CACHE VALLEY WETLAND MAPPING: SUPPLEMENTAL REPORT

by

Peter Goodwin and Rebecca Molinari

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EXECUTIVE SUMMARY

This report summarizes a recently completed mapping project in Cache County that had three components: mapping wetland and riparian areas to update National Wetland Inventory (NWI) mapping; applying additional Landscape Position, Landform, Water Flow path, and Waterbody Type (LLWW) attributes to enhance utility and information provided by the new mapping; and developing landscape-scale models identifying likely functions provided by wetlands across the entire project area. The project area and extent of the mapping effort covers 533,000 acres of the county and includes the entire Cache Valley as well as parts of the Blacksmith Fork, Logan River, and High Creek watersheds in the Bear River Range. The project area includes most wetland areas in Cache County and the wetlands most likely affected by agricultural and urban development.

Wetlands and riparian areas were mapped according to U.S. Fish and Wildlife Service (USFWS) guidelines using recent, high-resolution imagery collected during 2016; 2016 imagery was used in lieu of more recent imagery because the more recent datasets were collected during drought years. Ancillary datasets such as lidar, spring and other hydrologic mapping, and several imagery datasets collected from 1980 to 2022 were reviewed to support wetland mapping and attribution. Wetland and riparian mapping were conducted concurrently. All wetlands greater than 0.1 acre (roughly 400 square meters) and riparian areas greater than 0.5 acre (roughly 2000 square meters) were identified in the updated mapping. The mapping effort identified 10,005 distinct wetland and riparian areas covering 29,704 acres, roughly 5.6% of the project area. Despite the presence of several large waterbodies including the Cutler, Hyrum, and Porcupine Reservoirs, Emergent Meadow wetlands were the most abundant type of mapped wetland in the project area.

Two distinct differences between our recent mapping and the previous (1984) NWI mapping are: (1) the recent mapping identifies more wetland features and (2) the recent mapping includes data on riparian features. Our recent mapping likely identified more features because mappers used high-resolution imagery and modern mapping technologies; these features may have existed in 1984 but could have been unmappable with technologies available at the time. Some wetlands identified in the outdated 1984 mapping have likely been replaced or dewatered through urban development, particularly in eastern Cache Valley as the cities of Logan, North Logan, Smithfield, and Hyde Park have expanded. However, comparisons between our recent mapping and the 1984 mapping are complicated by several factors, including differing climatic conditions between source imagery; ability of new mapping technologies to better identify smaller, isolated wetlands; and changing conventions guiding how wetland features are identified, demarcated, and described. Riparian mapping conventions were established after 1984 and no riparian areas were mapped in the 1984 mapping. However, many areas mapped as forested or shrub-scrub wetland in the 1984 data were mapped as riparian areas in our recent update.

We applied LLWW attributes to our mapping to provide additional information about each mapped wetland and expand the types of analyses that could be conducted with the data. The standard NWI attribution describes wetlands with characteristics readily visible in imagery: dominant vegetation and substrate, hydroperiod, and typical impacts to wetlands. However, the standard attribution does not consider abiotic characteristics like a wetland's shape or location within a watershed and thus misses key information. LLWW attributes bridge this data gap by considering the geomorphic setting, the shape and form, connectivity to stream networks, and more wetland modifiers describing human impacts, wetland hydrology, and type.

LLWW attributes were applied to wetlands and waterbodies according to keys developed by the Colorado Natural Heritage Program (CNHP). Riparian areas are not included in the keys and LLWW attributes were not applied to these features. For this project, we applied LLWW attributes using a multi-step process of manual assignment, automated queries, and subsequent manual correction and review to develop final LLWW attributes. Utah Geological Survey (UGS) application methods differed from other organizations conducting LLWW mapping throughout the state, but all organizations apply LLWW attributes with the same set of keys and regularly meet to ensure consistent mapping across organizations.

The combination of LLWW attributes with the standard NWI attributes provides very detailed information about each wetland and allows greater distinction between more wetland types than what is possible through each dataset alone. This ability to distinguish a wide variety of wetlands, combined with spatial analysis of the wetland mapping, allows for evaluation of which wetlands are likely to provide unique habitats or functions at a landscape level. Wetland functionality has become an increasingly important component of watershed conservation and has increasingly been used to prioritize restoration efforts. This prioritization has created a need for spatial data depicting wetland functions across the landscape.

We modeled wetland functions across the project area using our updated mapping to create a dataset that not only depicts the distribution and extent of wetlands, but also identifies which wetlands are likely to provide a given function and how likely it is to provide that function. We modeled nine important wetland functions, of which five were physical functions such as bank and shoreline stabilization and four were unique habitat types such as waterfowl habitat. Eight of these models relied on CNHP-developed crosswalks linking the NWI attributes and LLWW attributes to the likelihood of a feature providing a particular function. The models categorized wetlands as having a “High” or “Moderate” likelihood; high likelihood wetlands had characteristics that were well-documented as providing that function and moderate likelihood wetlands had potential but were limited by some characteristic like nearby disturbance or lack of woody vegetation. The final function model identifies suitable habitat for the Ute ladies’-tresses (*Spiranthes diluvialis*); model development followed a similar approach, but the model was developed by the UGS in collaboration with the USFWS.

The CNHP models identified roughly 75% of all mapped wetland features and about 83% of all mapped wetland area as providing some level and variety of function. Wetlands not identified as providing any of the modeled functions were predominantly intermittent channels, artificial canals and ditches, or small, isolated features. Most (66%) wetland features provided at least one physical function and fewer (39%) provided at least one unique habitat function, with sediment and particulate retention and surface water detention being the most common functions by feature.

The Ute ladies’-tresses habitat model was applied to all riparian and wetland mapping and identified roughly 75% of all features and mapped areas as likely to provide habitat for the species. Non-habitat features were typically above 7000 feet elevation, intermittent channels, or outlying riparian habitats lacking a stream bank. The model identified most features and mapped areas as highly likely to provide habitat for the species, except for riverine terraces where most features were identified as moderate.

The CNHP-modeled functions showed distinct clustering in the project area, with several areas having significant, locally high scores for all CNHP-modeled functions, physical functions and CNHP habitats in a hotspot analysis. These areas include Cutler Reservoir, headwaters of the Little Bear and Blacksmith Fork Rivers, confluence of the Little Bear River, Logan River, and Cutler Reservoir and surrounding marshes, wet meadows and fields near the Logan Airport, parts of Clarkston Creek and Newton Reservoir, and parts of the Bear River floodplain. Hotspot analysis of the Ute ladies’-tresses habitat model showed significant clustering of high-quality habitat in central parts of Cache Valley, in a rough band extending from the confluence of Davenport Creek and the South Fork of the Little Bear River north to the floodplains of the Bear and Cub Rivers. An additional cluster of high-likelihood features were identified around Clarkston Creek and Newton Reservoir.

The function models were developed through GIS exercises and validated through desktop reviews. Reviewers generally found the physical models more reliable than the habitat models but noted issues with all models. The largest issue was that the models only evaluated function within mapped areas; care should be taken to avoid interpreting model results as the only places providing a given function. Riparian areas were not assigned functions by most models, despite literature documenting their ability to provide several of the modeled functions, and we know more areas provide functions than what are captured by our models. To improve the function models for future use, we recommend (1) validating the models against field measures of wetland function, (2) assigning function to riparian areas, and (3) subjecting the final data to external review by wildlife professionals.

INTRODUCTION

Wetlands provide functions benefitting wildlife, plants, humans, and the ecosystem as a whole, and responsible development, conservation, and land use planning relies on accurate data of wetland location, type, and distribution. The U.S. Fish and Wildlife Service (USFWS) maintains the National Wetland Inventory (NWI), a spatial dataset describing wetland location and type across the entire nation that is the primary data source referenced by resource managers to make informed wetland conservation decisions. Despite the broad use, the NWI in much of Utah relies on imagery collected between 1980 and 1990 to identify wetlands and much of the mapping throughout our state is outdated and coarse. The Utah Geological Survey (UGS) and other organizations have been remapping wetlands in several areas of the state using recent, high-resolution aerial imagery to better map the current extent, location, and type of wetlands. This new mapping is provided to the USFWS as an update to the NWI and made publicly available through their Wetlands Mapper online application (USFWS, 2022).

This report summarizes a recently completed mapping project in Cache County (figure 1) that had three components: mapping wetland and riparian areas to update NWI mapping; applying additional Landscape Position, Landform, Water Flow path, and Waterbody Type (LLWW) attributes to enhance utility and information provided by the new mapping; and developing landscape-scale models identifying likely functions provided by wetlands across the entire project area. This mapping project aimed to accurately map and describe wetlands and provide stakeholders in Cache County with reliable, accessible data that can be used for planning and management purposes.

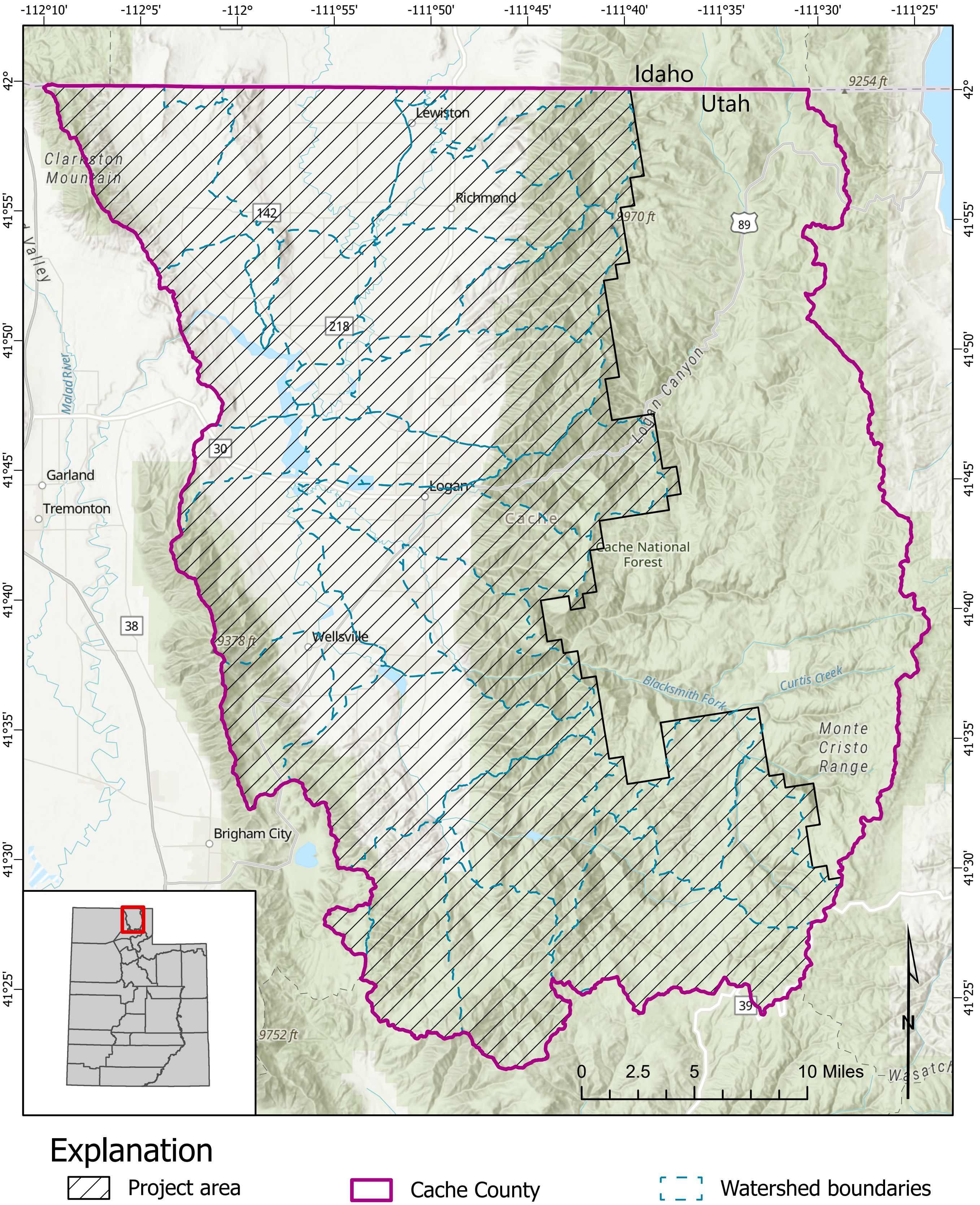

Figure 1. *Project area location map. Project area includes all of Cache Valley and several montane watersheds in the Bear River Range and Wasatch Mountains.*

Cache County was identified as a priority project by the UGS based on three factors: (1) outdated NWI mapping based on 1980s imagery, (2) rapid expansion of urban and suburban areas throughout the county, and (3) extensive wetland complexes and known wetland development conflicts within the county. The project area included the entirety of Cache Valley, the county portion with the highest density of wetlands and the most potential conflict with agriculture and urban development, as well as portions of the montane parts of the county. The project area covers 533,000 acres of Cache County and includes the communities of Lewiston, Smithfield, Hyde Park, Logan, Hyrum, Clarkston, and Newton.

Project Area Description

Geography

The project area is primarily located in Cache Valley in northern Utah and extends from near the town of Paradise north to the Utah–Idaho border (figure 1), and also includes the foothills and some montane slopes of the Wellsville Mountains and the Bear River Range. The project is within Cache County and includes all municipalities within the county. The project falls within three level 3 ecoregions and six level 4 ecoregions (Woods and others, 2001). The extents of all ecoregions within the project area are summarized in table 1 along with a detailed description of each level 4 ecoregion.

The project area is dominated by Cache Valley, an elongate, north-south-trending valley that was once flooded by ancient Lake Bonneville (Williams, 1974). Topography within Cache Valley is predominantly flat to gently sloping but has been dissected into several terraces and floodplains by numerous creeks and rivers including the Bear, Little Bear, Logan, Blacksmith Fork, and Cub Rivers. These rivers are all part of the Bear River hydrologic network and all flow into the Bear River or the Cutler Reservoir, a large reservoir on the Bear River that extends beyond the western boundary of the project area into Box Elder County. Below the North Cutler Dam, the Bear River continues to flow west before eventually terminating in Great Salt Lake.

Table 1. *Ecoregions in the project, adapted from Woods and others (2001).*

Level 3	Level 4	Description	Acres in Project area
Central Basin and Range	Wetlands	The nearly level Wetlands ecoregion contains rushes, reed grasses, and areas of open water. It is critical habitat for migratory birds and many state and federal wildlife refuges are found within it. Water levels are often managed, but, nevertheless, marshes can be periodically contaminated by rising saline lakes or drowned by high river runoff. Soils are poorly drained or very poorly drained and often salty.	10,778 (2.1 %)
	Malad and Cache Valleys	The Malad and Cache Valleys ecoregion contains wide terraces, narrow floodplains, and alluvial fans. Mountain-fed perennial streams and canals provide water to pastureland, municipalities, and hay, small grain, sugar beet, and fruit crops.	234,431 (44.0%)
Wasatch and Uinta Mountains	Wasatch Montane Zone	The partially glaciated Wasatch Montane Zone consists of forested mountains and plateaus underlain by sedimentary and metamorphic rocks. Douglas-fir and aspen parkland are common and Engelmann spruce and subalpine fir grow on steep, north facing slopes. Perennial streams provide water to lower, more arid regions.	93,538 (17.5%)
	Mountain Valleys	The unforested Mountain Valleys ecoregion contains terraces, flood plains, alluvial fans, and hills. It is affected by cold temperatures and has a short growing season. Potential natural vegetation is mostly Great Basin sagebrush. irrigated cropland, irrigated pastureland, and rangeland are common. Turkey farms, feedlots, and dairy operations occur locally. Land use contrasts with that of nearby high plateaus and mountains.	18,019 (3.4%)
	Semiarid Foothills	The Semiarid Foothills ecoregion is found between about 5000 and 8000 feet elevation. Widely spaced juniper and pinyon typically occur in a matrix of sagebrush, grama grass, mountain mahogany, and Gambel oak. Maple-oak scrub is common in the north but, southward, it is gradually replaced by pinyon juniper woodland at lower elevations and ponderosa pine at upper elevations. Livestock grazing is common. Some rangeland has been cleared of trees and reseeded to grasses.	169,171 (31.7%)
Northern Basin and Range	Semiarid Hills and Low Mountains	The Semiarid Hills and Low Mountains ecoregion is composed of mountain slopes, hills, and alluvial fans existing in an elevational belt between higher elevation montane forests and valley bottoms. Cool season grasses are more common and there is more available moisture than much of the valley bottom.	7272 (1.4%)

The project area also contains significant amounts of montane and alpine terrain in the Wellsville Mountains and Wasatch and Bear River Ranges, respectively, to the west, south, and east of Cache Valley. Terrain in these ranges varies from steep slopes to relatively flat and narrow canyons supporting seasonal and perennial streams. Topography in these ranges also varies with features draining variously east, north, or south depending on their aspect, but all montane regions within the project area ultimately drain to Cutler Reservoir or Cache Valley. However, extensive fracturing of limestone and dolomite bedrock has created some karst topography features complicating these drainage patterns (Spangler, 2001); many streams lose surface flow to subterranean networks, sinks, and numerous springs or seeps.

Seeps, springs, and other areas of diffuse groundwater discharge are prevalent throughout Cache Valley (Anderson and others, 1994; Kariya and others, 1994), extending generally outward from Cutler Reservoir to include areas north of Hyrum, west of Richmond, and east of Newton. These groundwater discharge areas appear as deep, permanent spring-fed ponds like Blue Spring or as saturated wetlands supported by shallow groundwater such as the Amalga Barrens.

The project area contains several perennial waterbodies, including large rivers like the Bear or Little Bear as well as several large reservoirs created by impounding those rivers such as the Hyrum, Porcupine, and Cutler Reservoirs. Several other smaller perennial waterbodies such as the Logan River and numerous ponds and spring-pools are also present in the project area.

Climate

The project area has two distinct climates—a cool desert climate in Cache Valley and a colder, wetter montane climate in the Bear River and Wasatch Ranges and the Wellsville Mountains. Summer temperatures in Cache Valley reach an average maximum of 85.7°F and winter temperatures reach an average minimum of 15.9°F (Western Regional Climate Center, 2021). Average annual precipitation is 17.8 inches, with the majority falling as snow during the winter and spring months (Western Regional Climate Center, 2021). Summer temperatures in the montane regions vary, but SNOTEL data for Tony Grove Lake (a high-elevation site in the Bear River Range) shows an average maximum temperature of 72.6°F and an average minimum temperature of 17.1°F (Natural Resources Conservation Service [NRCS], 2021). Average annual precipitation at Tony Grove is 48.9 inches with roughly 75% occurring as snowfall during the winter months (NRCS, 2021).

Land Use

Cache Valley and surrounding mountains were occupied by the Northwestern band of the Shoshone (America West Center, 2021), and human use in the region likely extends to the Paleoindian era (National Park Service, 2021). Shoshone traditionally hunted and gathered throughout Cache Valley, and wetlands were largely unaltered until the arrival of settlers in the 1850s. Since the 1850s, much of Cache Valley has been extensively converted for agriculture, and a network of canals, ditches, and large impoundments has been created to distribute irrigation diversions throughout the valley. A network of tile drains, drainage ditches, and wells has also been developed within the valley to drain low-lying or saturated areas and create arable farmland (Gardner and Israelsen, 1954). Urban and residential development has occurred throughout Cache Valley, with most of the historical and recent development occurring along the western front of the Bear River Range. Land uses in the montane parts of the project area include grazing, historical mining, recreation, and development to supply water to residents in Cache Valley. These uses have resulted in the creation of numerous and variously sized impoundments along seasonal and perennial streams to create water sources for domestic use in Cache Valley and for livestock and recreation.

NWI WETLAND AND RIPARIAN MAPPING

Imagery and Supporting Data

Source Imagery

The mapping was conducted using National Agricultural Imagery Program (NAIP) imagery collected during June and July of 2016. Mapping was conducted using the 2016 NAIP imagery because it better captured seasonal high-water conditions during an average water year compared to more recent NAIP imagery, which was collected in late summer 2018 and captured seasonal low-water conditions during a historical drought.

Supporting Data

Spatial data

All wetland boundaries were mapped to features visible in the source imagery, but several other datasets were reviewed alongside the 2016 NAIP imagery to support mapping wetland boundaries, types, and water regimes. These spatial datasets included historical and recent imagery, high-resolution light detecting and ranging (lidar) data, existing wetland and hydrography mapping, soil surveys, and water-related land use information (table 2).

Non-spatial data

In addition to the spatial datasets described above, mappers reviewed other data including historical precipitation data from sites near Tony Grove, Logan, the Little Bear River, and Temple Fork of the Logan River, and USGS stream gaging records for the Bear, Cub, Little Bear, Blacksmith Fork, and Logan Rivers. These data helped mappers better understand precipitation, runoff, and flooding patterns in the project area, and were used to corroborate the broad avoidance of the intermittently flooded water regime and to distinguish between riparian areas and temporarily flooded wetlands along the rivers listed above.

Field Data

Field reconnaissance surveys were conducted to view problematic wetland mapping situations and correlate wetland vegetation types and water regimes to aerial imagery signatures. Reconnaissance surveys also focused on understanding the general distribution of wetlands within the project area, understanding landscape features likely to support wetlands, and distinguishing between riparian areas, wetlands, and surrounding uplands.

Reconnaissance surveys consisted of visiting pre-identified sites that were either (1) representative of typical wetlands, (2) difficult to map based on aerial imagery alone, (3) located in a unique landscape or feature, or (4) had a unique aerial imagery signature. All sites were either located on public land, easily viewed from public roads, or accessed through landowner permission. For each site the most appropriate wetland type and water regime were recorded along with a representative photograph and GPS location using Collector running on an Apple iPad Air 2 tablet. If access and conditions allowed, additional information about the wetland hydrology indicators, hydric soil indicators, and the dominant herbaceous and woody vegetation species present at each site was collected. These field data and photographs were invaluable throughout the mapping but were particularly useful in distinguishing between groundwater-fed and irrigation-fed wetlands in Cache Valley.

Wetland types were determined based on the current condition as visible in the field—presence of wetland vegetation, vegetation growth forms, and evidence of modification. Water regimes, as well as distinctions between wetlands, riparian areas, and uplands, were determined based on current conditions and discussion of likely conditions throughout the year. Current conditions assessed included features visible in the field (presence of standing water or saturation, extent of flooding and saturation, general vegetation communities) whereas discussion of likely conditions throughout the year focused on landscape position, possible hydrology sources, and seasonal water patterns. These discussions helped mappers understand likely hydrology sources, whether the site was flooded, saturated, or both, and the duration and frequency of flooding or saturation.

Field surveys were conducted by UGS mappers Rebecca Molinari, Lydia Keenan, and Pete Goodwin over several visits from June 26, 2019, to May 12, 2021, with all visits happening in May, June or July to best capture peak growing season and average high-water periods. Hydrologic conditions at the time of surveys varied, with surveys conducted in 2019 and 2020 taking place in average to above-average precipitation years and surveys conducted in 2021 taking place in a year receiving 60%–75% of average annual precipitation. These below average conditions were considered by the mappers when discussing likely water regimes (NRCS, 2021).

General Methods

Mapping for this project was accomplished with "heads up" interpretation of 2016 NAIP imagery by UGS wetland mappers Lydia Keenan, Rebecca Molinari, Elisabeth Stimmel, and Pete Goodwin from 2019 to 2022. All mapping was completed by hand-digitizing polygons in ArcGIS software to establish boundaries and assign a wetland or riparian type according to USFWS guidelines (USFWS, 2019; Dahl and others, 2020). John Swords of the USFWS provided several clarifications and mapping reviews. Mapping of linear features, such as riverine channels, followed current USFWS guidelines to emphasize surface network connectivity while maintaining the priority of traditional polygonal wetlands (USFWS, 2021).

Table 2. *Supporting data for NWI mapping in Cache County.*

Dataset	Description	Source	Relevant Date(s)
Imagery			
Historical Orthophotos	1-meter resolution, historical black and white orthophotos collected in the summer of 1997.	Utah Geospatial Resource Center (UGRC)	Summer 1993
NAIP 2011	1-meter resolution, 4-band aerial imagery collected during the summer of 2011.	USDA NAIP	07/15/2011 to 08/12/2011
NAIP 2014	1-meter resolution, 4-band aerial imagery collected during the summer of 2014.	USDA NAIP	06/30/2014 to 09/02/2014
NAIP 2018	1-meter resolution, 4-band aerial imagery collected during the summer of 2018.	USDA NAIP	08/15/2018 to 09/18/2018
Google Earth Imagery	Publicly available, true-color imagery from several years and sources. Imagery available in the project area includes NAIP imagery, Landsat imagery, and imagery collected by Google Imagery services. Imagery was collected over several years, usually during the growing season, but one leaf-off dataset was collected in March of 2012.	Google Earth	Various
ESRI World Imagery	30-centimeter, true color imagery available as an ESRI service. Imagery mosaiced from several sources and collection dates, but much of the project area collected in 2017.	ESRI	Various
Lidar and Elevation			
Wasatch Front and Wasatch Fault	0.5-meter resolution, first return and bare earth lidar data of the Wasatch Front collected during fall 2013	UGRC	Fall 2013
Bear Lake, Bear River, Cache Valley, and Upper Weber Valley	0.5-meter resolution, first return and bare earth lidar data of the Cache Valley collected during fall 2016	UGRC	Fall 2016
Franklin Bear	1.0-meter resolution, first return and bare earth lidar data of northwestern Cache Valley collected during fall 2017	UGRC	Fall 2017
Northern Utah	0.5-meter resolution, first return and bare earth lidar data of southern Cache Valley collected during summer 2018	UGRC	Summer 2018
5-m DEM	5.0-meter resolution digital elevation model collected during 2006 aerial photography flights	UGRC	Summer 2006
Existing Mapping			
National Wetland Inventory (NWI) Mapping	Existing wetland mapping included in the NWI dataset.	USFWS	Summer 1984
National Hydrography Dataset Flowlines	Centerlines of ephemeral, intermittent, seasonal, and perennial channels identified in the NHD.	USGS	2016
National Hydrography Dataset Spring points	Point data of known springs and seeps identified in the NHD	USGS	2016
Soil Survey of Cache Valley Area	Soil map units, including hydric component ratings, as identified in the Cache Valley Soil Survey	NRCS	1974
Cache County Canals	County-wide dataset of canals and ditches corrected to recent aerial imagery	Cache County GIS	Summer 2019
Cache County Drains	County-wide dataset of drainage ditches and tile drains compiled from several sources	Cache County GIS	Summer 2019
Utah Valley Bottoms	State-wide dataset depicting valley bottom areas for all perennial streams within the state of Utah	Utah State University	Winter 2016
Land Use			
Water Related Land Use	Land use data showing the extent and type of irrigated crops, urban areas, and relatively natural landscapes	Utah Division of Water Resources	2017
Water Points of Diversion	Agricultural irrigation and other diversion points along water features identifying wells, stock ponds, and springs	Utah Division of Water Resources	Summer 2019

Wetland and riparian mapping were conducted concurrently, and all features were mapped at 1:3000 scale. Wetlands were mapped to a target mapping unit (TMU) of 0.1 acre (roughly 400 square meters), whereas riparian areas were mapped to a TMU of 0.5 acre (roughly 2000 square meters). This TMU difference arose from likely applications of the wetland and riparian mapping dataset. The wetland mapping is commonly used as initial mapping for aquatic resource delineations or to identify small, dispersed habitats such as springs or ponds, applications where fine-scale mapping is required. The riparian mapping is often used for broader applications—selecting treatment areas for salt cedar control, identifying habitats for nesting birds, evaluating the presence and extent of riparian buffer around a stream or wetland, or some other purpose looking to identify broad vegetation communities. Due to the finer TMU and greater use, wetlands were mapped with precedence over riparian areas.

The 2016 NAIP imagery was the source imagery for all wetland and riparian mapping, and all wetlands and riparian areas were demarcated and classified based on features visible in the source imagery. Supporting data were used to determine water regimes and map approximate boundaries if boundaries were indistinct in the source imagery.

Water regimes were determined by reviewing imagery collected across several years and considering several factors for each feature including (1) presence of water across several years, (2) likely water sources, (3) if water was present as surface inundation or saturation, (4) extent of flooding or saturation and any changes in extent, (5) timing of imagery, and (6) landscape position. Along the various floodplains, lidar datasets were used to compare the elevation of floodplain features relative to the river to help classify features as either riparian areas, floodplain wetlands, or isolated groundwater-fed wetlands.

Wetland and riparian boundaries were largely drawn based on vegetation, hydrology, and topographic differences readily visible in the source imagery. For features with less apparent boundaries where canopy vegetation, grazing, or crop production obscured vegetation or topography, mappers reviewed supporting data when drawing boundaries including 1-meter elevation data created from lidar, leaf-off imagery collected in fall 2014, and existing spring, stream, and wetland mapping. These supporting datasets were most often used when mapping channels and small wetlands in montane regions and distinguishing between irrigation and groundwater-fed wetlands in Cache Valley. Supporting data that identified depressional areas, canals or other constructed features, consistently wet areas, and known locations of streams, springs, or historical wetlands were helpful when determining if and how to map a feature.

Lidar-derived datasets were used extensively throughout Cache Valley to identify likely wetlands and corroborate polygon boundaries. Lidar-derived slope datasets were especially useful for identifying small ditches draining or irrigating features, as well as identifying the extent of small depressions or slope breaks that indicate saturated, groundwater-fed features. As the lidar datasets used throughout the project were variously collected from 2013 to 2018, all features mapped using lidar datasets were reviewed against the source imagery to verify the feature's presence and attribution.

Mapping Conventions

The project area contains two distinct regions—Cache Valley and the surrounding montane areas—and wetland-specific conventions were developed to address mapping issues found in each of these regions. Riparian mapping conventions were also developed to help mappers consistently identify and map riparian areas.

Cache Valley Wetland Conventions

Farmed wetlands

- The f modifier was reserved for areas that would revert to a wetland if irrigation was stopped and was applied in situations consistent with the 2020 guidelines (Dahl and others, 2020).
- Wetland features where agriculture has replaced wetland vegetation with something that cannot be considered emergent (wheat, corn, alfalfa, soy, etc.) were mapped as Pf.
- Wetlands appearing to receive additional water from irrigation (but not actively farmed, planted, plowed, or cropped) were mapped as a regular wetland (i.e., PEM1A) with no f modifier.
- Wetlands that looked to be actively mowed as hayfields in the 2016 imagery were mapped with an f modifier to capture that agricultural land use.

Development

- Wetlands visible in 2016 imagery but replaced by urban development in 2018 NAIP were not mapped if completely replaced or were mapped to the edge of development visible in the 2018 imagery.

Irrigation

- Wetlands were mapped in irrigated areas if several years of imagery showed a consistently wet portion or core of the feature.
- Irrigation was considered temporary flooding and irrigated features were mapped with A water regimes.
- Features that were created from irrigation and would likely return to upland if irrigation were to stop were not mapped as wetlands unless field data or other supporting data confirmed persistent hydric soils or other wetland characteristics.

Pioneering annuals

- Vegetation in large lacustrine areas mapped having an A or C water regime was assumed to be dominated by pioneering annuals and was not mapped as a vegetated wetland even if cover exceeded 30%. These areas were instead mapped as L2USA or L2USC features.
- Vegetation in small, isolated ponds having an A or C regime was treated conservatively and not assumed to be dominated by pioneering annuals. These features were mapped as vegetated wetlands if vegetation cover exceeded 30%.

Forested wetlands

- Forested features were mapped as wetlands only if:
  - surface water or saturation was visible in several years of imagery, or
  - supporting data identified the feature as a groundwater-supported wetland.
- Woody species like Russian olive (*Elaeagnus angustifolia*) typically less than 20 feet, but capable of reaching greater heights, were treated as scrub-shrub species and mapped as scrub-shrub wetlands regardless of height.

Groundwater

- The B, D, and E water regimes were applied only to features where the dominant hydrology appeared to be groundwater, springs, or seepage from canals, dams, and other features.
- Areas of groundwater discharge in the valley were identified in part through:
  - landscape position along the toes and slopes of alluvial fans and deltaic deposits near the Wellsville Mountains and Bear River Range, locations near known discharge zones or artesian wells, or in the headwater position of channels originating in the valley,
  - existing mapping of National Hydrography Dataset (NHD) seeps and springs, Utah Division of Water Resources Points of Diversion, and previous NWI mapping, and
  - "spring-fed pond" appearance with a distinctive pool and defined channel outflow or wetter hydrology than expected based on the size of the contributing area or associated stream.

Canals and irrigation ditches

- C water regimes (R4SBCx) were applied to all canals and irrigation ditches regardless of size or apparent use to simplify mapping.
- Canals and irrigation ditches were mapped in greater detail with smaller TMUs to emphasize the connectivity of irrigated features and groundwater-fed wetlands throughout the valley.

Drained wetlands

- The d modifier was applied to wetlands located in:
  - areas with mapped drainage networks identified in the supporting data, and
  - areas of groundwater discharge where ditches or canals appeared to drain surrounding areas rather than convey irrigation water.

Aquatic beds

- Aquatic bed features were mapped only if algae or other visible aquatic vegetation was visible in imagery. We did not assume ponds supported submerged aquatic vegetation without corroborating evidence.

Montane Wetland Conventions

Groundwater

- The B, D, and E water regimes were applied to features where the dominant hydrology appeared to be groundwater, springs, or seepage from canals, dams, or other features.
- Areas of groundwater discharge in the montane areas were identified in part through:
  - landscape position along hillslopes, cliff bases, and slope changes; lidar datasets were used extensively to corroborate these topography breaks as well as identify small slumps typical of saturated zones, and
  - existing mapping of NHD seeps and springs, Utah Division of Water Resources Points of Diversion, and previous NWI mapping.

Beaver ponds and meadows

- The b modifier was applied to beaver-created ponds (generally mapped as PUBFb) as well as the emergent and scrub-shrub wetlands upstream of the pond.
- Beaver-modified wetlands were mapped with priority over linear channels due to:
  - the difficulty of identifying a single channel through these features, and
  - many of the upstream emergent and scrub-shrub wetlands would have been below the 0.1-acre TMU if split by a linear feature.

Avoidance of J regimes

- J regimes were not used in montane regions as most features were assumed to flow or accumulate water during annual spring runoff.

Riparian Mapping Conventions

Riparian mapping posed a challenge throughout the entire project area. In the Cache Valley region, relatively high groundwater tables allowed woody species like willows (*Salix* spp.), Russian olive, or cottonwoods (*Populus* spp.) to establish in areas removed from waterbodies and wetlands. In the montane regions, abundant non-riparian woody species like Gambel oak (*Quercus gambelii*), big-tooth maple (*Acer grandidentatum*), and various conifers including silver fir (*Abies concolor*) and Douglas fir (*Pseduotsuga menziesii*) complicate distinguishing between riparian areas and surrounding uplands.

Additionally, extensive irrigation for pasture has resulted in the creation of areas that are indistinguishable from riparian emergent areas and often contain the same assemblage of mesic grass species. To help mappers distinguish riparian areas from patches of vegetation with similar signatures, riparian areas were mapped using a functional approach which evaluated the likelihood of a given patch of vegetation providing key riparian functions such as sediment and pollutant trapping, slowing surface flows, or shading. This approach was premised on the idea that one of the main interests in riparian areas is their ability to protect downstream water quality and habitats. Areas providing a greater degree of riparian functions were considered more likely to protect downstream waters and were mapped as riparian areas.

Mappers assessed the potential riparian functions of a given patch of vegetation by considering (1) proximity to a wetland or waterbody, (2) vegetation density, (3) patch size, and (4) landscape position. In general, riparian functions were considered to diminish with decreasing vegetation density, decreasing patch size, and increasing distance from a waterbody. Riparian functions were expected to be greater along active floodplains and within confined channels, but mappers also considered the presence of roads, development, or intervening bands of upland vegetation and did not map riparian areas in appropriate landscape positions where these features separated an area from a waterbody.

In general, features were mapped along active floodplains and confined channels and adjacent to waterbodies in locations where riparian vegetation could be expected to reduce surface flow velocities, shade flowing water, and intercept sediments or other pollutants before they could enter surface waters. Similar to wetland mapping, several riparian mapping conventions were established to consistently identify riparian areas.

TMU

- Riparian areas were mapped with a 0.5-acre TMU, and most mapped riparian areas are 0.5 acre or larger. However, riparian areas smaller than 0.5 acre were mapped if they were part of a distinct patch of riparian vegetation that had been split by a mapped wetland or were distinctly different from surrounding areas such as a small sandbar supporting riparian vegetation or isolated cottonwood stands in larger floodplain wetlands.

Classification level

- Riparian areas were classified to the class level, and riparian areas dominated by salt cedar were not distinguished from areas dominated by willow, birch (Betula ssp.), or Russian olive.

Distinguishing between forested and scrub-shrub classes

- Due to the lack of reliable canopy height data, scrub-shrub and forested areas were distinguished by the dominant woody species. Russian olive, most willows, and water birch (*Betula occidentalis*) were considered shrub species, and areas dominated by these species were mapped as scrub-shrub areas. Cottonwoods and crack willows (*Salix fragilis*) were considered tree species and stands of these trees were mapped as forested areas.

Features supporting riparian areas

- Emergent riparian areas were only mapped in unirrigated areas located in constrained floodplain areas such as along floodplains of the Bear or Cub Rivers.
- Forested and scrub-shrub riparian areas were mapped along all features that could support riparian areas.
- Riparian areas were not mapped along channels assigned an A regime.

Minimum width

- Linear stretches of riparian vegetation less than 20 feet wide were not mapped.

Riparian emergent areas

- Emergent riparian areas were nearly indistinguishable from irrigated pastures and were only mapped in areas that were clearly not irrigated.
- Extensive areas along the Bear and Cub Rivers above Cutler Reservoir were mapped as riparian emergent based on the distinctly terraced floodplains and lack of apparent irrigation.

Slope

- Riparian areas were assumed to exist on relatively flat floodplain areas, and steep slopes above montane channels were not mapped.
- Lidar-derived slope datasets and other elevation data were used to map montane riparian areas and emergent riparian areas along Cache Valley floodplains.

Mapping Comparison

This 2022 mapping project replaces existing mapping from a 1984 project using imagery collected from 1981 to 1983 (USFWS, 1984). Wetland extents and distributions have changed over the past three decades, but so have mapping conventions and guidelines. Several revisions to the mapping guidelines have allowed modern mappers to (1) use the farmed modifier to identify wetlands affected by crop production, (2) discontinue the use of the unknown perennial river subclass, and (3) map riparian areas along floodplains and other waterbodies. Additionally, the availability of high-resolution imagery, an increased emphasis on linear features, and avoidance of mixed classes have also affected the wetland mapping. Finally, climatic conditions for the 1984 and this 2022 mapping project are very different; the periods between 1982 to 1984 were a historically wet period versus the more average conditions that occurred in 2016 (National Integrated Drought System, 2022). All these changes have affected how some features in the project area were mapped and complicate comparisons between the existing 1984 mapping and the 2022 update. Despite these changes, comparisons are possible when wetland and riparian types are viewed at a more general level. Table 3 summarizes the two mapping datasets by broad wetland and riparian categories and also provides a crosswalk to detailed Cowardin codes. The comparisons in table 3 should be viewed primarily as a comparison of differences between the two datasets rather than any indication of wetland gain or loss since 1984.

Table 3. Summary of 1984 and 2022 mapping data.

Broad Wetland Type	2022 Mapping[1]			1984 Mapping[1]		
	Cowardin Codes	Features	Acres	Cowardin Codes	Features	Acres
Lacustrine Systems						
Deep Water	L1UBHh	2	573.5	L1UBHh, Lh	7	1317.2
Aquatic Bed		0	0.0	L2ABF, L2ABFh, L2ABFx, L2ABGh, L2ABGx	17	690.7
Shallow Water	L2UBH, L2UBHh	7	3058.4	L2UBFh, L2UBGh	18	2618.5
Lacustrine Shore	L2USAh, L2USC, L2USCh	18	210.2	L2USAh, L2USC, L2USCh, L2USCx	52	200.2
Artificially Flooded	L2ABKx, L2UBKx	12	637.6		0	0.0
Lacustrine Total		39	4479.7		94	4826.5
Palustrine Systems						
Aquatic Bed	PABF, PABFb, PABFh, PABFx, PABG, PABGb, PABGh, PABGx, PABH, PABHh, PABHx, PABKx	511	588.2	PAB/EM1F, PAB/EM1Fh, PAB/EM1Fx, PABF, PABFh, PABFx, PABG, PABGb, PABGh, PABGx, PABHh	890	1089.1
Emergent Meadow	PEM1A, PEM1Af, PEM1Ah, PEM1Ax, PEM1B, PEM1Bb, PEM1Bd, PEM1Bf, PEM1Bh, PEM1Bx, PEM1C, PEM1Cb, PEM1Ch, PEM1Cx	3048	9124.7	PEM1/FOCh, PEM1/ABF, PEM1/ABFh, PEM1/ABFx, PEM1/SSC, PEM1/SSCh, PEM1/SSCx, PEM1/USA, PEM1/USAh, PEM1/USAx, PEM1/USC, PEM1/USCh, PEM1/USCx, PEM1A	2258	9537.1
Emergent Marsh	PEM1E, PEM1Ed, PEM1Ex, PEM1F, PEM1Fb, PEM1Fh, PEM-1Fx, PEM5E	1144	3349.8	PEM1F, PEM1Fh, PEM1Fx	893	2374.5
Farmed	Pf	87	373.3		0	0.0
Forested	PFO1A, PFO1B, PFO1Bb, PFO1C, PFO1Cb, PFO1Ch, PFO1E	104	90.5	PFO/EM1A, PFO/SSA, PFO/SSCh, PFOA, PFOAh, PFOAx, PFOC	185	557.1
Scrub-shrub	PSS1A, PSS1Ah, PSS1B, PSS1Bb, PSS1C, PSS1Cb, PSS1E, PSS1Eb	377	450.2	PSS/EM1B, PSS/EM1C, PSS/EM1Ch, PSS/EM1Cx, PSS/FOC, PSS/USC, PSS/USCh, PSSA, PSSC, PSSCh, PSSCx	451	1266.3
Permanent Pond	PUBF, PUBFb, PUBFh, PUBFx, PUBG, PUBGb, PUBGh, PUBGx, PUBH, PUBHh, PUBHx	575	512.1	PUBF, PUBFx	15	15.1
Seasonal Pond	PUSA, PUSAh, PUSAx, PUSC, PUSCb, PUSCh, PUSCx, PUSJx	338	215.5	PUS/EM1C, PUSA, PUSAh, PUSC, PUSCh, PUSCx	227	371.5
Artificially Flooded	PUBKx, PUSKx	16	59.3		0	0.0
Palustrine Total		6168	14,648.1		4919	15,210.8
Riverine Systems						
Lower Perennial	R2UBF, R2UBG, R2UBGr, R2UB-Gx, R2UBH, R2UBHx, R2USC	108	1254.9	R2UBFx, R2UBG, R2UBH, R2USA, R2USC	66	659.0
Upper Perennial	R3RBF, R3RBG, R3RBH, R3RSA, R3RSC, R3USC	73	370.8	R3UBG, R3UBH	12	111.5
Intermittent Streambed	R4SBA, R4SBC, R4SBCx	1519	4064.5	R4SBC, R4SBCh, R4SBCx	1050	3293.5
Unknown Perennial		0	0.0	R5UBFx, R5UBH	1075	674.4
Riverine Total		1732	5805.4		2203	4738.5
Riparian Systems						
Riparian Emergent	Rp1EM, Rp2EM	390	2060.4			
Riparian Forested	Rp1FO, Rp2FO	1205	1933.6			
Riparian Scrub-shrub	Rp1SS, Rp2SS	471	777.2			
Riparian Total		2066	4771.3		0	0.0
Total Mapping		10,005	29,704.6		7216	24,775.8

[1] Mapping conventions have changed drastically between 1984 and 2022 and care should be taken when comparing the two datasets.

There are several differences between the outdated 1984 mapping and the 2022 update. Excluding riparian areas, the 2022 update identifies more wetland features in a relatively similar total acreage. This increase in wetland features largely stems from differing TMUs and improved imagery quality allowing mappers in the 2022 update to reliably identify and map smaller features. Many wetlands identified in the outdated 1984 mapping have been replaced or dewatered through urban development, particularly in eastern Cache Valley as the cities of Logan, North Logan, Smithfield, and Hyde Park have expanded westward into low-lying areas. These losses may be reflected in the overall decrease of mapped Emergent Meadow acreage in the 2022 update, but different mapping conventions complicate that comparison. Additionally, differing TMUs and improved image quality could also account for the shifts in acreage and number of mapped features seen in Emergent Marsh and Emergent Meadow.

More definite trends can be seen with the inclusion of riparian mapping and apparent decrease in both acreage and number of mapped forested and scrub-shrub wetlands in the 2022 update. Riparian mapping guidelines were created in 1997, and the 1984 mapping did not identify any riparian areas. However, many scrub-shrub and forested wetlands identified in the outdated mapping were mapped as riparian areas in the 2022 mapping. Most of the riparian mapping occurred along the various floodplains in Cache Valley, where almost all forested or scrub-shrub features identified in the 1984 mapping have been remapped as riparian areas in the 2022 mapping. Although not mapped as scrub-shrub or forested wetlands by the 1984 mapping, the 2022 mapping also identifies extensive riparian areas along the Blacksmith Fork, Logan River, and upper reaches of the Little Bear River.

LLWW WETLAND MAPPING

The Landscape Position, Landform, Water Flow Path, and Waterbody Type (LLWW) classification system was developed by Ralph Tiner of the USFWS to supplement the Cowardin classification system used for the NWI mapping and better relate the NWI dataset to Hydrogeomorphic (HGM) classes (Tiner, 2014). The Cowardin classification system was designed to allow accurate wetland mapping from aerial imagery at a national scale and evaluates characteristics readily visible in imagery: dominant vegetation and substrate, hydroperiod, and typical impacts to wetlands (Dahl and others, 2020). It does not consider abiotic characteristics like a wetland's shape or location within a watershed and thus misses key information needed to accurately assign an HGM class (Brinson, 1993). The LLWW classification system bridges this data gap by considering the geomorphic setting, the shape and form, and connectivity to stream networks. It also includes significantly more wetland modifiers to better describe human impacts, as well as wetland hydrology and type. When combined, the Cowardin code and LLWW attributes can provide very detailed information about a given wetland.

Like the Cowardin system, the LLWW system describes wetlands with coded attributes that correspond to certain wetland types or characteristics (Tiner, 2014). The LLWW attribute consists of two parts: a six to seven-digit base code and a list of applicable LLWW-specific modifiers. The base code includes information about (1) the landscape position, (2) the landform or waterbody type, and (3) the flow path. The landscape position information is indicated by the first two digits of the base code and describes the geomorphic setting or where the wetland is on the landscape in relation to the surrounding terrain and features. The middle two or three digits indicate the wetland's landform or waterbody type. Waterbody type descriptions are applied to rivers, streams, ponds, and lakes with near-permanent water; landform descriptions are applied to all other features and describe the shape and form of the wetland. The final two digits in the LLWW base code indicate the water flow path which describes both the wetland's surface water connection to other wetlands as well as the direction water flows through that wetland. Unlike the Cowardin system, the LLWW system is not limited to a single modifier per wetland; multiple LLWW-specific modifiers further describing various human-impacts, water sources, and unique wetland types can be applied. Descriptions for all LLWW attribute codes, LLWW-specific modifiers, and their general application can be found in appendix A.

We applied the LLWW attributes to our updated Cache Valley mapping to (1) enhance the dataset's utility for planning and management, (2) support detailed analyses of wetland functions and habitats, and (3) be consistent with other wetland mapping efforts within Utah.

The Bureau of Land Management (BLM) has contracted with the Geospatial Lab of St. Mary's University and the Ecological Mapping, Monitoring, and Assessment Laboratory (EMMA) of the University of Montana to update NWI mapping and enhance the dataset with LLWW attributes across BLM lands throughout the West, which will result in nearly 15 million acres of updated mapping throughout Utah (National Wetland Inventory, 2021 Active Projects). These 15 million acres comprise about 27% of the state; we strongly support providing consistent, seamless data across Utah. We engage in periodic meetings with mappers from organizations mapping BLM contracted areas to discuss problematic mapping and appropriate application of LLWW attributes. All organizations conducting LLWW wetland mapping apply LLWW attributes according to the keys developed by the Colorado Natural Heritage Program (CNHP; Lemly and others, 2018).

Applying both the Cowardin code and LLWW attributes allows us to distinguish more wetland types than what is possible through each classification system alone; isolated wet meadows supported by near-permanent groundwater, emergent wetlands temporarily inundated by river flooding, and montane forested wetlands are all distinguishable by combining Cowardin and LLWW attributes. The application of both attributes also allows for identification of distinct wetland habitats like wetlands supporting shorebirds or Ute ladies'-tresses (*Spiranthes diluvialis*), as well as wetlands with unique shapes and locations that provide certain functions such as depressional wetlands on floodplains that capture sediments and detain floodwaters. The ability to distinguish a wide variety of wetlands, combined with spatial analysis of the wetland mapping, allows us to evaluate which wetlands provide unique habitats or functions at a landscape-level.

Wetland mapping data can be applied many ways, and the most common use involves assessing wetland presence or absence on individual properties. This use mostly ignores wetland classifications, but other uses such as setting management priorities, establishing floodplain protection ordinances, or identifying conservation priorities benefit from the flexibility of combined Cowardin and LLWW attributes. This flexibility enhances managers' and planners' abilities to identify particular wetlands using the mapping dataset. We hope the updated spatial data, combined with greater wetland descriptions, will better serve local land managers and planners.

Data Used

LLWW mapping considered the same source imagery and supporting data used for NWI mapping (table 2), but also used several additional datasets to evaluate landscape position and application of several LLWW modifiers (table 4).

Table 4. *Supporting data for LLWW mapping in Cache County.*

Dataset	Description	Source[1]	Relevant Date(s)
Lidar and Elevation			
10-m DEM	5.0-meter resolution digital elevation model collected during 2006 aerial photography flights	UGRC	Summer 2006
Land Use			
Fish Hatchery Facilities	Utah Department of Wildlife and U.S. Fish and Wildlife Service fish hatchery locations	UGRC	2020
Fire Perimeters	Historical fire perimeters from 2011 to 2020 within project area	GeoMac	2020
Golf Courses	Known golf courses within the project area	UGRC	2021
Hot Springs	Known locations of selected geothermal springs and wells in project area	UGS	2020
Timber Harvests	Nationwide dataset of timber harvest locations on U.S. Forest Service lands	USFS	2020
Gravel Mines	Active, permitted gravel mine locations from the Utah Department of Oil, Gas and Mining	OGM	2020
Dam Inspection Points	Dam locations with dam size, type, and inspection agency information from the Utah Department of Water Rights	UDWRi	2020
Mineral Mines	Active and historical hard rock and mineral prospect claims from the Utah Department of Oil, Gas and Mining	OGM	2020
Restoration Sites	Restoration projects funded by the Watershed Restoration Initiative	WRI	2020

[1] Abbreviations: Utah Geospatial Resource Center (UGRC), Geospatial Multi-Agency Coordination (GeoMac), Utah Geological Survey (UGS), United States Forest Service (USFS), Department of Oil, Gas and Mining (OGM), Utah Department of Water Rights (UDWRi), Watershed Restoration Initiative (WRI).

General Methods

LLWW attributes were applied after NWI mapping; wetland polygons were identified and demarcated according to current USFWS guidance, described with the Cowardin code (Dahl and others 2020), and then described with LLWW attributes. LLWW attributes were applied following keys developed by Lemly and others (2018) to streamline LLWW application to inland wetlands of the western U.S. Riparian NWI features were not included in the keys and LLWW attributes were not applied to these features. In practice, applying LLWW attributes involved a multi-step process:

1. "Heads-up" interpretation and digitization of 2016 NAIP imagery and other supporting data to produce NWI mapping.
2. Review of several years of imagery, geomorphic setting, and other nearby, mapped features to manually determine dominant water source, flow path, and LLWW-specific modifiers that require photointerpretation to accurately assign.
3. Automated assignment of landscape position, landform or waterbody type, and several LLWW-specific modifiers based on attribute queries.
4. Review and correction of automation outputs using "heads up" interpretation of 2016 NAIP imagery and supporting data.
5. Semi-automated assignment of several LLWW-specific modifiers based on attribute and spatial queries.
6. Compilation of all corrections and assigned LLWW-specific modifiers to complete LLWW base attributes and modifiers.
7. Complete review of NWI mapping and LLWW attribution by a second mapper.

The NWI mapping was completed following the methods and workflows described earlier in this report. Generally, manual determination of water sources, flow path, and certain LLWW-specific modifiers was completed alongside the Cowardin attribution and polygon delineation and did not affect wetland delineation or the assigned Cowardin code.

Although not part of the LLWW base attributes, information on dominant water sources serves as important breaks in the 2018 LLWW key so we assigned all mapped features one of seven water sources to allow automated assignment of LLWW base attributes using only attribute queries. We chose this approach to address the limitations of using spatial queries like buffers or intersects when determining landscape position and resulting landform types. Mappers interpreted multiple years of imagery and lidar-derived DEMs and slope data sets to identify (1) patterns of inundation or saturation, (2) changing land uses, (3) surrounding terrain and shape of mapped feature, and (4) possible relationships with other nearby mapped features. Water sources were assigned based on the geomorphic setting and imagery signatures for each mapped feature (table 5).

Irrigated features and groundwater-fed features were especially difficult to distinguish in low-lying areas of Cache Valley, and mappers relied on saturation patterns and timing across multiple years of imagery. Groundwater-fed features appeared saturated in most years of imagery with a relatively stable extent whereas irrigation-fed features were much more variable with the extent of the wet area changing drastically between years. Mappers relied on supporting spring data from the NHD and the Utah Department of Water Resources Points of Diversion to separate spring-fed features from the rest of the groundwater-fed features.

Mappers assigned flow paths to each feature by assessing the connectivity to nearby features and the direction water traveled in a feature. Features were considered connected if they were mapped contiguously to features with surface water present for at least a month during the growing season (i.e., Cowardin water regimes of C, E, F, G, or H). Mappers assumed connectivity if (1) a feature was interrupted by a road and culverts allowed surface water to flow underneath, (2) a feature was an impoundment located within a stream channel, (3) a feature was contiguous to a canal or ditch, or (4) a feature was part of a larger wetland complex that was connected to other features. All features that were considered disconnected from nearby features were assigned a vertical (VR) flow path and all connected features were assigned flow paths consistent with the western LLWW keys (Lemly and others, 2018).

Mappers manually assigned several LLWW-specific modifiers when determining water sources or flow paths. Some of these were assigned to capture other water sources influencing a feature like irrigation or artificial controls, whereas others captured wetland characteristics that are readily interpreted from imagery but difficult to automate. Some of these difficult-to-automate, LLWW-specific modifiers include land uses like pasture or mining, unique wetland types like playas or fens, and descriptions of the feature's geomorphic setting like oxbow or toe-slope. A complete list of the LLWW-specific modifiers considered for the project is included in appendix A.

Much of the LLWW attribution for each feature was automated through a series of queries based on the dominant water source, flow path, and Cowardin codes assigned during manual mapping and review. These queries replicated breaks in the western

Table 5. Water sources assigned for automating LLWW attribution.

Water Source	General Description	Geomorphic Setting	Imagery Signature	Applied To
Overbank flooding	Feature has surface water connection when nearby river or lake is flooded.	Adjacent to creeks, rivers, lakes. Features are typically flat floodplains and small depressions.	Variable and affected by location on floodplain and extent of recent flooding. Higher floodplain wetlands typically vegetated, and water absent from most images. Lower floodplain wetlands vegetated or not, water present in many or most images.	Fringe-like features, stream-bank shrub wetlands, gravel bars and shores, floodplain wetlands.
Alluvial aquifer	Feature seems to be connected to the river or lake water table–as the river and associated water table rises, feature is flooded. Direct surface connection to river rare.	On the floodplains of larger creeks, rivers, or lakes. Features are generally depressions, ponds, and basins well removed from typical flooding extent.	Surface water in ponds generally present in most images but appears to raise or lower with amount of water in nearby river or lake. Vegetated features have more robust vegetation than surrounding areas and may occasionally appear saturated or flooded.	Floodplain depressions, oxbows, areas on the floodplain not directly adjacent to the river.
Precipitation accumulation	Feature collects water from non-channelized runoff, snow melt, or is part of a stormwater system.	Topographic low points without clear surface water inputs. Features are typically shallow depressions or basins found in montane areas or isolated, excavated pits.	Variable. Montane basins usually barren with surface water present only in spring/early imagery. Low-lying areas may be vegetated or not and typically dry in most imagery.	Playas, stormwater retention ponds, flats, shallow montane depressions.
Stream flow accumulation	Feature that collects water from a stream (ephemeral to perennial) or is a flowing stream itself, includes canals.	Located within, or includes, part of a stream channel. Features are streams, rivers, canals, or basins and ponds interrupting the channel.	Channels with or without water depending on the size of the stream and timing of imagery. Basins and impoundments variously dry, drying, or flooded depending on the size of the channel feeding them and timing of imagery.	Impoundments built across the stream, lakes with an obvious inlet, reservoirs, streams, canals.
Irrigation	Feature fed by canals, diversions outside the floodplain, runoff from irrigated fields. OR Areas that have been obviously constructed and water source seems to be entirely human-controlled.	Level, agricultural areas outside or river floodplains with clear signs of canals or ditches. Features are typically flat or gently sloping fields and pastures without extensive crops. OR Excavated and constructed ponds with surface water supplied by canals or ditches.	Natural vegetation without distinct rows or lines indicating crops or plowing. Water usually present as saturation or shallow flooding; the total extent of wet area changes drastically between years of imagery and often appears wet during dry parts of the year. OR Water typically present in most images. If vegetated, usually supports dense emergent vegetation or floating algal mats typical of high-nutrient systems.	Irrigation retention ponds, irrigated pastures and fields, features collecting irrigation runoff, sewage lagoons, constructed ponds with no clear water source.
Groundwater	Features supported by groundwater emergence or shallow groundwater creating saturated conditions. Features generally lack obvious surface water inputs, are unlikely to be affected by rivers, don't exist in a distinct depression collecting surface water, and were not identified as a spring.	Topographic low areas in valley bottoms, toes and slopes of alluvial fans and deltaic deposits, bases of cliffs, terraces, and other steep slope breaks. Features are variable but generally lack obvious surface water inputs, are unlikely to be affected by rivers, and don't exist in a distinct depression collecting surface water.	Variable and depends on the amount of groundwater as well as the supported vegetation. Emergent vegetation supported by shallow groundwater typically appears saturated in spring or early summer imagery or unusually robust in later imagery but may be indistinct from surrounding uplands in other images. When wet, the total extent of wet area remains roughly similar across multiple years of imagery. Areas with greater amounts of groundwater appear saturated or flooded, or support robust vegetation in most imagery, with the total extent of the wetted area remaining similar across multiple years of imagery.	Big emergent flats, disconnected oxbows, areas downstream of springs but not obviously flooded or connected via surface water.
Spring	Groundwater-fed features identified as springs in the NHD, WRPOD, or other USFS layers.	Same as groundwater features.	Similar to groundwater-fed features, but spring-fed features usually have surface water present as pools or small rills in most years of imagery.	Spring pools, adjacent areas with surface water supplied by that spring, or single pond containing springhead.

LLWW keys and were developed to be consistent with how other organizations have applied LLWW attribution to their mapping (Lemly and others 2018). Broadly, features were (1) split into wetland and waterbodies based on Cowardin codes, (2) assigned a landscape position through a combination of dominant water source and parts of the Cowardin code, and (3) assigned a waterbody type or wetland landform based on a combination of dominant water source, parts of the Cowardin code, and presence of certain LLWW-specific modifiers. The resulting landscape position, waterbody type or wetland landform, and manually assigned flow path were combined to create an initial LLWW base attribute. Several LLWW-specific modifiers were also assigned through automated queries; some like beaver or drained are directly related to modifiers included in the Cowardin code, others like groundwater-driven or snow+rain are directly related to dominant water source, and still others like intermittent or artificial flow were assigned based on unique Cowardin codes. These automated and manually assigned LLWW-specific modifiers were compiled to create a single list of LLWW-specific modifiers for each feature.

Due to how dominant water sources were assigned, the automated queries were unable to accurately apply some parts of the LLWW attribute in certain problematic situations. Mappers corrected this problem by reviewing the initial automated attributes with GIS software and selectively correcting LLWW attributes for these features. During this review, mappers also applied a series of spatial and attribute queries to assign several additional LLWW-specific modifiers in a semi-automated approach. These LLWW-specific modifiers either had unique spatial relationships to other mapped features such as island wetlands or were mapped by supporting datasets such as the Utah Geospatial Resource Center golf course dataset or Utah Division of Oil, Gas and Mining active mines dataset. The corrected LLWW attribution and additional LLWW-specific modifiers were reprocessed through automated attributes to develop a draft LLWW base attribute and a full list of applied LLWW-specific modifiers.

Draft LLWW attribution was reviewed alongside NWI mapping in a single review consistent with USFWS review guidelines (Dahl and others, 2020). All features mapped with LLWW attributes were reviewed by another UGS mapper familiar with the LLWW and NWI workflows who suggested revisions to the draft LLWW attributes and LLWW-specific modifiers based on consistency with the western LLWW key and project-specific mapping conventions. The primary mapper revised their draft mapping based on the reviewer's comments, recompiled the LLWW attribution and LLWW-specific modifiers to a final LLWW base attribute and complete list of LLWW-specific modifiers, and created a final wetland mapping dataset with Cowardin codes and LLWW attribution.

LLWW Conventions

Several project-specific conventions were developed to help mappers consistently apply LLWW-specific modifiers, identify dominant water sources and resulting landscape positions, and apply similar LLWW attributes to similar features.

Waterbodies vs. wetlands

- The LLWW system distinguishes two types of features—waterbodies with near-permanent surface water and wetlands with non-permanent water or dense vegetation—and applies different LLWW attributes and modifiers to each. We defined waterbodies based on these Cowardin codes: all R4SB, R2UB, R3RB features, L2UB and L1UB features with F, G, H, K regimes, and PUB or PAB features with F, G, H, K regimes. Linear, vegetated channels mapped as PEM1A, PEM1C, or PEM1F that functioned as flowing channels were also considered waterbodies and generally mapped with a Stream waterbody type.

Irrigation

- Features where irrigation was the dominant water source were attributed with a TE landscape position and the ir modifier.
- Features affected but not dominated by irrigation were attributed according to the dominant water source and the ir modifier applied to track the irrigation influence.
- Field and pasture wetlands dominated by irrigation were mapped as slope wetlands with a TE landscape position. The flow path for these features was determined by their relationship to mapped, adjacent canals. Features between two canals were considered throughflow (TH) flow path, features below a canal were considered an inflow (IN) flow path, and features separated from any mapped canal were considered a vertical (VR) flow path.

Floodplains

- The extent of the geomorphic floodplain was determined through review of the Utah State University Valley Bottoms dataset and several lidar-derived DEMs.

- Mappers assigned LO landscape positions to a subset of features located on the geomorphic floodplain based on whether a feature was likely to receive overbank flooding 1 out of 5 years or was connected to the alluvial aquifer.
- Features separated from overbank flooding by berms, elevated roads, or built-up basins were assigned a TE landscape position.
- The gf modifier was not applied to features with a LO landscape position.

Artificial channels and canals

- Four types of human-modified channels were identified with the LLWW attribution:
  - ditches and canals constructed by excavating uplands or new channels are mapped as LOST5TH with the ag, ar, and ex modifiers;
  - natural channels being used as irrigation ditches were mapped as LOST_TH with the ag, ch, and ir modifiers;
  - natural channels that have been excavated or straightened were mapped as LOST_TH with the ch and ex modifiers; and
  - natural channels receiving irrigation water were mapped as LOST_TH with the ir modifier.

Mixed groundwater and irrigation water sources

Shallow groundwater exists throughout low-lying areas of Cache Valley, but historical agricultural improvement efforts have built networks of ditches, drains, and wells to capture this shallow groundwater and redistribute it elsewhere in the valley as irrigation. These efforts have created wetlands significantly affected by both groundwater and irrigation. However, mappers assigned these mixed hydrology wetlands a single dominant water source to consistently assign flow paths and modifiers, as well as maintain consistency with other mapping organizations. Mappers took the following approach to consistently identify and attribute these mixed hydrology wetlands:

- Groundwater features
  - Identification: near mapped springs or known groundwater discharge areas, strong, stable saturation signatures in several years of imagery, appropriate geomorphic setting such as toe slopes, alluvial fans, or "headwaters" of canal network, or upgradient of expected flow from a canal.
  - Cowardin code: usually vegetated (PEM, PSS, or PFO) with water regimes including a saturation component (B, D, E). The drained, excavated or farmed (d, x, f) modifiers were sometimes applied, and the impounded modifier (h) was never applied.
  - LLWW attribute: feature was always mapped with a TE landscape position with an outflow (OU) or VR flow path depending on connectivity to nearby canals or streams. The gw modifier was always applied and the ir, ds, hf, or other modifiers were applied if appropriate.
- Irrigation features
  - Identification: adjacent to mapped canals and ditches, variable and weak saturation signals across several years of imagery, appropriate geomorphic setting such as flat, agricultural areas, or downgradient of expected flow from a canal.
  - Cowardin code: usually dominated by emergent vegetation (PEM) with water regimes lacking any saturation component (A, C, F). The drained modifier (d) was never applied, but the excavated, farmed, or impounded modifiers (x, f, h) were applied if appropriate.
  - LLWW attribute: feature was always mapped with a TE landscape position and a TH or inflow (IN) flow path depending on how adjacent canals were mapped. The ir modifier was always applied, and the gw or ds modifiers never applied.

Lotic wetland flow paths

Drier, vegetated wetlands with an LO landscape position were typically mapped with a Floodplain (FP) landform and TH flow path, but distal, dry, vegetated wetlands affected more by alluvial aquifer fluctuations were mapped with a Basin (BA) landform and a VR flow path. Mappers used the following approach to distinguish these features:

- Lotic floodplain throughflow
  - Adjacent to the main river, located on flat areas without distinct depression, isolated wetlands.

- Lotic basin vertical
  - Adjacent to pond, oxbow, or depressional features with VR flow paths, located within obvious depression, disconnected from main channel if flooded in imagery.

Beaver complex landscape positions

Beaver complexes were mapped with either LO or TE landscape positions depending on the dominant water source, with beaver complexes along flowing streams mapped with an LO landscape position and beaver complexes near mapped springs, above flowing streams, or with abnormal amounts of water were assumed to be groundwater-fed and mapped with a TE landscape position.

Modifiers

LLWW-specific modifier conventions were developed to limit attribute redundancy, consistently apply modifiers, and more accurately describe features.

- Forty percent rule
  - Some modifiers were evaluated through spatial selections with supporting datasets and were applied if at least 40% of the feature was within the boundary of the supporting dataset.
- Discharge to stream
  - The discharge to stream (ds) modifier was only applied to OU flow path features directly adjacent to streams, canals, lakes, and ponds or to groundwater and spring-fed features with VR flow paths adjacent to temporary stream features.
- Toe slope
  - The toeslope (ts) modifier was considered broadly and only applied to areas where the slope change was visible at 1:5,000 scale.
- Pond-fringe
  - The pond fringe (pd) modifier was only applied to Fringe (FR) landform features that existed as relatively narrow bands along pond or lake features.
- Distinguishing between agriculture, hayfield, and grazed
  - The agriculture, hayfield, and grazed (ag, hf, and gz) modifiers were applied to describe wetlands used for agricultural and livestock purposes and only one of these three modifiers was applied to a feature;
  - ag was used to identify wetlands altered or created for crop and livestock production such as center pivots, irrigation retention ponds, or stock tanks;
  - hf was used to identify wetlands used as livestock pasture or hayfields where cattle or signs of mowing could be seen in some years of imagery; and
  - gz was used to identify wetlands with visible grazing impacts such as patches of bare ground, trampling, or water flowing over bare ground

WETLAND FUNCTION MODELS

Wetlands are uncommon features in the project area and throughout Utah, occupying roughly five to eight percent of the total landscape (UGS, 2022). Despite their rarity, wetlands disproportionally benefit Utah's plants, wildlife, and human populations by providing a wide variety of ecosystem functions such as unique habitats, filtering sediments from runoff, or contributing to stream base flows. Individual wetlands provide varying types of functions and degrees to which they provide those functions; the suite and level of functions is provided by a given wetland largely controlled by biotic and abiotic factors intrinsic to that wetland (Brinson, 1993). Biotic factors such as vegetation height, vegetation type, or extent of human disturbance greatly affect habitat functions, whereas abiotic factors such as the shape, geomorphic setting, and connectivity to other water sources greatly affect several of the physical functions. Additionally, wetlands with similar characteristics provide similar types and degrees of function. For instance, wetlands located on a floodplain are all likely to provide some level of floodwater attenuation.

Increasingly, local communities and land-managers have recognized the value of wetland functions and have prioritized conservation, management, and restoration of high-functioning or potentially high-functioning wetlands. This prioritization has created a need for spatial data depicting wetland functions across the landscape to support watershed planning, wetland loss evaluations, or mitigation efforts. We attempted to fill this data need by modeling wetland functions across our project area using our updated mapping to create a dataset that not only depicts the distribution and extent of wetlands, but also identifies which wetlands are likely to provide a given function and how likely it is to perform that function.

Methods

Wetlands provide a diverse array of functions, and the value of those functions is highly dependent on management objectives. The UGS surveyed Utah stakeholders to identify which functions would be most valuable for their work and reviewed approaches taken by other regional mapping organizations to develop a list of functions to model (table 6). Additional conversations with USFWS botanists highlighted a need to identify wetlands that provide habitat for the federally threatened Ute ladies'-tresses.

The UGS developed function models following methods established by Marshall and others (2018) that utilize a series of spatial and attribute queries to identify wetlands' distinctive shapes, locations, or vegetation that are likely to provide a certain function. The models rely heavily on both the Cowardin and LLWW attributes included in the updated mapping but also make use of several supporting datasets to evaluate slope, elevation, topographic wetness index (a measure of how likely a given area is to accumulate surface runoff), and extent of human disturbance at each wetland. The slope, elevation, and topographic wetness index datasets were all derived from a 10-meter-resolution DEM. The extent of human disturbance was determined using landscape integrity models that calculate disturbance scores based on proximity to known aquatic habitat stressors (Menuz, 2015).

Table 6. *UGS modeled wetland functions.*

Function	CNHP Model	Function Type	Supporting Data	General Features
Bank and Shoreline Stabilization	Bank and Shoreline	Physical		Woody wetlands and other wetlands adjacent to streams and rivers
Carbon Sequestration	Carbon Sequestration	Physical	Disturbance	Beaver complexes, fens, and other minimally disturbed vegetated wetlands
Sediment and Particulate Retention	Sediment Capture and Retention	Physical	Slope	Beaver ponds, lakes, ponds, basins and vegetated wetlands on floodplains, isolated wetlands adjacent to streams, rivers, or other waterbodies
Streamflow Maintenance	Streamflow Maintenance	Physical		Headwater wetlands connected to streams and rivers, groundwater-dependent wetlands adjacent to streams and rivers, isolated wetlands on floodplains
Aquatic Invertebrate Habitat	Aquatic Invertebrate	Habitat	Disturbance	Minimally disturbed wetlands with seasonal flooding and temporarily flooded basins
Shorebird Habitat	Shorebird Habitat	Habitat	Disturbance	Minimally disturbed saline ponds, playas and lakes, shorelines and unvegetated floodplains, dry playas, and irrigated fields
Waterfowl and Water Bird Habitat	Waterfowl Habitat	Habitat	Disturbance	Lakes, ponds, herbaceous wetlands with seasonal flooding and moderate disturbance
Surface Water Detention	Flood Attenuation	Physical	Slope, Wetness Index	Isolated wetlands likely to accumulate surface runoff, ponds, floodplain wetlands, isolated headwater wetlands adjacent to streams
Ute Ladies'-tresses Habitat	Not Modeled	Habitat	Elevation	Groundwater-fed meadows, riverine and lentic floodplains, margins of ponds or flooded oxbows

The function models identified wetlands likely to provide functions listed in table 6 and categorized the likelihood they would provide that function. We followed the categorization approach developed by Marshall and others (2018) and identified features having a "High" or "Moderate" likelihood where wetlands with a High likelihood had either optimal conditions or were well documented as providing a function. Moderate was used to describe wetlands that had the potential to provide a particular function but were limited by some characteristic like nearby disturbance or lack of woody vegetation. The approach intentionally excludes a "Low" category; wetlands not assigned as High or Moderate are either unlikely or unknown to provide a particular function.

Colorado Natural Heritage Program Models

All but one of the functions listed in table 6 were included in the CNHP LLWW mapping and function modeling effort (Marshall and others, 2018), which involved substantial research into functions provided by certain types of wetlands and the development of detailed crosswalks linking Cowardin and LLWW attributes to wetlands likely to provide a particular function (appendix B). The general types of wetlands associated with individual functions are identified in table 6. This CNHP effort produced a series of spatial and attribute queries that could be applied to wetland mapping enhanced with LLWW attributes to identify wetlands providing particular functions and assign a High or Moderate likelihood of providing that function. We revised the CNHP queries to fit our database schema and better reflect disturbance, slope, and wetness index thresholds present in our project area and applied those queries to our updated mapping through a series of GIS models. These models were not applied to riparian NWI features as many models relied heavily on LLWW attributes and could not be consistently applied to features lacking LLWW attributes.

Model outputs were assigned scores ranging from 0 to 2 based on the model outputs, with High likelihood wetlands receiving a 2, Moderate likelihood wetlands receiving a 1, and all other wetlands receiving a 0. Scoring for the sediment and particulate retention model differed slightly as the model identified wetlands likely to intercept sediments during average high flows, historic high flows, and during both types of flows; these were respectively scored as 1, 2, and 3.

We then evaluated spatial patterns within the model outputs using a hotspot analysis to identify distinct clusters with locally high or low densities of wetlands and waterbodies likely to provide certain functions. The sum of the model scores was calculated for each wetland polygon for (1) all CNHP models, (2) physical models, and (3) habitat models, excepting Ute ladies'-tresses. Individual wetland scores were aggregated into a 1-square-kilometer grid derived from the project area and average scores for all CNHP models, physical models, and habitat models were calculated for each cell in the grid. We supplied this grid to a hotspot analysis (Getis-Ord Gi statistic) in ArcPro 2.9 defining the spatial neighborhood for the analysis as all eight adjacent cells, corrected for spatial dependency, and calculated Getis-Ord Gi statistics for all three average scores.

Ute ladies'-tresses

Ute ladies'-tresses is a rare orchid found throughout the western U.S. in wet meadows and other herbaceous-dominated wetland and riparian habitats. The species is listed as Threatened under the Endangered Species Act (ESA) and is a species of concern for federal, state, and local management agencies, particularly the USFWS which manages ESA-listed species and recommends consideration of impacts and intensive presence/absence surveys for projects that may affect potential habitat for the species. The USFWS recently developed a model of potential habitat that considers, among many other parameters, subsets of the NWI mapping when defining potential habitat. The USFWS model identifies potential habitat across the species' range and is known to locally overestimate the extent of potential habitat. This is particularly true in Cache County where the model identifies much of Cache Valley as potential habitat. We built a model using our revised NWI mapping with enhanced attribution to identify wetlands having a High or Moderate likelihood of supporting Ute ladies'-tresses in Cache County. We hoped this model would provide a narrower sense of habitat than the USFWS model and be more useful for locating new occurrences, land use management, and conservation planning.

We reviewed USFWS survey guidelines, species status reviews, and recent, local survey reports to identify species-specific habitat requirements and categorize wetlands likely to support Ute ladies'-tresses into four broad types: groundwater-fed meadows, riverine terraces, lentic terraces, and perimeter features like ponds or semi-permanently flooded oxbows where individuals could exist in the saturated margins (USFWS, 1992; Fertig and others, 2005). We identified habitat constraints from the same literature review and removed wetlands from consideration in the model based on the following constraints: saline soils, dense invasive *Phragmites australis* ssp. *australis* (Phragmites), dense salt cedar (*Tamarix* sp.), farmed wetlands, artificial sewage lagoons, intermittent and flashy water regimes, and elevations above 7000 ft (USFWS, 1992; Fertig, 2005; Cirrus, 2021).

We followed an approach similar to the CNHP models and identified wetlands and riparian areas likely to support Ute ladies'-tresses and categorized their likelihood to support the species as High or Moderate based on our literature review and conversations with USFWS botanists. Wetlands were considered to have a High likelihood of supporting the species if the wetlands matched habitat descriptions or were documented as potential habitat in the literature review. Wetlands were considered to have a Moderate likelihood of supporting individuals if wetlands matched habitat descriptions or were documented as potential habitat, but one or more characteristics known to negatively impact the species were present (e.g., intensive grazing, high canopy cover, excavation, or past disturbance).

We reviewed the model by validating outputs with occurrence data obtained from the USFWS and Utah Natural Heritage Program (UNHP). Occurrence data obtained from USFWS and UNHP consisted of point data depicting both occurrences and individuals throughout Cache County. UGS mappers grouped the occurrence data into four general populations based on proximity and best professional judgment to account for differences in scale between the datasets and better assess the model across the project area.

We also validated the model through a "heads-up" spatial review to evaluate consistency and coherence of the output and by conducting a hotspot analysis similar to that conducted for the CNHP models. We assigned scores from 0 to 2 based on the model outputs, with High likelihood wetlands receiving a 2, Moderate likelihood wetlands receiving a 1, and all other wetlands receiving a 0. Individual wetland scores were aggregated into a 1-km^2 grid derived from the project area and average scores for Ute ladies'-tress habitat likelihood calculated for each cell in the grid. We supplied this grid to a hotspot analysis (Getis-Ord Gi statistic) in ArcPro 2.9 defining the spatial neighborhood for the analysis as all eight adjacent cells, corrected for spatial dependency, and calculated Getis-Ord Gi statistics for this average value.

Results

Colorado Natural Heritage Program Models

The CNHP models were applied to all wetlands in the project area and identified roughly 75% of all mapped wetland features and about 83% of all mapped wetland area as providing some level and variety of function (table 7). Wetlands not identified as providing any of the modeled functions were predominantly intermittent channels, artificial canals and ditches, or small, isolated features; of these non-identified wetlands roughly 65% were intermittent channels or artificial canals. Most (66%) wetland features provided at least one physical function and fewer (39%) provided at least one unique habitat function, with sediment and particulate retention and surface water detention being the most common functions by feature. By mapped wetland area, most wetlands provided at least one physical function (67%) and at least one modeled habitat (57%), with sediment and particulate retention and shorebird habitats being the most common functions by area.

The distribution of modeled functions within the project area showed distinct clustering of high-functioning wetlands (figures 2, 3, and 4) as "hot spots" within the project area with significant, locally high scores for all CNHP-modeled functions,

Table 7. *Summary of mapped wetland features and acres identified by CNHP-based models.*

Function	Wetland Features				Wetland Acreage			
	Count	Percent Total	Percent High	Percent Moderate	Sum	Percent Total	Percent High	Percent Moderate
Bank and Shoreline Stabilization	1618	20.1	2.7	17.5	4589	18.2	1.1	17.1
Carbon Sequestration	1324	16.5	4.3	12.1	1762	7.0	0.7	6.3
Sediment and Particulate Retention	3839	47.8	2.6	30.4	14,265	56.6	1.6	34.0
Streamflow Maintenance	1882	23.4	3.4	20.1	5575	22.1	0.9	21.2
Aquatic Invertebrate Habitat	2696	33.6	11.1	22.4	10,378	41.2	6.2	35.0
Shorebird Habitat	1792	22.3	18.4	3.9	11,916	47.3	38.3	9.0
Waterfowl and Water Bird Habitat	1564	19.5	12.5	7.0	9066	36.0	34.2	1.8
Surface Water Detention	3173	39.5	7.8	31.7	5139	20.4	2.7	17.7
Any Physical	5284	65.8	-	-	16,811	66.7	-	-
Any Habitat	3114	38.8	-	-	14,286	56.7	-	-
Both Physical and Habitat	2296	28.6	-	-	10,201	40.5	-	-
Any Function	6102	76.0	-	-	20,895	83.0	-	-

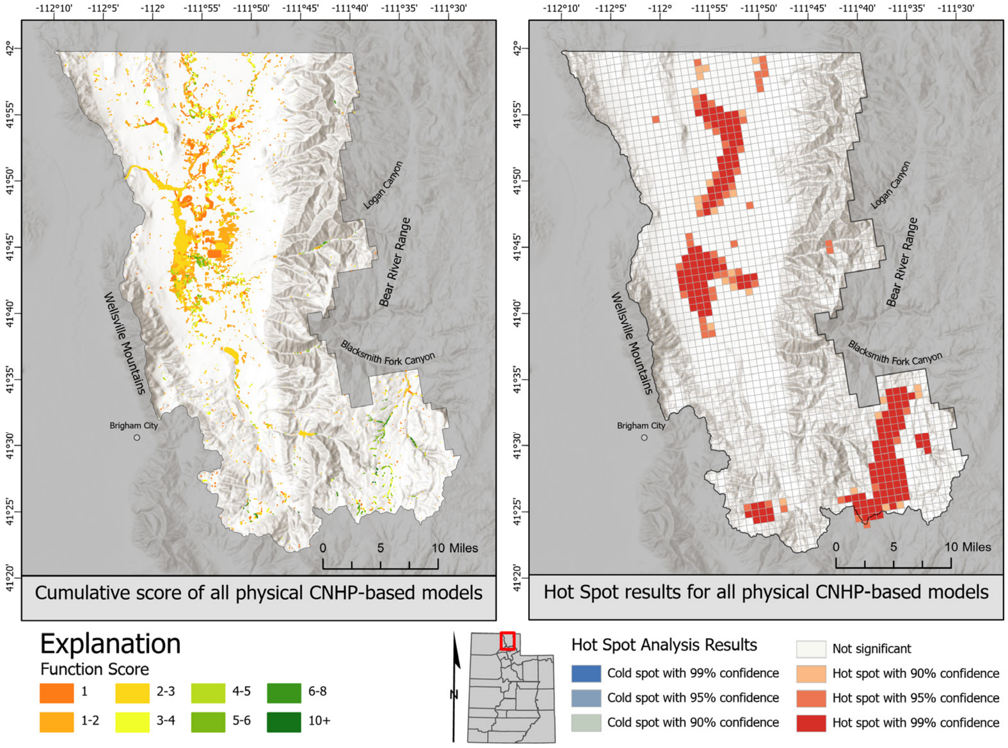

Figure 2. *Cumulative score and hot spot analysis for all wetlands identified as providing physical functions by the Colorado Natural Heritage Program (CNHP)-based models. Cumulative scores calculated for each wetland as the sum of each individual physical function model score. Wetlands unlikely to provide any physical function (cumulative score of zero) are not shown. Hot spot analysis based on 1-km grid with values representing the average cumulative score for all wetlands within each cell. Hot or cold spots indicate cells with significantly higher or lower scores relative to neighboring cells.*

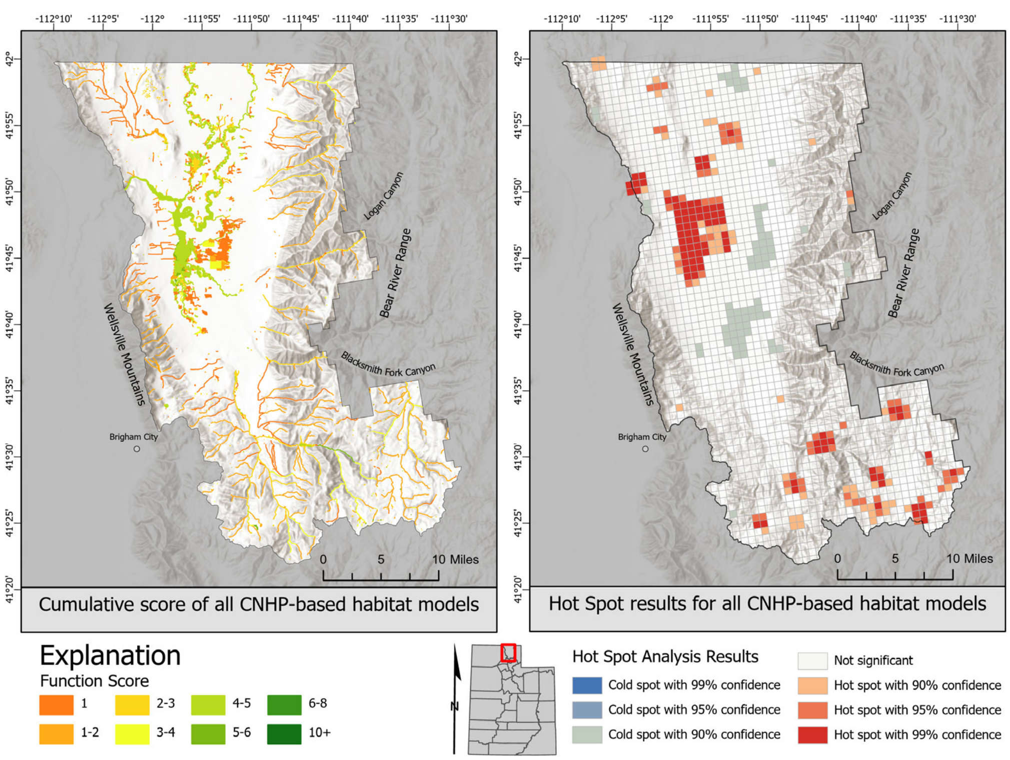

Figure 3. *Cumulative score and hot spot analysis for all wetlands identified as providing habitat functions by the Colorado Natural Heritage Program (CNHP)-based models. Cumulative scores calculated for each wetland as the sum of each individual habitat function model score. Wetlands unlikely to provide any habitat function (cumulative score of zero) are not shown. Hot spot analysis based on 1-km grid with values representing the average cumulative score for all wetlands within each cell. Hot or cold spots indicate cells with significantly higher or lower scores relative to neighboring cells.*

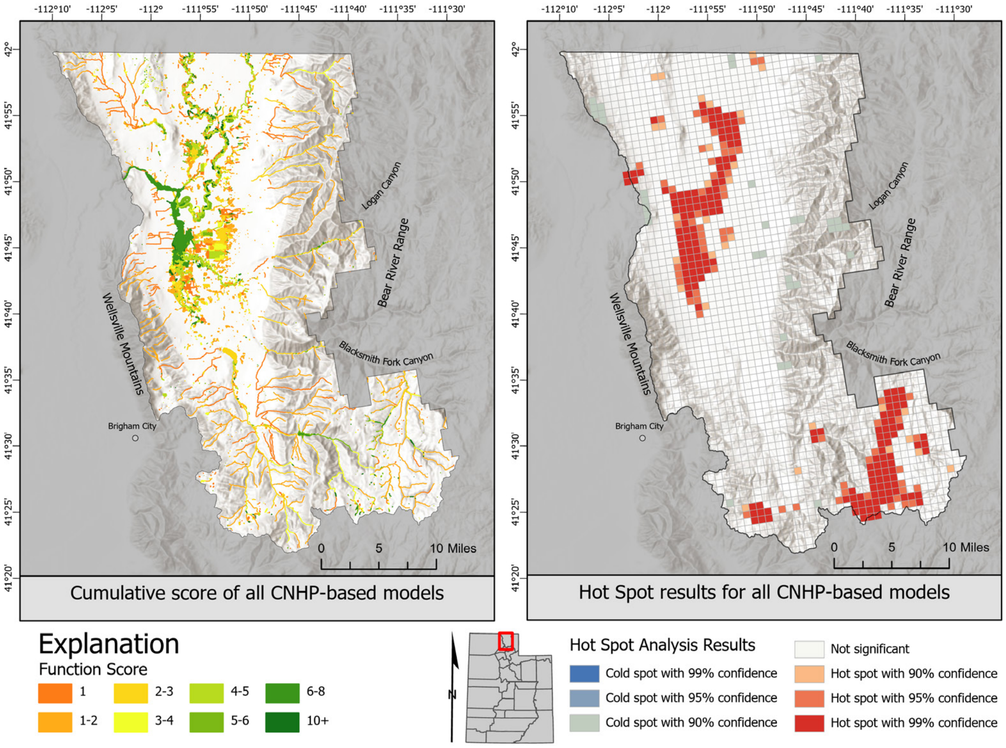

Figure 4. *Cumulative score and hot spot analysis for all wetlands identified as providing any function by the Colorado Natural Heritage Program (CNHP)-based models. Cumulative scores calculated for each wetland as the sum of each individual function model score. Wetlands unlikely to provide any function (cumulative score of zero) are not shown. Hot spot analysis based on 1-km grid with values representing the average cumulative score for all wetlands within each cell. Hot or cold spots indicate cells with significantly higher or lower scores relative to neighboring cells.*

physical functions, and unique habitats. These high-functioning hot spots include Cutler Reservoir; headwaters of the Little Bear and Blacksmith Fork Rivers; confluence of the Little Bear River, Logan River, and Cutler Reservoir and surrounding marshes; wet meadows and fields near the Logan Airport parts of Clarkston Creek and Newton Reservoir; and parts of the Bear River floodplain. Physical function models displayed additional hot spots of high-functioning wetlands in areas of the Logan River floodplain, and the entirety of the Bear River floodplain. Habitat models displayed additional clustering of high-function wetlands in the Amalga Barrens, near Davenport and Miles Creeks, and Porcupine Reservoir.

Ute ladies'-tresses

The Ute ladies'-tresses habitat model was applied to all riparian and wetland mapping and identified roughly 75% of all features and mapped areas as likely to provide habitat for the species (table 8). Non-habitat features were typically above 7000 feet elevation, intermittent channels, or outlying riparian habitats lacking a stream bank. The model identified features in each of the four habitat types with riverine terraces being most common (30%). Few lentic terrace features were identified (0.5%). By mapped area, perimeter features were the most common habitat type identified by the model (39%). For each individual habitat type and for all habitats combined, the model identified most features and mapped areas as highly likely to provide habitat for the species, except for riverine terraces where most features were identified as moderate.

Four hundred and fifty-six of the 1377 Ute ladies'-tresses occurrence points (roughly 33%) were directly in or within 20 feet of mapped wetlands or riparian areas. The remaining 921 occurrence points were located within 20 to 200 feet of mapped features. A single, general population accounted for 1371 of the occurrences, which was partly captured by the updated mapping. The remaining six occurrences belong to the three other general populations, of which two were fully captured by the updated mapping and the last was entirely unmapped.

All 456 occurrences captured by the mapping were within 20 feet of just five mapped wetlands, all of which were identified by the model as likely to provide Ute ladies'-tresses habitat. Four of these features were identified as Groundwater Meadows that were highly likely to provide habitat and the final feature was a canal identified as a Perimeter Feature that was moderately likely to provide habitat. The 921 occurrences not captured by the mapping were located within irrigated hayfields that appeared consistently mowed in imagery but were not consistently saturated to justify mapping as a wetland.

Manual review found the model grouped similar wetland types into consistent Ute ladies'-tresses habitats and excluded wetlands unlikely to provide habitat (figure 5). These unlikely habitats typically were features constructed for sewage treatment or intermittent channels, but also included dense Phragmites areas along the Cutler Reservoir and distal riparian areas of several floodplains throughout Cache Valley. The model identified likely habitat-providing wetlands throughout the project area, but the majority were located within Cache Valley along the Cutler Reservoir, surrounding groundwater emergence areas, and floodplains of major rivers.

The hotspot analysis shows significant clustering of wetland and riparian areas that were more likely to provide Ute ladies'-tresses habitat in central parts of Cache Valley, in a rough band of hot spots extending from the confluence of Davenport Creek and the South Fork of the Little Bear River north to the floodplains of the Bear and Cub Rivers as they flow into Utah (figure 5). An additional cluster of High-likelihood features was identified around Clarkston Creek and Newton Reservoir. The hotspot analysis also showed significant clustering of wetland and riparian areas that were unlikely to provide Ute ladies'-tresses habitat. These "cold spots" were in montane regions of the project area including parts of the Wasatch and Bear River Ranges and the Wellsville Mountains and closely correspond to the 7000-foot-elevation threshold used to exclude features from the model.

Table 8. *Summary of mapped wetland and riparian features and acres identified by the Ute ladies'-tresses habitat model.*

Habitat Types	Wetland and Riparian Features				Wetland and Riparian Acreage			
	Count	Percent Total	Percent High	Percent Moderate	Sum	Percent Total	Percent High	Percent Moderate
Groundwater Meadow	1868	20.1	15.5	4.6	6618	22.8	21.7	1.1
River Terrace	2797	30.0	13.0	17.0	6342	21.8	12.6	9.2
Perimeter Feature	2434	26.1	19.0	7.1	11,257	38.8	33.3	5.4
Lentic Terrace	51	0.5	0.5	0.1	203	0.7	0.7	0.0
All Habitats	7151	76.8	48.0	28.7	24,421	84.1	68.3	15.7

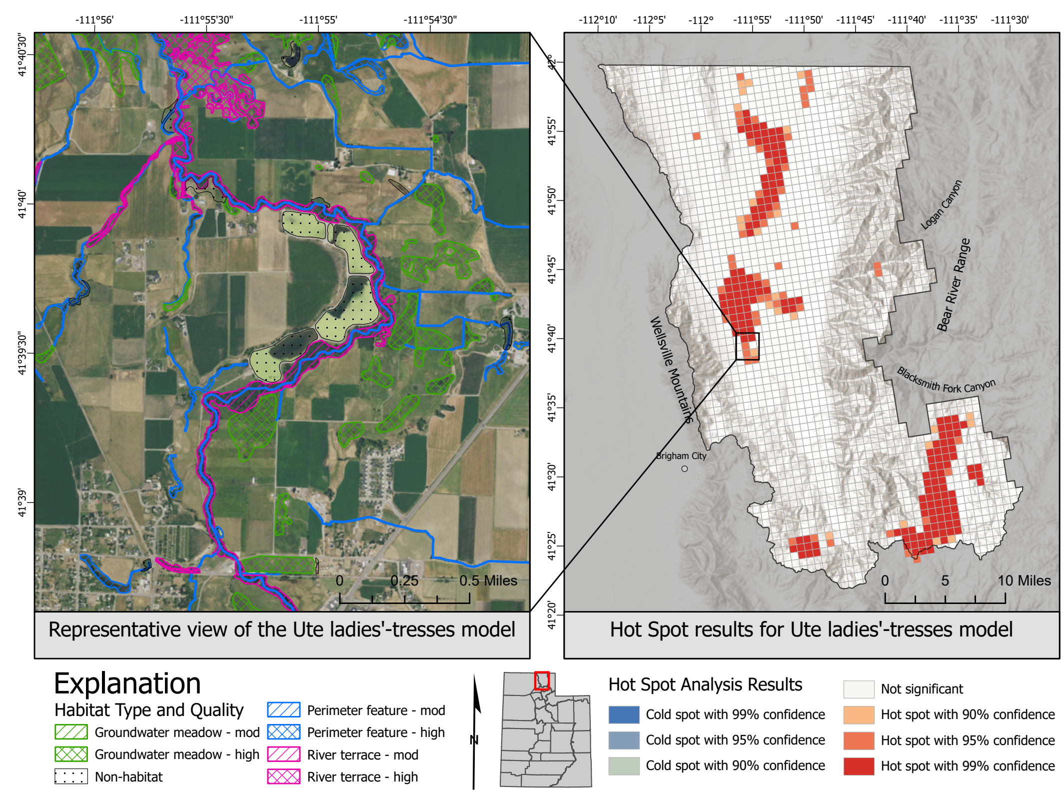

Figure 5. *Cumulative score and hot spot analysis for all wetlands identified as providing any function by the Colorado Natural Heritage Program (CNHP)-based models. Cumulative scores calculated for each wetland as the sum of each individual function model score. Wetlands unlikely to provide any function (cumulative score of zero) are not shown. Hot spot analysis based on 1-km grid with values representing the average cumulative score for all wetlands within each cell. Hot or cold spots indicate cells with significantly higher or lower scores relative to neighboring cells.*

Discussion and Recommendations

We applied a series of models to our updated mapping to identify wetlands and riparian areas likely to provide certain functions throughout the project area. These models were largely based on attribute queries developed by the CNHP as part of their LLWW pilot mapping project and relied heavily on literature reviews and best professional judgment to link unique wetland attributes to characteristics indicating the likelihood of providing particular functions (table 7; Marshall and others, 2018). Based on our results, we found most of the model outputs passed a "laugh test" review by other wetland specialists and identified features that could reasonably provide certain functions: vegetated wetlands capable of accumulating carbon, depressional features on floodplains that could store and detain floodwaters, etc. None of the models performed perfectly with all reviewers noting areas that should or should not have been identified by each model. Reviewers generally had less concerns about the physical models compared to the habitat models, likely due to (1) complications with disturbance thresholds, (2) problems inherent in modeling habitat across broad categories, and (3) reviewer expertise.

All CNHP-based habitat models incorporated disturbance thresholds to select wetlands with low to moderate levels of disturbance as likely to provide modeled habitat. Disturbance thresholds affected the models by (1) creating threshold selection artifacts where two similar, nearby wetlands were differently identified as habitat or non-habitat based on distances to unobvious disturbances, (2) disproportionately identifying habitat in the outlying foothill and montane regions as the bulk of disturbances are centered in Cache Valley, and (3) incorporating disturbances that might affect downstream wetland hydrology. The landscape integrity models we used to develop disturbance thresholds are based on disturbance models used by the CNHP but differ slightly by including hydrology-specific disturbances such as canals, impoundments, and irrigation when calculating overall disturbance; these hydrology-specific disturbances may not affect a wetland's ability to provide habitat, particularly if the disturbances occur downgradient.

The CNHP-based habitat models were organized into broad wildlife categories which required the models to identify habitat-providing wetlands based on broad generalizations of habitat requirements. This resulted in several wetlands being identified as highly likely despite reviewers agreeing they were marginally likely to provide habitat. However, none of the reviewers have wildlife ecology backgrounds and generally had low confidence in their ability to accurately assess the success or shortcomings of the CNHP-based habitat models.

Reviewers generally rated the Ute ladies'-tresses habitat model performance as similar to the CNHP-based habitat models. Reviews found the Ute ladies'-tresses habitat model to consistently identify habitat types and wetlands likely to provide habitat, but also noted the model seemed overly inclusive with over 75% of all mapped features identified as likely habitat. This inclusivity stems from two sources: Ute ladies'-tresses can occupy a broad variety of wetland types and exist in small patches of habitat well below our mapping threshold, and information on wetlands likely to support the species was developed largely from USFWS clearance survey guidelines intended to capture all possible potential habitats. Conversations with USFWS botanists confirmed that habitat models for the species generally overestimate habitat extents for similar reasons. Those conversations also identified a need for assessing more than if a wetland contains suitable habitat for the species. A model that assessed whether the species would be likely to occur within a wetland given factors such as dispersal limitations and habitat stability would be more useful in planning wetland restorations, species recovery efforts, and targeting new surveys. Such a model should consider connectivity to permanent streams or other stable water sources, historical land uses, and distance to other known populations.

The Ute ladies'-tresses habitat model successfully identified all mapped wetlands containing known occurrences as likely providing habitat, but not all occurrences were within mapped wetlands, highlighting an issue common to all function models. The models only evaluate functions within mapped features; unmapped areas may also provide several of these functions and care should be taken to avoid interpreting the model results as the only places on the landscape providing a given function. This is particularly true for the CNHP-based models which exclude riparian mapping from consideration, despite riparian areas being well documented as stabilizing riverbanks, providing wildlife habitat, and filtering sediments, amongst other functions. Another issue common to all these models is lack of validation. These models have largely been developed and applied through GIS exercises and, though based on research and supported by common sense reviews, field surveys or other location-specific data have not been used to validate individual models.

We recommend validating the models through field surveys directly assessing model outputs or through other data collected during field surveys such as the Utah Rapid Assessment Protocol (McCoy and others, 2021), BLM Lentic Assessment and Inventory and Monitoring (Reynolds and others, 2022), or other surveys that include functional assessments. Based on the results of that validation, the models may need revision to improve their accuracy (1) in identifying features likely to provide certain functions and (2) assessing the likelihood of providing that function. Model accuracy may also be improved by revising the landscape integrity models to better reflect disturbance at a particular wetland. Review of the CNHP habitat models by wildlife professionals may identify other ways to improve the accuracy of those models.

The CNHP-based function models are limited to wetland features mapped with LLWW attributes and are unable to identify mapped riparian areas as likely to provide certain functions, despite literature concluding that these areas provide similar function. Wetland ecologists with EMMA have begun developing keys to standardize application of LLWW attributes to riparian features, and we recommend using those keys to apply LLWW attributes to mapped riparian areas within the project area and revise the function models to better capture parts of the landscape providing beneficial functions.

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APPENDICES

APPENDIX A

LANDSCAPE POSITION, LANDFORM, WATER FLOW PATH, AND WATERBODY TYPE ATTRIBUTES

Overview

The Cowardin wetland classification scheme used by National Wetland Inventory (NWI) has become the standard way to describe wetlands, but it was developed for use with coarse aerial imagery and only considers vegetation, hydroperiod, and a few human-use modifiers. As such, it lacks key pieces of information useful in a wetland dataset—whether the wetland is on a floodplain, the general shape, position or connection to other features, and how water might move through the feature. These pieces of information are needed to properly classify a wetland according to the Hydrogeomorphic (HGM) system used by the U.S. Army Corps of Engineers (USACE) or gauge the likely functions provided by a certain wetland. The Landscape Position, Landform, Water Flow Path, and Waterbody Type (LLWW) system was developed to supplement the Cowardin mapping and allows mapping to be crosswalked to HGM classes as well as allow function modeling. The LLWW system considers three aspects of a feature—landscape position, waterbody type or landform, and flow path—that are identified with coded attributes and aggregated into a six- to seven-digit base code. The LLWW system also includes an expanded list of modifiers to better describe impacts, hydrology, and unique wetland characteristics. All applicable LLWW-specific modifiers are included as a list following the base code. This appendix describes each of the coded attributes applicable to Utah, all applicable LLWW-specific modifiers, and their general application.

Landscape Position

All features are assigned a landscape position based on their relationship to other features and their position on the landscape. For example, a temporarily flooded meadow adjacent to a big river receiving floodwaters would be assigned a different landscape position than a temporarily flooded meadow located in a small, montane depression that collects snowmelt. Three possible landscape positions are applicable to the western U.S. (table A1).

Waterbody Type and Landform

The LLWW system has two sets of codes to describe feature type, one for waterbodies (Waterbody Type) and another for wetlands (Landform). Some waterbody types or landforms identified were not applied in Cache Valley, but all are applicable to the western U.S. (table A2).

Flow path

Flow paths are used to describe how water moves through a feature and how connected that feature is to other nearby features. Features are considered connected if they are adjacent to features with surface water present for a least a month during the growing season. Six possible flow paths are applicable to the western U.S. (table A3).

LLWW-specific modifiers

The LLWW system has a much greater set of modifiers than the Cowardin system which are used to describe human disturbances, water sources, landforms, and specific wetland types. Multiple LLWW-specific modifiers can be applied to a single feature and 56 LLWW-specific modifiers are applicable to the western U.S. (table A4).

Table A1. *Landscape positions used in LLWW attribution.*

Landscape Position	Code	Description
Lotic	LO	Rivers and channels, impoundments, lakes, stream-fed ponds and basins, floodplains and features connected to the alluvial aquifer.
Lentic	LE	Features connected to lakes or affected by the rising and lowering of lake levels including features like shorelines, fringe wetlands, and occasionally flooded areas at the upstream end of impoundments.
Terrene	TE	Features that are wholly surrounded by uplands, isolated, artificially created or irrigated, fed by precipitation accumulation, collect sheet flows, or are groundwater and spring-fed.

Table A2. *Waterbody types and landforms used in LLWW attribution.*

Type	Code	Description
Waterbody Types		
Permanent stream	ST1	Stream with flowing water generally year-round
Seasonal stream	ST2	Stream with flowing water for at least one month throughout the growing season
Temporary stream	ST3	Stream with flowing water for short periods during most years
Intermittent stream	ST4	Stream with occasional flows following rainstorms and precipitation events
Artificial	ST5	Ditch or canal constructed in uplands
River	R1	River with flowing water generally year-round
Pond	PD	Waterbody with still, generally permanent water that is less than 20 acres
Lake	LK	Waterbody with still, generally permanent water that is greater than 20 acres
Landforms		
Basin	BA	Distinct depression
Floodplain	FP	Flat areas near streams or rivers supported by alluvial aquifers or inundated by floodwaters every 1 to 5 years
Fringe	FR	Wetlands occurring along the banks of streams, rivers, or ponds that are generally permanently saturated or flooded
Flat	FL	Flat areas fed only by precipitation with less than 2 percent slopes
Slope	SL	Sloped areas fed by groundwater, irrigation, sheet flow or other water sources with slopes greater than 2 percent.

Table A3. *Flow paths used in LLWW attribution.*

Flow path	Code	Description	General Application
Throughflow	TH	Water flows through the waterbody, even if interrupted by small impoundments (e.g., impounded ponds along a stream channel); waterbody is not a lake with periodic raising or lowering of lake levels	Rivers, ditches, regularly flooded wetlands, impoundments along intermittent channels, river shores, irrigated fields
Throughflow-bidirectional	TB	Water flow is through a lake where residence time of water is generally longer and accompanied by periodic raising or lowering of lake levels; this often occurs in large dammed or excavated lakes or lakes situated in historical floodplains that are now separated by manmade or natural levees	Large, dammed lakes, wetlands near streams along lake bottoms
Outflow	OU	Water flows out of the waterbody via a river, stream, or ditch, with little or no observable surface water inflow (inflow could be from ephemeral drainages, non-channelized inputs of snowmelt, precipitation, local surface runoff, or groundwater discharge); waterbody serves as a source for surface water	Headwater ponds, discharging slope wetlands and other groundwater-fed or spring-fed wetlands
Inflow	IN	Water flow enters via a river, stream, ditch, or is pumped in, but does not exit the pond, lake, or reservoir (outflow could be through ephemeral drainages or groundwater discharge); waterbody serves as a sink for surface water	Terminal sinks or ponds
Bidirectional	BI	Waterbody is a large, isolated lake and water levels fluctuate due to both rising and falling lake levels and wind-driven wave action	Isolated lakes or ponds, lake shores along large impoundments, ponds regularly flooded by lake fluctuations
Vertical	VR	Waterbody is a pond or small isolated lake; water levels rise as the pond or lake fills with precipitation, surface runoff, and/or groundwater discharge and lowers as water is evaporated or lost to groundwater seepage; wave action is rare or nonexistent. This can apply to Lotic or Lentic Ponds that lack a dominant surface water connection with a stream or lake but are driven by fluctuation in the aquifer	Floodplain ponds, ponds fed by intermittent channels, irrigation ponds, other disconnected features

Table A4. *LLWW-specific modifiers used in LLWW attribution, adapted from Lemly and others (2018).*

Modifier	Code	Description
agriculture	ag	Waterbody or wetland used for agricultural purposes, such as crop production or livestock watering.
alpine	al	Waterbody or wetland is located above treeline
aquaculture	aq	Waterbody or wetland used for aquaculture
artificial flow	ar	Hydrologic regime is artificial, typically controlled through ditches or pumps or hydrologic connectivity is regulated by water control structures (e.g., diked/impounded wetlands along streams)
augmented flow	au	Hydrologic regime is augmented by large trans-mountain or trans-basin diversions of water
arroyo	ay	Temporary or ephemeral stream in an arid region
burn area	ba	Waterbody or wetland is located within a burn area perimeter
bog	bg	Wetland (or waterbody within a wetland) is peat-accumulating, has the minimum required organic soil depth to qualify as a peatland (40 cm in the upper 80), and saturation is maintained by precipitation
beetle kill forest	bk	Waterbody or wetland is located within a beetle kill area
beaver	bv	Waterbody or wetland formed or influenced by beaver activity
channelized	ch	River or stream has been artificially straightened or redirected or deeply incised from excess erosion
partially drained	dr	Waterbody or wetland is partially drained
discharge to stream channel	ds	Wetland contributes to streamflow (e.g., sloped wetland adjacent to the stream or within a stream valley)
excavated	ex	Waterbody or wetland is excavated
floating mat	fm	Floating mat of vegetation extending into or over open water; can be used for the vegetation itself and the waterbody containing the vegetation
fen	fn	Wetland (or waterbody within a wetland) is peat-accumulating, has the minimum required organic soil depth to qualify as a peatland (40 cm in the upper 80), and saturation is maintained by groundwater discharge
flashy	fs	Hydrologic regime is considered flashy, or surface-runoff dominated, with high variability in the occurrence and magnitude of peak flow events; levels are often rainfall-driven and unpredictable; includes waterbodies in catchments with shallow soil and/or bedrock that are prone to flash flooding, as well as urbanized catchments with a high amount of impervious surfaces
geomorphic floodplain	gf	Waterbody or wetland is located within a geomorphic floodplain (up to the approximate 100-year floodplain boundary), even if fed by water sources outside the floodplain
glacial	gl	Waterbody or wetland is located within a historical or current glacial landscape
golf	go	Waterbody or wetland is located within a golf course
gravel	gr	Waterbody or wetland is excavated or impounded for mining of sand or gravel
groundwater-driven	gw	Hydrologic regime is primarily groundwater-driven, such that levels are predictable and dominated by stable groundwater inflow for most (if not all) of the year
grazed	gz	Wetland shows obvious signs of intensive grazing by livestock or native ungulates
hayfield	hf	Wetland is managed as a hay field and/or pasture with grass cover
hot-spring	hs	Waterbody or wetland is influenced by a geothermal spring (can be warm to hot)
headwater	hw	Waterbody or wetland is located in the upper reaches of a watershed and often the source of a stream network
hydropower	hy	River, stream, or lake is dammed for hydropower generation
interdunal	id	Waterbody or wetland located within a dune field
island	il	Waterbody or wetland located on land completely surrounded by water within either a lake, pond, or stream (not formed by ditches that encircle the wetland)
impounded	im	Waterbody or wetland is impounded
irrigation-influenced	ir	Hydrologic regime is strongly influenced by irrigation, either direct application or seepage
temporary-intermittent flow	it	Hydrologic regime is temporarily intermittent or ephemeral (including inflow driven by short duration precipitation event, including monsoonal events). Cowardin water regimes of A or J.
kettle	kt	Lake, pond, or wetland located within a formerly glaciated landscape (but not in the Prairie Pothole region) and formed by ice blocks left by retreating glaciers
locked and dammed	ld	Channelized river with a series of locks and dams to aid navigation
logged	lg	Waterbody or wetland is subject to or within the perimeter of recent timber harvest area, particularly clear-cutting or other large-scale timber harvests

Table A4. *LLWW-specific modifiers used in LLWW attribution, adapted from Lemly and others (2018).*

Modifier	**Code**	**Description**
mineral	ml	Wetland is composed of mineral soils, within an emphasis on mineral soil flats rather than any mineral soil wetland
mining	mm	Waterbody or wetland is excavated or impounded for mining of coal or hard rock (e.g., quarry pond or pond to capture mining waste)
mire	mr	Wetland has accumulation of peat, but not of sufficient depth to qualify as a bog or fen; often interspersed with, or along the margins of a bog or fen
oxbow	ox	Lake, pond, or wetland located in a distinct depression within the floodplain of a river or stream, including recently active oxbows and meander scars
pond fringe	pd	Wetland formed along the shore of a pond
permafrost	pf	Waterbody or wetland is located on permafrost
playa	pl	Shallow lake, pond, or wetland with fluctuating water levels depending on local precipitation patterns and extent of groundwater connection; typically with no natural outlet; can be saline or not
prairie pothole	pp	Lake, pond, or wetland located within the formerly glaciated Prairie Pothole region; water sources include direct precipitation, runoff from surrounding areas, and groundwater; generally associated with Quaternary glacial deposits such as moraines, glacial valleys, and outwash plains
restoration site	re	Waterbody or wetland has been modified by known restoration or enhancement activities (e.g., earthwork, planting, vegetation removal, beaver re-introductions, etc.); requires site-specific data to apply
regulated flow	rf	Hydrologic regime is regulated by dam(s) or diversion(s) upstream, such that the flow regime has been substantially altered in terms of the timing, frequency, magnitude, and duration of peak and low flows
rainfall	rn	Hydrologic regime, including mean annual flow and peak flows, is primarily driven by rainfall
run of river dammed	rr	River or stream section with low dam(s) allowing flow during high water periods; often used for low-head hydropower generation or irrigation diversion(s)
saline	sa	Lake, pond, or wetland that occurs on saline soil, often with obvious salt crust visible
spring-fed	sf	Hydrologic regime includes inputs from a natural spring
seepage lake	sl	Lake dominated by inputs from surface runoff, groundwater seepage and precipitation; may be subject to seasonal water level fluctuation; typically with no natural inlet or outlet
snowmelt	sn	Hydrologic regime, including mean annual flow and peak flows, is primarily driven by snowmelt
snow + rain	sr	Hydrologic regime, including mean annual flow and peak flows, is driven by a mixture of snowmelt and rainfall
stream valley	sv	Slope wetland located in a narrow valley
stormwater	sw	Waterbody or wetland is used to detain or retain stormwater runoff
toe-of-slope	ts	Slope wetland located at the base of a hill or slope
wildlife management	wm	Waterbody or wetland is managed for wildlife (e.g., waterfowl habitat); includes the management of water levels
wastewater	ww	Waterbody or wetland is used for wastewater retention and/or treatment (e.g., oil and gas, domestic)

APPENDIX B

COLORADO NATURAL HERITAGE PROGRAM FUNCTION MODELS AUTOMATED QUERIES AND SUPPORTING INFORMATION

Content from Colorado River Watershed Planning Toolbox, used with permission from Sarah Marshall, 2021.

APPENDIX C: GEOSPATIAL DATA PROCESSING AND QUERIES FOR LIKELY WETLAND FUNCTIONS

Data Preparation

- Attribute NWI wetland dataset with Landscape, Landform, Water Flow Path, Waterbody (LLWW) and associated modifiers (see Appendix A)
- Calculate Geometry in Acres
- Zonal Statistics as a Table (mean only) for Elevation, Slope, LDI
- Join all three tables and bring in the values
- Feature to Point to get centroids for small polygons that are missed with Zonal Statistics, enforce that point is inside, delete fields to make table simpler
- Extract Values to Points for Elevation, Slope, LDI
- Join those tables to bring over the point values

Notes

- Appendix B provides supporting information used to generate geospatial data queries.
- Please see Classification of Wetlands and Deepwater Habitats of the United States for definitions of vegetation types, water regimes and other National Wetland Inventory codes used in the GIS queries (FGDC 2013).
- Interpreting Landscape Disturbance Index (LDI) scores:
    - LDI <= 250 = low landscape disturbance
    - 250 > LDI <=500 = moderate landscape disturbance
    - LDI >= 500 = high landscape disturbance

Habitat Functions

Conservation of Biodiversity

<u>Rare species and ecosystems, high integrity landscape (Biodiv_Fn = 1)</u>

Rare EORs (buffered) with LDI <= 250 (excludes streams and impounded lakes)

- *Select by Location, Select features from:* Target [Wetland Layer], Source [EORs (Not S4, S5) selected]. Spatial selection method: Intersect the source layer feature. Apply a search distance of 10 m.
- *Select by Attribute, Select from current selection:* AveLDI <= 250
- *Select by Attribute, Remove from current selection:* LLWW_Waterbody LIKE 'ST%' OR (LLWW_Waterbody LIKE 'LK%' AND im = 'im')
    - *Assign Biodiv_Fn = 1 to selected features*

Rare wetland types with LDI <= 250 (excludes streams and impounded lakes)

- *Select by Attribute, Create a new selection:* AveLDI <= 250 AND (al = 'al' OR fm = 'fm' OR fn = 'fn' OR kt = 'kt' OR pl = 'pl' AND sf = 'sf') AND Biodiv_Fn IS NULL
    - *Assign Biodiv_Fn = 1 to selected features*

<u>*Rare species and ecosystems, moderate integrity landscape (Biodiv_Fn = 2)*</u>

Rare EORs (buffered) with LDI <= 500 (excludes streams and impounded lakes)

- *Select by Location, Select features from:* Target [Wetland Layer], Source [EORs (Not S4, S5) selected]. Spatial selection method: Intersect the source layer feature. Apply a search distance of 10 m.
- *Select by Attribute, Select from current selection:* AveLDI <= 500 AND Biodiv_Fn IS NULL
- *Select by Attribute, Remove from current selection:* LLWW_Waterbody LIKE 'ST%' OR (LLWW_Waterbody LIKE 'LK%' AND im = 'im')
    - *Assign Biodiv_Fn = 2 to selected features*

Rare wetland types with LDI <= 500 (not streams or impounded lakes)

- *Select by Attribute, Create a new selection:* AveLDI <= 500 AND (al = 'al' OR fm = 'fm' OR fn = 'fn' OR kt = 'kt' OR pl = 'pl' AND sf = 'sf') AND Biodiv_Fn IS NULL
    - *Assign Biodiv_Fn = 2 to selected features*

<u>*Rare species and ecosystems, low integrity landscape (Biodiv_Fn = 3)*</u>

Rare EORs (buffered) with LDI > 500 (excludes streams and impounded lakes)

- *Select by Location, Select features from:* Target [Wetland Layer], Source [EORs (Not S4, S5 selected]. Spatial selection method: Intersect the source layer feature.
- *Select by Attribute, Select from current selection:* Biodiv_Fn IS NULL
- *Select by Attribute, Remove from current selection:* LLWW_Waterbody LIKE 'ST%' OR (LLWW_Waterbody LIKE 'LK%' AND im = 'im') *Assign Biodiv_Fn = 1 to selected features*
    - *Assign Biodiv_Fn = 3 to selected features*

Rare wetland types with LDI >500 (excludes streams and impounded lakes)

- *Select by Attribute, Create a new selection:* (al = 'al' OR fm = 'fm' OR fn = 'fn' OR kt = 'kt' OR pl = 'pl' AND sf = 'sf') AND Biodiv_Fn IS NULL
    - *Assign Biodiv_Fn = 3 to selected features*

High biodiversity support, high integrity landscape (Biodiv_Fn = 4)

Common EORs with LDI <= 250 (excludes streams and impounded lakes)

- *Select by Location, Select features from:* Target [Wetland Layer], Source [EORs]. Spatial selection method: Intersect the source layer feature. Apply a search distance of 10 m.
- *Select by Attribute, Select from current selection:* AveLDI <= 250 AND Biodiv_Fn IS NULL
- *Select by Attribute, Remove from current selection:* LLWW_Waterbody LIKE 'ST%' OR (LLWW_Waterbody LIKE 'LK%' AND im = 'im')
    - *Assign Biodiv_Fn = 4 to selected features*

Wetland types with high general biodiversity and LDI <= 250 (excludes streams and impounded lakes)

- *Select by Attribute, Create a new selection:* ((bv = 'bv' OR fp = 'fp' OR mr = 'mr' OR hw = 'hw') AND rf IS NULL) AND AveLDI <=250 AND Biodiv_Fn IS NULL
- *Select by Attribute, Remove from current selection:* LLWW_Waterbody LIKE 'ST%' OR (LLWW_Waterbody LIKE 'LK%' AND im = 'im')
    - *Assign Biodiv_Fn = 4 to selected features*

High biodiversity support, moderate integrity landscape (Biodiv_Fn = 5)

Common EORs with LDI <= 500 (excludes streams and impounded lakes)

- *Select by Location, Select features from:* Target [Wetland Layer], Source [EORs]. Spatial selection method: Intersect the source layer feature. Apply a search distance of 10 m.
- *Select by Attribute, Select from current selection:* AveLDI <= 500 AND Biodiv_Fn IS NULL
- *Select by Attribute, Remove from current selection:* LLWW_Waterbody LIKE 'ST%' OR (LLWW_Waterbody LIKE 'LK%' AND im = 'im')
    - *Assign Biodiv_Fn = 5 to selected features*

Wetland types with high general biodiversity and LDI <= 500 (excludes streams and impounded lakes)

- *Select by Attribute, Create a new selection:* ((bv = 'bv' OR fp = 'fp' OR mr = 'mr' OR hw = 'hw') AND rf IS NULL) AND AveLDI <=500 AND Biodiv_Fn IS NULL
- *Select by Attribute, Remove from current selection:* LLWW_Waterbody LIKE 'ST%' OR (LLWW_Waterbody LIKE 'LK%' AND im = 'im')
    - *Assign Biodiv_Fn = 5 to selected features*

High biodiversity support, low integrity landscape (Biodiv_Fn = 6)

Common EORs with LDI >500 (excludes streams and impounded lakes)

- *Select by Location, Select features from:* Target [Wetland Layer], Source [EORs]. Spatial selection method: Intersect the source layer feature. Apply a search distance of 10 m.

- *Select by Attribute, Select from current selection:* Biodiv_Fn IS NULL
- *Select by Attribute, Remove from current selection:* LLWW_Waterbody LIKE 'ST%' OR (LLWW_Waterbody LIKE 'LK%' AND im = 'im')
    - *Assign Biodiv_Fn = 6 to selected features*

Wetland types with high general biodiversity and LDI >500 (excludes streams and impounded lakes)

- *Select by Attribute, Create a new selection:* ((bv = 'bv' OR fp = 'fp' OR mr = 'mr' OR hw = 'hw') AND rf IS NULL) AND Biodiv_Fn IS NULL
- *Select by Attribute, Remove from current selection:* LLWW_Waterbody LIKE 'ST%' OR (LLWW_Waterbody LIKE 'LK%' AND im = 'im')
    - *Assign Biodiv_Fn = 6 to selected features*

Aquatic Invertebrate Habitat

High potential to provide aquatic invertebrate habitat (AqInvrt_Fn = 1)

- *Select by Attribute, Create a new selection:* Hydro IN ('C', 'D', 'E', 'F', 'G', 'H') AND rf IS NULL AND mi IS NULL AND AveLDI <= 250
    - *Assign AqInvrt_Fn = 1 to selected features*

Moderate potential to provide aquatic invertebrate habitat (AqInvrt_Fn = 2)

- *Select by Attribute, Create a new selection:* Hydro IN ('C', 'D', 'E', 'F', 'G', 'H') AND mi IS NULL AND AveLDI <= 500 AND AqInvert_Fn IS NULL
    - *Assign AqInvrt_Fn = 2 to selected features*
- *Select by Attribute, Create a new selection:* LLWW_Landform = 'BA' AND Hydro = 'A' AND AqInvert_Fn IS NULL
    - *Assign AqInvrt_Fn = 2 to selected features*

Shorebird Habitat

High potential to provide shorebird habitat (Shrbird_Fn = 1)

- *Select by Attribute, Create a new selection:* (pl = 'pl' OR ((LLWW_Landform = 'BA' OR LLWW_Waterbody IN ('PD', 'LK')) AND sa = 'sa')) AND Hydro IN ('C', 'F') AND AveLDI <= 500
    - *Assign Shrbird_Fn = 1 to selected features*
- *Select by Attribute, Create a new selection:* (LLWW_Landform = 'BA' OR LLWW_Waterbody = 'PD') AND Class IN ('AB', 'EM1') AND AveLDI <= 500
    - *Assign Shrbird_Fn = 1 to selected features*
- *Select by Attribute, Create a new selection:* ((LLWW_Landscape = 'LE' AND LLWW_Landform IN ('FP', 'FR')) OR (Class IN ('US', 'UB') AND (LLWW_Landform = 'FR' OR il = ‘il’)) OR (LLWW_Landscape = 'LO' AND Class = 'US')) AND AveLDI <= 500
    - *Assign Shrbird_Fn = 1 to selected features*

- *Select by Attribute, Create a new selection:* LLWW_Waterbody = 'LK'
- *Select by Location, Select features from:* Target [Wetland Layer, select from selected features], Source [Wetland Layer with LLWW_Waterbody = 'LK' selected]. Spatial selection method: Intersect the source layer feature. Apply a search distance of 50 m.
- Select by Attribute, Remove from current selection: Class IN ('SS1', 'FO', 'FO1', 'FO4')
    - *Assign Shrbird_Fn = 1 to selected features*

Moderate potential to provide shorebird habitat (Shrbird_Fn = 2)

- *Select by Attribute, Create a new selection:* (((pl = 'pl' OR LLWW_Landform = 'BA') AND Hydro IN ('A', 'J')) OR (Class = 'EM1' AND LLWW_Landform = 'SL' AND ir = 'ir'))) AND AveLDI <= 500 AND Shrbird_Fn IS NULL
    - *Assign Shrbird_Fn = 2 to selected features*

Waterfowl Habitat

High potential to provide waterfowl habitat (Wfowl_Fn = 1)

- *Select by Attribute, Create a new selection:* ((Class = 'EM1' AND Hydro IN ('C', 'E', 'F', 'G', 'H') AND Acres >= 2) OR LLWW_Waterbody IN ('PD', 'LK')) AND AveLDI <= 500
    - *Assign Wfowl_Fn = 1 to selected features*

Moderate potential to provide waterfowl habitat (Wfowl_Fn = 2)

- *Select by Attribute, Create a new selection:* Class = 'EM1' AND Hydro IN ('C', 'E', 'F', 'G', 'H') AND Acres >= 0.25 AND Acres < 2) AND AveLDI <= 500
    - *Assign Wfowl_Fn = 2 to selected features*

Water Quality and Biogeochemical Functions

Nitrogen Uptake and Transformation

High potential to provide N functions (WQN_Fn = 1)

- *Select by Attribute, Create a new selection:* LLWW_Landscape = 'TE' AND LLWW_Landform = 'SL' AND fp = 'fp'
    - *Assign WQN_Fn = 1 to selected features*
- *Select by Attribute, Create a new selection:* LLWW_Landscape = 'TE' AND (LLWW_Landform = 'BA' OR LLWW_Waterbody = 'PD') AND Class IN ('AB', 'EM1') AND WQN_Fn IS NULL
    - *Assign WQN_Fn = 1 to selected features*
- *Select by Attribute, Create a new selection:* (bv = 'bv' OR (fp = 'fp' AND (LLWW_Landform = 'BA' OR LLWW_Waterbody = 'PD'))) AND WQN_Fn IS NULL
    - *Assign WQN_Fn = 1 to selected features*

Moderate potential to provide N functions (WQN_Fn = 2)

- *Select by Attribute, Create a new selection:* LLWW_Landscape = 'LO' AND LLWW_Landform IN ('FP', 'FR') AND LLWW_Flowpath IN ('IN', 'TH') AND Class IN ('EM1', 'SS1', 'FO', 'FO1', 'FO4', 'US') AND WQN_Fn IS NULL
    - *Assign WQN_Fn = 2 to selected features*

Phosphorus Removal and Storage

High potential to provide P functions (WQP_Fn = 1)

- *Select by Attribute, Create a new selection:* LLWW_Landscape = 'TE' AND (LLWW_Landform = 'BA' OR LLWW_Waterbody = 'PD') AND LLWW_Flowpath IN ('VR', 'IN') AND Class IN ('AB', 'EM1')
    - *Assign WQP_Fn = 1 to selected features*
- *Select by Attribute, Create a new selection:* fn = 'fn' AND dr IS NULL AND WQP_Fn IS NULL
    - *Assign WQP_Fn = 1 to selected features*

Moderate potential to provide P functions (WQP_Fn = 2):

- *Select by Attribute, Create a new selection:* LLWW_Landscape = 'LO' AND (LLWW_Landform = 'BA' OR LLWW_Waterbody = 'PD') AND LLWW_Flowpath IN ('TH', 'IN') AND Class IN ('AB', 'EM1') AND WQP_Fn IS NULL
    - *Assign WQP_Fn = 2 to selected features*
- *Select by Attribute, Create a new selection:* Sed_FnHiQ = 1 OR Sed_FnAvgQ = 1
    - *Assign WQP_Fn = 2 to selected features*

Metal Removal and Storage

High potential to provide metal removal and storage functions (Metal_Fn = 1)

- *Select by Attribute, Create a new selection:* fn = 'fn' AND dr IS NULL
    - *Assign Metal_Fn = 1 to selected features*
- *Select by Attribute, Create a new selection:* (LLWW_Landform = 'BA' OR LLWW_Waterbody = 'PD') AND Hydro IN ('C', 'E', 'F', 'G', 'H') AND Class <> 'US' AND Metal_Fn IS NULL
    - *Assign Metal_Fn = 1 to selected features*

Moderate potential to provide metal removal and storage functions (Metal_Fn = 2)

- *Select by Attribute, Create a new selection:* mr = 'mr' AND Metal_Fn IS NULL
    - *Assign Metal_Fn = 2 to selected features*
- *Select by Attribute, Create a new selection:* LLWW_Landform = 'BA' AND Hydro = 'A' AND Metal_Fn IS NULL
    - *Assign Metal_Fn = 2 to selected features*
- *Select by Attribute, Create a new selection:* LLWW_Landscape = 'LO' AND LLWW_Landform = 'BA' AND LLWW_Flowpath IN ('IN', 'TH') AND Class IN ('EM1', 'SS1', 'FO', 'FO1', 'FO4', 'US') AND Metal_Fn IS NULL
    - *Assign Metal_Fn = 2 to selected features*

Carbon Sequestration and Storage

High potential to provide C functions (CStore_Fn = 1)

- *Select by Attribute, Create a new selection:* fn = 'fn' AND AveLDI <= 250
  - *Assign CStore_Fn = 1 to selected features*
- *Select by Attribute, Create a new selection:* bv = 'bv' AND CStore_Fn IS NULL
  - *Assign CStore_Fn = 1 to selected features*

Moderate potential to provide C functions (CStore_Fn = 2)

- System = 'P' AND AveLDI <= 250 AND CStor_Fn IS NULL
  - *Assign CStore_Fn = 2 to selected features*

Temperature Regulation

High potential to provide temperature regulation function (TempR_Fn = 1)

- *Select by Attribute, Create a new selection:* (hw = 'hw' OR sn = 'sn') AND (LLWW_Flowpath IN ('OU', 'TH') OR sd = 'sd')
- *Select by Attribute, Remove from current selection:* LLWW_Waterbody LIKE 'ST%'
  - *Assign TempR_Fn = 1 to selected features*
- *Select by Attribute, Create a new selection:* (fn = 'fn' OR gw = 'gw') AND (LLWW_Flowpath IN ('OU', 'TH') OR sd = 'sd') AND TempR_Fn IS NULL
- *Select by Attribute, Remove from current selection:* Hydro = 'X' (specific to South Platte dataset)
  - *Assign TempR_Fn = 1 to selected features*
- *Select by Location, Select features from:* Target [Wetland Layer], Source [NDHFlowlines_Perenn_Intermit]. Spatial selection method: Intersect the source layer feature. Apply a search distance: 10 m.
  - *Assign TempR_Fn = 1 to selected features*
- *Select by Attribute, Select from current selection:* fp = 'fp' AND Class LIKE 'FO%' AND TempR_Fn IS NULL
  - *Assign TempR_Fn = 1 to selected features*

Moderate potential to provide temperature regulation function (TempR_Fn = 2)

- *Select by Attribute, Create a new selection:* Class IN ('FO', 'FO1', 'FO4', 'SS1') AND (LLWW_Landscape = 'LO' OR (LLWW_Landscape IN ('LE', 'TE') AND Hydro IN ('C', 'E', 'F', 'G', 'H'))) AND TempR_Fn IS NULL
  - *Assign TempR_Fn = 2 to selected features*

Water Quantity and Geomorphic Functions

Surface Water Storage

High (permanent or semi-permanent) storage *(H2OStor_Fn = 1)*

- *Select by Attribute, Create a new selection:* (LLWW_Waterbody = 'LK' AND Hydro IN ('F', 'G', 'H')) OR (LLWW_Waterbody = 'PD' AND Hydro IN ('G', 'H'))
    - *Assign H20Stor_Fn = 1 to selected features*

Moderate (seasonal) surface water storage *(H2OStor_Fn = 2): Wetlands that may or may not frequently store and delay water.*

- (System LIKE 'L%' AND Hydro IN ('A', 'C', 'E')) OR ((LLWW_Landform = 'BA' OR LLWW_Waterbody = 'PD') AND Hydro IN ('C', 'E', 'F'))
    - *Assign H20Stor_Fn = 2 to selected features*

Flood Attenuation

High flood attenuation potential (FloodAt_Fn = 1).

- *Select by Attribute, Create a new selection:* LLWW_Landscape = 'TE' AND (LLWW_Landform = 'BA' OR LLWW_Landform = 'SL') AND AveSlope <= 2 AND TPI <=2.5 AND Hydro IN ('A', 'B', 'C', 'E', 'J')
    - *Assign FlootAt_Fn = 1 to selected features*
- *Select by Attribute, Create a new selection:* fp = 'fp' AND (LLWW_Landform IN ('BA', 'FP') OR (LLWW_Waterbody = 'PD' AND ex IS NULL AND im IS NULL)) AND Class IN ('SS1', 'FO', 'FO1', 'FO4') AND Hydro IN ('A', 'B', 'C', 'E', 'F', 'J')
    - *Assign FlootAt_Fn = 1 to selected features*

Moderate flood attenuation potential (FloodAt_Fn = 2):

- *Select by Attribute, Create a new selection:* (fp = 'fp' AND (LLWW_Landform IN ('BA', 'FP')) OR LLWW_Waterbody = 'PD' OR bv = 'bv') AND FloodAt_Fn IS NULL
    - *Assign FlootAt_Fn = 2 to selected features*
- *Select by Attribute, Create a new selection:* LLWW_Landscape = 'TE' AND hw = 'hw' AND LLWW_Flowpath IN ('OU', 'TH') AND Class IN ('EM1', 'FO', 'FO1', 'FO4', 'SS1') AND AveSlope <= 2 AND FloodAt_Fn IS NULL
    - *Assign FlootAt_Fn = 2 to selected features*

Sediment Capture and Retention

Frequent Sediment Accumulation *(Sed_FnAvgQ = 1)**:** Wetlands that are most likely to intercept and accumulate sediment on a frequent basis (e.g., <1-2 yr recurrence interval events, such as surface runoff from bare ground during precipitation).*

- *Select by Attribute, Create a new selection:* bv = 'bv'
    - *Assign Sed_FnAvgQ = 1 to selected features*

- *Select by Attribute, Create a new selection:* fp = 'fp' AND (LLWW_Landform IN ('BA', 'FR') OR LLWW_Waterbody = 'PD') AND Class IN ('EM1', 'SS1', 'FO', 'FO1', 'FO4', 'US') AND Sed_FNAvgQ IS NULL
    - *Assign Sed_FnAvgQ = 1 to selected features*
- *Select by Attribute, Create a new selection:* LLWW_Landscape = 'TE' AND LLWW_Flowpath IN ('OU', 'TH') AND Class IN ('EM1', 'SS1') AND (LLWW_Landform = 'BA' OR AveSlope <= 2) AND Sed_FnAvgQ IS NULL
    - *Assign Sed_FnAvgQ = 1 to selected features*
- *Select by Attribute, Create a new selection:* (LLWW_Waterbody IN ('LK', 'PD') OR im = 'im') AND Sed_FnAvgQ IS NULL
    - *Assign Sed_FnAvgQ = 1 to selected features*

Storm and Large Geomorphic Disturbance Event Accumulation *(Sed_FnHiQ = 1): Wetlands that may or may not frequently accumulate sediment, but are capable of storing sediment during monsoons, floods, and other >2 yr recurrence interval events.*

- *Select by Attribute, Create a new selection:* fp = 'fp' AND (LLWW_Landform = 'BA' OR (LLWW_Waterbody = 'PD' AND im IS NULL))
    - *Assign Sed_FnHiQ = 1 to selected features*
- *Select by Attribute, Create a new selection:* fp = 'fp' AND LLWW_Landform = 'FP' AND Class IN ('SS1', 'FO', 'FO1', 'FO4') AND Sed_FnHiQ IS NULL
    - *Assign Sed_FnHiQ = 1 to selected features*

For combined field (Sed_Fn): *Sed_FnAvgQ = 1 → 1, Sed_FnHiQ = 1 → 2, Both field = 1 → 3*

Streamflow Maintenance

High potential to maintain base flows (BaseQ_Fn = 1)

- *Select by Attribute, Create a new selection:* (hw = 'hw' AND (LLWW_Flowpath = 'OU' OR sd = 'sd')) AND Hydro IN ('B', 'C', 'D', 'E', 'F', 'G', 'H')
    - *Assign BaseQ_Fn = 1 to selected features*
- *Select by Attribute, Create a new selection*: fn = 'fn' AND dr IS NULL AND LLWW_Flowpath <> 'VR' AND BaseQ_Fn IS NULL
    - *Assign BaseQ_Fn = 1 to selected features*

Moderate potential to maintain base flows (BaseQ_Fn = 2)

- *Select by Attribute, Create a new selection:* bv = 'bv' AND LLWW_Flowpath <> 'VR' AND BaseQ_Fn IS NULL
    - *Assign BaseQ_Fn = 2 to selected features*
- *Select by Attribute, Create a new selection:* LLWW_Landform = 'SL' AND (LLWW_Flowpath = 'OU' OR sd = 'sd') AND Hydro IN ('B', 'C', 'D', 'E', 'F', 'G', 'H') AND BaseQ_Fn IS NULL
    - *Assign BaseQ_Fn = 2 to selected features*
- *Select by Attribute, Create a new selection:* LLWW_Landform = 'SL' AND LLWW_Flowpath <> 'VR' AND fp = 'fp' AND ir IS NULL AND Hydro IN ('B', 'C', 'D', 'E', 'F', 'G', 'H') AND BaseQ_Fn IS NULL
    - *Assign BaseQ_Fn = 2 to selected features*

Groundwater Recharge

Recharge of the alluvial aquifer (GWRech_Fn = 1)

- *Select by Attribute, Create a new selection:* bv = 'bv'
  - *Assign GWRech_Fn = 1 to selected features*
- *Select by Location, Select features from:* Target [Wetland Layer], Source [Alluvial Aquifer]. Spatial selection method: Intersect the source layer feature.
- *Select by Attribute, Remove from current selection:* LLWW_Waterbody LIKE 'ST%' OR GWRech_Fn IS NOT NULL
- *Select by Attribute, Remove from current selection:* Hydro = 'X' (specific to South Platte dataset)
  - *Assign GWRech_Fn = 1 to selected features*

Recharge of non-alluvial groundwater (GWRech_Fn = 2)

- *Select by Attribute, Create a new selection:* LLWW_Landscape = 'TE' AND (LLWW_Landform = 'BA' OR LLWW_Waterbody IN ('LK', 'PD')) AND LLWW_Flowpath = 'VR' AND GWRech_Fn IS NULL
  - *Assign GWRech_Fn = 2 to selected features*
- *Select by Attribute, Create a new selection:* (kt = 'kt' OR (pl = 'pl' AND sa IS NULL) OR pp = 'pp') AND GWRech_Fn IS NULL
  - *Assign GWRech_Fn = 2 to selected features*

Bank and Shoreline Stabilization

High potential to stabilize banks and shorelines (BnkShr_Fn = 1)

- *Select by Attribute, Create a new selection:* (LLWW_Landform = 'FR' AND Class IN ('SS1', 'FO', 'FO1', 'FO4'))
  - *Assign BnkShr_Fn = 1 to selected features*
- *Select by Attribute, Create a new selection:* LLWW_Landscape = 'LO' AND LLWW_Landform = 'FP' AND Class IN ('SS1', 'FO', 'FO1', 'FO4')
- *Select by Location, Select features from:* Target [Wetland Layer, select from selected features], Source [Wetland Layer with ST1, ST2, ST3, ST4 selected]. Spatial selection method: Intersect the source layer feature.
  - *Assign BnkShr_Fn = 1 to selected features*

Moderate potential to stabilize banks and shorelines (BnkShr_Fn = 2)

- *Select by Attribute, Create a new selection:* LLWW_Landform = 'FR' OR (LLWW_Landscape = 'LO' AND LLWW_Landform = 'FP') AND Class IN ('AB', 'EM1')
- *Select by Location, Select features from:* Target [Wetland Layer, select from selected features], Source [Wetland Layer with ST1, ST2, ST3, ST4 selected]. Spatial selection method: Intersect the source layer feature.
  - *Assign BnkShr_Fn = 2 to selected features*

Appendix B: Supporting Information for Modeled and Mapped Wetland Functions

Each wetland function described below includes an overview (repeated on the Colorado Wetland Information Center "Why are Wetlands Important" webpage), along with a brief literature review and other key model information, justification, assumptions, and limitations associated with a landscape (Level 1)-scale wetland assessment. GIS data processing steps and queries can be found in Appendix C.

Biodiversity and Wildlife Habitat Functions

Conservation of Biodiversity

Biodiversity, or the presence of the full suite of organisms capable of inhabiting a given environment, is a critical part of maintaining Colorado's wetland and terrestrial ecosystems into the future. In the web of living organisms, each species is tied to many other species, and removing one species—from a tiny aquatic invertebrate to a large carnivore—may have rippling direct and indirect effects on the rest of the ecosystem. Often, these effects include an ecosystem's ability to sustain the clean water and natural resources that we depend on to meet our basic needs. As Aldo Leopold once said, *"If the land mechanism as a whole is good then every part is good, whether we understand it or not… To keep every cog and wheel is the first precaution of intelligent tinkering."* Beyond the web of life, biodiversity provides aesthetic values, and many of our essential Colorado landscapes are tied to specific communities of plants, animals, and other organisms.

Supporting Information for Model Development

Wetlands that provide a high degree of biodiversity support include those known to host endemic and rare species, such as fens, as well as riparian wetlands and other ecosystems known to host high overall biodiversity (e.g., Gregory et al. 1991). Riparian wetlands like beaver complexes are known to support overall enhanced biodiversity (e.g., Law et al. 2016), as well as higher diversity for specific groups of organisms like fish (e.g., Smith and Mather 2013). Many areas (including beaver complexes) that support high biodiversity also provide refugia for Colorado's native aquatic and terrestrial species, which allow species to persist and relocate/disperse as needed during droughts or other extreme climate or disturbance events (e.g., Gregory et al. 1991).

For this function, we relied heavily on CNHP biodiversity data, including (buffered) element occurrence records for rare species and plant communities as well as mapping for specific wetland types like fens. The biodiversity function was split into two parts: 1) rare species and ecosystems and 2) general biodiversity support. Each component was ranked by landscape condition, using LDI scores (e.g., rare species and ecosystems with high landscape condition vs. moderate or poor landscape condition). Rare species and ecosystems included wetlands intersecting buffered element occurrence records for state-rare species (S1, S2, S3), along with rare wetland types like kettle ponds, playas, spring-fed wetlands, alpine wetlands, floating mats, and fens. Wetlands considered to provide high biodiversity support included more common wetland types such as beaver complexes, riparian wetlands, mires, and headwater wetlands that often support diverse plant and animal communities. Assumptions and Data Limitations

Some site-specific biodiversity information is not public domain data, including occurrences of rare species and ecosystems on private lands. This information must often be generalized from a point location to lower-resolution polygons such as PCAs. The model provides a landscape-scale assessment of potential hotspots for biodiversity, based on available biodiversity data and mappable landscape attributes associated with elevated capacity to support rare biota and ecosystems.

Aquatic Invertebrate Habitat

Aquatic invertebrates, including insect larvae, inhabit a variety of wetland habitats from bare areas with flowing water in the mountains to vegetated areas with standing water in the plains. Larval and adult invertebrates provide a critical food source for fish (including trout and other recreationally important species), amphibians, reptiles, migratory shorebirds, wading birds, ducks and other waterfowl, mammals, and other wetland-dependent species, and often help break down leaves, woody material, algae, and other material in streams and other aquatic environments. Depending on the duration of standing water, and other habitat characteristics like water chemistry and vegetation type, each wetland or waterbody may host an entirely different, yet diverse community of aquatic invertebrates. The types of invertebrates present in a wetland or waterbody are often used as an indicator of water quality (temperature, dissolved oxygen, etc.), and other habitat characteristics like the degree to which the natural hydrologic regime (including the magnitude, duration, frequency, rate of rise and recession, and variability in flows or water levels) has been altered by human water management.

Supporting Information for Model Development

In a review of aquatic invertebrate habitat preferences by Batzer and Wissinger (1996), invertebrates were found to inhabit a wide variety of habitats, from seasonally flooded systems to permanently flooded areas. Whiles and Goldowitz (2005) documented higher macroinvertebrate species diversity and productivity in intermittent and perennial wetlands. The only factors documented as consistently reducing habitat quality included sedimentation, and insecticides and herbicides in agricultural areas (Batzer and Wissinger 1996). Gleason et al. (2003) also observed impacts from sedimentation, including a 99.7% decrease in invertebrate emergence in soils from wetland basins in the Prairie Pothole region with sediment deposition depths as low as 0.5 cm.

Flow reduction, and the associated decrease in instream habitat diversity, is generally associated with decreased invertebrate species richness, though abundance may increase or decrease and degree of community alteration depends on the level of surface water diversions and other flow reductions (e.g., Rader and Belish 1999; McKay and King 2006; Dewson et al. 2007). Lammert and Allan (1999) found that assemblages of aquatic macroinvertebrates were strongly associated with local habitat drivers/conditions and that bed substrate size had a strong correlation with nearly every measure of macroinvertebrate community composition that they evaluated. Altered flow and sediment regimes are tightly coupled.

Mining activity, including dissolved metals and suspended sediments in downstream areas, had a strong negative correlation with overall macroinvertebrate biological integrity in a study of 86 different randomly located Colorado Rocky Mountain stream reaches (Griffith et al. 2005). Stream water containing elevated heavy metals in Colorado has been found to influence the composition and productivity of benthic invertebrate communities, and reduce the abundance of sensitive species at moderate to high metal concentrations (e.g., Clements 1994; Carlisle and Clements 2003). Caddisflies and other macroinvertebrates have demonstrated a similar sensitivity to acidic (low pH) water (Courtney and Clements 1998), which is often associated with mining pollution in the Rocky Mountains.

Temporary ponds (drying out each year) may support fewer aquatic macroinvertebrate species, but maintain species richness, rarity, and community composition (e.g., Collinson et al. 1995; Whiles and Goldowitz 2005). Created, or managed agricultural wetlands, including ponds and standing water in fields, and grazed pastures, often support diverse aquatic invertebrate populations (e.g., Colwell and Dodd 1995; Taft and Haig 2005; Davis and Bidwell 2008; Ruggiero et al. 2008). A study in France found that 40% of regional aquatic macroinvertebrate species, including several rare species, were found in agricultural ponds. Discing/plowing may reduce habitat quality, and diversity for macroinvertebrates (e.g., Davis and Bidwell 2008).

Based on the literature review, we used NWI water regime, LLWW modifiers for regulated flow and mining, LLWW landforms (basins), and average LDI scores to rank wetland polygons as having a high or moderate potential to provide aquatic invertebrate habitat. LDI scores were used to filter out ponds with a high likelihood of impaired water quality (heavy metals, low pH, pesticides, sediment, etc.) or soil disturbance, including tilled agricultural fields, mining ponds and some urban stormwater features.

Assumptions and Data Limitations

Aquatic invertebrate assemblages are generally dictated by factors that occur on smaller scales than NWI-level wetland mapping, and factors like ponding frequency and timing that may vary from year to year. Many small wetlands also fall below the minimum mapping threshold for NWI.

Shorebird Habitat

Shorebirds like sandpipers, plovers, and curlews utilize a variety of Colorado wetland habitats from lake shores to river sand bars and playas. Most Colorado shorebirds are migratory species, and rely on Colorado wetlands and adjacent grassland habitats to rest, forage, and sometimes nest between seasonal flights across state and international boundaries. While shorebirds can often coexist with agricultural and ranching activities, they are sensitive to wetland and grassland conversion and loss (including woody species encroachment), impacts to insect prey from insecticides, human disturbance, and factors that increase their exposure to native and non-native predators. In addition to being an important part of Colorado's wetland ecosystems, these avian travelers often benefit Colorado's rural communities when birders flock to local wildlife areas to observe shorebirds during migration.

Supporting Information for Model Development

Wetlands ranked as having a high potential to provide shorebird habitat included saline lakes and playas (e.g., Oring et al. 2000), as well as freshwater marshes, ponds, and lake fringes in all landscape positions, with a variety of vegetation cover types depending on species (e.g., Oring et al. 2000). Other shorebird habitat features include sand and gravel bars, along with mud flats in riverine areas (e.g., Oring et al. 2000), and other wetland areas with less than 25% vegetation cover (Helmers 1992). The NWI classes with vegetation thresholds below 30% include Rock Bottom, Unconsolidated Bottom, Unconsolidated Shore, and Rocky Shore. Species like the Least Tern prefer areas with very low vegetation and abundant bare ground next to water (Helmers 1992; CPW 2016), and many shorebird species use flooded agricultural fields used for foraging (e.g., Oring et al. 2000; Plauny 2000).

Ephemeral playas and other dry-end basins (e.g., Oring et al. 2000) were ranked as having a moderate potential to provide shorebird habitat. All wetlands included in shorebird habitat queries had to have at least moderate landscape integrity (LDI score < 500).

Assumptions and Data Limitations

Shorebird habitat varies greatly by species (e.g., species that inhabit upland grasslands adjacent to water vs. species that require large, mostly bare islands for nesting), life stage (e.g., nesting vs. migrating), and time of year. Many factors, such as detailed information on substrate and vegetation height, that influence the suitability of shorebird habitat cannot be mapped or detected at the scale of NWI mapping.

Waterfowl Habitat

Colorado's wetlands provide important stopover habitat during spring and fall migration, along with habitat for overwintering and breeding ducks and geese. Seasonal and permanently inundated wetlands provide waterfowl habitat across Colorado's diverse landscapes, from agricultural areas in intermountain valleys like North Park and the San Luis Valley to riverine wetlands along the South Platte as it flows through the eastern plains and montane beaver complexes. Key habitat elements include submerged and emergent aquatic vegetation (interspersed with open water), along with other food sources like invertebrates, seeds and grains. Waterfowl provide prey for raptors and other wildlife, as well as hunting and other recreational (birding) resources for humans.

Supporting Information for Model Development

Waterfowl occupy a wide array of seasonally and permanently flooded wetland habitats, from freshwater marshes to cattle ponds, reservoirs, playa lakes, riparian wetlands, rivers, irrigation canals, and flooded agricultural land (e.g., Davis et al. 2014). Johnson et al. (1996) note that the key to providing habitat for a diverse array of waterfowl species along the South Platte (and presumably other larger Colorado rivers) is to have a variety of habitat types. Dabbling ducks were observed using large pools, side channels, riffles, the main river channel between pools and riffles, and sand bars, whereas diving ducks were observed in large and small pools, along with the main river channel (Johnson et al. 1996). McKinstry et al. (2001) found that waterfowl density in beaver complexes was higher (7.5 ducks/km) than similar stream systems without beaver (0.1 ducks/km), due to increased habitat complexity and riparian width. Neff (1957) also documented higher waterfowl nesting activity in beaver-occupied stream segments in the Colorado Rockies. The Colorado Parks & Wildlife Dabbling Ducks habitat scorecard (CPW 2016) was also used to inform mapping for this function.

Waterfowl use of wetlands varies throughout the year. During spring and winter migration, dabbling ducks rely on features like beaver ponds, emergent marshes, warm water sloughs, managed waterfowl areas, wet meadows, and herbaceous riparian wetlands (CPW 2016). In the winter, dabbling ducks utilize deeper water areas like river channels, warm water sloughs, reservoirs, lakes and ponds associated with gravel mining, and open sand bars (CPW 2016). While waterfowl will use wetlands in disturbed landscapes, certain factors like high levels of grazing by cattle and other ungulates, and some burning, may reduce nesting density (e.g., Gilbert et al. 1996). Wetlands queried for high waterfowl habitat functions included palustrine emergent wetlands with seasonally flooded or wetter hydrologic regimes that are greater than 2 acres in size and ponds, lakes, and streams. Wetlands with palustrine emergent vegetation that are less than or equal to 2 acres and greater than 0.25 acres in size, with seasonally flooded or wetter hydrologic regimes, were ranked as providing moderate waterfowl habitat.

Assumptions and Data Limitations

The model provides a coarse, landscape-scale assessment of potential waterfowl habitat, based on mappable landscape attributes associated with waterfowl habitat throughout different times of year. Factors such as wildlife stressors (including excess predation, poor water quality, or reduced food resources) are difficult to map at this scale, and are not explicitly included.

Amphibian Habitat (models shown in Supporting Habitat Information in the Toolbox Mapper)

Wetlands provide critical breeding, foraging, and overwintering habitat for Colorado's 17 species of native amphibians. All of Colorado's amphibians require temporary or permanent standing water for breeding habitat, but many species spend the remainder of the year in adjacent terrestrial habitats. Some species, or individuals of a species, retain juvenile characteristics (neotenic larvae) and spend multiple years in standing water. Colorado's frogs, toads, and salamanders consume a variety of aquatic and terrestrial organisms for food, from aquatic insects, worms, crustaceans, mollusks, and other invertebrates to small vertebrates and sometimes algae and plants. Amphibians have highly absorbent skin, and are particularly sensitive to water quality, including the presence of excess nutrients (eutrophication), pesticides and other synthetic chemicals, along with land use/management adjacent to the full range of habitats that they utilize throughout the year. Boreal toad populations have also been greatly reduced by the chytrid fungus (*Batrachochytrium dendrobatidis*), which is widespread across the toad's Colorado range. Many of the state's amphibians, including boreal toads and the state's only salamander (barred tiger salamander), are also restricted to narrow elevation or temperature ranges.

Model Development

Two CNHP inductive suitable habitat models are included for CPW Tier 1 amphibians, including the northern leopard frog and boreal toad. Model descriptions are taken directly from Fink and Siemers (2015).

Boreal toad (Southern Rocky Mountain population; *Anaxyrus boreas boreas*)

This is a Maxent (v. 3.3.3e) inductive model. CNHP EORs were used as known locations for the species. The model is based on 120 EORs, which were translated into 652 input points. 522 input points used for training, 130 for testing. Training AUC is 0.954, test AUC is 0.951. Model results with a value of 0.15 (15% probability of occurrence) or greater were retained, based on model performance statistics and expert review. The output extent was modified with a mask to limit extent to known range. This model was reviewed by Colorado zoology and wildlife professionals in 2011. Model variables include growing degree days, distance to water, elevation, summer precipitation, vegetation type, and landforms.

Northern leopard frog (*Lithobates pipiens*)

This is a Maxent (3.3.3e) inductive model. CNHP Element Occurrence Records (EORs) were used as known locations for the species. The model is based on 63 EORs and 646 Observations, which were translated into 846 species presence points. 631 input points were used for training and 157 for testing. Training AUC is 0.883, test AUC is 0.879. Model results with a value of 0.7 (70% probability of occurrence) or greater were retained, based on model performance statistics and expert review. No other modifications were made. This model was reviewed by Colorado zoology and wildlife professionals in 2011. Model variables include distance to water, elevation, vegetation type, distance to wetlands, and landforms.

Assumptions and Data Limitations

Site-specific biodiversity information is not public domain data, including occurrences of rare species and ecosystems on private lands. The inductive models provide a landscape-scale assessment of potential habitat for two priority amphibians in Colorado, based on available biodiversity data and mappable landscape attributes. The models do not indicate occupancy, or account for boreal toad mortality due to the chytrid fungus.

Water Quality and Biogeochemical Functions

Nitrogen Uptake and Transformation

Humans have greatly increased the amount of available nitrogen in the environment, from atmospheric deposition to fertilizer application, animal waste, and septic systems. As one of several limiting nutrients in most ecosystems, excess nitrogen can lead to eutrophication of waterbodies (and associated algal blooms), altered plant community composition, and drinking water contamination (especially with nitrate-nitrogen). Many wetlands are local and regional hotspots for denitrification (nitrate removal) and processing other forms of nitrogen. Terrene and riparian wetlands that excel at removing nitrate have sufficient soil carbon (for denitrifying bacteria), are intercepting flow (and have higher soil water residence time for that flow), and have reducing conditions in the soil when water passes through the system.

Supporting Information for Model Development

The length of contact between wetlands and uplands is important for denitrification in riparian zones, particularly where wetlands are downslope of agricultural nitrate sources (McClain et al. 2003). Toe-of-slope wetlands along riparian areas (that have the potential to intercept groundwater-dominated irrigation return flows) were mapped as having a high likelihood of providing nitrogen uptake and transformation functions, as well as vegetated wetland basins and ponds with longer retention times for water, which are likely to have the highest capacity for N retention and denitrification (e.g., Saunders and Kalff 2001; Clary et al. 2017), including wetlands in agricultural landscapes (Hansen et al. 2018).

In lotic environments, transient storage zones, such as pools, side channels, and back channels with longer retention times for water often serve as biogeochemical hot spots for nitrate transformation and other nutrient cycling (Wollheim et al. 2014). Fluvial wetlands with a high degree of flow connectivity with stream channels are more likely to capture and cycle nutrients on a frequent basis. Beaver complexes with multi-thread channels may serve as a sink for ammonium-N, nitrate-N, dissolved organic N (DON), and total dissolved N (TDN) during high flows (e.g., spring snowmelt), a source for all of these forms of N during low flows, and a net sink for nitrate-N, DON, and TDN (e.g., Hammerson 1994; Law et al. 2016; Wegener et al. 2017).

Other low-elevation areas in riparian zones in semi-arid climates have been documented as hotspots for nutrient cycling (Harms and Grimm 2008). Floodplain wetlands are included as high-functioning for nitrogen uptake and transformation, as they are likely to assist in nutrient capture during flood events (e.g., Wollheim et al. 2014). Excavated ponds are excluded, given that they are often highly disturbed systems and devoid of vegetation.

Vegetated wetland channels have a moderate capacity for capturing and processing various forms of nitrogen (Clary et al. 2017).

Assumptions and Data Limitations

Mapping potential water quality functions at the landscape scale, particularly functions that rely on complex biogeochemical processes, is challenging. The model provides a landscape-scale assessment of potential hotspots for nutrient cycling, based on key fundamental processes (e.g., retention of water) and mappable landscape attributes associated with elevated capacity to capture and transform various forms of nitrogen. Plant community characteristics, presence of denitrifying bacteria and a sufficient carbon source, presence or absence of bypass flowpaths, and a myriad of other site-scale factors influence nitrogen cycling.

Phosphorus Removal and Storage

Phosphorus is a key limiting nutrient in many aquatic and terrestrial systems, and in excess, can cause eutrophication and associated algal blooms in surface water. Common phosphorus (P) sources include fertilizer, animal waste, septic systems, and bank erosion (P bound to soil and sediment particles). The ability of wetlands to remove and store P depends on a complex array of biogeochemical, hydrologic, and biological processes. Phosphorus is often bound to soil and sediment particles, so this function is correlated with sediment retention and capture. In general, wetlands are better at capturing particulate P than removing and storing dissolved forms of P.

Supporting Information for Model Development

In a review of 60 wetland publications, Fisher and Acreman (2004) concluded that particulate P is more likely to be retained in wetlands, and that drier-end wetlands with non-reducing substrates most effectively remove P. Vegetated systems with high water retention time (NWI seasonally flooded hydrologic regime or wetter in the model) have the highest capacity for P retention and removal, given that longer retention time allows for more plant uptake and capture of suspended soil and sediment particles (e.g., Woltemade 2000; Fisher and Acreman 2004; Clary et al. 2017). Non-lotic wetlands with limited surface water connections to streams, and emergent or floating macrophytes may provide high P assimilation and storage (Reddy et al. 1999).

Aldous et al. (2005) found that the histosols they examined (>20 mg/cm^3 organic C) had 30-50% of P as humic-P, and that peat oxidation may be partly responsible for eutrophication problems in Klamath Marsh in Southwestern Oregon. Reflooding marsh areas released a substantial amount of soluble reactive phosphorus, and the authors also note that semi-permanent flooding of lentic areas could result in the release of Fe-bound P under anoxic conditions (Aldous et al. 2005).

Vegetated wetland basins and wetland channels, and other types of ponds have a moderate capacity for P retention (e.g., Clary et al. 2017). Other wetlands with a moderate to high sediment capture and retention function are likely to capture P bound to soil and sediment particles, and limit bank erosion. Riparian floodplain sediments may have high P retention from flooding, and general sediment accumulation (Reddy et al. 1999). Forested riparian buffer strips may also provide P removal and storage (Woltemade 2000).

Assumptions and Data Limitations

Mapping potential water quality functions at the landscape scale, particularly functions that rely on complex biogeochemical processes, is challenging. The model provides a landscape-scale assessment of potential hotspots for nutrient cycling, based on key fundamental processes (e.g., retention of water) and mappable landscape attributes associated with elevated capacity to retain and store P. We acknowledge that this model does not capture site-scale spatial or temporal variations in nutrient cycling. Factors that were not captured during this landscape-scale assessment include a detailed evaluation of how different forms of P (including soluble P) move through, are stored, and are released in the landscape; bypass flow (e.g., direct groundwater transport of soluble phosphorus that bypasses wetlands prior to discharge into a stream); seasonal P dynamics, P release from decomposing plant matter; and degree and extent of livestock use of wetlands and surrounding upland contributing areas. For example, P release is enhanced during the summer growing season due to high temperatures and plant matter decomposition rates (e.g., Beutel et al. 2014).

Metal Removal and Storage

Metals are naturally present in soils and rock formations, but often a concern for water quality in Colorado streams, rivers, lakes, and wetlands due to historic and current mining and industrial activities, as well as runoff from urban land use. Many of our state's streams and rivers are on the 303(d) list of impaired waterways for metals like lead, arsenic, zinc, iron, uranium, and cadmium. These metals are detrimental to fish and other aquatic life, as well as recreational and water supply uses. The ability of wetlands to remove and store metals is highly dependent on factors like pH, temperature, and substrate (e.g., soil vs. sediment and organic vs. mineral soil). Wetland soils with a high organic matter content, including peat-forming fens and mires, and certain types of clay particles, generally have the highest capacity for adsorbing metals (referred to as cation exchange capacity). Overall, wetlands are most effective in removing total metals (solids) than removing dissolved metals, and may often be sources of dissolved metals depending on their hydroperiod, hydrologic regime, water inflows and outflows (including dissolved metals and metals adsorbed to suspended sediment and soil particles), pH, temperature, and history of metal loading.

Supporting Information for Model Development

A USGS study found that 67 of 145 sampled Colorado mountain wetlands contained uranium in their sediments, and that the humic and fulvic acids found in well-decomposed peat have a high sorption capacity for uranium and other metals considered harmful to human health in low concentrations (Owen and Otton 1995). The authors suggest that mining and oxidation of peat (resulting from drainage or other hydrologic alteration of organic soils), as well as acidification from acid mine drainage, has the potential to release stored uranium and other metals to surface and groundwater (Owen and Otton 1995). A study of wetland functions in Colorado reference wetlands is consistent with these findings for organic soil wetlands (Kolm et al. 1998), with a decrease in the concentration of Zn with distance along hydrologic flow paths in one wetland in a historic mining area. Mires were mapped as having a moderate potential to store metals (if they were not captured in other model queries), since they have less peat accumulation than fens.

In the International Stormwater BMP Database, which included data collection for many Colorado stormwater wetlands, vegetated wetland basin/retention pond combinations had statistically significant reductions in total Zn, Ni, Pb, Fe, Cu, Cr, and Cd, along with dissolved Zn and Cu (Clary et al. 2017). Generally, *retention* ponds and basins tend to have longer retention times for water than *detention* ponds and basins. In the functional assessment of Colorado reference wetlands, soils consistently had the highest cation loading, compared to water and vegetation storage pools, with the exception of potassium (Kolm et al. 1998). In the International Stormwater BMP Database (Clary et al. 2017), wetland basins had statistically significant reductions in total zinc, lead, and copper, along with dissolved zinc and copper. Wetland channels had statistically significant reductions in total Zn, P, Cu, Cr, and Cd (Clary et al. 2017).

Assumptions and Data Limitations

Mapping potential water quality functions at the landscape scale, particularly functions that rely on complex biogeochemical processes, is challenging. The model provides a landscape-scale assessment of potential hotspots for metal removal and storage, based on key fundamental processes (e.g., retention of water) and mappable landscape attributes associated with elevated capacity to capture and transform various metal species commonly present in areas impacted by mining and urban development. Soil organic matter, degree of metal loading, pH, metal transport pathways (including hydrologic flow paths) and temperature all influence how metals are transported through/stored in wetlands.

Carbon Sequestration and Storage

Carbon storage in wetlands is a complex phenomenon that is geographically and temporally (seasonally and over longer periods of time) variable. Wetlands often store a disproportionately large volume of carbon for their relatively small area on the landscape, but can also be sources of methane and other greenhouse gases (e.g., Bridgham et al. 2006). The ability of wetlands to sequester carbon in the form of soil organic matter, sediment, and biomass (roots, woody plants, etc.) depends on growing season length (influenced by elevation and climate), the balance between production and decomposition of organic matter, degree of soil and vegetation disturbance, the duration (and depth) of soil or sediment saturation and inundation, soil temperature, and other environmental factors. In general, least-altered wetlands have the greatest potential to store carbon. Fens and beaver complexes are two types of Colorado wetlands that provide abundant carbon storage relative to forests and other adjacent terrestrial ecosystems. Wetlands with altered groundwater levels, such as drained fens, often become carbon sources rather than sinks when stored carbon is oxidized.

Supporting Information for Model Development

Bridgham et al. (2006) estimate that around 98% of carbon stored in North American wetlands is in the soil, and that peatlands like bogs and fens account for approximately 83% of this stored carbon (mostly in Canadian peatlands). Undisturbed histosols and other deep organic soils have some of the highest soil organic carbon densities (e.g., Nahlik and Fennessey 2016). Overall, least-disturbed wetland sites (few to no physical, chemical, or biological stressors related to land use/management) are more likely to have higher mean organic carbon density in the soil profile (approximately twice the storage of most disturbed sites; Nahlik and Fennessey 2016). In Colorado peatlands, Chimner and Cooper (2003) found that CO_2 emissions in a subalpine fen in Rocky Mountain National Park were highly sensitive to water table manipulation, with emissions nearly doubling with each decrease in water table elevation above the ground surface from +6-10cm to +1-5cm to 0-5cm below ground. The highest CO_2 emissions were observed as soil temperatures increased in early summer, with lower emissions observed along with cooler temperatures in the fall, and with an abrupt water table decline and ground surface exposure (Chimner and Cooper 2003).

Beaver complexes, including multi-thread channels, are well-documented in providing organic matter retention (e.g., Naiman et al. 1986; Hammerson 1994; Law et al. 2016), and may serve as a sink for dissolved organic carbon (DOC) during high flows (e.g., spring snowmelt) and a source for DOC during low flows (Wegener et al. 2017). Wohl (2012) estimated that beaver complexes (including beaver meadows) can comprise around 8% of total landscape carbon storage at low levels of activity ("relict" complexes) and around 23% at high levels of activity in Colorado montane headwater catchments, with an average of around 3.3% of total organic carbon stored in sediment within relict beaver complexes and 12% in active complexes.

Least-disturbed, vegetated, mineral soil wetlands (e.g., Nahlik and Fennessey 2016) not included in the queries for a "high" degree of carbon storage were ranked as providing a moderate degree of carbon storage.

Assumptions and Data Limitations

Mapping potential water quality functions at the landscape scale, particularly functions that rely on complex biogeochemical processes, is challenging. The model provides a landscape-scale assessment of potential hotspots for carbon sequestration and storage, based on key fundamental processes (e.g., accumulation of organic matter) and mappable landscape attributes associated with elevated capacity to capture and transform various forms of carbon. Plant community characteristics, degree of soil and hydrologic disturbance, and a myriad of other site-scale factors influence carbon sequestration and storage.

Temperature Regulation

Many of Colorado's fish and other aquatic organisms occupy narrow thermal niches within streams and waterbodies. Water temperatures that are too high in the summer and fall can often lead to trout and other cold water fish mortality and increased susceptibility to disease, as well as allowing competition from non-native fish species. Wetlands help maintain low surface water temperatures during the growing season in several key ways. First, many headwater wetlands are subsurface flow-through systems (including wetlands that intercept seeps and springs) that augment summer and fall base flows with cool groundwater. Second, wetlands collect and store surface water (including snowmelt), often in the subsurface, which can then be slowly released to streams and other waterbodies throughout the growing season. Finally, trees, shrubs, and other dense wetland vegetation can physically shade surface water—especially on smaller streams. Riparian forested wetlands and shrublands (including willow carrs and lowland willow thickets) often provide dense shade over surface water.

Supporting Information for Model Development

Wetlands identified as having high potential to provide temperature regulation included headwater and snowmelt-driven wetlands that discharge to streams, fens and other groundwater-fed (discharge) wetlands that have a connection to streams, and forested riparian wetlands immediately adjacent to an intermittent or perennial stream or river. Wetlands identified as having a moderate potential to provide temperature regulation included other shrublands and woody plant communities along streams, including beaver-influenced wetland complexes.

Assumptions and Data Limitations

The model provides a landscape-scale assessment of potential temperature regulation, based on fundamental processes (e.g., likely groundwater discharge) and mappable landscape attributes. We acknowledge that this model does not capture site-scale spatial or temporal variations in temperature regulation, including the duration of snowmelt in mountain systems, degree of stream shading by trees and other riparian vegetation, and the amount of groundwater vs. surface water in a given wetland's water budget.

Water Quantity and Geomorphic Functions

Surface Water Storage

Colorado's wetlands provide both seasonal and semi-permanent surface water storage, along with associated subsurface groundwater storage. Surface water storage is associated with habitat for waterfowl, shorebirds, amphibians, fish, aquatic invertebrates, and other wildlife species, along with supporting wetland plant communities and adjacent terrestrial ecosystems. Natural wetlands and waterbodies also store water used to recharge groundwater aquifers and supply surface water for drinking water, irrigation, and other human water use.

Supporting Information for Model Development

This function focuses on wetlands and waterbodies that collect and store large volumes of surface water per areal extent on the landscape. Many of Colorado's surface water storage features are artificially impounded or excavated to enhance water storage, including reservoirs for drinking water and transmountain diversion water storage. The high and moderate ranks do not distinguish between natural and impounded or excavated water storage features, which are indicated in the NWI mapping attributes with an "h" or "x" modifier, respectively, or the "ip" or "ex" LLWW modifiers. Lakes, reservoirs, and ponds with semi-permanent to permanent water storage were ranked as providing a high degree of surface water storage.

Lake areas (often margins) with temporary or seasonal inundation, and wetland basins and ponds with temporary, seasonal, or semi-permanent inundation were ranked as providing a moderate degree of surface water storage.

Assumptions and Data Limitations

The mapping used to evaluate surface water storage lacks information on water depth, or specific information about the timing and duration of ponding or flooding.

Flood Attenuation

Many types of wetlands store and delay water during rain storms or spring snowmelt; lowering and delaying peak flows and extending the overall duration of elevated stream flow. These wetlands can help save human lives and property downstream, buffer aquatic ecosystems from extreme peak flows, and store water during drier periods following floods. Wetlands with the greatest potential to attenuate flood flows include floodplain wetlands, and basins and ponds with available water storage capacity during peak runoff or flooding. Some headwater wetlands, including slope wetlands that are saturated during runoff or flooding events, may increase flood peaks during larger storm events, but delay surface runoff with vegetation during smaller storms.

Supporting Information for Model Development

Terrene wetland basins (with available storage capacity) and dry wetland soils (when peak precipitation occurs) have greater water storage potential during rainfall events (vs. wetlands that are saturated during rainfall or runoff events). Wetlands with little to no available storage capacity are more likely to generate runoff (e.g., Acreman and Holden 2013). Lindsay et al. (2004) observed that in glacially-influenced headwater catchments with bedrock-controlled basins (often with organic soils) and abundant depressional and valley-bottom wetlands, bottomland wetland area (i.e., wetlands at, or within 10 m of a valley bottom landscape position), total wetland basin volume, total wetland area (and wetland area as a percent of catchment area), and gentle slopes were all moderately to strongly associated with peak flow attenuation. Interactions between wetland types, antecedent soil moisture, and wetland surface water connectivity were found to be critical to the ability of catchments to attenuate flood flow (Lindsay et al. 2004).

Floodplain wetlands and upland riparian areas that are not within the main channel (or the approximate floodway) have a high potential for storing flood flows (e.g., Bullock and Acreman 2003, in a review of 439 wetland water quantity studies), especially wetlands with woody vegetation (Acreman and Holden 2013). Artificially elevated water elevations (e.g., flood-irrigated areas or artificially impounded basins and ponds) and features like levees that disconnect stream channels and floodplains reduce flood storage capacity (Acreman and Holden 2013).

Wetlands ranked as providing a moderate flood attenuation function included floodplain wetlands and upland riparian areas not included in the “high” rank, along with features like beaver complexes that provide water storage during both peak flows and low flows (e.g., Wegener et al. 2017), but may have limited additional water storage capacity during a flood. The flood attenuation potential of beaver complexes is dependent on a variety of factors such as density of beaver dams, degree of valley confinement, peak flow magnitude, dam construction material (e.g., large wood vs. finer sediment), and available surface water storage capacity.

Other wetlands queried for moderate flood attenuation potential included wetlands with vegetation capable of impeding overland flow in headwater, precipitation-fed areas that have the potential to reduce flood peaks during lower-magnitude precipitation events (Acreman and Holden 2013). This query was restricted to gently sloping wetlands (less than 2% slopes).

Assumptions and Data Limitations

The flood attenuation rankings in this model are not intended to serve as a substitute for FEMA floodplain maps or more detailed evaluations of flood routing and water storage (e.g., hydraulic modeling using high-resolution LiDAR-derived digital elevation models and field survey verification). The ability of wetlands to store and delay peak flows is highly dependent on factors like antecedent soil moisture conditions (or surface water storage), and these factors are often highly variable over space and time. Many of Colorado’s peak flow or flood events occur either during spring snowmelt, or during the summer and fall (e.g., flash flooding). Wetlands that are wet from the spring into early to mid-summer may have sufficient storage capacity for summer and fall rain.

Sediment Capture and Retention

Soil erosion and sediment transport are natural landscape-scale processes that are often altered or accelerated by land and water management (e.g., excess bank and channel erosion due to reduced sediment loads in streams and rivers downstream of dams or excess soil erosion from tilled soil). Excess sediment in streams can be detrimental to aquatic organisms that depend on gravel and cobble beds that are free of fine sediment (including spawning trout and many aquatic invertebrates), and costly for water providers to remove from in-stream reservoirs used to store drinking and irrigation water. Vegetated wetlands can stabilize soil and sediment to limit erosion, or intercept and physically filter sediment particles entrained in surface runoff or stream flow. The ability of wetlands to capture and retain sediment has both positive and negative consequences for wetland ecosystems. Most riverine wetland plant communities, including willow thickets in beaver complexes, have evolved to survive and thrive in dynamic environments, including periodic sediment scouring and deposition associated with floods. Playas and other natural wetland basins may have some natural sediment deposition, but can be filled by excess sediment in surface runoff from surrounding areas with tilling and other soil disturbance. Montane and subalpine fens and mires are relatively stable environments, and may be lost if large volumes of sediment are deposited by soil erosion or landslides (e.g., from a catastrophic wildfire).

Supporting Information for Model Development

Beaver dams, particularly in geomorphically unconfined (and to some extent partially confined) stream systems, have been shown to store large volumes of sediment and increase channel complexity in Colorado and elsewhere in the Western U.S. (e.g., Naiman et al. 1986; Butler and Malanson 1995; Wohl 2011; Wohl 2013). Wetland basins with high hydraulic retention time, wetland channels, and detention basins all have high sediment retention capacity (e.g., Clary et al. 2017). Lotic wetlands that are impounded are likely to intercept sediment during low to moderate flows, but may become *sources* of sediment during high flow/intense storm events due to bypass flow AND because berms may become eroded. Other vegetated riparian wetlands are likely to capture sediment during low/normal flow events. Systems that are heavily influenced by irrigation are excluded from the highest rank for sediment capture/retention. In-channel islands and bars are included here, as they are, by definition, locations of sediment deposition (e.g., Cooper et al. 1998).

Other wetlands included as having a high potential to capture and retain sediment during more frequent precipitation and flow events include vegetated wetlands that receive overland flow, and have the potential to capture or retain sediment prior to flow leaving the wetland and traveling into stream channels or ditches, including vegetated swales and vegetated gently sloping wetlands. Other impounded waterbodies and basins, including many of Colorado's reservoirs, also trap sediment moving downstream.

Wetlands that may or may not frequently accumulate sediment, but are capable of storing sediment during monsoons, floods, and other >2 yr recurrence interval events include floodplain wetlands and upland riparian areas that are not within the main channel (or the approximate floodway). Impounded lotic wetlands are excluded here, which tend to capture sediment during lower flow events, as they may fail during high flow events and become sediment sources.

Assumptions and Data Limitations

The mapping used to evaluate sediment capture and retention lacks detailed information on soil erodibility, surface runoff and hydraulic characteristics (e.g., eroded channels vs. diffuse flow), or specific information about stormwater systems, irrigation systems and water application rates.

In addition to data and mapping limitations, the model assumes healthy, relatively dense vegetation that provides physical straining of sediment. In areas with extensive bare ground, or where vegetation has been heavily grazed, stressed by heat or drought, or is dominated by shallow-rooted annual plant species, the capacity of a wetland to capture and retain sediment will likely be reduced.

Stream Flow Maintenance

Headwater wetlands collect and store water from precipitation, snowmelt, surface runoff, and groundwater seeps and springs that is then discharged to streams and rivers during the growing season, or throughout the year. Often, wetlands help maintain stream base flows and cool water temperatures into the late summer and fall. These base flows sustain fish and other aquatic organisms, along with human water uses from fishing and whitewater boating to drinking water and irrigation.

Supporting Information for Model Development

Base flow in many Colorado streams is often a combination of local and regional groundwater discharge (Winter 1999). Wetlands identified as augmenting base flows in streams and rivers include many groundwater-dependent ecosystems with hydrologic regimes that are dominated by subsurface lateral flow of groundwater. While these wetlands are not “generating” base flow, they often serve as critical intermediaries that store and delay groundwater moving through them, maintain low water temperatures, and maintain or improve the quality of water passing through them (e.g., Owen and Otton 1995).

Headwater wetlands with a seasonally or permanently saturated (e.g., fens) or wetter hydrologic regime, and outflows to streams or rivers or a stream discharge modifier were ranked as having a high potential to maintain base flows.

Beaver-influenced wetlands provide in-stream/floodplain low-flow attenuation (via water storage, raising the water table, and altering hydraulic gradients) upstream and downstream of dams (e.g., Hammerson 1994; Westbrook et al. 2006; Wegener et al. 2017), and were ranked as having moderate potential to maintain base flows.

Assumptions and Data Limitations

This model does not account for variability in the volume and timing of wetland discharge to streams, including the volume of water contributed per wetland area. It can be assumed that large wetland complexes are likely to provide more stream flow maintenance than small wetlands.

Groundwater Recharge

Groundwater recharge, or downward flow of water through the soil to replenish groundwater aquifers, is a commonly cited wetland function that varies spatially and temporally due to factors like subsurface geology, soil type, surface water depth, depth to impermeable soil or rock layers, regional and local groundwater flow gradients, and wetland water source(s) and outflow(s), and evapotranspiration rates (surface water evaporation + transpiration by plants). Many of Colorado’s wetlands are groundwater discharge systems, as opposed to recharge-dominated systems, during all or part of the year. Select Colorado wetlands recharge local alluvial aquifers during all or part of the year (e.g., floodplain wetlands, many beaver complexes, and some irrigated wetlands), or other local and regional aquifers during spring snowmelt (e.g., kettle ponds) or summer monsoons (e.g., playas).

Supporting Information for Model Development

Kettle ponds have been documented to provide groundwater recharge in spring and early summer (Johnson and Steingraeber 2007). Some mountain lakes and ponds collect snowpack and snowmelt runoff and provide focused recharge along their margins, leading to temporary or relatively permanent water table mounding and enhanced groundwater percolation (e.g., Winter 1999). Seepage lakes, by definition, provide groundwater recharge. Increasing lake depth can also lead to increased seepage (to groundwater) (Winter 1999). While we currently lack data to confirm the presence of true seepage lakes, we can identify waterbodies with the potential for seepage, including waterbodies in glacial terrain and waterbodies lacking distinct intermittent or perennial inflows and outflows.

Streams, rivers, floodplain wetlands fed by stream flow/overbank flow (e.g., Acreman and Holden 2013) and irrigated areas (along with delivery ditches and canals) on unconsolidated alluvium, glacial outwash, and basin-fill deposits may recharge groundwater—particularly in late spring and early summer following peak snowmelt (e.g., Watts 2005; Watts et al. 2014). Beaver complexes may enhance groundwater recharge to the alluvial aquifer due to increased extent and depth of surface water, as well as lateral connectivity between streams and floodplains (e.g., Westbrook et al. 2006).

Playas in the Southern High Plains may have locally high recharge rates (12.7-82 mm/yr; Nativ and Riggio 1989), though recharge rates may be highly variable and most playa hydrologic studies reporting recharge have been conducted in New Mexico and Texas (e.g., Wood and Sanford 1995; Gurdak and Roe 2010). Playas providing groundwater recharge tend to be less saline (evaporite minerals) than playas that receive groundwater discharge (Rosen 1994). Recharge rates for Colorado playas need further field research.

Assumptions and Data Limitations

Groundwater recharge is a complex process, and many wetlands and waterbodies have a combination of groundwater recharge and discharge depending on water source (including snowpack), spatial location, underlying soil and geologic formations, and time of year. Groundwater recharge is not well-studied in Colorado wetlands. Our identification of wetlands and waterbodies with the potential to provide groundwater recharge does not include the potential magnitude (volume), or duration of recharge.

Bank and Shoreline Stabilization

Vegetated wetlands help to minimize waterbody shoreline and stream bank erosion from wave action and flowing water by providing structural stability for soil and sediment, and hydraulic (surface) roughness. The ability of wetlands to stabilize banks and shorelines depends on many environmental factors, including vegetation density, rooting depth, strength and structural complexity of vegetation (e.g., multi-layered vegetation canopies with a mixture of woody and emergent herbaceous plants), soil and/or sediment composition and structure, amount and distribution of bare soil and sediment, degree of soil and plant disturbance (e.g., from livestock or wild ungulate grazing), and the degree of alteration of the natural flow regime (streams), surface water levels (lakes and ponds), or wave action.

Supporting Information for Model Development

Vegetated fringe wetlands or riparian wetlands along stream channels with woody plant communities provide bank and shoreline stabilization (e.g., Johnson 1994). Grasses such as switchgrass (*Panicum* sp.) have been documented to have higher root strength than trees and shrubs, given their high root area ratio, but may provide less bank stability under wetter soil conditions (as opposed to drier conditions) than woody vegetation (Simon and Collison 2002). Increased stream bank strength from vegetation is also a key driver of stream meandering in streams and rivers with gravel bed/coarse bed material (e.g., Gran and Paola 2001; Braudrick et al. 2009). A study of wet meadow vegetation (dominated by sedges and rushes) along a low-gradient mountain stream in California (average width = 30 m; average depth = 1 m; channel slope = 0.001) found that sedges and other graminoids were associated with reduced bank erosion by a factor of 10 (relative to upland vegetation; Micheli and Kirchner 2002a) and stream banks vegetated with wetland graminoids were around five times stronger than banks colonized by xeric vegetation (Micheli and Kirchner 2002b).

Vegetated fringe wetlands or riparian wetlands along stream channels with aquatic bed plant communities (e.g., Gran and Paola 2001) were ranked as having moderate potential to stabilize banks and shorelines.

Assumptions and Data Limitations

The mapping used to evaluate bank and shoreline stabilization lacks detailed information on soil and sediment erodibility, hydraulics, or plant rooting characteristics. In addition to data and mapping limitations, the model assumes healthy, relatively dense vegetation that provides physical retention of sediment. In areas with extensive bare ground, or where vegetation has been heavily grazed, stressed by heat or drought, or is dominated by shallow-rooted annual plant species, the capacity of wetlands to retain soil and sediment along banks and shorelines will likely be reduced.

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