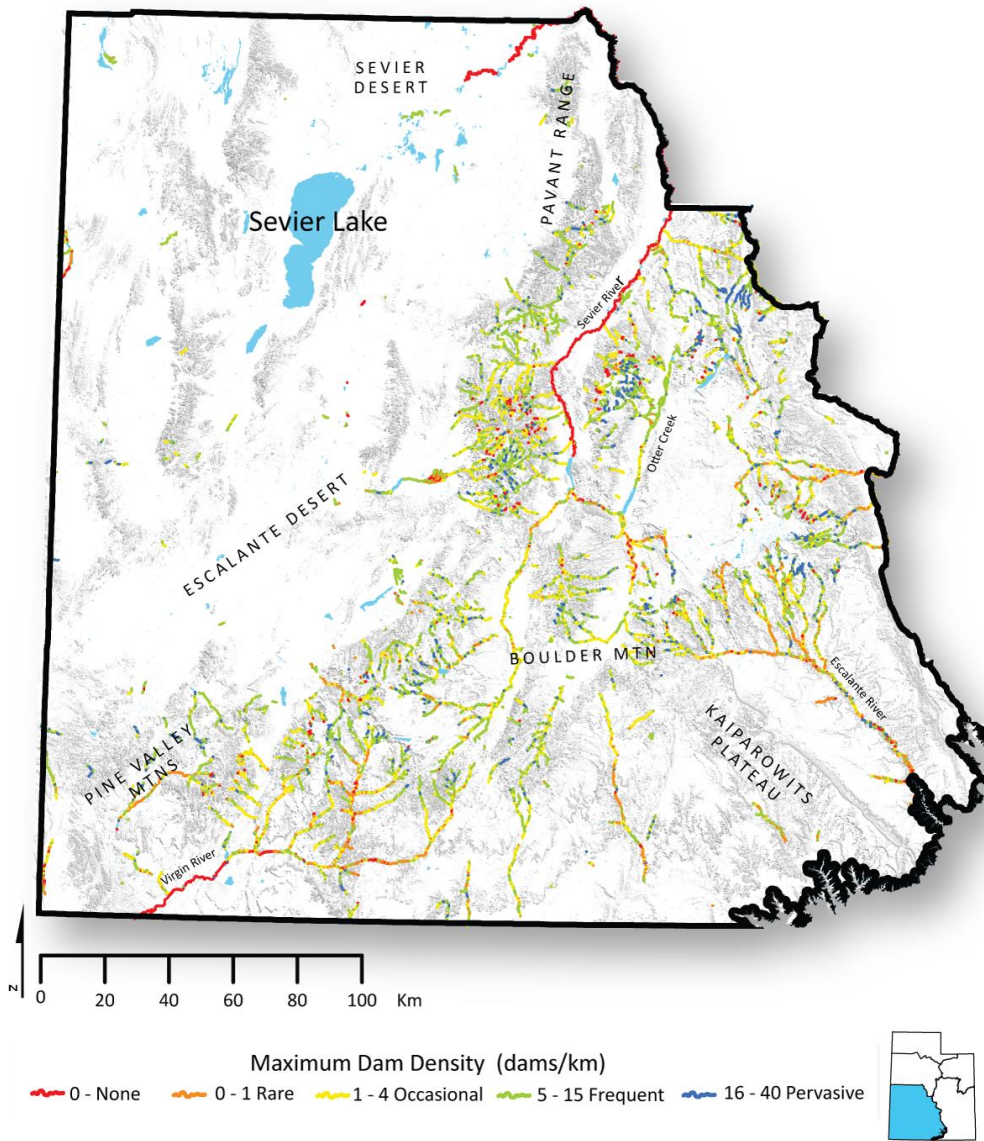
EXISTING BEAVER DAM CAPACITY

Figure 51 – Existing beaver dam capacity for Northeastern UDWR Region (based on 2011 satellite imagery).

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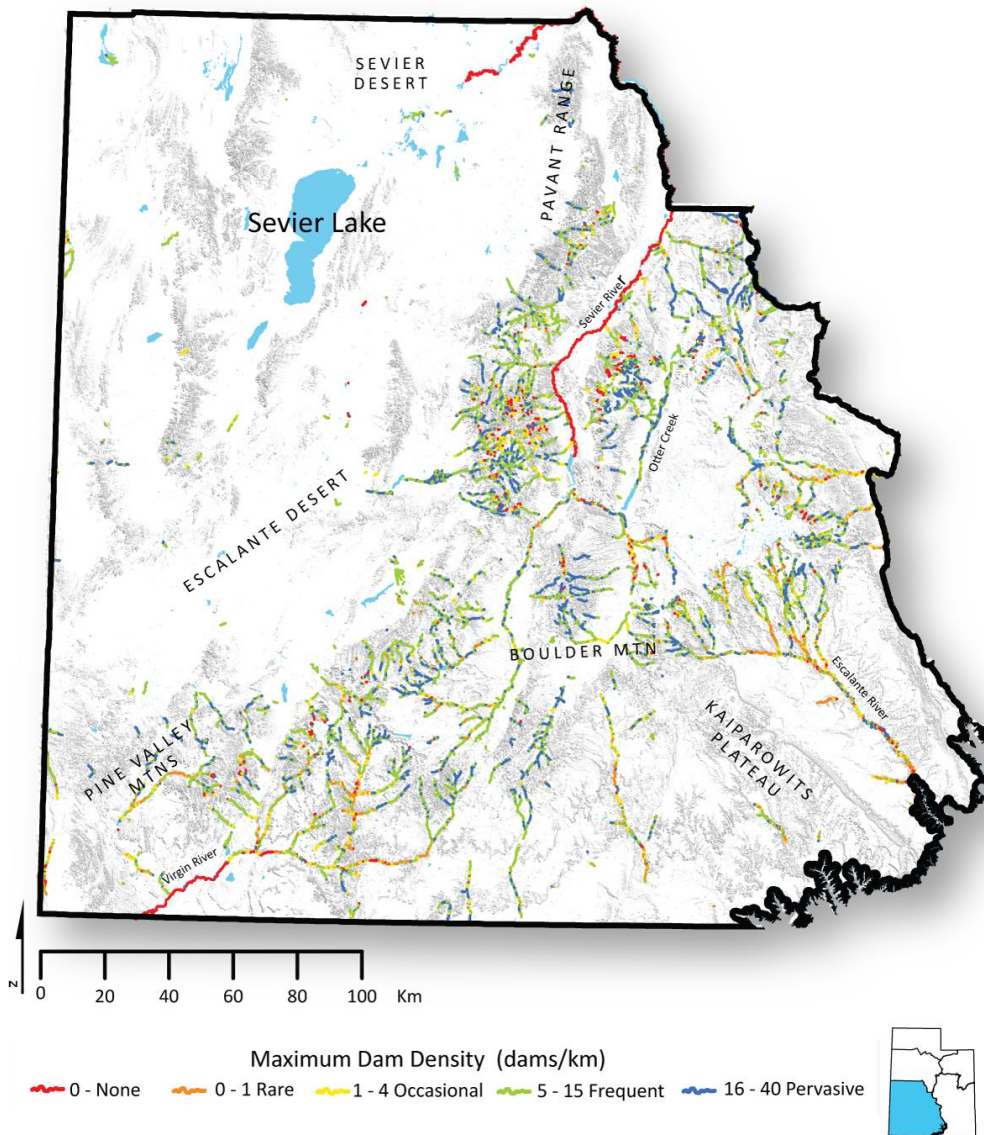
HISTORIC BEAVER DAM CAPACITY

Figure 52 – Historic estimate of beaver dam capacity for Northeastern UDWR Region (based on 'potential' LANDFIRE).

DECISION SUPPORT MODELS

PROBABILITY FOR HUMAN-BEAVER CONFLICT
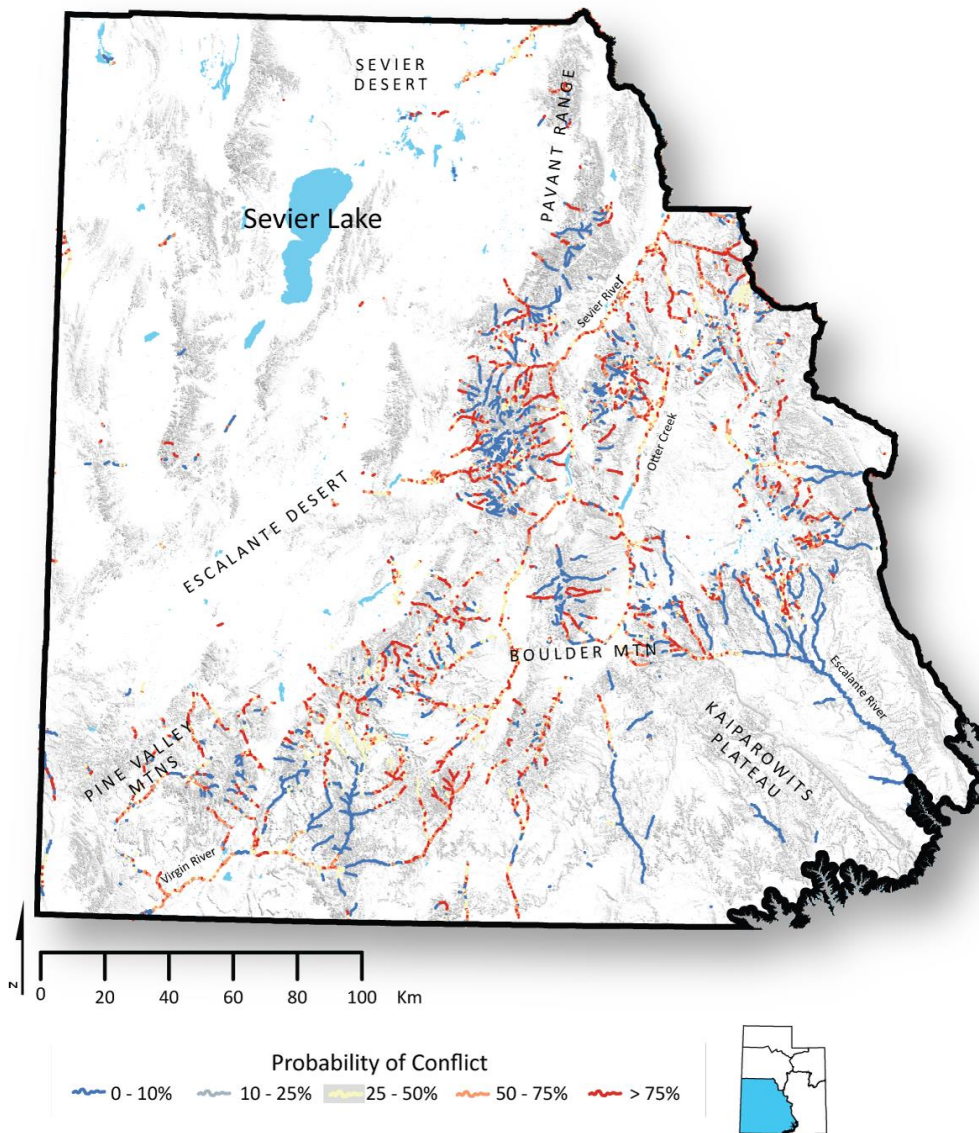

Figure 53 – Existing estimate of probability for human-beaver conflict for UDWR Northeastern Region.

PRELIMINARY BEAVER RESTORATION / CONSERVATION MANAGEMENT MODEL

Figure 54 – First cut model of suggested beaver management zones for UDWR Northeastern Region.

SOUTHERN

BEAVER DAM CAPACITY MODELS

EXISTING BEAVER DAM CAPACITY

Figure 55 – Existing beaver dam capacity for Southern UDWR Region (based on 2011 satellite imagery).

HISTORIC BEAVER DAM CAPACITY

Figure 56 – Historic estimate of beaver dam capacity for Southern UDWR Region (based on 'potential' LANDFIRE).

DECISION SUPPORT MODELS

PROBABILITY FOR HUMAN-BEAVER CONFLICT

Figure 57 – Existing estimate of probability for human-beaver conflict for UDWR Southern Region.

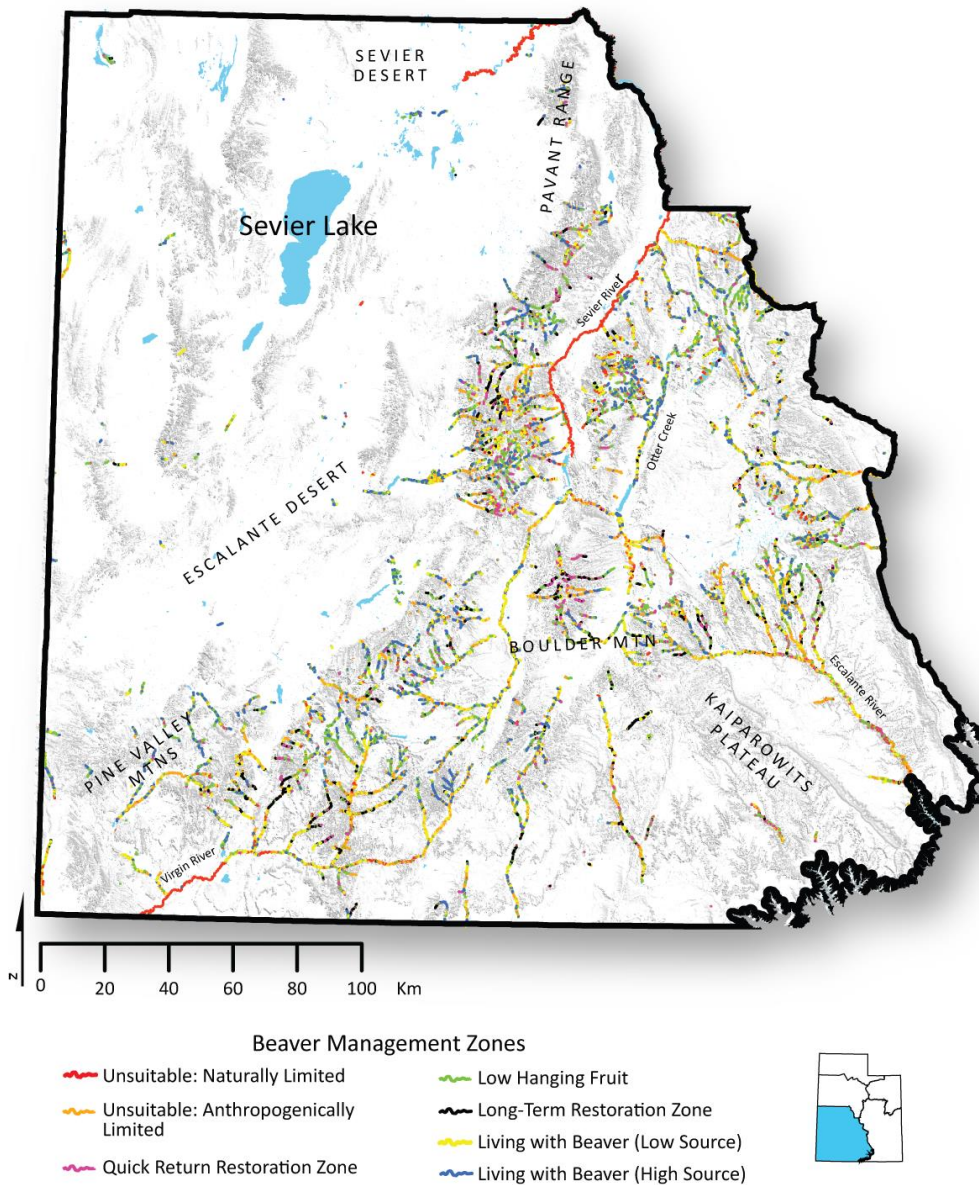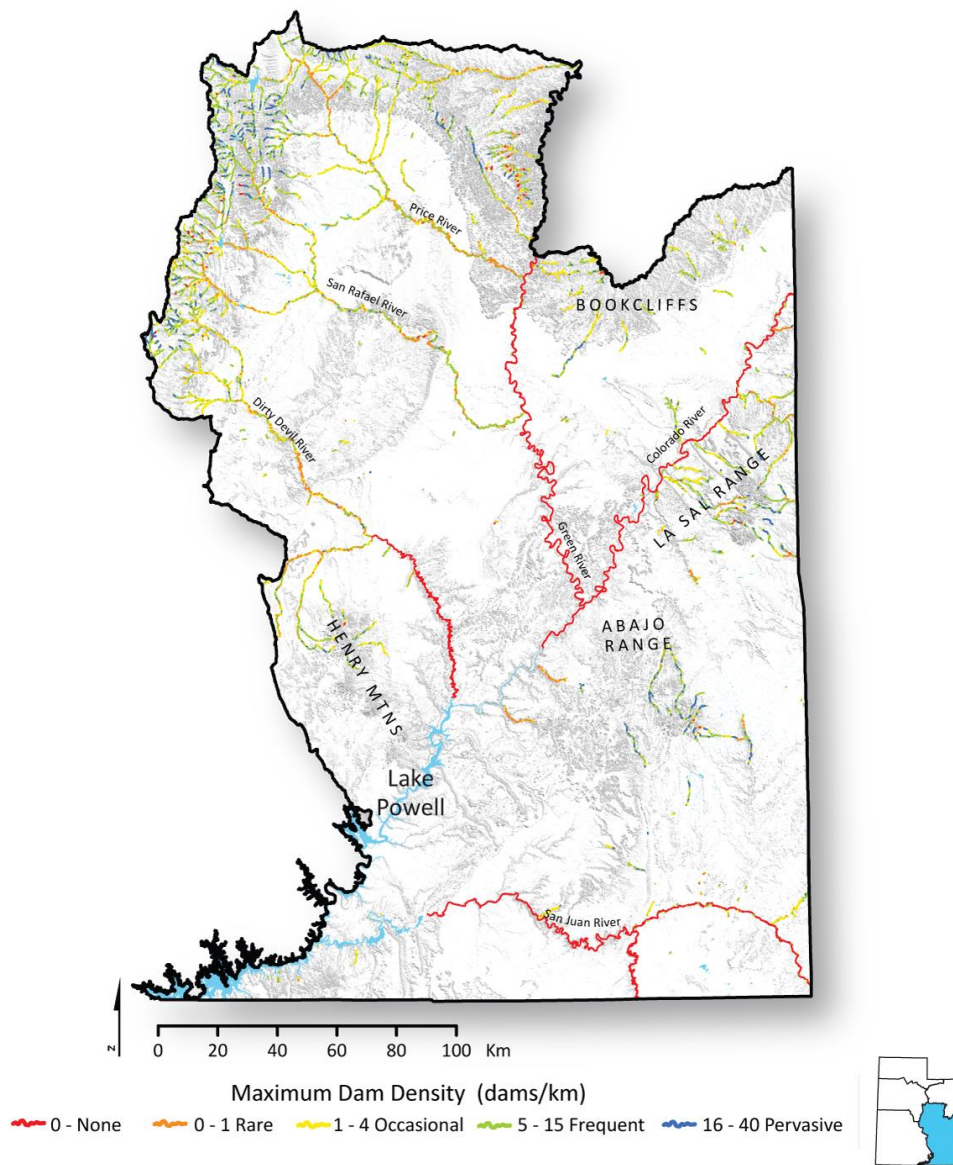## PRELIMINARY BEAVER RESTORATION / CONSERVATION MANAGEMENT MODEL

Figure 58 – First cut model of suggested beaver management zones for UDWR Southern Region.

SOUTHEASTERN

BEAVER DAM CAPACITY MODELS

EXISTING BEAVER DAM CAPACITY

Figure 59 – Existing beaver dam capacity for Southeastern UDWR Region (based on 2011 satellite imagery).

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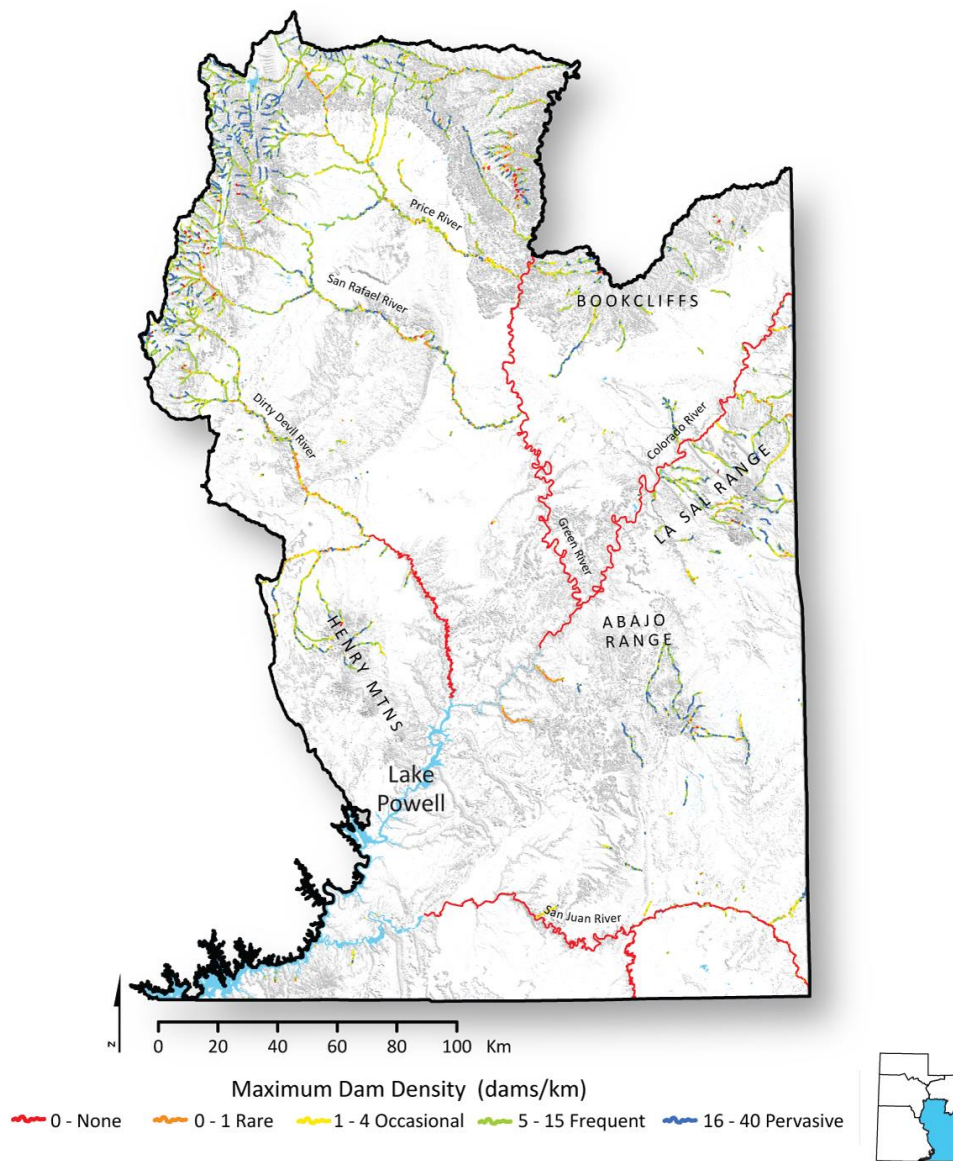ANALYSIS LABORATORY

HISTORIC BEAVER DAM CAPACITY

Figure 60 – Historic Estimate of Beaver Dam Capacity Model for Southeastern UDWR Region (based on 'potential' LANDFIRE).

DECISION SUPPORT MODELS
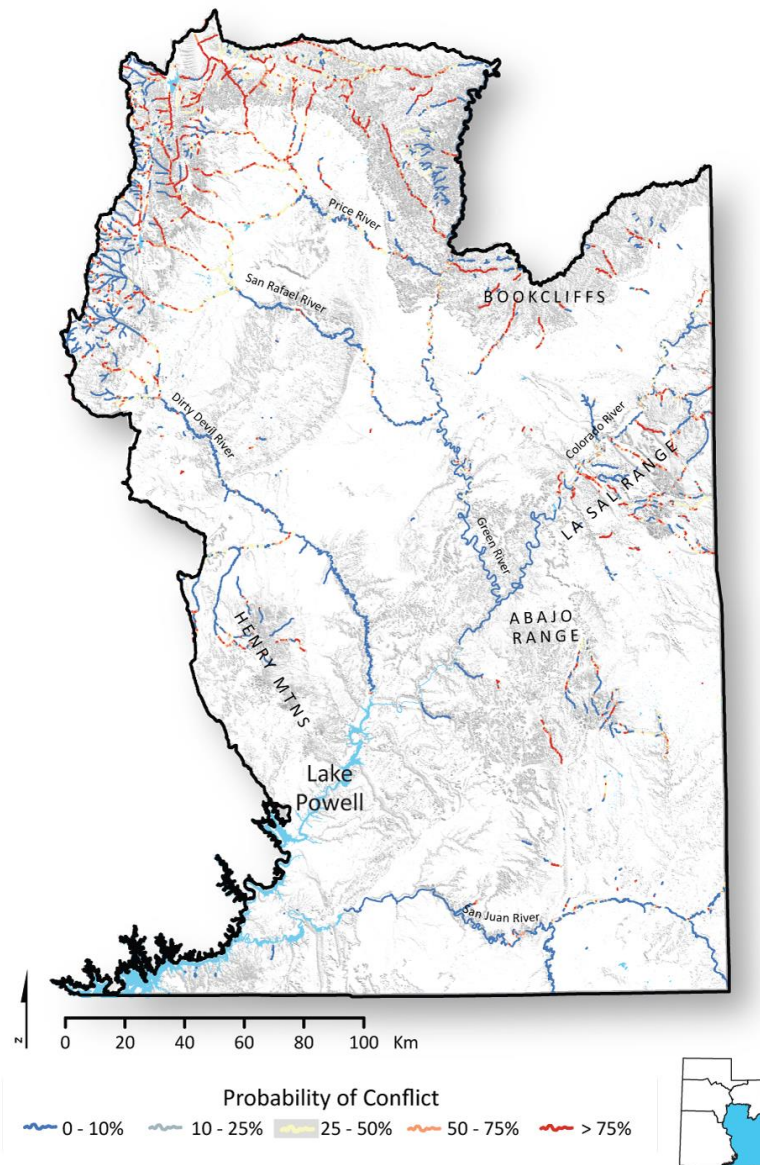
PROBABILITY FOR HUMAN-BEAVER CONFLICT

Figure 61 – Existing estimate of probability for human-beaver conflict for UDWR Southeastern Region.

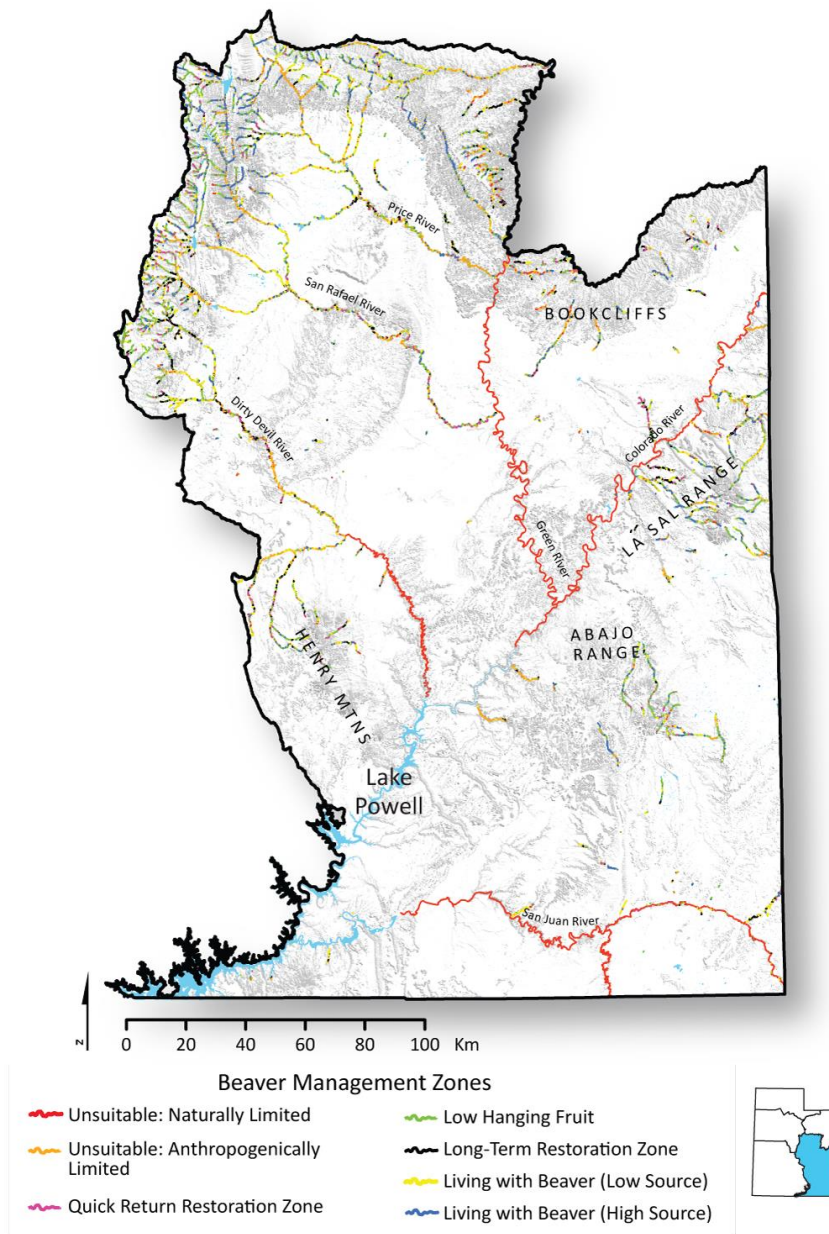## PRELIMINARY BEAVER RESTORATION / CONSERVATION MANAGEMENT MODEL

Figure 62 – First cut model of suggested beaver management zones for UDWR Southeastern Region.