WETLAND MAPPING AND LOSS IN UTAH VALLEY

by

Peter Goodwin, Grant Mauk, Rebecca Molinari, and Elisabeth Stimmel

Suggested citation:
Goodwin, P., Mauk, G., Molinari, R., and Stimmel, E., 2026, Wetland mapping and loss in Utah Valley: Utah Geological Survey Open-File Report 776, 36 p., 2 appendices, https://doi.org/10.34191/OFR-776.

Disclaimer

OPEN-FILE REPORT 776
UTAH GEOLOGICAL SURVEY
UTAH DEPARTMENT OF NATURAL RESOURCES
2026

CONTENTS

FIGURES

TABLES

ABSTRACT

Wetland mapping informs a wide range of planning efforts by demarcating important habitats and areas where development and wetland conversion may pose greater risks of flooding, higher costs, and potential impacts to downstream communities. The Utah Geological Survey recently mapped over 7000 distinct wetlands (covering 123,000 acres) to update the National Wetland Inventory (NWI) across a rapidly urbanizing area in Utah Valley. We also mapped spring locations and applied supplemental Landscape Position, Landform, Water Flow Path, and Waterbody Type (LLWW) attributes to the wetland mapping to support conservation needs by identifying unique wetland habitats. By comparing archived wetland mapping to landcover datasets, we evaluated wetland losses within Utah Valley following an adapted NWI difference product methodology. Identified losses overwhelmingly resulted from converting wetlands to impervious surfaces and generally coincide with population centers along the north and east shores of Utah Lake. Clustered wetland losses near the cities of Lehi, Saratoga Springs, and Vineyard indicate a general shift of wetland loss westward towards Utah Lake and the Jordan River that mirrors urban population growth and greenfield development of former agricultural lands. Some areas experienced nearly continuous losses over 40 years, indicating increasing urbanization drives ongoing wetland loss in Utah Valley.

INTRODUCTION

Purpose and Scope

Rapid population growth and development in central Utah's Utah Valley have increased concerns about natural resource management, particularly of Utah Lake and the surrounding wetland habitats. Despite their importance and development pressures in the region, Utah Valley lacks a reliable wetland inventory. Prior to this project, wetland mapping was twenty to forty years out of date across the region and did not reflect several decades worth of development. Out of date mapping limits the identification of potential wetland resource conflicts and hampers conservation efforts by obscuring the current distribution of wetland resources. Up to date and reliable mapping promotes sustainable development and supports wetland conservation.

The Utah Geological Survey (UGS) developed this project to provide city planners, land managers, and other stakeholders with current, accurate wetland mapping. Updating the National Wetland Inventory (NWI) mapping best met these needs as the methods and scale used to map wetlands allowed this project to be completed within a reasonable timeframe while producing data suitable for fine-scale habitat analyses that can also guide permitting decisions. Additionally, many stakeholders already incorporate the NWI into their existing workflows and updating the NWI mapping easily expanded project reach.

UGS updated the NWI mapping across the entire Utah Valley as well as parts of nearby Cedar, Goshen, and Juab Valleys to include most developed parts of the larger central Utah region (Figure 1). Application of additional Landscape Position, Landform, Water Flow Path, and Waterbody Type (LLWW) attributes improved utility (Tiner, 2014). We tested a novel spring mapping workflow to evaluate our ability to map these important habitats concurrent with NWI mapping. This project produced three new wetland and spring spatial datasets—the 2024 NWI mapping, LLWW mapping, and the spring mapping—and published each to a publicly accessible, online database.

Effective wetland conservation requires contextual information beyond wetland location. Land managers must consider the value of a particular wetland in context of the larger landscape to prioritize key habitats and address distinct threats. To help meet these needs, we evaluated landscape-level patterns of wetland function and wetland loss over time using a series of spatial analyses. These analyses identify significant concentrations of high-value, high-function wetlands and describe patterns of wetland loss over time.

Project Setting

The project area covers nearly 790,000 acres of Utah and Juab Counties in central Utah, encompassing Utah, Cedar, and parts of Juab and Goshen Valleys that include 30 distinct municipalities (Figure 2). Population and development are unevenly distributed throughout the project area, with most major cities located along the northern and eastern shores of Utah Lake. Utah County has grown rapidly, with the population doubling between 2000 and 2019 and projected to nearly double again by 2045 (Kem C. Gardner Policy Institute, 2010, 2017, 2019).

All project areas between Nephi and the Salt Lake County boundary are located within the Jordan River Basin (HUC6: 160202) and parts of the Provo, Spanish Fork, and Utah Lake Sub-basins (HUC8s: 16020203, 16020202, and 16020201). The project

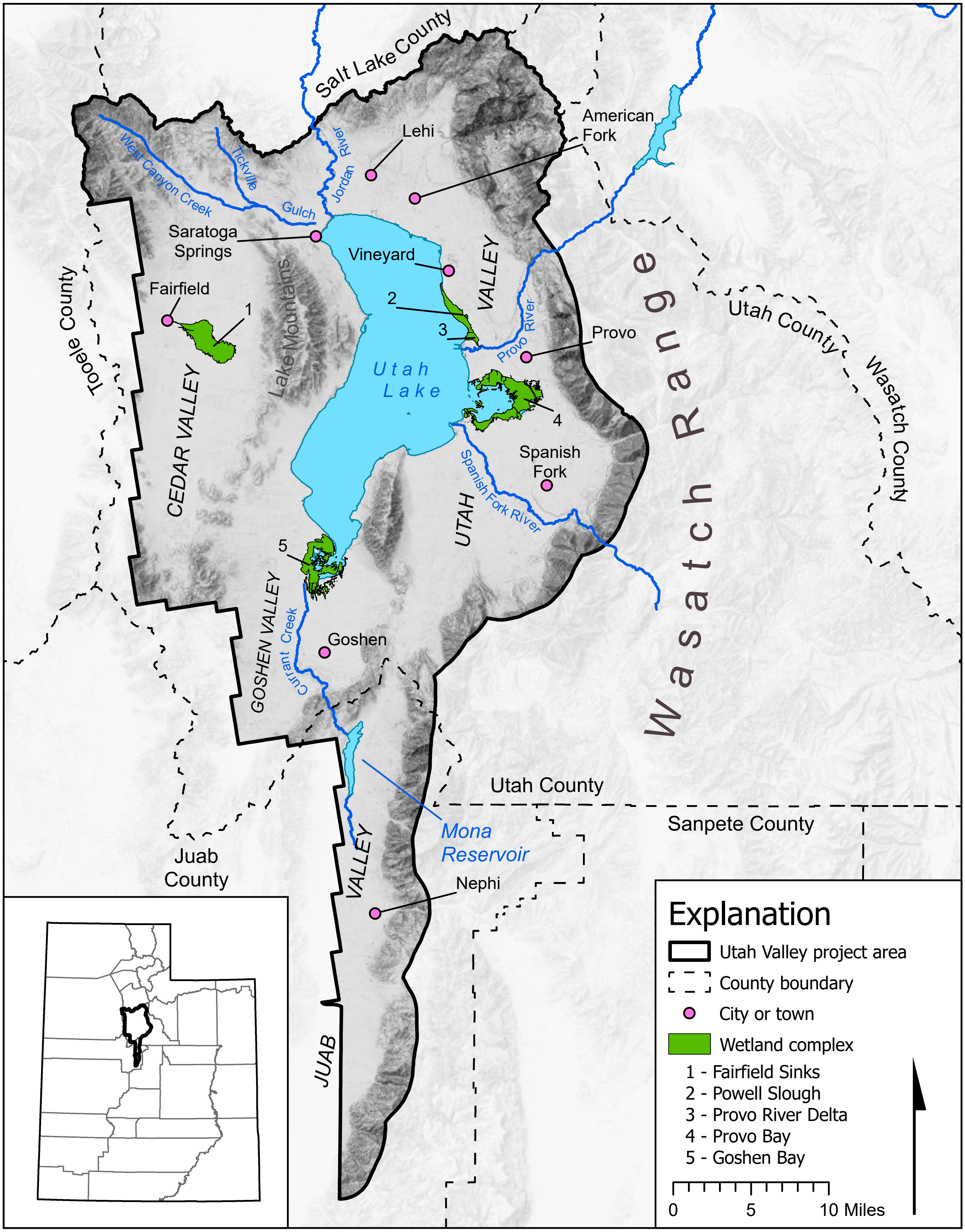


Figure 1. *Project area overview.*

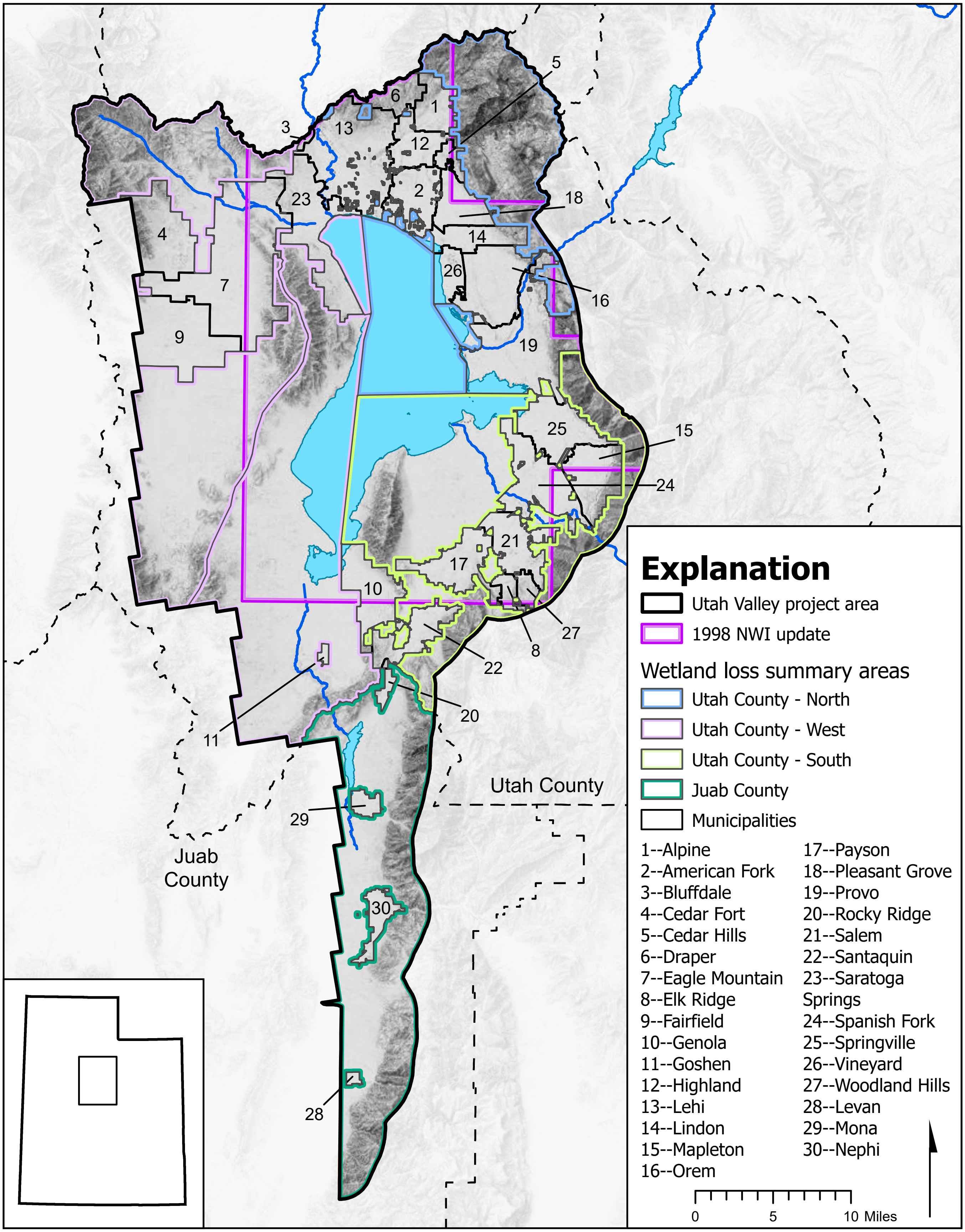


Figure 2. *Municipal boundaries of cities and towns in the project area. Unincorporated county boundaries and comparison areas used to summarize estimated wetland losses are also shown.*

area contains segments of several large rivers including the Provo, Spanish Fork, American Fork, and Jordan Rivers in addition to numerous perennial streams and creeks primarily flowing west and north from the Wasatch Range. A small part of the project area south of Nephi exists within the Escalante Desert-Sevier Lake Basin (HUC6: 160300). Surface water and groundwater in this part flow south and west from the project area to ultimately reach the Sevier River.

Northern Juab Valley and all of Utah Valley drain to Mona Reservoir and Utah Lake, with both valleys ultimately draining to the Jordan River and Great Salt Lake. The northern quarter of Cedar Valley drains east to Utah Valley via West Canyon Creek and Tick Ville Gulch. The rest of Cedar Valley forms a closed basin with all surface water draining to the Sinks east of Fairfield. However, groundwater does exit the closed basin, flowing east to Utah Valley near Goshen and Saratoga Springs and emerging as distinct springs or areas of shallow groundwater (Jordan and Sabbah, 2012). Shallow groundwater exists throughout Utah and Juab Valleys with extensive spring and groundwater-dependent wetland complexes along the southern and eastern shores of Utah Lake and Mona Reservoir as well as in southern Juab Valley. Brooks and Stolp (1995) illustrated areas in southern Utah County covered by phreatophytes, and Kirby et al. (2022) produced a depth-to-groundwater map of Goshen Valley and adjacent areas.

Utah Lake Wetlands

Utah Lake is a shallow, eutrophic lake surrounded by multiple metropolitan areas (Figure 2). Utah Lake creates unique recreation opportunities and supports thousands of acres of shoreline wetlands. These wetlands provide crucial wildlife habitats and filter sediment, nutrients, and other pollutants from surface runoff, effectively intercepting these contaminants and protecting the water quality of downstream waterbodies (Brinson, 1993; Millennium Ecosystem Assessment Program, 2005; Mitsch and Gosselink, 2015; Utah Wildlife Action Plan [UWAP] Core Team, 2025). Millions of migratory birds depend on Utah Lake's shoreline wetlands as stopover habitat during spring and fall migrations (Abbott et al., 2022). Many other aquatic wildlife species, including the federally threatened June Sucker (*Chasmistes liorus*) depend on shoreline and other connected wetlands for foraging, breeding, and nursery habitats (U.S. Fish and Wildlife Service [USFWS], 2019; UWAP Core Team, 2025).

Utah Lake and surrounding shorelines are the focus of wetland conservation within Utah Valley. Large restoration efforts like the Provo River Delta and Hobble Creek restoration projects created or restored over 200 acres of new wetland habitats along the Utah Lake shoreline for June Sucker habitat and recreation access (Utah Reclamation Mitigation and Conservation Commission, 2015). The Utah Reclamation Mitigation and Conservation Commission also owns and preserves several thousand acres of wetland and playa habitats along Utah Lake's southern shores for similar habitat and recreation access. The Utah Department of Forestry, Fire and State Lands (FFSL) has invested significant resources to remove phragmites (*Phragmites australis* ssp. *australis*), a highly invasive grass, from Utah Lake shorelines to improve habitat and access (FFSL, 2024).

Local and county governments have also protected Utah Lake shorelines through the Utah Lake Shoreline Protection Overlay Zone, a zoning ordinance limiting new development near the lake with the intent to 1) protect natural resources, 2) preserve and improve water quality, and 3) maintain public ownership and lake access (Utah Lake Commission, 2009). Rapid population growth within Utah Valley, and the resulting residential, commercial, and transportation development, contributes to the need for protective zoning and other wetland conservation actions. Recent development is well linked to wetland impacts and is frequently identified as a primary driver of wetland losses within the past 20 years (Fluet-Chouinard et al., 2023; Lang et al., 2024).

WETLAND AND SPRING MAPPING

Wetland spatial data inform a wide range of planning efforts by identifying important habitats, areas sensitive to development, and landscape features that maintain healthy watersheds. These datasets range from generalized, national mapping to highly accurate, local delineations with each dataset having appropriate applications and limitations. The NWI has the broadest application and most frequent use (USFWS, 2024a). The U.S. Fish and Wildlife Service (USFWS) maintains the NWI as a freely accessible Geographic Information Systems (GIS) database mapping individual wetlands as discrete polygons (Dahl et al., 2020; USFWS, 2024b). The free access, clearly defined wetlands, and easily queried data allow the NWI to answer the two most common wetland planning questions: are there wetlands on this property and where are they?

NWI mapping relies on photo-interpretation to identify the unique vegetation, topography, or hydrology of wetlands. The NWI dataset represents a static snapshot of the wetland extent depicted in the source imagery. Much of Utah's NWI mapping was completed using imagery from the 1980s or 1990s and the dataset does not reflect several decades-worth of development.

The outdated mapping reduces the NWI dataset's effectiveness in large-scale planning efforts (Utah Lake Commission, 2009; UWAP Core Team, 2025; Mountainland Association of Governments [MAG], undated) and may contribute additional costs to development projects (Van Beveren, 2022).

Updating NWI mapping provides a clear benefit to the state of Utah (R. Allen, MAG, written communication, 2020; Menuz and Downard, 2017). The UGS, Utah Division of Wildlife Resources (DWR), Bureau of Land Management (BLM), and other organizations regularly complete NWI update projects and have remapped 35% of the state since 2014 (USFWS, 2024b). These updates remap wetlands to recent conditions and modern standards, greatly improving the NWI dataset.

The NWI classifies wetlands according to the Cowardin classification which describes several important wetland characteristics (substrate, vegetation type, hydroperiod) observable from aerial imagery. This classification omits descriptions of a wetland's shape or location within the watershed, important characteristics when evaluating wetland function and overall watershed health (Brinson, 1993; Tiner, 2014; Goodwin and Molinari, 2022). The LLWW classification system was developed to supplement NWI mapping by further describing a wetland's geomorphic position and connectivity to other wetlands or waterbodies (Tiner, 2014). The LLWW system also includes significantly more modifiers to describe human impacts, wetland hydrology, and unique wetlands. Applying the additional LLWW attributes provides detailed information about an individual wetland and allows highly specific queries (Goodwin and Molinari, 2022). Tiner (2014) intended LLWW to bridge the gap between NWI mapping and the hydrogeomorphic (HGM) classification used by the U.S. Army Corps of Engineers (USACE) to assess a wetland's physical, chemical, and biological functions (Brinson, 1993).

The NWI dataset represents wetlands at a scale of 1:12,000 (approximately 30-foot accuracy) and typically only maps wetlands greater than a 0.1 acre (approximately 60 feet by 60 feet) (Dahl, 2020). Springs and associated pool, rill, and seep wetlands rarely exceed 0.1 acres in size and are rarely included in the NWI dataset as distinct features (Stevens et al., 2023). Despite their small size, springs are hugely important for drinking water, stream baseflow, and wildlife habitat in Arid West ecosystems (UWAP Joint Team, 2015; Gurrieri, 2020; Rohde et al., 2020; Stevens et al., 2023; Rohde et al., 2024).

Utah lacks a reliable inventory of spring locations which hampers wildlife managers' ability to conduct species surveys or estimate habitat condition (Kate Holcomb, DWR, written communication, 2020; Paul Thompson, DWR, written communication, 2020). Other datasets like the National Hydrography Dataset (NHD) or the Utah Division of Water Rights' Points of Diversion (WRPOD) include some spring locations but frequently omit smaller springs or seeps, misidentify points of emergence, or include dewatered or destroyed historical springs. The Spring Stewardship Institute (SSI) frequently conducts field-based spring inventories and publishes the results to their Springs Online (SO) database—a public, online database housing spring location and condition data. However, the SSI has conducted limited work in Utah and the SO dataset for the state largely consists of points ingested from the NHD or regional springsnail surveys.

In June 2024, the UGS updated the spring and wetland mapping across the project area (Figure 1) to provide city planners, land managers, and other stakeholders with current, accurate NWI mapping. Conservation planning or wildlife management often require detailed information or mapping of small features beyond the limited descriptions and scale of the NWI dataset. To meet this need, we applied additional LLWW attributes to the 2024 NWI mapping. We also conducted a pilot project evaluating the feasibility of mapping identifiable spring locations as point features while updating NWI mapping. This work produced three new wetland and spring spatial datasets the 2024 NWI mapping, LLWW mapping, and the spring mapping. The USFWS incorporated the 2024 NWI mapping into the national NWI dataset accessible through their Wetland Mapper application (USFWS, 2024b) whereas the UGS provides the LLWW mapping through the Utah Wetlands application (UGS, 2025). The SSI published all spring mapping to the Springs Online database as well as the DWR Springs database (UWAP Core Team, 2025).

Mapping Methods

We mapped the 2024 NWI wetland and riparian areas by hand-digitizing features visible in 2021 National Agricultural Imagery Program (NAIP) aerial imagery using ArcGIS software according to USFWS guidelines (USFWS, 2009; Dahl et al., 2020). These guidelines define wetlands as areas with one or more of the following indicators: hydric soils, hydrophyte dominance, and shallow flooding or near-surface saturation during the growing season. The USFWS guidelines differ from the more stringent regulatory definition adopted by the USACE and EPA which require the presence of all three indicators (USACE, 2008; Dahl et al., 2020). USFWS guidelines define riparian areas as those lacking any of the wetland indicators but still supporting distinct vegetation communities through hydrologic connections to nearby waterbodies (USFWS, 2009). Accordingly, riparian areas are not considered wetlands, and we map them adjacent and contiguous, but never overlapping with mapped wetlands.

USFWS guidelines and standard practice recommend using the most recent NAIP imagery as the primary source for identifying and digitizing features (Dahl et al., 2020; St. Mary's University, 2021; Hartshorn et al., 2024). In our project area, the most recent NAIP was collected during September, October, and November of 2021 and captured seasonal low-water conditions during a historic drought. We used the 2021 NAIP for our source imagery because it best represented current development in the rapidly developing project area. We mapped all wetland boundaries to features visible in the source imagery but reviewed several other datasets alongside the NAIP imagery to better understand average wetland conditions and support our mapping effort (Table 1). These datasets included historical and recent imagery, high-resolution light detecting and ranging (lidar) data, existing wetland and hydrography mapping, and water resource use information. UGS mappers Elisabeth Stimmel, Grant Mauk, Rebecca Molinari, and Pete Goodwin conducted field surveys to visit difficult to interpret wetlands and verify initial mapping. We conducted all surveys between November 2021 and May 2023.

We mapped wetlands at a 1:3000 scale to a minimum target mapping unit (TMU) of 0.1 acres (roughly 400 square meters). Riparian areas were mapped at a 1:3000 scale but to the larger TMU of 0.5 acres identified in USFWS guidelines (roughly 2000 square meters). The larger riparian TMU allowed us to focus our efforts on wetland mapping. We do not expect our riparian mapping to inform infrastructure, and the larger mapping TMU should support uses such as selecting treatment areas for tamarisk (*Tamarix* sp.) or Russian olive (*Elaeagnus angustifolia*) control.

Cowardin attribution followed Dahl et al. (2020) and the broad conventions described by Goodwin and Molinari (2022). Distinct Cowardin attributes were applied to wetlands and riparian areas with 30% or greater cover of several common invasive plants: phragmites, Russian olive, and tamarisk. We applied the additional LLWW attributes to all wetland polygons in the 2024 NWI mapping following keys developed by Lemly et al. (2018) and the semi-automated methods described by Goodwin and Molinari (2022). The semi-automated methods required mappers to assign a dominant water source for each wetland polygon (Table 2). The LLWW attribute keys only apply to wetlands. LLWW attribution relied on the same source imagery and supporting data for wetland identification (Table 1). To address issues unique to Utah Lake, the extensive playas and groundwater-supported wetlands, we followed several project-specific conventions to consistently apply Cowardin and LLWW attributes (Appendix A).

We developed the spring mapping workflow in coordination with DWR biologists and SSI with the intent of producing a single dataset that reliably identifies springs for habitat surveys. We took a conservative approach and only mapped springs clearly visible in our supporting aerial imagery or lidar. We focused on springs with available surface water that matched common notions of spring habitats. We also mapped seeps and diffuse springs if other datasets corroborated the presence of a spring. Springs were described according to the Stevens et al. (2021) schema, focusing on four primary types with distinct geomorphologies (Figure 3):

1. Helocrene: spring emerges diffusely without obvious pools or channelized flow, typically appearing as wet meadows.
2. Hillslope: spring emerges mid-slope in upland area, usually has some sort of channelized outflow.
3. Limnocrene: Spring forms a distinct pool with no inflow channel.
4. Rheocrene: spring emerges in defined channel, with obvious channels above and below springhead.

In addition to mapping spring location and type, we also assessed simple hydrology and disturbance metrics reflecting spring condition. Our spring mapping workflow depended on detailed review of recent aerial imagery, lidar, and hydrography datasets assembled for our 2024 NWI mapping (Table 1).

Springs were mapped as point features, with the point located at the springhead or the first visible surface water if the springhead was unidentifiable due to vegetation cover or ground disturbance. At each mapped spring, we 1) noted the landscape features used to identify the springhead location, 2) listed which other datasets also mapped the spring, 3) assigned spring type, 4) assessed several condition metrics, and 5) described any other important features. Agreement between our mapping and other datasets varied greatly and we relied on best professional judgement to link mapped springs to records in other datasets. We assessed condition metrics for each spring that could be confidently identified using imagery, including permanence and amount of available water in current imagery. A full list of all criteria used to evaluate spring location, type, and condition are included in Appendix A (Table A1). We did not conduct a field validation to determine location or condition accuracy of our spring mapping. The SSI reviewed 10 randomly selected perennial spring points before incorporating our mapping into the SO database.

Table 1. *Datasets used for wetland and riparian mapping.*

Dataset[1]	Description	Source[2]	Relevant Date(s)
Imagery			
Historical Orthophotos	1-meter resolution, historical black and white orthophotos collected in the summer of 1993.	UGRC	Summer 1993
NAIP 2011	1-meter resolution, 4-band aerial imagery collected during the summer of 2011.	USDA NAIP	8/6/2011
NAIP 2014	1-meter resolution, 4-band aerial imagery collected during the summer of 2014.	USDA NAIP	7/1/2014
NAIP 2016	1-meter resolution, 4-band aerial imagery collected during the summer of 2016.	USDA NAIP	8/2/2016
NAIP 2018	1-meter resolution, 4-band aerial imagery collected during the summer of 2018.	USDA NAIP	9/11/2018 to 9/27/2018
NAIP 2021	0.6-meter resolution, 4-band aerial imagery collected during the fall of 2021.	USDA NAIP	9/1/2021 to 11/30/2021
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.	Google Earth	Various
ESRI World Imagery	30-centimeter, true color imagery available as an ESRI service. Imagery mosaiced from several sources and collection dates.	ESRI	Various
Lidar and Elevation			
Wasatch Front	0.5-meter resolution, bare earth lidar data of the Heber Valley collected during fall 2013 and spring 2014.	UGRC	Fall 2013 and spring 2014
Utah Lake	0.5-meter resolution, bare earth lidar data of Utah Lake collected during fall 2016.	UGRC	Fall 2016
Heber Valley and Uinta Basin	0.5-meter resolution, bare earth lidar data of the Heber Valley collected during fall 2018.	UGRC	Fall 2018
2018 Southern Utah	1 meter resolution, bare earth lidar of parts of southern Utah collected during 2018.	UGRC	2018
2018 Central Utah	0.5-meter resolution and 1-meter, bare earth lidar data of parts of central Utah collected from spring to fall 2018.	UGRC	Spring to fall 2018
2020 Northern and Central Utah	0.5-meter resolution, bare earth lidar data of parts of northern Utah collected during summer 2020.	UGRC	Summer 2020
Existing Mapping			
NWI	Existing wetland mapping included in the NWI dataset.	USFWS	Summer 1984, 1998, 2014
NHD Flowlines	Centerlines of ephemeral, intermittent, seasonal, and perennial channels identified in the NHD.	USGS	2020
NHD Spring points	Point data of known springs and seeps identified in the NHD.	USGS	2020
SO Spring Points	Statewide dataset depicting spring locations contained in the SO database.	SSI	2020
Utah Valley Bottoms	Statewide dataset depicting valley bottom areas for all perennial streams within the state of Utah.	USU	Winter 2016
Utah Lake Bathymetric Contour Lines	Bathymetric contour lines generated from historic Bureau of Reclamation depth measurements through surface ice	Utah County	Winter 1960
Land Use			
Water Points of Diversion	Agricultural irrigation and other diversion points along water features identifying wells, stock ponds, and springs.	UDWRI	2022
Phragmites treatments	Dataset depicting all phragmites treatments along Utah Lake shorelines	FFSL	2021

Table 2. *Water sources assigned for automating LLWW attribution.*

Water Source	General Description	Geomorphic Setting	Imagery Signature	Assigned 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, streambank shrub wetlands, gravel bars and shores, floodplain wetlands.
Alluvial aquifer	Feature appears connected to the river or lake water table–as the river and associated water table rises, feature is flooded. Direct surface connection 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 and similar to 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, snowmelt, or is part of a stormwater system.	Topographic low points without clear surface water inputs. Features are typically shallow depressions or basins or isolated, excavated pits.	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.	Level, agricultural areas outside of river floodplains with clear signs of canals or ditches. Features are typically flat or gently sloping fields and pastures without extensive crops.	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.	Irrigation retention ponds, irrigated pastures and fields, features collecting irrigation runoff.
Artificial	Areas that have been constructed and water source entirely removed from any natural system.	Variable but often well removed from any natural waterbodies.	Water typically present in most images. If vegetated, usually supports dense emergent vegetation or floating algal mats typical of high-nutrient systems.	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, do not 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 do not 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. 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.	Extensive emergent flats, disconnected oxbows, areas downstream of springs but not obviously flooded or connected via surface water.
Spring	Definite pools, rills, springheads, or groundwater-fed features identified as springs in the NHD, WRPOD, SO or other 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.

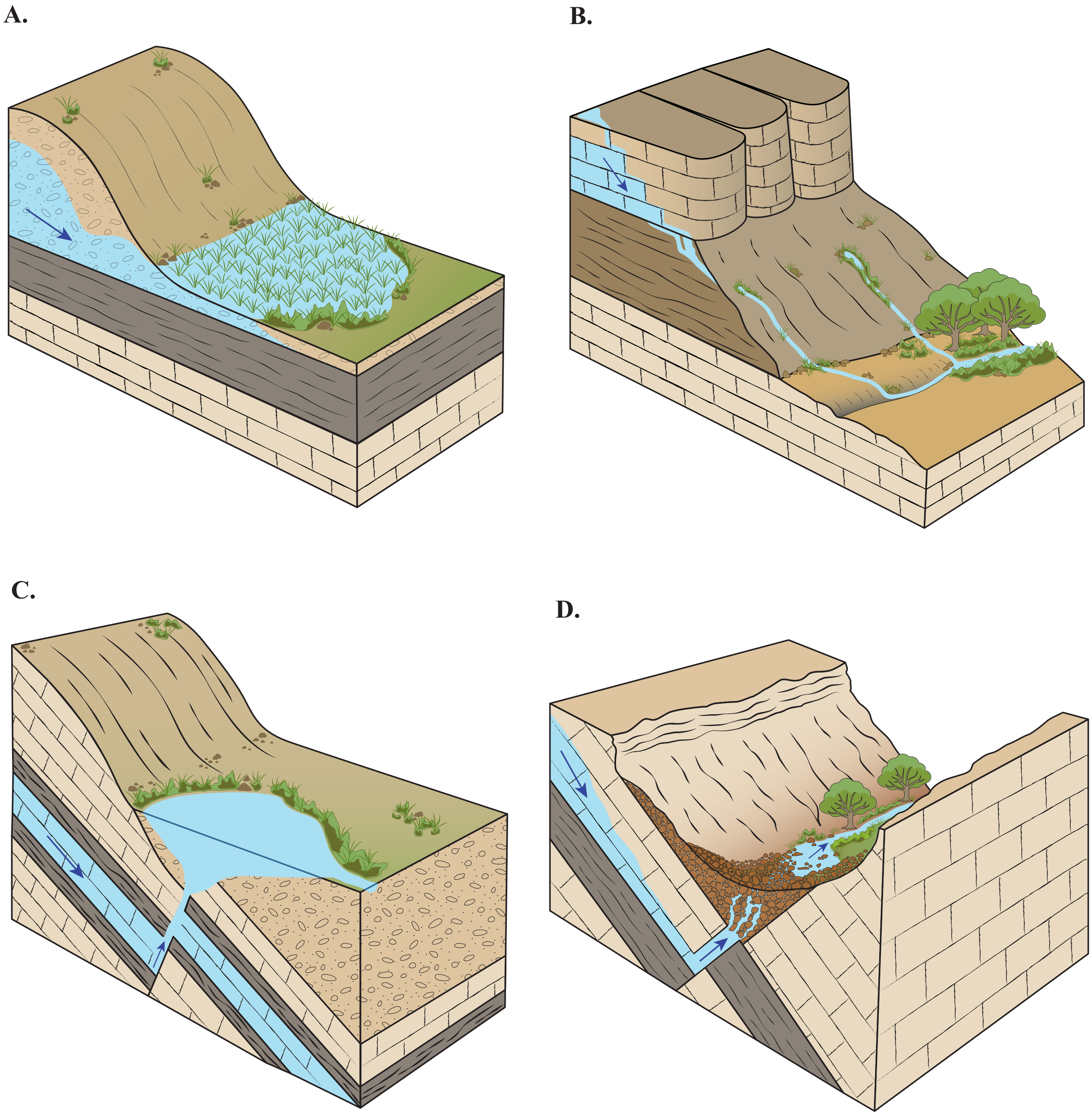


Figure 3. *Generalized block diagrams of primary spring types identified in the UGS spring mapping workflow. Modified from Stevens et al. (2021). Clockwise from top left: helocrene* ***A)*** *emerging diffusely as a wet meadow, hillslope* ***B)*** *emerging mid-slope with a channelized flow, limnocrene* ***C)*** *emerging as a distinct pool with no obvious inflows, and rheocrene* ***D)*** *emerging as flowing water within a defined channel.*

Mapping Results

This project mapped over 7000 distinct wetland and riparian areas that cover nearly 123,000 acres, about 15% of the total project area (Figure 4, Table 3). Lacustrine features account for 75% of the 2024 NWI mapping acreage, with nearly 95% of all lacustrine features belonging to Utah Lake and the surrounding shorelines. Vegetated wetlands (emergent marshes and meadows, farmed, scrub-shrub and forested wetlands) account for 17% of all 2024 NWI mapping acreage, with emergent meadows mapped most frequently and extensively. Isolated ponds, rivers, seasonal streams, and riparian areas account for the remaining 5%–10% mapping acreage.

Wetlands or riparian areas invaded by phragmites, Russian olive, or tamarisk were identified with 22 distinct Cowardin attributes (Table 4). These highly invaded wetland and riparian areas account for 31% and 12% of all mapped riparian areas and vegetated wetland acreage, respectively (Table 4). Their distribution extends across the entire project area with concentrations along the Jordan River and Utah Lake shorelines (Figure 5).

We applied LLWW attributes to the 6400+ mapped wetlands, covering nearly 120,000 acres (Table 5). Large, lotic lakes (those fed by streams and rivers) like Utah Lake or Mona Reservoir make up nearly 70% of the total LLWW mapping area and their connected ponds, shorelines and other lentic wetlands account for another 12% of the total mapping area. Lentic wetlands identified by LLWW attributes extend beyond the NWI lacustrine wetlands identified only by Cowardin attributes (Figure 4). The remaining lotic features, mostly seasonal, intermittent and ephemeral channels, account for only 5% of the total mapping. Isolated terrene lakes (those unconnected to streams and rivers), ponds, and wetlands make up the remaining 14% of the total mapping area, with basin and slope wetlands contributing nearly three-quarters of that area. Water sources varied little for lotic and lentic features with stream flow and overbank flooding accounting for 99% and 87% of respective lotic and lentic acreage (Table 6). Groundwater and spring-fed water sources make up just over 60% of the terrene acreage and precipitation accumulation and irrigation contribute nearly 20% each. Artificially fed wetlands accounted for minimal amounts of the terrene acreage but were the second-most frequently mapped terrene feature.

We mapped spring-fed wetlands throughout the project area, generally as small, isolated areas directly adjacent to the source springhead (Figure 6). However, large spring-fed wetland complexes extending hundreds to thousands of acres exist at Fairfield Sinks below Big Springs and on the Goshen playa below the Goshen Warm Springs. We mapped groundwater-fed wetlands throughout the project area and identified several large wetland complexes in southern Utah Valley between Goshen and Spanish Fork. Irrigation-fed wetlands were similarly concentrated in southern Utah Valley and generally mapped along diversions from groundwater and spring-fed wetlands or surface waters like the Spanish Fork River and Currant Creek near Goshen. Excepting the playa wetlands north of Goshen, we mapped most wetlands supported by precipitation accumulation (non-channelized runoff or stormwater) as small features generally concentrated in northern Utah Valley between Saratoga Springs and Provo.

We mapped 277 springs, 219 of which were new to the SO database and 113 were not mapped within any dataset we reviewed (Figure 7). Of the 277 mapped springs, 153 were perennial and mostly contained observable extensive or patchy surface water in the 2021 NAIP imagery. Mappers identified several perennial springs lacking observable surface water where surface water was either undetectable due to dense vegetation canopies or spring hydrology consisted of permanent soil saturation. None of the 36 ephemeral springs had extensive surface water in the 2021 imagery but all displayed patchy surface water or saturated soils. Only 26 of the remaining 98 unknown springs had extensive surface water in the 2021 imagery.

We located most (51%) springs by visible inundation or saturation. Mappers also located springs through distinct vegetation (19%) and microtopography (16%) changes apparent in supporting elevation datasets. Most springs (50%) were categorized as helocrene. Nearly equal proportions were classified as limnocrene or hillslope (24% and 23%, respectively); very few (4%) were rheocrene springs. We identified clear disturbances at a quarter of all mapped springs, with impoundments, berms, or other flow regulations as the most common disturbances. We observed one spring that had been completely covered by recent development in Lehi, Utah. There were clear impacts from construction at 13 other springs. Of the 10 points reviewed by SSI, they agreed with most spring types, seasonality, and observed water (90%, 70%, and 80% respectively).

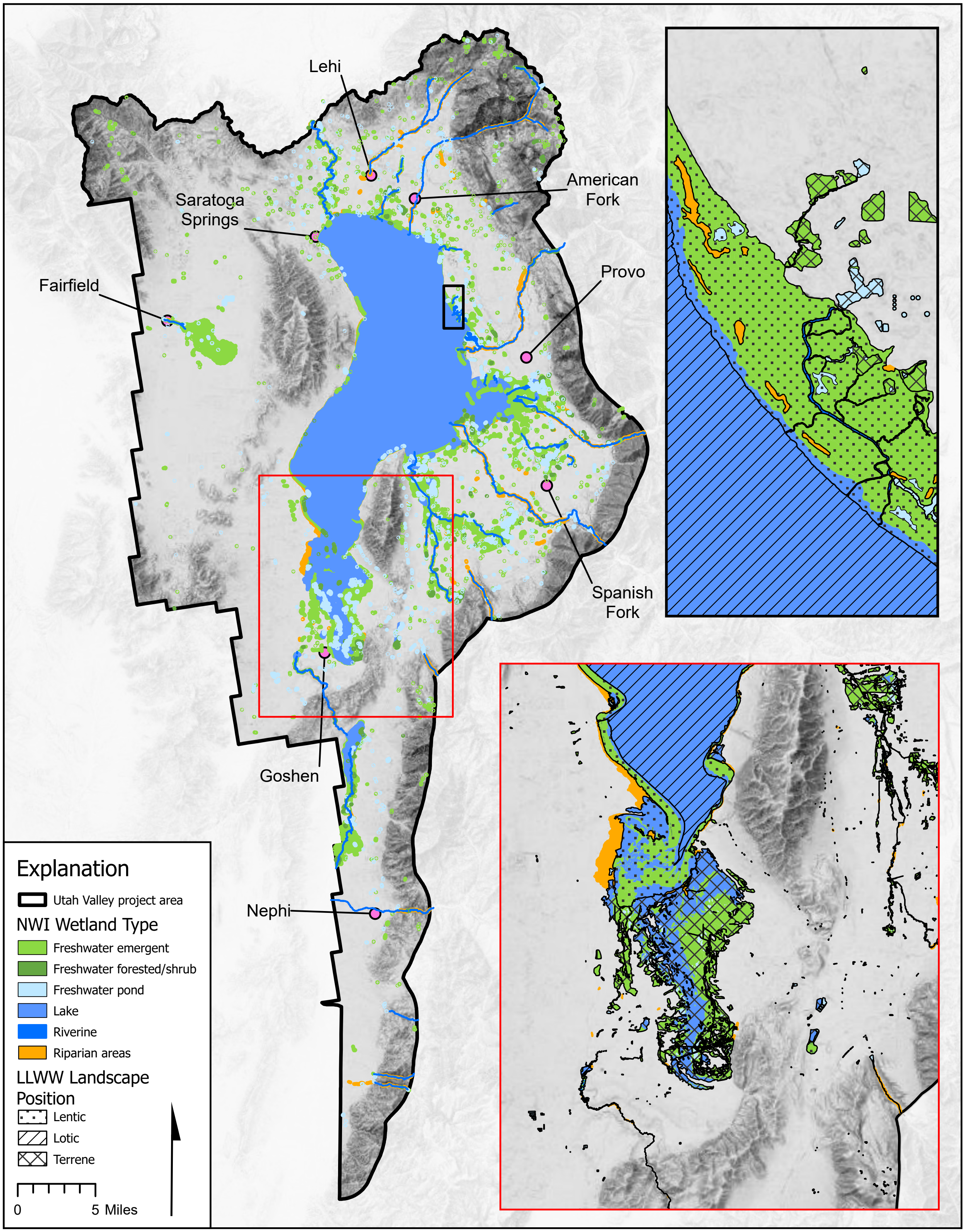


Figure 4. *NWI wetland type in the project area. LLWW landscape position is shown near Goshen (red bordered box) and Powell Slough (black bordered box). Overlaid LLWW information helps identify which wetlands are associated with Utah Lake (lentic wetlands with dot fill), which wetlands are supported by riverine water sources (lotic wetlands with hatch fill), and which wetlands are supported by other water sources (terrene wetlands with cross hatch fill). Note that Utah Lake is considered a lotic waterbody and riparian areas lack any LLWW information.*

Table 3. *Summary of 2024 NWI mapping.*

Broad Wetland Type	New Mapping		
	Cowardin Attributes	**Features**	**Acres**
Lacustrine Systems			
Deep Water	L1UBGh, L1UBH, L1UBHh	3	18,670.5
Aquatic Bed		0	0.0
Shallow Water	L2UBF, L2UBFh, L2UBG, L2UBGx, L2UBH, L2UBKx	10	64,351.0
Lacustrine Shore	L2USA, L2USAh, L2USC, L2USCh, L2USJ	175	8633.8
Artificially Flooded		0	0.0
Lacustrine Total		188	91,655.4
Palustrine Systems			
Aquatic Bed	PABF, PABFb, PABFh, PABFx, PABG, PABGh, PABGx, PABH	142	109.3
Emergent Meadow	PEM1A, PEM1Ah, PEM1Ax, PEM1B, PEM1Bb, PEM1Bd, PEM1Bh, PEM1Bx, PEM1C, PEM1Ch, PEM1Cx, PEM1D, PEM1J, PEM1Jh	2657	18,340.0
Emergent Marsh	PEM1E, PEM1Eb, PEM1Eh, PEM1Ex, PEM1F, PEM1Fh, PEM1Fx, PEM5E, PEM5Eh, PEM5Ex, PEM5F, PEM5Fh, PEM5Fx	560	2522.9
Farmed	Pf	15	16.1
Forested	PFO1A, PFO1Ah, PFO1Ax, PFO1B, PFO1Bx	50	80.0
Scrub Shrub	PSS1A, PSS1Ah, PSS1Ax, PSS1B, PSS1Bb, PSS1Bx, PSS1C, PSS1Ch, PSS1Cx, PSS1E, PSS1Eb, PSS1J, PSS1Jx, PSS2A	288	418.4
Permanent Pond	PUBF, PUBFh, PUBFx, PUBG, PUBGh, PUBGx, PUBH, PUBHh, PUBHx	626	620.3
Seasonal Pond	PUSA, PUSAd, PUSAh, PUSAx, PUSC, PUSCd, PUSCh, PUSCs, PUSCx, PUSJ, PUSJh, PUSJx	474	704.3
Artificially Flooded	PABKx, PUBKx	128	213.8
Palustrine Total		4940	23,025.2
Riverine Systems			
Lower Perennial	R2UBF, R2UBFx, R2UBG, R2UBH, R2USC	60	525.7
Upper Perennial	R3RBF, R3RBG, R3RBH, R3RBHr, R3UBF	21	120.7
Intermittent Streambed	R4SBA, R4SBC, R4SBCx, R4SBJ, R4SBJx	1180	4542.6
Unknown Perennial		0	0.0
Riverine Total		1261	5189.1
Riparian Systems			
Riparian Emergent	Rp1EM, Rp2EM	48	521.5
Riparian Forested	Rp1FO6CW, Rp1FO6MD, Rp1FO6WI, Rp2FO6CW, Rp2FO6MD, Rp2FO6WI	403	868.6
Riparian Scrub Shrub	Rp1SS6MD, Rp1SS6RO, Rp1SS6SC, Rp1SS6WI, Rp2SS6CW, Rp2SS6GW	421	1326.9
Riparian Total		872	2716.9
Total Mapping		7261	122,586.5

Table 4. *Highly invaded wetlands identified in the 2024 NWI mapping.*

Invasive Species	Cowardin Attributes[1]	Features	Acres
Phragmites	PEM5A, PEM5Ah, PEM5Ax, PEM5B, PEM5Bh, PEM5Bx, PEM5C, PEM5Ch, PEM5Cx, PEM5D, PEM5E, PEM5Eh, PEM5Ex, PEM5F, PEM5Fh, PEM5Fx	655	2676.8
Russian olive	Rp1SS6RO, Rp2SS6RO	178	326.8
Tamarisk	Rp1SS6SC, Rp2SS6SC, PSS2A, PSS2B, PSS2C	108	576.4
Total		941	3580.0

[1] List for this project only. Other NWI mapping may use other Cowardin attributes to denote highly invaded wetlands.

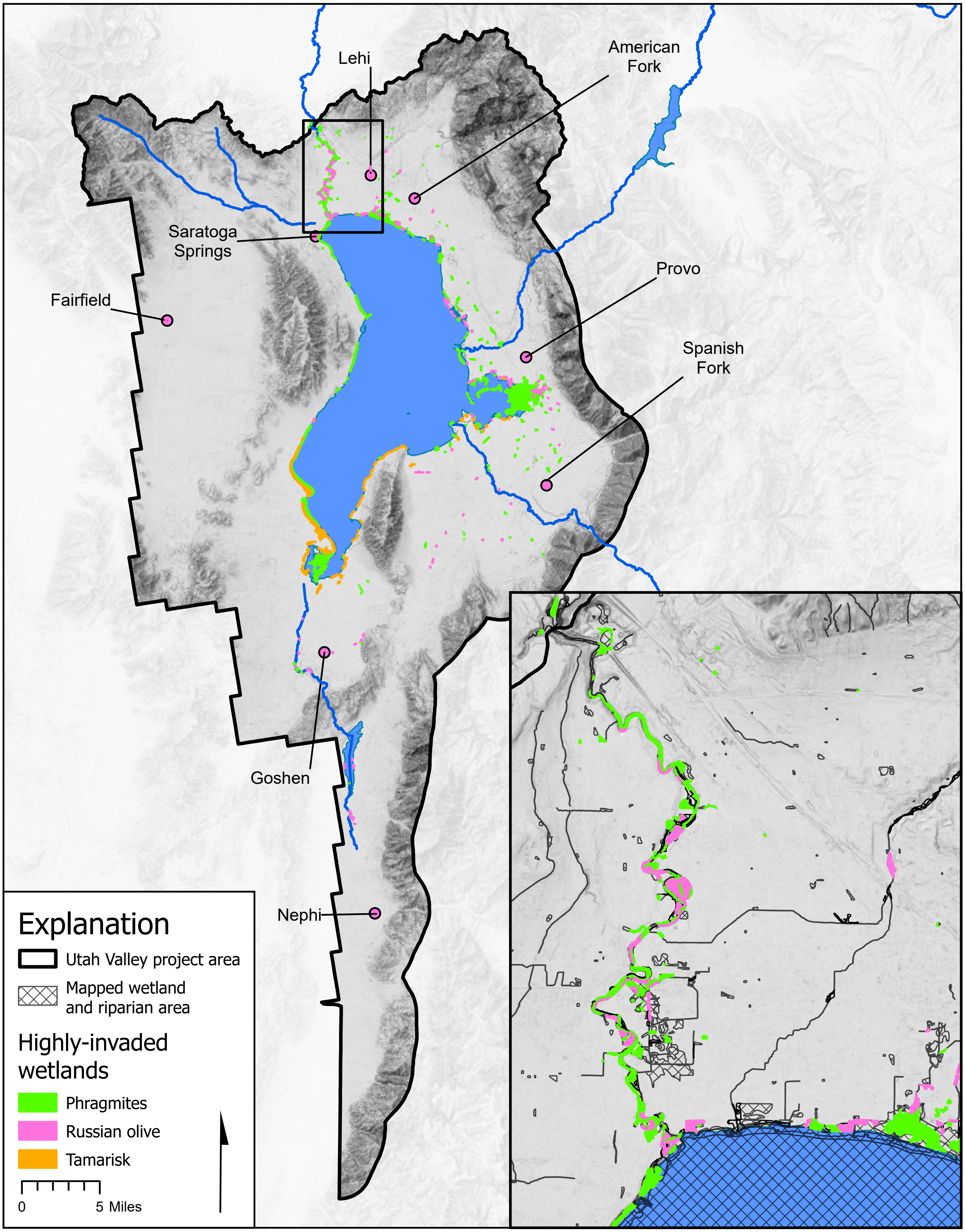


Figure 5. *Highly invaded wetlands and riparian areas with greater than 30 percent invasive cover identified in the 2024 mapping across the project area as well as the Jordan River (black box).*

Table 5. *Hydrogeomorphic classes and description of all features included in LLWW mapping.*

Landscape Position	Landform	HGM Class[1]	Description	Count[2]	Acres[2]
Lotic	River		Perennial rivers and streams like the Jordan River or Currant Creek	72	642.2
	Streams		Seasonal, intermittent, and ephemeral channels	895	3626.9
	Artificial		Man-made canals and ditches	305	915.7
	Lake[3]		Lakes (>20 acres) formed or influenced by riverine inflows	6	82,845.6
	Pond		Ponds (<20 acres) hydrologically connected to nearby rivers through surface flows, alluvial aquifer, or frequent flooding	115	106.0
	Fringe	Riverine	Wetlands along river banks, typically below bankfull elevation and nearly always flooded or saturated	122	128.8
	Floodplain	Riverine	Flat, level wetlands on the active riverine floodplain that are typically flooded every 1–5 years	263	417.9
	Basin	Riverine	Shallow, depressional wetlands either hydrologically connected or periodically flooded by nearby river	130	160.2
Lotic total				1908	88,843.3
Lentic[3]	Ponds		Ponds hydrologically connected to a nearby lake through the alluvial aquifer	45	52.0
	Fringe	Lacustrine fringe	Wetlands along lake shores that are almost always inundated or saturated. This also includes barren shores and beaches	282	6245.9
	Floodplain	Lacustrine fringe	Wetlands along lake shores that are typically flooded by the lake every 1–5 years	539	7387.4
	Basin	Lacustrine fringe	Depressional wetlands hydrologically connected to or periodically flooded by nearby lake	73	314.1
Lentic total				939	13,999.4
Terrene	Lake		Isolated lakes formed by groundwater, springs, irrigation, or artificial sources. This includes large wastewater treatment lagoons	7	175.6
	Pond		Isolated ponds formed by groundwater, springs, irrigation, surface runoff, or artificial sources.	737	765.4
	Fringe	Depressional	Wetlands within isolated ponds, typically below average elevation and nearly always flooded.	24	46.0
	Basin	Depressional	Depressional wetlands typically supported by springs, groundwater, surface runoff or irrigation.	1439	4770.2
	Slope	Slope	Sloping (typically > 2% grade) wetlands where springs, irrigation, or groundwater flow across the surface or subsurface. This includes wetlands formed in irrigated fields	1340	8191.6
	Flat	Flat	Flat (always <2% grade) wetlands supported entirely by surface runoff or groundwater fluctuations. This includes large playas	28	3077.4
Terrene total				3575	17,026.2
Total				6422	119,868.9

Notes

[1] HGM (hydrogeomorphic) classes only identified for wetlands, excluding rivers, streams, lakes or ponds.

[2] Riparian areas not considered for LLWW mapping and exact count and acreages will differ from NWI mapping.

[3] Lentic features include all features associated with a large lake like Utah Lake, but not the lake itself which is considered lotic.

Table 6. *Water sources of all features in LLWW mapping.*

Landscape Position	Water Source	Count	Acres
Lotic	Stream flow	1444	88,238.4
	Overbank flooding	384	540.8
	Alluvial aquifer	77	62.9
	Spring[1]	3	1.3
Lotic total		1908	88,843.4
Lentic	Overbank flooding	795	12,112.4
	Alluvial aquifer	105	482.0
	Irrigation[2]	1	5.5
	Streamflow	38	1399.6
Lentic total		939	13,999.5
Terrene	Precipitation accumulation	501	3469.2
	Groundwater	1605	7724.1
	Artificial	544	676.1
	Irrigation[3]	531	2649.5
	Spring	394	2507.3
Terrene total		3575	17,026.2
Total		6422	119,868.9

Notes

[1] Some spring rills were large enough to map as distinct channels.

[2] One irrigation retention area located near Geneva Steel and along Utah Lake shoreline.

[3] Includes some fringe and retention ponds assigned as overbank flooding and streamflow water sources.

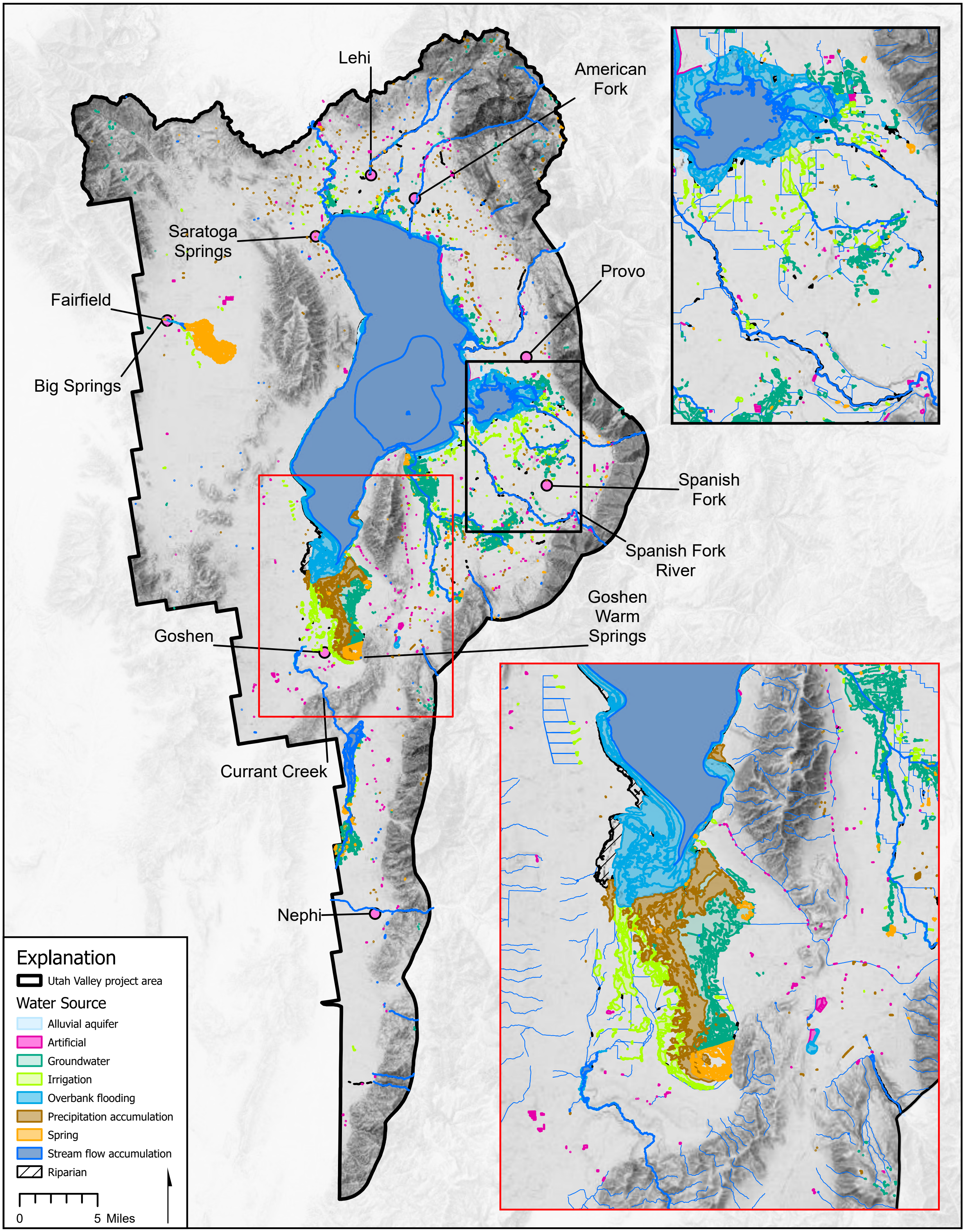


Figure 6. *Wetland water sources identified in the 2024 mapping across the entire project area as well as near Goshen (red bordered box) and Provo Bay (black bordered box). For clarity, the overview map omits seasonal, intermittent, ephemeral and artificial channels.*

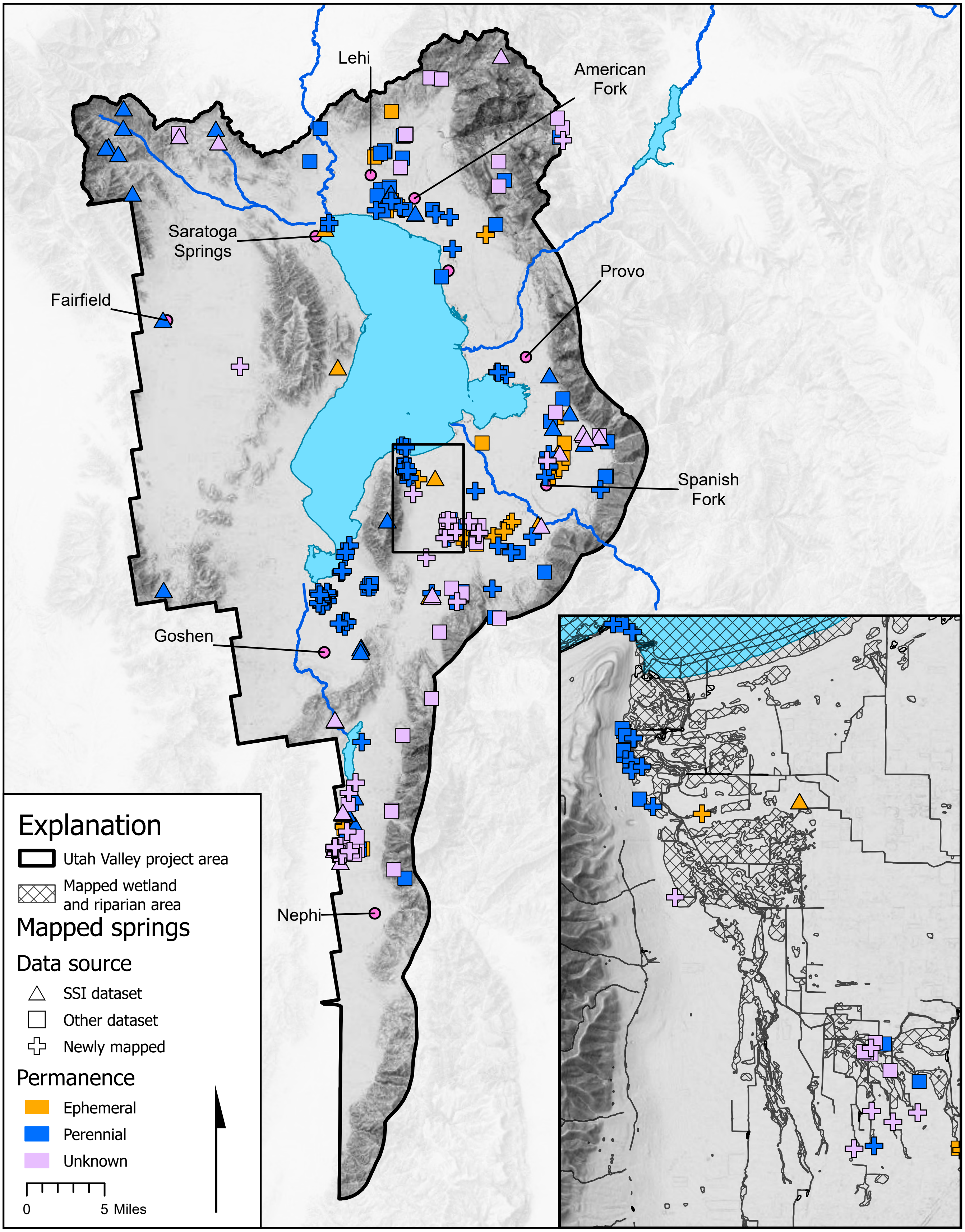


Figure 7. The data source and permanence of all mapped springs across the project area as well as near southern Utah Valley (black box). Shape outline identifies if the individual spring was previously included in the Spring Stewardship Institute dataset, another dataset like the National Hydrography Dataset, or newly identified by this project. Estimated spring permanence based on review of several years of imagery.

PATTERN ANALYSES

Landscape Function

Wetlands provide valuable services like water quality protection that benefit both the environment and human communities (Brinson, 1993; Millennium Ecosystem Assessment Program, 2005; Mitsch and Gosselink, 2015). Estimates of wetlands economic value vary depending on the suite of services and scale considered. National assessments estimate wetlands contribute $7.7 trillion annually to the U.S. economy (Lang et al., 2024). More localized estimates typically value wetlands relative to the cost of infrastructure needed to replace those services (e.g., wastewater treatment plants or flood control structures). Such efforts consistently estimate wetland values on the order of millions of dollars and conclude that wetland conservation costs less than infrastructure construction (Costanza et al., 1997; Trochell and Bernthal, 1998; Mitsch and Gosselink, 2015).

Wetland services extend from unique physical and chemical processes occurring within a wetland that combine to produce a distinct wetland function. For example, water quality protection services are a result of dense wetland vegetation intercepting sediments (Mitsch and Gosselink, 2015). Wetlands provide a suite of functions ranging from wildlife habitat to carbon sequestration. The type and degree of functions provided are determined by intrinsic biotic and abiotic factors like vegetation type, human disturbance, or geomorphic setting (Brinson, 1993; Marshall et al., 2018). Combined, the Cowardin attribution and LLWW attribution describe many of these biotic and abiotic factors and support queries identifying individual wetlands that provide distinct functions (Marshall et al., 2018).

Geomorphic setting provides a general sense of how wetland function might be distributed across the landscape and past functional analyses have broadly described wetland function at landscape levels (Tiner, 2014; U.S. Environmental Protection Agency, 2015). The spatial aspect of the 2024 NWI and LLWW mapping and granular identification of wetland functions support quantitative and geostatistical assessments of wetland function and pattern.

Function Methods

We followed methods established by Marshall et al. (2018) and described in Goodwin and Molinari (2022) to model wetland functions using the combined 2024 NWI and LLWW mapping. Models consisted of a series of spatial and attribute queries identifying wetlands with distinct shapes, locations, or vegetation types documented by Marshall et al. (2018) as providing certain functions (Table 7). The models rely heavily on the combined Cowardin and LLWW attribution. Some queries required supporting datasets to evaluate slope, topographic wetness index (a measure of how likely a given area is to accumulate surface runoff), and degree of human disturbance. Slope and topographic wetness index values were derived from 10-meter DEMs using tools readily available within ArcGIS. Human disturbance values were obtained from landscape integrity models calculating disturbance scores based on proximity to known aquatic habitat stressors (Menuz, 2015). We modeled eight distinct functions and categorized each as a “Physical” function resulting from biogeochemical processes or as “Habitat” functions describing distinct wildlife habitat types (Table 7).

Table 7. *UGS-modeled wetland functions, additional non-mapping data, and general description of wetlands identified by each model.*

Function	Function Type	Additional Data	Provisioning Wetland Type
Bank and Shoreline Stabilization	Physical		Woody wetlands and other wetlands adjacent to streams and rivers
Carbon Sequestration	Physical	Disturbance	Beaver complexes, fens, and other minimally disturbed vegetated wetlands
Sediment and Particulate Retention	Physical	Slope	Beaver ponds, lakes, ponds, basins and vegetated wetlands on floodplains, isolated wetlands adjacent to streams, rivers, or other waterbodies
Streamflow Maintenance	Physical		Headwater wetlands connected to streams and rivers, groundwater-dependent wetlands adjacent to streams and rivers, isolated wetlands on floodplains
Aquatic Macroinvertebrate Habitat	Habitat	Disturbance	Minimally disturbed wetlands with seasonal flooding and temporarily flooded basins
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	Habitat	Disturbance	Lakes, ponds, herbaceous wetlands with seasonal flooding and moderate disturbance
Surface Water Detention	Physical	Slope, Topographic Wetness Index	Isolated wetlands likely to accumulate surface runoff, ponds, floodplain wetlands, isolated headwater wetlands adjacent to streams

We applied each function model to the roughly 6400 mapped wetlands with Cowardin and LLWW attributes to identify individual wetlands with a "High" and "Moderate" likelihood of providing a certain function (Marshall et al., 2018; Goodwin and Molinari, 2022). "High" likelihood indicated either optimal conditions or well documented provision of a distinct function; "Moderate" likelihood indicated a wetland could provide a particular function but characteristics like nearby disturbance limited the degree of function. We reduced uncertainty in the overall model by excluding a "Low" or "None" category to limit the model outputs to wetlands reliably providing a particular function (Goodwin and Molinari, 2022).

We evaluated spatial patterns within the model outputs using two hot spot analyses to identify distinct areas with significant locally high or low densities of wetlands likely to provide certain functions. For each modeled function, we scored individual wetland polygons according to the likelihood it provides that function: High = 2, Medium =1, all others = 0. We also calculated cumulative scores for 1) all functions, 2) physical functions, and 3) habitat functions to generate 11 distinct function scores for each individual wetland polygon.

We aggregated all scores across a 1-square kilometer (247 acres) grid and calculated the mean score of all polygons within an individual cell for each distinct function score. Utah Lake occupies much of the project area and the functions provided by the lake overshadow contributions from surrounding wetlands during a standard hot spot analysis. To account for this, we applied a disparity index to highlight regions with greater than average function. Disparity index values were calculated from the previous 1 km grid as the difference between an individual cell's mean score and the project mean score divided by the project mean score. We calculated disparity index values for each cell in the grid and for all 11 distinct function scores. The two hot spot analyses were conducted using the final 1 km grid and the Hot Spot Analysis (Getis-Ord-Gi statistic) tool in ArcPro 3.3, defining the spatial neighborhood for each analysis as all eight adjacent cells and correcting for spatial dependency. We conducted the Average analysis using the mean values for all 11 distinct function scores and the Disparity Index analysis using the disparity index values.

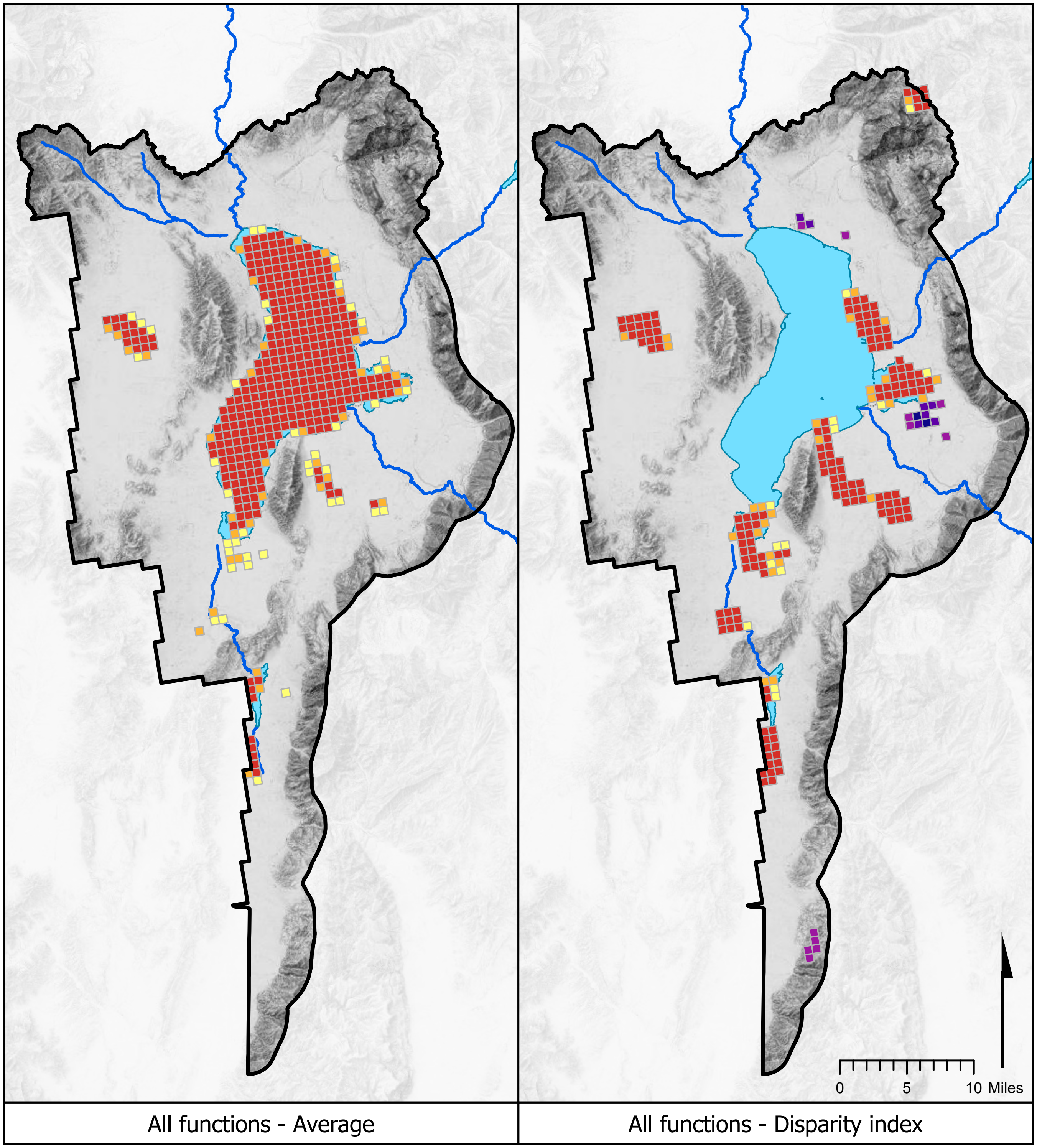
Function Results

From our models, nearly 70% of all mapped wetlands provide at least one well-documented physical or habitat function (Table 8). Wetlands that did not provide any of the eight modeled functions fell into three distinct categories: intermittent channels, canals, or wetlands within highly disturbed areas. The models show Utah Lake and the surrounding shorelines provide over 82,000 acres of sediment and particulate retention and aquatic macroinvertebrate, shorebird, and waterfowl/waterbird habitat. Utah Lake represents between 76% and 93% of the total area that provides each of those functions and 73% of the total area of all wetlands providing at least one function.

Average analyses of all, habitat, and physical functions consistently identified Utah Lake and Fairfield Sinks as high-functioning hot spots (Figures 8, 9, and 10). Disparity Index analyses identified the Provo River Delta as consistently providing significantly greater function than Utah Lake and other shoreline habitats (Provo Bay and Powell Slough) as providing relatively greater or lesser physical or habitat function than the lake itself. Irrigated wetlands near Goshen, Benjamin, and Mona Reservoir variously emerged as all, habitat, or physical hot spots through both the Average and Disparity Index analyses. Headwater wetlands near American Fork were similarly mapped as all and physical hotspots. Hot spot analysis results for individual functions are included in Appendix B.

Table 8. *Summary of wetland features and extent (acres) in project area identified as providing some function by the UGS function models.*

Function	Wetland Features			Wetland Extent		
	Count	Percent High	Percent Moderate	Acres	Percent High	Percent Moderate
Bank and Shoreline Stabilization	645	10.0	0.0	3861	3.2	0.0
Carbon Sequestration	521	0.2	7.9	5040	0.0	4.2
Sediment and Particulate Retention	2315	6.5	29.5	92,925	1.6	76.0
Streamflow Maintenance	944	1.2	13.5	3618	0.1	3.0
Aquatic Invertebrate Habitat	1800	4.1	24.0	96,669	1.6	79.1
Shorebird Habitat	1785	19.9	7.9	107,145	82.8	6.5
Waterfowl and Water Bird Habitat	789	9.6	2.7	88,649	73.8	0.1
Surface Water Detention	1520	3.4	20.2	2718	0.7	1.6
Any Physical	2910			96,081		
Any Habitat	2567			108,870		
Both Physical and Habitat	1114			91,495		
Any Function	4363			113,455		



Explanation

Hot spot analysis results

🟦 Cold Spot with 99% Confidence
🟪 Cold Spot with 95% Confidence
🟪 Cold Spot with 90% Confidence
🟥 Hot Spot with 99% Confidence
🟧 Hot Spot with 95% Confidence
🟨 Hot Spot with 90% Confidence

Figure 8. *Hotspot analysis for all wetlands identified as providing any of the eight modeled functions. Hotspot analyses based on 1-km grid with values representing the average cumulative score (Average) and the average score difference from Utah Lake (Disparity index). Hot or cold spots indicate cells with significantly higher or lower scores relative to neighboring cells.*

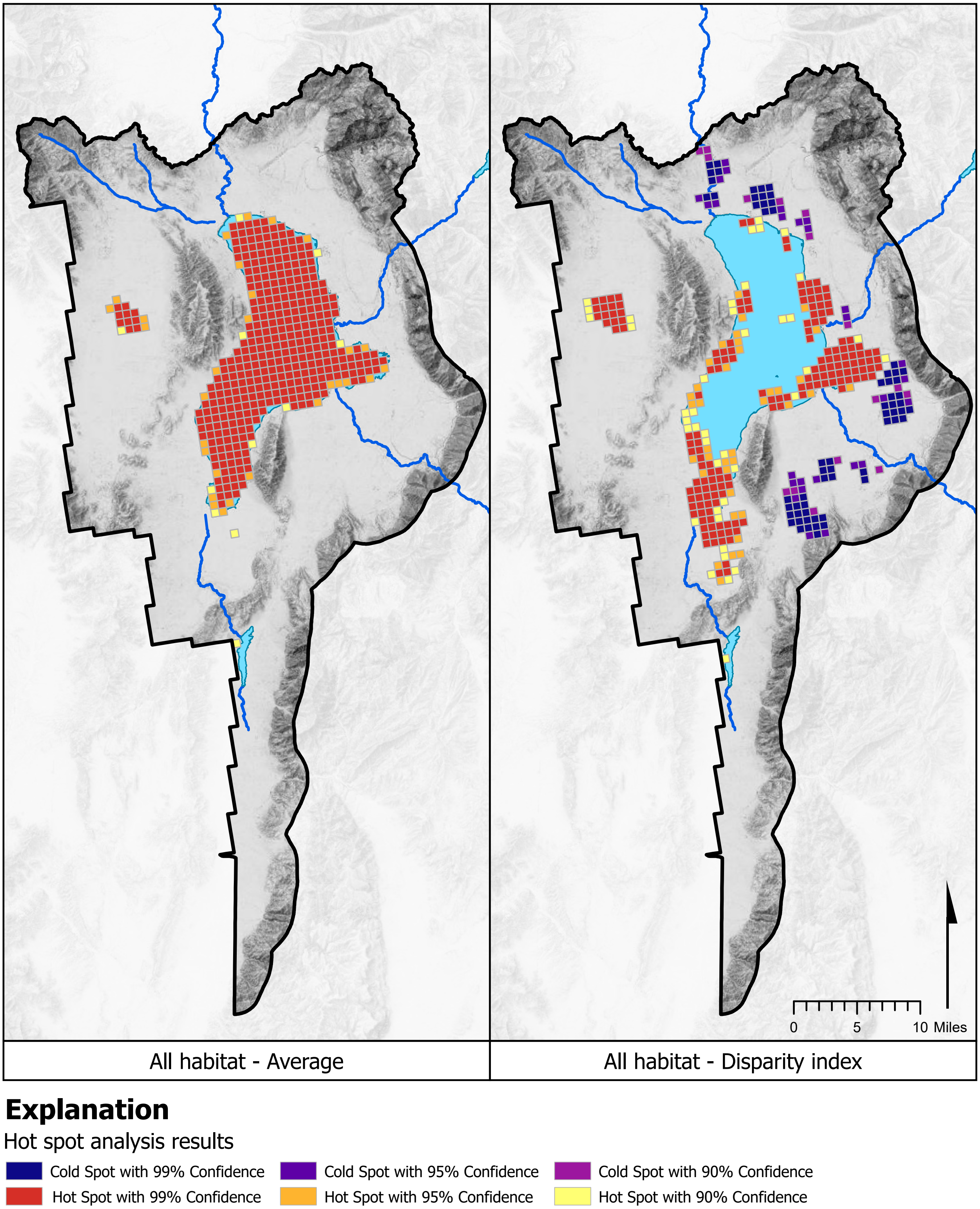


Figure 9. *Hotspot analysis for all wetlands identified as providing any of the modeled habitat functions (Aquatic invertebrate, Shorebird, or Waterfowl). Hotspot analyses based on 1-km grid with values representing the average cumulative score (Average) and the average score difference from Utah Lake (Disparity index). Hot or cold spots indicate cells with significantly higher or lower scores relative to neighboring cells.*

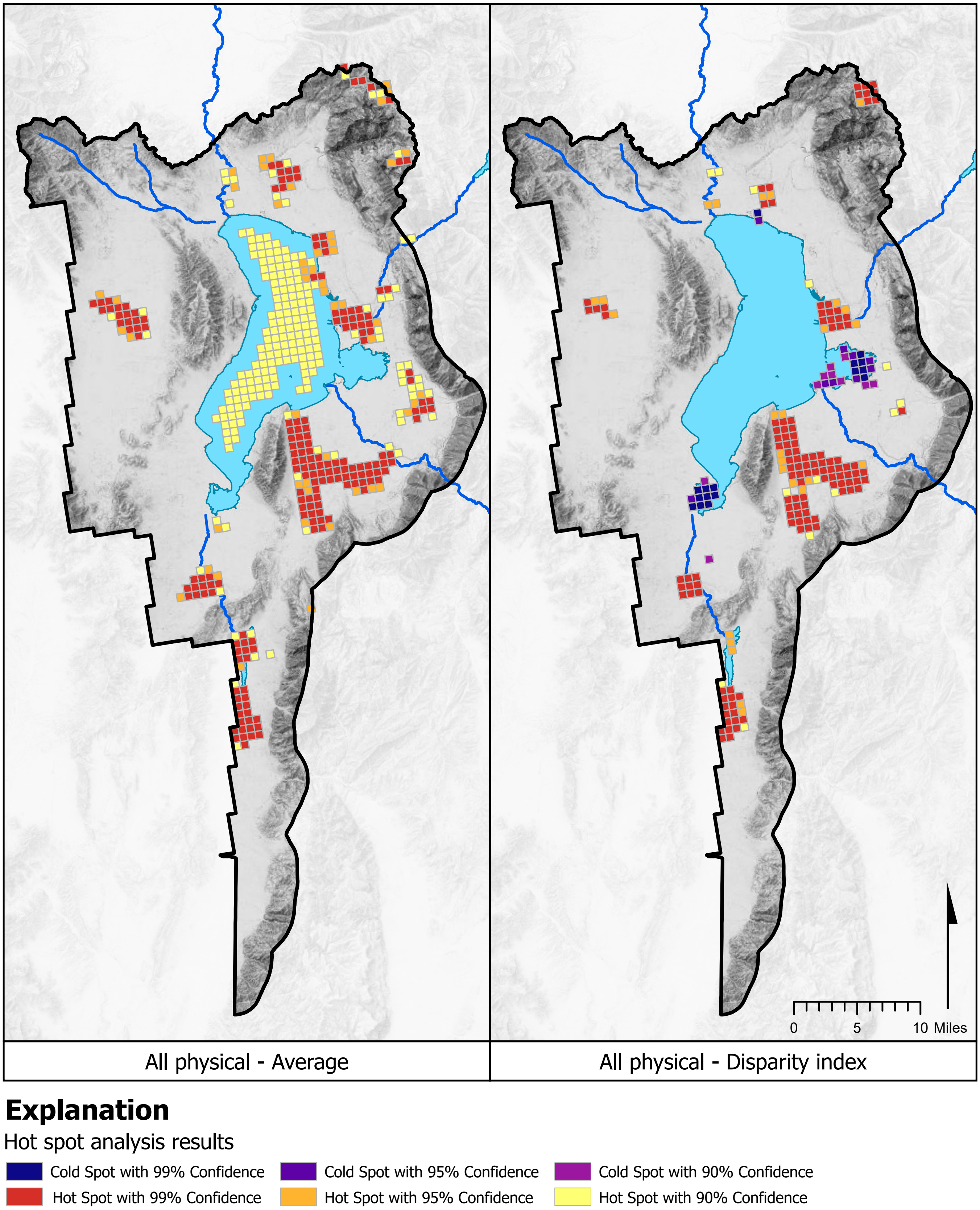


Figure 10. *Hotspot analysis for all wetlands identified as providing any of the modeled physical functions (Bank stabilization, Carbon sequestration, Sediment retention, Streamflow maintenance, Surface water detention). Hotspot analyses based on 1-km grid with values representing the average cumulative score (Average) and the average score difference from Utah Lake (Disparity index). Hot or cold spots indicate cells with significantly higher or lower scores relative to neighboring cells.*

Analyses of all functions included most hot spots identified by analyses of either the habitat or physical functions. There was less agreement between habitat and physical function analyses, and the Disparity Index analyses of both function types identified many wetlands as both hot spots and cold spots. Most Utah Valley wetlands forming habitat cold spots are adjacent to disturbances in the landscape integrity models. Wetlands near Benjamin, the Jordan River, and American Fork provided relatively greater physical function while also providing reduced habitat functions. Conversely, wetlands in Provo and Goshen Bays provided increased habitat function but relatively less physical function.

Wetland Loss

Over one-half of the United States' wetlands have been lost to cropland, infrastructure, or dewatering since 1780 (Mitsch and Gosselink, 2015). Draining or filling of wetlands to create arable agricultural lands drove national wetland loss until the mid-1900s. Losses associated with urban and rural development, including construction of buildings, roads, or other infrastructure, account for 34% to 53% of total net loss since 1970 (Frayer et al., 1983; Dahl, 2000; Dahl, 2006; Lang et al., 2024). Lang et al. (2024) report changing rates of loss and disproportionate net loss by wetland type, with net loss accelerating by over 50% from 2004—2009 to 2009—2019 and mostly occurring in vegetated wetlands (swamps, shrublands, wet meadows, or marshes).

Wetland loss in Utah has been less extreme than some coastal or midwestern states and Mitsch and Gosselink (2015) estimate nearly one-third of Utah's wetlands have been lost to agriculture or development. Watershed-specific estimates of historical wetland loss in northern Utah report losses ranging from 6% to 100% and cite agriculture, pasture conversion, and dewatering as the primary causes (Clement, 2019). Relict peat deposits identified during the Provo River Delta Restoration Project (BIO-West, 2019) and dewatering of several Utah Lake tributaries (Abbott et al., 2022) indicate early European agricultural efforts also substantially drained and dewatered Utah Valley wetlands.

More recent wetland loss has been well linked to residential and commercial development, and these pressures exist throughout Utah Valley (Dahl, 2000, 2006; Fluet-Chouinard et al., 2023; Lang et al., 2024). The population of Utah County nearly doubled between 2000 and 2019 with influx and natural growth adding nearly 300,000 new residents and expanded infrastructure (Kem C. Gardner Policy Institute, 2019). This growth has contributed to increased wetland resource conflicts and frequent public inquiries to the UGS (Menuz, written communication, 2024).

Local governments recognize the value of their wetlands and some Utah Valley cities like Provo, American Fork, or Lehi regulate development of wetlands and other sensitive lands with additional permitting or building practices (Utah Lake Commission, 2012; Design Workshop, 2023; Lehi, Utah, Municipal Code §36.1 [2012]). An updated NWI dataset helps planners identify which wetlands would be protected by conservation practices but lacks information regarding declining wetland condition or loss. Planners need this information to determine where additional conservation practices might be required or which practices would be most effective.

Some datasets like the NWI difference product identify distinct areas of wetland change across the U.S. by intersecting the NWI with recent landcover datasets to identify where wetlands have been lost or converted to other landcovers (Zou et al., 2022). The NWI difference product identifies three distinct types of wetland change:

1. Wetland to Impervious: All wetlands now mapped as developed by landcover dataset,
2. Dry Wetland to Water: Drier vegetated wetlands like meadows or willow thickets now mapped as open water by landcover dataset, and
3. Upland to Water: Non wetland areas now mapped as open water by landcover dataset.

Zou et al. (2022) created the difference product as a nation-wide analysis identifying individual HUC12 watersheds needing updated NWI mapping. As a local wetland conservation planning tool, it has several shortcomings. By summarizing wetland loss across an entire watershed, it lacks the granular data to identify patterns within the boundaries and zoning authority of individual municipalities. This limits planners' ability to develop and implement conservation practices specific to their community's needs. The NWI difference product identifies change from the national NWI dataset, which consists of a patchwork of individual NWI projects. This complicates interpretation in areas like Utah Valley which contain wetland mapping from two different NWI projects mapped to different base imagery (Figure 2). In western and southern Utah Valley, the NWI difference product identifies change that occurred over the 40 years since the original mapping in the 1980s but only 20 years of change in the urban areas along the northeastern shore with updated 1998 mapping. This mismatch overemphasizes change from areas with older mapping and limits understanding of wetland change within communities spanning both NWI projects.

To better understand patterns of wetland loss in Utah Valley, we adapted methodology from Zou et al. (2022) to develop difference products specific to our project area that 1) evaluated wetland change over consistent time periods and 2) identified discrete points of wetland change. We conducted additional spatial analyses across multiple time periods to better illustrate wetland loss patterns and how those patterns may have shifted over time. We hope these difference products and additional analyses will aid county and local governments by identifying threatened wetlands, patterns of wetland loss, and potential local factors driving wetland loss in Utah Valley.

Loss Analysis Methods

We followed methodology established by Zou et al. (2022) to identify wetland change by intersecting NWI mapping with the National Land Cover Dataset (NLCD). Dr. Zou provided several python scripts that allowed us to replicate the NWI processing, reclassification, and NLCD categorization necessary to identify areas of wetland change consistent with their 2022 work. Dr. Zou also provided Google Earth Engine (GEE) scripts for correcting known errors within the NLCD with several indices derived from Landsat imagery. We modified both the python and GEE scripts to 1) limit analysis extent to our Utah Valley project area, 2) simplify data inputs, and 3) update GEE script parameters to accommodate the Landsat Level 2 collection (Google, 2024).

We modified the Zou et al. (2022) methodology by identifying wetland losses as distinct points rather than aggregations to HUC12 or census tract boundaries and using archival NWI mapping rather than the current national NWI. We harmonized our NWI and NLCD inputs to 30-meter rasters and conducted a pixel-level change analysis between the two rasters. This analysis detected specific pixels with mismatched wetland and landcover values, i.e., where the NWI cell value corresponds to wetland and the NLCD cell value corresponds to a developed land-category. We converted mismatched cells to distinct points representing a known wetland loss. These points supported our spatial analyses and allowed us to summarize wetland loss by project area, municipalities, and other project-specific units not possible with the original NWI difference product.

To examine wetland loss over time we collated two NWI datasets representing wetland extent during the early 1980s and during 1998 by requesting archival NWI mapping from the USFWS (Jane Harner, USFWS, written communication, 2023). Archival 1980s mapping did not exist as polygonal data for several locations within our Utah Valley project area. At these locations, we orthorectified and digitized scanned copies of the original, hand-drawn NWI maps. Wetland data for 1998 was extracted from a 1998 NWI update along the larger Wasatch Front region. We input the 1980s and 1998 wetlands data, along with NLCD data from 2001 and 2021—the NLCD datasets nearest to our 1998 and 2024 NWI wetlands data—to our modified python scripts to identify wetland losses across three time periods: 1980s–2021, 1980s–2001, and 1998–2021 (Table 9). Because the 1998 NWI update was not completed across our entire Utah Valley project area, we limited our analyses of 1980s–2001 and 1998–2021 wetland losses to the 1998 NWI update boundary (Figure 2).

Wetland losses were reported using two of the wetland change categories from the NWI difference product that represent an observable wetland loss and dramatic function reduction: Wetland to Impervious and Dry Wetland to Water (Lang et al., 2024). We excluded lacustrine waterbodies, riparian areas, and all riverine features from our analysis and general wetland definition. Similarly, we defined all dry wetlands as vegetated wetlands without seasonally flooded-saturated (E) or semi-permanently flooded (F) water regimes (Zou et al. 2022). For both categories and each of the three time periods, we produced a separate change raster and excluded small, isolated changes from the analysis by conditionally filtering cells with few wetland neighbors. This effectively limited our analysis to wetlands mapped as one acre or larger and helped reduce errors resulting from rasterizing polygonal NWI data or spatial misalignments between the NWI or NLCD datasets.

We determined the extent of wetland loss by multiplying the percentage of impervious surface or Landsat-corrected open water from the NLCD datasets by the total cell area (900 m^2) (Zou et al., 2022). For example, a wetland loss occurring where NLCD identified 50% impervious surface would be estimated as a 0.11-acre (450m^2) loss. We summarized wetland loss by cities or towns using current municipal boundaries (Utah Geospatial Resources Center, 2023), unincorporated Juab County, and unincorporated Utah County, which was divided into three zones (north, west, and south) (Figure 2).

Table 9. *Overview of datasets, comparison areas, and time periods used for the loss analysis.*

Source NWI Mapping	Compared Landcover	Comparison Area	Time Period
Archival 1980s	2001 NLCD	1998 Update boundary	1980s–2001
1998 Update	2021 NLCD	1998 Update boundary	1998–2021
Archival 1980s	2021 NLCD	Utah Valley project boundary	1980s–2021

We evaluated wetland loss patterns using both hot spot and clustering analyses. Hotspot analyses incorporate Getis-Ord-Gi statistical methods (ESRI, 2025) assessing the extent of discrete losses to identify areas with significantly greater wetland loss. The hot spot analyses provided statistical certainty while describing any patterns. The clustering analyses identified grouped areas of wetland loss independent of an arbitrary aggregation boundary and at scales more appropriate to land use planning efforts. Discrete Wetland to Water losses were too sparse for robust analysis and we limited the spatial analyses to Wetland to Impervious losses from each of the three time periods (1980s–2001, 1998–2021, and 1980s–2021). Due to the limited extent of the 1998 NWI mapping, we limited both analyses for the 1980s–2001 and 1998–2021 periods to the 1998 update boundary (Figure 2).

We ran the wetland loss hot spot analysis similarly to the function hot spot analyses by aggregating Wetland to Impervious losses to a 1-square-kilometer grid, creating a grid for each of our three time periods, and using the Hot Spot Analysis and Optimized Hot Spot Analysis tools in ArcPro 3.3. Each grid was supplied to two differing hot spot methods to generate six distinct hot spot analyses. Hot spot methods differed by neighborhood, with an "optimized" hot spot method to broadly identify areas with significant wetland losses and a "restricted" hot spot method with an eight-cell neighborhood to identify small, local areas with significant wetland losses.

The clustering analysis consisted of spatial clustering to group wetland losses into distinct clusters and a kernel density calculation to circumscribe the general boundaries of each cluster. All steps were completed using tools available in ArcPro 3.3. The Density-based tool clustered the Wetland to Impervious losses from each time period using the OPTIC method, a 1500-meter search distance, and a sensitivity and minimum cluster size of 10. Appropriate clustering thresholds were determined through best professional judgement and sought to balance the number of distinct clusters, cluster size, and reasonable grouping. We used the Kernel Density tool to generate a raster depicting wetland loss densities, which we divided with the Contour tool into 50-unit increments. The contour best aligned with the clustered points was used to represent wetlands lost to impervious surfaces.

Loss Analysis Results

We identified nearly 1800 acres of total wetland loss in the project area from 1980s to2021 with 98% of that loss occurring as conversion to impervious surfaces (Table 10). Total losses during the 1980s–2001 and 1998–2021 periods followed a similar pattern. The 800 acres of Wetland to Impervious losses from 1980s–2001 accounted for 72% of the total losses in that period. Seven hundred and fifty acres from 1998 to 2021 accounted for 90% of total losses. Dry Wetland to Water losses of 150 and 50 acres accounted for the respective remaining total losses from the 1980s–2001 and 1998–2021 periods.

Of the 1800 acres of total wetland lost across the project area from 1980s to 2021, 56% of those losses occurred within Provo, Lehi, and Orem. Those three municipalities contain thousands of acres of mapped wetlands (9% of all mapped wetlands in project area from 1980s to 2021) and proportional losses range from 13% to 76% of all mapped wetlands within municipal boundaries. During the 1980s–2021 period, Orem experienced the greatest proportional total wetland loss (76%). Pleasant Grove, American Fork, Lehi, Nephi, and Lindon all experienced greater than 15% losses (42%, 21%, 19%, 18%, and 16% respectively). Total wetland losses within some municipalities increased from the 1980s–2001 period to the 1998–2021 period (Table 10). Vineyard, Spanish Fork, and Saratoga Springs all experienced at least a two-fold increase of total wetland losses (740%, 230%, and 240% increases respectively), with Wetland to Impervious losses increasing by an order of magnitude in Vineyard and Saratoga Springs (1220% and 1330% respectively).

Optimized and restricted hot spot analyses identified significantly greater wetland losses in northeastern Utah Valley for all time periods (Figures11 and 12). For the 1980s–2021 period, the optimized hot spot identified a single hot spot extending from Lehi to Spanish Fork and including nearly the entire northeastern shoreline of Utah Lake. The restricted hot spot analysis divided this into five distinct areas roughly centered on Lehi, Vineyard, Provo, Provo Bay, and Springville (Figure 11). Restricted hot spot analyses for the 1980s–2001 and 1998–2021 periods also identified significantly greater wetland losses at these areas, with each analysis identifying slightly different hot spots (Figure 12). The 1980s–2001 analysis identified no significant losses near Lehi and smaller hot spots near Vineyard and Springville. The 1998–2021 analysis identified hot spots at all five hot spots from the 1980s–2021 analysis but identified each as a smaller area.

The cluster analysis similarly identified distinct areas of wetland loss along Utah Lake's northeastern shore (Figure 13). Wetland losses from 1980s to 2021 extended across most of the shoreline as three major clusters covering an area from Saratoga Springs to Provo, and from Provo Bay to Spanish Fork. Other isolated clusters exist along the southern and western shores of Utah Lake as well as near Salem and Payson. Identified wetland losses from 1998 to 2021 only partially overlap with losses

Table 10. *Estimated wetland losses (acres), total wetland area (acres), and relative amount converted to impervious surfaces (percentage) summarized by municipal or unincorporated county area for the 1980s–2001, 1998–2021, and 1980s–2021 time periods. Total wetland area includes ponds, vegetated wetlands, and dry wetlands provided to analysis regardless of size or shape. Some municipalities exist entirely or partly outside the comparison area of the 1980s–2001 and 1998–2021 time periods and estimated losses may be only partly represented. Cell shading highlights impervious conversions between 5 and 10% (pale), 10 and 15% (medium), and greater than 15% (dark).*

Municipality	**1980s-2001**				**1998-2021**				**1980s-2021**			
	Total Wetland Area	**Dry Wetland to Water**	**Wetland to Impervious**	**Impervious Conversion (%)**	**Total Wetland Area**	**Dry Wetland to Water**	**Wetland to Impervious**	**Impervious Conversion (%)**	**Total Wetland Area**	**Dry Wetland to Water**	**Wetland to Impervious**	**Impervious Conversion (%)**
Alpine[2]	1	0	0	0	17	0	0	1	1	0	0	0
American Fork	439	0	23	5	262	0	10	4	439	0	91	21
Bluffdale	0	0	0	0	0	0	0	0	0	0	0	0
Cedar Fort[1]	-	-	-	-	-	-	-	-	13	0	0	0
Cedar Hills[2]	1	0	0	0	9	0	3	35	1	0	0	0
Draper	0	0	0	0	2	0	0	0	0	0	0	0
Eagle Mountain[2]	0	0	0	0	0	0	0	0	57	0	0	0
Elk Ridge[2]	3	0	0	0	0	0	0	0	3	0	0	0
Fairfield[1]	-	-	-	-	-	-	-	-	1148	0	0	0
Genola[2]	2411	4	0	0	2432	5	0	0	2515	2	0	0
Goshen[1]	-	-	-	-	-	-	-	-	29	0	0	0
Highland[2]	46	0	1	1	88	1	13	14	47	0	2	4
Lehi	1434	10	49	3	693	4	70	10	1434	4	268	19
Lindon	386	8	42	11	343	0	24	7	386	4	57	15
Mapleton[2]	21	0	0	0	25	0	1	3	33	0	0	1
Orem	313	0	126	40	131	0	54	41	313	0	239	76
Payson[2]	506	0	1	0	511	0	13	2	506	0	26	5
Pleasant Grove[2]	107	0	21	20	42	0	7	18	113	0	47	42
Provo[2]	3821	11	378	10	3383	4	214	6	3825	3	490	13
Rocky Ridge[1]	-	-	-	-	-	-	-	-	0	0	0	0
Salem[2]	416	0	3	1	710	2	9	1	418	0	16	4
Santaquin[2]	1	0	0	0	2	0	0	0	6	0	0	0
Saratoga Springs	653	9	2	0	486	1	25	5	653	1	63	10
Spanish Fork[2]	919	3	39	4	1000	0	97	10	948	0	123	13
Springville	974	0	71	7	801	0	31	4	974	0	103	11
Vineyard	1565	9	13	1	1524	0	159	10	1565	0	171	11
Woodland Hills[2]	0	0	0	0	0	0	0	0	0	0	0	0
Levan[1]	-	-	-	-	-	-	-	-	0	0	0	0
Mona[1]	-	-	-	-	-	-	-	-	57	0	0	0
Nephi[1]	-	-	-	-	-	-	-	-	38	0	7	18
Utah County – North[2]	5296	18	9	0	5062	0	13	0	5393	0	24	0
Utah County – West[2]	17,503	33	0	0	17,831	27	1	0	22,980	15	1	0
Utah County – South[2]	12,375	42	16	0	12,621	8	10	0	12,468	15	19	0
Juab County[1]	-	-	-	-	-	-	-	-	2834	0	0	0
Entire comparison area	49,192	147	795	2	47,975	52	753	2	59,195	44	1746	3

Notes

[1] Nephi, Fairfield, Cedar Fort, Levan, Mona, Goshen, Rocky Ridge, Juab County communities are wholly outside the 1998 NWI update and no wetlands or losses were identified for the 1980s–2001 and 1998–2021 periods.

[2] Salem, Woodland Hills, Elk Ridge, Alpine, Pleasant Grove, Spanish Fork, Mapleton, Genola, Payson, Cedar Hills, Highland, Eagle Mountain, Santaquin, Provo, and all unincorporated Utah County communities are only partially within the 1998 NWI update. Mapped wetlands and identified losses may only represent portions of total wetland resources and losses.

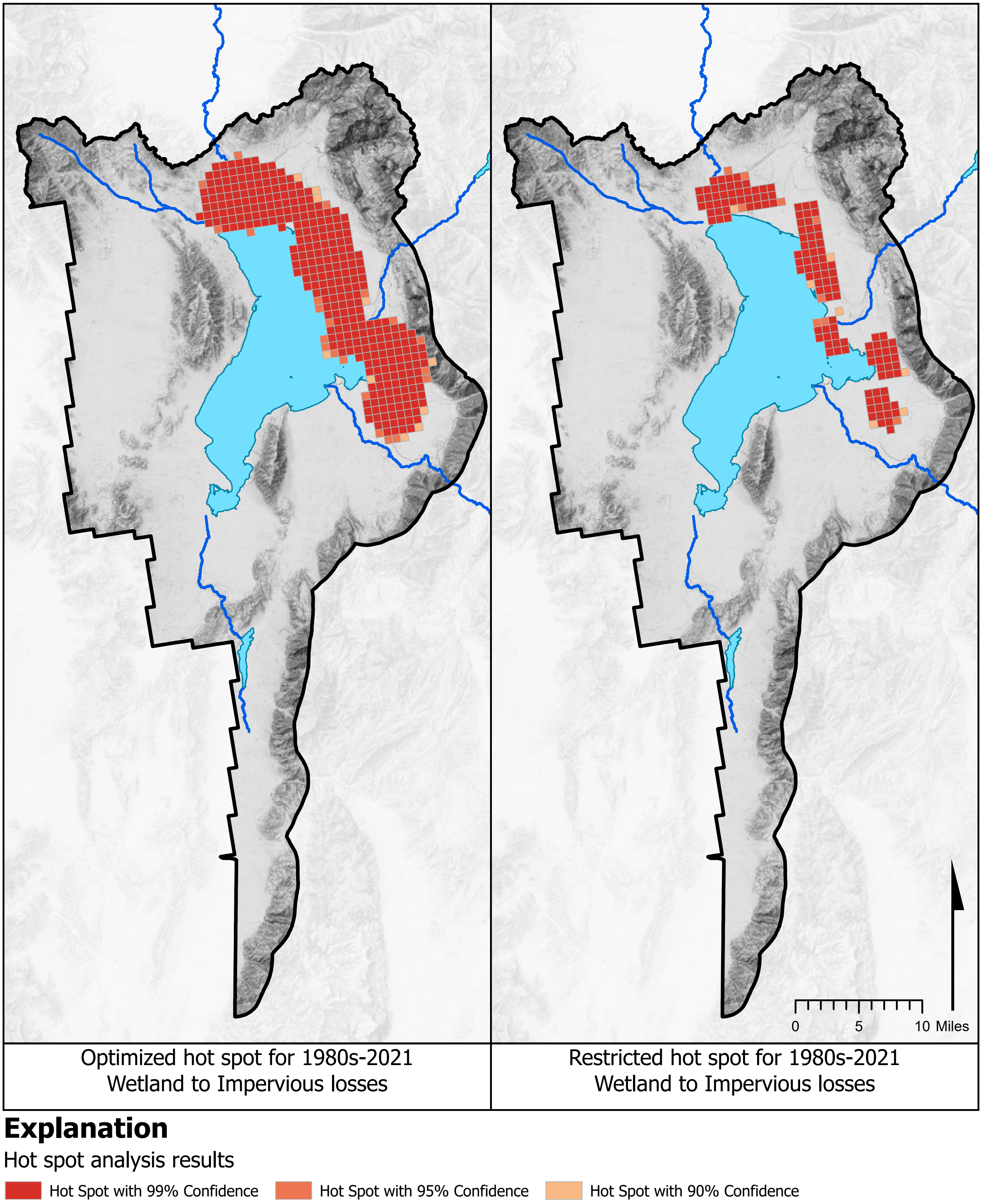
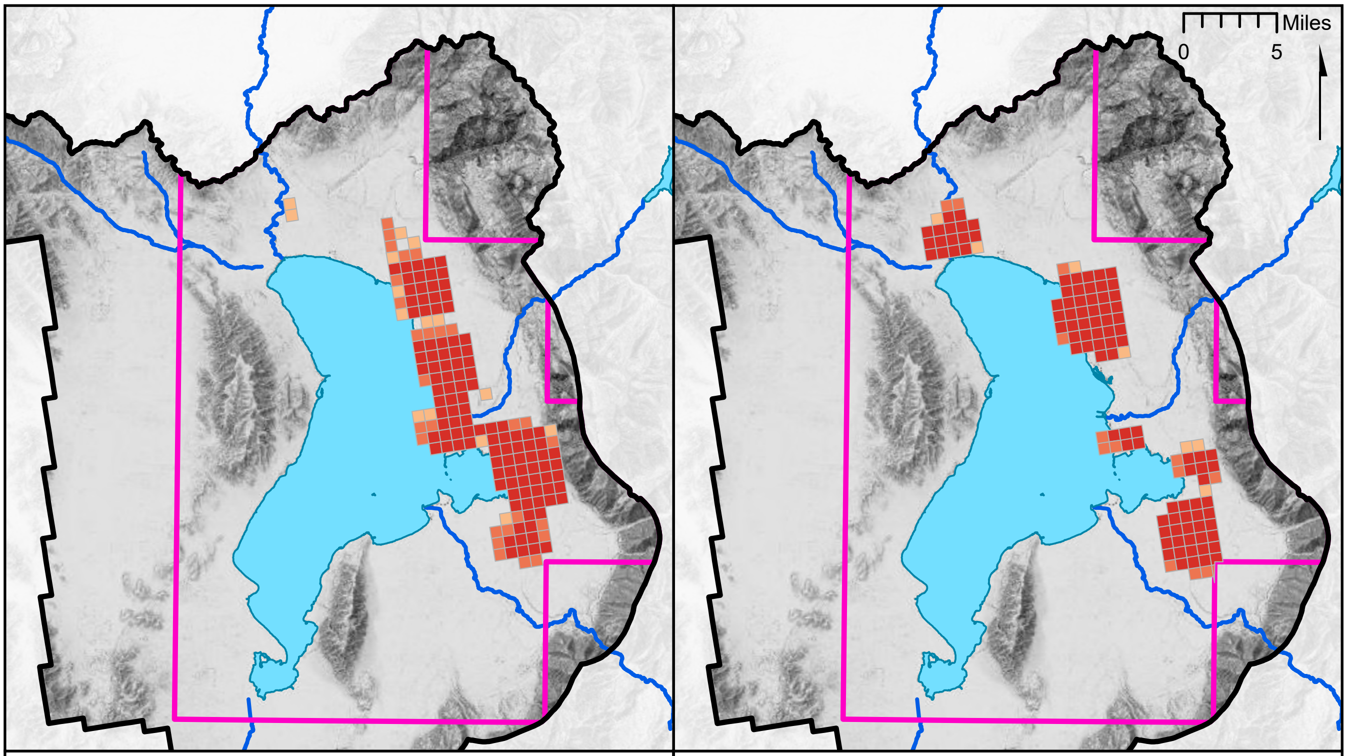
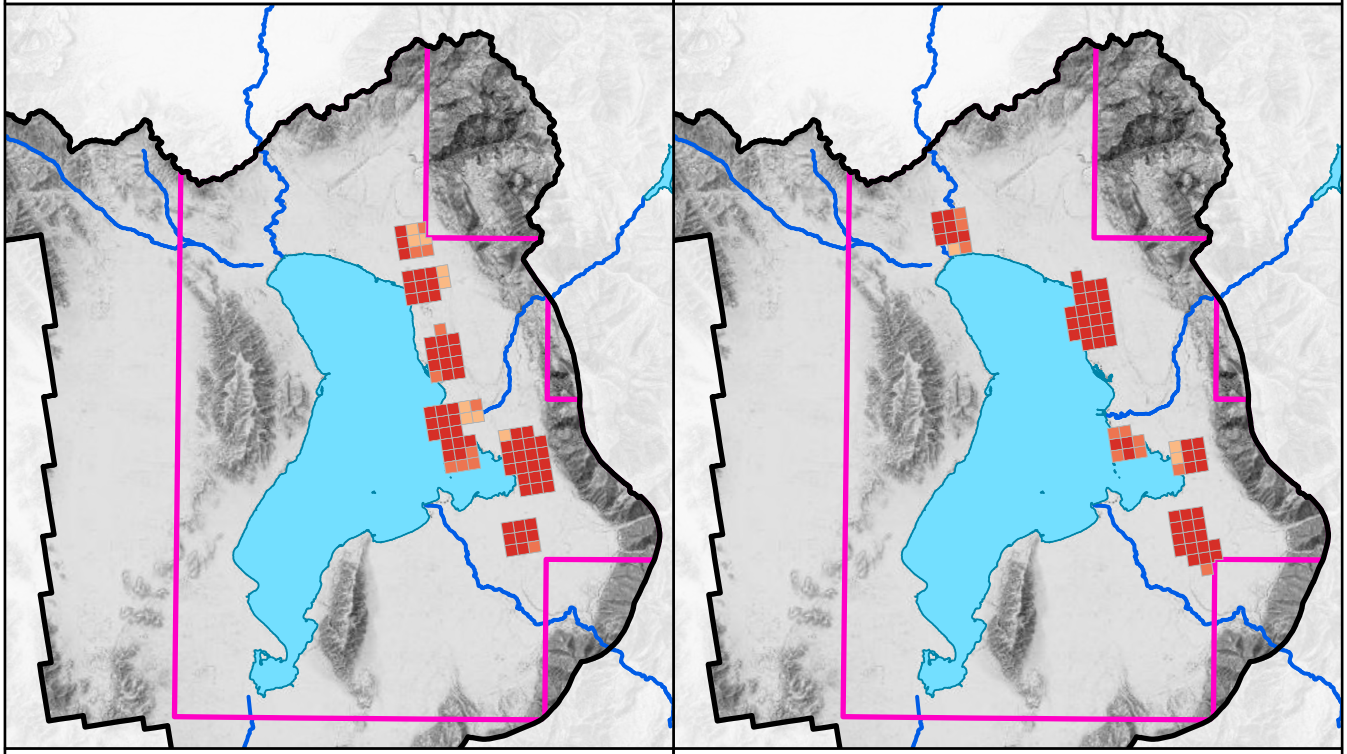


Figure 11. *Hotspot analyses of estimated wetland losses from 1980s to 2021. Hotspot analyses based on 1-km grid with values representing the Wetland to Impervious losses. Hotspot analyses were conducted using either a broadly defined neighborhood (Optimized) or a narrowly defined neighborhood (Restricted).*



Optimized hot spot for 1980s-2001
Wetland to Impervious losses

Optimized hot spot for 1998-2021
Wetland to Impervious losses



Restricted hot spot for 1980s-2001
Wetland to Impervious losses

Restricted hot spot for 1998-2021
Wetland to Impervious losses

Figure 12. *Hotspot analyses of estimated wetland losses from 1980s to 2001 and from 1998 to 2021. Hotspot analyses based on 1-km grid with values representing only Wetland to Impervious losses. Hotspot analyses were conducted using a broadly defined neighborhood (Optimized) or a narrowly defined neighborhood (Restricted).*

from 1980s to 2001 with novel losses occurring near Saratoga Springs, Lehi, and Salem. Wetland losses from the 1980s to 2001 and from 1998 to 2021 cluster along the northeast shore, with both time periods having distinct clusters around Provo, Provo Bay, and Spanish Fork. The analysis identified clusters extending from Vineyard to Saratoga Springs for both time periods. For the 1980s–2001 time period, these clusters mostly centered on the I-15 corridor whereas the 1998–2021 clusters were mostly west or south of I-15 and nearer to Utah Lake and the Jordan River. The analysis identified fewer isolated clusters during the 1980s–2001 period than the 1998–2021 period; the additional 1998–2021 clusters centered near Salem and Alpine.

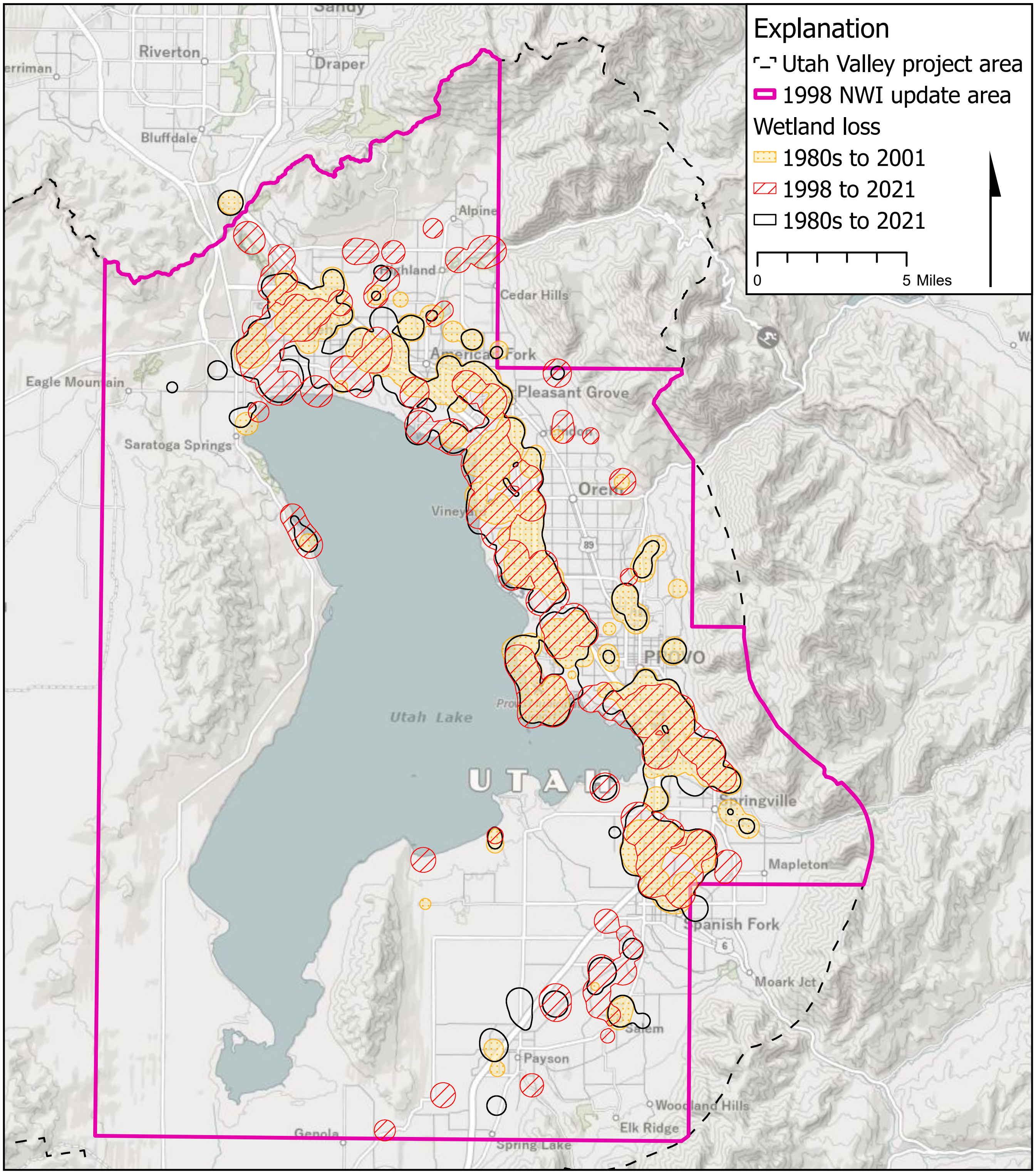


__Figure 13.__ Cluster analysis of Wetland to Impervious losses from 1980s to 2001, 1998 to 2021, 1980s to 2021, and overlapping losses from each period. Wetland loss boundary illustrates general areas where losses have occurred.

DISCUSSION

The mapping and data produced by this project support planners and conservations with current, accurate wetland mapping and improve understanding about wetland resources within Utah Valley by identifying landscape level patterns of wetland function and loss. Visual guides of Utah's wetland mapping and potential applications provide additional support (Willmore et al., 2024). The NWI dataset was updated with over 7000 distinct wetland and riparian features in one of the state's most rapidly developing regions. Additional LLWW attribution increased the usefulness of the final mapping and allowed us to identify wetlands that provide beneficial functions throughout Utah Valley. Mapping springs produced substantial value—locating and describing hundreds of previously unmapped springs—without substantially adding to the mapping effort. The spring locations and simple condition data were easily incorporated into the SO database as well as the Utah-specific Springs App (DWR, 2024) to improve spring inventory and field surveys. Functional hot spot analyses clearly identify Utah Lake and adjacent wetlands as important areas as well as large spring-fed or groundwater-fed wetland complexes near Fairfield, Mona, and Benjamin. Similar analyses of wetland losses over time indicate areas with greater losses overlap with developed and developing cities in northern and eastern Utah Valley.

Utah Lake is the largest freshwater lake in Utah and nearly 88,000 acres of lacustrine, riparian and vegetated wetlands—roughly 70% of all mapped area in the 2024 NWI mapping—adjoin the lake or wetlands directly adjacent to the lake. LLWW attributes support a more comprehensive inventory Utah Lake and associated wetlands by uniquely identifying lentic wetlands indirectly connected to the lake through frequent flooding or shallow alluvial aquifers. LLWW attributes identify an additional 8500 acres of vegetated lentic wetlands. In total, Utah Lake and associated wetlands provide nearly 97,000 acres of waterbody, shoreline, and vegetated wetland habitats.

Our updated LLWW mapping indicates that most isolated wetlands in the project area rely on shallow groundwater to maintain hydrology and hydrophytic vegetation. As surface expressions of groundwater, these wetlands are uniquely susceptible to dewatering and associated reductions in plant diversity, habitat availability, and water quality (Grantham, 1996; Bartholomew et al., 2020; Green et al., 2024). Detecting and measuring dewatering-driven wetland declines can be difficult due to climate fluctuations, shifting irrigation practices, and dynamic vegetation responses (Downard, 2024; Spangenberg Kellner et al., 2025).

Declining groundwater levels can reduce discharge from valley-floor springs and water levels in connected wetlands or waterbodies (Halford and Plume, 2011; Masbruch and Garnder, 2014; Grover, 2019). Hurlow et al. (2022) anecdotally noted reduced or discontinued flow at several Juab Valley springs and identified substantial, drying hydroperiod shifts at Mona and Chicken Creek Reservoirs. Menuz and Sempler (2018) observed several wetland plant community shifts indicative of wetland dewatering in northern Juab Valley and interviews with local landowners consistently attributed water level decline to overallocation. Neither Jordan and Sabbah (2012) nor Kirby et al. (2022) noted similar phenomena, but as both reported comparable water level declines, discharge and surface water extent have presumably been reduced at springs in Cedar and Goshen Valleys. Total impacts and the extent of groundwater-fed wetlands lost to groundwater declines throughout the project area remain unquantified.

Utah Valley wetlands provide crucial habitats for migrating shorebirds and the threatened June Sucker as well as numerous other waterfowl and wildlife species (USFWS, 2019; Audubon Society and Point Blue Conservation Service, 2024). Hotspot analyses clearly indicate Fairfield Sinks and Utah Lake as high-value habitat but also demonstrate the value of adjacent and connected wetlands. Mapped hot spots near Goshen, Powell Slough, Provo Bay, and the southern and western shores of Utah Lake coincide with dense mosaics of relatively undisturbed wetlands providing high-value wildlife habitats. Many of these areas are publicly protected through state or federal landownership. Fairfield sinks and many shoreline areas are privately owned and impacts to these wetlands may reduce their ability to provide wildlife habitat and decrease overall landscape-level function.

As the terminus of the Provo, Spanish Fork, and American Fork Rivers, Utah Lake accumulates sediments at rates of 1 to 2 mm/year (Brimhall and Merritt, 1981). Individual wetlands incrementally contribute to significant watershed-scale filtration of sediments from waterbodies (Ross and McKenna, 2022). Wetland sediment interception also serves to filter nitrogen (N) and phosphorus (P) from Utah Lake by limiting particles and adsorbed cations from reaching the lake. Utah Lake's unique geochemistry precipitates and removes much of the inorganic P and N from the water column (Merrit and Miller, 2016). Fringe wetlands like those in Provo Bay denitrify and assimilate P and N from wastewater treatment effluent in plant tissue and help reduce nutrient loading (Mitsch and Gosselink, 2015; Abbott et al., 2022). Sediment retention and nutrient cycling functions are especially crucial for eutrophic lakes receiving additional nutrients from multiple wastewater treatment plants. The function model and hotspot analysis corroborate this importance, flagging the entire lake and surrounding shorelines as high-functioning wetlands likely to intercept or accumulate sediments.

Development within Utah County has contributed to wetland losses along the Utah Lake shoreline, especially the northern and eastern shorelines (Figure 13). These direct losses contribute to habitat fragmentation, increased erosion and runoff, and greater risk of flooding, property loss, and harmful algal blooms driven by excessive nutrients (Brody et al., 2007; Tomscha et al., 2019; Lang et al., 2024). National studies show increased urbanization also indirectly affects nearby wetlands through hydrology alteration and invasion by non-native plants and leads to decreased wetland function (Li et al., 2022). Expanding and infilling cities have likely affected the functionality of the remaining Utah Valley wetlands as reflected by the significant cold spots throughout developed Utah Valley (Figure 8). Hot spot results also highlight emerging concerns along the eastern shores of Utah Lake where high-functioning wetlands in Powell Slough and Provo Bay may be impacted by nearby losses.

Development and conversion to impervious surfaces consistently drove wetland loss in Utah Valley over the last 40 years. Clustered wetland losses from 1998 to 2020 near Lehi, Saratoga Springs and Vineyard indicate a general shift in wetland conversion westward towards Utah Lake and the Jordan River (Figure 13). Recent wetland losses clustered near Payson and Salem indicate a similar shift in impervious surface development towards agricultural lands south of Utah Lake as these communities expand along the I-15 corridor (MAG, undated). Generally, these shifts mirror the rapid population growth and greenfield development of former agricultural lands. Populations within each of these communities more than doubled or tripled between 2000 and 2020 (Table 11) and corresponding wetland losses nearly doubled or tripled during the 1998–2020 period.

Table 11. *Census data within the project area summarized as total population and relative growth within each municipality.*

Municipality[1]	**Total population**[2]					**Relative growth**[3]	
	1980	**1990**	**2000**	**2010**	**2020**	**1980-2000**	**2000-2020**
Alpine	2649	3492	7325	9555	10,251	176.5	39.9
American Fork	12,564	15,696	21,925	26,263	33,337	74.5	52.1
Cedar Fort		284	341	368	427		25.2
Cedar Hills			3098	9796	10,019		223.4
Eagle Mountain			2203	21,415	43,623		1880.2
Elk Ridge			1865	2436	4387		135.2
Fairfield				119	160		
Genola			1002	1370	1548		54.5
Goshen			862	921	978		13.5
Highland	2435	5002	7966	15,523	19,348	227.1	142.9
Lehi	6848	8476	19,150	47,407	75,907	179.6	296.4
Lindon	2796	3818	8368	10,070	11,397	199.3	36.2
Mapleton	2726	3572	5688	7979	11,365	108.7	99.8
Orem	52,399	67,561	84,333	88,328	98,129	60.9	16.4
Payson	8246	9510	12,825	18,249	21,101	55.5	64.5
Pleasant Grove	10,833	13,537	23,541	33,509	37,726	117.3	60.3
Provo	74,108	86,848	105,258	112,491	115,162	42	9.4
Rocky Ridge			403	733	848		110.4
Salem	2233	2284	4387	6423	9298	96.5	111.9
Santaquin	2175	2386	4900	9128	13,725	125.3	180.1
Saratoga Springs			930	17,781	37,696		3953.3
Spanish Fork	9825	11,272	20,271	34,691	42,602	106.3	110.2
Springville	12,101	13,950	20,519	29,466	35,268	69.6	71.9
Vineyard			192	139	12,543		6432.8
Woodland Hills			1027	1344	1521		48.1
Nephi	3285	3515	4804	5389	6443	46.2	34.1
Mona		584	836	1547	1750		109.3
Juab County[4]	5350	5817	8238	10,246	11,786	54	43.1
Utah County[4]	218,106	263,590	368,536	516,564	656,399	69	78.1

Notes

[1] Includes only municipalities identified in 2020 census data

[2] Several communities were below reporting threshold in 1980, 1990, and 2000 census data

[3] Relative growth calculated as population increase relative to previous population

[4] County-wide census results include additional populations within unincorporated areas and unreported communities

Our loss analysis considers wetland change over two nearly consecutive time periods (1980s–2001 and 1998–2021) using two distinct wetland mapping datasets (original 1980s and the 1998 update). Evaluating change across only two periods limits our ability to identify changing patterns of wetland loss by reducing any trends to two or three datapoints. The differing mapping datasets introduce error through inconsistent mapping, apparent as the nearly 60 to 140 acres of mismatched losses observed in Lehi, American Fork, and Orem. Applying our adapted python scripts to recently released annual NLCD datasets spanning 1985 to 2023 and evaluating wetland losses from the original 1980s mapping (U.S. Geological Survey, 2024) would improve consistency and allow for quantitative analyses of wetland loss trends.

Other areas of Utah Valley, like Provo or Orem, grew less between 1980 and 2020 and relative wetland loss rates remain stable or decreased from 1980s–2000 to the 1998–2020 period. However, the extensive overlap between 1980s–2000 and 1998–2020 wetland loss clusters indicate ongoing loss through these periods as infill, increasing urbanization, or co-location of new development with existing infrastructure all serve to maintain development pressure (Figure 13). Despite these losses, extant wetlands in these communities continue to provide high functionality, with Provo Bay and Powell Slough consistently identified as high-functioning hot spots for wildlife habitat and water quality protection.

High functioning wetlands exist beyond Utah Lake and the developed areas of Utah Valley. The hot spot analyses flagged Fairfield Sinks and areas near Mona, Goshen, and Benjamin as high-value wetlands that similarly provide important wildlife habitats and water quality protections. As part of the supplemental LLWW attribution, we identified that the hydrology of these wetlands was primarily supported by shallow groundwater or spring outflows. Understanding the hydrology of these important wetland areas better helps us understand their unique functions, threats, and important contributions to the base flows of nearby streams during summer months (Winter et al., 1998 ,Marshall et al., 2018).Nearby communities (Fairfield, Mona, Genola, and Benjamin) grew slower than other areas within Utah County and we identified few wetland losses in these areas (Figure 11). Regional groundwater declines threaten to reduce areal extent, biodiversity and water quality at individual locations but also reduce the overall landscape-level function (Grantham, 1996; Bartholomew et al., 2020; Green et al., 2024).

Our wetland loss analysis identified losses with very distinct aerial imagery signatures, such as wetlands converted to impervious surfaces or open water. The analysis did not identify losses with less distinct changes, such as agricultural conversions of densely vegetated wetlands with hydrophytic vegetation to densely vegetated fields with crops. Throughout Utah, agricultural producers have increasingly replaced flood-irrigation with center-pivot sprinkler irrigation as a water optimization measure (Utah Department of Agriculture and Food, 2023). This replacement typically involves extensive grading, tilling, and reseeding to replace pasture vegetation with commodity crops (Utah Division of Water Resources, 2021). These practices remove wetland vegetation, soils, or hydrology formerly supported by flood irrigation and would contribute to wetland losses. Our analysis does not include these losses as the conversion does not result in a distinct land cover change. Sprinkler irrigated fields remain a densely vegetated land cover, relatively indistinct from the densely vegetated wetlands within flood irrigated fields. Conversion to sprinkler irrigation also reduces return flows to adjacent fields, streams or other waterbodies, further reducing hydrology and function of surrounding wetlands (Martin et al., 2017; Donnelly et al., 2024). Our hot spot analyses identified several irrigation-fed wetlands near Goshen and the southern shores of Utah Lake as important habitats that might be threatened by some of these water optimization measures (Figures 6 and 8).

The difference product we adapted for our analysis restricts identified losses to definitive landcover changes in large (greater than 1 acre) wetlands. This produces a consistent national dataset but does not consider all wetlands losses (agricultural conversion or dewatering) occurring throughout the project area. These other types of losses coincide with vegetation community shifts which may be detectable through remote sensing or other landcover datasets like the Water Related Land Use. Any observed remote-sensing trend may need validation with vegetation surveys, stream gages, or high-frequency measurements of local groundwater levels (Ladig et al., 2024; Spangenberg Kellner et al., 2025). Changing groundwater levels and any wetland response can be highly localized, and we recommend initial attempts focus on distinct wetland complexes with recent mapping adjacent to accurate and high-frequency hydrologic monitoring.

ACKNOWLEDGMENTS

This project was made possible through funding from the Environmental Protection Agency Wetland Program Development Grants (CD-95811000) and review from FWS NWI coordinators John Swords, Kyle Lemaire, and Sara Owen—all of whom provided valuable feedback during several reviews. Several individuals and organizations aided the project and we would like to thank them as well: Professor Zhenhua Zou of the University of Maryland graciously shared his python scripts and expertise to support our loss analysis, Jeri Ledbetter and Jeff Jenness reviewed and guided our spring mapping effort, Sarah Marshall with

Colorado Natural Heritage Program researched and wrote the queries underpinning our functional models, Keith Hambrecht with the Utah Division of Forestry, Fire and State Lands shared phragmites treatment locations to aid our mapping, and Tyler Allred with Allred Restoration shared proposed wetlands restoration boundaries during the Delta River Restoration Project. Diane Menuz and Becka Downard of the UGS provided administrative support and invaluable technical expertise throughout the project. Grant Mauk, Rachel Wilmore, and Mackenzie Cope developed the online guides to explain Utah's wetland mapping, we are especially grateful for their efforts.

REFERENCES

Abbott, B., Errigo, I., Follett, A., Lawson, G., Meyer, M., Moon, H., Shurtleff, K., Proteau, M., Davis, K., Nelson, K., Rushforth, S., Abbott, S., Wang, W., Westwater, J., and Edgar, K., 2022, Utah Lake—An ecosystem in recovery: Provo, Utah, Brigham Young University, 39 p.

Audubon Society and Point Blue Conservation Service, 2024, Intermountain West shorebirds preliminary data summary—November 2024: Online, https://static1.squarespace.com/static/66b5066527e47020d0e0b7b0/t/673d0bf4ca1419202f3e9a2e/1732054007209/Intermountain+West+Shorebirds+-+Preliminary+Data+Summary+-+November+2024+Updated.pdf, accessed February 2025.

Bartholomew, M.K., Anderson, C.J., and Berkowitz, J.F., 2020, Wetland vegetation response to groundwater pumping and hydrologic recovery: Wetlands, v. 40, no. 6, p. 2609–2619, https://doi.org/10.1007/s13157-020-01383-5.

BIO-West, 2019, Appendix A—Final vegetation management plan for the Provo River Delta Restoration Project: Utah Reclamation Mitigation and Conservation Commission, 143 p.

Brimhall, W.H., and Merritt, L.B., 1981, Geology of Utah Lake—implications for resource management: Great Basin Naturalist Memoirs, v. 5, p. 25–42.

Brinson, M.M., 1993, A hydrogeomorphic classification for wetlands: US Army Corps of Engineers Wetlands Research Program Technical Report WRP-DE-4, 103 p.

Brody, S., Highfield, W., Ryu, H.-C., and Spanel-Weber, L., 2007, Examining the relationship between wetland alteration and watershed flooding in Texas and Florida: Natural Hazards, v. 40, p. 413–428, https://doi.org/10.1007/s11069-006-9003-3.

Brooks, L.B., and Stolp, B.J., 1995, Hydrology and simulation of groundwater flow in southern Utah and Goshen Valleys, Utah: Utah Department of Natural Resources Technical Publication 111, 96 p., 1 plate.

Clement, M., 2019, Historical wetland change assessment in TNC's northern Utah service region: Salt Lake City, unpublished report prepared for The Nature Conservancy, 13 p.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., and van den Belt, M., 1997, The value of the world's ecosystem services and natural capital: Nature, v. 387, no. 6630, p. 253–260, https://doi.org/10.1038/387253a0.

Dahl, T.E., 2000, Status and trends of wetlands in the conterminous United States 1986 to 1997: U.S. Fish and Wildlife Service, 82 p.

Dahl, T.E., 2006, Status and trends of wetlands in the conterminous United States 1998 to 2004: U.S. Fish and Wildlife Service, 112 p.

Dahl, T.E., Dick, J., Swords, J., and Wilen, B.O., 2020, Data collection requirements and procedures for mapping wetland, deepwater, and related habitats of the United States (version 3): Madison, Wisconsin, U.S. Fish and Wildlife Service Division of Habitat and Resource Conservation, National Standards and Support Team, 91 p.

Design Workshop, 2023, River and lakeshore plan—Final Plan: Provo, Utah, land use planning document prepared for the City of Provo, 81 p., 4 appendices, https://www.provo.gov/DocumentCenter/View/921/Provo-River-and-Lakeshore-Plan-PDF?bidId.

Donnelly, J.P., Jensco, K., Kimball, J.S., Moore, J.N., Ketchum, D., Collins, D.P., and Naugle, D.E., 2024, Beneficial 'inefficiencies' of western ranching—Flood-irrigated hay production sustains wetland systems by mimicking historic hydrologic processes: Agriculture, Ecosystems & Environment, v. 370, p. 109051, https://doi.org/10.1016/j.agee.2024.109051.

Downard, B., 2024, Great Salt Lake wetland vegetation and what it tells us about environmental gradients, drought, and disturbance, *in* Vanden Berg, M.D., Ford, R.L., Frantz, C., Hurlow, H., Gunderson, K., and Atwood, G., editors, Great Salt Lake and the Bonneville Basin—Geologic history and Anthropocene issues: Utah Geological Association, v. 51, 25 p., https://doi.org/10.31711/ugap.v51i.140.

ESRI, 2025, Hot spot analysis (Geti-Ord Gi*) (Spatial Statistics): https://pro.arcgis.com/en/pro-app/3.4/tool-reference/spatial-statistics/hot-spot-analysis.htm, accessed October 2025.

Fluet-Chouinard, E., Stocker, B., Zhang, Z., Malhotra, A., Melton, J., Poulter, B., Kaplan, J., Klein Goldewijk, K., Siebert, S., Minayeva, T., Hugelius, G., Joosten, H., Barthelmes, A., Prigent, C., Aires, F., Hoyt, A., Davidson, N., Finlayson, M., Lehner, B., and McIntyre, P., 2023, Extensive global wetland loss over the past three centuries: Nature, v. 614, p. 281–286, https://doi.org/10.1038/s41586-022-05572-6.

Frayer, W.E., Monahan, T.J., Bowden, D.C., and Graybill, F.A., 1983, Status and trends of wetlands and deepwater habitats in the conterminous United States 1950s to 1970s: U.S. Fish and Wildlife Service, 36 p., https://www.fws.gov/sites/default/files/documents/Status-and-Trends-of-Wetlands-and-Deepwater-Habitats-in-the-Conterminous-United-States-1950s-to-1970s.pdf.

Goodwin, P., Inkenbrandt, P., Menuz, D., Hurlow, H., and Dittmer, D., 2021, Snake Valley hydrologic monitoring—ten-year report: Utah Geological Survey Open-File Report 732, 36 p., 2 appendices, https://doi.org/10.34191/OFR-732.

Goodwin, P., and Molinari, R., 2022, Cache Valley wetland mapping—supplemental report: Utah Geological Survey Open-File Report 744, 28 p., 2 appendices, https://doi.org/10.34191/OFR-744.

Google, 2024, Landsat collection 1 to collection 2 migration—Google Earth Engine: Online, https://developers.google.com/earth-engine/landsat_c1_to_c2, accessed January 2025.

Grantham, C., 1996, An assessment of the ecological impacts of ground water overdraft on wetlands and riparian areas in the United States: Idaho Water Resources Research Institute, University of Idaho, 103 p.

Great Salt Lake Resolution (HCR-10) Steering Group, 2020, Recommendations to ensure adequate water flows to Great Salt Lake wetlands—Final report: Utah Department of Natural Resources, 46 p.

Green, A.J., Guardiola-Albert, C., Bravo-Utrera, M.Á., Bustamante, J., Camacho, A., Camacho, C., Contreras-Arribas, E., Espinar, J.L., Gil-Gil, T., Gomez-Mestre, I., Heredia-Díaz, J., Kohfahl, C., Negro, J.J., Olías, M., Revilla, E., Rodríguez-González, P.M., Rodríguez-Rodríguez, M., Ruíz-Bermudo, F., Santamaría, L., Schmidt, G., Serrano-Reina, J.A., and Díaz-Delgado, R., 2024, Groundwater abstraction has caused extensive ecological damage to the Doñana World Heritage Site, Spain: Wetlands, v. 44, no. 2, p. 20, https://doi.org/10.1007/s13157-023-01769-1.

Grover, M.C., 2019, Effects of groundwater fluctuations on the distribution and population structure of two cyprinid fishes in a desert spring complex: Journal of Freshwater Ecology, v. 34, no. 1, p. 167–187, https://doi.org/10.1080/02705060.2019.1578699.

Gurrieri, J.T., 2020, Rangeland water developments at springs—best practices for design, rehabilitation, and restoration: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station General Technical Report RMRS-GTR-405, 21 p., https://doi.org/10.2737/RMRS-GTR-405.

Halford, K.J., and Plume, R.W., 2011, Potential effects of groundwater pumping on water levels, phreatophytes, and spring discharges in Spring and Snake Valleys, White Pine County, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey Scientific Investigations Report 2011-5032, 52 p.

Hartshorn, E.S., Sempler, R.T., Heberer, L.N., Owen, S.K., Hajek, K.L., and Hardin, F.O., 2024, Mapping of wetland and riparian habitat for the National Wetlands Inventory—Grand Staircase-Escalante National Monument & Bears Ears National Monument: O'Connor Center for the Rocky Mountain West, 20 p.

Hurlow, H.A., Inkenbrandt, P.C., and Schlossnagle, T.H., 2022, Hydrogeology, groundwater chemistry, and water budget of Juab Valley, eastern Juab County, Utah: Utah Geological Survey Special Study 170, 101 p., 1 appendix, 2 plates, https://doi.org/10.34191/SS-170.

Jordan, J.L., and Sabbah, W.W., 2012, Hydrogeology and simulation of groundwater flow in Cedar Valley, Utah County, Utah: Utah Geological Survey Special Study 145, 125 p., 7 appendices, 2 plates, https://doi.org/10.34191/SS-145.

Kem C. Gardner Policy Institute, 2010, State, county, and place demographic trends—1990–2010: Salt Lake City, University of Utah, 355 p., https://d36oiwf74r1rap.cloudfront.net/wp-content/uploads/49_Utah_County_Demographic_Trends_1990_2010.pdf.

Kem C. Gardner Policy Institute, 2017, Utah's long-term demographic and economic projects: Salt Lake City, University of Utah, 181 p., http://gardner.utah.edu/demographics/population-projections.

Kem C. Gardner Policy Institute, 2019, State and county population estimates for Utah—2019: Salt Lake City, University of Utah, 12 p., https://d36oiwf74r1rap.cloudfront.net/wp-content/uploads/State-of-Utah-Demographic-Profile-2010-2019.pdf.

Kirby, S.M., Jordan, J.L., Wallace, J., Payne, N., and Hardwick, C., 2022, Hydrogeology and water budget for Goshen Valley, Utah County, Utah: Utah Geological Survey Special Study 171, 66 p., 2 appendices, https://doi.org/10.34191/SS-171.

Ladig, K., Molinari, R., Smith, K., Schlossnagle, T.H., Jordan, J.L., Menuz, D., Wallace, J., Hurlow, H., Inkenbrandt, P.C., and Hardwick, C., 2024, Matheson Wetlands Preserve water monitoring, water budget, wetland mapping, and wetland change analysis: Utah Geological Survey Special Study 174, 81 p., 6 appendices, https://doi.org/10.34191/SS-174.

Lang, M.W., Ingebritsen, J.C., and Griffin, R.K., 2024, Status and trends of wetlands in the conterminous United States 2009 to 2019: U.S. Department of the Interior, Fish and Wildlife Service, 43 p.

Lemly, J., Marshall, S., Stark, K., Lindquist, E., Robertson A., Hutchins, H., 2018, Keys to LLWW for inland wetlands of the western United States: Fort Collins, Colorado, Colorado Natural Heritage Program, 39 p.

Li, Z., Ma, L., Gou, D., Hong, Q., Fai, L., and Xiong, B., 2022, The Impact of urban development on wetland conservation: Sustainability, v. 14, no. 21, p. 13747, https://doi.org/10.3390/su142113747.

Marshall, S., Lemly, J., and Smith, G., 2018, Appendix C—Geospatial data processing and queries for likely wetland functions: Fort Collins, Colorado, Colorado Natural Heritage Program,10 p.

Martin, D., Kranz, W., Smith, T., Irmak, S., Burr, C., and Yoder, R., 2017, Center pivot irrigation handbook: Department of Biological Systems Engineering, University of Nebraska-Lincoln Extension Circular, 136 p.

Masbruch, M.D., and Gardner, P.M., 2014, Potential effects of existing and proposed groundwater withdrawals on water levels and natural groundwater discharge in Snake Valley, Juab and Millard Counties, Utah, White Pine County, Nevada, and surrounding areas in Utah and Nevada: U.S. Geological Survey Open-File Report 2014-1176, 24 p.

Menuz, D.R., 2015, Landscape integrity model for Utah's wetlands: Utah Geological Survey Contract Deliverable for ESMF Project #1215, 57 p.

Menuz, D., and Downard, R., 2017, Utah Wetland Program Plan: program planning document prepared for the U.S. Environmental Protection Agency, 26 p., https://www.epa.gov/sites/default/files/2018-01/documents/utahwetlandprogramplan_version1_december2017.pdf.

Menuz, D., and Sempler, R., 2018, Jordan River watershed wetland assessment and landscape analysis: Utah Geological Survey Contract Deliverable to the U.S. Environmental Protection Agency, 91 p.

Merrit, L.B., and Miller, A.W., 2016, Interim report on nutrient loadings to Utah Lake: Jordan River, Farmington Bay and Utah Lake Water Quality Council, 39 p.

Millennium Ecosystem Assessment Program (Ed.), 2005, Ecosystems and human well-being—wetlands and water synthesis—a report of the Millennium Ecosystem Assessment: Washington, DC, World Resources Institute, 68 p.

Mitsch, W.J., and Gosselink, J.G., 2015, Wetlands: Hoboken, New Jersey, John Wiley and Sons, Inc, 736 p.

Mountainland Association of Governments, undated, TransPlan50—2019–2025 Regional Transportation Plan: Provo, Utah, 48 p., https://frontrunner2x.utah.gov/assets/documents/Mountainland_Association_of_Governments_MAG_TransPlan50.pdf.

Rohde, M.M., Saito, L., and Smith, R., 2020, Groundwater thresholds for ecosystems—A guide for practitioners: The Nature Conservancy, https://www.groundwaterresourcehub.org/content/dam/tnc/nature/en/documents/groundwater-resource-hub/GroundwaterThresholdFramework_Final_updated_Dec2020.pdf.

Rohde, M.M., Stella, J.C., Singer, M.B., Roberts, D.A., Caylor, K.K., and Albano, C.M., 2024, Establishing ecological thresholds and targets for groundwater management: Nature Water, v. 2, no. 4, p. 312–323, https://doi.org/10.1038/s44221-024-00221-w.

Ross, C., and McKenna, O., 2022, The potential of prairie pothole wetlands as an agricultural conservation practice—A synthesis of empirical data: Wetlands, v. 43, https://doi.org/10.1007/s13157-022-01638-3.

Spangenberg Kellner, C., Molinari, R., Menuz, D., Goodwin, P., and Hurlow, H., 2025, Great Salt Lake shorelands preserve water budget, stream monitoring, vegetation mapping, and remote sensing analysis: Utah Geological Survey Report of Investigation 289, 52 p., 3 appendices, https://doi.org/10.34191/RI-289.

St. Mary's University, 2021, Supplemental map information—BLM Lands Utah: Winona, Minnesota, Saint Mary's University of Minnesota, 11 p.

Steed, B., 2024, The Great Salt Lake strategic plan: Utah Office of the Great Salt Lake Commissioner, 42 p.

Stevens, L.E., Schenk, E.R., and Springer, A.E., 2021, Springs ecosystem classification: Ecological Applications, v. 31, no. 1, p. e2218, https://doi.org/10.1002/eap.2218.

Stevens, L.E., et al., 2023, Springs of the world—Distribution, ecology, and conservation status: Online, https://docs.springs-data.org/PDF/GlobalSpringsReduced.pdf, accessed December 2024.

Tiner, R.W., 2014, Dichotomous keys and mapping codes for wetland landscape position, landform, water flow path, and waterbody type: Version 3.0: U.S. Fish and Wildlife Service, National Wetlands Inventory Program, Northeast Region, 65 p.

Tomscha, S., Deslippe, J., de Róiste, M., Hartley, S., and Jackson, B., 2019, Uncovering the ecosystem service legacies of wetland loss using high-resolution models: Ecosphere, v. 10, no. 10, p. e02888, https://doi.org/10.1002/ecs2.2888.

Trochell, P., and Bernthal, T., 1998, Small wetlands and the cumulative impacts of small wetland losses—A synopsis of the literature: Wisconsin Department of Natural Resources, 18 p.

U.S. Army Corps of Engineers, 2008, Regional supplement to the Corps of Engineers wetland delineation manual—Arid West Region (Version 2.0): U.S. Army Engineer Research and Development Center, 135 p.

U.S. Environmental Protection Agency, 2015, Connectivity of streams and wetlands to downstream waters—A review and synthesis of the scientific evidence (final report).: U.S. Environmental Protection Agency EPA/600/R-14, 206 p., 2 appendices, https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=296414.

U.S. Fish and Wildlife Service, 2009, A system for mapping riparian areas in the western United States: U.S. Department of the Interior, 43 p.

U.S. Fish and Wildlife Service, 2019, Endangered and threatened wildlife and plants—Reclassification of the endangered June Sucker to threatened with a Section 4(d) Rule: Proposed rule 50 CFR Part 17, 19 p.

U.S. Geological Survey, 2024, USGS releases new products that map four decades of land cover change: U.S. Geological Survey, https://www.usgs.gov/news/national-news-release/usgs-releases-new-products-map-four-decades-land-cover-change, accessed March 2025.

USFWS, 2024a, National Wetlands Inventory—What We Do: U.S. Fish and Wildlife Service: https://www.fws.gov/program/national-wetlands-inventory, accessed December 2024.

USFWS, 2024b, National Wetlands Inventory: Online, https://fwsprimary.wim.usgs.gov/wetlands/apps/wetlands-mapper/, accessed October 2024.

Utah Department of Agriculture and Food, 2023, UDAF Grant—$20 million available for agricultural water optimization projects: Online, https://ag.utah.gov/2023/04/18/udaf-grant-20-million-available-for-agricultural-water-optimization-projects/, accessed September 2025.

Utah Division of Forestry, Fire and State Lands, 2024, Utah Lake phragmites control: Online, https://storymaps.arcgis.com/stories/4ba238d169f043f89e1eec1c37d066cd, accessed February 2025.

Utah Division of Water Resources, 2021, Water-related land use inventories—Statewide 2020 inventory: Online, https://opendata.gis.utah.gov/datasets/3602f55dbd6b498cbfcbc9cb22aa00db_0/explore?location=39.822962%2C-111.604167%2C-1, accessed September 2025.

Utah Division of Wildlife Resources, 2024, Springs inspections v4 Field Maps: Online, https://utahdnr.hub.arcgis.com/maps/utahDNR::springs-inspections-v4-public/about, accessed September 2025.

Utah Geological Survey, 2025, Utah Wetlands: Online, https://wetlands.geology.utah.gov/, accessed September 2025.

Utah Geospatial Resources Center, 2023, Utah Municipal Boundaries: Online, https://gis.utah.gov/products/sgid/boundaries/municipal/, accessed January 2025.

Utah Lake Commission, 2009, Utah Lake master plan: Utah Lake Commission, 59 p.

Utah Lake Commission, 2012, Can you believe it? It's been five years!—Utah Lake: Online, https://utahlake.gov/can-you-believe-it-its-been-five-years/, accessed November 2025.

Utah Reclamation Mitigation and Conservation Commission, 2015, Provo River Delta Restoration Project—Final environmental impact statement: U.S. Department of Interior, 394 p.

Utah Wildlife Action Plan Core Team, 2025, Utah Wildlife Action Plan, 2025-35: Utah Division of Wildlife Resources Publication 25–23, 618 p.

Utah Wildlife Action Plan Joint Team, 2015, Utah Wildlife Action Plan—A plan for managing native wildlife species and their habitats to help prevent listing under the Endangered Species Act: Utah Division of Wildlife Resources Agency Report 15–14, 385 p.

Van Beveren, R., 2022, It's time to invest in a modern map of our nation's wetlands: Online, https://www.policyinnovation.org/insights/investing-in-a-modern-map-of-our-nations-wetlands, accessed August 2025.

Willmore, R., Mauk, G., Goodwin, P., Stimmel, E., and Menuz, D., 2024, Wetland Mapping—A guide to Utah's National Wetland Inventory: Online, https://storymaps.arcgis.com/collections/581ac0b202154028bb27bbc3f75c765b, accessed January 2026.

Winter, T., Harvey, J., Franke, O., and Alley, W., 1998, Ground water and surface water—A single resource: U.S. Geological Survey Circular 1139, 79 p.

Zou, Z., Huang, C., Lang, M., and Griffin, R., 2022, Derivation of wetland difference products by comparing the NWI geospatial dataset with C-CAP (10-m) and NLCD (2019) data: U.S. Fish and Wildlife Service, 46 p.

APPENDICES

APPENDIX A—Project Specific Mapping Conventions

NOTES ON PROJECT SPECIFIC MAPPING CONVENTIONS

NWI Wetland and Riparian Mapping

Riparian

- Forested or Scrub-shrub Riparian areas were classified to the Dominance Type level to help distinguish woody riparian areas dominated by non-native species, such as Russian olive, and provide additional detail for riparian habitats.
- We assumed roads and other paved surfaces interrupted surficial hydrology connections and limited riparian mapping to areas between waterbodies and paved surfaces.

Irrigation

- Wetlands were mapped in irrigated areas if several years of imagery showed a consistently wet portion or core of the feature.
- We considered irrigation as surface flooding and mapped irrigated features with temporary (A) or seasonally (C) flooded water regimes.
- Features created from irrigation and that would likely return to upland if irrigation ceased were not mapped as wetlands unless field data or other supporting data confirmed persistent hydric soils, hydrophytic vegetation, or other wetland characteristics.

Springs and groundwater

- We considered wetland complexes supported by springs or shallow groundwater as saturated features and mapped these features with seasonally saturated (B), permanently saturated (D), or seasonally flooded and saturated (E) water regimes.
- Springs typically identified by:
    - proximity to mapped springs or known groundwater discharge areas,
    - strong signatures that appeared stable over several years of imagery, and
    - appropriate landscape positions at slope breaks, start of channel features, or locations upgradient of nearby waterbodies.

Utah Lake shorelines

- Unvegetated areas below the ordinary high-water mark of Utah Lake were all mapped as lacustrine features (L2US) regardless of size.

Playas

- We mapped the playas throughout Goshen Valley and other isolated areas with temporary (A) or intermittently (J) flooded water regimes regardless of probable groundwater contributions.

Dry channel water regimes

- We assigned water regimes by region, assuming dry channels in the Wasatch Mountains flowed during spring runoff and assigned these channels a temporary (A) water regime. We assumed channels draining drier mountain ranges only flowed following rain events and assigned these channels an intermittent (J) water regime.

LLWW Mapping

Playas

- We assigned large playas a Flat (FL) landform regardless of probable groundwater contributions.

Shorelines

- Lentic (LE) wetlands along Utah Lake were assigned LLWW flow paths according to their longest shared boundary. Wetlands sharing their longest boundary with the lake or other shoreline features were assigned a bidirectional (BI) flow path while wetlands sharing their longest border with a river or lotic floodplain feature were assigned a throughflow-bidirectional (TB) flow path.

Spring Mapping

Table A1. *Fields and criteria used to evaluate spring location, type, and condition.*

Field name	Description	Options[1]	Notes	Mandatory[2]
ReMapOption	Identifies if point is within SSI3 database and needs to be corrected	• Relocate: move existing SSI point • New: new spring to SSI • Nonexist: spring entirely replaced • Unmoved: existing SSI location accurate		Yes
SSImoveJustify	Justification to move points included in SSI database	• Unsurveyed: spring never visited by SSI staff • Inaccurate: surveyed but not near visible hydrology • Unmoved: SSI point not relocated		Yes
IdentifiedBy	Attribute used to confirm spring presence and location from imagery	• Veg: vegetation change • Hydrology: visible hydrology • Landuse: visible diversion or other use • Trailing: extensive cattle trailing to source • Topography: microtopography typical of springs		Yes
Springtype	Spring type classification[4]	• Helocrene: spring emerges diffusely without obvious pools or channelized flow, typically appearing as wet meadows • Hillslope: spring emerges mid-slope in upland area, usually has some sort of channelized outflow • Limnocrene: Spring forms a distinct pool with no inflow channel • Rheocrene: spring emerges in defined channel, with obvious channels above and below springhead	We avoided classifying springs as Cave, Exposure, Fountain, Geyser, Gushet, Hanging, Hypocrene, and Mound types	No
Permanence	Estimate of spring permanence based on review of several years of imagery	• Permanent: water visible in all imagery • Ephemeral: spring dry or water absent from some imagery • Unknown: unable to assess with any confidence		Yes
Surfacewater	Estimate of the extent and amount of visible water in current imagery	• Dry: no evidence of groundwater • Saturated: saturated with no open water • Patch: patches of standing or flowing water • Standing: extensive standing water • Flowing: extensive flowing water in developed channel • Both: extensive standing and flowing water	Assessing patches vs extensive proved difficult. We approached this as a scale from 0 to 5, with 0 being completely dry.	Yes
Disturbance	Record of any obvious disturbance	• Construction: construction effects • Fire: fire influence • Flowreg: flow regulation like diversions or impoundments on spring brooks • Herbivory: mammalian herbivory and visible game trailing • Recreation: recreational effects like trash around hot springs • Road: road, trail, railroad effects, rarely applied by UGS • Surface: surface water quality	Disturbance metrics were adopted from SSI field methods. Given our office/imagery-based mapping, we conservatively assessed this criteria and only identified disturbances with clearly visible impacts.	No
CommonNotes	Common issues noted during mapping	• Multiple points: spring has several discrete discharge points • Possibly artificial: uncertain hydrology wholly natural • Possible emergence elsewhere: points placed at visible hydrology but actual emergence might be further upslope or obscured by trees.		No
Notes	Additional notes or comments describing spring ecology or disturbance			No
SSI_ID	Existing unique identifier in the SSI database		Automated	-
RelatedRecords	Unique identifiers from all existing datasets relating to mapped spring		Automated	-
UGS_ID	Unique identifier specific to UGS projects		Automated	-
ImageDate	Date of imagery used to identify spring		Automated	-
MapDate	Date point created by UGS		Automated	-
Mapper	Name of UGS mapper		Automated	-

Notes

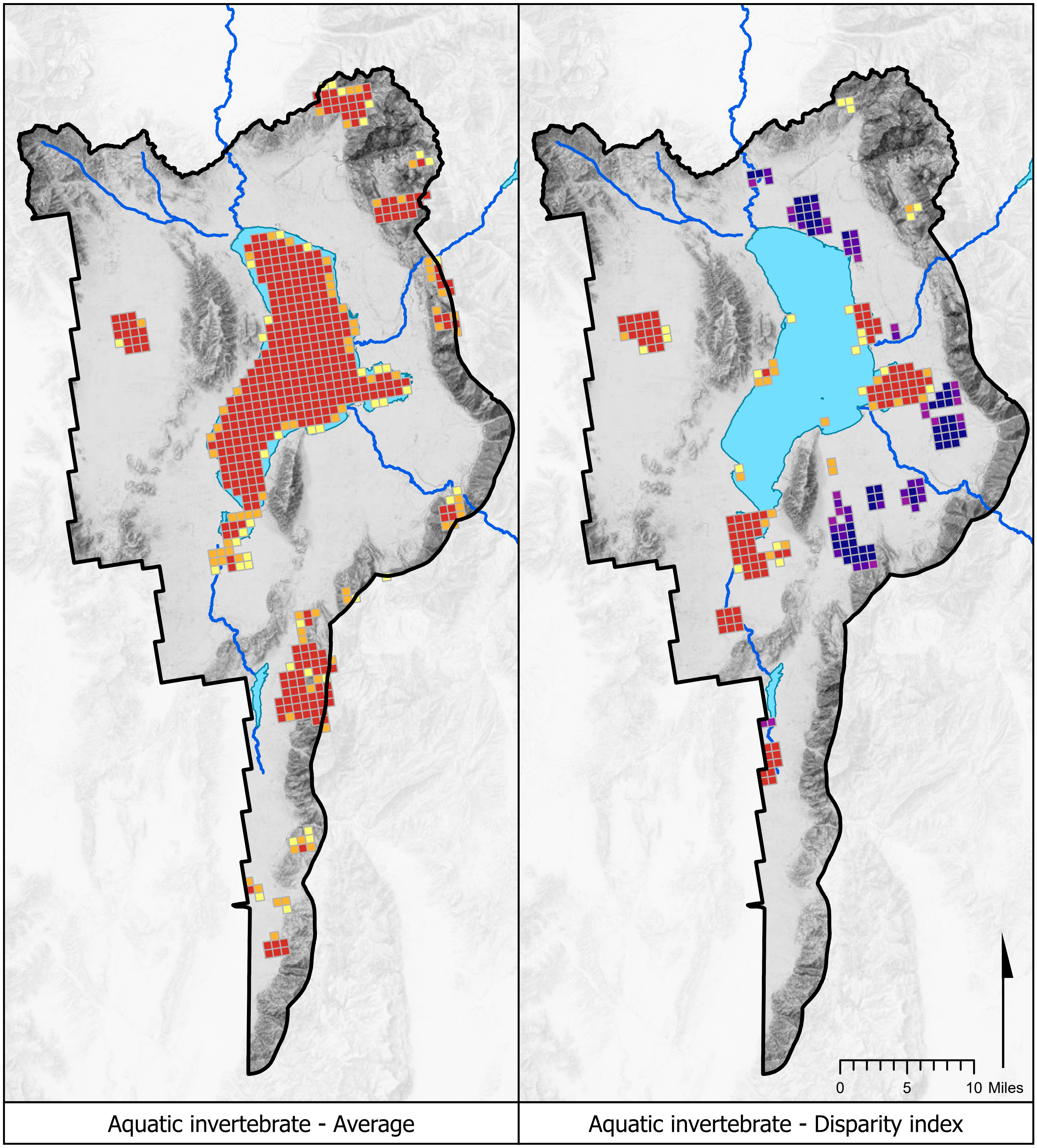
[1] Choice names align with coded values used in domains for mapping spring points.

[2] We did not require assessments of some criteria (spring type, disturbance) where we lacked confidence assessing from imagery alone. Some criteria (ImageDate, relatedRecords) were automated with custom Python scripts and completed for all mapped points.

[3] Spring Stewardship Institute

[4] Adapted from Stevens et al., 2021.

APPENDIX B—Individual Wetland Function Hot Spot Analyses



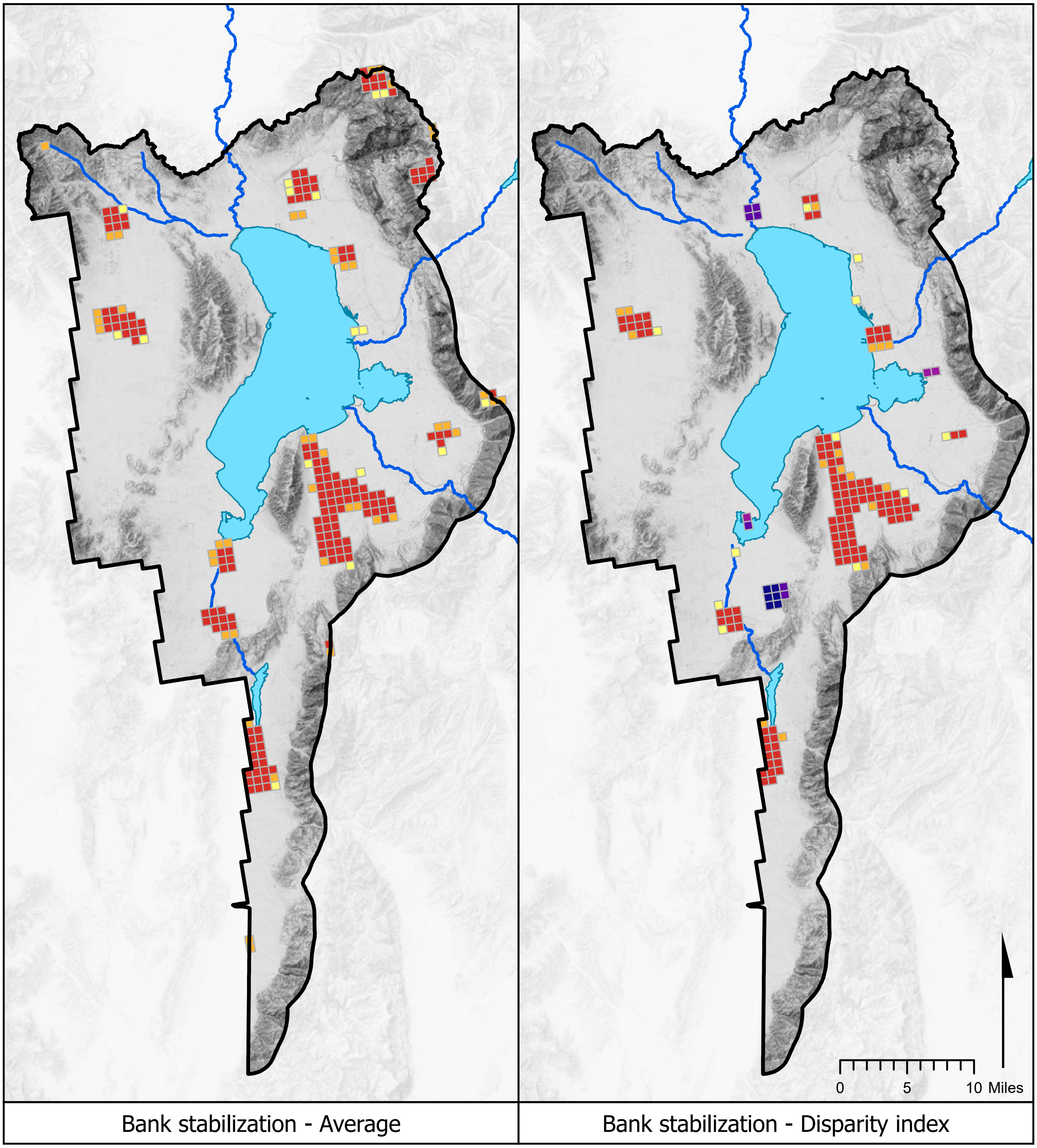
Aquatic invertebrate - Average

Aquatic invertebrate - Disparity index

Explanation

Hot spot analysis results

🟦 Cold Spot with 99% Confidence
🟪 Cold Spot with 95% Confidence
🟪 Cold Spot with 90% Confidence
🟥 Hot Spot with 99% Confidence
🟧 Hot Spot with 95% Confidence
🟨 Hot Spot with 90% Confidence



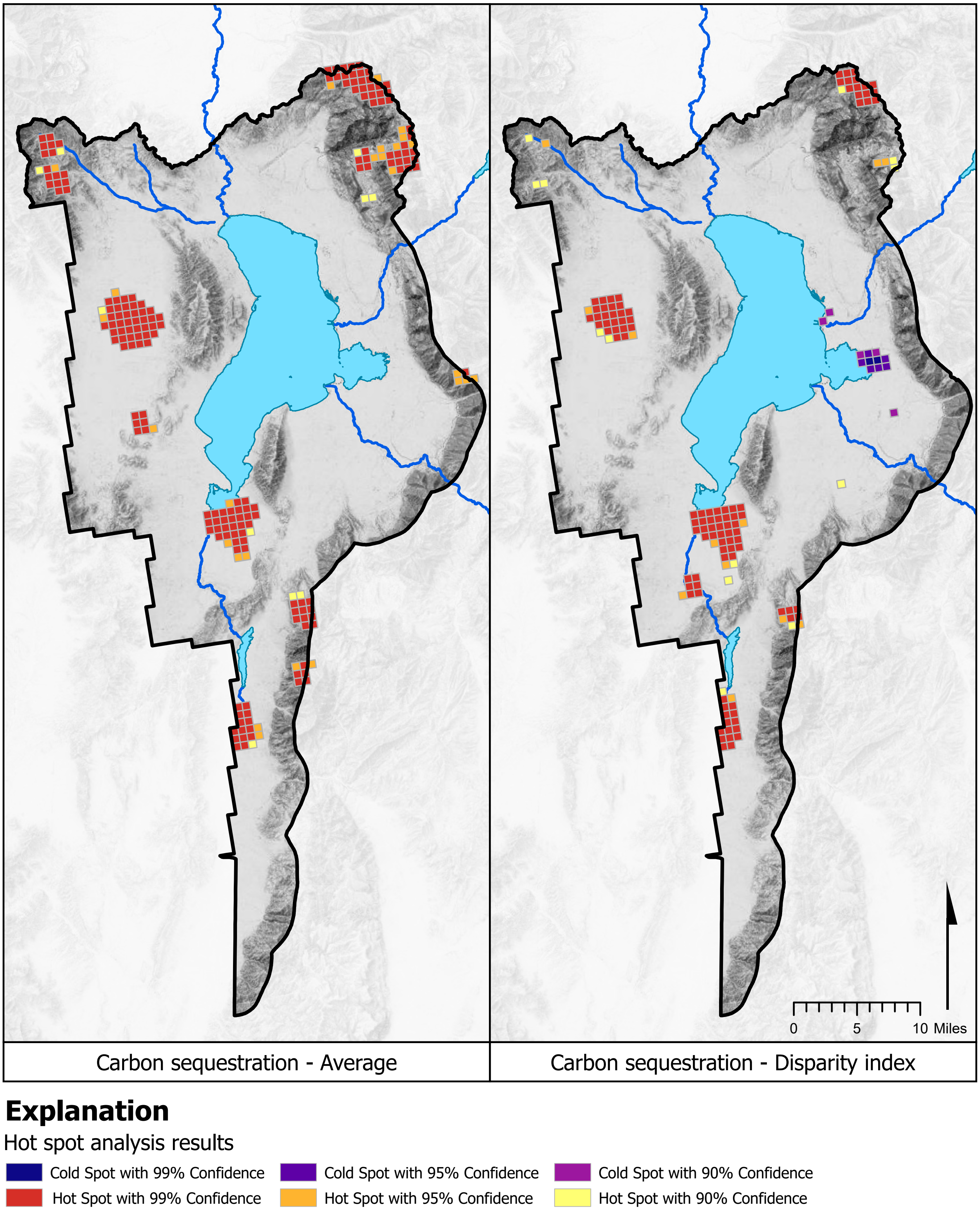
Bank stabilization - Average

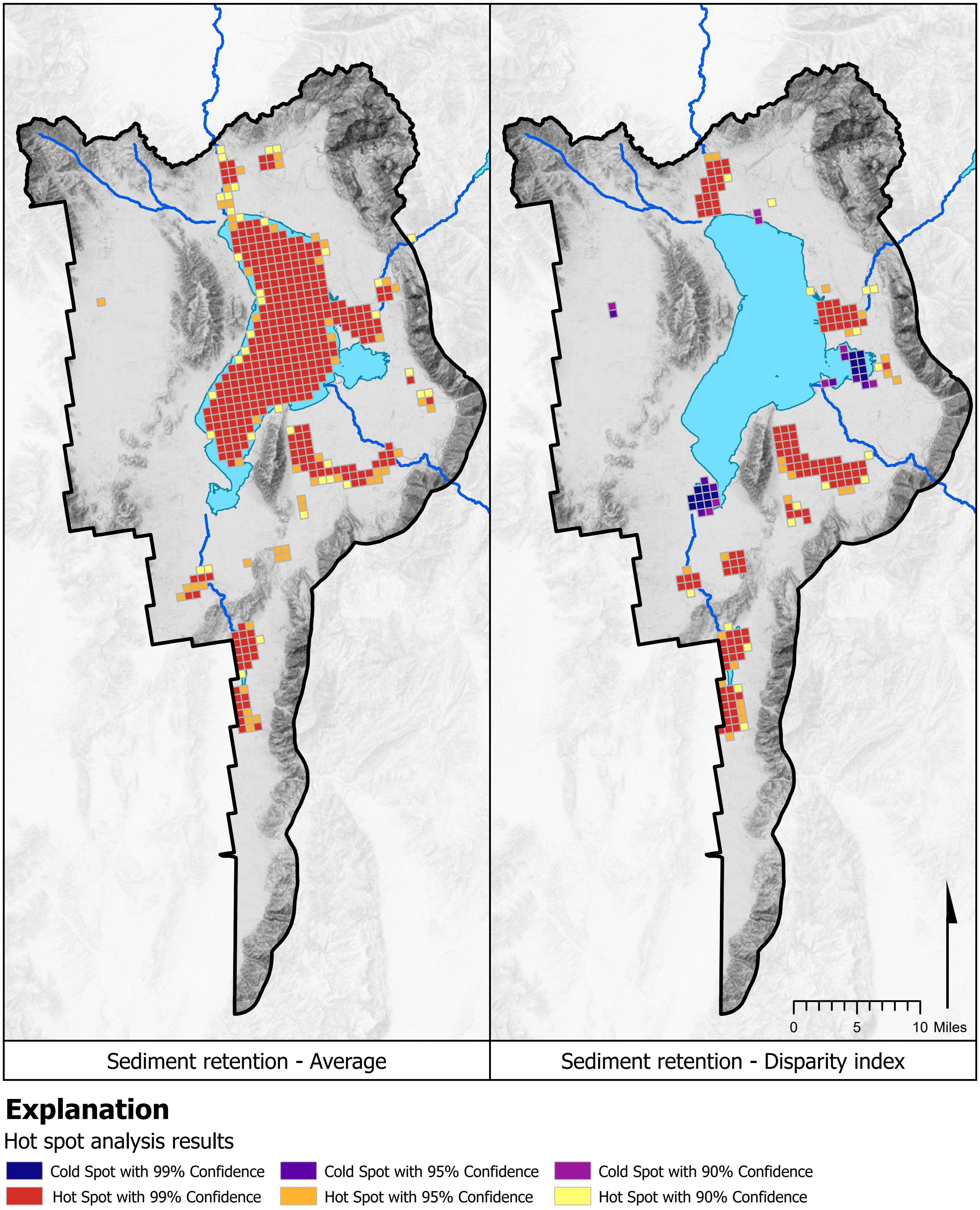
Bank stabilization - Disparity index

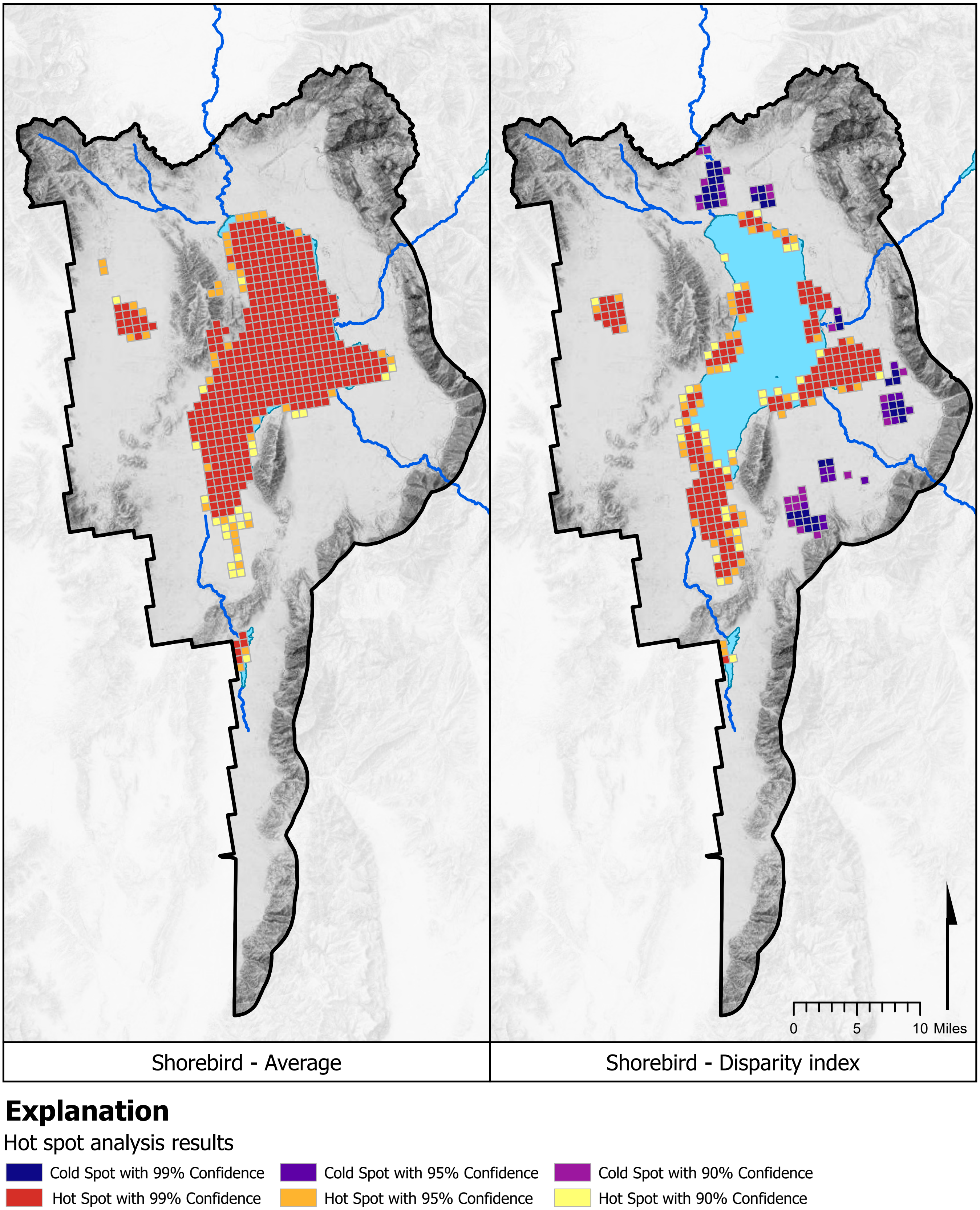
Explanation

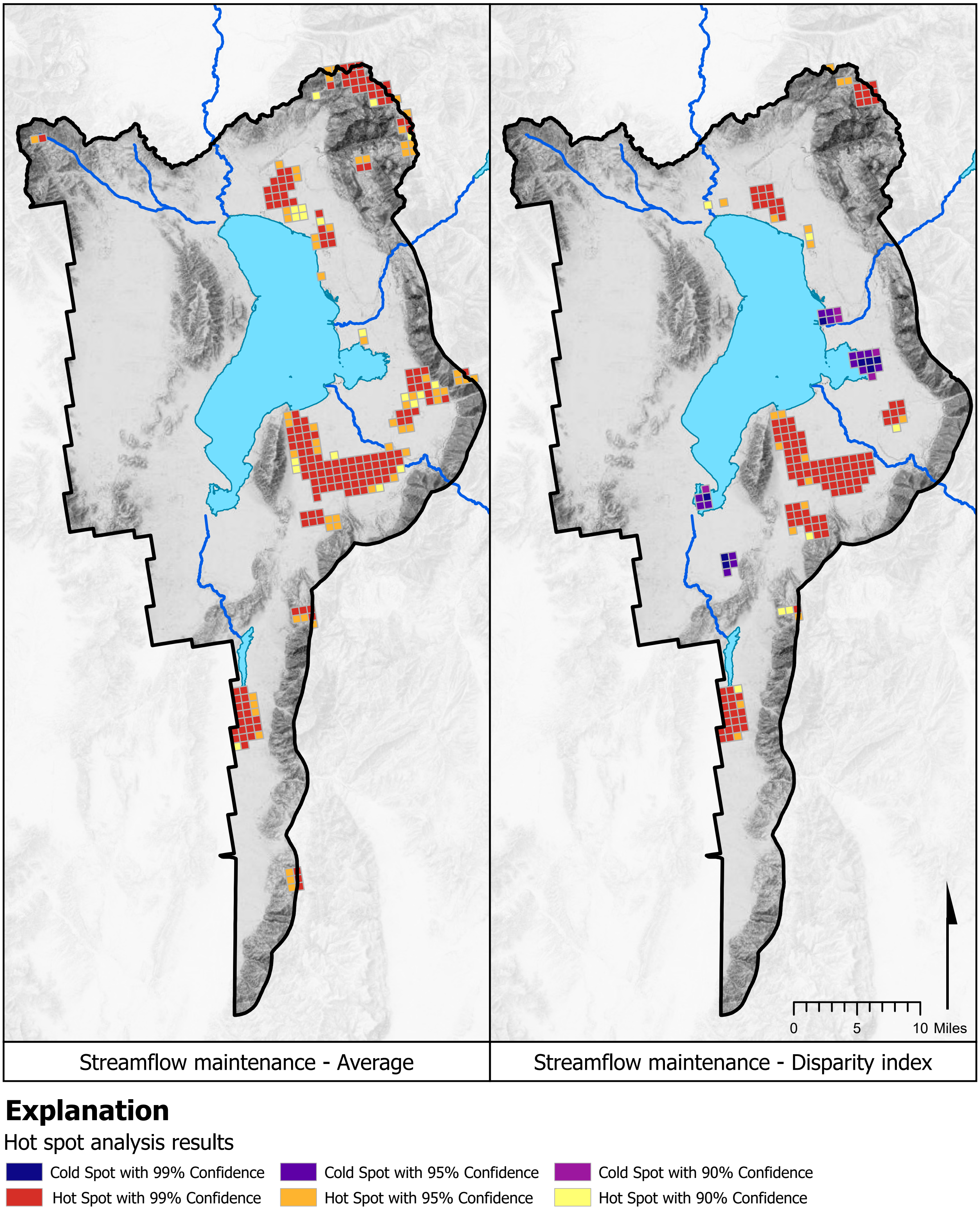
Hot spot analysis results

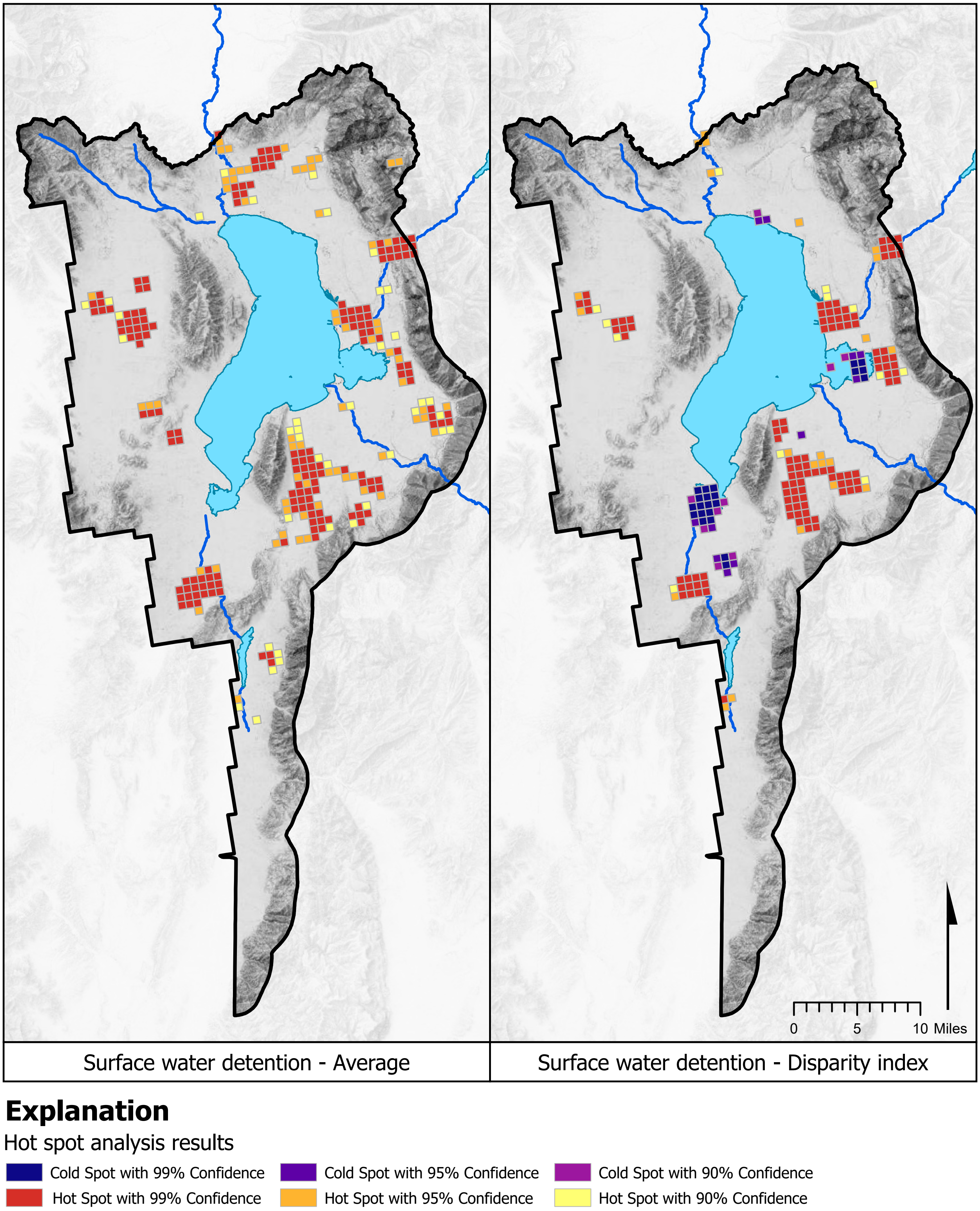
🟦 Cold Spot with 99% Confidence
🟪 Cold Spot with 95% Confidence
🟪 Cold Spot with 90% Confidence
🟥 Hot Spot with 99% Confidence
🟧 Hot Spot with 95% Confidence
🟨 Hot Spot with 90% Confidence


0
5
10 Miles
Carbon sequestration - Average
Carbon sequestration - Disparity index
Explanation
Hot spot analysis results
Cold Spot with 99% Confidence
Cold Spot with 95% Confidence
Cold Spot with 90% Confidence
Hot Spot with 99% Confidence
Hot Spot with 95% Confidence
Hot Spot with 90% Confidence


0
5
10 Miles
Sediment retention - Average
Sediment retention - Disparity index
Explanation
Hot spot analysis results
Cold Spot with 99% Confidence
Cold Spot with 95% Confidence
Cold Spot with 90% Confidence
Hot Spot with 99% Confidence
Hot Spot with 95% Confidence
Hot Spot with 90% Confidence

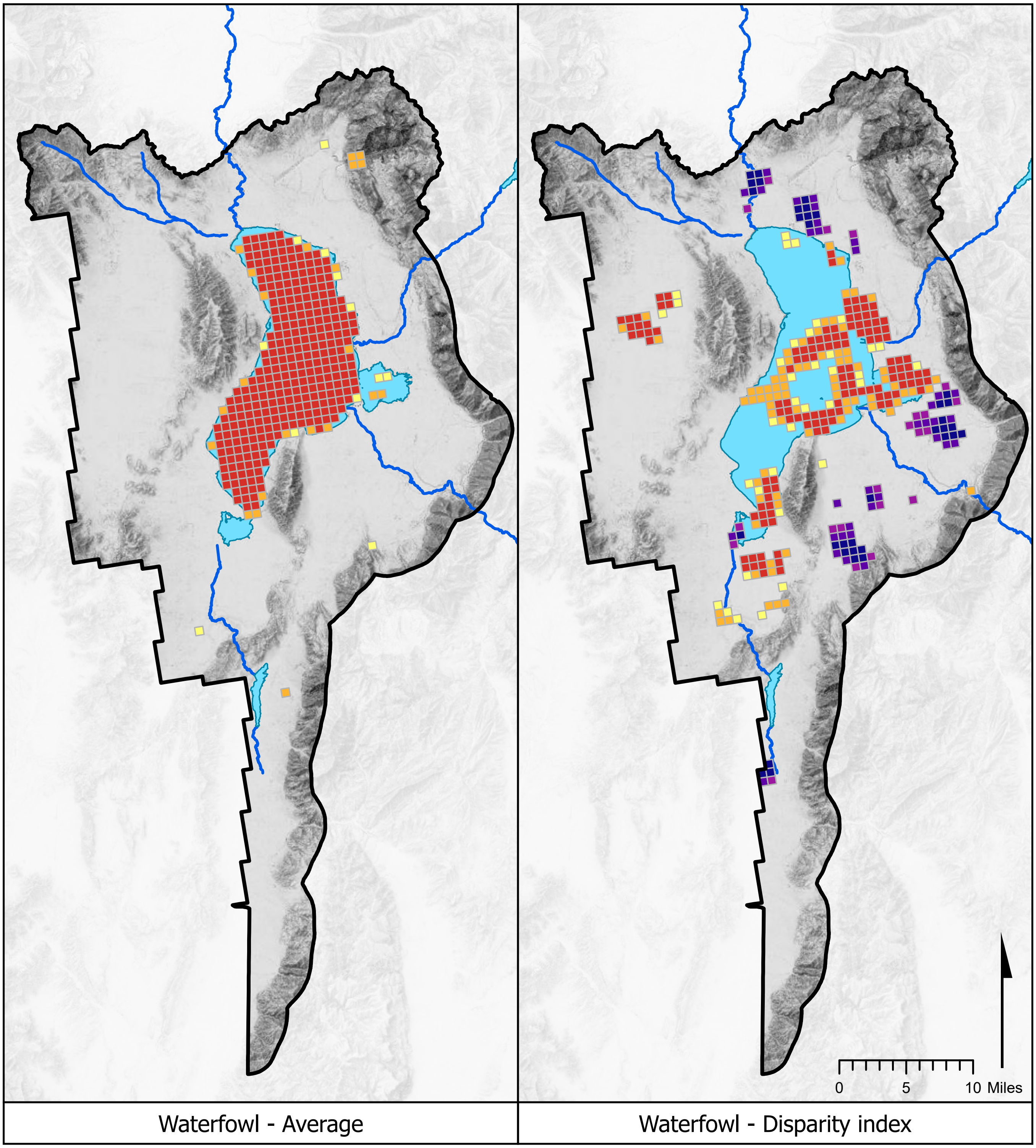

0
5
10 Miles
Shorebird - Average
Shorebird - Disparity index
Explanation
Hot spot analysis results
Cold Spot with 99% Confidence
Cold Spot with 95% Confidence
Cold Spot with 90% Confidence
Hot Spot with 99% Confidence
Hot Spot with 95% Confidence
Hot Spot with 90% Confidence


0
5
10 Miles
Streamflow maintenance - Average
Streamflow maintenance - Disparity index
Explanation
Hot spot analysis results
Cold Spot with 99% Confidence
Cold Spot with 95% Confidence
Cold Spot with 90% Confidence
Hot Spot with 99% Confidence
Hot Spot with 95% Confidence
Hot Spot with 90% Confidence



Surface water detention - Average

Surface water detention - Disparity index



Waterfowl - Average

Waterfowl - Disparity index

Explanation

Hot spot analysis results

🟦 Cold Spot with 99% Confidence
🟪 Cold Spot with 95% Confidence
🟪 Cold Spot with 90% Confidence
🟥 Hot Spot with 99% Confidence
🟧 Hot Spot with 95% Confidence
🟨 Hot Spot with 90% Confidence