A Satellite-Based Approach to Detecting Small Livestock and Agricultural Ponds to Monitor Change Over Time

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Learning Objectives

Identify needs and challenges to characterizing and monitoring surface water.

Understand how to use a satellite-based approach to inventory surface water bodies.

Learn how our results compare with the existing National Hydrography Dataset.

Determine small pond distributions and changes over time.

Need for Surface Water Detection and Monitoring

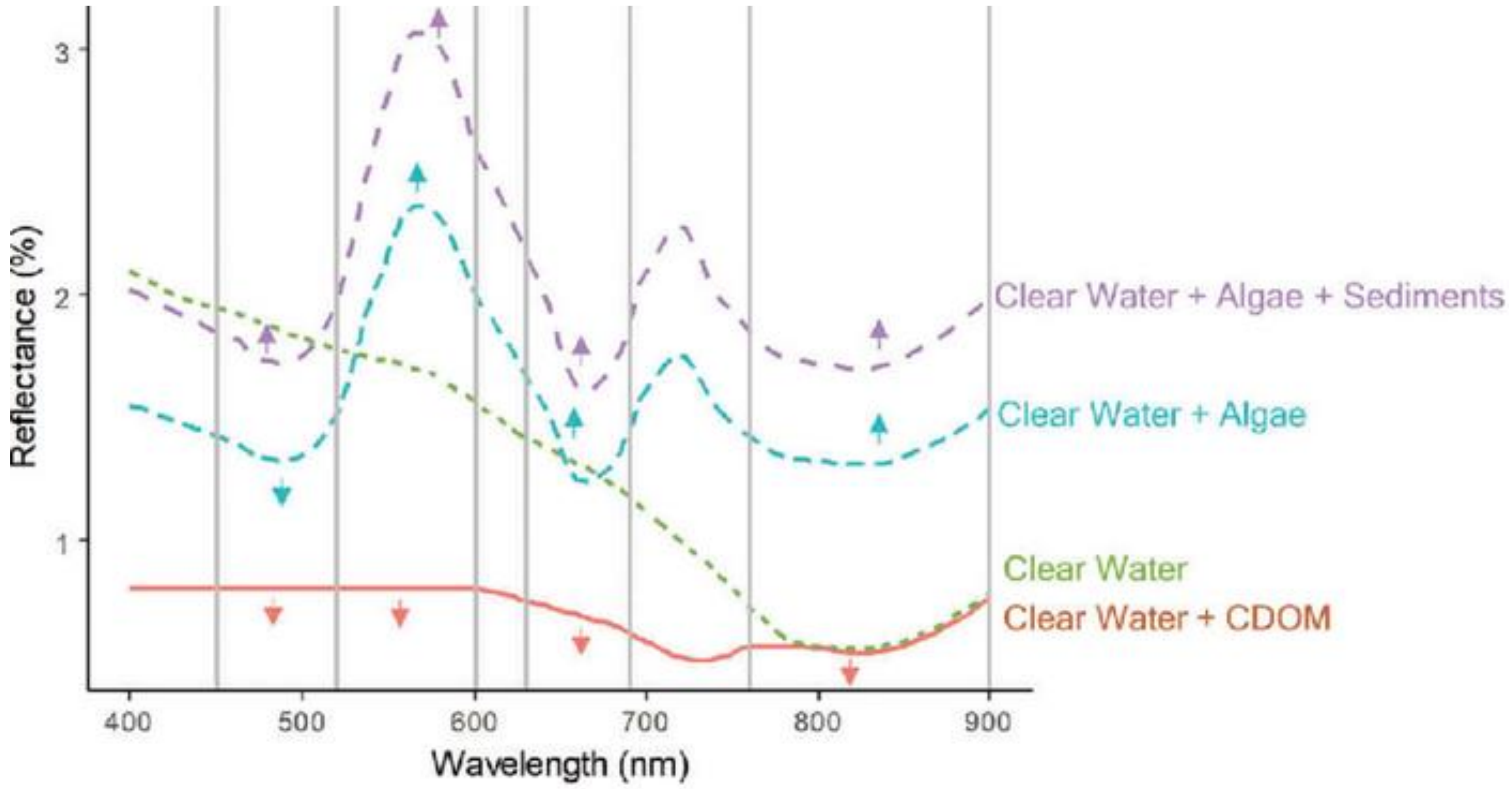
- Critical for studying hydrological and ecological processes and monitoring trajectories of change.

- Over the past 40 years, remote sensing technologies have enabled surface water mapping to be much more efficient and comprehensive compared to traditional manual methods (Bijeesh and Narasimhamurthy, 2020).

- A review of the Web of Knowledge database conducted by Huang et al. (2018) noted a steady increase in the number of studies that used remote sensing to research surface water or flood inundation
  - A three-fold to seven-fold increase in the number of studies since 2008.

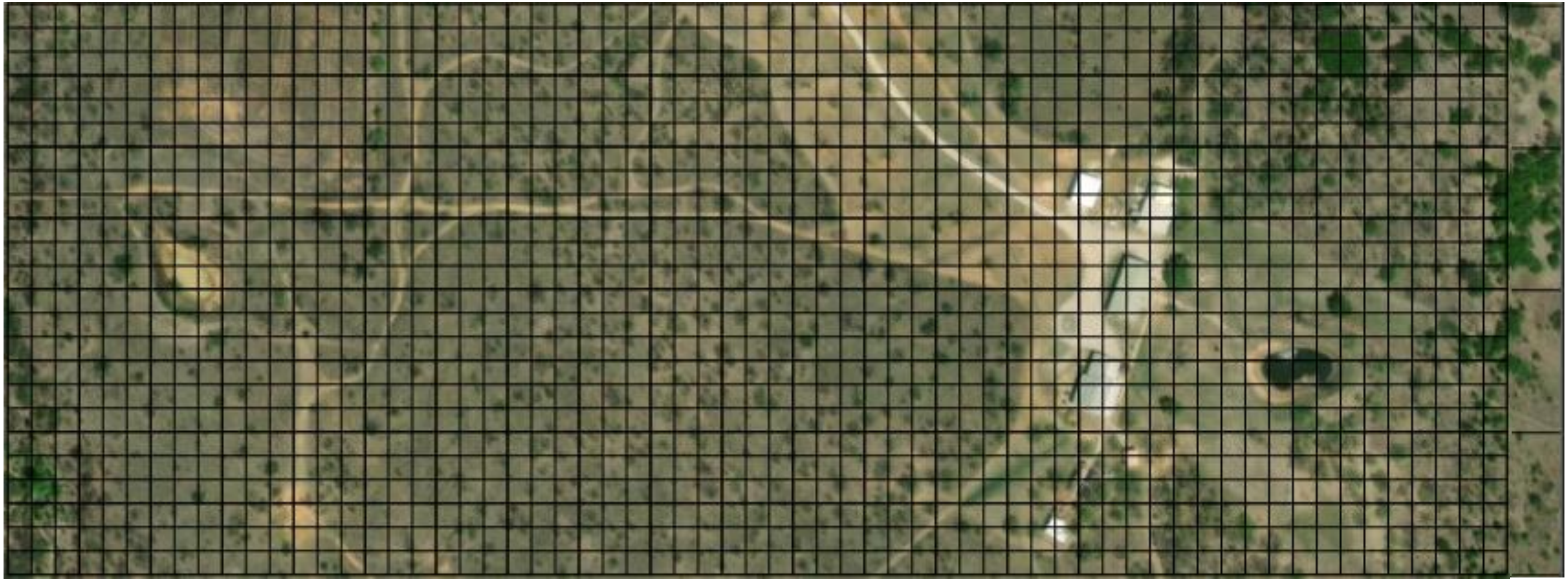
Challenges with Surface Water Detection and Monitoring

- Pure water reflects shorter wavelengths of energy (i.e., ~400 – 550 nm) and absorbs longer visible, near-infrared (NIR), and shortwave infrared (SWIR) wavelengths (i.e., ~550 nm – 2,900 nm).
- Unfortunately, pure water is the exception to the rule and many surface water bodies water columns include sediments and algae that increase turbidity and alter the basic spectral response.



Challenges with Surface Water Detection and Monitoring

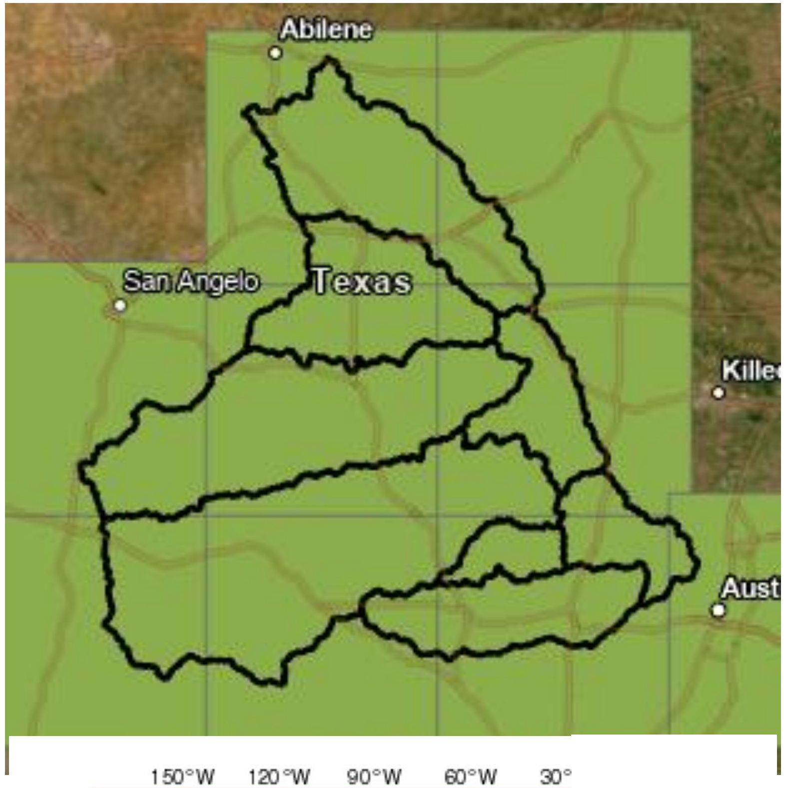
Challenges with Surface Water Detection and Monitoring

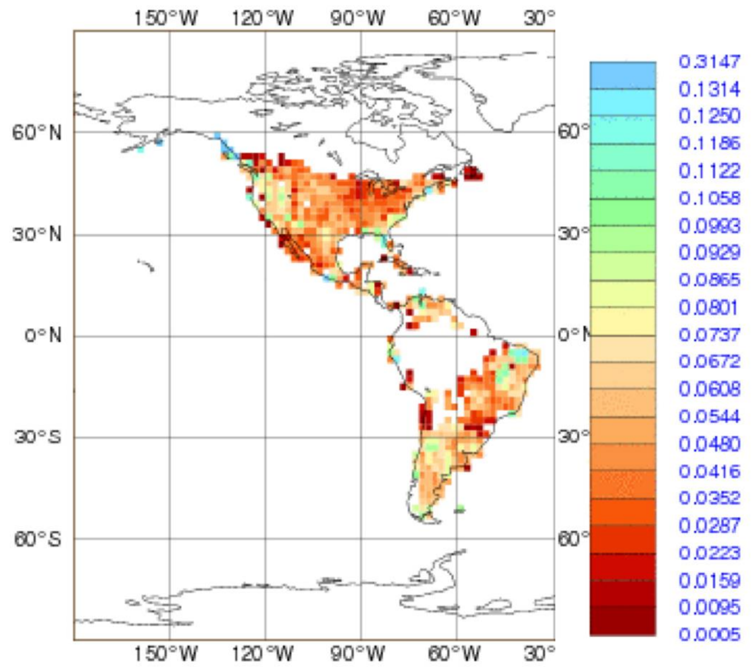


Challenges with Surface Water Detection and Monitoring

Our Study Area, Data, and Time Periods of Analysis

- Highland Lakes watershed/subwatersheds
- Sentinel-2 data (10 m RGB-NIR; 20 m SWIR)
- 10 m Digital Elevation Model to identify sinks
- Soil Moisture Active Passive (SMAP) to determine wettest periods of:
  - 2023 (March)
  - 2019 (February)
  - 2016 (December/January)





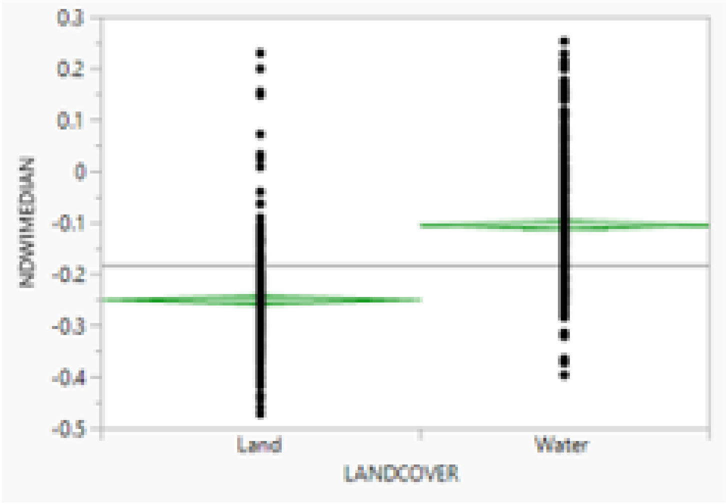
A Spectral Index-Based Approach to Inventory Surface Water Bodies

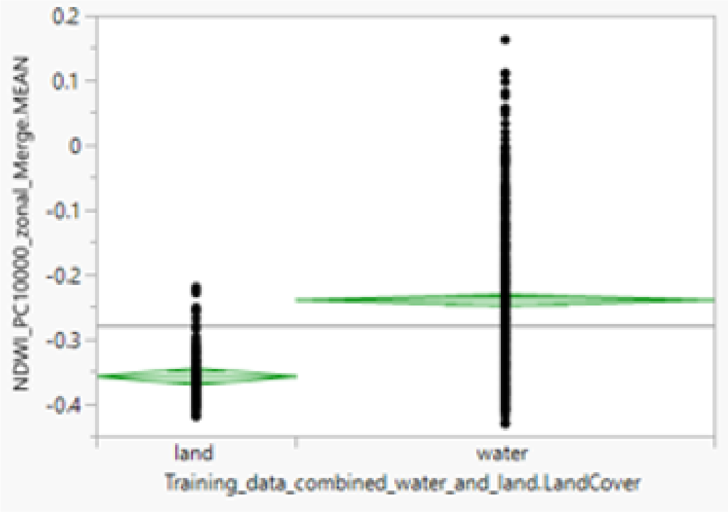
- A spectral index is a simple equation that uses the reflectance characteristics of a surface to create a new, more easily interpretable output.

Index	Equation	Reference
NDVI	$NDVI = \frac{NIR - Red}{NIR + Red}$	Rouse et al., 1974
NDWI	$NDWI = \frac{Green - NIR}{Green + NIR}$	McFeeters, 1996
MNDWI	$MNDWI = \frac{Green - SWIR}{Green + SWIR}$	Xu, 2006
WNDWI	$WNDWI = \frac{Green - \alpha \times NIR - (1-\alpha) \times SWIR}{Green + \alpha \times NIR + (1-\alpha) \times SWIR};\ \alpha \in [0,1]$	Guo et al., 2017
AWEI (Non-Shadow)	$AWEI_{nsh} = 4 \times (Green - SWIR) - (0.25 \times NIR + 2.75 \times SWIR)$	Fisher et al., 2016
AWEI (Shadow)	$AWEI_{sh} = Blue + 2.5 \times Green - 1.5 \times (NIR + SWIR) - 0.25 \times SWIR$	Fisher et al., 2016
WRI	$WRI = \frac{Green + Red}{NIR + SWIR}$	Shen and Li, 2010
NDMI	$NDMI = \frac{NIR - SWIR}{NIR + SWIR}$	Gao, 1996
EWI	$EWI_{PC} = \frac{(MNDWI - (PC1 + PC2))}{(MNDWI + (PC1 + PC2))}$	Yang and Du, 2017

Process Sentinel-2 images to classify water bodies

- Calculated 10 spectral indices and assessed for spectral separability using 399 verified water bodies and 442 verified land features.
- Determined the Normalized Difference Water Index (NDWI) provided best initial results using a -0.1 threshold.
- NDWI misclassified some land pixels as water
    - Removed 'bright' pixels identified from a PCA analysis
- NDWI + PCA misclassified some water pixels as land
    - Incorporated a 10 m DEM to identify sinks
- Removed roads, lower order streams, built-up/developed areas, very large water bodies, etc.

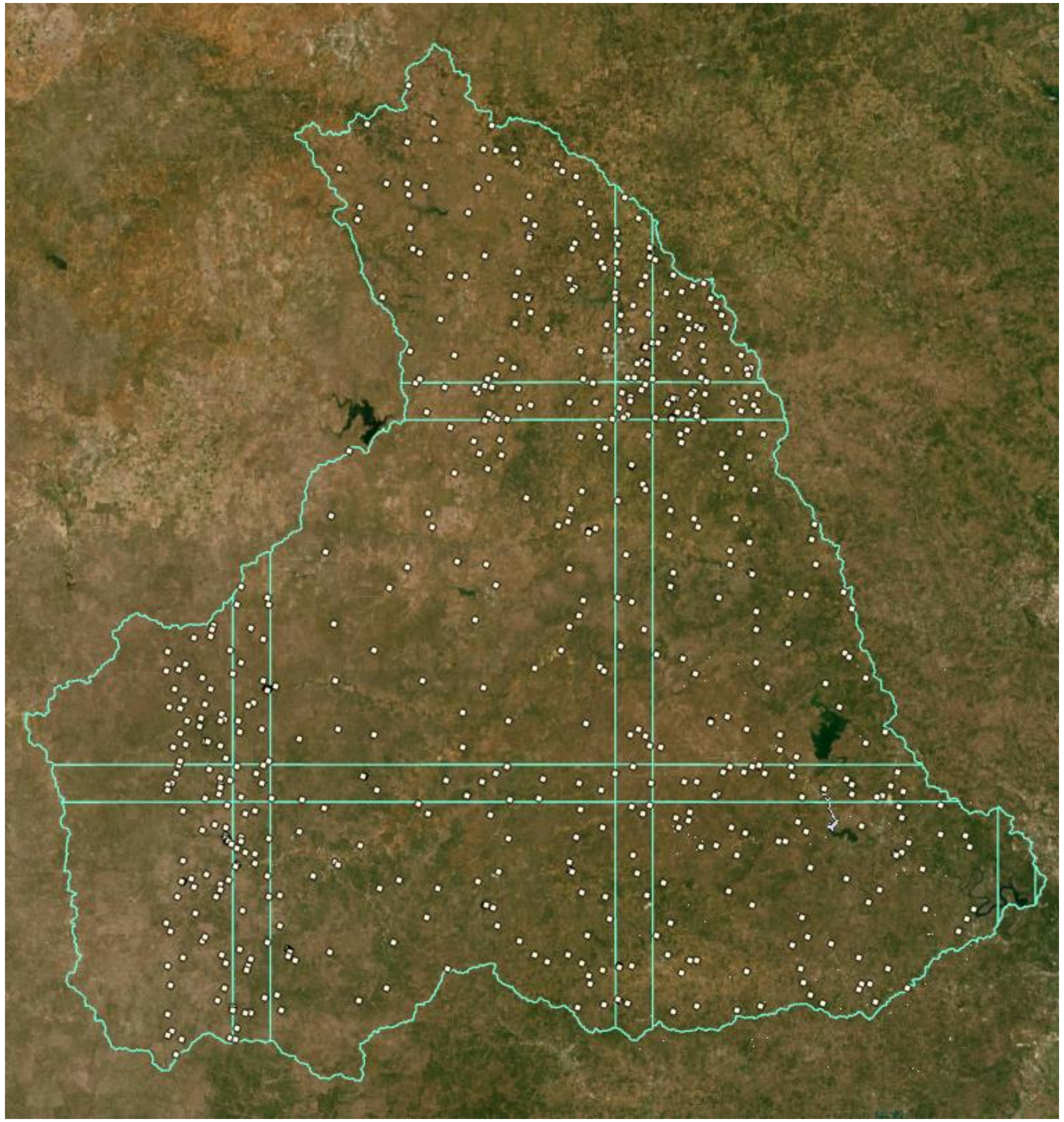




Assess classification accuracy and apply model throughout watershed

- Calculated sample size
  - Expected 95% accuracy and 5% allowable error
  - Needed minimum of 38 AA points; used 80 in a stratified random sample

- Used ArcGIS Pro base maps and Google Earth with historic imagery to conduct accuracy assessment



Assess classification accuracy and apply model throughout watershed

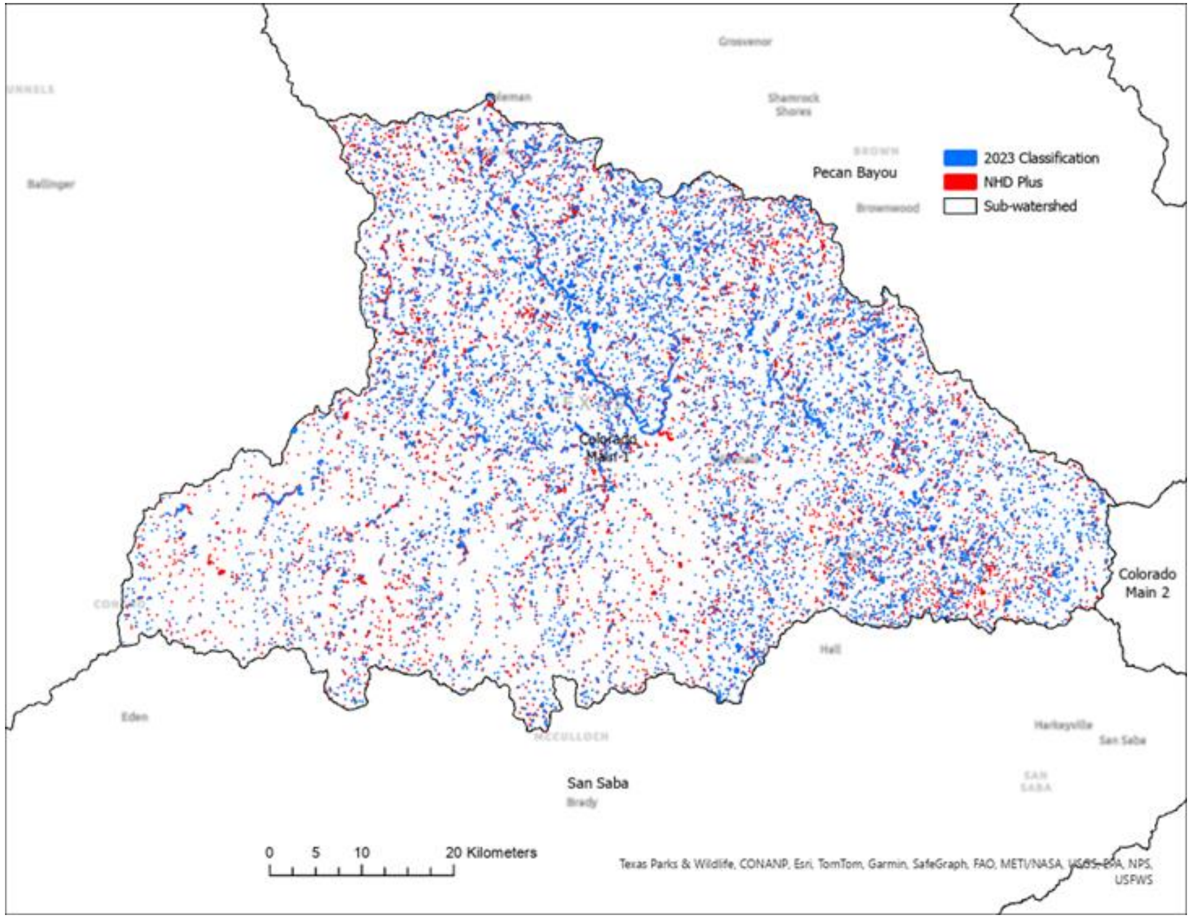
- Overall accuracies

2023: 94.8% (Kappa = 0.896)
2019: 84.5% (Kappa = 0.891)
2015: 96.7% (Kappa = 0.934)

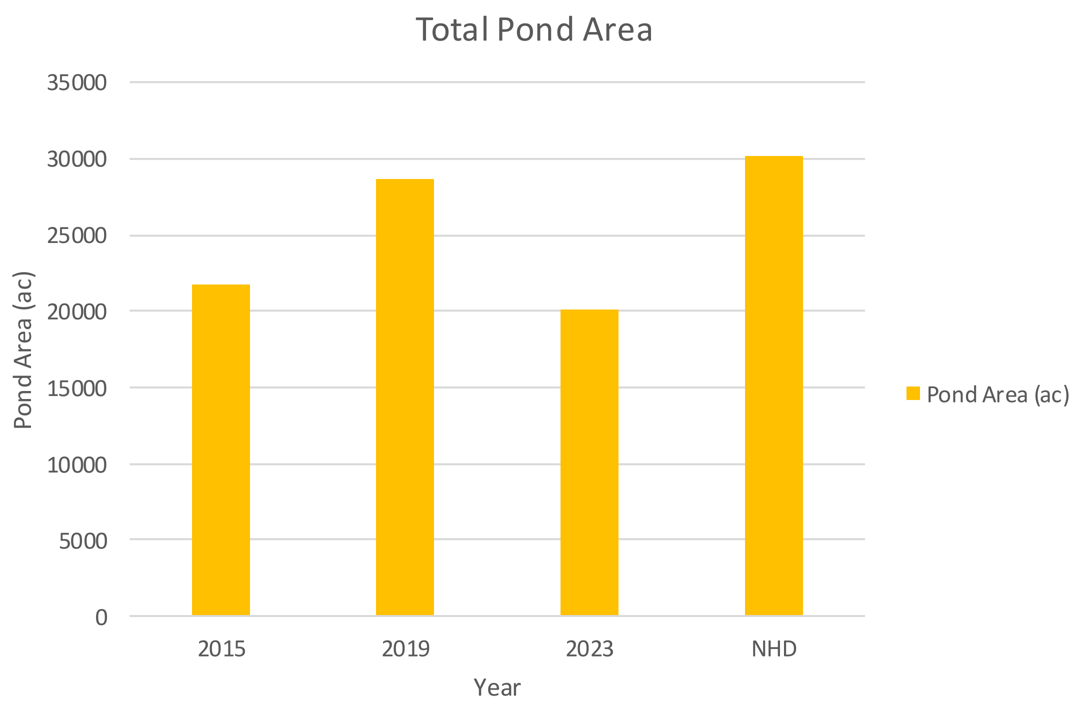
	2023			2019			2015		
Sentinel-2 Tile	Overall Acc (%)	Kappa	User Acc	Overall Acc (%)	Kappa	User Acc	Overall Acc (%)	Kappa	User Acc
T14SNA	97.5	0.95	0.95	97.5	0.95	0.98	98.8	0.98	1
T14SMA	97.5	0.95	0.98	96.3	0.93	1	97.5	0.95	0.98
T14RNV	95.0	0.90	0.93	95.0	0.90	0.98	98.8	0.98	0.98
T14RNU	95.0	0.90	0.90	93.8	0.88	0.90	96.3	0.93	0.95
T14RMV	96.3	0.93	0.93	97.5	0.95	1	96.3	0.93	0.95
T14RMU	100.0	1	1	92.5	0.85	0.90	98.8	0.98	0.98
T14RLV	96.3	0.93	0.93	**87.5**	**0.75**	**0.78**	93.8	0.88	0.93
T14RLU	93.8	0.88	0.88	96.3	0.93	0.98	93.8	0.88	0.88

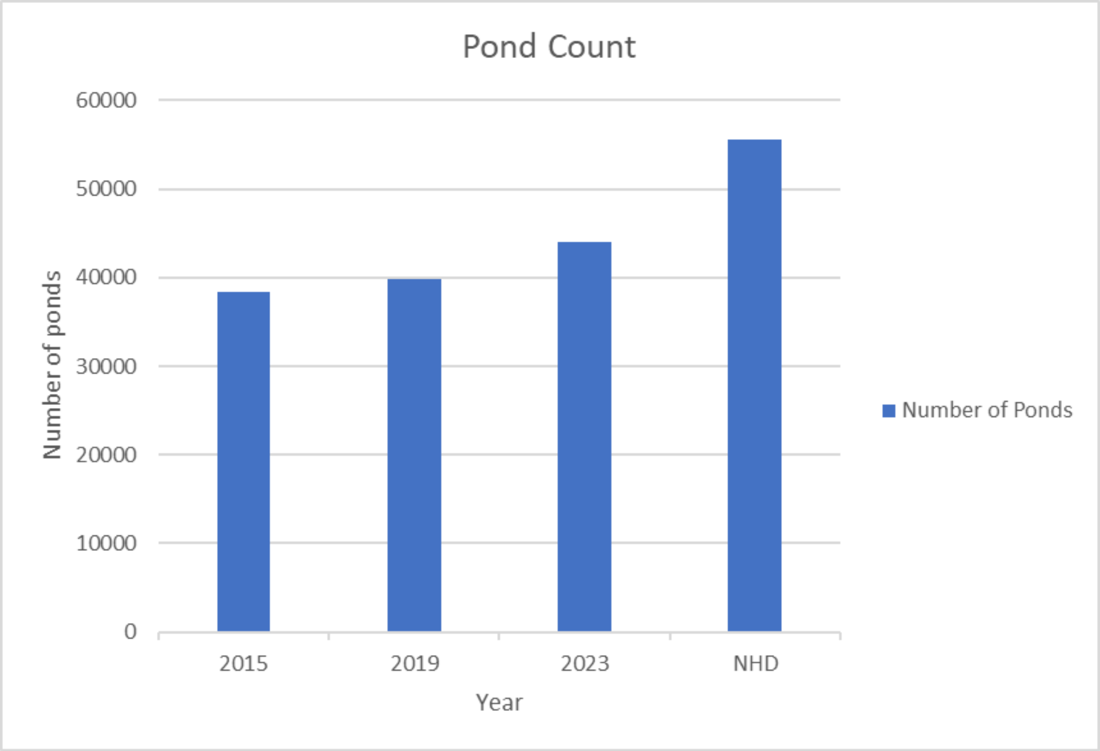
Inventory water bodies within subwatersheds, determine size distributions, and compare to NHD dataset

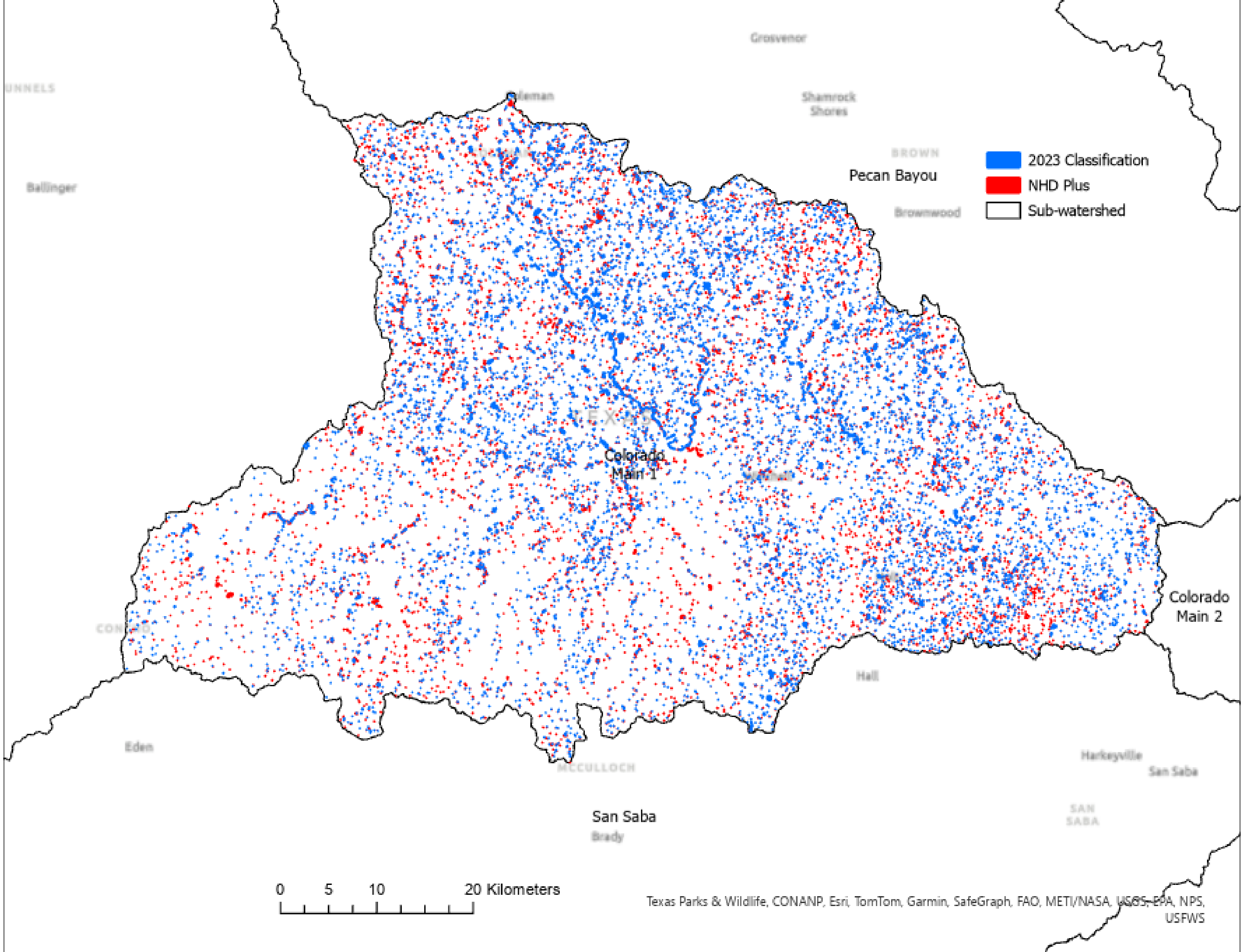
- Merged all modeled tiles and clipped by subwatershed
- Inventoried ponds
- Calculate distributions by size class in 10 bins
- Three classified years and NHD dataset
- Counts and distributions by sub-watershed



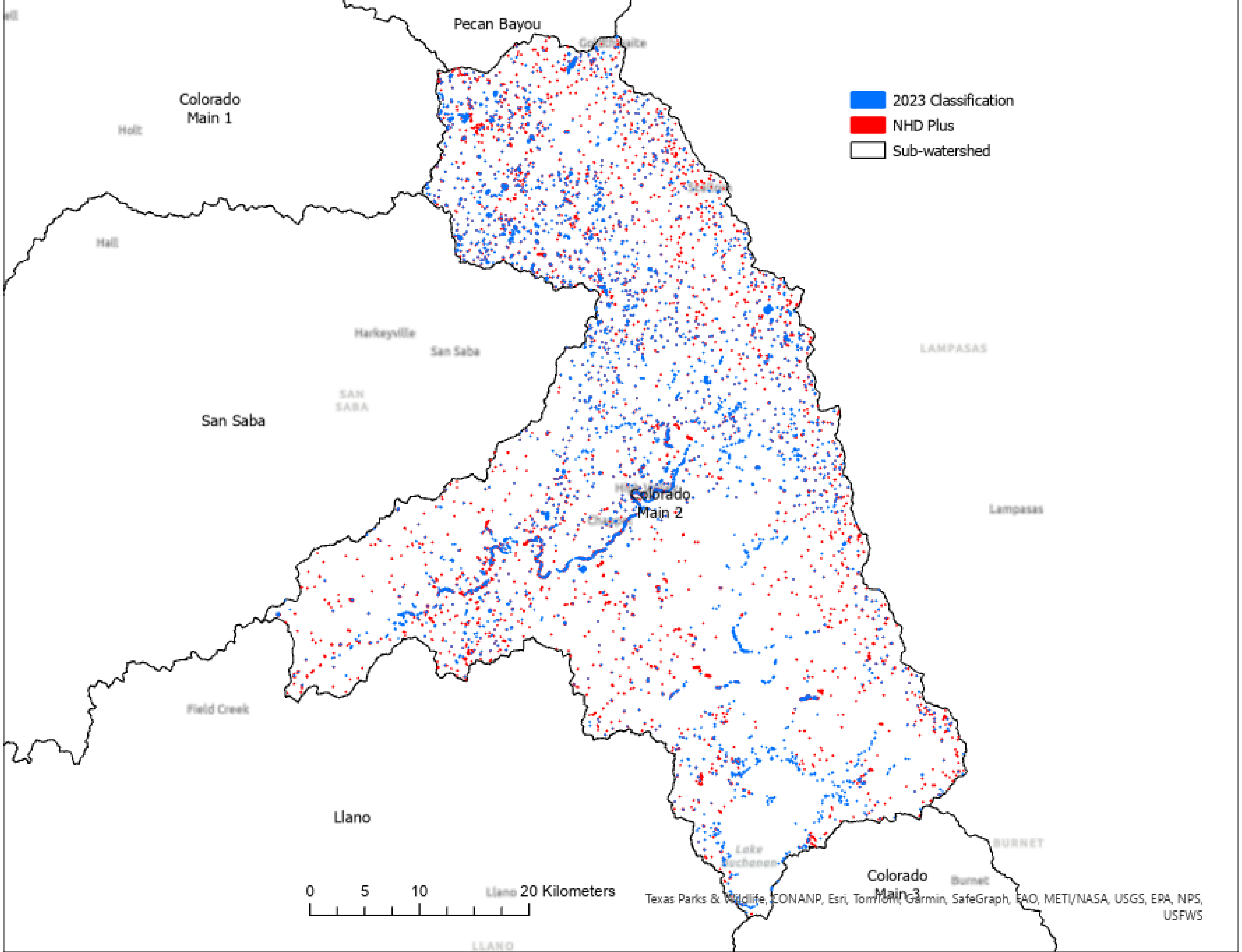
Highland Lakes Watershed Pond Area and Count December 2015 – March 2023



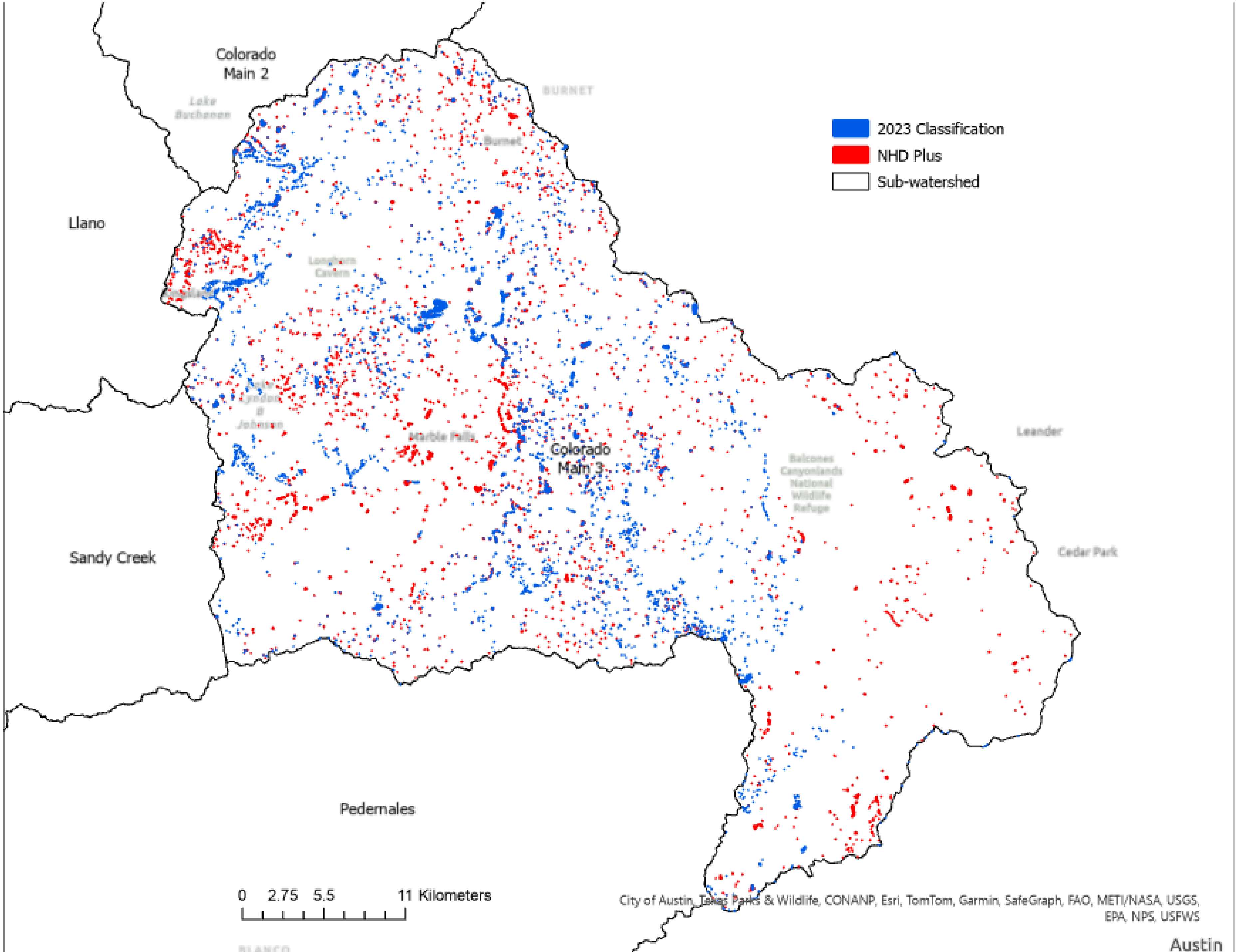


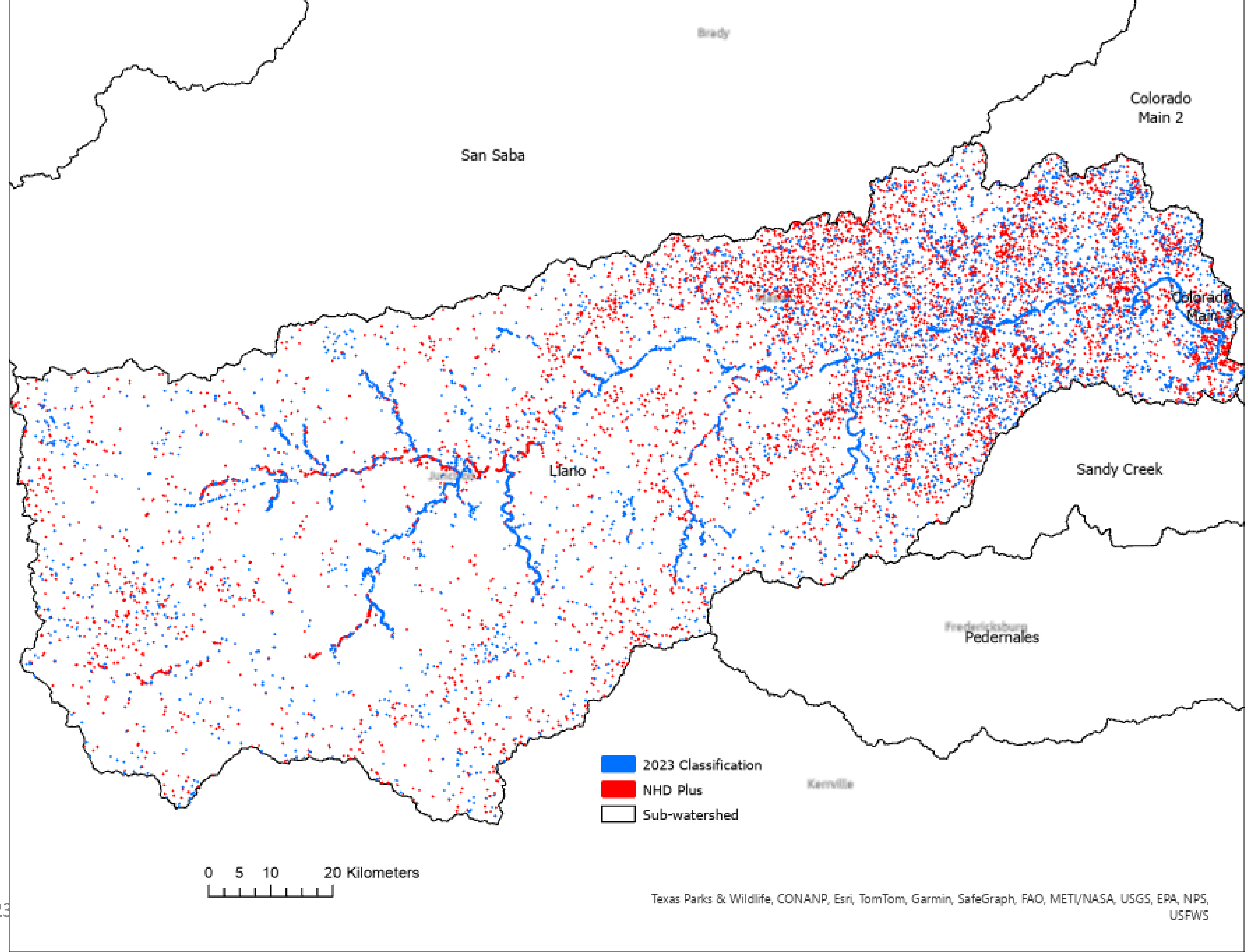


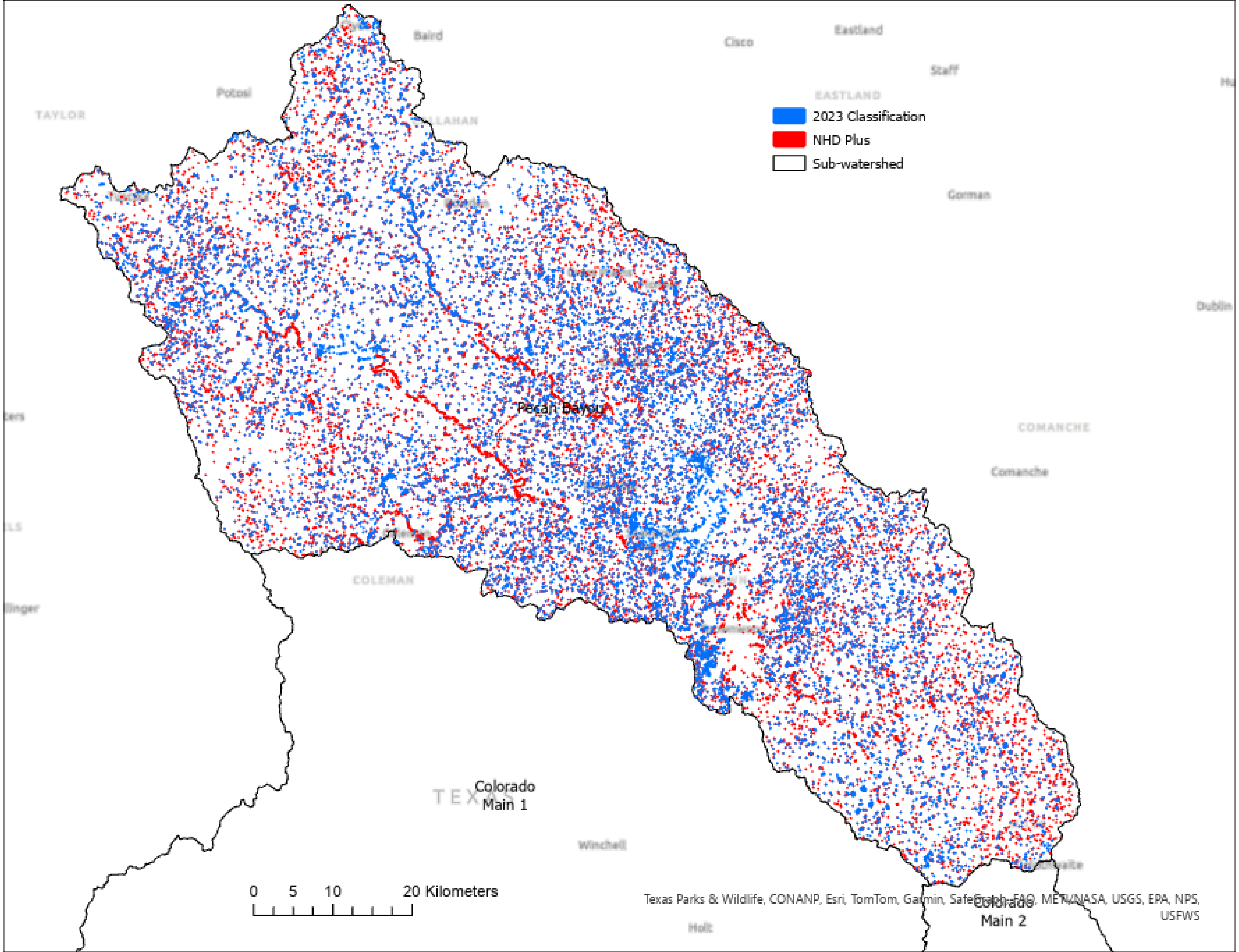
Grosvenor
Coleman
Shamrock Shores
BROWN
Pecan Bayou
2023 Classification
NHD Plus
Sub-watershed
Brownwood
Ballinger
TEXAS
Colorado Main 1
Colorado Main 2
Hall
Eden
MCCULLOCH
Harkeyville
San Saba
SAN SABA
San Saba
Brady
0 5 10 20 Kilometers
Texas Parks & Wildlife, CONANP, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

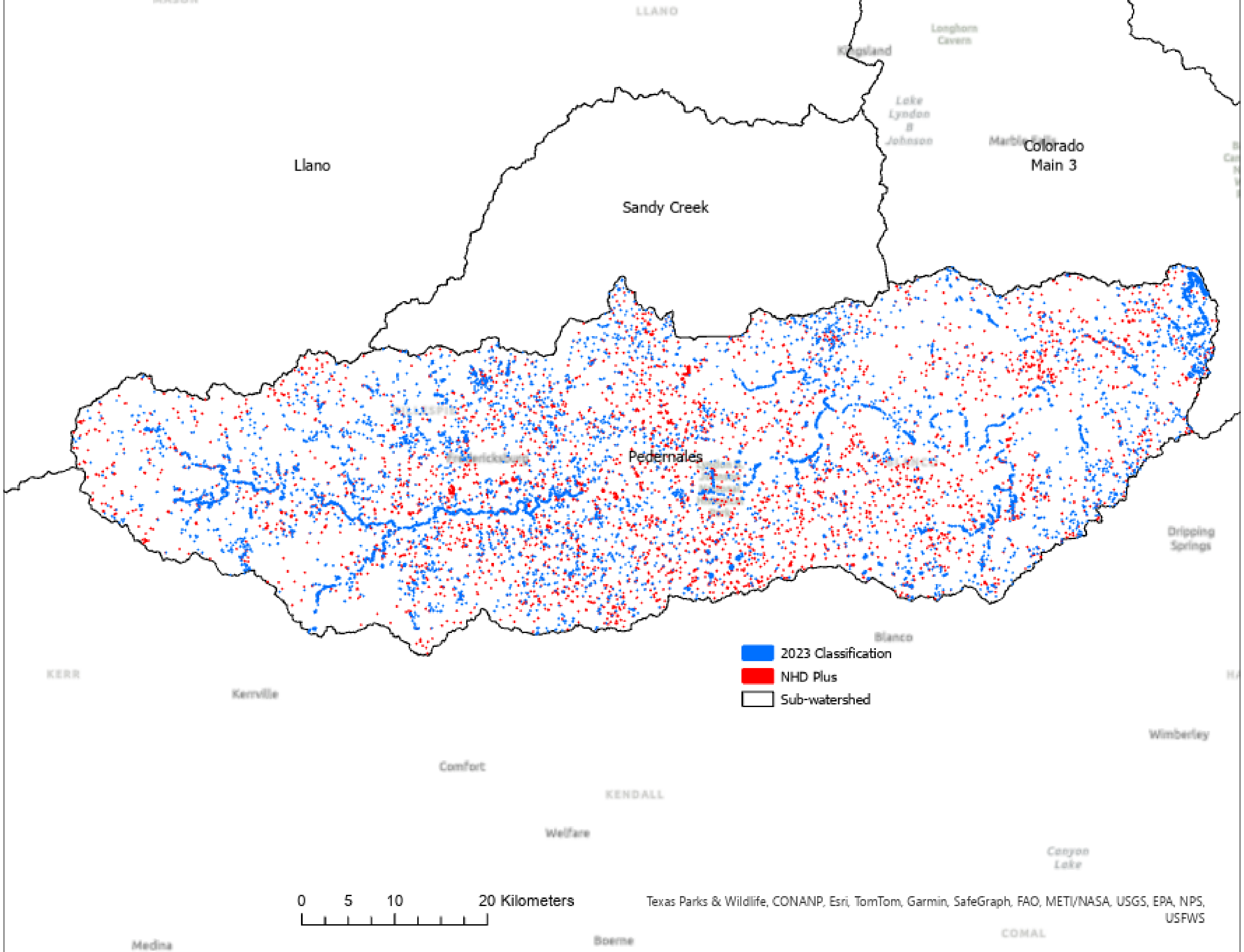


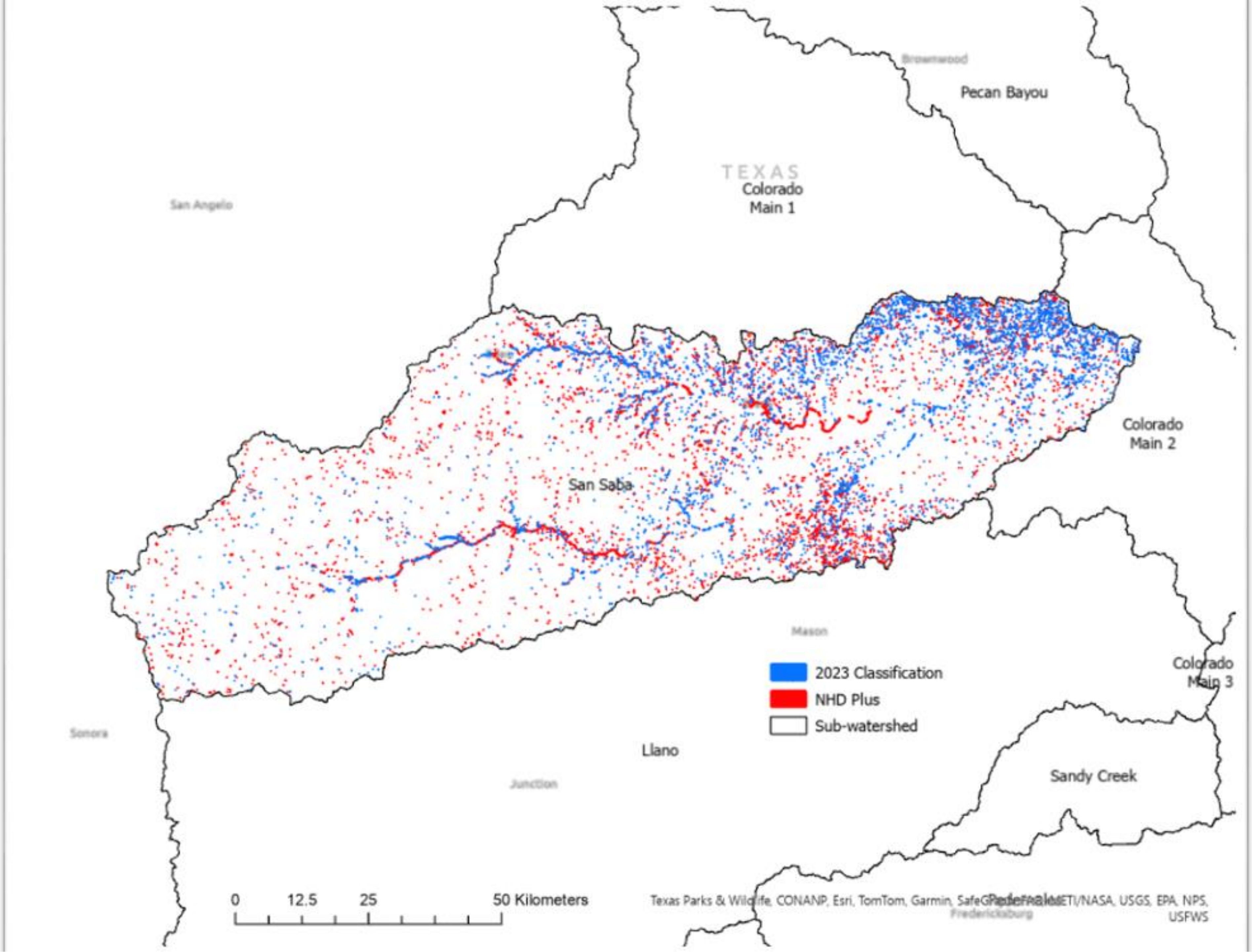
Pecan Bayou
Colorado Main 1
San Saba
Colorado Main 2
Llano
Colorado Main 3
2023 Classification
NHD Plus
Sub-watershed
0 5 10 20 Kilometers
Texas Parks & Wildlife, CONANP, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

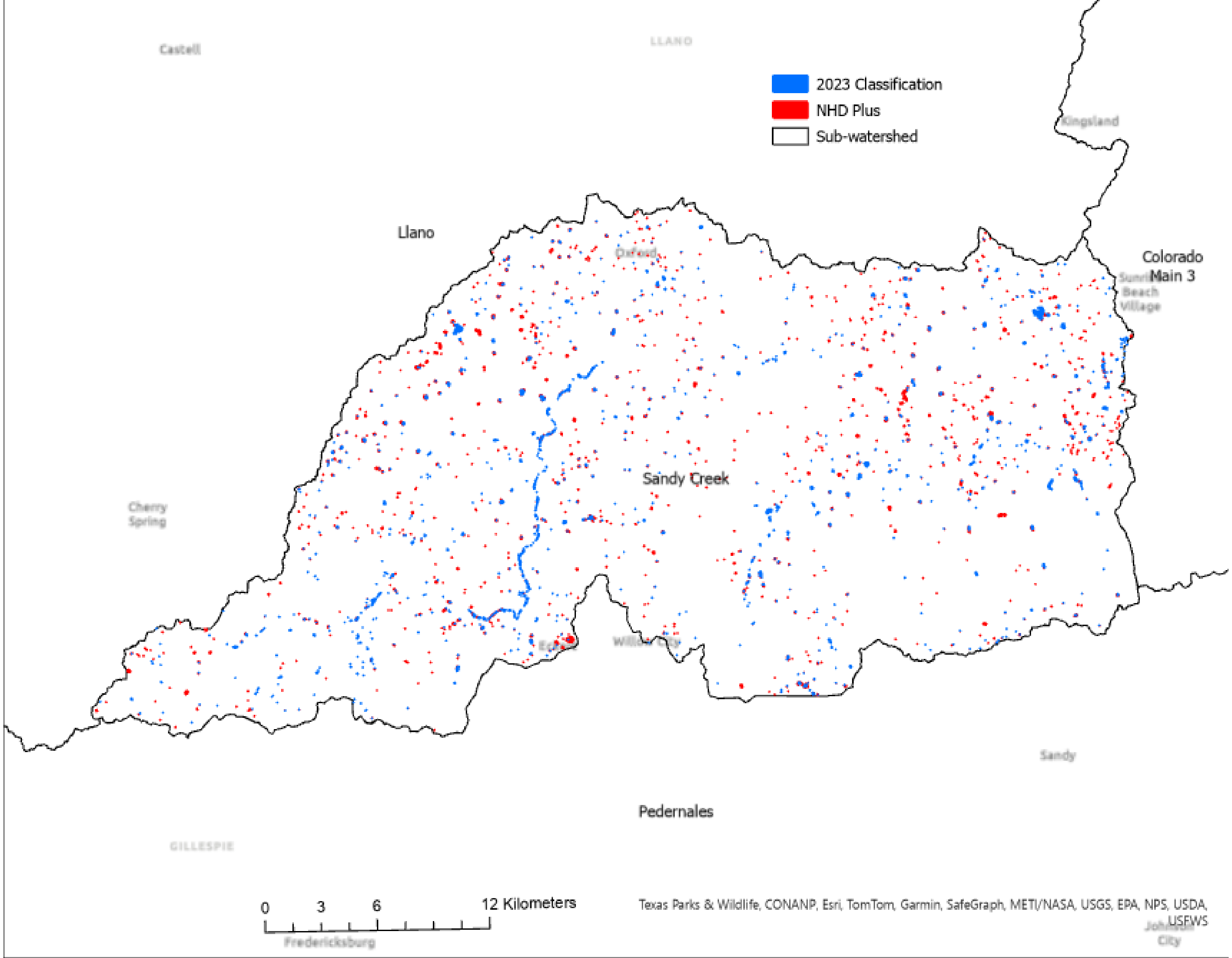

Colorado Main 2
Llano
Sandy Creek
Pedernales
Colorado Main 3
BURNET
Burnet
Leander
Cedar Park
Marble Falls
2023 Classification
NHD Plus
Sub-watershed
0 2.75 5.5 11 Kilometers
City of Austin, Texas Parks & Wildlife, CONANP, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS
Austin

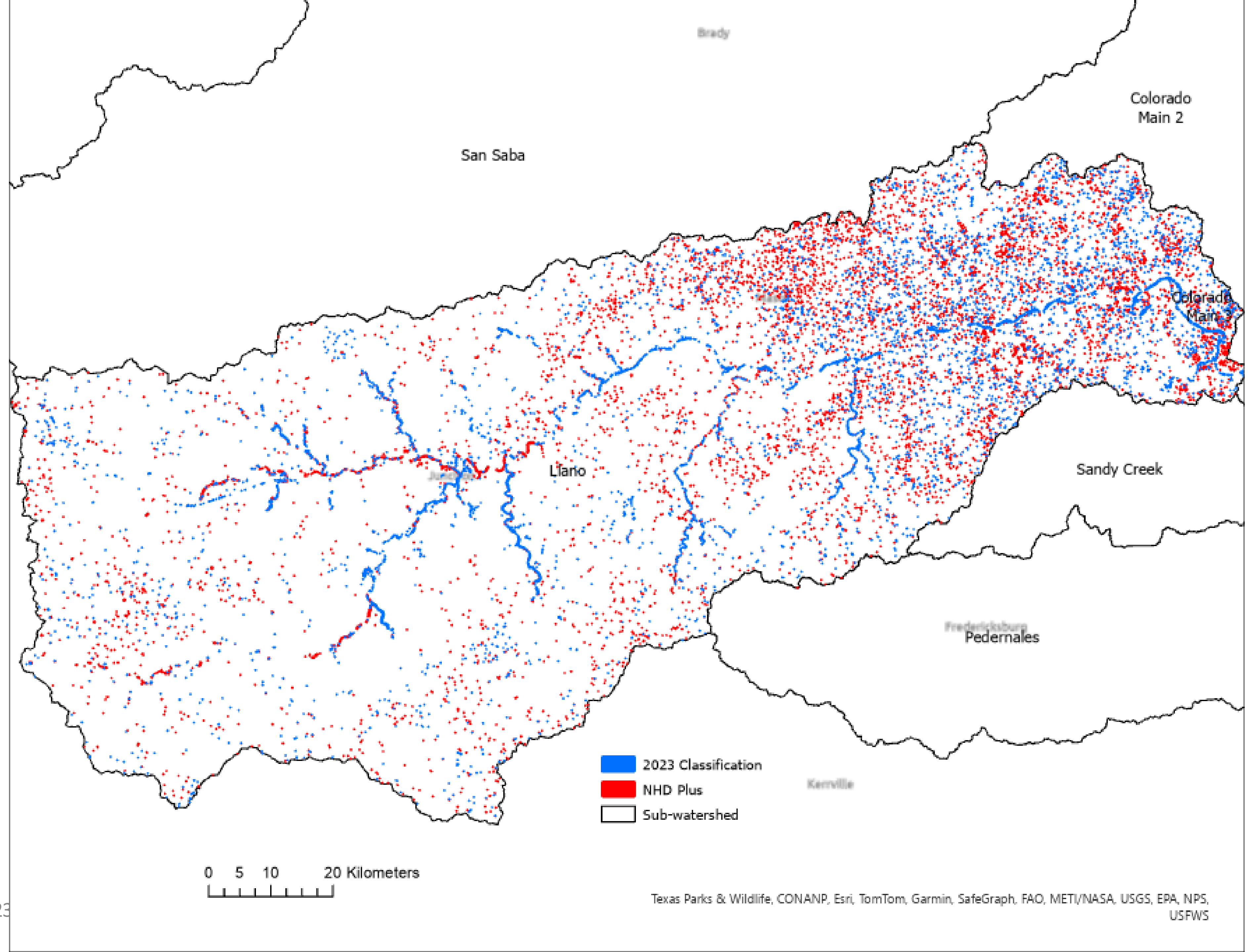

Colorado
Main 2
San Saba
Colorado
Main 3
Llano
Sandy Creek
Pedernales
2023 Classification
NHD Plus
Sub-watershed
0 5 10 20 Kilometers
Texas Parks & Wildlife, CONANP, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS


2023 Classification
NHD Plus
Sub-watershed
Baird
Cisco
Eastland
Staff
EASTLAND
Potosi
TAYLOR
Gorman
Dublin
Pecan Bayou
COMANCHE
Comanche
COLEMAN
Colorado
Main 1
TEXAS
Winchell
Colorado
Main 2
Holt
0 5 10 20 Kilometers
Texas Parks & Wildlife, CONANP, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

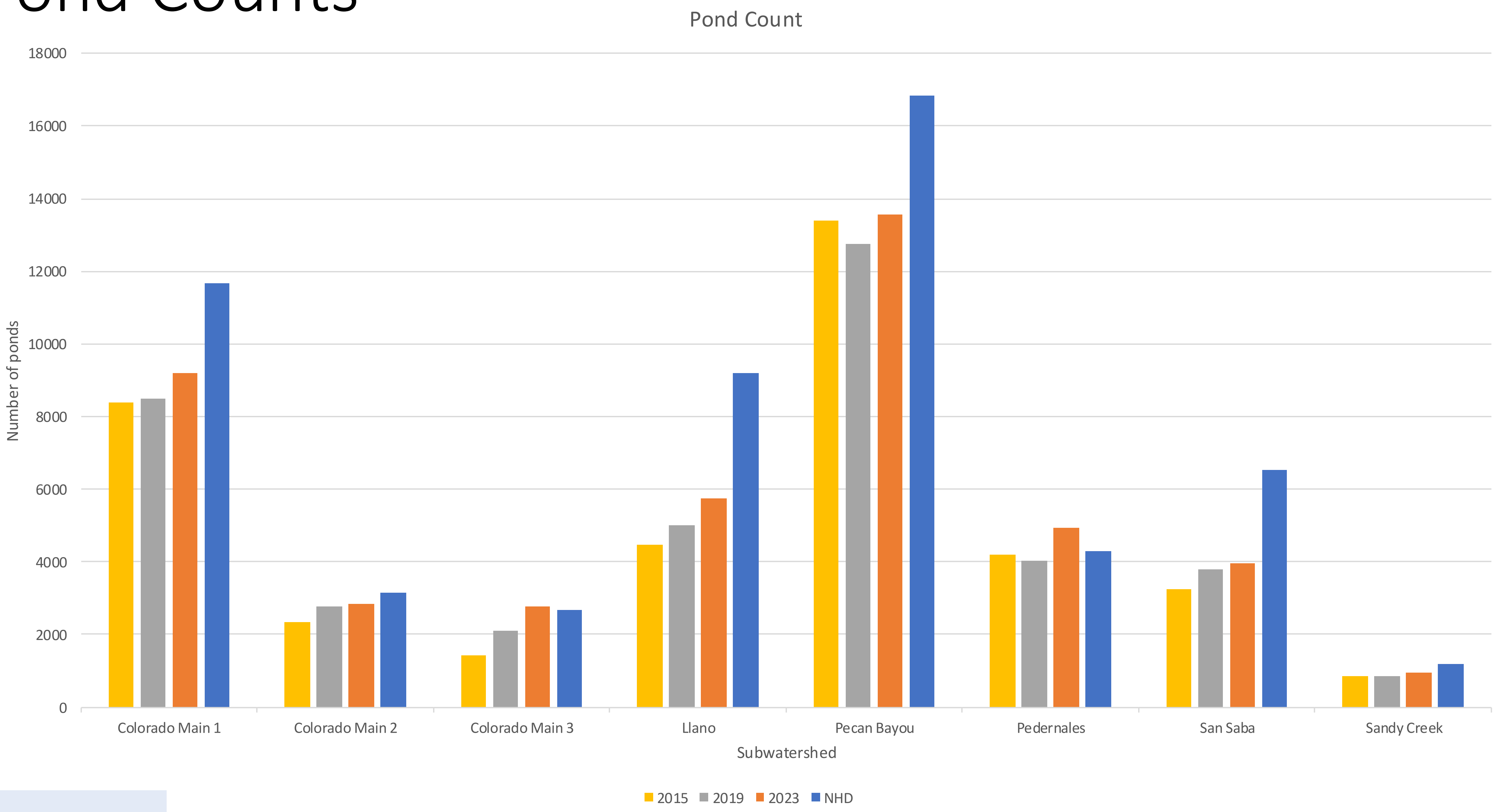

Llano
Sandy Creek
Colorado
Main 3
Pedernales
2023 Classification
NHD Plus
Sub-watershed
0 5 10 20 Kilometers
Texas Parks & Wildlife, CONANP, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS


Brownwood
Pecan Bayou
TEXAS
Colorado
Main 1
San Angelo
San Saba
Colorado
Main 2
Mason
2023 Classification
NHD Plus
Sub-watershed
Colorado
Main 3
Sonora
Llano
Junction
Sandy Creek
0
12.5
25
50 Kilometers
Texas Parks & Wildlife, CONANP, Esri, TomTom, Garmin, SafeGraph, METI/NASA, USGS, EPA, NPS, USFWS
Pedernales
Fredericksburg


2023 Classification
NHD Plus
Sub-watershed
Castell
LLANO
Kingsland
Llano
Colorado Main 3
Sandy Creek
Cherry Spring
Pedernales
Sandy
GILLESPIE
0
3
6
12 Kilometers
Fredericksburg
Texas Parks & Wildlife, CONANP, Esri, TomTom, Garmin, SafeGraph, METI/NASA, USGS, EPA, NPS, USDA, USFWS

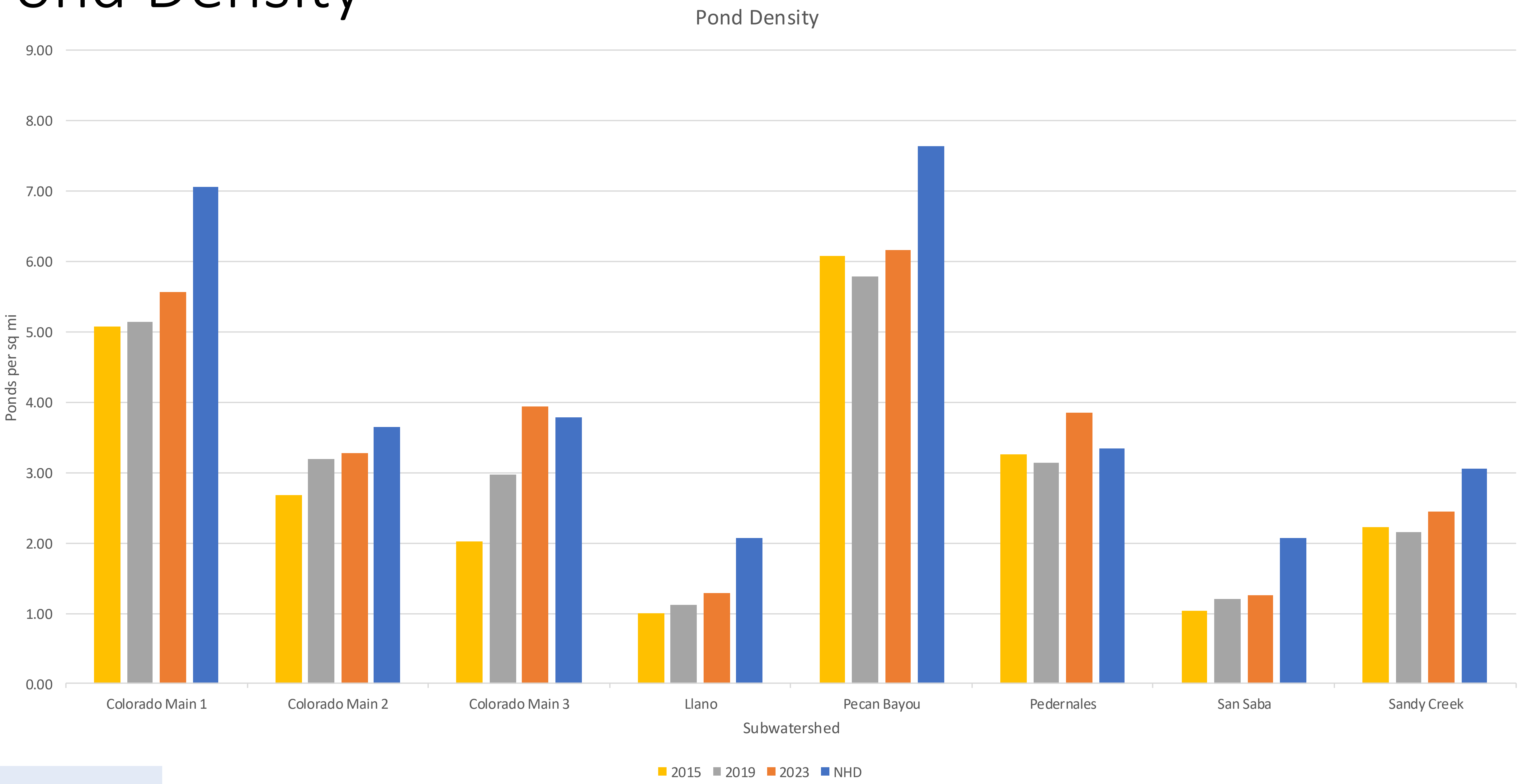

Brady
Colorado
Main 2
San Saba
Colorado
Main 3
Llano
Sandy Creek
Pedernales
2023 Classification
NHD Plus
Sub-watershed
Kerrville
0 5 10 20 Kilometers
Texas Parks & Wildlife, CONANP, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

Pond Counts



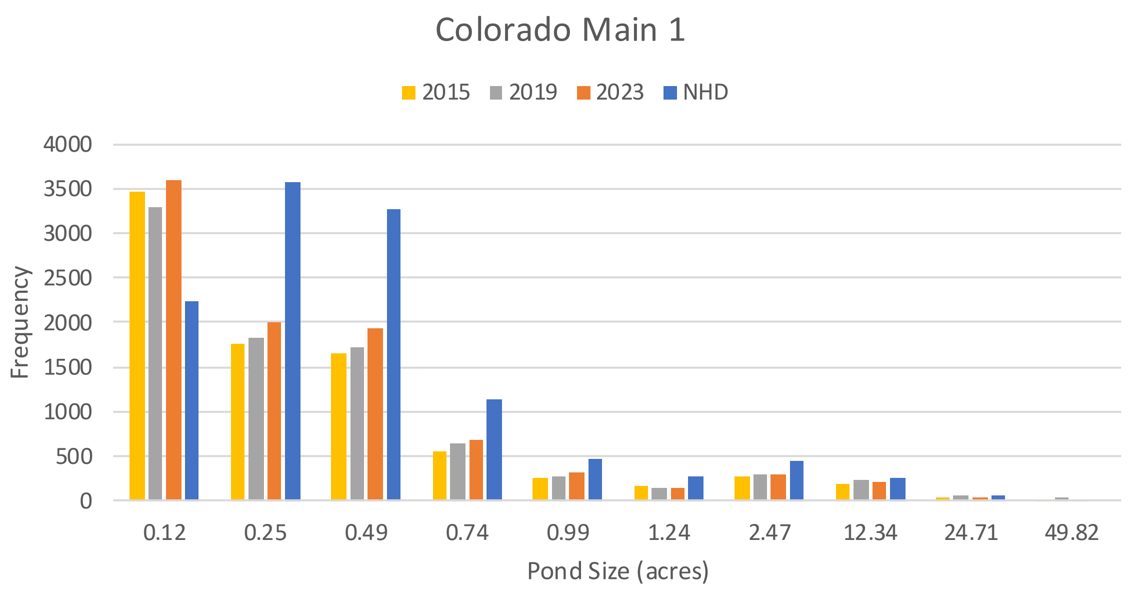
Pond Count
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Number of ponds
Colorado Main 1
Colorado Main 2
Colorado Main 3
Llano
Pecan Bayou
Pedernales
San Saba
Sandy Creek
Subwatershed
2015
2019
2023
NHD

Pond Density

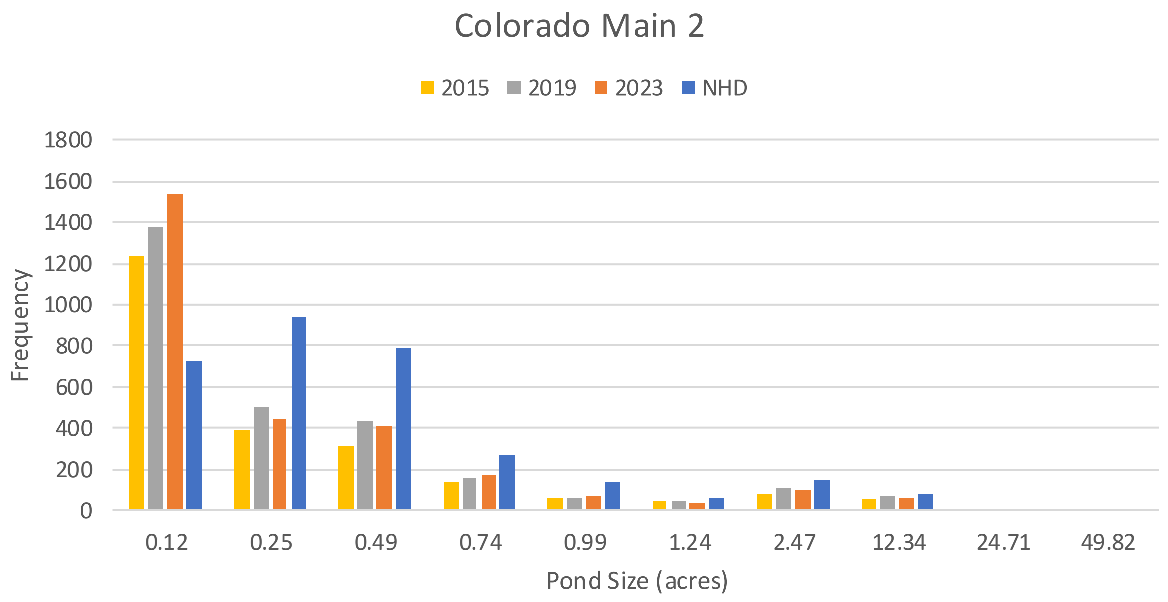


Annualized percent increase in number of ponds for three time intervals for Highland Lakes subwatersheds for all ponds greater than 1,076 ft^2 (100 m^2).

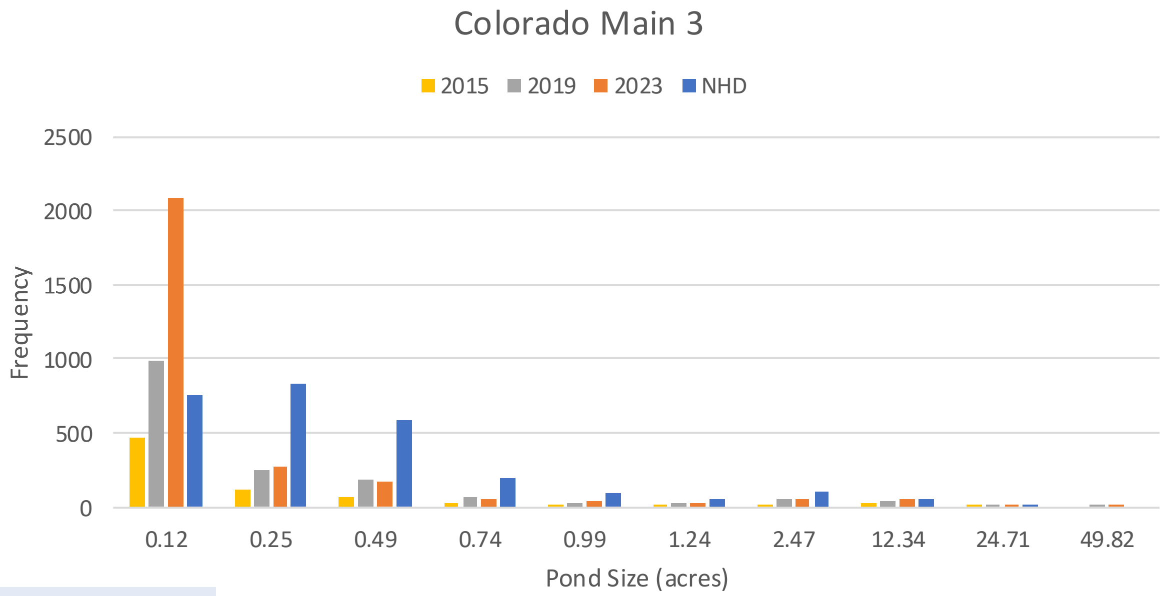
Subwatershed	December 2015-February 2019	February 2019-March 2023	December 2015-March 2023
Colorado Main 1	0.35	2.01	1.28
Colorado Main 2	5.68	0.62	2.80
Colorado Main 3	12.93	7.18	9.65
Llano	3.55	3.47	3.50
Pecan Bayou	-1.54	1.53	0.18
Pedernales	-1.22	5.10	2.29
San Saba	4.91	0.91	2.64
Sandy Creek	-0.78	3.04	1.35



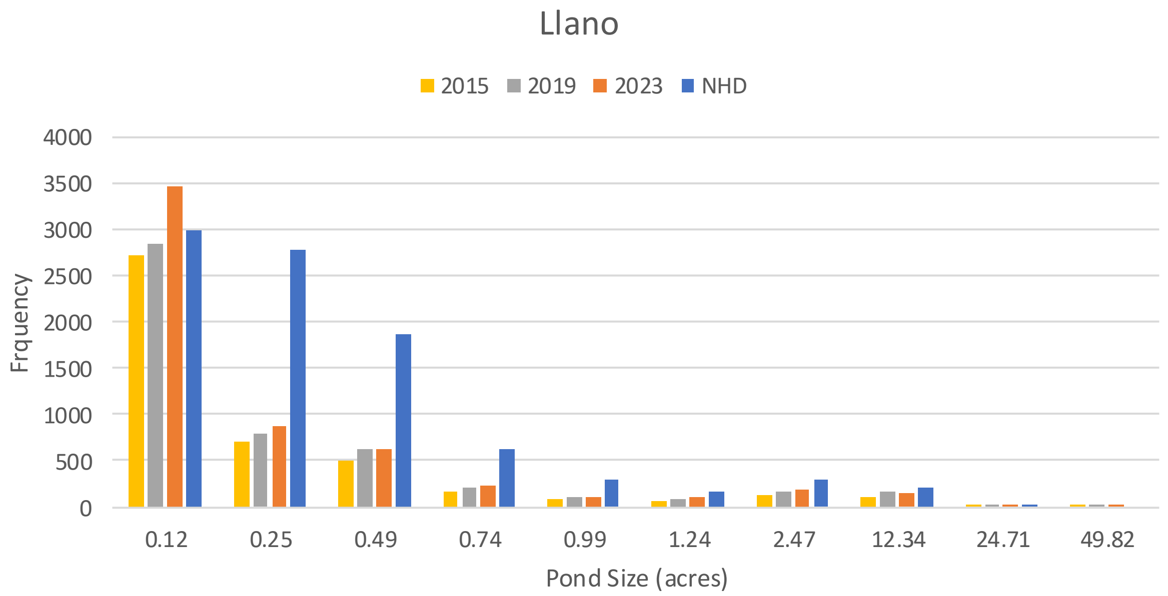
Colorado Main 1
2015
2019
2023
NHD
Frequency
0
500
1000
1500
2000
2500
3000
3500
4000
0.12
0.25
0.49
0.74
0.99
1.24
2.47
12.34
24.71
49.82
Pond Size (acres)



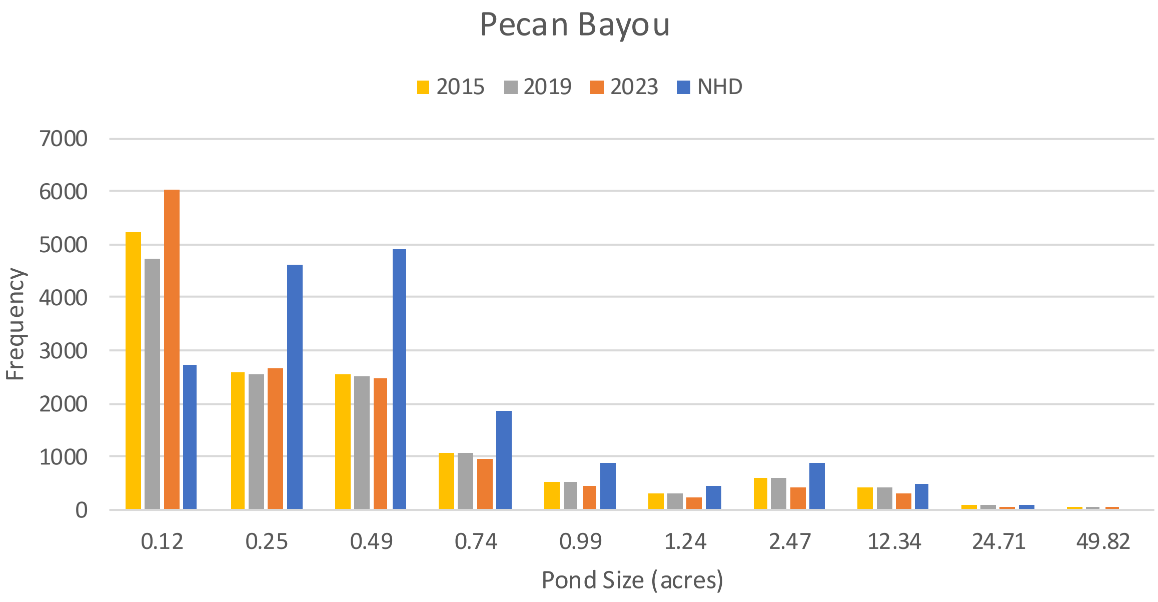
Colorado Main 2
2015
2019
2023
NHD
Frequency
0
200
400
600
800
1000
1200
1400
1600
1800
0.12
0.25
0.49
0.74
0.99
1.24
2.47
12.34
24.71
49.82
Pond Size (acres)

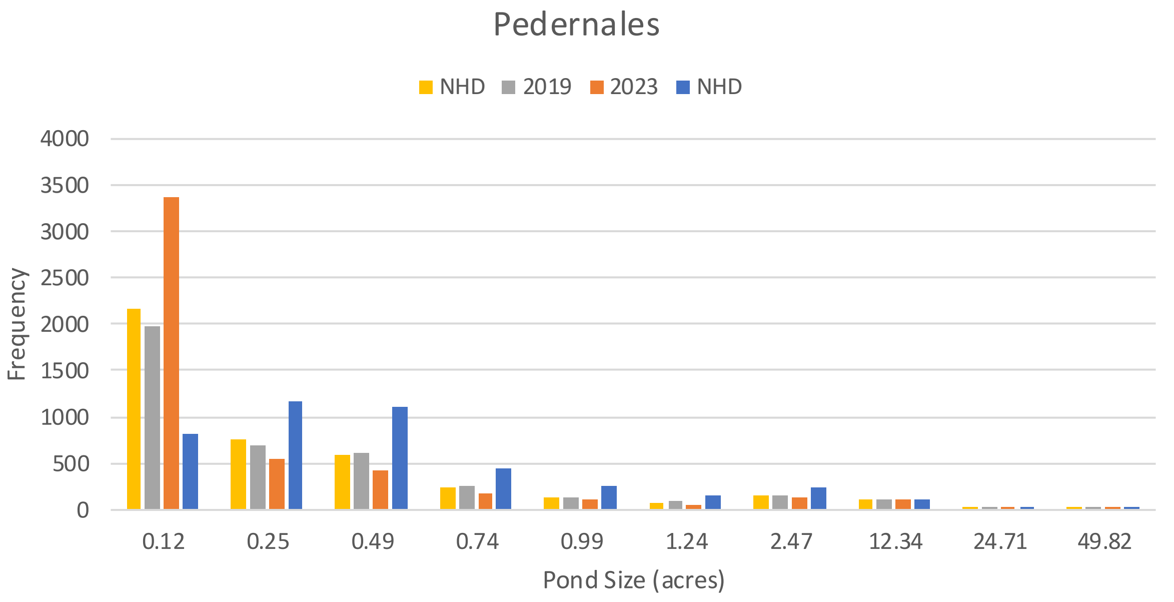


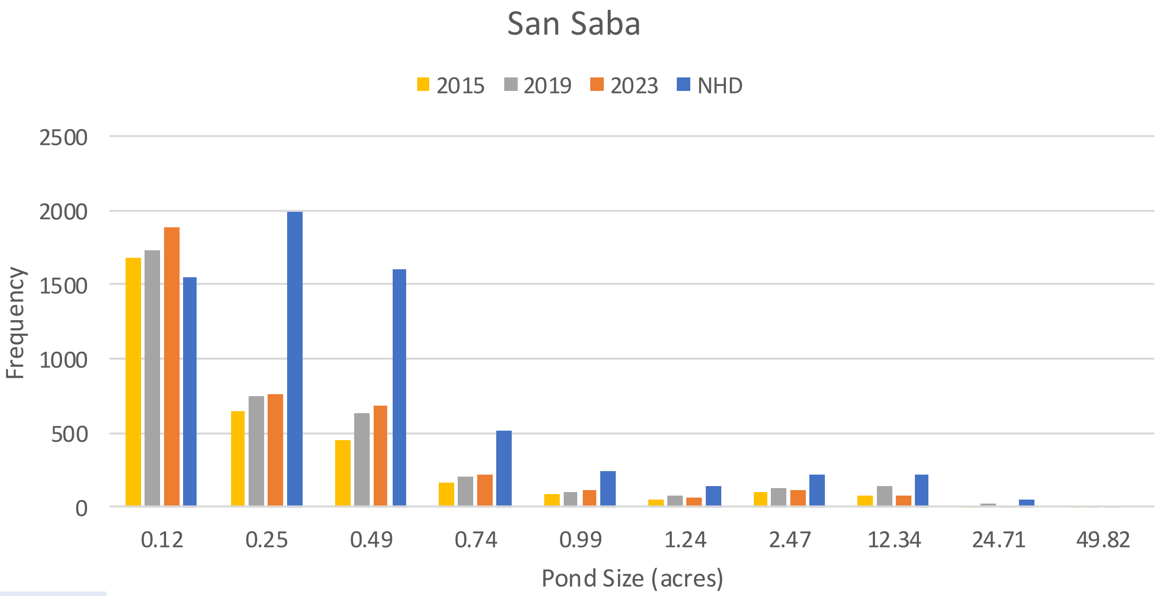
Colorado Main 3
2015
2019
2023
NHD
Frequency
0
500
1000
1500
2000
2500
0.12
0.25
0.49
0.74
0.99
1.24
2.47
12.34
24.71
49.82
Pond Size (acres)

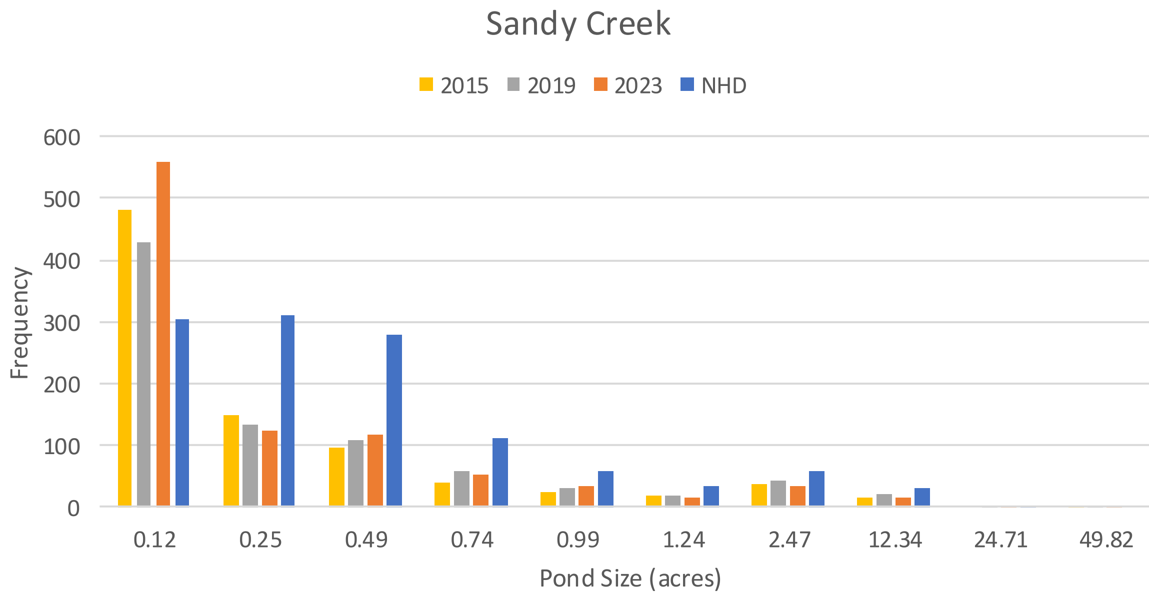


Llano
2015
2019
2023
NHD
Frquency
0
500
1000
1500
2000
2500
3000
3500
4000
0.12
0.25
0.49
0.74
0.99
1.24
2.47
12.34
24.71
49.82
Pond Size (acres)


Pecan Bayou
2015
2019
2023
NHD
Frequency
7000
6000
5000
4000
3000
2000
1000
0
0.12
0.25
0.49
0.74
0.99
1.24
2.47
12.34
24.71
49.82
Pond Size (acres)

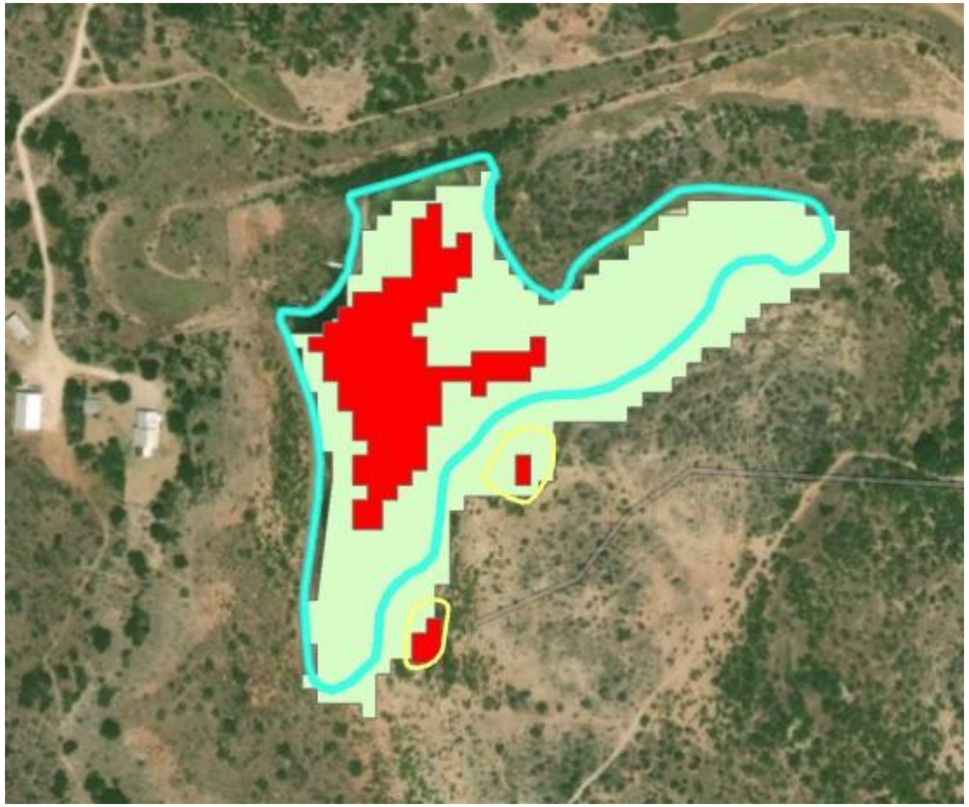

Pedernales
NHD
2019
2023
NHD
Frequency
4000
3500
3000
2500
2000
1500
1000
500
0
0.12
0.25
0.49
0.74
0.99
1.24
2.47
12.34
24.71
49.82
Pond Size (acres)

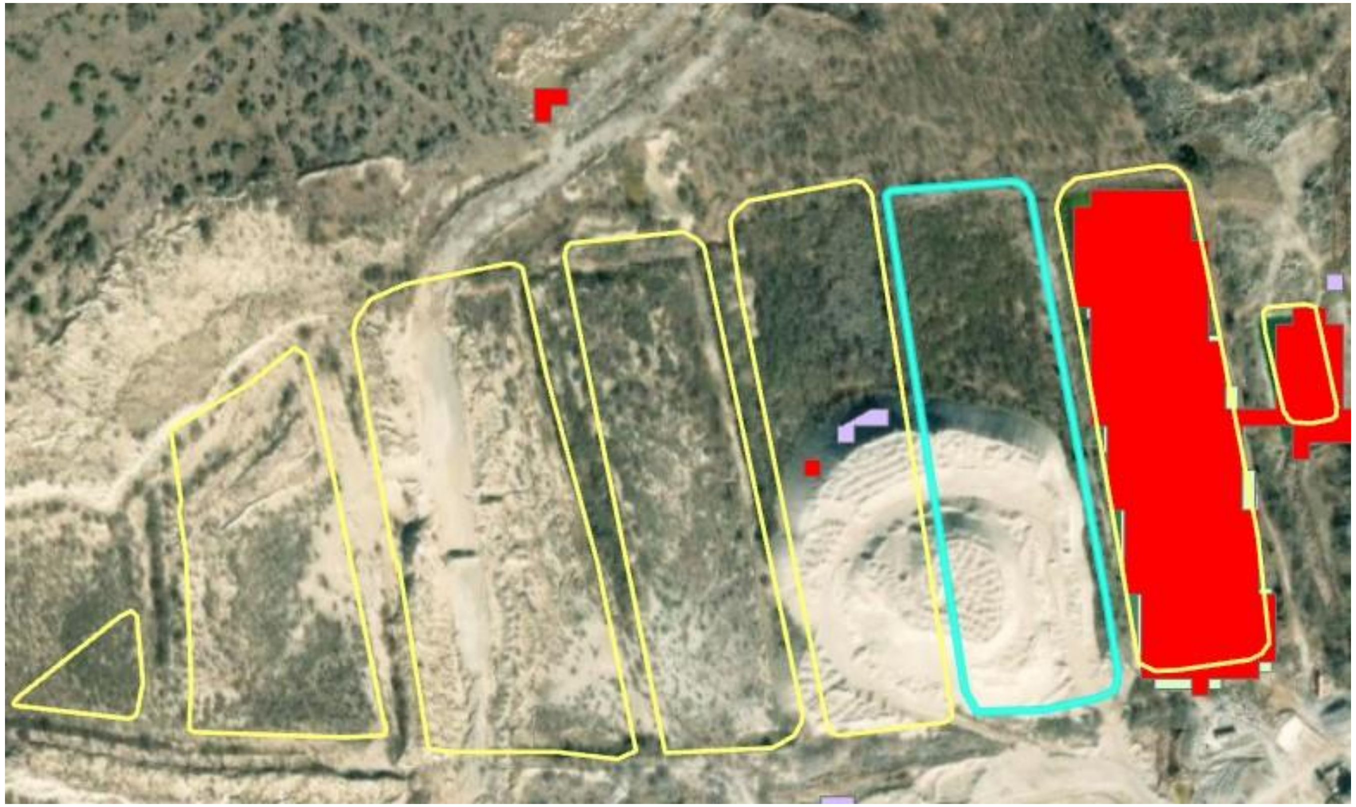

San Saba
2015
2019
2023
NHD
Frequency
2500
2000
1500
1000
500
0
0.12
0.25
0.49
0.74
0.99
1.24
2.47
12.34
24.71
49.82
Pond Size (acres)


Sandy Creek
2015
2019
2023
NHD
Frequency
600
500
400
300
200
100
0
0.12
0.25
0.49
0.74
0.99
1.24
2.47
12.34
24.71
49.82
Pond Size (acres)

Overall Results

- Sentinel-2 + DEM data performed well for pond classification
  - High classification accuracies and relatively low omission errors (2023 highest at 8.5%)
- Analysis over time indicates an increased number of ponds and pond density, though increases vary depending on subwatershed
- Comparison with NHD indicated a large discrepancy between total NHD ponds and our 2023 classification
  - Some 2023 omission errors
  - **Many** NHD pond ‘double-counts’






Brady Creek
Brady Creek
FM 2028


Landfill Rd


84
US Highway 283

Summary

- Spectral index-based classification of small ponds in the Highland Lakes watershed produced reliable results for detection, inventory, and longer-term monitoring of surface water.

- Simple, customizable procedure using publicly available datasets.

- Excellent potential to extend to additional areas and/or years.

Acknowledgements

- LCRA provided funding for this project through an Inter-Agency Cooperation Agreement (A 2023-0065)
  - Thanks to Ron Anderson, P.E., D. WRE and Hank Zook, Cartographer, Water Engineering Department
  - Multiple experts at LCRA that provided feedback
- Garrett Pugh (MS Geography; current PhD student) and Grayson Wylie (PhD candidate)

- Questions?

Thank you! Questions?

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