Headwater Wetlands in the Missouri River Basin of Southwestern Montana: Characterization and Description of their Extent, Distribution and Condition

Prepared for:
U.S. Environmental Protection Agency, Region 8

Prepared by:
Linda Vance, Claudine Tobalske, Jennifer Chutz and Kyla Zaret

Montana Natural Heritage Program
a cooperative program of the
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EXECUTIVE SUMMARY

This project involved the creation of a clear and consistent strategy for describing the extent, distribution, characteristics and functions of headwater wetlands, so that protection of headwater wetlands can be linked to watershed plans, environmental plans, and forest stewardship plans as appropriate. We used GIS-based methods to identify headwater wetlands on our existing NWI mapping in the Missouri River Headwaters (HUC 1002), so that in subsequent versions of our databases we can add an attribute field that indicates headwater status. The methods were field verified to ensure that photointerpretation and modeling were accurate. We also identified, assessed and described over 50 headwater wetlands that contribute to perennial streams. These were chosen to represent a range of natural variability in terms of water source, elevation, precipitation, and geology.

We began by creating a model in ArcGIS 10 to help identify headwater areas. We created a cumulative elevation over area curve to identify the elevation "bins" that best captured the landscape profile of the basin, and used Jenness' Land Facet Corridor Designer to create a Topographic Position Index (TPI) raster, which assigns pixels in an elevation raster to one of four categories: valley bottoms and plateaus; gentle slopes; steep slopes; and mountain tops and ridges. Visual inspection verified that the lower 40 elevation bins contained most of the valley bottom features and lower elevation gentle slopes, while almost all steep slopes and ridgetops were found in the top 60 elevation bins. We created a mask with a Digital Elevation Model, and used the mask to create two datasets: all portions of 12-digit (6^{th} code) HUCs above the 2100 m cutoff for Bin 40 and all portions lying below that elevation. These datasets were designated as representing "headwater" and "non-headwater" areas for further analysis.

In the subsequent analysis, we found that mean values for each TPI category were significantly different between headwater and non-headwater areas. Lower elevation subwatersheds were characterized by a high percentage (32%) of valley bottom landforms and a low percentage (3%) of mountaintops and ridges, while upper elevation subwatersheds had a low percentage (3%) of valley bottoms and a high percentage (48%) of steep slopes.

Using the Montana Land Cover and Land Use dataset, we examined differences in human impacts in headwater and non-headwater areas. Mean values for each land cover and land use category were significantly different ($P \leq 0.01$, except for shrubland and steppe, which was significant at $P \leq 0.05$) between upper and lower subwatersheds. Not surprisingly, human land use was more common in lower elevation portions of subwatersheds, although roads, mining and ski area development were seen in upper elevation portions.

We compared the hydrology of headwater and non-headwater areas, and found that overall stream density is significantly higher in lower elevations of subwatersheds than in higher regions (1.98 km/km^2 vs 0.88 km/km^2). We also saw a statistically significant difference in the density of intermittent streams, with a greater density in higher areas than in lower ones. Thirteen percent of upper areas had no perennial reaches at all, while this was true for only two of the lower elevation areas, or less than 1%. Our analysis further determined that wetland features in both upper and lower portions of the subwatersheds were dominated by Palustrine Emergent (PE) types, i.e., wetlands with erect, rooted herbaceous vegetation constituting at least 30 % of

the areal cover. Flooding regimes were either temporary (A) or seasonal (C), representing wetlands flooded for only a brief time during the growing season or wetlands flooded for most, but not all, of the growing season. Palustrine Emergent saturated (PEMB) wetlands, most commonly associated with fens, were more plentiful in upper areas, constituting 2% of total wetlands, while in the lower regions they were a minor (<0.10%) type. In all cases, however, there were significant differences in average wetland size, with upper elevation emergent wetlands being significantly smaller. The distribution and extent of Palustrine scrub-shrub wetlands also varied according to subwatershed position. In upper areas, these wetlands were both less frequent and less extensive by area than in lower subwatersheds.

Palustrine wetlands in the lower subwatershed areas were also more likely to be modified than those in the upper areas, reflecting both ownership patterns and concentrations of human land use. Modified wetlands –those that are excavated, dammed, ditched or farmed—made up only 1% of the total wetland hectares in upper areas, but 5% in lower areas. By number, 1% of upper elevation and 9% of lower elevation Palustrine wetlands were altered.

Field crews visited 231 wetlands in all. After initial trips to assess the success of the model in distinguishing between headwater and lower elevation wetlands, crews focused on eight 6th code HUCs. During this focused field campaign, they completed brief site notes at 161 wetlands, carried out Level 2 surveys at 13 sites, and completed Level 3 surveys at 57 sites. The surveys were mined for subwatershed descriptions, included in the body of this report, and to calculate floristic quality metrics.

Most sampled wetlands were in areas of very good to excellent ecological integrity, where stressors were at a minimum. None of the sampled wetlands had hydrologic modifications or stressors on-site or within a 200m buffer area. Thirty-six percent (36%) of the sampled wetlands had no human disturbances on-site or within the 200m buffer. Twenty-nine percent (29%) of sites had only one human disturbance on-site or within the buffer; however, 76% of these disturbances were "human visitation," often evidenced only by the trail that the crews had used to access the wetland. Forty-two of the wetlands were considered to be in top "reference condition" based on field surveys.

We calculated floristic quality metrics, and compared a key indicator score (the cover-weighted adjusted floristic quality indicator, or CWAFQI) for sites in our study area to those calculated for all sites during an earlier probabilistic survey in the area. Overall, the CWAFQI scores for the sites in our study were consistent with those observed during the earlier survey. In the current study, the mean score for all assessed sites was 53.23. However, there was a significant difference between scores for sites falling within identified headwater areas (mean of 56.00) and those outside (mean of 43.83). We also found that sites in our study were less weedy than sites in Southwest Montana as a whole; as noted above, the percent of exotic species found across all sites in our study was only 3%, while in the earlier study it was 12.44%.

ACKNOWLEDGEMENTS

This project was funded by a U.S. Environmental Protection Agency Region 8 Wetland Program Development Grant. We would like to thank Toney Tot of EPA Region 8 for her continued support and commitment to wetland assessment and monitoring in our region. We also thank the late Mitra Jha for the work he put into this project, and his devoted work on wetland health within the Rocky Mountain West. His untimely passing was a great loss to the Region.

We thank Dorothy Wallace-Senft, Ryan Sullivan, Sara Owen Westcott and Emily Luther for spending long days in the field collecting data for this project. Several people worked on the digital wetland mapping that was integral to the completion of this project: Joe Fortier, Gary Carnefix, Robin Lium, Sara Owen, Meghan Burns, Tom Schemm, Steve Hernandez, Jessica Clarke and Alexis Buchwald. Karen Newlon, formerly with the Montana Natural Heritage Program, provided helpful suggestions for data analyses and interpretation. Melissa Hart of the Montana Natural Heritage Program offered her considerable expertise in editing. Any errors or omissions remaining in the report are entirely the responsibility of the authors.

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INTRODUCTION

Within stream and river networks, headwater streams are the most abundant in both length and number, typically contributing over two-thirds of total stream length in a river drainage (Freeman et al. 2007). Headwater streams supply downstream reaches with coarse and fine sediment, large woody debris, coarse and fine organic matter, and nutrients (MacDonald and Coe 2007), including dissolved organic carbon (Andersson and Nyberg 2008). These streams may be perennial, intermittent or ephemeral, with considerable variation in flow on both an intra- and interannual basis (Dollar 2004). This diversity and variability translates to a plethora of unique habitats for a range of aquatic and terrestrial species, thus supporting high levels of biodiversity (Meyer et al. 2007).

Many of these streams originate in high elevation wetlands whose soils store early season snowmelt, recharging groundwater and/or discharging surface water to the streams. As such, these headwater wetlands provide critical functions for the maintenance of aquatic systems, including water storage, maintenance of surface/groundwater connections and biochemical processes, support for hydrodynamic balance, and habitat for diverse assemblages of wetland –dependent native species (Meyer and Wallace 2000). However, recent decades have brought an increased level of disturbance to headwater areas. These range from direct anthropogenic actions such as residential and recreational development to the unprecedented loss of forest habitat to insects and disease, brought on in large part by fire suppression policies (Jenkins et al. 2012). Furthermore, with current climate change models for the northern Rocky Mountains predicting warming temperatures, decreased snowpacks, and a shift in runoff patterns over the next 50 years (Rasmussen et al. 2014), the long-term persistence of headwater wetlands and their hydrological connectivity with downstream waters appears increasingly uncertain.

Despite their significance, the extent, distribution, characteristics and functions of headwater wetlands have not been systematically described in the Rocky Mountain west in general, or in Montana particularly. Although the Montana Natural Heritage Program (MTNHP) has been mapping wetlands across the state since 2007, none of our mapping explicitly indicates whether a wetland is in a headwater position, making it impossible for decision-makers to execute a rapid query for these ecologically and hydrologically significant wetlands within their jurisdiction. This project was devised to address this gap by creating a clear and consistent strategy for describing the extent, distribution and characteristics of headwater wetlands using available GIS datasets.

STUDY AREA

We chose the Missouri River Headwaters Basin (Hydrologic Unit 1002) as our initial study area (Figure 1). Situated in southwest Montana, this four-digit Hydrologic Unit (4th code HUC) covers 36,351 square kilometers, with elevations ranging from 1,229 meters to 3,443 meters. Three major rivers, the Gallatin, Madison and Jefferson (formed from the Ruby, Big Hole, Beaverhead and Boulder Rivers) join near the town of Three Forks, Montana, to become the Missouri River (Figure 2). All or part of 21 mountain ranges, including the Anaconda, Beaverhead, Gallatin, Gravelly, Madison, Pioneer, and Tobacco Root ranges, occur in the study area.

Figure 1. Study area (outlined in red), the Missouri River Headwaters Basin.

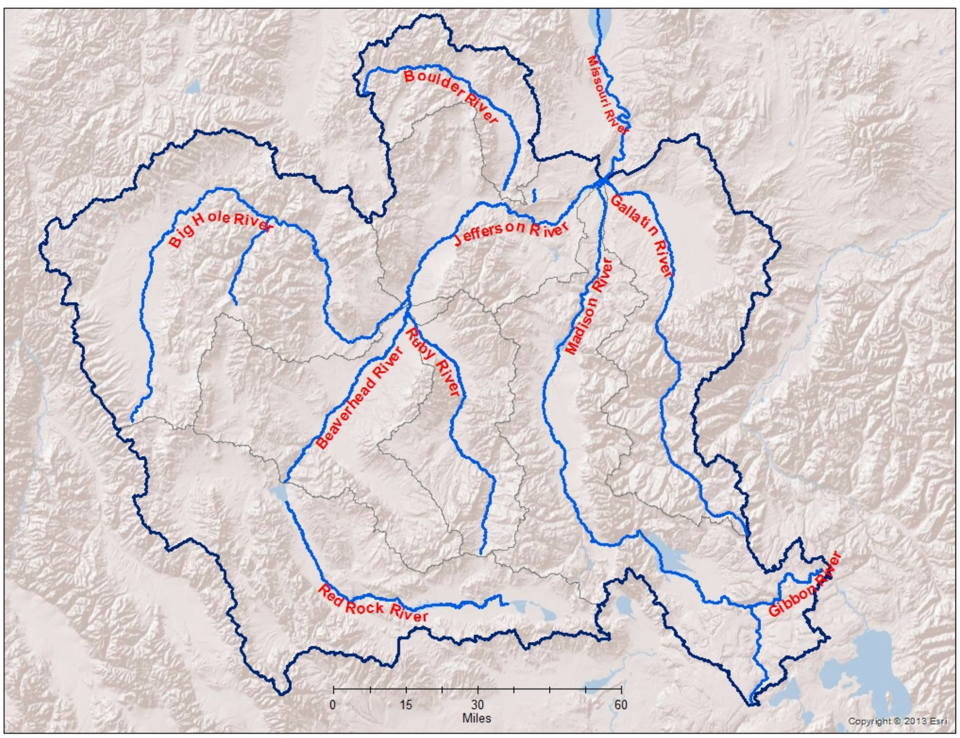

Figure 2. The Missouri River Headwaters basin.

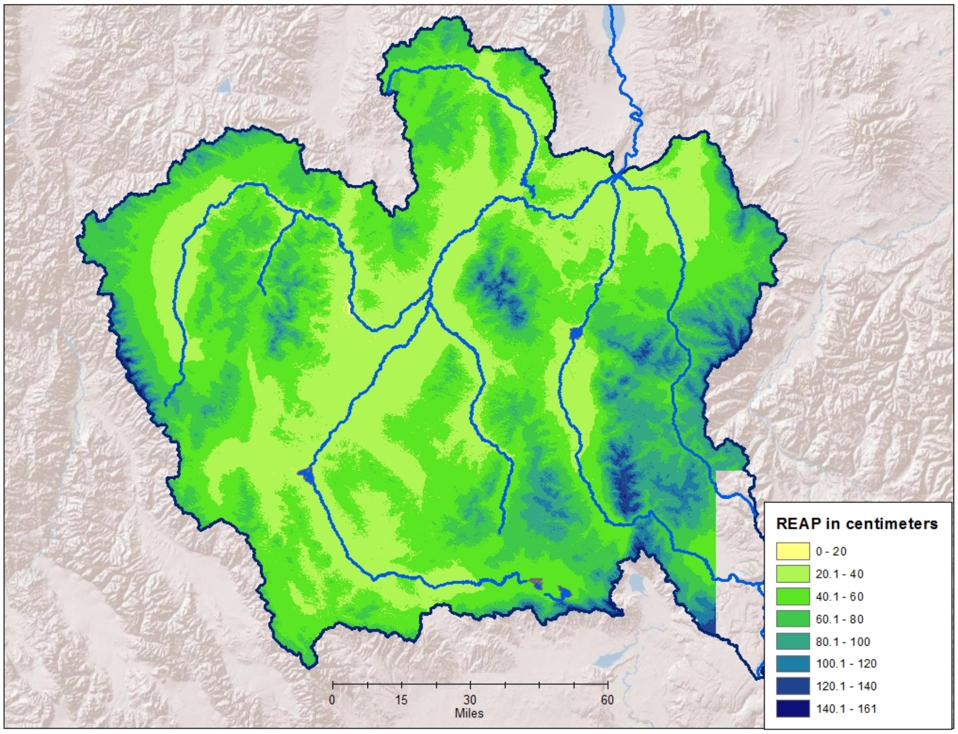

Figure 3. Relative effective annual precipitation (REAP) in the Montana portion of the Missouri River Headwaters basin.

Climate in the study area is cold, dry, and continental (McNab and Avers 1994). Mean January temperatures range from -6 C in Dillon to 0 C in Wisdom; in July, mean temperatures range from 8.9 C in Dillon to 4.9 C in Wisdom. Relative effective annual precipitation (REAP), which is an indicator of the amount of moisture available at a given location accounting for precipitation, slope, aspect, and soil properties, ranges from a low of 13 cm in the western and central valleys of the study area to 161 cm at the highest elevations in the eastern mountains (Figure 3).

Over 1,200 named creeks and rivers are found in the HUC, totaling more than 16,000 km. Unnamed creeks and channels (including human-made channels) constitute an additional 39,600 km. Of the total stream and river kilometers, 15,750 km are classified as perennial in the high-resolution National Hydrography Dataset (NHD) and 34,343 km are classified as intermittent. 2,195 km are mapped as "artificial paths." [1] The remainder are canals, ditches, and other anthropogenic features.

[1] Artificial paths, in the NHD scheme, are mapped flowlines in areal features. For example, much of the Big Hole River is mapped as an area (polygon) rather than a line because of its width; the artificial path feature is the imputed center line through that polygon. Artificial paths also flow from one end of a reservoir to another.

Except for the Anaconda mountains in the northeastern part of the study area, all of the study area is part of the Level 3 Middle Rockies ecoregion, characterized by the absence of the maritime influence more common in the Northern Rockies. There are 23 Level 4 ecoregions (Figure 4 and Table 1, Woods et al. 2002). In general, shrublands and grasslands dominate the lower elevations of the study area, while coniferous forests cover higher elevations (Figure 5). Dominant coniferous species vary by elevation with lower elevation forests composed of Douglas-fir (*Pseudotsuga menziesii*) with limber pine (*Pinus flexilis*) and Rocky Mountain juniper (*Juniperus scopulorum*) common on calcareous sites. Higher elevation forests are dominated by subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*). Lodgepole pine (*Pinus contorta*) and whitebark pine (*Pinus albicaulis*), although greatly diminished by insects and disease, are still common in dry subalpine forests and in alpine parklands.

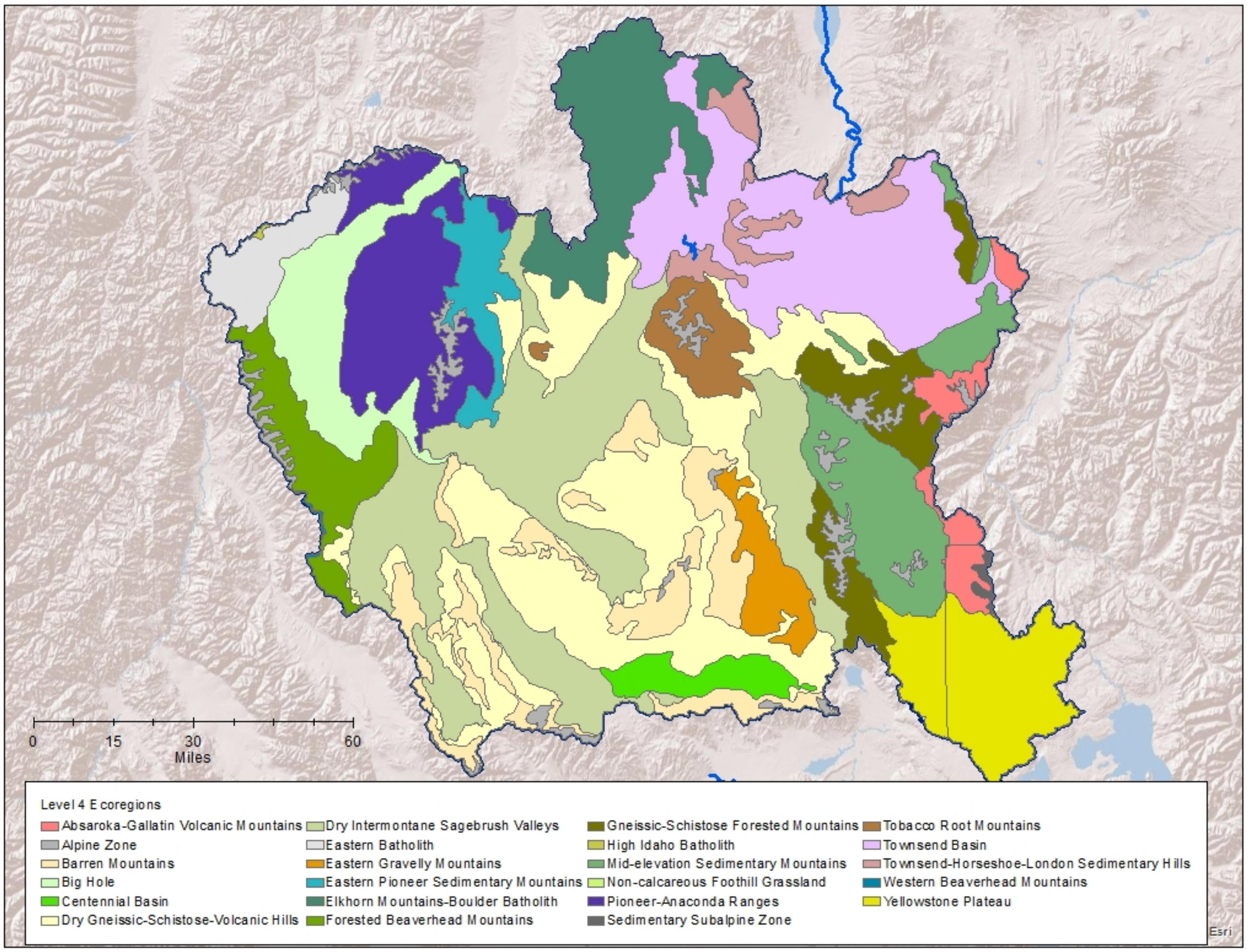

Figure 4. Level 4 ecoregions in the Missouri River Headwaters basin.

Table 1. Level 4 ecoregions in the Missouri River Headwaters basin.

Level 4 Name	Code	Hectares	Sq. Miles
Eastern Batholith	16a	72,203.59	278.78
High Idaho Batholith	16h	1,019.31	3.94
South Clearwater Forested Mountains	16i	0.20	0.00
Dry Intermontane Sagebrush Valleys	17aa	596,821.97	2304.34
Dry Gneissic-Schistose-Volcanic Hills	17ab	581,221.38	2244.11
Big Hole	17ac	162,361.91	626.88
Western Beaverhead Mountains	17ad	1,139.02	4.40
Forested Beaverhead Mountains	17ae	115,899.21	447.49
Centennial Basin	17af	55,558.47	214.51
Pioneer-Anaconda Ranges	17ag	240,107.12	927.06
Eastern Pioneer Sedimentary Mountains	17ah	75,662.73	292.14
Elkhorn Mountains-Boulder Batholith	17ai	226,837.98	875.83
Eastern Gravelly Mountains	17d	67,704.51	261.41
Barren Mountains	17e	211,258.26	815.67
Mid-elevation Sedimentary Mountains	17g	201,886.96	779.49
Alpine Zone	17h	90,036.94	347.63
Absaroka-Gallatin Volcanic Mountains	17i	47,519.99	183.48
Yellowstone Plateau	17j	53,459.46	206.41
Gneissic-Schistose Forested Mountains	17l	125,591.10	484.91
Townsend-Horseshoe-London Sedimentary Hills	17w	66,231.47	255.72
Townsend Basin	17y	391,690.52	1512.33
Tobacco Root Mountains	17z	70,089.94	270.62
Non-calcareous Foothill Grassland	43s	44.67	0.17

Shrublands are dominated by mountain big sagebrush subspecies (*Artemisia tridentata* ssp. *vaseyana*), although basin big sagebrush (*A. t.* ssp. *tridentata*) and Wyoming big sagebrush (*A. t.* ssp. *wyomingensis*) are found locally. Large stands of greasewood (*Sarcobatus vermiculatus*) occur on saline or alkaline sites. The herbaceous layer is comprised mainly of bunchgrasses, including bluebunch wheatgrass (*Pseudoroegneria spicata*), Idaho fescue (*Festuca idahoensis*), and needle and thread (*Hesperostipa comata*). Human land uses include agriculture, recreation (including extensive four-wheel drive use in the western foothills and mountains), and residential/urban development. Dillon and Bozeman are large population centers within the study area; most other residential use is found in small towns and dispersed rural communities. The Big Sky ski area is a major recreation center. Light manufacturing and small-scale resource extraction occur throughout the area, although manufacturing tends to be concentrated near the cities.

Land ownership is a mix of federal, state, and private. The U.S. Forest Service is the largest public land owner, with 1.3 million hectares (~5000 square miles) of land, primarily in the Gallatin and Beaverhead/Deerlodge National Forests. The U.S. Fish and Wildlife Service manages Red Rocks National Wildlife Refuge (26,632 hectares or ~103 square miles) in the southeastern part of the study area.

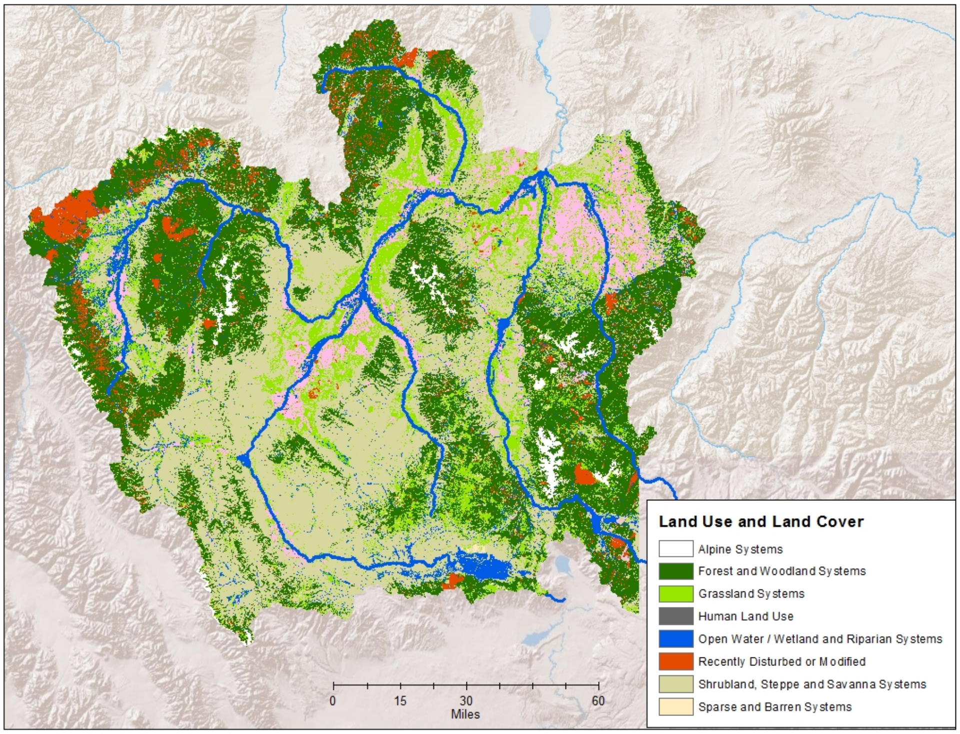

Figure 5. Land use and land cover within the Missouri River Headwaters basin.

METHODS

GIS Analysis

We began by building a project geodatabase in ArcGIS 10.x, in Montana State Plane coordinates (NAD 1983 datum, StatePlane_Montana_FIPS_2500), using the Lambert Conformal Conic projection. Main datasets incorporated into the geodatabase are shown in Table 2.

Although the entire study area can be characterized as a headwater basin, our goal was to develop a method for identifying local headwater source areas within the basin. To do this, we began by developing a cumulative elevation over area curve. Similar to the hypsometric curve used in hydrology (Vivoni et al. 2008), a graphical depiction of the distribution of elevation "bins" helps identify the landscape profile of a basin. To plot the curve, we used Spatial Analyst in ArcGIS 10.2 to reclassify a 30m Digital Elevation Model (DEM) into 100 equal elevation bins. The attribute table, containing a Value field (1-100) for each bin, and a Count field indicating the number of pixels in that bin, was then exported to Excel. To convert the Count to area in square kilometers, we multiplied the number of pixels by 900 (to get square meters) and divided by 1,000,000. We then calculated cumulative area by adding each cell from the square kilometer area to the sum of previous cells. Approximately half the basin area (~18,300 square kilometers) lies in the first 40 elevation bins, i.e., below 2100 m. (Figure 6).

Table 2. Major datasets used in the analysis.

- ***National Wetlands Inventory.*** This data set, produced and maintained by MTNHP, represents the extent of wetlands and deepwater habitats that can be determined with the use of remotely sensed data, typically aerial imagery, within the timeframe for which the maps were produced. Maps used in this project were digitized from 2005 to 2013 NAIP imagery, accurate at a scale of 1:12000, and available in the same projection as the project geodatabase.

- ***Land cover and land use.*** We used the Montana Land Cover/Land Use theme, produced and maintained by the MTNHP as part of Montana's Spatial Data Infrastructure. The data are modeled from multi-season satellite imagery (Landsat ETM+) and NAIP imagery, in conjunction with digital elevation model (DEM) derived datasets (e.g. elevation, landform, aspect, etc.), and include both natural and semi-natural vegetation. The data are at a 1:100000 scale and are in the same projection as the project geodatabase.

- ***Public land ownership boundaries***. Land ownership data for the project area are complete with varying degrees of accuracy at a scale of 1:24000, and are also in the same projection as the project geodatabase. The data are updated on a weekly basis by the Montana State Library's Geographic Information Program.

- ***Administrative boundaries***. State, federal, tribal and local boundaries are available in a series of datasets from the Montana State Library's Geographic Information Program at a scale of 1:24000, again in the same projection as the project geodatabase.

- ***Aerial imagery.*** During the project, we used United States Department of Agriculture (USDA) National Agricultural Imagery Program (NAIP) digital aerial images from 2009, 2011 and 2013. The images have a one meter ground sample distance with a horizontal accuracy matching within three meters of digital orthophoto quarter quads (DOQQs). The horizontal ground sample distance of DOQQs is also 1 meter, with 1:12,000 scale accuracy, so that 90 percent of the well-defined features are within 33.3 feet (1/30 inch) of the true mapped ground position. The NAIP images were obtained from the Natural Resource Information Service (NRIS), part of the Montana State Library, in the same projection as the project geodatabase. We also used ESRI's World Imagery map service for visual inspection of features. Available in most state locations at 15 cm resolution, this dataset cannot be manipulated but can be displayed for verifying features or for determining access points for field data collection.

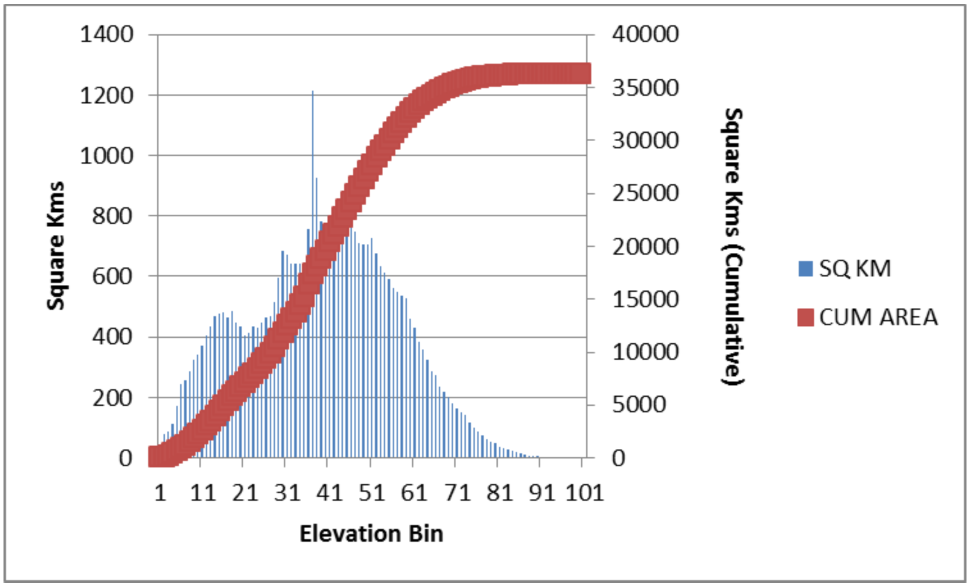

Figure 6. Cumulative area curve for elevation bins in HUC 1002, the Missouri River Headwaters basin.

We also calculated a Topographic Position Index (TPI) using Jenness' Land Facet Corridor Designer Revision 1.2.884 (Jenness et al. 2013). The TPI uses a DEM to assign pixels to one of four categories: valley bottoms and plateaus; gentle slopes; steep slopes; and mountain tops and ridges. User-defined inputs determine the definition of "steep." We chose 12 degrees, or 21.3 %, as the cutoff for "steep" areas based on an examination of slope values for Palustrine wetlands in the basin. Although Palustrine wetlands are sometimes found in steeply sloping valleys, they are more characteristic of toe slopes, flats and gentle slopes. The value of 12 degrees represents the mean slope value plus two standard deviations for all Palustrine wetlands in the study area. We built individual TPIs for each 5th code HUC in the basin, and then mosaicked them into a single raster. The TPI highlights the basin and range topography of the study area (Figure 7).

From these two rasters, we created an elevation/topography model by multiplying the values of each bin by a value for each TPI category: valley bottoms = 0, gentle slopes = 1, steep slopes = 2, and mountaintops/ridges = 3. The result is displayed in Figure 8. Visual inspection of the three rasters verified that the lower 40 elevation bins contained most of the valley bottom features and lower elevation gentle slopes, while almost all steep slopes and ridgetops were found in the top 60 elevation bins. We used the DEM to create a mask, and from that mask created two datasets: all portions of 12-digit (6th code) HUCs above the 2100 m cutoff for Bin 40 and all portions lying below that elevation. These datasets were further subsetted to eliminate those 6th code HUCs for which wetland mapping is incomplete, to ensure consistency in the analysis. All subsequent spatial calculations and analyses were performed on these final datasets, using ArcGIS and Excel.

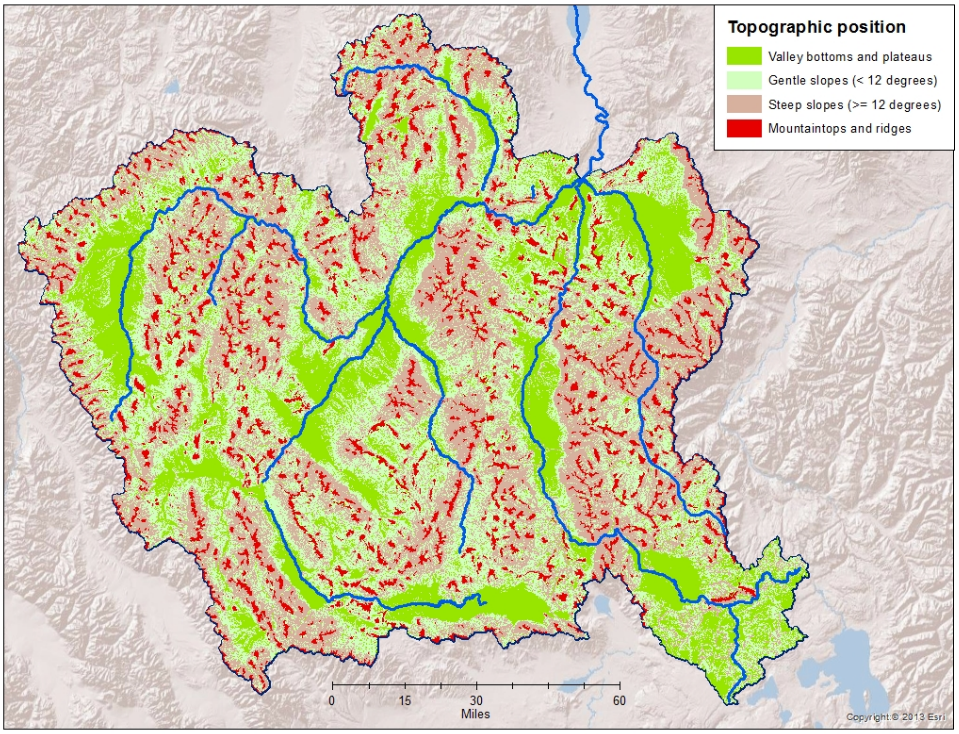

Figure 7. Topographic Position Index for the Missouri River Headwaters basin.

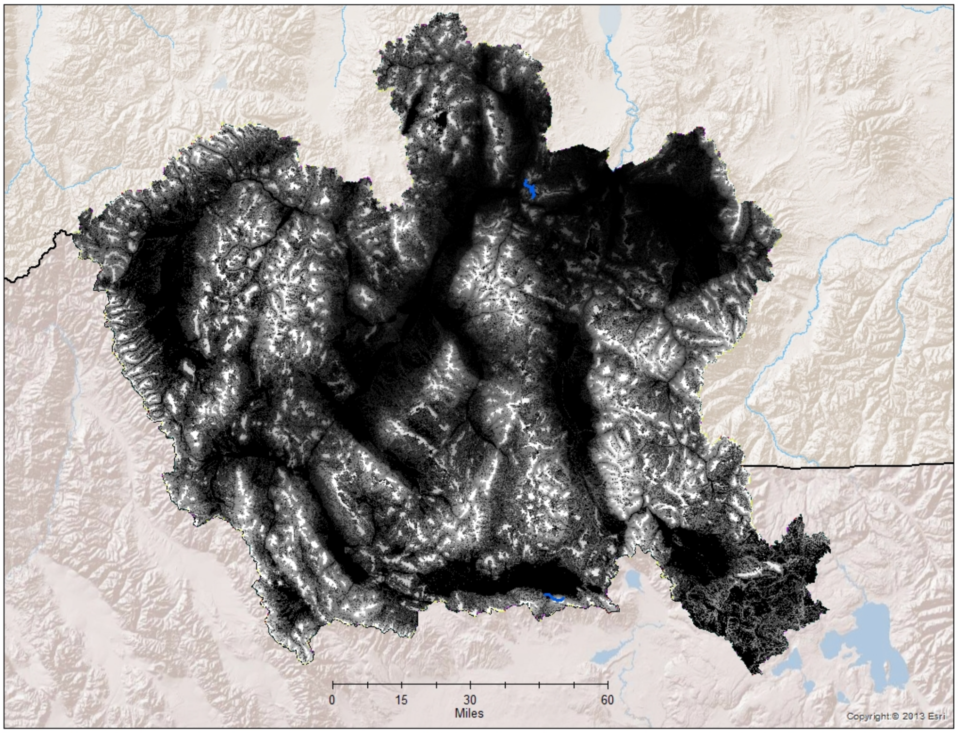

Figure 8. TPI x DEM for the Missouri River Headwaters basin. Values range from 0 (darkest) to 300 (lightest), with darkest areas representing valleys and low-elevation gentle slopes.

Field Data Collection and Analysis

Our field data collection had two components. The first was a qualitative verification. We visited subwatersheds (6th code HUCs) throughout the study area to determine whether our elevational cutoff made good ecological sense, based on such indicators as surficial geology, slope, vegetation communities, stream features, and wetland characteristics. In total, we visited 75 of the 413 6th code HUCs in the study area.

The second component involved field surveys aimed at capturing quantitative data and qualitative information about the characteristics of headwater areas. These surveys were carried out in the summers of 2012 and 2013, with some revisits in 2014. We limited these field surveys to the Big Hole subbasin (10020004) because our broader scale field verification indicated that there were distinct differences between subbasins. For example, subwatersheds in the Gallatin subbasin (10020008) tended to be much steeper than in other basins, and consequently, much drier, with fewer wetland and riparian features. The Big Hole, at 7228 square kilometers, was large enough to allow crews to explore interbasin variability without the confounding effects of the multiple environmental variables found in the larger study area.

In the field, crews travelled through the basin, carrying out Level 2 and/or 3 Ecological Integrity Assessments at selected wetlands (n=61), and compiling notes and a photographic record. At each wetland site, we begin by classifying the wetland system we are surveying. For the purpose of this project, we used the Ecological Systems classification developed by NatureServe (Comer et al. 2003). Ecological systems are groupings of biological communities occurring in similar physical environments, and influenced by similar ecological processes such as flooding, fire, wind, and snowfall. Systems typically occur on a landscape at scales of tens to thousands of acres, and generally persist in a recognizable state for 50 or more years. By integrating both biotic and abiotic features, the ecological system concept incorporates elements of both the Hydrogeomorphic Method (HGM) and the vegetation-based National Vegetation Classification Standard. They are intended to be identifiable in the field by land managers, resource specialists, and planners. Unlike the Cowardin system (Cowardin et al. 1979), in which floristically or hydrologically differing areas of a single wetland may have different classifications, the Ecological Systems classification generally assigns each wetland to a single category. For example, a saturated wetland with a sedge-dominated sector, an open water pond with a floating mat, and a shrub-carr fringe might be mapped with four distinct Cowardin codes (e.g., PEMB, PABF, PEMC and PSSB); the Ecological Systems approach would describe it simply as a Rocky Mountain Subalpine-Montane Fen. In this study, almost all the sites we visited were either Rocky Mountain Subalpine-Montane Fens, Alpine-Montane Wet Meadows, or Emergent Marshes. Crews used a dichotomous key contained in our wetland assessment protocol[2] to classify each site, basing their decisions on soil composition, hydrology, and floristic features. The MTNHP assessment protocol applies an Ecological Integrity Assessment (EIA) framework to assess the condition of wetlands. This framework relies on key ecological indicators, metrics, and stressors that can be readily measured, monitored, or observed. Indicators of structure and function are measured with metrics that use narrative ratings scaled along a gradient reflecting wetland condition relative to a natural or undisturbed state (i.e., reference standard). Ratings are assigned on an ordinal scale, recorded on the EIA form, and then integrated to produce overall scores for four attributes: 1) Landscape Context; 2) Vegetation; 3) Physicochemical; and 4) Hydrology. Ratings for these four attributes can be combined to produce an overall EIA score (Newlon 2012). MTNHP's EIA form also contains a list of observed stressors or disturbances commonly found in Montana. Along with recording the occurrence of a stressor, the scope and

[2] The protocol used for this study was the same used for our rotating basin assessments; the most recent version can be downloaded from http://mtnhp.org/wetlands/docs/EIAProtocol_2015.pdf

severity of each stressor are also estimated. Stressor scope and severity scores are rolled up into an overall stressor impact score.

We surveyed the sites in our study using both Level 2 and Level 3 assessments. Together, these involve recording general information on wetland condition, and detailed, quantitative data collection emphasizing vegetation and soils. At each site, we established a 0.5 ha assessment area (AA) for sampling, attempting to locate it in an area that was most representative of the general site. Standard site variables were recorded, including:

- UTM coordinates
- Elevation, slope, and aspect
- Ecological System classification
- Dominant plant species
- HGM classification (Hauer et al. 2002)
- Cowardin classification (Cowardin et al. 1979)
- Nearby landforms (alluvial fans, narrow bedrock valley, alluvial valley, etc.)
- Description of onsite and adjacent ecological processes and land use
- Description of general site characteristics and a site drawing
- Selected soils data: depth and identification of soil horizons, texture, and color
- Water table depth

At least four photos were taken from the AA center at each site. Photos were taken 90° from each other, and the aspect was recorded to the nearest 5° at all photo points. Photo placards were placed in the corner of each photo. Additional photos were taken as needed to document the wetland and surrounding landscape.

At Level 3 survey sites (n=57), we collected vegetation data using a 20 m x 50 m relevé plot(Peet et al. 1998). The structure of the plot consists of 10 10 m x 10 m (100 m^2) modules typically arranged in a 20 m x 50 m array (Figure 9). The plot was subjectively placed within the AA to maximize abiotic/biotic heterogeneity. Capturing heterogeneity within the plot ensures adequate representation of local variations produced by hummocks, water tracks, side-channels, pools, wetland edge, microtopography, etc. Absolute cover of all vascular species was estimated within four of the 100 m^2 modules, referred to as intensive modules. When all species within a module had been identified, cover was visually estimated for the 100 m^2 module using the following cover classes (Peet et al. 1998):

Class 1 = trace (one or two individuals)	Class 6 ≥ 10–25%
Class 2 < 1%	Class 7 ≥ 25–50%
Class 3 ≥ 1–2%	Class 8 ≥ 50–75%
Class 4 ≥ 2–5%	Class 9 ≥ 75–95%
Class 5 ≥ 5–10%	Class 10 ≥ 95%

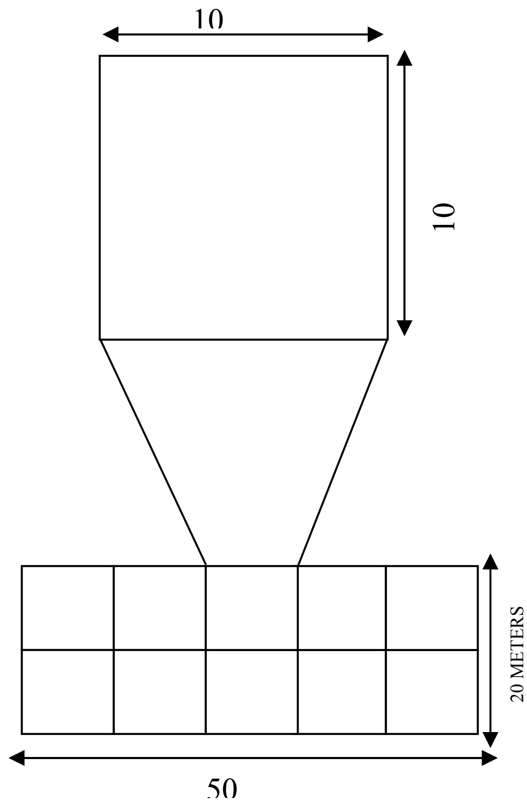

Figure 9. Releve plot layout (adapted from Peet et al. 1998).

After sampling each of the intensive modules, the remaining, or residual, modules were walked to document presence of any species not recorded in the intensive modules. Percent cover of these species was estimated over the entire 1,000 m^2 plot.

In the field, vascular plants were identified using the Vascular Plants of Montana (Dorn 1984) and the Manual of Montana Vascular Plants (Lesica 2012) as well as ancillary dichotomous keys specific to certain plant genera (e.g., carices). The state-based nomenclature was cross walked to nationally accepted nomenclature based on the USDA PLANTS Database (http://plants.usda.gov).

At each sampling location, we also collected detailed soil data by excavating two soil pits 45–60 cm in depth. For each horizon, we recorded depth, soil layers, matrix color, redoximorphic feature color and abundance (%), and soil texture. Soil color was determined using Munsell Soil Color Charts (Munsell Color Company 2009).

We created a relational database in Microsoft Access®. All EIA data and vegetation plot data were entered into the database after field data collection was complete. For vegetation data, plant species mean cover values were averaged across modules to get an average cover value for each plant species for the entire vegetation plot. Unknown species or ambiguous species (e.g., species described only as “Carex sp.”) were entered into the database, but these were not included in data analysis. We calculated multiple vegetation metrics for each Level 3 survey sites, and summarized site and assessment data.

RESULTS

Partitioning study area subwatersheds by elevation highlighted differences in environmental variables and ecological conditions between upper elevation and lower elevation segments. These variables and conditions are discussed separately in the following subsections.

Topographic Position

Mean values for each TPI category were significantly different ($P <= 0.01$) between upper and lower subwatersheds (Table 3, Figure 10). Lower elevation subwatersheds were characterized by a high percentage (32%) of valley bottom landforms and a low percentage (3%) of mountaintops and ridges, while upper elevation subwatersheds had a low percentage (3%) of valley bottoms and a high percentage (48%) of steep slopes. Although there was a statistical difference between the mean percentage of gentle slopes in each elevation profile, these features made up more than a quarter of topographic positions in both low and high elevation contexts, reflecting the rolling topography of both foothills and upper basins (Figure 11).

Table 3. Distribution of topographic positions in lower and upper elevation areas.

Topographic Position	Lower Elevation	Upper Elevation
Valley bottoms	32%	3%
Gentle slopes	36%	27%
Steep slopes	29%	48%
Mountaintops/ridges	3%	22%

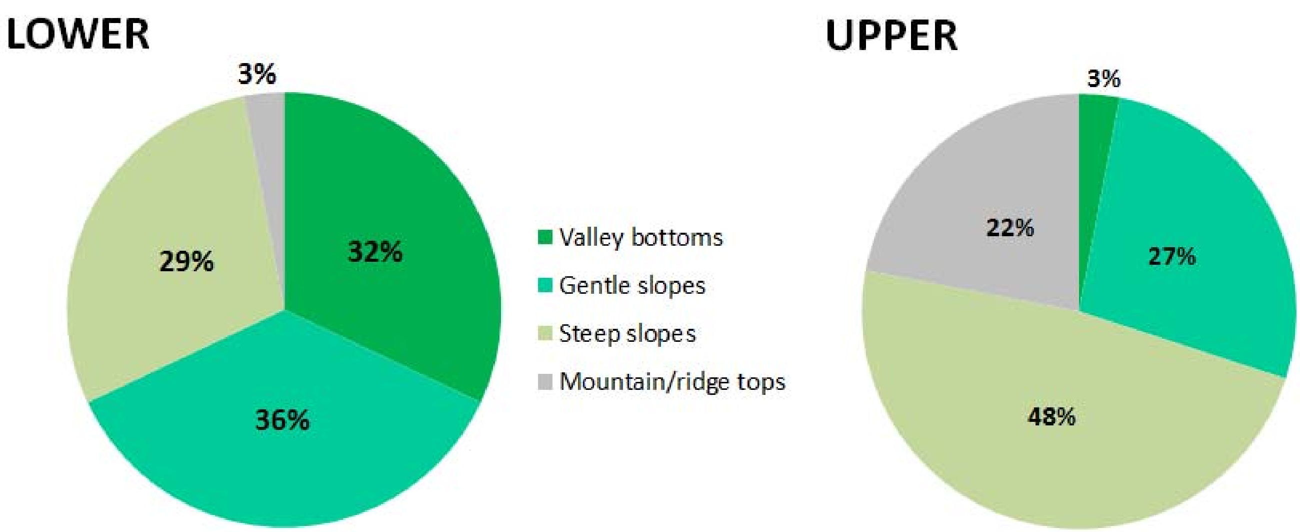

Figure 10. Distribution of landform types in lower and upper elevation areas.

Figure 11. Looking east from Odell Mountain (elevation 2867 m) showing rolling topography of upper subwatershed just below escarpment. The Pioneer Mountains are seen in the background.

Land Cover and Land Use

Mean values for each land cover and land use category were significantly different ($P \leq 0.01$, except for shrubland and steppe, which was significant at $P \leq 0.05$)) between upper and lower subwatersheds (Table 4, Figure 12). Not surprisingly, human land use was more common in lower elevation portions of subwatersheds, although roads, mining and ski area development are reflected in the 1% human land use in upper elevation portions. Notable here is the "recently disturbed" category, which is higher in upper elevation areas. This is a function of the insect and disease disturbances that have affected lodgepole and whitebark pine in recent years, as well as wildland fires, which have been widespread in upper elevations in the past decade.

Table 4. Land cover and land use categories, lower and upper elevation areas.

Land Cover/Land Use	Lower Elevation	Upper Elevation
Water/wetlands	9%	2%
Human land use	10%	1%
Sparse/barren	<1%	<1%
Alpine systems	<1%	3%
Forest and woodland	24%	58%
Shrubland and steppe	38%	22%
Grasslands	16%	7%
Recently disturbed	3%	7%

Figure 12. Land cover and land use categories in lower and upper elevation areas.

Hydrology

At the large scale, headwater streams account for the majority of stream kilometers in a river drainage system (Freeman et al. 2007). At the more local scale of our study area, which is all a headwater system for the greater Missouri River drainage, overall stream density is significantly higher in lower elevations of subwatersheds than in higher regions (1.98 km/km^2 vs. 0.88 km/km^2). We also see a statistically significant difference in the density of intermittent streams, with a greater density in higher areas than in lower ones. However, there is no statistically significant difference between the relative percentage of intermittent vs. perennial streams in upper and lower watersheds. What is notable, however, is that 13% of upper areas have no perennial reaches at all, while this is true for only two of the lower elevation areas, or less than 1%. This is largely a feature of topography and drainage; in the steeper slopes and ridges of the upper portions of subwatersheds, the source of surface water is primarily snowmelt, augmented by groundwater discharge at breaks in slope. Many of these small streams appear as a "chain of pearls," with small pools linked by narrow channels or groundwater seepage (Figure 13).

Figure 13. Pool in headwater channel.

Strahler stream order is commonly used as a surrogate for stream size based on a hierarchy of lower order tributaries joining to form higher level channels as water flows downstream. It provides a useful approximation of catchment size and distance from source water and supports modeling of mean annual discharge (Hughes et al. 2011). NHD Plus, a derived product based on the 1:100,000 medium-resolution NHD, includes modeled Strahler order for each stream reach in the dataset. It is not entirely accurate; the 1:100,000 NHD clearly misses small, low order streams that are picked up on the 1:24,000 dataset, such that NHD Plus-defined 1st order streams are more likely to be 2nd or 3rd order streams. However, it provides a useful basis for comparison. In NHD Plus, the mean Strahler order for all streams in the upper portions of the subwatersheds is 1.12, while in lower portions of the subwatersheds, it is 4.33, significantly different at $P \leq 0.01$. Even if the true means are greater, the ratio is likely to be the same, indicating that we are successfully distinguishing between headwater source areas and the receiving areas downstream.

Lakes and ponds also are more common in lower subwatershed areas, averaging one for every 20 km^2, compared to one for every 40 km^2 at higher elevations. Lower elevation lakes are also larger, with a mean size of 10 ha, compared to the mean of 2 ha found in upper regions (Figure 14). Lower subwatersheds also feature more reservoirs, averaging 67 ha in size. By contrast, no reservoirs are mapped in the upper elevations of the study area.

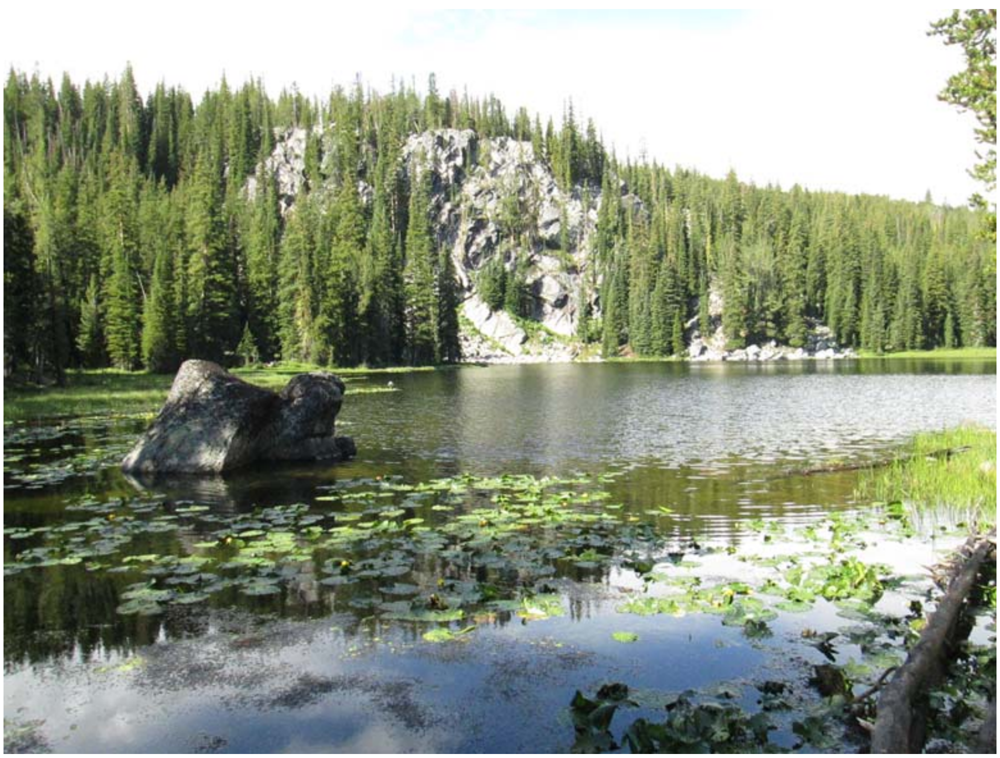

Figure 14. Small lake typical of those found in headwater portions of the study area.

Wetland Types, Extent and Distribution

Spatial Analysis

Wetland features in both upper and lower portions of the subwatersheds are dominated by Palustrine Emergent (PE) types, i.e., wetlands with erect, rooted herbaceous vegetation constituting at least 30% of the areal cover.

Flooding regimes are either temporary (A) or seasonal (C), representing wetlands flooded for only a brief time during the growing season or wetlands flooded for most, but not all, of the growing season. Together, PEMA and PEMC wetlands make up 77% and 73% of total wetland cover in upper and lower areas respectively. Palustrine Emergent saturated (PEMB) wetlands, most commonly associated with fens, are more plentiful in upper areas, constituting 2% of total wetlands, while in the lower regions they are a minor (<0.10%) type. In all cases, however, there are significant differences in average wetland size, with upper elevation emergent wetlands being significantly smaller ($P \leq 0.01$, Table 5).

Table 5. Average size, in hectares, of Palustrine Emergent wetlands.

Wetland Type	Upper Elevation	Lower Elevation
PEMA	0.58	1.39
PEMC	0.58	1.49
PEMB	0.83	2.92

The distribution and extent of Palustrine scrub-shrub wetlands also varies according to subwatershed position. In upper areas, these wetlands are both less frequent and less extensive by area than in lower subwatersheds (Table 6). This is largely a function of topography and substrate; while Palustrine scrub-shrub wetlands do occur as a narrow band along low-gradient streams at higher elevations (Figure 15), they are more common and more extensive in the alluvial soils of broad, lower elevation valleys.

Table 6. Distribution of Palustrine scrub-shrub wetlands as a percentage of all Palustrine wetlands.

	Upper Elevation	Lower Elevation
% PSS by number	9%	27%
% PSS by hectare	9%	19%

Figure 15. Palustrine scrub-shrub wetland in upper LaMarche Creek drainage.

Palustrine wetlands in the lower subwatershed areas are also more likely to be modified than those in the upper areas, reflecting both ownership patterns and concentrations of human land use. For example, modified wetlands –those that are excavated, dammed, ditched or farmed—make up only 1% of the total wetland hectares in upper areas, but 5% in lower areas. By number, 1% of upper elevation and 9% of lower elevation Palustrine wetlands are altered.

Lacustrine wetlands are those wetlands having the following characteristics: 1) situated in a depression or in a dammed river (i.e., a reservoir); 2) with less than 30% areal coverage of trees, shrubs, persistent emergents or other vegetation; and 3) a total area greater than 8 hectares (20 acres) or, if smaller, with a low water depth of 2 meters (6.6 feet) or more at the deepest point. Although they are a small percent of the total wetland extent throughout the study area, lacustrine wetlands are both more numerous and larger (a mean of 53 vs. 24 hectares in size) in lower subwatershed areas than in higher elevations. In part this is because basin characteristics and water sources in upper drainages favor ponds more than lakes, and in part it is because the Lacustrine system includes entirely anthropogenic water bodies, which tend to be located near human development. Of the 212 Lacustrine wetlands in lower elevation portions of the study area, 199 —representing 94% of Lacustrine wetlands and 96% of Lacustrine wetland hectares—are impoundments or excavated basins. This is in contrast to the upper portions, where only 27% by number and 52% by hectare are similarly altered.

The Riverine system contains all wetlands within a channel dominated by continuously flowing water. As with Lacustrine systems, these are both less common and smaller in size (2.6 vs. 8.1 hectares) in upper drainages than in lower ones. Similarly, while less than 0.5% of upper elevation riverine systems are altered in some way, that percentage rises to 10% by number and 8% by hectare in the lower subwatershed areas. Table 7 summarizes the distribution of wetlands by system for upper and lower elevations.

Table 7. Distribution of wetlands by number and areal extent.

Wetland System	Upper Elevation				Lower Elevation			
	Number	Percent	Hectares	Percent	Number	Percent	Hectares	Percent
Palustrine	33,735	98.5	45,628	94.2	70,704	91.4	72,706	78.7
Lacustrine	67	0.2	1,936	4.0	212	0.3	10,375	11.2
Riverine	453	1.3	897	1.9	6,438	8.3	9,332	10.1

It should be kept in mind with all these figures that wetland numbers reflect NWI mapping conventions. A wetland that a field observer sees as a continuous unit may be mapped as three or four distinct wetlands based on vegetation zones or differences in hydrology. A large wetland may have both scrub-shrub and emergent vegetation zones, as well as temporarily and seasonally flooded areas. Consequently, measures of areal coverage are better summaries of wetland extent and distribution than are simple numbers.

Field Observations

Crews visited 231 wetlands in all. After initial trips to assess the success of the model in distinguishing between headwater and lower elevation wetlands, crews focused on eight 6th code HUCs (Figure 16). These subwatersheds were selected after inspection of aerial imagery and data layers for their wetland diversity, trail access opportunities, and public land ownership. Traveling through the subwatershed, crews familiarized themselves with the characteristics of wetlands and surrounding uplands before selecting representative wetlands for sampling. During this field campaign, they completed brief site notes at 161 wetlands, carried out Level 2 surveys at 13 sites, and completed Level 3 surveys at 57 sites.

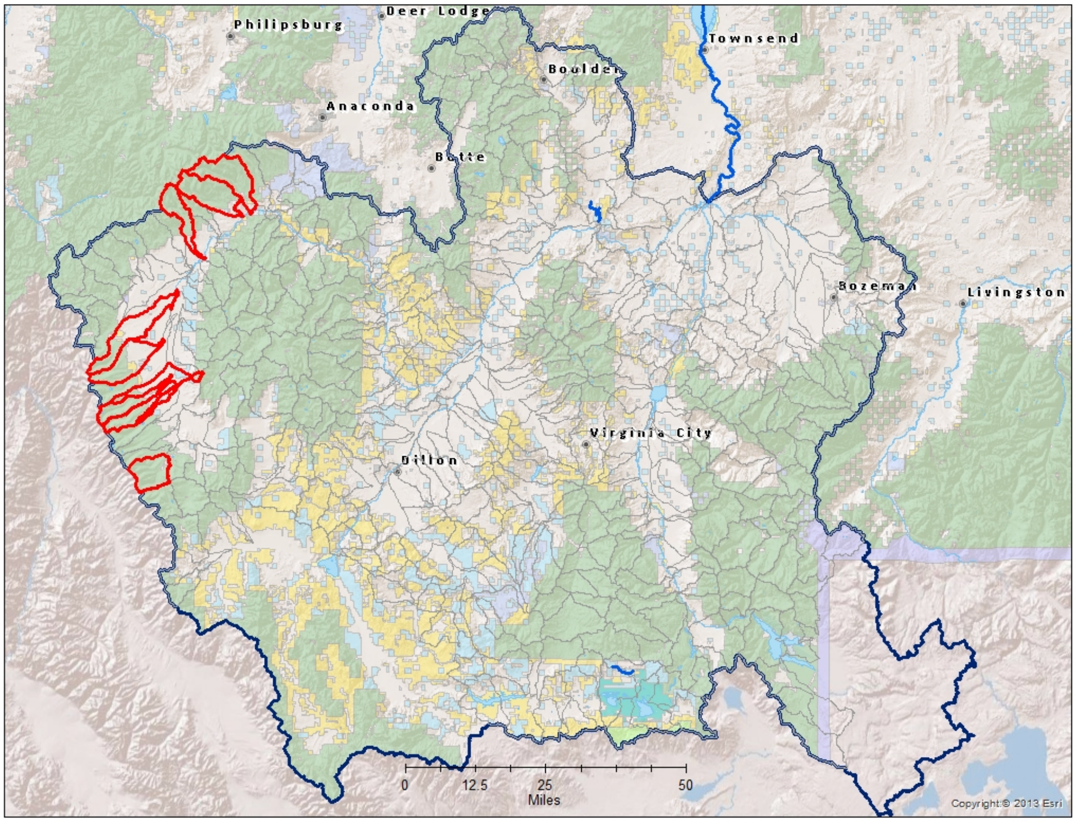

Figure 16. Subwatersheds selected for sampling in the Upper Big Hole subbasin, shown in red.

The majority of wetlands encountered during reconnaissance and initial evaluation were wet meadows (59%), followed by fens (21%). Marshes, riparian shrublands and riparian woodlands made up the remainder. Regardless of ecological system, 90% of these wetlands occurred in a slope topographic position, often right beneath, or closely adjacent to, a break in slope. Wetlands along streams or rivers made up the bulk of the remaining sites, although many near-stream wetlands were considered to be slope wetlands, receiving hydrologic inputs from groundwater discharge rather than from stream bank flooding, as evidenced both by gradient and presence of high water levels in streams well past the peak runoff period (Figure 17).

Figure 17. This riparian shrubland is sustained by groundwater discharge rather than overbank flows. Note that the stream is still at bankfull over a month after peak runoff.

This distribution was approximated during Level 2 and Level 3 assessments, with 57% of assessed sites being wet meadows, 27% being fens, and the remaining sites split between marshes and riparian shrublands/woodlands (9% and 7% respectively).

Most sampled wetlands were in areas of very good to excellent ecological integrity, where stressors were at a minimum. None of the sampled wetlands had hydrologic modifications or stressors onsite or within a 200m buffer area. Thirty-six percent (36%) of the sampled wetlands had no human disturbances on site or within the 200m buffer. Twenty-nine percent (29%) of sites had only one human disturbance onsite or within the buffer; however, 76% of these disturbances were "human visitation," often evidenced only by the trail that the crews had used to access the wetland. In only one instance did crews observe trampling of the wetland by humans and/or pack stock. Livestock grazing in the buffer area was noted in 26% of the assessments. However, while human disturbance was uncommon in the areas sampled for this study, forest disturbance caused by insects or disease was noted in the buffer area at 57% of sites, and indeed is widespread in the intensively sampled subwatersheds (Figure 18).

Figure 18. Forest loss typical of headwater watersheds in the study area.

Study area wetlands were generally dominated by herbaceous vegetation typical of wet meadows, notably *Eleocharis quinqueflora* (few-flowered spikerush), *Carex neurophora* (alpine nerved sedge), *Senecio triangularis* (arrow-leafed groundsel), *Senecio pseudaureus* (Western golden groundsel), *Calamagrostis canadensis* (bluejoint reedgrass), *Carex aquatalis* (water sedge), *Deschampsia cespitosa* (tufted hairgrass), *Gentiana calycosa* (explorer's gentian), *Ligusticum tenuifolium* (slender-leaf lovage) and *Pedicularis groenlandica* (elephant's head lousewort). *Symphyotrichum foliaceum* (leafy-bracted aster), an upland obligate, was common in the drier edges of wet meadows throughout the area. However, in all but two of the sampled sites, wetland obligates and facultative wetland species made up more than half of the identified plant species. Fen sites tended to be drier than those noted in other parts of the state and in lower-elevation locations. Although *Carex* species were common in both fens and marshes, especially *Carex utriculata (*Northwest Territory sedge), *Carex aquatilis*, *Carex neurophora* and *Carex illota* (small-head sedge), other graminoids and forbs were well-represented, especially *Calamagrostis canadensis, Deschampsia cespitosa* and *Pedicularis groenlandica.* Woody species were frequently found on hummocks and around the edges of fens and marshes. These included *Betula pumila* (bog birch) and *Betula glandulosa* (dwarf birch), *Salix* species, and *Picea engelmannii* (Engelman spruce).

Subwatershed Characterizations

Crews made extensive notes on six of the eight subwatersheds visited. In the remaining two, limited trail access precluded broad generalizations, although Level 3 assessments were still possible in selected sites. We describe the subwatersheds that were thoroughly explored in Appendix A.

Level 2 Assessment

Level 2 scores are available on request from MTNHP (Jennifer Chutz, jchutz@mt.gov).

Level 3 Assessment

We completed 130 Level 3 intensive assessments during the project, encountering 189 plant taxa that we identified to the species level. Of these, 56 species were encountered at only one site and 86 species were encountered at only two sites. The average number of species encountered per site was 18 (range 5-60). Of the 189 species identified to species, 184 (97%) were native species and 5 were exotic species. However, there were only 9 unique occurrences of non-native species, and only one of the species encountered (*Cirsium arvense*, or Canada thistle) is considered to be a noxious weed, while the others are ubiquitous occurrences in both upland and wetland habitats (e.g., dandelion, meadow timothy, Kentucky bluegrass, etc.).

The most commonly encountered plant species was *Symphyotrichum foliaceum* (leafy-bracted aster, Table 8). None of the ten most commonly encountered plant species were exotic species. Forty percent of the most commonly encountered species were wetland obligates.

Table 8. Ten most frequently encountered plant species in intensive assessments.

Scientific name	Number of sites encountered	C-value	Wetland indicator Status	Native Status
Symphyotrichum foliaceum	25	5	FACU	Native
Eleocharis quinqueflora	22	7	OBL	Native
Carex neurophora	18	7	FACW	Native
Senecio triangularis	18	5	OBL	Native
Senecio pseudaureus	17	7	OBL	Native
Calamagrostis canadensis	15	5	FACW	Native
Carex aquatilis	15	5	OBL	Native
Deschampsia cespitosa	15	7	FACW	Native
Gentiana calycosa	15	7	FACW	Native
Ligusticum tenuifolium	15	7	FAC	Native

Floristic Quality Assessment

We calculated a variety of floristic quality assessment (FQA) metrics (Appendix B) for all 58 Level 3 assessment sites (Table 9). Average mean C-value at these sites was 5.95. In this study, we used a cover-weighted adjusted Floristic Quality Assessment Index to compare sites. The non-adjusted Floristic Quality Index is sensitive to species richness, so species poor sites will receive a lower FQI value despite being in or close to a natural state. The adjusted FQI (Miller and Wardrop 2006) incorporates a "maximum attainable FQI score" based on the highest possible value plants could have, as well as both native and non-native species scores, into the final index. A cover-weighted adjusted FQI score (CWAFQI) extends this by using the relative average cover of a species in the entire plot as a weighting factor.

Table 9. Floristic quality metric scores, all sites.

Total species	189
Number of native species	184
Number of exotic species	5
Percent exotic species	3
Mean C-value of all species	5.95
Cover-weighted Mean C-value of all species	5.32
Mean C-value of native species	6
Cover-weighted Mean C-value of native species	5.35
Cover-weighted FQI of all species	21.55
Cover-weighted FQI of native species	21.57
Adjusted cover-weighted FQI	53.23
Wetness index	-1.57

Overall, the CWAFQI scores for the sites in our study were consistent with those observed during other studies in the area. Newlon (2012), in her probabilistic study of wetland condition in Southwest Montana, reported average CWAFQI scores of 48.71. In this study, the mean score for all assessed sites was 53.23. However, there was a significant difference between scores for sites falling within identified headwater areas (mean of 56.00) and those outside (mean of 43.83)[3]. We also found that sites in our study were less weedy than sites in Southwest Montana as a whole; as noted above, the percent of exotic species found across all sites in our study was only 3%, while in Newlon's study it was 12.44%. We attribute this to the more roadless nature of our study area, even for the non-headwater sites, and to the overall distance of our sites from residential and agricultural development. While site-specific disturbances such as grazing, logging and recreational use have affected the composition of native plant communities in the more easily accessible portions of our study area, they have not introduced non-native species to the same degree as is seen in lowland areas.

DISCUSSION

This study demonstrates that headwater wetlands in the Missouri River Headwaters basin differ in size, type and distribution from those in lower-lying areas. Within the subwatersheds covered by our field surveys, there are also significant differences in condition, with headwater wetlands having higher scores on a range of floristic quality metrics than lower elevation wetlands. In our quantitative observations, we also observed that headwater wetlands appear to have more hydrologic connectivity to each other, and to rely more heavily on groundwater and local snow melt than on surface precipitation. Soils in headwater wetlands were seen to have a deeper organic layer than lower-elevation wetlands, probably because the more saturated conditions present in these wetlands supports a faster rate of decomposition.

While it is tempting to assume that headwater wetlands are immune from disturbance, this is not the case. The two biggest threats are the immediate threat posed by beetle- and disease-caused forest mortality, and the longer-term threat of climate change. The past decade has seen an unprecedented degree of change in western forest land cover, largely due to direct and indirect consequences of the infestation of mountain pine beetle (*Dendroctonous ponderosae*), the most severe insect disturbance in recorded history (Bentz et al. 2010). In the

[3] The majority of Level 3 sites were in headwater areas, and so skew the mean score for all sites upward.

study area, mid-elevation pine species, notably lodgepole pine (*Pinus contorta*), has been decimated across much of its range. Similarly, in subalpine areas, the keystone species whitebark pine (*Pinus albicaulis*) has been extensively depleted by white pine blister rust (*Cronartium ribicola*) and the pine beetle (Jewett et al. 2011; Larson 2011). The changing canopy structure is altering the amount of snowfall reaching the forest floor, as well as its retention time, leading to earlier snowmelt and an increase in runoff vs. infiltration (Ellis et al. 2013), while increasing the availability of downed wood as a structural feature in streams and wetlands (Janisch et al. 2011). While there is current debate over increased fire risk due to pine mortality, most modeling efforts suggest that changing climate patterns will result in lengthening fire seasons, higher large-fire frequency, more lightning-caused fire starts, and longer wildfire duration (Flannigan et al. 2009). Climate change, to the extent it results in warmer conditions in headwater areas, threatens even greater changes. In the past century, a gradual decline in mountain snowpack has been occurring minimally at the ridgetop, while being most pronounced closer to snowline (Mote et al. 2005). Under a warming climate scenario, where precipitation occurs more frequently in the form of rain rather than snow, the loss of snowpack at higher elevations is likely to increase, resulting in more ephemeral wetlands and a shorter wetland hydroperiod, as well as a potential loss of connectivity between headwater wetlands (Ryan et al. 2014). The loss of water storage in headwater wetlands will result in changing water supply to lower elevation wetlands, and in turn, to streams and rivers.

Modeling and quantification of changes in water supply and availability under future climate scenarios is, of course, beyond the scope of this project. However, we note that the subject has received very little attention in the inland Northwest. While studies from other states, such as Colorado (e.g. Rasmussen et al. 2014), provide some guidance for predicting future scenarios in Montana, this area is ripe for further research.

While the current study focuses on a specific headwater area, we note here that the GIS methodology is broadly applicable to other basins in Montana, and indeed, across the West. In the Missouri River Headwaters basin, the elevation range between headwaters and valleys is dramatic, and not surprisingly, leads to dramatic results. In basins with less relief, our preliminary explorations indicate that the differences in wetlands at "higher" and "lower" elevations will not be extreme. In areas where snow accumulation is lower during winter months, or where snowmelt occurs earlier, we would expect similar differences in size (smaller wetlands at higher elevations), but fewer saturated and semi-permanently flooded headwater wetlands than are seen in the study area. Consequently, while these wetlands might still have a significant impact on water supply in streams and rivers, they may contribute less subsurface flow to lower elevation wetlands. However, this too is an area for further research.

LITERATURE CITED

Andersson, J. O., and Nyberg, L. 2008. Spatial variation of wetlands and flux of dissolved organic carbon in boreal headwater streams. *Hydrological Processes* 22:1965–1975.

Bentz, B. J., Regniere, J., Hansen, E. M., Hayes, J. L., Hicke, J. A., Kelsey, R. G., Negron, J. F., and Seybold, S. J. 2010. Climate change and bark beetles of the western United States and Canada: direct and indirect effects. *BioScience* 60:602–613.

Comer, P., Faber-Langendoen, D., Evans, R., Gawler, S., Josse, C., Kittel, G., Menard, S., Pyne, M., Reid, M., Schulz, K., Snow, K.,and Teague, J. 2003. *Ecological Systems of the United States: A Working Classification of U.S. Terrestrial Systems*. Arlington, VA.

Cowardin, L. M., Carter, V., Golet, F.C., and LaRoe., E.T. 1979. *Classification of wetlands and deepwater habitats of the United States*. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 131 pp.

Dollar, E. S. J. 2004. Fluvial Geomorphology. *Progress in Physical Geography* 28:405–450.

Dorn, R. D. 1984. *Vascular Plants of Montana*. Mountain West Publishing, Cheyenne, WY.

Ellis C, Pomeroy J, and Link. T. 2013. Modeling increases in snowmelt yield and desynchronization resulting from forest gap-thinning treatments in a northern mountain headwater basin. *Water Resources Research* 49:936–949.

Flannigan, M. D., Krawchuk, M.A., de Groot, W.J., Wotton, B.M., and Gowman, L.M. 2009. Implications of changing climate for global wildland fire. *International Journal of Wildland Fire* 18:483–507.

Freeman, M. C., Pringle, C.M., and Jackson, C.R. 2007. Hydrologic connectivity and the contribution of stream headwaters to ecological integrity at regional scales. *Journal of the American Water Resources Association* 43:5–14.

Hauer, F.R., B.J. Cook, M.C. Gilbert, E.J. Clairain, Jr., and R.D. Smith. 2002. A regional guidebook for applying the hydrogeomorphic approach to assessing wetland functions of intermontane prairie pothole wetlands in the northern Rocky Mountains. ERDC/EL TR-02-7.

Hughes, R. M., Kaufmann, P.R., and M. Weber, M.H. 2011. National and regional comparisons between Strahler order and stream size. *Journal of the North American Benthological Society* 30: 102-121

Janisch, J. E., Foster, A. D., and Ehinger, W. J. 2011. Characteristics of small headwater wetlands in second-growth forests of Washington, USA. *Forest Ecology and Management* 261:1265–1274.

Jenkins, M. J., Page, W.G., Hebertson, E.G., and Alexander, M.E. 2012. Fuels and fire behavior dynamics in bark beetle-attacked forests in Western North America and implications for fire management. *Forest Ecology and Management 275*:23-34

Jenness, J., B. Brost, and P. Beier. 2013. Land Facet Corridor Designer: Extension for ArcGIS. Accessible at: http://www.jennessent.com/arcgis/land_facets.htm.

Jewett, J. T., Lawrence, R.L., Marshall, L.A., Gessler, P.E., Powell, S.L. and Savage, S.L. 2011. Spatiotemporal Relationships between Climate and Whitebark Pine Mortality in the Greater Yellowstone Ecosystem. *Forest Science* 57:320–335.

Larson, E. R. 2011. Influences of the biophysical environment on blister rust and mountain pine beetle, and their interactions, in whitebark pine forests. *Journal of Biogeography* 38:453–470.

Lesica, P. 2012. *Manual of Montana Vascular Plants*. BRIT Press, Fort Worth, TX.

MacDonald, L. H., and D. Coe. 2007. Influence of headwater streams on downstream reaches in forested areas. *Forest Science* 53: 148-168.

McNab, W.H. and P.E. Avers, eds. 1994. Ecological subregions of the United States: section descriptions. U.S. Department of Agriculture, Forest Service. Publication WO-WSA-5, Washington, DC.

Meyer, J. L., Strayer, D.L., Wallace, J.B., Eggert, S.L., Helfman, G.S., and Leonard, N.E. 2007. The contribution of headwater streams to biodiversity in river networks. *Journal of the American Water Resources Association* 43:86–103.

Meyer, J. L., and J. Wallace, J.B. 2000. Lost linkages and lotic ecology: rediscovering small streams. Pages 295–317 in *Ecology: Achievement and Challenge*.

Miller, S. J., and Wardrop, D.H. 2006. Adapting the floristic quality assessment index to indicate anthropogenic disturbance in central Pennsylvania wetlands. *Ecological Indicators* 6:313–326..

Mote, P. W., Hamlet, A. F., Clark, M. P., and Lettenmaier, D. P. 2005. Declining mountain snowpack in western North America. *Bulletin Of The American Meteorological Society* 86:39–49.

Munsell Color Company. 2009. *Munsell Soil Color Charts.* Munsell Color, Grand Rapids, MI.

Newlon, K. R. 2012. *Southwest Montana Wetland Assessment: Developing a statewide assessment and monitoring strategy for Montana. Report to the U.S. Environmental Protection Agency.* Montana Natural Heritage Program, Helena, MT. 39pp plus appendices.

Peet, R. K., Wentworth, T.R, and White, P.S. 1998. A flexible, multipurpose method for recording vegetation composition and structure. *Castanea* 63:262–274.

Rasmussen, R., Ikeda, K., Liu, C., Gochis, D., Clark, M., Dai, A., Gutmann, E., Dudhia, J.,. Chen, F., Barlage, M., Yates, D., and Zhang, G. 2014. Climate Change Impacts on the Water Balance of the Colorado Headwaters: High-Resolution Regional Climate Model Simulations. *Journal of Hydrometeorology* 15:1091–1116.

Ryan, M. E., Palen, W. J., Adams, M. J., and Rochefort, R. M. 2014. Amphibians in the climate vice: loss and restoration of resilience of montane wetland ecosystems in the western US. *Frontiers in Ecology and the Environment* 12:232–240.

Vivoni, E. R., Di Benedetto, F., . Grimaldi, S., and Eltahir, E.A.B. 2008. Hypsometric control on surface and subsurface runoff. *Water Resources Research* 44(12).

Woods, A., Omernik, J., Nesser, J.A., Shelden, J., Comstock, J.A., and Azevedo, S. J. 2002. *Ecoregions of Montana, 2nd edition (color poster with map, descriptive text, summary tables, and photographs). Map scale 1:1,500,000.*

APPENDIX A. Subwatershed characterizations in the Missouri River Basin, southwestern Montana.

A1. Big Swamp Creek

While a dozen or more high mountain lakes provide water high in the Big Swamp Creek watershed, the steep nature of the higher elevations prevents the development of large wetlands. Wetlands become more common about 4 km east of the Continental Divide, where both the Big Swamp Creek and Slag-a-Melt Creek drainages begin opening up adjacent to the riparian area (Figure A-1). Here and through much of each drainage, wetlands are generally located in or adjacent to the creeks' riparian areas. Those not directly associated with the creek receive most of their water input from groundwater, and are either fens or developing toward fen-like conditions.

We visited wetlands in both headwater drainages within the subwatershed, and on BLM lands in the valley below the confluence. Wetlands in mid-upper Big Swamp Creek had less developed organic soil than in lower elevation areas or in Slag-a-Melt Creek, generally with sand, clay and/or gravel found above 40 cm in depth. We found little *sphagnum* and few fens in this drainage. Nearly all wetlands received water inputs from groundwater, creek overflow/high creek water table, and some snowmelt, and so qualified as riparian scrublands. We found only one completely groundwater-dependent fen in this area. Vegetation in Big Swamp Creek above its confluence with Slag-a-Melt was characterized by less developed scrub-shrub hummocks with some *sphagnum*, *Salix spp.*, *Ledum glandulosum*, *Vaccinium occidentale*, *Lonicera caerula*, *Carex utriculata*, *Carex aquatilis*, *Eleocharis palustris* and *Calamagrostis canadensis* (Figure A-2). Cattle were prolific throughout the entire drainage, and impact was moderate to serious in the Big Swamp Creek drainage, with heavy grazing and browsing of shrubs, and some areas of pugging from hooves. Graminoids were often grazed <4" from the ground and seed heads were hard to find.

Dominant vegetation in Slag-a-Melt was similar to that in Big Swamp Creek, although the overall species richness was higher, especially in wetlands with denser and more developed *sphagnum* hummocks. Approximately half of the wetlands in Slag-a-Melt Creek drainage were groundwater-dependent fens with saturated soils, few or no inlets, and one to many outlets to the creek (Figure A-3). Wetlands in this drainage often had some surface water connection to their adjacent moderate to steep slopes, with seasonal inlets coming off the slopes. We saw no evidence of cattle impacts. A steep east-west ridge separating the Big Swamp Creek and Slag-a-Melt Creek drainages inhibits cattle movement, and –we surmise—the denser forest characteristic of the Slag-a-Melt drainage is less appealing.

In the valley below the headwater area, the landscape flattens out and Big Swamp Creek spreads out into a braided floodplain. Land ownership changes from U.S. Forest Service (USFS) to Bureau of Land Management (BLM) and private. All wetlands we found in this lower floodplain (on BLM land) that weren't directly adjacent to flowing creeks/rivulets were fens, almost completely depending on groundwater discharge for their water. This extensive area of saturated ground is presumed to be the "Big Swamp" that gives the subwatershed its name. Wetlands here typically consisted of both shrub-dominated and emergent-dominated patches.

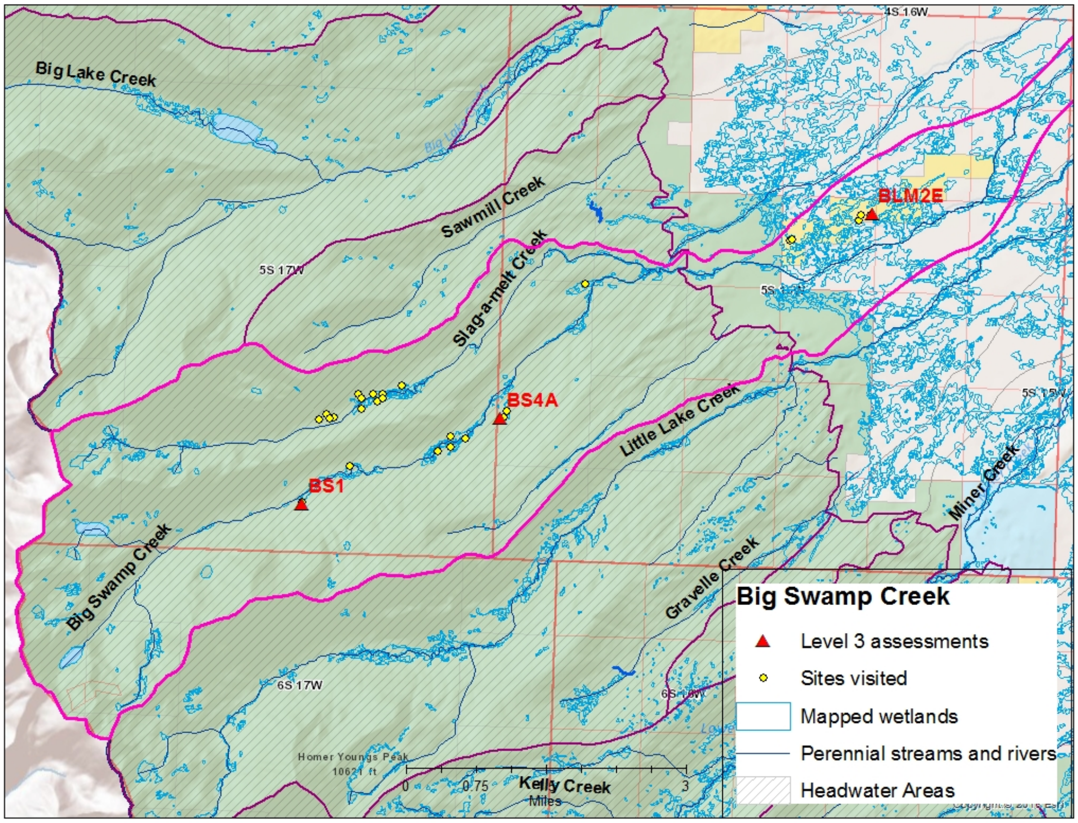

Figure A- 1. Big Swamp Creek subwatershed. The headwater area (hatched) is entirely within the Beaverhead-Deerlodge National Forest.

Figure A- 2. Wetland in upper Big Swamp Creek drainage (note evidence of logging).

Figure A- 3. Fen in Slag-a-Melt Creek drainage.

Sphagnum hummocks were also well developed, indicating longevity on the landscape, but vegetation diversity was lower than in the upper watershed, even though all the non-riverine wetlands were fens (Figure A-4). *Betula* and *Dasiphora* were dominant in the shrub community, but were heavily browsed, as were *Salix* spp., to the extent that new growth was suppressed. Cattle impacts were moderate to extreme in the drier portions of fens and along riparian areas. In the most impacted upland areas, vegetation is dominated by non-native species, including noxious species. In the BLM/private land areas, stream bank sides were sloughing off into the creek with exposed soil, vertical banks and isolated sedge hummocks cut off from the nearby banks due to heavy trampling. Wet/dry meadow areas in BLM were grazed to 1' to bare soil with cattle trail highways connecting areas. Saturated areas were less impacted by cattle than drier areas. However, there is no true upland in the lower subwatershed, only patches of dry meadow created by microtopographic conditions. Continued pugging and hummocking is likely to enhance development of microtopography, and the spread of upland plants, including noxious weeds, into wetlands (Figure A-5).

Human visitation to the upper subwatershed appeared to be linked to hunting and fishing. Elk scat was common throughout wetlands and riparian areas, and we encountered several bow hunters moving in and out of the watershed. Both spruce and ruffed grouse were also common in the uplands, and several black bear tracks were seen, especially in dense moist habitat and where *Vaccinium occentale* was found. Non-native brook trout were the only game fish species seen in both drainages.

Logging occurred in forested wetlands of mid-upper Big Swamp Creek within the past 20-30 years, and trees had been cut up to the perimeter of shrub- and emergent-dominated wetlands. This probably accounts for the non-native species found in the drainage. While there are fewer patches of non-native species in Slag-a-Melt Creek, we noted that a gravel road adjacent to one fen has contributed to sediment accumulation, and may represent a pathway for the spread of invasive species.

Figure A- 4. Outlet from fen in lower Big Swamp Creek subwatershed.


Figure A- 5. Heavy grazing in drier areas adjacent to fens.

A2. Fishtrap Creek

Wetland types in the Fishtrap Creek subwatershed varied by watershed position, but were most common in lower regions where the main drainages meet (Figure A-6).

In these downstream areas, wetlands were primarily supported by streamflow (both seepage and overbank flow), and were largely dominated by tall shrubs (Figure A-7). However, we also encountered numerous pothole wetlands, with neither inlets nor outlets. In the middle portion of the subwatershed, at the edge of what we had delineated as the "headwater area," beaver-formed wetlands were large and ubiquitous (Figure A-8). Springs and seeps were also frequent in this part of the subwatershed, where the interplay of water sources creates a rich diversity of patch types, and, consequently, plant communities.

However, there was a ditched canal in the middle of these ponds and wetlands, presumably diverting water for agricultural use in the lower subwatershed.

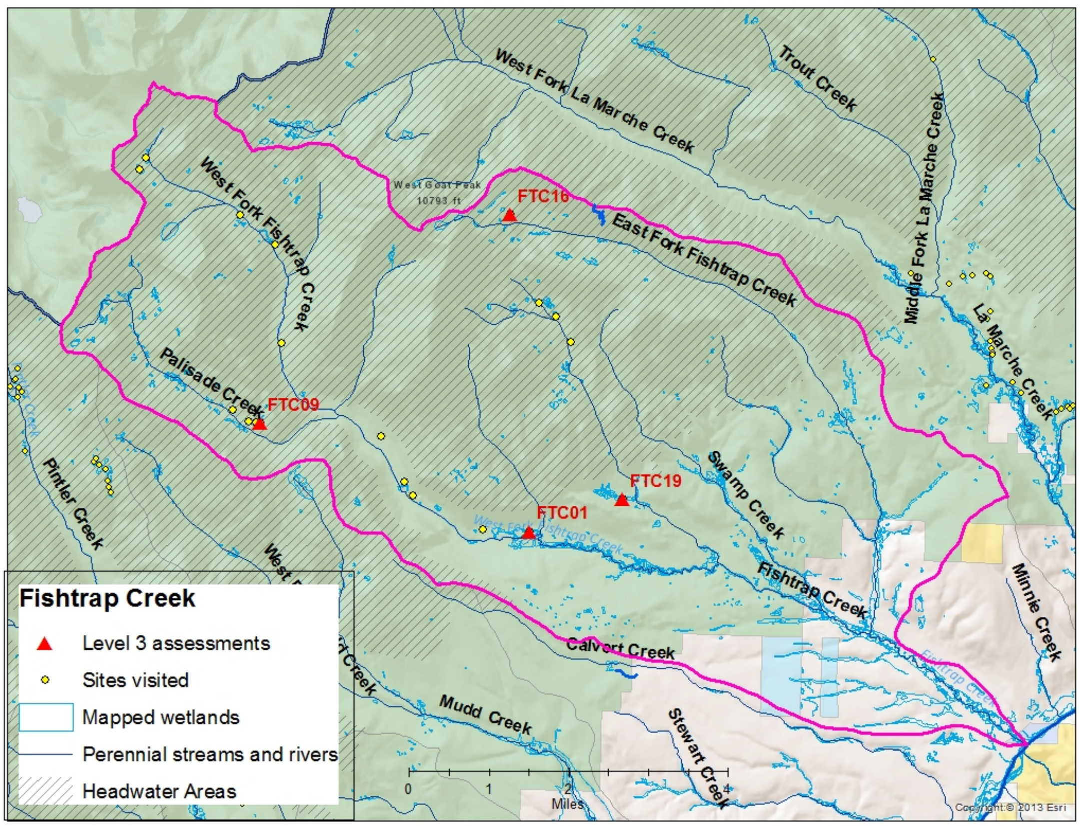

Figure A- 6. Fishtrap Creek subwatershed.

Figure A- 7. Wetlands in the lower reaches were dominated by tall shrubs.

Figure A- 8. Beaver pond in middle Fishtrap Creek subwatershed.

In the headwater sections, fens and wet meadows dominated the wetland community. Here too water sources were diverse, with inflows into wet meadows coming from upslope rocky creek beds, muddy rivulets, and groundwater upwellings, especially in the Palisade Creek area, where *Mimulus guttatus* and *Carex interior* dominated springs. Overall plant diversity in wetlands of the Palisade Creek area was especially high, with almost every sampled wetland dominated by a different *Carex* species, and sporting the rich forb diversity characteristic of undisturbed subalpine wetlands. In this headwater region, the complex pattern of springs, seeps, meadows, fens and vegetated channels makes it challenging, and sometimes impossible, to delineate individual wetlands (Figure A-9).

Figure A- 9. Seeps and rivulets in the Fishtrap Creek headwaters.

A3. LaMarche Creek

We sampled wetlands throughout LaMarche Creek, although trail access limited our assessments of headwater wetlands to the East and Middle Forks (Figure A-10). Below the confluence of the East, West and Middle Forks, most wetlands were found with the creek corridor and its floodplain. These occurred as large patches of *Salix*-dominated scrub-shrub wetlands, with a horizontal wetness gradient. Outside the stream corridor, wetlands were smaller and wetter, mostly seeping slope wetlands joined by small rivulets flowing over mossy rocks and boulders. While surface water connections between these wetlands were often ephemeral, probing with a soil auger revealed subsurface flow.

In the lower subwatershed, most of LaMarche Creek is surrounded by lodgepole pine forest, with approximately 20% beetle-killed. The understory is sparse and heavy with pine needles and elk scat. Cattle graze the area, although not heavily, and both horse and dog droppings indicate active cattle management. We noted that in the lower subwatershed, the wetlands on the east side of the creek were steeper, smaller, and seepy, generally surrounded by forest (Figure A-11). On the west side, topography is flatter, and meadows are more common. Here, wetlands tend to be temporary or seasonal wet meadows. Elk and moose prints were common, as were heavily used game trails, but browsing appeared to be light to moderate. Soils generally had a top organic layer of peat/mucky peat followed by sandy clay to silty clay and some mucky mineral mixtures. Sand and gravel were often found in soil cores. Some soil cores had a metallic/copper smell in the middle through the bottom of the core.

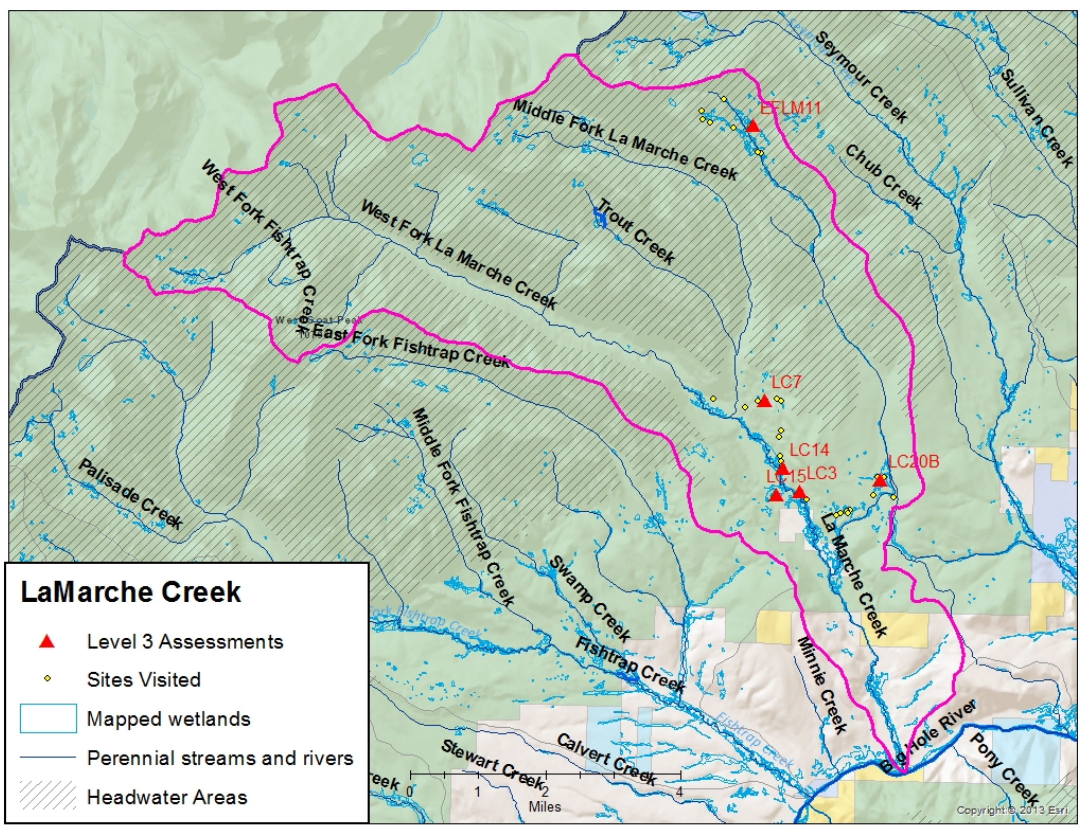

Figure A- 10. LaMarche Creek subwatershed.

Figure A- 11. Typical wetland in lower LaMarche Creek subwatershed.

Human alteration was evident in one area of the lower subwatershed, where the East Fork of LaMarche Creek is bermed. Water appears to be intentionally siphoned from a large wetland into this canal, with apparent maintenance occurring via an ATV trail running from the Forest Road accessing this area.

In the upper portions of the East Fork of LaMarche Creek, we could see a distinct pattern in vegetation growth, with similarly distinct wetland types: large wet meadows with flowing channels, and sloping, seepy patches (Figure A-12). Where water was flowing freely, vegetation was tall and lush, with *Carex scopulorum* dominating. In larger wet meadows, *Carex neurophora* was also very lush. *Dodecatheon pulchellum*, *Symphyotrichum foliaceum*, and *Ligusticum tenuifolium* were common in all wetlands, while *Senecio triangularis* seemed to be restricted to wetlands with throughflow or a riparian influence. In these lower, flowing water settings, we also found *Mimulus moschatus, Epilobium spp*., and *Micranthes oregana*. One wetland had curious patches of very tall *Carex luzulina* with an understory of *Carex echinata*. This was not found in other wetlands, which, although they had abundant *C. luzulina* in mossy, slightly drier areas, had no *C. echinata.* The patches below were very distinct.

The mid-elevation and upper wetlands in both the East Fork and Middle Forks of LaMarche Creek were dominated by springs, some of which engendered peaty enough situations for *Eriophorum*. Others had *Sphagnum* and small amounts of *Mimulus primuloides*. Wet muddy areas were common in flat areas below the springs, almost always with *Eleocharis spp*. The elk had trampled a lot of ground and seemed to be bringing *Trifolium longipes* into the drainage with them. We were surprised at one point to find an extensive patch of *Cirsium arvense* in an area with no apparent human activity. The high bench wetlands on the east side of the East Fork were a complicated mix of patch areas, with some species present only in one small area. It was also interesting to note how uncommon *Caltha leptosepala* was after its predominance in Fishtrap Creek. As was true below, we sometimes found distinct differences in plant communities on the east and west sides of the creek. For example, the east side had *Larix lyallii* surrounding it while the west branch did not. In these higher reaches, only one sampled wetland had a shrub component, and overall the wetland was less diverse than the others. The upland vegetated talus slope above the east-most headwater wetlands had a very diverse and unusual dry flora, and active populations of pikas, weasels, squirrels and birds.

Figure A- 12. Extensive wet meadows and fens are common in the upper subwatershed.

A4. Pintler Creek

In the lower reaches of this subwatershed (Figure A-13), wetlands had only ephemeral overland connections, but appeared to have a common subsurface water source. The ephemeral connections had few areas of channelized flow, and tended to be rocky, with tall, hydrophilic vegetation forming a narrow fringe, and dry upland vegetation beyond. Most of the wetlands were no to low slope, with a saturated water regime, although there were often drier, temporarily flooded interspersions. All were dominated by *Carex utriculata* and *Calamagrostis canadensis*, with some *Salix* and *Alnus* along the drier edges. We saw very few seeps near these wetlands, suggesting that most surface inflow was from snowmelt or precipitation. However, the degree of saturation in an otherwise flat landscape indicated that groundwater discharge was a significant hydrologic source.

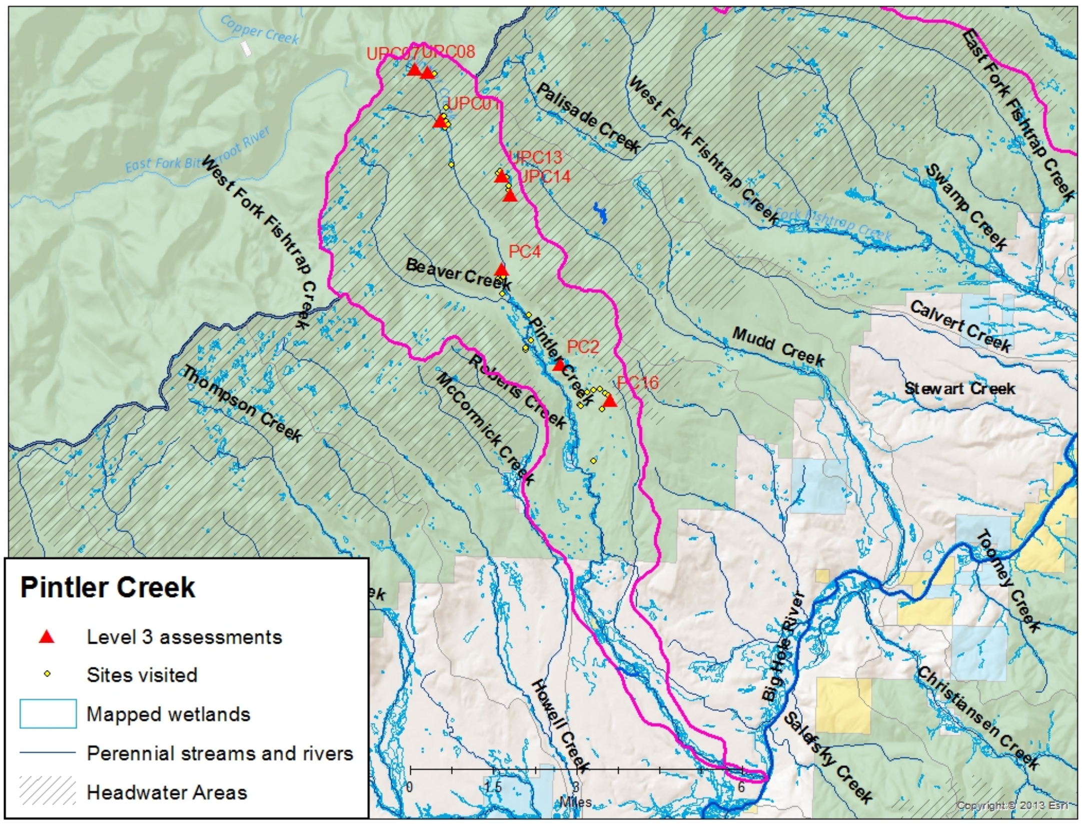

Figure A- 13. Pintler Creek subwatershed.

The most complex wetland in the subwatershed occurred at the base of a steep slope with a relatively small inlet. Here, most of the vegetation and hydrologic patterns found elsewhere in the subwatershed were represented. Water pooled at the base of the steep southern slope, to the east of the two main beaver berms and amidst the large *Salix* hummocks in the western portion of the wetland. Cowardin classes PSSJ, PEMA, PEMB and PABH were all found here (Figure A-14).

Along the wider Pintler Creek riverine corridor, steep eastern slopes had only occasional seeps and rocky channels feeding into the creek. This eastern slope was mostly a dry, bouldered lodgepole pine and *Vaccinium spp*. habitat. The main characteristic of the large river bottom expanse was a mixture of wet and dry meadow dominated by graminoids and *Carex spp*., with *Salix spp.* directly adjacent to flowing creek. Pintler Creek was clear, wide and meandering, with a mixed cobble, sand, and silt bottom. The intersection of the west slope with the river bottom was relatively dry with very few hydrologic inputs except for a large spring coming directly out of the talus slope at one of the sampled wetlands (Figure A-15). This spring supplied a large channel of very cold water with neutral pH and very low conductivity.

Higher up the subwatershed, wetlands adjacent to the East Fork of Pintler Creek were small open pockets in a densely forested habitat situated between a steep slope and the creek itself. These wetlands exhibited a mixture of very hummocked and hollowed microtopography, some seeps amidst dry meadow areas with dense *Calamagrostis canadensis*. Wetlands often had natural berms within them from water erosion and from downed trees, now covered with soil, that direct flowing water and groundwater expression off steep slopes into the creek. This area likely experiences a peak in water flow early in the season due to snowmelt. Again, we found a range of Cowardin classes here (PEMJ, PEMA, PEMB). Seeps were dominated by moss, *Mimulus spp*. and *Viola spp*., while tree hollows and small pools (PEMF) held *Ranunculus millennia*, *Mimulus guttatus*, and *Veronica americana*. There were several clusters of fens in this upper area, fed mostly by groundwater discharge, with some input from seeps. Water appeared to move downward through the fens, ultimately exiting into Pintler Creek. Dominant vegetation included *Carex luzulina var. ablata, Eleocharis pauciflora* and *Carex scopulorum var. bracteosa*. A Montana Species of Concern, *Mimulus primuloides*, was found in one site (UPC01, Figure A-16). Soils in these fens were deeply organic for the most part. We also found clusters of wet meadows, with small discrete inlets and outlets, and occasionally, a channelized flow through the wetland.

Figure A- 14. Highly diverse wetland in lower part of Pintler Creek subwatershed.

Figure A- 15. Spring feeding Pintler Creek site 9B.

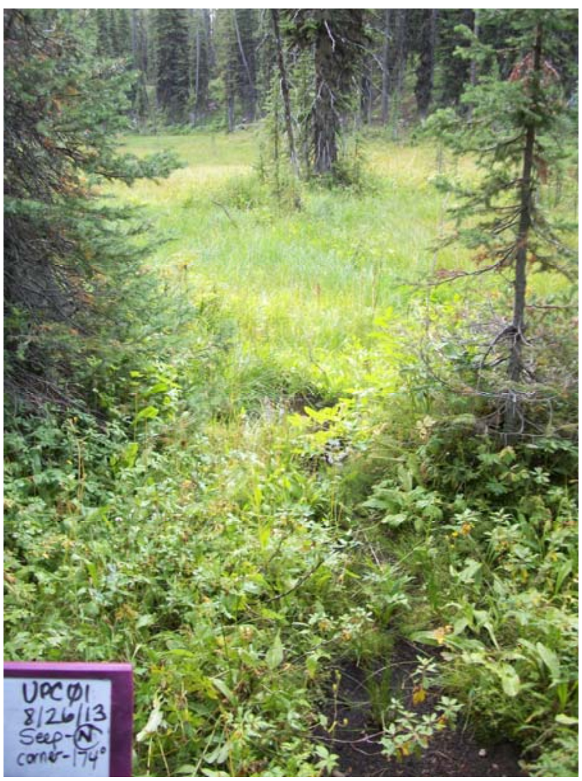

Figure A- 16. *Mimulus primuloides* in UPC01.

Overall in this subwatershed, wetlands that have or had a riverine component showed a generally silty clay soil with a sandy clay, then sand/gravel component in the lower layers. Soil in wetland areas near seeps gained an organic top layer as moss began to accumulate. Soil in the higher elevation headwater wetlands receiving mostly groundwater expression had a much deeper organic layer. Upland forests near the valley bottom were dominated by *Pinus contorta*, *Vaccinium scoparium*, *Vaccinium membranaceum* and *Xerophyllum tenax* amidst sparsely vegetated large boulders/ rock outcroppings. Uplands at higher elevations were co-dominated by *Pinus contorta* and *Picea englemanii*. Very steep slopes had *Pseudotsuga menziesii*. The understory at higher elevations was primarily *Calamagrostis rubescens* and *Carex geyeri* with both *Vaccinium scoparium*, and *Vaccinium membranaceum.* Some tall stands of *Populus tremuloides* occurred in drainages. Human use of official trails seemed moderate, although trails also receive much use by cattle, especially near the lower Pintler Creek river bottom. All wetlands in these lower to middle elevations, except those on steep slopes, showed moderate to heavy cattle use (Figure A-17). Grazing and hoof action was most evident in large wet and dry meadows, where vegetation is trending towards more disturbance tolerant species. We saw very little native ungulate scat, and deer/elk/moose browsing ranged from none to minimal. Beetle kill affected about 5-15% of lodgepole pine in the parts of the subwatershed we surveyed. Dead and down woody material was slightly above what would be expected (from natural thinning) due to this beetle kill. Logging is currently underway along the road access, where we saw heavy soil disturbance and weedy species taking hold.

Figure A- 17. Cattle hoof action in lower subwatershed wetland.

A5. Headwaters Big Hole River

The entire area of this 6th code HUC lies within our identified headwater area (Figure A-18). We sampled along the North and Main Forks of Pioneer Creek, Jahnke Creek, and Dark Horse Creek, with Level 3 assessments being concentrated in Pioneer and Jahnke.

In general, wetlands were mosaics of wet and dry patches, with the degree of saturation influenced by onsite seeps, often from steep adjacent slopes (Figure A-19). Wetlands were often linked to each other by intermittent channels, which themselves were sometimes ponded, and sometimes flowed subsurface. *Carex utriculata* and *Carex neurophora* were common in these seepy areas, especially in Pioneer Creek. Much of the subwatershed had evidence of historic mining, sometimes in the form of small, abandoned cabins, and other times visible as large tailings piles (Figure A-20). Around Pioneer Creek itself, *Salix*-dominated scrub-shrub wetlands were interspersed with herbaceous patches, seeps and pools, although these were less frequent at higher elevations. We saw some evidence of heavy grazing, most notably in the lower reaches of Pioneer Creek, where soils and stream banks showed significant impacts.

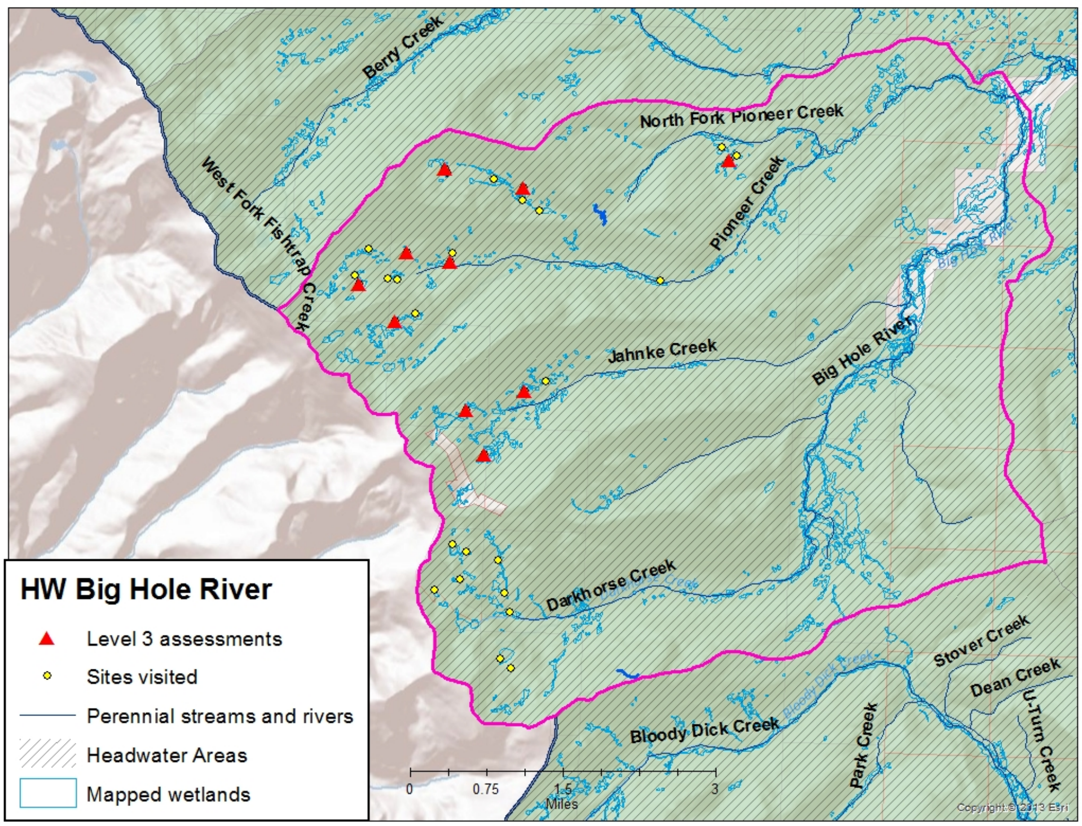

Figure A- 18. Headwaters of the Big Hole River subwatershed.

Figure A- 19. Wetland at base of steep slope.

Figure A- 20. Tailings pile in Headwaters Big Hole River subwatershed.

In one of the headwater areas of Jahnke Creek, we found two headwater wetlands located near the base of an avalanche path, primarily influenced by overbank flooding from a series of channels that began in the avalanche path and ran through the wetland. We saw evident berms along these streams, which clearly alter water flow and residence time, but could not determine whether they were originally built by beavers or humans (Figure A-21). These channels all converge to form the start of Jahnke Creek. The riparian zone continues downstream of the surveyed area. Jahnke Lake is a second headwater region to Jahnke Creek. Jahnke Lake receives water from surrounding hillslopes in the early season. A wetland complex to the east of the lake receives water via seeps and from adjacent hillslopes. Dominant vegetation in seepy areas is *Eleocharis spp*., *Calamagrostis canadensis, Carex neurophora*, and *Carex scopulorum*, with zones of *Ledum spp*. and *Abies lasiocarpa*. A large historic mine, Jahnke mine, and its ruins are present near Jahnke Lake. Ultimate effects of mining operation on hydrology and ecosystem quality were difficult to assess, but did not seem pervasive.

The area surrounding Dark Horse Creek was similar to Jahnke and Pioneer Creek catchments, although we saw more evidence of typically high elevation species in lower reaches (e.g., *Salix wolfii, Carex scopularum, Phleum alpinus,* and *Alopecurus magellanicus*). Only one site in this basin had *Sphagnum* moss and *Eriophorum,* even though peat soils were common. Here, we wondered whether historical mining might have changed water chemistry. However, we noted that most springs were highly alkaline, with much M*imulus guttatus* and *Senecio triangularis.* Overall, the Dark Horse Creek catchment had fewer, smaller wetlands than the other two, even though upland vegetation *(Xerophyllum tenax, Veratrum viride, and Carex geyeri*) was similar.

Figure A- 21. Berm of unknown origin in Jahnke Creek headwaters.

A6. Little Lake Creek

The Little Lake Creek subwatershed is narrow with one main valley staying flat for three to four miles, before climbing fairly quickly to a broad fanned out bowl at the headwaters, with complex but gentle topography (Figure A-22).

The lower wetlands are greatly affected by cows which we encountered immediately and scared up the valley several miles ahead of us. The wetlands in this section are riparian meadows with numerous springs creating saturated conditions on upper meadow edges and along their rivulets. The lower seeps were often *Mimulus guttatus* dominated, often including *Sphagnum* moss mounds, while seeps further up the valley were mostly *Eleocharis*/*Carex scopulorum* dominated. We saw only two small areas with tall *Salix* shrubs in the lower subwatershed. Above this, subalpine vegetation was ubiquitous, probably because of the higher elevation.

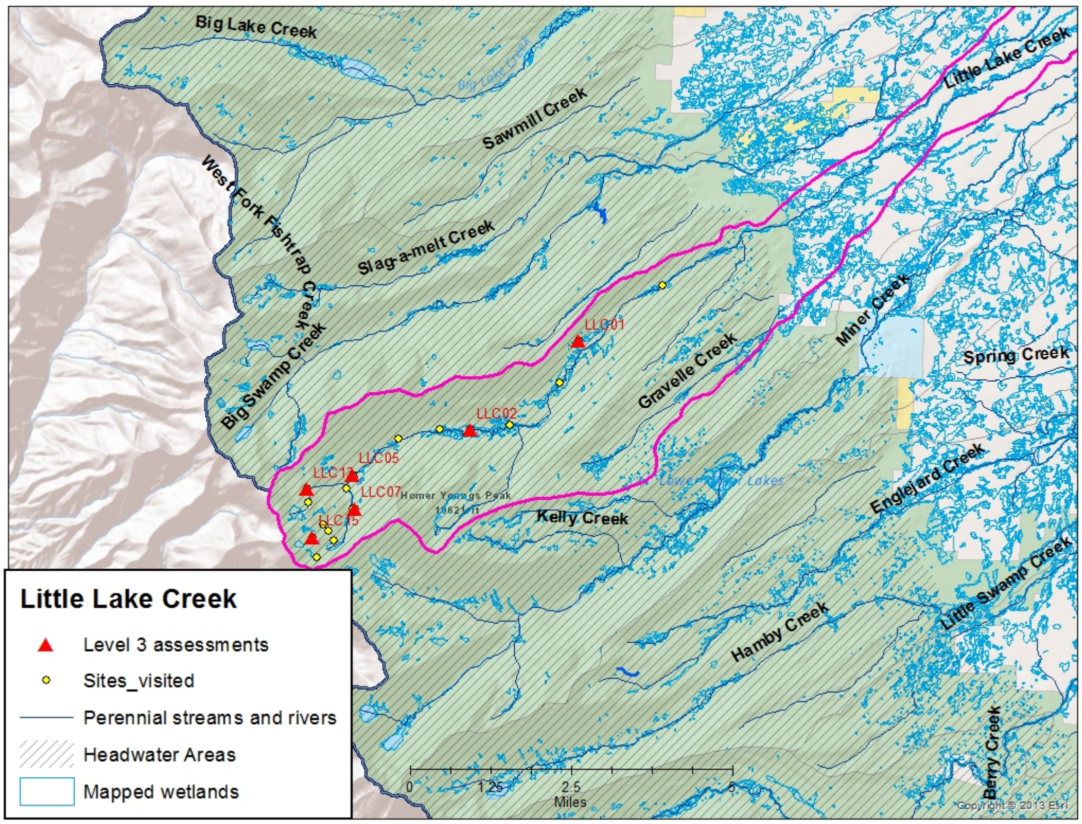

Figure A- 22. Little Lake Creek subwatershed.

At mid- to higher elevations, dwarf shrubs and *Carex aquatilis* flats characterized big open complexes (Figure A-23), often with a small fen inclusion taking advantage of a spring. The SOC *Mimulus primuloides* was found several times, both on *Sphagnum* mounds and thin soil of springs. The mid-elevation wetlands had diverse vegetation, with healthy edges and peak *Sphagnum* mounds, suggesting more acidic conditions. Interestingly, the *Sphagnum* mounds themselves became less common as we moved away from the talus slopes of Homer Young Peak.

Moving higher in the subwatershed, we found *Muhlenbergia richardsonis* mats on dried down flats and depressions, while *Eleocharis spp.* and *Carex canescens* dominated the springs. Upper wetlands had high

Carex and forb diversity, with some interesting holding points in places and lots of spring influence. Riparian areas were lavishly bordered by lush *Mertensia ciliata*, *Mimulus lewisii* and *Senecio triangularis*. Benches and springs created many small wet meadow wetlands again with high diversity, but no *Sphagnum* (Figure A-24). *Mimulus guttatus* or *Carex scopulorum* were frequent at spring heads, while *Carex illota* and a suite of rich forbs were nearly always present on fringes.

Figure A- 23. Open wetland complex in Little Lake Creek subwatershed.

Figure A- 24. High-elevation seep.

APPENDIX B. Terminology, description, and calculation of the floristic quality assessment metrics.

N_n = count of native species, N_a = count of all species, N_e = count of non-native species, C_i = index of conservatism for the i^{th} species, x_i = percent cover for the i^{th} species, W = coefficient of wetness.

Indices	Description	Calculation
Total species richness	Number of plant species observed	N_a
Native species richness	Number of native plant species observed	N_n
Non-native species richness	Number of non-native plants	N_e
Mean C	Average C-value of all plants	$\sum_{i=1}^{n} \frac{C_i}{N_a}$
Mean C_{nat}	Average C-value of only the native plants	$\sum_{i=1}^{n} \frac{C_i}{N_n}$
Cover-weighted Mean C	Sum of each species C-value multiplied by its cover values, then divided by the sum of cover values for all species	$\sum_{i=1}^{n} x_i C_i \Big/ \sum_{i=1}^{n} x_i$
Cover-weighted Mean C_{nat}	Sum of each native species C-value multiplied by its cover values, then divided by the sum of cover values for native species	$\sum_{i=1}^{n} x_i C_i \Big/ \sum_{i=1}^{n} x_i$
Cover-weighted FQI	Cover-weighted Mean C for all species multiplied by the square-root of all species	$\left(\sum_{i=1}^{n} x_i C_i \Big/ \sum_{i=1}^{n} x_i\right) \times \sqrt{N_a}$
Cover-weighted FQI_{nat}	Cover-weighted Mean C for native plants multiplied by the square-root of native plants	$\left(\sum_{i=1}^{n} x_i C_i \Big/ \sum_{i=1}^{n} x_i\right) \times \sqrt{N_n}$
Adjusted FQI_{nat}	Mean C of native plants divided by 10 multiplied by square-root of native plants divided by the square-root of number of all plants multiplied by 100	$\left(\frac{(\sum_{i=1}^{n} C_i/N_n)}{10} \times \frac{\sqrt{N_n}}{\sqrt{N_a}}\right) \times 100$
Wetness Index	Average coefficient of wetness for native species	$\overline{W} = \sum W/N_n$