Statewide Application of the Restorable Wetland Identification Protocol: Final Report

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EXECUTIVE SUMMARY

The Oklahoma Conservation Commission (OCC) has developed a desktop screening tool to identify potential wetland restoration opportunities across Oklahoma. The Restorable Wetland Identification Protocol (RWIP) identifies where wetlands have likely been lost by comparing the potential historic extent of wetlands to the current extent of wetlands. Restorable wetlands are further filtered by topography, land-use, and hydrologic data to identify locations where restoration is more likely to be successful. All restorable wetlands are then ranked based on their potential to improve water quality to downstream receiving waterbodies. In 2019, RWIP was applied in all 70 HUC-8 watersheds across Oklahoma. Approximately 30,000 sites were identified as potentially restorable wetlands statewide. In 2020, RWIP accuracy was assessed through the field verification of 26 sites in three HUC-8 watersheds. Although field verification was significantly limited by COVID-19, 88% of field verified sites possessed indicators (e.g., remnant hydric soils, hydromodification, or marginal wetland hydrology) that historic wetlands likely existed. Based on these results, we conclude that RWIP is a reliable tool for identifying likely historic wetlands with soil and topography conducive to support wetland conditions should the wetland's hydrology be restored.

During this statewide application, we identified potential areas for method improvement, including misclassifications of existing wetlands as restorable, and coarse restorable wetland boundaries resulting from relatively low-spatial resolution elevation data (10 meter). Most importantly, we recognized that although RWIP can consistently identify historic wetlands, all historic wetlands do not have equal restoration potential. Restoration feasibility is limited by the potential to reestablish wetland hydrology at the site. Hydrological alterations, such as ditching or pond excavation, are generally easier to restore when compared with more permanent alterations, like groundwater table drawdown or stream incision. To address these concerns, two HUC-8 watersheds, the Lower Verdigris, and the Lower Cimarron-Skeleton, were selected for reapplication of RWIP along with additional attribution of local hydrological modifications. RWIP boundary delineation was improved with the use of high-resolution LiDAR data and enhanced smoothing techniques. In addition, we reduced confusion between existing wetlands and restorable wetlands by calculating the ratio of existing wetlands (i.e., National Wetlands Inventory [NWI] maps) to RWIP polygons. RWIP polygons with a high percentage of NWI wetlands were considered better suited for wetland enhancement, rather than wetland restoration. Lastly, to improve the overall utility of RWIP we evaluated local hydrological alterations. We created a layer to represent the extent of ditching within restoration wetland boundaries, and we generated an updated pond layer to better represent the number of ponds in Oklahoma. Restorable wetlands with significant ditching and/or the presence of ponds within the upstream watershed were designated as having high restoration feasibility.

In an ongoing project, the improvements to RWIP accomplished through this project, including the addition of a feasibility estimate, will be applied to at least 30 additional HUC-8 watersheds across Oklahoma (OCC 2021). This project will provide opportunities to explore regionally appropriate thresholds for hydrological alterations (e.g., length of ditching, distance to upstream ponds, etc.) based on watersheds and to adjust overall expectations in estimating restoration feasibility.

SECTION I: STATEWIDE APPLICATION OF RWIP

INTRODUCTION

Wetland restoration success is highly dependent on the development and implementation of detailed project plans, with the first critical step of site selection. Although site selection is typically limited by the availability of land, it is important to recognize that all land is not equally restorable, and preference should be given to areas with characteristics conducive to successful wetland restoration. The selection of suitable restoration sites requires the consideration of soils, hydrology, topography, geomorphology, and the surrounding landscape (Bedford, 1996; Russell et al.,1997; O'Neill et al., 1997; White and Fennessy 2005).

To maximize the effectiveness and expediency of wetland restoration, the Oklahoma Conservation Commission (OCC) has developed a desktop screening tool to identify potential wetland restoration opportunities across Oklahoma. The Restorable Wetland Identification Protocol (RWIP) identifies where wetlands have likely been lost by comparing the potential historic extent of wetlands (i.e., poorly drained soils) and the current extent of wetlands represented by National Wetlands Inventory (NWI) maps (Appendix A). Restorable wetlands are further filtered by topography, land-use, and hydrologic data to identify locations where restoration is more likely to be successful. All wetlands are then ranked based on their potential to improve water quality to downstream receiving waterbodies. Through this prioritization process, the protocol provides the State with a formal mechanism to integrate all water resources into a common watershed planning framework. The top ranked restorable sites are then entered into the Wetland Registry to market potentially restorable sites to developers and agencies in need of restoration opportunities. The Wetland Registry is a searchable database housed on the OCC server. Those in need of restoration opportunities can submit a fillable form hosted on the Oklahoma Wetlands Program Website to identify sites in the registry that meet their requirements (OCC 2016a). This project expands on several previous studies (OCC 2018, OCC 2017, OCC 2016b) where RWIP was applied within three HUC-8 watersheds and within an additional five priority watersheds to identify and rank suitable sites for wetland restoration. RWIP application in these watersheds confirmed that the protocol is a useful and reliable tool for identifying historic wetlands with the potential for wetland restoration. With these initial RWIP studies complete, our objective for this project was to apply RWIP statewide in all HUC-8 watersheds in Oklahoma.

METHODS

RWIP Application and Site Prioritization

In 2019, RWIP was applied in all 70 HUC-8 watersheds across Oklahoma to generate a statewide list of potentially restorable wetlands (Figure 1). RWIP steps outlined in Appendix A were completed in ArcGIS Desktop with readily available datasets, including National Wetland Inventory maps, 10-meter resolution Digital Elevation Models, the 2016 National Land-Cover Dataset, and 2017 and 2019 aerial images from the National Agriculture Imagery Program. As a secondary step in the protocol, RWIP polygons were then prioritized based on their potential ability to improve water quality to downstream receiving waterbodies. Each site was attributed with (1) wetland size, (2) watershed to wetland ratio, and (3) percent of crop and urban land-use within the watershed. Larger sites can capture and treat more runoff than smaller sites. Sites that are relatively large compared to their watersheds have a greater probability of receiving and treating runoff prior to outflow, and lastly, sites surrounded by human-altered land-uses are more likely to receive runoff in need of treatment (e.g., high quantities of nutrients and sediment). Each attribute (e.g., wetland size) was scored 1 to 4 and scores were summed to overall scores ranging from 3 (least likely to improve water quality) to 12 (most likely to improve water quality). Sites were ranked based on attribute specific thresholds at the state scale to identify candidate restoration sites most likely to improve water quality in Oklahoma. However, because restoration opportunities are often required within specific watersheds, sites also received a watershed specific rank based on attribute quartiles, to help prioritize restoration at the HUC-8 scale.

RWIP Accuracy Assessment

To assess the accuracy of the protocol, a portion of the top ranked sites identified as potentially restorable wetlands were field verified. Initially, we planned to verify the top 10 ranked sites within five different ecoregions, resulting in a target of 50 sites. However, field verification was scheduled for the summer of 2020 and was limited due to COVID-19. Although we did not reach our target of 50 sites, we were able to conduct field verification on 26 sites between May and August 2020. Sites with evidence of marginally wet plant communities, hydromodification and/or soils and topography conducive to holding water, were considered to be potentially restorable wetlands, and correctly identified by the protocol.

RESULTS

RWIP Application and Site Prioritization

A statewide application of RWIP identified 29,852 individual polygons as potential locations for wetland restoration. The number of polygons varied by watershed from 0 to 1,000 (Table 1). In watersheds with a significant number of restorable wetlands identified, the top ranked 1,000 sites were selected (e.g., 17 watersheds) for inclusion the database.

RWIP Accuracy Assessment

We field verified 26 sites divided among three HUC-8 watersheds (Table 2). The majority of sites were field verified on the ground, with a few sites verified from the road using windshield surveys. Sites were considered accurately mapped by RWIP if there was an indication that the site was marginally wet with some indication of modified hydrology. For example, an RWIP polygon would be considered accurately mapped if the site has the presence of FAC or FACW plants and the presence of ditches within or near the polygon boundary (Figure 2). The accuracy assessment resulted in an overall accuracy of 88% across all field verified sites. Sites identified incorrectly as restorable wetlands occurred in areas where wetlands already exist, but because these wetlands were not included in NWI maps, they were not filtered out during RWIP processing steps (Figure 3).

DISCUSSION

Our study confirms that RWIP is a reliable tool for identifying sites that were likely historic wetlands with soil and topography conducive to supporting wetland conditions should the wetland's hydrology be restored. Through the statewide application of RWIP, a list of potentially restorable wetlands was generated for every watershed (Appendix B), where possible. Appendix B lists all potentially restorable sites and includes coordinates for the polygon centroids. Polygon shapefiles of potentially restorable wetlands for each watershed are available upon request using the fillable form on the Oklahoma Wetland Program Website. This allows parties in need of wetland mitigation or restoration the ability to select suitable sites within a particular area of need (i.e., mitigation service areas). In addition, the prioritization of sites based on their ability to improve water quality promotes the consideration and inclusion of wetland restoration activities in the watershed planning process.

Although RWIP was applied statewide, the protocol identified fewer than 20 restorable sites in seven watersheds and no restorable sites in four watersheds. For 9 of these 11 watersheds, less than five percent of the watershed falls within the state's boundary. The remaining two watersheds are relatively small and are limited by a lack of hydric soils in the watershed or inaccuracies in hydric soil layers. Although frequently and occasionally flooded soils are present in these watersheds, the corresponding soil drainage class does not indicate that these soils will hold water (e.g., well-drained, extremely well-drained). Additional work is needed to further evaluate whether restoration opportunities exist in these watersheds. However, wetland distribution on the landscape is heterogenous based on regional hydrogeomorphology.

During field reconnaissance, we recognized several limitations of RWIP and identified potential areas for method improvement. For example, we found that all RWIP polygon misclassifications were a result of the protocol identifying areas where wetlands already exist on the landscape. Additional effort to reduce the confusion between RWIP polygons and existing wetlands could help distinguish between restorable wetlands and areas better suited for wetland enhancement. In addition to misclassifications, we also found that RWIP polygon boundaries were often coarse representations of potentially restorable wetlands and boundaries did not always reflect hydric soil boundaries and topographic basins. This is likely due to the use of 10-meter resolution DEMs and extraction processing steps, such as the clip tool. The inclusion of higher resolution LiDAR data and additional processing steps (e.g., Cartography tools) could improve the generation of more refined RWIP polygon boundaries. Lastly, and most importantly, we determined that all historic wetlands identified through RWIP may not be restorable, and the feasibility of wetland restoration is likely tied to the types of hydrological alterations impacting the historic wetland. Future efforts to attribute RWIP polygons with the primary cause of hydrological alteration (e.g., pond excavation, ditches and diversions, impervious surface, etc.) could help estimate the feasibility of restoring a wetland’s hydrology. These potential areas for improvement were addressed through a second phase of this project and are further discussed in Section 2.

FIGURES

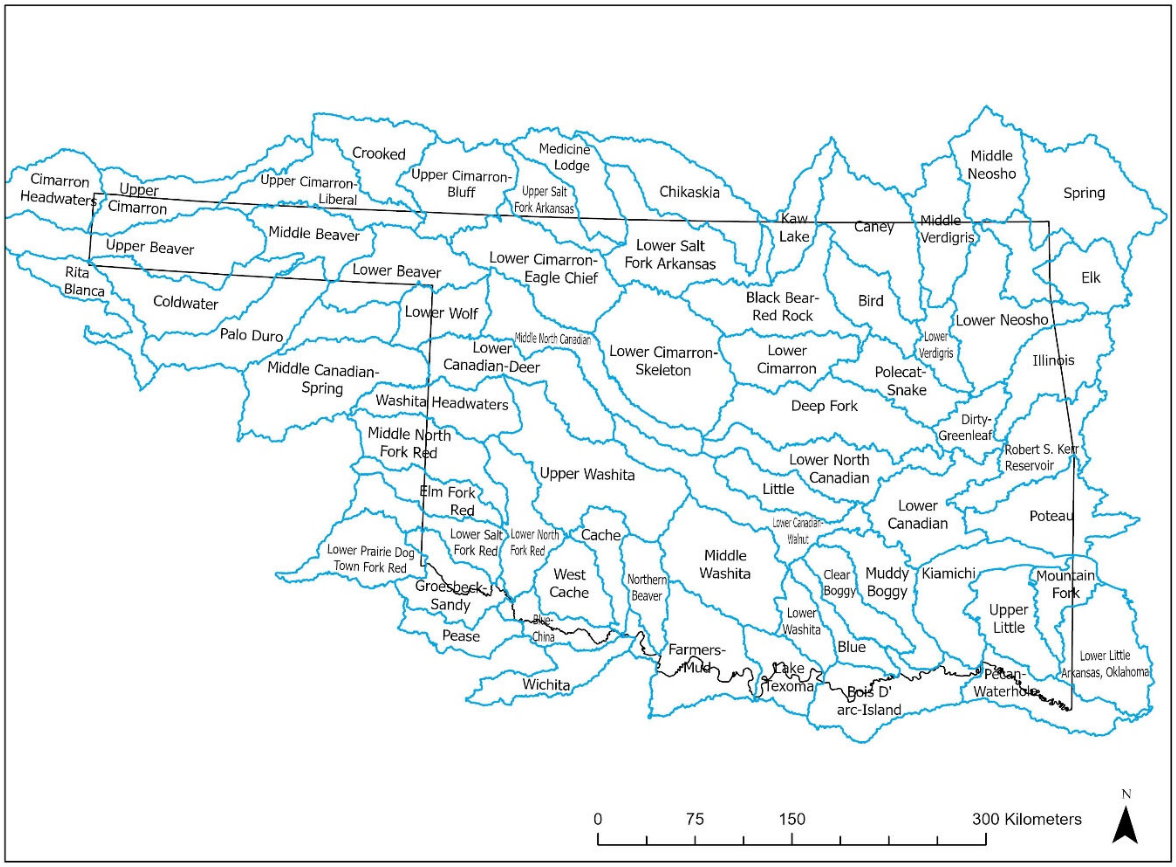


Fig 1. Map of HUC-8 Watersheds in Oklahoma

Fig 2. Field verification photos of confirmed historic wetlands identified through RWIP

a. Historic wetland in the Lower Verdigris watershed, Wagoner County

b. Historic wetland in the Lower Canadian watershed, Pittsburg County

Fig 3. Existing wetland misclassified through RWIP in the Lower Canadian watershed, Pittsburg County

TABLES

Table 1: HUC-8 watersheds contained within Oklahoma along with the total number and acreage of RWIP sites identified in the watershed.

HUC-8 Code	Watershed Name	% Watershed in OK	Total Num. RWIP Sites	Total Area of RWIP Sites (ac)
11070107	Bird	100	909	12,143.5
11060006	Black Bear-Red Rock	100	309	1,404.8
11140102	Blue	100	165	827.4
11130102	Blue-China	49	6	238.7
11140101	Bois D'arc-Island	28	676	11,876.5
11130202	Cache	100	23	208.7
11070106	Caney	56	1000	13,272.8
11060005	Chikaskia	18	172	7,146.5
11040001	Cimarron Headwaters	2	0	0.0
11140104	Clear Boggy	100	1000	12,043.1
11100103	Coldwater	17	30	775.4
11040007	Crooked	1	18	333.9
11100303	Deep Fork	100	1000	11,048.9
11110102	Dirty-Greenleaf	100	1000	8,099.4
11070208	Elk	5	17	32.8
11120304	Elm Fork Red	61	67	276.7
11130201	Farmers-Mud	64	134	2,405.3
11130101	Groesbeck-Sandy	39	240	5,413.3
11110103	Illinois	54	168	1,184.6
11060001	Kaw Lake	48	108	610.0
11140105	Kiamichi	100	917	6,896.3
11070206	Lake O' The Cherokees	80	1000	20,132.1
11130210	Lake Texoma	57	88	386.7
11090203	Little	100	575	4,591.0
11100201	Lower Beaver	75	295	6,994.6
11090204	Lower Canadian	100	1000	8,351.6
11090201	Lower Canadian-Deer	98	490	12,184.9
11090202	Lower Canadian-Walnut	100	602	17,721.3
11050003	Lower Cimarron	100	92	490.8
11050001	Lower Cimarron-Eagle Chief	98	1000	21,951.3
11050002	Lower Cimarron-Skeleton	100	1000	21,431.4
11140109	Lower Little Arkansas, Oklahoma	10	338	8,223.8
11070209	Lower Neosho	94	1000	15,134.2
11100302	Lower North Canadian	100	1000	14,852.6
11120303	Lower North Fork Red	100	678	6,695.9
11120105	Lower Prairie Dog Town Fork Red	1	2	60.9

HUC-8 Code	Watershed Name	% Watershed in OK	Total Num. RWIP Sites	Total Area of RWIP Sites (ac)
11060004	Lower Salt Fork Arkansas	82	1000	22,312.5
11120202	Lower Salt Fork Red	57	438	4,532.0
11070105	Lower Verdigris	100	1000	23,597.6
11130304	Lower Washita	100	132	1,090.7
11100203	Lower Wolf	60	533	6,543.4
11060003	Medicine Lodge	15	30	308.2
11100102	Middle Beaver	98	405	5,364.0
11090106	Middle Canadian-Spring	< 1	2	20.9
11070205	Middle Neosho	< 1	10	93.0
11100301	Middle North Canadian	100	1000	21,752.9
11120302	Middle North Fork Red	52	250	3,327.1
11070103	Middle Verdigris	54	1000	9,632.0
11130303	Middle Washita	100	337	8,506.0
11140108	Mountain Fork	71	102	2,440.2
11140103	Muddy Boggy	100	1000	13,001.5
11130208	Northern Beaver	100	34	175.1
11100104	Palo Duro	7	34	775.8
11130105	Pease	< 1	0	0.0
11140106	Pecan-Waterhole	29	830	19,532.9
11110101	Polecat-Snake	100	1000	13,561.8
11110105	Poteau	71	354	4,878.4
11090103	Rita Blanca	0	0	0.0
11110104	Robert S. Kerr Reservoir	81	931	13,606.4
11070207	Spring	4	135	1,348.2
11100101	Upper Beaver	67	119	1,023.1
11040002	Upper Cimarron	40	4	10.7
11040008	Upper Cimarron-Bluff	17	106	1,102.1
11040006	Upper Cimarron-Liberal	21	57	548.6
11140107	Upper Little	100	1000	13,208.7
11060002	Upper Salt Fork Arkansas	32	137	2,035.5
11130302	Upper Washita	100	672	4,656.7
11130301	Washita Headwaters	70	49	828.0
11130203	West Cache	100	32	3,781.2
11130206	Wichita	< 1	0	0.0
Total			**29,852.0**	**459,036.9**

Table 2: Field verified RWIP sites in three HUC-8 watersheds in Oklahoma where historic wetlands were confirmed based on the presence of hydric soils, hydrophytic vegetation, topography, and hydrological alterations.

Site ID	HUC-8 Watershed	Verification Method	Historic Wetland	Reason for Misclassification
33	Lower Verdigris	On-site	Yes	N/A
215	Lower Verdigris	On-site	Yes	N/A
386	Lower Verdigris	On-site	Yes	N/A
305	Lower Verdigris	Road-check	Yes	N/A
467	Lower Verdigris	On-site	Yes	N/A
483	Lower Verdigris	On-site	Yes	N/A
549	Lower Verdigris	On-site	Yes	N/A
398	Lower Cimarron-Skeleton	On-site	Yes	N/A
612	Lower Cimarron-Skeleton	On-site	Yes	N/A
410	Lower Cimarron-Skeleton	On-site	Yes	N/A
989	Lower Cimarron-Skeleton	On-site	Yes	N/A
976	Lower Cimarron-Skeleton	On-site	Yes	N/A
931	Lower Cimarron-Skeleton	On-site	Yes	N/A
256	Lower Cimarron-Skeleton	On-site	Yes	N/A
266	Lower Canadian	On-site	Yes	N/A
87	Lower Canadian	On-site	Yes	N/A
24	Lower Canadian	On-site	No	Existing wetland
72	Lower Canadian	On-site	No	Existing wetland
86	Lower Canadian	On-site	No	Existing wetland
604	Lower Canadian	On-site	Yes	N/A
674	Lower Canadian	On-site	Yes	N/A
691	Lower Canadian	On-site	Yes	N/A
547	Lower Canadian	Road-check	Yes	N/A
12	Lower Canadian	On-site	Yes	N/A
25	Lower Canadian	On-site	Yes	N/A
111	Lower Canadian	On-site	Yes	N/A

SECTION II: RWIP IMPROVEMENTS AND RESTORATION SITE FEASIBILITY

INTRODUCTION

Through the statewide application of RWIP, we identified several areas where RWIP could be improved to better represent potentially restorable wetlands across Oklahoma. For example, the RWIP polygon boundaries generated through the protocol were often coarse and inaccurate reflections of hydric soils and topographic basins. RWIP polygon boundaries could be refined with the use of higher spatial resolution datasets, (i.e., LiDAR) and additional processing steps, including polygon aggregation and smoothing techniques. Secondly, we found that the main source of RWIP misclassification was confusion between RWIP polygons and existing wetlands. Additional efforts to identify RWIP sites where wetlands already exist would improve the overall utility of the method. Most importantly, during our field reconnaissance it became evident that although RWIP can consistently identify marginally wet areas that were likely historic wetlands, not all historic wetlands can feasibly be restored.

Because hydrology is the primary driver of wetland physiochemical and biological processes, it is necessary to consider the feasibility of restoring wetland hydrology, in order to focus restoration efforts on areas with a higher likelihood of success. RWIP is intended to direct entities in need of mitigation and voluntary restoration efforts to suitable locations for wetland restoration based on soils, topography, hydrology, and land-use. We improved the protocol, by including additional processing steps to estimate the feasibility of restoring these areas based on the types of hydrological modifications at or near the site. The main source of hydrological alterations that can be potentially remediated through restoration is artificial drainage. The primary mechanism for artificial wetland drainage in Oklahoma is through the construction of a drainage network or conveyances (i.e., ditches) that carry water away from a wetland. A secondary mechanism for wetland drainage, occurs primarily in topographic depressions, and consists of excavating deeper topographic basins to create ponds. These basins move water that would normally be distributed throughout a larger wetland basin and concentrates the water in a smaller area that is generally too deep to support hydrophytic vegetation. Because these practices are known sources of hydrological alterations to wetlands in Oklahoma, we attributed RWIP polygons with the extent of ditching and nearby pond excavation, in an effort to identify areas with the greatest restoration potential.

The objectives of our study were to:

1. Improve the generation of RWIP polygon boundaries with the use of higher spatial resolution datasets, polygon aggregation, and smoothing techniques.
2. Reduce RWIP misclassifications in areas where wetlands already exist.
3. Improve RWIP utility by attributing polygons with hydrological alterations to estimate restoration feasibility.

METHODS

Study Area

Two HUC-8 watersheds were selected for the reapplication of RWIP, including the addition of hydrological modifications attributes to RWIP polygons to assess wetland restoration feasibility. The Lower Verdigris (LV) and the Lower Cimarron-Skeleton (LCS) were selected to represent two distinct types of watersheds in Oklahoma. The LV watershed is in the wetter, eastern half of the state where land cover is primarily urban development and pastureland, while the LCS is in the much drier western region of Oklahoma, which is dominated by agricultural land (Figure 4).

Improved Mapping of Restorable Wetlands

We replaced 10m DEMs with 1- and 2-meter high-resolution LiDAR data to generate more accurate data layers that are used in RWIP including, topographic basins, and flow accumulation lines. We also used several simplification and smoothing tools in ArcGIS Pro (e.g., Simplify Polygons, Eliminate Polygon Part, and Smooth Polygons) to adjust polygon boundaries and produce more naturally shaped polygons. Because the goal of RWIP is to identify general areas (e.g., fields) where restoration potential is high, the exact boundaries of the polygons are less critical. We then grouped together clusters of polygons within a specified distance (e.g., 50 meters) into larger polygons using the aggregation tool to better estimate restoration potential in the area. Overly precise boundaries give the illusion of higher spatial accuracy than RWIP provides, so boundary generalization aids in the interpretation of RWIP polygons as local areas for investigating restoration opportunities. We also improved land-use accuracy by using the most recent version of the National Land Cover Dataset (NLCD, 2019), which was previously not available.

In addition, we refined RWIP polygon designations, where existing NWI polygons represented a relatively large portion of the basin where restoration potential was identified. In these situations, it is difficult to determine if the RWIP polygon has actual restoration potential, or if the polygon simply represents a larger topographic basin surrounding an existing wetland. Because RWIP is designed to identify local areas where restoration potential is high (with lower confidence in exact polygon boundaries), a mapped NWI polygon may represent that maximum wetland area supported by local hydrologic variables. Additionally, NWI boundaries may be smaller than actual wetland extent on the ground. During field verification the greatest source of RWIP misclassification errors was due to the presence of an existing wetland. By calculating the ratio of NWI wetland to RWIP polygon, we can distinguish between sites suitable for wetland restoration and sites that are more suitable for wetland enhancement. RWIP polygons with more than 20% of their area comprised of existing NWI polygons were considered more suitable for wetland enhancement.

Attribution of Hydromodifications to Restorable Wetlands

Generated Ditching Network

Restoration feasibility was assessed based on the length of ditching present within restorable wetland boundaries. Because a spatial layer of ditches does not currently exist for the state of Oklahoma, we created a ditching network in ArcGIS Pro to estimate restoration feasibility. With the use of high-resolution LiDAR data (1-meter or 2-meter depending on availability), we were able to generate highly accurate flow accumulation layer. We then created flow lines from the flow accumulation layer by restricting the pixels included based on drainage area. A minimum threshold was set to remove small insignificant flow paths and a maximum threshold was set to remove large natural drainages. Because appropriate thresholds varied regionally across the state based on average annual rainfall, ditch layers were generated at the HUC-8 scale based on visual observation of flow patterns and best professional judgement. For example, a minimum threshold of 10,000 pixels was used for LV while a threshold of 20,000 pixels was used for the LCS; the LCS watershed is in western Oklahoma and receives significantly lower annual precipitation, requiring a greater accumulation of pixels to result in water flow. Once thresholds were established, the resulting flow accumulation raster was then vectorized to generate flow lines for each HUC-8.

To reduce confusion between ditches and natural drainages, flow lines intersecting with the National Hydrography Dataset (NHD) lines were removed. To further distinguish anthropogenically manipulated ditches from natural drainages, sinuosity was calculated for each flow line segment using a plug-in tool in ArcGIS Pro. Sinuosity values that are closer to 1 represent straighter lines, which were used represent potential man-made ditches or channelized drainages. Flow line segments with sinuosity greater than 1.25 were removed from the ditch network layer. Because a large majority of ditching has occurred in agricultural fields and pastures, only ditches intersecting with NLCD cropland and pastureland were included. Finally, the total length of ditches was calculated within each restorable wetland boundary. Within each watershed, the 50th percentile of total ditch length was used as a threshold to categorize sites in three classes: (1) no ditching, (2) light ditching, less than the 50th percentile, and (3) significant ditching, greater than the 50th percentile. For all restorable wetlands in the third category, ditching was considered to be the primary source of hydrological alteration, indicating that these sites can feasibly be restored.

Given time constraints, the difficulty of gaining landowner access, and the inability to accurately assess ditches from the roadside, we were unable to conduct field verification on the generated ditch network. However, we were able to informally assess the accuracy of ditches generated in areas where we previously conducted field reconnaissance during the initial application of RWIP in 2020. This informal accuracy assessment consisted of determining whether known ditches were captured in the generated ditch network. Additionally, we were able to visually inspect aerial imagery, as well as Google Earth historical imagery, to identify where ditches likely occur and make comparisons with our generated ditch network.

Identification of Upstream Ponds

To further estimate wetland restoration feasibility, all restorable wetlands were attributed with the number of ponds and total surface area of ponds within 200 m in the upstream watershed. NWI maps offer the only readily available spatial pond layer, and many of these maps are outdated (~40 years old) and likely misrepresent the actual number of ponds currently on the landscape. To improve accuracy in our attribution of nearby ponds, we generated a new layer in ArcGIS Pro to better capture the current extent of ponds. Sentinel-2 imagery (10-meter resolution) was downloaded from the Copernicus Online Data Hub. Imagery was selected based on recent precipitation data to prioritize dry image dates and reduce pond confusion with wetlands and other temporarily flooded areas. Based on the imagery resolution and the minimum mapping unit for NWI maps being 0.5 acre, we focused our classification on identifying all ponds 0.5 acre and larger. Image tiles were mosaiced together and clipped to the HUC-8 watershed scale. A composite image was created using bands 11 (short-wave infrared [SWIR]), 8 (infra-red [IR]), and 4 (red [RED]), because this band combination has been shown to be ideal for distinguishing between water and non-water pixels. Object-based classification was then used to classify two classes of water pixels (i.e., turbid, and dark water) and other land use classes (e.g., developed, cropland, forested, and herbaceous). Prior to classification, training pixels were sampled to represent each of these land-use classes. The random trees classification model provided the greatest differentiation between water pixels and non-water pixels. The classification raster output was then vectorized and all non-water classes were removed to generate a pond layer. Because some confusion remained between water features and developed features (e.g., rooftops, pavement), we removed all polygons that intersected with urban areas. The potential loss of actual ponds in urban areas has a negligible impact on assessing restoration feasibility. It is unlikely that wetland restoration will occur in highly developed urban areas due to the difficulty in removing impervious surfaces and other logistical constraints, such as proximity to residential areas. To further improve this layer, we removed polygons that intersected with NHD flowlines to reduce confusion between ponds and larger streams where open water was identified through image classification. Sites were considered feasible for wetland restoration if at least one pond was present within 200m in the upstream watershed.

Accuracy of the updated pond layer was assessed in both the LV and LCS watersheds by visually inspecting NAIP aerial imagery from the same year as the Sentinel-2 imagery to confirm the presence or absence of ponds. The grid index tool was used to section watersheds into equal areas (approximately 2 km x 2 km). A random number generator was used to select approximately 5% of these sections for the accuracy assessment. For all ponds 0.5 acre and larger, the following confusion matrix elements were calculated: User's Accuracy (a measurement of errors of commission or false positives) and Producer's Accuracy (a measurement of errors of omission or false negatives). The same accuracy assessment was completed on the NWI pond layer for comparison.

RESULTS

Improved Mapping of Restorable Wetlands

In the LV watershed, the reapplication of RWIP with improved processing steps identified 921 individual polygons as potentially restorable wetlands, ranging in size from 1.0 acre to 5,012 acres. These results are similar the first RWIP application, which identified 1,000 polygons, ranging in size from 1.0 to 4,617 acres. Of these, 34 were designated as more suitable for wetland enhancement based on the ratio of NWI polygon to RWIP polygon. In the LCS watershed, reapplication of RWIP identified 784 polygons as potentially restorable wetlands, ranging in size from 1.0 acre to 3,675 acres. As with the LV watershed, there were more restorable polygons identified in the LCS with the first RWIP application (i.e., 1,000, ranging in size from 1.0 to 2,166 acres). The identification of fewer individual polygons in the reapplication of RWIP is likely a result of the aggregation of smaller polygons, as indicated by the increase in restorable wetland size. Of these, 53 were designated as more appropriate for wetland enhancement (Figure 5). For a complete list of RWIP polygons identified in each the LV and LCS watersheds, along with hydromodification attributes, estimates of restoration feasibility, and prioritization rankings, see appendices C and D, respectively.

Attribution of Hydromodifications to Restorable Wetlands

Generated Ditching Network

In the LV watershed the length of ditches identified within polygon boundaries ranged from 0 to 377,081 ft. Of the 921 restorable wetlands generated in this watershed, 216 had no ditches, 352 had light ditching, and 353 had significant ditching within the restorable wetland boundary. In the LCS watershed the length of ditches identified within polygon boundaries ranged from 0 to 38,562 ft. Of the 784 restorable wetlands generated in this watershed, 295 had no ditches, 245 had light ditching, and 244 had significant ditching within the restorable wetland boundary. Although we were unable to complete an accuracy assessment on this layer, we were able to confirm that our generated ditch network detected the majority of obvious ditches identified on aerial imagery. We also confirmed that known ditches from our 2020 field verification were captured.

Identification of Upstream Ponds

In the LV watershed, 2,010 ponds were classified ranging in size from 0.5 acre to 241 acres. Furthermore, 314 of the 921 restorable wetlands identified through RWIP had at least one pond present and 74 restorable wetlands had two or more ponds within 200 m in the upstream watershed. The total surface area of ponds within these watersheds ranged from 0.5 acre to 107 acres. In the LCS watershed, 5, 918 ponds were classified and ranged in size from 0.5 acre to 124 acres. Of the 784 restorable wetlands identified in the LCS, 121 restorable wetlands had one or more ponds in the upstream watershed, and the total surface area of ponds within the restorable wetland watersheds ranged from 0.5 acre to 104 acres.

An accuracy assessment of ponds 0.5 acre and larger was completed in both the LV and LCS watersheds. In the LV watershed, our accuracy assessment resulted in a producer's accuracy of 83% (omission errors = 17%) and a user's accuracy of 92% (commission errors = 8%; Table 3). When inspecting these errors, it became apparent that our protocol did not exclude all polygons overlapping urban areas as we had intended, because the layer used to represent urban areas did not cover the full extent of urban development in the watershed. As a result, several polygons remained in the final pond layer that were misclassifications of developed pixels (e.g., rooftops, pavement). Because RWIP excludes all developed areas in the identification of potentially restorable wetlands, none of these pond misclassifications fell within restorable wetland boundaries. As such, all polygons mapped as ponds that overlap urban areas were removed from the pond layer using the 2020 TIGER Urban Area spatial layer. This processing step improved both errors of omission and errors of commission. For example, in the LV watershed, omission errors improved to 13%, with a producer's accuracy of 87%, and commission errors improved to 6%, with a user's accuracy of 94%. Our classified pond layer had similar accuracy results in the LCS watershed, with a producer's accuracy of 79% and a user's accuracy of 93%. Again, when excluding urban areas overall accuracy improved to 85% and 95% respectively. We compared our accuracy assessment results with the accuracy of NWI mapped ponds to evaluate whether our methods improved overall pond mapping. Urban areas were excluded from the NWI pond accuracy assessment for consistency. NWI ponds had lower accuracy than our classification in both the LV watershed (72% producer's and 72% user's) and LCS watershed (producers' 70% and user's 76%).

Estimation of Restoration Feasibility

Following prioritization ranking, all potentially restorable wetlands were attributed with two hydromodifications to estimate restoration feasibility, (1) Extent of ditching (e.g., none, light, or significant) and (2) Presence of ponds within 200 m in the upstream watershed. Sites with minimal ditching and no upstream ponds were categorized as having low restoration feasibility, whereas sites with significant ditching and/or upstream ponds were categorized as having high restoration feasibility. In the LV watershed, 532 of the 921 restorable wetlands were considered to have high restoration feasibility (Figure 6). In the LCS watershed, 323 of the 784 restorable wetlands were considered to have high restoration feasibility (Figure 7).

DISCUSSION

The identification of potentially restorable wetlands through RWIP was improved with the use of high-resolution LiDAR data to delineate more accurate basins and flow lines and smoothing techniques to create more generalized polygon boundaries. Highly detailed boundaries give the false impression that RWIP generates exact restorable polygons, rather than small-scale regions that include areas with restoration potential. Furthermore, confusion between existing wetlands and RWIP polygons, which was the primary source of misclassification during RWIP field verification, was improved by evaluating the area of mapped NWI wetland within RWIP boundaries. Most importantly, the utility of RWIP was further enhanced with the addition of a restoration feasibility designations, with the goal of directing those in need of restoration to locations with a greater likelihood of successful restoration. Attributing RWIP polygons with hydromodification from ditching and pond construction, will allow users to identify likely historic wetlands, as well as evaluate the potential to remedy hydrologic alterations.

Although we were unable to field verify the generated ditch network, visual comparisons with aerial imagery revealed that obvious ditches within restorable wetland boundaries were detected. While this layer may overestimate the extent of ditching, it can be used as an estimate of potential hydrological alterations near restorable wetlands and can direct restoration efforts to highly altered areas where hydrology may be restored. The accuracy assessment of our classified pond layer revealed that both errors of omission and commission were an improvement from NWI. These improvements are likely due to the inclusion of a large number of ponds that were constructed after NWI maps were generated. Based on these results, our updated pond layer offers a more reliable measure of the actual extent of ponds greater than 0.5 acres within the LV and LCS watersheds.

In the LCS and LV watersheds we identified the most suitable locations for potential wetland restoration as those with high restoration feasibility and with a high priority designation (e.g., score of 9-12) for water quality improvement. However, given that locations for wetland restoration are highly dependent on either the availability of land for purchase or voluntary enrollment by landowners, we retained the full list of sites identified through the protocol to increase the likelihood of finding suitable locations in each watershed. Furthermore, when incorporating estimates of restoration feasibility into the existing prioritization and ranking process, it is important to recognize that all watersheds are not equal in terms of the extent of historic wetlands, the severity of wetland degradation, and the number of restoration opportunities identified through RWIP. For example, in the initial statewide RWIP application, there were no restoration sites identified in four watersheds, while there were over 1,000 restoration sites identified in 17 watersheds. With spatial heterogeneity in historic and current wetland distributions taken into consideration, our approach for integrating estimates of restoration feasibility focused on retaining restoration sites, rather than excluding sites.

In an ongoing project, the improvements to RWIP accomplished during this project, including the addition of a restoration feasibility determination, will be applied to at least 30 additional HUC-8 watersheds across Oklahoma (OCC 2021). This project will provide opportunities to explore regionally appropriate thresholds for hydrological alterations (e.g., length of ditching, distance to upstream ponds, etc.) based on watersheds and to adjust overall expectations in estimating restoration feasibility.

Dissemination of RWIP data to the public is critical to its utility. Currently, those pursuing wetland restoration opportunities can contact OCC staff directly or through a fillable form on the Oklahoma Wetland Program Website. RWIP data are distributed upon request. We are currently working on an improved data sharing interface on the Oklahoma Wetland Program Website, so RWIP data is easily accessible, viewable, and downloadable.

Conclusion

A statewide application of RWIP confirmed that the protocol can consistently identify areas that were likely historic wetlands with the potential to serve as locations for future wetland restoration. The subsequent prioritization of these sites can effectively direct entities in need of mitigation to locations that can provide the additional benefit of improving water quality to downstream receiving waterbodies. To achieve successful restoration, a wetland's hydrology must be adequately restored, and it is important to recognize that all historic wetlands are not equally restorable. Our additional work to estimate restoration feasibility can focus efforts to sites with obvious hydromodifications, such as ditching and pond excavation, with a greater potential to restore wetland hydrology and therefore wetland functions.

FIGURES

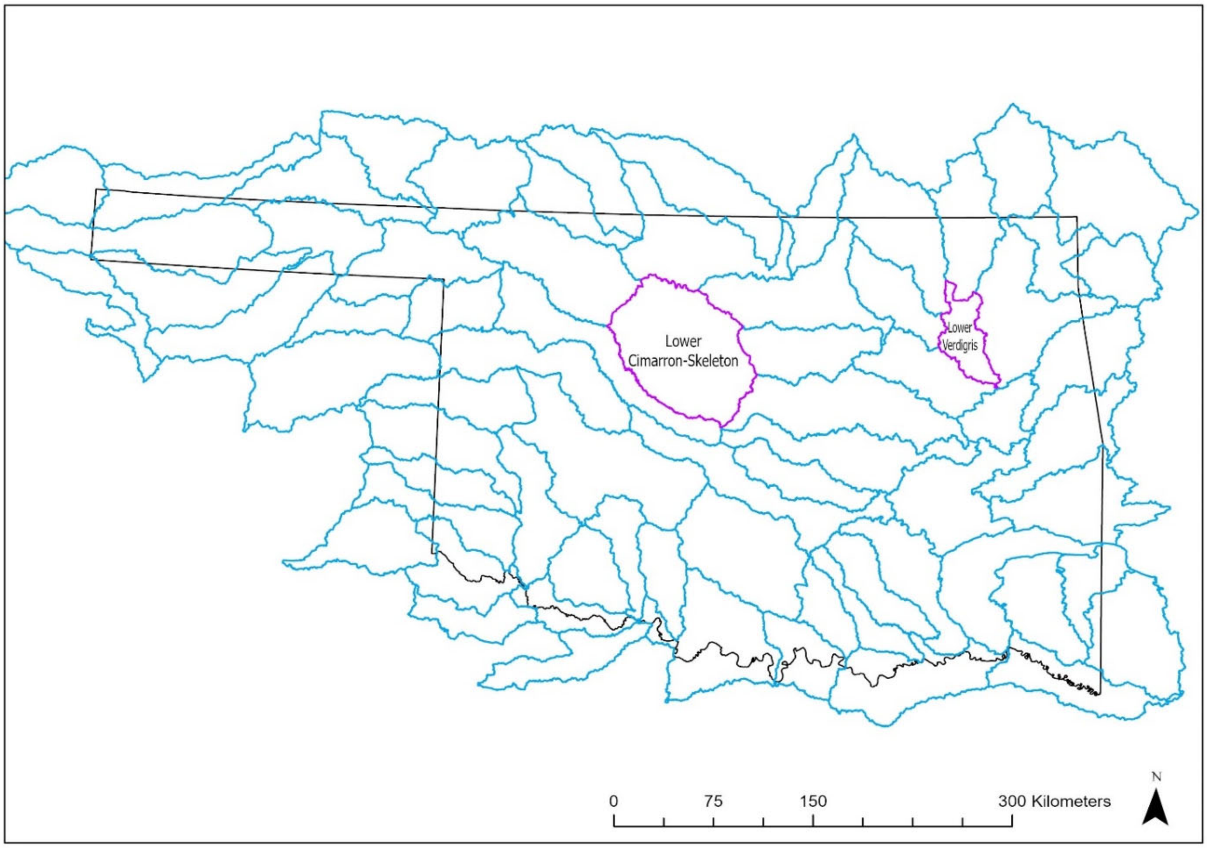


Fig. 4: Lower Verdigris and Lower Cimarron-Skeleton Watersheds

Fig. 5: Example of an RWIP polygon with a significant overlap of NWI acreage indicating that this site may be better suited for wetland enhancement rather than wetland restoration.

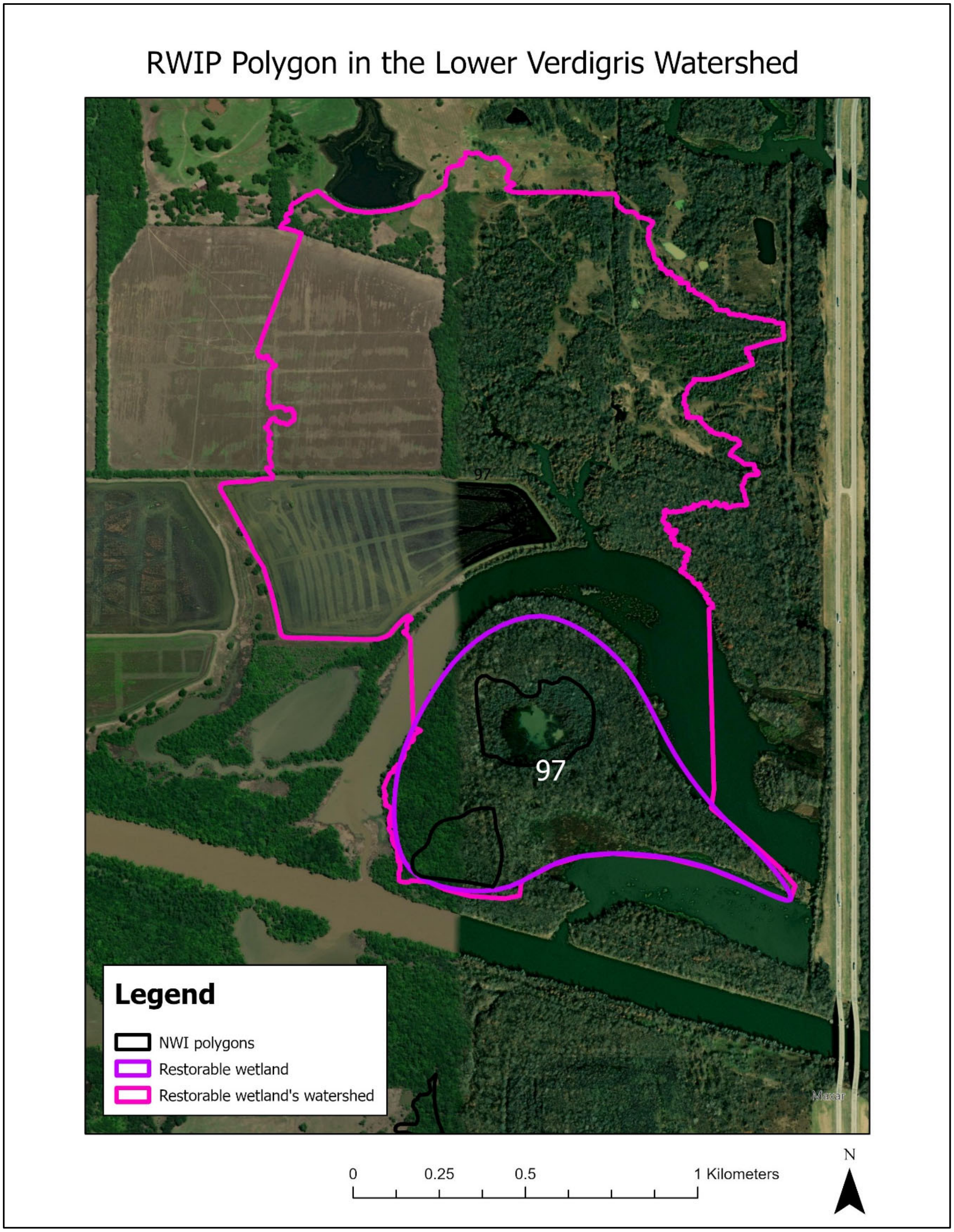
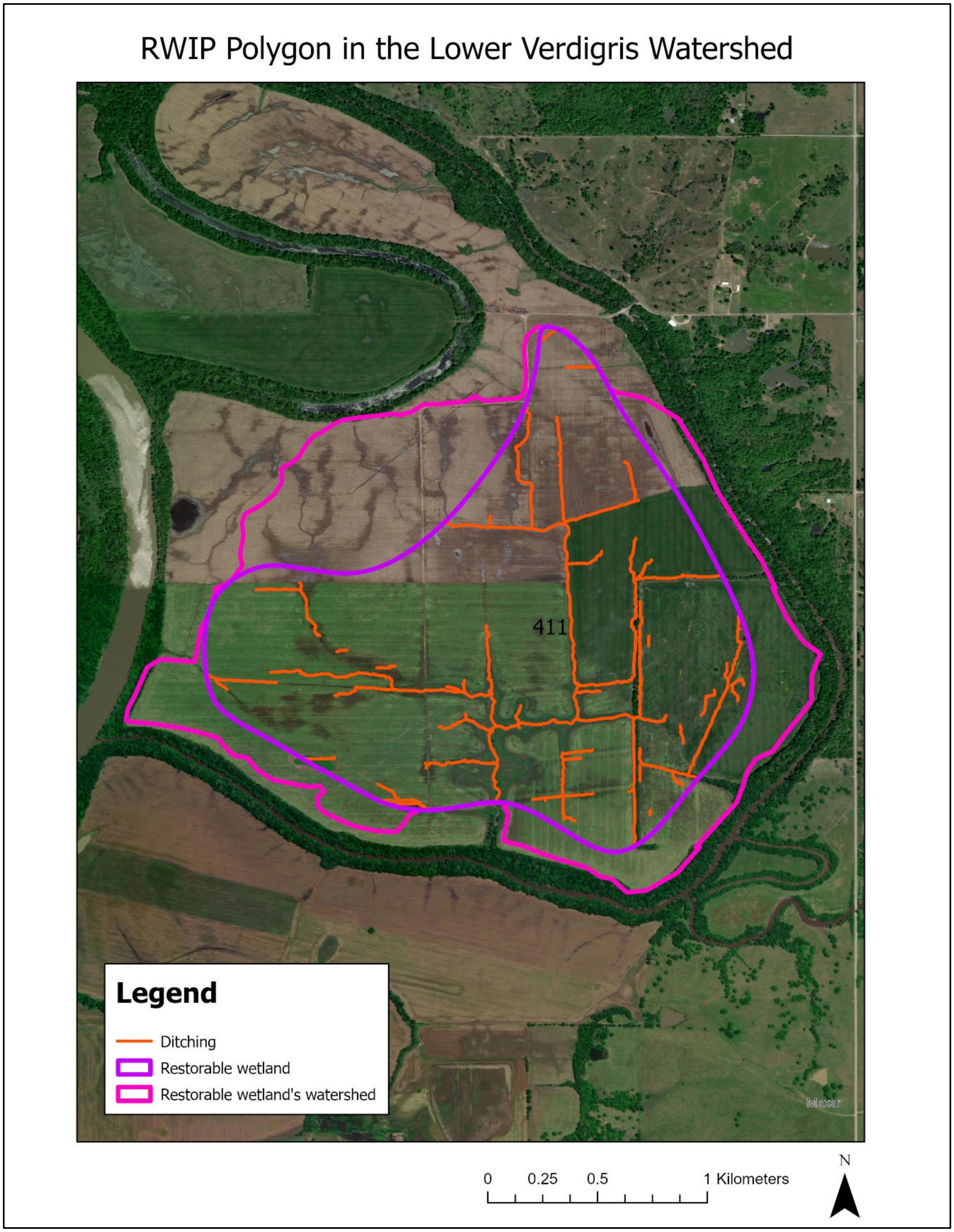


Fig. 6: Examples of RWIP polygons in the Lower Verdigris watershed with high restoration feasibility based on the presence of significant ditching and/or ponds.



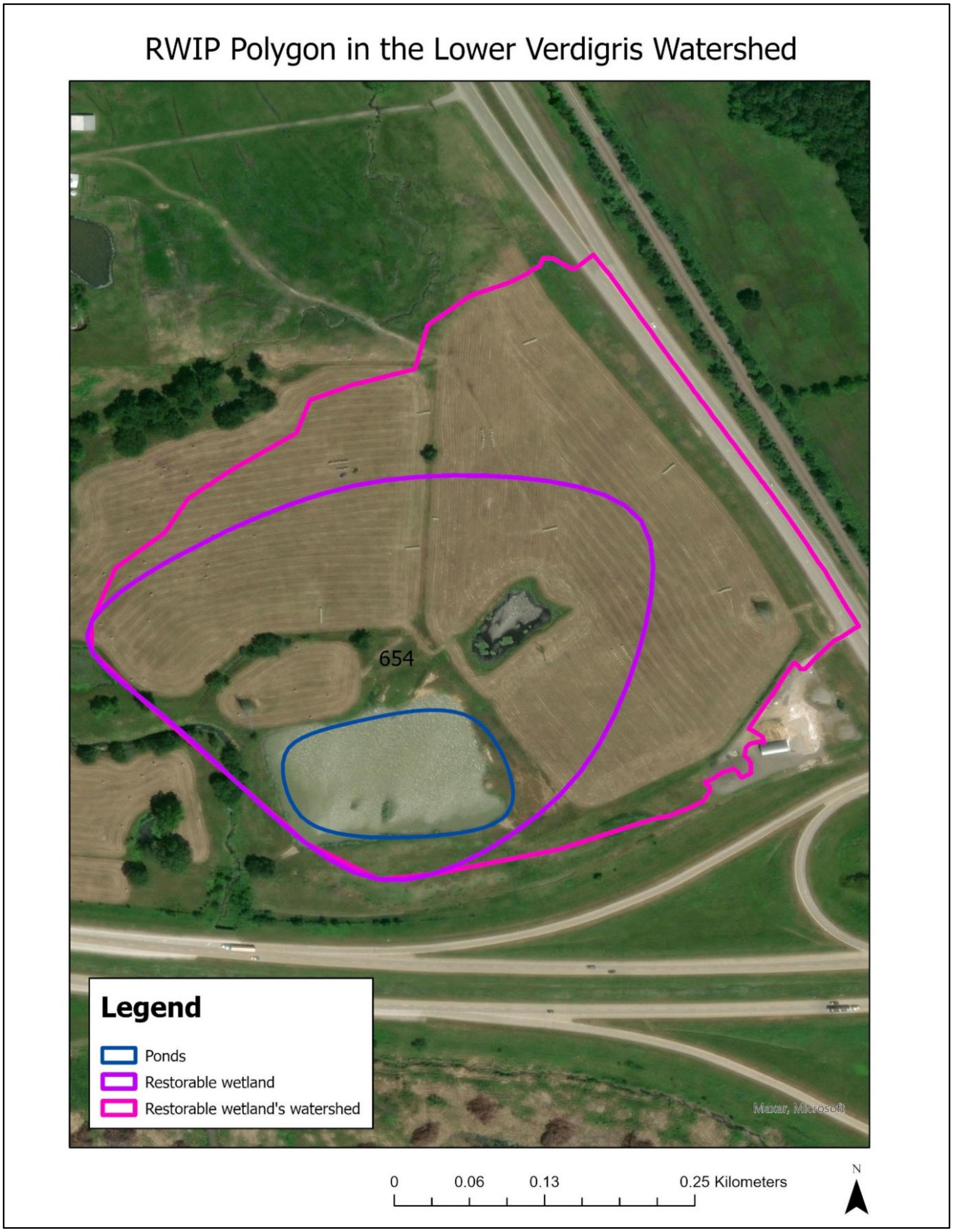
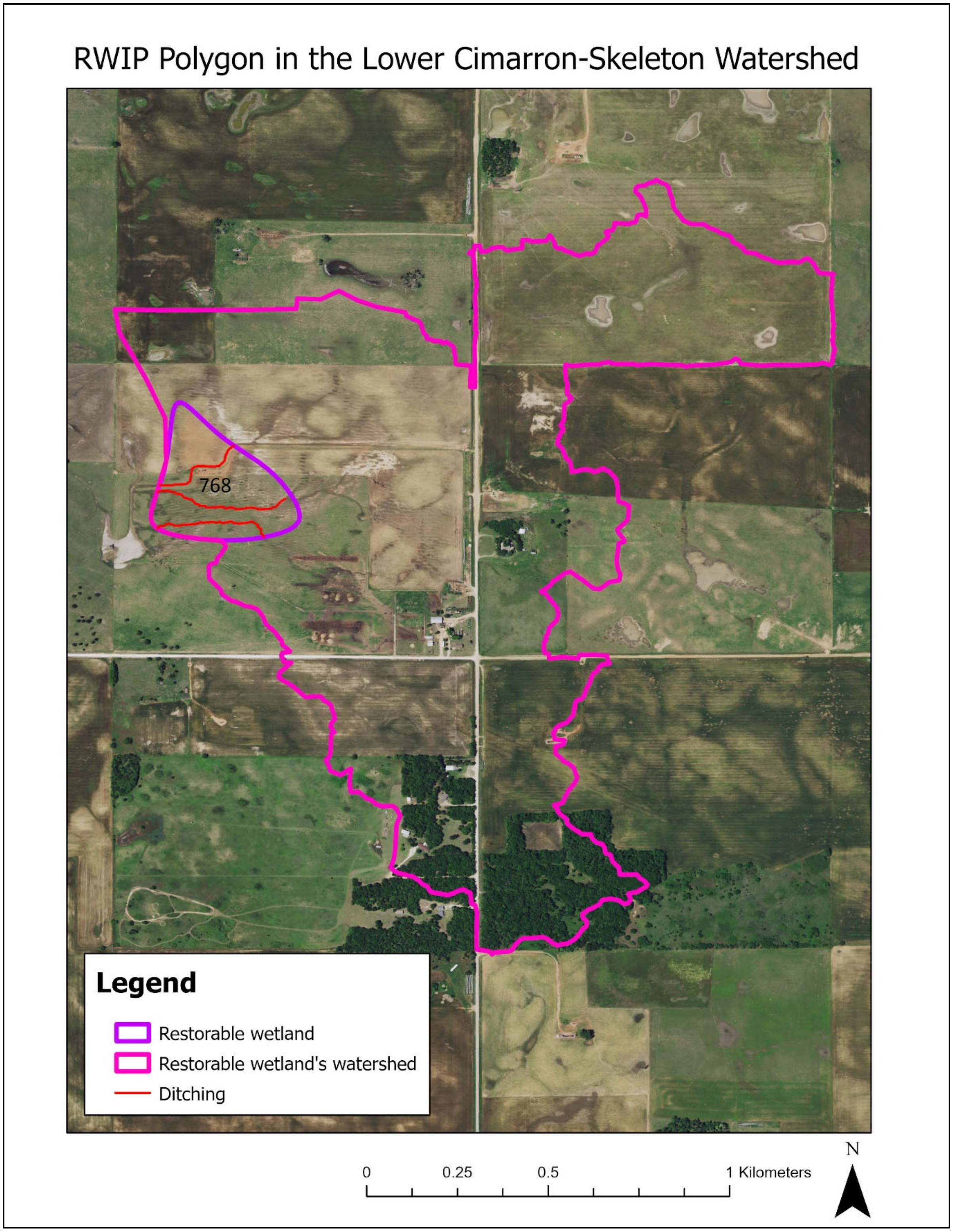
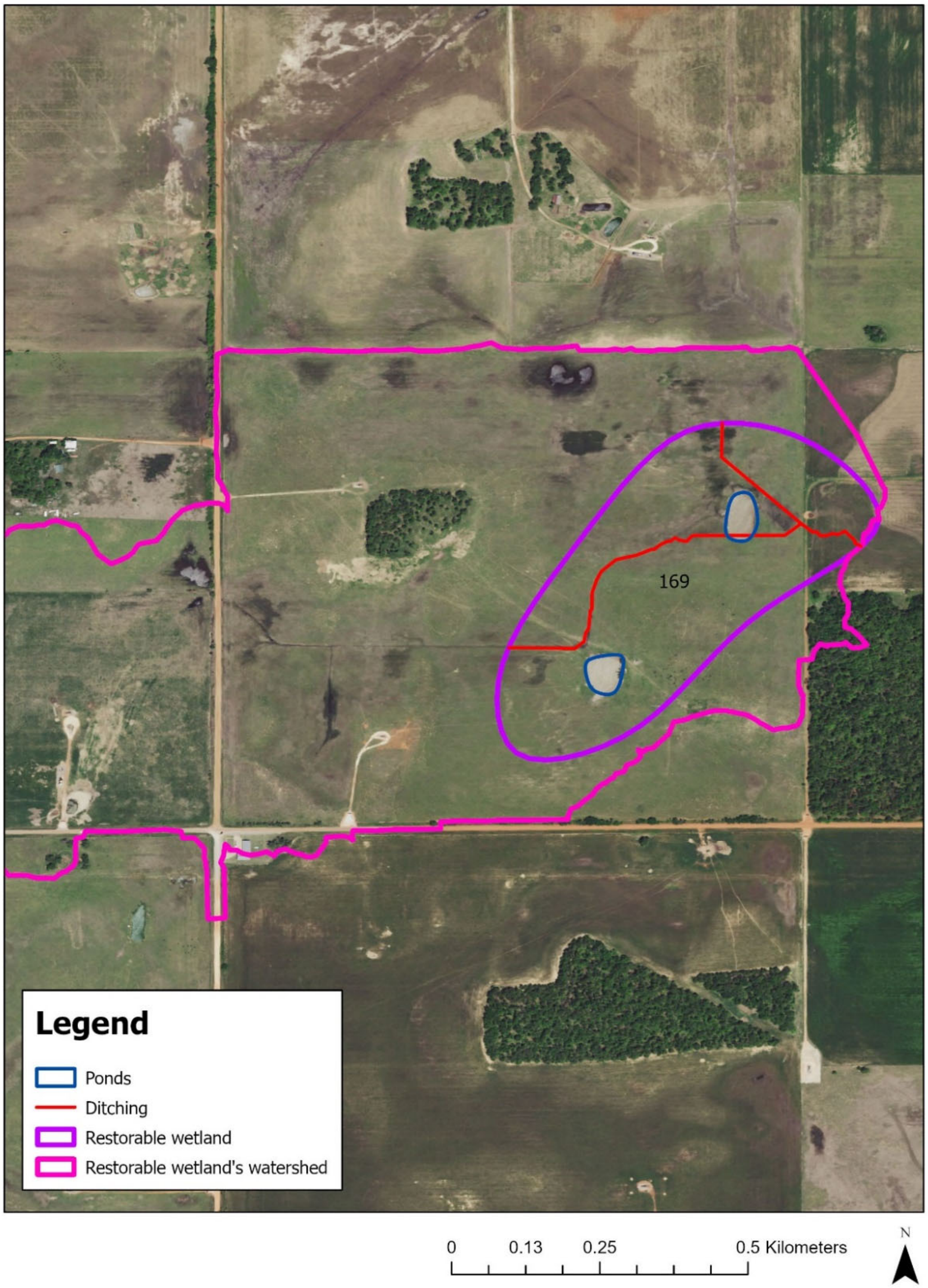

RWIP Polygon in the Lower Verdigris Watershed
654
Legend
Ponds
Restorable wetland
Restorable wetland's watershed
Maxar, Microsoft
0
0.06
0.13
0.25 Kilometers
N

Fig. 7: Examples of RWIP polygons in the Lower Cimarron-Skeleton watershed with high restoration feasibility based on the presence of significant ditching and/or ponds.



RWIP Polygon in the Lower Cimarron-Skeleton Watershed



TABLES

Table 3: An accuracy assessment comparison between ponds mapped using object-based classification and ponds mapped in NWI for all areas and when excluding urban areas in the Lower Verdigris and Lower Cimarron-Skeleton watersheds.

Lower Verdigris Watershed				
	All Areas		**Excluding Urban Areas**	
Accuracy Metric	Mapped Ponds	NWI Ponds	Mapped Ponds	NWI Ponds
Producer's Accuracy	83%	75%	87%	72%
User's Accuracy	92%	71%	94%	72%

Lower Cimarron-Skeleton Watershed				
	All Areas		**Excluding Urban Areas**	
Accuracy Metric	Mapped Ponds	NWI Ponds	Mapped Ponds	NWI Ponds
Producer's Accuracy	79%	68%	85%	70%
User's Accuracy	93%	76%	95%	76%

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APPENDICES

APPENDIX A: RESTORABLE WETLAND IDENTIFICATION PROTOCOL (RWIP)

Identify Restorable Wetlands

1. Create a poorly drained soils layer representing the potential historic extent of wetlands in the study area
    a. Download and prepare county soil data from Web Soil Survey
        i. Add field headers to Muaggatt table
        ii. Join by Muaggatt table – Join field = Musym
    b. **Query** wettest drainage class (poorly drained, somewhat poorly drained, and very poorly drained)
    c. **Export** to a new shapefile for each county
    d. **Merge** soil data for all counties
    e. **Clip** to study area
    f. **Dissolve** adjacent polygons
        i. Uncheck create multipart features

2. Create National Wetlands Inventory (NWI) layer representing the current extent of wetlands in the study area
    a. Download NWI data by watershed from the NWI Wetland Mapper
    b. **Delete** NWI wetlands with designations representing hydrological alterations (d = partly drained/ditched, f = farmed, h = diked/impounded, x = excavated)
    c. **Dissolve** adjacent polygons
        i. Uncheck create multipart features

3. Create basins layer from a Digital Elevation Model (DEM)
    a. **Clip** DEM to HUC-8 watershed
    b. **Fill sinks** on DEM
    c. Use **slope** to convert filled DEM to slope
    d. When using high-resolution data following this step to improve processing time:
        i. Use **focal statistics** to complete a neighborhood analysis (parameters: rectangle, 5 x 5 window, minimum value)
    e. **Reclassify** slope maps to separate values 0.25 from all other slope values
    f. Use **raster to polygon** to vectorize reclassed map
    g. **Delete** slope values larger than 0.25 (gridcode = 2)
    h. **Delete** small polygons (< 0.5 ac) to improve processing time
    i. **Simplify polygons** (parameters: type = Zhou-Jones; tolerance = 150 m)
    j. **Eliminate polygon part** (parameters: type = area (< 0.5 ac) or percentage (99%)
        i. Uncheck eliminate contained parts only
    k. **Smooth polygons** (parameters: type = PAEK; tolerance = 250m)
    l. **Dissolve** adjacent polygons
        i. Uncheck create multipart features
    m. **Delete** small polygons (< 0.5 ac) to improve processing time

4. Create urban land-use layer from National Land Cover Database
    a. **Reclassify** NLCD 2019 raster
        i. 1: Water, barren, developed low intensity, developed medium intensity, developed high intensity
        ii. 2: All other cover
    b. Use **raster to polygon** to vectorize reclassed map
    c. **Delete** all polygons with a reclassified land-use class of "2"
    d. **Clip** to watershed area

5. **Union** NWI (layer 2) and poorly drained soils (layer 1)
    a. **Delete** polygons where NWI wetlands currently exist

6. **Union** poorly drained soils with no NWI wetlands (layer 5) with basins (layer 3)
    a. **Delete** basins not on poorly drained soils
    b. **Delete** poorly drained soils not in basins

7. **Union** poorly drained basins (layer 6) with developed land-use (layer 4)
    a. **Delete** developed land

8. Clean up poorly drained basins not developed (layer 7)
    a. **Aggregate polygons** (parameters: aggregation distance = 50 m)
    b. **Multipart to singlepart** polygons
    c. **Simplify polygons** (parameters: type = Zhou-Jones; tolerance = 250 m)
    d. **Eliminate polygon part** (parameters: type = area (< 0.5 ac) or percentage (99%)
        i. Uncheck eliminate contained parts only
    e. **Smooth polygons** (parameters: type = PAEK; tolerance = 500m)
    f. **Dissolve** adjacent polygons
        i. Uncheck create multipart features
    g. **Delete** small polygons (< 1.0 ac)

9. Limit polygons by flow
    a. Create **flow direction** raster from filled DEM (layer 3b)
    b. Create **flow accumulation** raster from flow direction (layer 9a)
    c. Manually determine flow threshold based on climate and drainage patterns (threshold will need to be adjusted based on DEM resolution; for Lower Verdigris with 1m LIDAR 75,000-pixel flow was used)
    d. Using **raster calculator** on flow accumulation raster (layer 9c) [con(layer>=threshold,1) create a raster of only pixels above determined threshold
    e. Use **stream to feature** with processed flow accumulation raster (layer 9d) and flow direction raster (layer 9a)
    f. Use **select by location** on poorly drained basins (layer 8g) that intersect stream feature (layer 9e)
    g. **Export** selected features to new shapefile called restorable wetlands

Prioritize Restorable Wetlands

10. **Create** Watershed layer
    a. **Intersect** restorable wetlands (layer 9f) with 75,000-flow lines (layer 9e)
        i. Specify output as point
        ii. Note: Wetland boundaries can contain multiple pourpoints
    b. **Multipart to singlepart**
    c. **Extract values to points** using flow accumulation (layer 9b)
    d. Use **split by attributes** on layer 10c to create a new shapefile for each pourpoint
        i. Split by ID
    e. Use **Model Builder** to i**terate** pourpoints (layer 10d) and **snap pour points** to flow accumulation raster (layer 9b) (parameters: Snap within 0 meters)
    f. Use **watershed** tool on snapped pour points (layer 10e) and flow direction (layer 9a)
    g. Use **raster to polygon** to vectorize watershed rasters
    h. **Merge** watershed vectors
    i. **Dissolve** merged layer by ID
    j. **Calculate area** for each watershed

11. **Create** crop and urban land-use layer
    a. **Reclassify** NLCD into two classes
        i. 1: All crops and urban land covers (22, 23, 24, 82)
        ii. 2: All others
    b. Use **raster to polygon** to vectorize reclassified layer
    c. **Delete** class “2” polygons
    d. Use **split by attribute** on watersheds (layer 10j) to create a new shapefile for each watershed
        i. Split by ID
    e. Use **Model Builder** to i**terate** watersheds (layer 11d) and use **pairwise clip** to clip NLCD crop and urban land-use (layer 11c) by each watershed
    f. **Merge** shapefiles together
        i. Check “add source information to output”
    g. **Dissolve** based on ID
    h. **Add field** to calculate area
    i. **Join** watersheds to restorable wetland basins (layer 9g)
    j. **Export** layer to new shapefile called prioritized restorable wetlands

12. **Calculate** attributes for prioritized restorable wetlands
    a. **Calculate** watershed ratio by creating new field called “wat_rat” and using field calculator (watershed area/restorable basin area)
    b. **Calculate** scores using standard statewide scoring applied for all watersheds in Oklahoma
        i. **Create** four new fields for restorable basin size score (bas_sc), watershed ratio score (rat_sc), land-use score (lu_score) and site score (site_sc)
        ii. Restorable basin score is calculated as follows:
            1. 1: <2.5 acres
            2. 2: 2.5-4.99 acres
            3. 3: 5.0-9.99 acres
            4. 4: >=10.0 acres
        iii. Watershed Ratio score is calculated using “wat_rat” as follows:

        1. 1: >50
        2. 2: 50-20.01
        3. 3: 20-10.01
        4. 4: <=10
    iv. Land-use score is calculated as follows
        1. 1: <25% urban and crop
        2. 2: 25%-49.99% urban and crop
        3. 3: 50-74.99% urban and crop
        4. 4: >=75% urban and crop
    v. **Sum** restorable basin (bas_sc), watershed ratio (rat_sc) and land-use scores (lu_sc) in the site score (site_sc) field

13. **Calculate** scores specific for each watershed
    i. **Create** four new fields for watershed specific restorable basin size score (ws_bas_sc), watershed specific watershed ratio score (ws_rat_sc), watershed specific land-use score (ws_lu_sc) and watershed specific site score (ws_site_sc)
    ii. "Ws_bas_sc", "ws_rat_sc" and "ws_lu_sc" are calculated using quartiles.
        1. First quartile =1 (<= First quartile)
        2. Second quartile=2 (> First quartile – Second quartile)
        3. Third quartile=3 (> Second quartile – Third quartile)
        4. Fourth quartile=4 (> Third quartile – Fourth quartile)
    iii. **Sum** "ws_bas_sc", "ws_rat_sc" and "ws_lu_sc" in the watershed specific site score (ws_site_sc) field.

<u>Site Suitability and Restoration Feasibility</u>

14. Designate the suitability of RWIP sites for wetland restoration or enhancement
    a. **Calculate** the percentage of overlap between NWI and restorable wetlands
        i. Use **pairwise intersect** on NWI (layer 2c) and restorable wetlands (layer 9f)
        ii. Use **calculate geometry** to calculate the acreage of NWI polygons within restorable wetland boundaries
        iii. Use **summarize** tool to sum the acreage of NWI polygons within restorable wetland boundaries based on "ID"
        iv. **Join** summary table to restorable wetlands (layer 9f)
        v. To **calculate** NWI percentage, divide the acreage of NWI polygons by the restorable wetland acreage and multiply by 100
    b. Designate site suitability
        i. For restorable wetland polygons with an NWI percentage ≥ 20% designate site suitability as "Wetland Enhancement"
        ii. For restorable wetland polygons with NWI percentage < 20% designate site suitability as "Wetland Restoration"

15. Estimate wetland restoration feasibility based on the presence of ditches and/or upstream ponds
    a. Calculate length of ditches within restorable wetland boundaries
        i. **Clip** ditch layer by restorable wetlands (layer 9f)
        ii. Use **calculate geometry** to calculate length of ditches
        iii. Use **summarize** to sum all ditches within restorable wetland polygons
        iv. **Join** summary table with restorable wetlands (layer 9f)

   v. Use the 50^{th} percentile of total ditch length within restorable wetlands as the threshold to categorize ditching extent
      1. No ditching = "None"
      2. < 50^{th} percentile = "Light ditching"
      3. ≥ 50^{th} percentile = "Significant ditching"

b. Calculate the number and acreage of ponds in the upstream 200-meter watershed
   i. Use **split by attribute** to separate restorable wetlands by ID
   ii. Use **model builder** to **iterate** restorable wetlands to **buffer** wetlands by 200 meters
   iii. Use **model builder** to **iterate** restorable wetland buffers and use **pairwise intersect** on buffers and restorable wetland watersheds
   iv. **Merge** all results
   v. **Delete** records where IDs do not match (buffer ID & watershed ID)
   vi. **Spatially join** pond layer (>0.5 ac) to the previous layer
   vii. Use **select by attribute** where "Join Count ≠ 0" and **export** to new layer
   viii. Use **summarize** tool to sum acreage of ponds within restorable wetland watersheds
   ix. **Join** statistics table to restorable wetlands (layer 9f)

c. Designate wetland restoration feasibility
   i. For restorable wetlands with significant ditching and/or at least one pond within 200-meters of the upstream watershed, designate as "High"
   ii. For all other restorable wetlands, designate as "Low"

Note: Many of the steps outlined above can be accomplished in batch processor and/or model builder to expedite data processing.