

Mapping Wetland and Beaver Activity across the Colorado River Basin using Machine Learning

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Overview

Why?

- Tracking **wetland change** - drought/aridification, beaver activity, restoration, policy change
- Better mapping for the most **dynamic wetlands**
- Manual wetland mapping across large geographic scales is expensive, time-consuming

Objectives:

- Track **extent of vegetated wetlands, open water, and beaver wetland complexes** over time in the Colorado River basin using **repeatable** and **low-cost Machine Learning (ML)** techniques

Metrics:

- Vegetated, valley bottom wetlands
- Open water
- Beaver ponds and beaver-influenced vegetated wetland area

Time Period

- 2012-2020 for initial study
- 3 independent years for each basin state

WALTON FAMILY
FOUNDATION



Wetland Mapping Challenges



Legend

River Basins

River Basins

- Major River Basins
- Major River Basin Boundary
- River Subbasins
- River Subbasin Boundary

Counties

Counties

- County Boundary

Wetland Mapping

Colorado Wetlands

- Emergent
- Forested
- Pond
- Lake
- Other
- Riparian
- Rivers & Streams
- Shrub-Scrub

Colorado Wetlands Greyscale

- Wetland

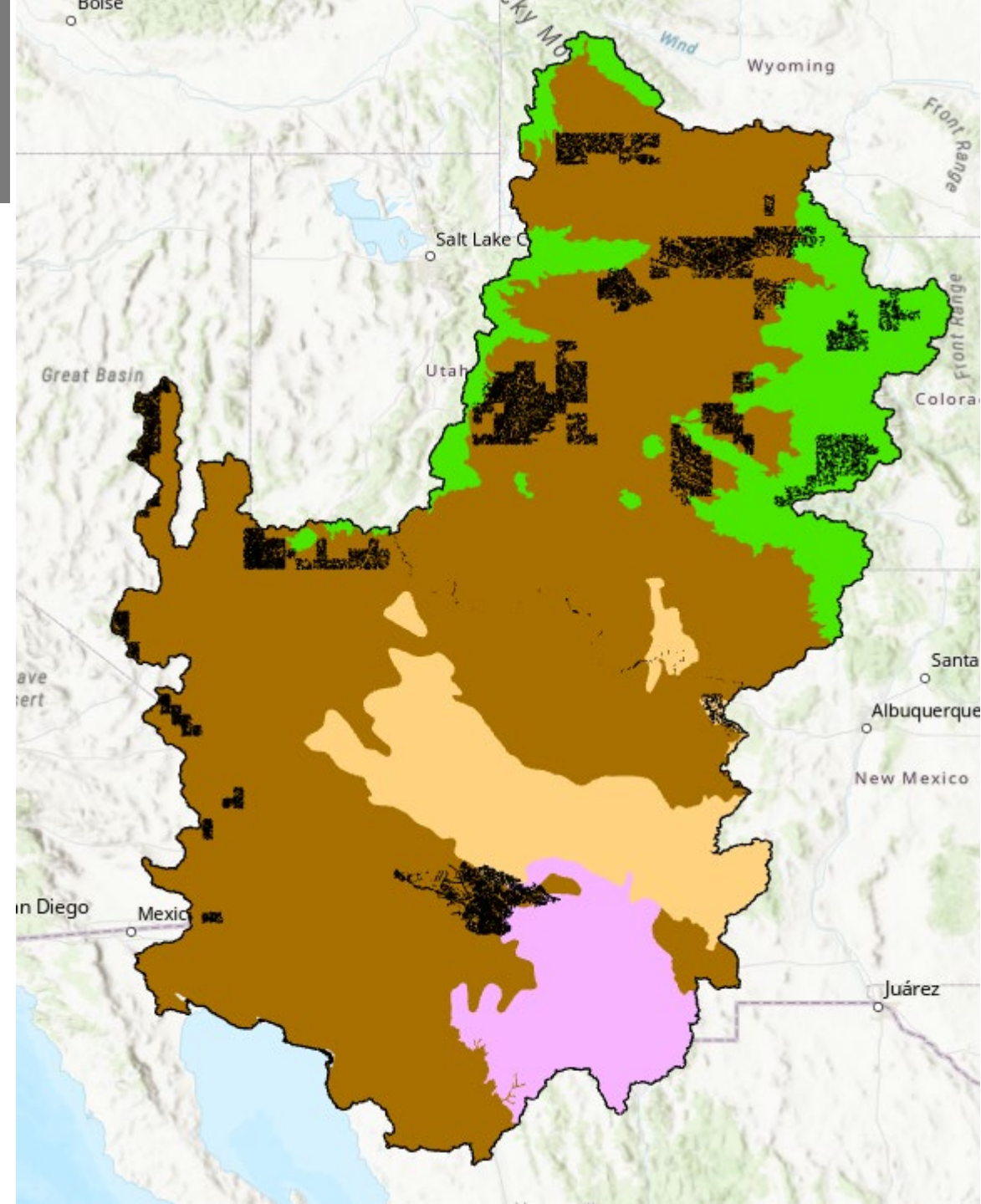
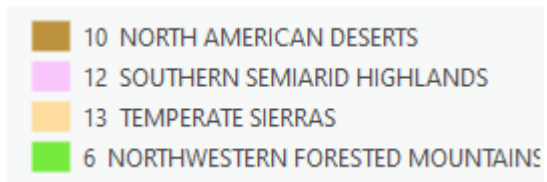
Study Area: Colorado River Basin (U.S.)

Model Extent: U.S. portion of CRB

Four Level 1 Ecoregions

Seven states

Training Areas: 24 NAIP tiles ($>300 \text{ mi}^2$)



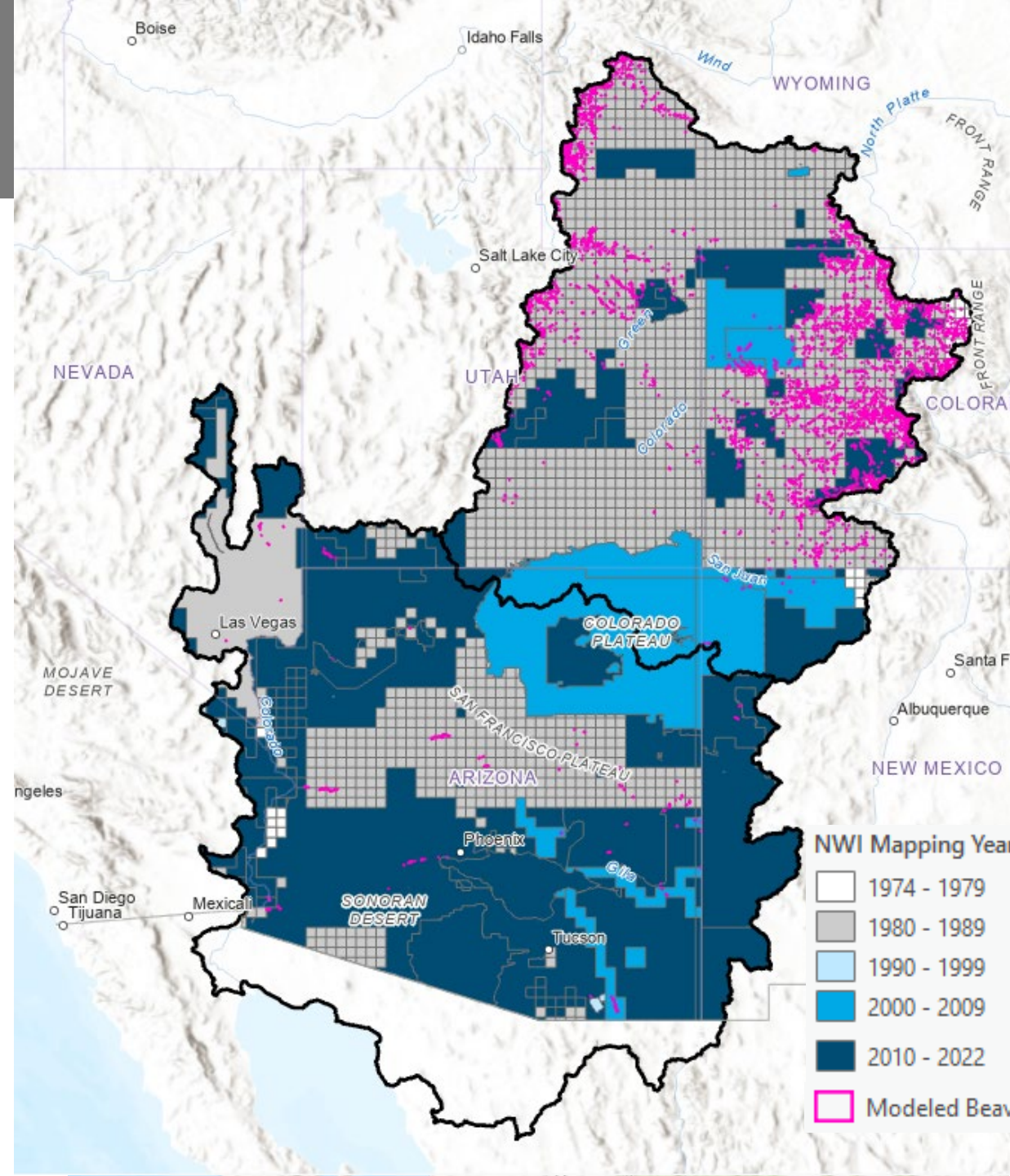
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Data Inputs: NAIP Imagery

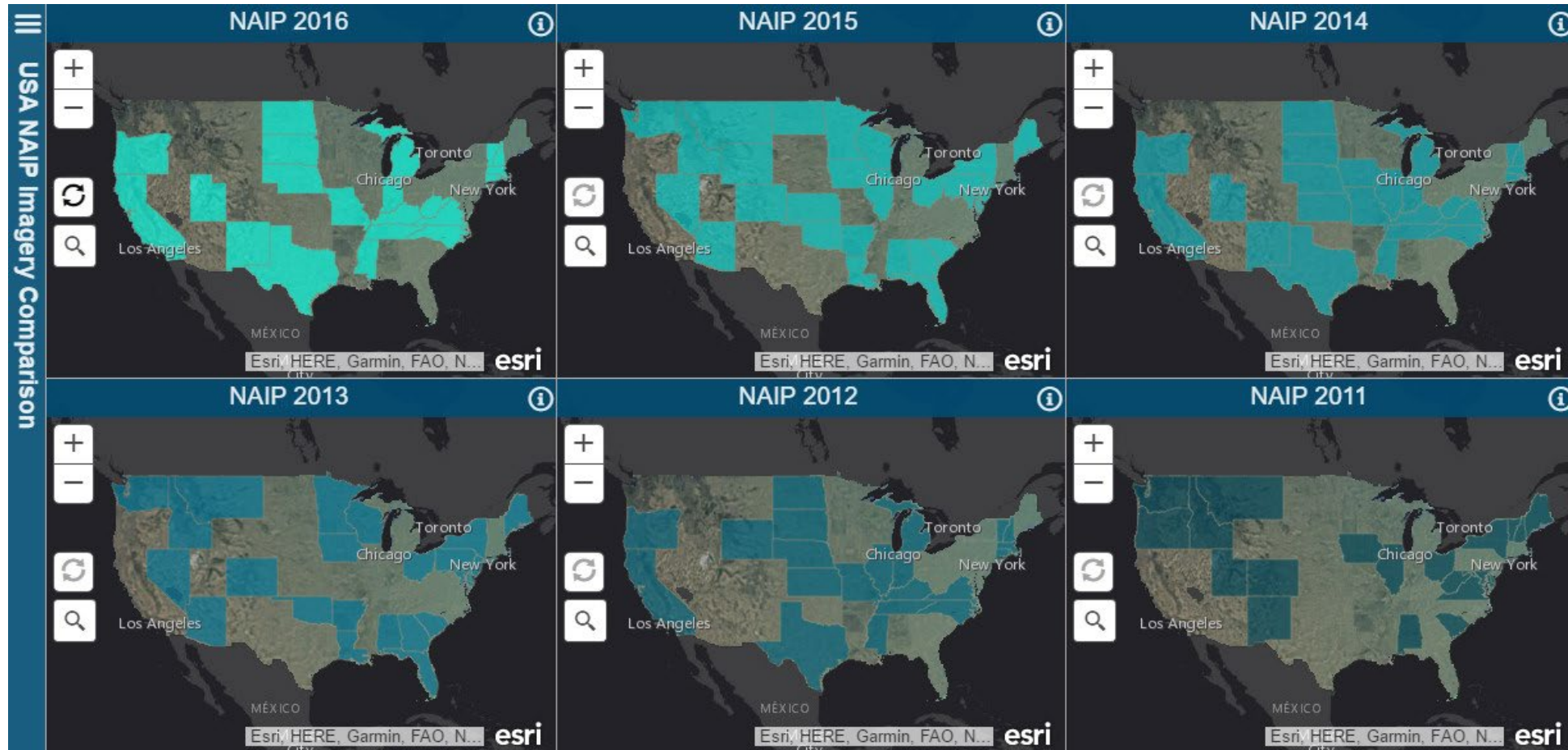
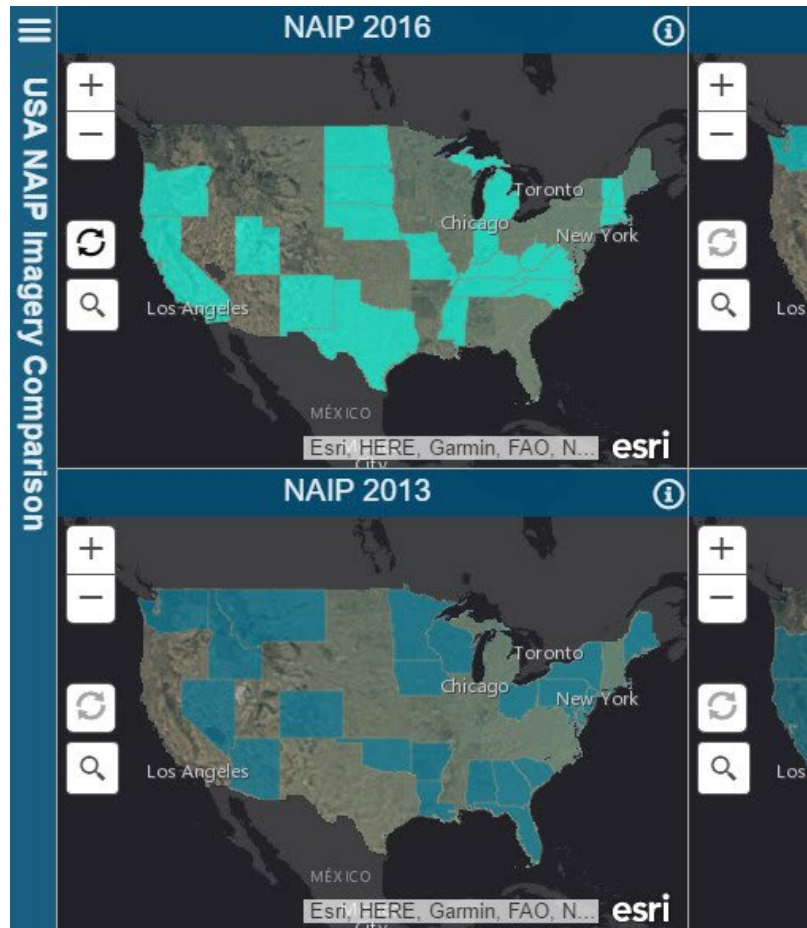


Image Source: ESRI

Data Inputs: NAIP Imagery



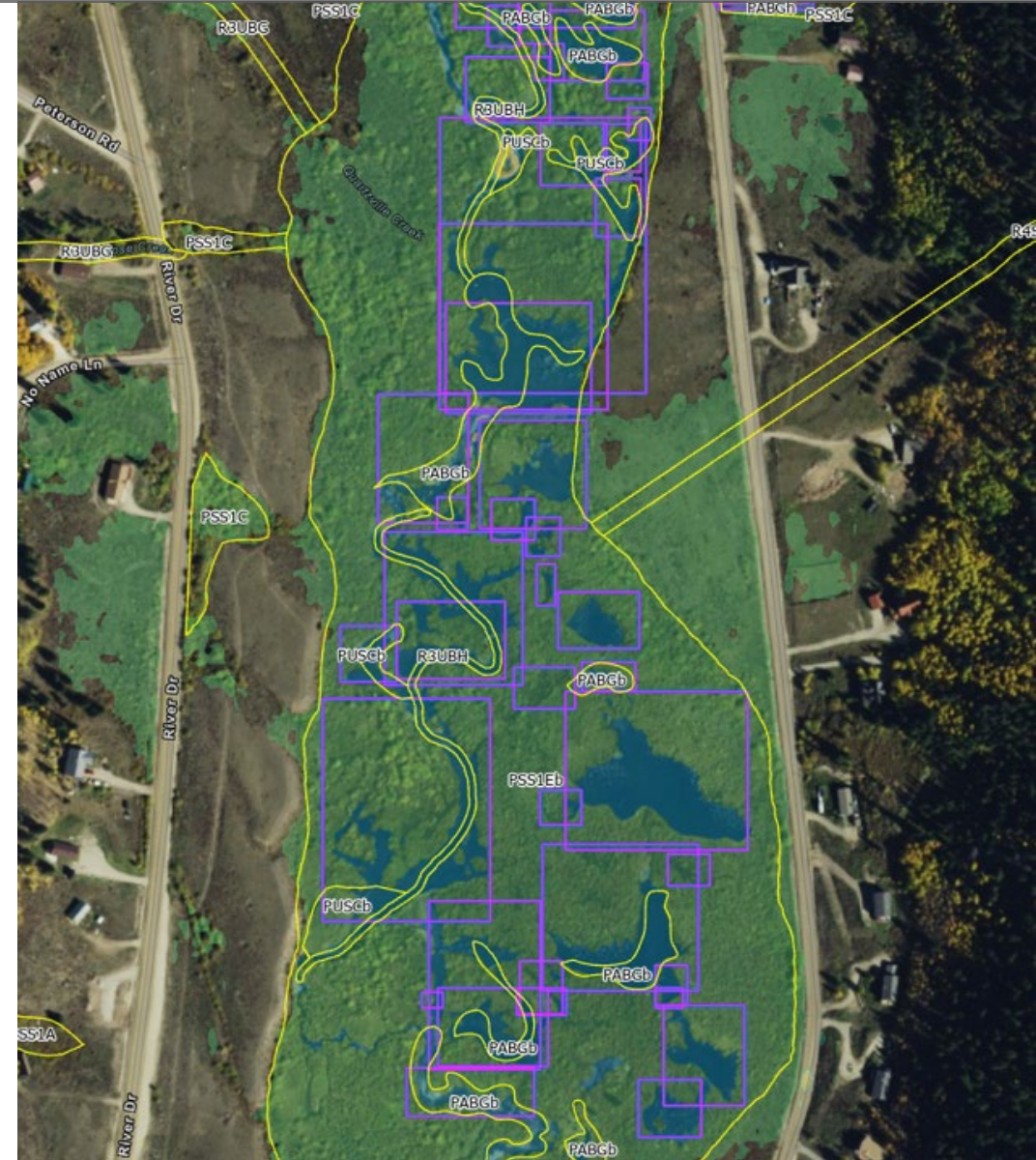
Period	State	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 - Early	AZ	2013	-	-	-	-	-	99%	1%	-	-	-	-	-
2 - Mid	AZ	2017	-	-	-	-	-	87%	6%	5%	3%	-	-	-
3 - Late	AZ	2019	-	-	-	-	-	64%	32%	-	4%	-	-	-
1 - Early	CO	2013	-	-	-	-	-	-	31%	7%	62%	-	-	-
2 - Mid	CO	2017	-	-	-	-	-	-	-	17%	36%	47%	-	-
3 - Late	CO	2019	-	-	-	-	-	-	-	35%	60%	5%	-	-
1 - Early	NM	2014	-	-	-	-	17%	80%	-	0%	3%	-	-	-
2 - Mid	NM	2016	-	-	-	-	58%	42%	0%	-	-	-	-	-
3 - Late	NM	2020	-	-	-	-	82%	18%	1%	-	-	-	-	-
1 - Early	NV	2013	-	-	-	-	-	-	12%	20%	68%	-	-	-
2 - Mid	NV	2017	-	-	-	-	-	53%	46%	1%	-	-	-	-
3 - Late	NV	2019	-	-	-	-	-	-	76%	24%	-	-	-	-
1 - Early	UT	2014	-	-	-	-	-	44%	0%	12%	43%	-	-	-
2 - Mid	UT	2016	-	-	-	-	-	9%	80%	11%	-	-	-	-
3 - Late	UT	2018	-	-	-	-	0%	-	16%	31%	53%	-	-	-
1 - Early	WY	2012	-	-	-	-	-	37%	22%	41%	-	-	-	-
2 - Mid	WY	2017	-	-	-	-	-	29%	20%	37%	4%	10%	-	-
3 - Late	WY	2019	-	-	-	-	-	-	44%	51%	5%	-	-	-

Figure 5. NAIP data acquisition by month/state across the study period

Desired Modeling Outcomes

Segmentation – defining boundaries of wetland/shoreline/water

Object Detection – identifying distinct beaver ponds



Methods

Imagery Data Collection (18 year/state combinations, ~50,000 NAIP images)

3-Band Segmentation Model (Wetland Area)

Develop Training Data
(35 NAIP tiles)

Inference

Tile Review

Iterate model

Generate 1m Wetland Raster

Image Cleanup and Vectorization

Filters (Valley Bottom, Irrigated
Lands, Model Artifacts)

GIS
Postprocessing

Final Wetland Polygons (Wetland/Water)

Object Detection Model (Beaver Ponds)

Human Training (15,000 beaver ponds
across 2015/17/19 in UT, CO)

Inference

Box Review

Iterate model

Generate "boxes" for each state/year

Combine OD boxes with
Wetland/Water Polygons

Generate Initial set of "Complexes"

Beaver
Pond
Clustering

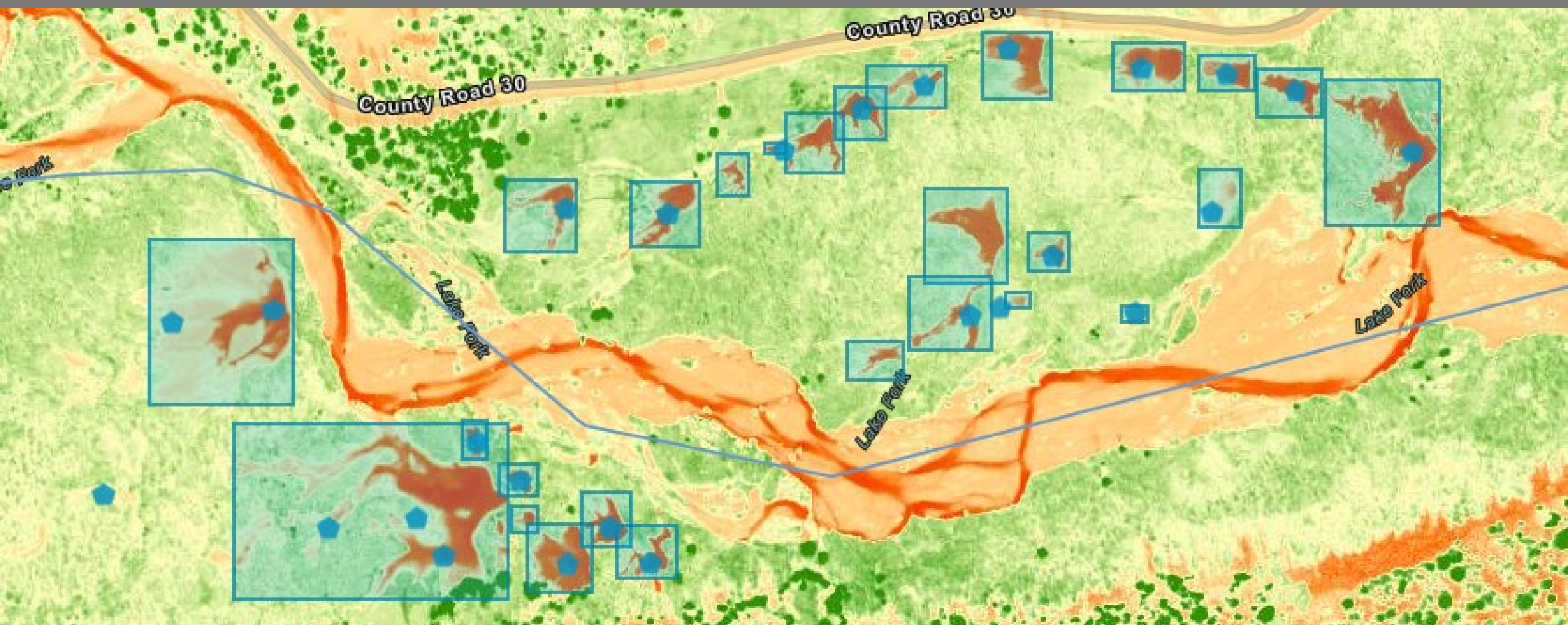
Manually Review and Flag Complexes

Final Beaver Complex/Vegetation/Water
Layers

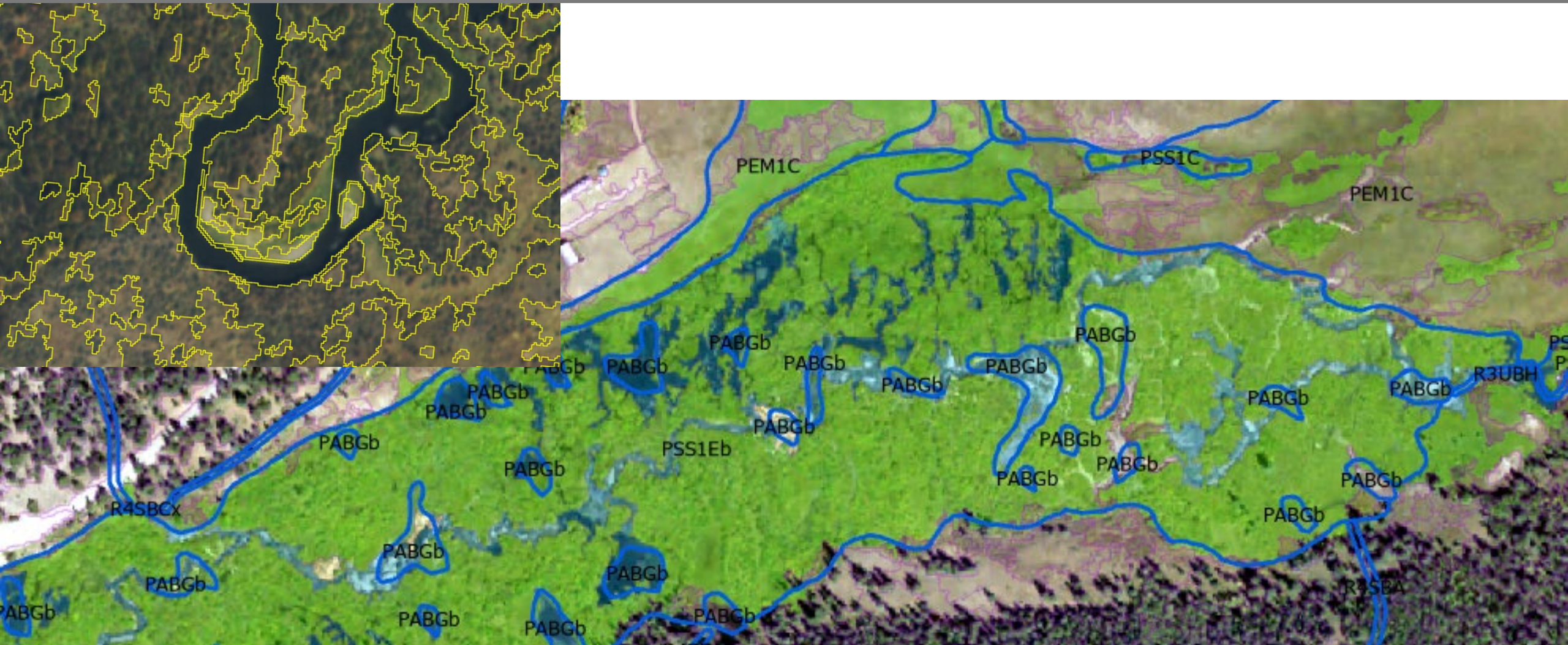
Summarize and Make Plots and Graphics



Object Detection Training



Segmentation Training and Early Performance



Model Accuracy

Segmentation Model

Intersection over union (IoU) Analysis

tile	year	wetland	water	shoreline	Multiclass F1 (no shoreline)
3710718_se	2017	0.627	0.793	0.175	0.710
3810601_sw	2017	0.821	0.873	0.076	0.845
3910737_se	2019	0.486	0.634	0.008	0.552
4210913_se	2012	0.619	0.900	0.013	0.764
4211014_nw	2012	0.972	0.796	0.057	0.899
All test		0.775	0.859	0.062	0.815

The F1 score of 0.815 suggests that this model is generally doing well across the study area and especially so in areas where wetlands are more abundant.

Object Detection Model

Twenty (HUC10) watersheds randomly selected for validation

State	True Positive	False Positive	False Negative	F1
CO	382	161	432	0.56
UT	350	239	435	0.50
WY	198	93	168	0.60
AZ	28	37	12	0.53
NM	1	2	93	0.020
Total	959	532	1140	0.53

The **model performed well in identifying beaver ponds** within wetlands where there was a **characteristic shape** and a **strong water signature**.

Model not ready for use without human review and integration with segmentation model.

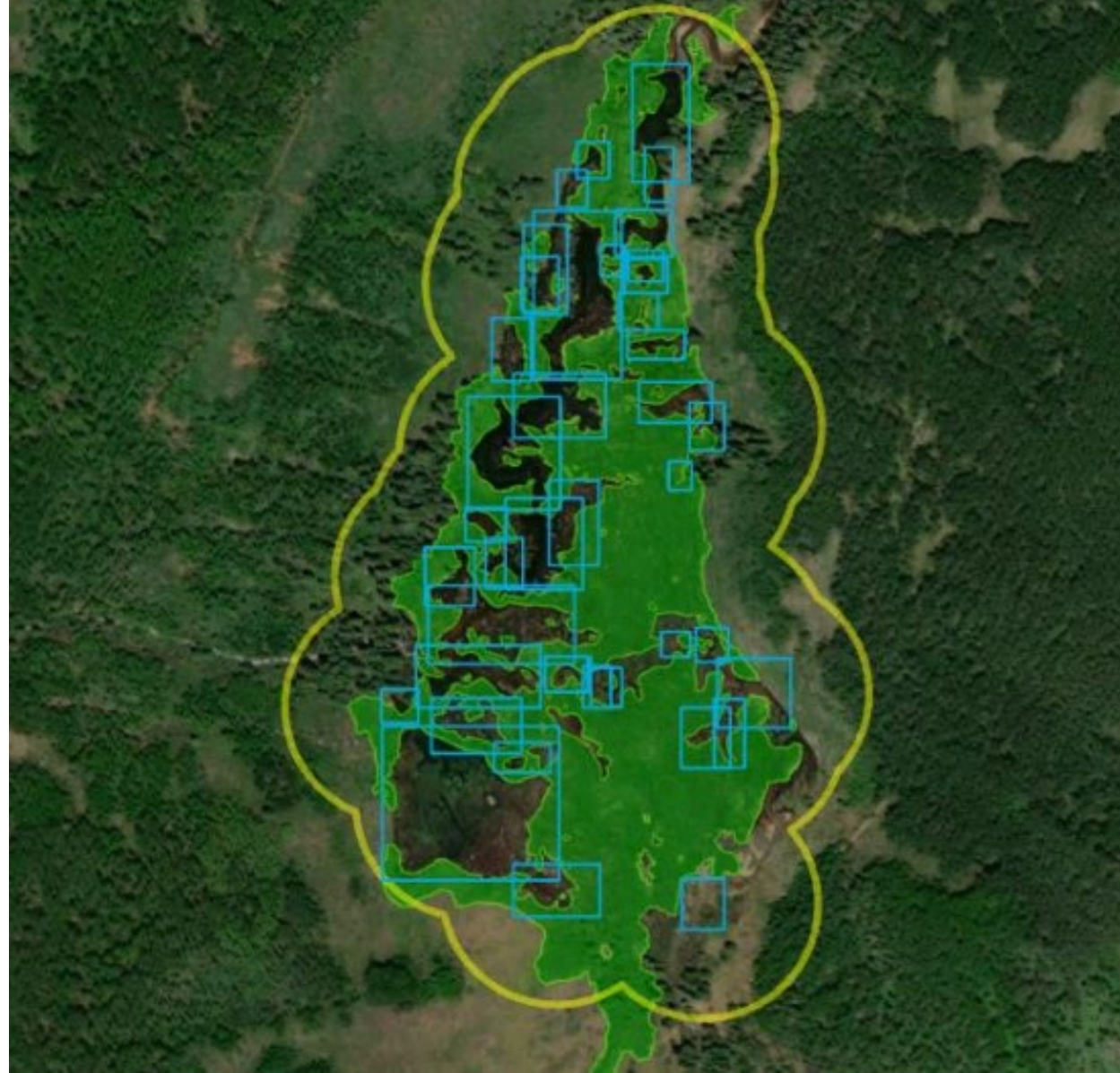
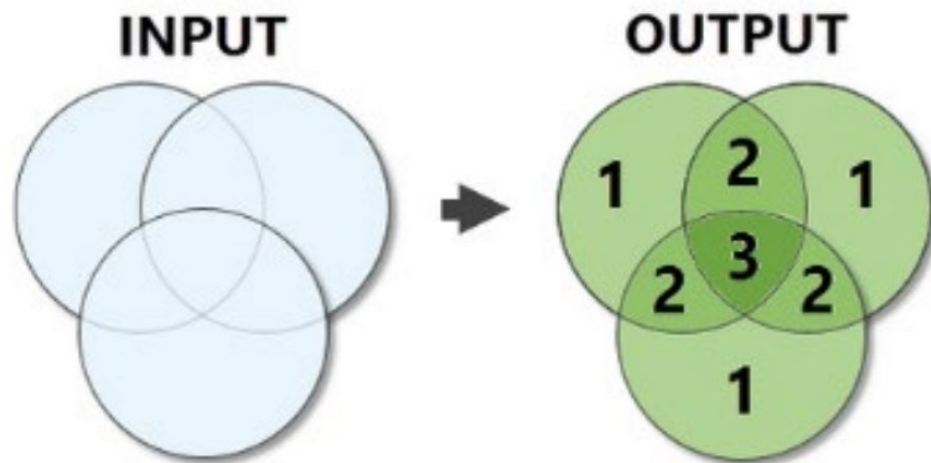
Bringing it All Together...

GIS Post Processing

- Raster data cleaning and to polygon
- Valley-bottom buffer filtering process
- Size thresholding
- False positive removal via intersection

Beaver activity areas

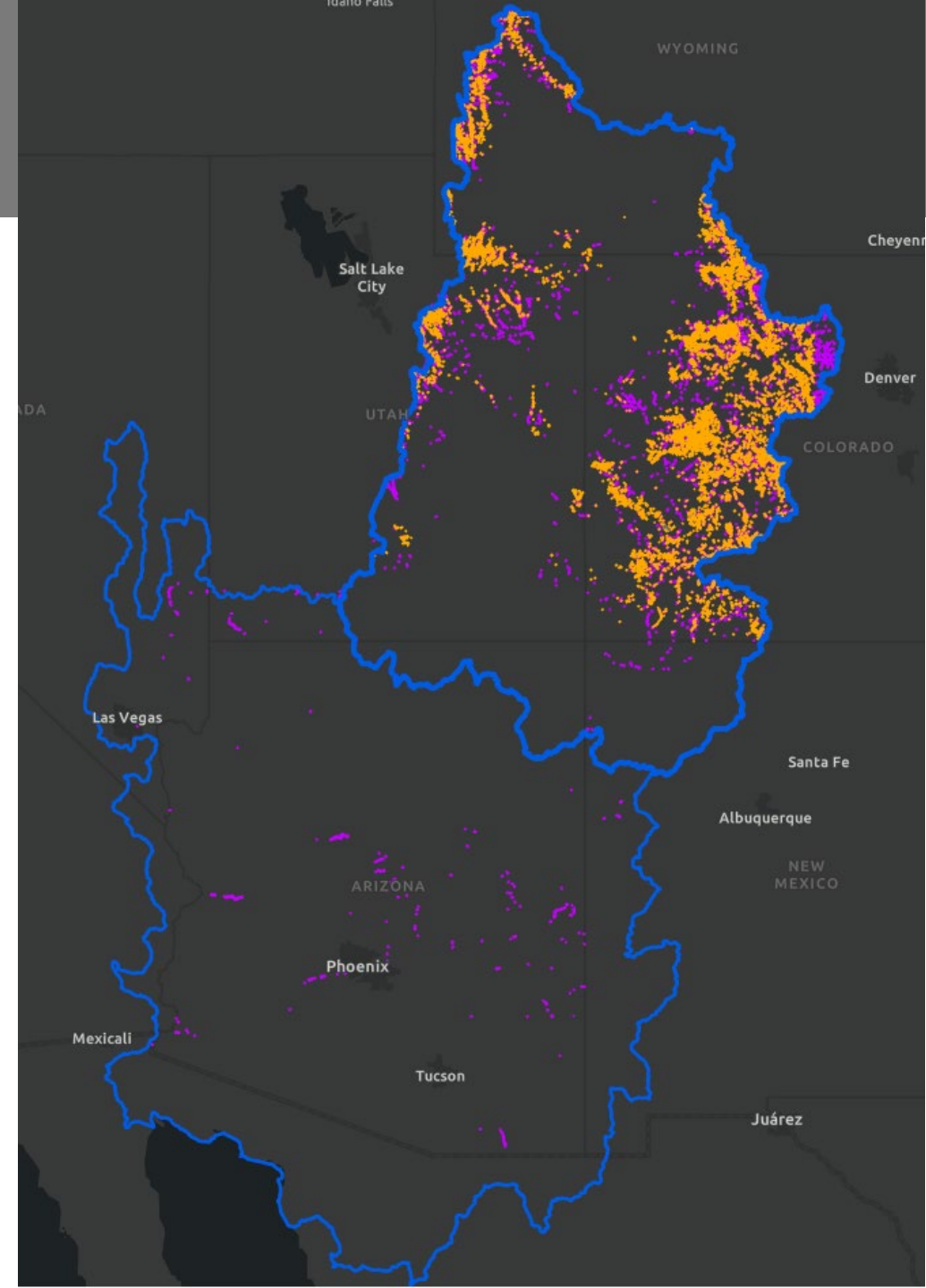
Decision by quorum



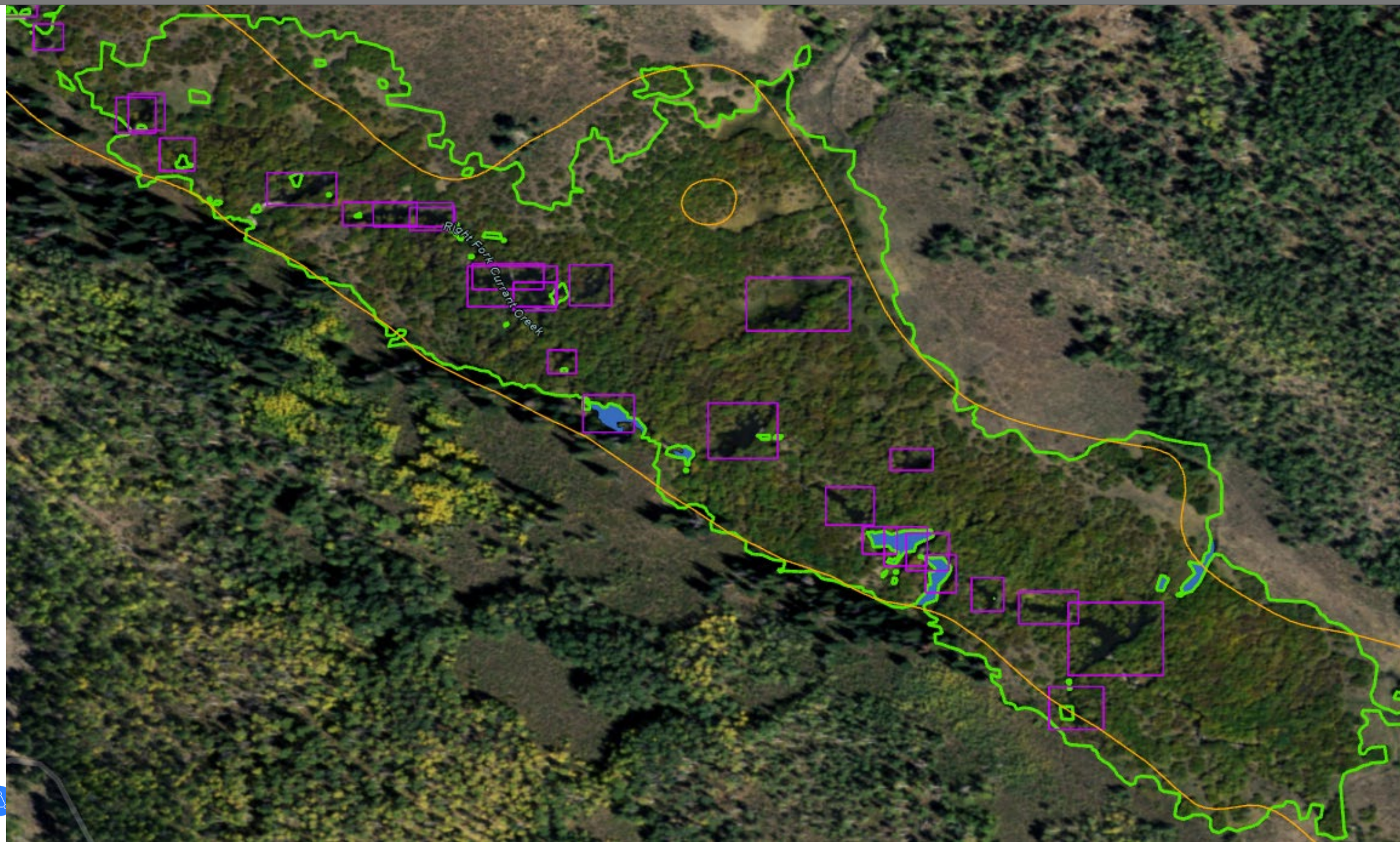
Beaver Activity

- **40,834** beaver ponds (~**5,242 acres**) in 2018/2019/2020
- **5,626** verified beaver activity areas (complexes)
- No NWI beaver wetlands in AZ, NM, or NV within the basin
- Expansion of mapped beaver areas in upper basin (CO, WY, UT)

State	Verified Activity Areas	Ponds in Activity Areas
Colorado	3,487	27,191
Wyoming	1,179	6,779
Utah	737	5,210
Arizona	182	1,470
New Mexico	23	110
Nevada	17	72
California	1	2
Total	5,626	40,834



Utah Example



North Fork Sheep Creek Example

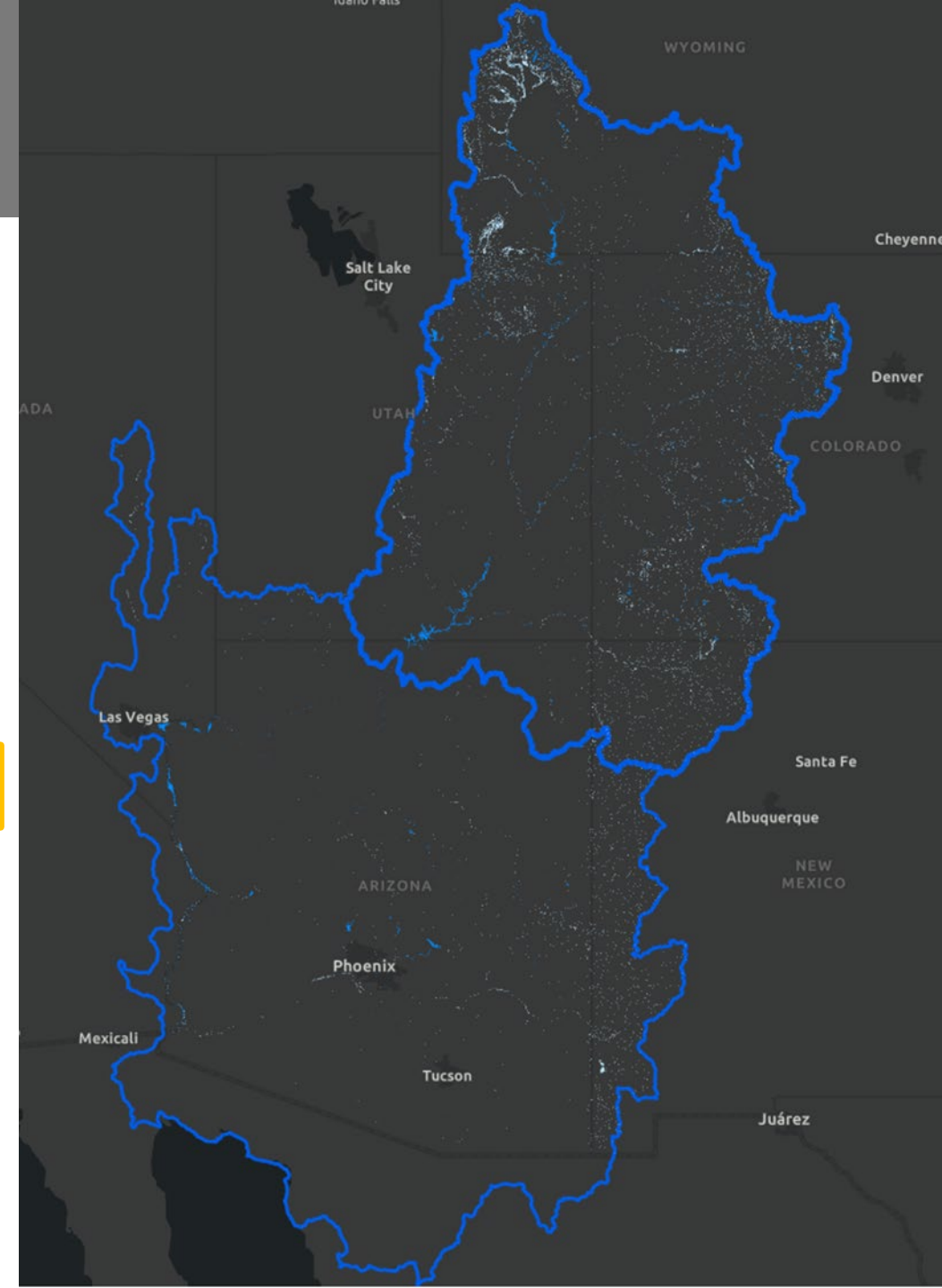


Modeled Wetland Acreage

Total vegetated wetland area: **954,104 acres**

Total open water area: **605,455 acres** (196,586 acres excluding lakes >200 acres)

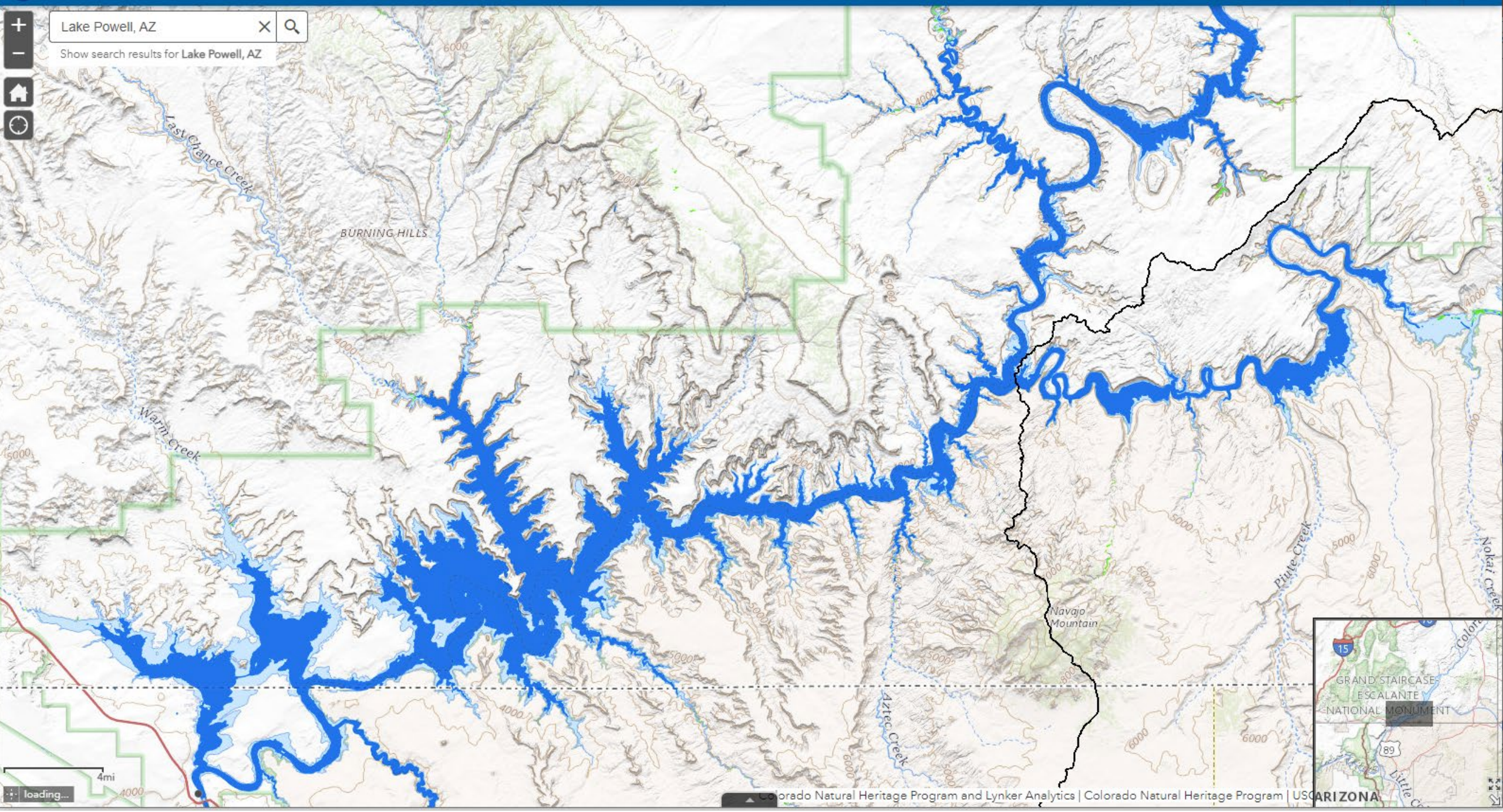
State	Wetland Area (acres)	Open Water Area (acres)	Combined Area (acres)	Combined NWI Wetland Area (acres)
Colorado	342,376	109,003	451,379	456,257
Wyoming	336,436	85,560	421,996	386,195
Utah	136,277	175,963	312,240	355,229
Arizona	94,079	131,732	225,811	375,289
Nevada	10,479	73,358	83,837	127,644
New Mexico	29,433	15,200	44,633	42,656
California	5,024	14,639	19,663	31,495
Total	954,104	605,455	1,559,559	1,774,765





Map controls and search bar:

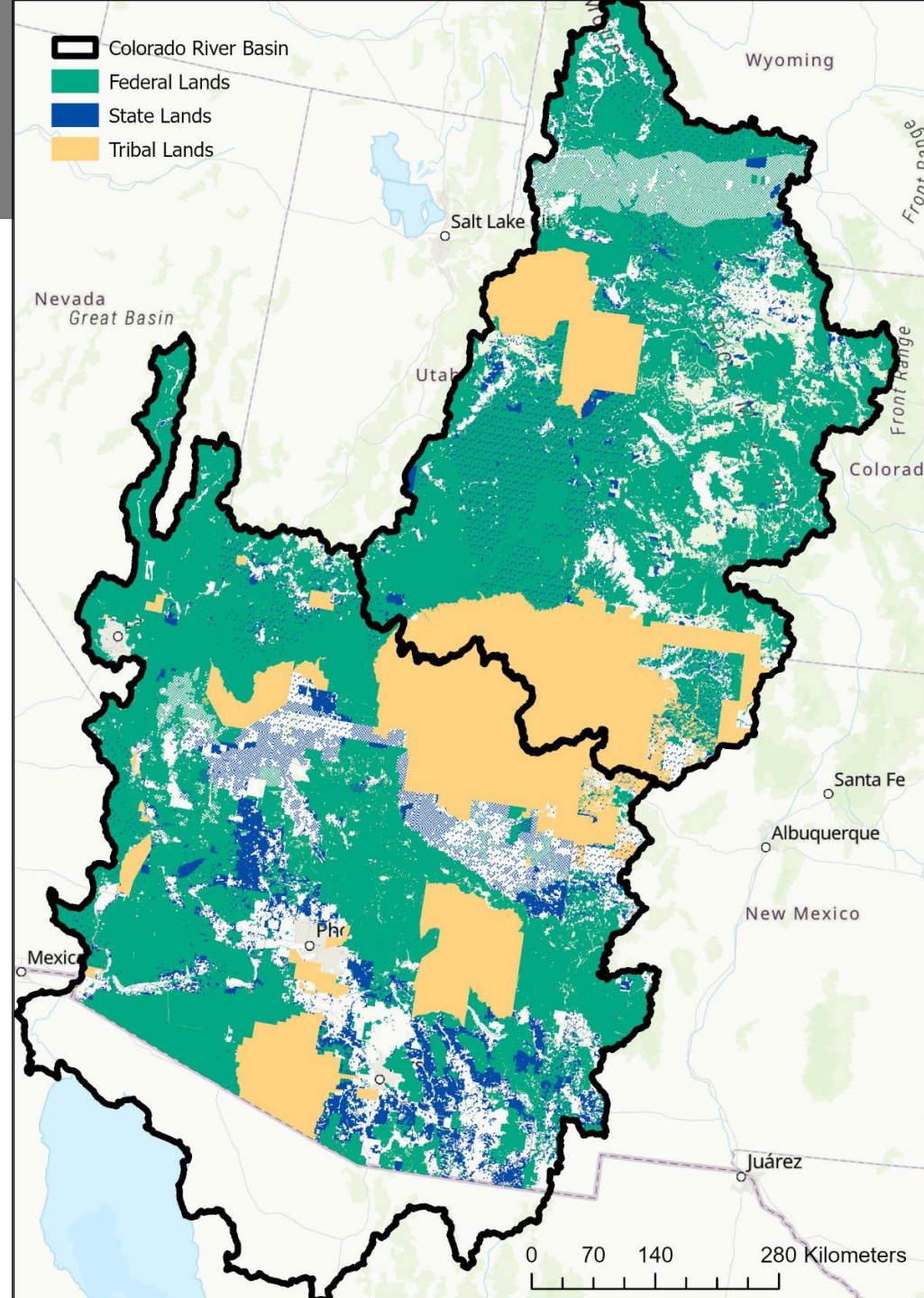
- Zoom in (+) and zoom out (-) buttons.
- Home button.
- Refresh button.
- Search bar containing "Lake Powell, AZ" with a clear (X) and search (Q) button.
- Text below search bar: "Show search results for Lake Powell, AZ".



Wetland Area by Ownership

Land Ownership/Management	Open Water Area (acres)	% of Total Area	Wetland Area (acres)	% of Total Area	Pond Area (acres)	% of Total Area	Pond Count (2018-2020)	% of Total Ponds
Entire Basin								
Federal	469,547	77.6	363,895	38.1	3,887	74.1	30,658	75.1
State	41,922	6.9	46,633	4.9	280	5.3	1,433	3.5
Tribal	30,948	5.1	99,164	10.4	229	4.4	1,757	4.3
Private and Other	63,038	10.4	444,412	46.6	846	16.1	6,986	17.1
Total	605,455	100.0	954,104	100.0	5,242	100.0	40,834	100.0

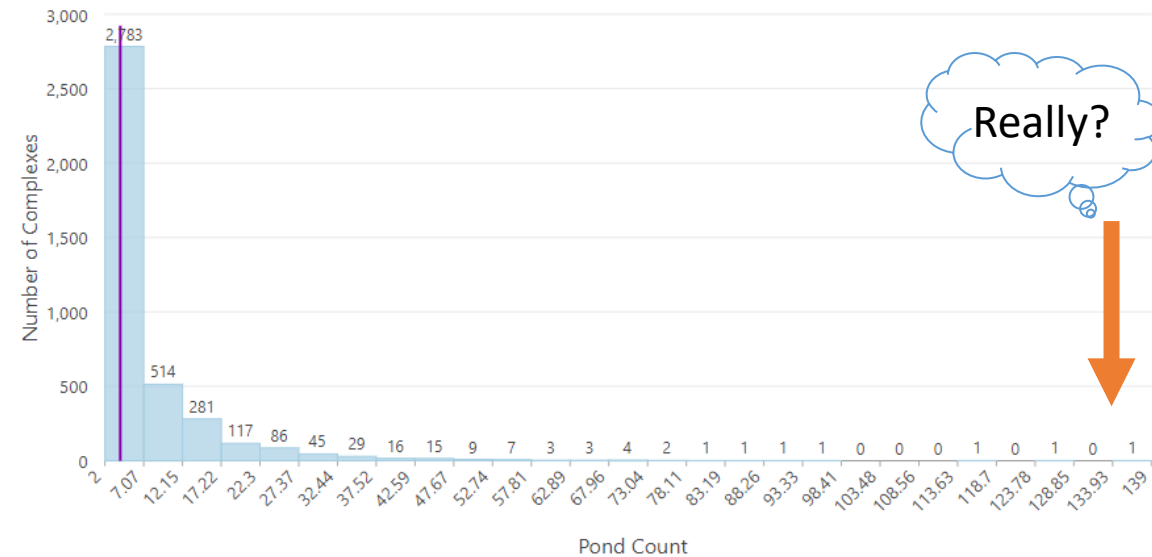
More open water and beaver activity on federal land, vegetated wetlands on private/other land.



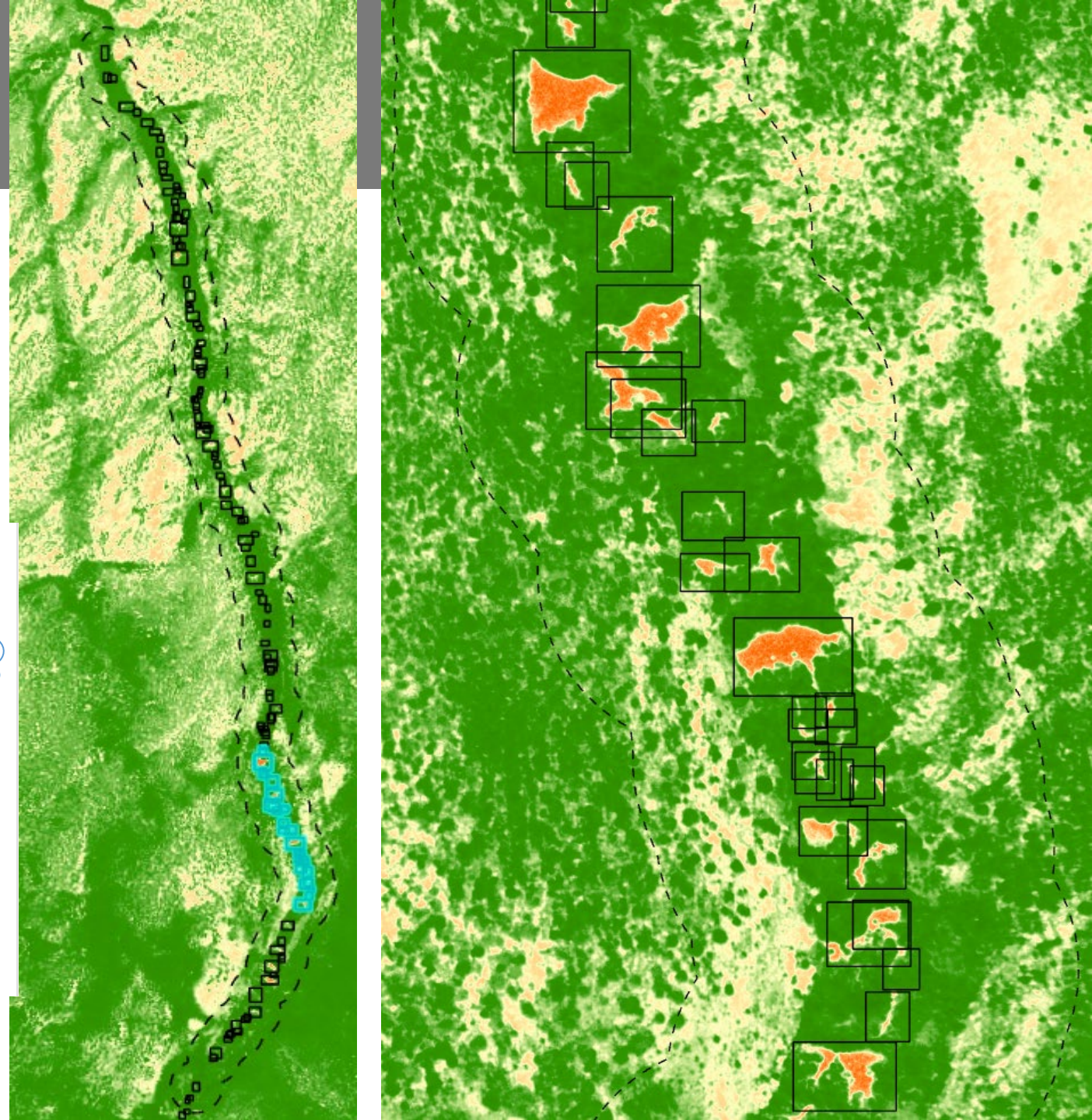
Most Ponds

- Middle Fork Powderhorn Creek (Cebolla Creek HUC10 in SW CO)
- 30+ ponds in this section!

Distribution of Beaver Ponds per Complex

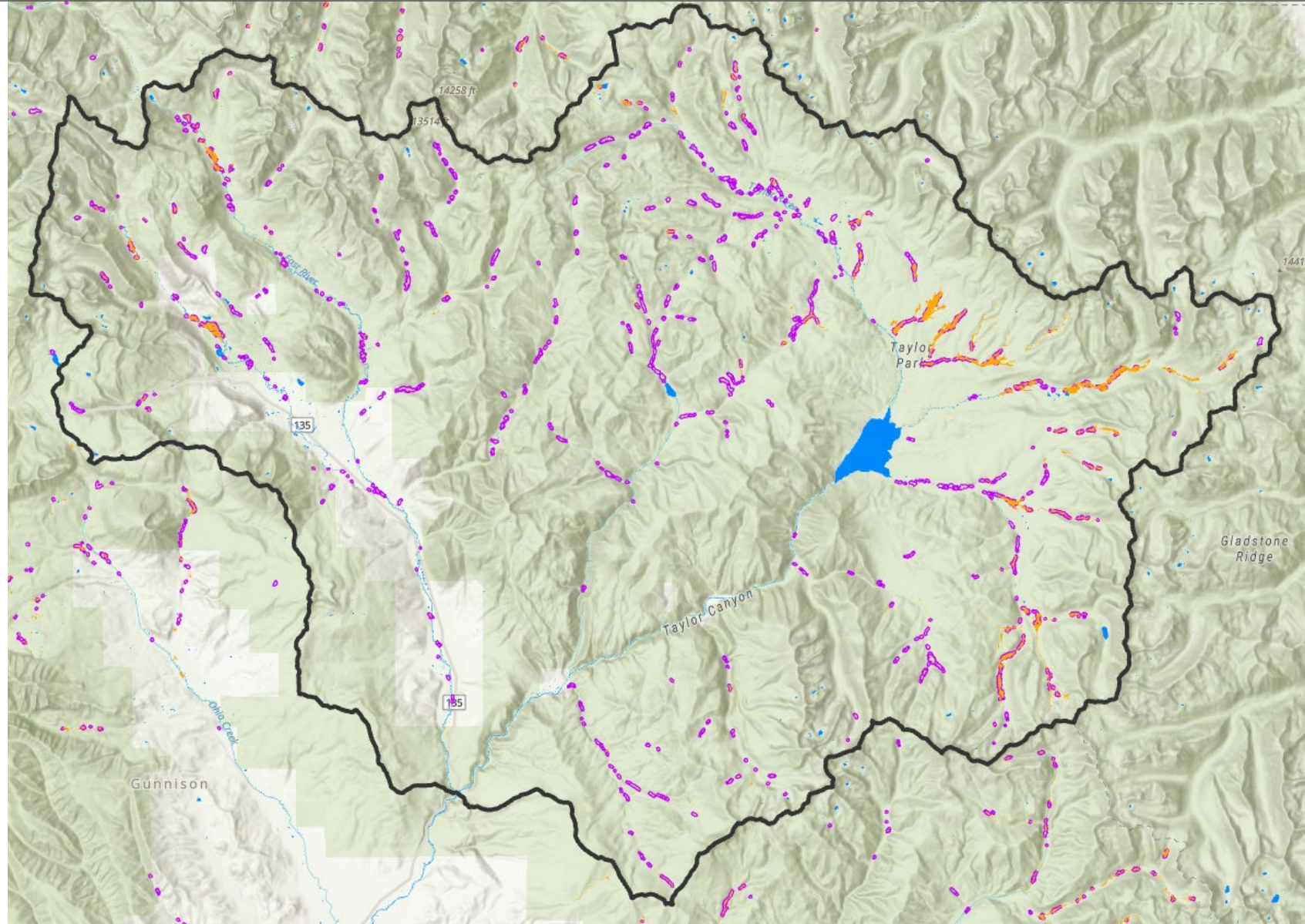


Really?

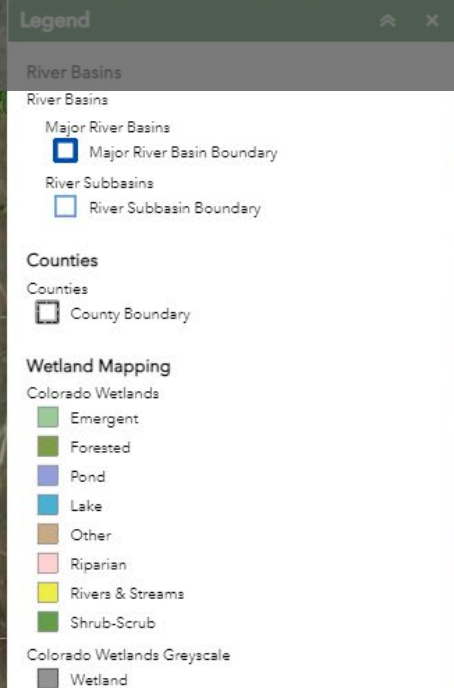


Most True Positives in CO: East-Taylor HUC8

- **87-94%** true positive beaver complexes, depending on year (2013, 2017, 2019)



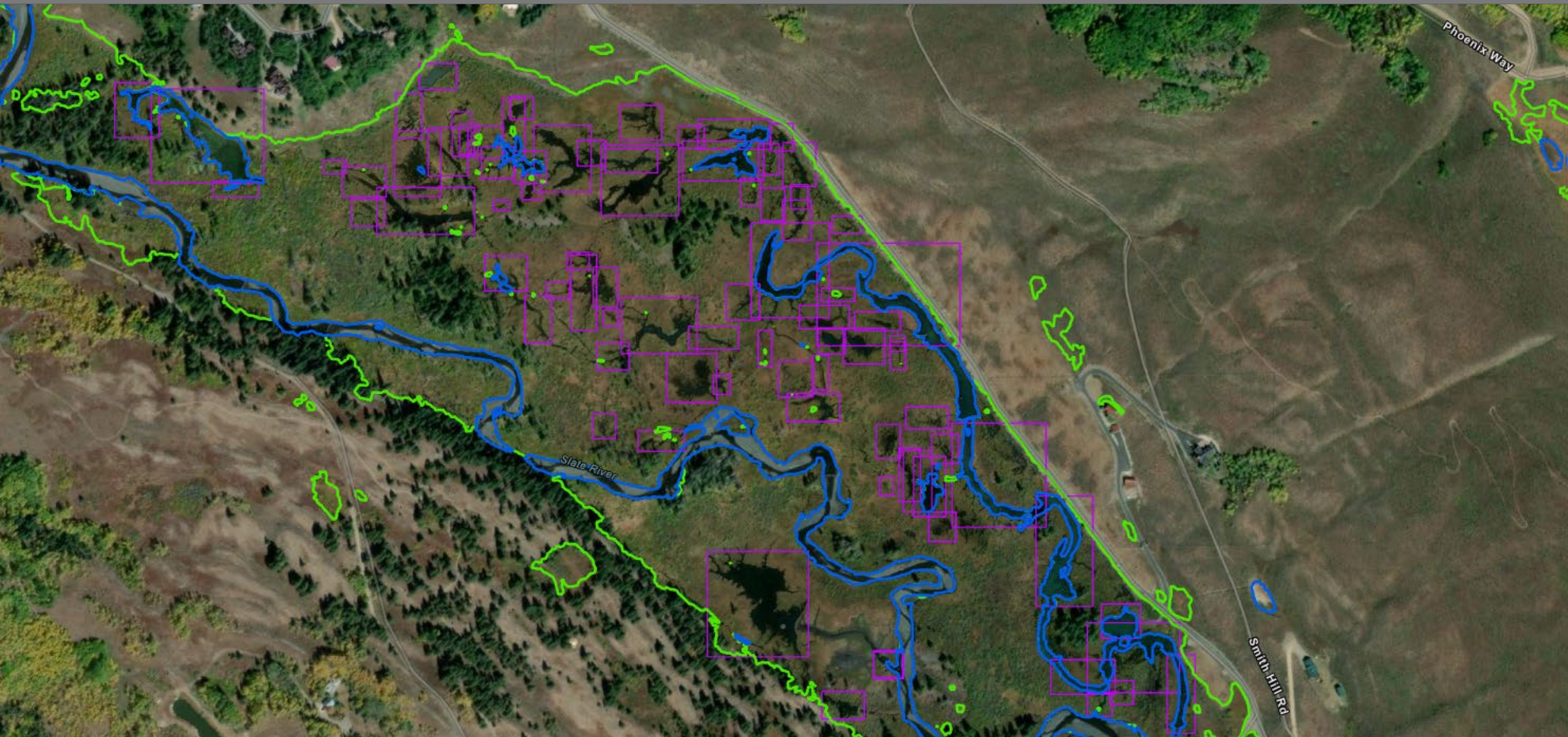
Model vs. NWI: Crested Butte Example



Model vs. NWI: Crested Butte Example



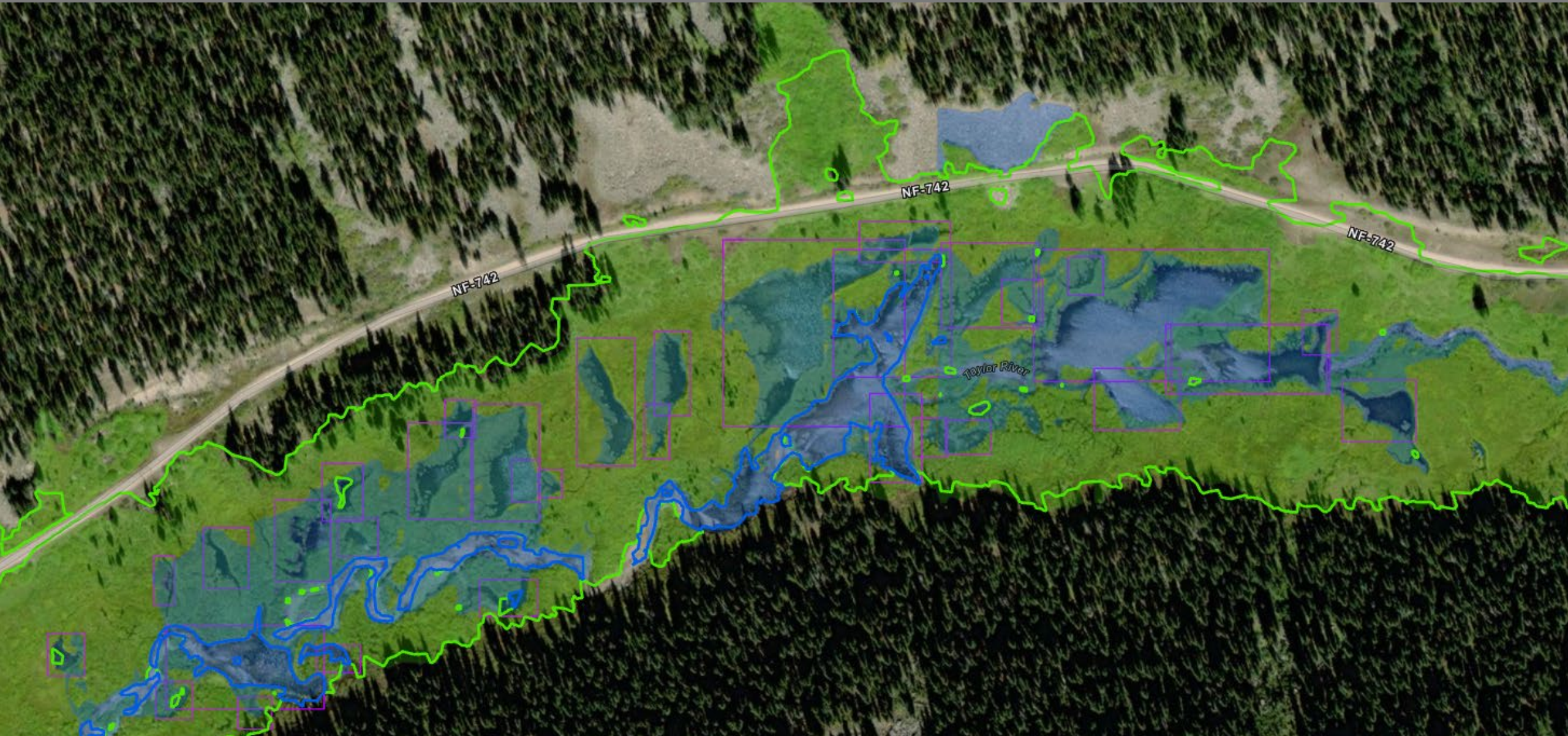
Slate River, Upstream of Crested Butte



Limitations

- **NAIP Data Variations** -
 - Large differences between years and states meant that at times comparing inference results between years showed larger variation than expected.
 - Corrected with a histogram match but still challenges with snow, variation in brightness, blurred portions of imagery, etc.
- **Seasonal variations** - A result from an early season image (e.g., June) is compared with the result from a later season image (e.g., October). Some of the change detected will be season differences, rather than year-to-year changes.
- **Imagery Resolution** - Earlier imagery (pre 2017) was 1-m resolution whereas later imagery was 0.6-m. Results from the later imagery showed better detail.

Current Work: Improve Water Class



Current Work: Add Topography

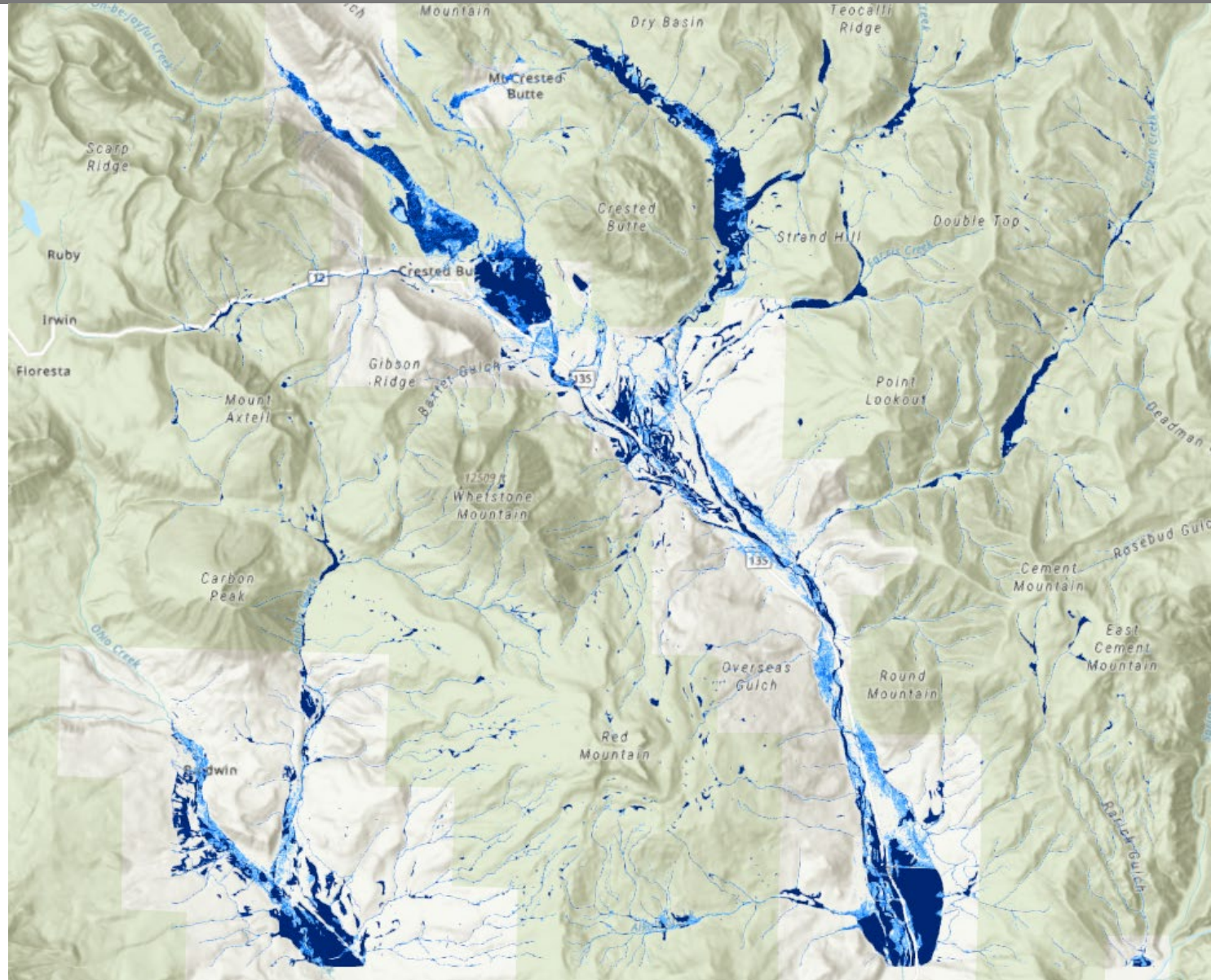
- Model wetlands, and beaver complexes across Colorado
- Add topographic data (LiDAR)
 - Probability of wetland occurrence
 - Valley bottoms
 - Depressions



COLORADO

Colorado Water
Conservation Board

Department of Natural Resources



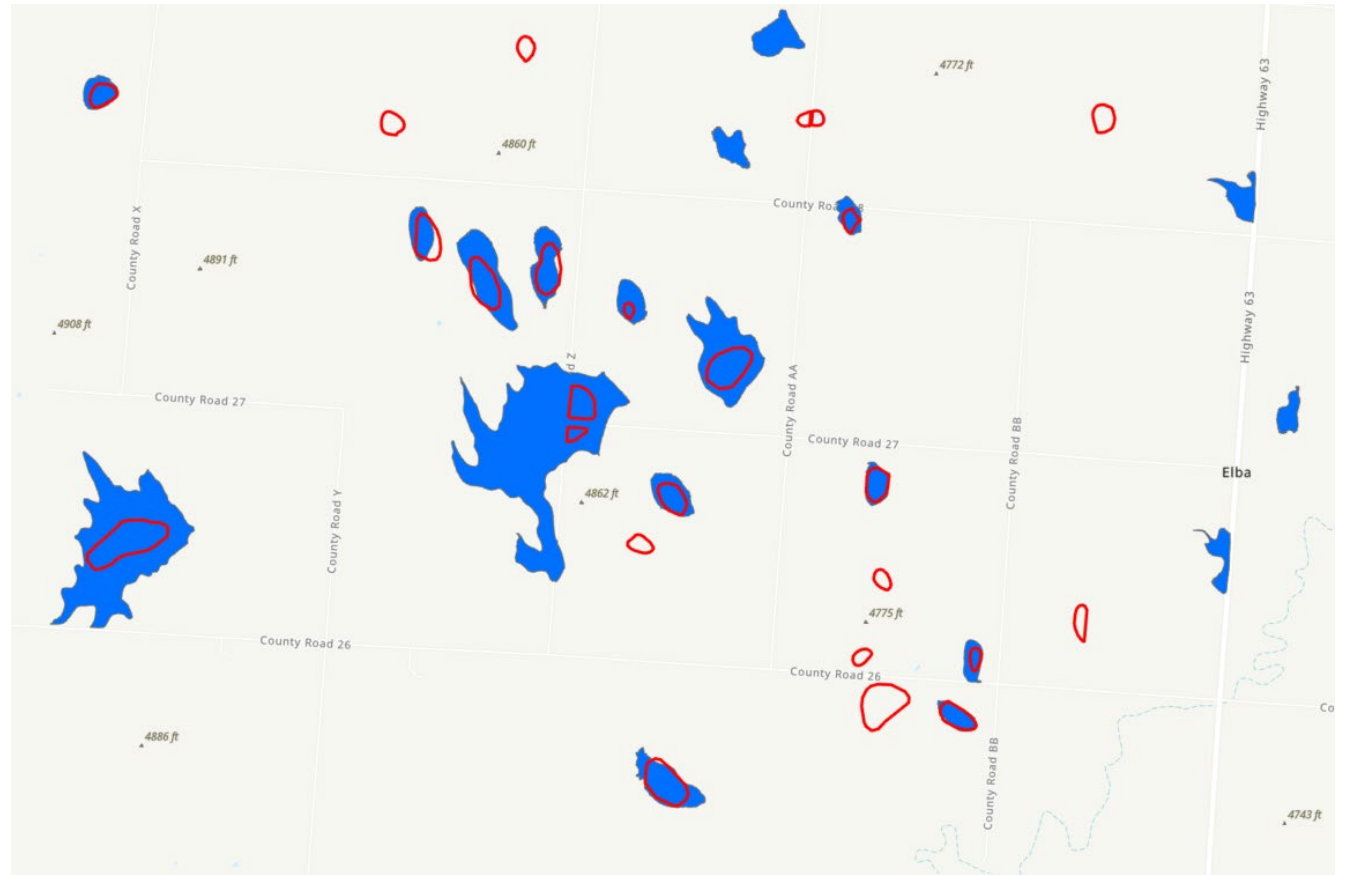
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Current Work: Add Wetland Classes (CO)

Emergent



Shrubland

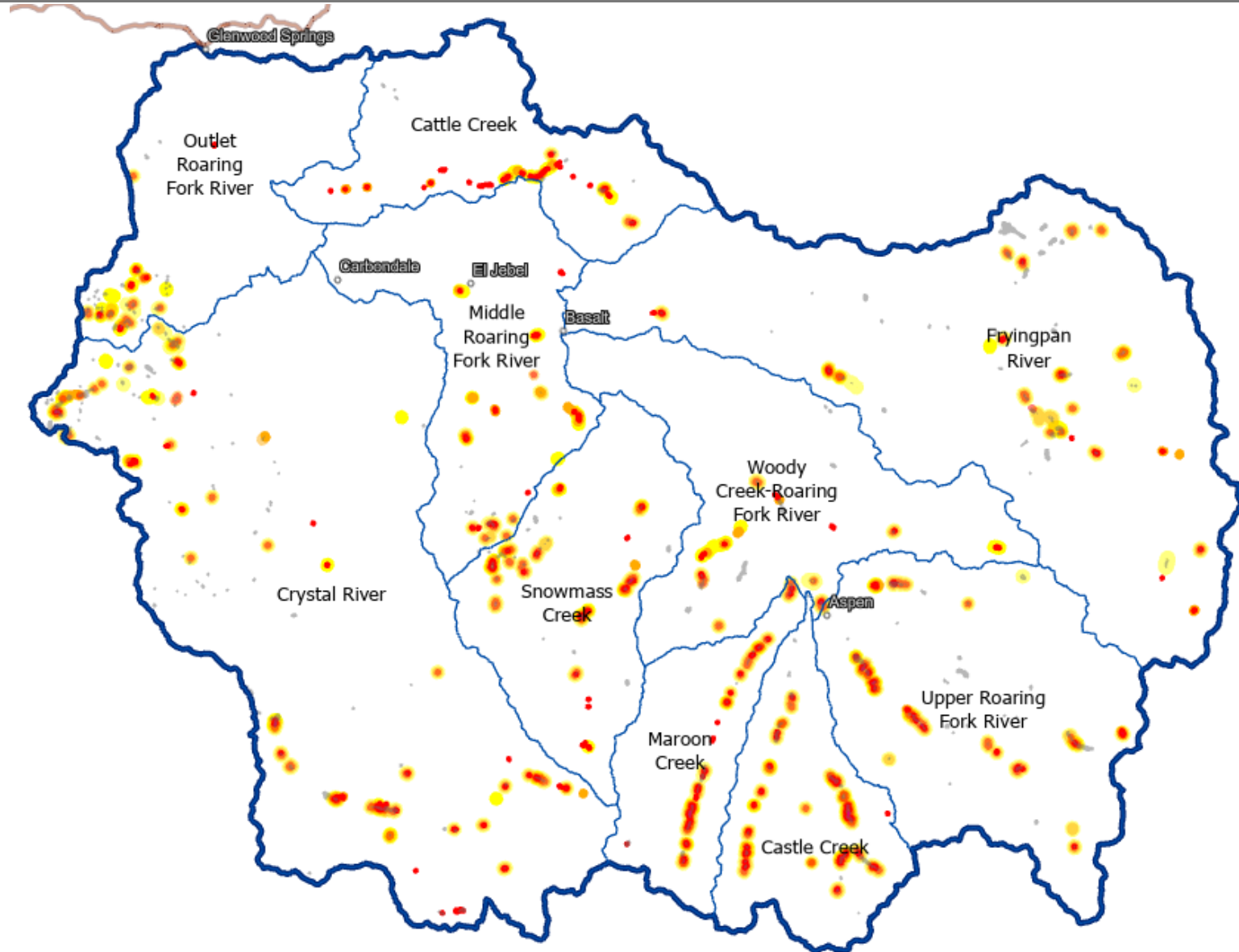
Forest

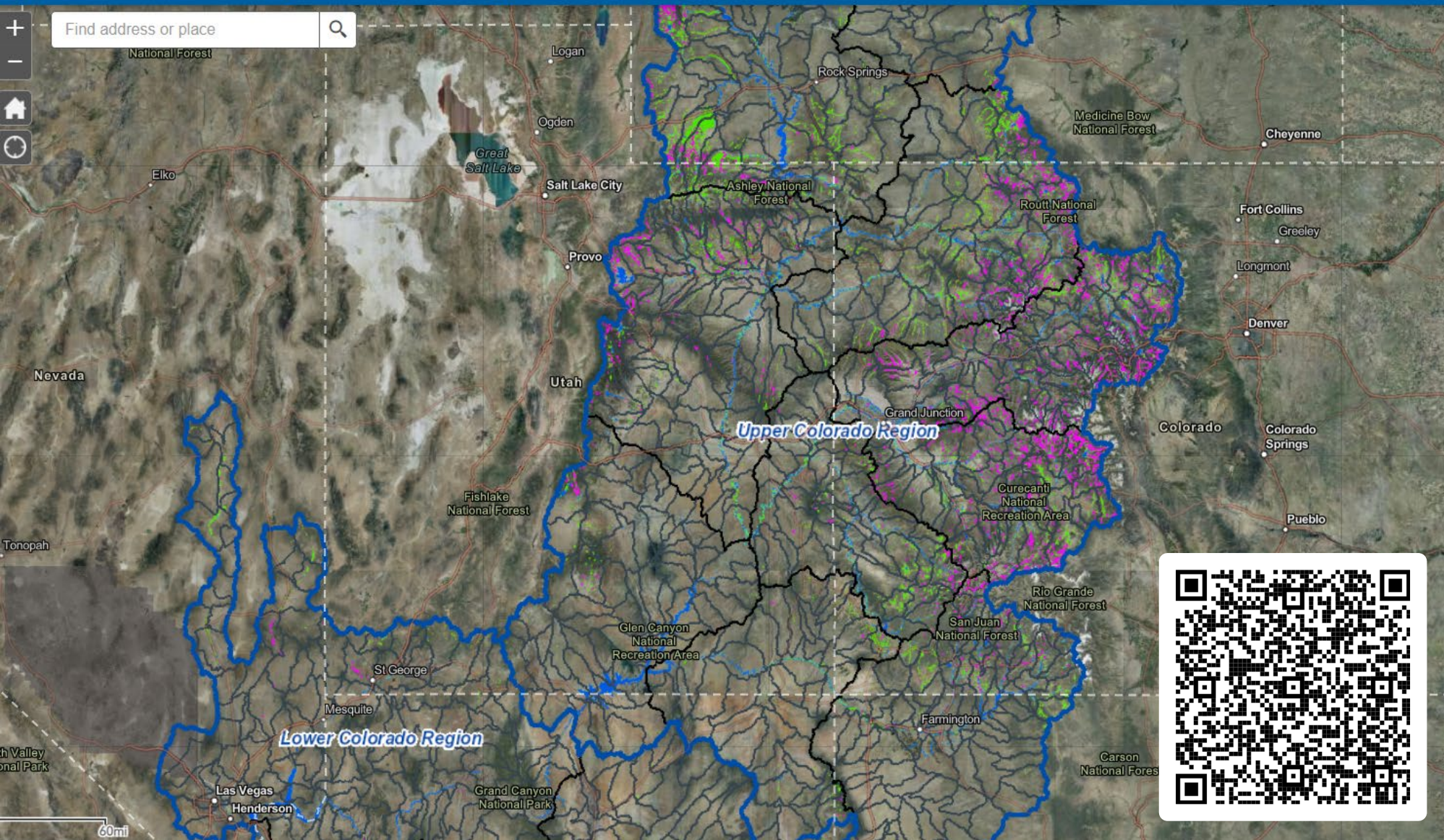


Early Applications: Beaver Activity Over Time

Beaver “hotspot” mapping

- 1980s NWI vs. 2013, 2017, 2019 beaver activity
- Potential **restoration** areas
- Helpful for looking at **beaver wetland functions**
 - Sediment capture
 - Fire
 - Drought resilience
 - Habitat





About



The Colorado River Basin Dynamic Wetland Mapper is intended to assist watershed managers, planners, and restoration practitioners explore modeled wetland and open water areas, along with recent beaver activity and potential beaver habitat suitability across the basin for riverscape restoration.

The mapper displays several modeled datasets depicting wetlands, open water, beaver activity areas (complexes), and summary information by HUC10 watershed across the entire Colorado River basin within the United States. Use the controls in the upper right to toggle between the [Legend](#), [Layer List](#) and [Base Maps](#).

Mapping was produced by Lynker and CNHP (2022) with funding from the Walton Family Foundation. The supporting segmentation and object detection machine learning models were developed by Lynker using wetland and beaver pond training data and technical guidance from CNHP. Model inputs included National Agricultural Imagery Program (NAIP) aerial imagery composites for three periods: 2012-2013, 2016-2017, and 2018-2020, and used a quorum approach to define final mapped vegetated and open water areas as meeting those criteria in at least 2/3 modeled time periods.

Watershed units (2-, 8-, and 10-) from the [Watershed Boundary Dataset](#) (WBD; USGS) are included in the mapper to support watershed-scale restoration and

Thank You!

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