# Assessing the Potential for Beaver Restoration and Likely Environmental Benefits

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# 1 ABSTRACT

In 2017, Boulder County Parks and Open Spaces (BCPOS) and the City of Boulder Open Spaces and Mountain Parks (OSMP) jointly funded an inquiry into the potential for Boulder County streams to support North American beavers. The resulting study includes a literature review into the benefits and habitat requirements of beaver as well as original research on the potential for streams to support beaver dams in Boulder County. Research included site visits to BCPOS and OSMP properties and remote characterization of potential habitat. The field study utilized a checklist approach to assess suitability for either beaver reintroduction or construction of beaver dam analogs. The remote characterization, which was conducted for the entire St. Vrain watershed stream network, uses the beaver restoration assessment tool (BRAT) model based on physical and vegetative characteristics of stream segments to predict potential habitat suitability. From both modeling and site visits, the BCPOS streams with the highest potential for successful beaver reintroduction are Delonde and Sherwood Creeks, and the OSMP streams with the high potential are Coal and South Boulder Creeks. According to hydrologic models created for segments of Delonde and Sherwood Creeks, the addition of a couple of beaver dams could increase inundated area by up to 537% at baseflow, thus increasing potential carbon storage in the valley bottom by up to 562%. Preliminary investigation into beaver restoration in Boulder County thus suggests that beaver reintroductions or beaver dam analogs are viable at multiple sites and could have a significant ecologic, hydrologic, and geomorphic effect on valley bottoms.

# 2 INTRODUCTION

## 2.1 BENEFITS OF BEAVERS AND BEAVER DAMS

The restoration of North American beaver (*Castor canadensis*) can be a self-maintaining resource management tool for promoting spatial heterogeneity and connectivity of streams and rivers. Sediment and excess nutrient storage, attenuation of flood peaks, increased surface and subsurface water storage, and greater habitat diversity created by beaver activities are some of the reasons why beaver reintroduction is increasingly being used in restoration of river corridors (Pollock et al., 2015). River corridor here refers to the channel(s) and the adjacent floodplain, as well as the underlying hyporheic zone (Harvey and Gooseff, 2015).

Beaver are ecosystem engineers and a keystone species, meaning they have a disproportionately large ecologic, geomorphic, and hydrologic effect on their environment compared to their abundance (Baker and Hill, 2003; Rosell et al., 2005). In low order streams, beaver build channel-spanning dams that obstruct flow, cause backwater ponding, and decrease stream power and velocity (Naiman et al., 1986; Stout et al., 2016). Decreased velocities allow for the aggradation of sediment and organic matter behind dams, which raises the stream bed and reconnects incised channels with old floodplains (Butler and Malanson, 1995; Pollock et al., 2007). Channel-spanning dams also force a greater magnitude of overbank flow at a greater frequency and duration, causing stable, multi-threaded channel networks to form (Westbrook et al., 2006; Polvi and Wohl, 2012). Increased overbank flooding from dams increases the lateral extent of groundwater recharge and hyporheic exchange, thus raising local water tables

(Westbrook et al., 2006; Janzen and Westbrook, 2011). Increased lateral connectivity and decreased stream power create a positive feedback, allowing for a higher density of beaver dams within a reach until the river corridor (channel(s) and floodplain) reaches a dynamic, wet equilibrium known as a beaver meadow complex (Pollock et al., 2014; Polvi and Wohl, 2012).

Healthy beaver meadow complexes could have significant implications for climate, including fire mitigation, water retention, and carbon storage (Polvi and Wohl, 2012; Wohl, 2013). Meadows, including those occupied and not occupied by beaver, comprise approximately 5% of the landscape in watersheds on the eastern side of Rocky Mountain National Park, but account for up to 23% of terrestrial carbon storage (Wohl, 2013). Beaver dams in the Rocky Mountains also retain water, both behind dams and in the banks (Wegener et al., 2017), which could increase late summer discharges needed to support ecological communities.

In addition to physical benefits of attenuation and resilience, beaver meadows increase the biodiversity of river corridors by creating a diversity of riparian and aquatic habitat. Beaver meadows provide suitable habitat for vegetation (Westbrook et al., 2011), aquatic insects and their riparian predators (McDowell and Naiman, 1986; Fuller and Peckarsky, 2011; McCaffery and Eby, 2016), fish (Pollock et al., 2003), frogs and other amphibians (Anderson et al., 2015; Arkle and Pilliod, 2015), butterflies (Bartel et al., 2010), birds (Aznar and Desrochers, 2008), and other semi-aquatic mammals such as mink and otter (Rosell et al., 2005).

The apparent ecosystem and environmental benefits of beaver activity warrant increased interest in maintaining beaver on the landscape. However, reintroduction of beaver is necessary due to the continental scale decrease of beaver post-European settlement. Prior to European settlement, an estimated 60 to 400 million individual beaver populated North America (Seton, 1929). Trapping for the commercial fur trade caused the near extirpation of beaver by the late 19th century (Rutherford, 1964; Baker and Hill, 2003). In Colorado, increased State regulations regarding trapping allowed for some beaver colonies to recover in the early 20th century (Retzer et al., 1956). However, beaver populations have not recovered in many watersheds once housing colonies across Colorado. Reasons hindering recovery include habitat loss due to urbanization and agriculture, herbivory competition by elk, moose, and cows (Baker et al., 2005; Small et al., 2006), and removal of beaver due to property damage concerns (McKinstry and Anderson, 1999). Contemporary beaver populations are estimated at approximately 10 million individuals across their ecological range in North America (Naiman et al., 1988; Pollock et al., 2015).

## 2.2 What makes suitable habitat for North American beavers?

The restoration of beaver starts with the identification of suitable habitat that is likely to support beavers or be viable for beaver dam analogs. A suitable habitat for North American beaver is one where a beaver colony can survive and reproduce. To survive, beavers need vegetation for food and for building dams and bank dens. Several studies have confirmed that aspen, willow, and cottonwood are the preferred dam building and foraging material of beaver (Allen, 1983; Kimball and Perry, 2008). However, beaver diets are seasonal and diverse. In the summer, beaver prefer high nutrient, herbaceous vegetation such as sedges and rushes as well as leaves from deciduous trees. In the winter, the beaver diet relies on the inner bark (cambium) of trees, preferably those previously mentioned. In the Colorado Front Range, suitable vegetation for beaver is also preferred vegetation by large grazers such as moose and elk. Heavy grazing by moose and elk degrades potential beaver habitat by reducing food supply and dam building materials (Baker et al., 2005). The diameter of the tree also matters, as beaver have predominantly been shown to forage trees with a diameter between 1 to 6 inches at breast height. Additionally, the maximum distance beaver will travel to harvest vegetation is 100 meters (Allen, 1983). Beaver also need access to the floodplain to harvest vegetation, so heavily incised streams can hinder dam building (Pollock et al., 2014). A suitable habitat for beaver would include both woody vegetation and herbaceous vegetation, with a moderate to abundant presence of 1-6" diameter aspen, willow, and/or cottonwood within 100 meters of the stream edge without heavy grazing from moose or elk.

Water is another important component of suitable beaver habitat. Beaver need a reliable water source to survive and build dams. Beaver have been reported on some intermittent streams, but predominantly inhabit perennial streams as a reliable water source (Albert and Trimble, 2000; Pollock et al., 2015). Beaver need a habitat where the dam building is capable at typical flows (i.e. baseflow) and will not blow out during typical floods (i.e. a 2-year flood). The suitability of flows are typically quantified using stream power, which is a product of channel gradient and discharge. Low gradients (<3%) and small- to medium- sized channels (first and second order streams) typically produce stream powers that are sufficiently low enough for beaver to build and sustain dams. Additionally, low gradient (<3%) channels typically have a pool-riffle habitat, which beavers prefer due to low velocities in the pools. Beaver generally avoid high- gradient, constrained valleys, and will typically only population these habitats if their population densities are high (Muller-Schwarze and Schulte, 1999). Therefore, habitat suitable for beaver would be a first or second order stream with a low gradient that is not prone to frequent, intense flooding.

In addition to food and water, other factors such as noise and man-made structures could limit the suitability of beaver habitat. Loud noises and frequent flashing lights have anecdotally been known to deter beaver (Nolte et al., 2005; McPeake, 2013). For this reason, areas that are highly trafficked by pedestrians, bikes, or vehicles often do not make suitable beaver habitats. Man-made structures such as culverts and grates in proximity to the flow could pose a threat to beaver if their dam were to fail during high flows. Therefore, a suitable habitat is one that would not pose a human threat to the beaver at typical visitation levels or during large floods.

## 2.3 WHAT MAKES A SUITABLE ENVIRONMENT FOR A BEAVER DAM ANALOG (BDA)?

A beaver dam analog is a man-made instream structure, typically made of natural material, meant to mimic a beaver dam. Beaver dam analogs are temporary features that are semi- porous and biodegradable. The purpose of a beaver dam analog is typically to create habitat for beaver or increase the possibility of success for beaver reintroductions (Pollock et al., 2014). However, beaver dam analogs have also been known to mitigate erosion, facilitate deposition, and raise the water table (Pollock et al., 2012; Silverman et al., 2018). The hydrologic effect of a beaver dam analog often results in an increased abundance of riparian vegetation.

The construction of beaver dam analogs often limits the scale and location at which they can be built. While there is no standard design or management for beaver dam analogs, the construction of a beaver dam analog requires transportation of large woody materials to the site and human-power to build the analog. Sometimes, the process of building BDAs requires heavy equipment. Therefore, accessibility is important. Narrow streams with low velocities are typically the best candidate for beaver dam analogs, because equipment is able to enter the stream or volunteers are able to construct an analog of proper size.

# 3 STUDY SITES

All sites within this study were located on public land. Stream reaches included in this study were chosen by Boulder County Parks and Open Spaces (BCPOS) and the City of Boulder Open Spaces and Mountain Parks (OSMP). The reaches investigated are listed below by managing agency and are shown on Figure 1.

BCPOS stream reaches:

1. Delonde Creek in Caribou Ranch Open Space
2. St. Vrain Creek in Montgomery and Western Mobile Plots
3. St. Vrain Creek in Braly Plot
4. Middle Boulder Creek in Rogers Park
5. Middle Boulder Creek in Platt-Rogers Park
6. Sherwood Creek in Mud Lake Open Space

City of Boulder OSMP stream reaches:

1. Coal Creek from Highway 72 to the town of Superior
2. Boulder Creek from 75th to 95th Street
3. South Boulder Creek from Marshall Road to South Boulder Road
4. Lefthand Creek from James Canyon Drive intersection to Buckingham Park
5. Boulder Creek from Valmont Road to 0.5 miles east of 61st Street

# 4 METHODS

## 4.1 SITE SUITABILITY ASSESSMENTS

Field measurements and visual assessment of each stream segment were recorded during a series of site visits from July to October 2017. Stream assessments were made by filling out a geomorphic site suitability checklist at discrete points along each study creek. Checklist points were chosen as a semi-random sample of all available habitat along the stream reach. Points were semi-random to include two considerations into the study design: (1) at least one checklist should be completed per kilometer of stream and (2) checklist points should be accessible by road, trail, or hike. In total, 45 geomorphology checklists were completed during the 2017 field season (see Appendix A for access to data).

The geomorphic checklist was created to record typical habitat characteristics that support or impede beaver establishment. Habitat characteristics that are important to take into account when considering beaver reintroduction are detailed in the introduction (Section 2.2), and broadly include stream discharge, gradient, valley bottom width, vegetation, and human or ecologic conflict. The checklist was also created to be compatible with the geomorphic scorecard (see Section 4.2) in order to compare suitability across sites. The checklist and scorecard were adapted from a similar site suitability analysis in the 2015 Beaver Restoration Guidebook and were used across all sites (Pollock et al., 2015).

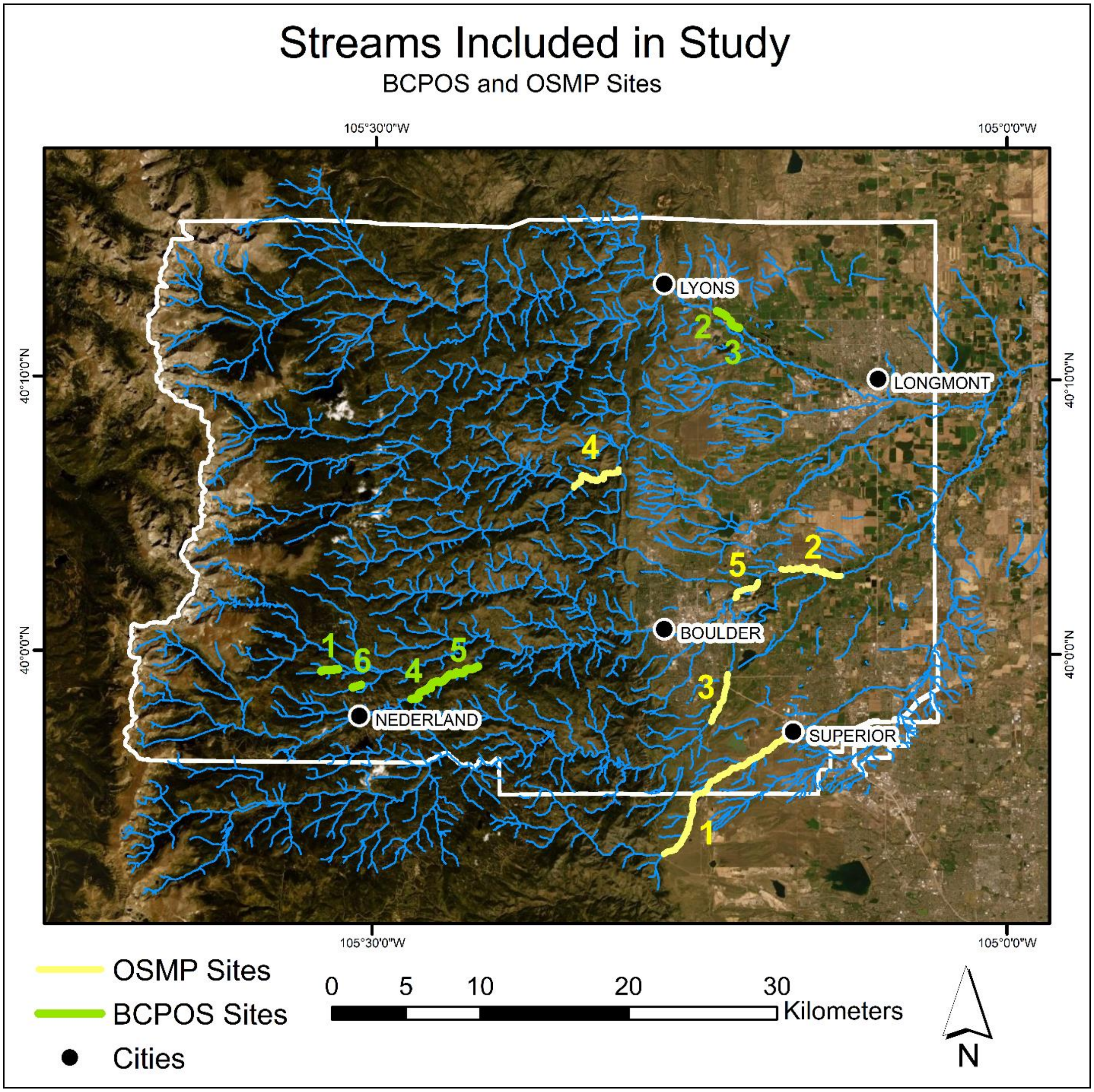


**Figure 1.** Map of City of Boulder OSMP and Boulder County POS study streams. Numbers indicate specific site name (see Section 3).

Certain characteristics were easier to measure remotely compared to in the field. Remotely measured variables included stream gradient, valley bottom width, and site length. Stream gradient and valley bottom width were calculated using ArcMap 10.4.1 and digital elevation models, while site length was measured in Google Earth.

Continuous stream gradient was calculated for all stream segments using a digital elevation model (DEM) for Boulder County (Figure 2). Three different channel classifications were identified from the resulting dominant bedforms that would be present at each range of stream gradients: gradients of 0.00 – 0.03 m/m are pool-riffle reaches, gradients from 0.03 to 0.10 m/m are step-pool reaches, and gradients > 0.10 m/m are cascade reaches (Montgomery and Buffington, 1997; Wohl, 2014). Beaver are most likely to build dams in pool-riffle channel segments, although they are capable of building dams within the lower gradient range of step-pool channels. If the intent of reintroducing beaver is to maximize attenuation of downstream fluxes of water, sediment, and nutrients, however, beaver reintroduction should focus on stream segments with gradient less than approximately 0.05 m/m.

The Valley Bottom Extraction Tool (V-BET) was used to calculate continuous valley bottom width. V-BET is an ArcGIS based tool developed at Utah State University to delineate valley bottom widths from 10 m DEM and threshold drainage areas (Gilbert et al., 2016). Valley bottom width is important in the context of beaver reintroduction or construction of beaver dam analogs (BDAs) because wider valley bottoms attenuate flood flows even in the absence of within-channel obstructions such as beaver dams. This attenuation of flow energy during peak flows enhances the stability of beaver dams or BDAs and the retention of water, sediment, and solutes via deposition of sediment and hyporheic exchange of water and solutes. Additionally, wider valley bottoms allow for more vegetation and subsequent beaver foraging.

Site characteristics measured in the field included channel dimensions, grain size class, vegetation presence and abundance, human hazards, grazing conflicts, and evidence of past beaver occupation. Geomorphic characteristics measured in the field included channel dimensions and dominant grain size, which can be indicative of the flow regime. Channel dimensions included bankfull channel width, bankfull depth, and bank incision depth, which were measured using a TruPulse 360°B Laser Rangefinder. Dominant channel grain size was estimated by conducting a random walk across a channel cross-section and noting the dominant substrate at the toe of each step (Wolman, 1954). Dominant grain size was estimated to be in one of the following categories: bedrock, boulders (0.25 – 4 m), cobbles (0.06 – 0.25 m), gravel (0.002 – 0.06 m), sand (0.06 – 2 mm), or silt/clay/mud (<0.06 mm). If a random walk produced large variability in dominant clast size, an average was recorded.

Type and abundance of vegetation was also recorded during site visits. Vegetation type was broadly split into grasses/sedges/rushes, shrubs, and trees. Sedges and rushes were included in a category with grasses due to their use as a seasonal food source for beaver. Trees were further identified as coniferous or deciduous, and trees that are highly suitable for beavers – aspen, cottonwood, willow, and alder – were classified by species. Abundance of suitable tree species was visually estimated within a 100 meter radius from the stream to reflect maximum beaver foraging distances (Allen, 1983). Distance from channel was measured using a TruPulse Laser Rangefinder. Reaches were labeled as not abundant if no suitable tree stems were present, moderately abundant if dozens of stems were present, and abundant if hundreds of stems were present. Abundance was recorded after walking the length of the reach to ensure all tree stands were identified and considered.

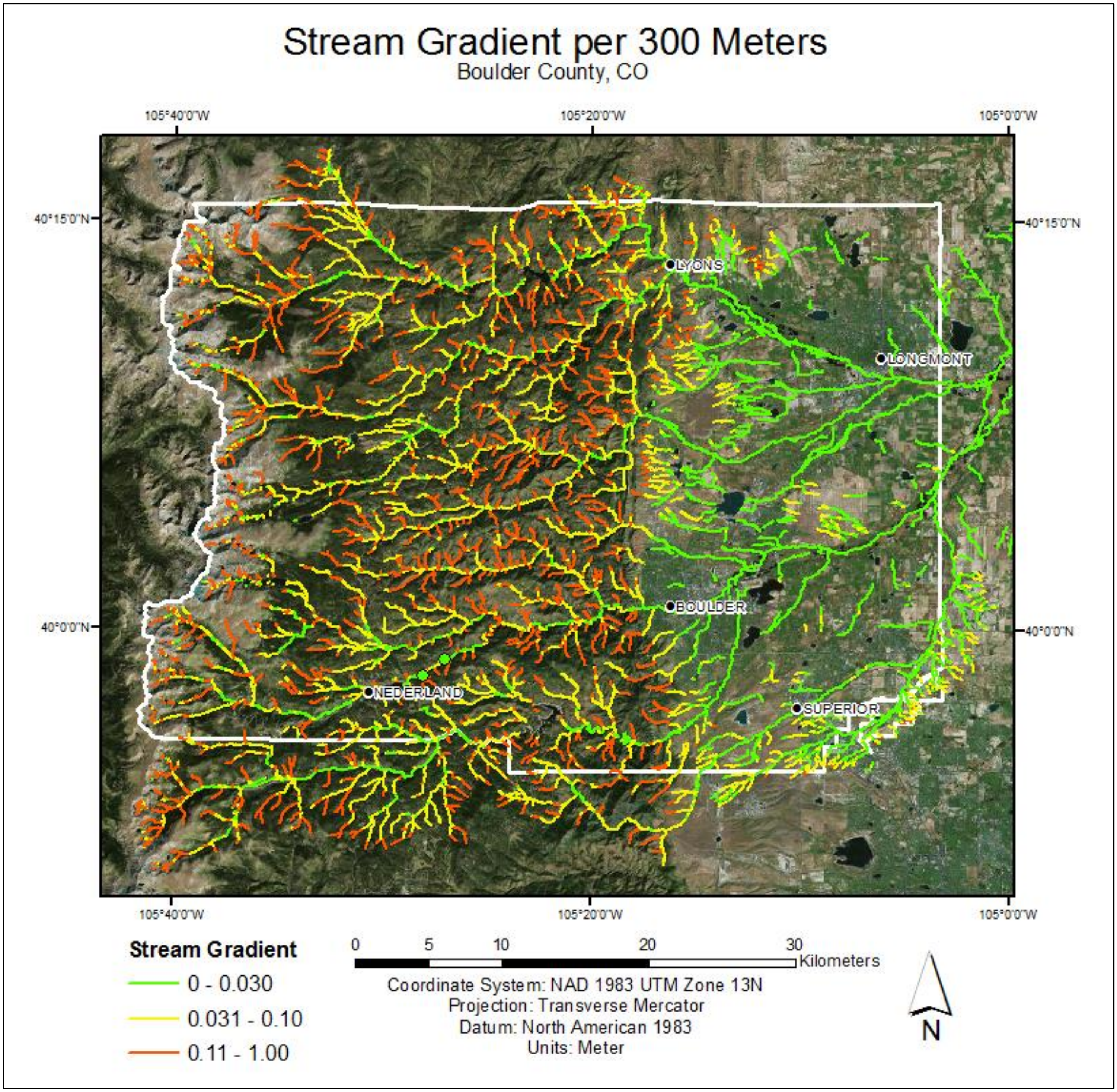


**Figure 2.** Stream Gradients of streams in Boulder County. Green stream segments are those with ideal gradients for beaver dams.

Grazing conflicts, past beaver occupancy, and human hazards were also noted in the field. Each of these categories represents a pre-existing condition that could hinder or help beaver restoration. Grazing and human hazards could hinder beaver restoration at a site due to conflict. Ungulates can outcompete beaver for suitable vegetation, thus limiting beaver establishment. Ponding from beaver dams can threaten human infrastructure, thus limiting community approval of beaver restoration. Conversely, evidence of past beaver occupation could help beaver restoration, because it indicates that beavers were previously successful in colonizing a stream and in some cases, abandoned dams could be used as a sturdy foundation for new dams. Evidence of grazing conflicts that were recorded included grazing marks on aspens and sightings of moose, elk, and cows. Abandoned beaver ponds, beaver chewed wood, and berms indicative of abandoned beaver dams were recorded as evidence of past beaver activity. The location and size of culverts, intakes, bridges, and roads or trails were recorded as human hazards. Grazing and past beaver activity were included in the scorecard, but human hazards were not because the extent to which human hazards can hinder restoration is not well calculated. Instead, human hazards should be used as an additional consideration on top of geomorphic scores.

## 4.2 Geomorphic Scorecards

Additionally, a scoring method was used to determine suitable versus unsuitable sites. A scorecard is included in the appendix. The highest score of 100 would indicate an extremely suitable site. The scorecard was adapted from the Methow Beaver Project Potential Release Site Score Card published in the Beaver Restoration Guidebook (Pollock et al., 2015). The scorecard ranks sites based on known suitable and unsuitable habitat characteristics mentioned in Section 2.2, as well as relative importance of each characteristic. The majority of a site score is based on water and vegetation availability, but also includes deductions for conflicts such as ungulate grazing and ease of site access.

Essentially, the geomorphic scorecard is a method to rank the relative site suitability across sites in a watershed. There is no known threshold score above which beaver survival is ensured, but sites with high scores should be prioritized for restoration over low scoring sites. Scorecards were filled out with site information gathered using the geomorphic site suitability checklists (Section 4.1).

## 4.3 Beaver Restoration Assessment Tool (BRAT)

The Beaver Restoration Assessment Tool (BRAT) is an ArcGIS based model that calculates the capacity of a river to support beaver dam building (MacFarlane et al., 2017). BRAT uses nationally available spatial datasets for hydrology, vegetation, and topography to estimate beaver dam capacity on a stream network using fuzzy inference systems. BRAT incorporates maximum foraging distance, preferred foraging and building material, low and high flow requirements, and other known beaver habitat preferences when estimating the capacity of beaver and beaver dams that a landscape can sustain. Scientists at Utah State University and in the Riverscapes Consortium (https://www.riverscapes.xyz/) have implemented BRAT in watersheds in Utah, Idaho, Oregon, New York, and beyond, which suggests that the model is broadly applicable across North America.

Current vegetation in Boulder County was estimated using the LANDFIRE existing vegetation type (https://www.landfire.gov/, 30 m resolution). Stream networks were downloaded from the USGS National

Hydrography Dataset (NHD, https://www.usgs.gov/core-science-systems/ngp/national-hydrography). The NHD is mapped at the 1:24,000 scale or better and includes perennial, intermittent, and ephemeral streams. Ephemeral streams were excluded from the BRAT analysis because they lack discharge necessary to support beaver colonies. Discharge was represented using regional regressions for the 2-year flood (Q2) and baseflow (Qlow) developed by the USGS for Colorado (Capesius and Stephens, 2009). The equation for the minimum 7-day, 2-year flow (${}_7Q_{10}^{MIN}$) was used as a proxy for baseflow. Regressions from the Mountains hydrologic region of Colorado were used to model discharge in the St. Vrain watershed (HUC: 10190005) which includes all streams in Boulder County.

## 4.4 Hydrologic Modeling

Detailed channel surveys along approximately 100 m reaches of Delonde and Sherwood Creeks were completed in August 2018 (Table 1). Channel cross-sections were surveyed with a real-time kinematic (RTK) station with 1 mm vertical accuracy. Survey cross-sections were used to model hydrology and potential flooding due to dams in the Hydrologic Engineering Center's River Analysis System (HEC-RAS) developed by the Army Corp of Engineers. Four scenarios were modeled at each site: (1) baseflow without dams, (2) baseflow with dams, (3) 2-year flood without dams, and (4) 2-year flood with dams. Discharges for baseflow and a 2-year flood at each site were estimated using U.S. Geological Survey regional regressions (Capesius and Stephens, 2009).

Currently, there is no known method of hydrologically modeling semi-permeable beaver dams in HEC-RAS or any other widely available platform. Regular dams and weirs can be modeled in HEC-RAS, therefore notched weirs are used to mimic beaver dams in Delonde and Sherman Creeks. Since a true beaver dam could be more permeable than a weir, the following model is a liberal estimate of overbank flooding in the event of a beaver dam. The number of weirs that were modeled at each reach reflects both abandoned dam density observed in aerial imagery and modeled dam capacity calculated using BRAT.

**Table 1.** Physical characteristics of reaches along Delonde and Sherwood Creek modeled using HEC-RAS.

| Creek | Site Length (m) | No. of Surveys | Baseflow ($m^3/s$) | $Q_2$ ($m^3/s$) |
|---|---|---|---|---|
| Delonde Creek | 68.3 | 8 | 0.002 | 0.7 |
| Sherwood Creek | 105.1 | 11 | 0.0001 | 0.3 |

# 5 RESULTS

## 5.1 BOULDER COUNTY PARKS AND OPEN SPACES (POS) SITE ANALYSES

Eighteen geomorphic assessments across five sites were completed on POS property. The location of geomorphic assessments are labeled on Figure 3.

### 5.1.1 Delonde Creek in Caribou Ranch Open Space

**Average geomorphology score: 85**

A series of 8 ponds directly south of the Delonde Homestead were identified as remnant beaver ponds. Remnant beaver dams are present at the downstream end of each pond as well as on the floodplain throughout the valley. Aerial imagery of Caribou Ranch dating back to 2008 shows a greater number of ponds that have since gone dry (Figure 4). Large stands of young willow and aspen are present within 30 m of Delonde Creek, and the valley bottom has abundant grasses. Heavy grazing of aspen and willow (the dominant dam building material at these sites) has occurred, likely by elk and moose (Figure 5). This suggests that beaver reintroduction might need to be accompanied by grazing exclosures.

### 5.1.2 St. Vrain Creek in Montgomery and Western Mobile Plots

**Average geomorphology score: 61**

The Burlington Northern Santa Fe Railroad runs nearly parallel to St. Vrain Creek in the Montgomery and Western Mobile Plots. Potential hydrologic changes from beaver dams or beaver dam analogs could pose a threat to the railroad, whereas proximity to the rail could be a hazard to beaver. Surrounding equipment and infrastructure from past industrial operations could also be at risk of trapping beaver at high flows. Viable vegetation is present but not abundant in these plots. Flow near bridges and culverts is un-wadeable at some points. Deep pools filled with fine sediment could provide viable beaver habitat without the aid of dams. The most upstream kilometer of St. Vrain creek in these plots has exposed bedrock banks, which is not conducive to dam building.

### 5.1.3 St. Vrain Creek in Braly Plot

**Average geomorphology score: 78**

The Braly plot is immediately downstream of the Montgomery and Western Mobile plots. St. Vrain creek turns south in this plot and no longer runs parallel to the Burlington Northern Santa Fe Railroad. Grain size is notably smaller in this reach. The riparian corridor is wider in the Braly plot, and viable dam building material is abundant. Deep pools are also present in this stretch, and could provide viable habitat without dam building. Incision is not present in this stretch. Ditches could be at risk of being dammed if beaver were reintroduced in this area.

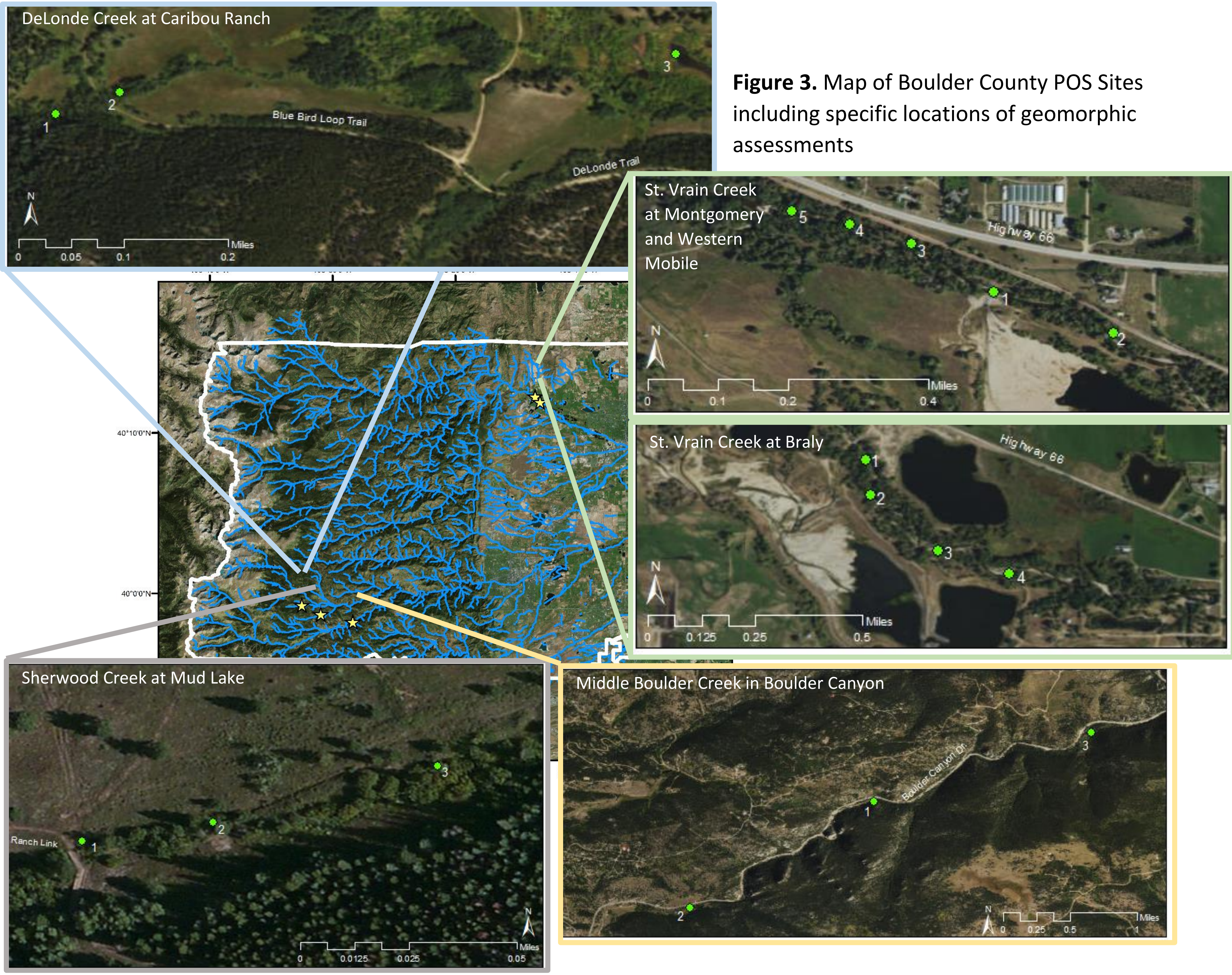


**Figure 3.** Map of Boulder County POS Sites including specific locations of geomorphic assessments

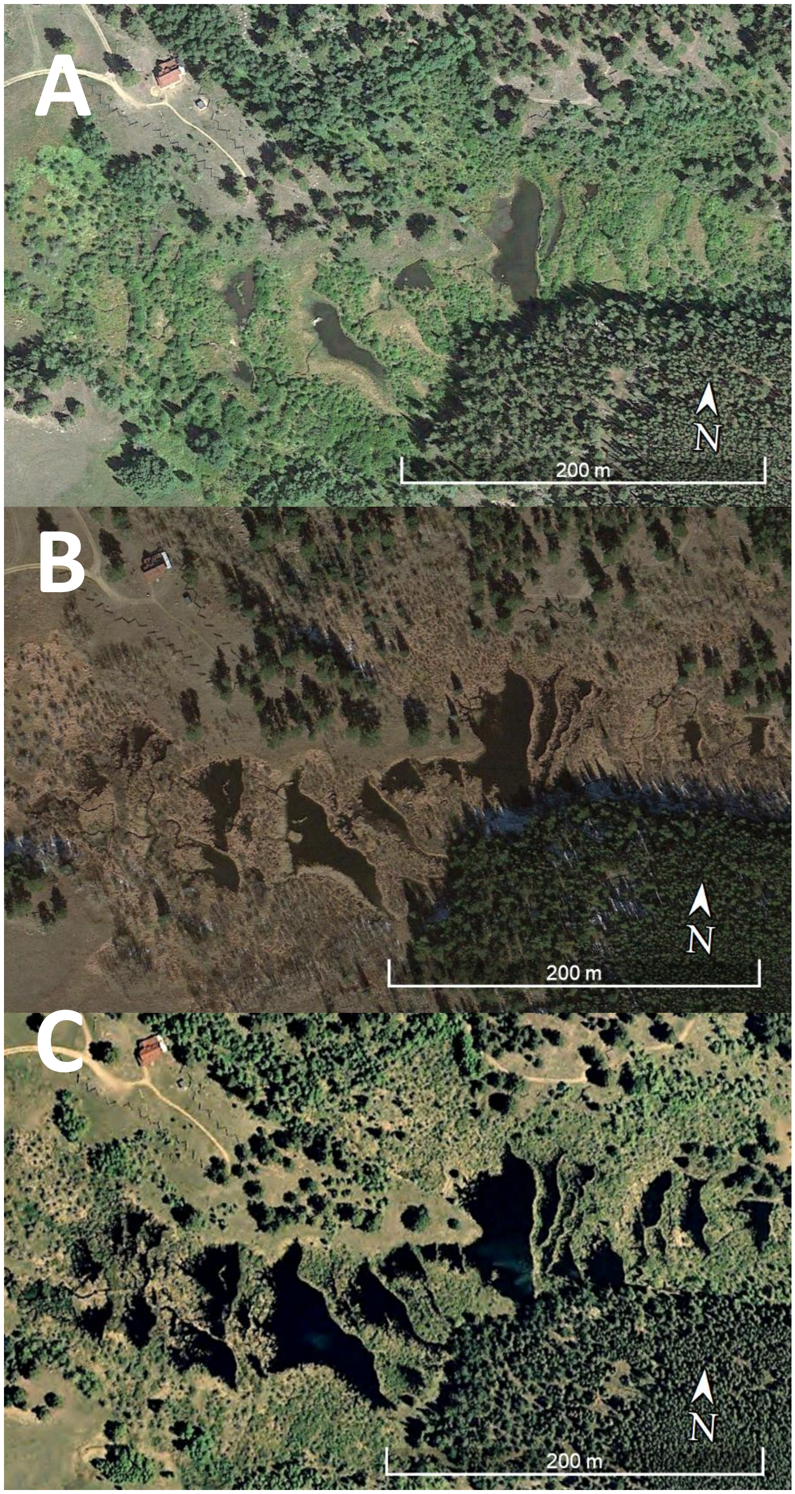


**Figure 4.** Google Earth imagery showing beaver pond surface area along Delonde Creek in Caribou Ranch Open Space over time. Imagery was taken on 9/7/2016 (A), 10/22/2013 (B), and 3/30/2008 (C). Beaver ponds have been shrinking in surface area due to beaver dam abandonment prior to 2008.

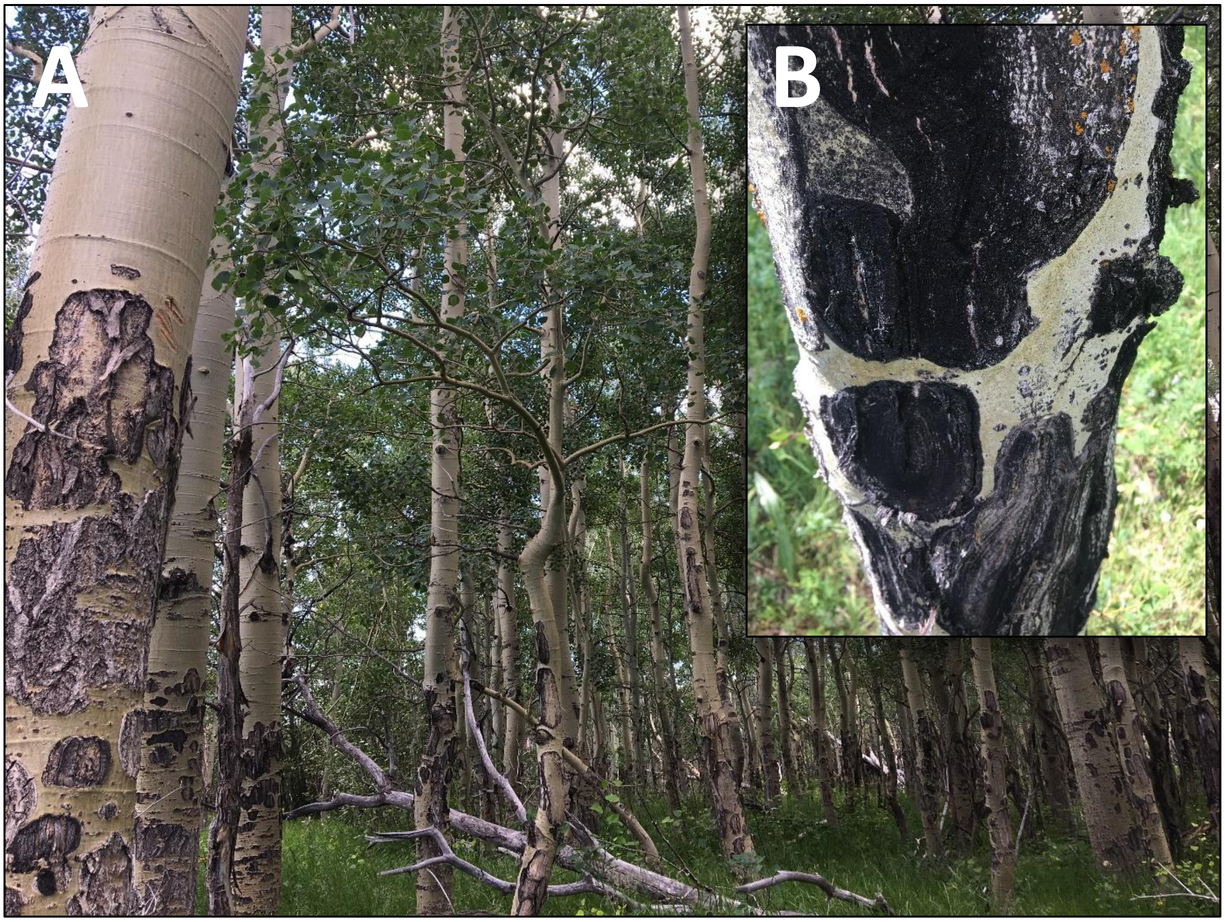


**Figure 5.** A stand of aspen grazed by moose and elk at Caribou Ranch Open Space near Nederland, Colorado. (A) While suitable vegetation is abundant, grazing is widespread and indicates a potential ecological conflict for beaver foraging. (B) Close-up of marks made my moose and elk. Similar evidence of grazing was made at multiple sites in the study.

### 5.1.4 Middle Boulder Creek at Rogers Park (Upstream)

**Average Geomorphology score: 49**

The valley bottom and floodplain along Middle Boulder Creek is confined by steep walls in Boulder Canyon. Valley bottom width in Roger Park varies from 50 to 70 m, which is narrower than typical beaver foraging distance. Un-wadeable flows in early August and large dominant substrate (cobbles/boulders) indicate that discharge may be too high for dam building. The proximity of Boulder Canyon Drive (Hwy 119) to Middle Boulder Creek further constricts the floodplain and limits habitat. Dam building material is moderately available along this stretch. Indicated by site 2 on Boulder Canyon map in Figure 2.

### 5.1.5 Middle Boulder Creek at Platt- Rogers Park (Downstream)

**Average geomorphology score: 60.5**

The valley bottom width doubles in the half-mile stretch of Platt-Rogers Park downstream of Rogers Park (Section 5.1.4). Dam building material and grasses are abundant, particularly aspen. Gradient and channel depth both decrease at these coordinates, and the flow regime becomes more suitable for dam building. However, the Platt-Rogers Park reach is isolated by less suitable vegetation and valley bottom widths directly up and downstream. Indicated by sites 1 and 3 on Middle Canyon map in Figure 2.

#### 5.1.6 Sherwood Creek at Mud Lake

**Average geomorphology score: 69**

Sherwood Creek is near Delonde Creek at Caribou Ranch, but is characterized by more incision and a drier valley bottom. Aspen and willow are abundant in patches along Sherwood Creek, and show signs of grazing from moose and elk. Bankfull widths are typically less than 4 m and depths are typically less than 1 m with exceptions in areas of high incision. The small channel geometry and low flow characteristics of Sherwood Creek make it a viable location for beaver dam analogs.

### 5.2 City of Boulder Open Space and Mountain Parks (OSMP) Site Analyses

Twenty-four geomorphic assessments across seven sites were completed on OSMP property. The location of geomorphic assessments are labeled on Figure 6.

#### 5.2.1 Coal Creek from Hwy 72 to Hwy93

**Average geomorphology score: 30**

The upstream stretch of Coal Creek from Hwy 72 to the Jefferson-Boulder County boundary is characterized by incision up to 2 m. Coal Creek upstream of Hwy 93 flows intermittently, and may not be enough water to create suitable ponds behind dams for beaver. Large boulders suggest that floods can be severe in this stretch, which could limit beaver and beaver dam survival. Viable vegetation is not abundant.

#### 5.2.2 Coal Creek from Hwy 93 to Eastern Boundary of Greenbelt Plateau (Co Hwy 25)

**Average geomorphology score: 62.5**

Bank incision and dominant grain size decrease east of Hwy 93, making the creek more suitable for dam building and accessible to the floodplain for foraging. Viable vegetation is moderately abundant east of Hwy 93, particularly along Coal Creek in Greenbelt Plateau. Stream gradient decreases downstream of Hwy 128 from 3% to 2%, which creates a more suitable baseflow stream power for beaver dam construction. Culverts associated with the highways could pose a threat to beaver in high water.

#### 5.2.3 Coal Creek from Eastern Boundary of Greenbelt Plateau (Co Hwy 25) to Superior

**Average geomorphology score: 52**

Access to Coal Creek from the downstream boundary of Greenbelt Plateau Open Space to the Mayhoffer Singletree Trail is limited due to ranching and fences. Viable vegetation is moderately abundant. Ditches running adjacent to Coal Creek in this area could be at risk of being dammed if beaver were reintroduced in this area. Most of the Coal Creek riparian area is fenced in this section. The presence of grazing cattle adjacent to a short section of the creek upstream of Superior could hinder beaver from colonizing this open reach, due to foraging competition.

### 5.2.4 Boulder Creek from 75th to 95th

**Average geomorphology score: 55**

Conflicts in this reach of Boulder Creek could both threaten beaver establishment and be threatened by beaver ponding. Human hazards proximal to the creek near 75th Street could be at risk of flooding or trapping beavers in high water: 75th Street Bridge, footpath beneath the bridge, a man-made boulder dam, a culvert, and a water intake. East of 75th Street, farming on adjacent property provides cattle access to the creek, which could discourage beaver establishment or foraging. Viable vegetation is present, but not abundant along Boulder Creek from 75th to 95th street. Grasses are more abundant than woody vegetation on the valley bottom adjacent to the stream. Grazing exclosures from cattle could make this site more viable. Note: the footbridge across Boulder Creek on the White Rock Trail was down in 2017 following the 2013 flood.

### 5.2.5 South Boulder Creek from Marshall to South Boulder Road

**Average geomorphology score: 59**

South Boulder Creek at Marshall Road is adjacent to private property on both banks for 0.7 km. The 36 Boulder-Denver bikeway runs adjacent to South Boulder Creek underneath the Hwy 36 Bridge, which constricts the floodplain and could be threatened by overbank flooding. Abundant dam building material and grasses are present up and downstream of Hwy 36. Between Marshall Road and Hwy 36 would be the most viable location for reintroduction on this stretch due to the presence of vegetation, lack of hazards from the highway, and wide valley bottom.

### 5.2.6 Left Hand Creek from James Canyon Dr. to Buckingham Park

**Average geomorphology score: 36**

Left Hand Creek near James Canyon Drive was un-wadeable in early August, suggesting discharge and channel gradient are too high for dam establishment (Figure 7). Cobbles and boulders are the dominant grain size in this stretch, which is further evidence that high flows could hinder dam building. Valley bottom width is narrow in Left Hand Canyon, but widens at Buckingham Park. Throughout the canyon, Left Hand Drive further restricts the valley bottom width (Figure 8). Viable vegetation for dam building is moderately abundant in Buckingham Park compared to sites upstream (Figure 8).

### 5.2.7 Boulder Creek from Valmont Road to 61st Street

**Average geomorphology score: 48**

While stream restoration was recently completed on Boulder Creek near 61st Street, the availability of dam building or foraging material is limited. Additionally, grasses are not abundant near Boulder Creek from Valmont Road to 61st Street except directly downstream of Valmont Road. Construction and the presence of Invasive New Zealand Mud snails directly downstream of Valmont Road limited access to the creek. Particularly the presence of invasive mud snails could make restoration work difficult in this reach, because equipment would have to be thoroughly cleaned and quarantined after use. Bankfull widths greater than 20 m make beaver dam analogs an unviable option for Boulder Creek.

**Figure 6.** Map of City of Boulder OSMP Sites including specific locations of geomorphic assessments

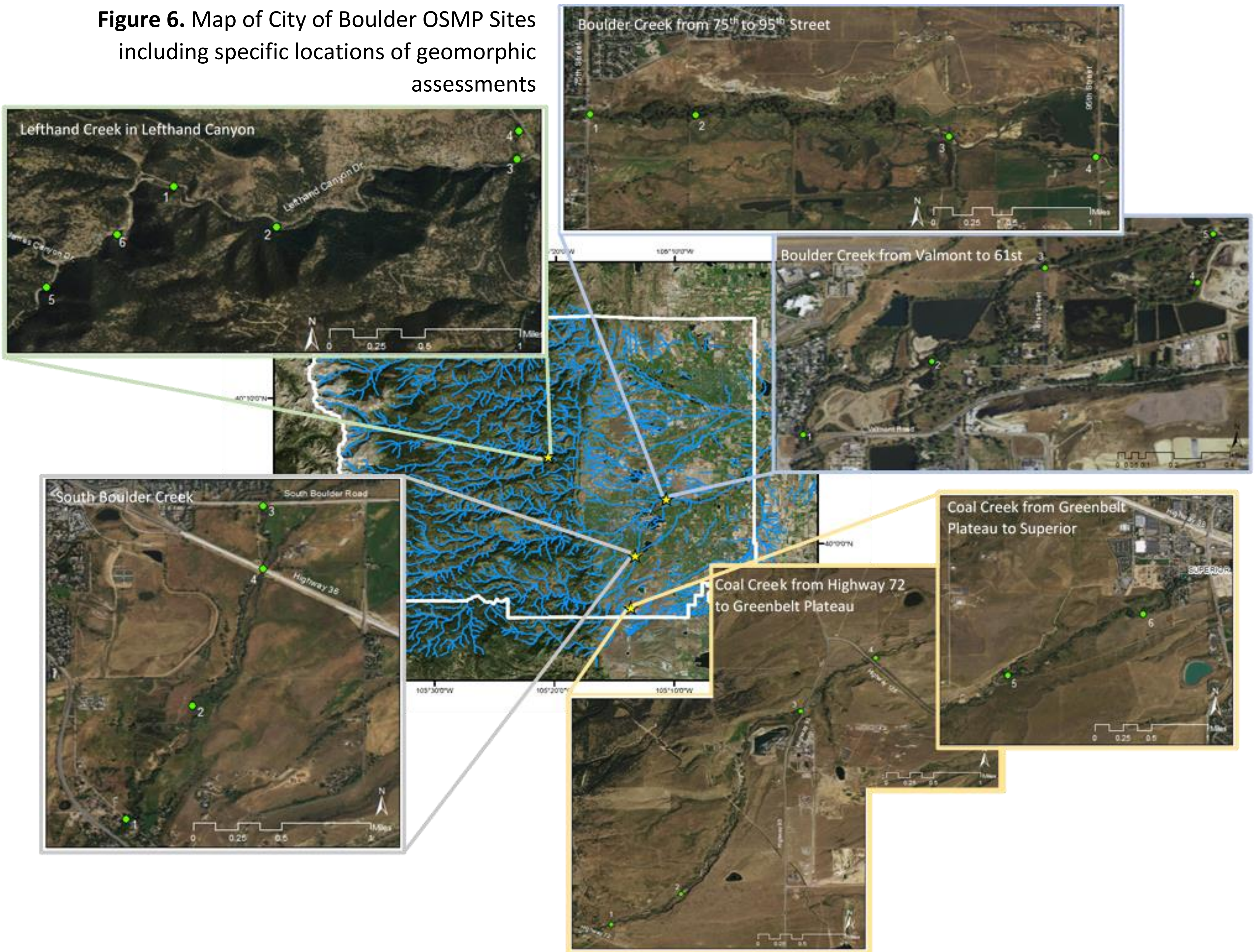

**Figure 7.** Left Hand Canyon near James Canyon Drive is steep in sections. Steep stream gradients are typically unsuitable for beaver establishment.

**Figure 8.** Lack of vegetation upstream of Buckingham Park could also limit beaver reintroduction along Left Hand Creek in Left Hand Canyon. Left Hand Canyon Drive further restricts the limited floodplain.

## 5.3 Beaver Dam Densities Across the Watershed

BRAT was modeled for the entire St. Vrain watershed in order to capture all the studied streams on OSMP and POS property (Figure 9). The BRAT output highlights areas of the watershed where beaver dams would not be viable such as steep, headwater streams in the mountains as well as deep, main-stem channels discharging onto the plains. High abundance of beaver dams are predicted in low-order, mid-elevation streams that typically alternate between confined and unconfined valleys and are flanked by suitable riparian vegetation.

The modeled density of beaver dams as determined by BRAT was identified for each location that a geomorphic assessment was completed in Boulder County. While these numbers are useful in tandem, there should not be a direct 1:1 correlation. Geomorphic assessments assign a score from 0 to 100 of site suitability based on vegetation abundance and size, human hazards, and grain size. BRAT assigns the capacity of dams per 300 meter reach of stream (usually less than 30). Additionally, BRAT does not consider human hazards, elk grazing, or the size of vegetation, which can affect the dam building capacity of beavers. BRAT does consider a range of hydrologic conditions that are difficult to assess in the field, such as the discharge at baseflow and during a typical 2-year flood. Site-by-site comparisons of the geomorphic assessments and BRAT are given by stream in Figure 10, below.

Where BRAT identified the capacity for zero dams, the hydrology does not permit dam building. The sites where the BRAT scores are zero – Boulder Creek and St. Vrain Creek – are not bad beaver habitat. Beavers are more likely to build bank dens rather than beaver dams on these streams. At sites where the BRAT score is higher than zero, beaver would need to build dams to make the sites suitable for habitation. Sites where the valley bottom width are confined by canyon walls, such as Left Hand Creek and Middle Boulder Creek, would not allow for the formation of side channels from overbank flooding. Therefore, the beaver dam density is limited in canyons.

We recommend that the City of Boulder OSPM and Boulder County POS focus potential beaver restoration efforts on streams located within the shaded rectangle of Figure 10.

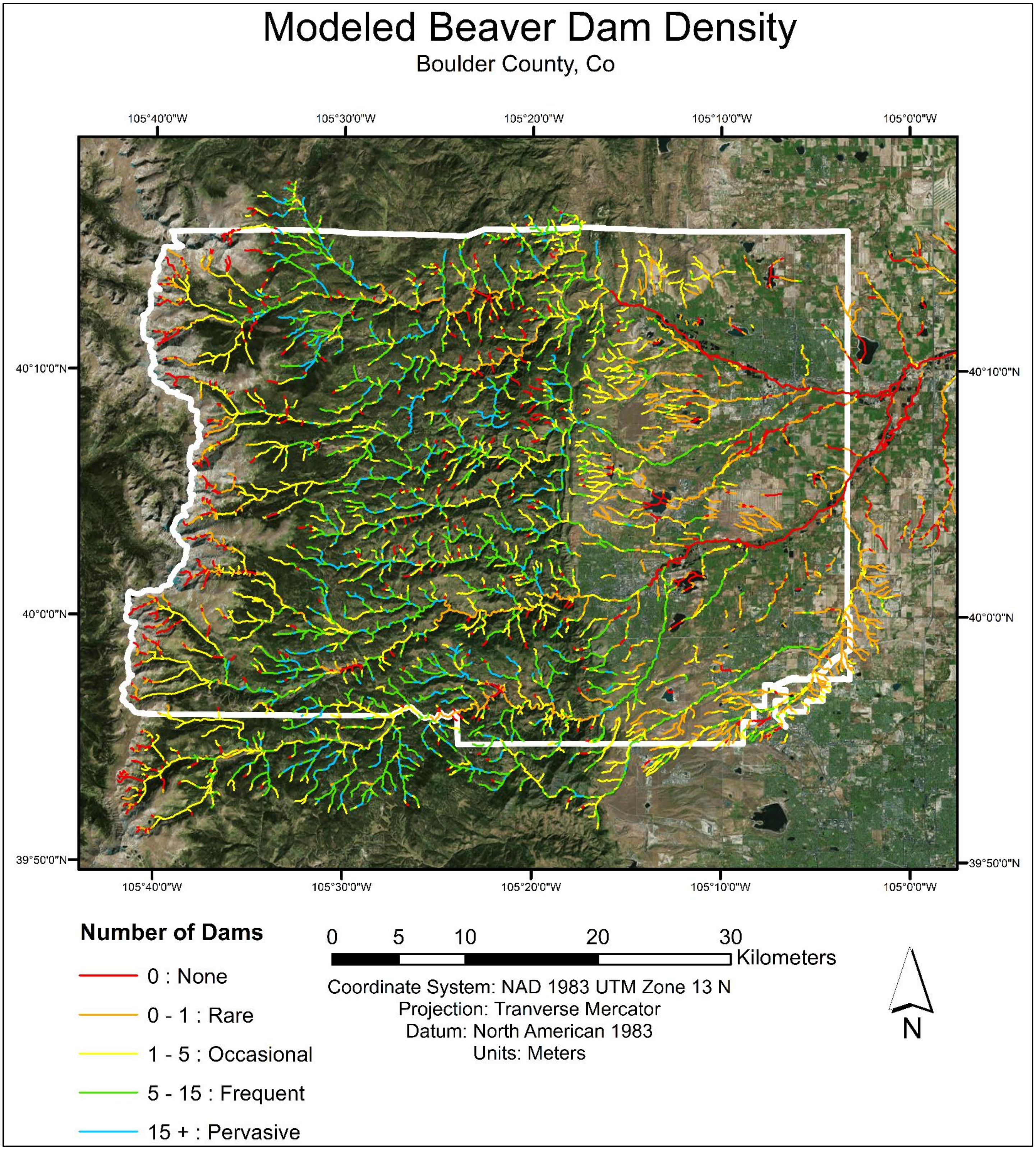


**Figure 9.** BRAT output for all streams in Boulder County. Blue lines indicate 300 meter segments where North American beaver are or would be pervasive.

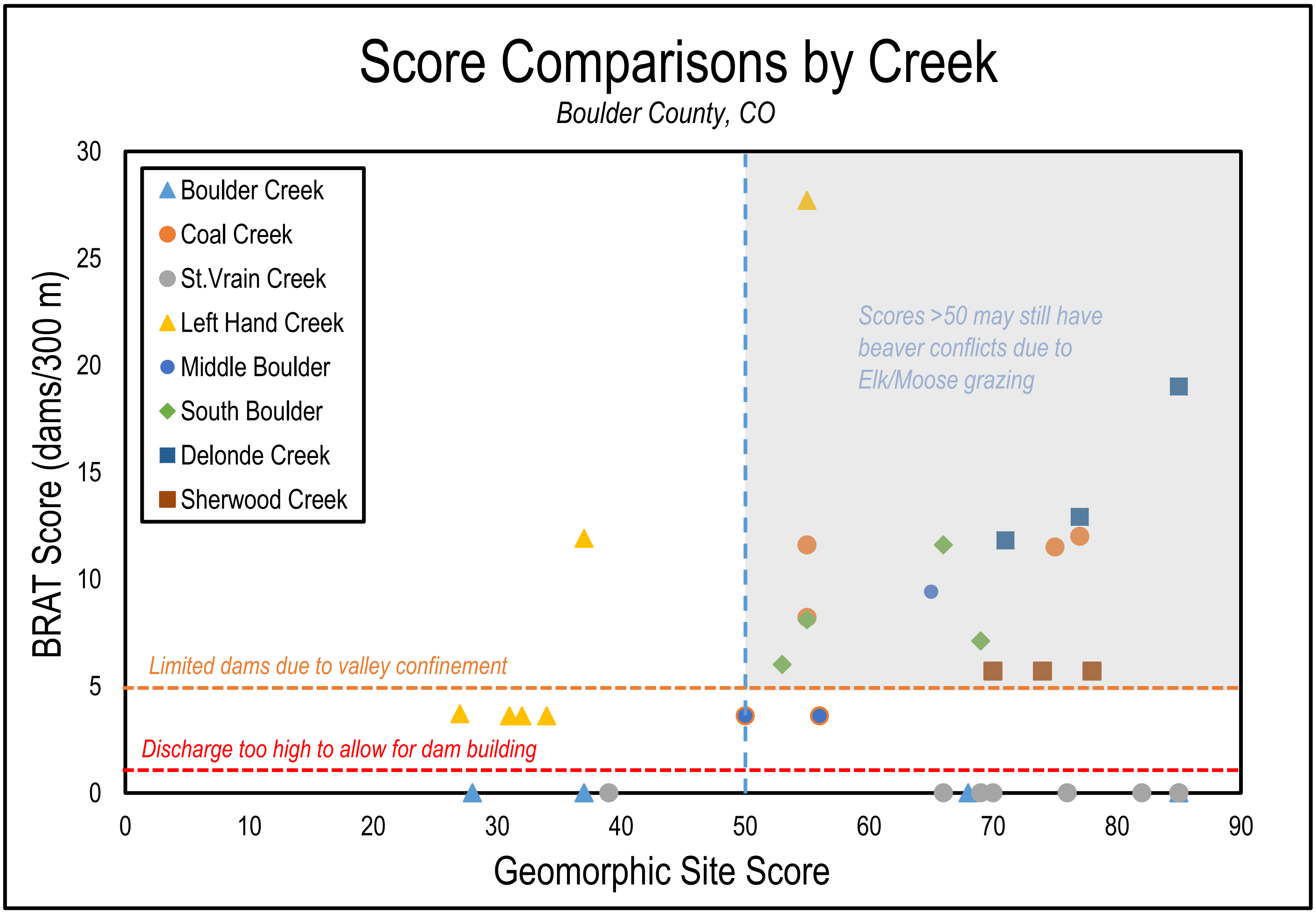


**Figure 10.** BRAT comparison by field site. Dashed lines represent a gradient between site suitability alternatives. Reasons for the dashed lines are given in text. Specific sites at each creek can be found in the supplemental Excel file.

## 5.4 Potential Hydrologic Change

As previously stated, there is no known method of hydrologically modeling beaver dams in HEC-RAS. Instead, notched weirs were used to provide a liberal estimate of overbank flooding at Delonde and Sherwood Creeks in the event of beaver reintroduction and dam building. Moving forward, modeled weirs will be referenced as dams. The number of dams modeled at each reach reflects both abandoned dam density observed in aerial imagery and modeled dam capacity calculated using BRAT. At Delonde Creek, historic beaver occupancy is visible from Google Earth imagery. A count of abandoned dams along the hydrologic model reach of Delonde Creek results in a historic dam density of 23.3 dams/km. Since partial weirs cannot be modeled, a dam density of 20 dams/km (or 2 dams per 100 m reach length) was used in the hydrologic model. Historic beaver use is not as apparent from imagery at Sherwood Creek even though berms were found during field surveys. BRAT estimates that historically, beaver dam densities would have been approximately 13.2 dams/km along the reach of Sherwood Creek used in the hydrologic model. A dam density of 10 dams/km (or 1 dam per 100 m reach length) was used to model beaver dam affects along Sherwood Creek.

Dams were modeled at reasonable places at each site. The two dams on Delonde Creek were modeled on top of old abandoned beaver dam berms, which would be the simplest place for a beaver to rebuild a dam (Figure 11). At Sherwood Creek where berms are less obvious on the landscape, the beaver dam was modeled where the stream was less incised and a stand of aspen is within foraging distance (Figure 12). Beaver are more likely to build a dam where the stream and dam building material are easily accessed. The dams were modeled to be 0.5 to 0.7 m high depending on channel dimensions. A 5.0 x 0.1 m notch was included at the top of each weir to account for some of the permeability of a beaver dam.

At both sites, dam building will increase inundated area (Table 2, Figures 11 and 12). The increase in inundated area will be more pronounced at baseflow than at high flow. For example, if one beaver dam was built at Sherwood Creek, it could increase wetted area during baseflow by over 500%. At high flows, the same dam would increase wetted area by 48%. Therefore, beaver dams could increase wetland area during typical low flows without causing devastating flooding during typical high flows.

Overbank flooding from beaver ponds could affect some of the trails at Caribou Ranch and Mud Lake Open Spaces. The Caribou Ranch Link Trail in Mud Lake Open Space has a bridge spanning Sherwood Creek that could be affected by rising water or overbank flow. The Blue Bird Loop Trail in Caribou Ranch Open Space crosses Delonde Creek just upstream of modeled reach and could also be subject to flooding due to beaver dam building.

**Table 2.** Inundated surface area within each modeled reach with and without beaver dams at baseflow and high flow. Percent increase in surface area is included for each site and flow scenario.

| Flow Type | With Dams? | Delonde Creek | | Sherwood Creek | |
|---|---|---|---|---|---|
| | | Inundated Area ($m^2$) | % Change | Inundated Area ($m^2$) | % Change |
| Baseflow | No | 363.6 | + 397% | 30.2 | + 537% |
| | Yes | 1808.3 | | 192.4 | |
| 2-year flow | No | 1368.1 | + 62% | 225.6 | + 48% |
| | Yes | 2221.9 | | 333.8 | |

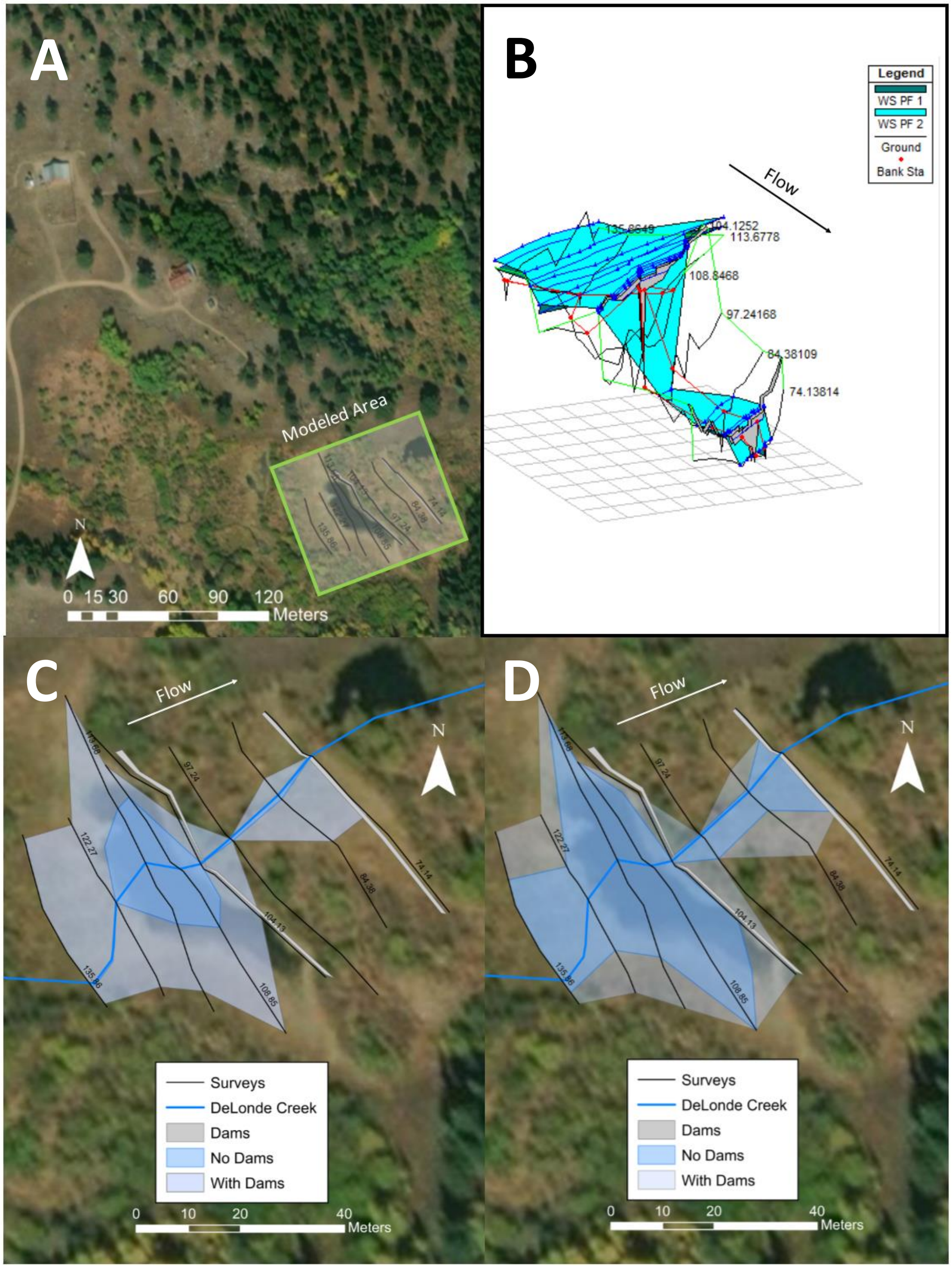


**Figure 11.** Model results from Delonde Creek. (A) Modeled area in context with surrounding infrastructure at Caribou Ranch Open Space. (B) Model setup and output in HEC-RAS. (C) Water extent at low flow with and without dams. (D) Water extent at high flow with and without dams.

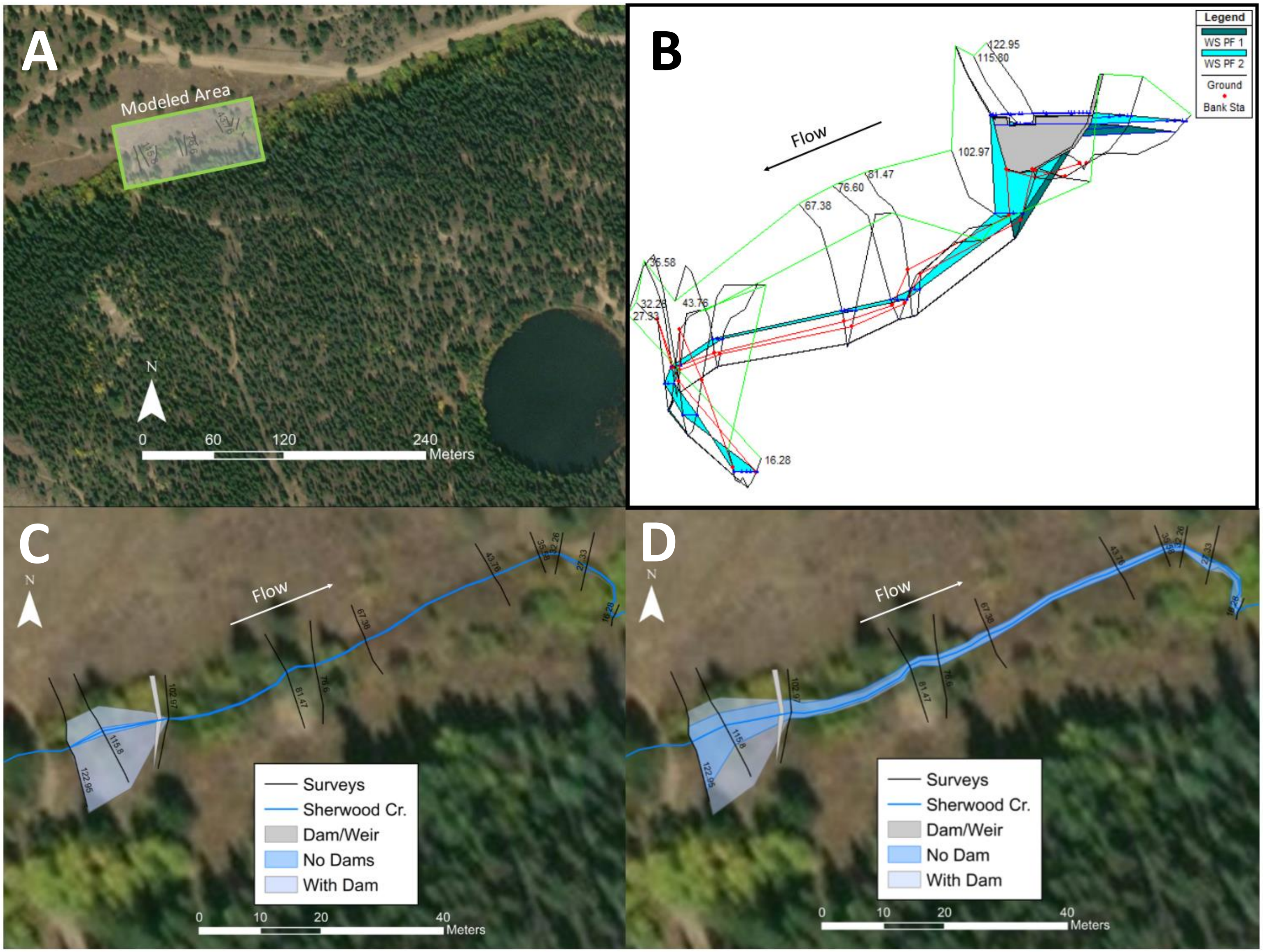


**Figure 12.** Model results from Sherwood Creek. (A) Modeled area in context with surrounding landforms at Mud Lake Open Space. (B) Model setup and output in HEC-RAS. (C) Water extent at low flow with and without dams. (D) Water extent at high flow with and without dams.

### 5.5 Potential Carbon Storage

Beaver meadows in Colorado have the potential to store up to 300 – 550 Mg of carbon per hectare of inundated land (Laurel and Wohl, 2018). According to the HEC-RAS models, inundated area would increase which means that the potential for carbon storage along Delonde and Sherwood Creeks would also increase. Carbon storage potentials are given for both creeks with and without dams in Table 3. Both a high and low estimate of carbon storage is given for each scenario on both creeks based on the range of potential carbon storage in Colorado.

While the potential for carbon storage is listed at both high and low flow, carbon storage at low flow is likely of more interest because it represents potential sequestration for a greater portion of the year. High flow carbon storage would likely only be relevant during spring runoff. At baseflow, Delonde Creek has the potential to store up to 99.4 Mg of carbon within the 100 m reach modeled in HEC-RAS if dam densities were to return to historic levels. This carbon storage would represent a 397% increase from the same reach without dams. The 100 m reach of Sherwood Creek modeled in HEC-RAS would have the potential to increase carbon storage by 562% at baseflow if one beaver dam were to be built. While the absolute amount of potential carbon storage is given for the modeled reaches of Delonde and Sherwood Creeks, these numbers could be extrapolated along the entire length of each creek where similar densities of beaver dams are expected.

**Table 3.** Upper and lower bounds of potential carbon storage in modeled reaches of Delonde and Sherwood Creeks with and without dams. Dams increased inundated surface area along both creeks which increases carbon storage in sediment.

| Flow Type | With Dams? | Delonde Creek | | Sherwood Creek | |
|---|---|---|---|---|---|
| | | Carbon Storage (low estimate) | Carbon Storage (high estimate) | Carbon Storage (low estimate) | Carbon Storage (high estimate) |
| Baseflow | No | 10.9 Mg | 20.0 Mg | 0.9 Mg | 1.6 Mg |
| | Yes | 54.2 Mg | 99.4 Mg | 5.8 Mg | 10.6 Mg |
| 2-year flow | No | 41.0 Mg | 75.2 Mg | 6.8 Mg | 12.4 Mg |
| | Yes | 66.7 Mg | 122.2 Mg | 10.0 Mg | 18.4 Mg |

# 6 Discussion

### 6.1 Discrepancies between Field Data and BRAT

While there should not be a direct 1:1 correlation between the geomorphic site suitability scores and the BRAT scores, a positive relationship should be expected. A number of factors limit the correlation between the two scores, such as grazing, vegetation mapping and human hazards. For example, certain types of restoration design, such as Rip Rap proximal to bridges, is unsuitable for beaver habitat and therefore is a human-made hazard. Human hazards such as these will affect the geomorphic site score, but not the BRAT score because hazard mapping is not present at the watershed scale. Rip Rap and human-engineered grain size affected geomorphic site scores at South Boulder and St. Vrain Creeks most notably.

Geomorphic site assessments also describe vegetation abundance and type more accurately than BRAT at a site. BRAT relies on LANDFIRE vegetation layers created at a national scale in 30 m grids. LANDFIRE does a poor job at capturing small, sporadic stands of aspen or other suitable woody vegetation that could support a beaver community. BRAT scores at Sherwood Creek are lower than expected because of inaccuracies in vegetation mapping and under-mapping of suitable vegetation. BRAT also cannot capture conflicts related to vegetation such as moose and elk grazing, which is not mapped at a watershed scale.

Overall, BRAT and the geomorphic site score can work in tandem to determine the most suitable sites for restoration. While BRAT can determine where the physical characteristics exist – such as valley width, slope, and discharge – to provide suitable habitat, site assessments are needed to determine site specific benefits or hindrances to restoration. Recommendations for restoration in Section 7 are based on both lines of evidence for determining suitable beaver habitat.

## 6.2 Potential Types of Beaver Restoration in Boulder County

The original intent of the report was to provide information on suitability for beaver reintroduction at select sites throughout Boulder County. However, beaver restoration can also include the installation of beaver dam analogs (BDAs), which are man-made structures meant to mimic beaver dams and their secondary effects. BDAs can create pools and trap sediment, which are often cited as desired restoration outcomes, without needing the ecological requirements of live beavers. Additionally, BDAs can potentially improve beaver habitat and make beaver reintroduction more viable in the future (Pollock et al., 2014). BDAs could be used prior to beaver reintroduction to aggrade incised streams and make the floodplain more accessible. However, since BDAs are not constantly maintained like a real beaver dam would be, they are more likely to fail in high flows, and are therefore are most successful in small, headwater streams with low flow depths.

A few sites in the study are already prime for beaver reintroduction, such as Delonde Creek in Caribou Ranch Open Space and Coal Creek in the Tracy-Collins and Greenbelt Plateau properties. Additional sites, such as South Boulder Creek and Sherwood Creek, could be candidates for beaver reintroduction or BDA installation. Specifically on Sherwood Creek, incision limits access to the floodplain downstream of the Caribou Ranch Link Trail bridge. BDAs could help aggrade the stream before beaver reintroductions and could also provide a stable foundation for beavers to create more permanent dams (Bouwes et al., 2015).

BDAs should not be installed on streams where beaver dams would not persist. Specifically, dams would not persist on St. Vrain Creek or Boulder Creek through Boulder Canyon due to high flows. Instead, BDAs would be most effective in streams that currently lack the vegetation necessary to support beaver or in streams that are deeply incised.

## 6.3 Potential Effects of Beaver Restoration in Boulder County

Beaver dams and BDAs will pond water behind the structure, thus causing overbank flooding and increasing water surface area. As can be seen at Delonde and Sherwood Creeks, building just a couple of beaver dams can significantly alter hydrology, especially during low flows (Table 2). While overbank flooding could affect trails at these sites, increased inundation would raise water tables (Westbrook et al., 2006), facilitate sedimentation (Naiman et al., 1986), and increase carbon storage in the floodplain (Wohl, 2013; Laurel and Wohl, 2018). While BDAs in small numbers have not been proven to cause the same magnitude of groundwater change in the Rocky Mountains (Scamardo, 2019), BDAs could be expected to aggrade the stream bed and increase pool surface area, thus having an effect on carbon storage.

While there are many hydrologic, ecologic, and geomorphologic benefits of beaver dams, there is also the possibility of unintended flooding or tree loss. Prior to beaver reintroduction, structures or trees deemed important and at risk should be identified. To limit overbank flooding, pond levelers can be installed to limit the height of water maintained behind a dam (Gerich, 2004). Additionally, suitable trees such as aspen, cottonwood, or alder within a 100 m radius of the stream that the managing agency does not want chewed or removed should be protected by individual fencing around the base of the tree.

# 7 Recommendations for Restoration

Based on preliminary analysis and modeling, the best sites for further consideration of beaver-related restoration on Boulder County Parks and Open Space land are Delonde Creek at Caribou Ranch Open Space and Sherwood Creek at Mud Lake Open Space. At both sites, historic beaver activity is evident and suitable vegetation is abundant. Additionally, dam building is unlikely to cause damage to major infrastructure. However, grazing of aspens and willows by elk and moose at these sites could limit beaver foraging. Therefore, if beaver reintroductions are considered, grazing exclosures for moose and elk should be included in the restoration design.

Within City of Boulder Open Space and Mountain Parks land further consideration of beaver-related restoration should concentrate on South Boulder Creek from Marshall Road to South Boulder Road and Coal Creek in the Tracy-Collins and Greenbelt Plateau properties. Narrow bankfull widths on South Boulder Creek upstream of Highway 36 could make beaver dam analogs (BDAs) a suitable restoration approach.

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# 9 APPENDIX: DATA AVAILABILITY AND ACCESS

The following data and datasheets are available at the listed locations:

- Geomorphology Site Checklist – Page 32
- Geomorphology Scorecard – Page 33
- Checklist and scorecard data by site – attached as BeaverReintroduction_CSU_FieldData.xlsx
- BRAT shapefile for St. Vrain Watershed – attached at StVrain_BRAT.shp

Additional information and data can be requested from Julianne Scamardo in the Department of Geosciences at Colorado State University.

**Boulder County/City Site Geomorphology Check List**

**Site Name/Location:** ______________________________________________________________

**GPS Coordinates:** ________________________________________________________________

**Physical Characteristics**

Channel Gradient: ______________________

Valley Bottom Width: ________________________

Site Length: __________________

Flow Regime: Ephemeral Intermittent Perennial

Channel Width: ____________ Channel Depth: ___________________ Ratio: ______________

Channel incision depth: ___________________

Dominant stream substrate: Silt/Clay/Mud Sand Gravel Cobbles Boulders Bedrock

**Ecological Characteristics**

Dominant riparian vegetation: _____________________________________________________

_____________________________________________________________________________

Distance of viable vegetation from stream: ___________________________________________

Presence of abundant 1-6" diameter woody vegetation? Yes No

Evidence of elk? (Ex: teeth marks on Aspen, evidence of grazed willows) Yes No

If yes, describe evidence: _________________________________________________________

Evidence of pre-existing berms? Yes No GPS coordinates of berms: _________________

**Human Hazards (Check if Present)**

______ Ditches Coordinates: _____________________

______ Culverts Coordinates: _____________________

______ Intakes Coordinates: _____________________

______ Bridges Coordinates: _____________________ Height above water: _____________

______ Roads or Trails Proximity to site: _____________________

______ Private Property Lines Proximity to site: _____________________

______ Other (Specify :___________________________________________) Location: ______________

**Geomorphology Scorecard**

**Site Name/Location:** ______________________________________________________________________

**GPS Coordinates:** _________________________________________________________________________

______**Channel Gradient**: ≤ 3% (**10 points**) 4 – 6 % (**0 points**) 7-9% (**-10 points**) ≥ 9% (**-30 points**)

______**Valley bottom width**: Wide, > 100 meters (**5 points**) Narrow, <100 meters (**0 points**)

______**Site Length**: > 1 km (**5 points**) < 1 km (**1 point**)

______**Flow Regime:** Ephemeral (**-10 points**) Intermittent (**5 points**) Perennial (**10 points**)

**Woody Food** (Select the highest possible in each line – then multiply the lines)

a. Aspen/willow (**3 points**) Alder (**2 points**) Other hardwoods (**1 point**)

b. Within 10 m (**3 points**) Within 30 m (**2 points**) Within 100 m (**1 point**)

c. Abundant, >100 stems (**2 points**) Moderately abundant (**1 point**) Not abundant (**0 points**)

______ **Woody food score = multiply a x b x c**

______**Herbaceous Food**: Grasses and forbs abundant (**10 points**) No grasses/forbs (**5 points**)

______**Dominant Stream Substrate:**

Silt/Clay/Mud (**5 pts**) Sand (**2 pts**) Gravel (**1 pt**) Cobbles (**0 pts**) Boulders (**-1 pt**) Bedrock (**-3 pts**)

______**Historical Beaver Use:** Old berms present (**15 points**) No indication of berms (**0 points**)

______**Presence of dam building materials:**

Abundance of 1-6” diameter woody vegetation (**5 points**) No building material present (**-20 points**)

______**Browsing/Grazing Impacts:** No browsing (**5 points**) Heavy browsing (**-10 points**)

______**Ease of Access:** Easy travel to deliver beavers and monitor (**2 points**) Long hike (**-5 points**)

______**Existing aquatic escape cover:** Multiple deep pools present (**10 points**) No Pools (-**10 points**)

______**Total Score** (100 points maximum)