Updating the National Wetland Inventory in Coastal Texas

Final Report

October 30, 2024

Prepared by:
Evelyn Magner, Geospatial Analyst
Alek Kreiger, Geospatial Developer
Jes Skillman, Regional Geospatial Manager

Ducks Unlimited, Inc.
Great Lakes/Atlantic Regional Office.
7322 Newman Blvd. Bldg. 2, Ste. 200. Dexter, MI 48130

This publication/report was funded in part through a grant from the Texas General Land Office (GLO) providing Gulf of Mexico Energy Security Act of 2006 funding made available to the State of Texas and awarded under the Texas Coastal Management Program. The views contained herein are those of the authors and should not be interpreted as representing the views of the GLO or the State of Texas."

AWARD No. 22-131-006-D412

Acknowledgements

The authors would like to acknowledge the photo interpreters who worked tirelessly to map these wetlands. Thank you to Alice Colville, Eli Fulcher, Erika Dodge, Heidi Marshall, and Nathan Barron. This would not have been a successful project without your hard work.

The authors would like to thank the late Mat Halliday for his immense contribution to this project.

Table of Contents

Project Background

Ducks Unlimited, Inc. (DU) updated the National Wetlands Inventory (NWI) spatial data for 3.8 million acres of Eastern Texas. This NWI update provides critical baseline information about wetland type and extent for an area that is coincident with the Texas Coastal Management Program (CMP) Coastal Zone Boundary (CZB). It also includes inland areas that are hydrologically connected to the CMP (Figure 1). These data were published in the U.S. Fish and Wildlife Service's (FWS) public Wetland Mapper in October, 2024. They will be used by governmental, private, and non-profit organizations for many purposes including planning, management, and mitigation.

The Gulf Coast is a dynamic landscape that experiences rapid change due to extreme weather events, sea level rise, climate change impacts, and human development. Coastal wetlands are critical habitat that provide millions of dollars in economic benefits each year by buffering storms, improving water quality, supporting wildlife habitat, and providing recreational and tourism opportunities.

Prior to this project, wetland maps for the coastal region of Eastern Texas were out of date and lacked consistency across the coastal zone and connected inland catchments. Much of the original northern portion of the study area included wetland data collected in the 1980s, while the south was mapped during the 1990s or 2000s. A small area of the coast was completed in the 2010s. The former NWI did not accurately represent currently existing wetland habitat, making it obsolete in terms of value for resource managers performing planning and analysis.

The Texas coastal project area is comprised of seven Hydrologic Unit Code 8 (HUC 8) watersheds totaling 3,971,188 acres, spanning east of Houston to the Louisiana border, and located centrally on Texas's Gulf Coast. These include the Lower Sabine (12010005), Lower Neches (12020003), Pine Island Bayou (12020007), Lower Trinity (12030203), Sabine Lake (12040201), East Galveston Bay (12040202), and North Galveston Bay (12040203). Much of the project area is rural, with a few urban areas in Beaumont and Jasper.

In the north, the landscape is dominated by pine plantations, rice fields, pastureland, and rural development. There are also many excavated ponds. Wetlands in the northern area are forested and are often include emergent wetlands within pine plantations too wet to grow pines. Two large rivers, Sabine and Neches, flow south through the project area. The floodplains of these rivers have many acres of forested wetlands with sloughs of cypress.

The coastal south is dominated by protected coastal plains: emergent wetlands with pockets of open water. Four National Wildlife Refuges, Anahuac, Moody, McFaddin, and

Texas Point, are within the coastal portion of the project area, and additionally J.D. Murphree Wildlife Management Area, managed by the state.

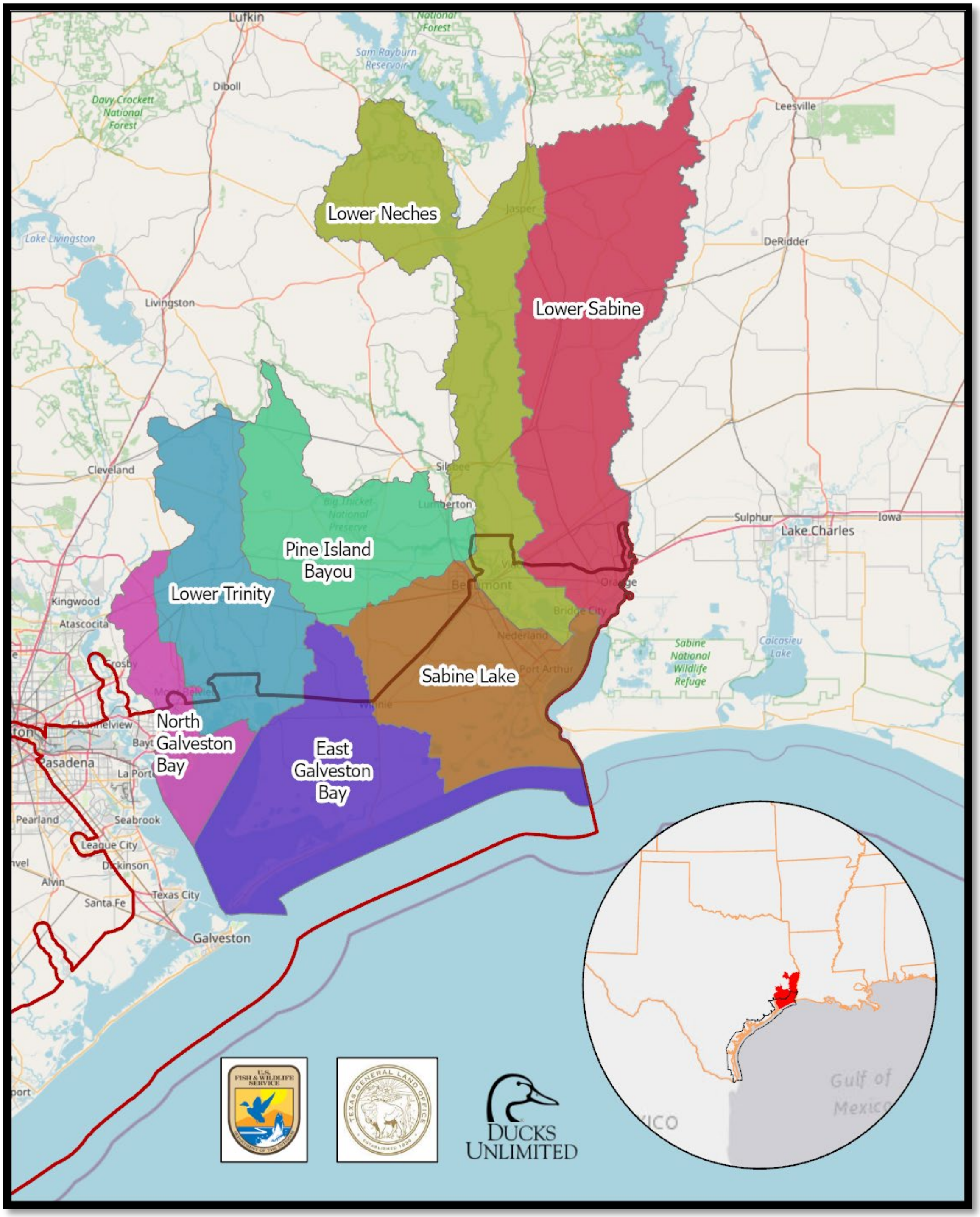


Figure 1 The HUC Watersheds included in this NWI update. The red line denotes the CMP Coastal Zone Boundary.

This project was completed in tandem with DU's US FWS funded project to develop a methodology for producing NWI data that will work seamlessly with USGS' National

Hydrography Dataset (NHD). Spatial data for rivers and streams (NHD) do not always align with wetland data (NWI) because of the differing methodologies used to create these datasets. DU partnered with the US Fish and Wildlife Service to test the feasibility of using high-resolution elevation-derived hydrography (EDH) as the main data input for NWI's linear habitats. USGS produced an updated EDH dataset through the 3-Dimensional Elevation Program (3DEP) that accurately represented rivers, streams, and drainages for 10 HUC-10 watersheds in the upper eastern coastal area (Figure 1). Within the EDH project area, DU developed a pre-processing step to convert this EDH data to linear habitats that meet or exceed NWI standards, then tested the efficiency of this process. A full report of this analysis can be found in Appendix A.

Task 1: Data Compilation, Processing, and Validation

Data Compilation

Ducks Unlimited collected ortho-imagery, LiDAR, and other collateral spatial data to support the photointerpretation process. DU also performed field work to collect on-the-ground information about wetland types in the study area.

All collected data met or exceeded the spatial resolution requirements as defined by the Federal Geographic Data Committee Wetlands Mapping Standard (FGDC Document Number FGDC-STD-015-2009).

The source imagery used for photointerpretation was 3-band natural color ortho-imagery with 6-inch spatial resolution, sourced from the Texas Imagery Service. Photo-interpreters used this imagery as the primary source for wetland classification and digitization. The source imagery was also used by the US FWS to check that the wetland data met classification and spatial accuracy standards as described in the FGDC Wetlands Mapping Standard. The imagery dates differed across the project area (Figure 2).

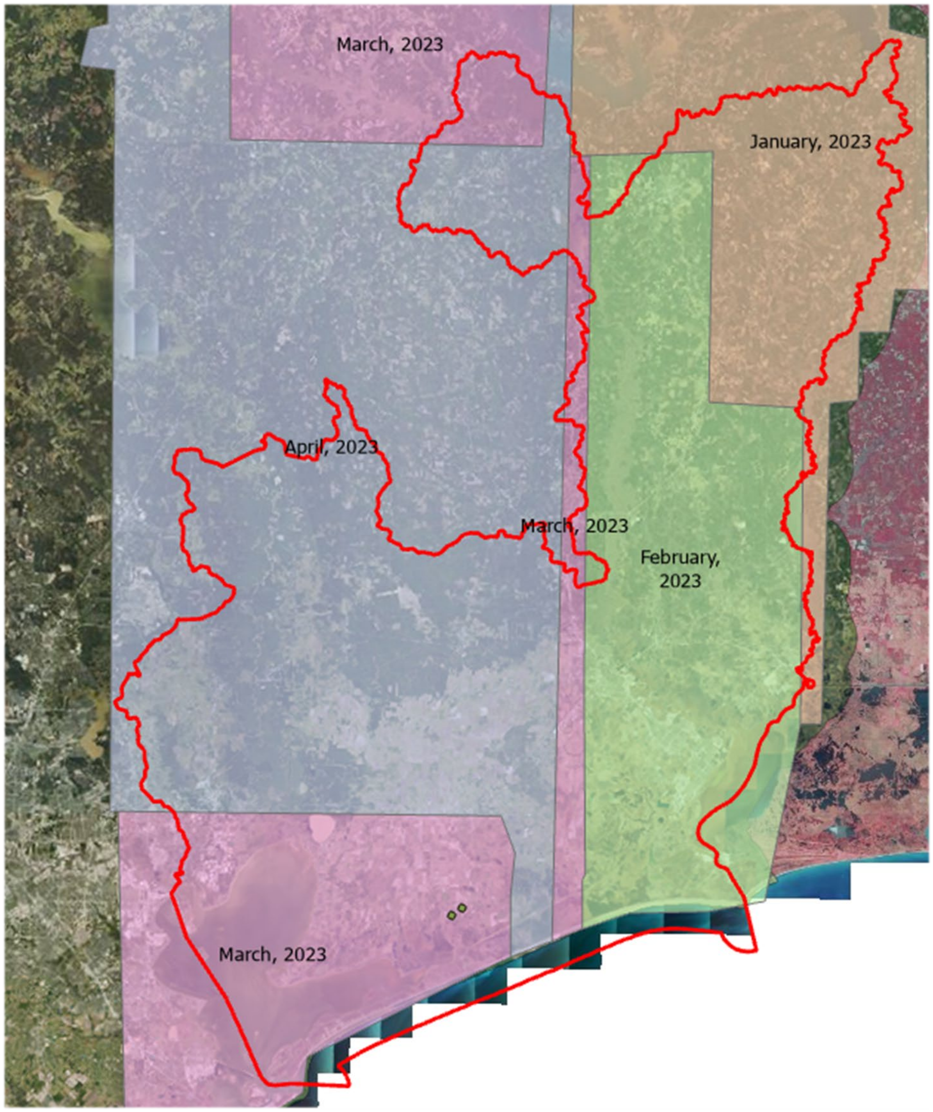


Figure 2 A map showing the dates the Texas ortho-imagery were captured for this project.

Ancillary data were also used to support wetland digitization and classification. These included:

1. Digital ortho-imagery, November 2022, distributed by the United States Department of Agriculture (USDA) Farm Service Agency (FSA) National Agriculture Imagery Program (NAIP) with 8-bit pixel depth, 4-band (R, G, B, NIR) with spatial resolution of 0.6.

2. USDA National Agricultural Statistics Service Cropland Data Layer. Published rice-specific data layer 2023, 2022, 2021. Available at https://nassgeodata.gmu.edu/CropScape/ USDA-NASS, Washington, DC.

3. Soil Hydric Class, Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at

https://websoilsurvey.nrcs.usda.gov/.

4. LiDAR acquired in 2022 with 3-meter resolution and obtained from the United States Geological Survey (USGS) at https://viewer.nationalmap.gov/launch/.
5. Preliminary Elevation-Derived Hydrography (EDH) and hydro-flattened Digital Elevation Model (DEM) for the area within the EDH boundary, acquired in 2022 from the United States Geological Survey (USGS). As these data were preliminary, they are not available for public download.

Data Processing

Ducks Unlimited processed the LiDAR and DEM data to create derived products for the photointerpretation process (Figures 3a-d, Figure 4).

In areas where USGS did not provide a DEM, DU derived a DEM from LiDAR using the LAS Dataset Tools in ArcGIS Pro using standard methods (ESRI, 2024).

The ArcGIS Pro Hillshade Spatial Analyst Tool was used to create the hillshade layer.

The Topographic Position Index (TPI) raster dataset was created by calculating the difference in elevation value at each cell in the DEM and the average elevation in the 80-cell neighborhood surrounding the cell as described in Tagil and Jennes (2008).

A stochastic depression analysis (SDA) was performed using Whitebox Tools version 2.0.0 (Lindsay, 2021) and is described in detail by Lindsay and Creed (2005).

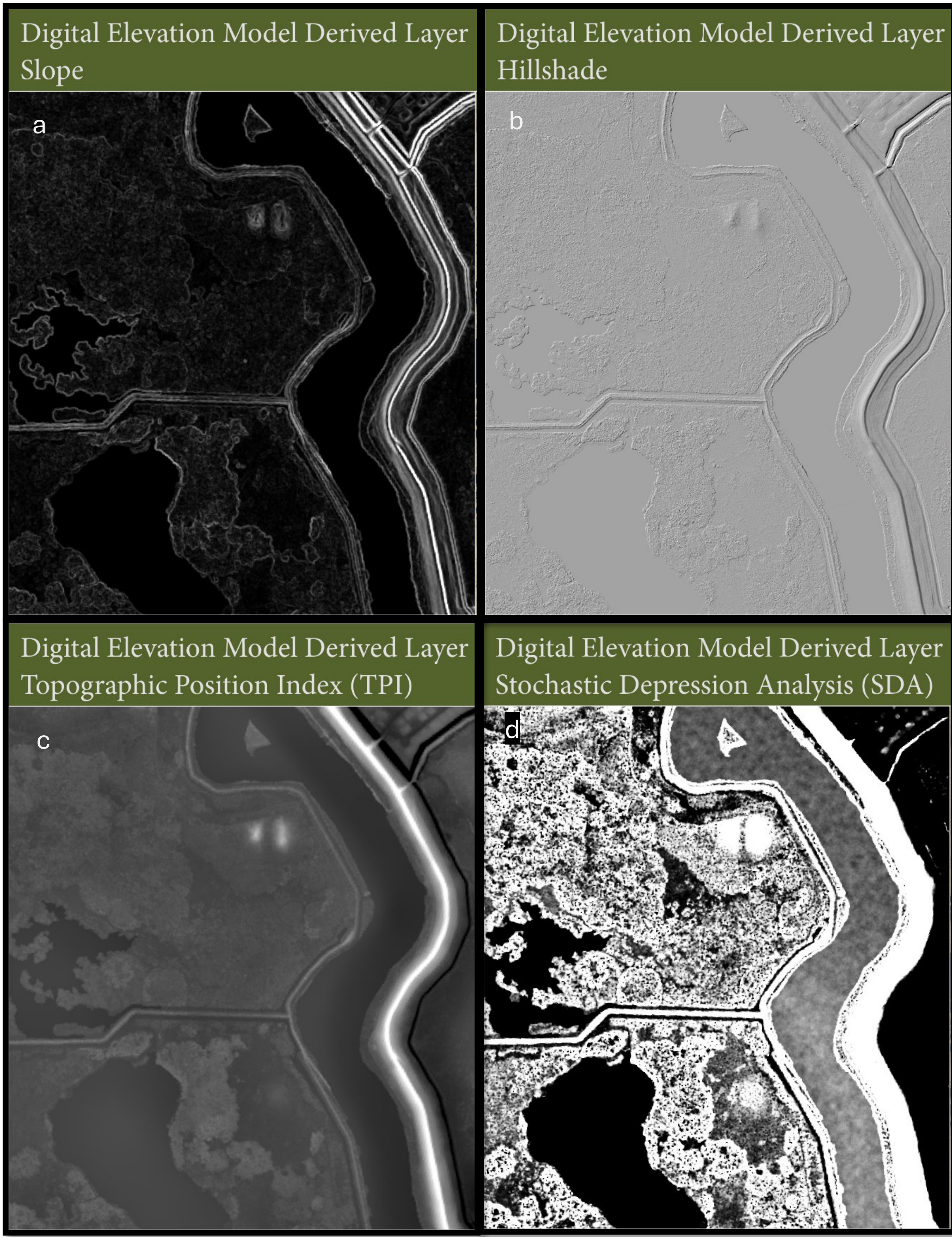


*Figure 3. **a.** The slope represents the rate of elevation change in each DEM cell and helps distinguish flat areas from sloped areas. **b.** The hillshade is a stylized visualization of the DEM that renders a 3-dimensional representation of the earth's bare surface. **c.** The topographic position index is used to determine the ruggedness of the terrain and better distinguish between hilltops, valleys, ridges, plains, and slopes. **d**. The stochastic depression analysis (d) shows the probability of a depression in the landscape and helps visualize where water might collect to form a wetland on the landscape.*

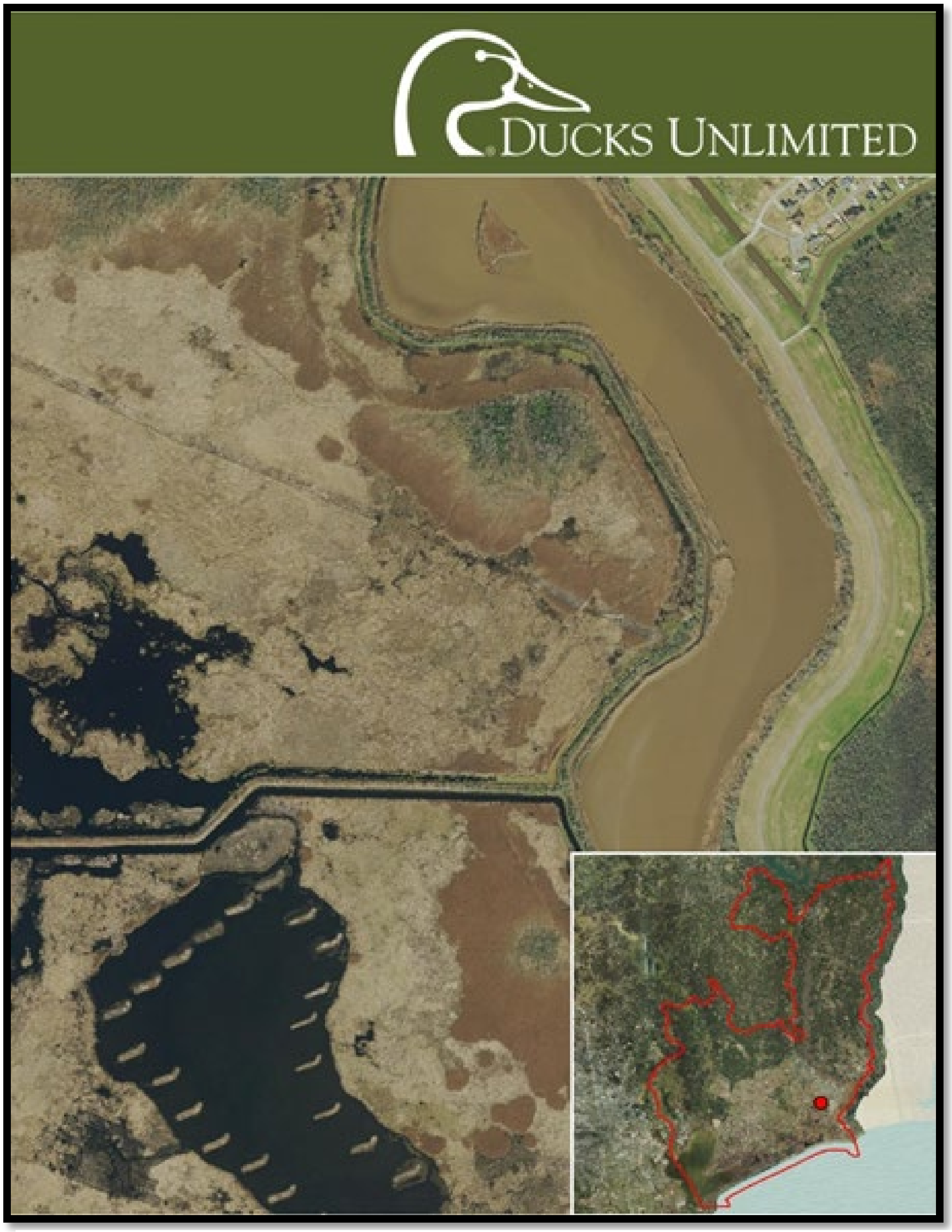


Figure 4 An aerial image of showing what this example area looks like with natural color imagery.

Field Work (Validation)

DU conducted field work for on-the-ground reconnaissance from October 17th to October 20th, 2022 (Figures 5 and 6). The purpose of the field work was to train the photo interpreters through on-the-ground experience to recognize and differentiate wetland types in the region.

The process and summary of findings are in Appendix B. DU submitted the data and photos collected during the field work process to the Texas GLO on November 10, 2022.

Figure 5 Mat Halliday and Alice Colville capturing information about a cypress wetland in Texas.

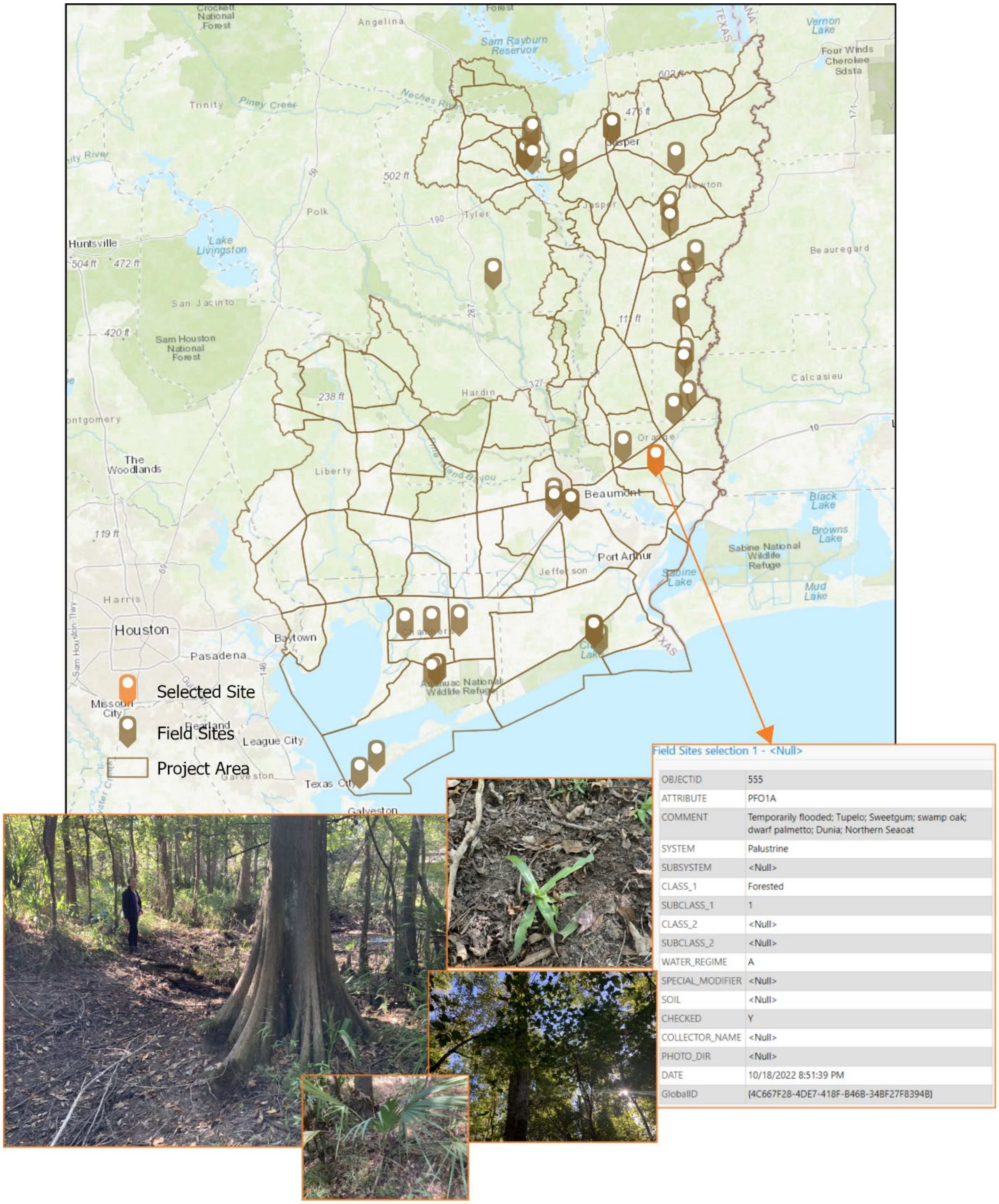


Figure 6 A map of wetland sites that the team visited during the field reconnaissance in October 2022. The orange marker shows an example of the collected data and images.

Task 2: Complete Wetland Inventory

Ducks Unlimited completed photointerpretation and manual digitization using ArcGIS Pro 3.0 to create a new National Wetland Inventory dataset. Wetlands were classified according to FGDC (2013) and were digitized to the accuracy and completeness standards described in the FGDC Wetlands Mapping Standard (FGDC, 2009) and the US FWS NWI Mapping Standard Compliant Wetland Data – Supplement (NWI, 2022). Data are downloadable and visible on the USFWS Wetlands Mapper page.

The Texas NWI update meets or exceeds the federal wetland mapping standard which requires that wetlands greater than or equal to 0.5 acres be consistently mapped. For this project, Ducks Unlimited mapped features as small as 0.05 acres, including all wetland features that are visible at a scale of 1:6,000. No ground truthing was performed on either wetland extent or attribution. At a minimum, feature boundaries can only be as spatially accurate as the source data used in interpretation.

A multi-step process was used for photointerpretation and quality control (Figure 6).

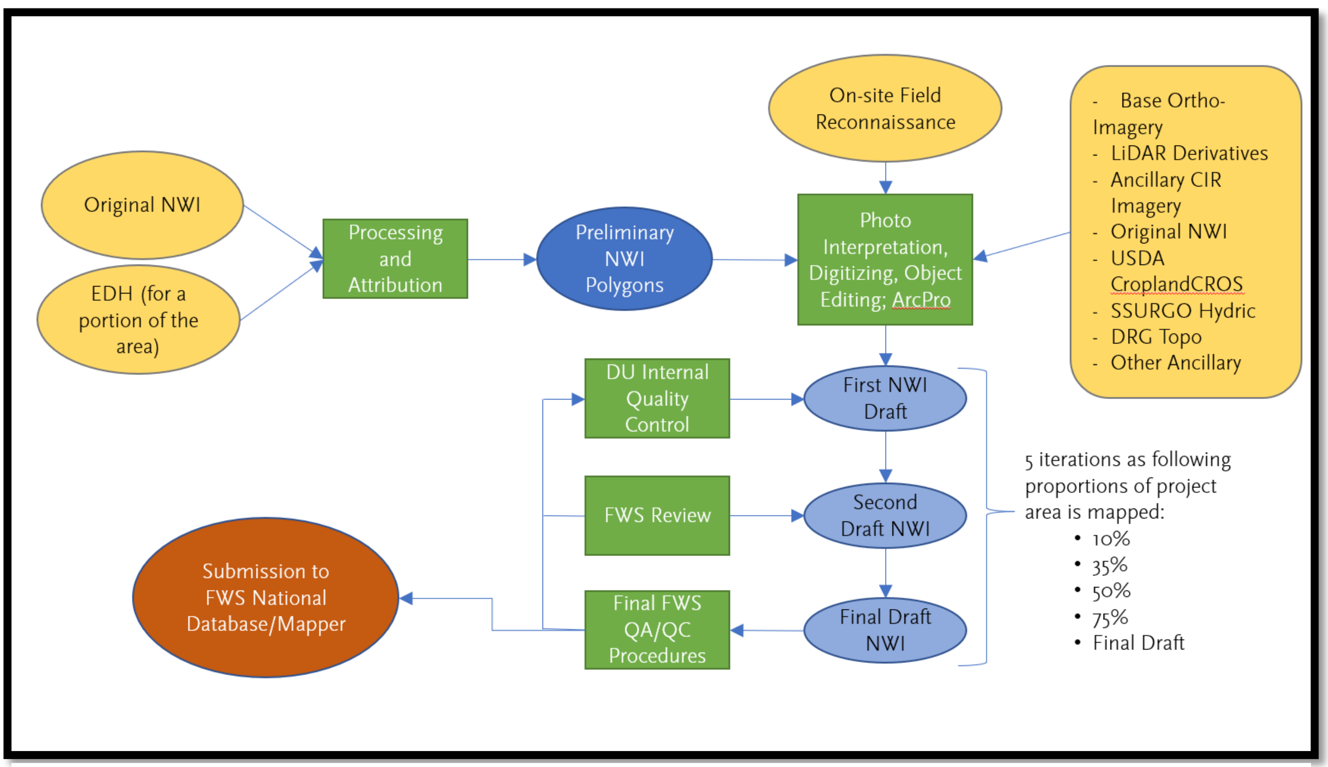


Figure 6 The multi-step process used for photointerpretation and quality control when updating the NWI.

This included the following steps:

1) Data preparation of imagery, ancillary data, and automated features, if available.
2) Photointerpretation by a trained technician.

3) On-screen data review by a second technician.

4) A second on-screen manual review and an automated review of draft data by a senior analyst.

5) Draft data review by stakeholders on the Texas NWI Hub.

6) Draft data review by the USFWS NWI Data Coordinator at various points of completeness (10%, 25% ,50%, 75% and 100% complete) to ensure the data met or exceeded the USFWS standards.

DU altered the processes for digitizing open water and narrow linear habitats inside the USGS Elevation-Derived Hydrography (EDH) study area. Inside the EDH study area, open water and rivers were copied from the NHD product and NWI codes were then transcribed from NHD metadata. Rivers were created using the EDH-provided polylines. Rivers greater than five meters in width were then converted to polygons using automated methods. These polygons were quality checked during the manual and automated quality control processes.

Rivers outside of the USGS EDH study area were digitized by hand. The photo-interpreters digitized all rivers and streams with a bank-width greater than 15 ft as a polyline feature, then buffered the lines to create NWI-compliant river polygons.

Areas that may indicate a wetland in the LiDAR (i.e., low and flat) but were in pine plantations were not included. The amount of rice fields in the study area required a special mapping convention whilst mapping (Figure 7).

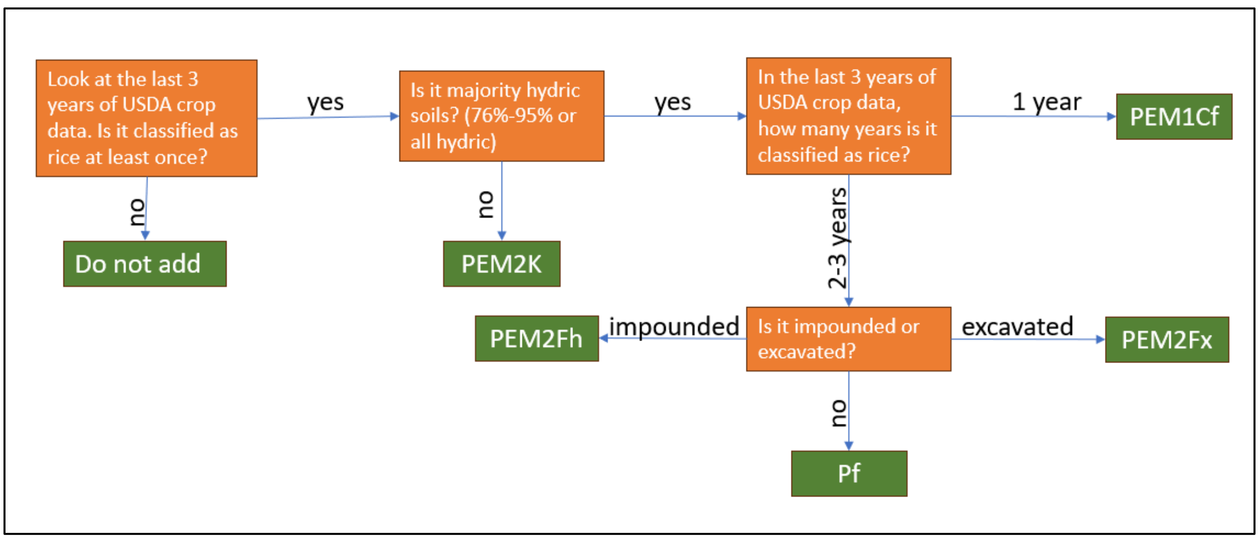


Figure 7 Protocol for rice field mapping.

Coordination Meetings with the USFWS

Ducks Unlimited met with the USFWS on an as-needed basis for this project. The meetings with the USFWS mostly focused on narrow linear habitat delineation. DU sent draft data into the USFWS on a regular schedule and incorporated edits and comments throughout the process. This was a highly efficient process, allowing for issues and concerns to be managed early in the photointerpretation process, thus negating the need for a big final edit of the data.

Description of Cowardin wetland habitats:

Cowardin is a hierarchical classification system that categorizes wetlands by system, substrate, vegetation, and water regime (FGDC, 2013). A diagram of the classification system is provided in Appendix D.

The study area has all five systems of wetlands: marine, estuarine, riverine, palustrine, and lacustrine. The final wetland dataset includes 90,250 wetland and deepwater features with a total area of 1,391,301 acres out of 3.8 million acres total, and mean area of 15.4 acres per wetland. Wetland and deepwater features encompass 35% of the total project acreage.

The original NWI data included approximately 1.44 million acres of wetlands. A comparison of the wetland acreage differences can be seen in Figure 8. While the new dataset shows a substantial decrease in wetland acreage, this data cannot be used for wetland change analysis over time. This is because recent improvements in imagery resolution, data standards, and the availability of ancillary data improved our ability to differentiate between wetlands and uplands. These technological and process improvements confound our ability to determine the true cause of change within the dataset. It should be noted that the 2019 US FWS Status and Trends report shows that nationwide, wetland loss increased substantially from 2009 to 2019 compared to the previous 10 years (Lang *et al.* 2024).

The top five most common wetland classifications used are, in descending order:

1. ‘PFO1C’- Palustrine Forested, Broad-Leaved Deciduous, Seasonally Flooded
2. ‘PUBHx’- Excavated Permanently Flooded Freshwater Ponds
3. ‘PFO1A’ – Palustrine Forested, Broad-Leaved Deciduous, Temporarily Flooded
4. ‘PEM1C’ – Palustrine, Persistent Emergent Vegetation, Seasonally Flooded
5. ‘E1UBL’ – Estuarine subtidal, unconsolidated bottom.

These five classifications total 53,340 features or 59 % of all wetland features mapped. 'E1UBL' accounted for the largest total area of wetlands mapped at 272,031 acres followed by 'PFO1C' with 194,344 acres. Marine deepwater, 'M1UBL', covered 139,543 acres. Despite its large area, there was only one 'M1UBL' feature in the entire project, the open ocean.

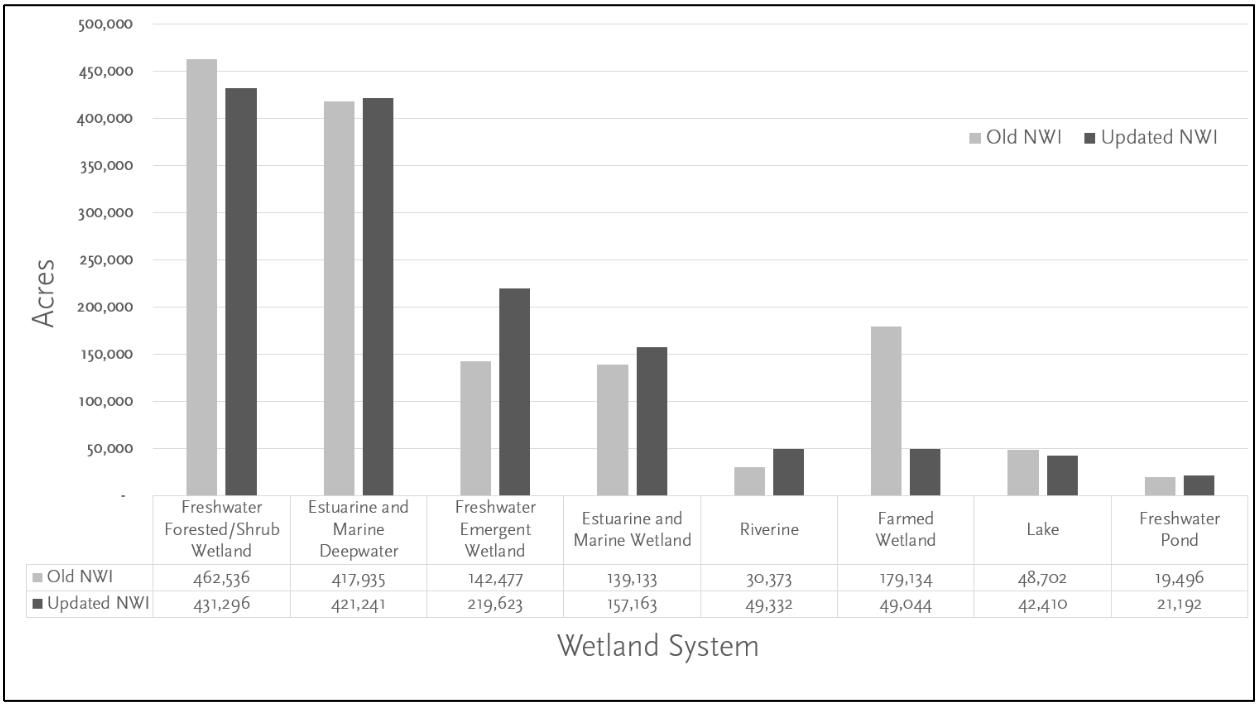


Figure 8 Comparison of total acres by wetland system in the old and new NWI.

A full accounting of all Cowardin codes is in Table 1.

Table 1 The Cowardin codes that were used while mapping the project area.

Wetland Code	Number of Features	Sum of Acres	Wetland Code	Number of Features	Sum of Acres
E1ABL	2	1.8	PFO1/4Ch	1	83.0
E1ABLx	1	5.4	PFO1/5F	4	43.2
E1UBL	5715	272,030.6	PFO1/EM1A	57	307.0
E1UBLd	1	1.1	PFO1/EM1C	101	592.7
E1UBLh	16	1,062.7	PFO1/EM1F	6	321.0
E1UBLx	464	8,594.9	PFO1/SS1A	4	23.7
E2AB1N	4	2.9	PFO1/SS1C	12	122.6
E2EM1/5P	1	259.8	PFO1A	7431	73,451.9
E2EM1N	724	24,693.5	PFO1Ad	4	8.9
E2EM1Nh	12	622.4	PFO1Ah	8	36.0
E2EM1Nx	3	47.5	PFO1Ax	2	0.4

E2EM1P	2269	122,662.7	PFO1C	17318	194,343.6
E2EM1Ps	1	1.6	PFO1Cd	4	58.3
E2EM1Px	4	17.2	PFO1Ch	33	92.6
E2EM2N	5	7.5	PFO1Cx	88	205.8
E2EM5P	302	5,221.2	PFO1F	179	1,100.1
E2FO1P	5	67.7	PFO1Fh	1	21.1
E2FO3P	1	10.4	PFO1Fx	3	2.5
E2SS1/EM1P	2	19.1	PFO2/4C	103	457.9
E2SS1P	18	90.0	PFO2/5F	3	3.4
E2SS1Ph	4	45.0	PFO2/ABF	1	3.7
E2SS3N	2	8.6	PFO2/EM1C	21	931.7
E2SS3P	3	6.2	PFO2/EM1F	6	153.7
E2SS3Ps	8	19.0	PFO2/SS2C	3	36.7
E2US1M	3	13.9	PFO2/UBF	2	15.6
E2USM	133	1,271.0	PFO2A	6	34.3
E2USMs	2	8.7	PFO2C	3310	53,061.7
E2USMx	2	14.2	PFO2Ch	3	7.9
E2USN	55	186.7	PFO2Cx	7	7.6
E2USP	83	422.8	PFO2F	812	19,878.4
E2USPs	47	105.2	PFO2Fh	4	39.8
L1ABHx	8	105.9	PFO2Fx	8	11.1
L1UBH	47	12,621.1	PFO4/1A	2	7.9
L1UBHh	25	12,231.0	PFO4/2C	1	22.0
L1UBHx	76	4,532.8	PFO4/EM1A	19	86.7
L1UBK	3	74.1	PFO4/SS1A	5	39.5
L1UBKx	6	411.7	PFO4A	2432	13,042.1
L2ABH	11	506.7	PFO4Ad	1	1.8
L2ABHh	4	106.5	PFO4Ah	2	4.1
L2ABHx	23	506.3	PFO4Ax	13	19.0
L2EM2F	1	53.1	PFO4C	222	944.3
L2EM2Fx	3	39.9	PFO4Cx	2	5.5
L2EM2H	1	24.8	PFO5F	9	65.4
L2EM2Hx	1	64.3	PSS1/2C	77	561.1
L2UBF	9	644.0	PSS1/2F	5	20.4
L2UBFh	7	501.7	PSS1/2Fx	5	5.4
L2UBFx	20	650.0	PSS1/4A	35	223.5
L2UBH	81	5,540.9	PSS1/4Ad	5	75.9
L2UBHh	4	330.6	PSS1/4Ax	4	8.7
L2UBHx	65	2,454.9	PSS1/4C	5	19.7
L2UBK	4	472.4	PSS1/EM1A	67	596.4
L2USA	2	16.7	PSS1/EM1Af	3	10.8

L2USAh	1	15.3	PSS1/EM1C	131	1,358.8
L2USAx	19	310.3	PSS1/EM1F	11	112.5
L2USCh	1	34.6	PSS1/EM1Fx	2	12.7
L2USCx	7	160.7	PSS1/EM5C	1	25.6
M1UBL	1	139,542.8	PSS1A	732	4,482.2
M2USM	1	48.4	PSS1Ad	4	19.1
M2USN	8	679.2	PSS1Ax	4	10.0
M2USP	3	607.5	PSS1C	1961	14,163.0
PAB/FO5H	3	19.2	PSS1Cd	1	0.9
PAB/FO5Hx	3	4.0	PSS1Ch	6	30.7
PABF	6	19.0	PSS1Cx	23	26.5
PABFx	2	3.1	PSS1F	62	491.0
PABH	222	473.4	PSS1Fx	4	154.7
PABHh	53	60.5	PSS1Ks	6	490.2
PABHx	934	979.2	PSS2/4C	2	1.2
PEM1/5C	3	279.6	PSS2/EM1C	7	208.5
PEM1/5Fx	1	60.2	PSS2/EM1F	10	97.4
PEM1A	4679	23,760.9	PSS2/EM1Fh	1	2.2
PEM1Ad	50	261.9	PSS2/EM1Fx	1	6.8
PEM1Ah	5	6.6	PSS2C	246	1,594.1
PEM1Ax	69	510.0	PSS2Cd	1	4.6
PEM1C	7229	80,024.2	PSS2Cx	4	10.2
PEM1Cd	16	46.2	PSS2F	123	900.9
PEM1Cf	256	12,784.4	PSS2Fx	6	14.8
PEM1Ch	41	1,203.0	PSS4/EM1A	21	61.6
PEM1Cx	361	1,165.7	PSS4A	68	165.1
PEM1F	2122	18,763.6	PSS4Ad	1	18.4
PEM1Fd	3	9.3	PSS4C	5	25.7
PEM1Fh	38	1,679.4	PUB2Fx	2	2.9
PEM1Fs	1	105.0	PUBF	162	257.4
PEM1Fx	289	1,314.0	PUBFh	9	43.5
PEM1K	9	788.5	PUBFx	764	1,250.9
PEM1Km	4	211.8	PUBH	2651	3,942.6
PEM1Ks	8	166.6	PUBHh	451	1,030.3
PEM1Kx	11	45.0	PUBHx	15647	12,594.9
PEM2F	140	225.3	PUBK	37	297.5
PEM2Fh	2	20.2	PUBKm	20	39.5
PEM2Fx	41	31.0	PUBKs	3	6.9
PEM2Hx	2	0.8	PUBKx	21	82.5
PEM2K	1330	84,126.9	PUSA	12	3.0
PEM5A	1	3.5	PUSAx	4	5.1

PEM5C	228	4,544.4	PUSC	23	29.9
PEM5Ch	5	137.4	PUSCx	12	18.7
PEM5F	7	85.3	PUSKs	3	30.7
PEM5Ks	1	13.2	R1UBV	35	6,168.4
Pf	689	36,248.5	R1UBVx	34	513.2
PFO1/2A	17	354.8	R2ABH	6	8.1
PFO1/2C	1846	33,407.5	R2UBF	28	144.0
PFO1/2Ch	3	11.4	R2UBFx	161	434.1
PFO1/2Cx	2	2.6	R2UBH	363	22,818.1
PFO1/2F	73	816.6	R2UBHx	786	17,130.3
PFO1/2Fx	2	81.4	R2US2C	22	426.9
PFO1/4A	1334	8,868.4	R2USA	74	298.4
PFO1/4Ad	1	6.8	R2USC	309	1,244.2
PFO1/4Ah	6	34.9	R4SBC	18	32.4
PFO1/4Ax	27	50.1	R4SBCh	1	2.3
PFO1/4C	150	2,001.0	R4SBCx	30	111.8

Task 3: Stakeholder Engagement

At the beginning of this project, Ducks Unlimited collaborated with the Texas General Lands Office to compile a list of stakeholders. Ducks Unlimited held three informational webinars for these stakeholders. The first was a kick-off meeting that discussed the objectives, process, and outcomes of the project. During this meeting, DU also invited stakeholders to follow this project on the Texas NWI Hub Site and to review draft data on the site. The presentation and video for this meeting were sent to Texas GLO on September 29, 2022.

The second meeting was held on March 6, 2024, and was attended by thirty-three people from twelve federal, state, non-profit, and academic entities. During this meeting, we discussed our progress and provided examples of how wetlands were mapped. During the question-and-answer period, the stakeholders provided important feedback on coastal wetland mapping. Ducks Unlimited incorporated this feedback into the photointerpretation process. DU sent a copy of this presentation to the Texas GLO on March 10, 2024.

The final stakeholder meeting was held on October 29, 2024, and was attended by 26-30 people representing federal, state, non-profit, and private entities. During the meeting, we provided an overview of the project background, methodology, and mapping results. We also provided information on how to access the data, and gave examples of how to use the data, as well as data restrictions.

Task 4: Project Reporting

DU provided monthly reports to the TX GLO. In these reports, we included a snapshot of the TX NWI dashboard, which showed mapping progress.

References

Dahl, T., & Bergeson, M. (2020). Data Collection Requirements and Procedures for Mapping Wetlands. Washington D.C.: USFWS.

ESRI. (2024). Create DEMS and DSMs from lidar using a LAS dataset. Website: https://pro.arcgis.com/en/pro-app/latest/help/analysis/3d-analyst/create-dems-and-dsms-from-lidar.htm Last Accessed: 6/10/2024.

Federal Geographic Data Committee. (2009). Wetlands Mapping Standard. Washington D.C.

Federal Geographic Data Committee. (2013). Classification of wetlands and deepwater habitats of the United States. FGDC-STD-004-2013. Second Edition.

Lang, M.W., Ingebritsen, J.C., 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, Washington, D.C. 43 pp.

Lindsay, John B. and Irena F. Creed. (2005). Sensitivity of Digital Landscapes to Artifact Depressions in Remotely-sensed DEMs. Photogrammetric Engineering & Remote Sensing 71 (9): pp 1029-1036.

Lindsay, John B. (2021). Whitebox Tools Version 2.0.0. Whitebox Geospatial, Inc. https://jblindsay.github.io/wbt_book/index.html.

National Wetlands Inventory. (2022). Mapping Standard Compliant Wetlands Data - Supplement. Washington D.C.: USFWS

Tagil, Sermin and Jeff Jenness. (2008). GIS-Based Automated Landform Classification and Topographic, Landcover, and Geologic Attributes of Landforms Around Yazoren Polje, Turkey. Journal of Applied Sciences 8 (6): pp 910-921.

Appendix A: EDH Analytical Report

Incorporating Elevation-Derived Hydrography Products into Updated National Wetland Inventory Data

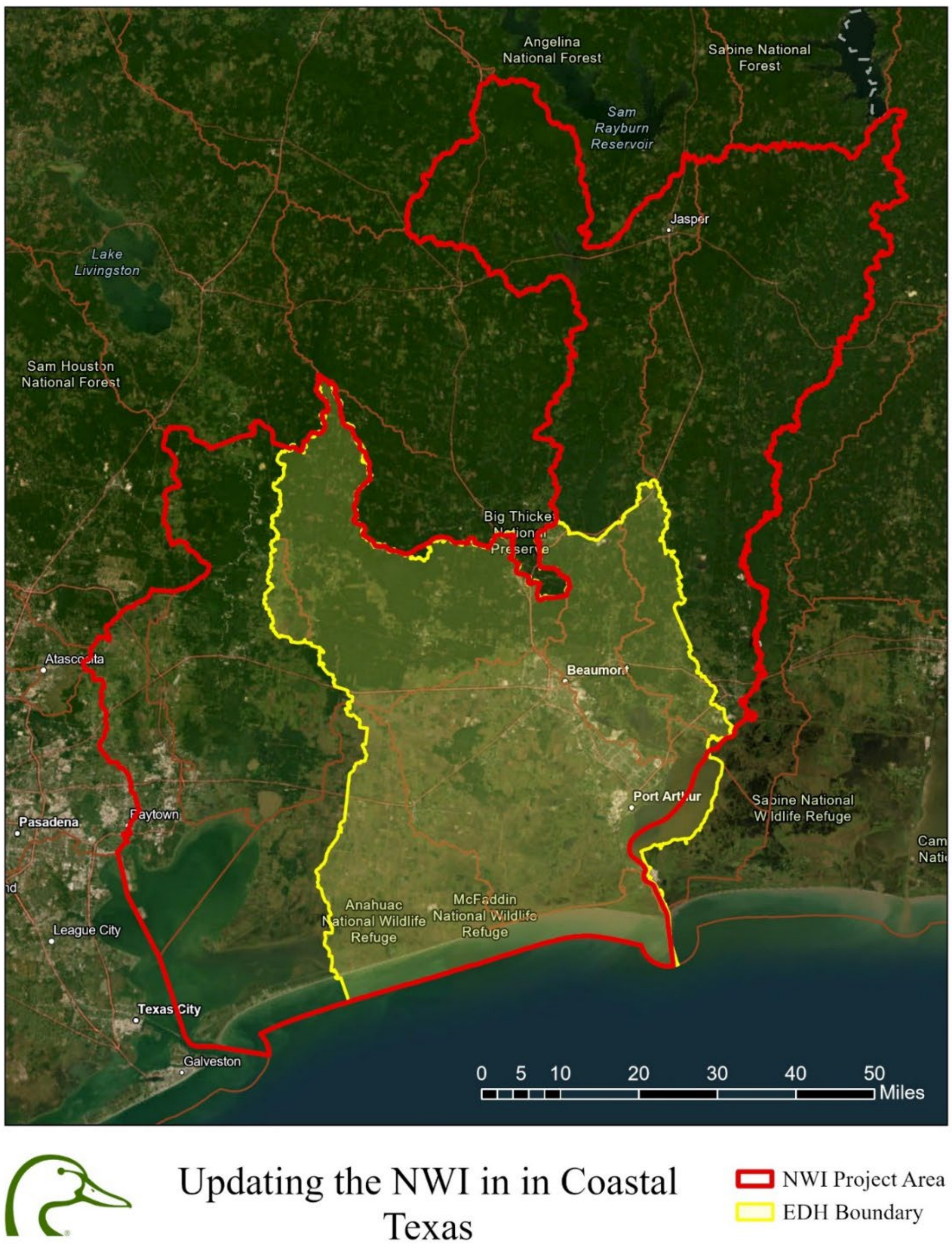


Figure 1. The project areas for the National Wetland Inventory (NWI) update (red) and the update that included Elevation-Derived Hydrography (EDH) data as an input (yellow).

Introduction

The goal of this project was to test the utility of high-resolution Elevation-Derived Hydrography (EDH) as a foundational data input for Narrow Linear Habitats while performing a FGDC-compliant National Wetland Inventory mapping update in Southeastern Texas. Ducks Unlimited was tasked with the following:

a) Produce FGDC wetland standard compliant data for the entire GLO-funded project area.
b) Derive narrow linear habitats from preliminary EDH data provided by the USGS where available.
c) Research, develop, and document the processes deployed to produce the final product.
d) Provide a final report that aggregates, summarizes and describes lessons learned, while providing best practices used and recommendations for applications for future wetland mapping products.

The project area consists of 1,464,315 acres located in Southeastern Texas and is located entirely inside of the concurrent Texas Coastal NWI project (Figure 1).

Partners

This project is in partnership with the Texas General Land Office, the Texas Parks and Wildlife Department, the USFWS Ecological Services Texas Coastal Program and the USGS.

Data Source

The high-resolution elevation-derived hydrography (EDH) and associated hydro-enforced digital elevation model (DEM) was sourced from USGS preliminary data acquired by DU in 2022. As these data were preliminary, they are not available for public download.

Other data were used to support wetland digitization and classification. These included:

6. Digital ortho imagery, November 2022, distributed by the United States Department of Agriculture (USDA) Farm Service Agency (FSA) National Agriculture Imagery Program (NAIP) with 8-bit pixel depth, 4-band (R, G, B, NIR) with spatial resolution of 0.6.

7. USDA National Agricultural Statistics Service Cropland Data Layer. Published rice-specific data layer 2023, 2022, 2021. Available at https://nassgeodata.gmu.edu/CropScape/ USDA-NASS, Washington, DC.

8. Soil Hydric Class, Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at https://websoilsurvey.nrcs.usda.gov/.

9. LiDAR acquired in 2022 with 3-meter resolution and obtained from the United States Geological Survey (USGS) at https://viewer.nationalmap.gov/launch/.

Methods

Assigning Widths to EDH Polylines

Using the ArcGIS Pro v2.9 Spatial Analyst extension, a Flow Accumulation raster was produced from the 1-meter resolution digital elevation model (DEM) from which the elevation-derived hydrographic (EDH) polyline data were derived. The "D8" method was used, which assigns flow direction to the steepest downslope neighbor. The "Zonal Statistics as Table" tool was used to calculate the maximum flow accumulation value for each EDH line segment. The maximum flow accumulation value was converted to square kilometers for use as the drainage area in the regression equation for river segment bankfull width for the Atlantic Plain physiographic division found in Bieger, et al. (2015). The standard error was added to the calculated bankfull widths (previous experience favors overestimation over underestimation of widths) before it was divided by two to determine the halfwidth, or the amount by which the line feature would be buffered on both sides to create a polygon feature.

DU manually reviewed the calculated halfwidths for a subset of the project area and found two key issues: too narrow halfwidths for constructed features and inaccurate halfwidths for connectors or culverts.

Constructed Features

A significant portion of segments had calculated halfwidths that were too narrow to meet FGDC standards. Further analysis found that over 80% of these segments were classified as constructed or artificial features like "Canal/Ditch" or "Culvert" (see Figure 3). Widths of manipulated or built features do not correlate well to the size of the drainage area assigned to each EDH line segment because the shape and size of these channels are not produced by water conveying earth via the least-cost path to the minimum achievable elevation but by machines.

To fix this error, all EDH line segments with an FTYPE like "Canal/Ditch" and a calculated halfwidth less than 2.75 meters were selected and the halfwidth attribute was changed to 2.75 meters. The rationale for this edit was that for all the "Canal/Ditch" type EDH line segments with an inaccurate calculated halfwidth, the mean value of the manually determined appropriate halfwidth was 3.19 meters, with a large majority falling between 2.5 and 3.1 meters (see Figure 4). Most of those that had calculated halfwidths that were found to be too wide were thought to have more appropriate halfwidths ranging from 2 to 3 meters, with a median of 2.65 meters (see Figure 5).

Connectors and Culverts

The distinction between Connectors and Culverts was unclear in the EDH dataset used in this project. The terms seemed to be interchangeable, and both occurred where riverine features passed under an obstruction, like a road of berm. The path of the channel beneath these obstructions to natural flow are not represented in the aerially sensed lidar-derived DEM, thus drainage area calculations produced from the DEM do not align well with Connectors and Culverts.

Adjacent features were identified programmatically for all EDH line features. Adjacency was identified using shared first points and end points of the line segments. If the calculated halfwidth of a feature had at least a 1-meter difference compared to its adjacent neighbors, the halfwidth was updated to the greater calculated halfwidth value of its two neighbors. This was intended to not only address issues with Connectors and Culverts, but any inconsistencies in width among contiguous features.

Creating Draft NWI Polygons

EDH polylines with FTYPE in "Stream/river" and "Culvert Stream/river" were classified as "R2UBH". All other FTYPES (excluding "Artificial path") were classified as "R2UBHx". EDH lines whose halfwidth is greater than or equal to 2.286 meters and classified as "R2UBH" or "R2UBHx" were buffered by their halfwidth value and dissolved based on their classification. The resulting riverine polygons were combined with the EDH waterbody polygons where those with FTYPE equal to "Lake/pond" were classified as "L2UBH" or "PUBH", and those with FTYPE of "Reservoir" were classified as "L2UBHh" or "PUBHx" based on their area. Tidally influenced riverine, estuarine, and marine features were distinguished from other waterbodies via photointerpretation. Any other modifications and corrections were done during the photointerpretation and quality control processes.

Quantifying the Number of EDH-derived Polygons Used and Edited

Once photo-interpreters edit the EDH-derived river and other waterbody polygons, add wetlands, and perform QAQC the data can be considered a draft NWI dataset. These draft NWI data can be compared to the original EDH-derived polygon features viz-a-viz the spatial relatedness of the draft and original data.

The geometry of the original features was compared with features they intersect in the draft data. Using the ratio of the area of intersection over the area of union (IoU), also referred to as the Jaccard Similarity Index, the degree of similarity between the original feature and the draft features can be assessed. Feature comparisons with an IoU value of 1 are geometrically identical while IoU values closer to 0 reflect very dissimilar geometry. Any features in the original EDH-derived data that do not intersect features in the draft NWI data, or have very little area of overlap, indicate that the original features were not used in the draft NWI.

An accounting of IoU was made on a per-feature basis, and by "quaddish" area to get an idea of the range of values across the dataset as well as any spatial variability within the project area (e.g., coastal areas vs. inland areas). Quaddish areas refer to USGS 25K quadrangle-sized subsets of the project area and are the unit at which each photo-interpreter works, so any patterns among photo-interpreters may also become apparent (Figure 2).

The draft NWI data was clipped to the shape and extent of the area of interest (AOI) of the EDH data. The AOI defines the boundary within which EDH data was produced. The EDH-derived polygonal features offered to photo-interpreters were clipped by individual quaddish area less a 5-meter buffer to limit the potential effect of the edge of the quaddish area, and the stitching together of quaddish areas during QAQC to create the seamless draft NWI dataset, on the geometry of features being compared. The draft NWI data was further clipped to the same area making all geometric constraints equal. All the draft NWI features that overlap the geometry of the EDH-derived feature were dissolved into a single feature. Additionally, the overlapping draft NWI features were filtered to only include waterbodies (i.e., the Attribute includes either the Unconsolidated bottom (UB) or aquatic bed (AB) class) and dissolved. The geometry of each individual EDH-derived feature was compared to the dissolved NWI features and dissolved NWI waterbodies by calculating the area of intersection between features and dividing that by the area of their union (i.e., IoU). The ratio of the area of intersection and total area of the EDH-derived feature was also calculated. Additionally, the

Cowardin attributes and number of intersecting draft NWI features were recorded for each EDH-derived feature.

Results

A total of 10,201 EDH-derived polygonal features were compared to the geometry of draft NWI waterbodies; 9,083 (89%) of which overlapped draft NWI waterbodies. 1,173 of those overlapped two or more draft NWI waterbodies. 6,577 (64%) of EDH-derived features overlapped draft NWI waterbodies with the same Attribute, 2,618 (26%) of which overlapped waterbodies with only the Attribute assigned to the EDH-feature.

An IoU value of 0.99 or greater indicates nearly identical geometry comparisons. The following table provides a summary of IoU values by attribute assigned to the EDH-derived polygons. Listed are the percentage of features with each attribute that have an IoU value of 0.99 or greater, an IoU value of 0.50 or greater, and do not intersect with any draft NWI waterbodies. Also included are the number of EDH-derived features with each attribute and the percentage those features comprise of the whole EDH-derived dataset used in the geometry comparisons.

ATTRIBUTE	IOU >= 0.99	MEDIAN	MEAN	DOES NOT INTERSECT NWI WATERBODY	COUNT	PERCENT OF TOTAL EDH-DERIVED DATASET
E1UBL	0.00%	0.46	0.46	0.00%	1	0.01%
L1UBH	23.97%	0.78	0.61	19.01%	242	2.38%
L1UBHh	39.39%	0.95	0.70	6.06%	33	0.32%
M1UBL	33.33%	0.93	0.95	0.00%	3	0.03%
PUBH	15.98%	0.97	0.81	12.01%	6,952	68.41%
PUBHx	37.47%	0.99	0.92	20.84%	451	4.44%
R2UBH	0.30%	0.01	0.17	2.74%	329	3.24%
R2UBHx	2.98%	0.01	0.20	5.86%	2,151	21.17%
TOTAL	13.94%	0.96	0.65	10.94%	10,162	100.00%

Note: Median and mean IoU value calculations do not include features that do not intersect with NWI waterbody.

EDH-derived lakes and ponds have more similar geometry to overlapping draft NWI waterbodies than riverine features. The histogram charts in Figures 8 and 9 further illustrates this point. Lakes and ponds originate as polygonal features in the EDH dataset while river features are incorporated as buffered polylines. Discrepancies between the geometry of EDH-derived lake and pond features and draft NWI features may be due to differences in standards and protocols in producing EDH data and NWI data, and/or to changes in the reference imagery used. Some features that were classified as a lake or pond in the EDH dataset may have similar geometry to features in the draft NWI dataset but have been subdivided and classified as different vegetated wetland types according to the Cowardin classification system. Of the 7,678 EDH-derived features classified as 'Lake/pond' or 'Reservoir', 20.2 % that overlap draft NWI waterbodies have an IoU value of at least 0.99 when the geometries are compared. 15.4 % do not overlap draft NWI waterbodies. Of those, 16.6 % have an IoU value greater than or equal to 0.99 when compared to vegetated wetlands in the draft NWI data set. 16.1 % have an IoU value of at least 0.99 and overlap only one draft vegetated

NWI wetland; and 36.5 % of those that overlap a single vegetated wetland have an IoU value of 0.99 or greater when compared to that draft NWI feature.

The greater dissimilarity of the geometry of the buffered linear riverine features is indicative of the difficulty in assigning channel width post-EDH data creation. The differences in how EDH linear features are categorized and either subdivided or combined relative to NWI classification and digitization of riverine features also makes geometric comparisons challenging. There are instances where buffered EDH-derived linear features produced two adjacent features with two different attributes; for example, a ditch (R2UBHx) connected to a stream or river (R2UBH). In the draft NWI data set the photo-interpreter had merged the two features together creating, say, one larger riverine feature classified as R2UBH. Even if the photo-interpreter did very little or no manual editing of the boundary of the individual EDH-derived features simply merging them together results in a great dissimilarity in the geometry of the resulting draft NWI riverine feature and the original EDH-derived ditch and stream feature(s). While only 0.3 and 16 % of EDH-derived riverine features (R2UBH and R2UBHx combined) have an IoU value greater than or equal to 0.99 and 0.50, respectively, when compared to draft NWI waterbodies, 51 and 84 % overlap draft NWI waterbodies by 99 and 50 %, respectively. It is difficult to determine how many of these were simply merged with adjacent waterbodies and how many have a high proportion of overlap yet very different geometry without extensive manual review requiring time that this project cannot allow. Only 2 % of those with 99 % or more overlap intersect two or fewer draft NWI waterbodies. Almost 11 % have at least 50% overlap with two or fewer NWI waterbodies. Just over 9 % also overlap with only riverine features in the draft NWI data.

The mean IoU value when comparing the EDH-derived riverine features to draft NWI riverine features on a per-feature basis is 0.19. When all EDH-derived riverine polygons are dissolved into a single multipart feature and all draft NWI rivers are likewise dissolved, comparing the results produces an IoU of 0.65. The more favorable geometric comparison of dissolved features than individual features, and the fact that there are 65% fewer riverine features in the draft NWI dataset than there are in the EDH-derived dataset but only a 25% difference in area may indicate that many of the EDH-derived riverine features were merged together to create fewer but larger NWI riverine polygons, and this may have contributed to the relatively low IoU values for individual riverine polygons.

Spatially, EDH-derived features nearer the Gulf Coast had more dissimilar geometry (i.e., required more manual editing by photo-interpreters) with overlapping draft NWI waterbodies than those further inland (see Figure 6). There is also a greater density of Canal/ditches nearer the Gulf Coast. There does not appear to be any correlation between quaddish area or photo-interpreter and calculated IoU values.

Qualitative Review of Using EDH-derived Polygons

DU photo-interpreters produced 40,384 draft features within the AOI of the EDH data.

They found that linear EDH-derived features provided a noticeable advantage during the photo interpretation process. EDH-derived water bodies classified as "lake/pond”, or "reservoir" rarely required a significant amount of editing of the feature extent (see Figure 9). Occasionally, larger E1UBL features (bays, inlets) required reshaping of shorelines.

Further south in the project area, EDH-derived segments required more manual editing in comparison to other regions of the project area. The volume of wetlands is higher in this coastal region, and the landscape frequently changes with the tidal influences. Photo-interpreters collectively agreed that the presence of EDH-derived segments in the gulf coast area was advantageous, despite needing corrections. The coastal plain had a high density of ditches, which required the most edits. This was often connecting two ditches through culverts, which were missing from the EDH river polygons.

EDH-derived polygons were helpful in identifying areas where the presence of rivers was difficult to identify due to forest coverage. Some of the EDH-derived river polygons were too narrow or too wide and photo-interpreters re-drew these areas to match the rivers width in the imagery.

Most of the manual editing performed by photo-interpreters involved adding segments that were not included in the EDH-derived river polygons. Additions included short segments to connect disjointed ends to create contiguous reaches as well as entire branches and tributaries of higher-order stream features. More rarely, there were EDH-derived river polygons in areas where there was no evidence of a stream channel present, either in the DEM or imagery. In these cases, photo-interpreters deleted the river polygons. Reshaping of stream channels also occurred when the EDH-derived feature deviated from the path of the channel apparent in the imagery and terrain data.

We cannot provide a quantitative time estimate for the effort needed to produce the riverine features within the NWI v3 research study area compared to the remainder of the Texas project area. We do not have sufficient information in our tracking system to compare the time effort needed to produce riverine features using head-up photointerpretation vs. using EDH analysis. In addition, the individuals who performed most of the river delineation no longer work for DU.

Conclusion

We found that EDH-derived data were valuable for producing updated NWI data. While few features in the draft NWI data set are identical copies of the EDH-derived features, many features were able to be transferred with little manual editing of the geometry. In most cases, photo-interpreters found the EDH workflow more efficient than digitizing those features from scratch.

Pond features converted from the EDH dataset performed exceptionally well in geometric comparisons. Almost 73% of the EDH-derived features used in this project area are ponds. The utility of EDH data for creating updated NWI data may be in proportion to the quantity of small waterbodies in the project area.

The geometry of EDH-derived riverine features required more editing than EDH-derived ponds and lakes because the automatically derived channel widths were not always consistent with the imagery. It is difficult to automatically estimate the buffer width of EDH linear features because of how EDH river networks are constructed and categorized. Single stream reaches can be divided into multiple parts to distinguish culverts from stream/river and connectors from artificial paths, making it difficult to consistently estimate their buffer width. In addition, when linear features are edited during the QC process of EDH data production, this can cause deviations in the flow path of riverine features and contribute to the difficulty in assigning channel width based on drainage area calculated using the original DEM.

Experience has indicated that the inclusion of a drainage-routed catchment area size attribute, like that of the "Value Added Attributes" of the NHD Plus database, may improve the conversion of linear features to riverine polygons when using a drainage area-based buffer width. Additionally, more work can be done to identify and correct segments that were assigned a width that is below the threshold for inclusion in the NWI dataset but is adjacent to upstream and downstream segments that meet the standard for inclusion as a riverine polygon to prevent instances where the connecting linear feature is not converted to a polygon and a gap is created in the resulting riverine polygonal feature.

Artificial features like ditches and canals are an additional challenge to converting linear geometry to polygonal geometry. In this project area, a single minimum width for artificial features was used. The more variation in channel width among artificial features that exists in the project area, the more difficult it can be to convert these linear features to polygons with horizontal accuracy.

EDH-derived polygons and rivers were helpful in Texas because the elevation and imagery data were acquired in the same year (2022). Wetlands and rivers are dynamic systems, but EDH and NWI are static snapshots of those systems standardized to elevation data or imagery, respectively, at a specific point in time. NWI producers will be less successful at incorporating EDH features into the NWI data-production process when change has occurred on the landscape between the acquisition date of the elevation and imagery data. This is especially true in more dynamic systems, like coastal or tidally influenced areas and braided alluvial systems. Areas of rapid development with increased ditching and/or retention pool installation will also make the date-alignment of reference data more important.

List of Figures

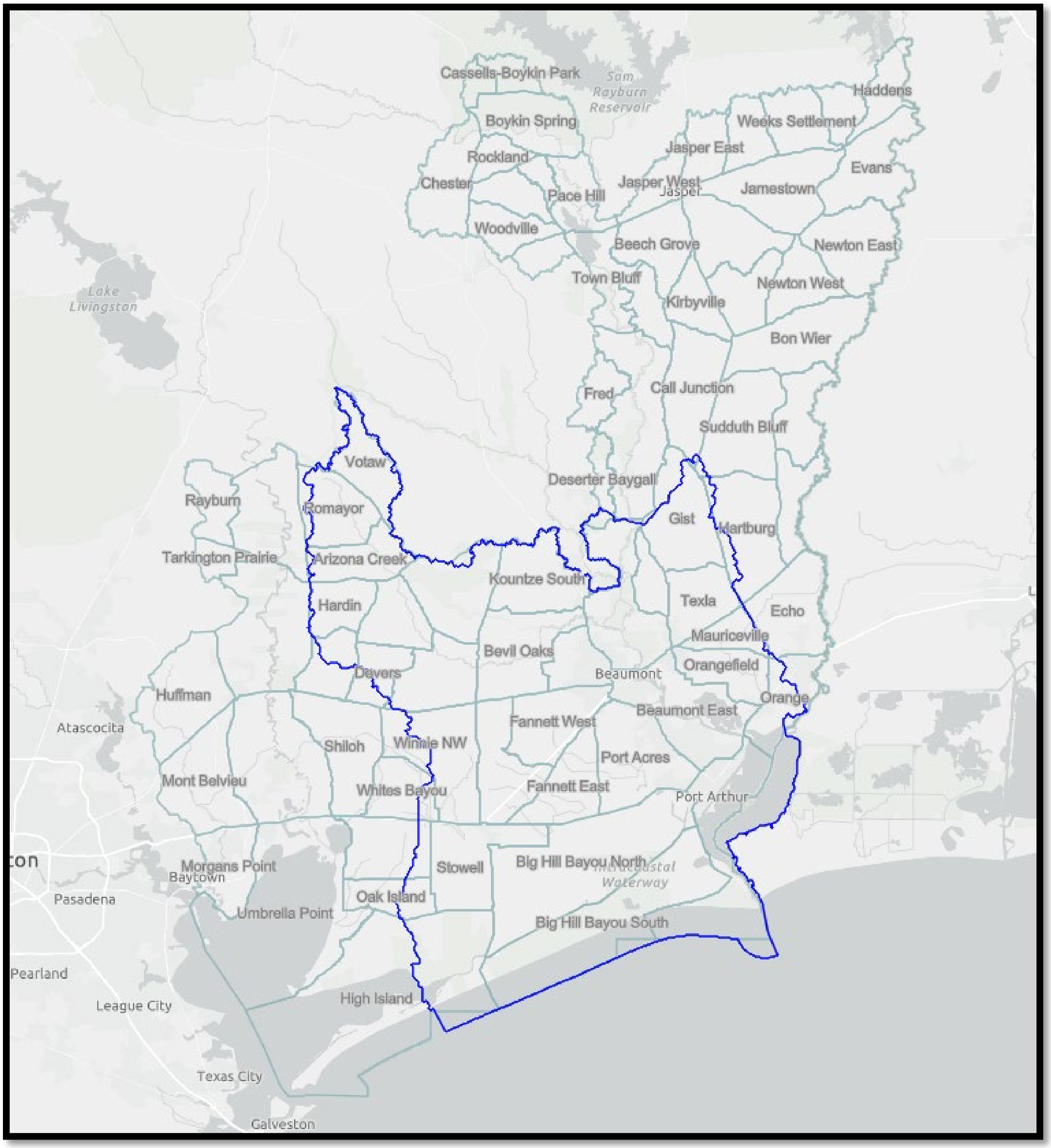


Figure 2. The quaddish areas used in the Texas Coastal NWI project. The area outlined in blue denotes the EDH area of interest.

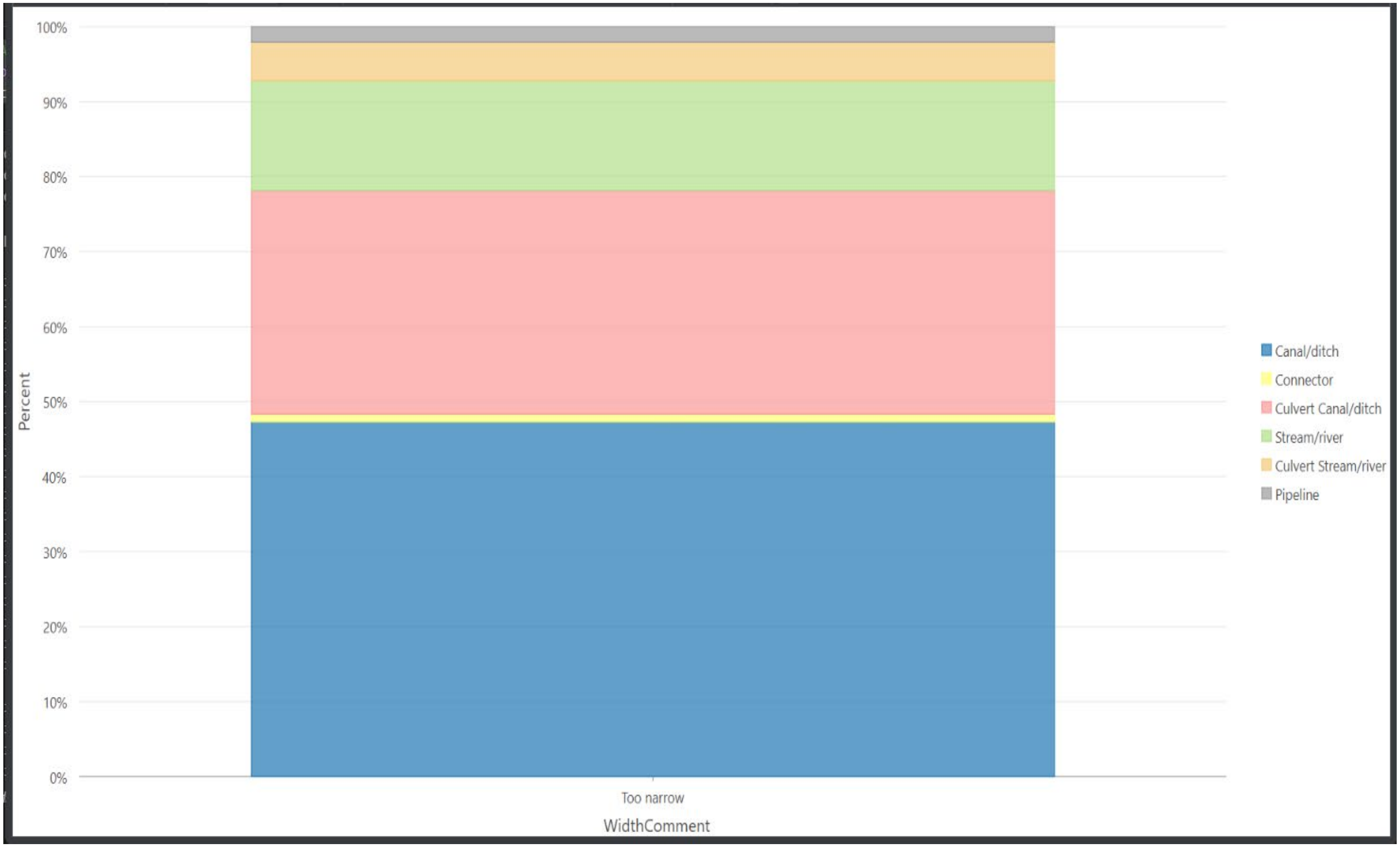


Figure 3. A manual review of a subset of programmatically assigned half-widths to EDH lines based on drainage area found that a large majority of those deemed too narrow were human-made features like canal, ditches, and culverts. Approximately 15% were classified in the EDH dataset as "Stream/river".

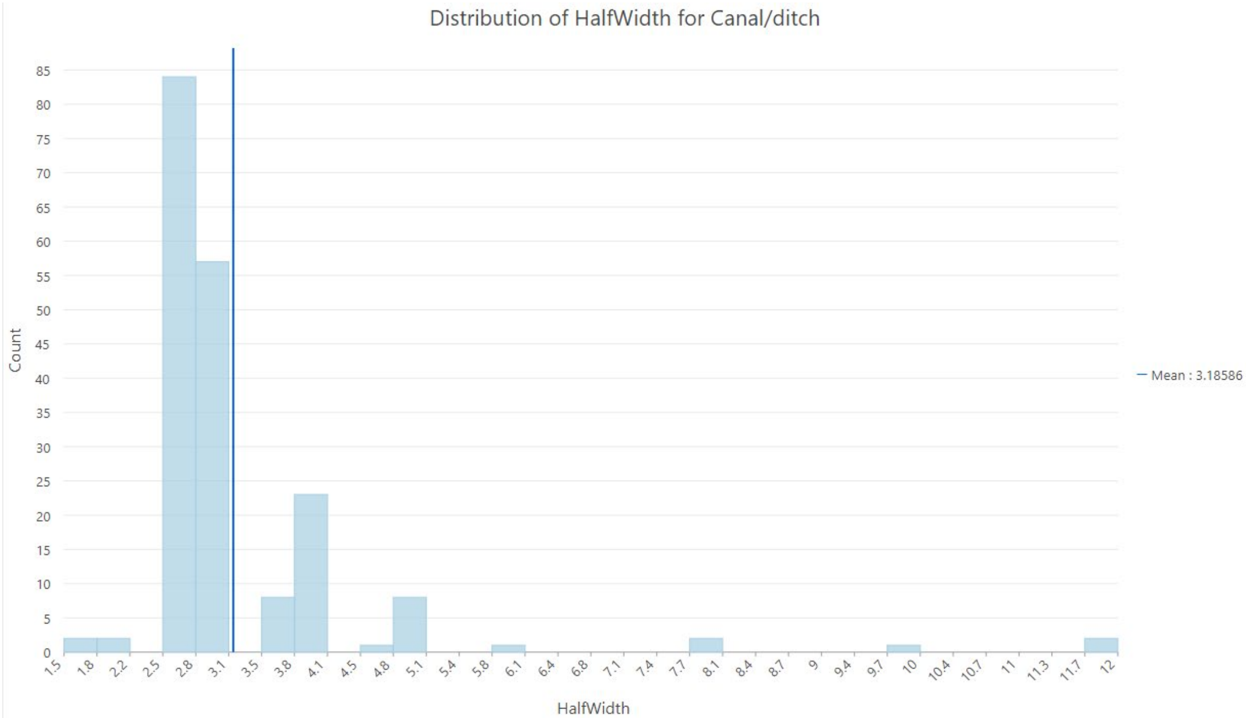


Figure 4. During manual review of calculated EDH line width based on drainage area, the width of the corresponding feature observed in aerial imagery was measured and the "Halfwidth" was assigned to the EDH feature. The majority of "Canal/ditch" type EDH features were assigned a HalfWidth between 2.5 and 3.1 meters with a mean of 3.19.

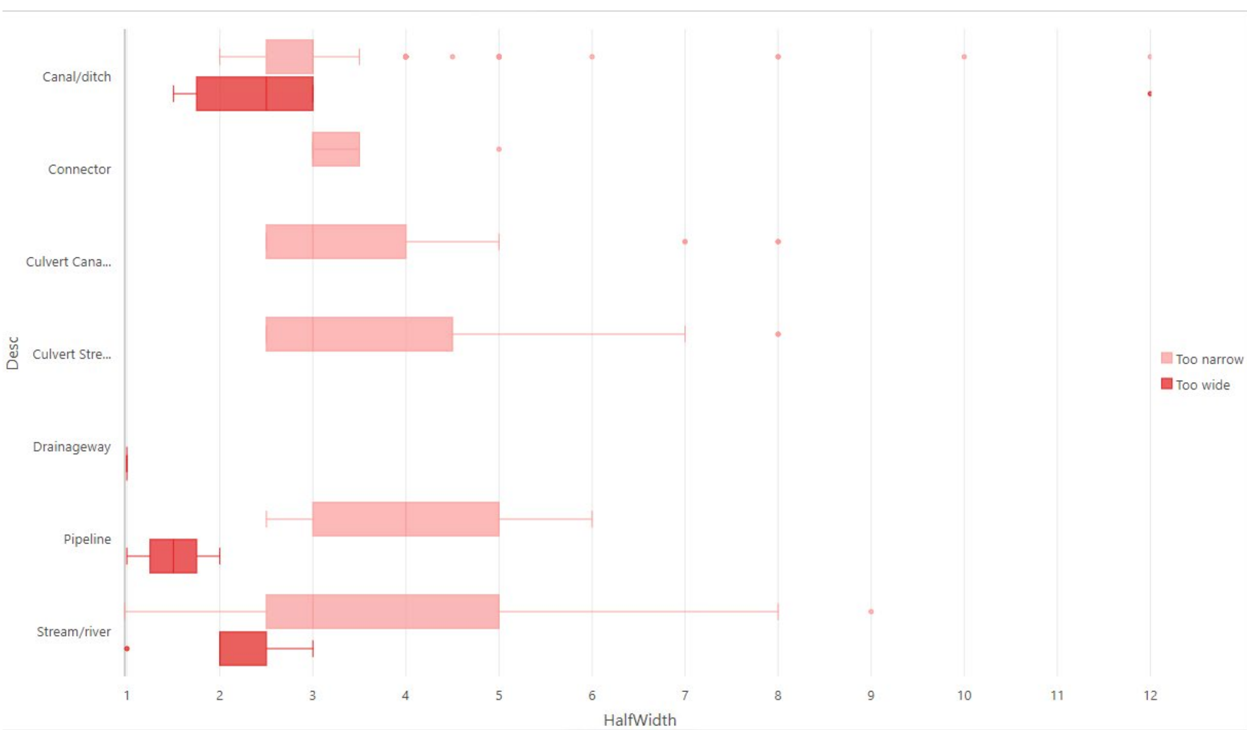


Figure 5. The manually assigned "Halfwidth" of EDH line features during review varied among type and whether the programmatically calculated width was determined to be too narrow or too wide. Culverts and Connectors were only too narrow – possibly an artifact of the EDH dataset production process where these are manually distinguished from neighboring Stream/river features during editing causing a disconnect between their path and their drainage area as represented in the DEM from which they were originally derived. The range of measured HalfWidth values of Stream/river features with poorly estimated widths is too great to correct programmatically and would be fixed during photointerpretation. Misrepresented Canal/ditch type features have a more constrained range in HalfWidth values with a median

of approximately 2.65 meters for those estimated to be too wide and 3 meters for those too narrow. Pipelines are generally not included in tne NWI dataset.

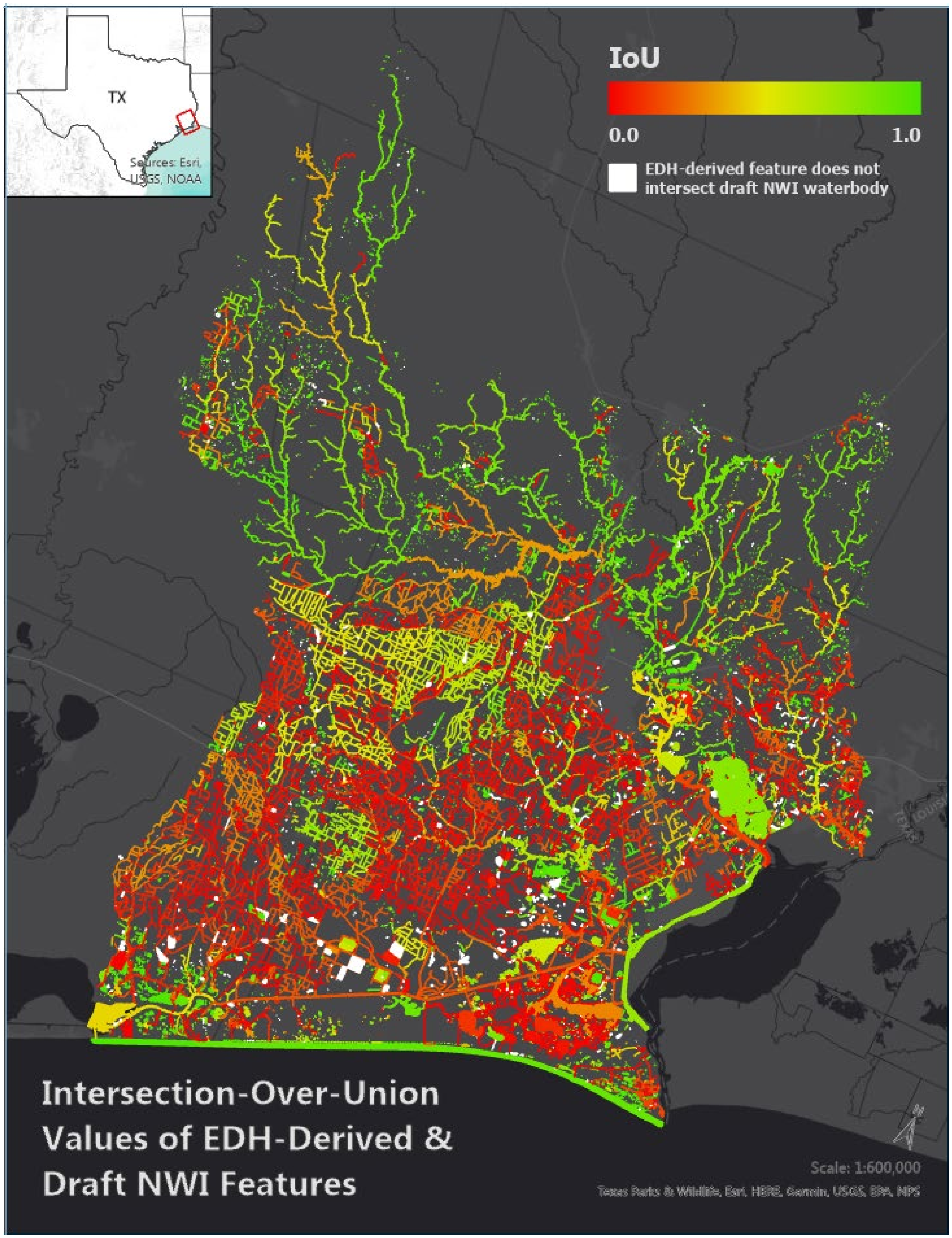


Figure 6. Map showing the spatial distribution of Intersection of Union (IoU) values of EDH-derived features compared to waterbodies in the draft NWI dataset.

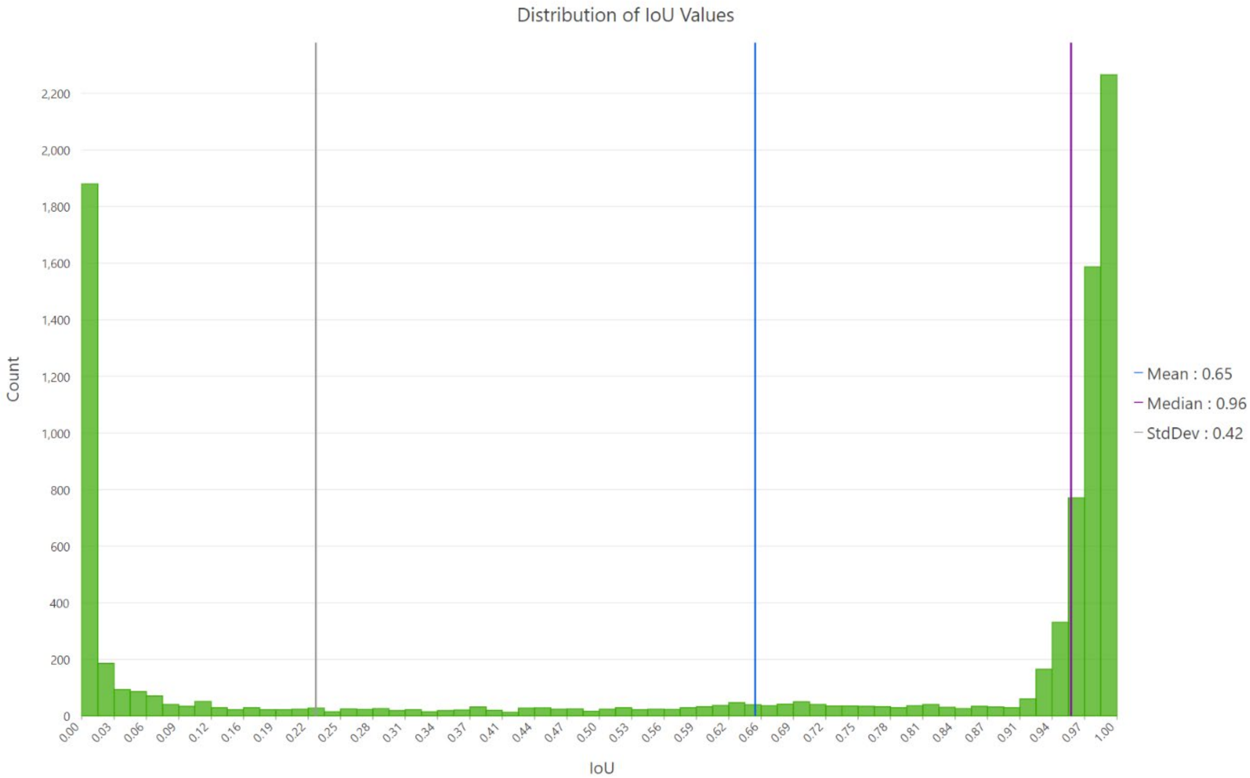


Figure 7. Histogram of Intersection-over-Union values (IoU) of EDH-derived features with a mean of 0.65, median of 0.96, and standard deviation of 0.42. Note: EDH-derived features that do not intersect draft NWI waterbodies are not included.

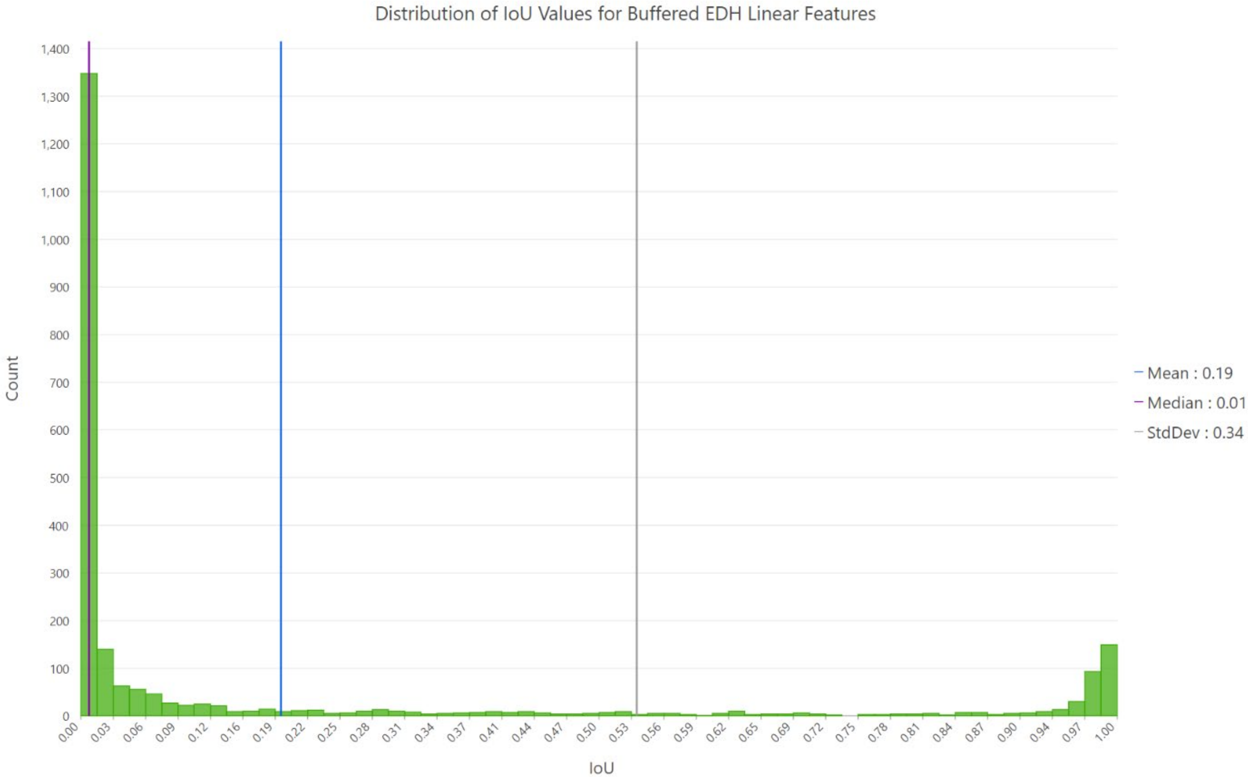


Figure 8. Histogram of Intersection-Over-Union (IoU) values for EDH line features (i.e., excludes EDH waterbody polygons). The mean IoU value for buffered linear features is 0.19, the median is 0.01, and the standard deviation is 0.34. Note: EDH-derived features that do not intersect draft NWI waterbodies are not included.

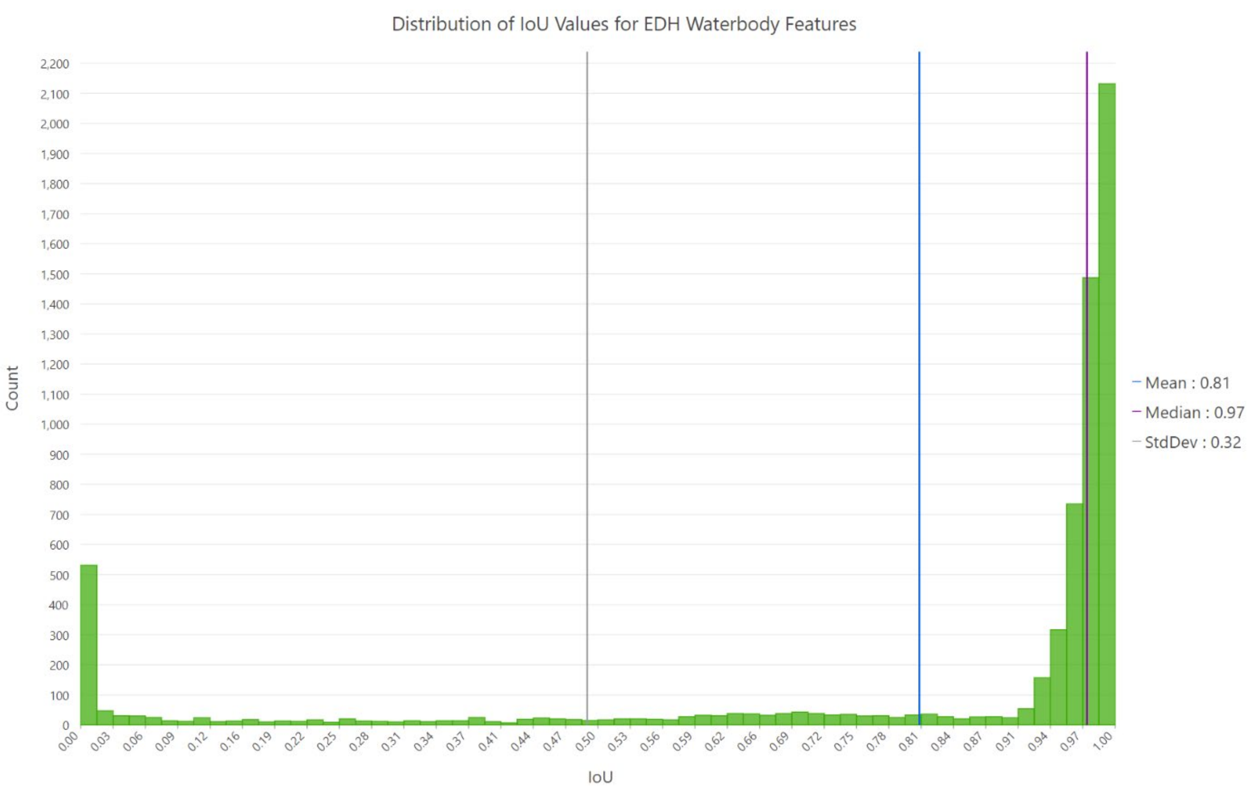


Figure 9. Histogram of Intersection-Over-Union (IoU) values for EDH waterbody polygons. The mean IoU value for non-linear features is 0.81, the median is 0.97, and the standard deviation is 0.32. Note: EDH-derived features that do not intersect draft NWI waterbodies are not included.

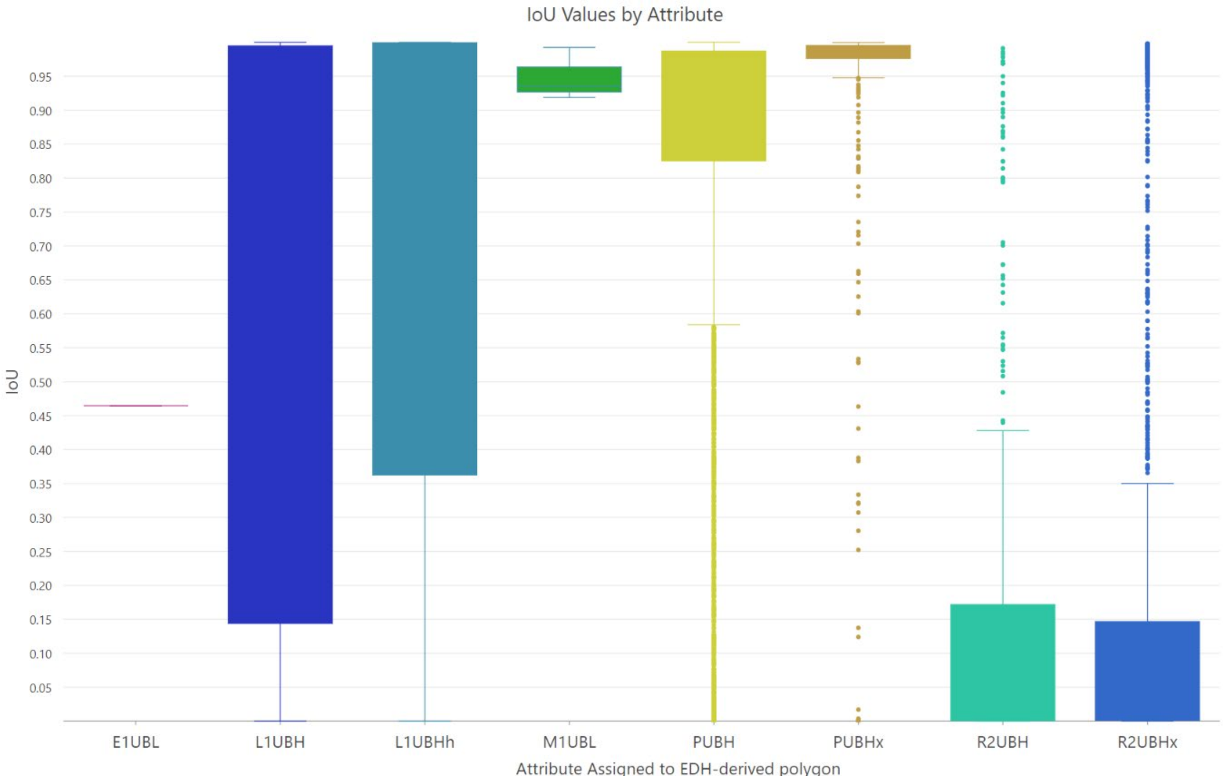


Figure 10. Distribution of Intersection-Over-Union (IoU) values comparing the geometry of EDH-derived features against waterbodies in the draft NWI dataset categorized by Cowardin attribute assigned to the EDH-derived features. The geometry of EDH features classified as ponds have greater similarity with draft NWI waterbodies than other types. PUBHx features have a median IoU value of 0.99. Riverine feauters have the least similarity with overlapping NWI waterbodies with a median value of 0.01.

Appendix B: Texas Field Report

Texas Field Report for the National Wetlands Inventory

1. **Dates:** October 17th – October 20th, 2022

2. **Areas visited in the field**: We visited points throughout the NWI update area in the southeast of Texas. The study area extends southwest through Galveston Island, northwest to outside Cleveland, northeast to the southern end of the Toledo Bend Reservoir, and southeast to the Texas Point National Wildlife Refuge on the Texas-Louisiana border.

   We also visited federally protected lands, including Anahuac National Wildlife Refuge, McFaddin National Wildlife Refuge, and Big Thicket National Preserve.

3. **Purpose of trip**: This trip was in preparation for an update the National Wetlands Inventory to be performed by Ducks Unlimited staff. Prior to field work, we identified wetlands of interest based on the imagery and old NWI. We assessed the wetlands visited in the field for the species composition and wetland type. The data points collected will be used to support the planned NWI update by providing field-verified training data for both supervised and unsupervised classification. The fieldwork also gave NWI interpreters experience and context to the wetland species of the region.

4. **Personnel**:
   - Mathew Halliday, DU
   - Evelyn Magner, DU
   - Alice Colville, DU
   - Erika Dodge, DU
   - Gary Hunt, USFWS

5. **Field Conditions:**

   Conditions were favorable for field work. Monday, October 17th was overcast, with the remaining days of the week partly cloudy or sunny. High temperatures were in the upper-60s/low-70s, with morning lows in the 40s, which is about 10 degrees below normal. According to the NOAA NOWData of Beaumont, temperatures so far in 2022 and so far in October were close to average, though precipitation is twenty inches below average.

   All the study region was in drought conditions at the time of visit. According to U.S. Drought Monitor conditions as of October 18th, 70% of the study area was categorized as D0 (abnormally dry), 27% categorized as D1 (moderate drought), and 3% as D2 (severe drought). The severe drought occurred in coastal regions in Chambers and Galveston Counties, including all of Galveston Island (NDMC, USDA, & NOAA, 2022).

The drought conditions during the date the NAIP imagery was flown on June 16th, 2020, was less severe, with 68% of the study area categorized as D0 (abnormally dry), and the remaining 32% with no drought conditions.

6. **Summary of findings**: There were two broad types of wetlands visited: palustrine and estuarine. The first site visited was on Galveston Island. This site was an emergent estuarine wetland and contained salt-tolerant emergent species, such as *Salicornia bigelovii*, *Borrichia frutescens*, and *Distichlis spicata*. We observed some shrubby *Avicennia germinans* at this site, but it was mostly dead.

   We visited the Anahuac National Wildlife Refuge, which was a managed wetland with palustrine emergent vegetation and open water. There were large stands of *Typha spp.* and invasive *Phragmites australis*. North of the refuge, we visited a wetland thick with invasive *Pontederia crassipes*.

   We visited the McFaddin National Wildlife Refuge which had estuarine sites. There was evidence of prescribed burns throughout the refuge, with the newly burned areas colonized by *Borrichia frutescens*. Other areas of the preserve, which were likely flooded by brackish water, had *Phragmites* stands and stands of what was likely *Typha domingensis*, which has a higher salt tolerance than other species of *Typha*. We also observed large stands of dead *Sesbania drummondii* in standing water.

   We visited a floodplain palustrine forest which had deciduous tree species such as *Quercus michauxii* and *Liquidambar styraciflua*. This wetland had a low area with *Nyssa sylvatica* and *Taxodium distichum* which, despite signs of prior saturation, was dry.

   We traveled to the BA Steinhagen Reservoir in the northern portion of the study area. The coast of this palustrine reservoir had stands of *Nyssa sylvatica* and *Taxodium distichum*. We observed thick masses of invasive *Salvinia molesta* in these coastal areas, a floating aquatic vegetation not detected in the prior NWI. According to the USGS, *Salvinia molesta* was first established in the Steinhagen Reservoir in 2007. Other floating aquatic vegetation included *Nymphaea odorata* and *Nelumbo lutea*.

   We visited the Big Thicket National Preserve which, through was outside of our study area, had some interesting wetland types, including a large mature *Taxodium distichum* swamp which was dry. We also went to a unique wetland which was defined by a large *Sarracenia alata* component, as well as *Pinus palustris*, a moisture-tolerant evergreen tree not seen elsewhere in our study area. We visited a managed wetland site near Beaumont which had thick stands of emergent vegetation like *Typha spp.*, as well as *Pontederia cordata* and *Thalia dealbata*. This wetland complex also had aquatic vegetation like invasive *Salvania spp*. and *Pontederia crassipes*, as well as native *Lemna L*.

7. **Wetlands**: Due to drought conditions and the time of year, many unmanaged wetlands across the region were dry. All estuarine wetlands visited contained emergent vegetation and contained distinctly different species than the palustrine wetlands. Non-managed palustrine wetlands were mostly forested, with some drier emergent grassy wetlands along the road. Managed wetlands were flooded and contained areas of non-native species, though non-natives were common in both managed and non-managed wetlands.

8. **Uplands**: Our study area was mostly rural, with a few large cities, namely Beaumont and Port Arthur. Much of the southern region is rangeland with many browsing herds of cattle. The north of the study area is a patchwork of rangeland and forests, with some smaller areas of development. The northern region also contains pine plantations.

9. **Vegetation List:**

Scientific Name	**Common Name**
Bolboschoenus maritimus	puruagrass
Distichlis spicata	saltgrass
Salicornia bigelovii	dwarf saltwort
Borrichia frutescens	sea ox-eye, bushy seaside tansy
Lycium carolinianum	Christmas berry
Salicornia bigelovii	woody glasswort
Avicennia germinans	black mangrove
Morella cerifera	wax myrtle, bayberry
Nelumbo lutea	American lotus
Nymphaea odorata	American white water-lily
Lemna L.	duckweed
Salvinia molesta	giant salvinia
Crinum americanum	swamp lily
Thalia dealbata	alligator flag
Alternanthera philoxeroides	alligator weed
Typha latifolia	broadleaf cattail
Sagittaria lancifolia	lanceleaf arrowhead
Leersia hexandra	cogen grass (southern cut grass)
Juncus effusus	common rush
Solidago spp.	goldenrod
Pontederia crassipes	common water hyacinth
Saururus cernuus	lizard’s tail
Chasmanthium latifolium	northern seaoat
Acmella oppositifolia	oppositeleaf spotflower
Hydrocotyle spp.	pennywort
Pontederia cordata	pickerel weed

Cortaderia selloana	pampas grass
Stillingia texana	queen's delight
Sesbania drummondii	rattlebush, poisonbean
Bidens laevis	smooth beggartick
Cyperus strigosus	straw-colored flatsedge
Apocynum venetum	swordleaf dogbane
Cyperus eragrostis	tall flat sedge
Sarracenia alata	pale pitcher plant
Rhynchospora corniculata	shortbristle horned beaksedge
Phragmites australis	common reed
Salix nigra	black willow
Cephalanthus occidentalis	buttonbush
Ilex opaca	American holly
Baccharis halimifolia	groundsel tree
Ludwigia leptocarpa	anglestem primrose-willow
Sabal minor	dwarf palmetto
Triadica sebifera	Chinese tallow
Carya spp.	hickory
Quercus michauxii	swamp chestnut oak
Magnolia virginiana	sweetbay magnolia
Liquidambar styraciflua	sweetgum
Nyssa sylvatica	tupelo, blackgum
Quercus nigra	water oak
Taxodium distichum	bald cypress
Pinus palustris	longleaf pine
Pinus taeda	loblolly pine

10. Quads visited:

- Port Acres
- Beech Grove
- Stowell
- Sudduth Bluff
- Jamestown
- Big Hill Bayou
- Bancroft
- Echo
- High Island
- Pace Hill
- Orangefield
- Hartburg
- Jasper East
- Texla
- Bleakwood
- Newton West

- Fannett West
- Oak Island

Works Cited

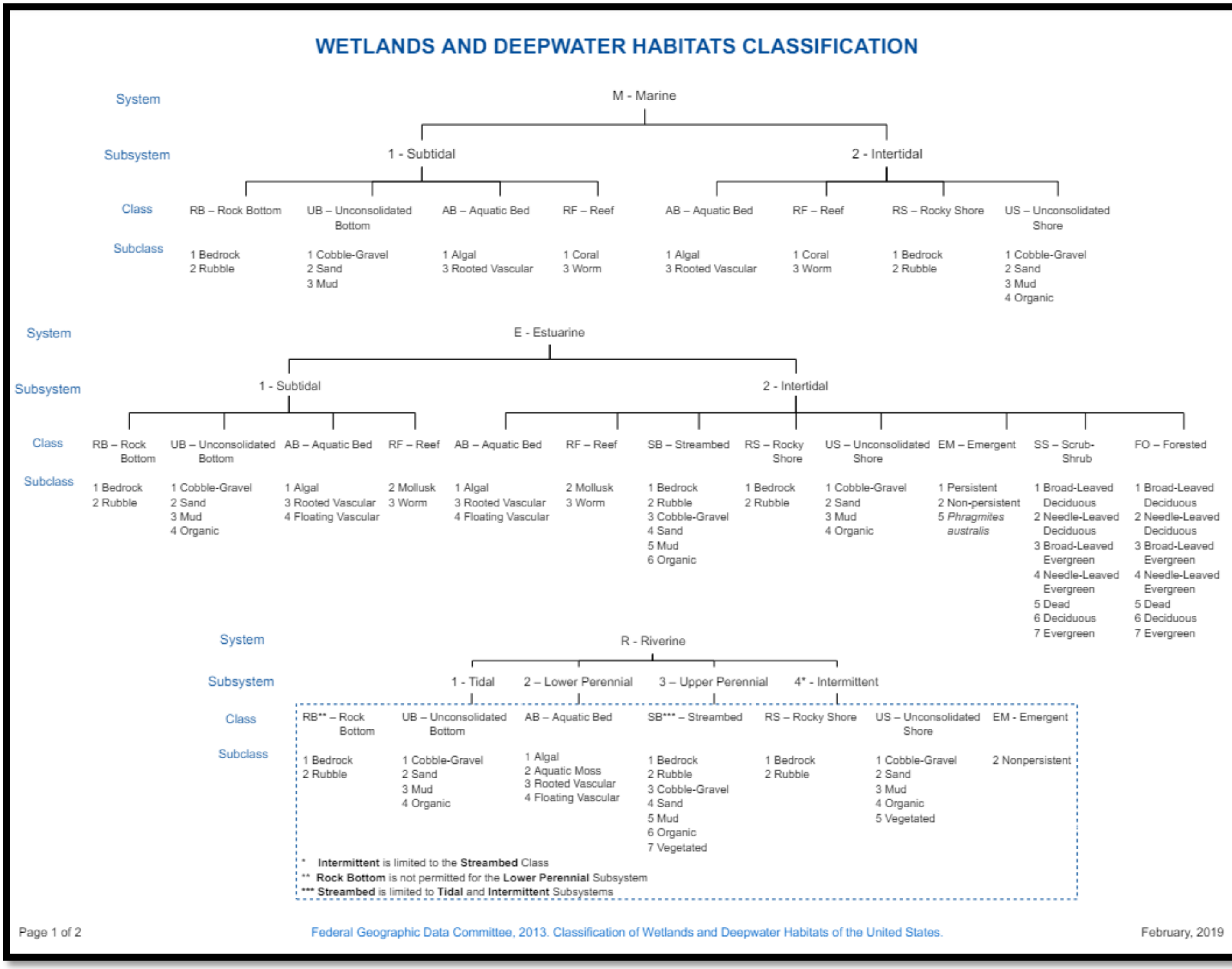
National Drought Mitigation Center, The U.S. Department of Agriculture, and The National Oceanic and Atmospheric Administration (2022). *U.S. Drought Monitor* (October 18th, 2022). [Data set]. https://droughtmonitor.unl.edu/CurrentMap.aspx

National Oceanic and Atmospheric Administration (2022). *NOWData: Monthly summarized data: Beaumont Research Ctr, TX*. [Data set]. https://www.weather.gov/wrh/Climate?wfo=lch

United States Geological Survey (2002). *Nonindigenous Aquatic Species Collection Info: Salvania molesta*. [Data set]. https://nas.er.usgs.gov/queries/CollectionInfo.aspx?SpeciesID=298

Appendix C: The Cowardin Classification Scheme

Also found at https://www.fws.gov/sites/default/files/documents/wetlands-and-deepwater-map-code-diagram.pdf



WETLANDS AND DEEPWATER HABITATS CLASSIFICATION

System: L - Lacustrine

- **Subsystem:** 1 - Limnetic
  - **Class:** RB – Rock Bottom
    - **Subclass:** 1 Bedrock, 2 Rubble
  - **Class:** UB – Unconsolidated Bottom
    - **Subclass:** 1 Cobble-Gravel, 2 Sand, 3 Mud, 4 Organic
  - **Class:** AB – Aquatic Bed
    - **Subclass:** 1 Algal, 2 Aquatic Moss, 3 Rooted Vascular, 4 Floating Vascular
- **Subsystem:** 2 - Littoral
  - **Class:** RB – Rock Bottom
    - **Subclass:** 1 Bedrock, 2 Rubble
  - **Class:** UB – Unconsolidated Bottom
    - **Subclass:** 1 Cobble-Gravel, 2 Sand, 3 Mud, 4 Organic
  - **Class:** AB – Aquatic Bed
    - **Subclass:** 1 Algal, 2 Aquatic Moss, 3 Rooted Vascular, 4 Floating Vascular
  - **Class:** RS – Rocky Shore
    - **Subclass:** 1 Bedrock, 2 Rubble
  - **Class:** US – Unconsolidated Shore
    - **Subclass:** 1 Cobble-Gravel, 2 Sand, 3 Mud, 4 Organic, 5 Vegetated
  - **Class:** EM – Emergent
    - **Subclass:** 2 Nonpersistent

System: P - Palustrine

- **Class:** RB – Rock Bottom
  - **Subclass:** 1 Bedrock, 2 Rubble
- **Class:** UB – Unconsolidated Bottom
  - **Subclass:** 1 Cobble-Gravel, 2 Sand, 3 Mud, 4 Organic
- **Class:** AB – Aquatic Bed
  - **Subclass:** 1 Algal, 2 Aquatic Moss, 3 Rooted Vascular, 4 Floating Vascular
- **Class:** US – Unconsolidated Shore
  - **Subclass:** 1 Cobble-Gravel, 2 Sand, 3 Mud, 4 Organic, 5 Vegetated
- **Class:** ML – Moss-Lichen
  - **Subclass:** 1 Moss, 2 Lichen
- **Class:** EM – Emergent
  - **Subclass:** 1 Persistent, 2 Nonpersistent, 5 *Phragmites australis*
- **Class:** SS – Scrub-Shrub
  - **Subclass:** 1 Broad-Leaved Deciduous, 2 Needle-Leaved Deciduous, 3 Broad-Leaved Evergreen, 4 Needle-Leaved Evergreen, 5 Dead, 6 Deciduous, 7 Evergreen
- **Class:** FO – Forested
  - **Subclass:** 1 Broad-Leaved Deciduous, 2 Needle-Leaved Deciduous, 3 Broad-Leaved Evergreen, 4 Needle-Leaved Evergreen, 5 Dead, 6 Deciduous, 7 Evergreen

MODIFIERS

In order to more adequately describe the wetland and deepwater habitats, one each of the water regime, water chemistry, soil, or special modifiers may be applied at the class or lower level in the hierarchy.

Water Regime			Special Modifiers	Water Chemistry		Soil
Nontidal	**Saltwater Tidal**	**Freshwater Tidal**		**Halinity/Salinity**	**pH Modifiers for Fresh Water**	
A Temporarily Flooded B Seasonally Saturated C Seasonally Flooded D Continuously Saturated E Seasonally Flooded / Saturated F Semipermanently Flooded G Intermittently Exposed H Permanently Flooded J Intermittently Flooded K Artificially Flooded	L Subtidal M Irregularly Exposed N Regularly Flooded P Irregularly Flooded	Q Regularly Flooded-Fresh Tidal R Seasonally Flooded-Fresh Tidal S Temporarily Flooded- Fresh Tidal T Semipermanently Flooded-Fresh Tidal V Permanently Flooded-Fresh Tidal	b Beaver d Partly Drained/Ditched f Farmed m Managed h Diked/Impounded r Artificial Substrate s Spoil x Excavated	1 Hyperhaline / Hypersaline 2 Euhaline / Eusaline 3 Mixohaline / M ixosaline (Brackish) 4 Polyhaline 5 Mesohaline 6 Oligohaline 0 Fresh	a Acid t Circumneutral i Alkaline	g Organic n Mineral

Federal Geographic Data Committee, 2013. Classification of Wetlands and Deepwater Habitats of the United States.

February, 2019