An inventory and baseline study of alpine groundwater dependent ecosystems at Buffalo Pass in Routt National Forest, Colorado

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# Table of Contents

**ABSTRACT**

**INTRODUCTION** ............................................................................................................. 1

- Impacts to GDE Health .............................................................................................................. 2
- Grazing ........................................................................................................................................ 2
- Recreation .................................................................................................................................... 3
- Study Site Changes ..................................................................................................................... 4

**METHODS** ......................................................................................................................... 5

- Study Area ................................................................................................................................... 5
- Data Collection ............................................................................................................................ 7

**RESULTS** ......................................................................................................................... 10

- Fen 2093 ..................................................................................................................................... 10
- Junction Wetland ...................................................................................................................... 12
- Fen 2314 ..................................................................................................................................... 12
- Fen 2318A .................................................................................................................................. 14
- Fen 2349 ..................................................................................................................................... 17
- Summit Lake Fen ...................................................................................................................... 17
- Campsite Fen ............................................................................................................................. 18

**DISCUSSION** ................................................................................................................... 18

**CONCLUSION** ................................................................................................................ 22

**ACKNOWLEDGEMENTS** ............................................................................................ 23

**REFERENCES CITED** ................................................................................................... 24

**APPENDIX** ....................................................................................................................... 28
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ABSTRACT

Buffalo Pass in northwest Colorado’s Routt National Forest has many groundwater dependent ecosystems (GDEs). These areas rely on seeps and springs to provide them with nutrients and water to sustain themselves, and are homes to many species of flora and fauna (Orellana et al., 2012). Deterioration due to grazing and recreation has caused some GDEs to shrink and caused disruptions in ecosystem and physical processes. Road improvement projects could also lead to worsening quality of groundwater dependent ecosystems. Hydrologists are worried about this change, so a study was conducted to establish baseline data on GDE conditions. In the future, they can compare baseline data with their work to determine the scope of new pressures facing these areas and respond appropriately. I collected soil cores as well as water table, water chemistry and plant assemblage data in areas where there had already been some human degradation. The size and location of all groundwater dependent ecosystems were measured and compiled in a geodatabase for future use, in combination with the background data. Detrimental uses identified include rut creation by vehicles and grazing, due to their impacts on water movement within the study area. Water movement was blocked in some areas and concentrated in others to change groundwater dependent ecosystem conditions. Changes in water movement influenced plant assemblages which shifted towards upland species and caused organic soils to decompose.

Keywords: groundwater dependent ecosystems, fens, Routt National Forest, human land use, grazing
INTRODUCTION

A groundwater dependent ecosystem (GDE) is a place where groundwater intersects the ground surface, supporting plants and animals that would not otherwise exist without the presence of a groundwater source (U.S. Forest Service, 2012). GDEs can be fed by springs or by the diffuse emergence of water across a large area (seeps). While lakes, streams and cave ecosystems can also be groundwater dependent ecosystems, this paper focuses on springs, fens and other wetlands.

GDE study systems include a combination of springs and fens. Springs often feed fens as a diffuse flow from a source point throughout the fen, saturating the area (Grootjans et al., 2006). Fens are peat wetlands that receive significant water and nutrients from a ground source. Water chemistry in a fen is different from that seen in bogs (which are fed by surface water), as the groundwater source provides nutrients to certain fen species that precipitation is unable to provide (Wassen et al., 1990; Boeye et al., 1995; Almendinger and Leete, 1998; Omelková et al., 2013). In these systems, ground saturation leads to poor aeration which limits the decomposition of organic matter. This leads to an accumulation of peat and other organic soils that form over layers of mineral soils. Because of the reliance on groundwater, fens and GDEs degrade when there are changes in water table or diffuse flow that affect ground saturation (Wieder and Vitt, 2006).

A GDE is considered a fen when organic soil accumulation reaches 30-40 cm in the top 80 cm of soil (NRCS, 1999; Weixelman and Cooper, 2009). Peat accumulation in GDEs sequesters 42% of all soil carbon and 20-30% of all terrestrial carbon (Gorham, 1991; IUCN, 2017). GDEs are also important sources of biodiversity in Colorado.
accounting for only 2% of land area but more than 14% of native plant species (Cooper, 1990). GDEs are also good sources of clean water for high alpine watersheds and can be especially important sources near the drainage divide. Rocky Mountain GDEs are also an important habitat for populations of elk, moose, amphibians and birds (Chimner et al., 2010).

**Impacts to GDE Health**

Since the arrival of Europeans to Colorado in the mid-1800’s, humans have modified the hydrology of the Rocky Mountain region and damaged GDE conditions through practices including ranching, water diversion for agriculture, road development and mining (Patterson and Cooper, 2007; Weixelman and Cooper, 2009; Austin and Cooper, 2016). Anthropogenic changes to hydrology can cause GDE damage (Fojt, 1994; Chimner and Cooper, 2003; van Diggelen et al., 2006). Lowering of the water table decreases plant production in peatland environments and cause a shift in species type due to the decrease in nutrient and water supplies that the groundwater system provide (Thormann and Bayley, 1997; Weltzin et al., 2000). This decrease in saturation creates growing conditions favorable for colonization by upland species such as most forb, herb and shrub species (Pritchett and Manning, 2012). Water level drawdown also increases aeration of organic soils, decreasing the deposition of organic matter and increasing the decomposition of organic matter, thereby releasing more carbon into the atmosphere (Strack and International Peat Society, 2008).

**Grazing**

Intense livestock grazing can damage GDEs through changes in channel geomorphology, decrease in plant cover and disruption of flow patterns. Heavy grazing
can shift plant communities near channels from obligate riparian and wetland species to upland species which may be more resistant to grazing (Swanson et al., 2017). Many riparian species have evolved to withstand the force of high water events and keep sediments in place with deep root systems, while many upland species have shallow root systems which lead to increased erosion and bank instability (Toledo and Kauffman, 2001). The increase in bank instability leads to incision and widening of the channel, which lowers the water table and causes a shift from wet vegetation to upland species, shrinking the area of the ecosystem (Loheide et al., 2009). Trampling in fens causes decreases in plant cover and leads to ponding and the creation of rivulets, changing the growing environment for plants (Trimble and Mendel, 1995). When more than 15% is bare ground, fens begin to lose peat as more organic material is being decomposed than is deposited resulting in a net flux of carbon to the atmosphere (Chimner et al., 2002). Areas exposed to intense grazing and trampling also see a decrease in species diversity and a change in plant type (Arnesen, 1999; Pellerin et al., 2006). Intense grazing can also limit the transport of water to certain parts of the fen, altering flow patterns (Weixelman and Cooper, 2009). In areas with minor ponding, ponds can provide places for species recruitment and help increase fen diversity, but when grazing becomes too intense, trampling can remove the water supply from certain parts of a fen and cause the organic layer to decompose, allowing for colonization by upland species (Lundquist et al., 2006; Zier and Baker, 2006; Loheide et al., 2009; Merriam et al., 2017).

Recreation

Recreational uses of the wetland can also have negative impacts on GDE health. The creation of ruts by driving vehicles through GDEs was observed in several study
sites. Ruts alter the flow of water, shift soil porosity and can lead to changes in soil type and species makeup of the ecosystem (Gatto, 2001; Elliot et al., 2009; Weixelman and Cooper, 2009). In systems with diffuse water flow originating from springs and seeps, rut creation leads to channelization and creates much higher energy flow, which increases erosion (Foltz and Burroughs, 1990). Decreases in porosity due to compaction can increase surface flow, also contributing to an increase in erosion (Naghdi and Solgi, 2014). Ruts also inhibit flow to farther parts of the GDE and can cause a transition in plant community to upland species through loss of saturation and a degradation of peat (Grover and Baldock, 2013; Schimelpfenig et al., 2014). These effects can decrease GDE size and soil stability, negatively impacting the ecosystem. Other recreational uses like campsites, hiking trails and trash dumping were observed in fens, but the effects of these uses are not clear.

**Study Site Changes**

Human-caused hydrologic changes have previously been observed at GDEs near Buffalo Pass in Routt National Forest. There are plans to widen and improve the access road to this area. Currently the Buffalo Pass area is only accessible by a rough road that is suggested for only high-clearance vehicles. However, the improvement plan calls for widening and regrading to make it accessible by low-clearance vehicles, making Buffalo Pass accessible to many more people (U.S. Forest Service, 2019). This will be a good way to allow more people to enjoy the forest and explore new areas. With the anticipation of an increase in visitors, the Forest Service hydrologists want baseline data so they can monitor the GDEs in this area and any damage occurring in them. Monitoring will help the hydrologists make decisions to protect GDEs and discourage practices that
unnecessarily degrade them. There are plans to eliminate dispersed campsites that adversely affect the forest in an effort to reduce human disturbance in the area (U.S. Forest Service, 2019). This baseline study, coupled with future work, will allow the Forest Service hydrologists to make decisions to keep GDEs healthy.

METHODS

Study Area

The study area was along a route over the Park Range and Continental Divide called Buffalo Pass that connects Steamboat Springs and North Park (Fig. 1). The road over Buffalo Pass is called National Forest Service Road 60.1 (NFSR 60.1). A 7.6 mile length of NFSR 60.1 is proposed for improvement to allow better access to the area and also constrains my study area (Fig. 1) (U.S. Forest Service, 2019). The Park Range is composed of Proterozoic metamorphic rocks and granitic plutons and is overlain by till deposited during the Pleistocene glaciation that ended 11,000 years ago (Snyder, 1980). The topography of this area is characterized by many of the catchment valleys eroded by glaciers and mountains formed from competent Pre-Cambrian igneous and metamorphic rocks (Madole, 1980). It has an elevation of 3,146 m and the study area is in the Spring Creek, Soda Creek and Fish Creek catchments. The area is a high alpine ecosystem and the GDEs are mostly high-alpine fens (Heidel and Jones, 2006; Rundel and Millar, 2016).
Figure 1. Overview of Routt National Forest location in Colorado denoted in dark green and the star shows the location of the study area. The topographic map focuses on the pink study area which encircles the 0.25 mi buffer from NFSR 60.1.
The study location was the area within 400 m of NFSR 60.1 in the section where improvements will occur (Fig. 1). A 400 m buffer was used because GDEs within that distance of a road are considered at high risk for human impact (U.S. Forest Service, 2012). A previous study of Routt National Forest using Landsat imaging tried to classify GDEs remotely using vegetation reflectance data. This map was used to help identify areas with GDEs, but is not very accurate as it misses many and mistakenly identifies riparian areas and some meadows as GDEs. An inventory by the Rocky Mountain Research Station, also done using the same inventory system as used here, only studied a few GDEs near Buffalo Pass and only one that overlapped with the study area. That study area, Fen 2349, was used as a standardization site where values and observation were compared to the previous study.

**Data Collection**

Using a Trimble handheld geospatial device, I walked the perimeter of each fen to create a shapefile marking the extent of the GDE. Within 400 m of NFSR 60.1, 21 GDE sites were found and mapped and only 7 had been noticeably altered by human use (Fig. 2). Groundwater Dependent Ecosystem Level I Inventory was used to measure the impacts that had already occurred, as well as baseline levels of water chemistry at springs, plant composition, soil type and groundwater level, which can be used to determine future impacts (Appendix 6). The Level 1 Inventory was chosen because it provided the right balance of depth and scope. The Forest Service also has Level 1/2 which records a site overview and a Level 2 Inventory which requires specialized equipment and takes 4 hours per site. First, site photos were taken, and a map was made to get site characteristics (Fig. 3). Any disturbances were also documented using photos and on the map. Using a soil auger, cores were taken until mineral soils (defined as anything that was not peat or muck) were reached. Classification of soils using Munsell soil color chart, soil type and depth as well as mineral soil texture were recorded. The soil hole was
Figure 2. GDE sites and extent in the study area highlighted in pink. Sites where the Level I Inventory was done are outlined in red. GDE extent was collected using Trimble geospatial device.
Figure 3. Characteristic GDE at Buffalo Pass. Sedges and bryophytes dominate the saturated area. Trees and other upland species are outside the boundary of the GDE saturated area. The boundary of the saturated and unsaturated area was walked to determine GDE extent.
left to allow water levels to equilibrate with groundwater level. Once it had equilibrated, water table depth was measured in the soil hole. Conductivity, pH and temperature data was taken with a Eutech PCTestr 35 from all springs that had sufficient water levels for measurement. Any channels, springs and flow types were noted. An estimate of plant species makeup was taken as well.

Once data was collected, it was combined into a single shapefile and field data was digitized in a spreadsheet (Fig. 2). The digitized data was put in a U.S. Forest Service database of GDEs. This will be compiled with the Spring Stewardship Institute database with extensive data from the western United States as well. Their compilation of data allows researchers to better study GDEs with much larger datasets and help protect groundwater systems.

RESULTS

The results of the inventory from the 7 fens that had human disturbances showed issues with grazing and recreational vehicle ruts in GDEs. The fens were impacted to varying degree but all except Fen 2093 were visible from NFSR 60.1 and had easy access.

Fen 2093

Fen 2093 (40.542752, -106.6829) has both helocrene and limnocrene groundwater sources. Most of the fen is wetland, with sporadic channels and two spring emergences (Fig. 4). The two springs have pooled and feed parts of the fen. The plant communities in water saturated areas are graminoids or forbs. The northern edge of the fen is bounded by
Figure 4. Fen 2093 overview and baseline data. Spring and seep sources are on the southern side of the GDE and flow downslope towards the northwest. Water table level is at 124 cm. Heavy grazing was observed in parts of this GDE. Organic soils dominate the soil core. More site overviews and a comparison of soil profiles can be found in the appendix.

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</table>

Table 1. Water chemistry values at each of the pools in Fen 2093. Temperature, pH and conductivity are all measured using PC Testr 35.
NFSR 60.1. At the southwestern edge of the fen, there is a horse trail, hitching post and parking lot. There is a 20 m section of the fen which has been heavily grazed by horses near the hitching post. The ground in this area is hummocky and trampled in areas by recent grazing, which has led to variable saturation levels in the fen with the pooling of water in some areas and dry soil in other areas. This has allowed upland forbs to dominate these areas (Fig. 5). Areas with heavy grazing do not have the even saturation of other areas in the fen. The water table was measured to be 1.2 m below the surface at the location of the soil core and was ponding in some other parts of the fen.

**Junction Wetland**

Junction Wetland (40.534759, -106.70219) is located south of NFSR 60.1 and just west of the junction between NFSR 60.1 and NFSR306. Junction Wetland is a circular pool with large areas dominated by sedges and areas of open water fed by a limnocrene groundwater system. A culvert under NFSR 60.1 is the only outflow channel for Junction Wetland but it was not active at the time of sampling. Tire tracks spanning the entire wetland channelize water near the culvert. The tire tracks have not regrown sedge and are a place where organic material collects (Fig. 6). The tire tracks are creating channels diverting water to collect in the fen as well.

**Fen 2314**

Fen 2314 (40.533528, -106.703847) is near a campsite and NFSR 60.1. It has limnocrene and helocrene groundwater sources and has four springs which form pools. All are fed by a combination of springs and seeps with no outflow channel and have similar pH and specific conductance. The organic layer is thinner at Fen 2314 with peat
Figure 5. Characteristic trampling in grazed areas leading to plant cover loss in the foreground. Pooling can be seen in the midground where hummocky ground has led to uneven saturation.

Figure 6. Head on view of a rut where no plants have grown back and dead organic matter is accumulating. Surrounding areas are covered in sedges but will not grow in the ruts.
to 0.1 m deep and mucky peat from 0.1 m to 0.5 m. Below the organic layer is clay from 0.5 m to 0.8 m, and sandy clay from 0.8 m to the bottom of the soil hole at 1.2 m. The fen is dominated by graminoids, which cover over 75% of its area with some forbs and bryophytes also found. The northern edge of the fen has many tire tracks which have caused pooling and channelization of water. There are tire tracks through pool 3 as well which have created channels in the eastern side of the pool. The tire tracks have created areas where no plants grow and dead organic matter collects (Fig. 5).

**Fen 2318A**

Fen 2318A (40.529161, -106.724314) is a helocrene groundwater dependent ecosystem and is on the hillslope above a channel which flows into Soda Creek. There is a campsite on the north side of the fen with tire tracks in the fen and a user vehicle trail on the southern side of the fen (Fig 7). Fen 2318A receives groundwater sources from seeps that occur at hillslope breaks. Water flows downslope toward the stream channel until it is diverted by the presence of tire ruts through the fen (Fig. 8). Water flows in the tire ruts to a small swale where it is diverted towards the channel. The ruts disconnect part of the original fen from the source of water. The disconnected area is dominated by forbs and graminoids and no peat is found at or near the surface and the connected fen is comprised of bryophytes and graminoids with some forbs (Fig. 9). Water is apparent in most of the fen with small areas of ponding. The water table depth is at or near the surface in Fen 2318A. Peat is the dominant soil type in all areas where water is apparent.
Figure 7. Overview of Fen 2318 A and soil profile. The campsite is partially built on GDE. Water generally flows from east at the hillslope seep source to southwest. Water from the GDE flows into the stream to the south of Fen 2318 A. The water table is at the surface in this GDE. The differences in plant assemblage on either side of vehicle ruts is most pronounced in this GDE.
Figure 8. GDE on Buffalo Pass in Routt National Forest with tire rut damage. Blue arrows show normal movement of water through fen on right. Red arrows on the left denote movement of water once it reaches vehicle ruts. The ruts channelize the diffuse flow from the GDE and concentrate its path to the stream in upper left part of the picture.

Figure 9. A channel created by vehicle ruts denoted on the right side in red inhibits the flow diffuses flow shown in blue. Wetland species like bryophytes and graminoids grow upgradient of the channel while upland species like forbs and shrubs grow downgradient where there is less water.
**Fen 2349**

Fen 2349 (40.539488, -106.699795) is located above NFSR 60.1 on a plateau. This fen was previously surveyed in 2017 by researchers from the Rocky Mountain Research Station and provided a calibration for the measurements in my study. It is fed by limnocrene and helocrene sources and most of Fen 2349 is a wetland with apparent water flow in many areas gathering in a channel on the eastern edge of the fen before flowing through an outlet into the main valley of Spring Creek. Graminoids dominate the western side of the fen and a large group of willow bushes dominate the center. There are 3 springs in Fen 2349, two of which pond on the western side of the fen and one that trickles directly into the outflow channel on the eastern edge. Spring 1 in the northwestern part of the fen is surrounded by forbs while springs 2 and 3 are in graminoid dominated areas. The organic layer is mucky peat from the surface to 0.5 m. There is a clay layer below the mucky peat layer to the bottom of the soil hole. This fen had no visible impacts from human use other than shotgun shells and other trash.

**Summit Lake Fen**

Summit Lake Fen (40.54693, -106.680604) is just east of the continental divide next to Summit Lake and Summit Lake Campground. The fen is a limnocrene and helocrene groundwater fed system with two channels in the southeast and northeast for outflow. There are three springs that form large pools in the central part of the fen. Water is apparent at the surface in or the ground is saturated throughout Summit Lake Fen. The fen is covered in a mix of graminoids and bryophytes. There was a large organic layer with peat from the surface to 0.8 m and mucky peat from 0.8 m to the bottom of the soil hole at 1.3 m. The surface material was pure peat and was saturated throughout the fen. The user trails and campsites were found in this fen and had caused minor pooling of
water in some places. There were multiple fire rings in the fen which had been created near the campsites.

**Campsite Fen**

Campsite Fen (40.530821, -106.714475) is a helocrene groundwater fed system located next to NFSR 60.1 and a dispersed (primitive) campsite. There are multiple channels that carry water to the southwest corner of the fen from the east and southeast parts of the fen where multiple seeps emerge from the hillslope. The seeps cause pooling and ground saturation downslope in the fen and graminoids and bryophytes are most common in these areas. There are also multiple topographic highs that are dominated by upland species like trees and forbs. Water is apparent throughout Campsite Fen and when measured, the depth to the water table was 0.3 m to 0.4 m. Two soil holes were dug with both containing muck or mucky peat to a depth of 0.6 m with sandy clay found below 0.6 m. The campsite and a firepit is on part of the fen and has led to the trampling of plants in the fen. Recent tire ruts are seen in and near the dispersed campsite on the northern edge of the fen. The tire ruts have created channelization and pooling of water in saturated areas and are restricting the flow of water from the seeps to locations downslope (Fig. 8).

**DISCUSSION**

This Level I Inventory contributes to a dataset within Routt National Forest that hydrologists can use to determine the impact of proposed recreational and commercial uses in the future. Water, soil, plant and spatial baseline data levels will measure different types of detrimental land use. Water table measurement can tell if levels have been drawn down significantly since the previous measurement, which could be due to grazing or
flow issues. Water chemistry in peatlands is typically acidic like our data showed, but if soils decompose, their pH will increase (Murayama and Bakar, 1996). Plant composition can be an indicator of changes in water levels and saturation. An increase in the percentage of upland species would indicate that there might be issues with water flow and levels decreasing (Patterson and Cooper, 2007; Merriam et al., 2017). The spatial data provides an accurate extent of the fen and would track changes over time in total area. The data will help create a baseline area for future hydrologists to study and determine what could be causing changes.

Most GDEs near NFSR 60.1 were clustered near the top of Buffalo Pass with fewer at low elevation. There was a distinct cluster at the top of Buffalo Pass, another cluster near Spring Creek in a valley below NFSR 60.1 and another 2 km down from the summit. Many of the GDEs were located at changes in hillslope and their sources were hillslope seeps. Spring pooling at the site was also observed at many locations. Surveyed GDEs with easy access from NFSR 60.1 were much more likely to be impacted by human land use. Removing user roads that lead to GDEs and placing barriers in places near Forest Service roads would help address this issue.

Livestock grazing is one of the largest land uses in Routt National Forest. Wildlife and recreational grazing near a horse trail were observed in the study area. No commercial grazing was observed in the study area on Buffalo Pass but it is prevalent in GDEs in other parts of the forest. Grazing in Fen 2093 has caused pooling and a disruption of diffuse flow. The change in water movement affects plant assemblages at sites of disturbance due to increasing water depth and also down gradient where flow patterns are diverted and cause a change towards upland species (Cooper et al., 1998;
Cooper and MacDonald, 2000). There are areas in Fen 2093 where grazing has decreased plant cover and exposed more than 15% bare ground which leads to decomposition of peat (Weixelman and Zamudio, 2001; Chimner et al., 2002). Though many of the livestock studies were done on cattle, similar impacts were observed at Fen 2093 as a result of horse grazing. There are other areas closer to the horse trail that appeared to have once been part of the fen, but now have mineral soils and receive no water flow from sources.

Vehicle ruts were found in the majority of GDEs where human impact occurred. At 3 sites, easy access from dispersed campsites allowed users to drive through fens. The effects of vehicle ruts varied between sites but all had some relation to water flow. In Fen 2318A, the ruts inhibited groundwater from reaching parts of the fen. Noticeable differences in plant assemblage, surface moisture level and soil type were observed on either side of the ruts. There is a higher presence of upland species and mineral soil in the low moisture area downslope of the vehicle ruts. Other studies similarly show a decrease in saturation, changing both plant communities towards upland species and decreasing peat accumulation (Belyea and Clymo, 2001; Riutta et al., 2007; Grover and Baldock, 2013). Ruts also caused flow to channelize instead of flow diffusely through the fen. This shift has been shown to increase the energy of water flowing through the system leading to higher erosion rates (Gatto, 2001). At Fen 2314 and Junction Wetland, ruts created pooling near springs and a place for dead organic matter to accumulate. No plants grow in the ruts and they create channels in which water may flow through the GDE in. The pooling and lack of plant growth could be due to compaction of the sediment. Studies have shown that vehicle ruts decrease porosity and cause increase density which would increase water’s pooling ability (Marra et al., 2018). At Campsite Fen, recent vehicle ruts were observed and not enough time had passed to observe any effects on soil
or vegetation in other parts of the fen. There was some water pooled in the ruts like at other sites but more monitoring needs to be done to determine its full effect on the fen.

Other types of disturbance like campsites, trails and garbage disposal were observed but are isolated to small parts of the fens. Summit Lake Fen and Campsite Fen had dispersed campsites located on the fen, with local trampling and bare ground exposure. This also occurred on some user trails. These types of disturbances were observed at each of the GDEs but were small compared to the broad-reaching impacts that were caused by changes in water flow through heavy grazing and vehicle ruts.

Ensuring the health of groundwater dependent ecosystems has been highlighted as a part of the Routt National Forest management plan (U.S. Forest Service, 2018). Using the U.S. Forest Service Groundwater Dependent Ecosystem Level I Inventory provides a detailed report of GDE conditions that can be used to address concerns of potential impacts in the future. The results collected are useful for measuring changes due to grazing and recreational users which were the main impacts observed when studying the area. These factors can lead to changes in groundwater level, change water flow type and direction, and change the composition of plant species and soil type (Chimner et al., 2010; Austin and Cooper, 2016). The collected data can give hydrologists an idea of the fen condition over time and determine if there are detrimental changes to the GDE.

Collecting data requires little background knowledge of the study system and includes procedures used in other data collection settings by the U.S. Forest Service. This makes it easy to collect and use when an environmental analysis is needed or Routt National Forest wants to expand their dataset. Data from my study sites will also be linked with the Springs Stewardship Institute database which includes thousands of other
groundwater dependent ecosystems across the U.S (SSI, 2020). This database is useful for researchers who want possible study sites or to look at large scale spatial data on many GDEs.

CONCLUSION

Groundwater dependent ecosystem monitoring is one of the goals of the Routt National Forest Plan (U.S. Forest Service, 2013). Being able to understand how the areas in and around fens are impacted by human use through recreational and commercial purposes is important for maintaining their health long-term. Channelization in fens by tire tracks and user roads can block the flow of water from seeps, increase erosion in areas near fens and decrease fen size. User-created ruts are especially pronounced in popular recreational areas like near NFSR 60.1, so finding ways to discourage motor vehicle use near groundwater dependent ecosystems will help mitigate some of the damage caused by going off-road. Issues of stability are also a concern in areas with overgrazing, as seen in Fen 2093. Intense grazing decreases the groundcover and creates pooling and channelization of the water. In cases where this happens at outflow channels, the channel can down cut, lowering the water table and causing peat decomposition and changes in plant community composition. Grazing is the largest commercial land use in Routt National Forest so monitoring channels for downcutting and checking the level of the water table will help improve range management to mitigate negative impact on GDEs. Collected baseline measurements in Routt National Forest will provide data for future hydrologists to compare changes over time. It will allow them to measure any impacts of more people visiting this area with the impending NFSR 60.1 expansion and
upgrade. This will help them determine the best actions for groundwater dependent ecosystem management now and in the future.

ACKNOWLEDGEMENTS

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Appendix 1. Selected baseline data for Junction Wetland.

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No Core Due To Small Size of GDE
Appendix 2. Selected baseline data for Fen 2314.

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<td>2314 S2</td>
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<td>6.7</td>
<td>23.6</td>
<td>11</td>
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<tr>
<td>2314 S4</td>
<td>6.4</td>
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Water Chemistry

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<th>Spring Name</th>
<th>pH</th>
<th>Temp °C</th>
<th>Conductivity (μS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2349 S1</td>
<td>7.4</td>
<td>7.4</td>
<td>32</td>
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<tr>
<td>2349 S3</td>
<td>7.2</td>
<td>12.7</td>
<td>13.5</td>
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</table>

Appendix 3. Selected baseline data for Fen 2349.
Appendix 4. Selected baseline data for Summit Lake Fen

<table>
<thead>
<tr>
<th>Spring Name</th>
<th>pH</th>
<th>Temp °C</th>
<th>Conductivity (μS)</th>
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</thead>
<tbody>
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<td>SLF P1</td>
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<td>18.9</td>
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<tr>
<td>SLF P2</td>
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<td>16.3</td>
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<tr>
<td>SLF P3</td>
<td>7.3</td>
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</table>
Appendix 5. Selected baseline data for Campsite Fen. Both soil holes have the same profile so only one was shown.
Appendix 6. An excerpt page for collecting soil data from the data sheet of the U.S. Forest Service Level 1 Inventory.

### Forest Service GDE Level I Inventory

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Recorder</th>
<th>Page of</th>
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</thead>
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**Soil (p. 55)**

Method of soil extraction

<table>
<thead>
<tr>
<th>Location</th>
<th>Depth of Peat, Mucky Peat, and Mud (such as 8 cm to 17 cm) (and UOM)</th>
<th>Depth to Mineral Layer (and UOM)</th>
<th>Texture of Mineral Layer</th>
<th>Color of Mineral Soil</th>
<th>Redoximorphic Features and Depths (and UOM)</th>
<th>Hydrogen Sulfide Odor</th>
<th>Reaction to Hydrogen Chloride</th>
<th>Depth of Hole (and UOM)</th>
<th>Comments</th>
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</tbody>
</table>

**Fen Characteristics (p. 60)**

Yes, fen characteristics observed or No, fen characteristics not observed

Comments

Yes, histosol or histic epipedon observed or No, histosol or histic epipedon not observed

Comments