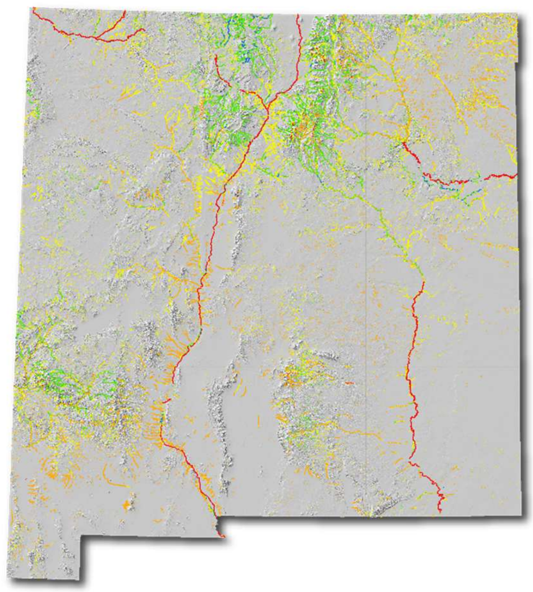
NEW MEXICO
BEAVER RESTORATION ASSESSMENT TOOL

A Decision Support and Planning Tool



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RIVERSCAPES ASSESSMENT & MONITORING LABORATORY

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EXECUTIVE SUMMARY

This report summarizes an application of the Beaver Restoration Assessment Tool (BRAT) v5.2.3 (tools.riverscapes.net/brat)—a spatial modeling framework that helps managers identify where beaver activity can effectively support riverscape restoration and where it may pose conflicts with human infrastructure (Macfarlane et al., 2017). In this analysis, 21,103 km of perennial streams and 16,962 km of canals and acequias across New Mexico were evaluated to estimate beaver dam capacity, identify human/beaver conflict risk and reaches suitable for beaver-based restoration, conservation, or coexistence management.

Model results estimate an existing statewide capacity for perennial streams at 155,941 beaver dams (4.5 dams/km) compared to a historic capacity of 206,358 dams (7.4 dams/km), indicating a 24% reduction. This loss is largely attributed to stream incision, riparian vegetation decline associated with grazing, land-use conversion for agriculture, and urban development. Despite these reductions, New Mexico's waterways are still capable of supporting and sustaining a substantial amount of beaver dam-building activity especially in the northern, mountainous ecoregions (Southern Rockies, AZ/NM Mountains). Our capacity model validation suggests that the model predicts dam building capacity well across the northern portion of the state; southern validation was limited by low dam counts.

Our analysis indicates that in 57% of the stream network where there is dam building capacity, beaver activity would pose negligible risk to infrastructure—representing substantial low-conflict opportunity for dam building beaver and beaver-based restoration—while 12% is classified as having considerable (4%) or some (8%) risk. When acequias are considered human beaver risk increased substantially. For example, the 'considerable' risk category increased to 32% of the network.

Management outputs show that 16% of the network is suitable for beaver conservation or translocation, and an additional 6% is suitable for encouraging beaver expansion or colonization, highlighting areas that are currently suitable for beaver-assisted restoration. Fourteen percent of the perennial network was identified as needing land management change and 4% were identified as needing beaver mimicry prior to being ready for beaver-based restoration.

Twenty-eight percent of the perennial network was categorized as unsuitable for dam building and this was split between reaches where dam building is limited by stream power (19%), too steep to support dam building (0.6%) in the mountainous headwaters and size limited (8%) in larger, higher-order streams. This illustrates how the morphology and hydrology of the state result in an optimal size range of stream for dam building which excludes small, but very steep streams and larger rivers.

Riverscape degradation driven by channel incision, riparian vegetation decline (grazing, fire suppression, land conversion), and hydrologic alteration is widespread. Recommended restoration actions include: prioritizing beaver-based restoration on the low-risk/high-capacity reaches; scaling up LT-PBR and riparian revegetation; implementing grazing adjustments and coexistence measures.

This statewide BRAT application provides spatially explicit decision-support for beaver-based restoration and management in New Mexico. The results identify where beaver activity can most effectively enhance water retention, habitat diversity, and climate resilience, while minimizing potential conflicts with infrastructure. These findings can guide strategic planning, prioritization, and implementation of beaver-related conservation and restoration actions across the state's diverse riverscapes.

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INTRODUCTION

Prior to European settlement, North America supported an estimated 250 million beaver (*Castor canadensis*) ponds, collectively impounding enough water to inundate the states of Washington, Oregon, and California (Goldfarb, 2018). Beaver dams raised water tables and re-wetted floodplains, which in turn curtailed channel incision and reduced sediment delivery to downstream reaches (Pollock et al., 2014). These hydrologic modifications fostered the formation of slow, low-gradient, geomorphically complex stream networks across connected floodplains, increasing habitat heterogeneity for plants, macroinvertebrates, fish, birds, and other wildlife (Fairfax & Small, 2018; Hood & Bayley, 2008; Washko et al., 2020) and lowered the wildfire vulnerability of valley bottoms through persistent wetting (Fairfax et al., 2024).In addition, beaver activity has been linked to improved water quality (Bason et al., 2017; Dewey et al., 2022), expansion of wetland area (Burchsted et al., 2010), higher biodiversity (Law et al., 2019), and greater carbon storage relative to undammed reaches (Laurel & Wohl, 2019; Wohl et al., 2012). However, intensive fur trapping across the western United States during roughly a 30-year span in the early 1800s drastically reduced beaver populations and removed their wetland-forming functions from many riparian systems. By the 20th century, beaver numbers had fallen to about 100,000 individuals—less than 1% of their historical population. The loss of beaver-driven wetland processes has contributed to widespread riparian degradation (Albert et al., 2021); notably, an estimated 45% of species listed under the U.S. Endangered Species Act rely on riparian habitats (Crozier et al., 2019).

There is increasing appreciation of the role of beaver and associated activities—dam construction, tree harvesting, and floodplain canal excavation—in creating and sustaining aquatic and riparian ecosystem function (Larsen et al., 2021). As a result, beaver-based restoration approaches—principally beaver dam mimicry, strategic coexistence, and translocation— are now widely recognized as one of the most cost-effective and sustainable strategies for geomorphic and ecological restoration, as well as for climate change mitigation and resilience. These approaches seek not only to restore beaver populations, but also to reestablish the myriad ecological and hydrological functions their dams provide. Low-tech process-based restoration (LT-PBR) employs simple, hand-built instream structures that deliberately mimic natural beaver dams and wood jams to re-establish hydrologic, geomorphic, and biological process rates. Beaver Dam Analogs (BDAs) are designed to reproduce the ecosystem services of natural beaver engineering, including:

- Elevated groundwater levels and recharge
- Increased water availability for riparian expansion
- Creation of pool habitat
- Sediment retention
- Acceleration of channel incision recovery
- Improved channel–floodplain connectivity

Although these outcomes might be achieved through human-built structures, their long-term persistence is unlikely without eventual natural colonization by, or translocation of, beavers.

LT-PBR and beaver-based tactics are increasingly adopted by agencies, landowners, Indigenous nations, and practitioners because they can rapidly reestablish water-dependent habitats and deliver durable, low-maintenance benefits for climate adaptation and biodiversity conservation (Washko et al., 2022). However, beaver-based restoration is not appropriate everywhere. Although beavers tolerate a wide range of habitats, their dam-building behavior is constrained by local conditions: flow regime and the availability of suitable dam-building materials strongly influence where dams are constructed. Additionally, beaver activity can conflict with human infrastructure and managed landscapes, where they are frequently perceived as a nuisance (McKinstry & Anderson, 1999). Accordingly, integrating beaver-based approaches with working-lands objectives—and selecting sites where geomorphic and hydrologic conditions support sustainable dam construction—is essential for long-term success.

Beavers are habitat generalists across various freshwater systems (streams, rivers, lakes, ponds), but their dam-building behavior concentrates where deep-water refugia are insufficient for secure foraging and access to lodges or bank dens. Consequently, small streams—characterized by limited water depths—are primary locations for dam construction. The degree to which beavers modify stream channels—and the specific changes to flow paths and resulting geomorphic features—depends on a suite of interacting factors: flow regime, channel gradient and stream power, availability of forage and dam-building materials, and demographic or ecological constraints on beaver populations (for example, predation pressure and the proximity of suitable habitat for emigration or immigration).

Beaver Restoration Assessment Tool (BRAT) was developed to support beaver-based restoration decision-making by mapping where riverscapes can support beaver dam-building and where beaver activity may conflict with human infrastructure. BRAT focuses on dam-building capacity (dams per kilometer) rather than general beaver presence, because dams are the primary drivers of hydrologic and geomorphic change. By integrating hydrology, vegetation, and proximity to infrastructure, BRAT provides spatially explicit, reach-scale guidance to identify:

- capacity of riverscapes to support beaver dam-building activity,
- areas unsuitable or limited for beaver dam building, and
- reaches offering the greatest potential for conservation, translocation, or beaver-assisted restoration.

BRAT helps managers determine where beaver activity may pose a nuisance—informing mitigation or relocation efforts—and where it may offer substantial restoration benefits. As a decision-support tool, BRAT enables resource managers, restoration practitioners, and researchers to evaluate where existing populations could be supported, where reintroductions may be appropriate, and what geomorphic or ecological benefits beavers could bring to those systems. Beyond restoration planning, BRAT can guide conservation and management actions such as establishing beaver trapping closures, identifying suitable translocation sites, and prioritizing riparian revegetation or timber and grazing management to improve riverscape health. It also helps identify areas where beaver activity should be avoided or where coexistence strategies—such as pond levelers, beaver deceivers, or vegetation protection—could be implemented to reduce conflicts and promote sustainable cohabitation.

Arid and semi-arid regions such as New Mexico present challenges and opportunities for beaver-based restoration. Many streams in New Mexico are intermittent or ephemeral, offering little stable habitat for beaver colonies, while historic grazing, channel incision, and invasive vegetation have reduced the availability of woody forage needed for dam construction. Intense, flashy floods can destroy dams and prevent long-term colony establishment. Recently, a generalized BRAT model was run across the contiguous United States. While this national dataset provides broad insights, it lacks calibration for local variation in vegetation, and hydrology found across New Mexico. In this project, we localized the BRAT model using imagery-based beaver dam inventories, along with regional vegetation classification datasets, to improve its accuracy and relevance. This localized modeling effort better represents the unique vegetation and hydrologic conditions of New Mexico, resulting in more precise identification of areas where beaver-based restoration is most feasible.

The main objective of this project is to provide Rio Grande Return with spatially explicit maps that prioritize stream reaches for beaver-based restoration and conservation across New Mexico. These data are intended to help the organization strategically leverage beavers as agents of ecological restoration while accounting for potential nuisance impacts. This report summarizes the foundations of the BRAT model, presents key findings and outputs, and offers management recommendations. Together, these elements form a framework for beaver management that highlights opportunities for:

- Riparian reforestation to enhance beaver forage and dam-building materials,
- Restoration of hydraulic conditions conducive to dam construction,
- Riverscape restoration to support and promote natural colonization,
- Coexistence strategies to mitigate infrastructure or agricultural conflicts, and
- Relocation or translocation efforts to establish beavers in suitable areas.

Through this approach, the BRAT model supports data-driven, regionally tailored strategies for using beaver activity to promote resilient and healthy riverscapes across the state of New Mexico.

This New Mexico application of BRAT localizes the model with regional vegetation data and an imagery-based dam census to better represent the state's unique hydrologic, climatic and vegetation conditions. The resulting maps and management layers are intended to help managers prioritize riparian revegetation, low-tech restoration, translocation or encouragement of natural colonization, and coexistence strategies—targeting actions that maximize ecological benefits while minimizing risks to infrastructure.

METHODS

Study Area – New Mexico

This study focuses on the perennial streams, canals, and acequias of New Mexico (Figure 1). We used the National Hydrography Dataset Plus High Resolution (NHD+ HR) to represent the stream network and canals. Stream reaches were subset to include only those classified as perennial based on the NHD *FCode* designations. We used an acequias layer produced by New Mexico Water Data. We used the New Mexico Game and Fish Regions to subdivide the state (Figure 1).

New Mexico encompasses an exceptionally diverse range of landscapes, including semiarid shrub- and grass-covered plains, forested mountain ranges, glaciated peaks, woodland and shrubland hills, volcanic plateaus and lava fields, fertile river floodplains, and arid deserts. Reflecting this diversity, the state spans eight U.S. Environmental Protection Agency (EPA) Level III Ecoregions: Arizona/New Mexico Mountains, Chihuahuan Deserts, Arizona/New Mexico Plateau, Colorado Plateaus, Southern Rockies, High Plains, Southwestern Tablelands, and Madrean Archipelago (Figure 2). Ecoregions are defined as areas characterized by similarities in ecosystems, including the type, quality, and quantity of environmental resources (US EPA, 2015). For our purposes they provide an effective spatial framework for assessing dam capacity by acknowledging the variations in the capacities and potentials of specific ecosystems. Below is a description of the ecoregions. Note: because of ecoregional similarities we have combined the Arizona/New Mexico Plateaus and Colorado Plateaus into a single description and the High Plains and Southwestern Tablelands into a single description.

The **Arizona/New Mexico Mountains** ecoregion in New Mexico is comprised of nine separate mountain complexes totaling 46,870 km^2 with elevations ranging from 1,300 to 3,800 m and terrain consists of steep mountains and some deeply dissected plateaus. Climates include desert, mid-latitude steppe, and subarctic. Mean annual temperatures range from 3 to 19 ^{o}C depending largely upon elevation; annual precipitation averages 49 cm (range: 27 to 100 cm) with half occurring from December to March as rain or snow and half occurring from July to September as summer thundershowers.

The **Chihuahuan Desert** ecoregion encompasses 69,900 km^2 of the southern third of New Mexico with elevations ranging from 850-2,600 m and terrain consists of broad basins bordered by isolated, rugged mountains. The ecoregion is arid, marked by hot summers and mild winters. Mean annual temperatures are 17-20 ^{o}C and annual precipitation averages 34 cm (range: 20-64 cm), most of which falls in summer.

The **Arizona/New Mexico and Colorado Plateaus** ecoregion encompasses 64,454 km^2 of the northwestern quarter of New Mexico with elevations ranging from 1,000-2,200 m and terrain consists of large plains dissected by plateaus, mesas, arroyos, and canyons. The climate is dry (average annual precipitation: 30 cm) and characterized by cold winters and hot summers, with frost-free periods ranging from approximately 50-220 days.

The **High Plains and Southwestern Tablelands** ecoregion encompasses 102,890 km^2 of eastern New Mexico with elevations ranging from 750- 2,000 m, and terrain is smooth to slightly irregular with intermittent mesas and plateaus. The climate is marked by hot summers and cold winters. Precipitation averages 40 cm (range 30-50 cm) with over half occurring as thundershowers during July- September.

The **Madrean Archipelago** ecoregion encompasses 4,330 km^2 of the southwestern corner of New Mexico with elevations ranging from 1,200-2,600 m. Terrain consists of broad basins bordered by isolated, rugged mountains. The climate is a dry, subtropical steppe with hot summers and mild winters. Mean annual temperatures range from 7-19 ^oC with 170-280 frost-free days, and precipitation averages 26 cm (range: 42-95 cm), mostly occurring from July-September.

The **Southern Rocky Mountains** ecoregion encompasses 26,450 km^2 and includes the Sangre de Cristo, Jemez, and San Juan Mountains in New Mexico with elevations ranging from 1,980-4,012 m; terrain is characterized by steep rugged mountains, complex masses of peaks, and some intermontane valleys. The climate is mostly characterized as mid-latitude continental but is subarctic at high elevations. Summers are cool to warm; winters are severely cold (occasionally <-20 ^oC). Precipitation averages 60 cm (range: 25-175 cm) and occurs as snow in winter and thundershowers in summer.

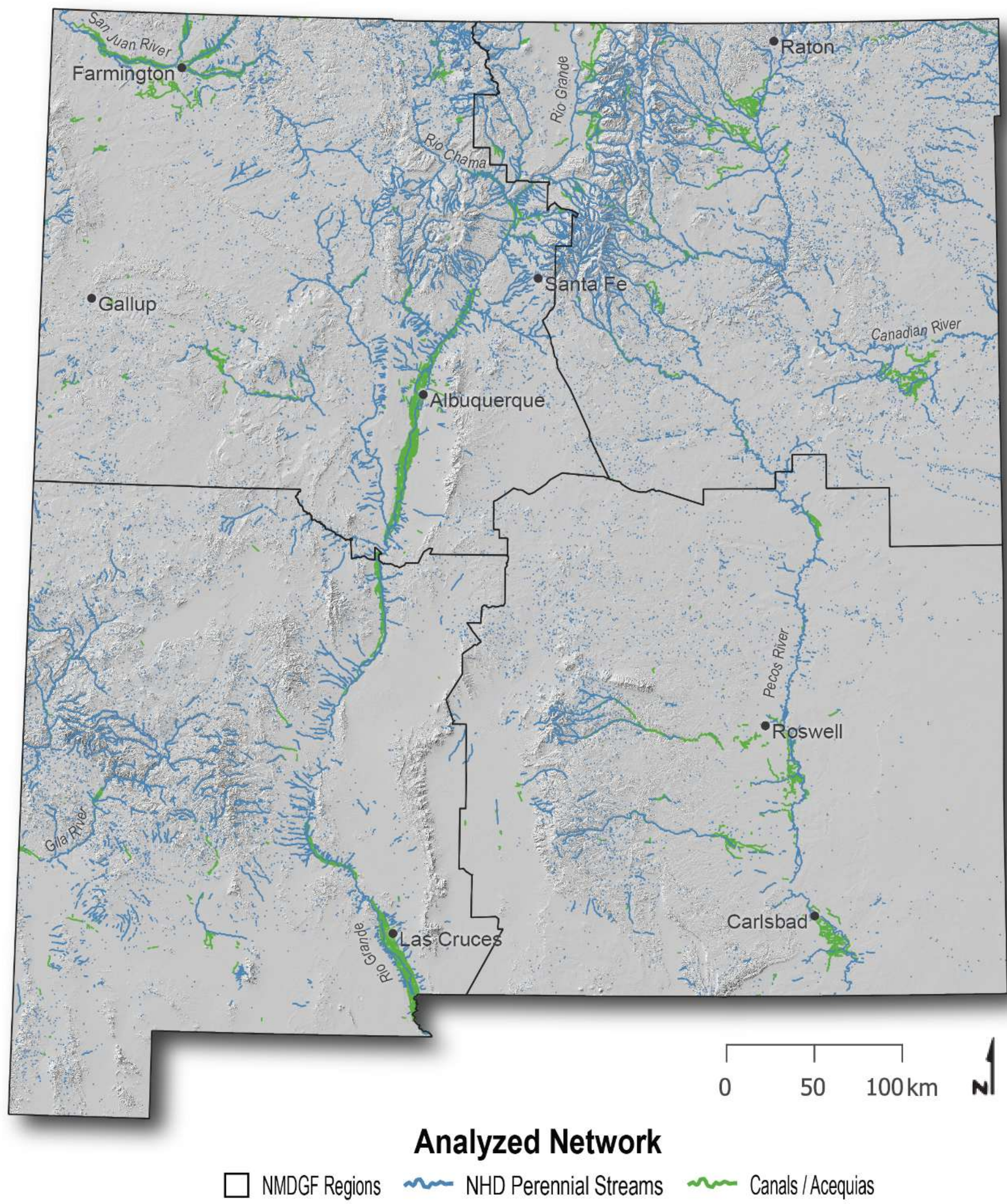

Figure 1: Map showing extent of 21,115 km of streams and 16,962 km of canals and acequias of New Mexico that were included within in this project analysis. This map also shows the four New Mexico Game and Fish Regions.

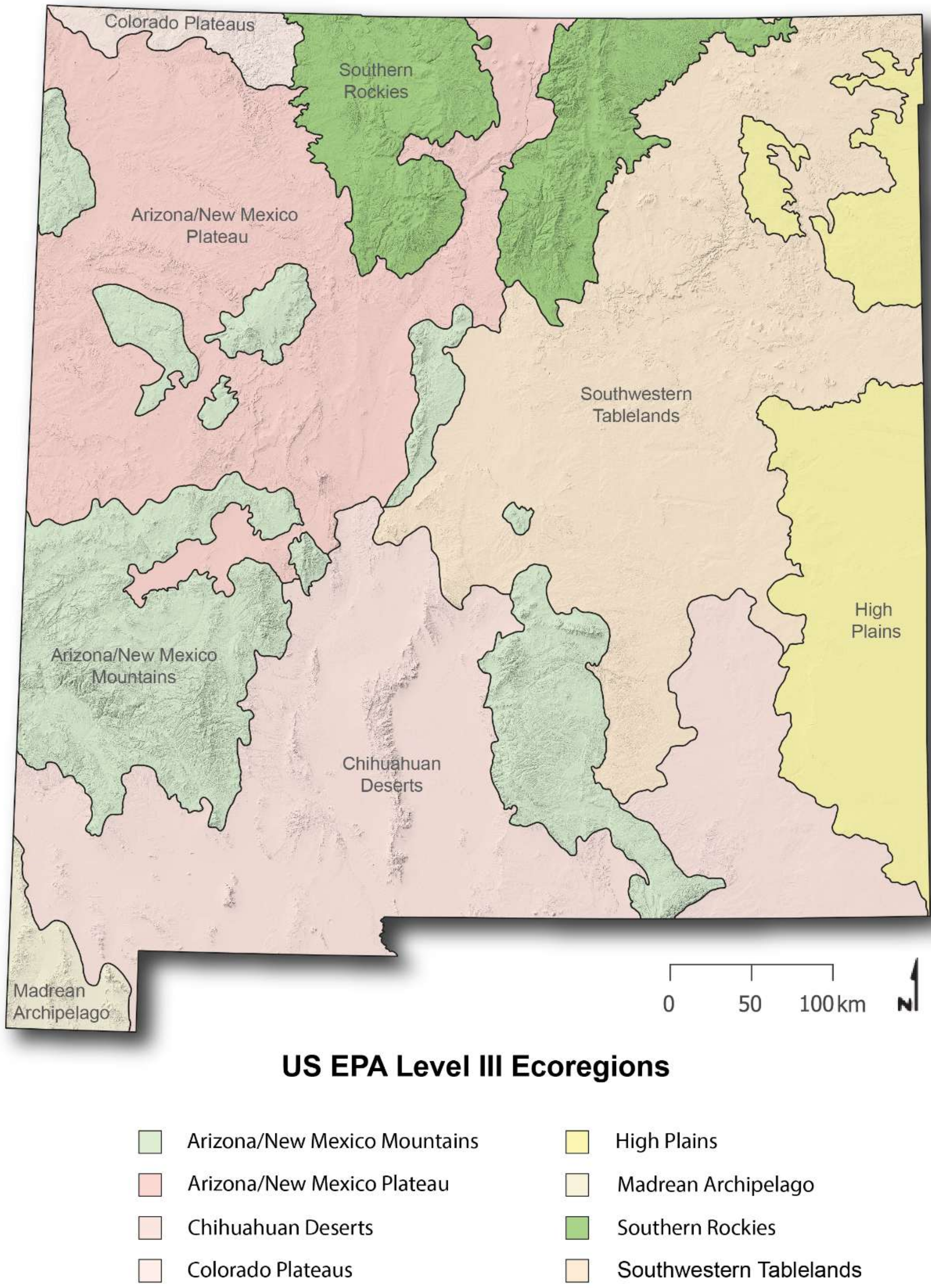

Figure 2: Map showing the eight U.S. Environmental Protection Agency (EPA) level III ecoregions of New Mexico.

BRAT – Beaver Dam Capacity Model

The BRAT beaver dam capacity model is described in detail by Macfarlane et al. (2017), and online at: https://tools.riverscapes.net/brat. Accordingly, this report provides an overview of the model.

Beaver dams—rather than beavers themselves—drive the eco-geomorphic impacts that influence stream processes and habitat formation. Therefore, BRAT estimates the capacity of a stream network to support beaver dam-building activity, rather than general beaver habitat suitability. While beavers can occupy a wide variety of environments, the locations where they build and maintain dams are much more restricted. Dam-building behavior is controlled largely by flow regime and the availability of suitable woody dam building materials.

At its core, BRAT is a capacity model designed to estimate the upper limits of a riverscape's potential to support dam-building activity. The model integrates seven key lines of evidence:

1. Presence of a reliable water source to sustain ponds.
2. Availability of bank vegetation suitable for foraging and dam construction.
3. Extent of woody vegetation within 100 m of the channel to support colony expansion.
4. Feasibility of dam construction across the channel during baseflow conditions.
5. Likelihood of dam persistence under typical flood events.
6. Stream gradient conditions conducive to dam stability.
7. Channel size constraints, where large rivers may preclude stable dam construction.

These criteria collectively address four fundamental questions central to beaver dam capacity:

1. Is there enough water to maintain a pond?
2. Are sufficient and suitable woody materials available for dam building?
3. Can beavers construct a dam under baseflow conditions?
4. Can dams withstand typical flood events?

BRAT uses geospatial datasets and regionally calibrated empirical relationships to generate quantitative estimates for each of these components. For this application, we relied on publicly available, remotely sensed datasets and regional data sources (Table 1) to parameterize the model and assess beaver dam capacity across the perennial stream network of New Mexico.

Table 1: Input data used to represent the lines of evidence of New Mexico BRAT beaver dam capacity model.

Input Data	Criteria	Source
Streams and rivers	Perennial water	USGS National Hydrography Dataset http://nhd.usgs.gov/
NMRipMap	Existing vegetation	Natural Heritage New Mexico https://nhnm.unm.edu/riparian/NMRipMap
LANDFIRE 2.2 (BPS)	Historic vegetation	LANDFIRE land cover data http://www.landfire.gov/
USGS baseflow equations	Dam could be built	https://pubs.usgs.gov/sir/2023/5058/sir20235058.pdf
USGS 2-year peak flow equations	Dam could withstand floods	https://pubs.usgs.gov/sir/2008/5119/pdf/sir2008-5119.pdf
10 m DEM	Evidence of stream gradient	USGS National Map https://www.usgs.gov/programs/national-geospatial-program/national-map

The BRAT capacity model estimates the potential of riverscapes to support beaver dam-building activity by approximating the maximum number of dams that can be sustained based on available vegetation resources and typical streamflow conditions. Model outputs are calibrated against observed dam densities reported in the literature, which can locally reach up to 40 dams per kilometer (approximately one dam every 25 meters). These high densities typically occur where multiple colonies maintain large dam complexes, ranging from 3 to 15 dams per colony (Gurnell, 1998).

Model results are expressed as dams per kilometer for three primary reasons:

1. They are directly comparable to field-based GPS measurements within GIS.
2. They can be validated through aerial imagery or overflight observations.
3. Linear dam density is a commonly reported metric in the scientific literature, enabling direct comparison with published estimates.

BRAT dam capacity output categories are defined as follows:

- None (0 dams/km): No capacity for dam building.
- Rare (>0–1 dams/km): Minimal capacity; may be used only by dispersing beaver.
- Occasional (>1–5 dams/km): Limited potential; suitable for small colonies or isolated dams.
- Frequent (>5–15 dams/km): Capable of supporting large colonies and dam complexes, though somewhat resource-limited.
- Pervasive (>15–40 dams/km): High potential for extensive dam complexes.

Hydrologic Inputs

To evaluate the reliability of water sources for dam-building, we used the NHD+ HR drainage network, which differentiates between perennial, intermittent, and ephemeral streams. Stream reaches were segmented into approximately 300 m reaches—a scale appropriate for estimating reach-averaged slope from a 10 m DEM and for sampling vegetation data from 30 m LANDFIRE datasets within adjacent buffers. We run the model for the entire drainage network (including intermittent and ephemeral) to make the information available for the entire network, however, to answer the question of if enough water is present to maintain a pond, we filter the results to only the perennial network in our output maps and default displays.

Vegetation Inputs & Classification

Standard BRAT runs use the Landfire Existing Vegetation Type (EVT) layer, a 30 m resolution Landsat derivative, to characterize streamside and riparian vegetation suitability. In this application, we leveraged the New Mexico Riparian Habitat Map (NMRipMap) Version 2.0. NMRipMap was produced by a combination of automated polygon extraction from 1 m resolution imagery and lidar, and image classification of the polygons using random forest models. The mapping was performed across the perennial riverscapes of New Mexico.

BRAT ingests vegetation rasters, using a lookup table to reclassify each distinct vegetation type in the input raster into dam building suitability scores from 0 (unsuitable) to 4 (preferred) (Figure 3). As such, we rasterized the polygons from NMRipMap, assigned each unique vegetation class a new ID value, and added these IDs and their associated suitability values to the BRAT lookup tables. BRAT generates average vegetation suitability values for each reach by performing zonal statistics within 30 m (streamside) and 100 m (riparian) buffers (described further below). Because the NMRipMap extent only covers riparian areas of perennial streams, in cases where those buffers extend onto adjacent hillslopes or along non-perennial streams, there are gaps in the data. To deal with this, we generated a 'hybrid' raster, where these gaps were filled in using the Landfire EVT layer. Because the NMRipMap data is mapped at 1 m resolution and the EVT layer is mapped at 30 m, we resampled both to 5 m to create the hybrid raster that was used as a model input. This customization resulted in the most accurate vegetation data that has been used to drive the BRAT model, especially at a large, regional scale. One tradeoff in using this data was that NMRipMap did not include a class specifically for aspen alone (it was lumped in mixed forest classes). Aspen is a preferred species for beaver, and thus, where present in extensive stands, the BRAT results may be underestimating capacity based on this vegetation dataset.

Riparian Buffers

Riparian corridor width strongly influences dam-building potential, with narrow corridors offering limited opportunity compared to broad riparian zones or adjacent deciduous forests with abundant woody browse and dam building materials. To represent this, BRAT evaluates vegetation suitability within two riparian buffers along the drainage network:

- 30 m buffer: Represents immediate streamside vegetation used for dam construction.
- 100 m buffer: Represents the maximum typical harvest distance for woody stems used in dam, lodge, and food cache construction (Figure 3).

These distances are supported by multiple field studies indicating that most beaver foraging and dam-building activity occurs within 100 m of the water's edge, with most of the woody vegetation use occurring within 30 m.

Vegetation suitability rasters are generated from the input vegetation rasters based on the lookup values for suitability of vegetation as dam building material (0: unsuitable, 1: barely suitable, 2: moderately suitable, 3: suitable, 4: preferred; Figure 3). The average cell value is then calculated within the 30 and 100 m buffers associated with each reach (Figure 3), and those values used to characterize overall streamside and riparian vegetation suitability.

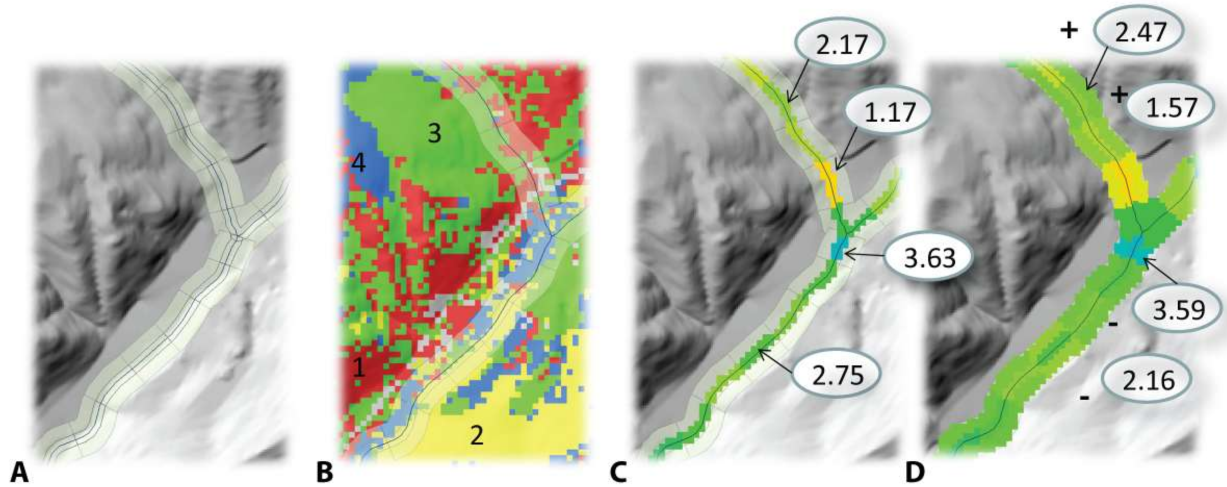

Figure 3: Reach scale illustration of derivation of streamside vs. riparian vegetation scores from 30 vs. 100 m stream network buffers. A shows the 30 m and 100 m buffers, which we used to summarize intersecting pixels from the New Mexico Riparian Habitat Map in B. Dam building suitability is shown in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

Hydrological Data Analysis

To infer whether it is likely that beaver could physically build a dam during low-flow conditions, we calculate stream power ($\Omega = \rho g Q S$) at baseflow, where Ω is the stream power (in watts), ρ is the density of water (1000 kg/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. To infer the likelihood that a beaver dam will persist once built, the two-year recurrence interval peak flood (Q_2) stream power was calculated for each reach.

Baseflow and flood values flow were calculated for each reach based on USGS regional curves, which include upstream contributing drainage area as one of the variables. Additional variables (e.g. precipitation, elevation, etc.) were averaged over HUC8 watershed scales and applied to those reaches. The drainage area attribute value of each stream reach then allowed the equations to scale discharge predictions from headwaters downstream. To calculate reach slope, we used the NHD+ HR network segmented into ~300 m long reaches and extracted elevations at top and bottom of each reach based on the DEM and divide by reach length. The two slope values that matter for the BRAT capacity model are < 0.5% slope, because dam density goes down in very flat areas, and > 23% slope, because dams cannot be built and sustained in very steep reaches.

Larger rivers may have very low stream power values driven by low gradients but simply be large enough that beaver can't dam them, or do not need to create habitat for themselves. Based on previous analyses, we have found that beavers tend not to build dams on channels wider than 25 m. As such, we found the drainage areas at which the channel width of the larger rivers of New Mexico exceeded 25 m and applied a drainage area threshold above which rivers were considered too large for dam building activity and capacity set to 0. In New Mexico these included the San Juan River, Animas River, Rio Grande, lower Pecos River, lower Canadian River, and lower Chama River.

Fuzzy Inference Systems

Inference systems allow for 'computing with words' by developing rule sets (if-then statements) that determine categorical outputs from categorical inputs. A Fuzzy Inference System (FIS) allows for actual values to be computed by having value ranges associated with the categorical inputs and outputs. It is 'fuzzy' because there can be overlapping values between categories to account for categorical uncertainty. An input can therefore have 'partial' membership in more than one category. The output reflects this partial membership (i.e., it can also have partial membership in output categories) but is 'defuzzified' to produce a discrete value.

BRAT uses two FISs, each applied to each reach of the input network. First, an FIS is applied to determine the capacity for dam building based on vegetation alone. This FIS has two inputs: the average suitability of streamside vegetation and the average suitability of vegetation within 100 m of the stream (Figure 4). These values are combined to estimate the dams per km that the reach could support based on vegetation alone (Figure 4).

A second FIS is then applied to incorporate the effects of hydrology and channel slope into the capacity estimates. This FIS has four inputs: the output of the vegetation FIS (dams/km vegetation could support), stream power at low flows, stream power during typical floods, and reach slope (Figure 5). This second FIS essentially takes the output of the vegetation FIS and adjusts capacity estimates downward if hydrology or slope create limitations on dam building capacity (Figure 6).

The BRAT capacity model estimates the potential of riverscapes to support beaver dam-building activity by approximating the maximum number of dams that can be sustained based on available vegetation resources and typical streamflow conditions. Model outputs are calibrated against observed dam densities reported in the literature, which can locally reach up to 40 dams per kilometer (approximately one dam every 25 meters). These high densities typically occur where multiple colonies maintain large dam complexes, ranging from 3 to 15 dams per colony (Gurnell, 1998).

Model results are expressed as dams per kilometer for three primary reasons:

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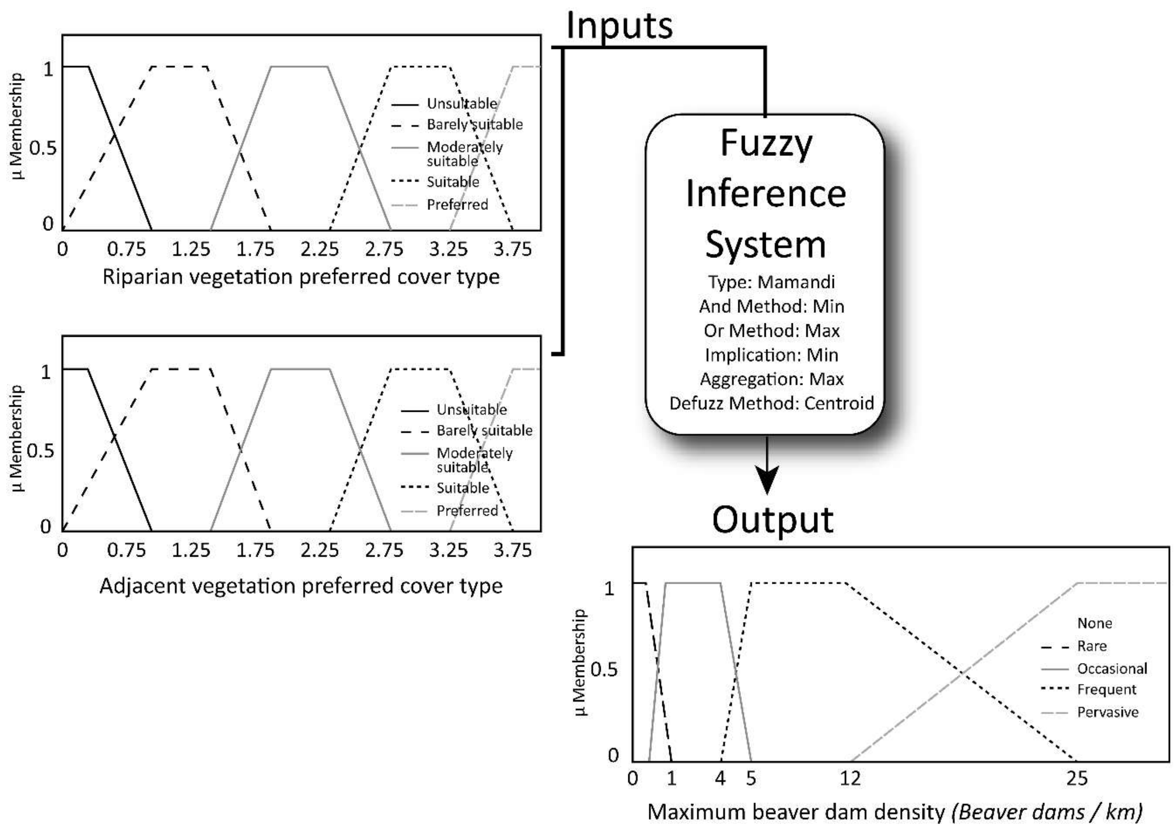


Figure 4: Vegetation Fuzzy Inference System for capacity of riverscape to support dam building beaver activity based only on vegetation available as a building material. This shows the specification of fuzzy membership functions with overlapping values for categorical descriptors in inputs and the output.

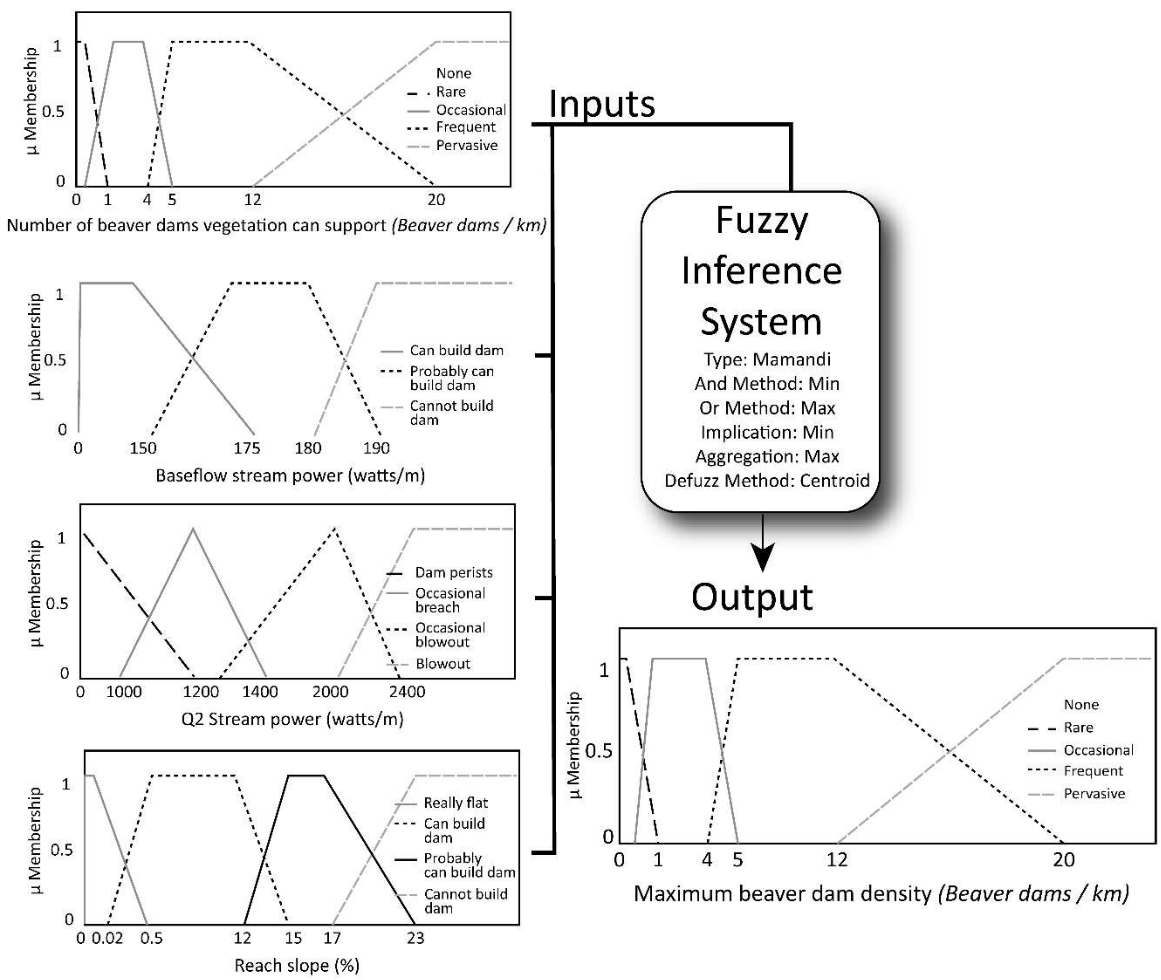


Figure 5: Combined Fuzzy Inference System for assessing beaver dam capacity estimates. This shows the specification of fuzzy membership functions with overlapping values for categorical descriptors in inputs and the output.

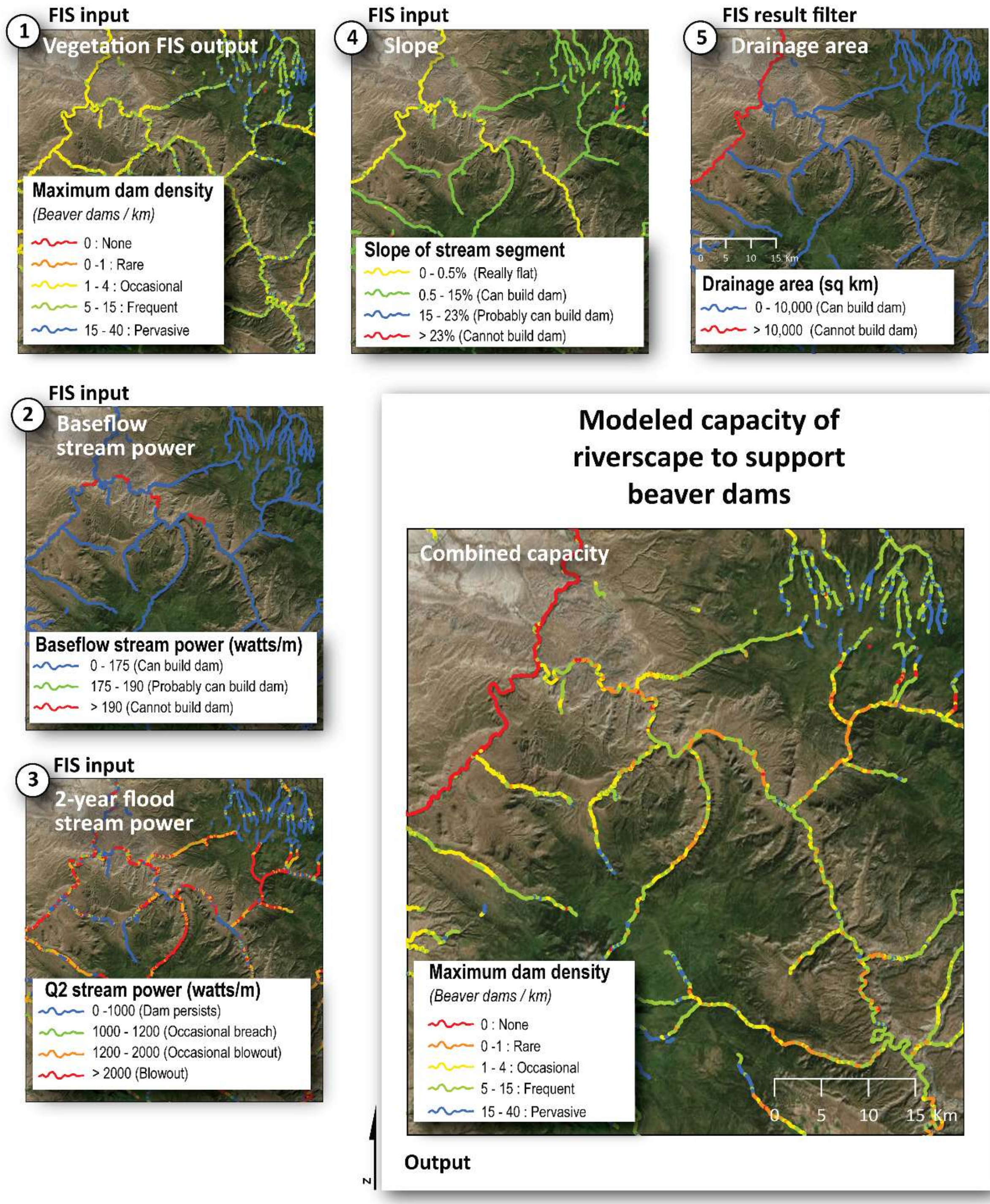


Figure 6: Methodological illustration of inputs (1-5) and output for beaver dam capacity estimates. Model output is expressed as dam density (dams/km).

BRAT – Risk Assessment Using Proximity to Human Infrastructure

While the BRAT capacity model identifies where riverscapes can support beaver dam-building, these outputs alone are insufficient for effective beaver management because beaver activity can also pose significant risks in developed areas. Beaver dams can clog culverts, obstruct irrigation diversions, flood public and private infrastructure, and fell trees in undesirable locations (Bhat et al., 1993; Hill, 1976; McKinstry & Anderson, 1999).

To account for these potential conflicts, BRAT includes a risk assessment component that evaluates the proximity of streams to 'floodable' or 'cloggable' infrastructure and high-intensity land use. The BRAT models the following key infrastructure:

- Distance to roads within valley bottoms,
- Distance to road crossings,
- Distance to diversion points,
- Distance to acequias/canals, and
- Distance to nearest infrastructure.

This proximity analysis highlights possible risks (i.e. flooding and clogging) that might occur to this infrastructure. This allows managers to identify areas where suitable beaver dam-building conditions overlap with infrastructure vulnerable to flooding or blockage. BRAT expresses proximity to human infrastructure in terms of 'beaver distances,' corresponding to zones of potential interaction:

- Immediately adjacent: High risk—direct overlap with infrastructure.
- Within normal forage range: Moderate risk—within typical daily foraging distance.
- Within plausible forage range: Low risk—beaver may occasionally reach these areas.
- Outside range of concern: Negligible risk—beyond typical foraging or movement distance.

This approach provides a spatially explicit method for identifying human–beaver conflict zones, supporting informed decisions in beaver-based restoration and conservation planning.

The model also quantifies land use intensity using an index from 0 (no land use) to 100 (completely urbanized) and incorporates this information into the risk calculation. Like vegetation suitability, this is accomplished using a lookup table associating land cover types with land use intensity values, then averaging these values across the riverscape associated with each reach.

The BRAT model identifies potential risks areas — streams that are close to human infrastructure or high land use intensity and where the capacity model estimates that beavers can build dams. The layer/map is called 'risk of undesirable.' The layer consists of the following four categories (Table 2).

Table 2: Risk analysis categories.

Category	Description
Considerable	Canals/acequias are within 20 m; nearest infrastructure is within 30 m or land use intensity is high and dam capacity is frequent or greater
Some	Nearest infrastructure is within 30 m or land use intensity is high but dam capacity is less than frequent; nearest infrastructure is 30 – 100 m away and capacity is frequent or greater
Minor	Nearest infrastructure is 30 – 100 m away but capacity is less than frequent; nearest infrastructure is 100 – 300 m away or land use intensity is moderate
Negligible	Nearest infrastructure is more than 300 m away and land use intensity is low

BRAT – Beaver-Based Conservation & Restoration Management Layers

The BRAT model generates management layers and associated maps focused on beaver-based conservation and restoration to facilitate prioritization and planning in restoration efforts. The 'beaver-based conservation and restoration opportunities' output highlight beaver restoration opportunities in streams, considering both the existing dam-building capacity and potential risks to infrastructure. This layer considers five primary forms of beaver-related conservation and restoration, as described by (Ritter & Hill, 2023). Along with two additional categories that highlight floodplain/side channel opportunities or areas unsuitable for dam-building. The layer consists of the following seven categories (Table 3).

Table 3: Beaver-based conservation and restoration opportunities.

Category	Description
Conservation/Appropriate for Translocation	Intact beaver habitat. If beavers are present, conservation should be prioritized. If not present, these are good places for translocation.
Encourage Beaver Expansion/Colonization	Good resources but some risk or land use to consider. Beaver should be able to successfully colonize or expand with some monitoring for living with beaver strategies.
Beaver Mimicry	Potential for uplift but also high potential for risk OR intermittent streams with low conflict potential; BDAs can be used for restoration objectives but probably not suitable for actual beaver.
Conflict Management	Areas where there are resources to support dam building, but where there is relatively high conflict, and any beaver activity or beaver mimicry would likely need to be paired with 'living with beaver' strategies for conflict mitigation.
Land Management Change	Due to current land management practices, vegetation resources need to be improved before beaver can actively build and maintain dams.
Potential Floodplain/Side Channel Opportunities	Floodplain vegetation resources exist and potential for conflict is low, so opportunities may exist on floodplains and side channels.
Natural or Anthropogenic Limitations	Capacity is naturally low (veg or flow i.e. ephemeral) or is low because of human infrastructure and influence is too high.

It is important to note that multiple categories may apply to a single reach, but each reach is assigned one category based on the model's logic. For instance, many reaches classified as 'encourage beaver expansion/colonization' might also benefit from beaver mimicry to promote effective colonization.

BRAT - Unsuitable or Limited Dam Building Opportunities

The BRAT model identifies areas where beaver cannot build dams now and differentiates these into anthropogenically and naturally limiting areas as well as resource constraints that need addressing to support beaver populations. The layer/map is called 'unsuitable or limited dam building opportunities'. The layer consists of the following eight categories (Table 4).

Table 4: Unsuitable or limited dam building opportunities.

Category	Description
Anthropogenically Limited	Capacity is 'None' and land use intensity is moderate or higher
Stream Power Limited	Low flow stream power is too high for dam building, or high flow stream power regularly blows out dams
Slope Limited	Reach-averaged slope is greater than 23%
Potential Reservoir or Land Use Change	Historic capacity is 'None' but there is existing capacity
Naturally Vegetation Limited	Historic capacity and existing capacity are both 'None'
Stream Size Limited	Streams are wider than ~25 m or sufficiently deep to preclude damming
Dam Building Possible	Dams can be built and persist
Other	Situation unhandled by any of the above logic

BRAT- Attribute Table

The BRAT attribute table contains extensive information including model input values (e.g., discharge and stream power values, vegetation suitability values, slope, etc.), some intermediate values (e.g., capacity to support dams based on just vegetation) and the various output values. The titles of fields reflect a legacy of when the model produced shapefile outputs with field titles limited to 10 characters and are thus not intuitive to understand without explanation. A description of each field can be found at https://tools.riverscapes.net/brat/Advanced/working-with-outputs#the-brat-attribute-table.

BRAT – Capacity Model Validation

We used three complementary approaches to evaluate the performance of the beaver dam capacity model:

1. **Capacity Analysis**: Are there surveyed dams located in areas where the model predicted no dam-building capacity?
2. **Density Comparison**: How well do predicted dam densities correspond with observed dam densities?
3. **Preference Assessment**: Do electivity indices increase consistently from reaches classified as 'none' to 'pervasive' capacity?

To address Questions 1 and 2, we compared modeled dam capacity estimates to actual dam densities derived from imagery-based beaver dam inventories. Observed dam counts from these datasets were plotted against predicted dam capacities, and quantile regression analyses were performed on the 50th, 75th, and 90th percentiles of the data. Quantile regression of upper percentiles (i.e., 75th and 90th) is particularly useful for evaluating habitat models where many systems exhibit low observed dam densities. These upper percentiles represent the maximum observed densities, which most closely approximate true carrying capacity (Cade & Noon, 2003)—the quantity the model seeks to estimate.

To address Question 3, we used an electivity index (EI) to assess whether beavers preferentially built dams in reaches predicted to have higher capacity values.

Aspen Analysis

Another approach we used to validate the model outputs is by intersecting the BRAT existing and historic capacity steam network with an aspen landcover layer. Since the NMRipMap layer does not distinguish between aspen and other deciduous riparian species, and beaver are highly preferential toward aspen (Doucet & Fryxell, 1993), we thought it useful to find a landcover layer that distinguished between aspen and other cover types and use it to validate the model. We buffered the stream segments by 100 meters to simulate the effective beaver foraging range and clipped the aspen layer to this buffered stream network. We then compared the dam capacity values of segments with aspen present within 100 meters to those without aspen within that range. We also collected the number of dams within the segments with aspen present to determine the proportion of dams built where aspen is present. This gives us a general idea of how much beaver are preferentially building dams near aspen.

Imagery-Based Beaver Dam Census

Because the BRAT capacity model outputs dam density, direct comparison with actual dam densities provides a meaningful form of model validation. To support this, we conducted a comprehensive imagery-based beaver dam census (Macfarlane et al., 2025) using high-resolution (60-centimeter) National Agriculture Imagery Program (NAIP) imagery from 2020-2021. A technician systematically navigated along every perennial stream in the drainage network using NAIP imagery at an 'eye altitude' of approximately 500–600 m above ground (roughly 1:2,000 scale). When potential dam sites were identified, the technician zoomed in to verify dam presence based on multiple lines of visual evidence, including pond morphology, dam structure, riparian harvest, and skid trails. False-color and NDVI conversions of this imagery were used alongside the true color imagery to increase chances of detecting these lines of evidence. Verified dam locations were recorded and compiled into a dataset used for model validation. A total of 4,372 beaver dam locations across the state's 21,115 km perennial stream network for an overall dam density of 0.21 per km (Macfarlane et al., 2025).

Although this process is referred to as a *census* because it systematically evaluates the entire perennial network, it represents a snapshot in time rather than a complete inventory of all existing dams.

Electivity Index

To evaluate whether beaver dam-building occurred preferentially within reaches predicted to have greater capacity, we calculated an electivity index (EI), following the conceptual framework of the *ideal free distribution* (Fretwell & Lucas, 1969). Under this framework, beaver dam distribution should reflect the spatial distribution of resources supporting dam construction and maintenance.

Following Pasternack (Pasternack, 2011), the EI for each segment type (*i*) was calculated as:

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

where $n_i$is the number of beaver dams surveyed within segment type *i*, and $l_i$is the total length of that segment type. The EI thus normalizes habitat use relative to availability:

- $EI = 1$indicates neutral use (no preference or avoidance),

- $EI < 1$indicates avoidance, and
- $EI > 1$indicates preference.

Segment types correspond to the linguistic capacity classes used in the FIS. If the capacity model effectively discriminates among actual dam densities, we would expect EI values near zero for the *none* and *rare* classes, less than one for the *occasional* class, greater than one for the *frequent* class, and substantially greater than one for the *pervasive* class.

RESULTS & INTERPRETATIONS

BRAT - Beaver Dam Capacity Model

Statewide Perennial Stream Capacity – Historic vs Existing

The perennial streams of New Mexico have an existing beaver dam capacity of 155,941 dams or 4.5 dams/km (Figure 7). By contrast, the same model driven with estimates of historic vegetation estimated the statewide perennial stream capacity at 206,358 dams or 7.4 dams/km (Figure 8) reflecting a 24% loss compared to historic capacity (Figure 9). The 'pervasive' category had the greatest decline from 14% historically to only 2% in the existing capacity estimates (Figure 9).

The capacity loss from historic conditions can be explained in terms of stream incision, riparian vegetation loss, vegetation conversion and degradation associated with high intensity livestock grazing, conversion of valley bottoms to urban and agricultural land uses. Conifer encroachment of aspen forests, non-native encroachment of wet meadow and riparian areas were also an important change agent. Despite the losses in beaver dam capacity, New Mexico's waterways are still capable of supporting and sustaining a substantial amount of beaver dam-building activity especially in mountainous northern portions of the state.

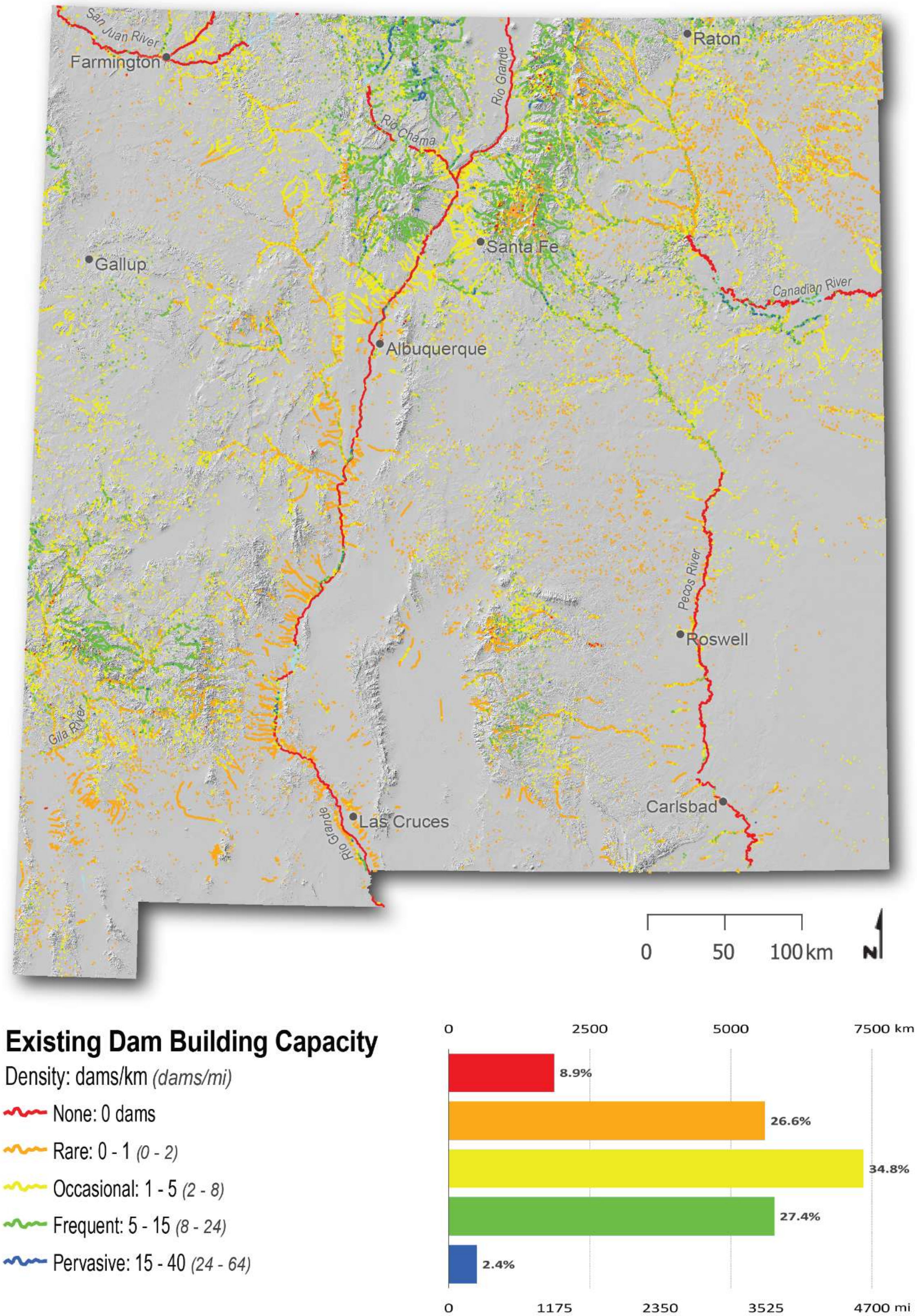


Figure 7: Modeled beaver dam capacity for existing conditions for the perennial streams of New Mexico.

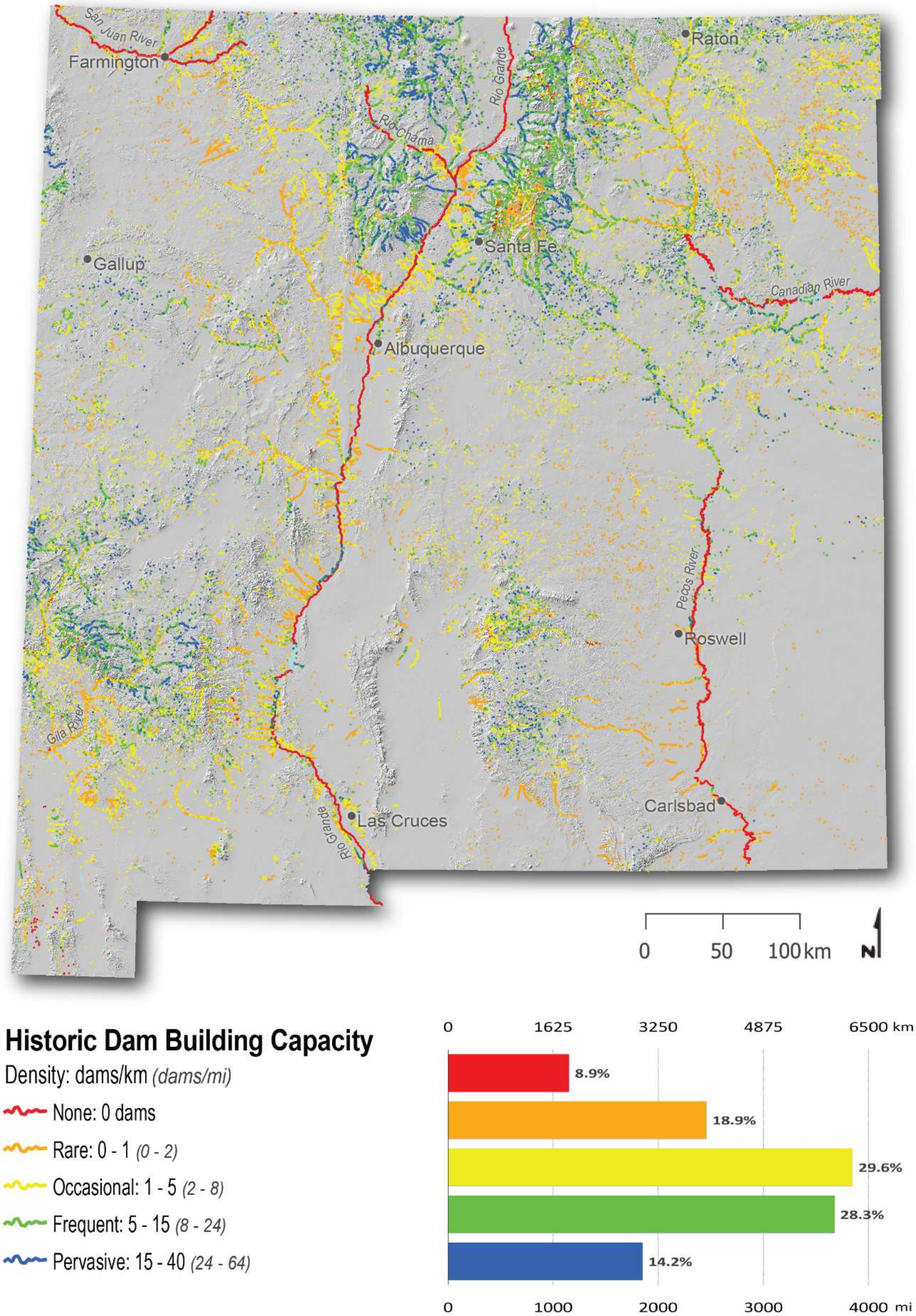


Figure 8: Modeled beaver dam capacity for historic conditions for the perennial streams of New Mexico.

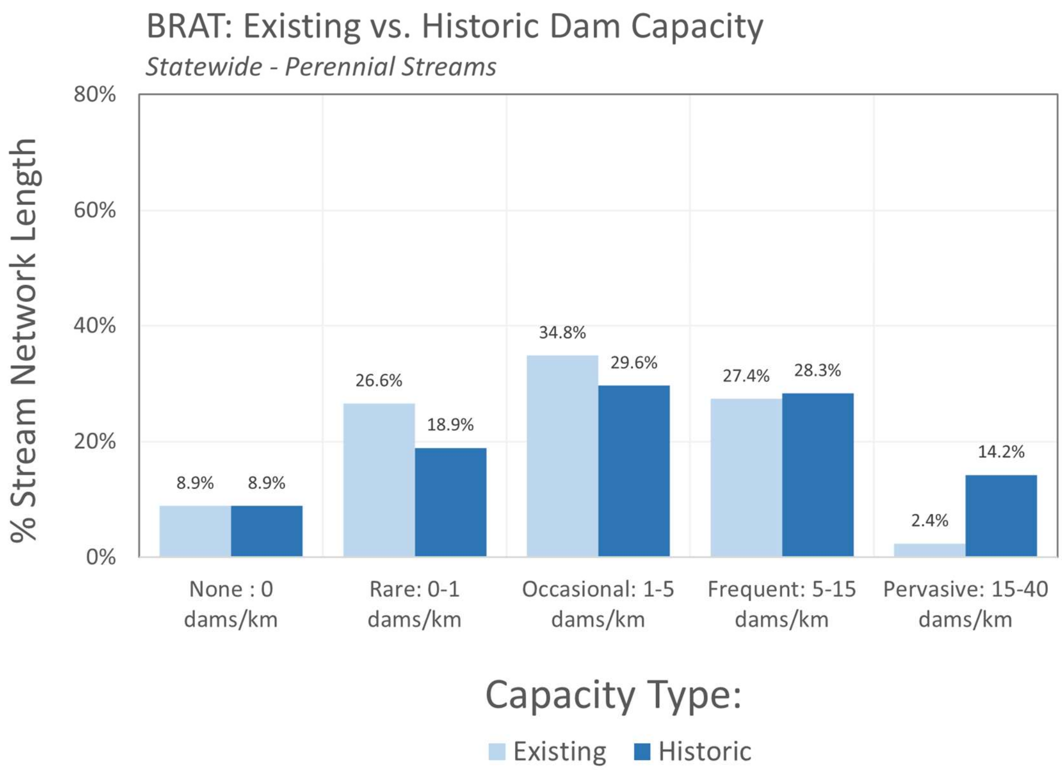


Figure 9: Modeled existing vs. historic dam capacity of the perennial streams by dam density category for New Mexico.

Statewide Acequias & Perennial Stream Capacity

The acequias and perennial streams of New Mexico have an existing beaver dam capacity of 203,675 dams or 4.2 dams/km (Figure 10). This is a 31% increase when only considering perennial streams (155,941 dams). Acequias are essentially man-made streams and therefore can support dam building activity like natural streams. However, because they are human infrastructure designed to deliver water, beaver activity in them is inherently high risk to the infrastructure. For this reason, in BRAT, we model the capacity of canals and acequias, but flag them as high risk in the management outputs. In this document, reported capacities are limited to the natural perennial stream network to avoid overstating dam capacity. However, we include maps that also display the acequias to communicate their potential to support dam building.

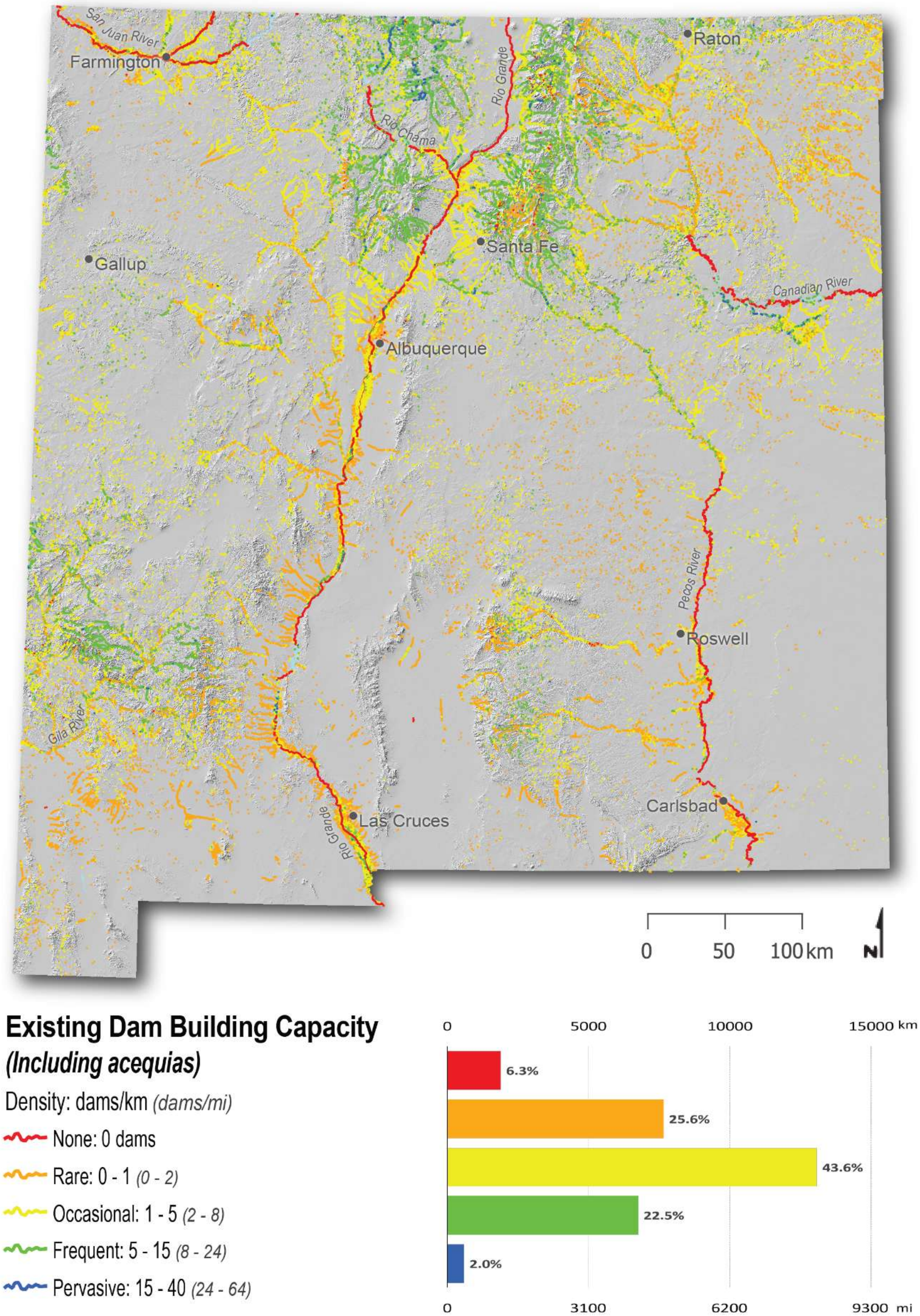


Figure 10: Modeled beaver dam capacity for existing conditions for the acequias and perennial streams of New Mexico.

Ecoregional Capacity – Historic vs Existing

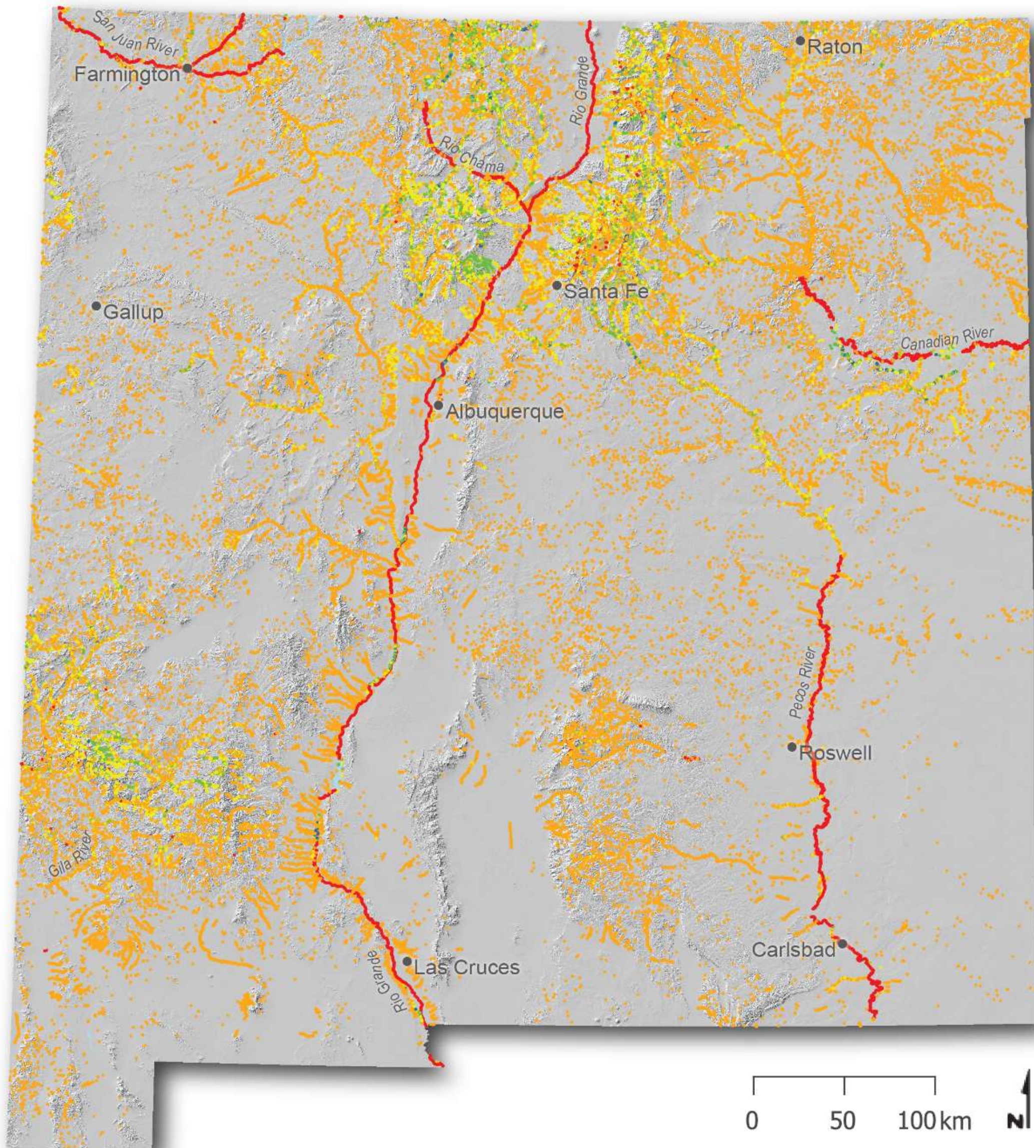
Comparison of the eight U.S. Environmental Protection Agency (EPA) level III ecoregions within New Mexico by perennial streams are illustrated in (Table 5). Not surprisingly, the Southern Rockies ecoregion had by far the highest existing capacity at 7.4 and historic capacity at 12.4. This mountainous ecoregion has the hydrologic and vegetative resources needed to support relatively high densities of beaver dams. The Southern Rockies ecoregion also had the greatest percent loss from historic at 32%, likely driven by high intensity livestock grazing that resulted in a decline in the woody riparian species needed to support high densities of beaver dams. The most arid ecoregions: Chihuahuan Deserts (1.8 dams/km), High Plains (1.5 dams/km) and Madrean Archipelago (1.8 dams/km) had very low dam capacity densities because there are not adequate water and/or the woody riparian resources to support much dam building by beavers.

Table 5: Summary and contrast between existing and historic beaver dam capacity estimates for perennial streams by the eight U.S. Environmental Protection Agency (EPA) level III ecoregions of New Mexico.

	Existing Capacity		*Historic Capacity*		
Ecoregion	**Estimated Dam Capacity**	**Estimated Dams/km total**	**Estimated Dam Capacity**	**Estimated dams/km total**	**% Loss**
Colorado Plateaus	2430	5.8	2532	6.6	4.0%
Southern Rockies	49215	7.4	72769	12.4	32.4%
AZ/NM Plateau	31316	4.3	37629	5.7	16.8%
AZ/NM Mountains	25234	4.4	36530	8.6	30.9%
Chihuahuan Deserts	17119	1.8	19809	3.5	13.6%
High Plains	2589	1.5	2754	3.4	6.0%
Southwestern Tablelands	27597	3.7	33842	6.1	18.5%
Madrean Archipelago	441	1.5	493	3.7	10.5%
Statewide:	155941	4.5	206358	7.4	24.4%

Statewide Dam Complex Size – Historic vs Existing

Dam building capacity can be re-cast in terms of what size dam complex (single dam, small complex (1-3 dams), medium complex (3-5 dams), or large complex (greater than 5 dams) can fit in a reach. Existing dam complex size for New Mexico is mapped in (Figure 11). Historic dam complex size for New Mexico is mapped in (Figure 12). Across the state, the existing average complex size is 1.2 dams down from 1.7 dams historically, demonstrating how the reduced overall capacity reduces average complex size as well. The 'large complex' category had the greatest decline from 10% historically to only 1% in the existing capacity estimates (Figure 11 and Figure 12). The relative lack of large (10%) and medium (19%) complex size reaches is indicative of the resource limitations of New Mexico's riverscapes.



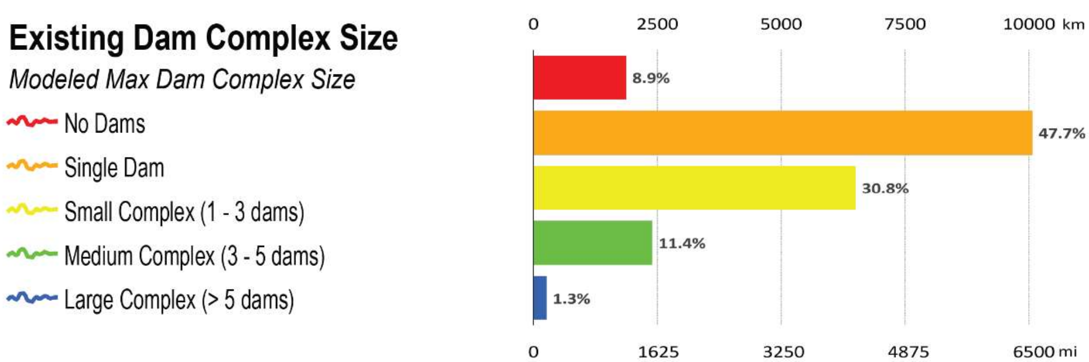


Figure 11: Modeled existing dam complex size for New Mexico.

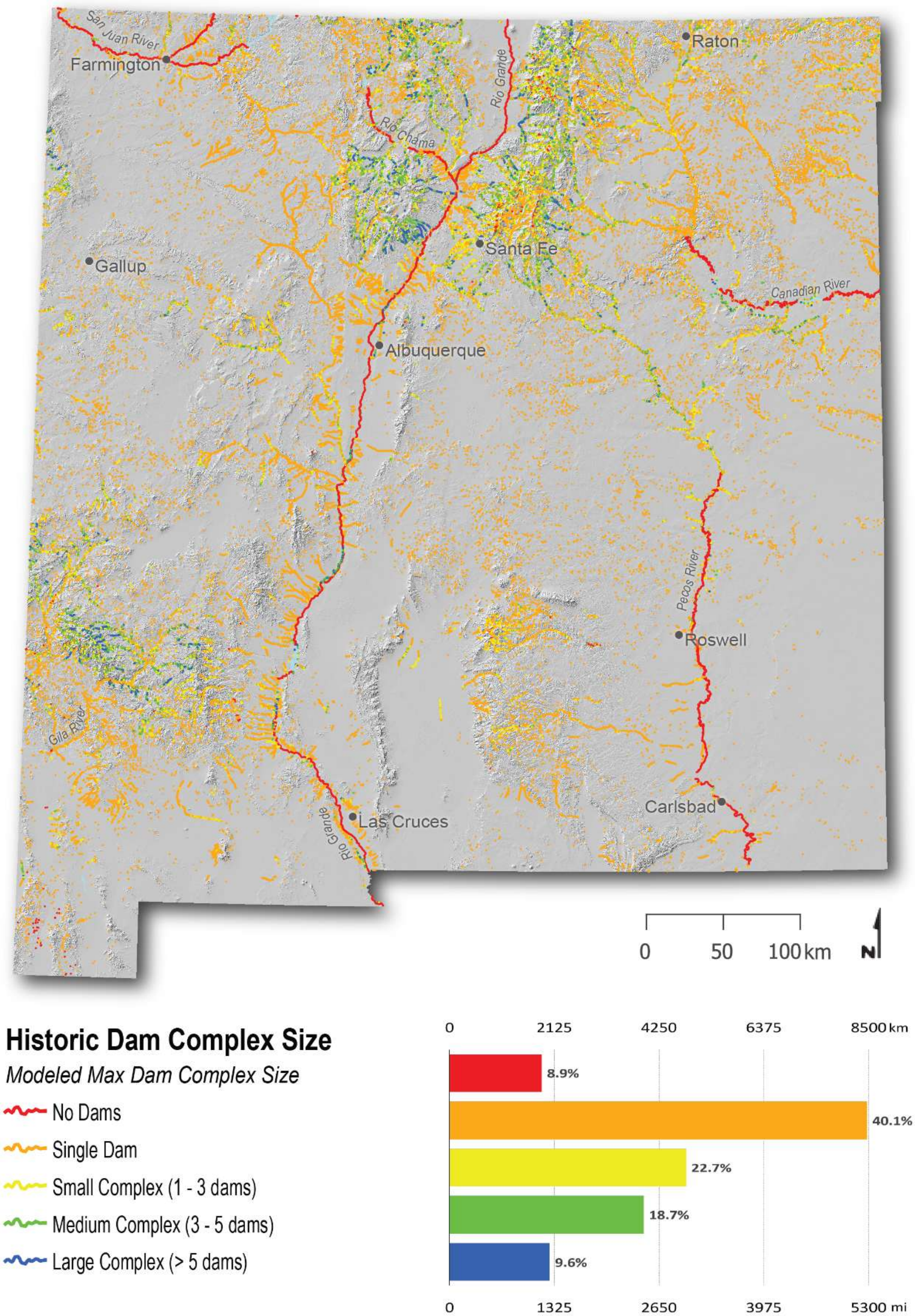


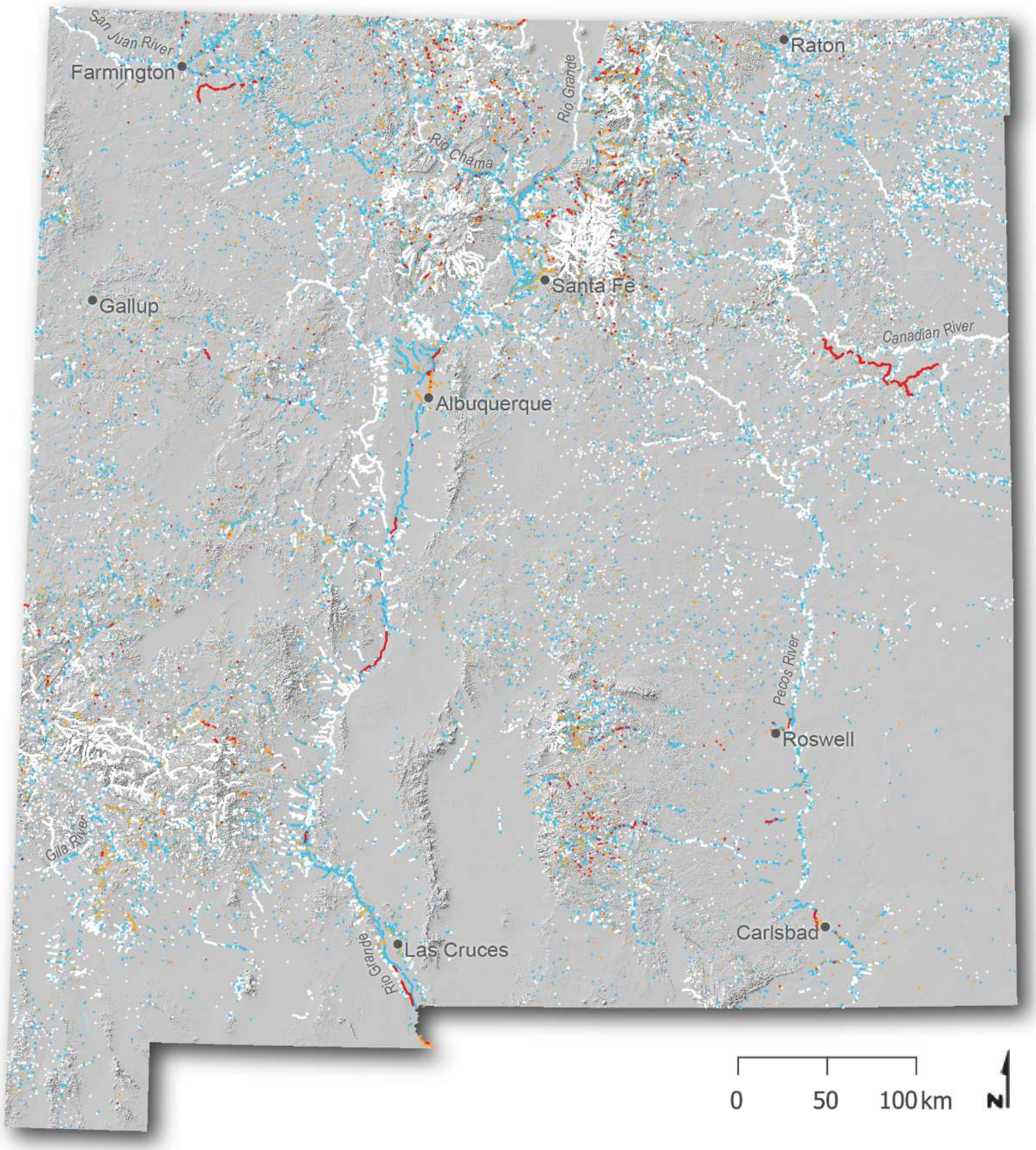
Figure 12: Modeled historic dam complex size for New Mexico.

BRAT – Potential Risk Areas

The BRAT model identifies potential risk areas – streams that are close to human infrastructure or high land use intensity and where the capacity model estimates that beavers can build dams. The layer/map is called ‘risk of undesirable dams’.

Statewide Perennial Streams Potential Risk Areas

When just considering the perennial streams of New Mexico, 57% were categorized as ‘negligible’ or 32% ‘minor’ risk, suggesting there are many low-risk beaver-related restoration opportunities available (Figure 13). Only a small fraction of the stream reaches (3.7%) are classified as having ‘considerable’ risk. These reaches are mainly near acequias or the portions of streams that pass through the urban areas, with isolated segments occurring at road crossings or near floodable roads.



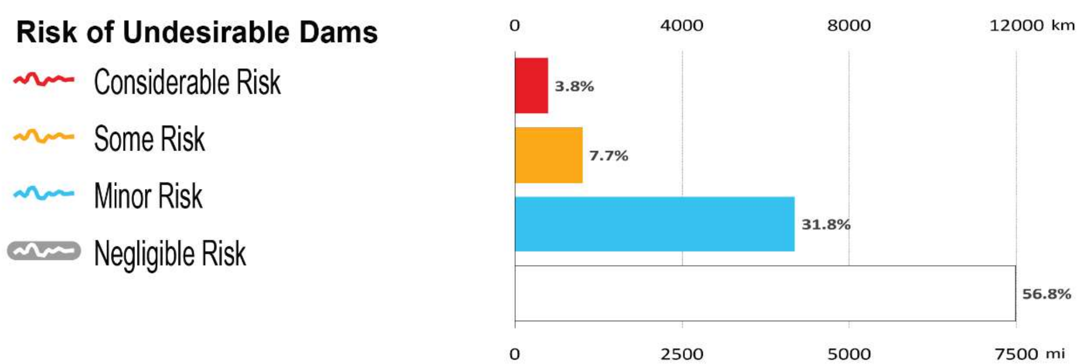


Figure 13: Areas along perennial streams where there is risk of undesirable dams within New Mexico.

Statewide Acequias & Perennial Streams Potential Risk Areas

The ‘considerable’ risk category increased to 32% of the network when acequias are considered (Figure 14). This highlights how the BRAT model considers these prone to human-beaver conflict features. Nevertheless, 62% of the network is still classified as having ‘negligible’ or ‘minor’ risk illustrating that there are plenty of low-risk stream reaches suitable for promoting beaver dam building across the state (Figure 14).

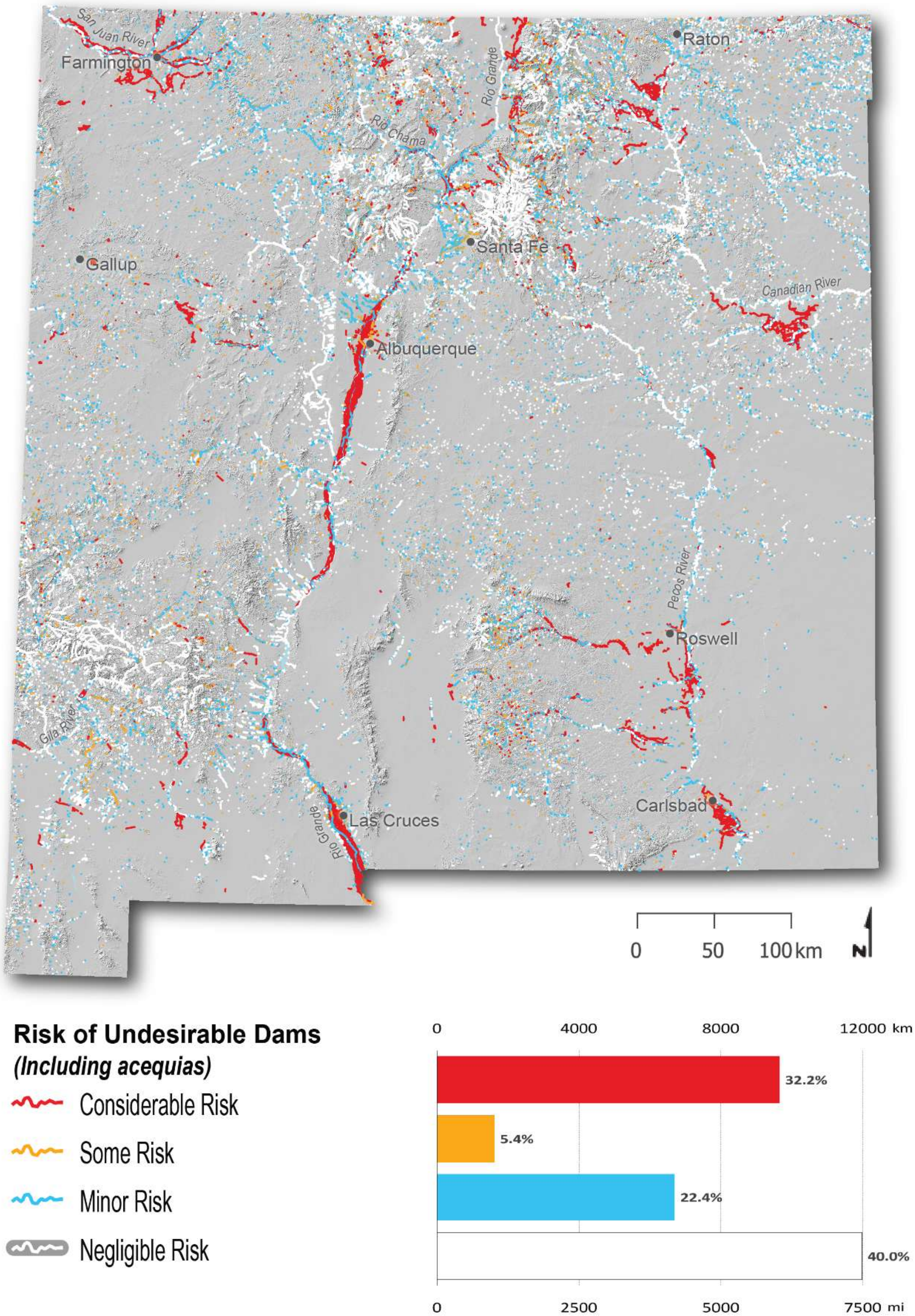


Figure 14: Areas along acequias and perennial streams where there is risk of undesirable dams within New Mexico.

The BRAT model identifies opportunities where low-risk beaver-based restoration and conservation opportunities exist (Figure 15). Results indicate that 16% of the perennial stream network is categorized as 'Conservation/Appropriate for Translocation' and an additional 6% is categorized as 'Encourage Beaver Expansion/Colonization', suggesting there are many low-risk, high potential uplift opportunities for beaver-related restoration (Figure 15). This output also shows that 14% of the streams could benefit from land management changes; 4% suitable for beaver mimicry; 46% unsuitable due to gradient/stream power/size.

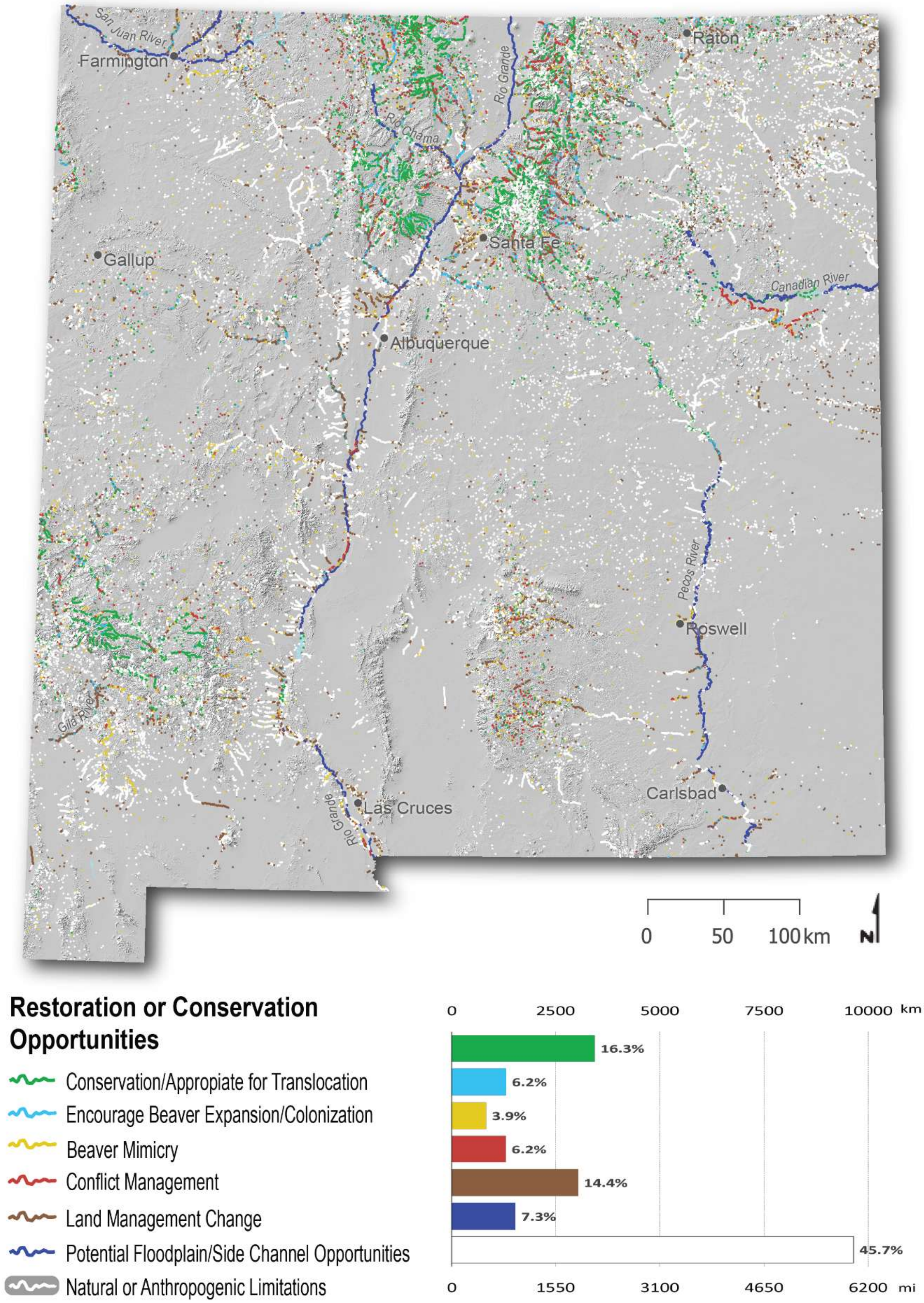


Figure 15: Beaver-based conservation and restoration opportunities for New Mexico.

BRAT – Statewide Perennial Streams Unsuitable or Limited Dam Building Opportunities

The BRAT model identifies areas where beaver cannot build dams now and differentiates these into anthropogenically and naturally limited areas. The layer/map is called 'unsuitable or limited dam building opportunities' (Figure 16). Seventy-two percent of the perennial streams of New Mexico were categorized as 'dam building possible'. Whereas 28% of the perennial network was categorized as unsuitable or limited for dam building this was split between reaches where dam building is limited by stream power (19%), too steep to support dam building (0.6%) in the mountainous headwaters and size limited (8%) in larger, higher-order streams. This illustrates how the morphology and hydrology of the state result in an optimal size range of stream for dam building which exclude small, but very steep streams and larger rivers (Figure 16).

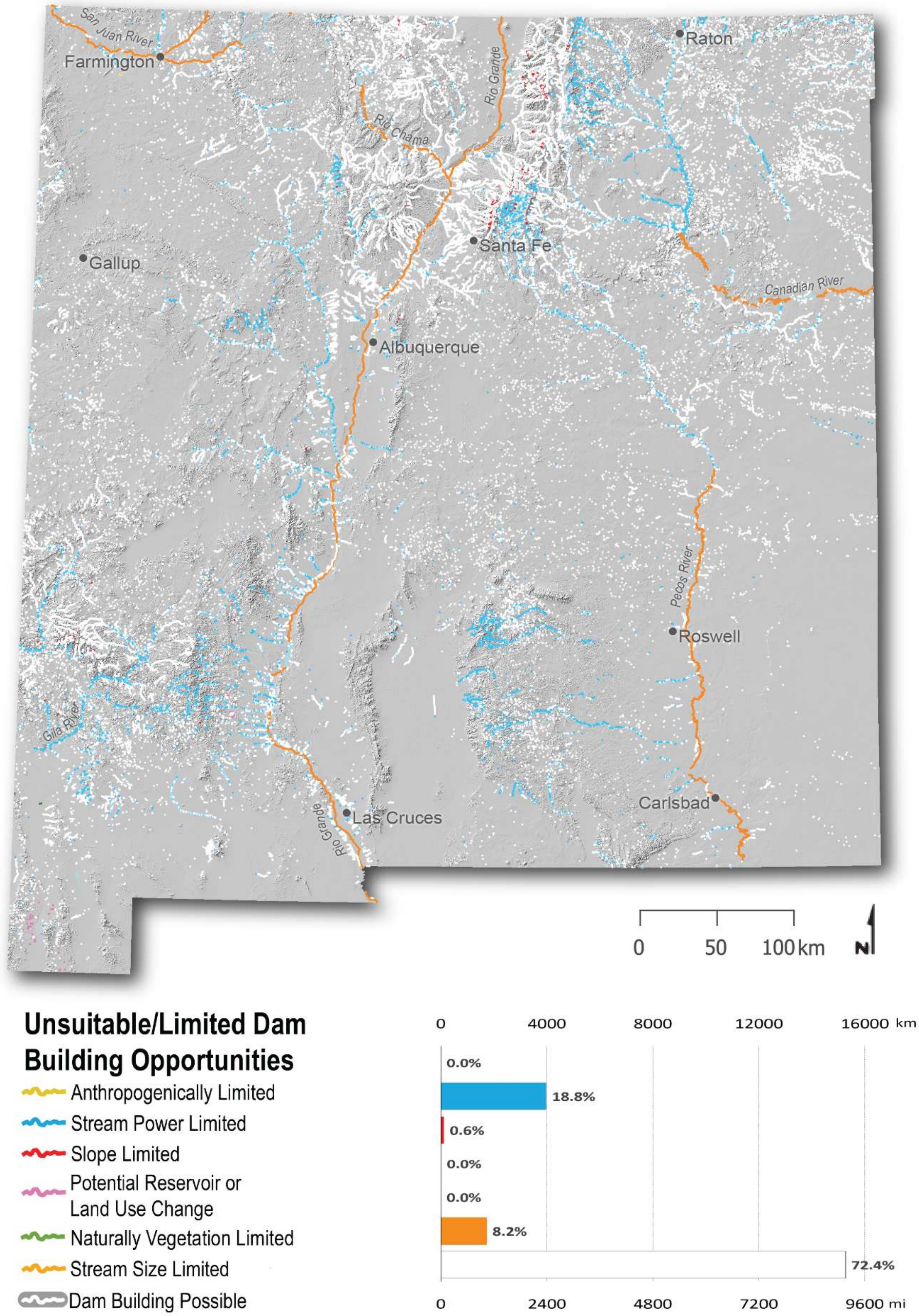


Figure 16: Modeled unsuitable/limited dam building opportunities for New Mexico.

BRAT Outputs per New Mexico Department of Game & Fish Region

Figure 17 shows the comparison between existing and historic capacity for the perennial streams of New Mexico statewide and by New Mexico Department of Game & Fish (NMDGF) regions. The NMDGF regions divide the state into four roughly equally sized regions: Northwest (NW), Northeast (NE), Southwest (SW) and Southeast (SE). Even though these regions are approximately the same size the beaver dam capacity varies greatly across these regions. The southern regions have far less historic and existing capacity. For example, the SE region has by far the least existing capacity at 12,063 dams and the least historic capacity at 13,407 dams whereas the NE region has the highest existing capacity at 51,784 dams and the highest historic capacity at 78,373 dams (Figure 17). These differences in capacity mirror differences in the landscape characteristics of these regions. The southern regions are arid with limited water and woody riparian needed for dam building whereas the northern regions are more mountainous and have more water and resources for dam building beaver. The northern regions also have higher recovery potential (the difference between existing capacity and historic capacity). For example, the SE region has the potential to increase capacity by only 10% if one was able to restore vegetation to historic estimates while the recovery potential of the NE region is much higher at 30% (Figure 17). Such complete recovery is highly unlikely, due in part to development, urbanization, and high intensity agriculture. Nevertheless, such recovery potential information can be useful to gauge how various riparian vegetation restoration might impact dam-building capacity across different regions. Figure 18 also shows the imagery-based dam census outputs and this mirrors the capacity outputs with the NE region having the most dams at 2,919 and the SE region having the least dams, at only 15 also shows the imagery-based dam census outputs and this mirrors the capacity outputs with the NE region having the most dams at 2,919 and the SE region having the least dams, only 15.

Figure 18 shows the comparison of existing and historic dam density by category. The southern regions percentage of capacity density categories are skewed toward the 'rare' category at the expense of the 'occasional', 'frequent', and 'pervasive' categories. The major changes between historic and existing capacity are a minor increase in reaches classified as 'rare', a major increase in reaches classified as 'occasional' associated with a minor reduction in reaches classified as 'frequent' and a major reduction in reaches classified as 'pervasive' when compared with historic capacity (Figure 18). The NW region shows the greatest reduction in 'pervasive' reaches and the largest increase in 'occasional' reaches (Figure 18).

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 now only support rare or occasional dam densities. Some of these streams are likely to have restoration potential while others are far less likely to recover due to land use pressures and other human induced limitations.

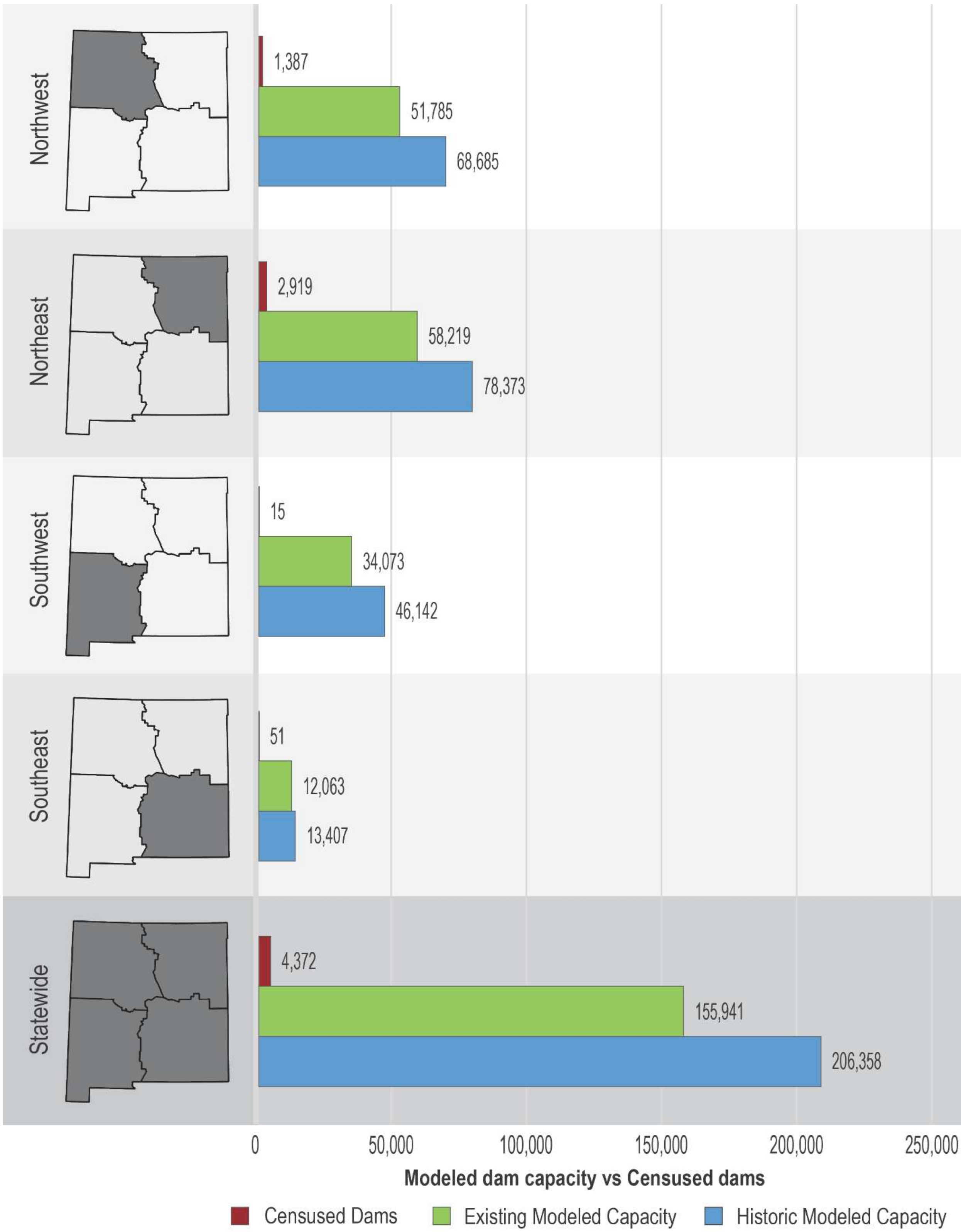


Figure 17: Censused dams, predicted existing and historic beaver dam capacity estimates of perennial streams at the NMFG Region and statewide level for New Mexico.

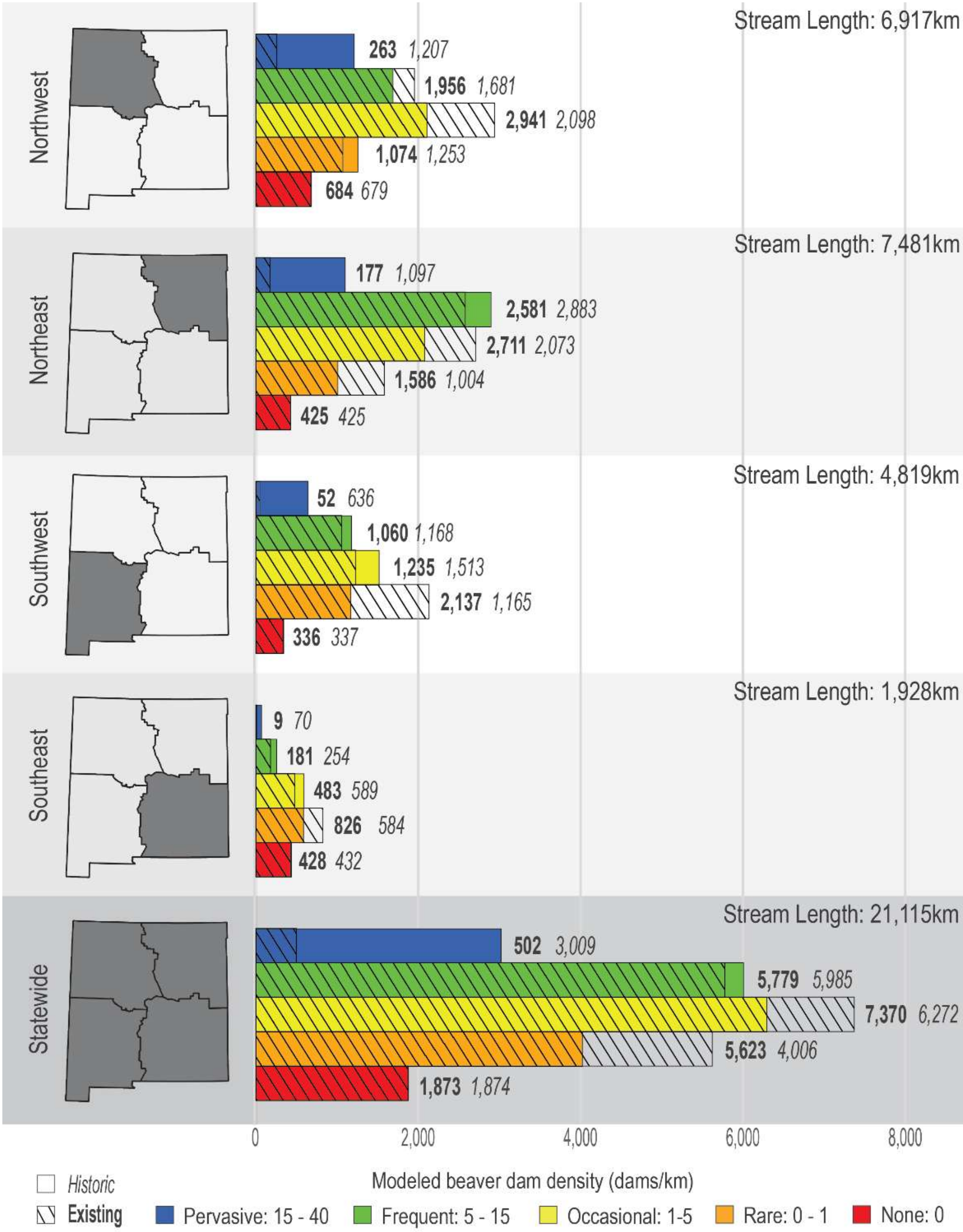


Figure 18: Predicted existing and historic beaver dam capacity by density category for perennial streams at the NMFG region and statewide level for New Mexico.

Northwest Region BRAT Outputs

The NW region BRAT outputs (Figure 19, Figure 20 and Figure 21) show existing and historic capacity, existing and historic complex size, risk, conservation and restoration opportunities, limitations, and current dam building. The NW region is characterized by 65 percent plateaus, 25 percent mountains, and 10 percent tablelands.

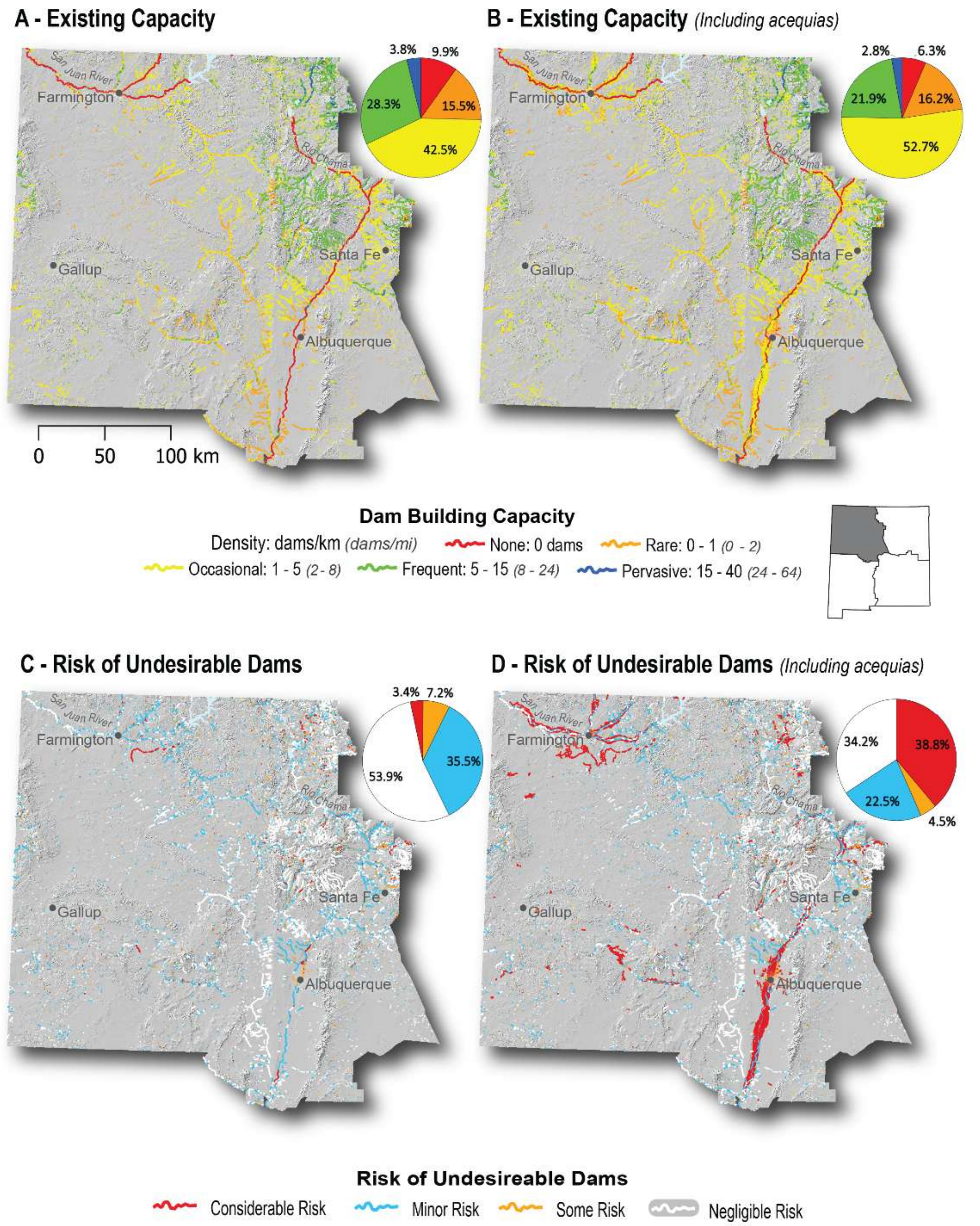


Figure 19: NMGF NW region A. existing capacity, B. existing capacity including acequias, C. risk of undesirable dams and D. risk of undesirable dams including acequias.

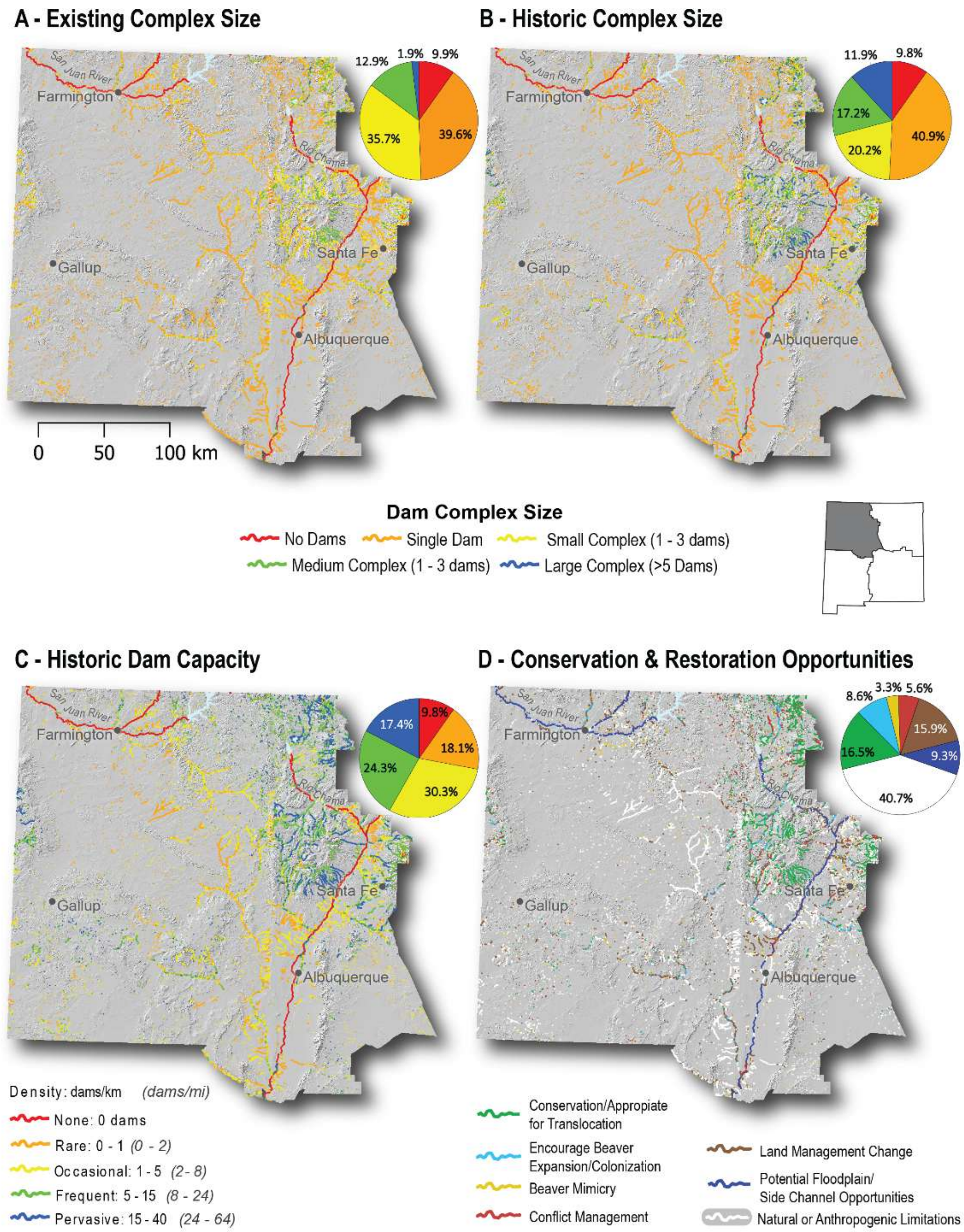


Figure 20: NMGF NW region A. existing complex size, B. historic complex size, C. historic dam capacity and D. conservation & restoration opportunities.

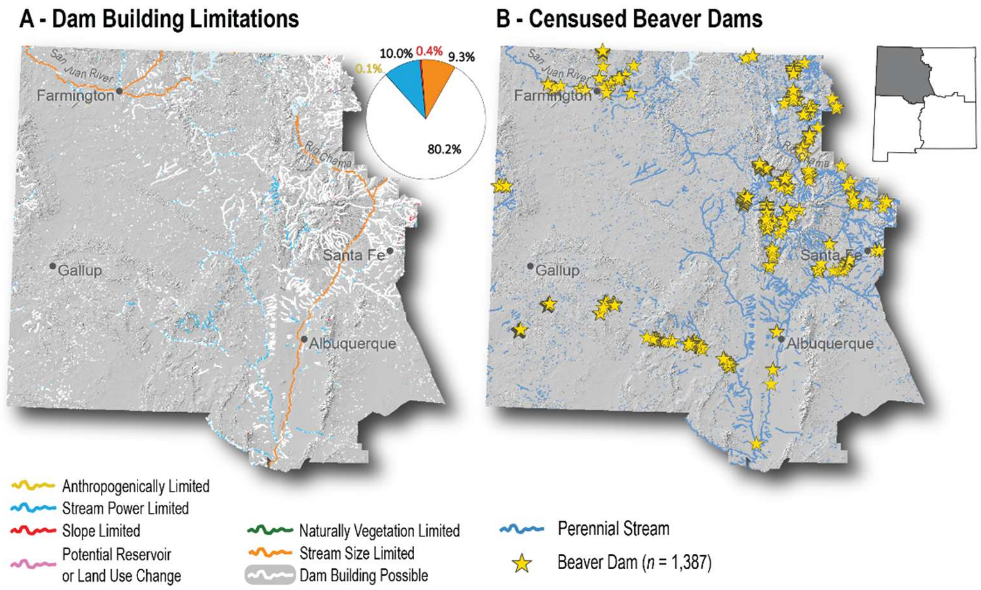


Figure 21: NMGF NW region A. dam building limitations and B. censused beaver dams.

Northeast Region BRAT Outputs

The NE region BRAT outputs (Figure 22, Figure 23 and Figure 24) show existing and historic capacity, existing and historic complex size, risk, conservation and restoration opportunities, limitations, and current dam building. The NE region is characterized by 60 percent tablelands, 25 percent mountains and 15 percent high plains.

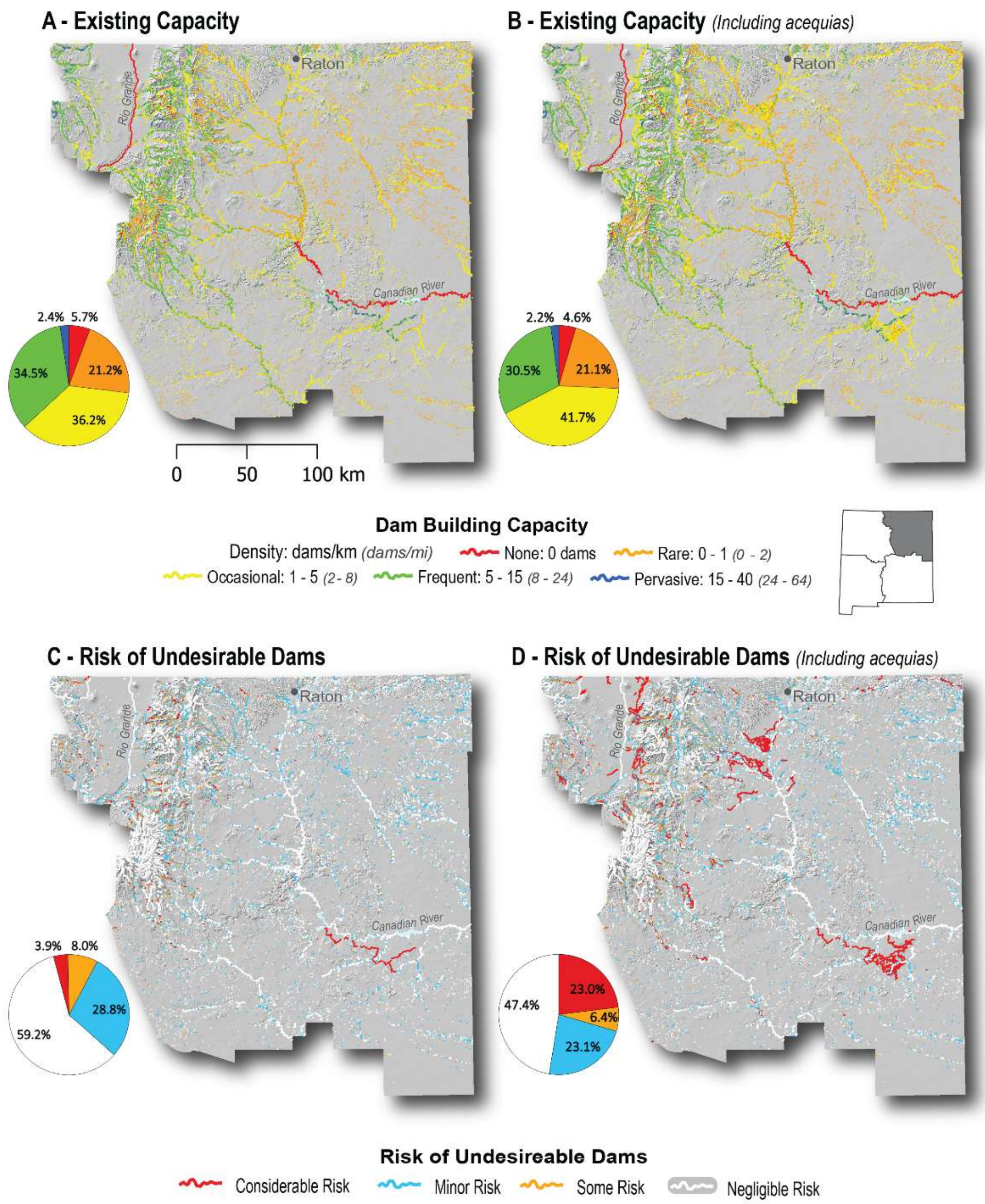


Figure 22: NMGF NE region A. existing capacity, B. existing capacity including acequias, C. risk of undesirable dams and D. risk of undesirable dams including acequias.

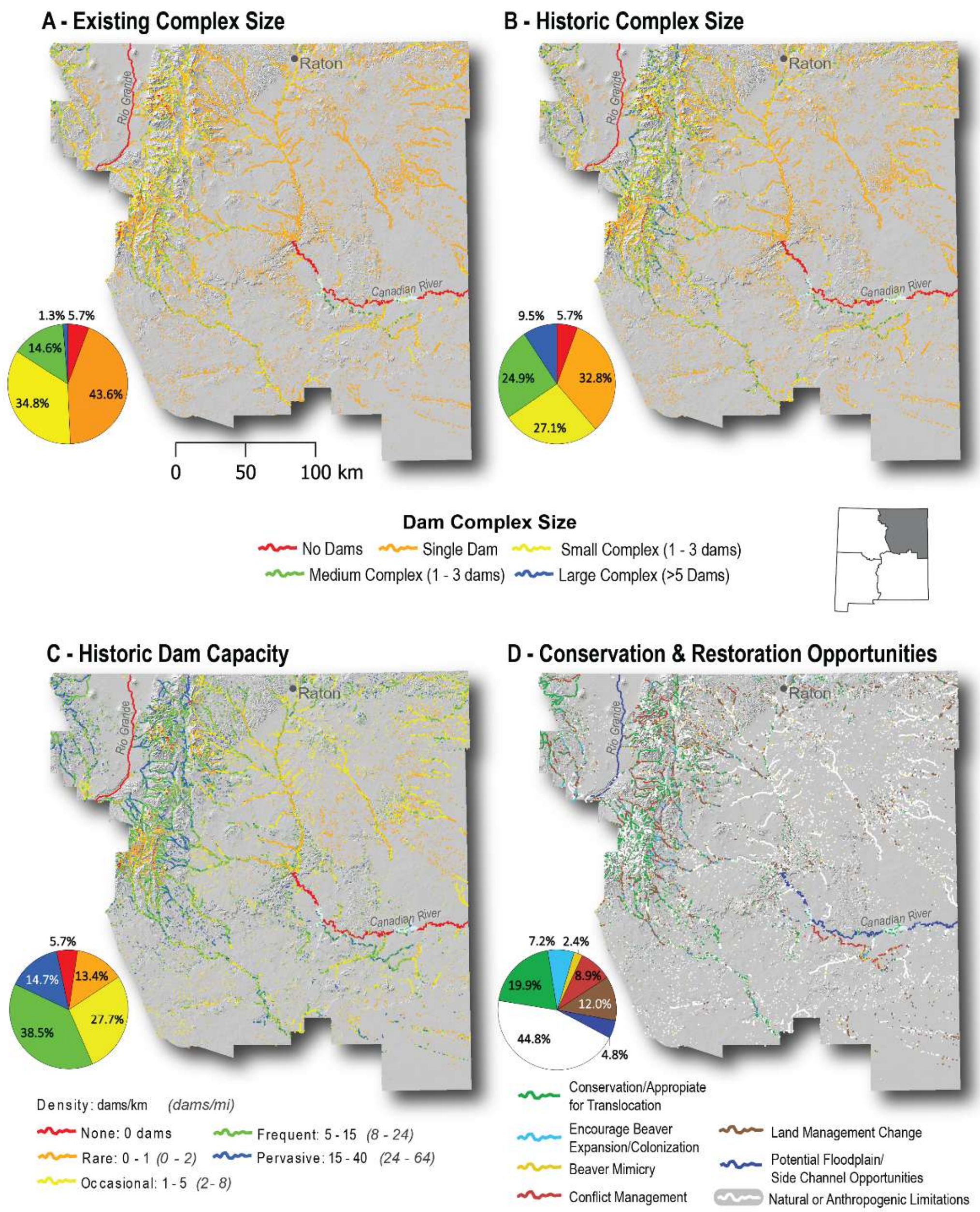


Figure 23: NMGF NE region A. existing complex size, B. historic complex size, C. historic dam capacity and D. conservation & restoration opportunities.

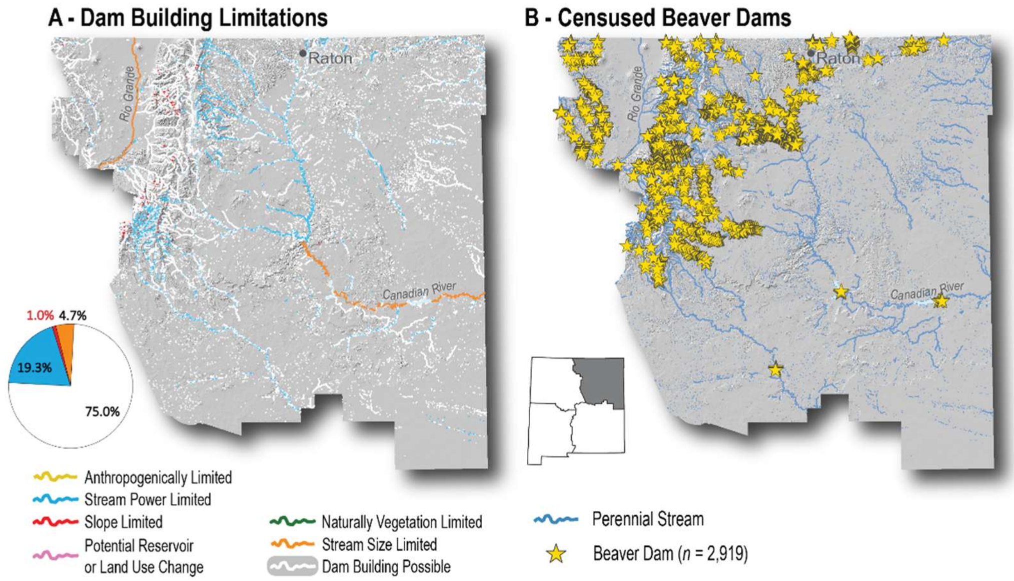


Figure 24: NMGF NE Region A. dam building limitations B. censused beaver dams.

Southwest Region BRAT Outputs

The SW region BRAT outputs (Figure 25, Figure 26 and Figure 27) show existing and historic capacity, existing and historic complex size, risk, conservation and restoration opportunities, limitations, and current dam building. The SW region is characterized by 60 percent desert, 30 percent mountains, and 10 percent plateaus.

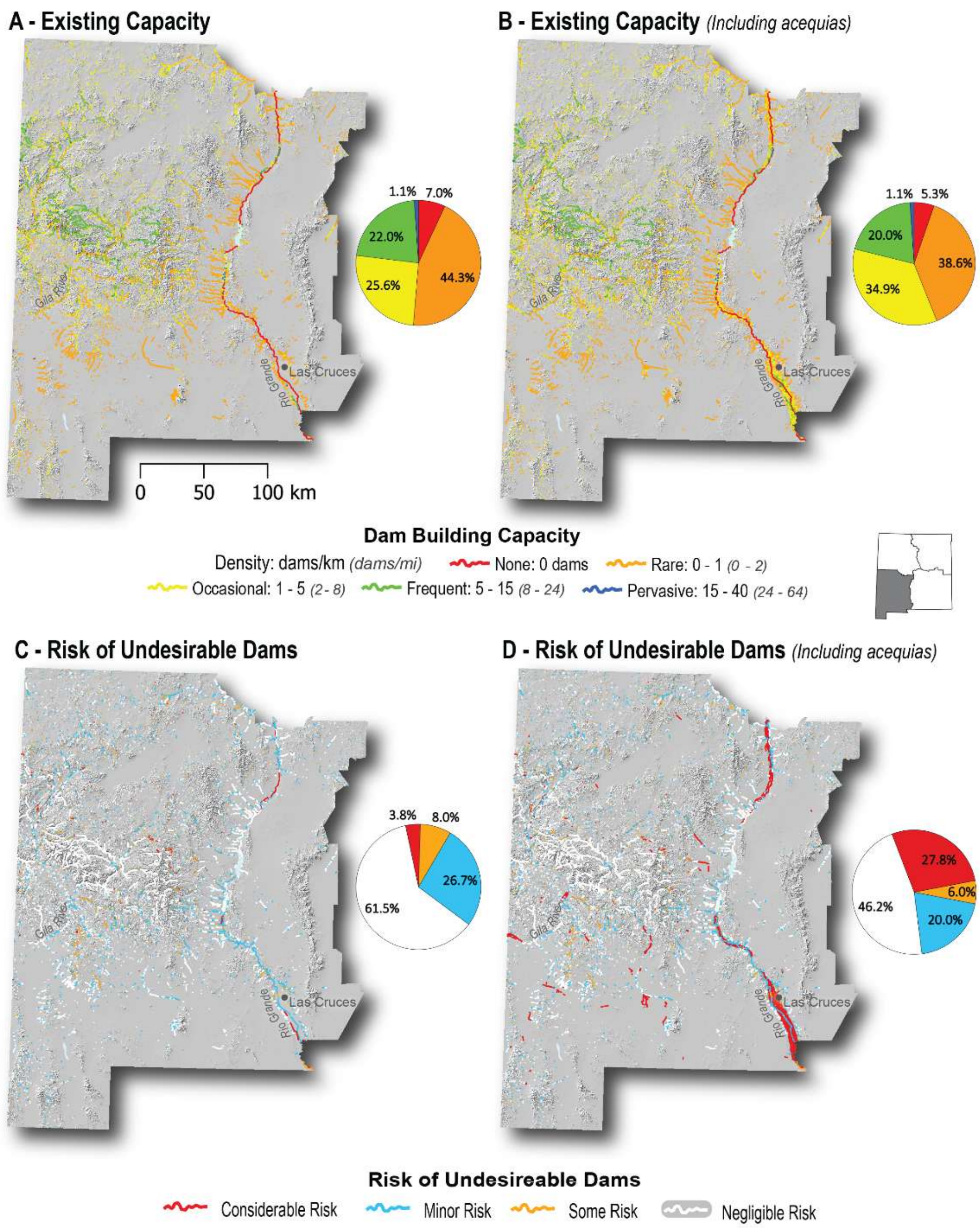


Figure 25: NMGF SW Region A. existing capacity, B. existing capacity including acequias, C. risk of undesirable dams and D. risk of undesirable dams including acequias.

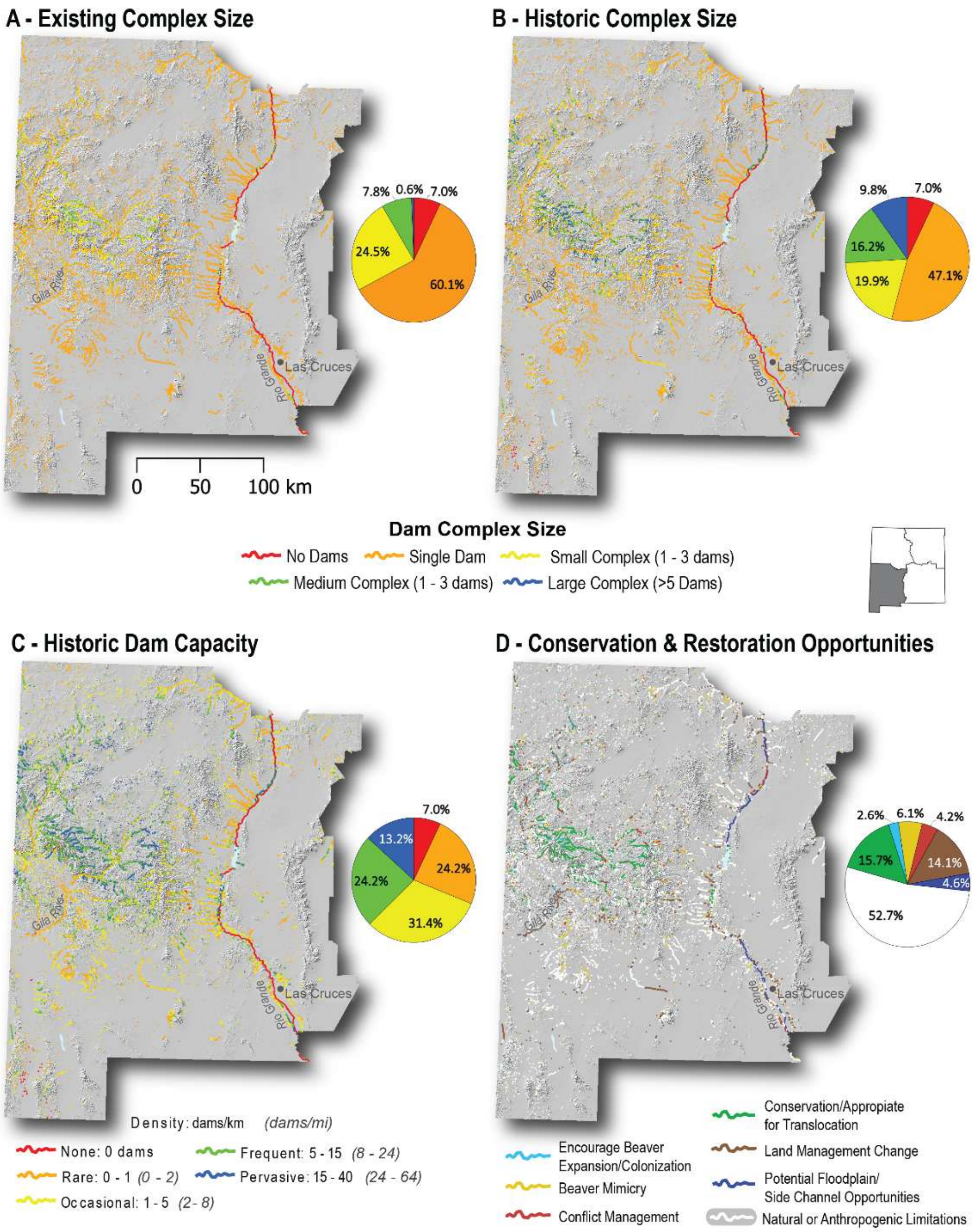


Figure 26: NMGF SW Region A. existing complex size, B. historic complex size, C. historic dam capacity and D. conservation & restoration opportunities.

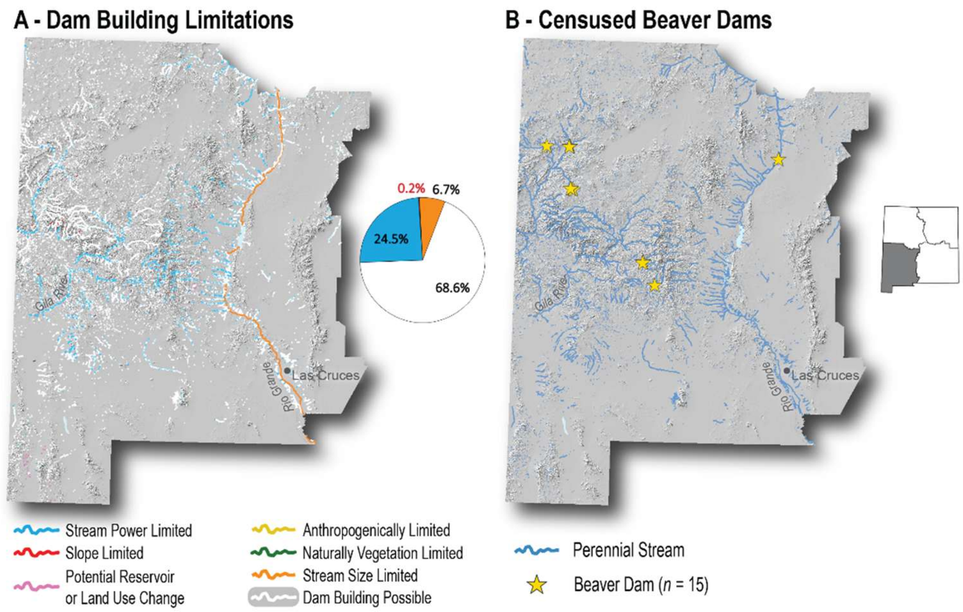


Figure 27: NMGF SW region A. dam building limitations and B. censused beaver dams.

Southeast Region BRAT Outputs

The SE region BRAT outputs (Figure 28, Figure 29 and Figure 30) show existing and historic capacity, existing and historic complex size, risk, conservation and restoration opportunities, limitations, and current dam building. The SE region is characterized by 35 percent desert, 30 percent tablelands, 20 percent high plains and 15 percent mountains.

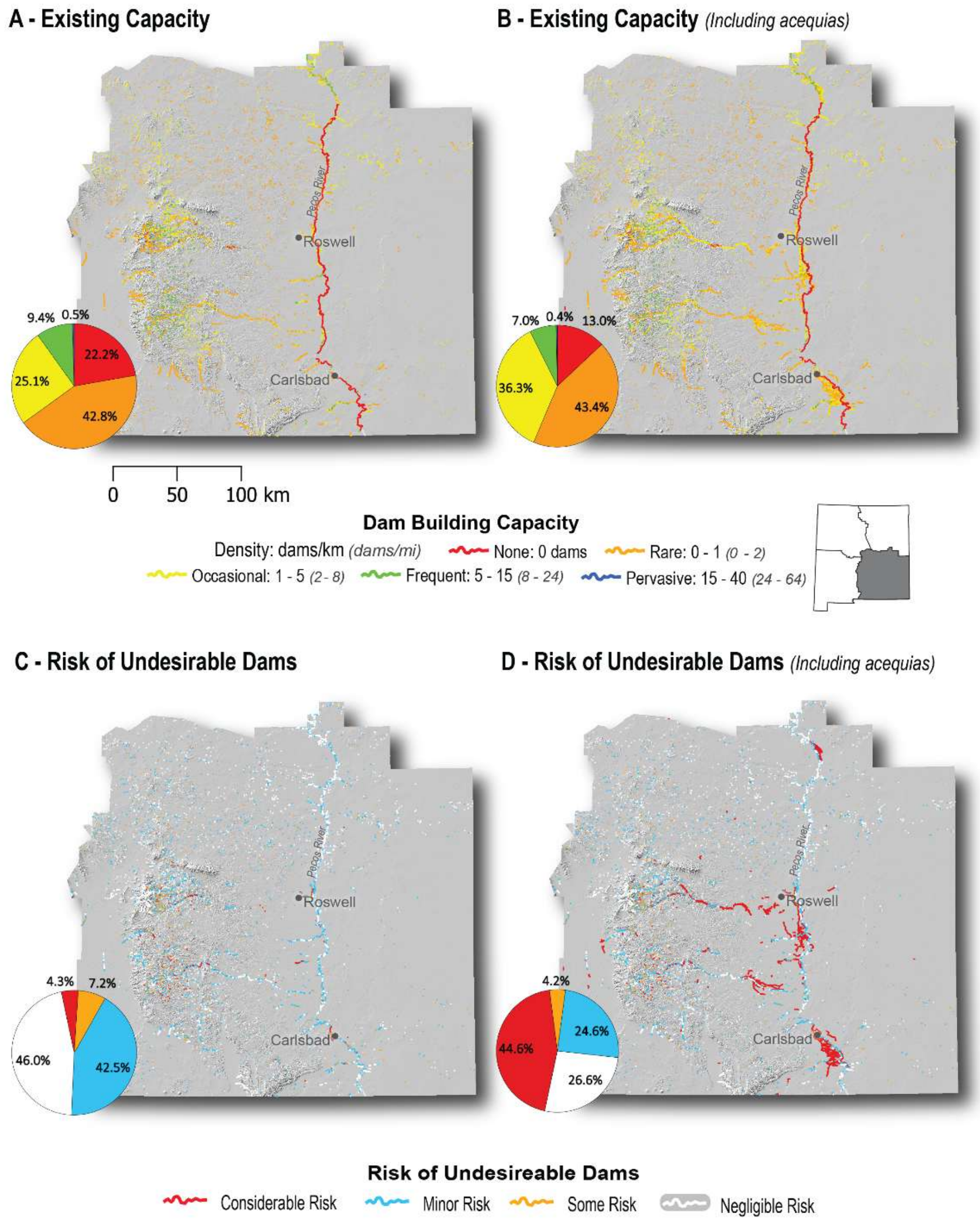


Figure 28: NMGF SE region A. existing capacity, B. existing capacity including acequias, C. risk of undesirable dams and D. risk of undesirable dams including acequias.

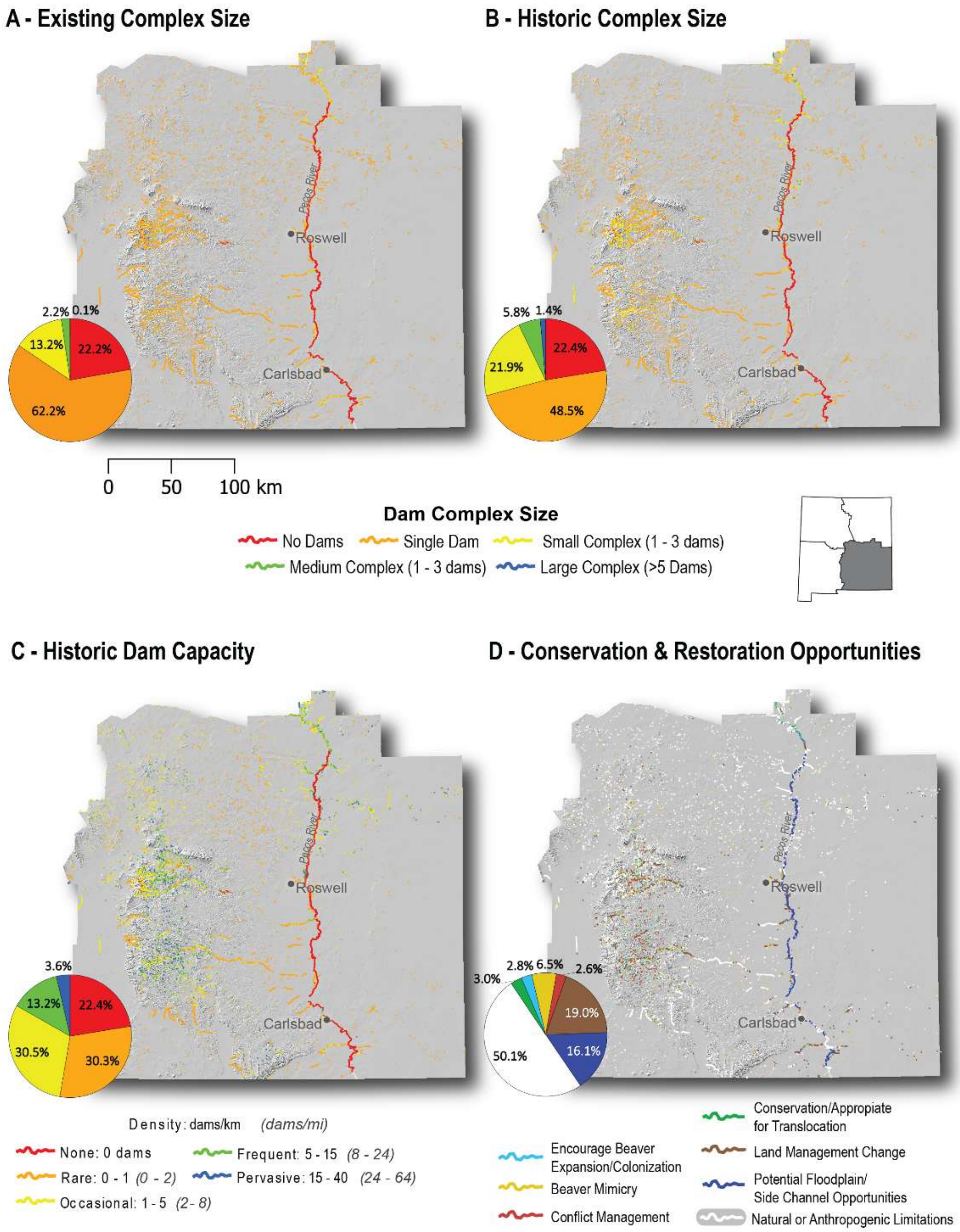


Figure 29: NMGF SE region A. existing complex size, B. historic complex size, C. historic dam capacity, D. conservation & restoration opportunities.

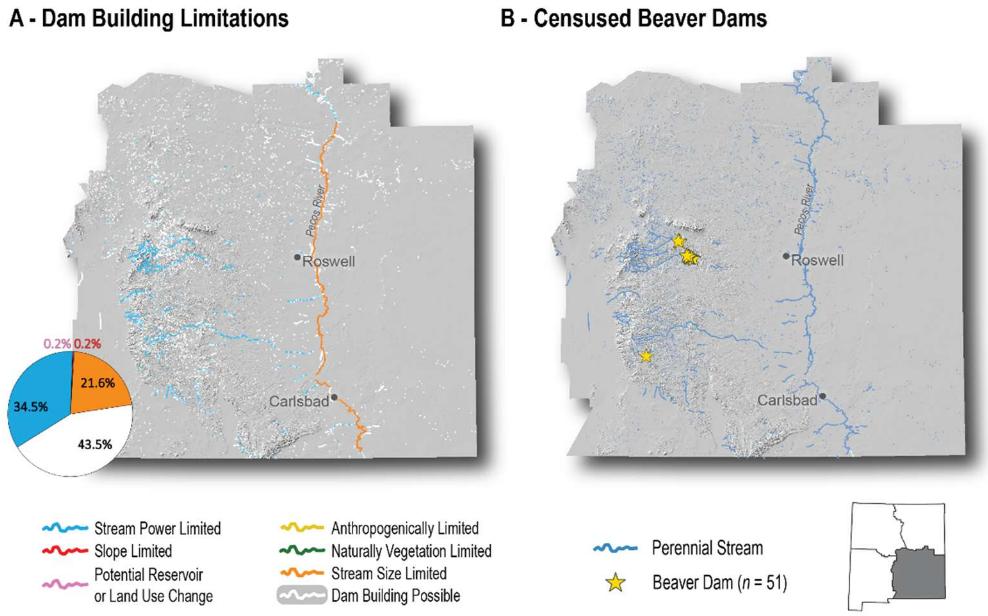


Figure 30: NMGF SE region A. dam building limitations B. censused beaver dams.

BRAT – Capacity Model Validation

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

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

Are there surveyed dams where the model predicted existing dam capacity as *none*?

We verified the performance of the existing capacity model using a total of 4,372 beaver dams collected during a 2020 NAIP imagery-based New Mexico statewide beaver dam census ((Macfarlane et al., 2025); Figure 31). We performed the validation at the HUC8 scale to try to aggregate enough beaver dams for statistical significance (~30 riverscape segments with dams). Across New Mexico, nine HUC8 watersheds had enough dams to use in validation, and an additional two were just below the threshold. Overall, dams were found in 24 HUC8 watersheds. None of the HUC8 watersheds in the SE or SW regions had enough dams for statistical analysis.

Twenty-five beaver dams were found where the model predicted no dams could be supported (0.5%). Of these, six were in dewatered tailwaters of the Canadian River (below Conchas Lake and Ute Lake, i.e., where there is altered hydrology that the model does not capture), and 16 were along floodplains of the Rio Grande River, where secondary channels are not well mapped.

How do dam densities track between predicted and actual? And do the electivity indices increase appreciably from the *none* to the *pervasive* class?

Actual dam densities tracked well with predicted capacities, with high percentile regression lines near the 1:1 line for all watersheds. In all the watersheds where there were abundant dams for validation, at the low end of capacity predictions there are many points above the 1:1 line (realized density is higher than modeled capacity). This is likely driven by two factors: first, the riverscape segments used for validation in small headwaters are relatively short (typically 100 m), resulting in a small numerator that can artificially inflate density values; second, while some secondary/side channels are mapped in large rivers in the NHD datasets, they are almost never mapped in small rivers, thus the very high actual densities may be lower in reality due to the presence of multiple channels. With one small exception in the watersheds used for validation below, EI values consistently increased from ‘none’ to ‘pervasive’. Overall, these results suggest that the model is predicting dam building capacity well across the northern portion of the state. We assume that this also applies to the southern part of the state, but dam numbers are too limited across those regions for actual validation.

Do beaver dam locations and high-capacity stream segment outputs correlate with aspen locations?

Aspen is uncommon in New Mexico and occurs primarily in the north-central and east-central parts of the state. Aspen was present within 100 meters of the stream for 4% of BRAT reach segments. Only 2% of all perennial BRAT segments contained dams, but 10% of all recorded dams were in segments with aspen nearby. Because of the low resolution (30 meters) of the aspen layer, it is difficult to establish a clear correlation between dams and aspen presence. However, this basic analysis suggests that beavers build a notable number of dams near aspen, though not enough to conclude with confidence that they preferentially select areas with aspen in New Mexico.

Reaches with nearby aspen have a mean existing capacity of 8.7, which falls well within the ‘frequent’ category, while reaches without aspen nearby have a mean existing capacity of 4.0, in the “occasional” category. Historic capacity shows a similar pattern, with aspen reaches having a mean capacity of 12.3 and non-aspen reaches 6.9 (both in the frequent category). These results indicate that even though the streamside vegetation input from NMRipMap does not include a distinct aspen category, the mixed deciduous class still allows the model to perform reasonably well. Incorporating a distinct aspen class would likely improve results, as aspen are generally preferred by beavers over other deciduous species.

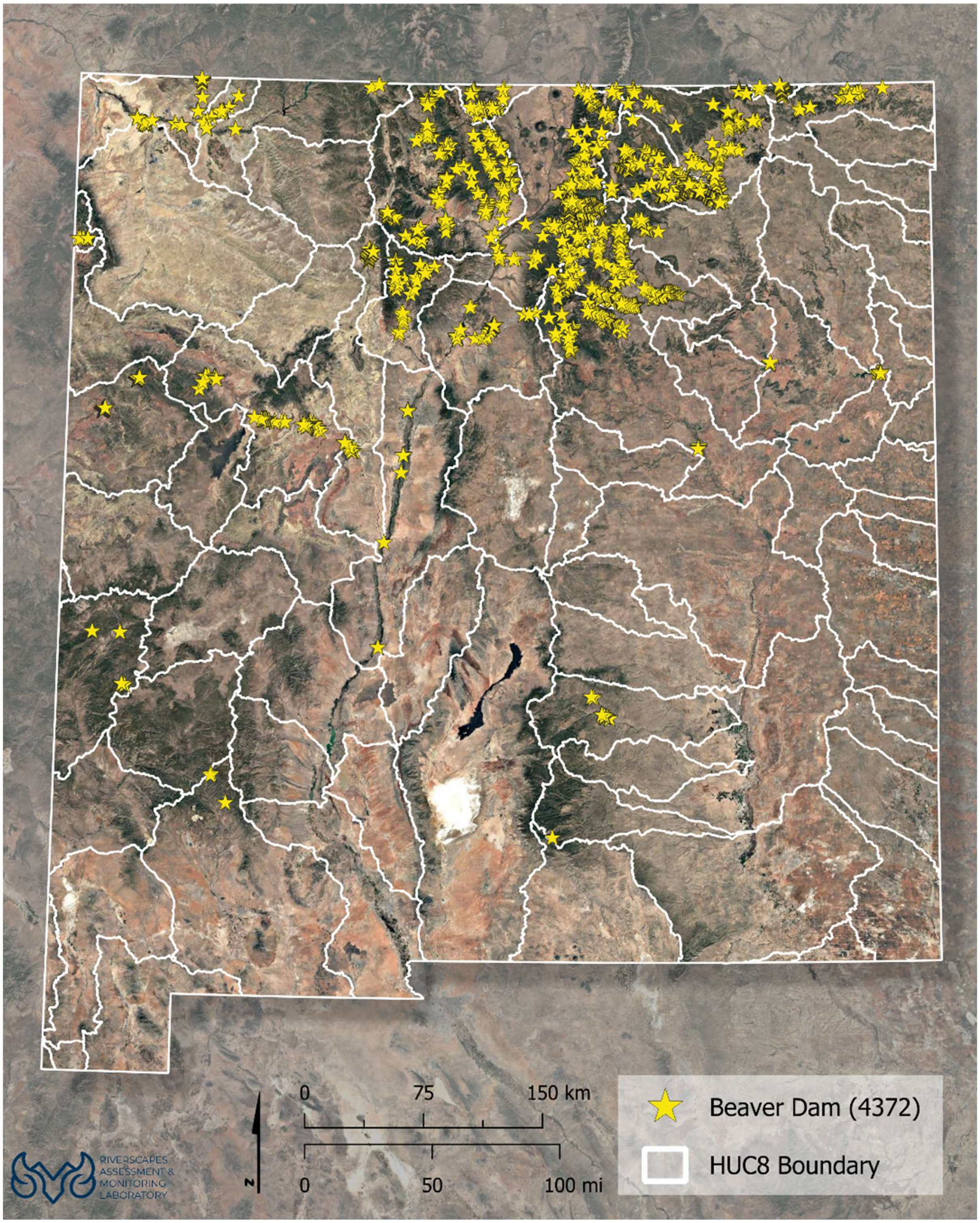


Figure 31: Beaver dam locations identified throughout New Mexico from imagery-based beaver dam censusing surveys.

Northwest Region

In the NW region, none of the HUC8 watersheds in the San Juan watershed had enough dams for statistical significance in the validation analyses, however we include HUC 14080105 here for completeness in reporting across that region. Two dams occurred on reaches where no capacity was predicted. These two dams were both in a small reservoir in the Rio Chama basin. Modeled capacity was zero because of the mapped waterbody, but in reality, fluctuating water levels allowed beaver to build dams when the water was lower. Actual densities tracked predicted capacities well with the upper percentile regression lines being close to the 1:1 line (Figure 32, Figure 33, Figure 34, Figure 35). In general, EI values increased from the 'none' to 'pervasive' categories, with 'frequent' and 'pervasive' consistently having the highest values (Table 6, Table 7, Table 8, and Table 9).

The few dams in the Middle San Juan watershed were concentrated in reaches where modeled capacity was 'pervasive' (Table 6). In the Jemez River watershed, four dams occurred on reaches with 'rare' modeled capacity, resulting in an EI value higher than the value for 'occasional'. This likely reflects reaches where overall, dam building capacity is relatively high (frequent), but due to locally steeper slopes, hydrology causes limitations, dropping some reaches to 'rare'. This creates streams with alternating 'frequent' and 'rare' reaches that indicate that the stream generally supports dam building activity, but dam density may occasionally be reduced due to high flows (further discussed in the discussion section).

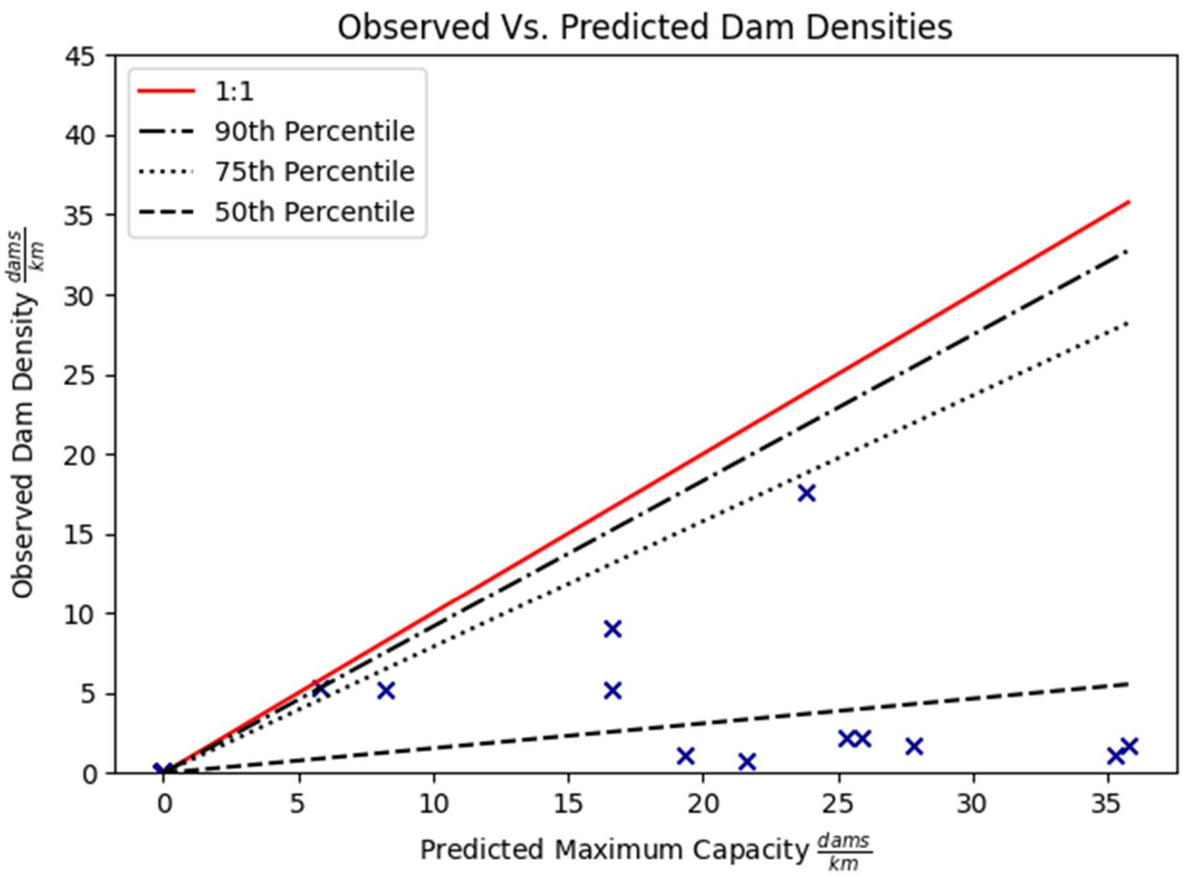


Figure 32: Predicted vs. observed dam densities (per reach) for HUC 14080105 Middle San Juan watershed. The red line is line of perfect agreement (1:1 relationship) and the dashed lines are the 50th percentile (median), 75th percentile, and 90th percentile regressions. The nearer the higher percentile regression is to the 1:1 ratio, the better the model is performing.

Table 6: Existing number of dams, BRAT modeled capacity estimates, and Electivity Index for HUC 14080105 (Middle San Juan watershed).

Capacity	Riverscape Length (km)	Percent of Riverscape Network	Surveyed Dams	BRAT Estimated Capacity	Average Surveyed Dam Density (dams/km)	Average Predicted Capacity (dams/km)	Percent of Modeled Capacity	Electivity Index
None	9	3.1	0	0	0	0	NA	0
Rare	36	11.9	0	17	0	0.48	0	0
Occasional	65	21.4	0	199	0	3.07	0	0
Frequent	108	35.8	6	1028	0.055	9.44	0.58	0.51
Pervasive	84	27.7	27	2271	0.321	27.01	1.19	2.95
Total	303	100	33	3516	0.109	11.58	0.94	NA

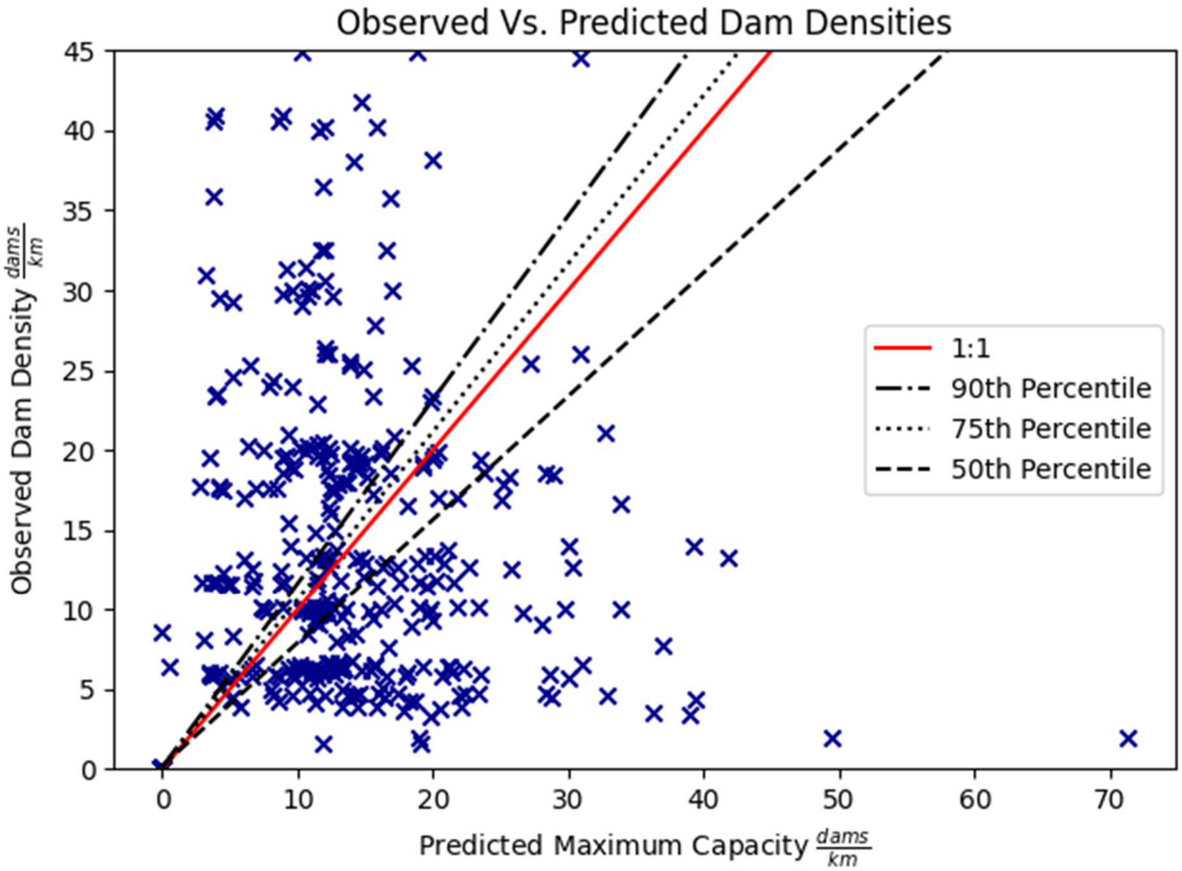


Figure 33: Predicted vs. observed dam densities (per reach) for HUC 13020102 Rio Chama watershed. The red line is line of perfect agreement (1:1 relationship) and the dashed lines are the 50th percentile (median), 75th percentile, and 90th percentile regressions. The nearer the higher percentile regression is to the 1:1 ratio, the better the model is performing.

Table 7: Existing number of dams, BRAT modeled capacity estimates, and Electivity Index for HUC 13020102 watershed (Rio Chama watershed).

Capacity	Riverscape Length (km)	Percent of Riverscape Network	Surveyed Dams	BRAT Estimated Capacity	Average Surveyed Dam Density (dams/km)	Average Predicted Capacity (dams/km)	Percent of Modeled Capacity	Electivity Index
None	85	5.2	2	0	0.023	0	NA	0.04
Rare	36	2.2	1	20	0.027	0.56	4.86	0.05
Occasional	366	22.1	76	1249	0.207	3.41	6.08	0.38
Frequent	896	54.1	499	9017	0.556	10.06	5.53	1.02
Pervasive	273	16.5	329	6817	1.204	24.95	4.83	2.2
Total	1658	100	907	17104	0.547	10.31	5.3	NA

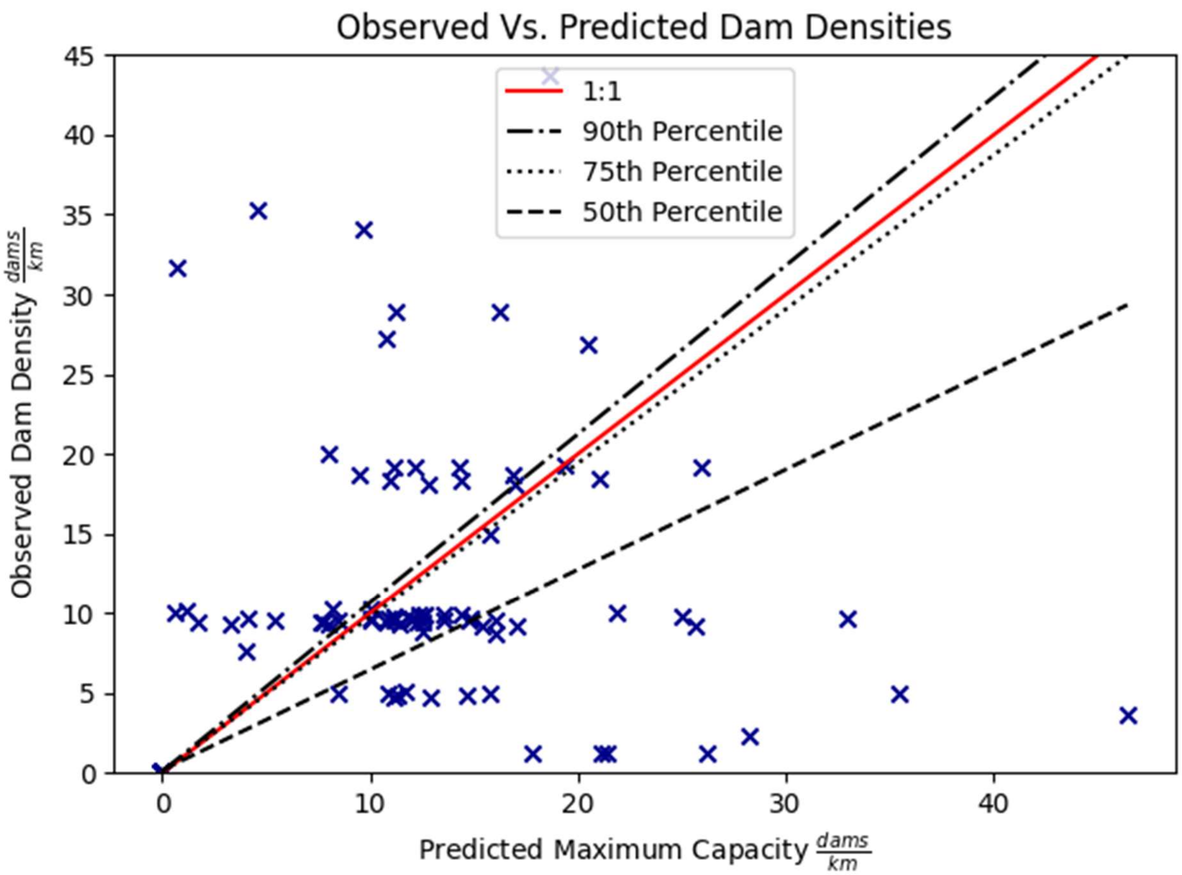


Figure 34: Predicted vs. observed dam densities (per reach) for HUC 13020202 Jemez River watershed. The red line is line of perfect agreement (1:1 relationship) and the dashed lines are the 50th percentile (median), 75th percentile, and 90th percentile regressions. The nearer the higher percentile regression is to the 1:1 ratio, the better the model is performing.

Table 8: Existing number of dams, BRAT modeled capacity estimates, and Electivity Index for HUC 13020202 watershed (Jemez River watershed).

Capacity	Riverscape Length (km)	Percent of Riverscape Network	Surveyed Dams	BRAT Estimated Capacity	Average Surveyed Dam Density (dams/km)	Average Predicted Capacity (dams/km)	Percent of Modeled Capacity	Electivity Index
None	4	0.8	0	0	0	0	NA	0
Rare	22	4.4	4	13	0.178	0.59	30.04	0.69
Occasional	193	38.1	12	655	0.062	3.38	1.83	0.24
Frequent	212	41.8	67	1980	0.315	9.33	3.38	1.22
Pervasive	75	14.9	48	1704	0.633	22.48	2.82	2.46
Total	508	100	131	4353	0.258	8.56	3.01	NA

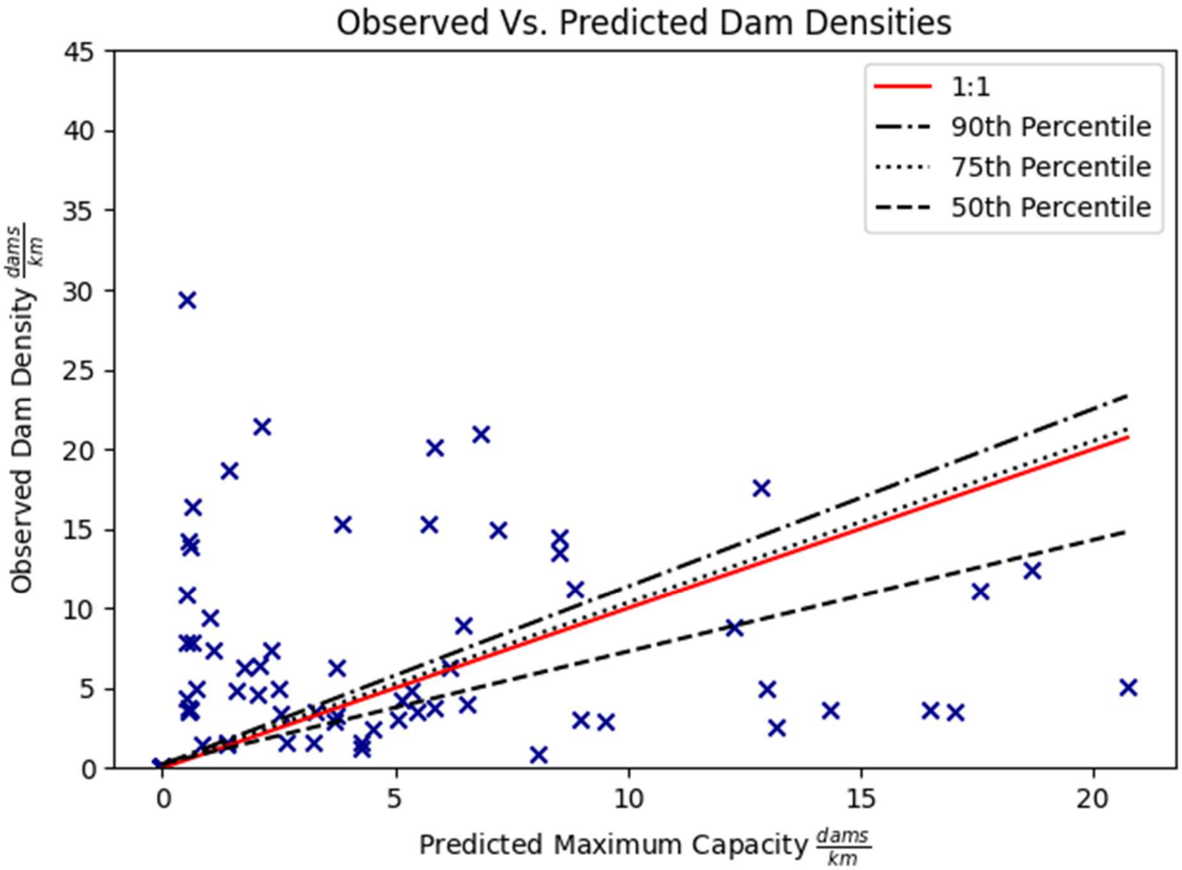


Figure 35: Predicted vs. observed dam densities (per reach) for HUC 13020207 Rio San Jose watershed. The red line is line of perfect agreement (1:1 relationship) and the dashed lines are the 50th percentile (median), 75th percentile, and 90th percentile regressions. The nearer the higher percentile regression is to the 1:1 ratio, the better the model is performing.

Table 9: Existing number of dams, BRAT modeled capacity estimates, and Electivity Index for HUC 13020207 watershed (Rio San Jose watershed).

Capacity	Riverscape Length (km)	Percent of Riverscape Network	Surveyed Dams	BRAT Estimated Capacity	Average Surveyed Dam Density (dams/km)	Average Predicted Capacity (dams/km)	Percent of Modeled Capacity	Electivity Index
None	16	4.6	0	0	0	0	NA	0
Rare	107	29.6	47	63	0.438	0.59	74.37	0.63
Occasional	157	43.6	70	453	0.443	2.87	15.42	0.63
Frequent	69	19.1	119	573	1.718	8.28	20.74	2.46
Pervasive	11	3	17	206	1.545	18.8	8.22	2.21
Total	362	100	253	1297	0.698	3.58	19.5	NA

Northeast Region

In the NE region, five HUC8 watersheds were used for validation. Across those watersheds, no dams occurred on reaches where capacity was modeled to be 'None'. Similar to the Northwest region, the upper percentile regression lines were very close to the 1:1 line, indicating that actual densities track predicted capacities well (Figure 36, Figure 37, Figure 38, Figure 39, Figure 40). In all cases, EI values increased through the capacity categories, highlighting that beavers are selecting the reaches with the highest modeled capacities for dam building (Table 10, Table 11, Table 12, Table 13, Table 14).

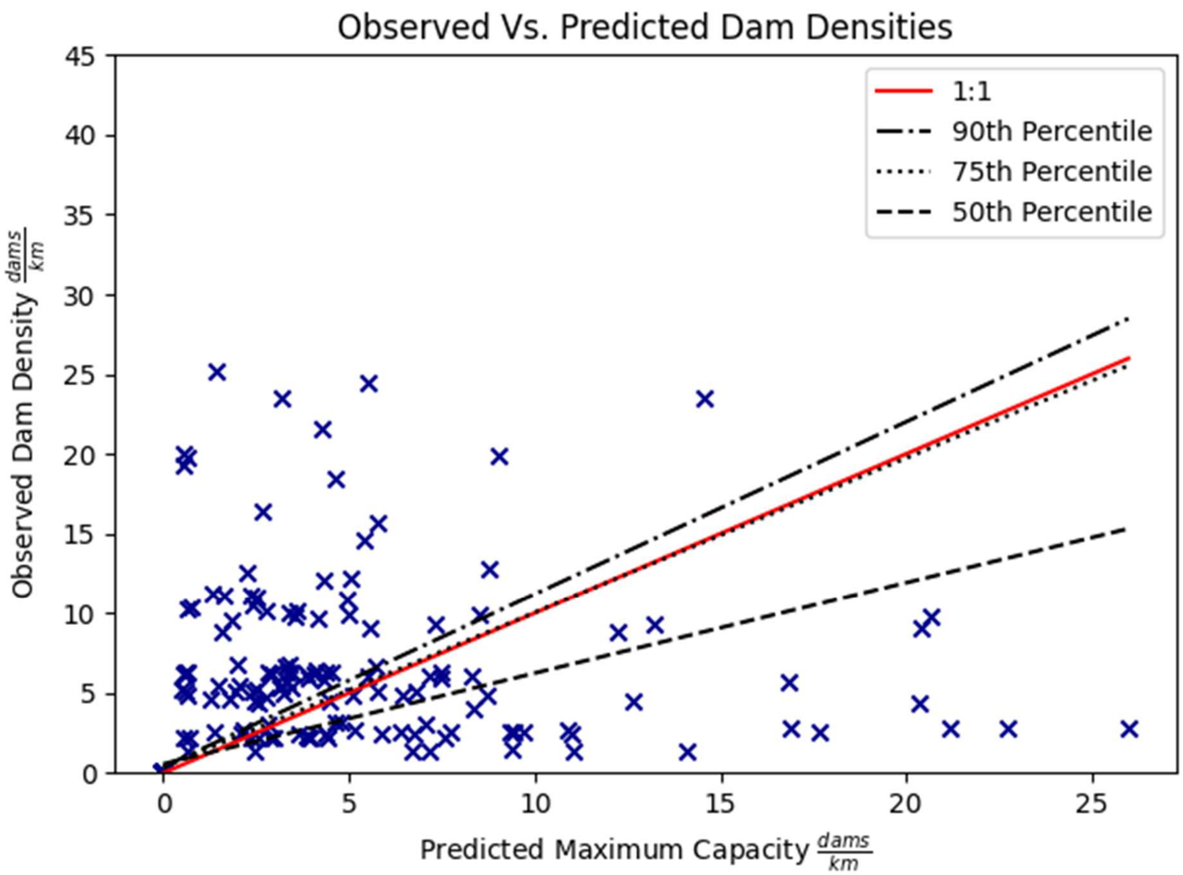


Figure 36: Predicted vs. observed dam densities (per reach) for HUC 11080001 Canadian Headwaters watershed. The red line is line of perfect agreement (1:1 relationship) and the dashed lines are the 50th percentile (median), 75th percentile, and 90th percentile regressions. The nearer the higher percentile regression is to the 1:1 ratio, the better the model is performing.

Table 10: Existing number of dams, BRAT modeled capacity estimates, and Electivity Index for HUC 11080001 Canadian Headwaters watershed.

Capacity	Riverscape Length (km)	Percent of Riverscape Network	Surveyed Dams	BRAT Estimated Capacity	Average Surveyed Dam Density (dams/km)	Average Predicted Capacity (dams/km)	Percent of Modeled Capacity	Electivity Index
None	10	1.7	0	0	0	0	NA	0
Rare	117	19	23	69	0.196	0.59	33.29	0.48
Occasional	297	48.1	126	870	0.423	2.92	14.48	1.04
Frequent	179	29	86	1545	0.478	8.59	5.57	1.17
Pervasive	13	2.2	18	258	1.327	19.08	6.96	3.25
Total	619	100	253	2743	0.408	4.43	9.22	NA

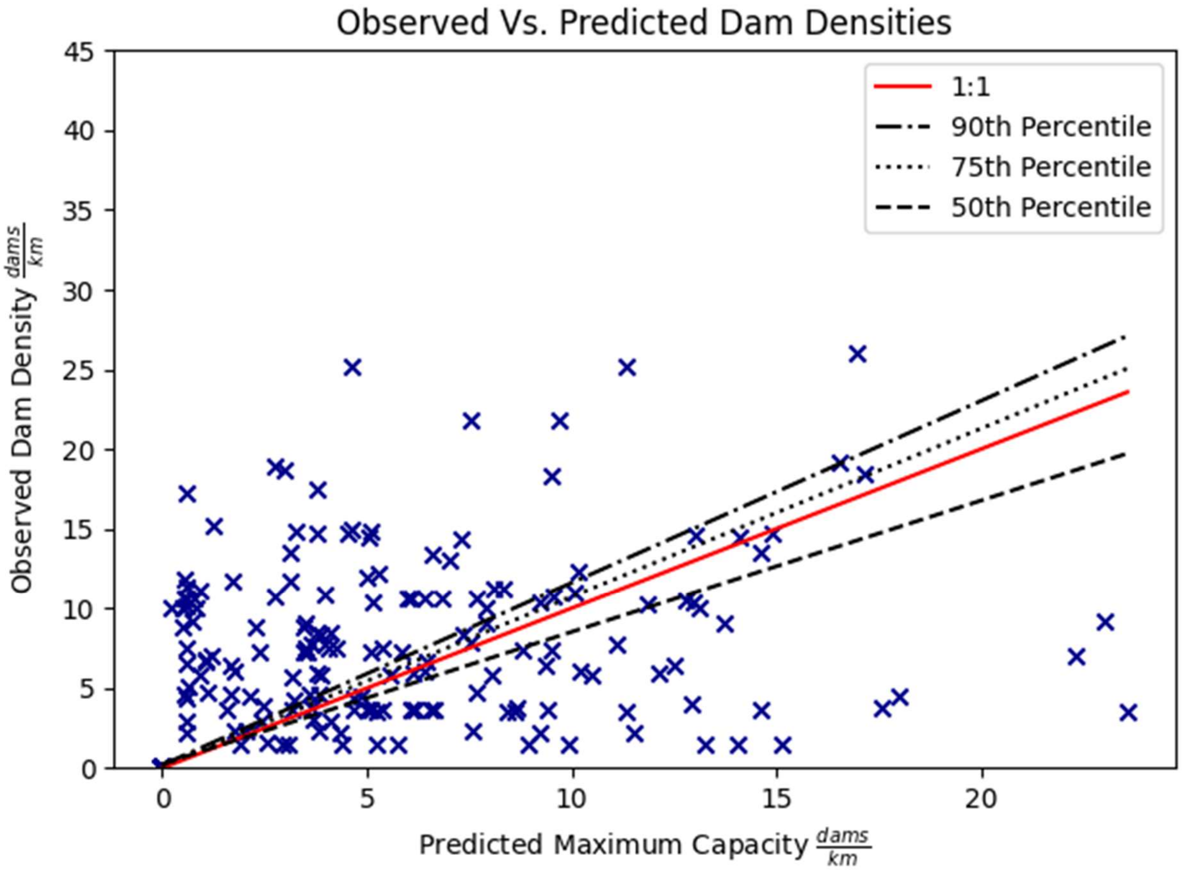


Figure 37: Predicted vs. observed dam densities (per reach) for HUC 11080002 Cimmaron watershed. The red line is line of perfect agreement (1:1 relationship) and the dashed lines are the 50th percentile (median), 75th percentile, and 90th percentile regressions. The nearer the higher percentile regression is to the 1:1 ratio, the better the model is performing.

Table 11: Existing number of dams, BRAT modeled capacity estimates, and Electivity Index for HUC 11080002 (Cimarron watershed).

Capacity	Riverscape Length (km)	Percent of Riverscape Network	Surveyed Dams	BRAT Estimated Capacity	Average Surveyed Dam Density (dams/km)	Average Predicted Capacity (dams/km)	Percent of Modeled Capacity	Electivity Index
None	11	1.9	0	0	0	0	NA	0
Rare	173	27.9	41	102	0.236	0.59	40.18	0.32
Occasional	191	30.7	172	580	0.898	3.03	29.62	1.22
Frequent	229	36.8	218	2079	0.95	9.07	10.48	1.29
Pervasive	17	2.8	28	340	1.597	19.42	8.23	2.17
Total	624	100	459	3103	0.736	4.97	14.79	NA

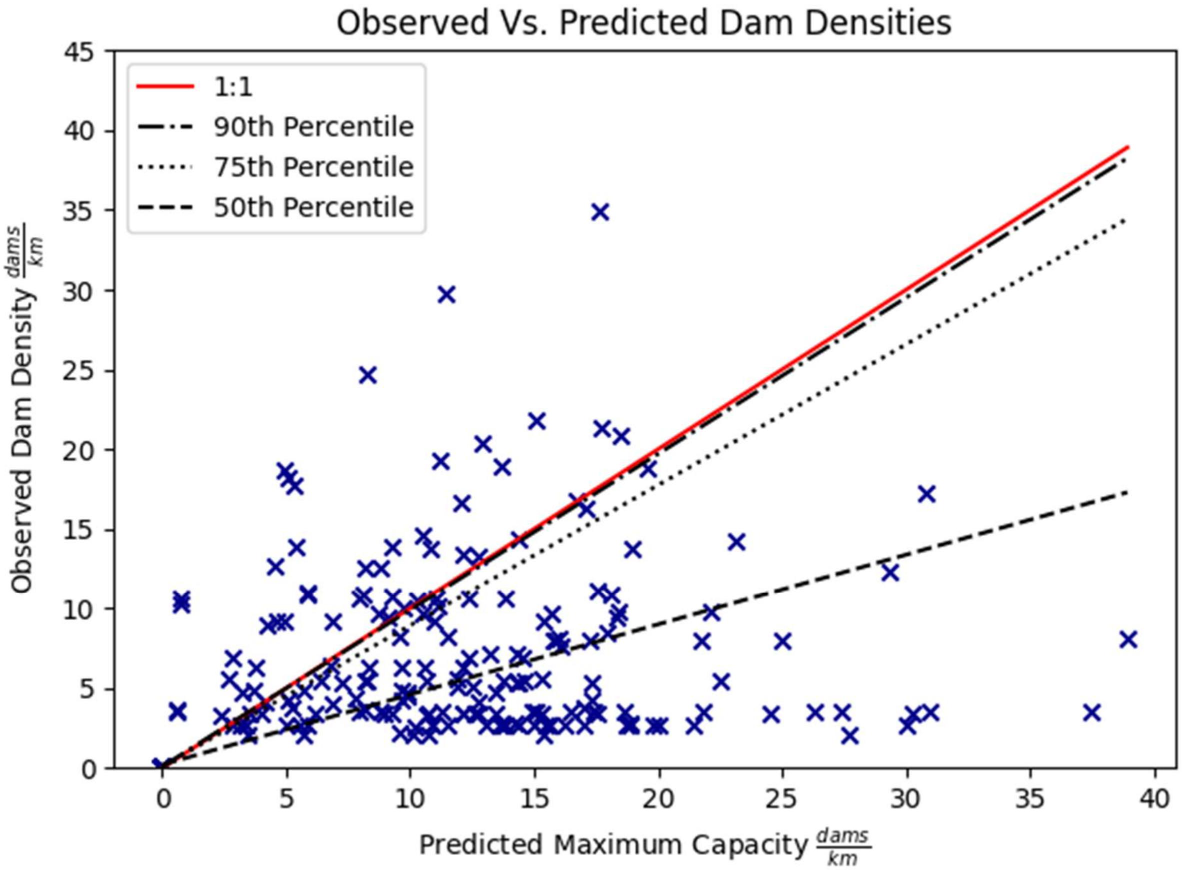


Figure 38: Predicted vs. observed dam densities (per reach) for HUC 11080004 Mora watershed. The red line is line of perfect agreement (1:1 relationship) and the dashed lines are the 50th percentile (median), 75th percentile, and 90th percentile regressions. The nearer the higher percentile regression is to the 1:1 ratio, the better the model is performing.

Table 12: Existing number of dams, BRAT modeled capacity estimates, and Electivity Index for HUC 11080004 (Mora watershed).

Capacity	Riverscape Length (km)	Percent of Riverscape Network	Surveyed Dams	BRAT Estimated Capacity	Average Surveyed Dam Density (dams/km)	Average Predicted Capacity (dams/km)	Percent of Modeled Capacity	Electivity Index
None	22	3.2	0	0	0	0	NA	0
Rare	108	15.4	8	58	0.074	0.54	13.67	0.13
Occasional	150	21.4	29	482	0.193	3.21	6.02	0.33
Frequent	355	50.7	219	3445	0.615	9.68	6.36	1.06
Pervasive	64	9.2	152	1296	2.347	20.03	11.72	4.04
Total	701	100	408	5283	0.581	7.53	7.72	NA

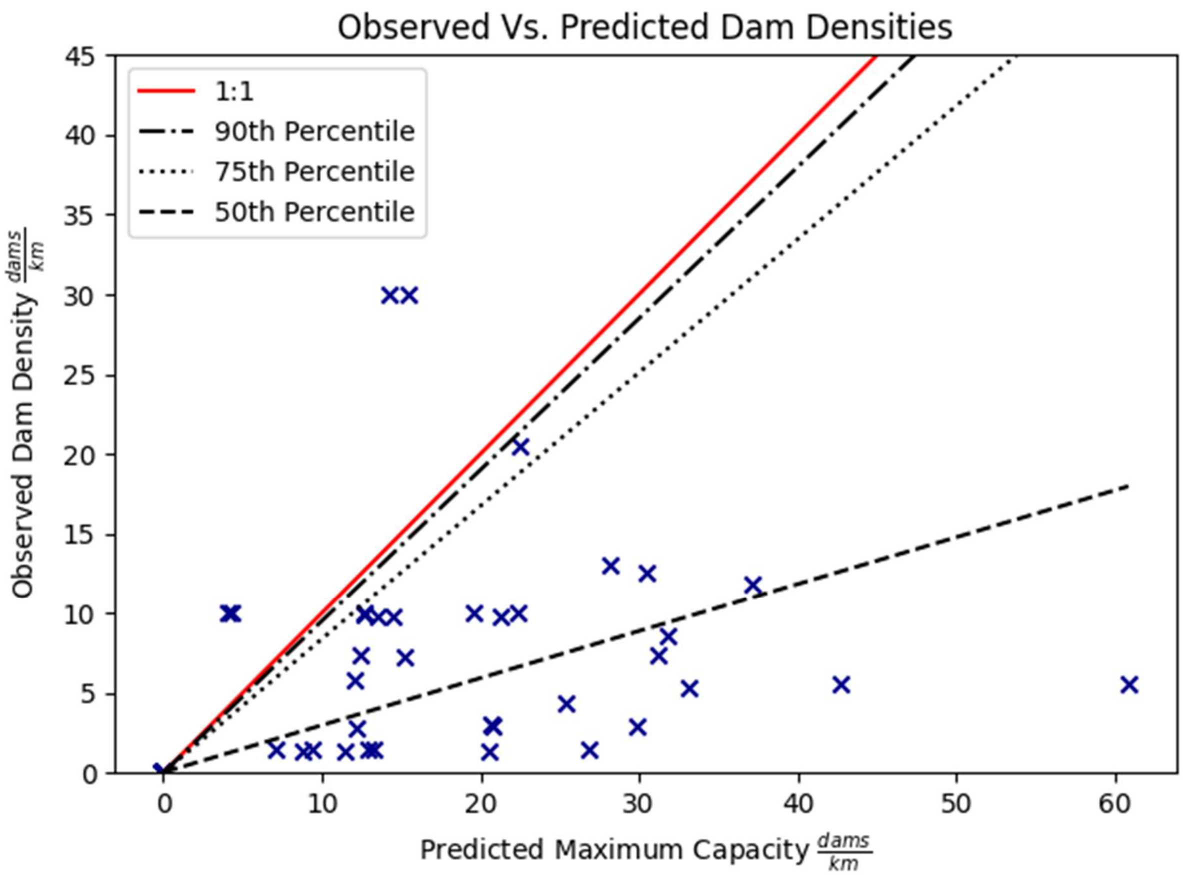


Figure 39: Predicted vs. observed dam densities (per reach) for HUC 13010005 Conejos watershed. The red line is line of perfect agreement (1:1 relationship) and the dashed lines are the 50th percentile (median), 75th percentile, and 90th percentile regressions. The nearer the higher percentile regression is to the 1:1 ratio, the better the model is performing.

Table 13: Existing number of dams, BRAT modeled capacity estimates, and Electivity Index for HUC 13010005 (Conejos watershed).

Capacity	Riverscape Length (km)	Percent of Riverscape Network	Surveyed Dams	BRAT Estimated Capacity	Average Surveyed Dam Density (dams/km)	Average Predicted Capacity (dams/km)	Percent of Modeled Capacity	Electivity Index
None	10	2.2	0	0	0	0	NA	0
Rare	5	1.2	0	2	0	0.5	0	0
Occasional	41	8.7	2	144	0.049	3.52	1.38	0.27
Frequent	228	48.4	21	2473	0.092	10.84	0.85	0.51
Pervasive	185	39.5	60	5023	0.323	27.01	1.19	1.79
Total	471	100	85	7644	0.176	16.22	1.09	NA

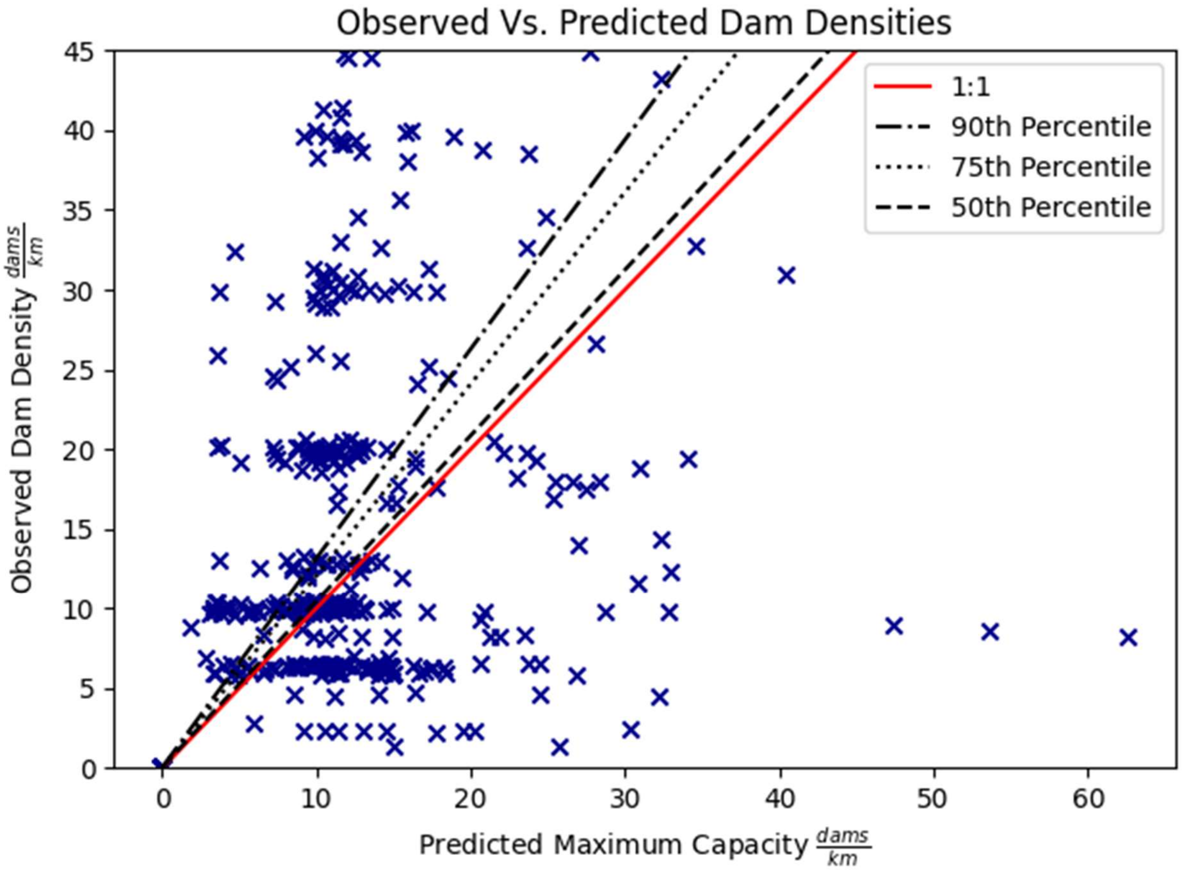


Figure 40: Predicted vs. observed dam densities (per reach) for HUC 13020101 Upper Rio Grande watershed. The red line is line of perfect agreement (1:1 relationship) and the dashed lines are the 50th percentile (median), 75th percentile, and 90th percentile regressions. The nearer the higher percentile regression is to the 1:1 ratio, the better the model is performing.

Table 14: Existing number of dams, BRAT modeled capacity estimates, and Electivity Index for HUC 13020101 (Upper Rio Grande watershed).

Capacity	Riverscape Length (km)	Percent of Riverscape Network	Surveyed Dams	BRAT Estimated Capacity	Average Surveyed Dam Density (dams/km)	Average Predicted Capacity (dams/km)	Percent of Modeled Capacity	Electivity Index
None	139	7.1	0	0	0	0	NA	0
Rare	62	3.2	0	31	0	0.51	0	0
Occasional	646	33.2	59	2227	0.091	3.44	2.65	0.21
Frequent	975	50	526	9127	0.539	9.35	5.76	1.26
Pervasive	125	6.4	248	2970	1.973	23.63	8.35	4.61
Total	1949	100	834	14357	0.427	7.36	5.8	NA

DISCUSSION

Sources of Uncertainty/Error in BRAT Modeling

Since BRAT was run with freely-available, moderately coarse, national data (except for the 1 m NMRipMap) some sources of potential uncertainty should be considered when assessing outputs. The BRAT capacity model is only as good as the model inputs. While the logic of the capacity model and model performance is robust (i.e. in many instances the model gets the right answers for the right reasons and the wrong answers for the right reasons – namely, if the inputs are inaccurate). The digital elevation model and drainage network (stream position) mapping are all relatively coarse and have inherent inaccuracies when examined at scales at the limits of their precision. The BRAT samples across reach-scale resolutions to make the significance of those inaccuracies less impactful. As such, model verification shows that the model does a good job at capturing capacity in most cases. However, that positional inaccuracy can impact channel slope calculations, which impacts stream power estimates.

NHD FCode classifications are imperfect. In some cases, perennial reaches are classified as intermittent or ephemeral or vice-versa. BRAT maps by default display what NHD codes as perennial, however the entire channel network is modeled. Therefore, users are free to 'bring in' additional streams they know are perennial or strongly intermittent or remove streams that are not perennial by adjusting the display filters or manually changing the FCode designations. Side channels and anabranches are infrequently mapped, both in larger rivers as well as smaller system. As a result, there is potential for significant additional dam capacity that is not being modeled. Additionally, as previously mentioned, aspen is one of the most desirable woody species for beavers, yet the current NMRipMap does not include aspen as its own distinct category (it is lumped into mixed forest categories), which may result in an underestimation of capacity in locations where aspen is within 100 m of channels. We recommend updating the classification to include aspen. In the future, running the model with this adjustment will yield more accurate capacity estimates. In many cases, the land use intensity assessment is likely an underestimate because it does not include livestock or wild ungulate grazing.

While dam capacity can be underestimated due to poor channel mapping, it can also be overestimated because the model is unable to capture all forms of degradation that impact beavers' ability to build dams. Specifically, in New Mexico, incision from high intensity land use and climate variability has increased stream power locally in a manner that we are unable to simulate with coarse, regional data.

Despite these limitations, we believe that with the spatially explicit data provided from this medium-sized contract, the expectation management and vision provided by the BRAT model could stand to save millions of dollars. If one considers the cost of current restoration practices, the scope of areas that could use improvement, and the relatively low-cost of beaver-assisted restoration, dramatic gains and improvements could be made. When higher resolution data become freely available in the future, it makes sense to run an updated version of the BRAT model with new inputs. However, we do not recommend undertaking expensive data acquisition campaigns for the sole purpose of improving the model outputs; rather, we think, that it's worth investing in calibrating the model based on field data collection.

Interpretation of BRAT Maps/Outputs

This section highlights some information that is good to know when interpreting the output maps/data layers that BRAT produces.

Perennial flow lines in NHD include both 'Perennial' (FCode 46006) and 'Artificial Path' (FCode 55800) reach types. Artificial paths are the lines drawn through NHD Area polygons (like larger rivers) and NHD Waterbody polygons. Including both results in a more extensive stream network than what is truly perennial because there are many small artificial path segments where intermittent or ephemeral channels cross stock ponds or other small waterbodies that end up in the output (this is why the output maps include many small, isolated line segments). In general, these segments can be disregarded. In larger systems, the NHD network often does not accurately map side channels and anabranches where there may be dam building capacity. In cases where it does map them, sometimes the incorrect anabranch is selected as the mainstem rather than a side channel, which results in no modeled capacity. Thus, outputs along large rivers should be assessed carefully to determine where anabranches are truly too large for damming, and where there may be opportunities in floodplains and side channels.

In some areas, a pattern is evident in the capacity maps of alternating ‘frequent’ and ‘rare’ capacity reaches. In BRAT, capacity estimates are initially driven by vegetation suitability and subsequently adjusted downward for the effect of hydrology. So, these areas can be interpreted as areas where vegetation is suitable for dam building, and can support dams much of the time, but have hydrology that occasionally breaches or blows out dams during high flows. BRAT is not explicitly temporal, however high flow events are stochastic in time. ‘Rare’ capacity segments in these reaches that alternate with higher capacity segments, therefore, should not be thought of as having ‘rare’ capacity at any given point in time, but instead having higher capacity reflected by the other reaches that is occasionally limited to ‘rare’ by high flow events (Figure 41).

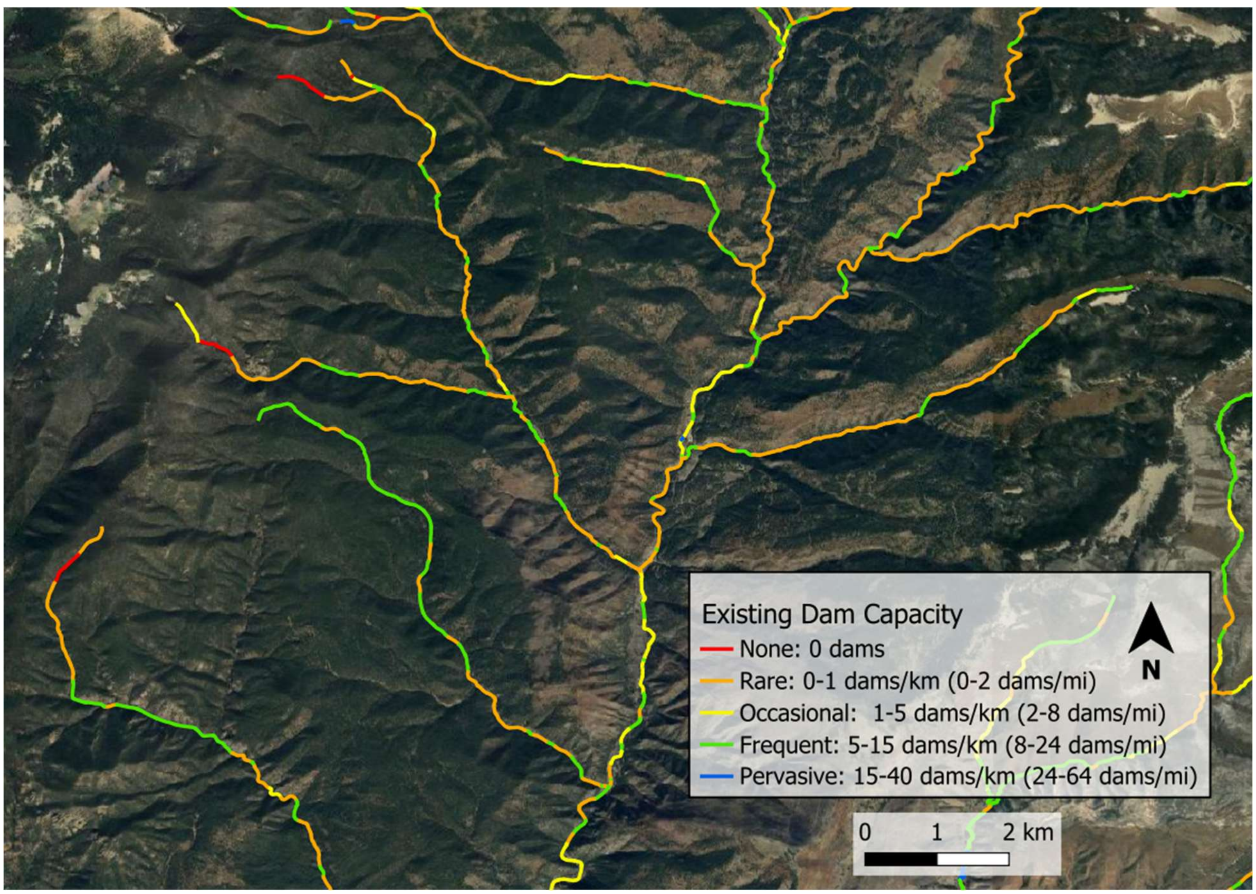


Figure 41: An example from the Upper Pecos watershed of alternating ‘frequent’ and ‘rare’ reaches indicative of vegetation that supports dam building but hydrology that occasionally limits it.

The risk analysis should also be taken as a first-order approximation. On one hand, BRAT does not include all forms of infrastructure (including buildings) that could be impacted by flooding, so reaches categorized as having low risk may have risk that needs to be considered. On the other hand, the road infrastructure layer we used includes even unimproved 4x4 roads, where there may, in some cases, not be risk to the infrastructure. In terms of the transportation network, this assessment is conservative and may overestimate risk in some places.

Outputs derived using coarse regional input data are most suitable for identifying larger patterns in outputs. In the BRAT context, this means that patterns over multiple ~300 m reaches are more informative and meaningful than the value at a single 300 m reach. For example, because stream power is sensitive to slope, and slope can vary locally based on how and where a stream reach is segmented, it is common for medium to large streams with suitable vegetation resources to vary between 'rare' or 'occasional' capacity and 'frequent' capacity based on changes to stream power from reach to reach. In this case, the larger pattern is that stream power is likely limiting, so the stream may not be the best candidate for beaver-based restoration if long-lasting structures are the desired outcome of the project (this can also be assessed in combination with the 'unsuitable or limited opportunities' output). Instead, searching for areas where the general pattern is a combination of 'frequent' and 'pervasive' capacity to work in first may be a better strategy.

The BRAT model predicts only the maximum number of dams that can be supported, not the expected number of dams across a given area. For dam capacity to be realized requires healthy population of beavers themselves, which is a function of complex interacting factors. Additionally, even the healthiest systems are never all at capacity at the same time. Beavers move location through time as they use resources, resulting in different locations along stream networks being at capacity at different times. In general, watersheds with the healthiest beaver populations can reach approximately 20% of capacity at any given time. The capacity model and infrastructure layers are also all based on a 2020 snapshot of conditions and therefore will be outdated as time passes and will require updates.

How does New Mexico's beaver dam capacity compare to Utah?

As previously stated, the estimated existing New Mexico beaver dam capacity across the perennial streams is 155,941 dams or 4.5 dams/km and the estimated historic capacity is 206,358 dams or 7.4 dams/km reflecting a 24% loss compared to historic capacity. For comparison, the BRAT capacity of, an adjacent state to the north, Utah was 226,939 beaver dams (8.3 dams/km) and the historic capacity at 320,658 dams (11.7 dams/km), reflecting a 29% loss compared to historic capacity. Utah has considerably more existing and historic dam building capacity than New Mexico because of the "spine of the state" which includes the high elevations of the Bear River range, Uintah range, Wasatch Mountain range and Wasatch plateau. These high elevation areas receive deep snowpacks, producing relatively dense stream density, lush riparian zones and aspen forests. These areas support high levels of pervasive and frequent dam densities. New Mexico has some areas that are similar but is less widespread and unfortunately it appears that many of these areas are impacted by legacy effects of high intensity grazing and fire suppression which has resulted in the decline of willow, cottonwood, and aspen forest. These areas have recovery potential which could increase the capacity for dam building beaver and allow for large complexes to be established and maintained but as mentioned elsewhere much of the state of New Mexico is dominated by desert where dam building beavers impact is sparser and more isolated because beavers are limited to single dams or small complexes.

Why is existing beaver dam-building capacity so much lower than historic capacity in New Mexico?

As described in the results section, current beaver dam-building capacity across New Mexico is estimated to be 24% lower than historic levels. This reduction reflects a combination of geomorphic, hydrologic, and ecological changes that have fundamentally altered riverscape function throughout the state.

Hydrologic Alteration

Over the past century, New Mexico's rivers have undergone extensive hydrologic modification through irrigation diversions, groundwater extraction, and flow regulation by reservoirs and stream diversions.

- Reduced baseflows and dewatered reaches have eliminated perennial habitat necessary for stable beaver dam complexes.
- Flashier hydrographs driven by stormwater runoff and diminished snowmelt buffering increase dam failure risk.
- Many stream segments that once flowed year-round are now intermittent or ephemeral, removing large portions of potential beaver habitat.

Fire Suppression

Historic fire regimes (10–100 year intervals) maintained aspen (*Populus tremula*) dominance by killing conifers and stimulating aspen root suckering. A century of fire exclusion has allowed shade-tolerant conifers (e.g., Douglas-fir, Engelmann spruce, white fir) to encroach and dominate.

Loss of Woody Riparian Vegetation

Beavers depend on woody riparian vegetation such as willow, cottonwood, and aspen for food and construction materials. Historic overgrazing, channel incision, fire suppression and lowered water tables have:

- Suppressed willow, cottonwood and aspen recruitment,
- Disconnected floodplains where riparian plants regenerate, and
- Shifted vegetation toward xeric or non-native species (e.g., sagebrush, saltcedar, Russian olive) that provide limited forage and dam and lodge building material.

Figure 42 highlights an example of a restoration site we visited in the field where a reduction in woody vegetation resources driven primarily by long-term grazing has resulted in lower beaver dam capacity compared to historic conditions. In these systems, riparian restoration can drastically improve the capacity of riverscapes to support dam building.

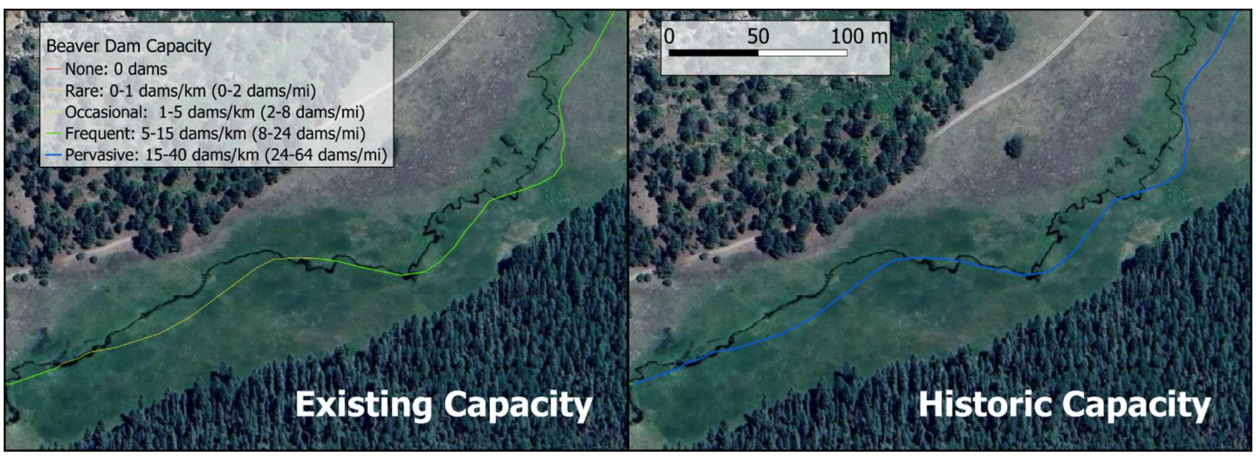


Figure 42: A restoration site along the Rio Cebolla above the Seven Springs Hatchery. Current vegetation supports 'occasional' to 'frequent' dam densities (left), whereas historic vegetation supported 'pervasive' dam densities. This reflects the loss and alteration of vegetation communities because of overgrazing, fire suppression, and channel incision.

Channel Incision and Floodplain Disconnection

Widespread incision of stream channels—driven by overgrazing, land-use change, and altered precipitation regimes since the late 19th century—has greatly diminished geomorphic complexity.
Deeply entrenched channels lower local water tables, placing moisture beyond the reach of riparian vegetation.
High stream power in incised channels prevents stable dam formation, as dams are frequently washed out.

The resulting loss of side channels, backwaters, and wetlands reduces the hydraulic and habitat diversity needed to sustain beaver dam complexes.

- Fortunately, emerging signs of recovery are evident, characterized by widening channels and expanding inset floodplains especially in areas where LT-PBR restoration is underway.

Historic Beaver Trapping and Local Extirpation

Intensive commercial beaver trapping during the 1800s eliminated populations from most New Mexico watersheds.

- Recovery has been slow because habitat conditions remain degraded in many areas.
- Isolated populations and limited dispersal opportunities constrain recolonization even where habitat has partially recovered.

Modern Human Conflict and Management Constraints

Even in reaches with adequate habitat, beaver populations are often suppressed due to conflicts with human infrastructure and land use.

- Beavers are frequently removed or excluded near roads, irrigation systems, or private lands.
- The cumulative effect of localized removals limits natural recolonization across broader drainage networks.

What could be done to improve dam building capacity?

Enhancing beaver dam-building capacity requires process-based restoration approaches that address hydrologic, geomorphic, and ecological constraints limiting the suitability of habitat. The first step in effective beaver-based restoration is to identify the primary riverscape impairments and develop targeted strategies to mitigate them. The strategies outlined below represent key pathways for restoring and expanding beaver-related capacity across New Mexico's riverscapes.

1. **Restore Hydrologic Regimes**

Reintroducing hydrologic stability and perennial flow is foundational for rebuilding beaver capacity.

- Enhance baseflows by improving irrigation efficiency, managing groundwater withdrawals, and implementing water conservation measures that maintain instream flow.
- Reconnect floodplains and wet meadows to increase water retention and shallow groundwater recharge.
- Reduce peak flow energy and stream flashiness through upstream infiltration structures (BDAs, PALs), wet meadow restoration, and improved watershed management.

These actions collectively sustain the slow-moving, perennial water conditions necessary for stable beaver dam construction and maintenance.

2. **Climate Change Adaptation**

Climate change has significantly affected the desert Southwest, manifesting as prolonged and severe droughts that lead to widespread drying of stream channels, followed by intense storms that result in flooding and new incision events. To mitigate these effects, we recommend enhancing system resilience by increasing the number and effectiveness of structures (BDAs, PALs), as well as fostering beaver populations on the landscape. Properly placed instream structures and beaver dams can accumulate sediment, thereby aggrading channels and facilitating recovery. Ongoing implementation efforts and the re-establishment of beaver colonies are crucial, particularly as we capitalize on current opportunities presented by storm events for ecosystem recovery.

3. **Reestablish Woody Riparian Vegetation**

Significant conifer encroachment has occurred in aspen stands of New Mexico, underscoring the need for targeted restoration efforts. Therefore, we advocate for effective management practices focused on aspen restoration along with other important riparian species. Restoring riparian vegetation provides the forage and construction materials needed to support beaver occupancy.

- Replant native woody species such as willow and cottonwood along degraded reaches. Utilize live pole or cutting plantings within the hydrologic influence zone to maximize establishment and survival.
- Thin or remove conifers that have encroached on former aspen stands.
- Manage grazing intensity and timing to allow for successful riparian regeneration.

Healthy riparian vegetation supports both beaver activity and broader riverscape health and resilience.

4. **Rebuild Channel–Floodplain Connectivity Using Low-Tech Process-Based Restoration**

As previously mentioned, legacy effects of overgrazing, coupled with changes in climate, have led to significant incision in many river systems. Geomorphic restoration is essential to create the physical conditions necessary for beaver dam building. We recommend ongoing use of the LT-PBR framework, which employs simple, cost-effective structures made from natural materials to stimulate self-sustaining ecosystem processes (https://ltpbr.restoration.usu.edu/manual). Key principles include:

- Focus on restoring natural processes such as sediment deposition and riparian vegetation recruitment.
- Utilize low-cost, hand-built structures with short design lifespans.
- Emphasize 'letting the system do the work,' allowing riverscapes and beaver activity to maintain and evolve restoration outcomes.

BDAs mimic natural beaver dams and can:

- Improve conditions for natural and/or translocated beaver colonization.
- Reinforce existing natural dams or replace lost structures.
- Create deep-water habitats that reduce predation risk for translocated beavers.
- Enhance channel aggradation and floodplain connectivity in incised reaches.

Field observations suggest that BDAs can shift beaver behavior from bank-lodging to active dam-building, resulting in self-sustaining systems.

PALS increase in-stream complexity and hydraulic roughness, promoting geomorphic responses that enhance habitat diversity and channel stability. When combined with BDAs, they can:

- Mimic the function of natural beaver dam complexes and large woody debris.
- Promote bed aggradation in incised channels.
- Reconnect floodplains and support riparian recruitment.

Each installation should have clear geomorphic objectives, such as sediment capture or floodplain formation.

We commend the LT-PBR practices currently underway in New Mexico and recognize its position as a leader in this field after observing efforts across the western states. Going forward, it is essential to scale up existing LT-PBR projects to holistically treat more contiguous lengths of riverscape. This comprehensive approach should encompass adjustments in land management practices, such as grazing and timber management, vegetation manipulation, revegetation efforts, and establishing a balance between land use and riparian health. Techniques like resting riparian zones, employing a combination of virtual fencing, fencing and riders, and supporting beaver populations through measures like trapping closures or vegetation management will be vital for fostering thriving beaver environments (beaver-hoods).

We believe that continuing the implementation of LT-PBR practices alongside beaver-based restoration will accelerate this recovery, reducing the time needed from centuries to just a few years.

- Implement process-based restoration structures such as BDAs, PALS, and rock grade controls to raise incised channels, trap sediment, and restore hydrologic connectivity.
- Allow sediment accretion to naturally elevate streambeds, reinitiate floodplain function and vegetation regrowth.

Over time, these interventions will foster conditions that support sustained beaver colonization and dam persistence.

The practices of LT-PBR are advancing faster than the scientific understanding that supports them. Improved data on project outcomes is critical to evaluate which processes are being restored, measure the results of these interventions, and assess their impact on ecosystem degradation. This includes analyzing the rates of incision reduction, assessing how restoration affects flooding dynamics, and measuring the recovery of riparian zones and desirable woody vegetation, as well as their influence on beaver populations.

Beaver Management Recommendations

1. **Develop Beaver Conservation and Restoration Plans**

We recommend creating detailed beaver conservation and restoration plans that acknowledge the ecological significance of beaver dam-building in maintaining healthy riverscapes. These plans should include a structured framework for prioritizing and implementing restoration projects within an adaptive management context, incorporating monitoring and evaluation to refine strategies.

Adaptive management is key to refining LT-BPR techniques. One must continually assess how effectively they are at mimicking beaver dam building activity. If structures cannot be maintained, one should encourage beavers to adopt these structures or to translocate beavers to take on the maintenance.

2. **Promote and Sustain Beaver Colonization**

Where suitable habitat exists but beaver populations are absent, targeted reintroductions can accelerate recolonization.

- Conduct assessments to ensure adequate forage, water, and dam-building potential before releasing beavers.
- Source beavers from local or regional populations to maintain genetic integrity.
- Pair translocations with habitat preparation measures (e.g., BDAs) and post-release monitoring to track outcomes and identify adaptive management needs.

Focus on conservation and restoration actions that promote and sustain natural colonization of beaver. Consider translocation carefully as success rates are variable (~25%) and depend on site conditions and seasonal timing. Natural colonization and when appropriate, translocation can:

- Restore beaver populations to unoccupied habitats.
- Enhance hydrologic and ecological function in degraded systems.
- Reduce human–beaver conflicts through strategic relocation.

Translocations should be conducted by qualified professionals under established programs with clear success criteria and post-release monitoring.

An important but often overlooked aspect is how to support existing dam building beavers that may be negatively impacted by land use practices leading to resource limitations. Fluctuating stream conditions and overgrazed riparian areas can force beavers to expend excessive energy while maintaining dams, and limited forage can affect population health and reproductive success.

3. **Prioritize Enhancement of Riparian Vegetation**

The lack of willow and cottonwood in valley bottoms across New Mexico highlights an urgent need to enhance conditions for the natural recruitment of these species. Where enhancement of natural processes fall short, revegetation efforts should be prioritized to ensure successful recruitment.

4. **Implement Trapping Closures**

The NMDG&F can establish trapping closures to protect populations serving as active restoration agents. These closures should be applied strategically in areas prioritized for beaver establishment, recolonization, or expansion.

5. **Create Livestock Grazing Exclosures**

Grazing exclosures can protect riparian vegetation from livestock and wild ungulates grazing, promoting recovery. Fencing requires significant investment and ongoing maintenance; without consistent management, exclosures can concentrate grazing pressure and exacerbate impacts. Implementation should only occur where long-term management commitments are feasible.

6. **Adjust Land Management Practices**

High intensity ungulate browsing has significantly diminished woody vegetation in the valley bottoms of New Mexico. This competition for resources results in ungulates appropriating critical forage and dam-building materials from beavers. To achieve a more balanced utilization of these resources, it is necessary to reduce the populations of livestock, elk, and deer, and adjust their grazing timing. Without adequate forage, beaver populations will continue to be suboptimal, with mating pairs struggling to survive rather than thriving as healthy colonies capable of producing dispersing offspring. While technologies like virtual fencing show potential, they should not be considered a comprehensive solution. Effective grazing management will require reductions in stocking rates, changes in timing of utilization to ensure beavers have access to healthy riparian vegetation.

Adaptive land management practices, including revised grazing regimes can enhance riparian resilience and support beaver habitat. Holistic range management has been shown to improve long-term success of beaver-based restoration efforts.

7. **Foster Human–Beaver Coexistence**

Long-term beaver management depends on coexistence rather than control. Modern strategies prioritize non-lethal interventions that allow beavers to remain while protecting infrastructure. Effective coexistence typically integrates multiple techniques:

Dam Breaching/Notching: Partial breaching reduces pond height and mitigates flooding while retaining ecological benefits.

Pond Levelers: Perforated pipes installed through dams maintain target pond elevations. Proper installation and routine maintenance prevent clogging and ensure functionality.

Vegetation Protection: Safeguard trees and shrubs using trunk wrapping, abrasive paint mixtures, or fencing to minimize damage while ensuring sufficient forage for beavers.

Live Trapping and Relocation: If coexistence measures fail, live trapping and relocation are preferred over lethal removal. Releases should avoid winter months, target suitable habitats, and may include starter BDAs to improve establishment success.

8. **Properly Manage Human-Beaver Conflicts**

The challenges associated with beaver populations are inherently social. In the absence of human pressures, beavers would thrive. Therefore, improving societal tolerance towards beavers is critical. Effective communication of the ecological and geomorphic benefits that beaver colonies and their dams provide to river ecosystems is necessary. If ranchers and farmers can shift their mindset from viewing beavers as pests to recognizing their value in water retention and agricultural productivity, beaver-based restoration efforts will become significantly more impactful. Until societal attitudes transform, we are likely to see only incremental improvements in addressing the extensive degradation we aim to mitigate. Conflict management plays a crucial role in addressing the challenges posed by beaver dam building activity by fostering positive coexistence between humans and beavers. Here are several conflict management strategies and their intended benefits:

- **Understanding and Education**: Conflict management involves educating landowners, ranchers, farmers, and the public about the ecological benefits of beavers, such as their role in creating wetlands, improving water quality, and enhancing biodiversity. Increased awareness can lead to greater acceptance of beavers in the landscape.
- **Mitigation Strategies**: Implementing practical mitigation measures, such as installing culvert fencing, beaver deceivers, or flow devices, can reduce beaver-related issues like flooding and tree damage. These tools allow beavers to remain in their habitats while minimizing negative impacts on human activities.
- **Encouraging Tolerance**: By addressing concerns about beaver activity and providing solutions, conflict management helps build tolerance among communities. This can lead to a more harmonious relationship with wildlife and an understanding that beavers are essential to ecosystem health.
- **Facilitating Relocation**: In cases where conflicts cannot be resolved through mitigation alone, conflict management programs often provide guidance on humane beaver relocation. This process helps establish beaver populations in areas where they can thrive without negatively impacting human activities.
- **Community Engagement**: Conflict management initiatives frequently involve community participation, allowing stakeholders to voice their concerns and contribute to solutions. This collaborative approach helps build trust and fosters a sense of shared responsibility for both human and beaver welfare.
- **Monitoring and Adaptive Management**: Implementing monitoring programs allows for the continuous assessment of beaver dam activities and their impacts. Adaptive management strategies can then be employed to fine-tune conflict resolution measures based on real-time feedback, ensuring that both human and ecological needs are met. Monitoring changes in landowners' perceptions of beavers is fundamental to addressing the broader issues related to beaver management.

Through these approaches, conflict management not only addresses immediate challenges posed by beavers but also encourages long-term coexistence and sustainability in ecosystems where both humans and beavers can thrive.

CONCLUSIONS

With the development of the New Mexico BRAT model, the scope of what is possible in terms of partnering with beaver for restoration in the state is now clearly defined and mapped. We believe the New Mexico BRAT model helps build realistic expectations about what beaver dam-building may achieve locally on a given stream reach and helps scale-up those expectations at the watershed, regional and statewide levels. BRAT model outputs can be used to initialize beaver-based restoration and conservation planning and can also support initial conceptual design and siting of specific beaver-based restoration actions. BRAT model outputs can also aid with expectation management, human-beaver conflict management, and conservation and restoration prioritization.

Improving beaver dam building capacity in New Mexico requires integrated action at multiple scales. Hydrologic and geomorphic restoration create the environmental foundation for beaver persistence, while vegetation recovery and coexistence strategies ensure long-term resilience. When implemented together, these efforts can gradually return many watersheds to a state resembling their historic condition—where beavers once played a central role in maintaining perennial flow, riparian productivity, and riverscape complexity. In the context of New Mexico, where deserts dominate, modeled historic conditions suggest that even historically beaver dam capacity was concentrated in two ecoregions: the Southern Rockies and the Arizona/New Mexico Mountains. Outside of these areas, capacity existed but was more isolated. A realistic expectation, therefore, is that the Southern Rockies and the Gila mountains, which have the greatest capacities now, also have the greatest potential for increasing capacity. Beaver dam building in the more arid ecoregions will likely be more limited and isolated, although it can still be encouraged where appropriate opportunities exist.

We believe the spatially explicit outputs from the New Mexico BRAT will provide the information needed to effectively identify where beaver dam building activities may cause conflict where valuable infrastructure and/or land use activities may be impacted. However, many potential beaver/human conflicts can be managed and/or mitigated with co-existence strategies to minimize damage while ensuring animal welfare and delivering ecosystem benefits. Understanding the capacity of streams to support beaver dam building and identifying areas of risk and opportunity is therefore critically important for effective beaver management. This application of BRAT provides the information needed to understand actual beaver presence on the landscape as well as beaver dam capacities, where human infrastructure is present, where beaver and infrastructure might collide causing potential conflict. These high-risk areas are highlighted as either places to avoid or where co-existence strategies may be needed. Prioritize working in low risk/high reaches to have the greatest potential to yield increases in biodiversity and ecosystem services especially with the lowest potential human-beaver conflict potential.

FINAL DATA PRODUCTS

Deliverable data products include:

1. Complete a calibrated run of the sqlBRAT capacity model on the perennial portion of the 1:24K NHD network segmented at 300 m including:
    - Existing (based on LANDFIRE 2.3 data and where available, NMRipMap, the most current data available) beaver dam capacity estimates (dams/km)
    - Historical beaver dam capacity estimates (based on LANDFIRE BPS data (dams/km)
2. Complete a standard BRAT management model run including:
    - Identifying potential human-beaver risk areas,
    - Identifying unsuitable or limited dam-building opportunities, and
    - Identifying conservation and restoration opportunities.
3. Generate BRAT model outputs as geopackages
4. Curate project data and serve out on Riverscapes Data Exchange
5. Develop a New Mexico Beaver Restoration Assessment Tool Report
6. Conduct a one-day field verification and validation site visit
7. Conduct a one-day workshop to share preliminary BRAT results with stakeholders.

The Riverscapes projects associated with this project (Beaver Activity and BRAT) can be retrieved from the Riverscapes Data Exchange (https://data.riverscapes.net). Within the Data Exchange, there is a 'Rio Grande Return' organization that owns the riverscapes projects related to this project (https://data.riverscapes.net/o/232ae9a1-4049-429e-8eca-128bb6fadf0d. After creating an individual user profile in the data exchange, users can request membership to organizations to be able to see and interact with any projects they own (public' projects can be viewed by any user, private' projects require membership).

The final BRAT project that encompasses the entire state of New Mexico can be found here: https://data.riverscapes.net/p/d74c8d3d-ca3a-4fd7-922c-41bc1e8d3875/ . The project can be viewed in the Web GIS integrated in the data exchange or downloaded to interact with via desktop GIS (e.g., ArcPro, QGIS). The statewide project is generated from all of the individual HUC10-scale projects across New Mexico which can be found in this collection: https://data.riverscapes.net/c/8383aab1-8aad-4fdd-9c74-27e9c1b1baef/.

Additional Riverscapes Network Models to Inform Beaver-Based Restoration Management

There are a variety of 'sister' network models in the Riverscapes Consortium (https://riverscapes.net). For example, the Riparian Condition Assessment Toolbox (RCAT: https://tools.riverscapes.net/rcat), could be quite helpful for examining riparian conditions to contextualize BRAT results as well as exploring recovery potential for riparian improvement to expand beaver dam-building capacity. The Valley Bottom Extraction Tool (VBET - https://tools.riverscapes.net/vbet/) could be helpful in terms of identifying where wide valley bottoms are located throughout New Mexico and these areas could be targeted as potential areas for beaver-based floodplain reconnection efforts.

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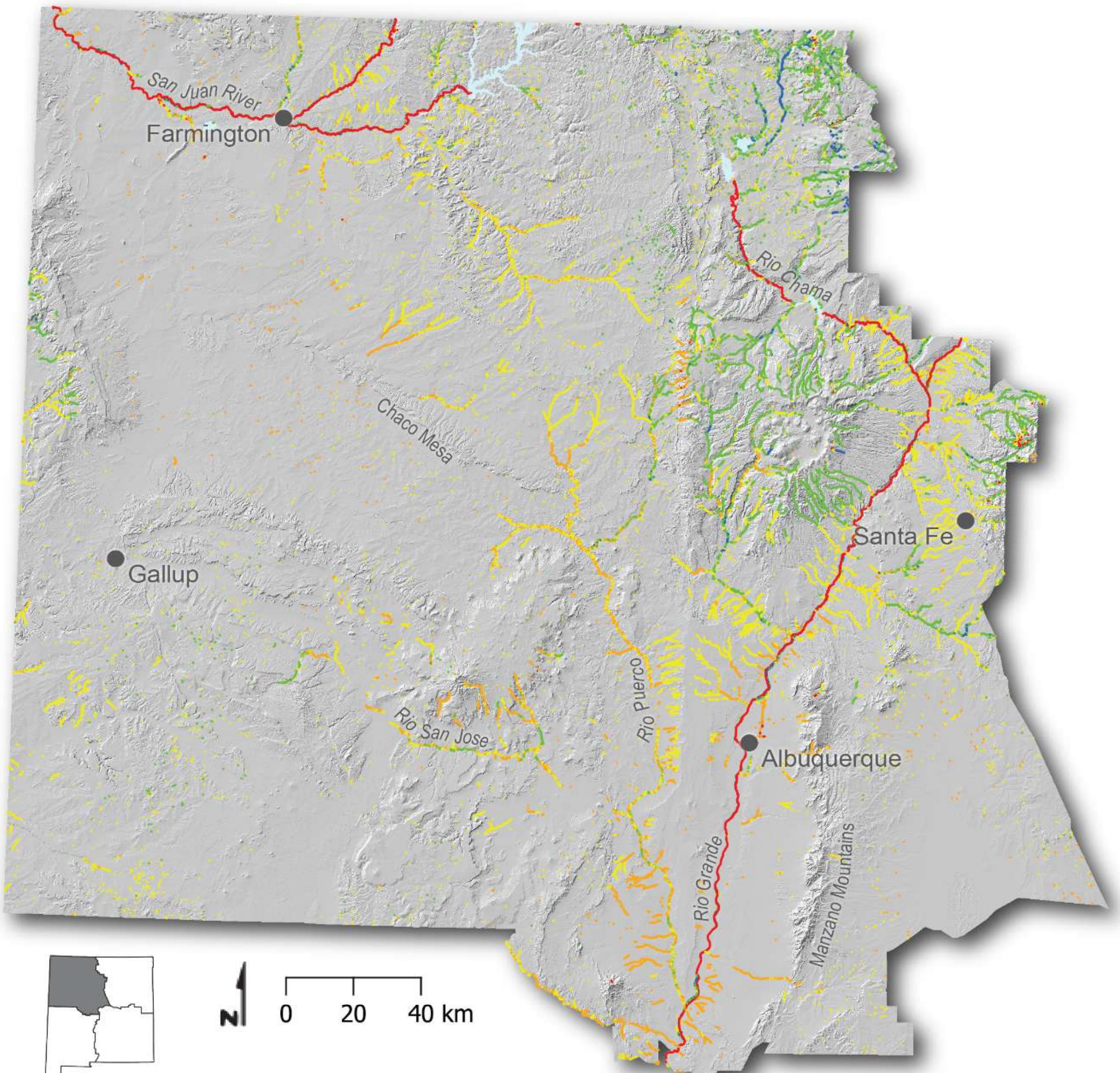
APPENDIX A: FULL PAGE BRAT OUTPUTS BY NMDGF REGION

This appendix provides full page versions of the BRAT output maps by NMDGF region.

Northwest Region



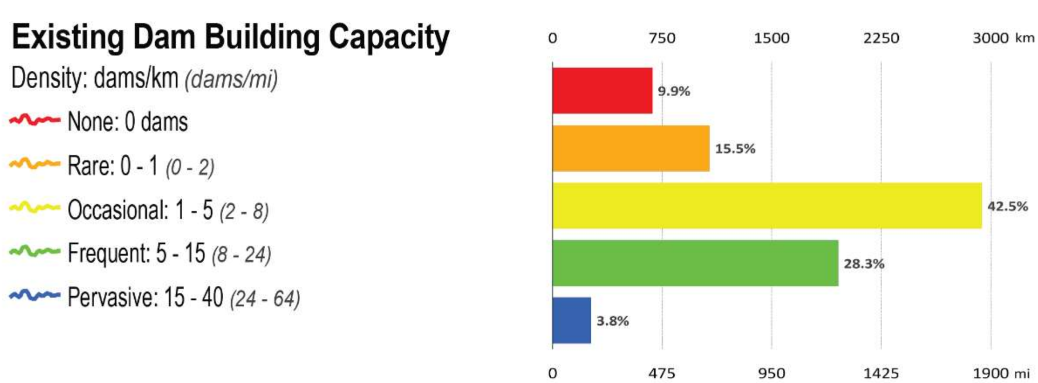


Figure 43: NMGF NW region existing capacity.

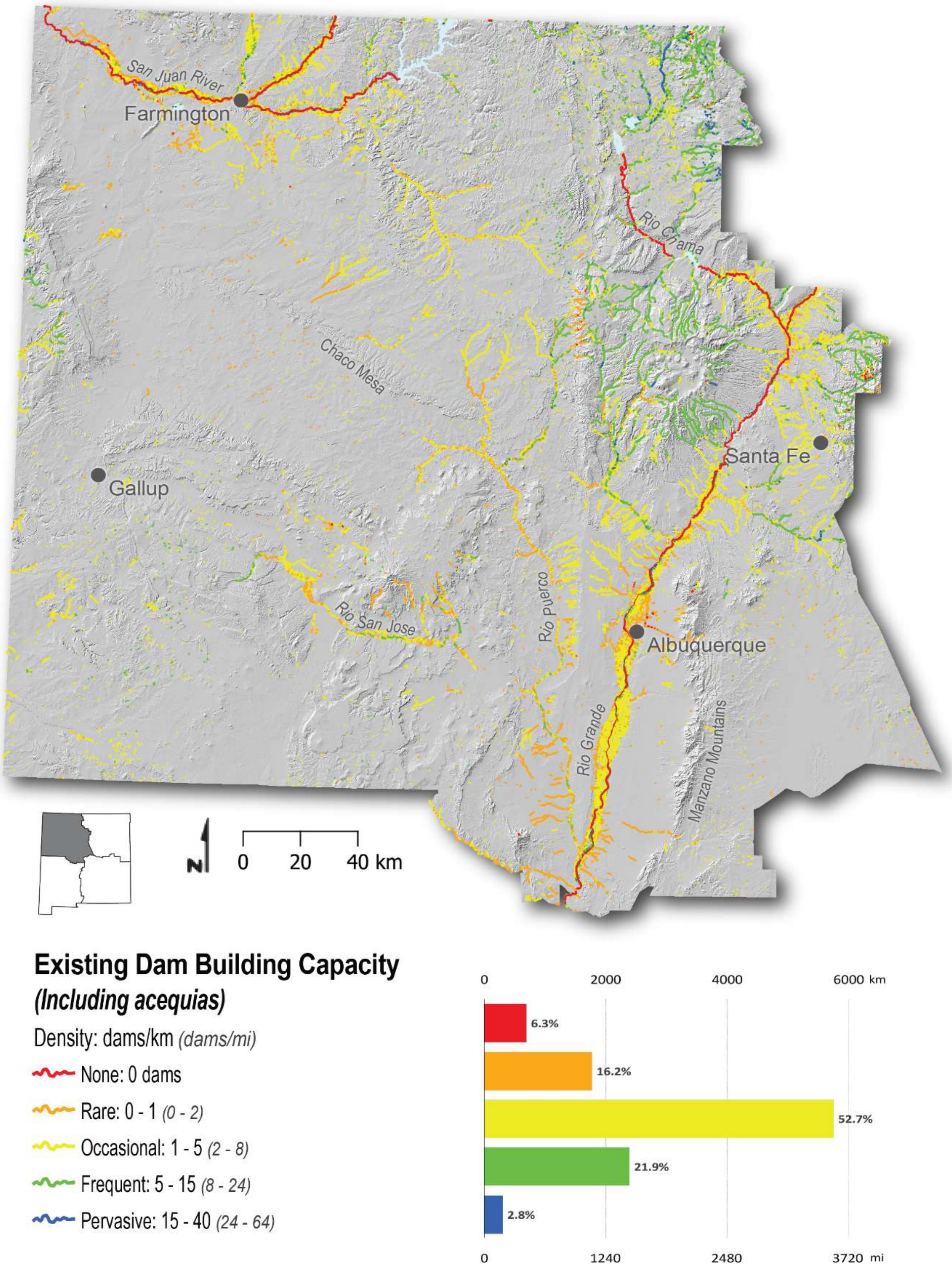


Figure 44: NMGF NW region existing capacity including acequias.

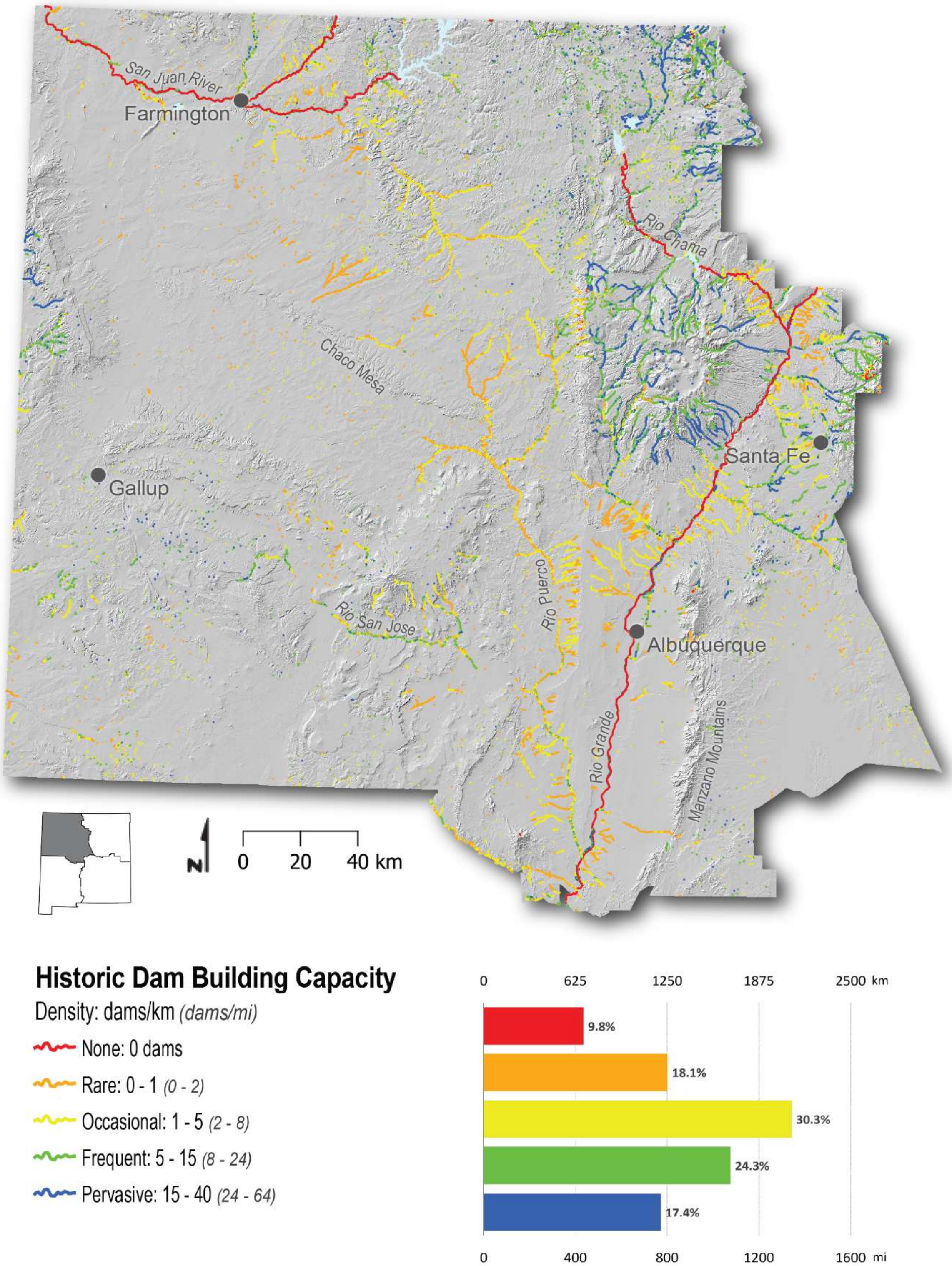


Figure 45: NMGF NW region historic capacity.

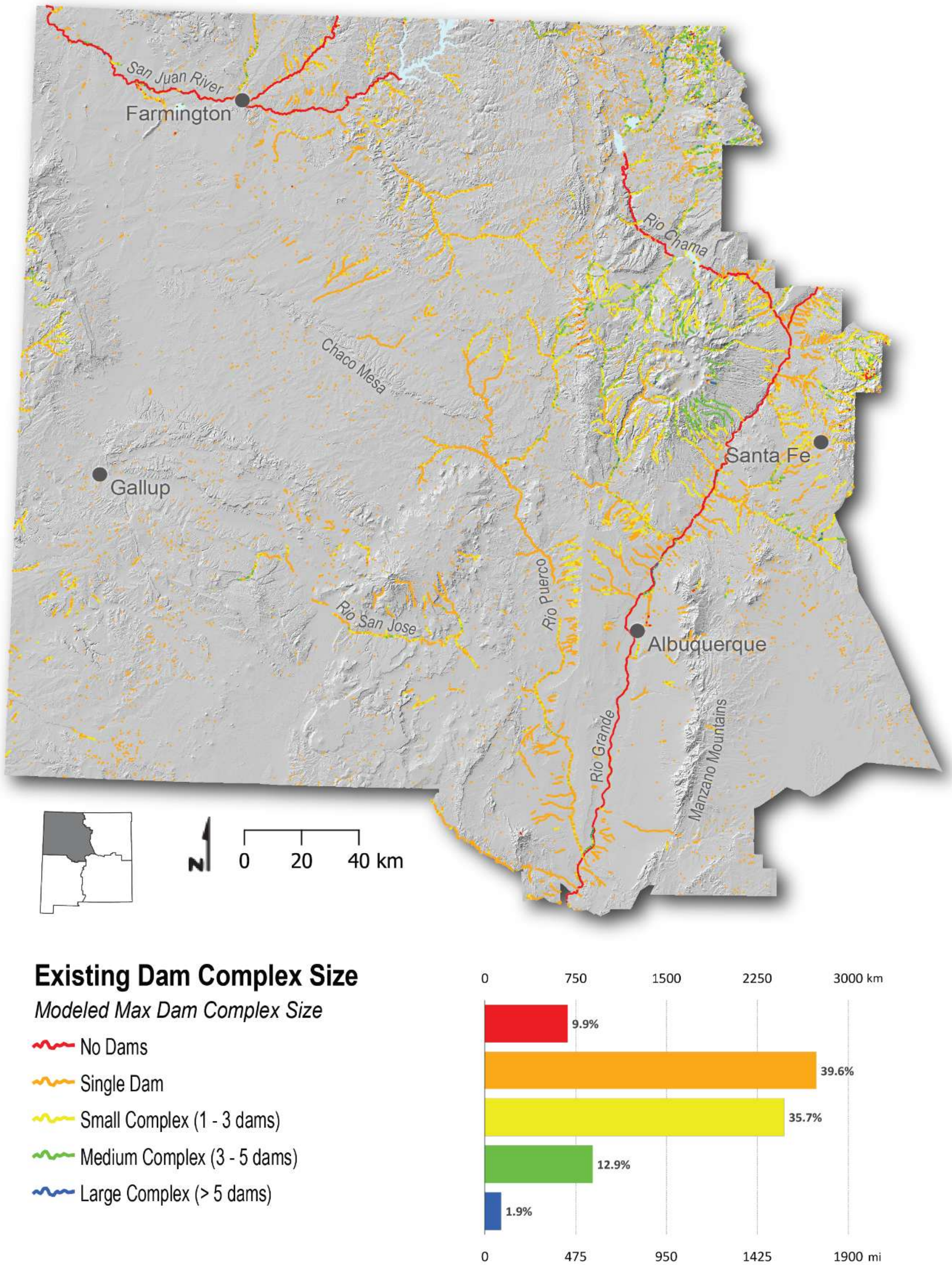
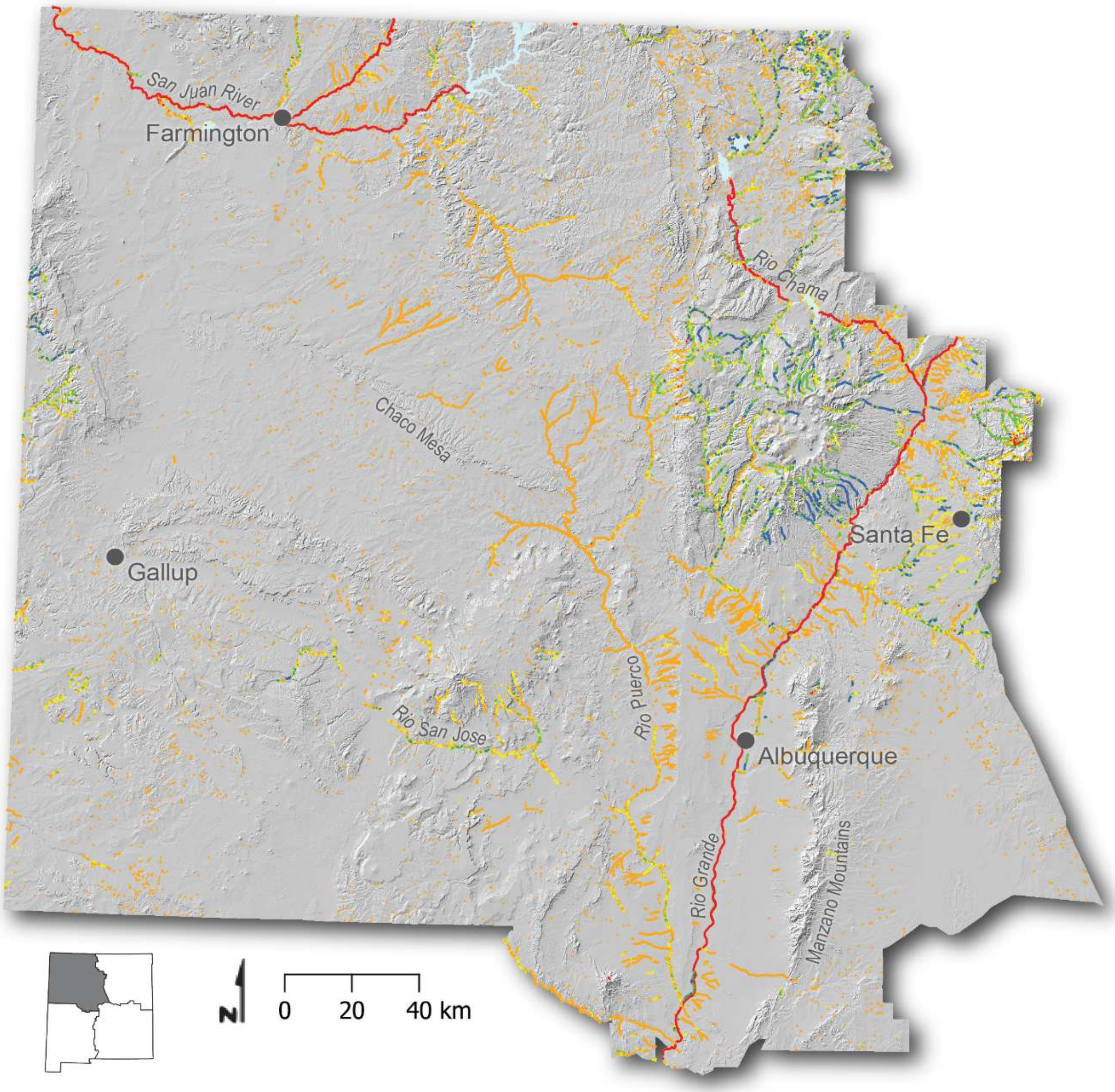


Figure 46: NMGF NW region existing dam complex size.



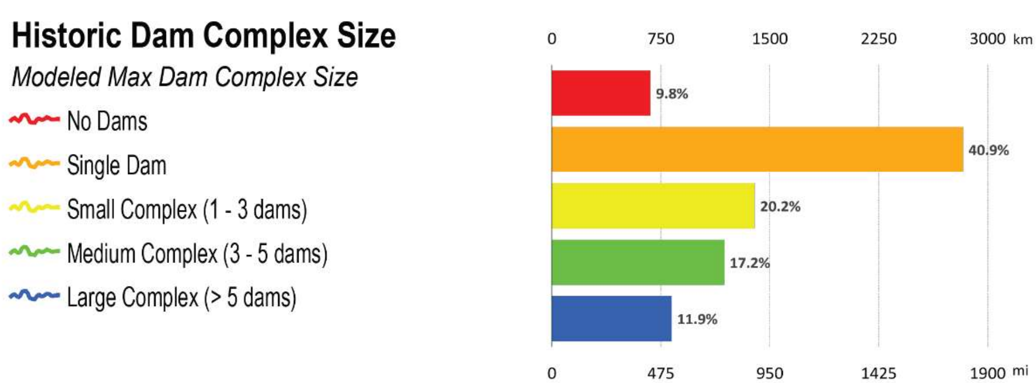


Figure 47: NMGF NW region historic dam complex size.

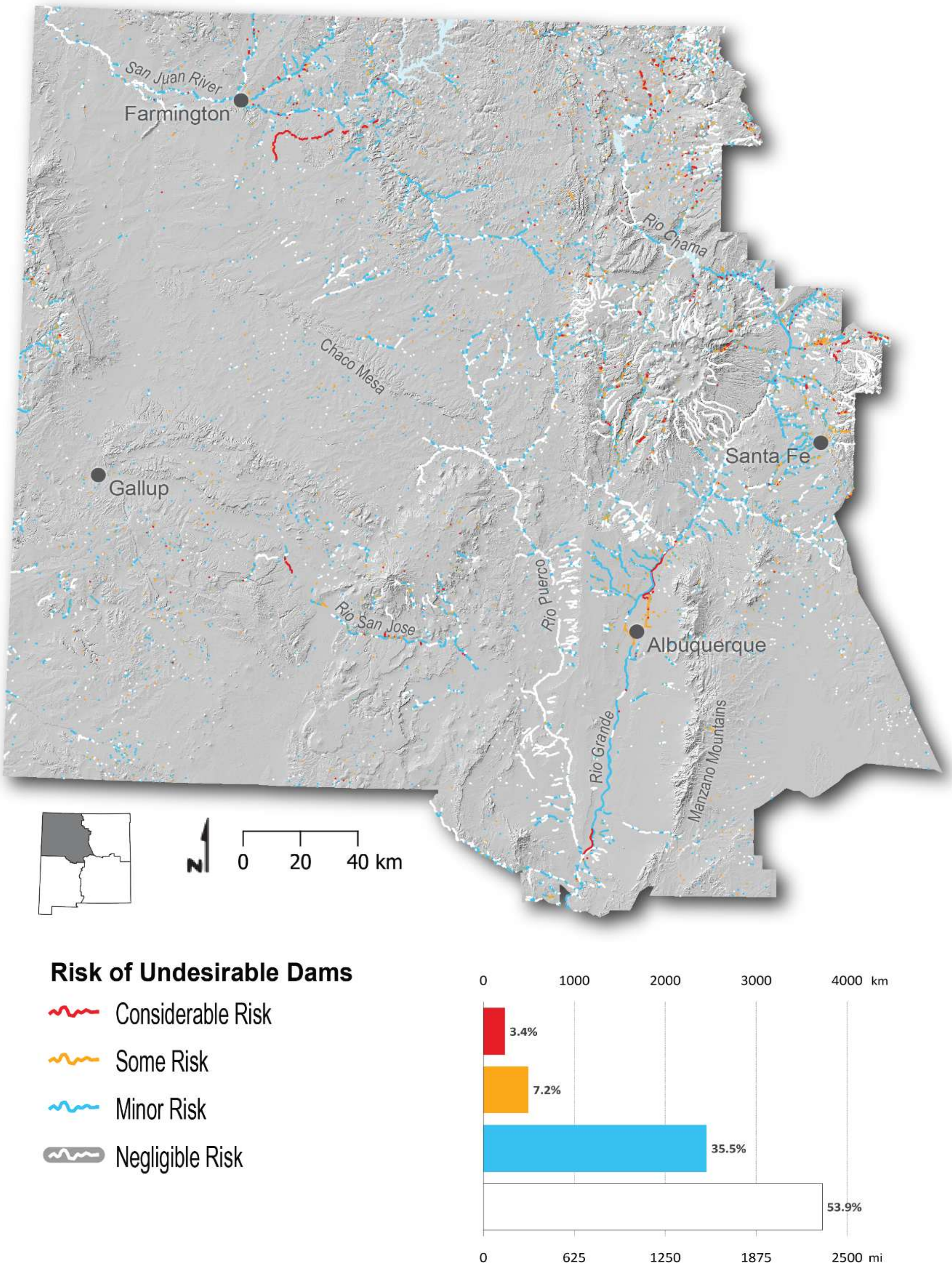


Figure 48: NMGF NW region risk of undesirable dams.

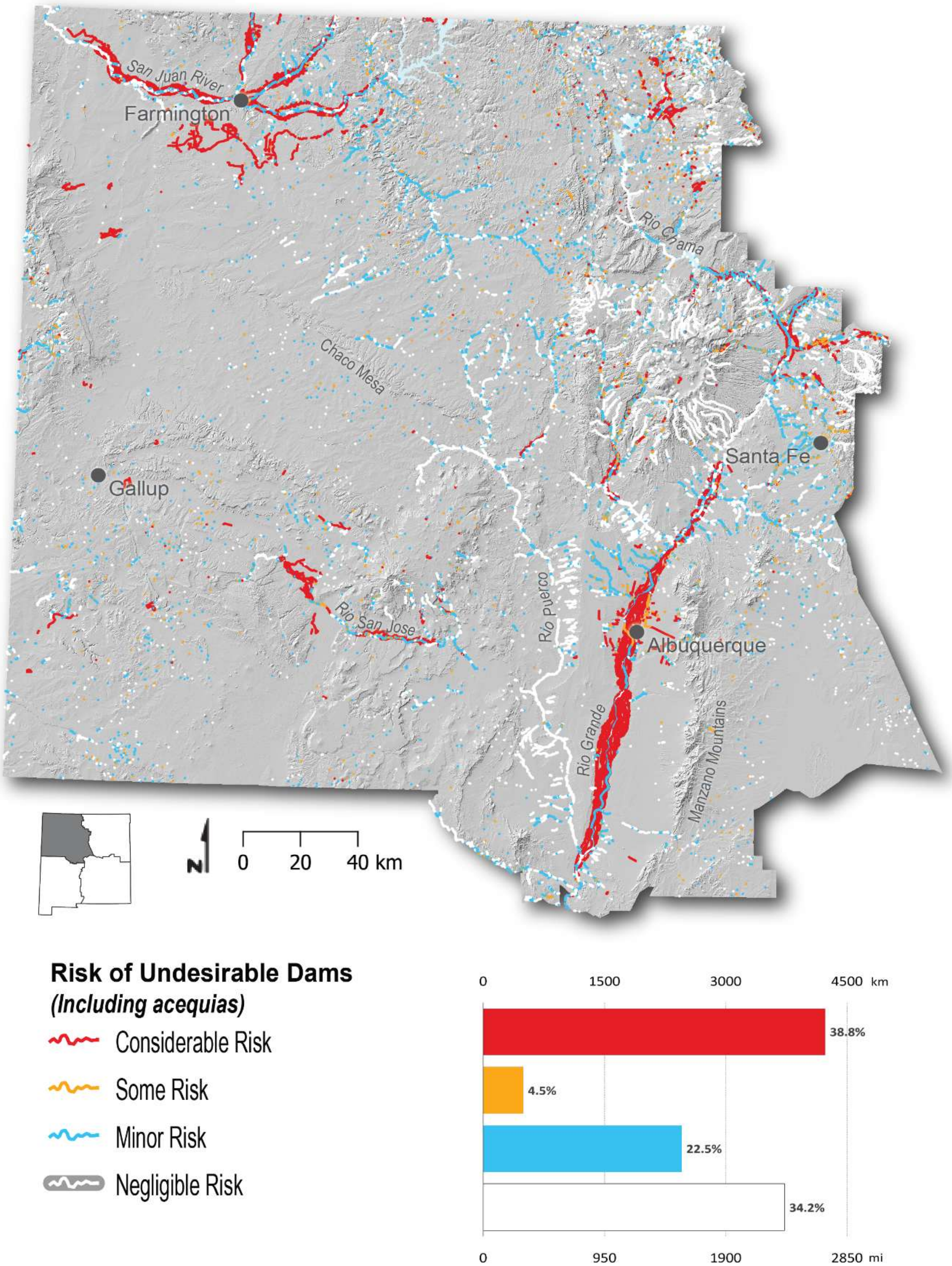


Figure 49: NMGF SW region risk of undesirable dams including acequias.

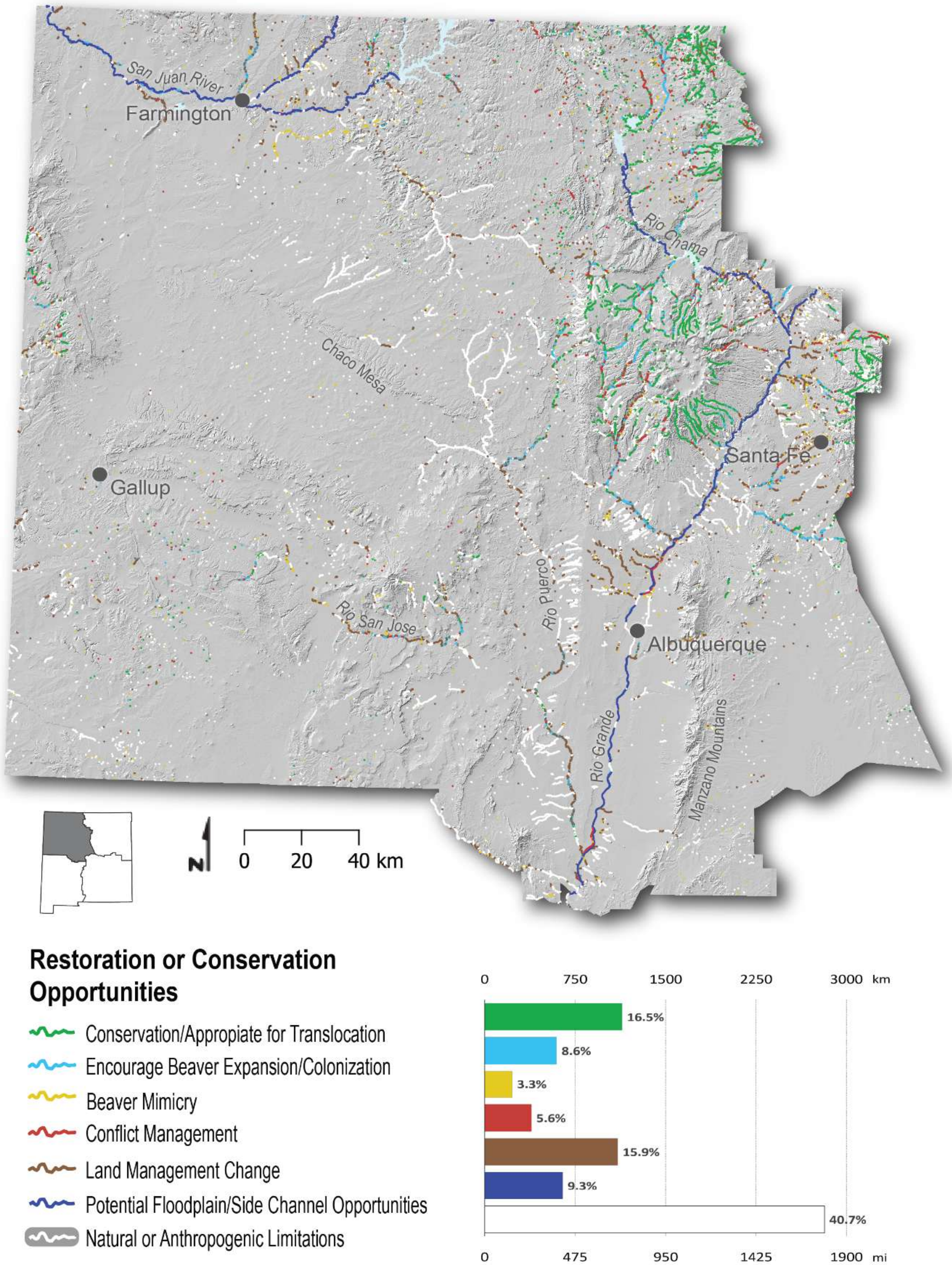


Figure 50: NMGF NW region restoration or conservation opportunities.

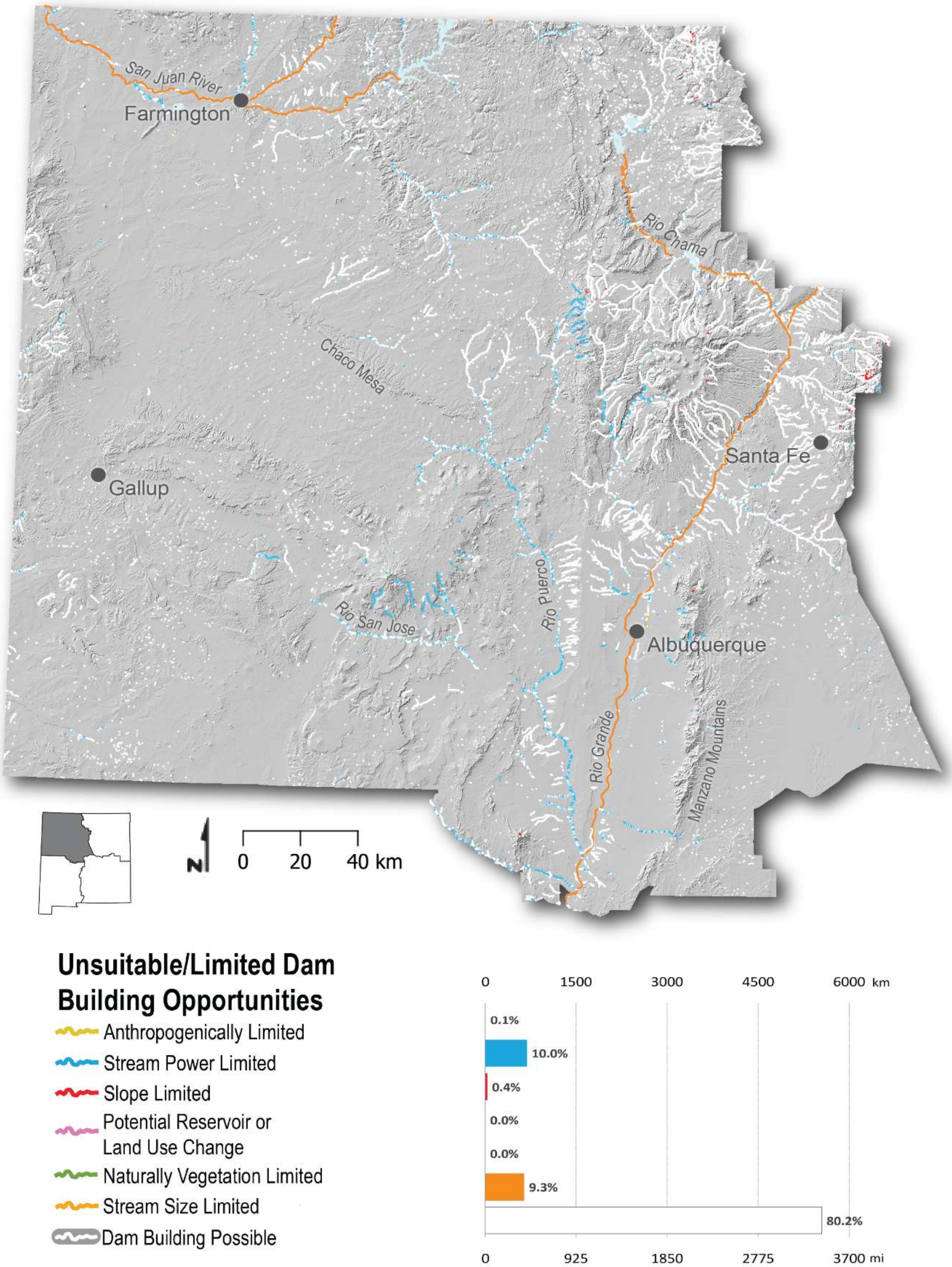


Figure 51: NMGF NW region unsuitable or limited dam building opportunities.

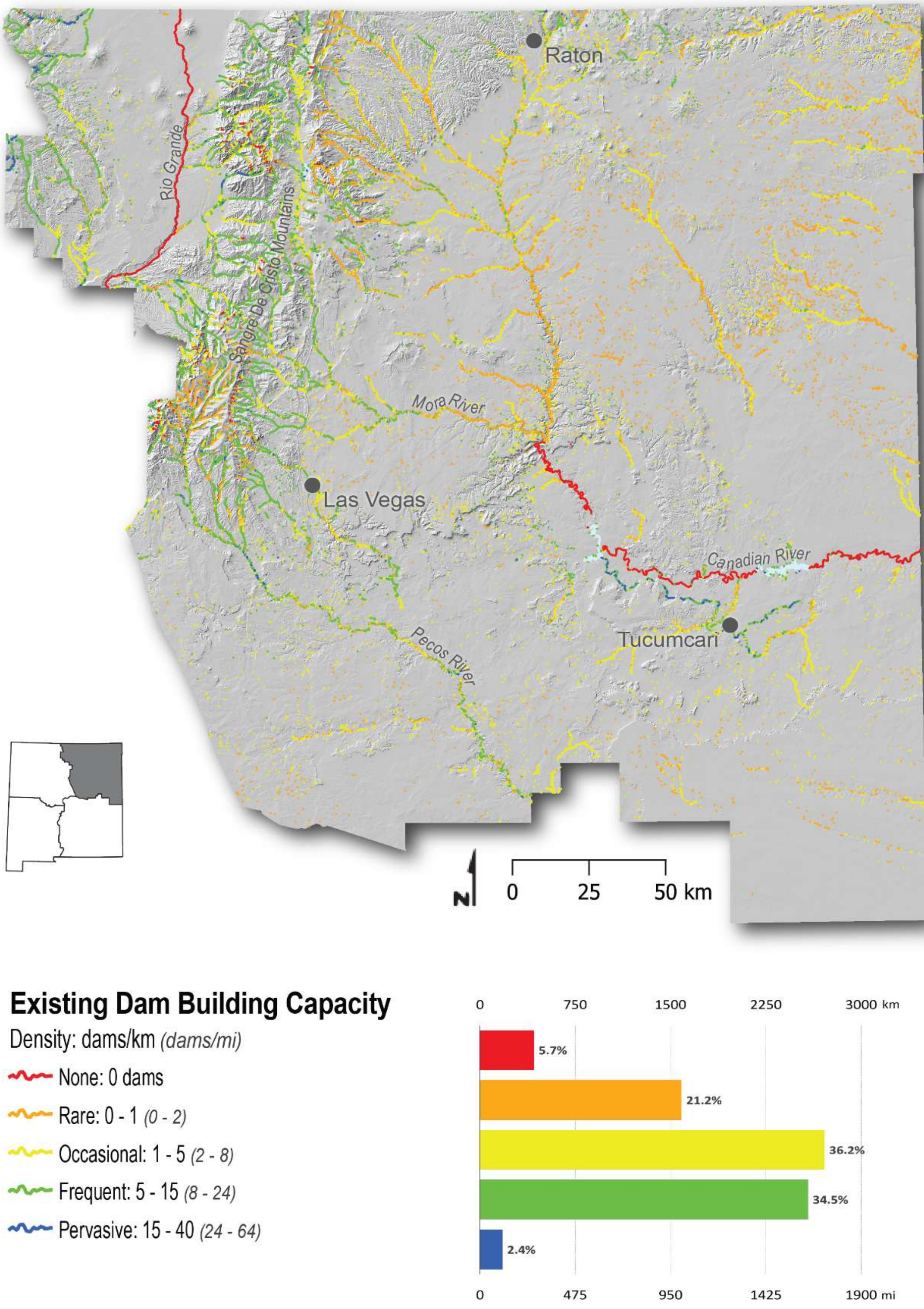
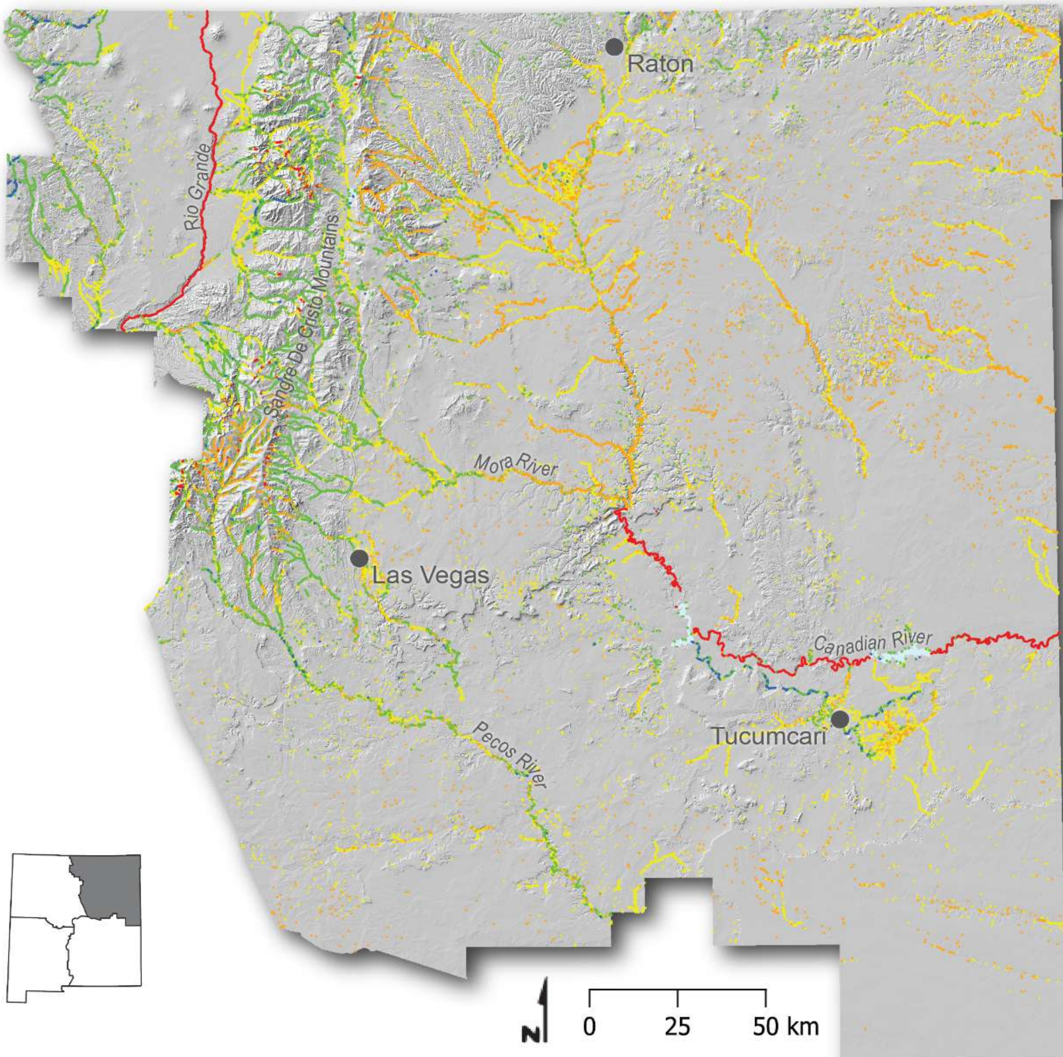


Figure 52: NMGF NE region existing capacity.



Existing Dam Building Capacity
(Including acequias)

Density: dams/km *(dams/mi)*

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

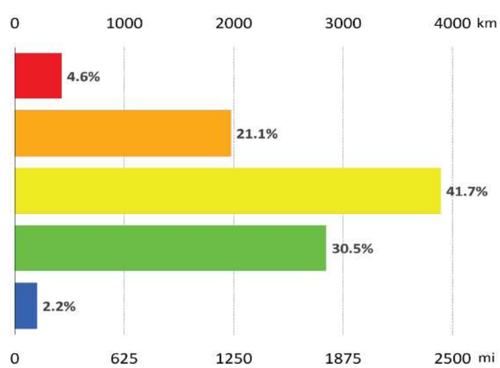
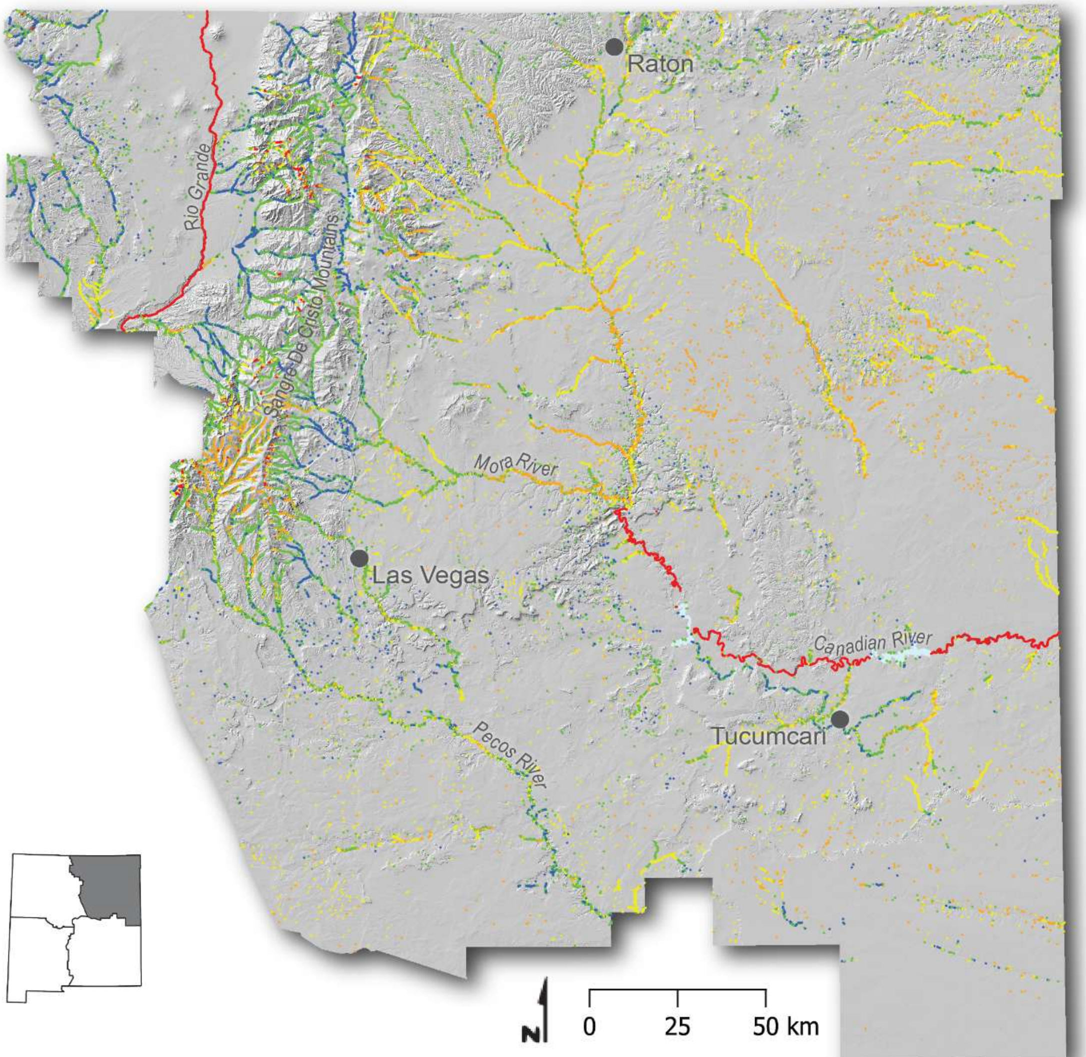


Figure 53: NMGF NW region existing capacity including acequias.



Historic Dam Building Capacity

Density: dams/km *(dams/mi)*

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

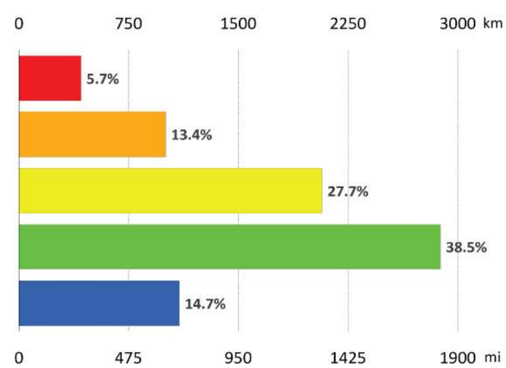


Figure 54: NMGF NW region historic capacity.

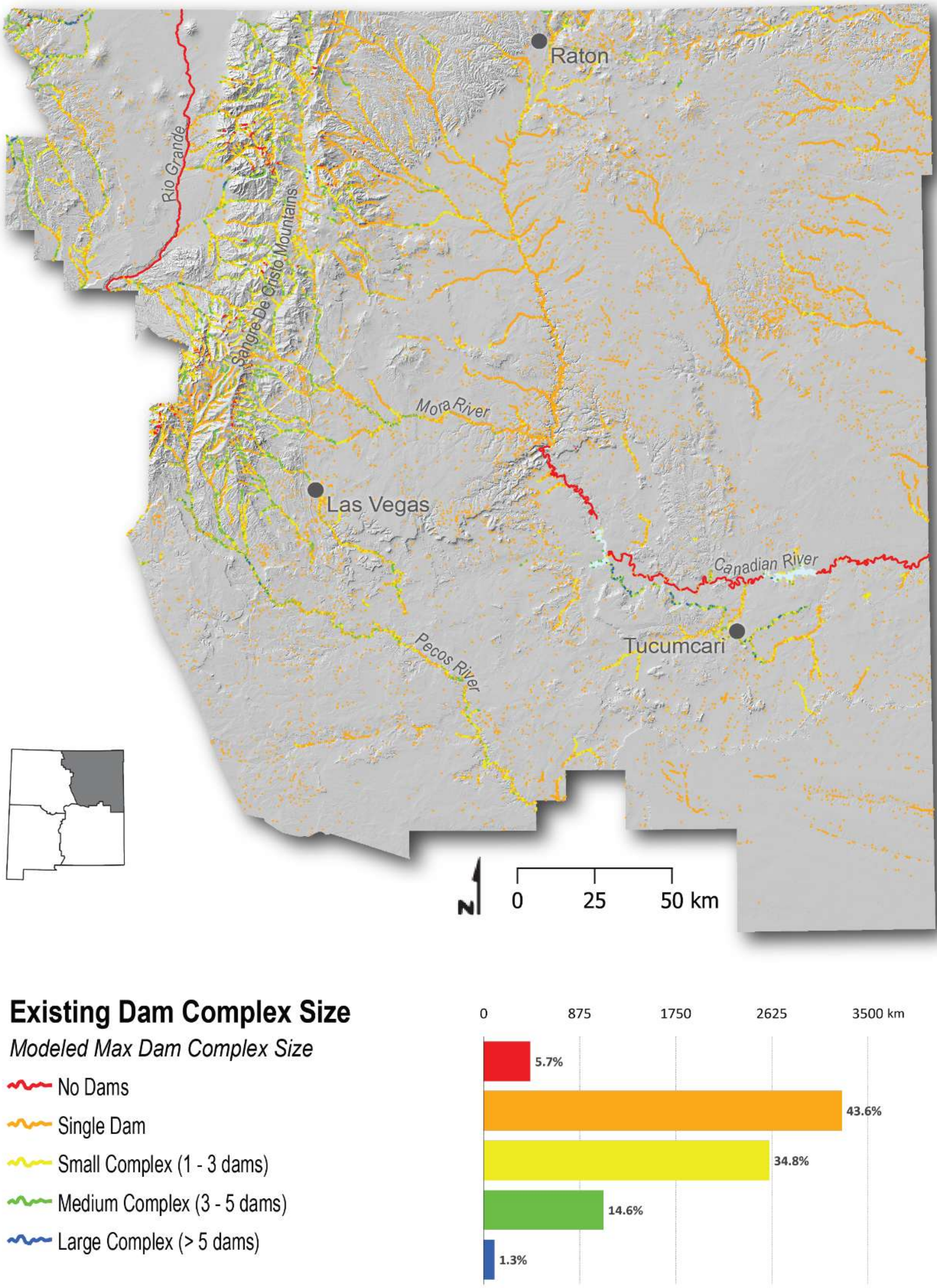


Figure 55: NMGF NE region existing dam complex size.

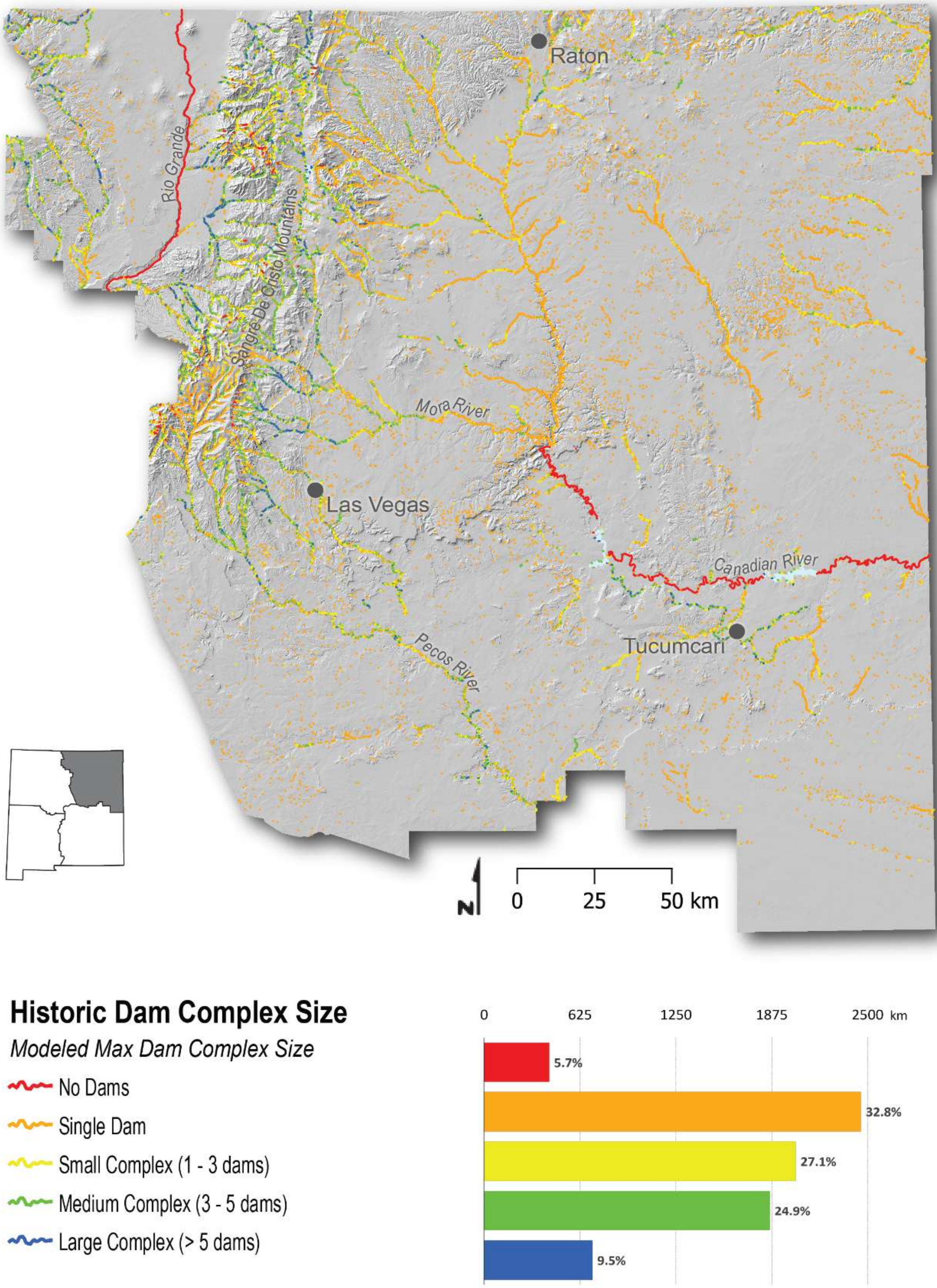


Figure 56: NMGF NE region historic dam complex size.

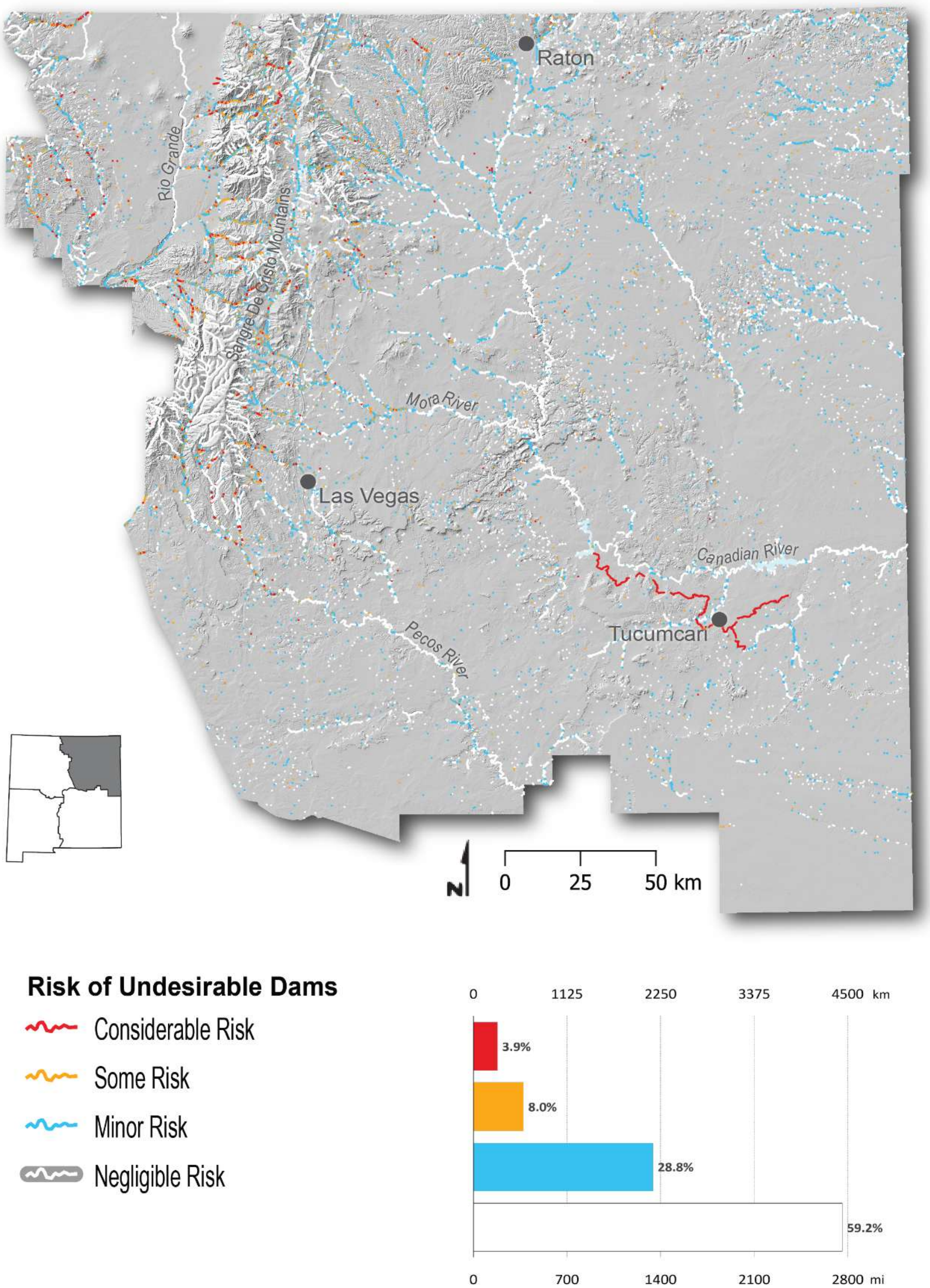


Figure 57: NMGF NE region risk of undesirable dams.

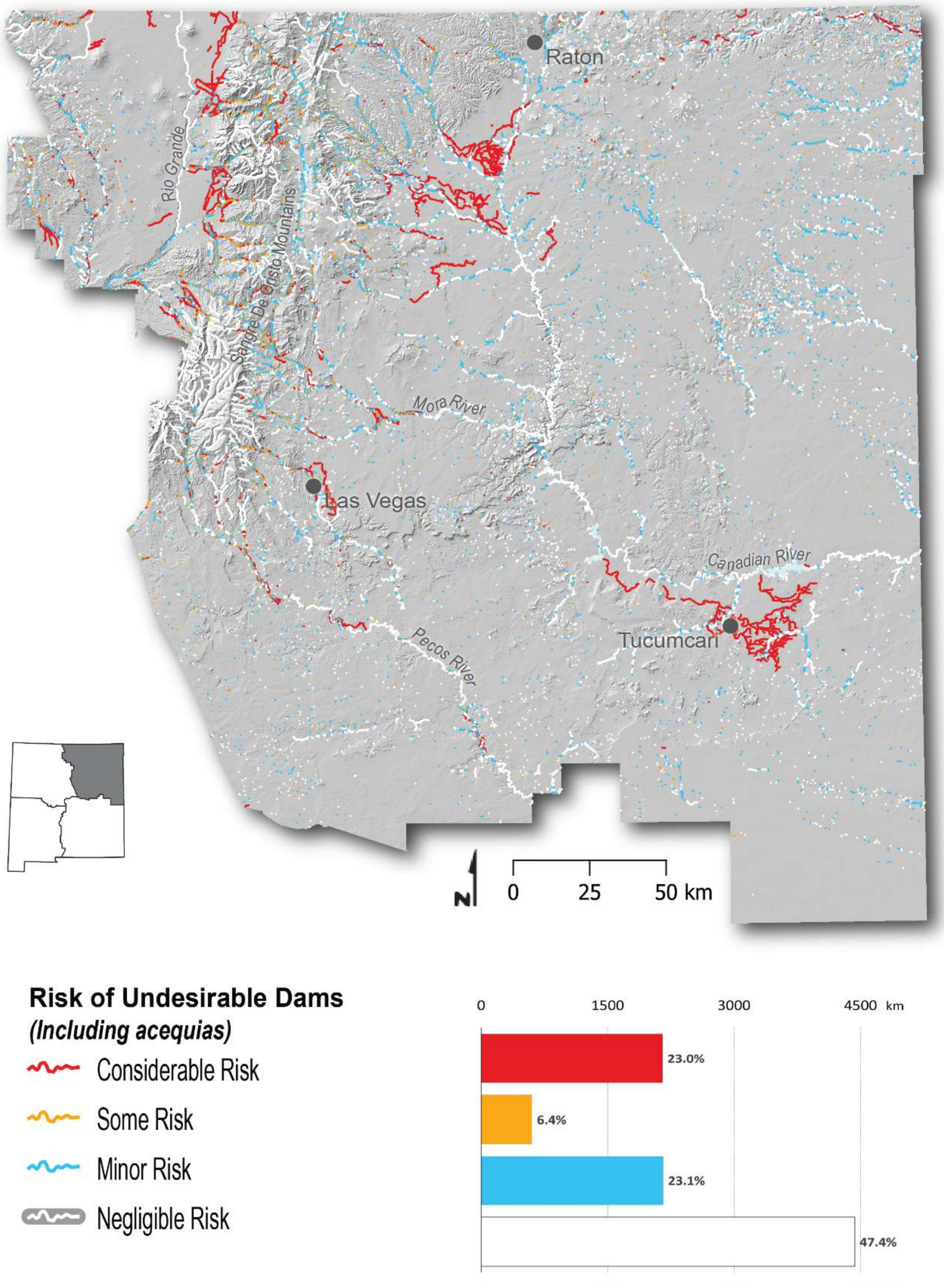


Figure 58: NMGF NE region risk of undesirable dams including acequias.

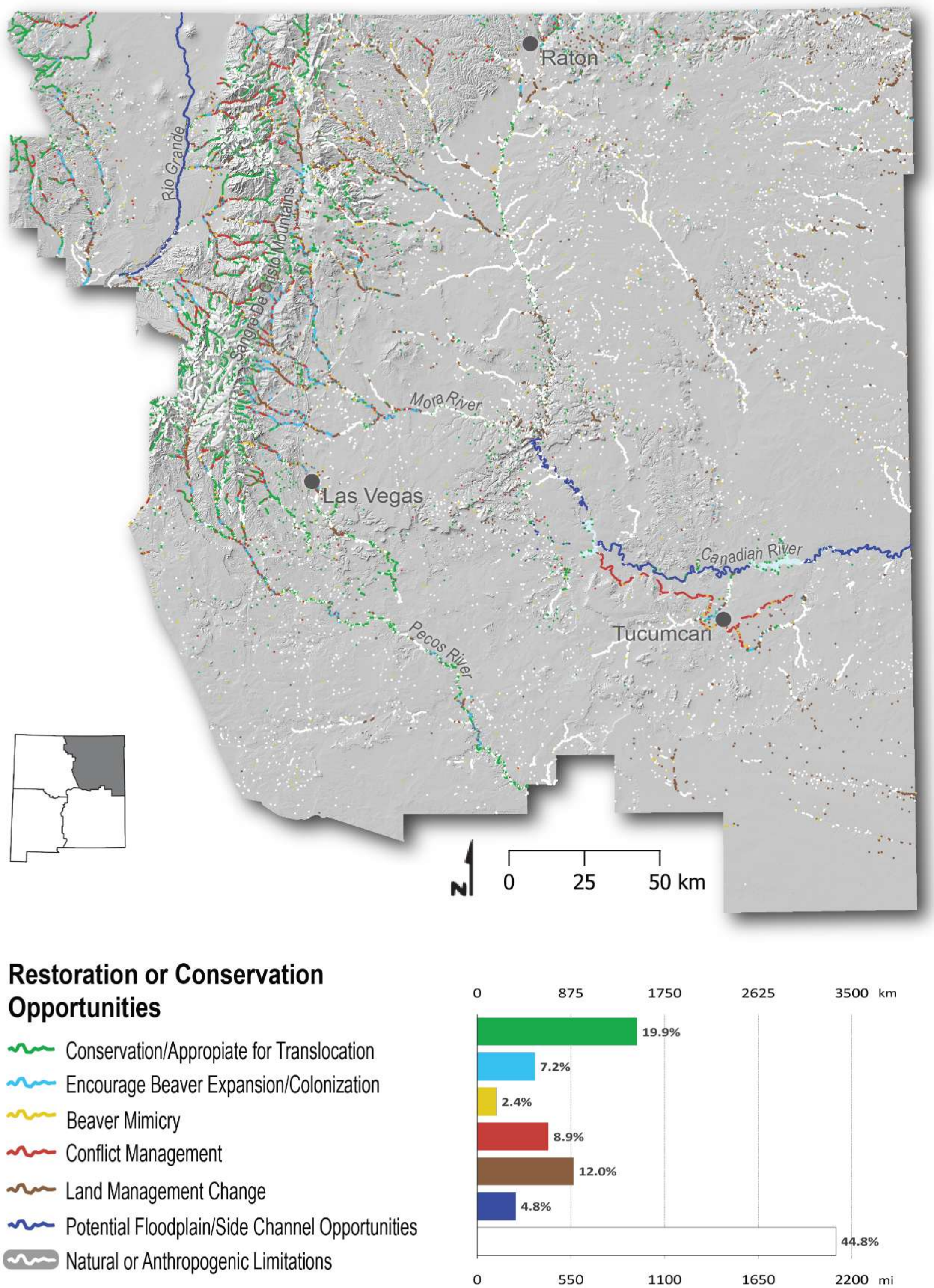
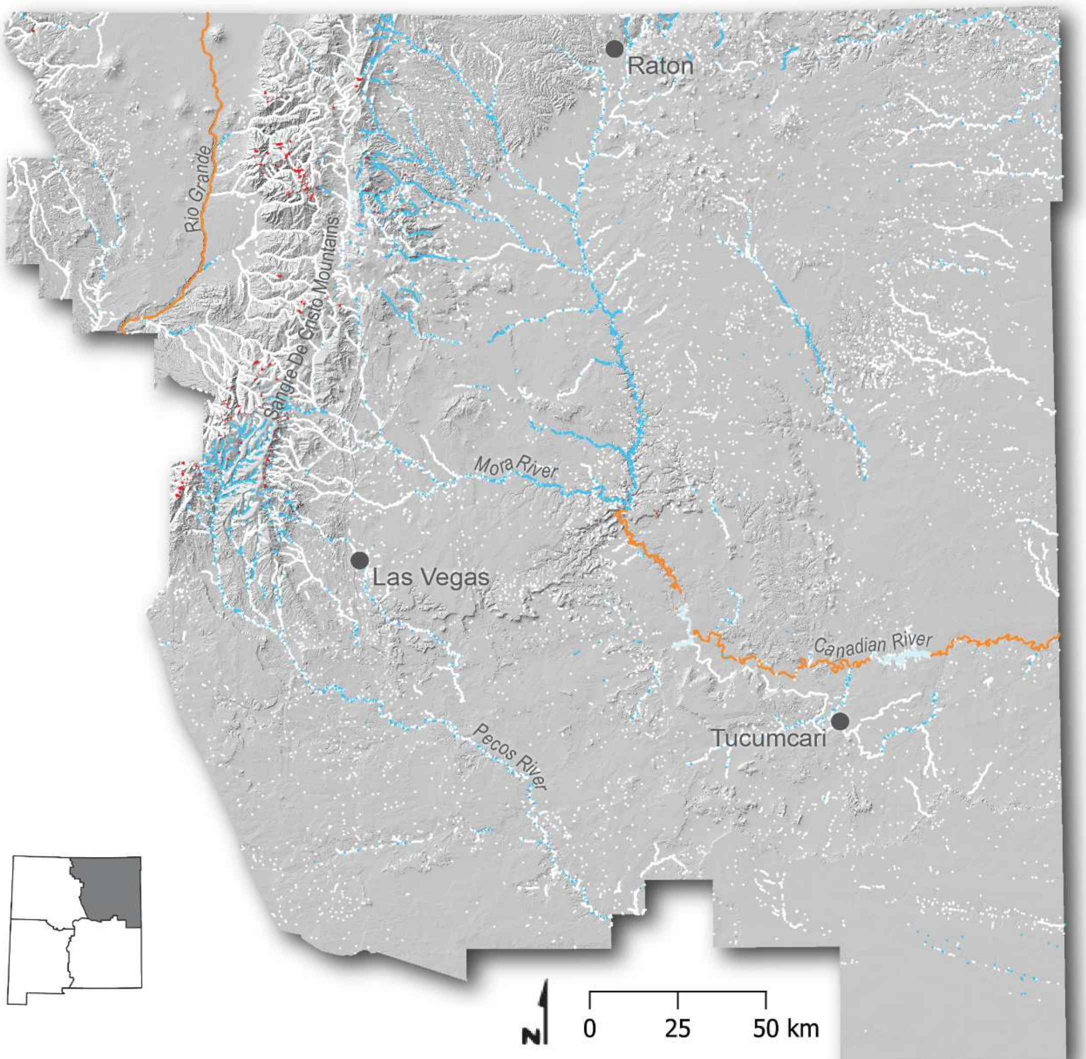


Figure 59: NMGF NW region restoration or conservation opportunities.



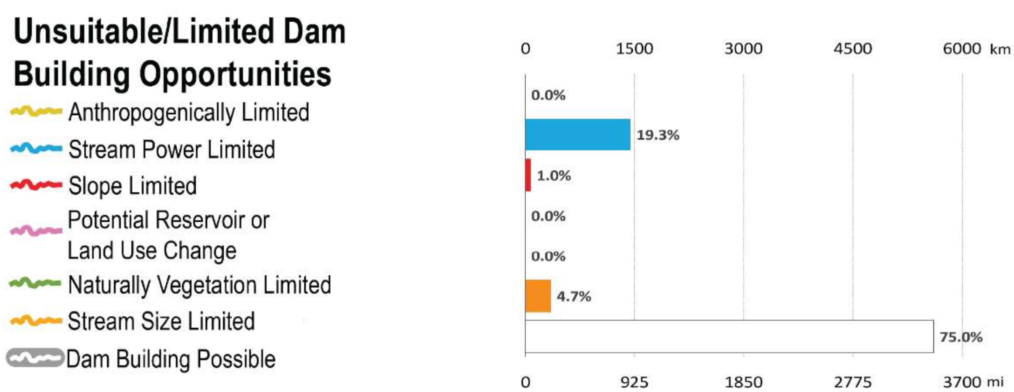
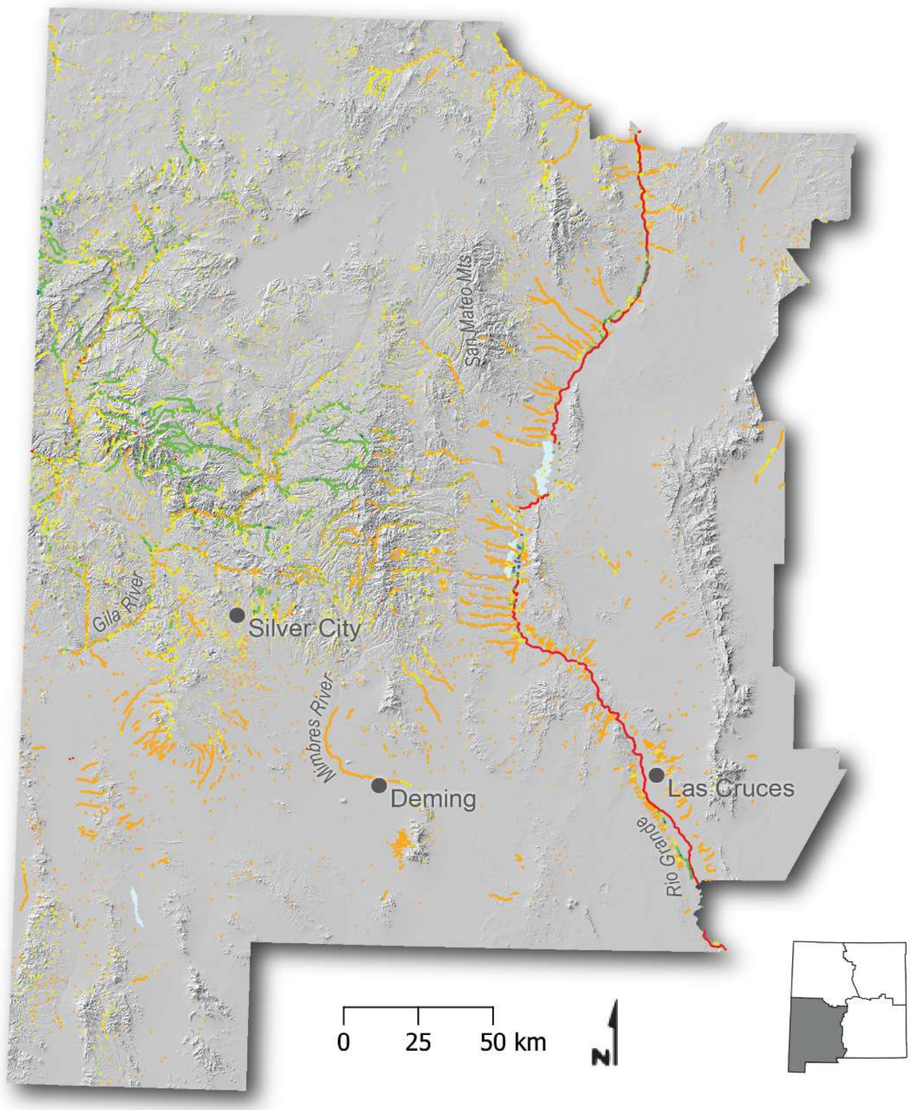


Figure 60: NMGF NE region unsuitable or limited dam building opportunities.



Existing Dam Building Capacity

Density: dams/km *(dams/mi)*

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

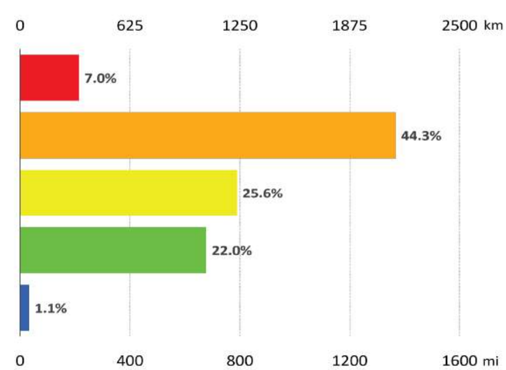


Figure 61: NMGF SW region existing capacity.

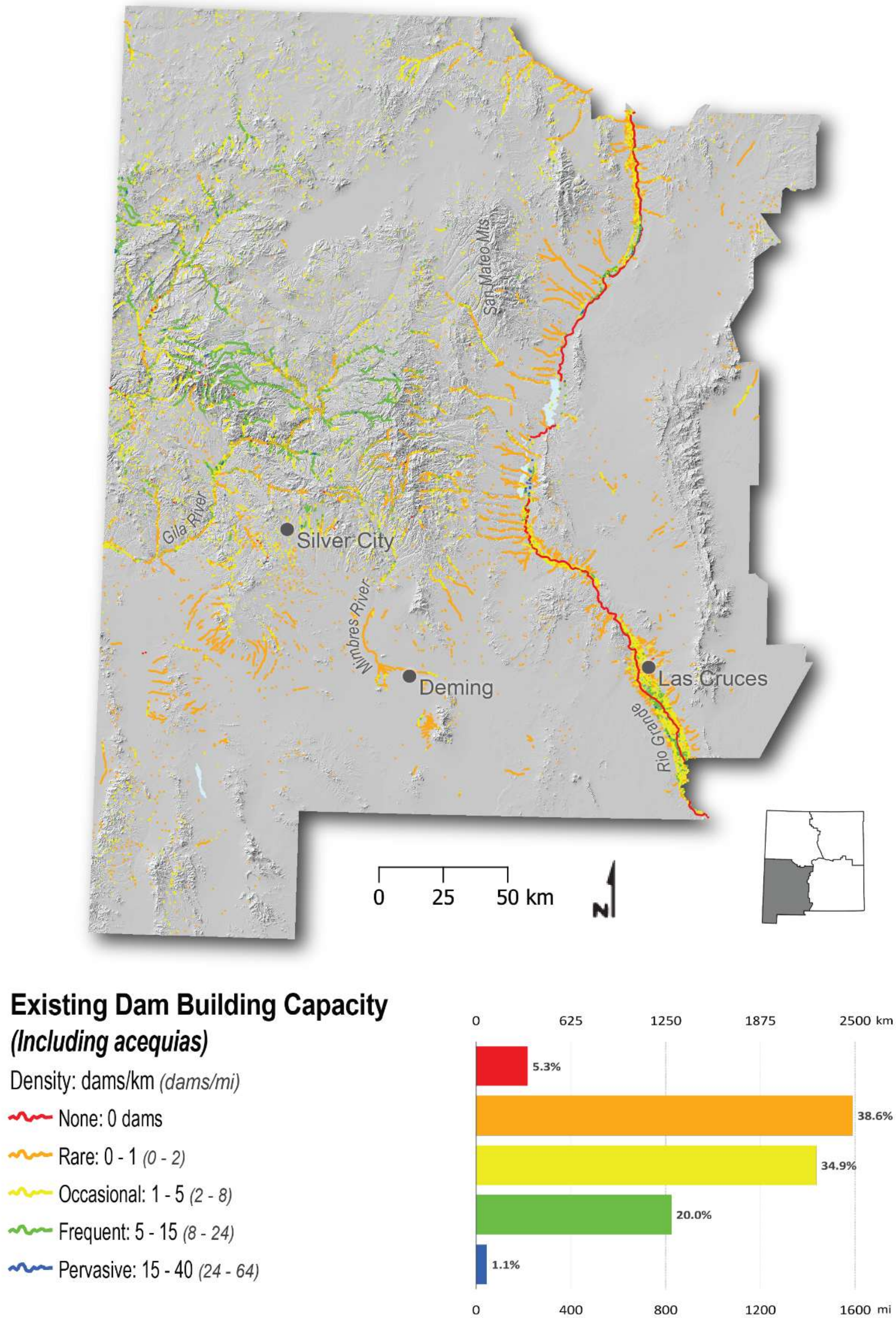


Figure 62: NMGF NW region existing capacity including acequias.

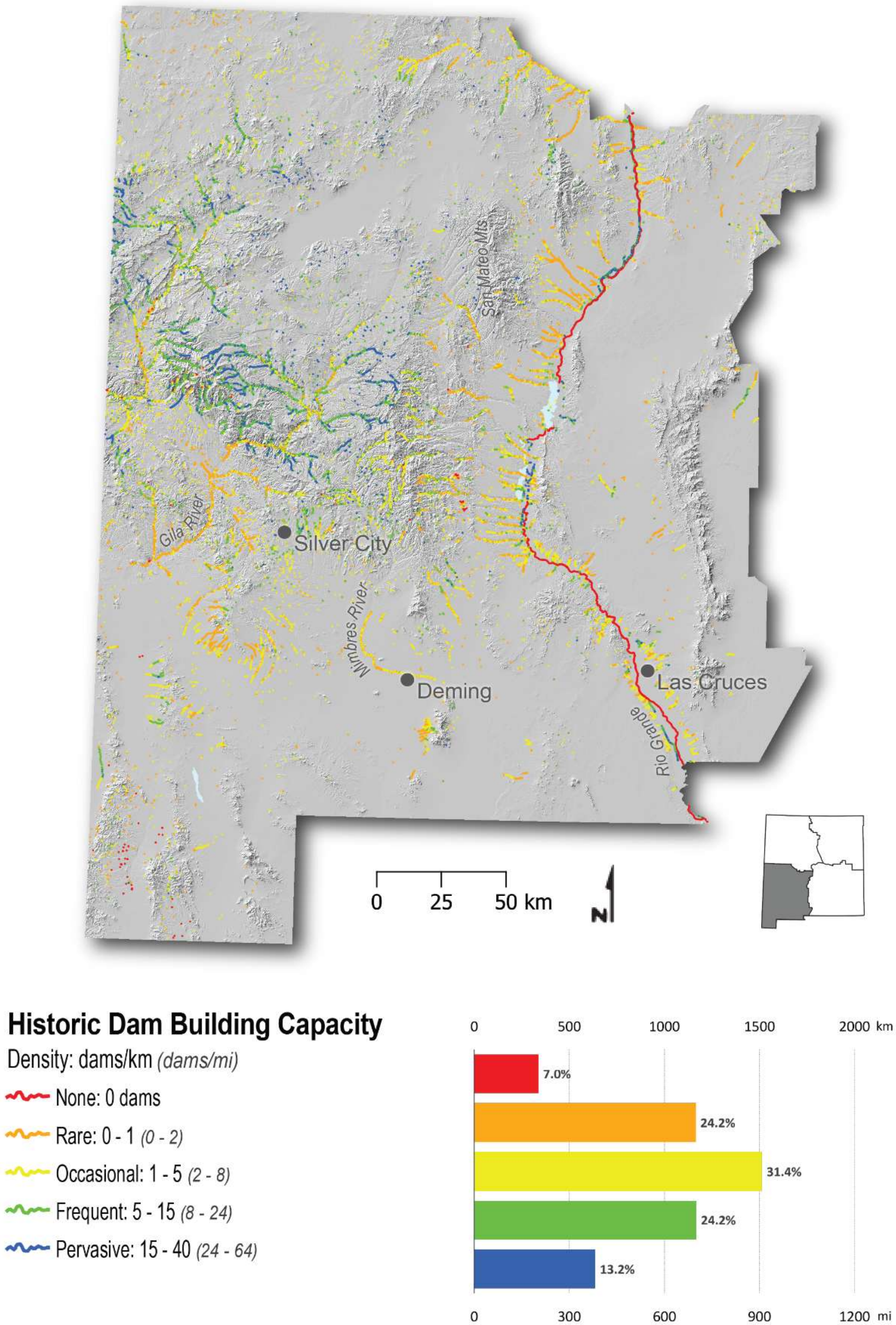


Figure 63: NMGF NW region historic capacity.

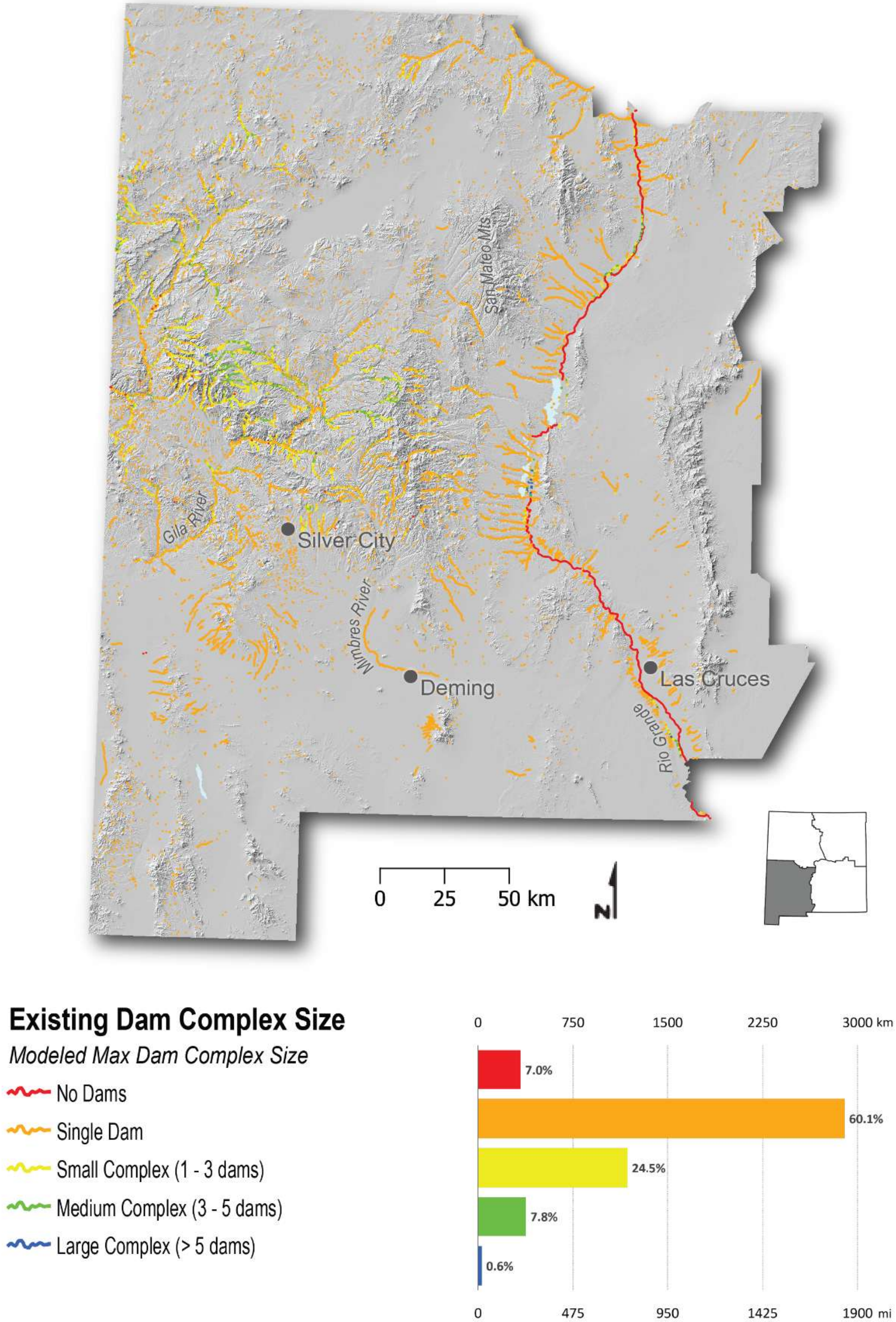
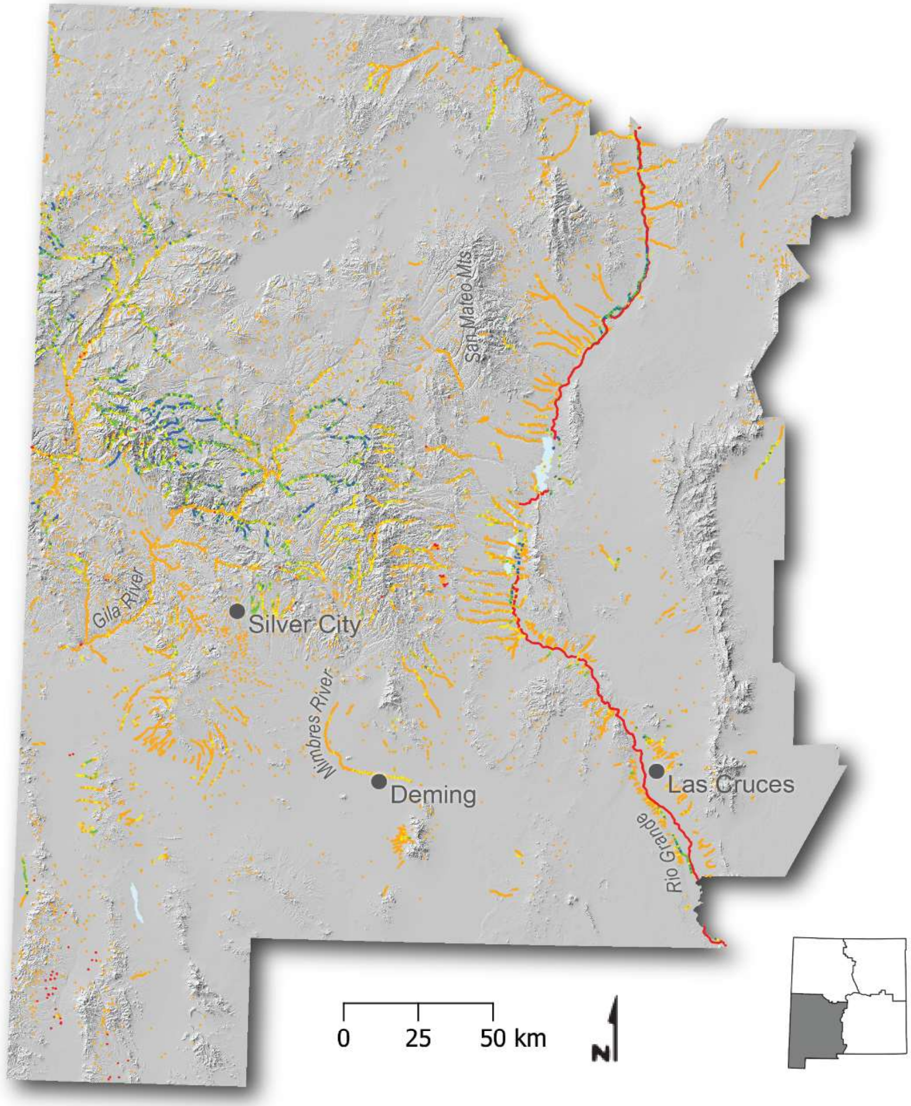


Figure 64: NMGF SW region existing dam complex size.



Historic Dam Complex Size

Modeled Max Dam Complex Size

- No Dams
- Single Dam
- Small Complex (1 - 3 dams)
- Medium Complex (3 - 5 dams)
- Large Complex (> 5 dams)

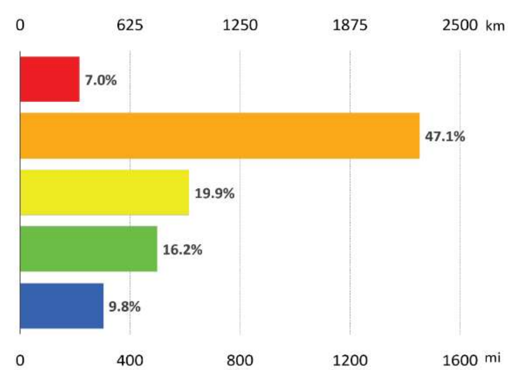


Figure 65: NMGF SW region historic dam complex size.

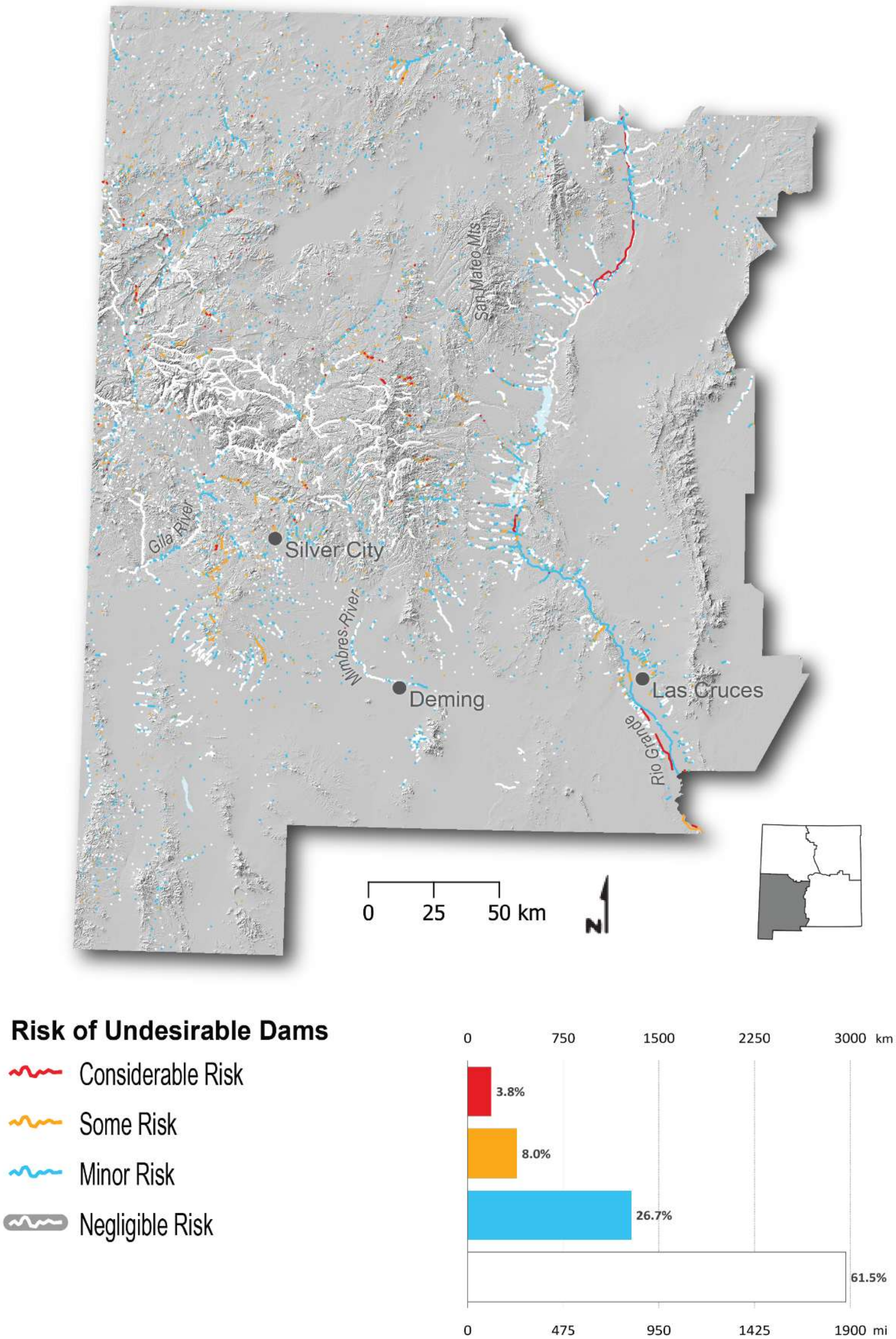


Figure 66: NMGF SW region risk of undesirable dams.

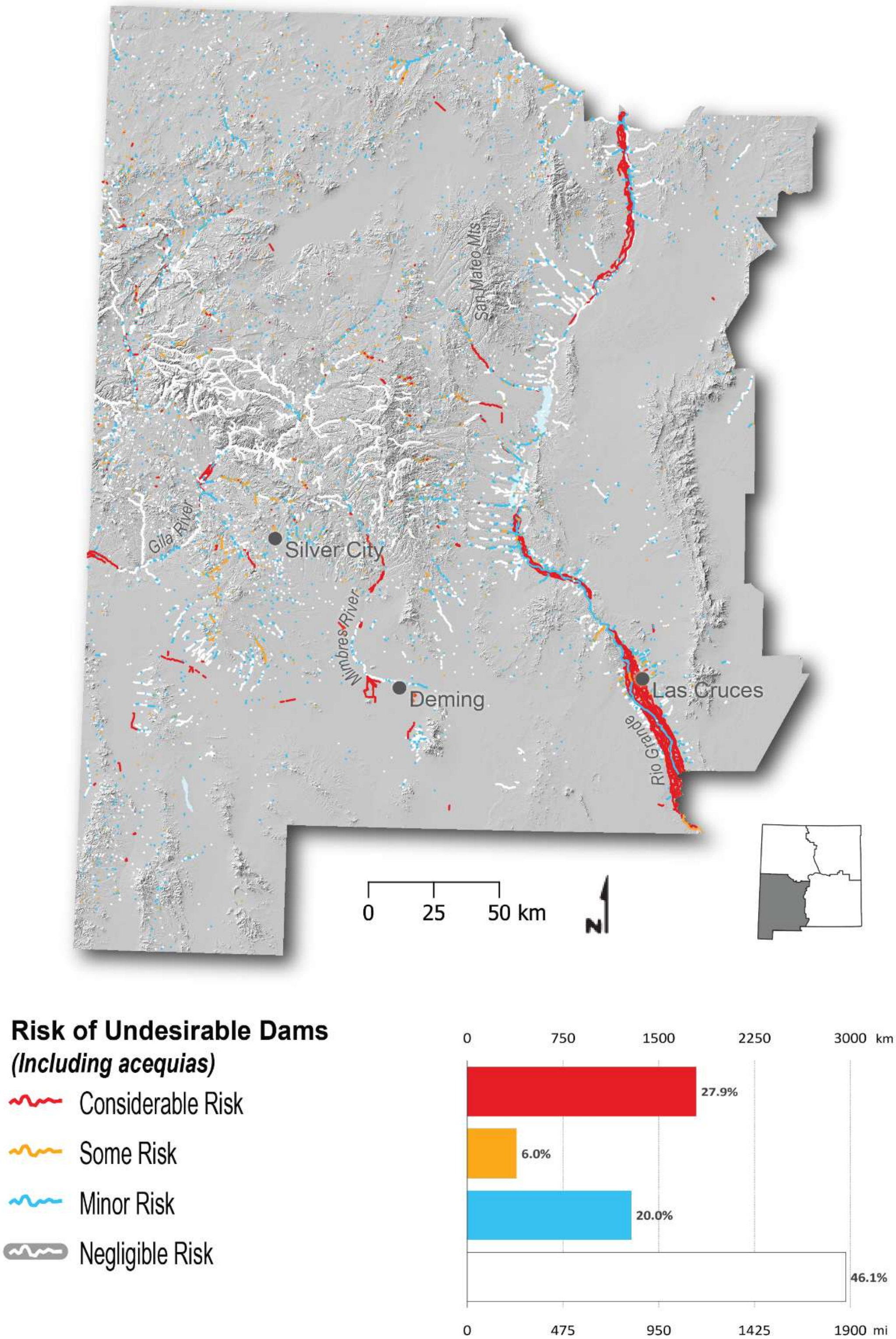


Figure 67: NMGF SW region risk of undesirable dams including acequias.

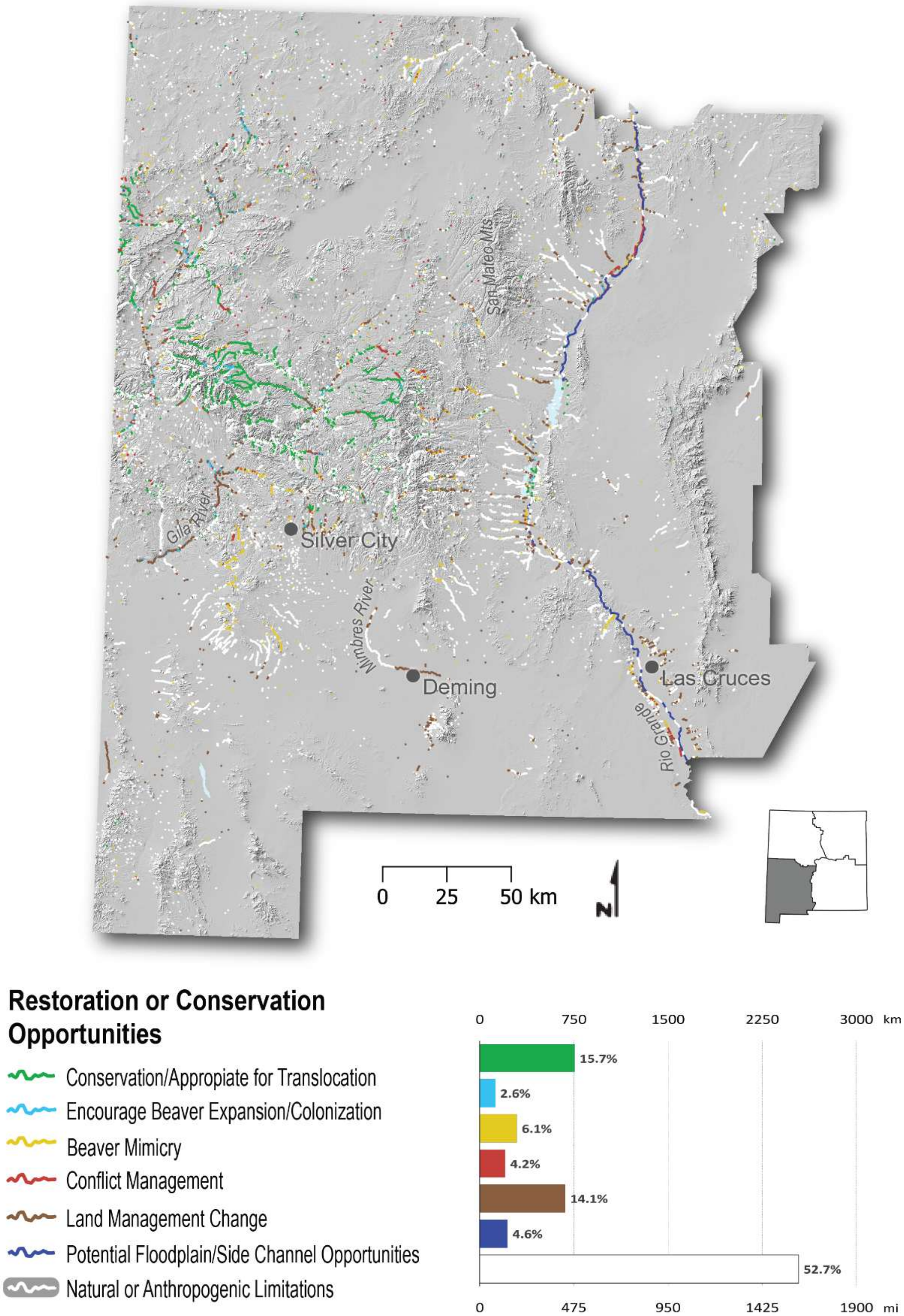


Figure 68: NMGF SW region restoration or conservation opportunities.

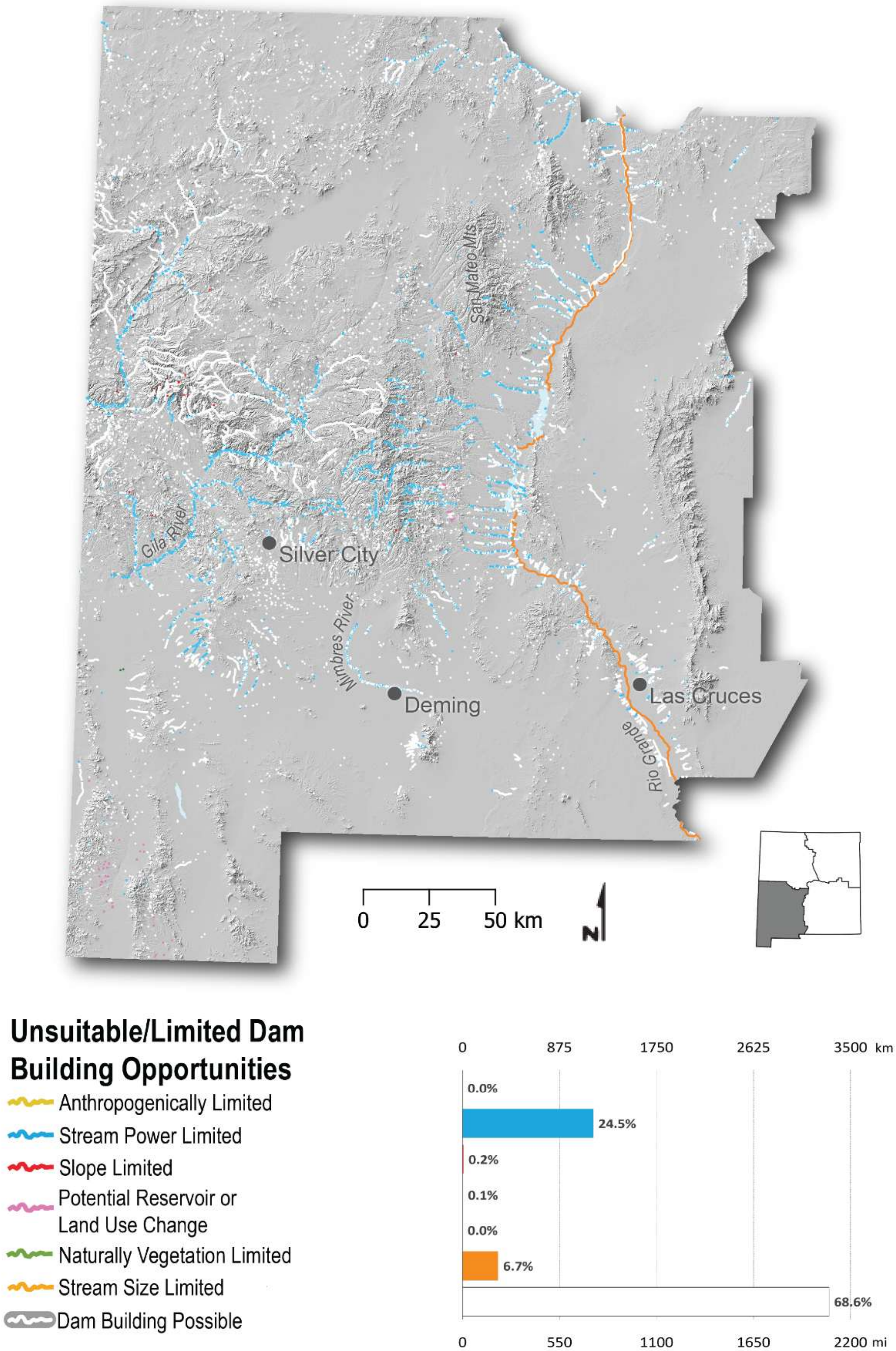


Figure 69: NMGF SW region unsuitable or limited dam building opportunities.

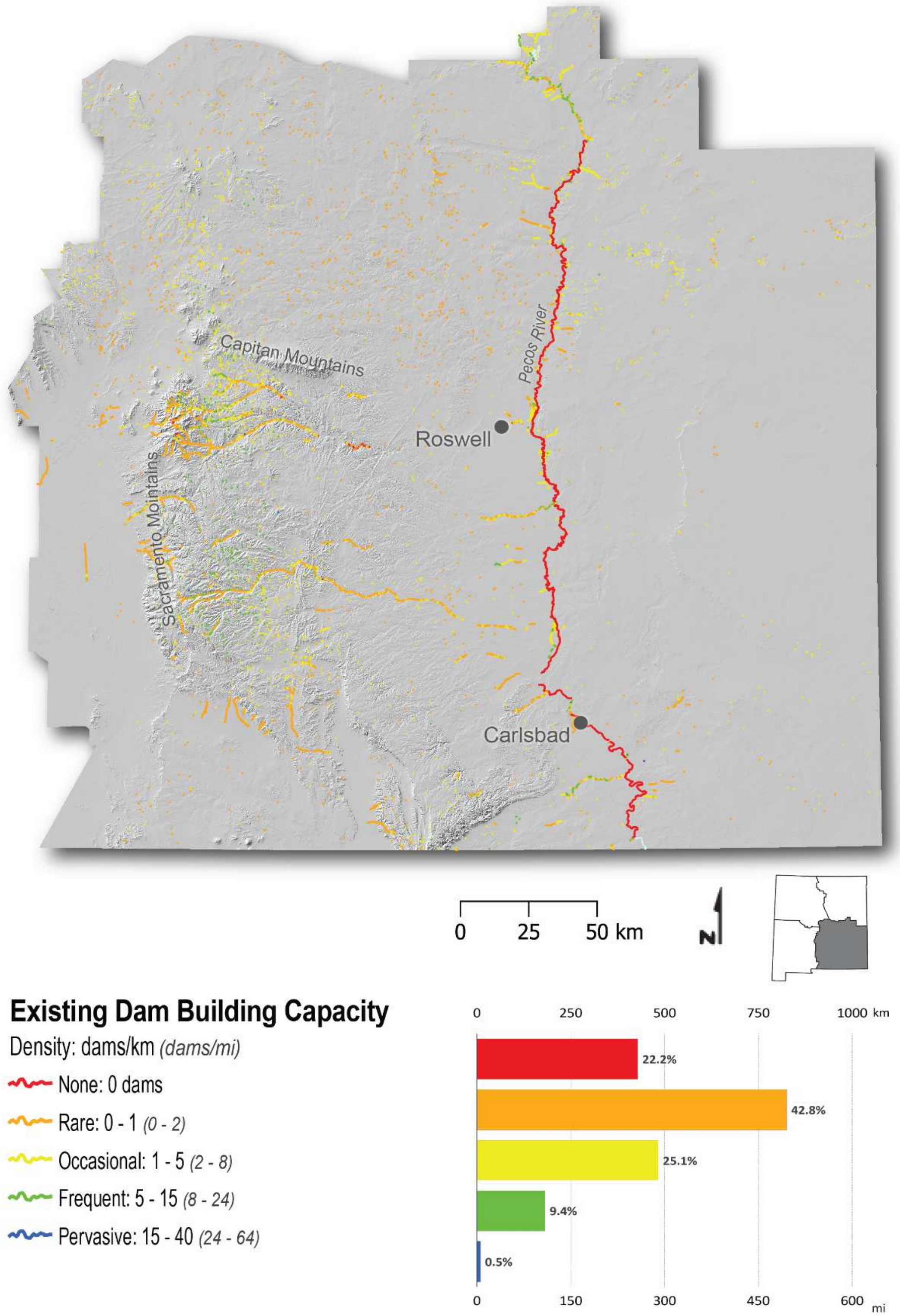


Figure 70: NMGF SE region existing capacity.

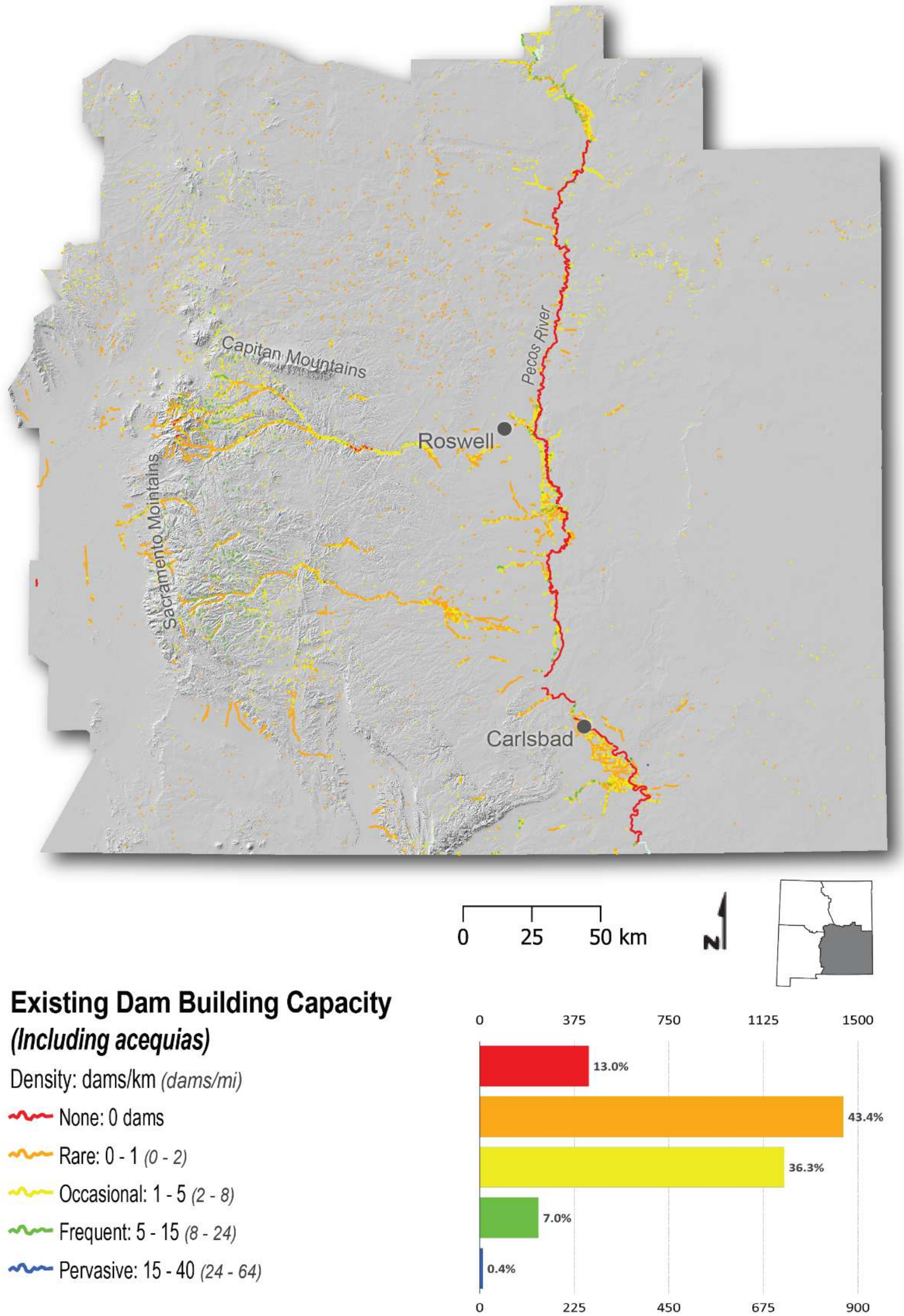


Figure 71: NMGF NW region existing capacity including acequias.

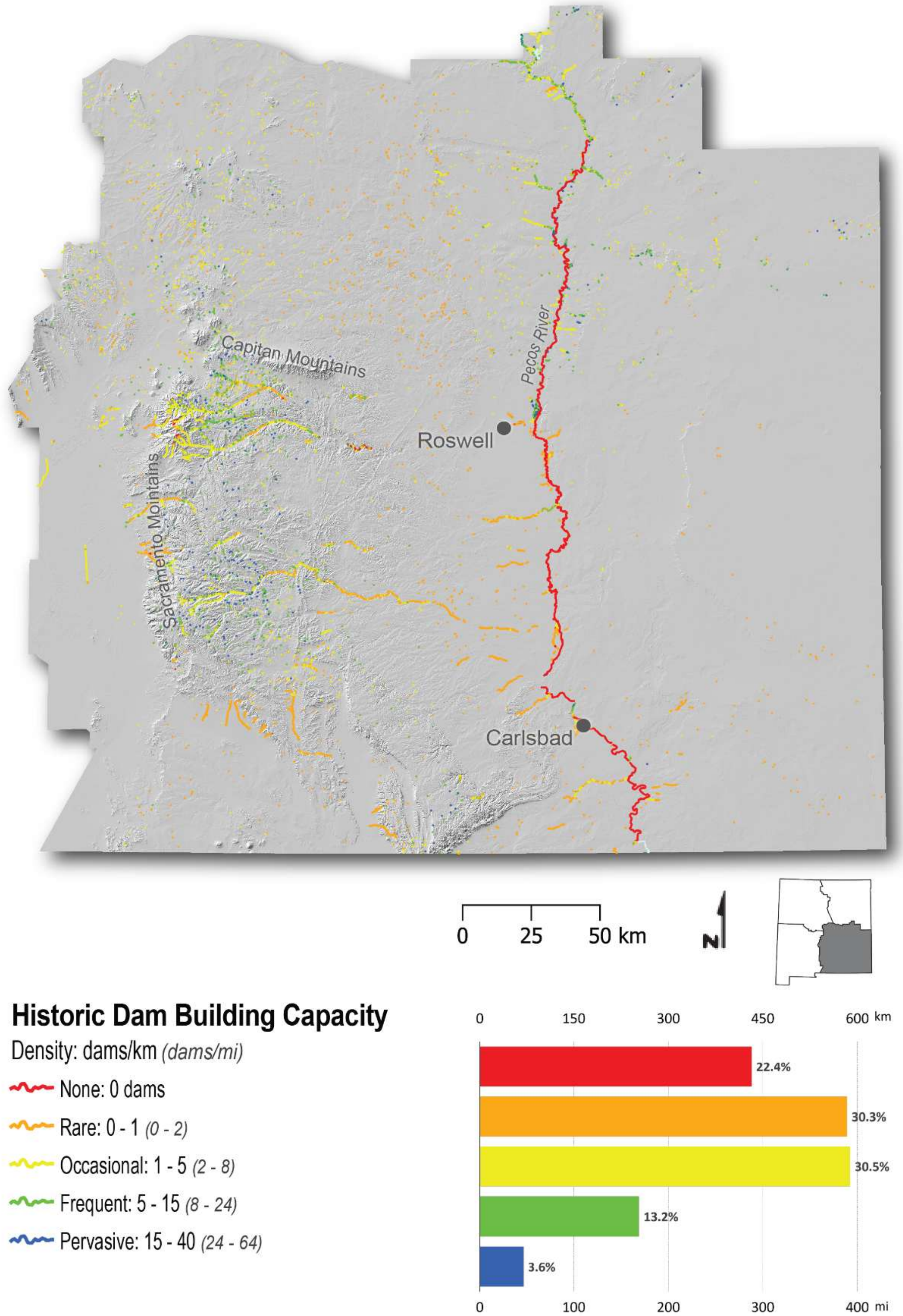


Figure 72: NMGF NW region historic capacity.

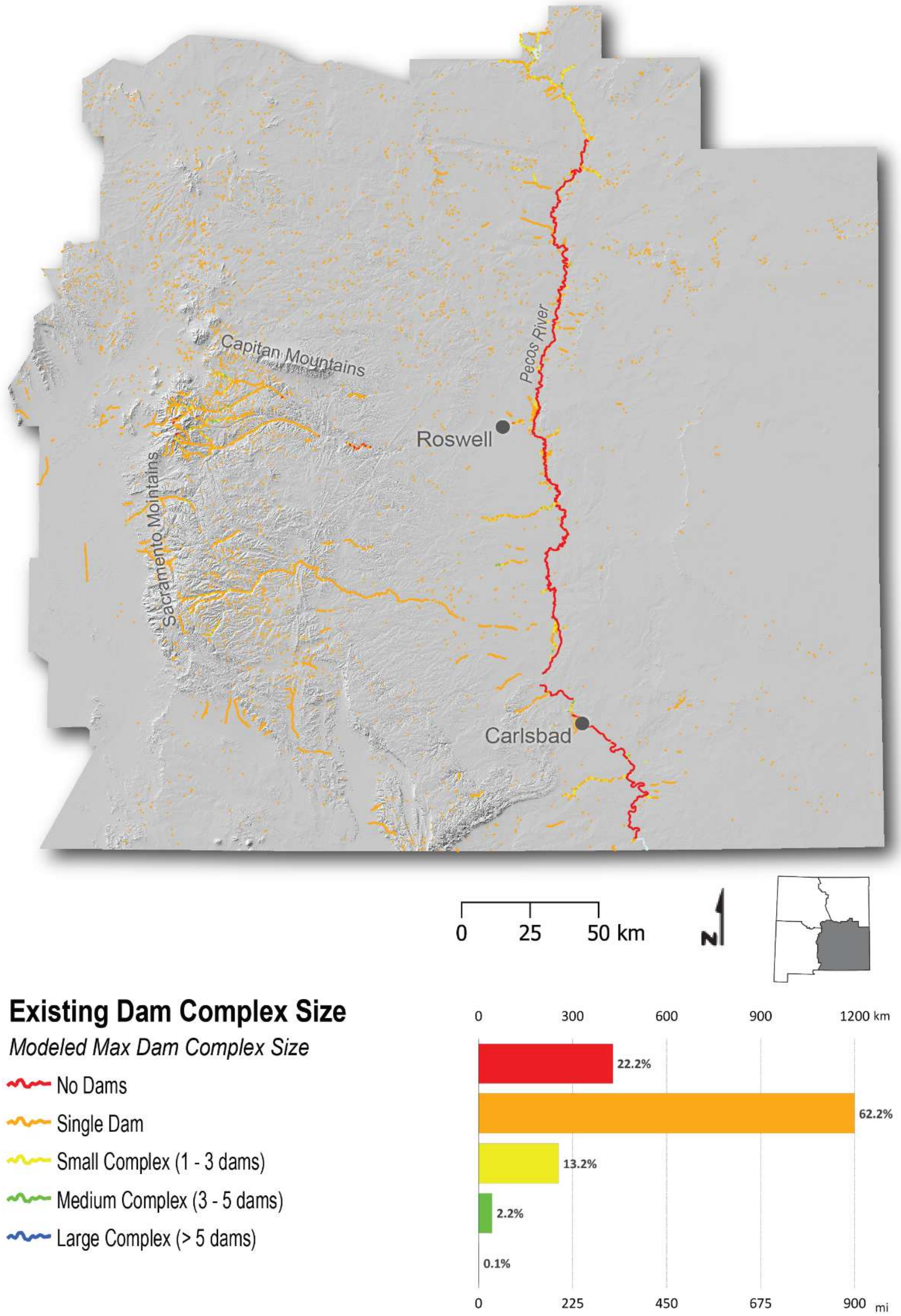


Figure 73: NMGF SW region existing dam complex size.

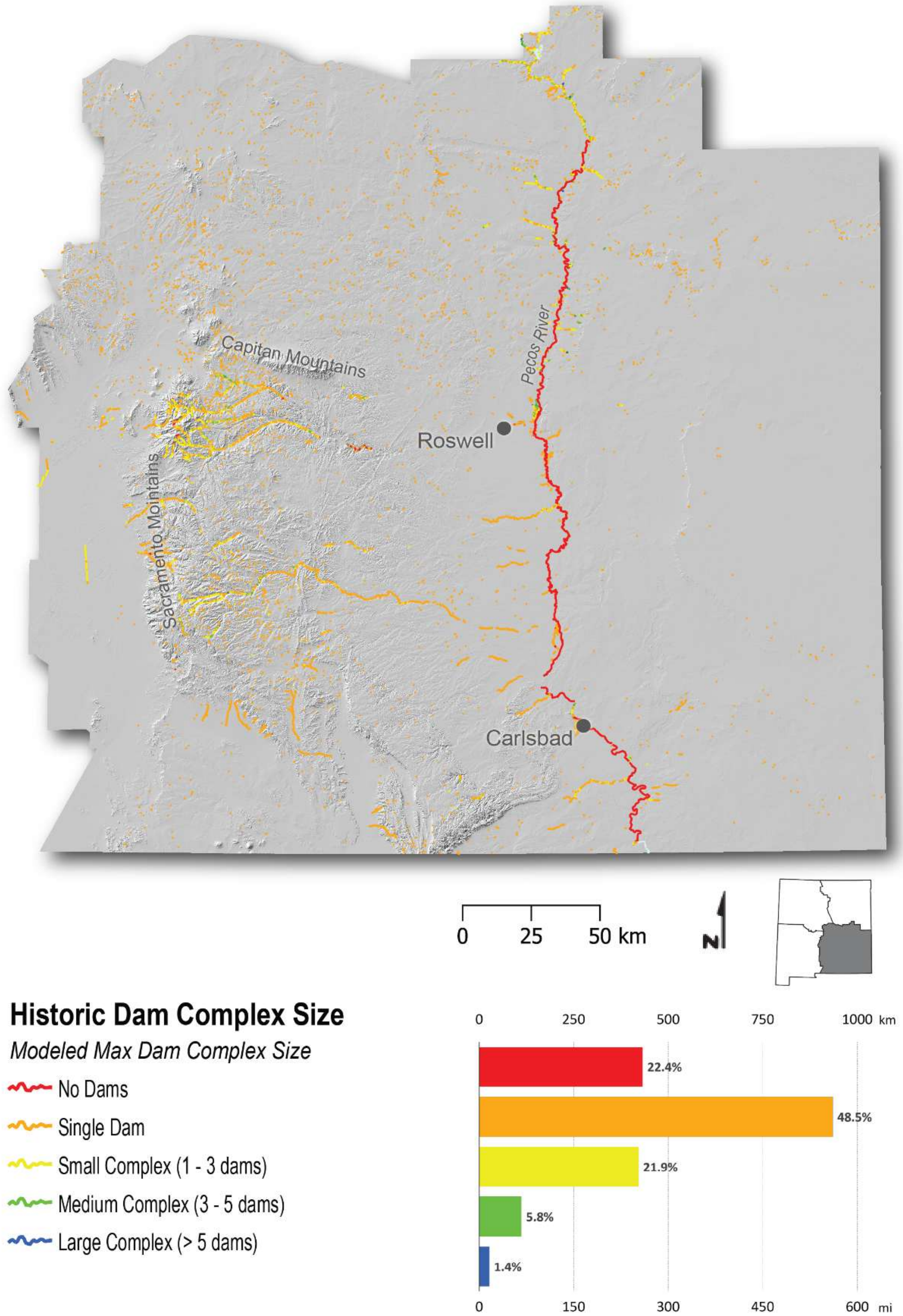


Figure 74: NMGF SW region historic dam complex size.

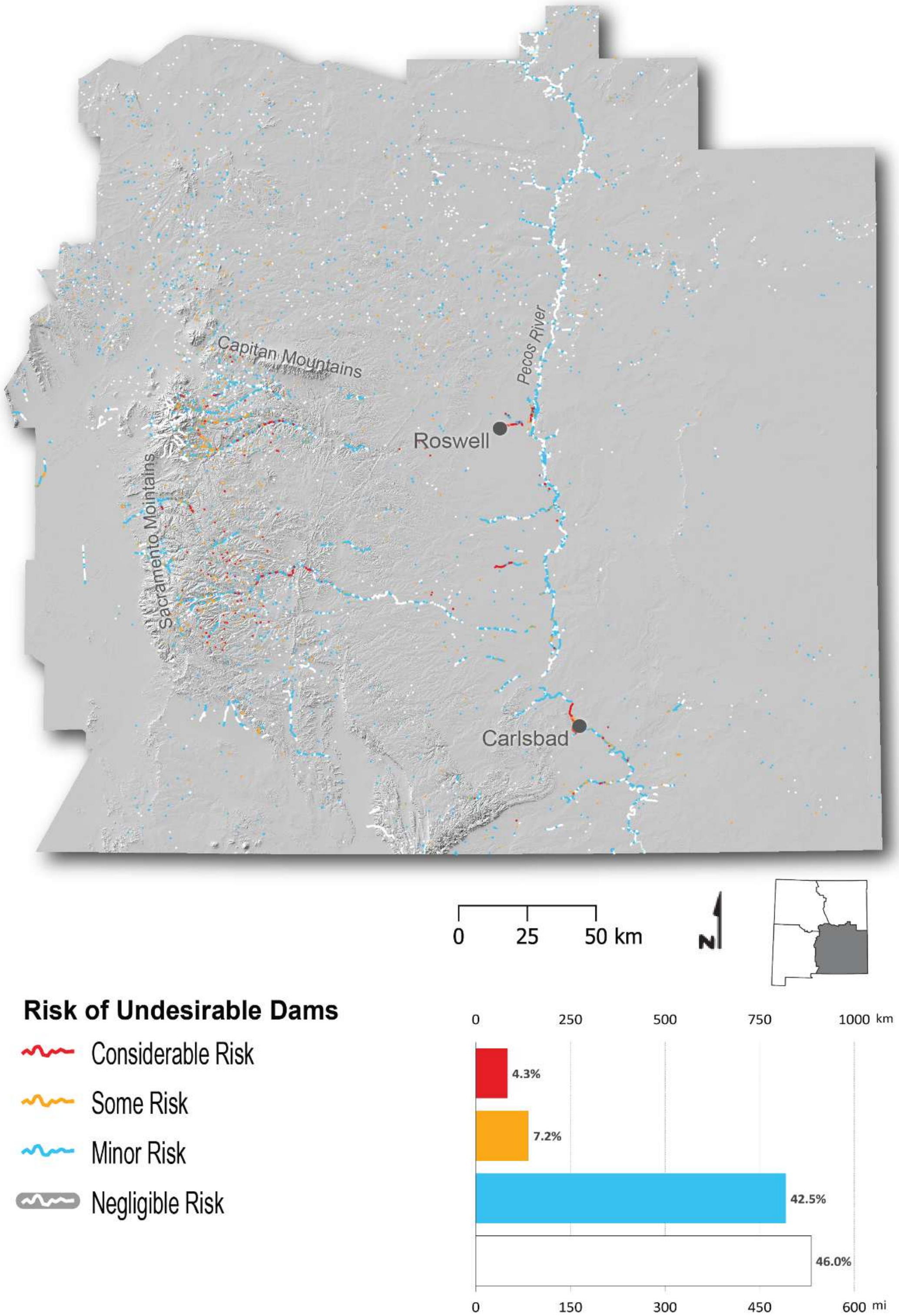


Figure 75: NMGF SW region risk of undesirable dams.

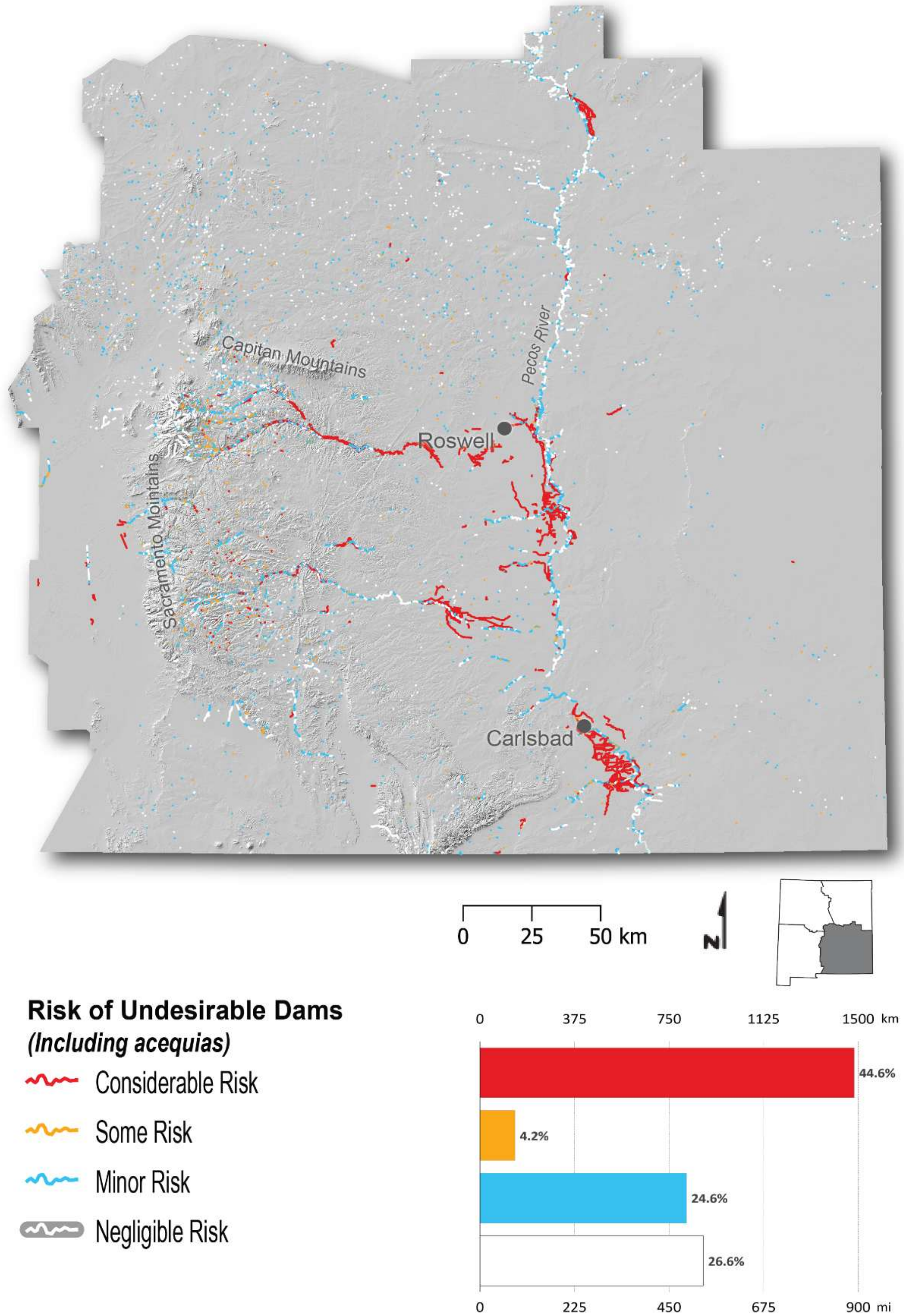


Figure 76: NMGF SW region risk of undesirable dams including acequias.

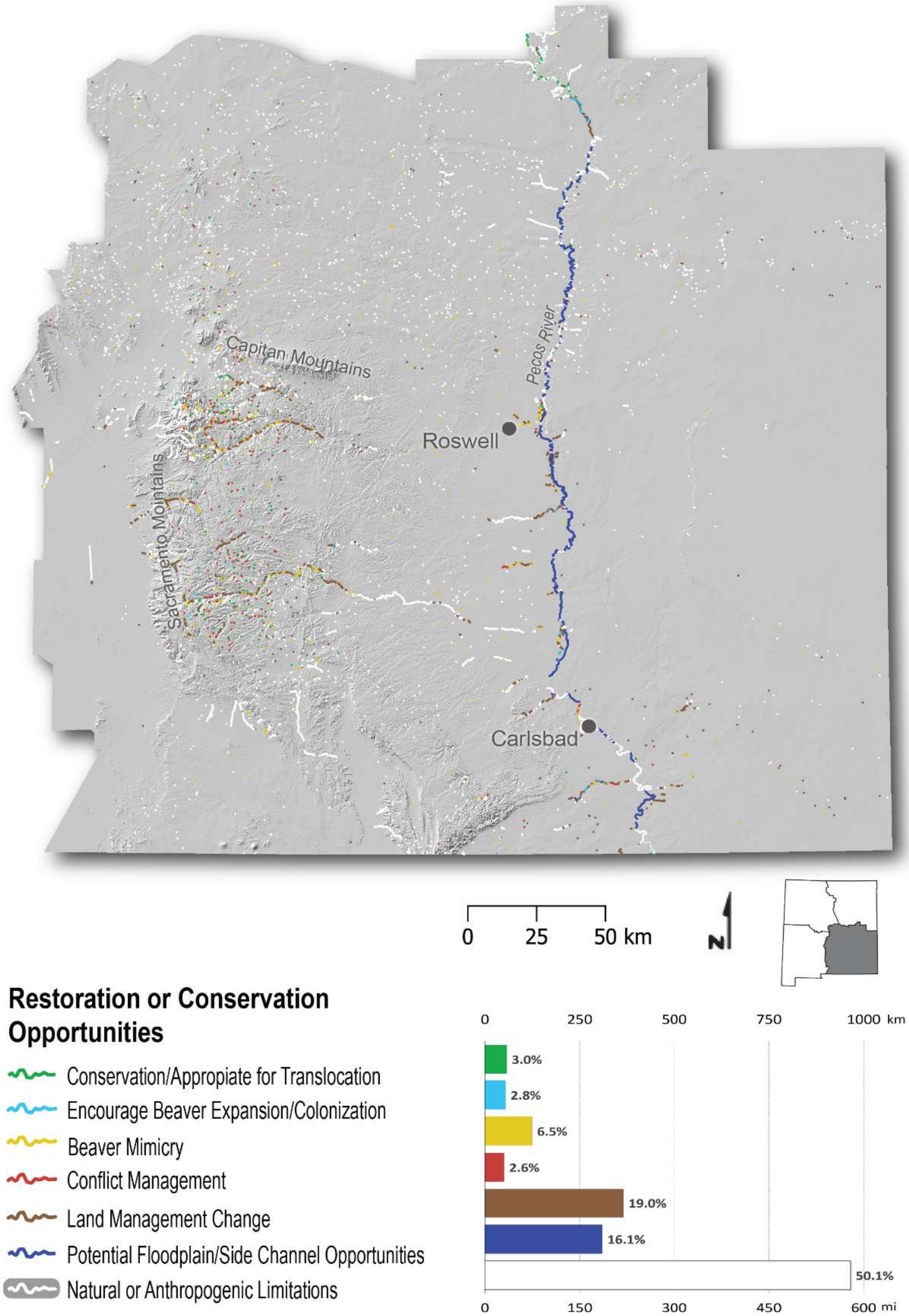


Figure 77: NMGF SW region restoration or conservation opportunities.

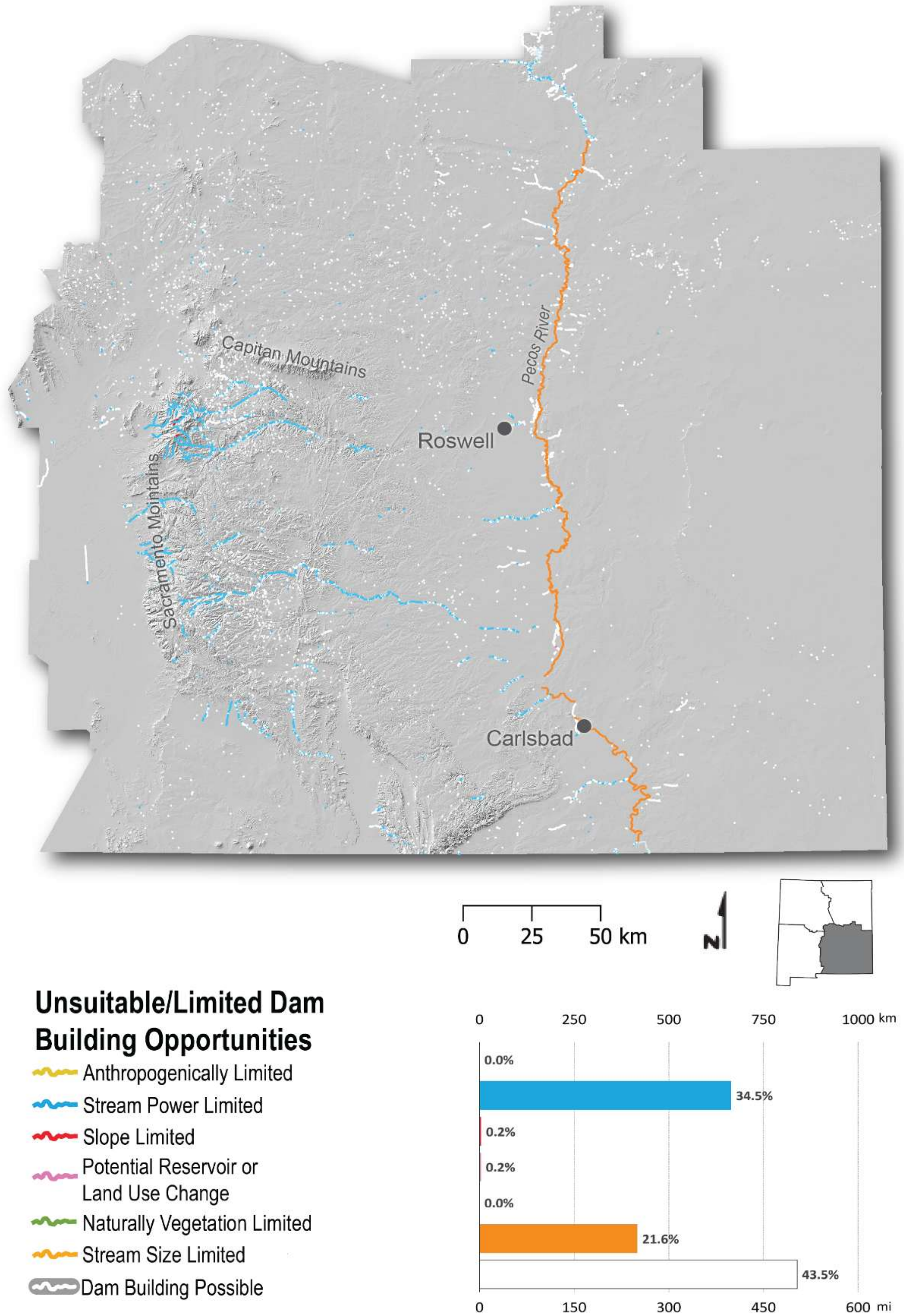


Figure 78: NMGF SW region unsuitable or limited dam building opportunities.