Mapping and Assessment of Mounded Vernal Pool Habitat in the Rogue River Valley of Southwest Oregon

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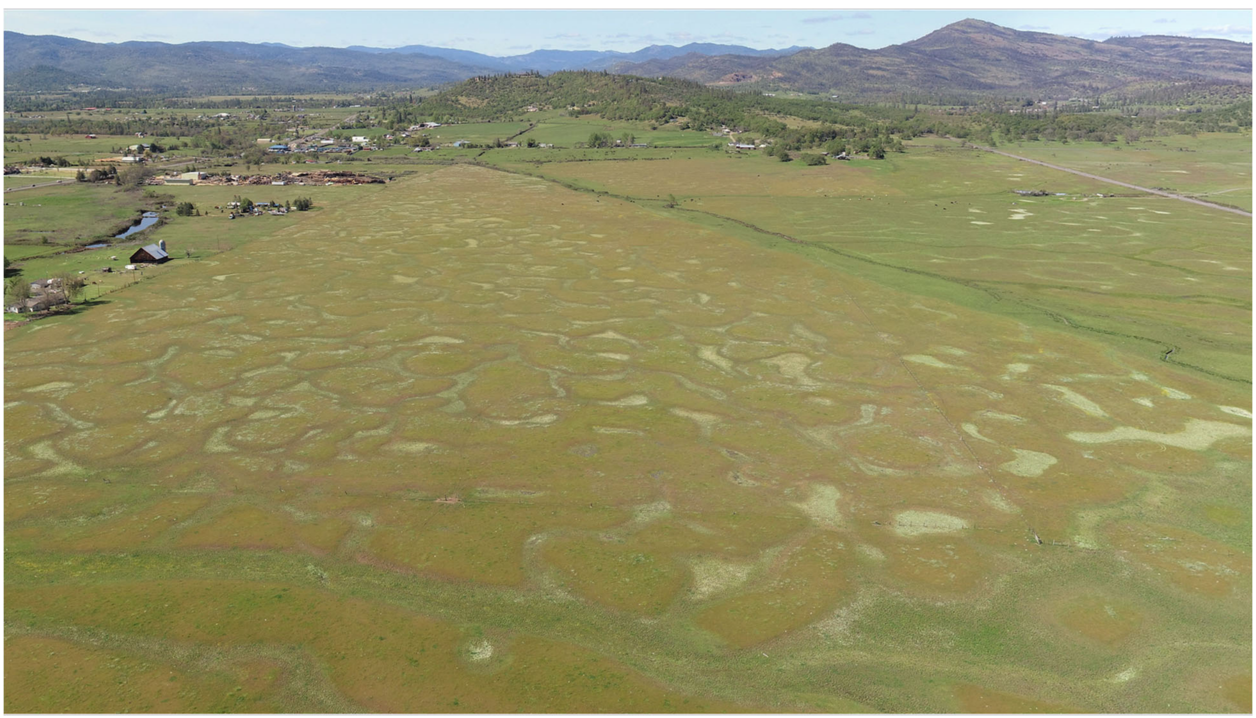


Natural mounded landform and vernal pool habitat in spring, Rogue River Valley, Jackson County, Oregon. © Cam Patterson

Summary

We used lidar (light detection and range) surface topography and hydrologic modeling, cross-referenced with aerial imagery to create a comprehensive map and assessment of remaining undeveloped mounded landform habitat in the Rogue River Valley of southwest Oregon (Jackson County). Mounded landform in this region is strongly associated with vernal pool and ephemeral wetland habitats essential for local Endangered Species Act (ESA) listed species: vernal pool fairy shrimp (*Branchinecta lynchi*), large-flowered woolly meadowfoam (*Limnanthes pumila* ssp. *grandiflora*), and Cook's desert parsley (*Lomatium cookii*). Our mapping and habitat condition assessment was developed to support US Fish and Wildlife Service (USFWS) recovery efforts for these species as well as habitat protection by other public agencies or private conservation organizations.

This report accompanies an attached set of spatial GIS (Geographic Information System) data providing a guide to its use, along with data summary, visualization, and interpretation. Our methods and integration of publicly available datasets allow for an unprecedented level of precision and accuracy in mapping and evaluating remaining habitat. Mapping products include polygons of mounded landform habitat with attributes for characteristics and condition, modeled surface hydrology of potential vernal pool basins and ephemeral surface flows, and 1-foot-pixel high-resolution lidar digital elevation model (DEM) topography coverage.

The Rogue Valley's characteristic mounded vernal pool landform developed on an Agate-Winlo soil complex, and this formation hosts most of the remaining habitat – but with less than 25% estimated to still be in functional condition. We mapped and described 16,466 acres of potential mounded vernal habitat across the Rogue Valley and surrounding foothills (below 3000 feet): 13,558 acres on Agate-Winlo soils and an additional 2,908 acres of unique mounded landforms on other soil types. Of these, 4,794 acres remain in strong to moderate condition on Agate-Winlo soils and 1,289 acres on other soils, representing the best current potential for habitat conservation. As an organizing structure to inform USFWS recovery planning, we grouped the mapped habitat into Recovery Focal Areas (RFAs) of relatively high habitat quality, continuity, and conservation potential. These recommended RFAs encompass 77% of all remaining habitat and 95% of habitat that is currently in strong to moderate condition.

Introduction

The Rogue River Valley of southwestern Oregon hosts a unique and beautiful complex of vernal pool and ephemeral wetland habitats associated with low-permeability soils and mounded landform topography (Johnson 1993; USFWS 2012; Perchemlides *et al*. 2020). These mounded vernal wetlands occur across grassland, oak, and shrub vegetation types and provide essential habitat for native plants and animals, including specialized rare, endemic, and federally listed species. Land use practices from the 1800's through present have caused widespread loss and degradation of these habitats through development, agriculture, fragmentation, topographic and hydrologic alterations, fire exclusion, and the spread of invasive weeds (USFWS 2012; Perchemlides *et al*. 2020). We estimate that less than 25% of the historic mounded vernal wetlands in the Rogue Valley remain as functional habitat, and none have escaped substantial impacts to hydrology, native plant communities, or ecosystem processes.

From a regional conservation perspective, protection of the Rogue Valley's vernal wetlands is uniquely important for conserving the range and diversity of the native species that rely on these habitats. The Rogue Valley mounded vernal wetlands are geographic and botanical outliers of California's Central Valley vernal pool system (Eriksen and Belk 1999) and at the northernmost extent of the California Floristic Province (Myers *et al*. 1999; Burge *et al*. 2016) where it overlaps the Klamath Mountains ecoregion. The Klamath Mountain ecoregion is recognized as a conservation priority area by the Oregon

Conservation Strategy for its unique geology and biodiversity, with the Rogue Valley's vernal pool and wetland habitats highlighted for strategic action (ODFW 2016). In addition to protecting remaining high-quality habitat, recent work in the Rogue Valley has demonstrated that topographic and hydrologic restoration of even heavily impacted vernal wetland sites and reintroduction of native species can be highly successful (Perchemlides *et al*. 2020).

In 2012, the US Fish and Wildlife Service (USFWS) defined the need and objectives for conserving these habitats in the *Recovery Plan for Rogue and Illinois Valley Vernal Pool and Wet Meadow Ecosystems*. This recovery plan focuses on essential habitat for three species covered by the federal Endangered Species Act (ESA): the threatened vernal pool fairy shrimp (*Branchinecta lynchi*), endangered Cook's desert parsley (*Lomatium cookii*), and endangered large-flowered woolly meadowfoam (*Limnanthes pumila* ssp. *grandiflora*). The USFWS plan identifies specific needs and actions to achieve recovery of these species and the long-term conservation of their habitat. Among these is the need for a regional assessment of the extent and condition of remaining habitat towards "*establishing a network of protected populations in natural habitat distributed throughout their native range*" (USFWS 2012, p. viii). Over a decade has passed since the plan was released, but the imperiled status of these species has not improved, and further actions are needed to achieve recovery (USFWS 2019).

To enable USFWS recovery actions, we have created a comprehensive map and assessment of the remaining mounded vernal pool and ephemeral wetland habitat in the Rogue River Valley, Jackson County, Oregon. Our mapping is based on remote sensing and includes all detected areas of non-montane mounded landform within the Rogue Valley and surrounding foothills. Mounded landform in the Rogue Valley is indicative of an impermeable subsurface layer and potential for seasonal inundation and saturated soils (Johnson 1993; Gabet *et al*. 2014) that could provide habitat for the above ESA-listed recovery species. This mapping supports the USFWS recovery goal of identifying potential new preserve areas and conservation easements for local land trust organizations, city, county, state, and federal agencies towards protecting a total of 4,300 acres or 90% of core habitat areas for these species (USFWS 2012), as well as independent protection or restoration efforts by other public agencies, private landowners, or conservation organizations.

Using lidar (light detection and range) surface topography and aerial orthophoto imagery in GIS (Geographic Information System), we mapped all remaining areas of undeveloped mounded landform, classifying each with descriptive attributes of landform condition, geophysical characteristics, and hydrologic metrics. High resolution lidar bare-earth shaded relief "hillshade" imagery revealed the underlying surface topography, and compiled publicly available spatial datasets provided important interpretive information such as ownership, land use zoning, protection status, soil type, and critical habitat for ESA species. Within each mapped habitat area, we modeled topographic basins and surface flow hydrology to estimate the physical potential for vernal pool and ephemeral stream habitat.

Here we present methods and results of our mapping as these apply to USFWS recovery strategies, including summary analyses of the spatial data and recommended focus areas for conservation or restoration efforts. This report is intended to accompany the attached ESRI ArcGIS Map Project, *RV_MoundedVernalHabitat*, and its linked geodatabases of spatial data (described below), providing a guide to their use and interpretation. Attributes and metadata in our GIS products provide further detail and information on our mapping, assessment, methods, spatial analysis tools, and metric definitions.

Methods

Remote sensing survey: Our work relied on public-access lidar surface topography data from the Oregon Department of Geology and Mineral Industries (DOGAMI) Oregon Lidar Consortium (OLC), and satellite and aerial orthophotography accessed through the ESRI GIS Imagery Basemap service and Google Earth Pro (GE) for current and historical imagery coverage. For our project area, the most current available DOGAMI lidar data were compiled as a mosaic of 2009 (Medford and southern Rogue Valley), 2010 (Eagle Point area), and 2015 (Upper Rogue and eastern foothills) flyover coverages.

For our initial survey, we viewed the lidar data as a bare-earth hillshade at the standard DOGAMI 3-foot pixel resolution and completed a systematic search of the entire Rogue Valley and surrounding foothills (below 3000 feet MSL elevation) to detect remaining areas of mounded landform. We cross-referenced the lidar with aerial imagery primarily from May 2016 (GE historical imagery) for assessing soil and vegetation patterns, and October 2020 (GE and ESRI) for current land use or development. This cross-referencing was especially important for areas where intentional leveling has removed the mounded landform, but its expression can still be seen in patterns of soil and vegetation, indicating the potential for restoration or remnant plant populations (Figure 1). In other areas, the 2020 orthophoto imagery revealed land use or development changes that had removed or heavily altered the mounded landform since the most recent available (2009, 2010, or 2015) lidar data – allowing us to track current conditions.

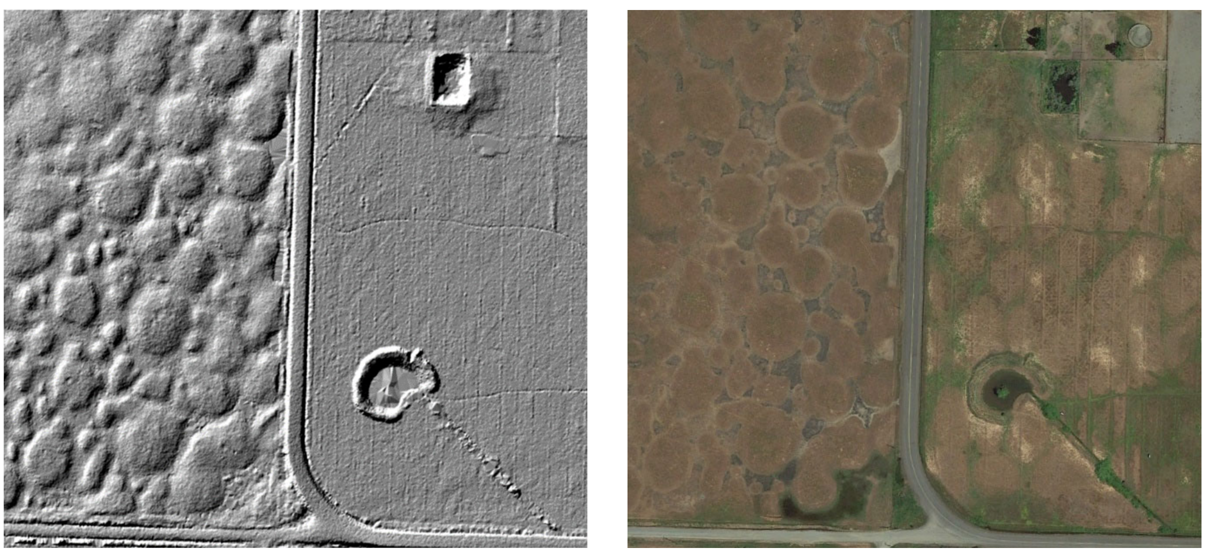


Figure 1. Two views of the same location in the Rogue River Valley, Oregon, illustrating cross-referencing of lidar hillshade imagery (left) with aerial orthophotography (right). In both frames, strongly mounded landform is clearly visible to the west of the bisecting road. East of the road, the 2010 lidar shows the land has been systematically leveled with no remaining mounded topography, but soil and vegetation landform patterns remain visible in the orthophoto view as lighter mounds and greener former pool basins (GE historical imagery, May 2016).

The Natural Resources Conservation Service soil map (NRCS 2022) and soil survey report (Johnson 1993) for Jackson County also provided important guidance for our survey. In the Rogue Valley, vernal pool habitat is primarily found on Agate-Winlo complex soils, which are characterized by an impermeable duripan layer, mounded topography, and seasonally perched water table. However, we also detected mounded landform on other soil types with shallow bedrock or heavy clay-pan substrates (Johnson

1993). We then carefully searched all other occurrences of these soil types within our project area to expand our landform detection. Often these other soil types were also soil “complexes”, patterned ground with a fine scale mosaic of two different upland and wetland soil types.

Targeted field checks conducted in the spring of 2022 informed our use of remote sensing. We visited a selection of representative sites across a range of soil types, locations, and disturbance impacts to calibrate our interpretation of the lidar and aerial imagery. This included walk-through surveys on public land or private conservation properties (with permission) and viewing private lands from public roadways. During these field checks, we informally assessed landform, habitat indicator plant species, surface inundation, and signs of topographic or hydrologic alteration.

Habitat landform mapping: We mapped all potential habitat in GIS by drawing polygons around the full extent of mounded landform expression as discernable in our cross-referencing of lidar and aerial imagery. Each polygon identifies a continuous area of mounded landform in similar condition. Separate polygons were drawn for areas in substantially different condition, or with distinct geomorphic characteristics, or where divided by substantial hydrologic barriers. Polygons tightly follow the edge of the mounded landform or boundaries of change in condition and were drawn to exclude interrupting features such as roads, major structures, or irrigation ditches. Habitat polygons often include some dispersed structures, dirt tracks, or other limited non-habitat features that do not substantially impact site condition or hydrology. Our mapping excludes all areas covered by development, including residential, commercial, or transportation infrastructure.

On Agate-Winlo soils we also inclusively mapped any remaining undeveloped areas, even where no mounded landform was detected, because of the strong association of these soils with vernal pool habitat and ESA-listed species. Prior to human-caused topographic alteration, mounded landform and vernal pools were the defining characteristic of Agate-Winlo soils across their entire extent (except at some limited transitional margins) (Borgias and Patterson 1999). Today, even leveled Agate-Winlo sites with intact duripan can host endangered plant species (USFWS 2012) and retain the capacity for ecological restoration (Perchemlides *et al.* 2020), making them important to map as remaining potential habitat. This inclusive mapping was not done on any of the other soil types in our project area because the same assumption of widespread historic mounded landform coverage does not hold. Habitat polygons on other soil types were drawn only where current mounded landform was detected.

Aerial imagery and lidar hillshade surface topography were also used to visually assess the condition and characteristics of each habitat polygon. We assigned categories for strength of landform expression, mound geomorphology, tree or shrub cover, degree of anthropogenic alteration, and current land use. These visual classifications are fully described in the results section below and as attribute metadata (see Appendix 1).

Hydro-topographic modeling: For a clearer, more precise view of the relevant topography, and to enable modeling of hydrologic features, we generated high-resolution surface topography coverage for all locations with mounded landform. Within and surrounding our mapped landform polygons, we reprocessed the raw DOGAMI lidar point-cloud data to a 1-foot pixel resolution digital elevation model (DEM). Viewed as hillshade topography in GIS, the high-resolution DEM allowed us to refine our habitat polygons and assessment of landform condition and geomorphology to greater accuracy.

We used this high-resolution lidar coverage and ArcGIS Spatial Analyst tools to model surface hydrology within all mounded landform habitat polygons. Potential vernal pools were modeled as undrained topographic depressions, or basins, in the landform with a depth of at least 0.5 inch and a minimum area of 50 ft^2. We manually reviewed the modeling results to remove artificial features such as irrigation ditches or ponds that obviously did not qualify as potential vernal pools – but retaining disturbed or altered basins along with more intact pools. For all basins, we calculated topography-based hydrologic metrics in GIS, resulting in full coverage of potential vernal pools as polygons with attributes of depth, area, volume, and contributing drainage area. We also modeled runoff surface flow patterns within our landform polygons to map and quantify the network of ephemeral streams interconnecting the vernal pool basins, and to compute contributing watershed values for basins.

The overall result of this hydro-topographical analysis was to map the physical potential for vernal pool habitat within each mounded landform polygon and illustrate the stream network patterns of the surface drainage tying those pools together. Because natural vernal pool habitat (especially on the Agate-Winlow soils) exhibits a characteristic pattern of drainage network and pool basins, these models provide a basis for evaluating habitat quality and disturbance as well as estimating the amount and condition of vernal habitat. We summarized the pool basin and ephemeral stream data to the mapped habitat polygons to quantify this hydrologic potential as attributes of pool density, average size, depth, and volume. Because of natural slope and drainage, or due to anthropogenic impacts, some mounded landform areas have little or no vernal pool basins present, but still support ephemeral stream networks and the potential for vernal wetland habitat.

Interpretation in context: To inform our mapping and assessment, we compiled and referenced existing public-access GIS features relevant to vernal pool habitat and conservation. These include NRCS soil mapping, Jackson County tax lot property coverage and ownership data, county and municipal land use zoning, USFWS Critical and Core Habitat for *Branchinecta lynchi*, *Limnanthes pumila* ssp. *grandiflora*, and *Lomatium cookii*, currently protected areas of vernal pool habitat, and prior 1998 mapping of vernal pool habitat on Rogue Valley Agate-Winlo soils (Borgias and Patterson 1999).

Results: Mapping Products

Our mapping generated 687 polygons of remaining mounded landform habitat covering 16,466 acres in the Rogue Valley and surrounding foothills (Map 1), containing more than 75,000 modeled pool basins and over 2,500 miles of ephemeral flow paths as potential vernal wetland habitat (Map 2). In this section we describe the final spatial data and attributes resulting from our mapping effort and delivered with this report. Data summaries that quantify remaining habitat status and condition are presented in the Habitat Assessment results section below; and summaries focused on priority areas for recovery conservation are covered in the Recovery Recommendations section (Map 3).

Project geodatabases: Our final mapping products are provided as a set of three primary ArcGIS geodatabases linked to an interpretive ArcGIS Pro map project, *RV_MoundedVernalHabitat*. These are described and presented as map images below. Copies of the map project and full spatial data, or stand-alone components, are intended for USFWS use and to be shared with interested partner agencies, organizations, or academic institutions to advance species recovery and habitat conservation.

All geodatabases and their raster or feature class content include descriptive metadata. In our file naming system, *RV* stands for Rogue Valley, and *VP* for Vernal Pool.

RV_VP_MosaicDatasets – Geodatabase with the tiled raster mosaic datasets for 3-foot pixel resolution DOGAMI lidar hillshade coverage of the project area, 1-foot pixel high-resolution lidar DEM tiles encompassing the mapped landform areas, and a slope analysis surface from the 1-foot DEM. This geodatabase also contains a raster output version of potential pool basins – the source of the modeled pool polygon feature class. The mosaic datasets are linked to parallel folders containing the underlying data and image LAS and TIFF files: LIDAR and RASTERS.

RV_VP_RecoveryHabitat – Contains the new feature class spatial data created for this project: Mounded landform habitat polygons, vernal pool basin polygons, ephemeral stream lines, and a related table of hydrologic metrics calculated from the pool and stream analysis that can be linked to the mounded landform polygons. This geodatabase also contains new features directly informing recovery efforts: properties providing some level of protection for remaining habitat and grouping polygons identifying recommended focal areas for recovery efforts by USFWS and partners. These feature classes are described below and summarized in the Habitat Assessment results section.

RV_VP_Reference – Geodatabase compilation of external-source public data used to inform and interpret our habitat mapping. Includes contemporaneous coverage of USFWS-designated critical habitat for *Branchinecta lynchi, Limnanthes pumila* ssp. *grandiflora,* and *Lomatium cookii* in the Rogue Valley, USFWS recovery core areas for all three species, the Jackson County soil map and property tax lots for Jackson County clipped to our project area, land use zoning for Jackson County, City of Medford, and City of Central Point, and previous mapping of vernal pool landform completed in 1998. Metadata for these features cite the data source and any alterations to the originals.

An additional supplemental geodatabase, *RV_VP_HydrologyAnalysis*, provides an archive of intermediate tables and feature classes from the analysis that generated potential pool and ephemeral stream coverages, along with calculated hydrologic metrics for each and summaries of those to the habitat polygons. This geodatabase is not directly linked to the map project and does not provide final mapping deliverables – it is shared with the USFWS to provide more detailed information on our hydrologic analysis but is not intended for general distribution. The final product of these analyses is the *HydroAnalysis_jointable* in the *RV_VP_RecoveryHabitat* geodatabase.

<u>Landform and hydrologic feature classes:</u> Below are brief descriptions of our mounded landform, pool, and stream feature classes, attributes, and related tables in the *RV_VP_RecoveryHabitat* geodatabase. Detailed metadata describing attribute fields, classes, and definitions are embedded in each of these GIS files. This mapping identifies potential remaining vernal wetland habitat as a foundation for recovery planning and field investigation, but the actual presence of vernal pool habitat or species has not been systematically confirmed by site surveys or wetland delineation.

RV_VP_MoundedLandform – Feature class of polygons identifying remaining undeveloped mounded landform across the Rogue Valley as an indicator of potential vernal pool or vernal wetland habitat for associated recovery species: vernal pool fairy shrimp (*Branchinecta lynchi*), large-flowered woolly meadowfoam (*Limnanthes pumila* ssp. *grandiflora*), and Cook's desert parsley (*Lomatium cookii*). Each polygon identifies a continuous area of mounded landform in similar condition. Areas of discernable mounded landform were comprehensively mapped across all soil types below 3000 feet elevation; on Agate-Winlo soils we also mapped any remaining undeveloped areas, even where no mounded landform or patterned ground was detected.

The attributes for *RV_VP_MoundedLandform* provide descriptive classes and quantified metrics for assessing the condition, characteristics, and habitat potential of each mapped area, including acres, slope, elevation, soil type, tree and shrub cover, and simple categories of current primary land use. See Appendix 1 for the complete list and definitions of *RV_VP_MoundedLandform* attributes.

Three fields classify habitat landform condition, geomorphology, and anthropogenic impacts:

Landform – The degree of current mounded landform expression
(*Strong, Moderate, Weak, Trace, or Absent*)
MoundForm – Descriptive geomorphic categories of mound surface topography
(*Continuous, Sparse, Irregular, Linear, Drainage, Unknown*)
Alteration – The intensity of anthropogenic physical alteration of the natural mounded landform
(*Light, Moderate, Heavy, Leveled, Restored, Transformed*)

And five fields provide measures of potential vernal pool hydrology summarized for each landform polygon: density of pools per acre, percent of the total polygon area covered by pools, average surface area of pool basins, average pool basin volume, and average pool basin maximum depth.

HydroAnalysis_jointable – Standalone table of in-depth hydrologic and topographic statistics that can be joined or related to the *RV_VP_MoundedLandform* feature class. Data metrics include the range, mean, and variance (SD) of polygon slope, elevation, and area, pool count and density per acre, pool basin surface area, depth, and volume, catchment drainage area, and density of ephemeral stream segments. These hydrology and topography statistics were calculated from the feature classes of modeled pools and streams or the high-resolution lidar DEM surface.

RV_VP_Pools – Feature class of potential vernal pools as topographic basin polygons modeled from the lidar 1-foot pixel DEM within the mapped habitat polygons. Pool basins meet minimum depth and area thresholds (0.5 inch and 50 ft^2) and were subjectively filtered to remove artificial water bodies assessed to be inconsistent with vernal pool habitat. Attributes for each pool polygon include maximum and mean depth, basin volume, and the contributing watershed catchment area.

RV_VP_Streams – Line feature class of potential ephemeral streams as surface drainage flows modeled from the lidar 1-foot pixel DEM within mounded landform polygons. Stream segments meet a minimum drainage catchment size of 2500 ft^2 and are clipped to the extent of the mounded landform polygons. Attributes include the stream order and length of each stream segment.

<u>Recovery conservation feature classes</u>: Two map layers summarize the status, opportunities, and priorities for mounded vernal wetland habitat conservation, responding to the USFWS goal of protecting 90% of core habitat areas for recovery species (USFWS 2012). Those feature classes and their attributes are summarized here and discussed in the Recovery Recommendations section below. More detailed metadata describing attribute fields, classes, and definitions are embedded in each of the GIS files.

ProtectedProperties – Properties in the Rogue River Valley, Jackson County, Oregon, identified by USFWS as meeting criteria for potentially protecting vernal pools or vernal wetland habitat and associated ESA-listed species or with land management compatible with recovery goals. These polygons are an edited subset of the Jackson County tax lots selected as public lands or private conservation lands overlapping our mounded landform habitat polygons. Properties included are either in public ownership (federal, state, county, municipal, local districts), owned by private conservation organizations, or privately owned but managed under a conservation easement or as a wetland mitigation bank; this status is identified in the **OwnerType** field as *PublicLand, ConsOwn*, or *ConsEase,* respectively. Inclusion of private land in this map layer is based entirely on existing voluntary conservation management and does not assign any new habitat protection or priority status beyond what is already in place. This feature class excludes all non-conservation private land.

The attribute field, **Protection**, classifies the current level of habitat protection for each property based on USFWS criteria and available information; these are estimates of functional habitat protection status, not formal or legal designations. Protection status is ranked in three classes:

Active = All private conservation ownership or easements, and any public lands with a formal protection agreement or actively managed in a manner aligned with species recovery goals.

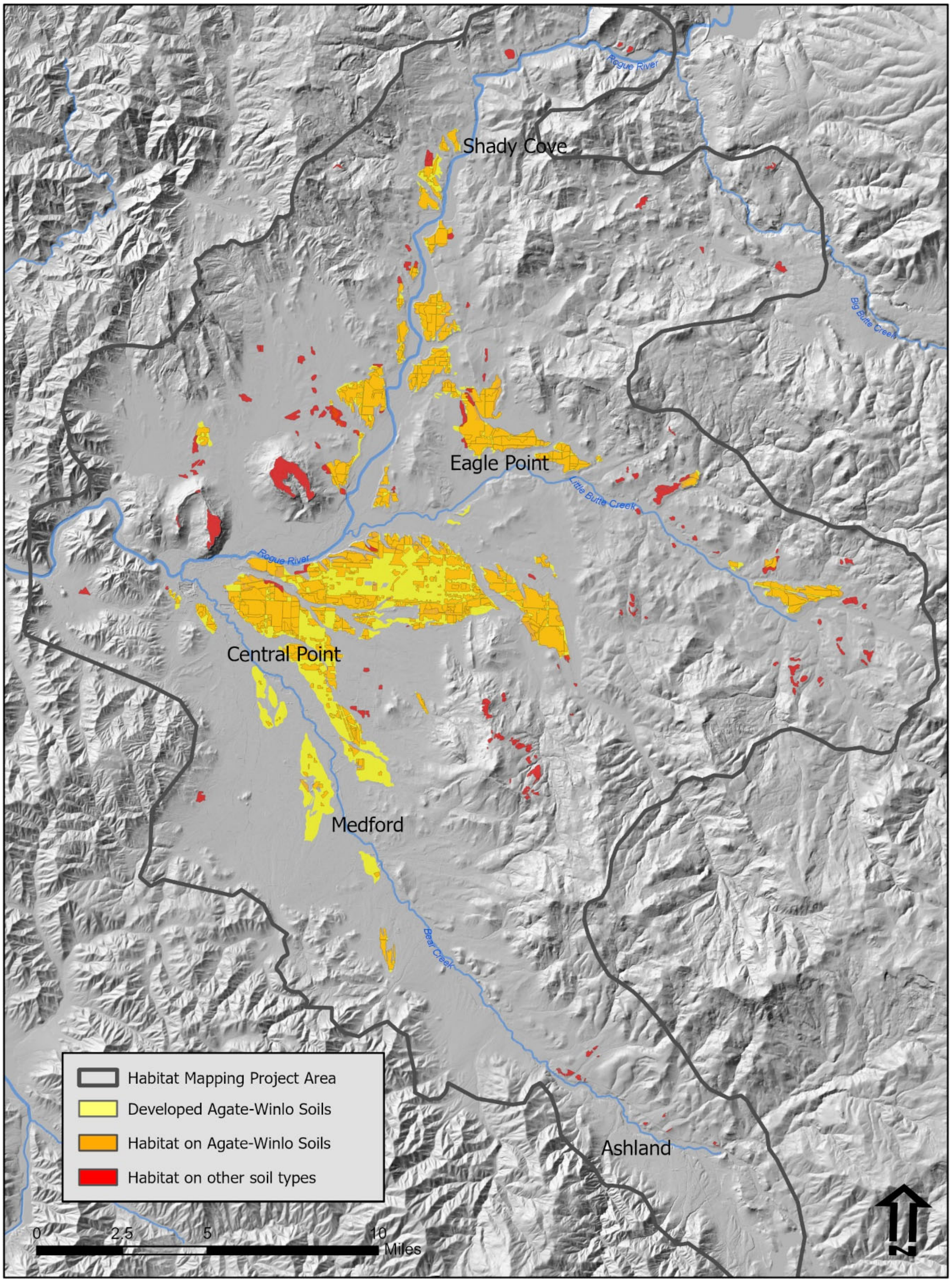
Passive = Any public lands managed for natural open space and not prioritizing development or other uses that are incompatible with species persistence and recovery. No private lands.

Unprotected = Public lands with uses or management priorities that are incompatible with habitat persistence. Sites managed for priorities other than natural open space, including development, without a plan or agreement for recovery species protection. No private land.

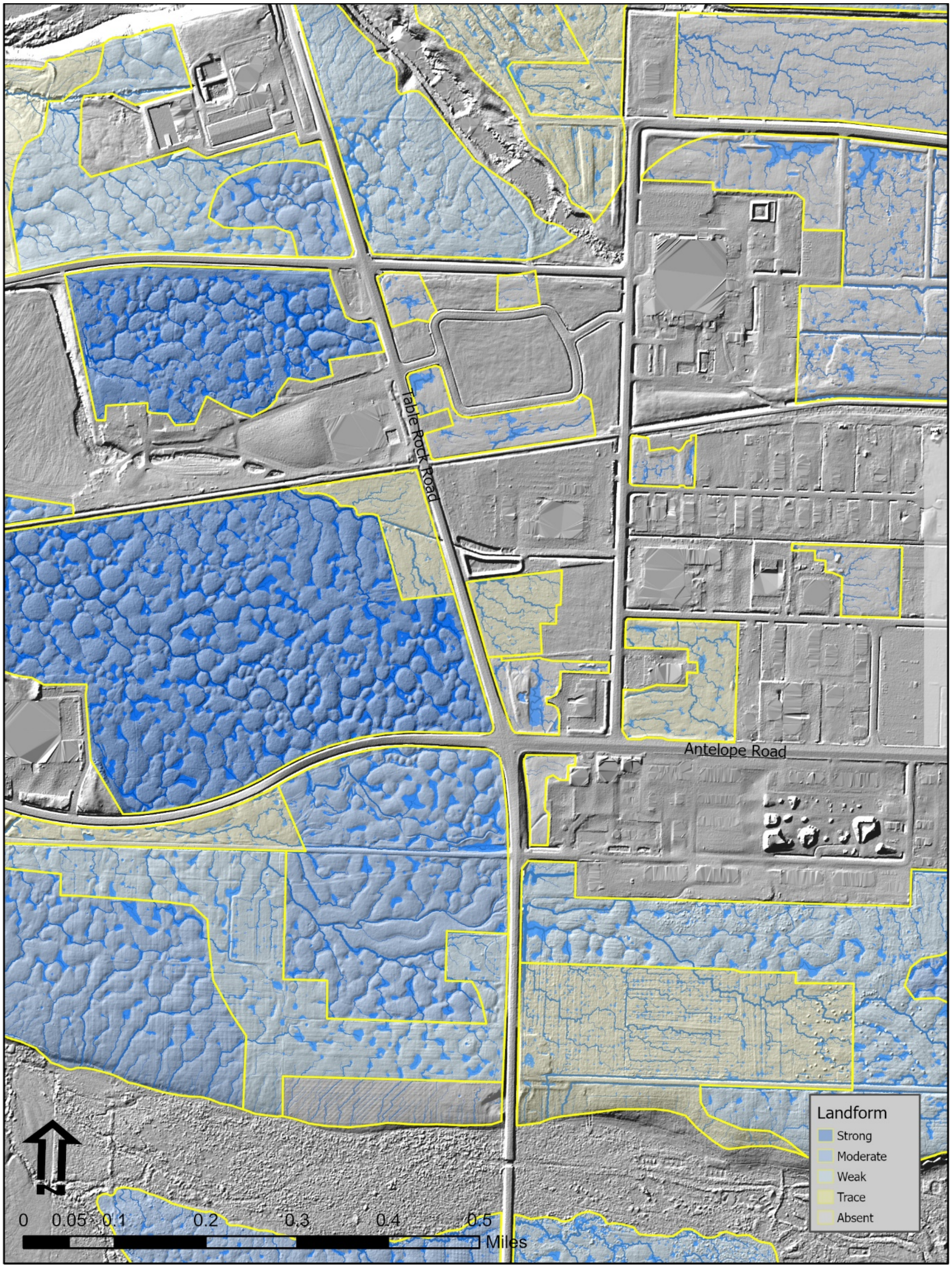
For the summaries in this report, habitat acres contained within properties identified with an *Active* or *Passive* protection status are treated as protected, and habitat on public lands identified as *Unprotected*, plus all non-conservation private lands, are treated as not protected.

RecoveryFocalAreas – Generalized polygons that spatially group clusters of remaining mounded landform and vernal wetland habitat with similar characteristics, relatively high habitat quality and continuity, and similar barriers or opportunities for recovery conservation success. Recovery Focal Area (RFA) polygons are intended to be used with the *RV_VP_MoundedLandform* feature class to assist USFWS recovery planning efforts in the Rogue Valley. RFA polygons apply only to the mapped habitat areas that they encompass and are not intended to delineate conservation boundaries or to be used independently. They do not indicate or assign any new protection status.

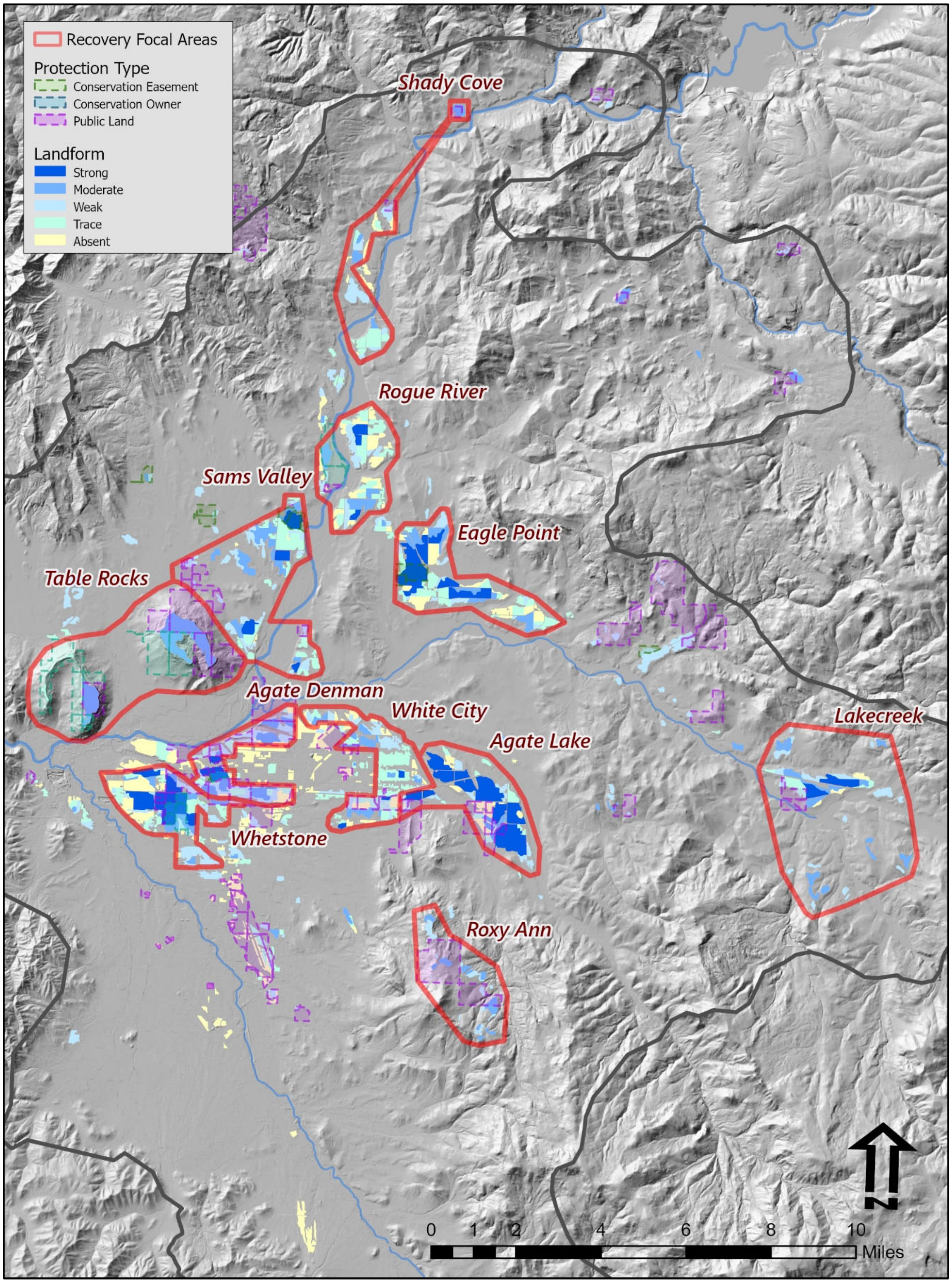
The RFAs were mapped referencing mounded landform habitat quality and characteristics, land ownership, with an emphasis on public land, private conservation land, or large undeveloped private tax lots, and county and municipal land use zoning with a preference for Open Space, Exclusive Farm Use, or Woodland Resource type zoning categories. The RFAs were intentionally mapped to include a range of diverse locations, underlying soil types, landforms and biophysical settings, the protection of which will likely support conservation of a diverse range of associated species and population genetics. Not all areas of remaining mounded landform or vernal pool habitat are included in these RFAs; excluded areas are generally smaller and more isolated, of lower quality, or have substantial physical or social barriers to conservation. The RFAs are intended to help focus USFWS recovery efforts on areas of greatest potential impact, but they are not intended to rule out conservation of any outlying habitat.



Map 1 – The mounded landform habitat mapping area on lidar topography shaded relief of the Rogue River Valley, Oregon. The remaining habitat on Agate-Winlo soils (orange) has been substantially reduced by development from its estimated historic extent (yellow), and much of what remains has lost landform and function. Mounded landform habitat is also found on other soil types in the surrounding landscape (red).



Map 2 – Detail of mounded vernal pool habitat mapping overlaid on high-resolution lidar topography in a partially developed area of White City, Oregon. Mounded landform polygons (yellow) outline the extent of remaining undeveloped habitat in a range of conditions, with modeled vernal pool basins and surface drainage ephemeral streams overlaid in blue.



Map 3 – Overview of the eleven recommended Recovery Focal Area (RFA) zones encompassing clusters of relatively high quality and continuous mounded landform habitat. The remaining habitat within each RFA shares similar characteristics and opportunities for recovery conservation. Habitat polygons are color-coded by condition and overlaid on properties identified as potentially meeting USFWS protection criteria.

Results: Habitat Assessment

Our mapping identified 16,466 acres of remaining mounded landform habitat across the Rogue Valley, centered on the valley bottom Agate-Winlo soil formation, but also occurring on other soil types across the valley floor and into the surrounding foothills (Map 1). Using lidar and aerial imagery, GIS analysis, and reference datasets, we described important habitat characteristics and assessed current conditions for all remaining sites; this section presents a summary analysis of that habitat assessment.

Much of the Rogue Valley's mounded vernal pool habitat has been lost or heavily impacted by land use and development (Maps 1 and 2), and no areas remain without substantial alteration. On Agate-Winlo soils, we estimate that over a third of the original habitat has been permanently lost to development, and less than 25% of its historic extent remains intact enough to provide well-functioning habitat. Even so, our results are encouraging for recovery of this habitat and species, showing large areas of remaining habitat with strong potential for conservation and restoration, and providing detailed information to guide those efforts. Table 1 presents an overview summary of selected results from our habitat mapping and assessment; far more information on these sites and their landscape context is contained in our spatial datasets, allowing for more in-depth or focused analyses by USFWS and other users.

Table 1. Overall summary of all remaining Rogue Valley mounded landform habitat by acres, protection status, and landscape-scale metrics of hydrology and topography. Results are split out by soil substrate, strength of landform expression (indicator of habitat quality), degree of anthropogenic alteration impacts, and current land ownership.

ALL MAPPED ROGUE VALLEY MOUNDED LANDFORM HABITAT	All remaining habitat acres	Protected habitat acres	Un-protected habitat acres	Pool basin volume per acre, feet^3	Total holding capacity, acre-feet	Elevation range, feet	Mean slope
All combined	16,466	3,590	12,876	536	203	1143 - 2970	3.3%
SOIL SUBSTRATE							
Agate-Winlo soils	13,558	2,557	11,001	615	191	1155 - 1887	2.9%
All other soil types	2,908	1,033	1,875	169	11	1143 - 2970	4.6%
LANDFORM EXPRESSION							
Strong	2,821	749	2,072	1,254	81		
Moderate	3,262	1,332	1,930	581	44		
Weak	3,696	715	2,981	413	35		
Trace	3,348	342	3,006	304	23		
Absent [1]	3,339	452	2,887	254	19		
ALTERATION INTENSITY							
Light	4,439	1,520	2,919	627	64		
Moderate	3,014	579	2,435	567	39		
Heavy	3,180	709	2,470	620	45		
Leveled	4,895	419	4,475	231	26		
Transformed [1]	712	143	569	189	3		
Restored [1]	227	220	7	4,847	25		
OWNERSHIP							
Public land	3,196	2,683	513				
Private conservation	908	908	0				
Private all other	12,362	0	12,362				

1 - These categories apply only to habitat on Agate-Winlo soils and were not mapped on other soil types.

The classification categories and terms used in these tables are fully defined in Appendix 1. Landform expression identifies how clear and distinct the patterned mound and basin topography is on a given site, ranging from Strong to Trace (barely discernable), and including fully Absent on Agate-Winlo soils. Landform is an indicator of potential habitat function, especially for Agate-Winlo soils, but does not discern between naturally limited topography and anthropogenically altered sites.

Alteration categories track the intensity of human-caused topographic disturbance, ranging from Light (there are no known fully intact sites) to Heavy, to sites where the natural landform has been systematically Leveled flat. On Agate-Winlo sites two other alteration categories apply: Transformed, where the land has been excavated, filled, or impounded but remains undeveloped, and Restored if the site has been intentionally recontoured to improve hydrologic function for ecological objectives and/or wetland mitigation. The Restored category does not assess the effectiveness of the recontouring in restoring historic landform or functional habitat and includes some sites with topography that is very different from natural Rogue Valley mounded landform. Hydrologic summary metrics reflect this with exceptionally large values for pool density or volume per acre compared to high-quality natural sites.

Across the Rogue Valley, mounded landform habitat conditions range from large, impressively intact expanses of clearly expressed mounded landform with strong hydrologic capacity, to small, isolated fragments so heavily altered that no landform or vernal pool hydrology remain (Map 2). Encouragingly, over a third of all remaining habitat has a strong to moderate mounded landform topography, an indicator of habitat intactness and potential quality. In contrast, more than half of the remaining undeveloped landform has been heavily topographically altered, severely limiting habitat function; even relatively minor surface disturbance can greatly reduce hydrologic function and undermine growing conditions for native wetland plants, including our recovery species (Perchemlides et al. 2020). Landscape-scale hydrology indicators of vernal pool basin volume and cumulative holding capacity align with these levels of landform expression and alteration, showing the decline of hydrologic function with higher levels of impact and diminished topography (Table 1).

The historic range of mounded vernal pool landform overlaps heavily with valley-bottom centers of settlement and agriculture, and over three-quarters of the remaining habitat is in private ownership (Table 1). Over 3,500 acres of the remaining landform is on properties providing some degree of habitat protection, but this is less than a quarter of the total acres and includes a wide range of habitat quality, including heavily impacted sites and outlying areas of uncertain suitability for recovery species.

Soils play a central role in determining the topography, hydrology, and suitability of mounded landform and vernal pool habitats (Rogers 2014). For the Rogue Valley, mounded vernal pool topography is strongly linked to the Agate-Winlo soil complex and 82% of all remaining habitat is found on that soil type (Table 2). Agate-Winlo soils developed on ancient alluvial-fan terraces and are characterized by an impermeable subsoil duripan, heavy clay basins, and seasonally perched water table that support widespread and sustained vernal pool inundation (Johnson 1993). They contain most of the known populations of our vernal pool associated recovery species and are estimated to have been almost entirely covered by mounded landform prior to anthropogenic disturbance. The Rogue Valley Agate-Winlo formation is an appropriate central focus of USFWS recovery efforts.

Table 2. Distribution of soil types underlying the remaining mounded landform habitat in the Rogue Valley and surrounding foothills. Acre values calculated from the majority soil type for each mapped habitat polygon.

SOIL SUBSTRATE	**All remaining habitat acres**	**Percent of total remaining acres**
Agate-Winlo complex	13,558	82.3%
McMullin-Rock outcrop complex	676	4.1%
Randcore-Shoat complex	641	3.9%
Provig-Agate complex	432	2.6%
Medco-McMullin complex	259	1.6%
Langellain-Brader loams	255	1.5%
Carney clay	167	1.0%
Brader-Debenger	139	0.8%
McMullin gravelly loam	106	0.6%
Medco clay loam	66	0.4%
Phoenix clay	58	0.4%
Coker clay	40	0.2%
Winlo very gravelly clay loam	33	0.2%
Barron coarse sandy loam	26	0.2%
McMullin-Medco complex	10	0.1%

Importantly, our mapping also found mounded landform on almost 3,000 acres of soil types other than Agate-Winlo, about 18% of the total mapped acres. These are a range of soils (Table 2) characterized by shallow bedrock or clay subsoil, alluvial fan origin, limited permeability, or prolonged seasonal wetness in soil series descriptions – indicating the potential for vernal pool or wetland habitat (Johnson 1993). Like Agate-Winlo soils, many of these other types are combinations or complexes, fine-scale mosaics of two distinct soil types typical of patterned ground, often with a drier “upland” mound soil and wetter “basin” soil occupying the space between mounds (Johnson 1993). The Randcore-Shoat soil complex on the Table Rocks mesa tops is a well-known example of vernal pool habitat on non-Agate-Winlo soils in the Rogue Valley. Beyond the Table Rocks, little is known about the presence of Rogue Valley recovery species, LOCO, LIPUGR, or BRLY, on these other soil types. Our mapping can guide future field surveys to investigate species presence and habitat suitability at these sites, expanding our understanding of the relationship between soil substrate and species ranges (USFWS 2012; Rogers 2014).

Because of important differences in landscape location, landform expression, and current knowledge of habitat suitability, we have separated our habitat assessment by soil type, with Table 3 summarizing mounded landform on Agate-Winlo soils and Table 4 covering all other soil types combined. Because of the documented habitat value of even heavily impacted Agate-Winlo sites for our listed plant species (USFWS 2019), we included all remaining undeveloped areas on Agate-Winlo soils in our assessment – even sites with Absent or Transformed landform; we did not include comparable sites on other soil types, instead mapping only where the landform was discernable.

Table 3. Summary assessment of remaining mounded landform habitat on Rogue Valley Agate-Winlo soil complex: Habitat acres and condition, hydrology metrics, ownership, and protection status. Compare with Table 4.

MOUNDED LANDFORM HABITAT ON AGATE-WINLO SOIL COMPLEX	**All remaining habitat acres**	**Protected habitat acres**	**Un-protected habitat acres**	**Proportion of habitat area in pools**	**Average pools per acre density**	**Area of average pool, feet²**	**Pool volume per acre, feet³**
Agate-Winlo habitat	13,558	2,557	11,001	5.4%	5.2	458	615
LANDFORM EXPRESSION							
Strong	2,821	749	2,072	9.2%	5.3	768	1,254
Moderate	1,973	553	1,420	6.9%	5.4	576	813
Weak	2,397	498	1,899	5.4%	5.8	411	572
Trace	3,028	305	2,723	3.7%	5.8	285	323
Absent [1]	3,339	452	2,887	2.7%	4.1	292	254
ALTERATION INTENSITY							
Light	2,821	614	2,207	7.5%	4.9	669	894
Moderate	2,252	553	1,699	6.0%	5.2	516	697
Heavy	2,808	636	2,172	6.1%	6.4	421	679
Leveled	4,739	392	4,347	3.0%	4.9	264	234
Transformed [1]	712	143	569	1.9%	2.6	337	189
Restored [1]	227	220	7	24.7%	7.3	1,514	4,847
OWNERSHIP							
Public land	2,412	1,928	484				
Private conservation	630	630	0				
Private all other	10,516	0	10,516				

1 - These categories apply only to habitat on Agate-Winlo soils and were not mapped on other soil types.

Table 4. Summary assessment of mounded landform habitat on soils other than Agate-Winlo in the Rogue Valley and surrounding foothills: Habitat acres and condition, hydrology metrics, ownership, and protection status. Compare with Table 3.

MOUNDED LANDFORM HABITAT ON ALL OTHER SOIL TYPES	**All remaining habitat acres**	**Protected habitat acres**	**Un-protected habitat acres**	**Proportion of habitat area in pools**	**Average pools per acre density**	**Area of average pool, feet²**	**Pool volume per acre, feet³**
Non-Agate-Winlo habitat	2,908	1,033	1,875	1.8%	2.8	289	169
LANDFORM EXPRESSION							
Strong	0	0	0	--	--	--	--
Moderate	1,289	779	510	2.4%	3.3	318	226
Weak	1,299	217	1,082	1.3%	2.2	262	121
Trace	320	37	283	1.7%	3.1	242	131
ALTERATION INTENSITY							
Light	1,618	906	712	1.8%	2.7	286	162
Moderate	762	26	736	2.0%	2.9	300	185
Heavy	372	73	299	1.6%	2.2	328	169
Leveled	156	27	128	2.3%	4.4	234	156
OWNERSHIP							
Public land	784	755	29				
Private conservation	278	278	0				
Private all other	1,846	0	1,846				

Mounded landform on other soil types ranges to higher elevations and steeper slope gradients than that found on Agate-Winlo soils (Table 1). Landform topography appears to be naturally less strongly expressed on these other soil substrates, with no landform expression comparable to Strong for Agate-Winlo sites (Table 4), and often differs in geomorphic patterning from the typical Agate-Winlo mounding (see **MoundForm** in Appendix 1). Pool basins on Agate-Winlo soils are, on average, larger, deeper, and more abundant than on other soils, indicating stronger hydrology and more aquatic habitat potential (Tables 3 and 4). These differences in pool basins are mainly explained by slope and mound patterning, with some non-Agate-Winlo sites hosting ephemeral stream wetlands instead of pools. Hydrologic function on all sites also depends on soil type, depth, and permeability.

Tables 3 and 4 summarize site-scale hydrologic metrics of pool density, area, volume, and the proportion of the habitat covered by modeled pool basins. Across all soil types, these hydrology statistics show a pattern of reduced pool size and capacity with diminished landform expression and at higher levels of alteration. The density of pools per acre can actually be higher on sites with moderate to heavy alteration because topographic disturbance causes fragmentation into more and smaller pools. Overall, the accuracy of our hydrologic modeling for estimating functional vernal habitats decreases at higher levels of alteration: Heavy disturbance can create relatively large surface depressions that lack inundation potential, or leveling can result in very wide, shallow basins with minimal holding capacity. We performed some filtering of the hydrology modeling results to remove obvious "false basins", but direct site surveys of hydrology or vegetation will be needed to determine actual function.

Compared to the Agate-Winlo formation, mounded landform sites on other soil types tend to be found further from municipal and agricultural development and more frequently on public lands. As a result, about a third of mounded habitat on other soil types currently meets USFWS criteria for protection, compared to under 20% protection for habitat on Agate-Winlo soils.

Direct comparisons of habitat quality or importance for species recovery between mounded landform on Agate-Winlo or other soil types are complicated by differences in natural geomorphic expression and topography, mapping inclusiveness, and limited data on recovery species ranges. In general, habitat on Agate-Winlo soil offers far more conservation potential in terms of total acres and confidence of suitability for recovery species. Outlying mounded landform on other soil types offers the potential to expand our understanding of recovery species habitat range and suitability, and an opportunity to preserve important population distribution and genetic diversity by protecting a wider range of landscape locations and geologic substrates.

Recovery Recommendations

Relevant to the USFWS recovery goal of protecting at least 4,300 acres of core habitat, our mapping found that over 2,500 acres of habitat on Agate-Winlo soils currently meets protection criteria (Table 3). However, only about 1,300 of those acres have Moderate to Strong landform expression indicating well-functioning habitat (Table 3). The currently protected Agate-Winlo habitat includes over 750 acres where the landform is Trace or Absent; these areas will be limited at best as LOCO or LIPUGR habitat and cannot contribute to vernal pool fairy shrimp (BRLY) recovery. Mounded landform habitat on other soil types includes about 1,000 additional protected acres (Table 4). Over 600 of those acres occur on the Table Rocks mesa tops and are known to host vernal pool fairy shrimp, but not LOCO or LIPUGR, while habitat suitability for the other protected non-Agate-Winlo acres is unknown.

The recovery plan protection targets were intended to cover a high percentage of the remaining habitat and species populations based on the best available data at the time the plan was written (USFWS 2012). The new mapping delivered with this report provides a foundation for updating habitat acres and condition status, guiding new species occurrence surveys, and potentially revisiting recovery core areas and protection targets.

<u>Recovery Focal Areas:</u> To support effective species recovery and habitat conservation, and as an organizing structure for our landscape-scale mapping, we have outlined a set of eleven Recovery Focal Areas (RFAs – Map 3). These RFAs are intended to help the USFWS identify and prioritize sites for recovery efforts but are not intended to rule out conservation of any outlying habitat. The RFAs are generalized map polygons that spatially group clusters of remaining mounded landform habitat with similar characteristics, relatively high habitat quality and continuity, and similar barriers or opportunities for recovery conservation success. Map 3 and the following tables provide an overview of the location and characteristics of the RFAs. The summary statistics in these tables are derived directly from the mapped mounded landform areas contained within the RFAs, not from the RFA polygons themselves.

The RFAs were drawn to include a range of diverse locations, underlying soil types, landforms and biophysical settings, the protection of which will likely support conservation of a diverse range of associated species and population genetics. Not all areas of remaining mounded landform or vernal pool habitat are included in these RFAs; excluded areas are generally smaller and more isolated, of lower quality, or have substantial barriers to conservation. The RFAs contain 77% of all remaining habitat, focused on areas with the strongest landform expression and ownership patterns compatible with conservation (Table 5).

The RFAs strongly overlap with USFWS Critical Habitat (USFWS 2003) and Core Habitat (USFWS 2012) areas for *Branchinecta lynchi, Limnanthes pumila* ssp. *grandiflora,* and *Lomatium cookie* (Table 5). The apparent divergence in overlap is due mainly to differences in the scale and precision of mapping between the coarsely mapped core area and critical habitat polygons and our detailed digitizing of landform expression. The RFAs are not intended to replace core or critical habitat, but our mapping could be applied to reassess those USFWS-designated areas.

Table 5. Overview summary of mounded landform habitat included in Recovery Focal Areas (RFAs) relative to all mapped mounded landform in the Rogue Valley. See Tables 6 – 8 for statistics on each individual RFA.

RECOVERY FOCAL AREAS (RFAs) OVERVIEW	**All remaining habitat acres**	**Acres in RFAs**	**Percent in RFAs**
All combined	16,466	12,680	77%
SOIL SUBSTRATE			
Agate-Winlo soils	13,558	10,769	79%
All other soil types	2,908	1,911	66%
LANDFORM EXPRESSION			
Strong	2,821	2,821	100%
Moderate	3,262	2,962	91%
Weak	3,696	2,544	69%
Trace	3,348	2,668	80%
Landform [1]	3,339	1,684	50%
OWNERSHIP			
Public land	3,196	2,490	78%
Private conservation	908	856	94%
Private all other	12,362	9,333	75%
USFWS CRITICAL HABITAT			
Lomatium cookii [2]	2,119	2,014	95%
Limnanthes pumila ssp. grandiflora	5,464	5,362	98%
Branchinecta lynchi [2]	6,198	6,078	98%
RECOVERY PLAN CORE AREAS			
Lomatium cookii [2]	2,888	2,632	91%
Limnanthes pumila ssp. grandiflora	6,661	6,327	95%
Branchinecta lynchi [2]	5,320	5,201	98%

1 - Applies only to habitat on Agate-Winlo soils; not mapped on other soil types.

2 - Includes habitat within the Rogue Valley only; species range extends beyond.

Tables 6, 7, and 8 provide different perspectives on the individual RFAs, suggesting strategies for assessment and prioritization. By cross-referencing these or similar summaries, the RFAs can be evaluated to inform recovery actions by weighing relative protection need, habitat quality, location, potential conservation gains, and opportunities.

Table 6 presents an assessment of the current level of habitat protection within each RFA, relative to land ownership (public, private, conservation) and the typical tax lot property size. The RFAs are ranked in order of increasing percent of habitat protected, with the least protected RFAs at the top. This is a simple view of where protection is most needed. Land acres in public or private ownership and the average property size can inform strategies for conserving additional lands.

Table 7 provides a comparison of the RFAs in terms of habitat quality (landform expression) and soil type (Agate-Winlo or other). Here, the RFAs are sorted by the number of acres of strong to moderate landform each contains – a coarse metric of potential direct conservation gain. Table 8 is a vernal-pool-centered view of the RFAs with hydrologic metrics for pool abundance, size, and capacity indicating the potential for inundating basins and wetland function. RFAs in Table 8 are ranked by the proportion of the habitat area covered by vernal pool basins from our hydrologic modeling.

Table 6. Protection and conservation summary for mounded landform habitat Recovery Focal Areas (RFAs) sorted by the percent of protected habitat within each RFA. See Map 3 for locations and extents of the eleven RFAs.

RECOVERY FOCAL AREA PROTECTION AND OWNERSHIP	All remaining habitat acres	Protected habitat acres	Percent of habitat protected	Un-protected habitat acres	Public land habitat acres	Conservation private land habitat acres	Private non-conservation habitat acres	Average property size, acres
Total for RFAs	12,680	3,016	24%	9,663	2,490	856	9,333	923
White City	1,341	33	2%	1,308	269	0	1,072	5
Lakecreek	965	33	3%	932	33	0	932	474
Shady Cove	609	27	4%	582	39	0	570	16
Rogue River	1,203	79	7%	1,124	4	75	1,124	19
Eagle Point	1,800	174	10%	1,626	0	174	1,626	28
Sams Valley	1,453	176	12%	1,278	62	116	1,275	26
Agate Lake	1,530	246	16%	1,284	280	0	1,250	36
Roxy Ann	292	76	26%	215	76	0	215	115
Whetstone	1,710	505	30%	1,205	279	226	1,205	7
Agate Denman	1,135	1,026	90%	109	1,018	53	65	46
Table Rocks	641	641	100%	0	430	211	0	150
Outside of RFAs	3,786	574	15%	3,212	705	52	3,029	11

Table 7. Habitat type and expression summary for mounded landform habitat Recovery Focal Areas (RFAs) sorted on the area of well-expressed (Strong + Moderate) habitat within each RFA. See Map 3 for locations and extents of the eleven RFAs.

RECOVERY FOCAL AREA (RFA) HABITAT AND CONDITION	All remaining habitat acres	Percent of habitat protected	Agate-Winlo soil, acres	All other soils, acres	Strong landform acres	Moderate landform acres	Weak landform acres	Trace or Absent [1] landform acres
Total for RFAs	12,680	24%	10,769	1,911	2,821	2,962	2,544	4,352
Agate Lake	1,530	16%	1,502	27	964	77	164	325
Eagle Point	1,800	10%	1,693	108	606	280	173	742
Whetstone	1,710	30%	1,673	37	583	208	347	572
Table Rocks	641	100%	0	641	0	624	0	17
Sams Valley	1,453	12%	1,155	298	228	370	375	481
Lakecreek	965	3%	629	336	174	349	277	165
Agate Denman	1,135	90%	1,086	50	123	316	379	317
White City	1,341	2%	1,339	2	40	266	267	768
Rogue River	1,203	7%	1,203	0	103	191	213	696
Roxy Ann	292	26%	0	292	0	166	126	0
Shady Cove	609	4%	489	120	0	115	224	270
Outside of RFAs	3,786	15%	2,789	998	0	300	1,151	2,335

1 - Applies only to habitat on Agate-Winlo soils; not mapped on other soil types.

Table 8. Summary of hydrology metrics for mounded landform habitat recovery focal areas (RFAs) sorted by the proportion of habitat area in vernal pools for each RFA. See Map 3 for locations and extents of the eleven RFAs.

RECOVERY FOCAL AREA (RFA) HYDROLOGY AND TOPOGRAPHY	All remaining habitat acres	Percent of habitat protected	Proportion of habitat area in pools	Average pools per acre density	Area of average pool, feet^2	Pool volume per acre, feet^3	Mean elevation, feet	Mean slope
Whetstone	1,710	30%	9.4%	6.33	662	212	1,237	3.2%
Agate Denman	1,135	90%	8.6%	6.91	562	162	1,272	3.3%
White City	1,341	2%	5.2%	6.72	346	80	1,237	3.2%
Sams Valley	1,453	12%	5.2%	5.21	446	123	1,329	2.7%
Eagle Point	1,800	10%	4.8%	4.41	485	114	1,445	2.4%
Agate Lake	1,530	16%	4.5%	4.39	451	109	1,475	3.0%
Rogue River	1,203	7%	3.4%	4.39	347	72	1,381	2.6%
Table Rocks	641	100%	3.0%	4.65	281	59	2,026	4.0%
Shady Cove	609	4%	2.9%	3.86	326	69	1,479	2.5%
Lakecreek	965	3%	0.6%	1.20	225	40	1,908	4.0%
Roxy Ann	292	26%	0.1%	0.34	132	25	2,575	7.9%
Outside of RFAs	3,786	15%	3.6%	4.47	357	82	1,438	3.2%

Conclusion: Past and future habitat assessment

Vernal pool habitat, perhaps more than any other wetland type, depends fundamentally on fine-scale topography for its expression and function. The first comprehensive mapping of Rogue Valley vernal pool habitat in 1998 relied on flyover aerial photography and aerial imagery in GIS (together with field surveys and soil maps) to track the location of vegetation patterns denoting vernal pool landscapes (Borgias and Patterson 1999). In 2009 the valley was first flown with an airborne lidar sensor that generated a "point cloud" dataset of hundreds of millions of 3D surface points that could be used to make extremely fine scale topographic maps. These mapping technologies can detect surface details smaller than 1 inch in height. Since that time, lidar point clouds have been used to help map, assess, and restore vernal pool landscapes at a variety of sites across the Rogue Valley (Perchemlides *et al*. 2020), and at individual sites over much of the full geographic range of the habitat.

This report and associated GIS datasets represent a first attempt to use publicly available lidar data (together with limited field surveys and aerial imagery) to create a comprehensive map of the distribution and condition of vernal pool habitat across the entire Rogue Valley region. Because much of the conservation planning and regulatory enforcement related to vernal pool wetlands in the Rogue Valley has depended on the initial regional mapping from 1998, this new mapping and modeling effort should be used (and updated with future regional lidar collections as available) to assist with conservation efforts and decisions by planners and regulatory agencies going forward.

A key finding of our mapping is that remote sensing lidar point clouds and hydro-topographic analysis tools in GIS can be used to model potential vernal pool basins and surface runoff flow paths across a regional terrain, resulting in detailed mapping of ponding and surface flow patterns that are highly correlated with the character and disturbance of individual sites. By applying this modeling across all of the habitat in the region, we were able quantify and describe the condition and quality of mounded landform habitat with unprecedented accuracy and scope. Encouragingly, our mapping found large areas of remaining high-quality habitat dispersed across the valley, confirming the potential to meet recovery goals, and providing a foundation of spatial data for planning efforts. Although this work largely confirms widespread habitat loss and that there are essentially no remaining examples of the undisturbed mounded vernal wetlands, opportunities for conservation and restoration abound.

In addition to new and more accurate mapping, an important finding of this work is that mounded landscapes with ephemeral wetlands capable of hosting rare or endangered species in the Rogue Valley are not confined exclusively to Agate-Winlow complex soils. We documented mound development on a variety of other impermeable-substrate soil types in the valley and surrounding foothills; and with limited field visits we identified the presence of wetlands and listed plant species in the pools and intermound flows on these soils. In some cases, mounded landscapes occurred on sloping sites without pool basin development where the wetland plant communities are supported in ephemeral intermound streams. An important application of our mapping and hydrology modeling will be to provide a detailed comprehensive spatial guide for future field surveys for ephemeral wetland habitats and associated rare species in the Rogue Valley region.

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Spatial data references: For external-source spatial data referenced in this report, the metadata embedded in the GIS feature classes and raster files provide source and credit information. Those GIS files and metadata are contained in the attached *RV_VP_References* and *RV_VP_MosaicDatasets* geodatabases. Metadata can be opened and viewed in the ArcGIS Pro Catalog.

Appendix 1: Full attribute definitions for the *RV_VP_MoundedLandform* feature class.

PolygonID – Simple sequential numeric unique identifier for each habitat polygon.

RFA_Name - Identifies the Recovery Focal Area that the mounded landform habitat polygon is included in - or "Outside of" for polygons not included in Recovery Focal Areas. See the RecoveryFocalAreas feature class for further information.

Acres – GIS-calculated acres within each habitat polygon, US Survey Acres.

SoilType – The primary soil type covering the majority of the polygon area. Sourced from the Jackson County Soil Survey map.

Landform – The degree of current mounded landform expression visible in lidar hill shade coverage and aerial imagery. Identifies the visual distinctiveness of mound and basin topography and relative elevations. Landform categories do not discern between natural or anthropogenic causes of condition. Polygons may have small inclusions of alteration, development, or a different landform category covering < 5% of the area. These are best-fit categories for a continuous range of landforms.

Strong – Landform clear and distinct with strong patterning and substantial elevation differences between mounds and basins. Natural landform with little or no obvious signs of topographic alteration - but not all minimally altered landforms are Strong, because some areas have naturally limited topography.

Moderate – Landform distinct but with lower visual clarity of pattern and less apparent difference in elevation between mounds and basins. The landform can appear natural or altered; alteration can range from continuous across the polygon to an uneven mix of type and intensity at a smaller scale than warrants separate polygons.

Weak – Landform present across the polygon but mound and basin forms are *not* clear and distinct and have little apparent difference in elevation between mounds and basins. The landform can appear natural or altered; alteration can range from continuous across the polygon to an uneven mix of type and intensity at a smaller scale than warrants separate polygons. Incomplete leveling is a typical alteration.

Trace – Landform is discernable only as faint traces of mounded topography in lidar hill shade and/or as mound and basin patterning in soils and vegetation visible in recent aerial imagery. Applies mainly to intensely altered Agate-Winlo soils and is evidence that natural hardpan and native soils may remain, with potential for habitat restoration. Can also occur on less intensely altered areas with naturally marginal landform expression or transitional zones.

Absent – Specific to Agate-Winlo soil sites lacking any evidence of mound and basin landform or soil and vegetation patterning. Applies primarily to undeveloped but intensely altered sites but can also occur on light to moderately altered naturally marginal sites that likely did not have clearly expressed landform prior to disturbance.

MoundForm – Descriptive geomorphic categories of mound and basin landform. Categories differ by the characteristic size, shape, coverage, and spatial arrangement of mounds as apparent in lidar hill shade and aerial imagery. Geomorphology is strongly linked to soil type, slope, hydrology, and topographic position. Cannot be consistently identified for Leveled areas where landform expression is lost (Pattern or Absent) – but can often be inferred on these areas based on adjacent landform.

Continuous – Large, regularly spaced generally oval to oblong mounds covering most of the land surface. Typical of flat or gently sloping Agate-Winlo valley bottom soils.

Sparse – Relatively small, regularly spaced oval to oblong mounds occupying approximately 50% or less of the land surface. Typical of low to moderate slope outlying clay soils on valley margins.

Irregular – Mounds naturally vary in size, shape, and spatial arrangement. Typical of outlying soils with shallow bedrock and uneven terrain with low to moderate slope.

Linear – Relatively small mounds arranged in elongated rows or linked chains oriented with the slope. Typical of outlying shallow soils with moderate to steep slopes.

Drainage – Mounds relatively large and elongated, often with an interlinked or braided arrangement following a converging pattern of drainage flows. Typical of slope and hydrologic transitions across a range of soil types on low to moderate slopes.
Unknown – Mound form no longer identifiable due to absence of landform.

TreeCover and **ShrubCover** – Two separate attributes identifying the current cover of woody vegetation as trees or shrubs, within the polygon. Estimated from current 2020 aerial imagery in 25% cover classes: 0, < 25%, 25 – 50%, 50 – 75%, >75%. This provides information on the type of habitat and likely vegetation communities, and may indicate differences in hardpan structure, drainage, and pool inundation – especially at higher levels of tree coverage. Inferences from visual assessments are limited by past clearing and land use confounding natural and altered conditions – especially for shrubs.

Alteration – The intensity of anthropogenic physical alteration of the natural mounded landform. Identifies the apparent degree of human-caused topographic disturbance as evident in lidar hill shade, aerial imagery, and hydrology modeling interpreted in the context of known land-use history. Alteration categories do not identify the specific cause or type of disturbance, only the apparent resulting intensity of change to the landform (except for known restoration areas). Polygons may have small inclusions of development or a different alteration category covering < 5% of the area.

Light – Landform shows little or no direct evidence of physical alteration. This is the lowest category of alteration because no sites are known to remain fully intact. A light alteration intensity does not necessarily correspond to strong landform expression; some habitat areas appear to have naturally limited landform.
Moderate – Clear evidence of substantial alteration across the area. The landform may remain distinct, but with diminished topographic form and clarity, or may be weak to absent for naturally limited landform. Evident disturbance may be continuous and systematic or an irregular mix of type and intensity at a finer scale than warrants separate polygons.
Heavy – Clear evidence of intense topographic alteration across the area. Mounded landform may remain present but is obscured by widespread disruption of topographic pattern. Disturbance may be continuous and systematic or an irregular mix of type and intensity at a finer scale than warrants separate polygons; can include limited impacts from added off-site soils, excavation, or small artificial water bodies.
Leveled – Intentional leveling of the ground surface has erased the mound and basin landform or diminished it to a weak or trace expression. Little or no relative elevation difference between mounds and basins; the area may appear completely flat or have faint scattered remnant mound forms. This disturbance can be smooth or rough-graded but is characteristically systematic and continuous across the polygon. Applies mainly to sites on Agate-Winlo soils.
Restored – The site is known to have been intentionally re-contoured to restore mound and basin landform and hydrologic function for ecological objectives and/or wetland mitigation. This category does not assess the effectiveness of the grading in restoring natural landform or functional habitat, and includes some "restored" sites with topography that is very different from natural Rogue Valley mounded landform. Effectively restored sites may not be easily distinguished from natural landform in lidar or aerial imagery; additional information on site history was used to identify the current topography as the result of restoration grading.
Transformed – Sites with no remaining landform where intense topographic alteration has removed, added, or rearranged soils without major development of structures or infrastructure. Applies primarily to artificial ponded or excavated areas on historic Agate-Winlo soils where vernal wetland habitat may remain or be restorable.

LandUse – The current primary land use *associated with* each polygon, grouped into broad categories based on relevance to habitat conservation and species recovery. Land use was visually assessed from 2020 aerial imagery and informed by existing zoning, ownership, and land use public information, but is *not* sourced from tax records, zoning categories, or owner-provided information. These are estimates only, with accuracy limited by detection uncertainty, recent land use changes, and multiple-use areas.

AgIrrigated – Irrigated intensive agriculture, including row crops, irrigated pasture or hayfield, nursery stock, orchard, or vineyard. Identified as distinct unseasonal green vegetation, visible crop rows, or freshly tilled fields in recent aerial imagery.
AgNonIrrigated – Non-irrigated intensive grazing land, hayfields, or fallow fields on agriculturally managed land. Does not include open range grazing.
OpenLand – Undeveloped public or private land in a generally natural condition with no apparent intensive land management. Includes grasslands and woodlands, dispersed recreation and natural areas, open range grazing land, and non-agricultural vacant land that is not in residential, commercial, or industrial settings.
Conservation – Private or public land known to be primarily managed for habitat conservation. Includes nature preserves, conservation easements, wildlife areas, and wetland mitigation land not managed for active use by the public. Similar to open land and identified using information on land ownership and status.
PublicPark – Designated natural areas or open space on public land specifically managed for focused public use and low-impact recreation. Can include limited structures.
Residential – Private properties with existing homes or vacant lots within rural or urban residential areas. Can include large private lots and limited secondary uses.
CommIndustrial – Private land in active commercial or industrial use or vacant lots in areas zoned or planned for those uses. Includes urban or rural industrial facilities, aggregate removal, business and shopping areas, and commercial recreational areas.
PublicFacility – Public land associated with developed facilities for a wide range of uses. Includes education, transportation, public utilities and services, sports or intensive recreation, cemeteries, and government facilities. Does not include nature parks.

PostLidar – Value of "1" identifies polygons where the landform appears to have been significantly altered since the most recent available DOGAMI lidar coverage at the time of mapping. Our lidar hill shade coverage and hydrology modeling will not be accurate for these polygons.

Soils_all – List-format field including all overlapping soil types for each polygon; with soil names and mapped extents sourced from Jackson County Soil Survey map layer.

Elevation – Mean elevation in feet of the polygon. Sourced from lidar DEM. Given elevational gradients of climate and plant communities, no landform occurrences were mapped above 3,000 feet.

Slope – Mean percent slope within the polygon, as modeled on high-resolution lidar surface DEM.

Pools_ac – Potential number of distinct vernal pool basins per acre within the polygon, calculated from hydrologic modeling on high-resolution lidar surface DEM.

Pool_Avg_ft2 – Average modeled pool area (square feet) within the polygon, calculated from hydrologic modeling on high-resolution lidar surface DEM.

Pool_Avg_ft3 – Average modeled pool basin volume (cubic feet) within the polygon, calculated from hydrologic modeling on high-resolution lidar surface DEM.

Pools_PctArea – Percent of total polygon area covered by vernal pool basins, as modeled on high-resolution lidar surface DEM.

Depth_MaxAvg_in – Average maximum depth in inches of modeled pools in polygon, as modeled on high-resolution lidar surface DEM.