Watershed Analysis of Beaver Restoration Potential in Park County

Final Report

Prepared for:
Colorado Water Plan Grant Program
Attn: Chris Sturm

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Introduction

There is a growing need for effective community planning tools to develop and implement landscape-scale restoration projects throughout Colorado. COL, EcoMetrics, CSU, and CNHP collaborated successfully piloting a watershed-scale geospatial analysis of beaver restoration potential in Park County, Colorado. This study and analysis framework serves as a model for a statewide beaver restoration prioritization resource. Extensive documentation of this work is presented in *Appendix 1*.

Background

Headwater wetlands and streams are crucial to landscape resilience, especially in a changing climate. The ecologic functionality of beavers in the formation and maintenance of healthy wetland riverscapes is gaining appreciation across communities and disciplines. In Park County, and more broadly across the American west, riverscape corridors became degraded following the eradication of beavers in the 18th and 19th centuries.

There is a growing body of evidence and knowledge that the health of wetland riverscapes weakened by beaver extirpation can be improved using process-based restoration treatments. Where though, can these types of projects be scaled and implemented efficiently and without onerous tradeoffs to land use value or infrastructure security?

The purpose of this study investigated this question by mapping the riverscapes and developing geospatial analysis tools that can be used in developing successful restoration sites.

Methods

The project combined extensive existing data collected by project partners throughout Park County with new field surveys, GIS modeling, and a decision support framework for restoration prioritization. These methods are described in detail in the *Methods* section of *Appendix 1*.

Results

See the *Results* section of *Appendix 1* that extensively documents results of this project.

Conclusions and Discussion

This project and development of the beaver restoration assessment tool (BRAT) is an encouraging template but, as we found in its' analysis of Park County, the results can easily be misinterpreted. The findings of this study offer an evidence-based framework for pragmatic professional-judgment approach for prioritizing riverscape restoration sites. This is the framework we have adopted and are implementing for the Riparian Reconnect program to assess LTPBR/beaver restoration potential, to evaluate limiting factors and, ultimately, create a pipeline of restoration opportunities. Details of this framework are described in detail thought *Appendix 1*.

COLORADO OPEN LANDS

Actual Expense Budget

COLORADO
Colorado Water Conservation Board
Department of Natural Resources

Colorado Water Conservation Board						
Water Plan Grant - Exhibit B						
Budget and Schedule						
Prepared Date: July 2022						
Name of Applicant: Colorado Open Lands						
Name of Water Project: Watershed Analysis of Beaver Restoration Potential in Park County						
Project Start Date: April 1, 2019						
Project End Date: July 30, 2022						
Task No.	**Task Description**	**Task Start Date**	**Task End Date**	**Actual Expenses**	**Match Funding**	**Total**
1	Beaver Restoration Assessment Tool (BRAT)	Q3 2019	Q1 2021	$13,395	$4,820	$18,215
2	Mapping of current beaver activity	Q3 2019	Q4 2020	$2,220	$24,595	$26,815
3	Detailed field surveys	Q3 2019	Q3 2020	$4,212	$19,475	$23,687
4	Prioritization of beaver restoration sites	Q4 2020	Q3 2022	$21,123	$11,880	$33,003
5	Reporting and management	Q3 2019	Q3 2022	$4,500	$17,400	$21,900
			Total	$45,450	$78,170	$123,620

Appendix 1.

Park County Beaver Restoration Assessment – *Identifying the best LTPBR/beaver restoration opportunities on a landscape*

Park County Beaver Restoration Assessment

Identifying the best LTPBR/beaver restoration opportunities on a landscape

EcoMetrics, *Riparian Reconnect*, February 28, 2022

ABSRTRACT

Low-tech process-based restoration (LTPBR) aimed at mimicking, promoting, and sustaining beaver activity is becoming increasingly appreciated as an effective strategy for restoring riverscape health and reclaiming beneficial ecosystem services. Like all nature-based restoration approaches, context and site selection are critical to success. As the practice gains popularity, there is growing need for practical guidance about when, where, and how LTPBR can be effectively applied. The beaver restoration assessment tool (BRAT) offers an enticing template but, as we found in Park County, the results can be misleading or easy to misinterpret. This study outlines a pragmatic professional-judgment approach we used for the *Riparian Reconnect* program in Park County to assess LTPBR/beaver restoration potential, to evaluate limiting factors and, ultimately, to triage restoration opportunities. The approach is being used to guide LTPBR/beaver restoration efforts in other Colorado mountain and foothills regions.

Introduction

Functional headwater wetlands are critical to watershed resilience, especially in a changing climate. The keystone importance of beavers in the formation and maintenance of healthy wetland riverscapes is becoming increasingly appreciated in the scientific, practitioner, and lay communities. In Park County, as in most of the Rocky Mountains, most natural stream-wetland corridors became degraded following the eradication of beavers in the 18th and 19th centuries. In a comprehensive inventory of water resources (EcoMetrics 2016), we found many of Park County's wetlands and streams to be in poor health due to the removal of beavers and subsequent use and development of riparian lands. Recovering the essential wetland functions that were lost depends, to a large degree, on restoring the keystone species and the natural processes they perform. Process-based restoration treatments aimed at mimicking, promoting, and sustaining beavers in riverscapes where they historically thrived are becoming increasingly recognized as a viable and efficient approach to riverscape restoration and watershed management.

If the health of wetland riverscapes was impaired by the extirpation of beavers in the past, could it now be improved by restoring them? Can it be done in a reasonable timeframe, efficiently and without onerous tradeoffs to land use value or infrastructure security? If so, where? And how?

The purpose of this study is to investigate these questions by mapping the riverscapes that were historically beaver complexes and identifying the ones that can be feasibly restored, given the current conditions and contemporary land use regime. It is easy to relate the benefits of beaver restoration in general terms, and it is easy to understand how restored beaver activity would benefit a specific degraded site; but it is not always obvious when, where, or how these approaches can be applied to realize practical gains on a larger landscape. Our goal is to clearly identify where and how low-tech process-based beaver restoration can be practically and appropriately applied in Park County. We aim to create a framework that gives practitioners and decision-makers a rational basis for triaging resources towards project sites where the most sustainable benefits can be achieved.

Beaver are being hailed as one of the most cost-effective and sustainable solutions for ecological restoration and climate change resilience[1], and "light-touch" low-tech process-based restoration projects that involve beaver are becoming increasingly popular in the western US. According to Wheaton *et. al.* (2019) low-tech process-based restoration, or LTPBR, is *a practice of using simple, low unit-cost, structural additions (e.g., wood and beaver dams) to riverscapes to mimic functions and promote specific processes. Hallmarks of this approach include an explicit focus on the promoting geomorphic and fluvial processes, a conscious effort to use cost-*

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[1] USFWS, Oregon Fish and Wildlife Office, Beaver Restoration website (2022)

*effective, low-tech treatments (*e.g., *hand-built, natural materials, non-engineered, short-term design lifespans) because of the need to efficiently scale-up application, and ‘l*etting the system do the work’*, which defers critical decision-making to riverscapes and beaver*. In our use, LTPBR includes structural treatments as well as any low-tech revegetation efforts, management actions (including potential beaver relocation), and maintenance work aimed at mimicking, promoting, and sustaining the natural processes typical of healthy stream-wetland corridors. Because it works by enabling natural processes, rather than trying to control them, LTPBR can be a very efficient way to improve stream and wetland function at a large spatial and time scale. But for the same reasons, it can’t work just anywhere. Site selection is critical!

Unlike more heavy-handed engineering and design-build enhancement strategies, beaver-related LTPBR is an inherently **ecological** (as per Palmer *et al.* 2005), **process-based** (as per Beechie *et al.* 2010), and **biomic** (as per Johnson *et al.* 2019 and Castro and Thorne 2019) approach to restoring riverscape health that can only work in proper settings. Beaver mimicry and/or beaver reintroduction are only appropriate on riverscapes where beaver complexes naturally existed prior to human disturbance (Wheaton *et al.* 2019, Pollock *et al.* 2017). For mimicry to be effective, and for the benefits to last, natural beaver activity must be promoted and eventually become self-sustaining. Selecting appropriate sites that meet these criteria is vital to the successful application of these progressive restoration approaches.

The LTPBR manual (Wheaton *et al.* 2019) and the Beaver Restoration Guidebook (Pollock *et al.* 2017) recommend using the Beaver Restoration Assessment Tool (BRAT) (MacFarlane *et al.* 2015) to evaluate restoration feasibility and to select sites. The BRAT, a computer model that predicts the capacity of streams to support beaver dams, was run for Colorado in 2020 by Juli Scamardo (Colorado State University). We began with this model but found the results to be unreliable for estimating beaver capacity, evaluating restoration feasibility, or selecting sites.

In this study, we outline a pragmatic professional-judgment approach that we use for the Riparian Reconnect program in Park County to (1) assess LTPBR/beaver restoration potential, to (2) evaluate limiting factors and, ultimately, to (3) triage restoration opportunities according to feasibility and benefit/cost analysis. Our approach requires more expertise and effort than the BRAT’s automated beaver dam capacity model, but we find the results to be more realistic and practically useful, at least here in Park County. The framework and assessment methods we used in Park County are generally applicable to other mountain and foothills regions in Colorado and other western states.

Methods

BRAT model

We used results from a BRAT 3.0.18 model run performed on ArcGIS 10.4 by Juli Scamardo (CSU) in 2021 for the state of Colorado (available on a website hosted by the Colorado Natural Heritage Program)[2]. Model inputs included LANDFIRE vegetation mapping (USDA and USDI) and stream segments from the National Hydrography Dataset (NHD; USGS). Model outputs are ArcGIS shapefiles with stream segments as linear features with the following attributes:

- Modeled existing dam building capacity (occ_EX, in dams/km) incorporates all BRAT vegetation, flow, and topographic characteristics.
- Modeled potential dam building capacity (oCC_PT, in dams/km) incorporates all BRAT vegetation, flow, and topographic characteristics.
- Modeled existing vegetation dam building capacity (oVC_EX, in dams/km) is based solely on LANDFIRE vegetation characteristics. Existing vegetation is a likely limiting factor when oVC_EX = 0. Current vegetation should be verified in the field, or using aerial imagery, given the coarse resolution of LANDFIRE data.
- Modeled potential vegetation dam building capacity (oVC_PT, in dams/km) is based solely on LANDFIRE historical vegetation characteristics. Potential/historical vegetation is a likely limiting factor when oVC_PT = 0. OVC_PT can be compared to oVC_EX to help evaluate potential to increase beaver dam building capacity by restoring native riparian vegetation such as willows or cottonwoods.
- Reach slope (iGeo_Slope) is a limiting factor when slope >= 0.23.
- Existing vegetation suitability is estimated within 100 m (iVeg_100EX) and 30 m (iVeg_30EX) buffers of a stream segment, using LANDFIRE vegetation data. Suitability values range from 0 (low) - 4 (high).
- Potential vegetation suitability is estimated within 100 m (iVeg_100PT) and 30 m (iVeg_30PT) buffers of a stream segment, using LANDFIRE historical vegetation data. Suitability values range from 0 (low) - 4 (high).
- Low flow stream power (iHyd_SPLow, in watts) is considered a limiting factor when <=190 watts.
- 2-year recurrence interval flood stream power (iHyd_SP2, in watts) greater than or equal to 2,400 watts is considered too high for dam building.

We obtained their result as ArcGIS shapefiles for the mountains and foothills regions. We imported these to QGIS 3.16, joined them into a single shapefile, then clipped it to remove all data outside of Park County. The resultant Park_County_BRAT shapefile was used to map BRAT results and export to a spreadsheet for analysis. The oVC_EX attribute was used as the BRAT-

[2] https://www.arcgis.com/apps/webappviewer/index.html?id=1051266316f0449f8d657ac3bf9a53ed

derived current capacity (dams/km) and the oVC_PT attribute for BRAT-derived historical capacity (dams/km).

Beaver activity assessment

Beaver activity was assessed by estimating the number of identifiable beaver dams clearly visible on the most recent aerial imagery (2017) in Google earth Pro. We chose this metric as an indicator of beaver activity to be consistent with the BRAT, repeatable, and easily measurable remotely using aerial images. As in the BRAT, the dams counted in this metric are those that are large enough to be easily identified in aerial imagery (typically the primary dams in a complex), not the total number of dams present (which also includes the many smaller secondary dams associated with larger primary dams in a complex). In our field surveys, we found that the total number of beaver dams on a reach is often many times greater than the number of dams recorded in remote surveys because the smaller secondary dams are usually difficult to observe on conventional aerial images and therefore usually not counted in remote surveys. The discrepancy between the actual number of beaver dams on a riverscape and the number of dams observable in aerial images is important when interpreting the results from field validation exercises. Beaver dam activity was rated on a scale of 0-4, based on the number of dams observable in aerial imagery over the length of a reach, expressed as dams/km, according to Table 1. For consistency, we used the same frequency categories defined in the BRAT.

Beaver dam activity (dam density categories from BRAT)		
☹☹	0	None; 0 dams/km (0 dams/mile)
☹	1	Rare; 0-1 dams/km (0-2 dams/mile)
😐	2	Occasional; 1-5 dams/km (2-8 dams/mile)
☺	3	Frequent; 5-15 dams/km (8-24 dams/mile)
☺☺	4	Pervasive; >15 dams/km (>24 dams/mile)

Table 1: Classification of beaver activity and capacity, rated by the metric of beaver dams/km using the categories defined in the beaver restoration assessment tool (BRAT).

The survey covered the entire stream network in Park County, eliminating reaches that were determined to have no natural historical potential to support beavers and beaver dams.

Beaver capacity assessment

We originally mapped the network of perennial streams as part of an inventory of Park County wetlands and streams (EcoMetrics 2016). The stream network was divided into 451 segments based on hydro-geomorphological process domain and functional condition. This database was imported to Google Earth Pro as a KML file to serve as a base layer for the beaver restoration assessment. During the assessment, we redrew stream segments to follow the center of the stream corridor and re-delineated segments to better represent natural breaks. The revised network had 589 perennial stream corridor segments to be assessed. Digitizing stream segment by hand, rather than importing models like the NHD dataset, can provide a more current and accurate map of perennial streams.

Stream segments were then systematically evaluated for each of the following factors using best professional judgment, incorporating evidence from aerial imagery, topography, and other readily available GIS data as well as our field experience and accumulated knowledge from working in these riverscapes over 25 years.

Historical beaver capacity

Historical beaver capacity is the level of beaver activity that the reach could have potentially supported in its natural condition, prior to modern anthropogenic disturbance (*i.e.,* prior to widespread beaver extirpation and settlement of the valley-bottoms in the in the 1700s and 1800s). It is the theoretical maximum amount of beaver activity that the reach could support given the natural constraints of geology, hydrology, and ecology, expressed as beaver dam density (dams/km) and rated on the same 0-4 scale used by the BRAT model (Table 2).

Beaver dam capacity (dam density categories from BRAT)		
☹☹	0	None; 0 dams/km (0 dams/mile)
☹	1	Rare; 0-1 dams/km (0-2 dams/mile)
😐	2	Occasional; 1-5 dams/km (2-8 dams/mile)
☺	3	Frequent; 5-15 dams/km (8-24 dams/mile)
☺☺	4	Pervasive; >15 dams/km (>24 dams/mile)

Table 2: Classification of beaver capacity and the associated metric of beaver dam density. The categories and criteria are those defined in the beaver restoration assessment tool (BRAT).

The evaluation of historical capacity was made by considering several lines of evidence:

Geomorphological context: The primary geomorphological factor influencing beaver dam capacity is valley-bottom width (a.k.a. width of the historically active alluvial stream corridor), or geological confinement. Wide unconfined valleys can support more beaver activity (*i.e.,* more dams/km) than narrow confined ones. Given its importance to beaver capacity, we classified stream corridor reaches by mean valley-bottom width using measurements made on Google Earth Pro's aerial imagery and terrain models according to Table 3.

Valley-bottom width considerations:		
☹☹	0	0-6 m (0-20 ft)
☹	1	6-15 m (20-50 ft)
😐	2	15-30 m (50-100 ft)
☺	3	30-60 m (100-200 ft)
☺☺	4	>60 m (> 200 ft)

Table 3: Criteria used to classify reaches by valley-bottom width.

Capacity for beaver activity may also be limited on streams that are excessively steep, so reach gradient was also factored into the assessment.

Natural flow regime: Only reaches with naturally dependable perennial flow were considered capable of supporting sustainable beaver complexes. Ephemeral, intermittent, and seasonal streams were therefore evaluated as having no capacity for beaver activity, even if they may support itinerant beavers and ephemeral beaver dams during wet periods. Capacity may be reduced on reaches where flows naturally dissipate in drought or, alternatively, on larger streams where a dominant high-energy channel may naturally inhibit the persistence of channel-spanning beaver dams (this limitation is related to the maximum stream power criterion in the BRAT). On these larger streams, typically 4th order or greater, beaver activity may be concentrated on floodplains and secondary (branching) channels. All these flow considerations were taken onto account when evaluating the capacity of a reach to support beaver activity. We relied heavily on our local knowledge of Park County streams and streamflow regimes to evaluate natural flow limitations, in addition to stream gauge records and, to a lesser extent, regression statistics like those provided in StreamStats[3].

Natural vegetation: Nearly all alluvial riverscapes in Park County were historically willow carrs with a variety of other woody and herbaceous wetland vegetation that supports beavers. Aspen, another preferred beaver food and material source, is also common on adjacent upland forests in the montane and subalpine regions. In some drainages, the capacity for beaver activity may be naturally limited by vegetation, even where geological and hydrological conditions would seem to be supportive. Examples of naturally vegetation-limited systems include super-saturated groundwater wetlands that are predominantly herbaceous (*e.g.,* fens), herbaceous wet meadows, and confined valleys that lack riparian zones or deciduous upland forest.

Direct evidence of beaver activity (past or present): This is a particularly useful line of evidence for evaluating capacity. Beaver complexes observed on past or present aerial imagery are obviously direct signs of capacity. The historical aerial time slider on Google Earth Pro was especially valuable for these evaluations, as were archived historical aerial images going back to 1938. Many riverscapes that are not too disturbed show signs of past beaver activity in the form of geomorphological and vegetation clues that are readily identifiable on contemporary aerial images and field observations. Experienced evaluators can easily interpret these clues to provide additional direct evidence of the historical capacity for beaver activity.

Current beaver capacity

Current beaver capacity is the maximum level of beaver activity that the reach could support in its current condition, considering both the natural constraints to beaver activity plus any

[3] https://www.usgs.gov/centers/colorado-water-science-center/science/streamstats-colorado

anthropogenic limitations imposed by anthropogenic impairment. 485 of the 589 segments in our original dataset were determined to have some historical capacity for beavers and beaver dams. These segments were systematically assessed to rate the degree to which anthropogenic impairment further limits beaver activity, considering the cumulative effects of present-day impacts plus legacy impacts from the past. The ratings, which follow the same dam density guidelines used to rate historical capacity (Table 2), reflect the level of beaver activity that the reach could currently support given the existing beaver metapopulation, hydrology, geomorphology, vegetation, and land use/infrastructure limitations. Methods used to evaluate the degree of impairment in each of these categories are described later.

Restorable beaver capacity

Theoretically, any level of anthropogenic impairment may be remediated to restore a site to its historical potential with enough effort and time but, in practice, restoration feasibility is often limited by pragmatic factors and legacy effects. In this assessment, we expressly focused on low-tech process-based restoration approaches. As an assessment of the feasibility for restoration via LTPBR, ***restorable beaver capacity*** is defined in this assessment as *the level of beaver activity that a riverscape could feasibly support within a short time frame (5 years) by effectively applying simple LTPBR structural treatments, management actions, and revegetation efforts*. Restorable capacity is frequently different from ***historical beaver capacity*** because many of the past and present causes of anthropogenic impairment are not amenable to remediation by these approaches, at least not in a short timeframe.

Impairment assessment

We assessed several categories of anthropogenic impairment to document the causes of reduced beaver activity *(i.e.,* the limiting factors) and, therefore, to understand what types of remediation efforts would be necessary to improve beaver activity via restoration.

Beaver population impairment

Beaver population impairment is the degree to which beaver activity is limited by conditions of the local and regional beaver metapopulations. Beaver activity may be limiting on sites that are no longer well-connected to a supporting metapopulation—either because the sites are isolated from extant populations by migration barriers or habitat fragmentation, or because habitat on the site has become unsuitable. This factor focuses on metapopulation connectivity; habitat suitability limitations are covered by the factors that follow (*i.e.,* hydrological, geomorphological, vegetation, and land use/infrastructure impairment). The factor is scored on a scale of 0-4 according to the guidelines in Table 4.

Beaver population impairment		
☹☹	0	Currently unoccupied, no recent occupation, poor metapopulation connectivity or ~0 chance of passive reestablishment w/in 5 years
☹	1	Currently unoccupied, no recent occupation, marginal metapopulation connectivity or low chance of passive reestablishment w/in 5 years
😐	2	Currently unoccupied, recently occupied or good chance of passive recolonization in 5 years
☺	3	Currently occupied, significantly below capacity; OR occupied with poor metapopulation connectivity
☺☺	4	Not beaver-limited; occupied at or near capacity

Table 4: Guidelines for the assessment of impairment to beaver metapopulation connectivity.

Hydrology impairment

Hydrology impairment is the degree to which anthropogenic alterations to flow regime (*e.g.,* depletions, diversions, augmentation, artificially managed flow) limit the capacity for beaver activity. The factor is scored on a scale of 0-4 according to the guidelines in Table 5.

Hydrology impairment		
☹☹	0	Impacts to flow regime have rendered the reach uninhabitable by beavers (*e.g.,* shift from perennial to intermittent or ephemeral)
☹	1	Impacts to flow regime occasionally make the reach unsuitable for sustained beaver activity (e.g., occasional dry-ups)
😐	2	Impacts to flow regime occasionally make the reach less suitable for beaver activity (*e.g.,* periods of very low flow, damaging peak flows)
☺	3	Slight impacts from depletions, augmentation, or managed flows rarely impact beaver habitat suitability or sustainability
☺☺	4	Natural flow regime, no impacts that would affect beaver activity

Table 5: Guidelines for the assessment of impairment to riverscape hydrology.

Geomorphology impairment

Geomorphology impairment is the degree to which channel incision and other anthropogenically induced geomorphological alterations to the riverscape limit the capacity for beaver activity. The factor is scored on a scale of 0-4 according to the guidelines in Table 6.

Geomorphology impairment		
☹☹	0	Profoundly atered riverscapes that preclude beaver activity (*e.g.,* developed or severely degraded riverscapes, channelized and armored streams, *etc.*)
☹	1	Severely altered riverscapes with poor beaver habitat suitability (*e.g.,* deeply incised > 1.0 m, SEM Stage 3-5, 2, or 3s, and/or channelized streams
😐	2	Significantly altered riverscapes with moderate habitat suitability (e.g., moderately incised 0.5-1.0 m, SEM Stage 3-5, 2, or 3s, and/or historically channelized streams
☺	3	Slightly altered riverscapes with good beaver habitat suitability (*e.g.,* slightly incised < 0.5 m, SEM Stage 1, 6, or 7, often with relic or abandoned beaver features)
☺☺	4	Unaltered or unincised streams with excellent beaver habitat suitability (*e.g.,* SEM Stage 0 or 8, usually with relic or abandoned beaver features)

Table 6: Guidelines for the assessment of impairment to riverscape geomorphology.

Vegetation impairment

Vegetation impairment is the degree to which anthropogenically induced vegetation alterations limit the capacity for beaver activity, including direct impacts (*e.g.,* vegetation clearing, disturbance, development, grazing) and/or indirect impacts such as invasive species, desiccation due to channel incision, *etc*. The factor is scored on a scale of 0-4 according to the guidelines in Table 7.

Vegetation impairment		
☹☹	0	Insufficient vegetation to support any beaver activity (vegetation must be established before considering beaver restoration)
☹	1	Scant vegetation could support transient beaver activity only (large-scale revegetation needed to reach capacity)
😐	2	Patchy or narrow vegetation can support transient beaveer activity or activity on a portion of riverscape (significant revegetation needed to reach capacity)
☺	3	Vegetation absent from small patches; persistent beaver activity could be sustained over most of the riverscape (optional spot-revegetation to support capacity)
☺☺	4	Unimpaired vegetation across most of the riverscape; vegetation can sustainably support a full capacity of beaver activity

Table 7: Guidelines for the assessment of impairment to riverscape vegetation.

Land use/infrastructure limitations

Land use/infrastructure limitation is the degree to which land use, land management practices, or infrastructure limits the capacity for beaver activity on the reach. The factor is scored on a scale of 0-4 according to the guidelines in Table 8.

Land use/infrastructure limitations		
☹☹	0	Altered riverscapes where beaver activity is no longer possible or cannot be tolerated (*e.g.,* reservoirs, fully developed riparian zones, *etc*.)
☹	1	Land use, infrastructure, or management practices severely limit potential (*e.g.,* extensive agricultural conversion, stabilized/enhanced channels)
😐	2	Land use, infrastructure, or management practices partially limit potential *(e.g.,* roads, bridges/culverts, patches of agriculture or development)
☺	3	Land use or infrastructure conflicts possible, but probably manageable to allow for full capacity with minimal concern (*e.g.,* grazed lands)
☺☺	4	No land use, infrastructure, or management practices would be threatened if beaver activity developed to full capacity

Table 8: Guidelines for the assessment of land use and infrastructure limitations.

Feasibility assessment

Data from the site capacity and impairment assessments were combined to rate the feasibility of restoring beaver-mediated riverscapes via low-tech process-based restoration according to specific criteria for potential beaver capacity, metapopulation connectivity, and restoration effort.

Potential beaver capacity

Beaver-related restoration efforts that target sites with the potential to support high levels of beaver activity are more feasible than sites where beaver activity is naturally or artificially constrained. We stratified stream segments by ***restorable beaver capacity*** scores (*i.e.,* level of beaver activity that a site could potentially support in a 5-year timeframe with appropriate LTPBR treatments) as follows:

- **High capacity:** segments with potential for > 15 beaver dams/km (***restorable beaver capacity*** score of 4).
- **Moderate capacity:** segments with potential for 5-25 beaver dams/km (***restorable beaver capacity*** score of 3).
- **Low capacity:** segments with potential for < 5 beaver dams/km (***restorable beaver capacity*** scores of 0, 1, or 2).

Metapopulation connectivity

Sites with good connectivity to stable beaver metapopulations are more feasible, over the long term, than sites with poor metapopulation connectivity. Large intact beaver populations are inherently more stable than small or more fragmented (disconnected) populations, because they are less susceptible to stochastic processes (less likely to be wiped out) and more likely to be recolonized if they do get wiped out. We stratified stream segments by ***beaver population impairment*** scores as follows:

- **Good connectivity:** segments that are currently or recently occupied by active beavers, or unoccupied segments with high potential for recolonization (***beaver population impairment*** scores of 2, 3, or 4).
- **Marginal connectivity**: unoccupied segments with low potential for recolonization (***beaver population impairment*** score of 1).
- **Poor connectivity**: unoccupied segments with no potential for recolonization (***beaver population impairment*** score of 0).

Restoration effort

Effort is the cost that would be required to restore a site to its potential, including human power, money, time, and other tradeoffs. Generally, sites that are more degraded—those that have more severe anthropogenic impairment—require more effort to restore. Similarly, sites with conflicting land uses may require concessions in those uses to relax constraints on beaver activity. Maintenance costs must also be factored in where special efforts may be necessary to protect valuable infrastructure or to allow for coexistence between land uses and expanding wetland riverscapes. These criteria are evaluated by the impairment factors: ***hydrology impairment***, ***geomorphology impairment***, ***vegetation impairment***, and ***land use/infrastructure limitations***. By rating these factors separately, practitioners and decision-makers can easily diagnose the limiting factors, to prescribe appropriate treatments, and to know what types of land use concessions or maintenance needs may be required.

- **Low effort:** segments with no significant land use tradeoffs and a degree of anthropogenic impairment that could be remediated efficiently and effectively with typical LTPBR low-tech treatments in a 5-year timeframe.
- **Moderate effort:** segments with a few land use constraints that would require only minor tradeoffs (*e.g.,* grazing management, deferred hay production, flow devices, etc.) and/or a degree of anthropogenic impairment that may require extra effort to remediate with typical LTPBR treatments (*e.g.,* larger, or more frequent LTPBR structures, multi-year maintenance, and/or moderate revegetation efforts)
- **High effort:** segments where the degree of anthropogenic impairment is great enough that typical LTPBR treatments may not succeed in overcoming it within a 5-year timeframe. These sites would likely require significant tradeoffs in land use and/or “heavy-handed” or “high-tech” restoration treatments to remediate anthropogenic impacts, or a long period of recovery (*e.g.,* significant earthwork, extensive revegetation/regrowth, or multiple iterations of LTPBR treatments repeated over many years).

Restoration opportunities

Table 9 defines how these factors are combined in a triage system to rate restoration opportunities based on the feasibility of restoring sustainable beaver activity.

Capacity	Connectivity	Effort	Restorable beaver capacity	Beaver population impairment	Water supply/flow limitation	Geomorphological limitation	Riparian vegetation limitation	Land use/ infrastructure limitation	Triage rating
High	Good	None	4	4	All categories 4				4 (capacity)
Moderate			3						
High	Good	Low	4	2, 3	All categories 3 or 4				3 (highest)
High	Good	Moderate	4	2, 3	One or more categories is 2				2 (high)
Moderate		Low	3		All categories 3 or 4				
High	Marginal	High	4	1	One or more categories is 2				1 (low)
Moderate	Good		3	2, 3					
High	Marginal or poor	High	4	0, 1	One or more categories is 1 or 0				0 (lowest)
Moderate			3						
Low	Any	Any	0, 1, 2	Any	Any values				

Table 9: Guidelines used to assign triage categories based on site capacity, connectivity, and effort.

- **Poor opportunities:** These sites likely have the **lowest** long-term benefit-to-cost ratio. The rating applies to the following categories of potential restoration sites:
  - Stream segments with **low capacity**, regardless of connectivity or effort.
  - Stream segments with **moderate to high capacity** and **marginal to poor connectivity** that require **high-effort** restoration treatments or **significant** land use changes.
- **Moderate opportunities:** These sites likely have a **low** long-term benefit-to-cost ratio. Metaphorically, these are the “high-hanging fruit”. The rating applies to the following categories:
  - Stream segments with **moderate capacity** and **good connectivity** that require **high-effort** restoration treatments and/or **significant** land use changes.

    - Stream segments with **high capacity** and **marginal connectivity** that require **high-effort** restoration treatments and/or **significant** land use changes.
- **Good opportunities:** These sites likely have a **high** long-term benefit-to-cost ratio, or metaphorically speaking, the "low-hanging fruit". The rating applies to the following categories:
    - Stream segments with **moderate capacity** and **good connectivity** that require only **low-effort** restoration treatments and/or **minor** land use changes.
    - Stream segments with **high capacity** and **good connectivity** that require **high-effort** restoration treatments and/or **significant** land use changes.
- **Best opportunities:** These sites likely have the **highest** long-term benefit-to-cost ratio. The metaphorical equivalent for these sites might be the "windfall". The rating applies to the following categories:
    - Stream segments with **high capacity** and **good connectivity** that require only **low-effort** restoration treatments and/or **minor** land use changes.
- **At capacity:** These sites are functioning beaver complexes that are already **at capacity** and, therefore, do not currently demand any restoration resources or tradeoffs besides continued stewardship. The rating applies to the following categories:
    - Stream segments with **moderate or high capacity**, **good connectivity** and **no** need for restoration treatments or land use changes.

GIS/map products

Data were compiled in QGIS 3.16 in an ArcGIS shapefile with the stream segments as line features coded with the following attributes:

- **ID:** a unique numerical identifier for the segment that correspond with the (revised) Park County stream inventory
- **V_width:** Valley width rating (0-4)
- **BEV_curr:** Current beaver activity rating (0-4)
- **CAP_hist:** Historical beaver activity rating (0-4)
- **CAP_curr:** Current beaver capacity rating (0-4)
- **CAP_rest:** Restorable beaver activity rating (0-4)
- **LIM_bev:** Beaver population limitation rating (0-4)
- **LIM_hyd:** Water supply/flow limitation rating (0-4)
- **LIM_geo:** Geomorphological limitation rating (0-4)
- **LIM_use:** Land use/infrastructure limitation rating (0-4)
- **BRA_rating:** Triage rating (0-4)

We used QGIS 3.16 to create layers that display the assessment data in ways we found useful for visualizing patterns.

Results

Beaver activity survey

Sheet 1 displays the results of the beaver activity survey as a map. In 2017 (the date of aerial imagery used in the survey), there was beaver activity equivalent to an estimated 2,539 dams in Park County, distributed by the frequency shown in Table 10. Current beaver activity is greatest on upper montane and subalpine headwaters streams in the mountains and foothills of the Mosquito Range. 67% of all beaver activity on the county is just 56.5 km of stream corridor with pervasive activity, and 21% is on another 54.3 km with frequent activity. The remaining 12% is scattered over 153.1 km with occasional or rare activity.

Current beaver activity		
Category	**Stream length (km)**	**Beaver activity (~dams)**
Pervasive	56.5	1,695
Frequent	54.3	543
Occasional	89.9	270
Rare	63.2	32
None	474.7	0
Total	**738.6**	**2,539**

Table 10: Current beaver activity on streams in Park County.

BRAT model

Historical capacity (BRAT model)

Sheet 2 shows the BRAT model output for historical capacity. The BRAT model calculated a historical capacity of 100,241 dams over 7,566.7 stream-km in Park County, distributed by frequency shown in Table 11. Geographically, the BRAT-predicted historical capacity is relatively evenly distributed across Park County on all stream types except where there are currently large reservoirs. 59% of historical capacity was modeled on 2,562.7 stream-km with capacity for pervasive activity, 35% on 3,162.1 km with capacity for frequent activity, and the remaining 6% over 1,847.1 km with capacity for occasional or rare activity.

BRAT historical capacity		
Category	**Stream length (km)**	**Beaver activity (~dams)**
Pervasive	2,562.7	58,840
Frequent	3,162.1	35,374
Occasional	1,709.0	5,937
Rare	138.1	90
None	0	0
Total	**7,571.9**	**100,241**

Table 11: BRAT model output for historical capacity on streams in Park County.

Current capacity (BRAT model)

Sheet 3 shows the BRAT model output for current capacity. The BRAT model calculated a current capacity of 51,642 dams over 7,571.9 stream-km in Park County, distributed by frequency shown in Table 12. Geographically, the BRAT-predicted current capacity is greatest on smaller streams in forested areas. 42% of current capacity is predicted on 921.9 stream-km with capacity for pervasive activity, 43% on 2123.8 km with capacity for frequent activity, and the remaining 15% over 4,521.0 km with capacity for occasional or rare activity.

Current beaver capacity		
Category	**Stream length (km)**	**Beaver activity (~dams)**
Pervasive	921.9	21,714
Frequent	2,123.8	22,403
Occasional	2,959.2	6,494
Rare	1,561.8	1,031
None	5.2	0
Total	**7,571.9**	**51,642**

Table 12: BRAT model output for current capacity on streams in Park County.

Historical loss and restoration potential (BRAT model)

Sheet 4 is a map of current beaver activity overlain on BRAT model results for current and historical capacity. Figure 1 illustrates how the data may be interpreted to infer the theoretical historical loss and theoretical restoration potential in Park County. The difference of -97,702 dams between current activity (2,539 dams) and historical capacity (100,241 dams) is a 98% decrease. The difference of -48,599 dams between current capacity (51,642 dams) and historical capacity (100,241 dams) is a 62% decrease. The difference of 49,103 dams between current activity (2,539 dams) and current capacity (51,642 dams) would be a 1933% increase.

A strict interpretation of these results would suggest that Park County once held capacity for beaver activity equivalent to 100,241 primary dams, of which only 2,539 (2.5%) currently exist. This indicates a historical maximum loss of beaver activity equivalent to 97,702 dams (a 97.5% loss). The model suggests that 49,103 dams could be recovered if beaver activity is restored to the current capacity of 51,642 dams. This would be a 19-fold increase in current beaver activity county-wide, bringing the number of dams up to 52% of the historical capacity.

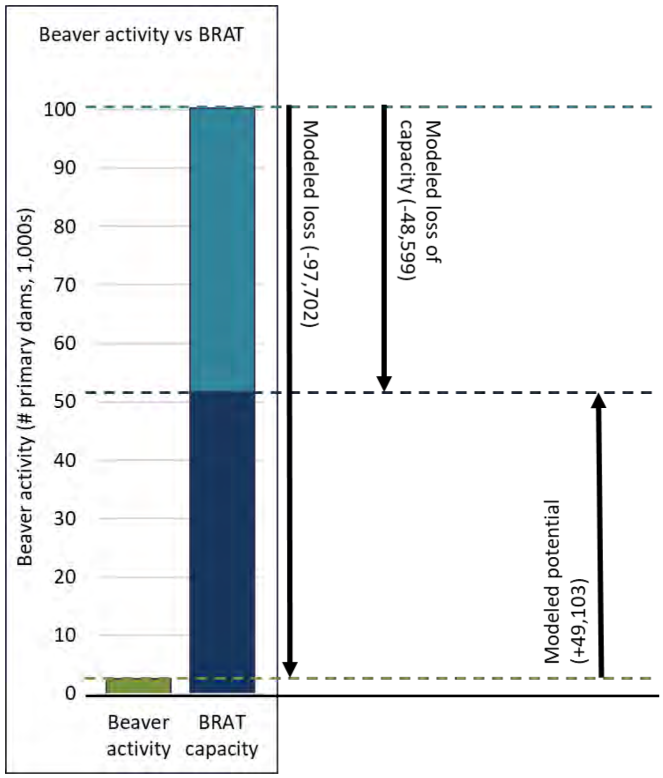

Figure 1: A comparison of current beaver activity to the BRAT model predictions of historical and current capacity in Park County is used to infer the historical loss of beaver activity and maximum restoration potential.

Beaver capacity survey

Historical beaver capacity

Sheet 5 shows the results of our professional assessment of the historical capacity for beaver activity on Park County streams. We identified 738.6 stream-km that likely had some level of natural capacity for sustainable beaver activity prior to anthropogenic impact. Other streams in the county were considered unable to naturally support sustainable beaver activity due to natural hydrological, geological, or ecological context. Following conventions in the BRAT, this does not mean that beavers did not (or do not) inhabit these streams. The lack of historical beaver capacity on a stream segment means that sustained beaver activity such as dam-building is not likely a key driver of riverscape form or function.

According to our survey, Park County could have had beaver activity that supported an estimated 16,802 primary beaver dams over 738.6 stream-km, at its historical potential, distributed by the frequency shown in Table 13. Geographically, we found the historical capacity for beaver activity to be limited to perennial waterways on mainstem streams as well as tributary streams in the montane and subalpine headwaters. 91% is on 510.5 stream-km with capacity for pervasive activity, 8% is on 126.1 km with capacity for frequent activity, and the remaining 1% is on 102.0 km with capacity for occasional or rare activity.

Historical beaver capacity		
Category	**Stream length (km)**	**Beaver activity (~dams)**
Pervasive	510.5	15,315
Frequent	126.1	1,261
Occasional	70.1	210
Rare	31.9	16
None	0	0
Total	**738.6**	**16,802**

Table 13: Professional assessment of historical capacity for beaver activity on streams in Park County.

Current beaver capacity

Sheet 6 shows the results of our professional assessment of the current capacity for beaver activity on Park County streams. We identified 617.8 km of stream corridor that could likely support beaver activity in current conditions which, at full potential, could support up to an estimated 8,153 primary beaver dams, distributed by the frequency shown in Table 14. Current capacity is greatest on headwaters streams where there is less anthropogenic impairment and less intensive land use. 81% is on 220.7 stream-km with capacity for pervasive activity, 12% is on 99.9 km with capacity for frequent activity, and the remaining 7% is on 297.2 km with capacity for occasional or rare activity.

Current beaver capacity		
Category	**Stream length (km)**	**Beaver activity (~dams)**
Pervasive	220.7	6,621
Frequent	99.9	999
Occasional	153.7	461
Rare	143.5	72
None	120.8	0
Total	**738.6**	**8,153**

Table 14: Professional assessment of current capacity for beaver activity on streams in Park County.

Restorable beaver capacity

Sheet 7 shows the result of our professional assessment of restorable capacity for beaver activity on Park County streams. We identified 669.2 stream-km that could likely support beaver activity following LTPBR treatments within 5 years which, at full potential, could support up to an estimated 9,145 primary beaver dams, distributed by the frequency shown in Table 15. Current capacity is greatest on small headwaters streams where there is less anthropogenic impairment and less intensive land use. 80% is on 243.1 stream-km with capacity for pervasive activity, 13% is on 117.9 km with capacity for frequent activity, and the remaining 8% is on 308.2 km with capacity for occasional or rare activity.

Restorable beaver capacity		
Category	**Stream length (km)**	**Beaver activity (~dams)**
Pervasive	243.1	7,293
Frequent	117.9	1,179
Occasional	207.4	622
Rare	100.8	50
None	69.4	0
Total	**738.6**	**9,145**

Table 15: Professional assessment of restorable capacity for beaver activity on streams in Park County.

Historical loss and restoration potential (professional assessment)

Sheet 8 is a map of current beaver activity overlain on our professional assessment of current, restorable, and historical capacity. Figure 2 illustrates how these data may be interpreted to estimate the historical loss and restoration potential in Park County. The difference of -14,263 dams between current activity (2,539 dams) and historical capacity (16,802 dams) is an 84% decrease. The difference of -8,649 dams between current capacity (8,153 dams) and historical capacity (16,802 dams) is a 48% decrease. The difference of +6,606 dams between current activity (2,539 dam) and restorable capacity (9,145 dams) would be a 360% increase.

A strict interpretation of these results would suggest that Park County once held capacity for beaver activity equivalent to 16,808 primary dams, of which 2,539 (15%) currently exist. This indicates a historical maximum loss of beaver activity equivalent to 14,263 dams (an 85% loss). The results suggest that a maximum of about 6,606 dams could be recovered if beaver activity is restored to all streams in Park County at the restorable capacity of 9,145 dams. This would be a 3.6-fold increase in current beaver activity county-wide, bringing the number of dams up to about 54% of the historical capacity.

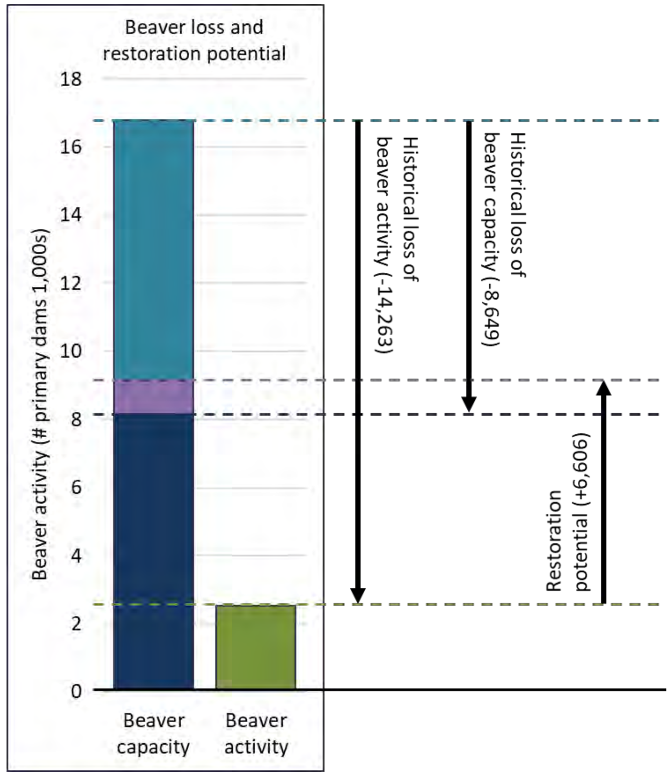

Figure 2: A comparison of current beaver activity to historical, current, and restorable capacity in Park County may be used to infer the historical loss of beaver activity and maximum restoration potential.

Comparing the BRAT and professional assessment

Sheet 9 shows a comparison between the BRAT model and professional assessment of the capacity for beaver activity in Park County. The BRAT predictions of historical and current capacity are both 6 times greater than the capacity levels we determined in the professional assessment, leading to estimates of both county-wide historical loss and county-wide maximum restoration potential that are 7 times greater than we estimated. The BRAT model predicted beaver dam capacity in nearly all topographic drainages across Park County, many of which do not have appropriate hydrology, geomorphology, vegetation, or any indication of past beaver activity. It was apparently unable to discriminate suitable streams from unsuitable ones the way professional evaluators can, leading potentially to a gross overestimation of capacity for beavers county-wide.

Impairment survey

Beaver population impairment

Sheet 10 displays our assessment of the degree to which anthropogenic impairment to beaver metapopulations limits the capacity for sustainable beaver activity. The degree of impairment is summarized in Table 16.

- 6% is not limited by impairments to beaver metapopulation connectivity; currently occupied by beavers with good connectivity.
- 28% is minimally limited; recently occupied by beavers or currently occupied with poor metapopulation connectivity.
- 15% is significantly limited; unoccupied but with high probability of passive reestablishment.
- 35% is severely limited; unoccupied with marginal metapopulation connectivity and low probability of passive reestablishment.
- 17% is profoundly limited; unoccupied with essentially zero probability of passive reestablishment.

Beaver population impairment	
Category	**Stream length (km)**
Not limited	43.7
Minimally limited	204.1
Significantly limited	108.9
Severely limited	257.1
Profoundly limited	124.8
Total	**738.6**

Table 16: Level to which beaver population impairment limits beaver activity on Park County streams.

Hydrology impairment

Sheet 11 displays our assessment of the degree to which anthropogenic impairment to hydrology limits the capacity for sustainable beaver activity. The degree of impairment is summarized in Table 17.

- 88% is not limited by impairments to hydrology; natural flow regime.
- 28% is minimally limited; slight impacts from depletions, augmentation, or managed flows rarely impact beaver habitat suitability or sustainability.
- 4% is significantly limited; impacts to flow regime occasionally make the reach less suitable for beaver activity (*e.g.*, periods of very low flow, damaging peak flows).
- 3% is severely limited; Impacts to flow regime occasionally make the reach unsuitable for sustained beaver activity (*e.g.,* occasional dry-ups.
- 2% is profoundly limited: impacts to flow regime have rendered the reach uninhabitable by beavers (e.g., shift from perennial to intermittent or ephemeral).

Hydrology impairment	
Category	**Stream length (km)**
Not limited	653.4
Minimally limited	28.6
Significantly limited	21.7
Severely limited	20.1
Profoundly limited	14.8
Total	**738.6**

Table 17: Level to which hydrology impairment limits beaver activity on Park County streams.

Geomorphology impairment

Sheet 12 displays our assessment of the degree to which anthropogenic impairment to geomorphology limits the capacity for sustainable beaver activity, by stream reach, in Park County. The degree of impairment is summarized in Table 18.

- 11% is not limited by impairments to geomorphology; not incised, SEM Stage 0 or 8, usually with relic or abandoned beaver features.
- 26% is minimally limited; slightly incised < 0.5 m, SEM Stage 1, 6, or 7, often with relic or abandoned beaver features.
- 34% is significantly limited; moderately incised 0.5-1.0 m, SEM Stage 3-5, 2, or 3s, and/or historically channelized streams that may be recoverable
- 20% is severely limited; deeply incised > 1.0 m, SEM Stage 3-5, 2, or 3s, and/or channelized streams.
- 10% is profoundly limited; massively altered riverscapes that preclude beaver activity (*e.g.,* developed, placer mined, dredged, filled, channelized, and armored streams, *etc.*).

Geomorphology impairment	
Category	**Stream length (km)**
Not limited	77.6
Minimally limited	192.1
Significantly limited	248.6
Severely limited	150.0
Profoundly limited	70.3
Total	**738.6**

Table 18: Level to which hydrology impairment limits beaver activity on Park County streams.

Vegetation impairment

Sheet 13 displays our assessment of the degree to which anthropogenic impairment to vegetation limits the capacity for sustainable beaver activity. The degree of impairment is summarized in Table 19.

- 32% is not limited by impairments to vegetation. Vegetation can sustainably support a full capacity of beaver activity.
- 14% is minimally limited with vegetation absent from small patches. Persistent beaver activity could be sustained over most of the riverscape. Optional spot-revegetation may be needed to support capacity.
- 19% is significantly limited with patchy or narrow vegetation can support transient beaver activity or activity on a portion of riverscape. Significant revegetation would be needed to reach capacity.
- 20% is severely limited with scant vegetation that could support transient beaver activity only. Large-scale revegetation would be needed to reach capacity.
- 15% is profoundly limited with insufficient vegetation to support any beaver activity. Vegetation would have to be established before considering beaver restoration.

Vegetation impairment	
Category	**Stream length (km)**
Not limited	236.5
Minimally limited	104.0
Significantly limited	137.5
Severely limited	146.5
Profoundly limited	114.1
Total	**738.6**

Table 19: Level to which vegetation impairment limits beaver activity on Park County streams.

Land use/infrastructure

Sheet 14 displays our assessment of the degree to which anthropogenic land use or infrastructure limits the capacity for sustainable beaver activity. The degree of limitation is summarized in Table 20.

- 38% is not limited by land use or infrastructure. No land use, infrastructure, or management practices would be threatened if beaver activity developed to full capacity.
- 25% is minimally limited. Land use or infrastructure conflicts are possible, but probably manageable to allow for full capacity with minimal concern (*e.g.,* grazed lands)

- 17% is significantly limited. Land use, infrastructure, or management practices partially limit potential (*e.g.,* roads, bridges/culverts, or patches of agriculture or development that are intolerant of beaver activity).
- 12% is severely limited. Land use, infrastructure, or management practices severely limit the potential for beaver activity (*e.g.,* extensive agricultural conversion, stabilized/enhanced channels where beaver activity cannot be tolerated.
- 8% is profoundly limited, with altered riverscapes where beaver activity is no longer possible or cannot be tolerated (*e.g.,* reservoirs, fully developed riparian zones, etc.)

Land use/infrastructure limitations	
Category	**Stream length (km)**
Not limited	277.7
Minimally limited	183.9
Significantly limited	125.7
Severely limited	92.3
Profoundly limited	59.0
Total	**738.6**

Table 20: Level to which land use and infrastructure limits beaver activity on Park County streams.

Composite impairment

Sheet 15 displays our assessment of the degree to which the combined effects of anthropogenic impairment to hydrology, geomorphology, vegetation, and land use or infrastructure limits the capacity for sustainable beaver activity. The degree of impairment is summarized in Table 21.

- 7% is not limited by impairments to geomorphology.
- 22% is minimally limited by one or more factors.
- 26% is significantly limited by one or more factors.
- 24% is severely limited by one or more factors.
- 21% is profoundly limited by one or more factors.

Composite impairment	
Category	**Stream length (km)**
Not limited	53.0
Minimally limited	161.7
Significantly limited	190.3
Severely limited	178.4
Profoundly limited	155.2
Total	**738.6**

Table 21: Level to which the combined effects of hydrology, geomorphology, vegetation, and land use/infrastructure impairment limits beaver activity on Park County streams.

LTPBR/beaver restoration opportunities

Sheet 16 shows our assessment of LTPBR/beaver restoration feasibility. Triage ratings and restoration opportunities based on feasibility are summarized in Table 22.

- 5% of the 738.6 stream-km that historically supported sustainable beaver activity is currently **at capacity**. These segments are good candidates for conservation, special protection, and/or ongoing stewardship.
- 13% is in the **highest** category of feasibility. These segments are the **best** candidates for the restoration of beaver activity via LTPBR approaches.
- 14% is in the **high** category of feasibility. These segments are **good** candidates for the restoration of beaver activity via LTPBR approaches. They may require more effort or time than the segments rated yellow, but the potential lift may be greater.
- 10% is in the **low** category of feasibility. These segments are **moderate** candidates for the restoration of beaver activity via LTPBR approaches. LTPBR may be valuable and appropriate on these segments, but they have a significantly lower potential to result in sustainable beaver activity in a short time frame. Heavier-handed restoration approaches, more extensive LTPBR treatments applied over longer periods of time, or significant land use concessions may be necessary, greatly increasing the effort/benefit ratio.
- 58% is in the **lowest** category of feasibility. These segments are **poor** candidates for the restoration of beaver activity via LTPBR approaches. LTPBR approaches are not likely to result in sustainable beaver activity due to natural or anthropogenic limitations.

LTPBR/beaver restoration feasibility	
Category	Stream length (km)
At capacity	34.2
Best	95.1
Good	106.7
Moderate	74.2
Poor	428.4
Total	738.6

Table 22: Park County LTPBR/beaver restoration opportunities triaged by feasibility.

Limiting factor analyses

Beaver metapopulation limitations

Sheet 17 shows the degree to which beaver metapopulation impairment may limit the development of sustainable beaver activity on LTPBR/beaver restoration opportunities. The analysis of beaver metapopulation limitation is summarized by feasibility category in Table 23.

- 23% of the **good** and **best** opportunities are significantly limited, and 13% are severely limited by beaver metapopulation impairment.
- 18% of the **moderate** opportunities are significantly limited, and 28% are severely limited by beaver metapopulation impairment.

Beaver population limitations					
Stream length (km)	Beaver population impairment rating				
	4	3	2	1	0
At capacity	34.2	0.0	0.0	0.0	0.0
Best	0.0	81.2	13.9	0.0	0.0
Good	0.0	47.2	32.9	26.6	0.0
Moderate	0.0	39.9	13.2	21.1	0.0
Poor	7.1	38.2	50.2	209.4	123.5

Table 23: Degree to which beaver metapopulation impairment may limit the establishment of sustainable beaver activity on restoration segments.

Hydrology limitations

Sheet 18 shows the degree to which hydrology impairment may limit the development of sustainable beaver activity on LTPBR/beaver restoration opportunities. The analysis of hydrology limitation is summarized by feasibility category in Table 24.

- None of the **good** and **best** opportunities are significantly or severely limited by hydrology impairment.

- None of the **moderate** opportunities are significantly or severely limited by hydrology impairment.

Hydrology limitations					
Stream length (km)	Hydrology impairment rating				
	4	3	2	1	0
At capacity	34.2	0.0	0.0	0.0	0.0
Best	95.1	0.0	0.0	0.0	0.0
Good	106.7	0.0	0.0	0.0	0.0
Moderate	72.4	1.8	0.0	0.0	0.0
Poor	357.6	15.1	20.6	31.0	4.7

Table 24: Degree to which hydrology impairment may limit the establishment of sustainable beaver activity on restoration segments.

Geomorphology limitations

Sheet 19 shows the degree to which geomorphology impairment may limit the development of sustainable beaver activity on LTPBR/beaver restoration opportunities. The analysis of geomorphology limitation is summarized by feasibility category in Table 24.

- 21% of the **good** and **best** opportunities are significantly limited, and none severely limited by geomorphology impairment.
- 60% of the **moderate** opportunities are significantly limited, and none are severely limited by geomorphology impairment.

Geomorphology limitations					
Stream length (km)	Geomorphology impairment rating				
	4	3	2	1	0
At capacity	31.0	3.2	0.0	0.0	0.0
Best	22.0	71.7	0.0	0.0	0.0
Good	9.5	54.7	42.5	0.0	0.0
Moderate	4.0	25.7	44.5	0.0	0.0
Poor	11.8	46.7	137.5	164.0	68.4

Table 25: Degree to which geomorphology impairment may limit the establishment of sustainable beaver activity on restoration segments.

Vegetation limitations

Sheet 20 shows the degree to which vegetation impairment may limit the development of sustainable beaver activity on LTPBR/beaver restoration opportunities. The analysis of vegetation limitation is summarized by feasibility category in Table 26.

- 10% of the **good** and **best** opportunities are significantly limited, and none severely limited by vegetation impairment.
- 54% of the **moderate** opportunities are significantly limited, and 1% are severely limited by vegetation impairment.

Vegetation limitations					
Stream length (km)	Vegetation impairment rating				
	4	3	2	1	0
At capacity	34.2	0.0	0.0	0.0	0.0
Best	76.9	18.2	0.0	0.0	0.0
Good	42.1	44.7	19.9	0.0	0.0
Moderate	23.1	9.7	39.9	1.5	0.0
Poor	71.9	33.6	59.2	161.5	102.2

Table 26: Degree to which vegetation impairment may limit the establishment of sustainable beaver activity on restoration segments.

Land use/infrastructure limitations

Sheet 21 shows the degree to which land use or infrastructure may limit the development of sustainable beaver activity on LTPBR/beaver restoration opportunities. The analysis of land use/infrastructure limitation is summarized by feasibility category in Table 27.

- 12% of the **good** and **best** opportunities are significantly limited, and none severely limited land use or infrastructure.
- 26% of the **moderate** opportunities are significantly limited, and 1% are severely limited by land use or infrastructure.

Land use/infrastructure limitations					
Stream length (km)	Land use/infrastructure impairment rating				
	4	3	2	1	0
At capacity	20.9	13.3	0.0	0.0	0.0
Best	67.9	27.2	0.0	0.0	0.0
Good	60.7	21.6	24.4	0.0	0.0
Moderate	19.5	17.8	19.5	1.6	0.0
Poor	89.9	99.7	83.9	94.3	60.6

Table 27: Degree to which land use or infrastructure may limit the establishment of sustainable beaver activity on restoration segments.

Composite limitations

Sheet 22 shows the degree to which combined impairment of hydrology, geomorphology, vegetation, and/or land use/infrastructure may limit the development of sustainable beaver activity on LTPBR/beaver restoration opportunities. The analysis of combined impairment of hydrology, geomorphology, vegetation, and/or land use/infrastructure limitation is summarized by feasibility category in Table 28.

- 31% of the **good** and **best** opportunities are significantly limited, and none are severely limited by combined impairment of hydrology, geomorphology, vegetation, and/or land use/infrastructure.
- 85% of the **moderate** opportunities are significantly limited, and 22% are severely limited by combined impairment of hydrology, geomorphology, vegetation, and/or land use/infrastructure.

Composite limitations					
Stream length (km)	Composite impairment rating				
	4	3	2	1	0
At capacity	20.9	13.3	0.0	0.0	0.0
Best	16.9	78.2	0.0	0.0	0.0
Good	6.3	38.3	62.1	0.0	0.0
Moderate	0.0	8.2	62.9	3.1	0.0
Poor	8.4	35.1	62.1	168.7	153.6

Table 28: Degree to which combined impairment of hydrology, geomorphology, vegetation, and/or land use/infrastructure may limit the establishment of sustainable beaver activity on restoration segments.

Potential lift

The potential for lift (*i.e.,* the potential increase in beaver activity via restoration) was estimated as the difference between restoration capacity and current beaver activity, evaluated by triage class (Sheet 23 and Table 29).

- Segments that are **at capacity** have no potential for lift but are candidates for protection.
- Segments with the **best opportunity** for LTPBR/beaver restoration have potential county-wide lift of 1741 primary beaver dams over 95.1 km for a mean potential gain of 18.3 dams/km.
- Segments with the **good opportunity** for LTPBR/beaver restoration have potential county-wide lift of 2369 primary beaver dams over 106.7 km for a mean potential gain of 22.2 dams/km.
- Segments with the **moderate opportunity** for LTPBR/beaver restoration have potential county-wide lift of 966 primary beaver dams over 74.2 km for a mean potential gain of 13.0 dams/km.

- Segments with the **poor opportunity** for LTPBR/beaver restoration have potential county-wide lift of 1456 primary beaver dams over 428.4 km for a mean potential gain of 3.4 dams/km.

Potential lift by triage class					
Triage class	Existing activity (1° dams)	Potential activity (1° dams)	Potential lift (1° dams)	Stream length (km)	Potential lift (dams/km)
At capacity	877	877	0	34.2	0.0
Best	1053	2794	1741	95.1	18.3
Good	372	2741	2369	106.7	22.2
Moderate	146	1112	966	74.2	13.0
Poor	92	1548	1456	428.4	3.4

Table 29: Potential lift in beaver activity by triage class for Park County.

Discussion

This study used a rational framework to systematically incorporate professional judgment into the assessment of beaver restoration feasibility in Park County, Colorado. While the approach requires more time, effort, and expertise than algorithmic landscape models, we believe it provides a more realistic estimation of beaver capacity and reliable practical guidance for practitioners, planners, and stakeholders who are interested in employing LTPBR to restore beaver-mediated wetland riverscapes.

Restoring Park County wetland riverscapes with LTPBR and beavers

This county-wide beaver restoration feasibility assessment identifies stream segments where LTPBR may be an efficient and cost-effective approach to restoring wetland riverscape health and function. Perhaps more importantly, it segregates the many kilometers of stream corridor where LTPBR/beaver restoration is not likely to yield satisfying results. By using a triage system (borrowed from emergency medicine) our approach lays out a strategy for how to allocate limited resources to restoration projects for the best overall benefit to the county. Focusing projects on the moderately impaired segments that are amenable to light-touch, low-tech treatments is an optimal strategy for enabling nature's wetland ecosystem engineers—beavers—to reclaim many of Park County's valuable natural aquatic resources that have been damaged for centuries.

For much of the past 40 years, stream restoration efforts in Park County, as well as elsewhere, have tended to focus on the most degraded streams. And they were usually focused on narrow objectives such as channel stabilization or gamefish habitat enhancement, often relying on heavy-handed approaches like engineered habitat stabilization and channel reconfiguration. These expensive techniques and the narrow objectives they aim to fill may be wholly justifiable if they meet well-articulated stakeholder needs or where the streams in question are so far gone (*i.e.,* so degraded or so constrained) that restoring a healthier ecological state is impractical. In some cases, stabilized channels with disconnected floodplains and artificially enhanced habitat may be, practically speaking, the most beneficial use of a stream segment, even if it is not an efficient means to restore ecological health and resilience. These are value judgments. Therefore, we refer to the triage classes in this report as restoration *opportunities*, not restoration *priorities*. When establishing restoration priorities, decision-makers must consider a suite of societal values beyond just natural ecological health and wetland benefits.

Ecologically healthy stream-wetland corridors provide many of the values that restoration proponents and practitioners aim to achieve. And they do it naturally, sustainably, and for free. In addition to the commonly cited ecosystem services that healthy wetland beaver complexes provide—such as stability, fish and wildlife habitat, sediment retention, flood attenuation, aquifer recharge, etc.—they are also critical factors in wildfire resilience (Fairfax and Whittle 2020) and combating climate change (Dittbrenner *et. al.* 2018). Scientists, practitioners, and laypeople have come to appreciate the value of healthy stream-wetland corridors in places like Park County. We are just beginning to realize the degree to which these systems have become degraded and the how effective low-tech process-based restoration approaches can be at restoring them, especially where beavers are concerned. LTPBR is not a replacement for all other restoration techniques, but where it can be feasibly applied it is an obvious, effective, and efficient solution to our most important restoration needs.

Although it has not been systematically laid out in an organized format until now, the thinking behind this assessment approach has guided Riparian Reconnect in our selection of recent Park County restoration projects. Sheet 24 shows the location of Riparian Reconnect's current or developing LTPBR/beaver restoration projects in the context of the county-wide network of restoration opportunities, giving the assessment results for each. Results of this survey will be used to guide our selection of projects in the future. We hope our assessment approach can be a valuable addition to LTPBR/beaver restoration planning efforts statewide.

Bigger picture

LTPBR and beaver restoration are justifiably gaining interest at a maniacal pace. Practitioners and planners statewide are desperate for guidance on where and how to implement it. While the approach can be applied almost anywhere without too much at stake or much risk of causing harm, the conditions where LTPBR/beaver restoration can have the most beneficial positive response can be quite narrow. Why not tilt the tables in our favor by picking the best sites? One of the key goals of this study is to share the methods we use to identify these prime locations with other practitioners, planners, and scientists. A common challenge to this work is knowing where to start, and people tend to rely on the simplest and most accessible information they can find to guide them, which at this time tends to be computer models.

The fidelity of the BRAT model to observed beaver dam density reported in Utah (Macfarlane *et. al.* 2015) did not seem to hold true for Park County, Colorado. The 6-7-fold discrepancy between the BRAT model and our professional assessment of beaver dam capacity is worrisome, especially as more people turn to the model for guidance. We fear it may lead people into unrealistic expectations about restoration potential—or unrealistic fears about the spread of beavers—depending on one's perspective about beavers and wetland. Looking at the BRAT results, one might think that beaver restoration is possible almost anywhere in Park County or, alternatively, that beavers might start showing up almost everywhere if their populations are not controlled. Our results suggest that the prospects are not really that good. Or that bad.

Computer models like the BRAT, being what they are, can be used to survey massive landscapes objectively, rapidly, and with little effort. But the simplifying assumptions and model inputs that make them so efficient do not always capture the important factors that actually determine the capacity for beavers and beaver dams on a stream. The BRAT model necessarily makes predictions using a very narrow set of input data that, in Park County at least, may poorly represent actual site conditions and lead to false predictions. This places serious limitations on how the model results ought to be interpreted and how they should be used in real-life planning efforts. We encourage practitioners to dig deeper.

Professionals, on the other hand, being what they are, can incorporate vast arrays of data to make qualified judgments. The tradeoff is that professional assessments are necessarily slower, more subjective, and they require more effort. Our goal with this approach is to capitalize on the knowledge and complex decision-making capabilities of professional evaluators by systematizing the assessment in a rational framework. The intent is to increase the speed and decrease the effort required for professionals to survey large landscapes while, at the same time, increasing objectivity by carefully defining assessment criteria. It is essentially a formalization of the decision-making process we go through, as professionals, to identify LTPBR/beaver restoration sites for our Riparian Reconnect program. We hope it provides (1) a more accurate view of the historical, current, and potential state of beaver-mediated wetland riverscapes in Park County, (2) guidance for the efficient allocation of resources to future LTPBR/beaver restoration projects in the county, and (3) a useful framework that professionals can adopt in other study areas.

Professionals who have expertise in beaver ecology, basic knowledge in hydrology, geomorphology, and vegetation, and practice in interpreting aerial imagery should be well-equipped to make qualified judgments on the criteria in this assessment framework for use in their areas. Other necessary skills include modest proficiency with Google Earth, GIS, spreadsheets, and data management. It is difficult to precisely estimate the amount of time and effort required to assess large landscapes with this approach. As we have begun applying it in other parts of the state, we have found it possible to survey complex watersheds of 500 km^2 in a couple days now that we have a template, including time to process the data.

One critical aspect to this type of assessment is that professional judgment depends on best available evidence, and the assessment gets better as the knowledge base grows. The learning never stops, and new data can and should be incorporated at any time. The simple GIS database makes updates easy. The GIS user interface is also easy to navigate, and the displays can be customized to suit user's needs.

A final concern is the use of dam density as an indicator of beaver activity. The actual impact of beavers on reach form and function is not limited to the construction of dams. It also includes the many other behaviors by which beavers modify the riverscape environment, such as excavating ponds and canals, building smaller secondary dams, entraining wood in caches and lodges, coppicing vegetation, *etc.* The density of beaver dams is simply an indicator of the degree to which beavers modify riverscapes where they are present and active.

We chose the dam density metric to be consistent with the BRAT and because it is relatively simple and straightforward to measure on aerial images. Recall that the dams counted in this metric are the large beaver dams that can be identified on aerial imagery, and these tend to be only the primary dams in beaver dam complexes. The total number of dams in a complex will often be much greater due to the many secondary dams that beavers usually build. Care must therefore be used when verifying dam counts in the field. In our field surveys, the number of actual dams on a site is often many times greater than the ones counted on aerial imagery. There can also be a lot of inconsistency when counting dams in the field because beaver dams vary so much in size. Dam counts from aerial imagery, however, tend to be more repeatable because smaller questionable dams are usually obscured. Our next research objective is to evaluate the use of beaver pond surface area as an alternative or complementary metric. Beaver pond surface area is also easily quantified from aerial images, while also being more repeatable and perhaps a better indicator of the influence that beavers have on riverscapes than dam counts. If digitization of beaver pond area can eventually be automated using artificial intelligence, the metric should quickly gain favor as a useful indicator of beaver activity.

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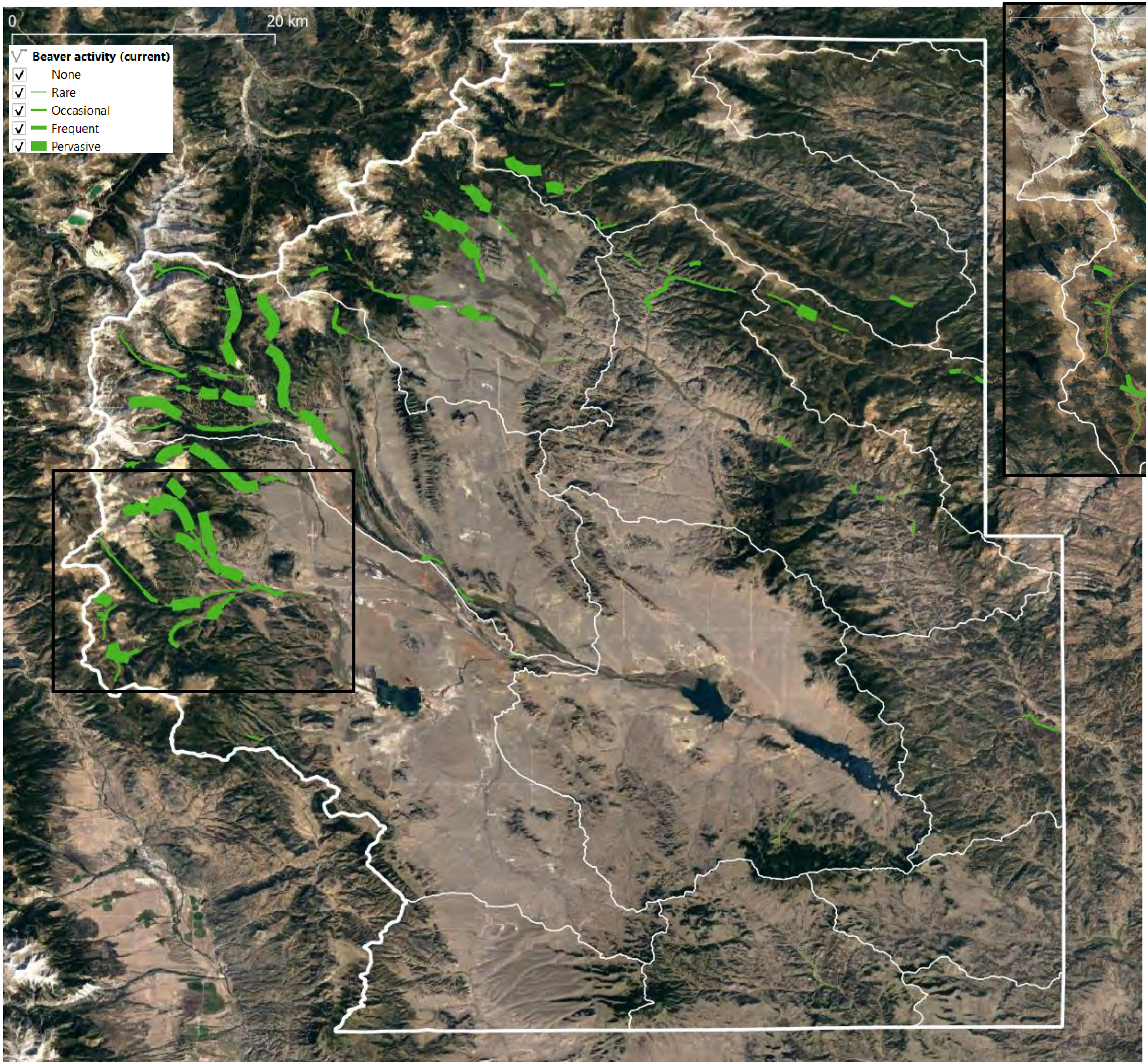
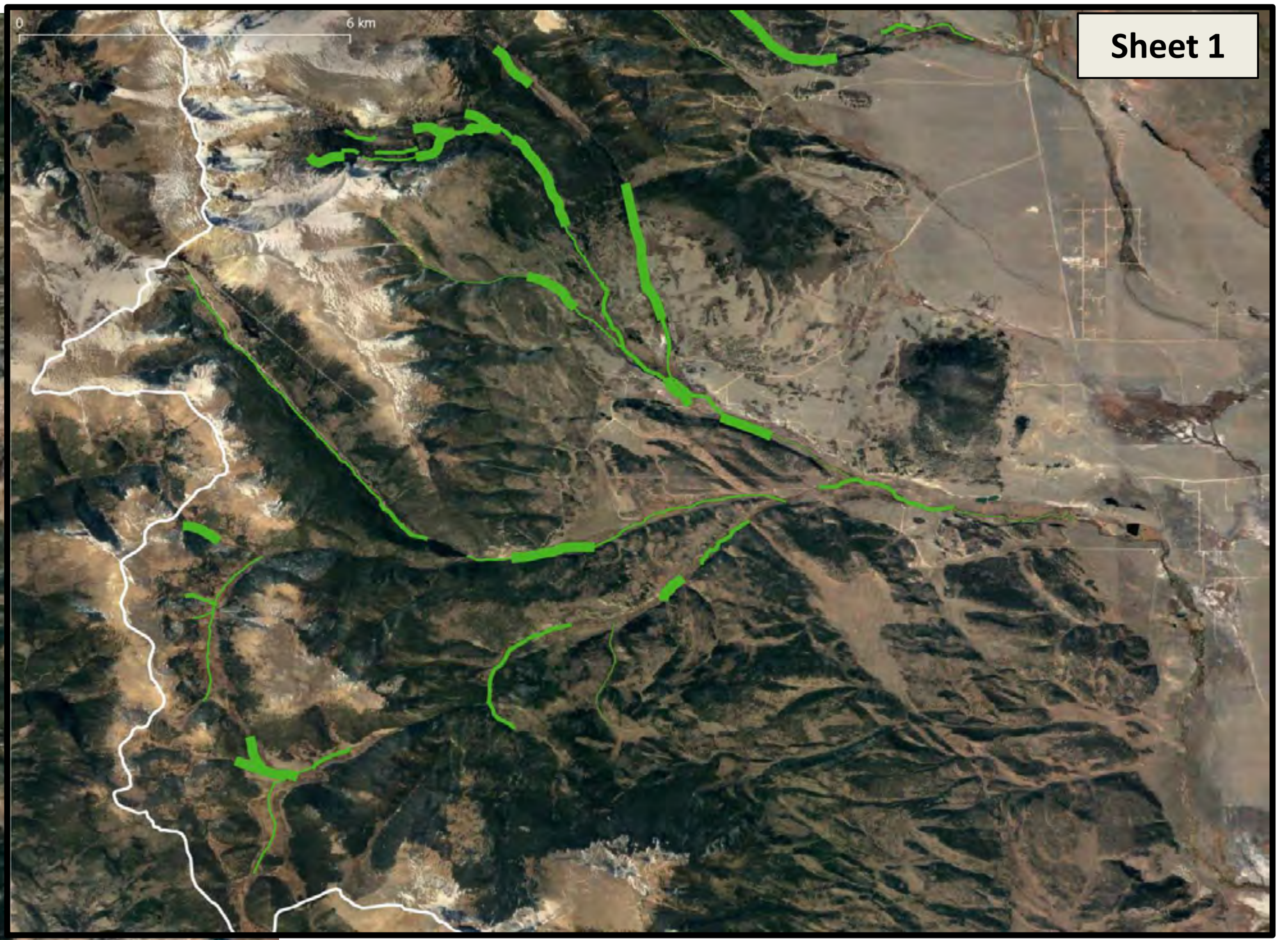


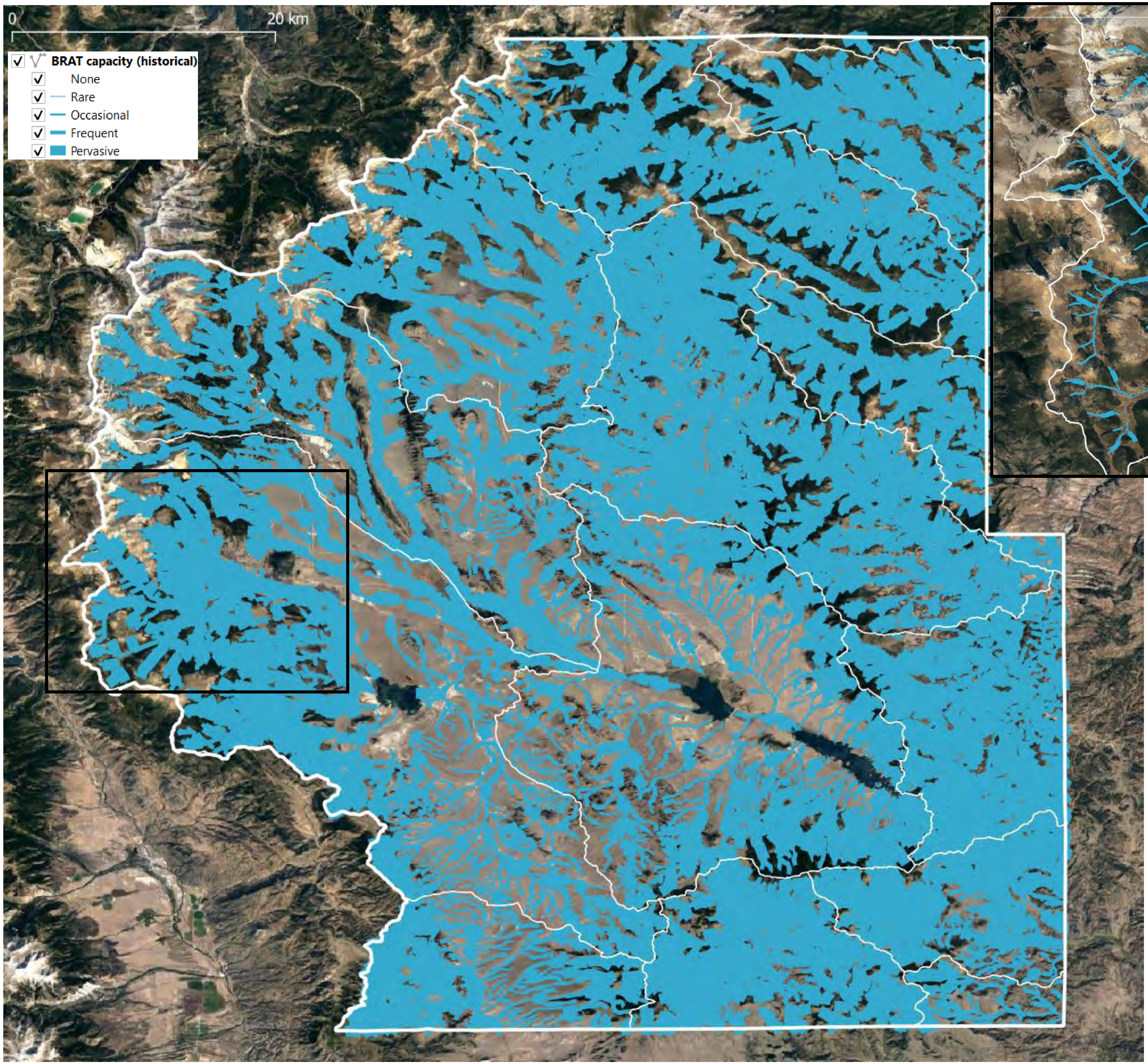


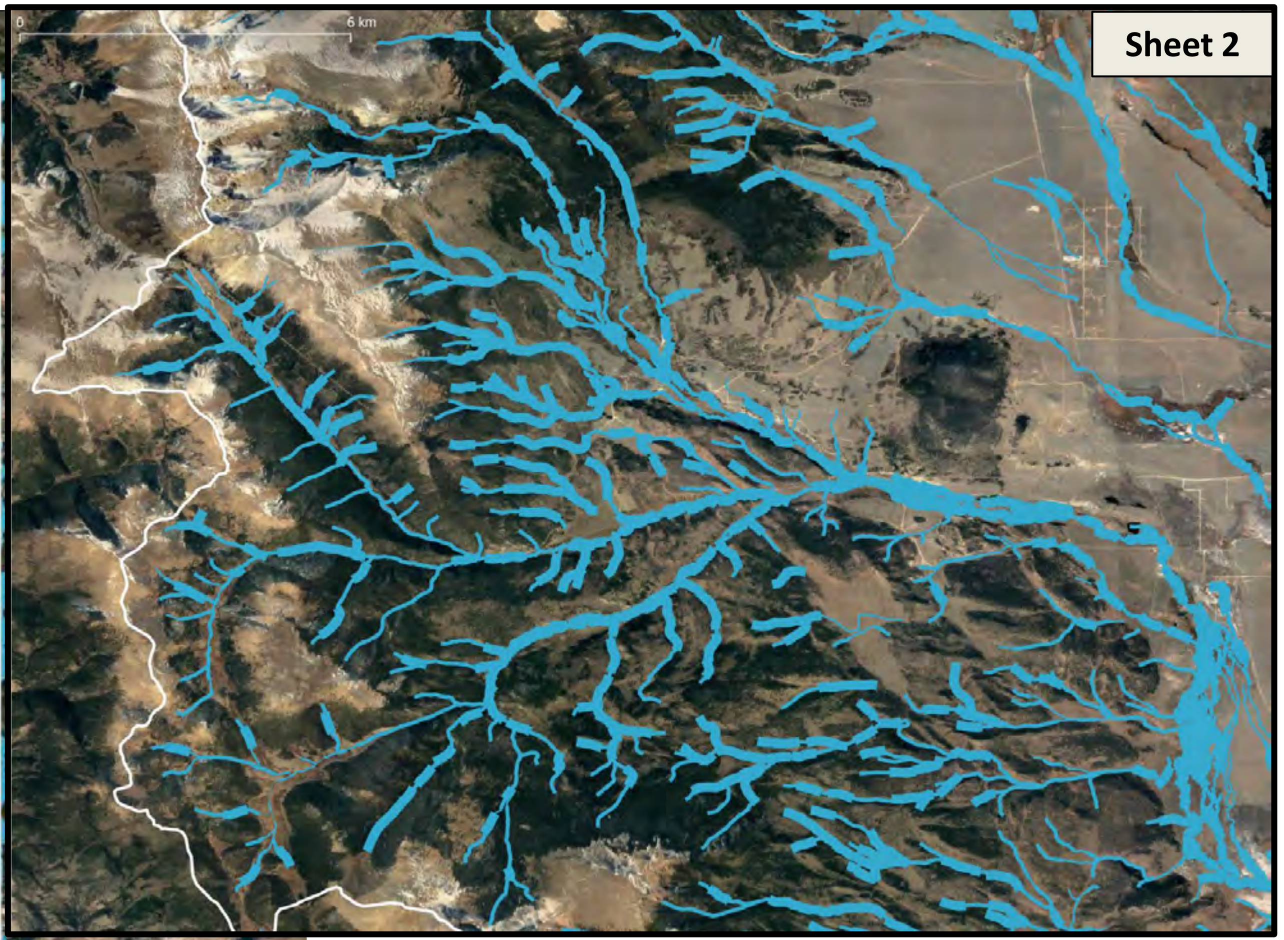
Beaver activity (current)

This map shows the level of current beaver activity by stream reach in Park County. The inset (above) shows a section of the South Fork headwaters, an example of what the data look like on closer resolution. The subdivisions are HUC 10- watershed boundaries.

In 2017 (the date of aerial imagery used in the survey), there was beaver activity equivalent to an estimated 2,539 primary beaver dams in Park County, distributed by frequency as shown in the table below.

Current beaver activity		
Category	**Stream length (km)**	**Beaver activity (~dams)**
Pervasive	56.5	1,695
Frequent	54.3	543
Occasional	89.9	270
Rare	63.2	32
None	474.7	0
Total	**738.6**	**2,539**

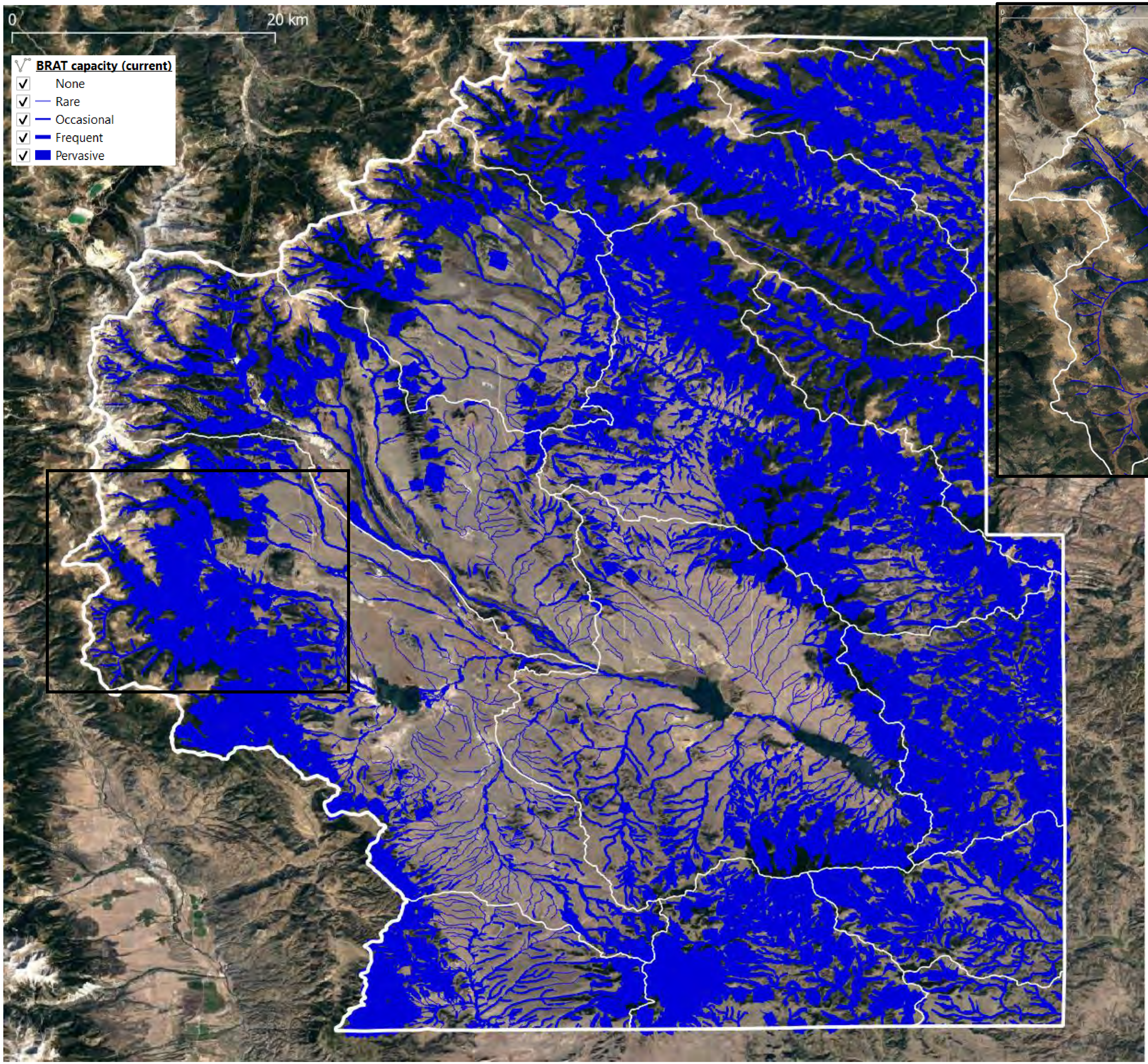


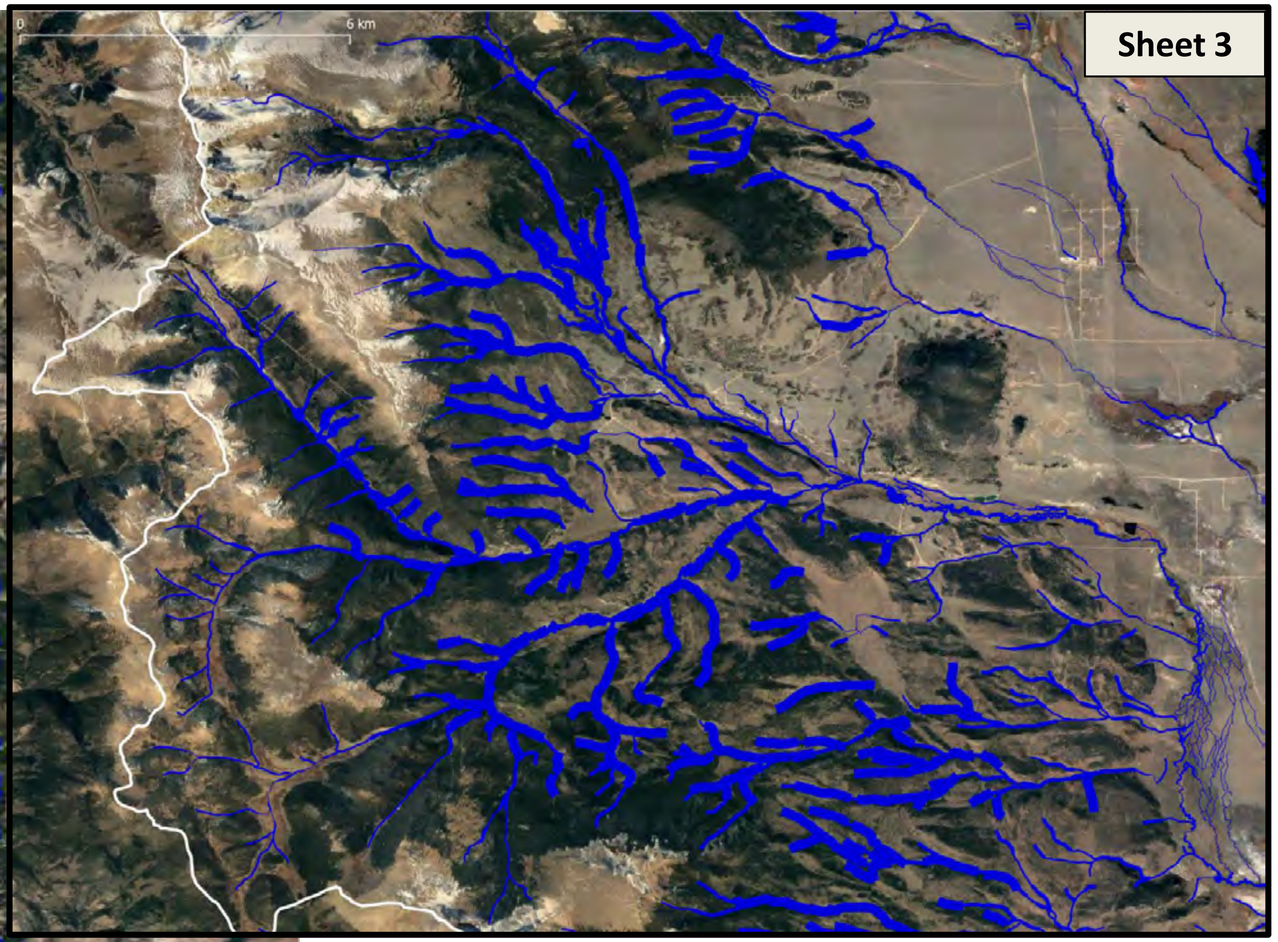


BRAT model (historical capacity)

The BRAT model calculates a historical capacity of 100,241 primary beaver dams in Park County, distributed by frequency as shown in the table below.

BRAT historical capacity		
Category	**Stream length (km)**	**Beaver activity (~dams)**
Pervasive	2,562.7	58,840
Frequent	3,162.1	35,374
Occasional	1,709.0	5,937
Rare	138.1	90
None	0	0
Total	**7,571.9**	**100,241**

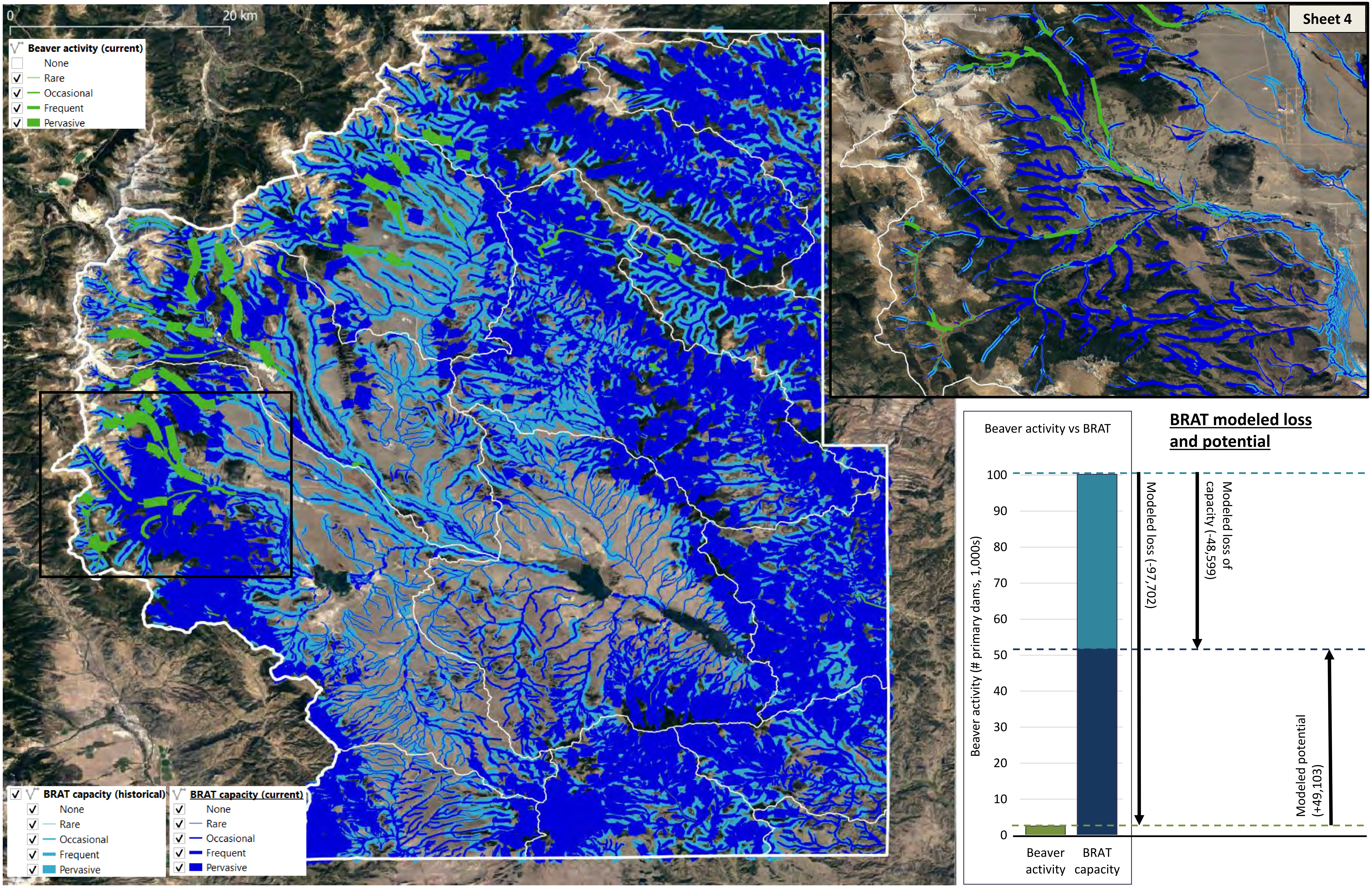


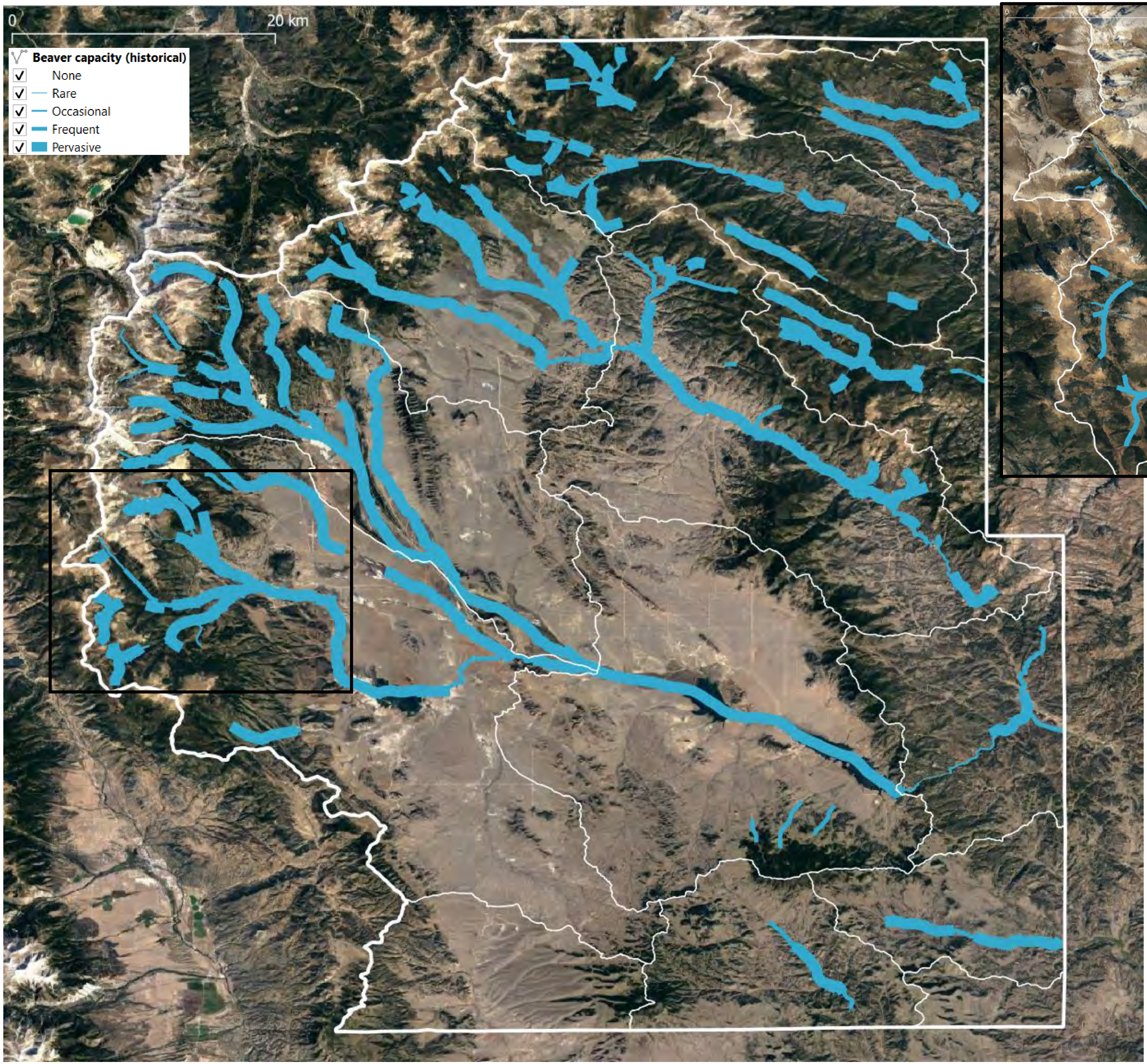


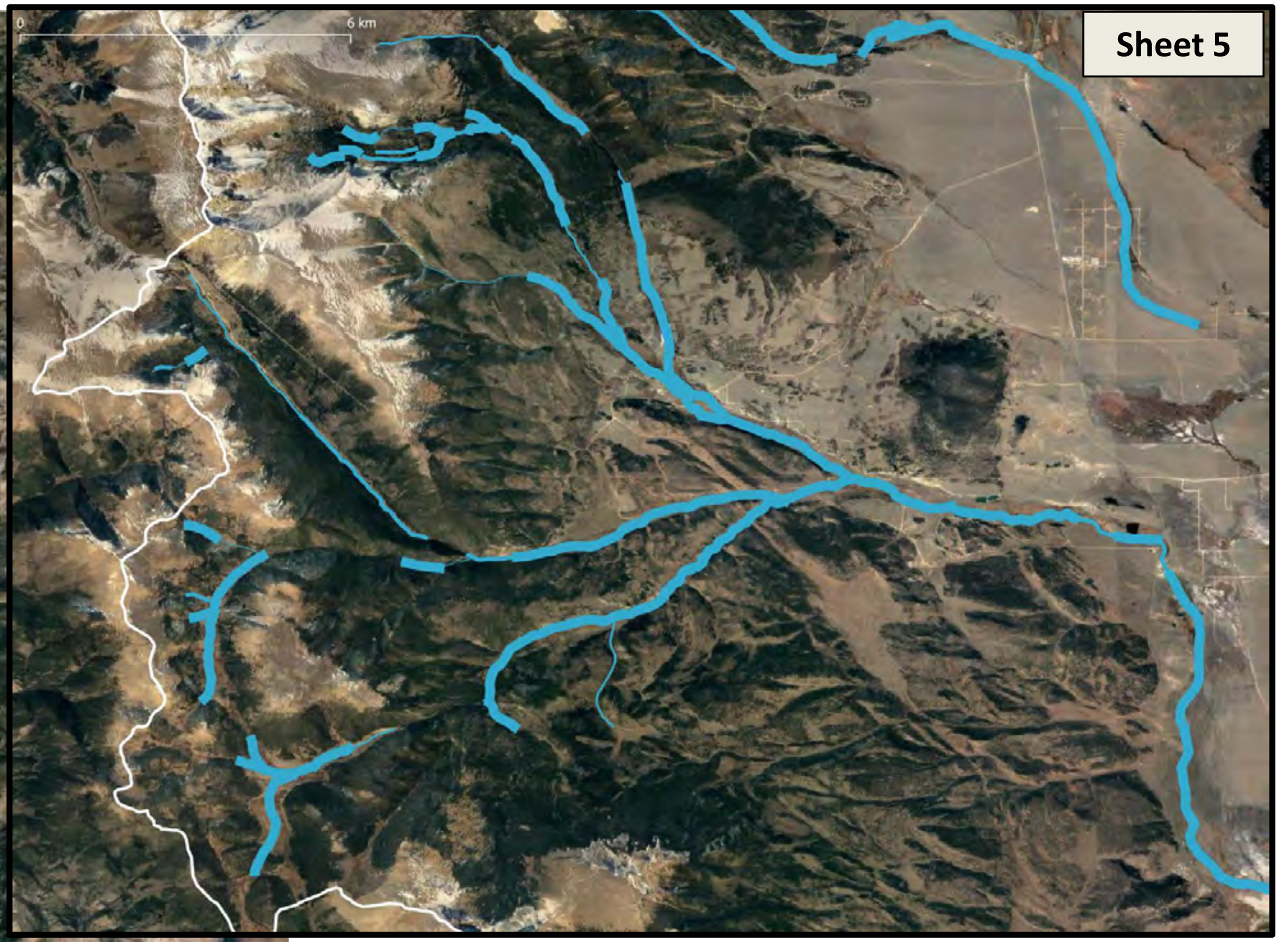
BRAT model (current capacity)

The BRAT model calculates a current capacity of 51,642 primary beaver dams in Park County, distributed by frequency as shown in the table below.

Current beaver capacity		
Category	**Stream length (km)**	**Beaver activity (~dams)**
Pervasive	921.9	21,714
Frequent	2,123.8	22,403
Occasional	2,959.2	6,494
Rare	1,561.8	1,031
None	5.2	0
Total	**7,571.9**	**51,642**


0
20 km
Beaver activity (current)
None
Rare
Occasional
Frequent
Pervasive
Sheet 4
6 km
BRAT capacity (historical)
None
Rare
Occasional
Frequent
Pervasive
BRAT capacity (current)
None
Rare
Occasional
Frequent
Pervasive
Beaver activity vs BRAT
BRAT modeled loss and potential
Beaver activity (# primary dams, 1,000s)
100
90
80
70
60
50
40
30
20
10
0
Beaver activity
BRAT capacity
Modeled loss (-97,702)
Modeled loss of capacity (-48,599)
Modeled potential (+49,103)

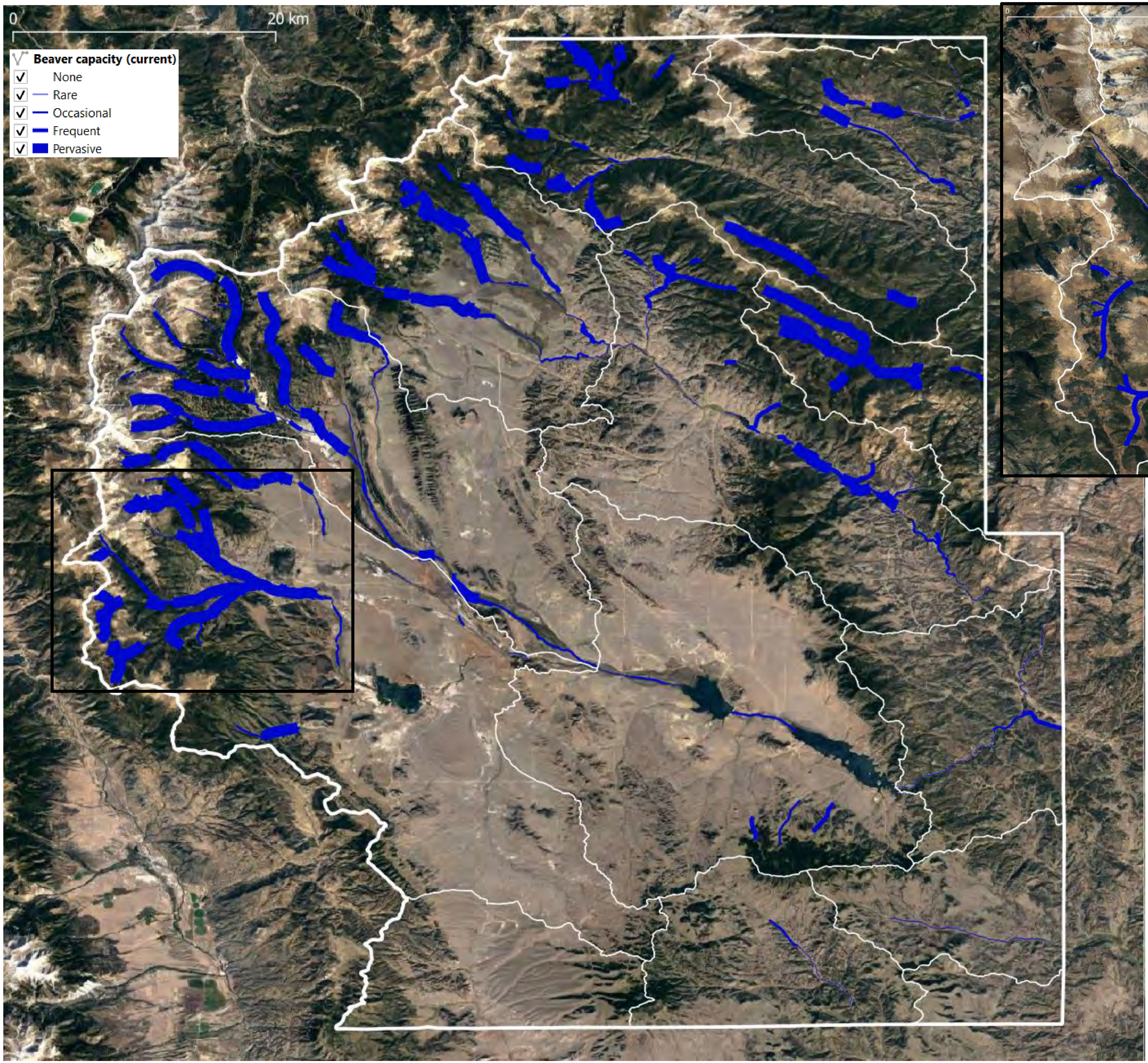


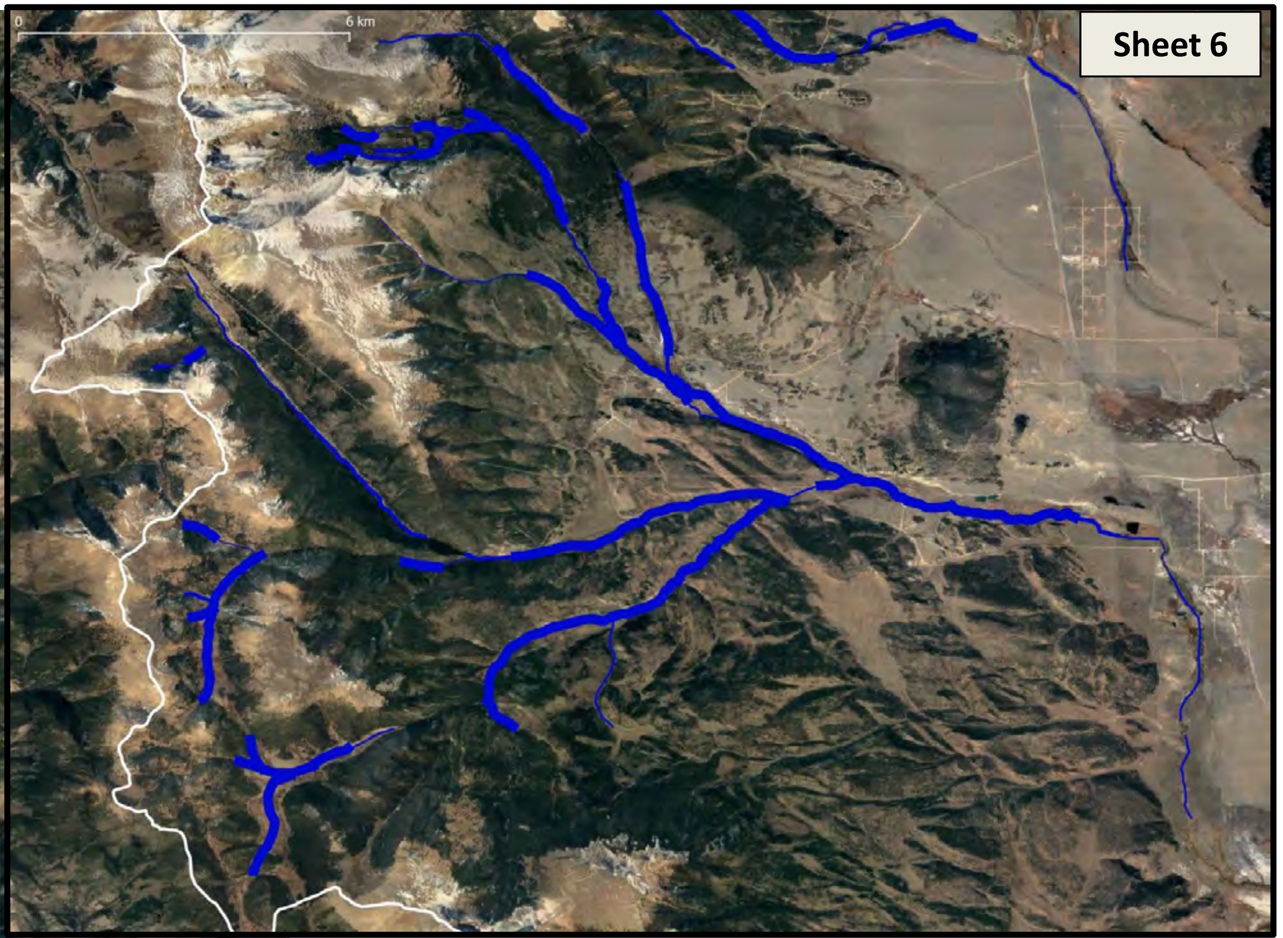


Beaver capacity (historical)

This map shows our assessment of the historical level of beaver capacity by stream reach in Park County. We identified 738.6 km of stream corridor that likely naturally supported some level. At its historical potential, Park County would have had beaver activity that supported an estimated total of 16,802 primary beaver dams.

Historical beaver capacity		
Category	**Stream length (km)**	**Beaver activity (~dams)**
Pervasive	510.5	15,315
Frequent	126.1	1,261
Occasional	70.1	210
Rare	31.9	16
None	0	0
Total	**738.6**	**16,802**

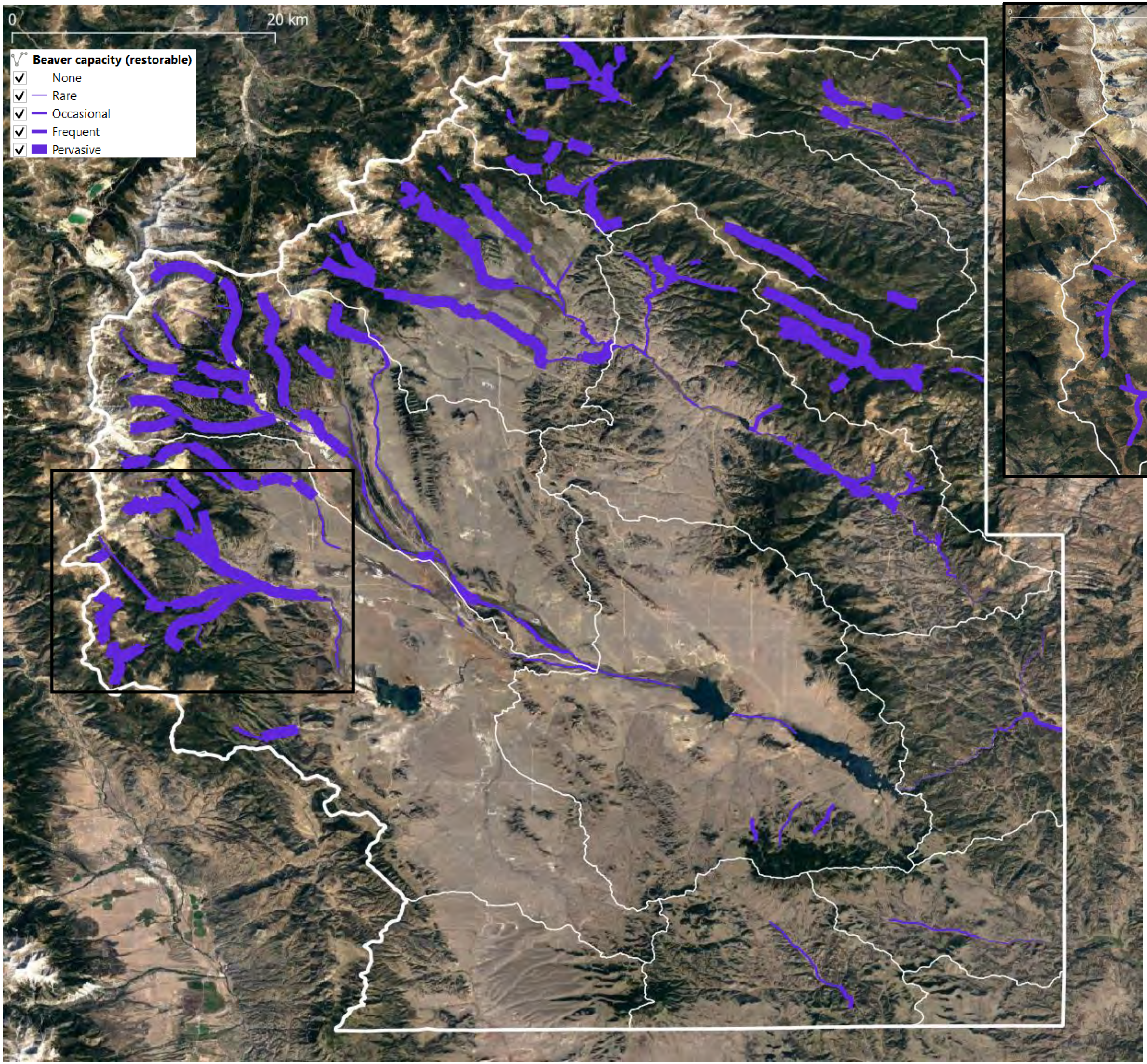


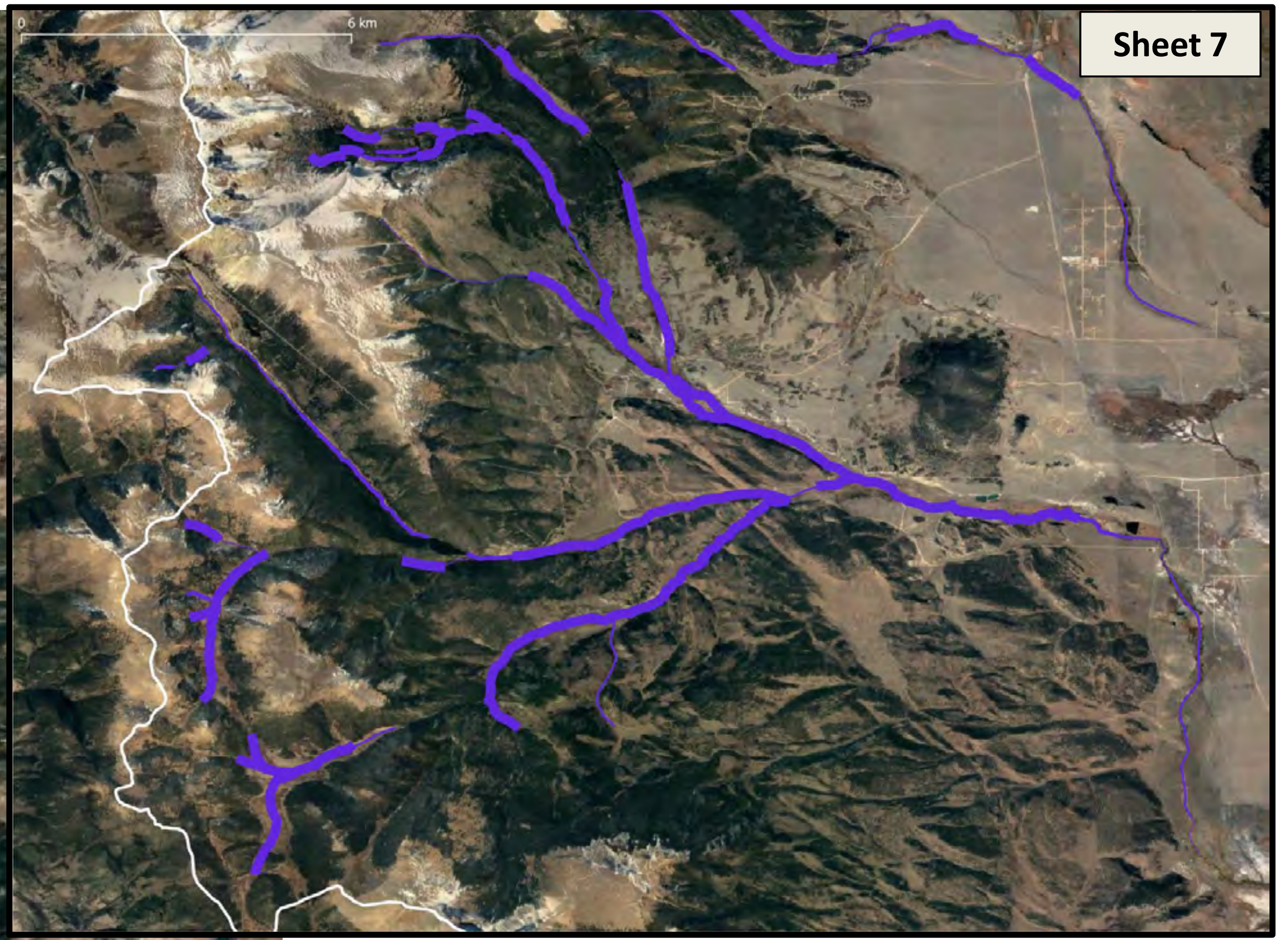


Beaver capacity (current)

This map shows our assessment of the current level of beaver capacity by stream reach in Park County. We identified 617.8 km of stream corridor that could likely support some level of beaver activity in current conditions. At full potential, Park County could have beaver activity that supports an estimated total of 8,153 primary beaver dams.

Current beaver capacity		
Category	**Stream length (km)**	**Beaver activity (~dams)**
Pervasive	220.7	6,621
Frequent	99.9	999
Occasional	153.7	461
Rare	143.5	72
None	120.8	0
Total	**738.6**	**8,153**

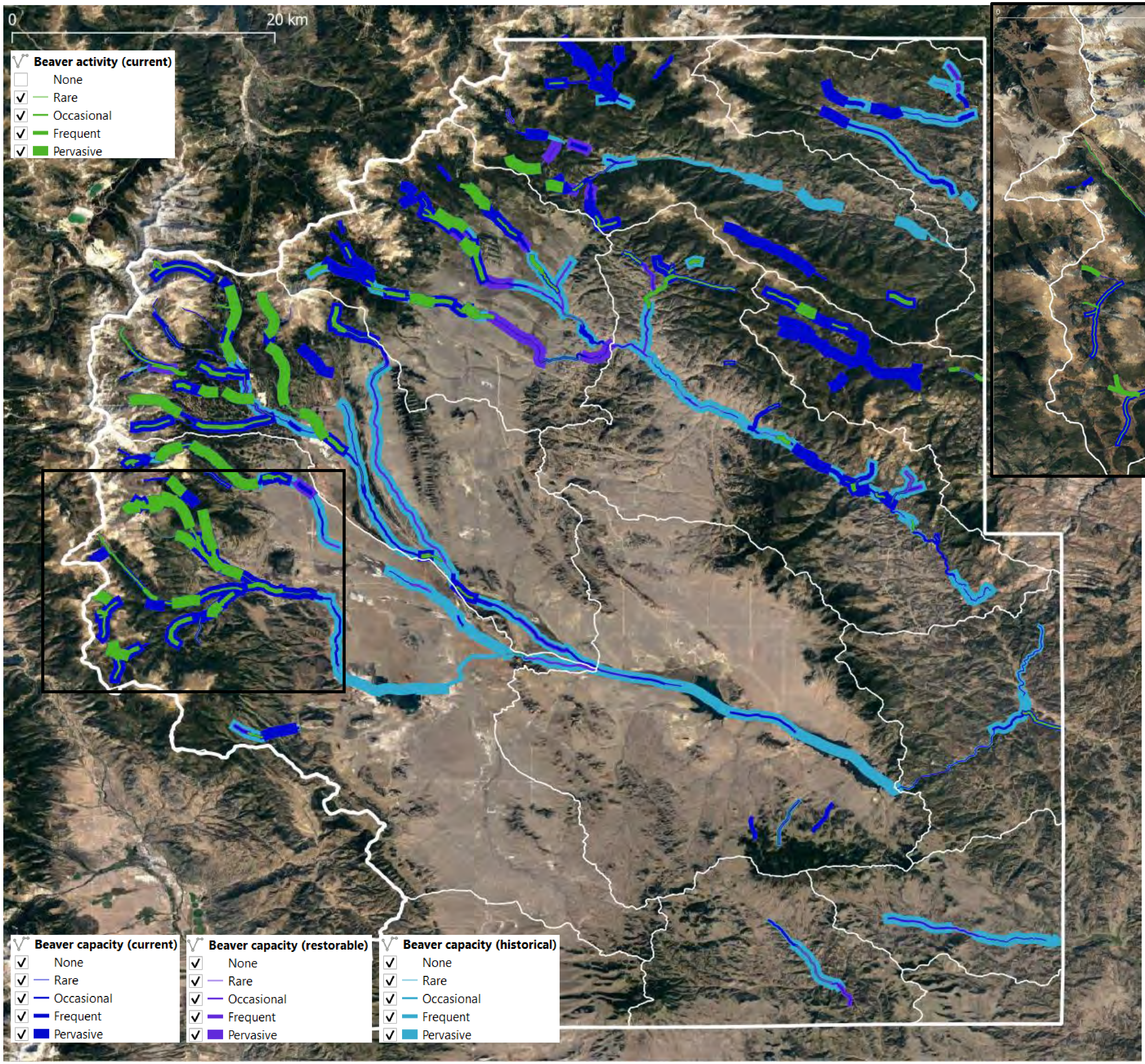


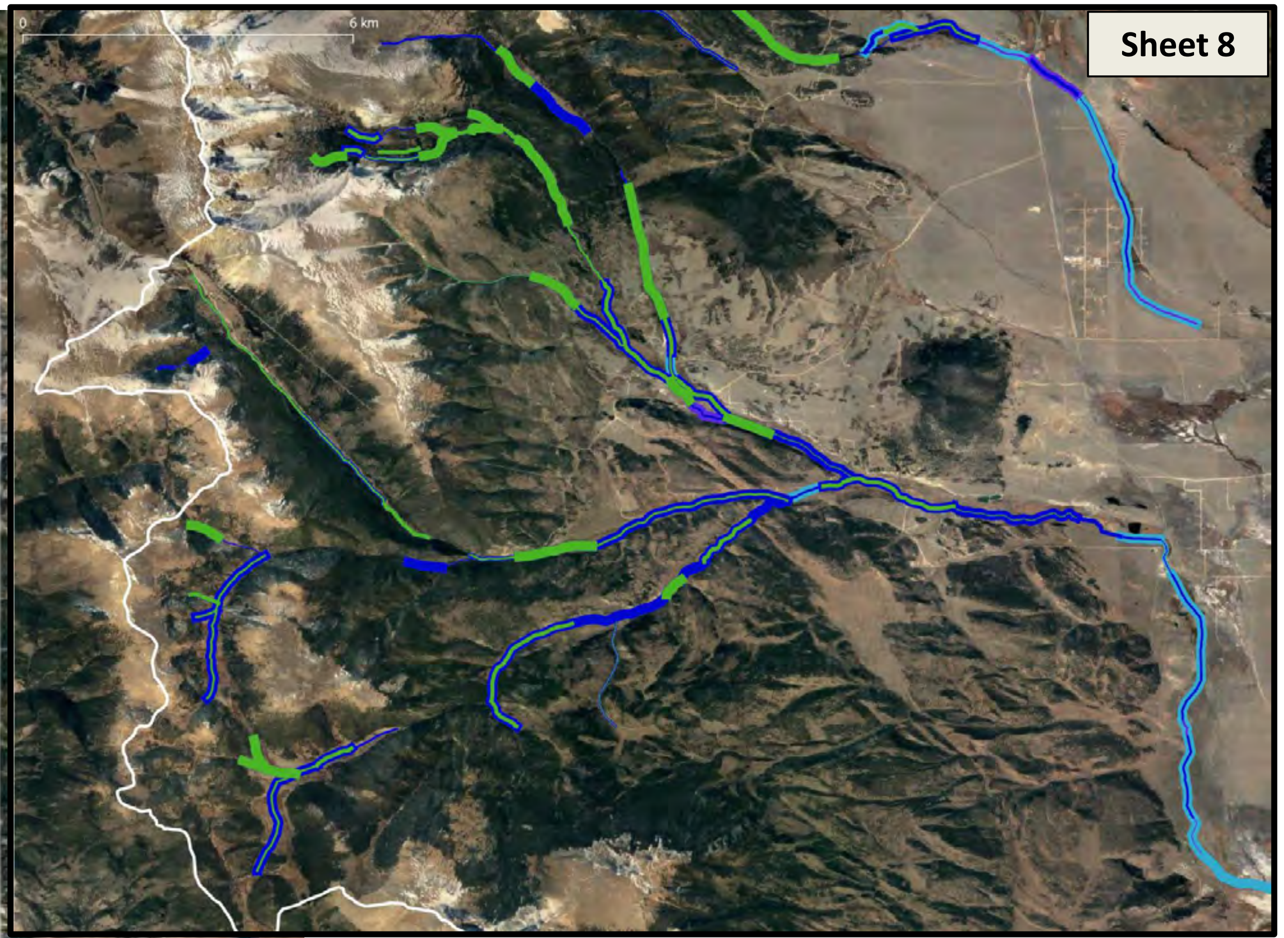


Beaver capacity (restorable)

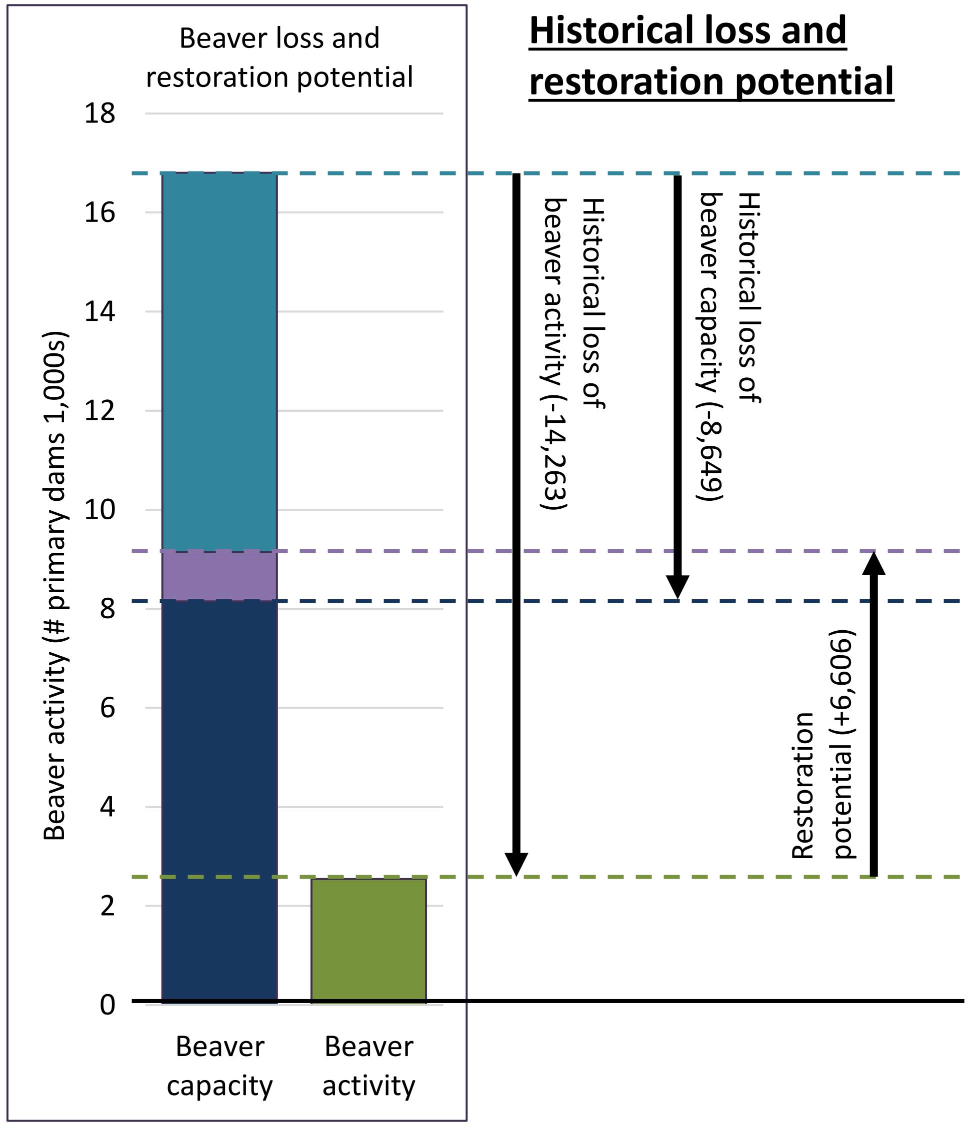
This map shows our assessment of the level of beaver capacity that could potentially be restored with low-tech, low-effort actions in a short time frame in Park County. We identified 669.2 km of stream corridor that could likely support some level of beaver activity with restoration by these simple methods. At full potential, Park County could have beaver activity that supports an estimated total of 9,145 primary beaver dams.

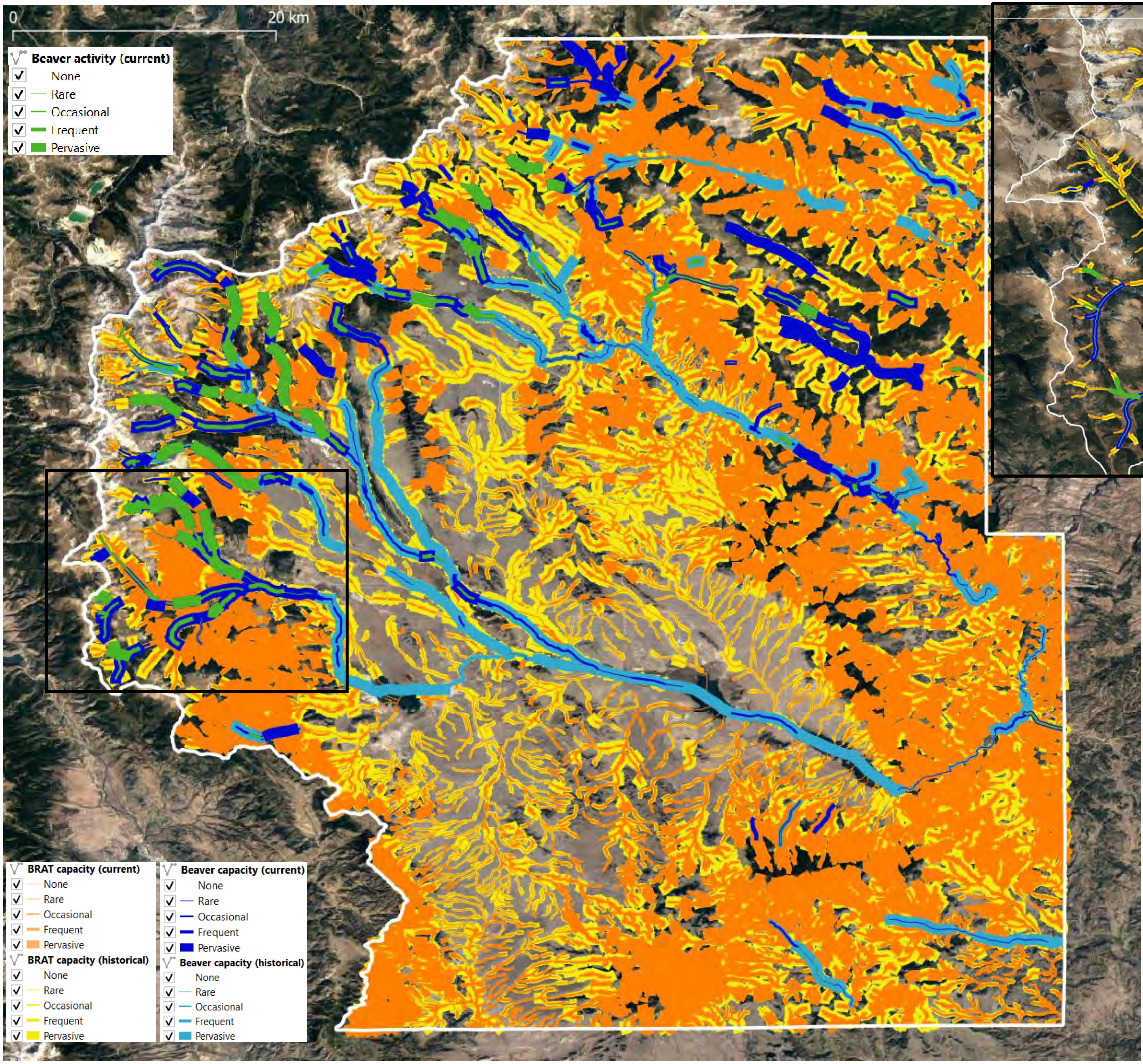
Restorable beaver capacity		
Category	Stream length (km)	Beaver activity (~dams)
Pervasive	243.1	7,293
Frequent	117.9	1,179
Occasional	207.4	622
Rare	100.8	50
None	69.4	0
Total	**738.6**	**9,145**

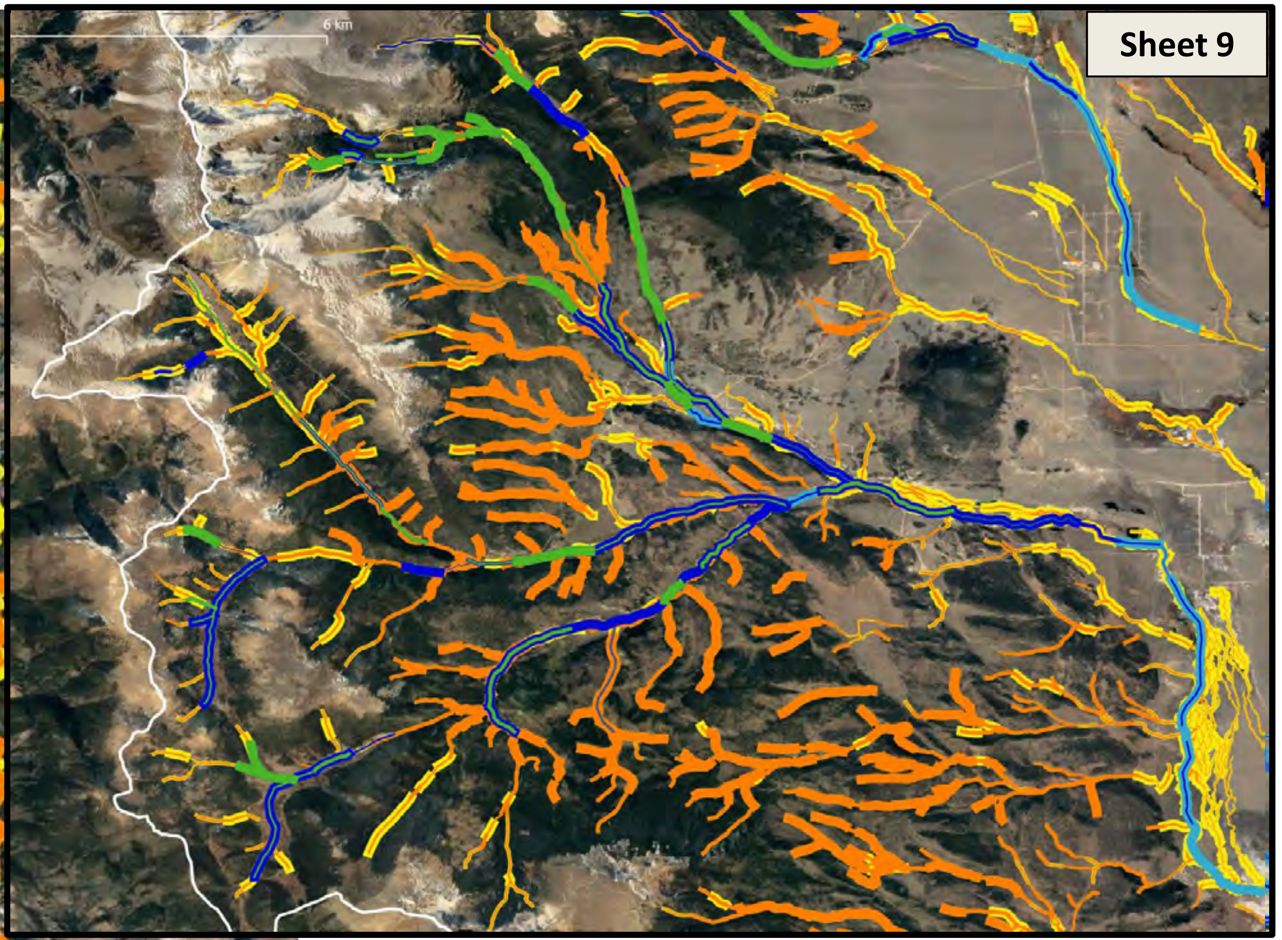


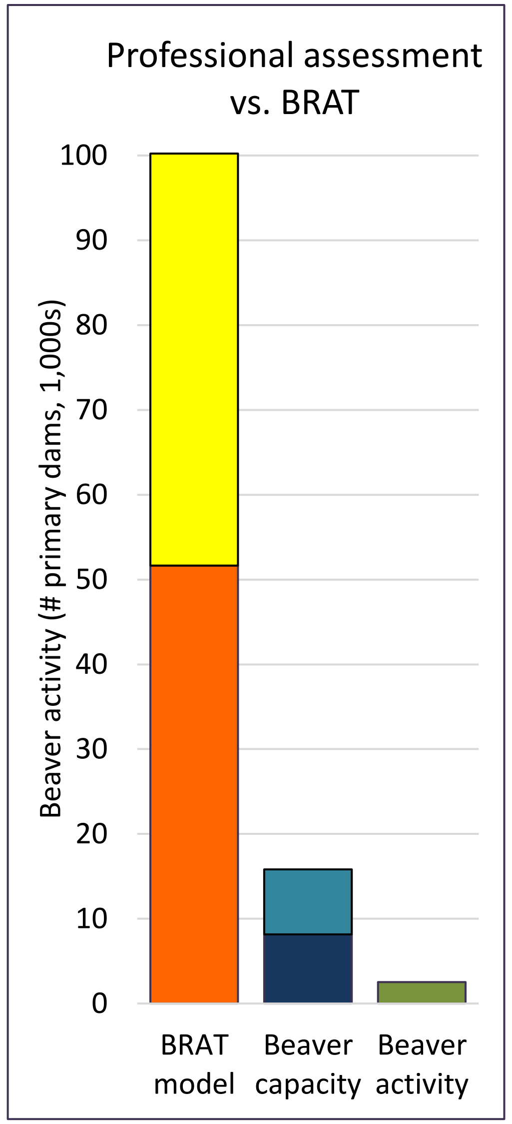


Historical loss and restoration potential



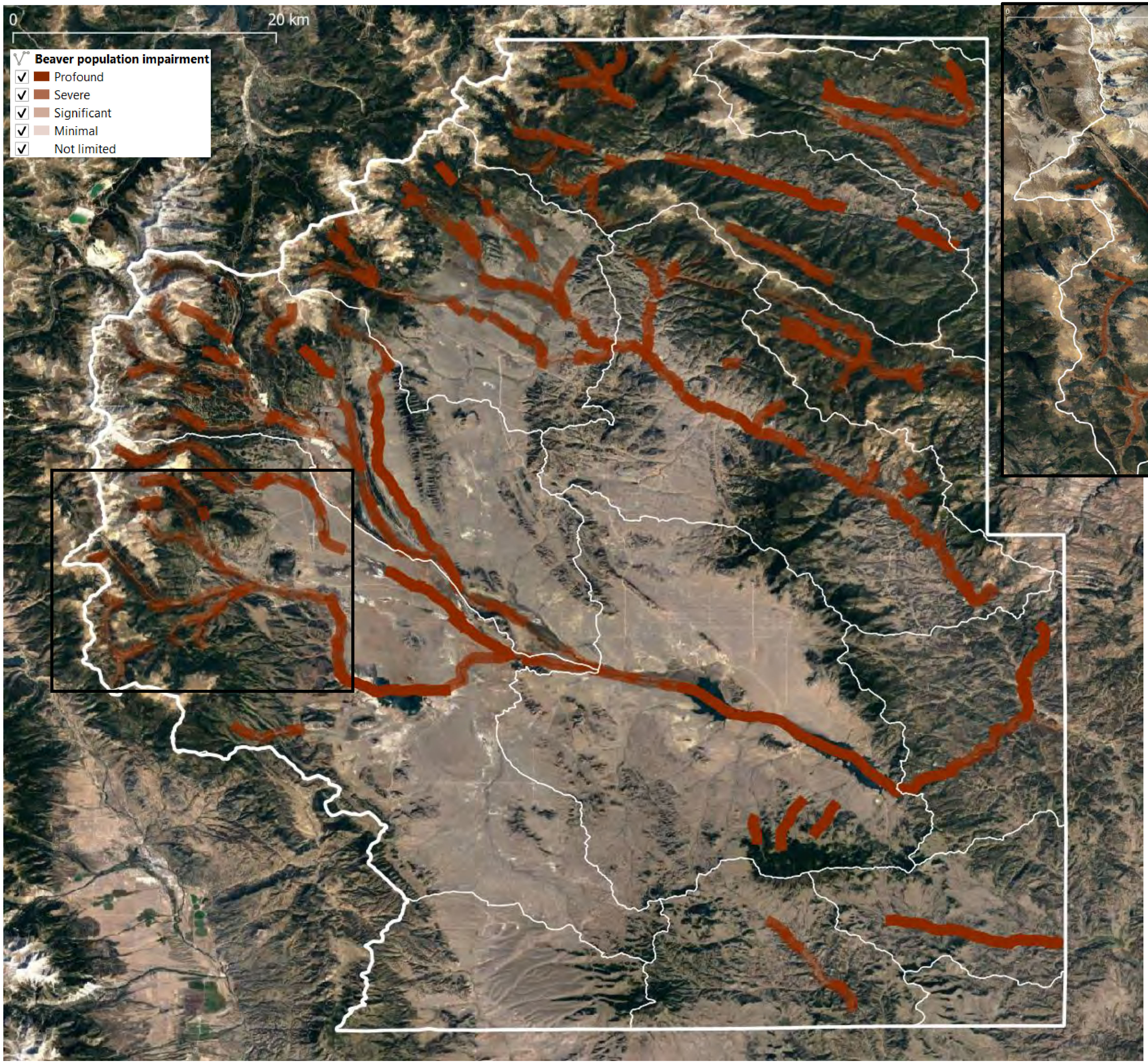


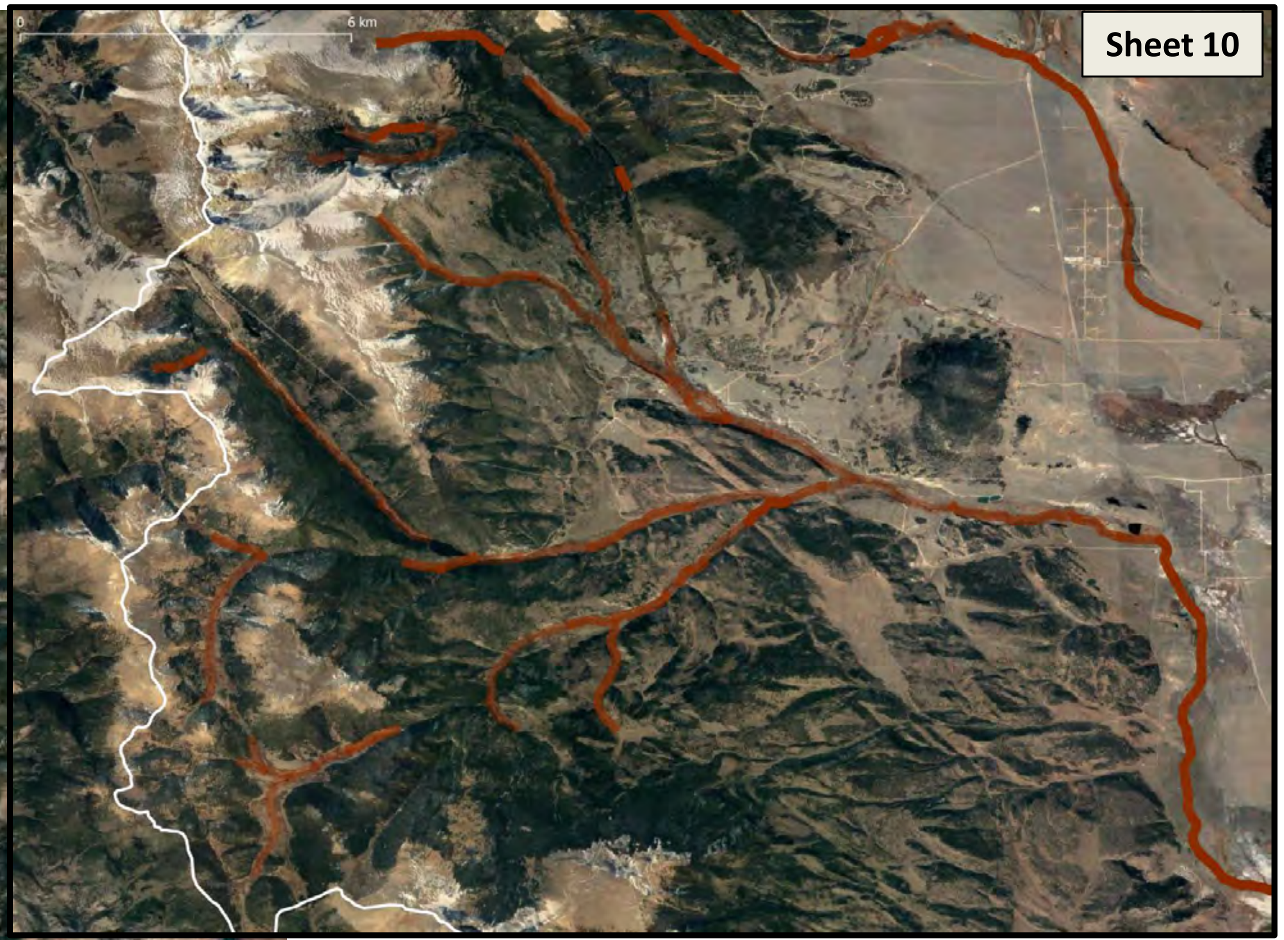




Comparing BRAT to professional assessment

The BRAT assessment of historical and current capacity are both 6 times greater than the professional assessment, leading to elevated estimates of both historical loss and restoration potential.

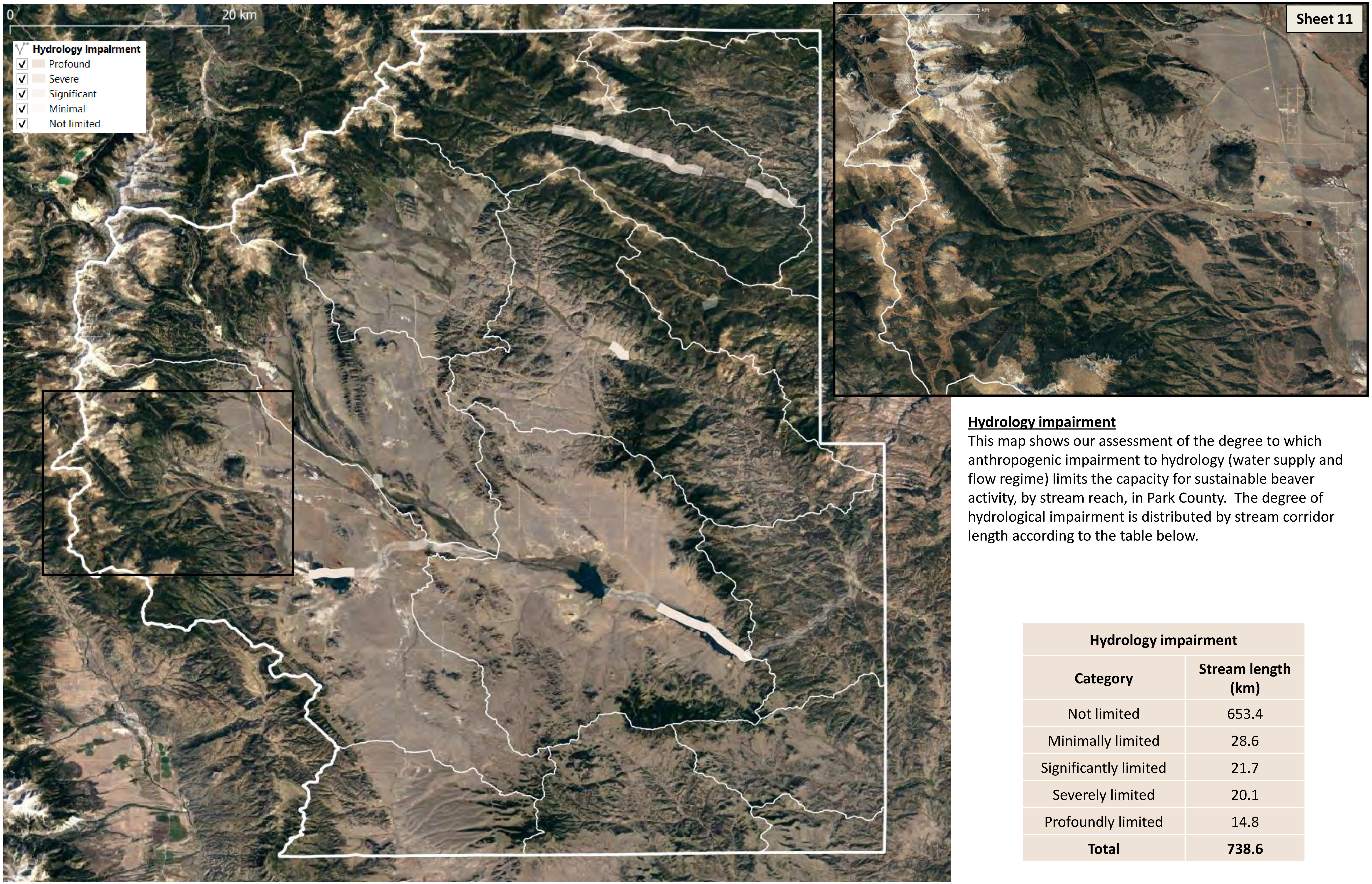




Beaver population impairment

This map shows our assessment of the degree to which anthropogenic impairment to beaver metapopulations limits the capacity for sustainable beaver activity, by stream reach, in Park County. The degree of beaver population impairment is distributed by stream corridor length according to the table below.

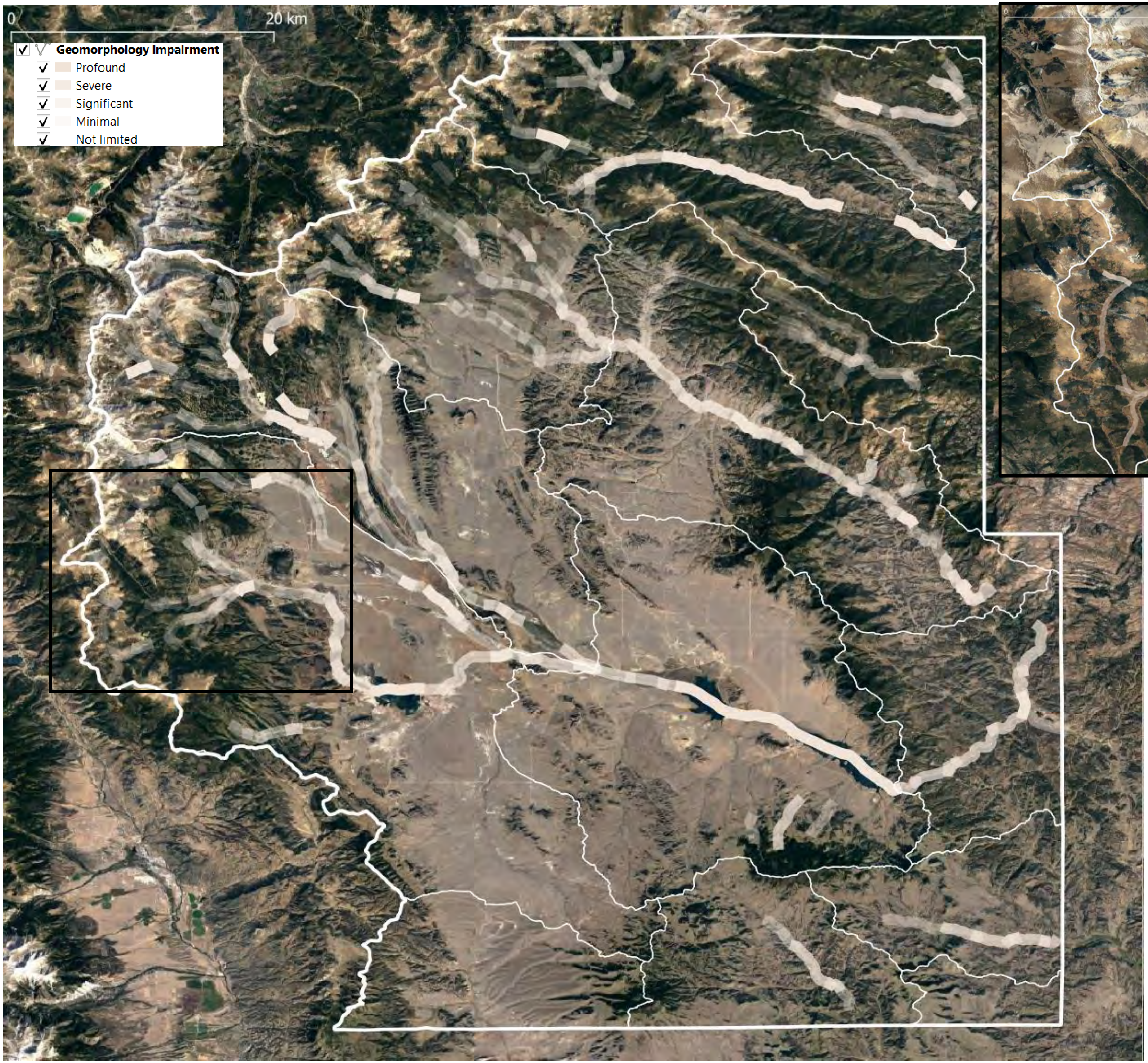
Beaver population impairment	
Category	**Stream length (km)**
Not limited	43.7
Minimally limited	204.1
Significantly limited	108.9
Severely limited	257.1
Profoundly limited	124.8
Total	**738.6**



Hydrology impairment

This map shows our assessment of the degree to which anthropogenic impairment to hydrology (water supply and flow regime) limits the capacity for sustainable beaver activity, by stream reach, in Park County. The degree of hydrological impairment is distributed by stream corridor length according to the table below.

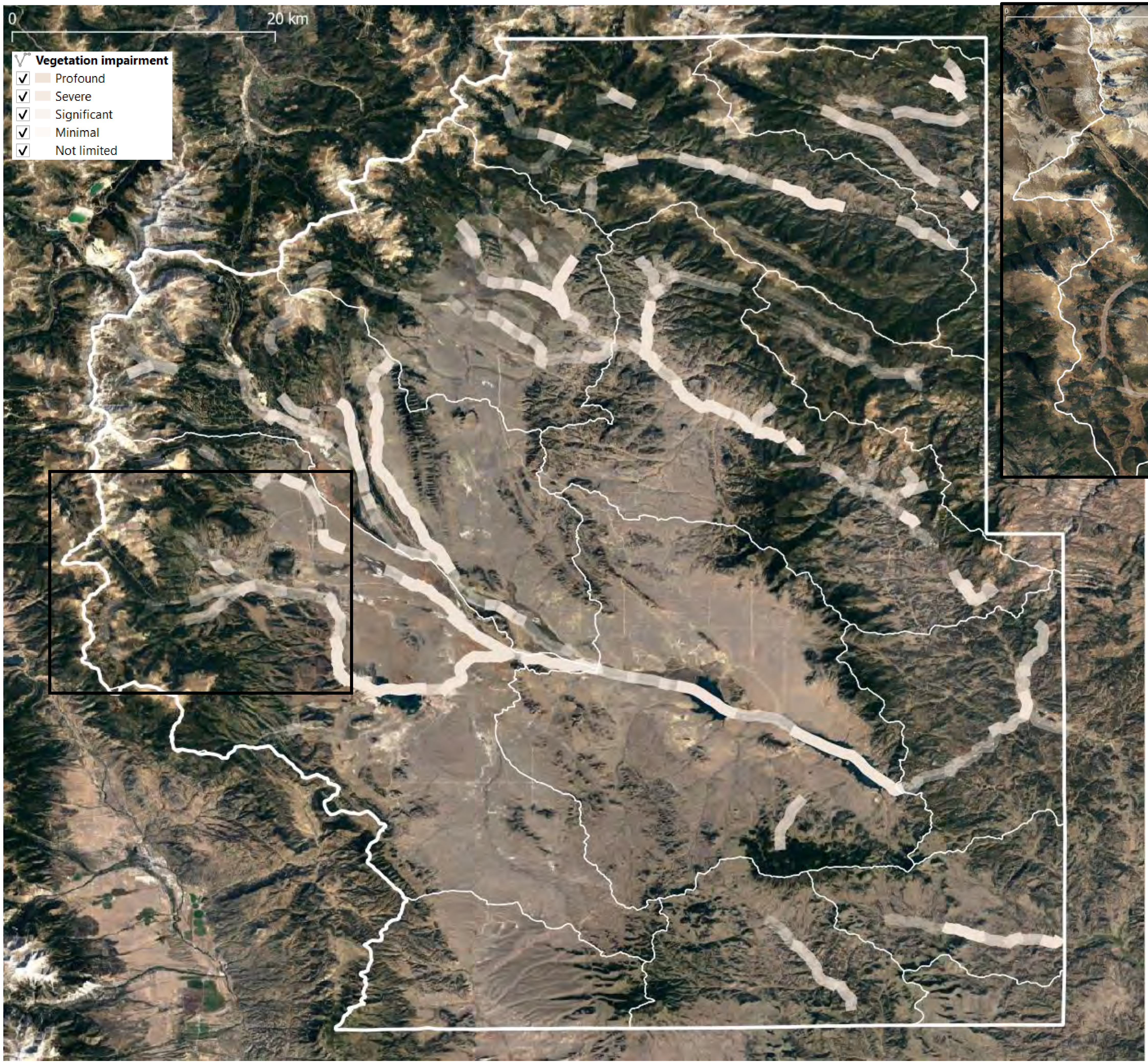
Hydrology impairment	
Category	**Stream length (km)**
Not limited	653.4
Minimally limited	28.6
Significantly limited	21.7
Severely limited	20.1
Profoundly limited	14.8
Total	**738.6**



<u>Geomorphology impairment</u>

This map shows our assessment of the degree to which anthropogenic impairment to geomorphology (stream incision, channelization, armoring, *etc.*) limits the capacity for sustainable beaver activity, by stream reach, in Park County. The degree of geomorphological impairment is distributed by stream corridor length according to the table below.

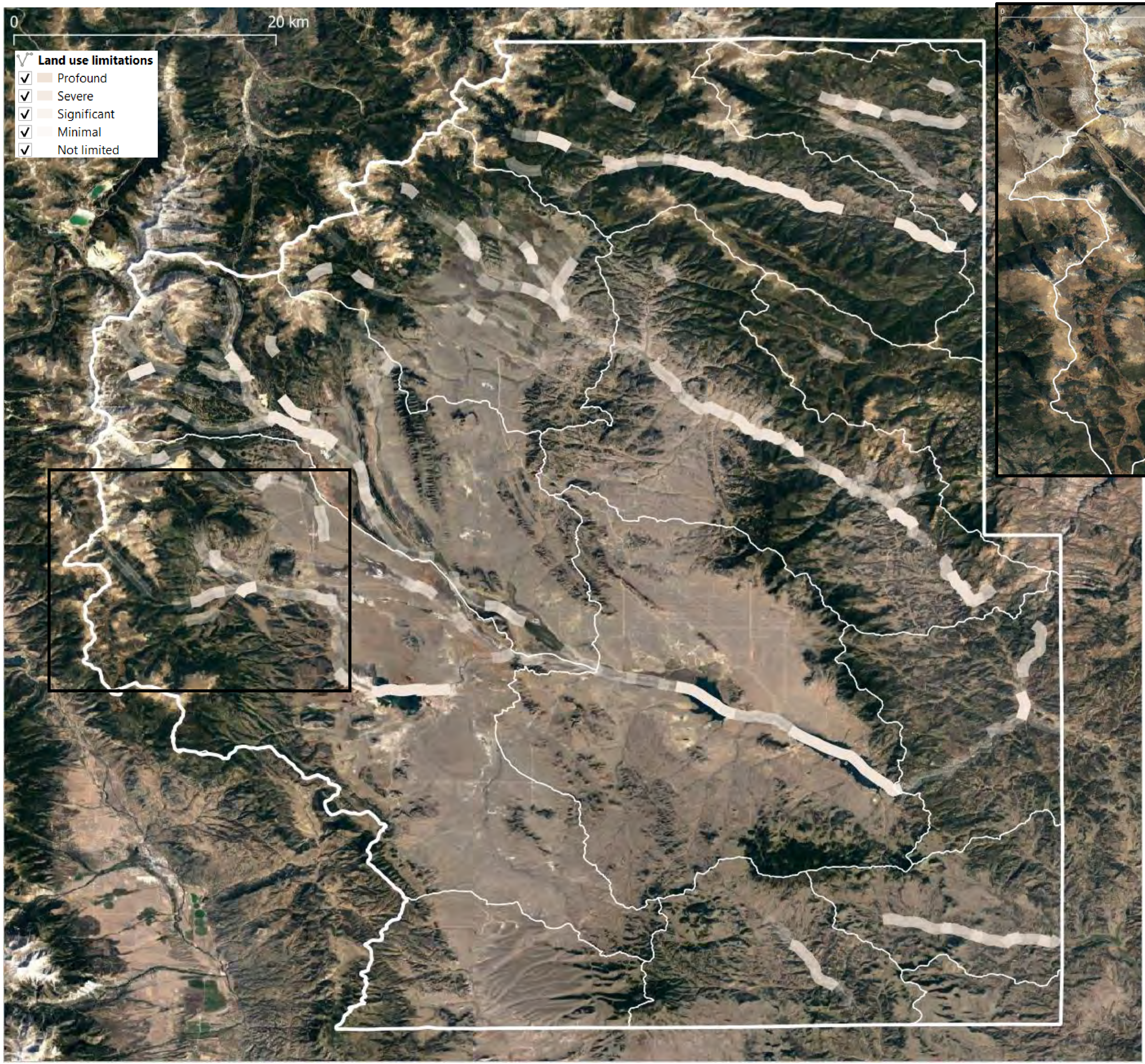
Geomorphology impairment	
Category	**Stream length (km)**
Not limited	77.6
Minimally limited	192.1
Significantly limited	248.6
Severely limited	150.0
Profoundly limited	70.3
Total	**738.6**



<u>Vegetation impairment</u>

This map shows our assessment of the degree to which anthropogenic impairment to vegetation (cleared, developed, or degraded riparian zones, deforestation, exotic species, *etc.*) limits the capacity for sustainable beaver activity, by stream reach, in Park County. The degree of vegetation impairment is distributed by stream corridor length according to the table below.

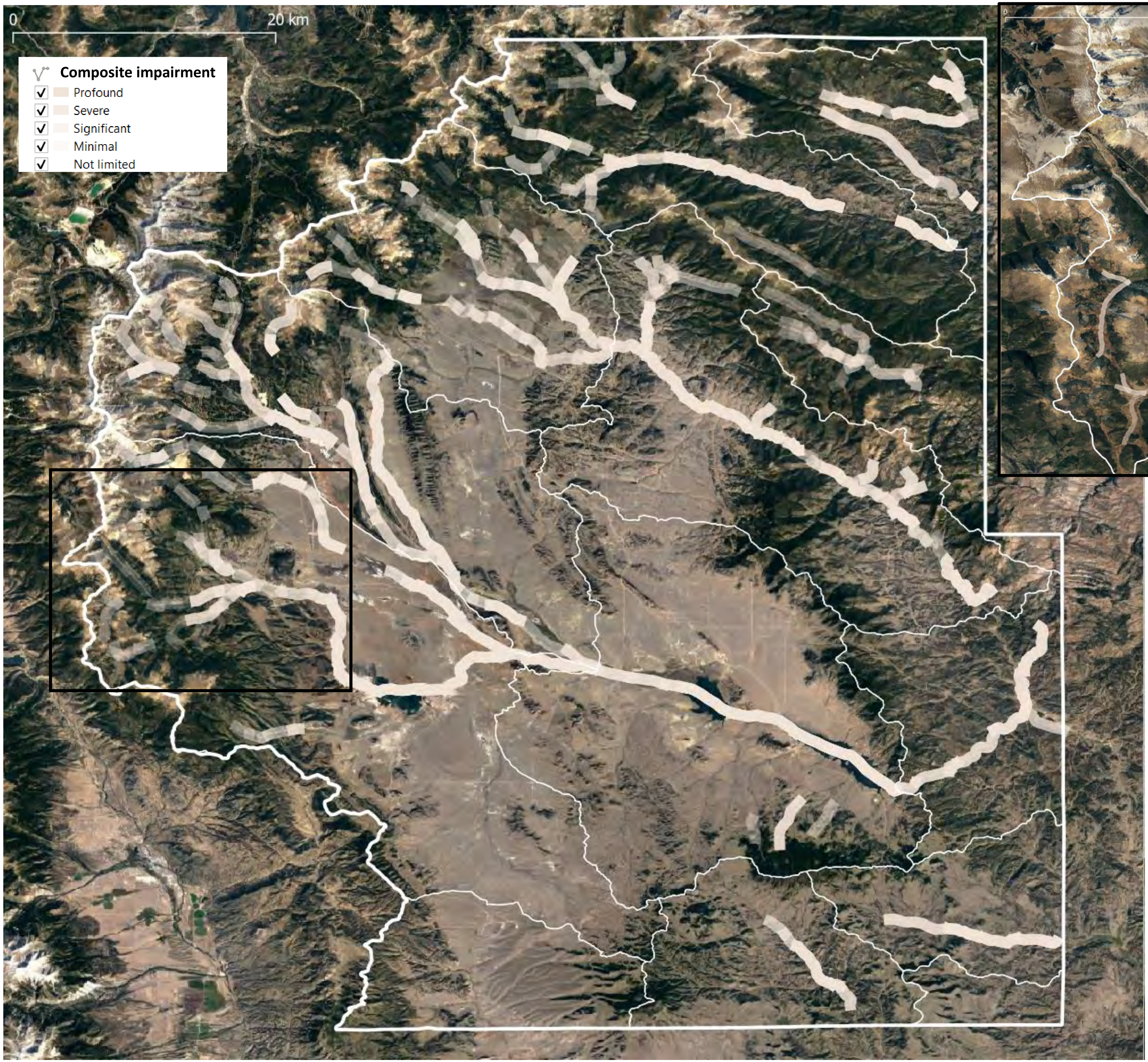
Vegetation impairment	
Category	**Stream length (km)**
Not limited	236.5
Minimally limited	104.0
Significantly limited	137.5
Severely limited	146.5
Profoundly limited	114.1
Total	**738.6**



<u>Land use/infrastructure</u>

This map shows our assessment of the degree to which anthropogenic land use or infrastructure (agriculture or development in riparian zones, roads, bridges, ditches, dams *etc.*) limits the capacity for sustainable beaver activity, by stream reach, in Park County. The degree of land use or infrastructure limitation is distributed by stream corridor length according to the table below.

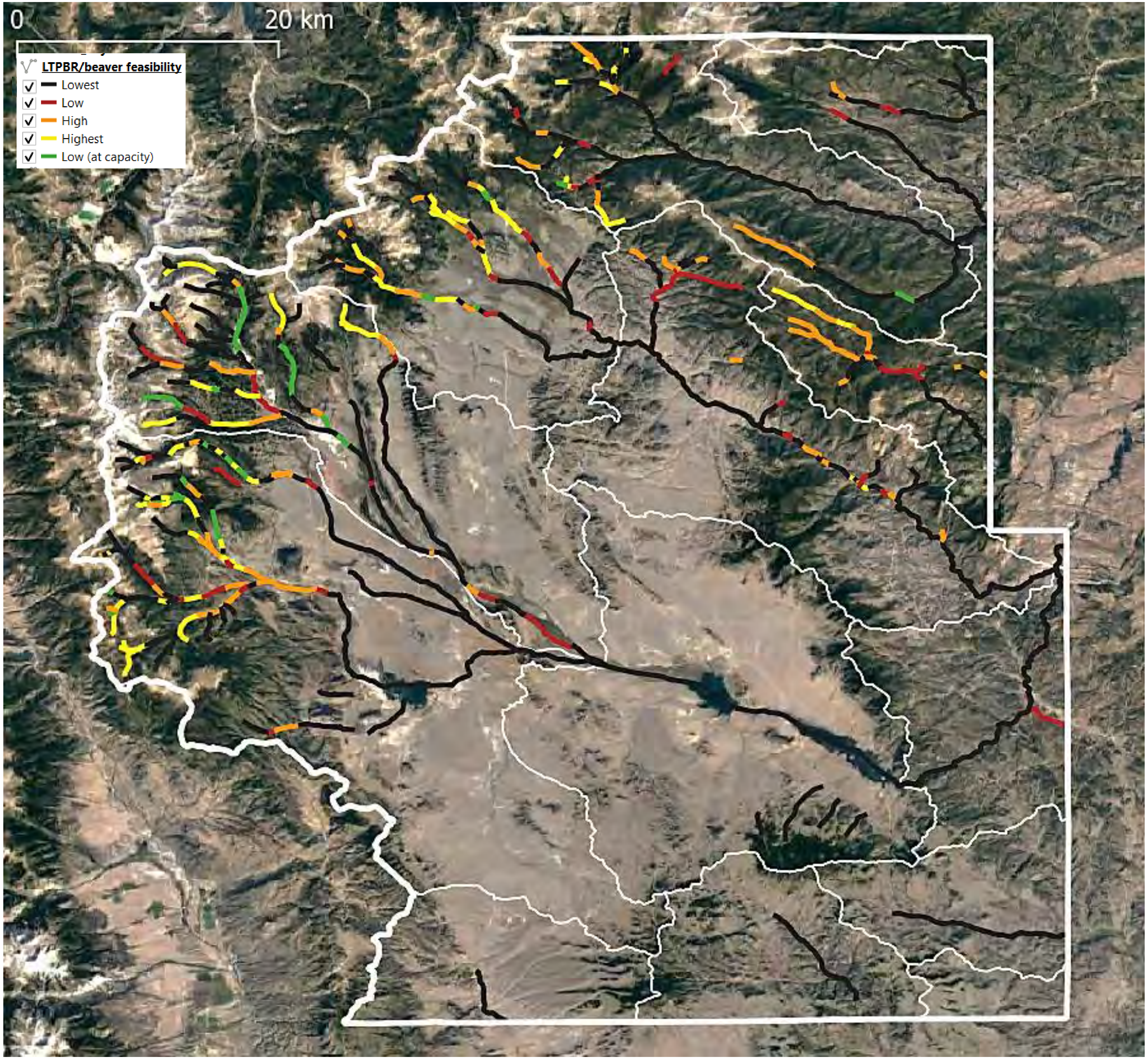
Land use/infrastructure limitations	
Category	**Stream length (km)**
Not limited	277.7
Minimally limited	183.9
Significantly limited	125.7
Severely limited	92.3
Profoundly limited	59.0
Total	**738.6**



Composite impairment

This map shows our assessment of the degree to which the combined effect of hydrological, geomorphological, vegetation, and land use impacts limits the capacity for sustainable beaver activity, by stream reach, in Park County. The degree of impairment is distributed by stream corridor length according to the table below.

Composite impairment	
Category	**Stream length (km)**
Not limited	53.0
Minimally limited	161.7
Significantly limited	190.3
Severely limited	178.4
Profoundly limited	155.2
Total	**738.6**



LTPBR/beaver restoration opportunities

This map shows our assessment of LTPBR/beaver restoration opportunities, rated by feasibility, in Park County.

At capacity:

- functioning beaver complexes that are already **at capacity**

Best opportunities: highest long-term benefit-to-cost ratio.

- **high capacity** and **good connectivity** that require only **low-effort** restoration treatments and/or **minor** land use changes.

Good opportunities: high long-term benefit-to-cost ratio

- **moderate capacity** and **good connectivity** that require only **low-effort** restoration treatments and/or **minor** land use changes.

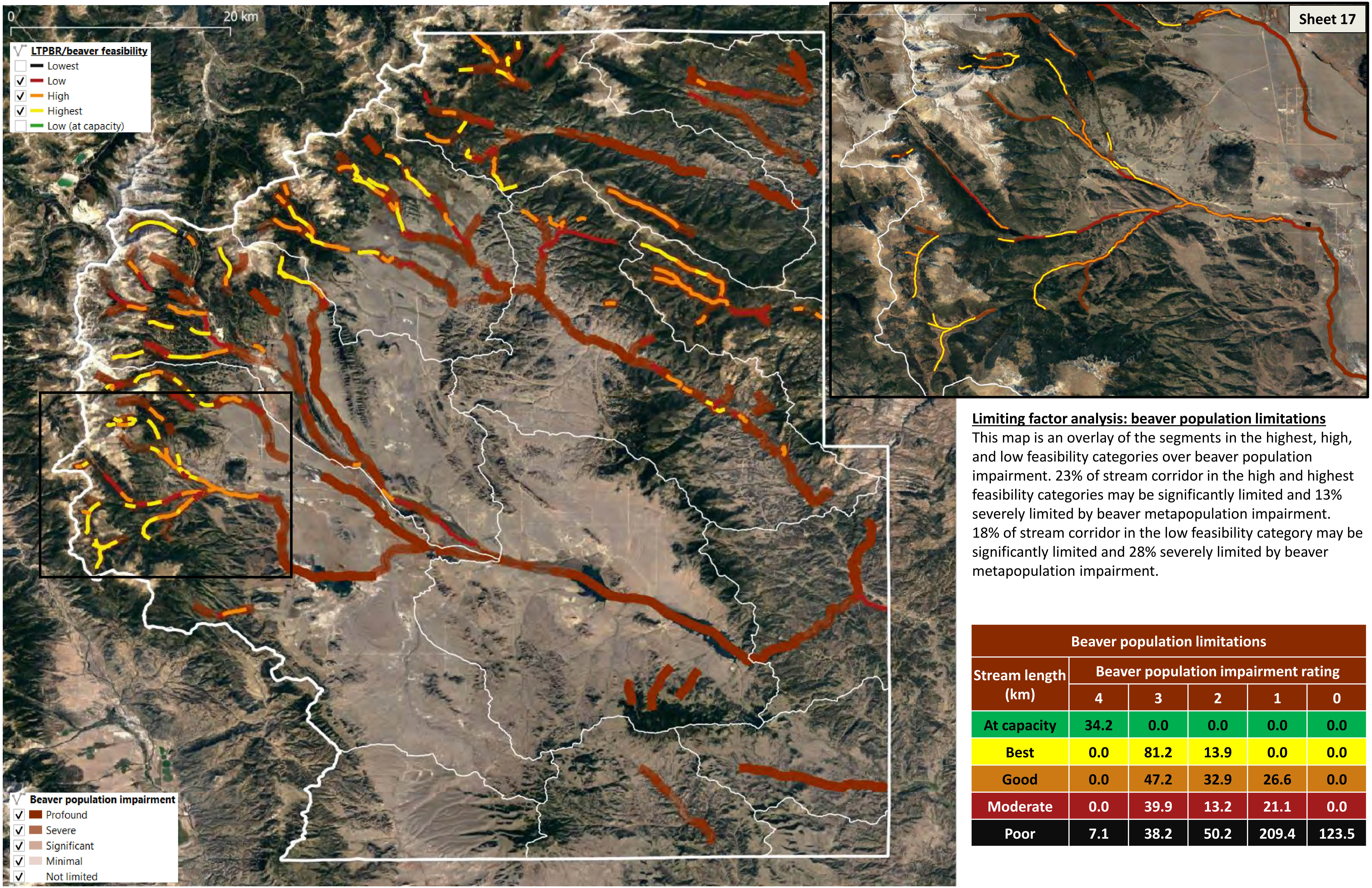
Moderate opportunities: low long-term benefit-to-cost ratio.

- **moderate capacity** and **good connectivity** that require **high-effort** restoration treatments and/or **significant** land use changes.
- **high capacity** and **marginal connectivity** that require **high-effort** restoration treatments and/or **significant** land use changes.
- **high capacity** and **good connectivity** that require **high-effort** restoration treatments and/or **significant** land use changes.

Poor opportunities: lowest long-term benefit-to-cost ratio.

- **low capacity**, regardless of connectivity or effort.
- **moderate to high capacity** and **marginal to poor connectivity** that require **high-effort** restoration treatments or **significant** land use changes.

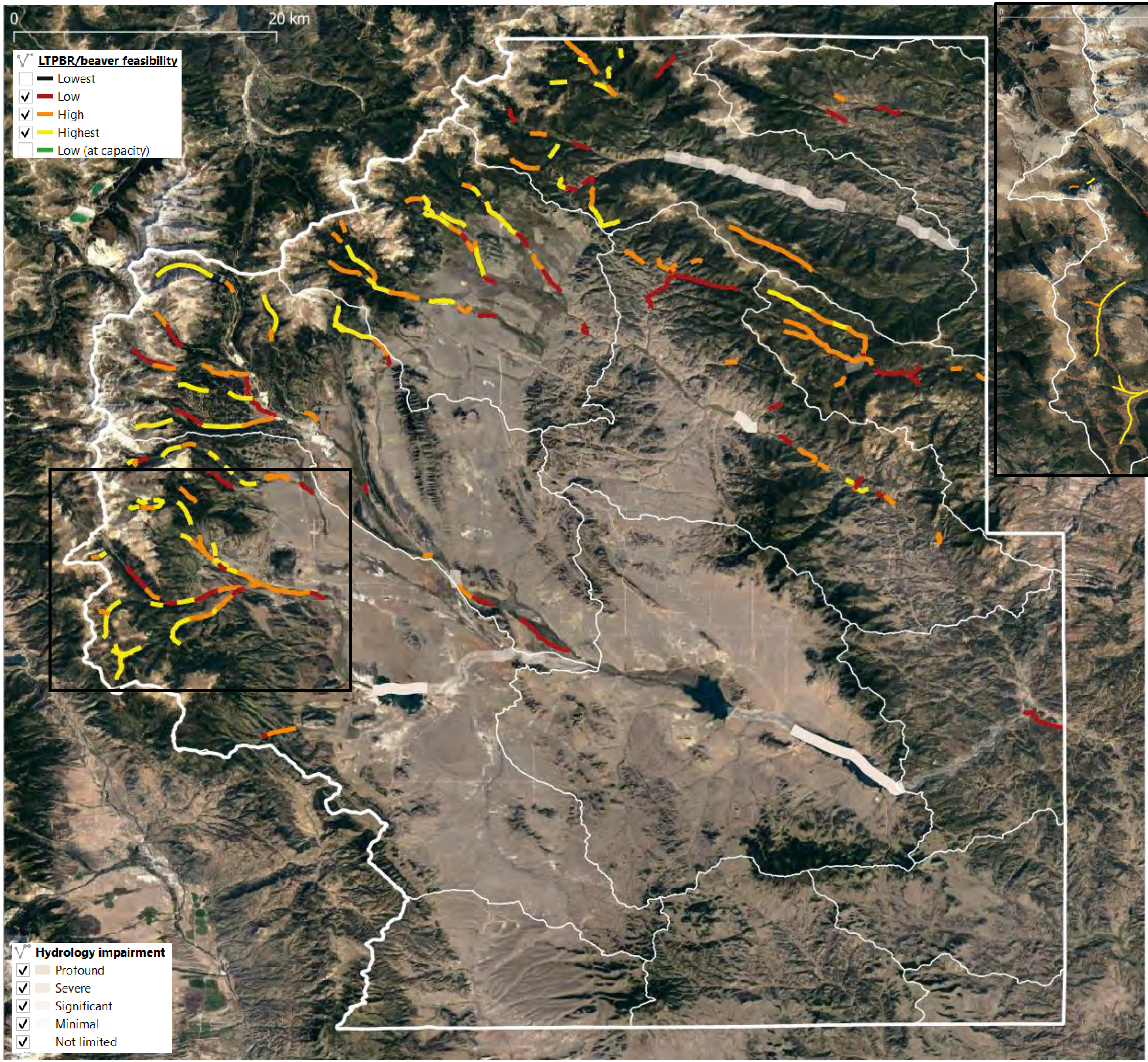
LTPBR/beaver restoration feasibility	
Category	Stream length (km)
At capacity	34.2
Best	95.1
Good	106.7
Moderate	74.2
Poor	428.4
Total	738.6

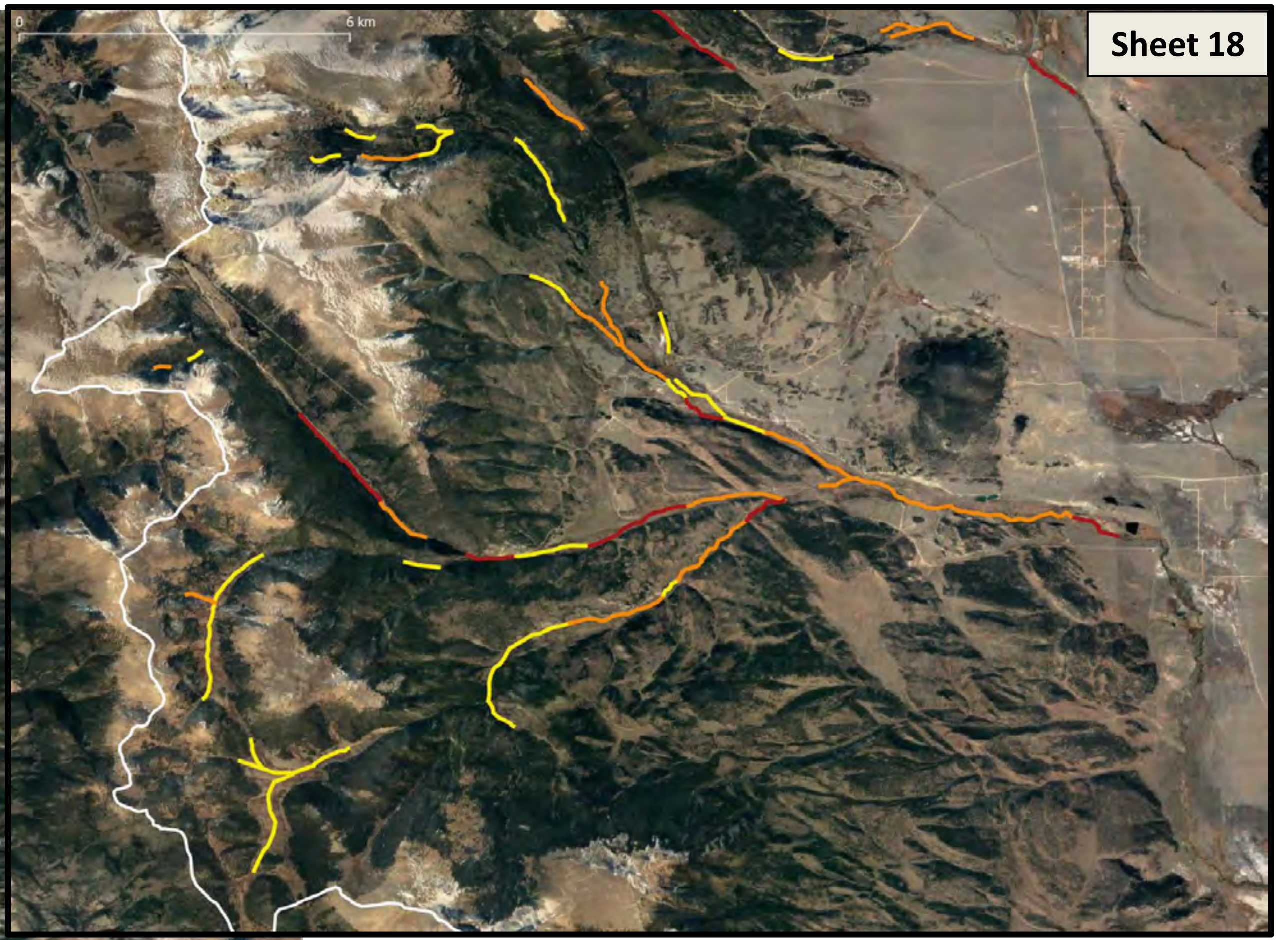


Limiting factor analysis: beaver population limitations

This map is an overlay of the segments in the highest, high, and low feasibility categories over beaver population impairment. 23% of stream corridor in the high and highest feasibility categories may be significantly limited and 13% severely limited by beaver metapopulation impairment. 18% of stream corridor in the low feasibility category may be significantly limited and 28% severely limited by beaver metapopulation impairment.

Beaver population limitations					
Stream length (km)	Beaver population impairment rating				
	4	3	2	1	0
At capacity	34.2	0.0	0.0	0.0	0.0
Best	0.0	81.2	13.9	0.0	0.0
Good	0.0	47.2	32.9	26.6	0.0
Moderate	0.0	39.9	13.2	21.1	0.0
Poor	7.1	38.2	50.2	209.4	123.5

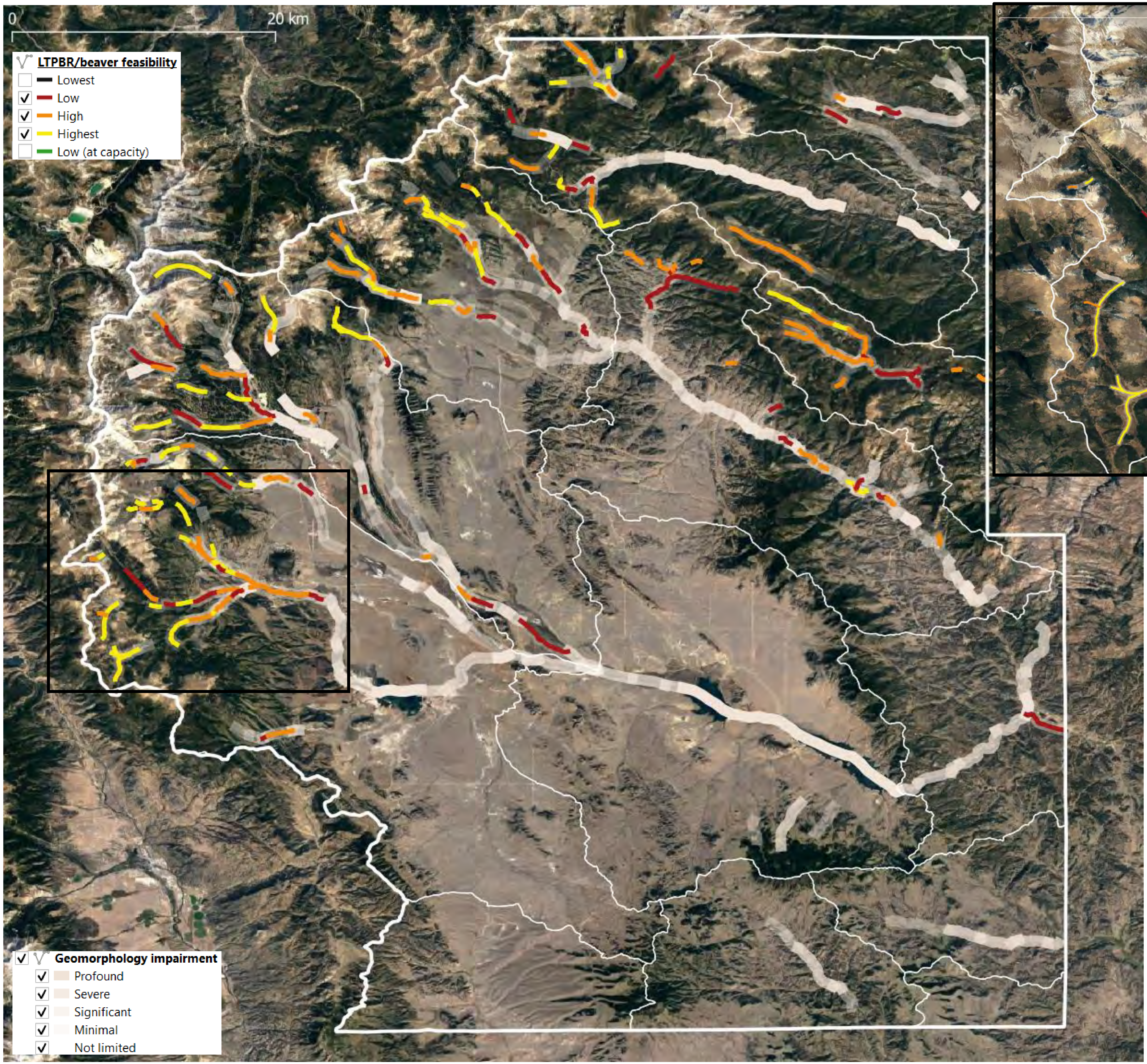


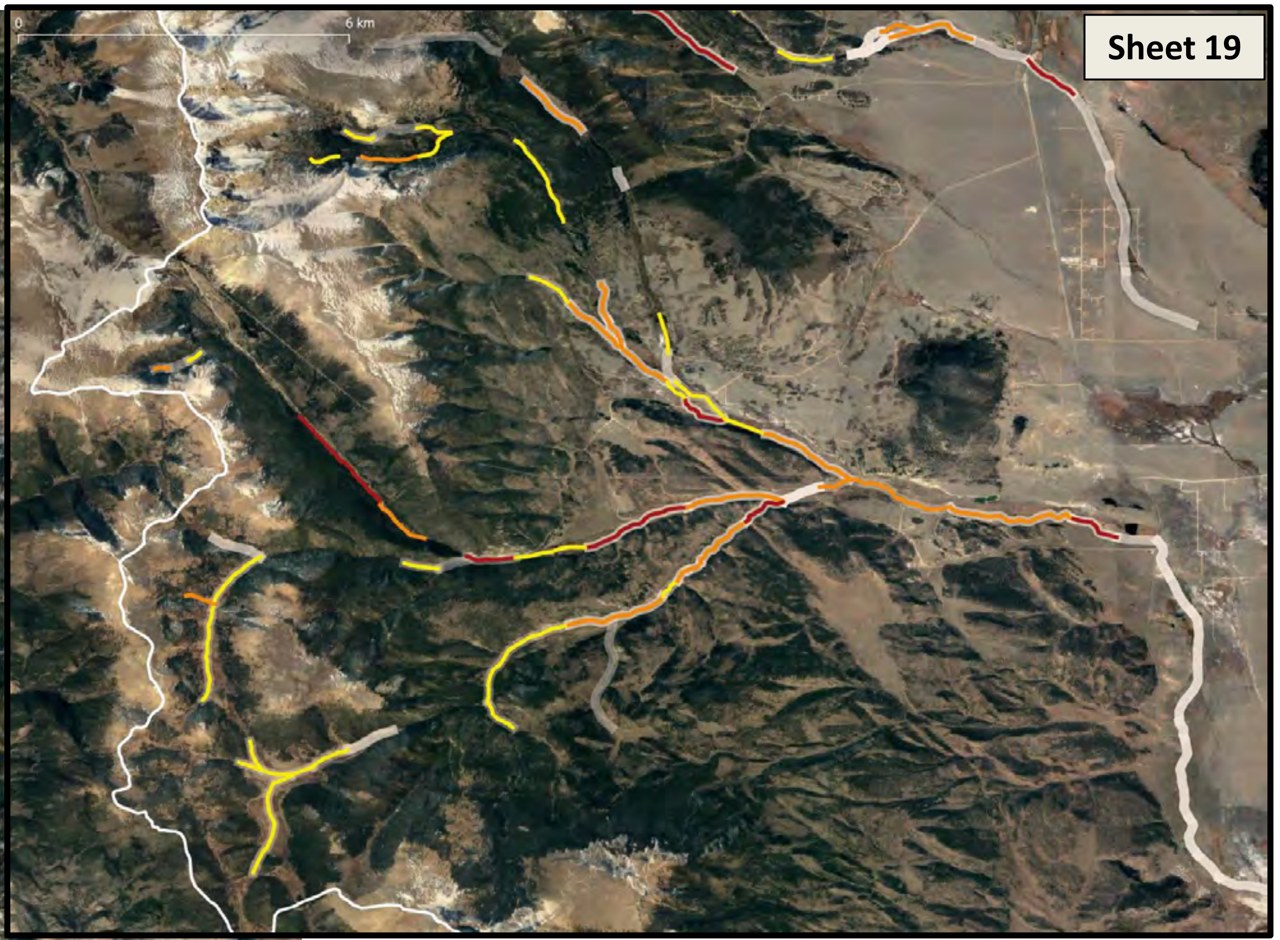


Limiting factor analysis: hydrology limitations

This map is an overlay of the segments in the highest, high, and low feasibility categories over hydrology impairment. None of the streams in the high-priority triage classes are significantly limited by anthropogenic impacts to hydrology.

Hydrology limitations					
Stream length (km)	Hydrology impairment rating				
	4	3	2	1	0
At capacity	34.2	0.0	0.0	0.0	0.0
Best	95.1	0.0	0.0	0.0	0.0
Good	106.7	0.0	0.0	0.0	0.0
Moderate	72.4	1.8	0.0	0.0	0.0
Poor	357.6	15.1	20.6	31.0	4.7



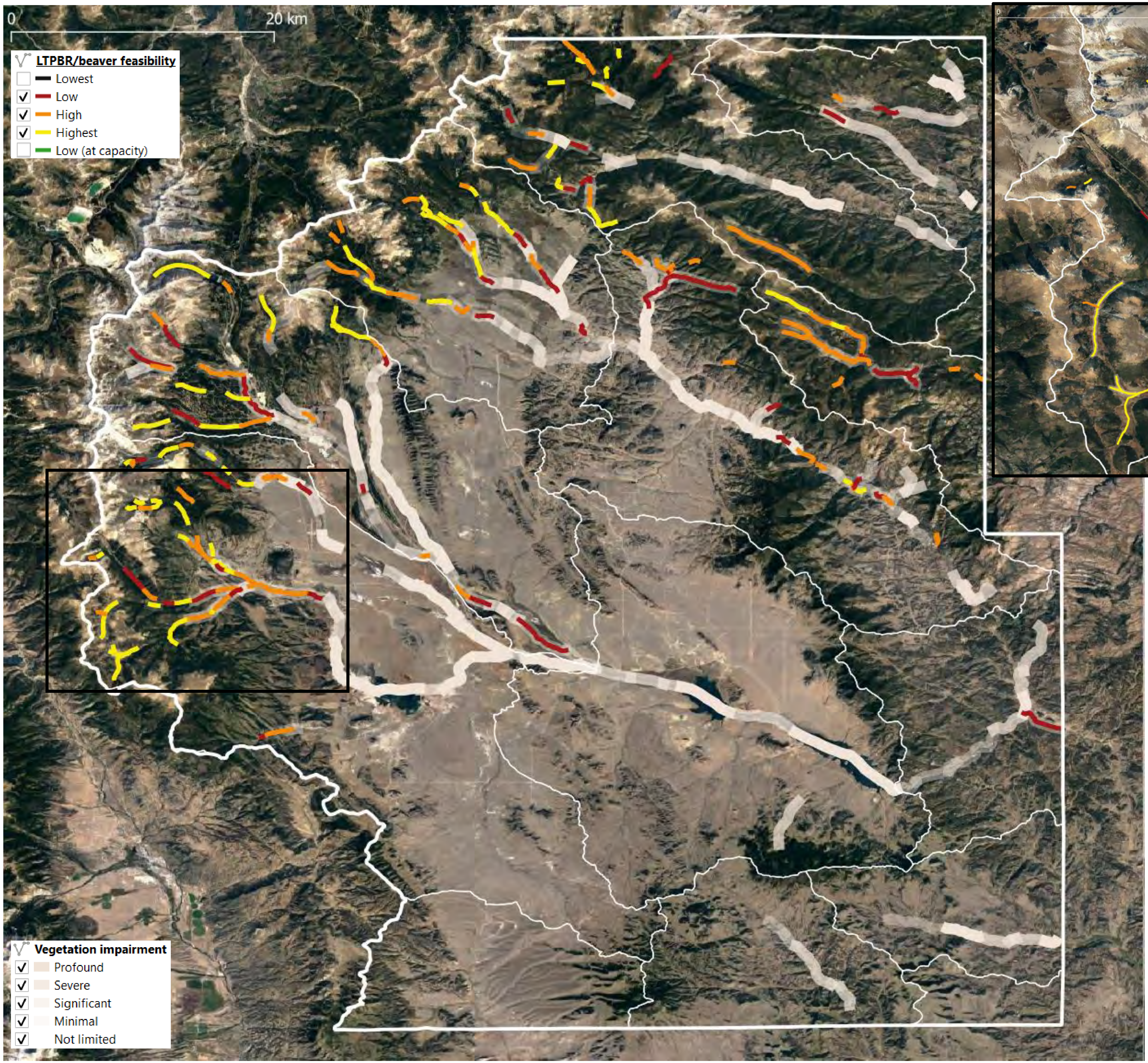


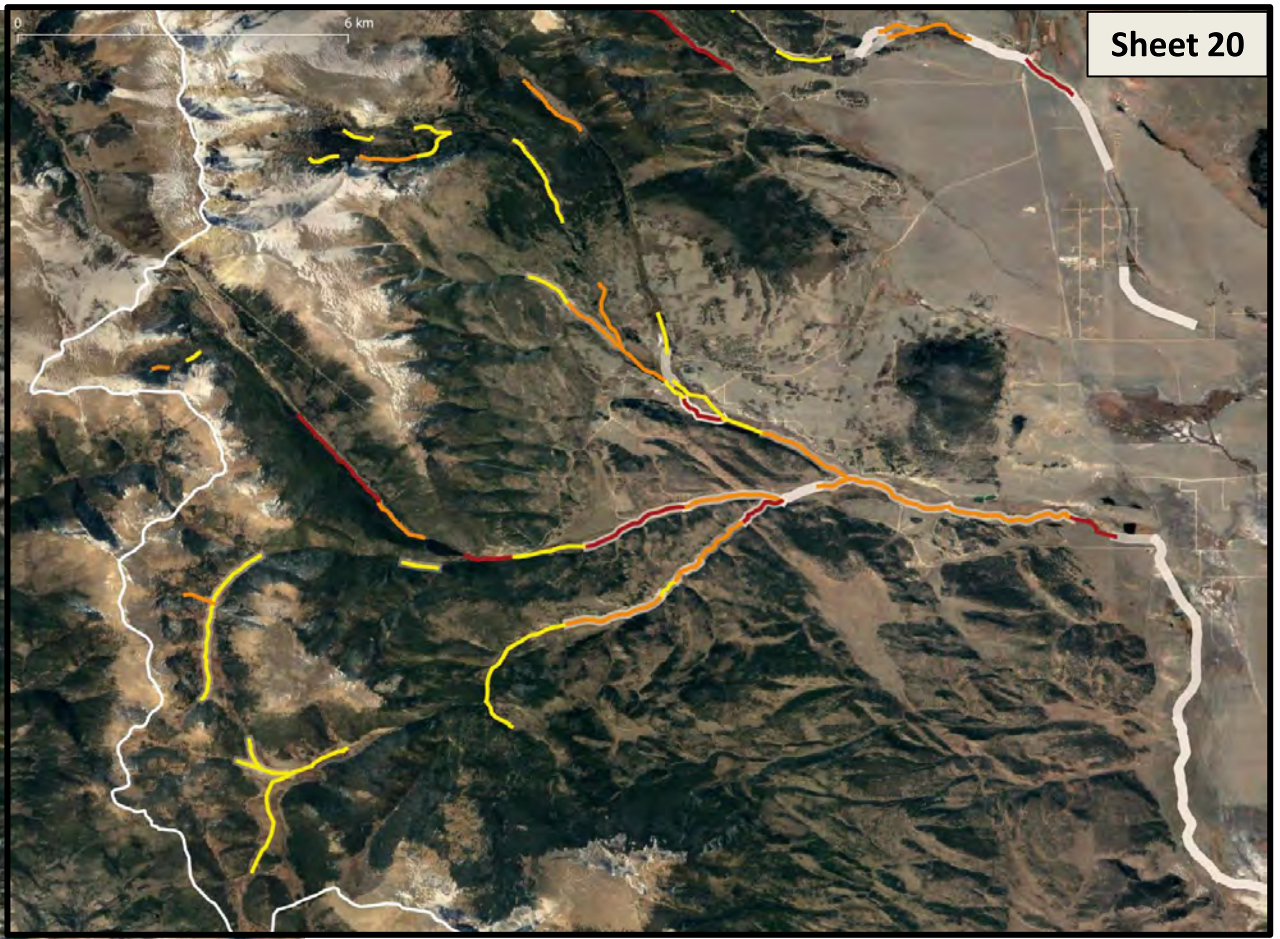
Limiting factor analysis: geomorphology limitations

This map is an overlay of the segments in the highest, high, and low feasibility categories over geomorphology impairment. 21% of stream corridor in the high and highest feasibility categories may be significantly limited and none severely limited by geomorphology impairment.

60% of stream corridor in the low feasibility category may be significantly limited and none severely limited by geomorphology impairment.

Geomorphology limitations					
Stream length (km)	Geomorphology impairment rating				
	4	3	2	1	0
At capacity	31.0	3.2	0.0	0.0	0.0
Best	22.0	71.7	0.0	0.0	0.0
Good	9.5	54.7	42.5	0.0	0.0
Moderate	4.0	25.7	44.5	0.0	0.0
Poor	11.8	46.7	137.5	164.0	68.4

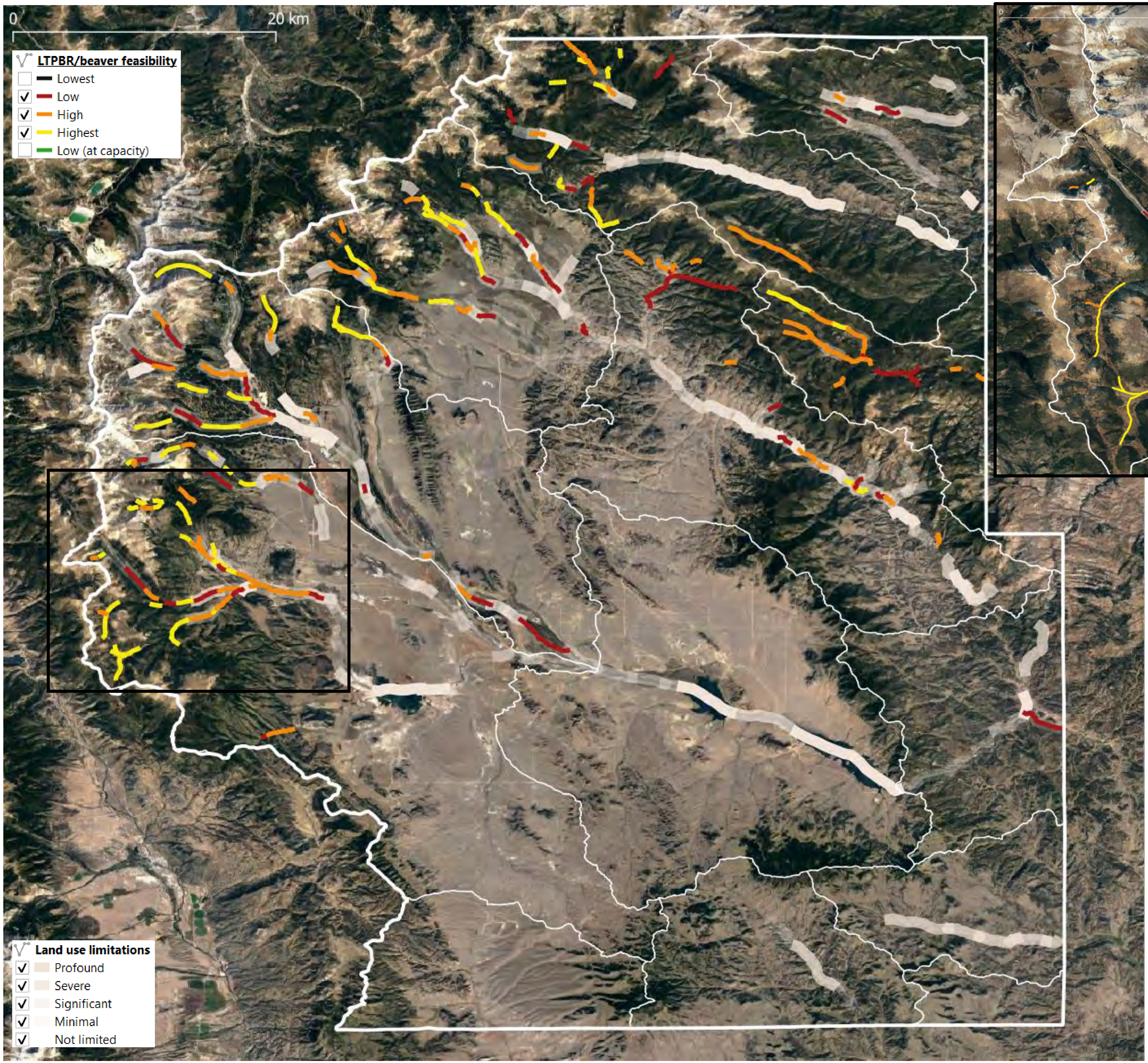


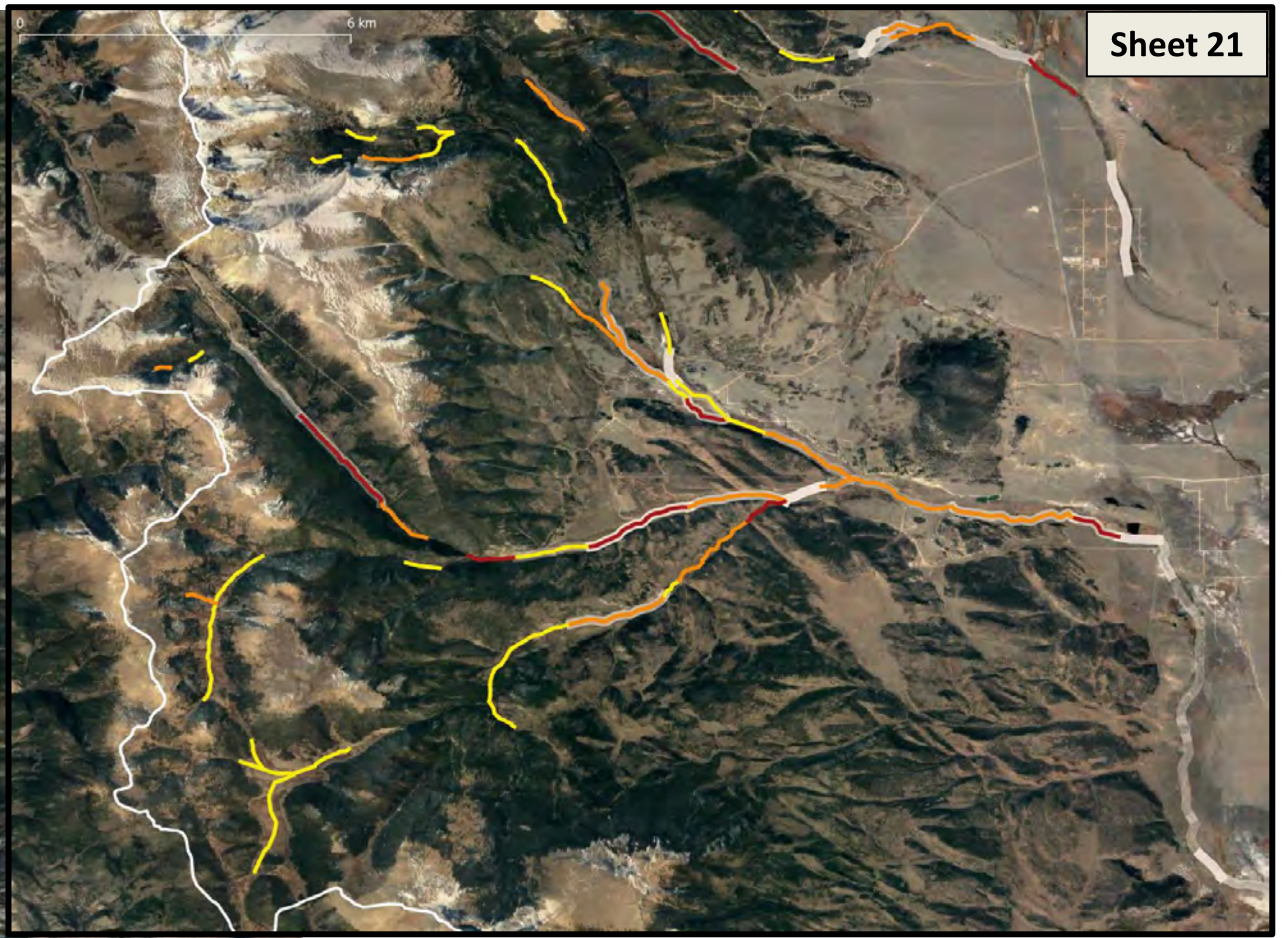


Limiting factor analysis: vegetation limitations

This map is an overlay of the segments in the highest, high, and low feasibility categories over vegetation impairment. 10% of stream corridor in the high and highest feasibility categories may be significantly limited and none severely limited by vegetation impairment. 54% of stream corridor in the low feasibility category may be significantly limited and 1% severely limited by vegetation impairment.

Vegetation limitations					
Stream length (km)	Vegetation impairment rating				
	4	3	2	1	0
At capacity	34.2	0.0	0.0	0.0	0.0
Best	76.9	18.2	0.0	0.0	0.0
Good	42.1	44.7	19.9	0.0	0.0
Moderate	23.1	9.7	39.9	1.5	0.0
Poor	71.9	33.6	59.2	161.5	102.2

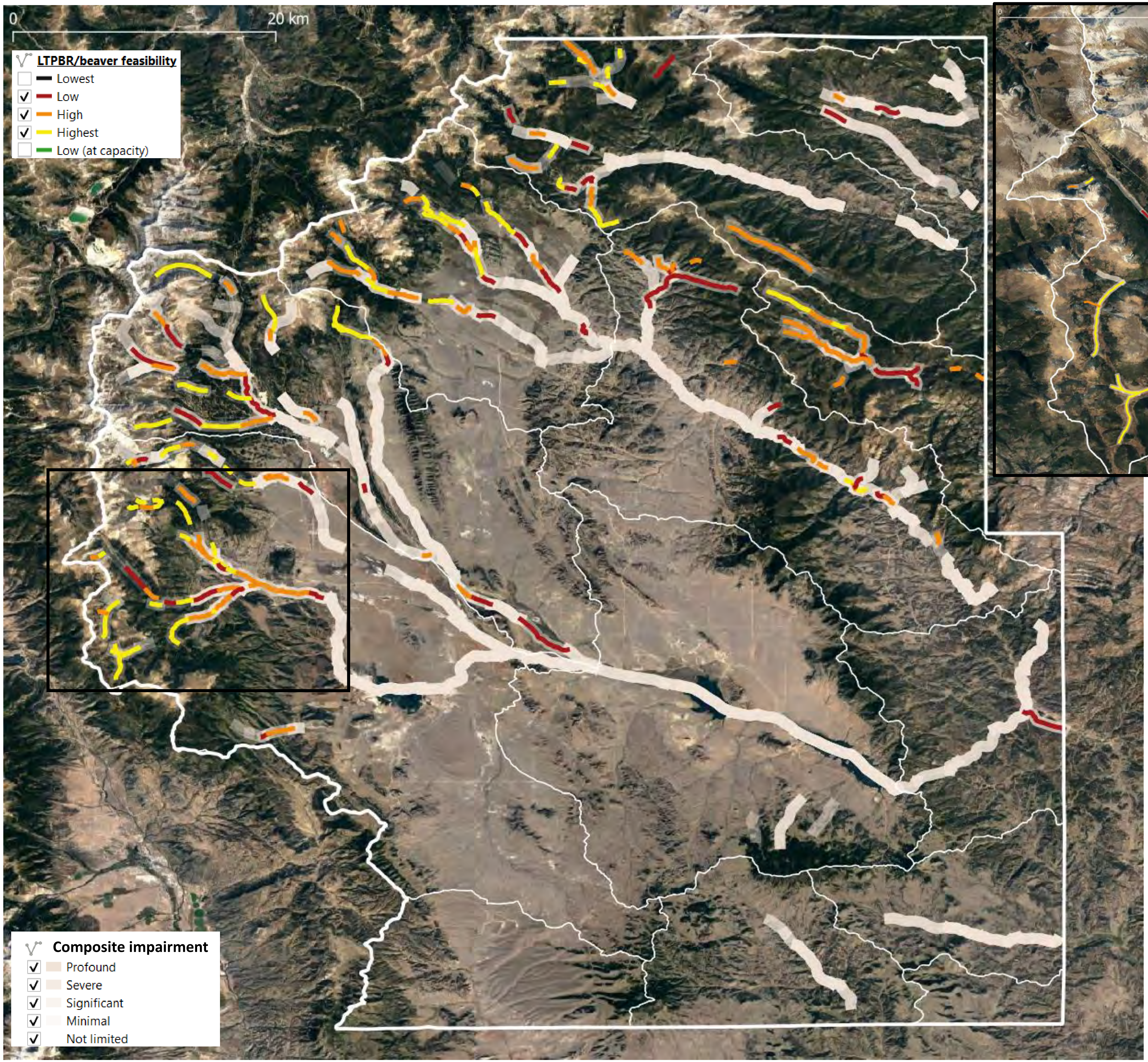


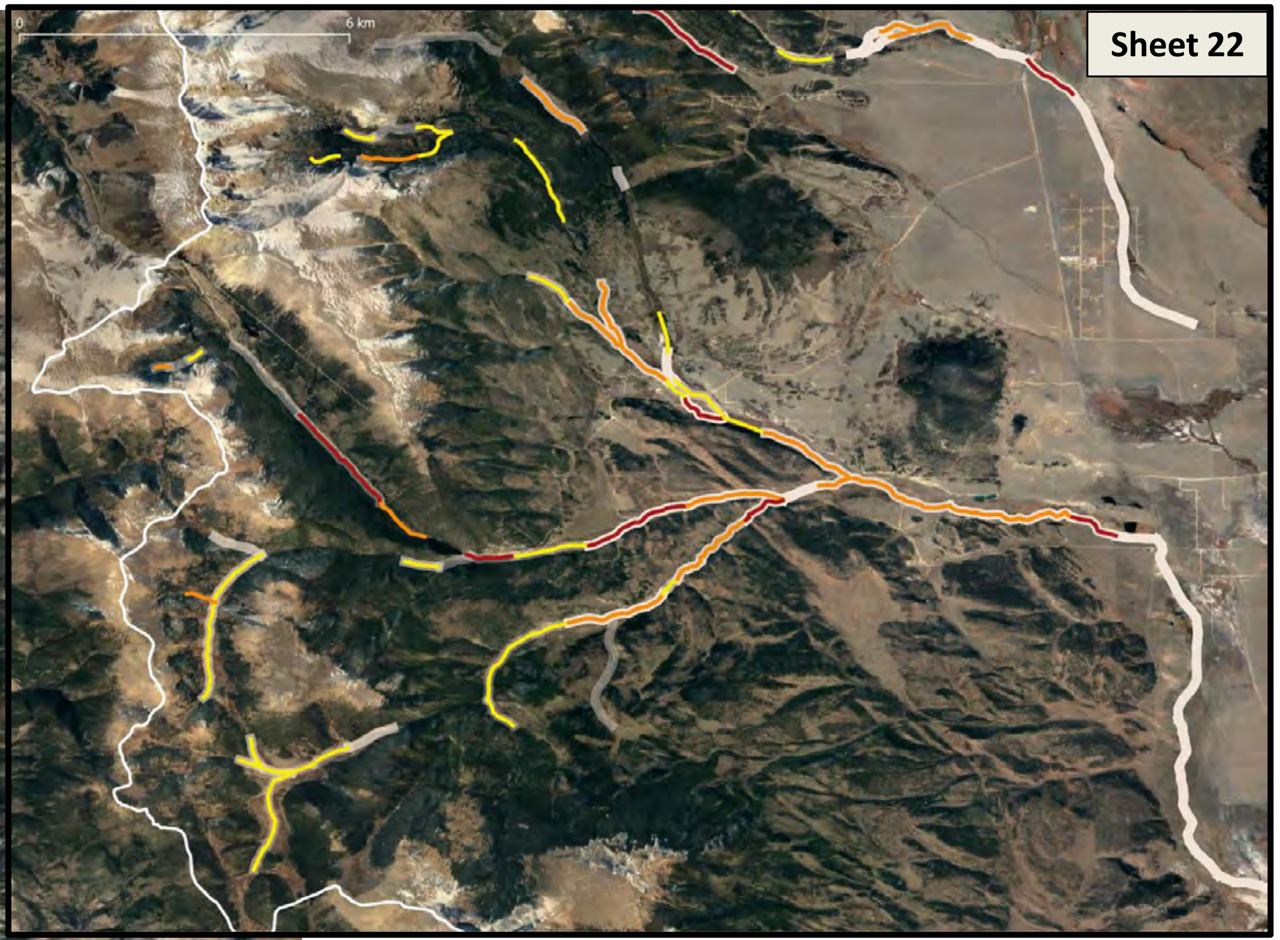


Limiting factor analysis: land use/infrastructure limitations

This map is an overlay of the segments in the highest, high, and low feasibility categories over land use/infrastructure limitations. 12% of stream corridor in the high and highest feasibility categories may be significantly limited and none severely limited land use or infrastructure. 26% of stream corridor in the low feasibility category may be significantly limited and 1% severely limited by land use or infrastructure.

Land use/infrastructure limitations					
Stream length (km)	Land use/infrastructure impairment rating				
	4	3	2	1	0
At capacity	20.9	13.3	0.0	0.0	0.0
Best	67.9	27.2	0.0	0.0	0.0
Good	60.7	21.6	24.4	0.0	0.0
Moderate	19.5	17.8	19.5	1.6	0.0
Poor	89.9	99.7	83.9	94.3	60.6

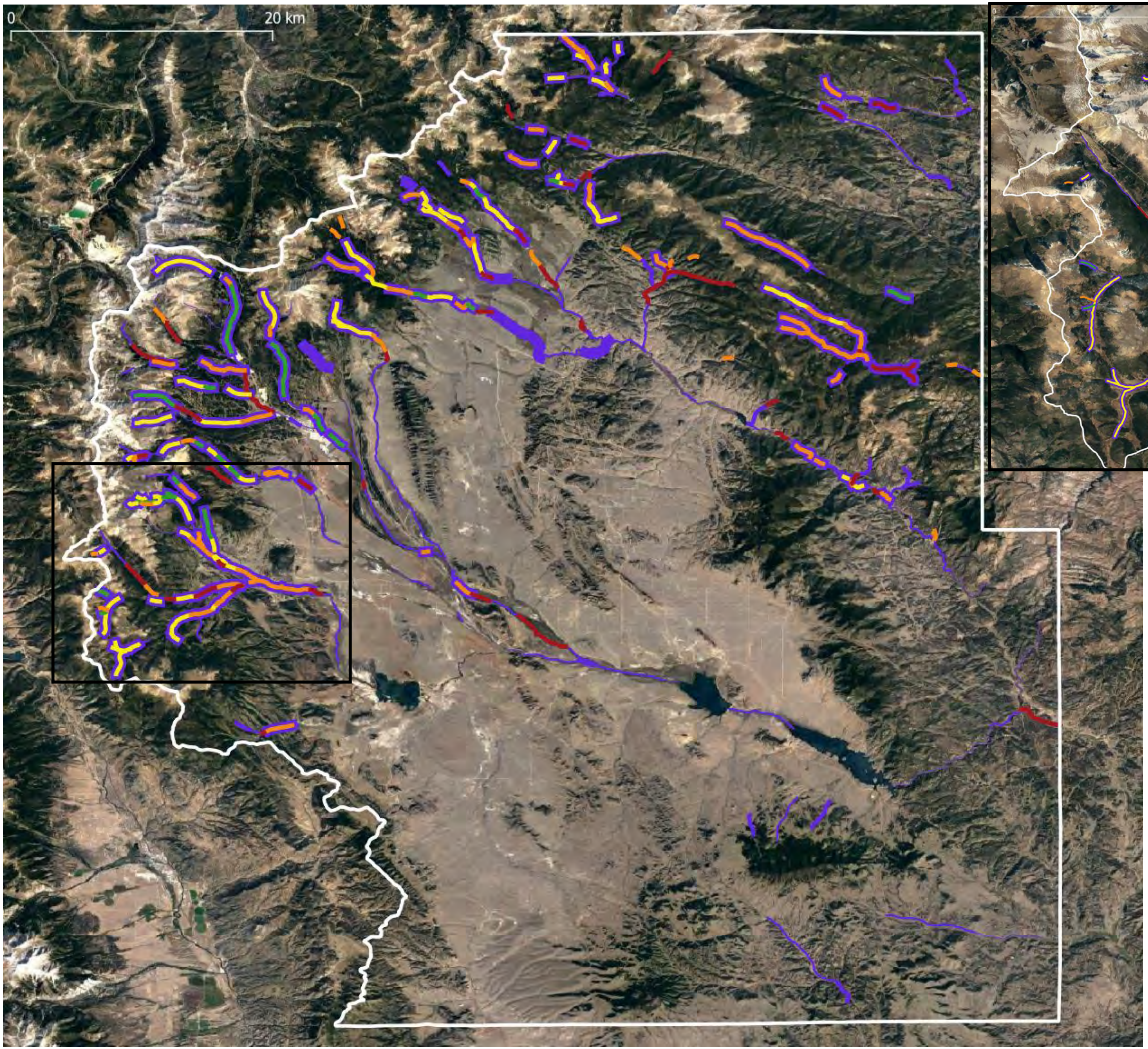


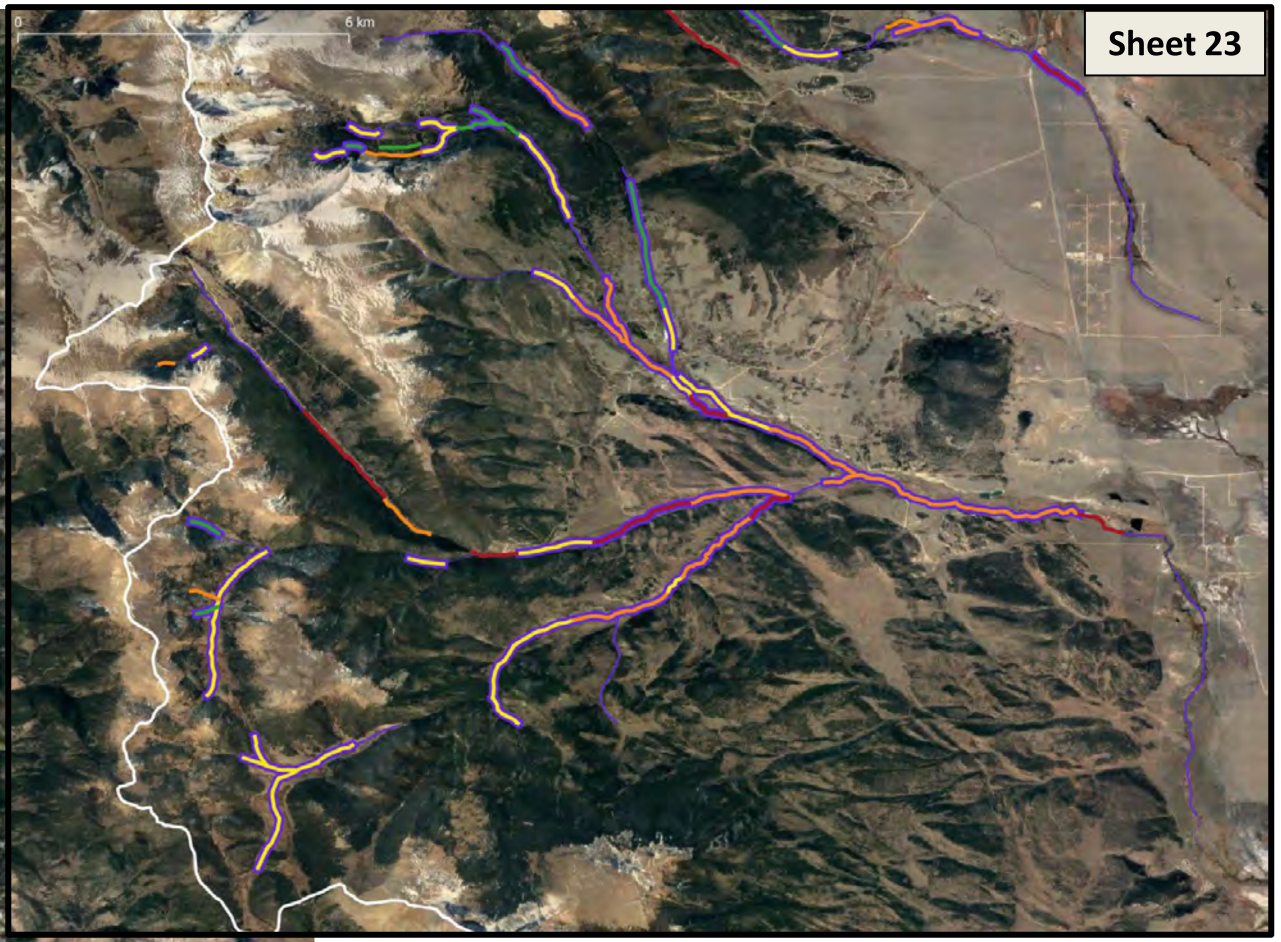


Limiting factor analysis: composite limitations

This map is an overlay of the segments in the highest, high, and low feasibility categories over the combined effects of anthropogenic impairment to hydrology, geomorphology, vegetation, and land use or infrastructure. 31% of stream corridor in the high and highest feasibility categories may be significantly limited and none% severely limited by combined impairment of hydrology, geomorphology, vegetation, and/or land use/infrastructure. 85% of stream corridor in the low feasibility category may be significantly limited and 22% severely limited by combined impairment of hydrology, geomorphology, vegetation, and/or land use/infrastructure.

Composite limitations					
Stream length (km)	Composite impairment rating				
	4	3	2	1	0
At capacity	20.9	13.3	0.0	0.0	0.0
Best	16.9	78.2	0.0	0.0	0.0
Good	6.3	38.3	62.1	0.0	0.0
Moderate	0.0	8.2	62.9	3.1	0.0
Poor	8.4	35.1	62.1	168.7	153.6



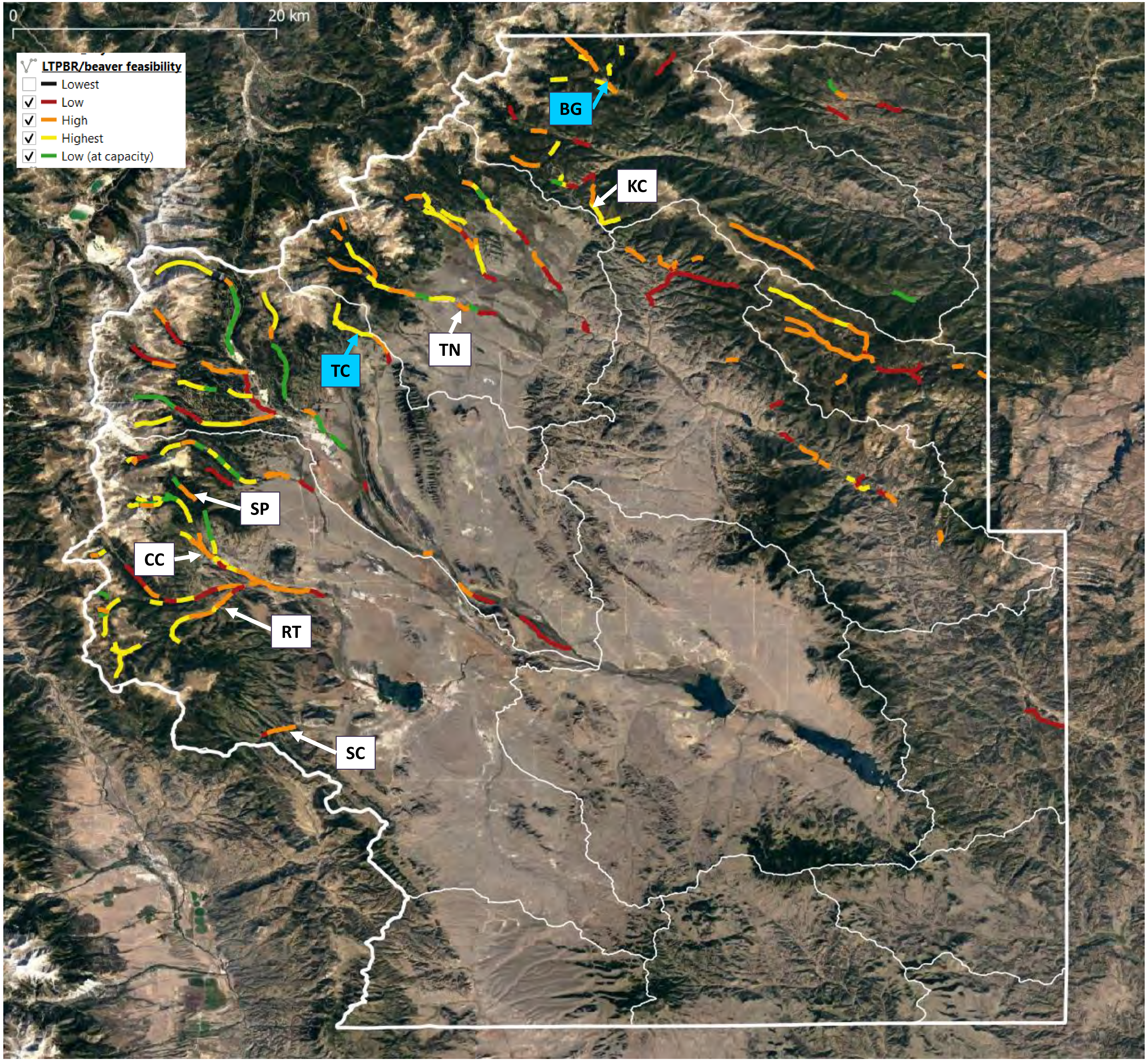


Potential lift

This map is an overlay of the segments in the highest, high, and low feasibility categories over restorable capacity. The potential for lift (the potential increase in beaver activity via restoration) was estimated as the difference between restoration capacity and current beaver activity and evaluated by triage class.

Potential lift by triage class

Triage class	Existing activity (1° dams)	Potential activity (1° dams)	Potential lift (1° dams)	Stream length (km)	Potential lift (dams/km)
At capacity	877	877	0	34.2	0.0
Best	1053	2794	1741	95.1	18.3
Good	372	2741	2369	106.7	22.2
Moderate	146	1112	966	74.2	13.0
Poor	92	1548	1456	428.4	3.4



LTPBR/beaver restoration projects in context

This map shows the location of Riparian Reconnect's current or developing LTPBR/beaver restoration projects in the context of the county-wide network of restoration opportunities. The table below shows how each project area scores in the assessment.

ID	V_width	BEV_curr	CAP_hist	CAP_curr	CAP_rest	LIM_bev	LIM_hyd	LIM_geo	LIM_veg	LIM_use	LIM_MIN	BRA_rating
BG	4	0	4	4	4	2	4	3	4	4	3	3
KC	4	2	4	4	4	3	4	3	4	4	3	3
TN	4	2	4	4	4	3	4	2	3	4	2	2
TC	4	1	4	4	4	3	4	3	4	3	3	3
SP	3	0	4	4	4	2	4	2	4	4	2	2
CC	4	2	4	4	4	3	4	2	3	4	2	2
RT	4	0	4	4	4	2	4	2	3	4	2	2
SC	3	0	4	4	4	2	4	2	3	4	2	2